Climate Variability, Water Resources and Agricultural Productivity:

Food Security Issues in Tropical Sub-Saharan Africa

Editors:
Hassan Virji
Cory Fleming
Amy Freise
Mayuri Sobti

WCRP Climate
The World Climate Research Programme

START
IHDP • IGBP • WCRP

SCOWAR

CONTENTS

Foreword

Welcome

Statement from WMO Secretary General, *Professor G.O.P. Obasi* …………………………..…… 1

Plenary Session 1 — Context and Issues

Keynote address: His Excellency Minister *Sékou Toure*, High Commissioner for Water, Côte d'Ivoire. Address: "Nécessité de la collecte et de la Dissémination de l'information Climatique dans la Planification des Ressources au Niveau National et Régional. Perspectives du Décideur"….…… 5

Seasonal Forecasting of African Rainfall: Prediction, Responses, and Household Food Security, *Thomas E. Downing and Richard Washington* ………………..…………………………………….. 16

Food Security Issues in sub-Saharan Africa, *Emem U. Nwa* ……………………………………... 49

Integrated Water Resources and Agricultural Management Under Increasing Climate Uncertainty, *Hartmut Grassl* …………………………………………………………………………..……… 62

Application of Global & Regional Climate Models in the Investigation of the African Climate, *Frederick Semazzi, Liqiang Sun, Laban Ogallo & Filippo Giorgi* ………………………………..… 63

Plenary Session 2 — Current Approaches to the Use of Information on Climate Variability Prediction, Crop Forecasting and Water Resources

Interannual to Decadal Variability of Rainfall in West Africa: diagnosis and modeling, *Luc Le Barbé & Thierry Lebel* ……………………………………………………………….………… 65

Summary of Lessons Learned from Climate Predictions for Southern Africa in 1992-1995, *Wassila Thiao* ……………………………………………………………………………………… 80

La Prévision Saisonnière du Climat Pour L'Afrique, *Jean-Claude André* ………………………..… 88

The Use of Satellite Data in Monitoring Rainfall and Riverflow Forecasting in Large River Basins of sub-Saharan Africa, *D.I.F. Grimes & M. Diop* ……………………………………………... 99

Modeling the Daily Rainfall in West Africa, *S.G.K. Adiku, N. Van de Giesen & G.N.N. Dowuona* …………………………………………………………………………………….. 111

Contribution to the Study of Inter-Annual Variability of Rainfall in Senegal, *Abdoulaya Sarr& Simeon Fongang* ………………………………………………………………………………….. 122

Plenary Session 3 — Tools and Strategies for Climate Variability Impact Assessment: Towards Regional Model Development for Agro-Hydrometeorological Purposes

Tools for the Assessment of Regionalised Climate Change Impact Studies in Agricultural Production and Hydrological Responses, *Roland Shulze* ……………………………….…………….. 143

A Strategy for Monitoring, Forecasting and Early Warning System and Integrated Pest Management in the Sudano-Sahelian Zone (SSZ), *Baba Mallam Wali* ……………………….……… 144

On Sahelian Disturbance Line Characteristics and Tropospheric Structure: A Climate Perspective from Daily Observations, *Peter S. Lamb, Michael A. Bell & Jonathon D. Finch* …………………. 157

Plenary Session 4 — Framework for Production, Dissemination and Use of Climate Variability Information

Climate Information and Prediction Services (CLIPS), *Fred Semazzi* ………………………….…. 171

Present and Future Climate Information Services in Africa, *Laban Ogallo* ….….……………….… 186

Plenary Session 5 — Developing a Regional Research Effort on Selected Crops: Proposed Case Studies of Sorghum and Cassava

Overview of Modeling Activities at ICRISAT: a case study of Sorghum, *Ramadjita Tabo* ……..… 188

Opportunities and Constraints in Realizing Yield Potential of Cassava Across Drought Environments: Science and Realities, *Indira J. Ekanayake & Shrikant Jagtap* ……………………. 198

Evolution Climatique au Tchad , ses Consequences sur les Productions Agricoles et les Strategies Adoptees, *Bekayo N. Derla* ………………………………………………………………….… 210

Poster/Paper Session

UNU/INRA Interests in Enhancing Africa's Food Security, *A. Uzo Mokwunye* ……………….… 213

A Modeling Approach Towards Crop Yield Assessment: A case study for Malawi Early Warning System for Food Security, *Gary K. Munthali* ……………………………………………………..… 215

Potential Increases in Agricultural Productivity through irrigation Development in sub-Saharan West Africa, *J. Oladipo Adejuwon* ……………………………………………………………..…. 226

Bilan D'eau des Sols, Dynamique des Paysages Végétaux et production Agricole dans la Plaine Côtière du Bénin entre Pahou et Ouidah, *Michel Boko* ……………………………………………. 237

Atelier Sur la Prediction de la Variabilite Climatique, les Ressources en Eau et la Productivite Agricole, *Kwami G. Kpakote* ………………………………………………………………….. 251

Changements Climatiques/Variabilite et Production Agricole, *Adama Alhassane Diallo* …………. 269

Climate, Water and Agriculture in Zambia, *Maurice Muchinda* ……………………………………. 299

Expérience de prévision saisonnière en temps réel des précipitations sur le Maghreb et le Sug-Est de la France, *Jean Philippe Piedelievre* ……………………………………………………………. 307

Wavelet transform-obtained Amplitude Modulations of the Annual and Semi-Annual Rainfall Cycles in the Congo-Gabon Region and their Connections with the SSTs, *Jean-Luc Melice, S. Bigot, & P. Vandergheynst* ………………………………………………………………………….. 314

Variations Hydroclimatiques en Afrique ed l'Ouest et Centrale, *Brou Kouame et al.* ……………. 325

Pluviometrie Et Production Agricole. Exemple De La Production Cerealiere De La Region De Kolda (Senegal), *Honore Dacosta and Lèonard Akpo* …………………………………………….. 328

Variabilite Climatique Et Comportement De La Cuvette Lacustre Du Niger Depuis Le Debut Du Siecle, *Fatogoma Bamba* ……………………………………………………………………..… 352

Climate Variability and Water Resources Potentials in Nigeria, *John A. Shamonda* ……………..… 363

Predicting Climate Variability in Southern Africa, *Mark R. Jury* ………………………………….. 375

Climate Variability and Crop Failures: The Role of Biodiversity in Smoothing Household Consumption in the Northern Senegal Wetlands, *John V. Magistro* ……………………………..… 381

Climate Variability and Prediction of Effective Precipitation in West Africa, *D.O. Adefolalu* ……. 397

Appendix

Working Group Discussions ……………………………………………………………………… 437

FOREWORD

Over large parts of the tropics, agricultural productivity is strongly linked to climate variability. This is especially true in Africa, where farmers rely on rainfed agriculture and water scarcity is a major constraint on food production. An in-depth understanding of the links between climate variability, water resources and agricultural productivity is essential for impact assessment, adaptation of cropping strategies to present climate variability and development of mitigation measures to reduce the vulnerability of agricultural systems and improve food security. This necessitates the integration of expertise from various global change research programmes and elements. Hence a joint START/WCRP/OSTROM/SCOWAR Workshop on Climate Variability Prediction, Water Resources and Agricultural Productivity: Food Security in Tropical Sub-Saharan Africa was organized in Cotonou, Benin from July 22-25, 1997.

The objectives of the workshop were:

- To describe the agro-hydrological impacts of interseasonal, seasonal and interannual climate fluctuations over West and Central Africa and identify the climate/weather events whose variability has to be studied and which need to be predicted;
- To assess the extent to which climate variability information is already used and how forecasts could be used to enhance crop yield production;
- To propose a framework for systematic production and dissemination of useful and reliable climate variability information and forecasts throughout the region and to suggest a pilot project to demonstrate a sustained regional capacity development effort; and
- To identify technological, policy and institutional opportunities to implement the successful use of information on climate variability.

The workshop was organized in five plenary sessions addressing: (1) context and issues; (2) current approaches to use of information on climate variability prediction, crop forecasting and water resources; (3) tools and strategies for climate variability impact assessment; (4) framework for production, dissemination and use of climate variability information; and (5) developing a regional research effort on selected crops. Following the plenary presentations, participants worked in smaller groups to discuss key issues and develop appropriate recommendations. The groups focussed on (1) climate variability prediction, (2) crop modeling and (3) water resources. Reports of the working groups were discussed in the plenary sessions and the recommendations made are listed in Appendix 1.

This volume is a proceeding of the papers presented at the Benin Workshop. The papers are organized by the plenary sessions in which they were presented. The research reported in these papers illustrates that a substantive amount of the underpinning research has been accomplished by African scientists on issues of climate variability prediction, crop forecasting and water resources. The research is the basis for developing a concerted program to reduce the vulnerability of agricultural productivity and improve food security in the face of climate variability and change.

Since the Benin workshop, START has continued to build upon this basis to develop an international program on Climate Prediction and Agriculture (CLIMAG). CLIMAG is a collaborative partnership between START, its sponsoring programmes (IGBP, IHDP, WCRP), Asia Pacific Network, European Union, National Oceanic and Atmospheric Administration, Food and Agricultural Organization of the UN, and components of the Consultative Group on International Agriculture Research system. An international workshop was held at WMO in Geneva, Switzerland in September 1999 to design a suite of regional demonstration projects in Africa, Asia and South/Central America. These projects will be implemented in 2000 and beyond. More information about CLIMAG is available at the START web site, http://www.start.org.

This publication would not have been possible without the invaluable assistance and contributions of a number of individuals and organizations. The workshop itself was made possible by the dedicated efforts of Dr. M. V. K. Sivakumar and Dr. Michel Hoepffner, and by the active participation by scientists who shared their valuable expertise through presentations and discussions. The staff at the International START Secretariat played a key role in compiling, editing and collating this publication. In particular, the organizational and editorial efforts of Amy Freise, Cory Fleming and Mayuri Sobti are recognized. Finally, this project would not have been possible without the financial support provided by grants from the Governments of Denmark, Netherlands and Norway, for which we are thankful.

Hassan Virji
Washington D.C., December 1999

Statement at the Opening of the Joint WCRP/START/SCOWAR Workshop on Climate Variability, Water Resources and Agricultural Productivity: Food Security Issues in Tropical Sub-Saharan Africa

G.O.P. Obasi
Secretary-General, World Meteorological Organization

Your Excellency Mr. Djidjoho Léonard Padonou, Minister of Education and Scientific Research, Your Excellencies, Mr. Felix Hounton, Chief of the National Meteorological Service and Permanent Representative of Benin with WMO, Representatives of the START Secretariat, Distinguished Scientists, Ladies and Gentlemen,

It is indeed an honour and a privilege for me to address you on the occasion of the opening of this workshop on *Climate Variability, Water Resources and Agricultural Productivity,* dealing with *Food Security Issues in Tropical Sub-Saharan Africa.* I would like to express my appreciation, on behalf of the World Meteorological Organization (WMO) to you, your Excellency, and through you to the Government of Benin for hosting this Workshop here in Cotonou and for your kind invitation to me. I would also like to thank Mr. Felix Hounton for the warm reception and generous hospitality accorded to us, and to commend him and the two organizing committees for the excellent arrangements made to ensure the success of the Workshop.

WMO is very pleased to be associated with the other sponsors of this workshop, which is the second in its series aimed at establishing integrated projects on *Climate Variability and Predictability for Agriculture.* The first workshop took place in Bogor, Indonesia in February this year, and a third one is being planned for South America. This second workshop brings together climatologists, crop modellers and social scientists from the region to define the objectives of an appropriate project for sub-Saharan Africa. The proposed project is expected to focus on the use of climate variability predictions on the scale of months to a year to improve decision-making and management with respect to the crop production at the national level. Through a multi-year study, the project is expected to evaluate and develop the present capability for predicting the impact of climate variability on the production of certain major crops for the selected locations along a network of sites.

As a background to the question of food security, one has to recognize that hunger and malnutrition occur to a certain extent in virtually every country of the world, but the major problem lies in the developing countries where over 800 million people are chronically undernourished, including a very large number of children. Additionally, over 80 countries are currently placed into the category of "low-income food-deficit countries" with about a half of these being in sub-Saharan Africa. Projections show that unless intensive and sustained remedial actions are taken over a long-term period, there could still be almost 700 million people who will be chronically undernourished by the year 2010, including about 300 million in sub-Saharan Africa. The 1996 World Food Summit in Rome took these facts into account in drawing up its Action Plan aimed at reducing the number of undernourished people in the world to half their present level by the year 2015.

Over the years, however, it has become clearer that any meaningful action plan to address food security issues should focus primarily on the socio-economic factors that most contribute to food insecurity, as well as on the important linkage with weather, climate and water, and in particular extreme weather events such as droughts and floods. One will recall, for example, the droughts in the Sahel region which caused considerable damage to food production systems during the late sixties and early seventies. As an African economic planning Minister once put it, "*the economic case of most African countries is agriculture. Agricultural production and weather are so highly interrelated that a good rainy season means a healthy economy, and failure of the rains…means famine and death.*" If one were able to reliably predict the gross feature of rainfall and temperature anomalies at least a few months ahead, decision-making and planning by farmers and governments could be facilitated and major famine disasters averted.

It is exactly the prospect of this type of prediction of climate variations, on timescales of a season up to a year, that the El Niño / Southern Oscillation (ENSO) phenomenon offers for areas in the tropics and subtropics where the signals are strong. The understanding of the ENSO phenomenon therefore represents the first major breakthrough to climate prediction and is an achievement of the greatest importance for the climate science research community with exciting potential benefits. In Africa, this global-scale interannual climate variability pattern is especially felt in the eastern and southern parts of the continent. For example, drought in these parts of Africa does appear to be linked to a strong positive ENSO anomaly. For western Africa, a sea surface temperature anomaly in the Atlantic Ocean also provides the basis for predicting the West African monsoon rainfall anomalies, especially in the western Sahel.

The questions of how to further enhance research in order to improve our prediction of rainfall, temperature and solar radiation anomalies, and how such predictions could be used to forecast the yield of major crops, are of major importance to the scientific and agricultural communities. Improvement of the prediction skill of ENSO is being undertaken within the *World Climate Research Programme* (WCRP) through the project on *Climate Variability and Predictability* (CLIVAR), while the use of the prediction skill is being developed, within the present project formulation, under the *Global Change and Terrestrial Ecosystems* (GCTE) study of the *International Geosphere-Biosphere Programme* (IGBP). GCTE has set up crop modeling networks for rice, wheat, cassava and potatoes, although it does not yet include those for maize and sorghum. Modellers in these networks use climate variability information to calculate potential yield, but presently neglect the impact of fertilizers, pests and diseases. The involvement of the *Scientific Committee on Water Research* (SCOWAR) of the *International Council of Scientific Unions* (ICSU) will ensure that hydrological expertise is included in the work on crop modeling.

In order to bring about the application of research results and related information to relevant sectors of national economies, and in particular to agricultural planning in areas where climate predictions have shown some skill, WMO established the *Climate Information and Prediction Services* (CLIPS) project. CLIPS is designed to provide an international framework for comprehensive multidisciplinary applications of climate information, particularly on the past and present climate, and prediction services of the near-future climate.

An African farmer who understands the concept of El Niño would immediately pose the following question, "*How much is my yield affected by the El Niño?*" To provide a proper answer, we need firstly to continue to work for improvements in the two major projects of CLIVAR and GCTE; secondly, there is the need to foster cooperation among the national Meteorological and Hydrological Services (NMHSs) and relevant institutions to ensure the timely dissemination of climate variability predictions and other information through CLIPS to end users. In all these efforts, the involvement of the regional network of START, the *Global Change System for Analysis, Research and Training,* will be found useful. START, whose major task is capacity building through research, involves various global change research programmes, namely IGBP, WCRP, and the International Human Dimensions Programme of Global Environmental Change (IHDP).

Your Excellency, Ladies and Gentlemen,

The climate research prospects for the project in tropical sub-Saharan Africa are particularly good at present. A study of the interannual variability of the climate of the African continent is being undertaken as one of the principal research areas under CLIVAR; capacity building initiatives, for example, at the African Centre of Meteorological Applications for Development (ACMAD) in Niamey, Niger, have been initiated under the aegis of CLIPS; and West African scientists are preparing a regional scale hydrometeorological experiment which could become one of the continental scale experiments within WCRP's *Global Energy and Water Cycle Experiment* (GEWEX). It is important that the project draws on the related expertise already available in the region, such as at ACMAD, the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), and the Regional Training Centre for Agrometeorology and Operational Hydrology and their Applications (AGRHYMET), all based in Niamey, Niger. AGRHYMET was established to enhance agricultural production and food self-sufficiency and to improve the management of natural resources and water resources through the use of agrometeorolgical and hydrological data and information.

With the combined efforts of these multi-agency programmes, the expected outcome of this workshop, designed to define an "end-to-end" project within tropical sub-Saharan Africa, are high. The term "end-to-end" is used in the sense that the project has to involve the full range of research, that is, climate, hydrological and agricultural, and move through the CLIPS Project and the NMHSs to the users. In discussing your tasks, particularly in defining the goals and objectives of the project, you would need to consider:

(a) the strengthening of existing crop modeling network for cassava;
(b) the creation of a network for sorghum and probably other major crops such as maize;
(c) the identification of a core group which would assist in the successful implementation of the project; and
(d) ways of ensuring the involvement of the NMHSs and the user community. As an example of the benefits of such involvement, we can think of the pilot projects in Burkina Faso and Mali, where farmers showed that crop yields could be increased by 20 to 30 percent through the operational use of weather information.

Your Excellency, Ladies and Gentlemen,

As we meet here in Cotonou, let me acknowledge the continuous effort of the Joint Scientific Committee for the WCRP which proposed the scientific scope and venue for this workshop. I hope that the resulting project proves to be particularly beneficial to the users of climate and agricultural information and predictions. Let me assure you of WMO's continuing support for this important activity, which contributes to the efforts of the Member countries to achieve food security and self-sufficiency. In this regard, I wish to recall, among others, a WMO / UNDP project completed in 1995, for the strengthening of the Agrometeorological Service of Benin, to improve traditional farming methods in its drive for long-term food self-sufficiency.

In closing, I wish once again to thank the Government of Benin for its hospitality to us all. I wish you a fruitful and enjoyable stay here in Cotonou.

Thank you

Nécessité de la collecte et de la dissémination de l’information climatique dans la planification des ressources au niveau national et régional.

Perspectives du Décideur

Sékou Touré
Haut Commissaire à l’Hydraulique
République de Côte d’Ivoire

1. Introduction

Mesdames, Mesdemoiselles et Messieurs :

Il m’est agréable de m’adresser à cette auguste assemblée ce jour, dans la charmante cité de Cotonou, capitale du Bénin, terre d’accueil, terre fraternelle, afin de faire une analyse succincte relative à un sujet aussi important que les travaux sur le changement climatique.

Les organisateur de cette rencontre m’ont fait l’honneur de me solliciter pour parler d’un point de vue spécifique, celui du décideur. Il m’a en effet été demandé d’établir le contexte dans lequel une initiative régionale pourrait être développée en matière de recherche sur le changement climatique ; l’objectif final est d’établir un partenariat entre les décideurs et la communauté scientifique.

Aussi, compte tenu du privilège qui est le mien, permettrez-vous que je remercie le gouvernement béninois de la qualité de l’accueil particulièrement chaleureux qui nous a été réservé. Je dois également féliciter le secrétariat de START, en particulier Dr Hassan Virji, pour avoir pris l’initiative d’organiser un forum sur un sujet aussi important et une préoccupation d’actualité.

Pour faire suite à la requête qui m’a été faite, mon exposé donnera le point de vue du décideur en matière d’approche de mécanisme à mettre en place pour collecter et disséminer l’information climatique dans la planification des ressources au niveau national et régional.

L’exposé comportera trois points :

- je commencerai tout d’abord par faire un bref aperçu de l’état de nos connaissances en matière de changement climatique ;

- je me permettrai ensuite de rappeler nos besoins. En d’autres termes, ce que nous cherchons à connaître ;

- enfin, je m'attellerai à proposer quelques pistes dans le sens la recherche d'un instrument approprié pour un tel objectif.

2. Quel est l'état de nos connaissances ?

La gestion des ressources aussi bien que la gestion des hommes et des biens requièrent de la part des décideurs une bonne appréciation des situations car le responsable est confronté quotidiennement au risque de prendre des décisions importantes qui ont un impact sur la société de plusieurs manières. Assez souvent, ces décisions sont retenues sur la base d'informations incomplètes. Pour l'ensemble des pays de l'Afrique au sud du Sahara qui dépendent presque exclusivement de l'agriculture pour l'essentiel de leur revenu, les fluctuations climatiques sont des éléments importants à considérer dans la prise de décisions relative au long ter. Aussi les résultats scientifiques récents qui permettent de prédire la variabilité climatique sont-ils de nouveaux instruments aux mains des décideurs pour leur permettre de réduire de tels risques.

Pour l'agriculture qui est notre préoccupation aujourd'hui, nous savons que le climat joue un rôle fondamental dans le processus de production dans ce secteur. Aussi, la variabilité climatique, en particulier les changements de fréquence et d'intensité des phénomènes météorologiques extrêmes tels que les sécheresses et les inondations peuvent entraîner des destructions importantes des cultures. Ceci pourrait affecter la sécurité alimentaire si indispensable au progrès des populations de nos états et de notre sous région.

Faut - il rappeler que la science du système climatique a connu un progrès significatif ces dernières années, de sorte que les prévisions des variabilités climatiques sont devenues plus précises et plus exactes, notamment à l'échelle des saisons et à l'échelle de la planète.

Notre planète a toujours été au centre d'un système climatique dynamique. A certains moments, il a été couvert, sur une partie importante par les glaciers. A d'autres périodes, des conditions favorables ont existé pour l'évolution humaine comme ce fut le cas dans le Sahel il y a environ 6000 ans. Au moment ou un débat s'est instauré au sein de la communauté scientifique sur les causes des changements dramatiques des conditions climatiques, un fait demeure : Des changements climatiques à grande échelle ont lieu avec en toile de fond une fréquence de variabilité plus grande à l'échelle journalière, saisonnière et annuelle. Le rôle de la variabilité climatique sur le court terme dans le développement social et économique est très important. La révolution agricole qui a influencé les cultures dans le monde et son système économique a trouvé son origine dans la capacité des hommes à observer et à anticiper les cycles journaliers et saisonniers du soleil. Nos ancêtres n'ont-ils pas profité de leur connaissance bien sûr limitée du système climatique en développant et en disséminant de nouveaux outils et des technologies spécialement conçues pour optimiser l'utilisation des ressources disponibles pour la sécurité alimentaire et l'habitat ? Les progrès accomplis aujourd'hui par les spécialistes du système climatique dans les domaines de la prédiction saisonnière et inter saisonnière sur le climat ont de même une implication très profonde pour une croissance économique durable et un développement soutenu.

La communauté scientifique est capable aujourd'hui de mettre à notre disposition un système de prévention sous forme de prévisions probabilistiques dans plusieurs points du globe. Ces nouvelles technologies offrent à la population affectée par les variabilités climatiques une opportunité de prendre des décisions averties dans l'anticipation d'épisodes pluvieuses et de conditions de variation de température. Les décisions basées sur un tel système peuvent aider à réduire les bouleversements socio-économiques et offrir une opportunité idoine à la société de bénéficier des conditions irrégulières du climat à travers des investissements dans des méthodes qui profitent de conditions favorables telles que les épisodes pluvieux plus importants durant les saisons de culture. Les décideurs et les agriculteurs dans beaucoup de pays tropicaux peuvent utiliser ces informations lors d'événements exceptionnels. Il est temps que les pays au sud du Sahara bénéficient des même retombées. Il s'agit d'intégrer, à l'échelle locale et régionale, les prévisions climatiques dans le processus de planification relative aux secteurs sensibles aux variations climatiques tels que l'eau, les énergies, l'agriculture, etc.

Par exemple, un pays comme la Côte d'Ivoire s'efforce depuis des années déjà à prendre en compte dans son processus de planification nationale les données relatives aux variations climatiques, notamment les précipitations et les variations de température. A cet effet, l'Agence Nationale de l'Aéronautique et de la Métrologie (ANAM) a été créée. Cette Agence collecte les données climatiques à l'échelle nationale et les dissémine aux structures techniques dont le Ministère de l'Agriculture pour informer les agriculteurs sur les conditions prévalant dans le pays. Il est proposé de mettre en place un organe spécifique pour prendre en compte tous les aspects liés an changement climatique pour que le cadre institutionnel intègre désormais toutes les questions liées au climat. Nous savons que cette démarche est envisagée dans d'autres pays au sud du Sahara aussi. Cependant les activités tendant à renforcer ces acquis sont loin d'être satisfaisantes. De sorte que des efforts restent à faire.

Tout récemment, le Gouvernement ivoirien vient d'achever une étude plus générale, conformément à ses engagements au niveau de la Convention cadre sur le Changement Climatique. Ainsi, les estimations ont été faites sur les émissions et puits des gaz à effet de serre. Les études sur les impacts du changement climatique ont également été initiées. Ainsi, en utilisant des modèles de simulations, la variation de température annuelle a été estimée à 2,78° C (CCCM Canadian Climate Centre Model) et de 2,17° C (GFD3, Géographical Fluid Dynamic Lab) dans le schéma d'un doublement de la concentration des gaz à effet de serre. Les variations de la précipitation seraient de 30% et 5% respectivement.

Avec ces données, des variations significatives ont été estimées pour certaines cultures. Pour le maïs par exemple, une variation de -18% a été calculée pour le rendement en tonne / hectare avec les données du CCCM et - 8% pour le GFD3. Les données pour le riz ont été estimées à - 16% pour le CCCM et - 3% pour le GFD3.

En Gambie, dans le cadre de travaux similaires, les estimations ont été faites avec les même modèles de circulation générale. Pour les scénarios identiques, une réduction du rendement de maïs a été notée, soit -15% et -35% respectivement. De même, une réduction de 14% et de 21% pour le mil et une augmentation de rendement d'arachide de 40% et de 50% ont été estimées. Pour le Zimbabwe, les résultats sont beaucoup plus disparates à cause des incertitudes des modèles utilisés Ainsi, sur certains sites, une augmentation du rendement de maïs de 37% a été estimée alors que pour d'autres localités ce chiffre était ramené à une réduction de 98%. L'ensemble de ces données a été obtenu par des travaux financés par le "US Country Studies Program".

Dans le cas d'un pays comme le Kenya, la production de café et de cacao contribue de manière significative à l'économie du pays. En conséquence, une perturbation importante de climat risquerait d'être très préjudiciable à l'économie de ce pays. Malgré cela, le kenyan moyen ne se préoccupe guère d'une potentielle élévation de la température à la surface des mers à l'autre bout du monde. Un lien entre le phénomène connu sous le sobriquet de EL NINO n'est point clair à ses yeux. Mais beaucoup de pays producteurs de café comme le Brésil ou l'Indonésie sont très affectés par ce phénomène d'EL NINO qui peut réduire leur capacité à satisfaire la demande mondiale de café sur le marché international.

Malgré ces avancés de la Science de la Prévision, beaucoup d'incertitudes sont à associer à ces chiffres car, les modèles utilisés pour les estimations sont en général conçus à l'échelle du globe. Aussi, est-il nécessaire que des modèles locaux (régionaux) soient développés pour réduire les incertitudes associes à ces données et permettre une prise de décision à partir d'informations plus fiables et plus précises ?

C'est pourquoi, un forum régional devrait pouvoir s'insérer actuellement dans la perspective de collecter des données adéquates indispensables pour une meilleure connaissance de la variabilité climatique dans notre sous - région. Au plan de la collecte de données, de la recherche et de la dissémination des résultats de la recherche, des modèles plus appropriés pourraient être développés pour permettre à toute la communauté (décideurs et utilisateurs) d'orienter leurs actions en conséquence.

Il faut noter que les défis à relever par la science ont trait à la manière dont les informations maintenant disponibles seront judicieusement bénéfiques à l'utilisateur final. Par exemple, si l'on est capable de prédire les phénomènes météorologiques extrêmes, il serait possible d'utiliser des techniques agricoles plus flexibles, de mettre en œuvre des stratégies et des pratiques de gestion des grains, des eaux et des réserves au moindre coût et avec le minimum d'impacts au plan budgétaire. Les décideurs des politiques économiques et sociales en seraient des utilisateurs privilégiés.

La science de la variabilité du climat concerne plusieurs niveaux, y compris l'échelle de la planète, l'échelle régionale ou locale, de même que, le processus de prise de décision en matière de politique. Aussi est-il nécessaire d'établir un partenariat entre les scientifiques et les décideurs à chacun de ces niveaux d'intérêt afin de maximiser l'utilisation des informations sur la variabilité climatique. Les scientifiques ont intérêt à savoir comment les décideurs pourraient utiliser au mieux les informations disponibles. L'ensemble des décideurs et la communauté scientifique ont intérêt à se mettre d'accord sur les données dont nous avons besoin.

Malgré donc l’existence et la disponibilité de données sur les variabilités climatiques à l’échelle de la planète, notre sous - région demeure relativement peut doter d’instrument de collecte et de dissémination efficace d’information et de données techniques. Cela a, à n’en point douter, des répercussions négatives sur les orientations des décideurs car ceux - ci disposent de peu d’information scientifique au plan local pour mettre en place de politiques efficaces et avisées. Cela est d’autant inquiétant que les ressources en eau et l’agriculture, tributaires des phénomènes de changement climatique, constituent des points d’ancrage unique pour nos économies. Aussi nos besoins sont-ils nombreux dans ce domaine.

3. De quoi avons - nous besoin?

Le phénomène du changement climatique est, dans la région au sud du Sahara, une préoccupation majeure pour les Etats car, des sécheresses récurrentes ont pendant ces dernières années créées des dégâts matériels et humains importants. L’ensemble des actions de développement, que ce soit au niveau de la satisfaction des besoins primaires ou bien les efforts de recherche en matière de phénomène climatique nécessite une lisibilité parfaite de la part du décideur politique ayant pour tâche de définir le cadre d’intervention des actions.

Pourquoi avons-nous besoin d’un système d’information sur le changement climatique?

La nécessité pour les pays africains du sud du Sahara de se doter d’un instrument de collecte et de dissémination de l’information relative au changement climatique pourraient avoir plusieurs intérêts pour le décideur.

Tout d’abord, les informations relatives au changement climatique qui seront rendues disponible grâce à ce système permettront aux décideurs de disposer de données réelles qu’il sera possible d’évaluer en permanence. Ceux - ci pourront ainsi poser des actes sur la base d’information fiables, réduisant ainsi les risques liés aux conséquences d’actions sans fondement scientifique. Il sera alors possible de mesurer quels sont les besoins et les priorités des utilisateurs, de ceux qui planifient et de l’ensemble des gestionnaires au niveau local, national et régional.

En emmenant le décideur à être informé, l’on procède indirectement par le sensibiliser non seulement au phénomène des variations climatiques et de leurs incidences sur les activités économiques et les ressources, mais aussi il devient, avec le temps et sa culture, complice dans les actions relatives au changement climatique.

De même, grâce aux connaissances qu’il aura acquises, le décideur sera beaucoup plus favorable à la recherche, à la collecte et à l’échange d’information sur le climat. Le décideur deviendra ainsi un partenaire de la communauté scientifique pour lequel il s’érigera en porte-parole.

Indirectement, dans ses actions quotidiennes, le décideur pourrait éventuellement faciliter la tâche de la communauté scientifique en orientant ses actions vers une meilleure compréhension des phénomènes par les administrés.

Ensuite, ce système permettra surtout d'avoir une vue générale de l'évolution de la problématique technique, judiciaire, financière et institutionnelle relative à la gestion de l'information dynamique sur le climat et de savoir gérer les écarts entre les demandes prioritaires et les besoins.

Cet instrument sera un outil indispensable pour la préparation de stratégie clair et précise dans le but d'établir des capacités réelles pour la collecte et la dissémination de l'information et des données indispensables à une bonne gestion des ressources. Entre autres, il faut :

- identifier les actions approprier à mettre en œuvre à court, moyen et long ter, y compris par exemple des actions allant dans le sens d'accéder aux bases de données déjà existantes de part le monde ;

- entreprendre des actions de formation ;

- assurer la coordination, au plan régional qui devrait favoriser la collecte et la dissémination de l'information ;

- aider les institutions nationales à mettre en œuvre les actions importantes dans les pays.

A ce niveau de mon intervention, qu'il me soit permis de rappeler que l'organisation effective de la recherche est un élément fondamental dans la plupart des études sur le climat. Deux aspects fondamentaux sont à retenir ici ; la coordination des actions de recherche, et la collaboration dans un cadre défini.

La recherche dans notre Sous - région pourrait attirer d'avantage l'attention des décideurs pour que cette recherche commence à jouer véritablement son rôle dans le processus de développement économique de nos Etats. Malheureusement, la coopération sous régionale en matière de recherche scientifique souffre de certaines lacunes. En effet, malgré l'existence d'un nombre important d'institutions d'enseignement et de recherche dans la sous région, la coopération inter universitaire est restée timide. Aussi bien les Universités de première génération, c'est à dire celles créées avant les indépendances, que les Universités de seconde et troisième génération (plus ou moins récentes) n'ont pu développer une coopération véritable. En prenant le cas des Etats de l'ex-Communauté Economique de l'Afrique de l'Ouest par exemple, des raisons de considération de pertinence de site ont guidé les Chefs d'Etat à mettre en place des institutions de recherche, entre 1978 et 1986. Mais les actions de recherche conjointe sont rares.

La recherche dans le domaine de la connaissance du climat pourrait être un puissant facteur de rapprochement de ces institutions, car le sujet est d'intérêt régional et global. Elle aboutirait à créer les conditions de travaux d'intérêt commun.

Il est important que l'on se rappelle que si l'humanité pouvait faire des prévisions plus fines et plus exactes des changements climatiques potentiels, l'on pourrait prendre des dispositions pour prévenir ou atténuer leurs impacts. En général, en plus de facteurs techniques, la réponse de la société dépend de plusieurs facteurs dont la crédibilité de l'information et la capacité des gouvernants à se préparer au pire des cas de désastre et surtout à leur capacité à communiquer à ses citoyens les risques liés aux événements de désastres naturels. Certaines sociétés sont pour cela adeptes des risques et elles prennent peu de précautions alors que d'autres sont plus prudentes et s'apprêtent longtemps avant les désastres.

Il serait souhaitable que les pays au sud du Sahara fassent partie du second Groupe car, les conditions à réunir sont souvent très coûteuses lorsque l'on réagit au lieu de prévenir.

L'information sur le changement climatique doit être le résultat de recherche intégrée. Ce type de recherche doit considérer non seulement le climat et les prévisions qui lui sont associées, mais aussi l'utilisation de l'information. De toutes les manières, un cadre institutionnel approprié est indispensable afin de gérer de manière satisfaisante la météorologie et les prévisions climatique au niveau régional.

Une solution intéressante et désirable pour une telle institution consiste à *établir un forum régional (ou des forums au niveau régional) pour discuter de l'ensemble des questions relatives à la variabilité climatique*. Il s'agit, entre autres, d'incertitudes liées aux prévisions et les besoins des utilisateurs dont les décideurs et les agriculteurs. Le fait de permettre des échanges dans un forum adéquat regroupant les partenaires de la production agricole entraînera à n'en point douter, une amélioration de la communication et l'échange d'information.

Essayons donc, Mesdames, Mesdemoiselles et Messieurs, de proposer quelques pistes pour la mise en place de forums pour combler le vide institutionnel pour une meilleure connaissance des variabilités climatiques dans nos Etats et dans notre sous région.

Un forum aussi important devrait s'appuyer sur les efforts déjà en cours. Il s'agit notamment de profiter des actions de planification et de gestion environnementale en cours de mise en œuvre dans les Etats de la Sous - région. Les Plans Nationaux d'Action Environnementale et les programmes d'assistance à la gestion de l'environnement sont à cet égard une niche toute indiquée.

Le nouveau cadre institutionnel pourrait être mis à profit aussi pour développer une meilleure synergie entre les institutions existantes telles que les réseaux dont le REDDA (Réseau pour l'Environnement et le Développement Durable en Afrique), et des initiatives telles que AGRHYMET, CILSS, etc., de même que des organisations préoccupées par l'évaluation et le suivi du système climatique et les incidences des risques liés à ce système ou des institutions d'échange d'informations liées au climat.

Il est possible aussi, et cela n'est pas du tout exclusif, de renforcer les actions des réseaux existants pour prendre en compte le volet spécifique du changement climatique. Cependant, l'inconvénient d'une telle stratégie serait de diluer les efforts dans le domaine.

Le Décideur dans nos Etats a, dans ce contexte, des préoccupations spécifiques. Il s'agit entre autres pour lui d'avoir des outils et des données sur lesquelles il pourrait s'appuyer pour définir les politiques globales et sectorielles. Par exemple, nos pays demeureront fortement tributaires de l'agriculture pour des années encore. De même, ils seront amenés à moderniser d'avantage les pratiques des cultures. La maîtrise de l'eau dans ce cas est indispensable. Pourtant, les ressources en eau et l'agriculture sont intimement liées à la variabilité climatique. Aussi le Décideur s'attend - il à recevoir l'appui technique de la communauté scientifique afin de prendre des décisions adéquates quant à la politique agricole et celle relative à la gestion des eaux dans un contexte de variabilité plus ou moins prononcée du climat.

Si un forum régional est préféré, il pourrait prendre plusieurs formes.

En effet, à l'image d'institutions déjà existantes sur le Continent et dans la Sous-région, ce forum pourrait être conçu comme une organisation bien structurée avec un Secrétariat. Dans ce cas, l'autonomie de gestion et une souplesse dans la mobilisation des ressources financières doivent être instituer pour permettre à la structure d'être rapidement opérationnelle.

Au plan de la stratégie de création de l'institution, il faudrait noter que c'est en général à cause de difficultés d'ordre institutionnelle et financière que la plupart des organismes qui ont été créés dans la Sous-région sont minés. C'est pourquoi, une organisation qui se veut une structure de concertation, de coopération et de promotion des questions relatives au changement climatique au plan régionale devrait tenir compte de cette donne.

En fait, pour éviter la création d'une autre structure à l'échelle du continent (il y a déjà beaucoup de structures existantes), il est possible et peut être préférable que l'on s'oriente plutôt vers l'instauration d'un FORUM.

4. Que pourrait - on attendre d'un tel forum ?

Il devrait agir au triple plan local, régionale et internationale. A tous ces niveaux, les objectifs majeures d'un tel forum devraient s'appuyer sur les besoins dans ce secteur. Il s'agira notamment de renforcer les programmes de formation et de sensibilisation, de promouvoir la communication et la collecte et la dissémination de l'information sur le climat, le renforcement des capacités de gestion (institutionnelle, juridique, humaine) et de la recherche étant indispensable.

Au plan local, le forum pourrait aider les gouvernements à établir des structures plus aptes à gérer les problèmes environnementaux en intégrant la vision intersectorielle. Il s'agira, de renforcer les capacités de formation de l'ensemble des secteurs y compris le secteur privé. Elle pourrait aussi s'intéresser aux questions relatives à l'information du public, à la communication et à la recherche.

Le forum pourrait aussi concevoir de nouvelles stratégies pour rendre les informations sur le climat plus accessibles et plus faciles à comprendre aux usagers et au agriculteurs. Les décideurs devraient être les premières cibles dans ce schéma car ceux - ci ont assez souvent peu d'expertise dans le domaine de la prévision de la variabilité climatique alors que la plupart des décisions leur incombent. L'un des rôles majeurs d'une telle organisation serait de trouver des voies et moyens appropriés pour que l'information scientifique collectée par les chercheurs et spécialistes des questions de variabilité climatique soit traduite en action ou mise en œuvre par les décideurs.

Il serait utile que les premières actions se focalisent sur la préparation de modules de formation à l'attention des décideurs dans les pays. La formation serait orientée vers l'établissement de système pour la planification et la gestion environnementale pour aider les décideurs à mieux comprendre les liens uniques entre les informations sur le climat et le processus de développement national.

Au plan des actions, il est courant maintenant de concevoir l'étude d'impact et les études d'incidence pour les projets de développement. L'idée est d'arriver à faire le meilleur choix en terme d'impact environnemental et de développement durable. Le renforcement de ces choix se fera nécessairement si les risques, en particuliers ceux causés par la variabilité climatique étaient pris en compte.

Au niveau international, plusieurs alternatives sont possible. Le forum pourrait éventuellement contribuer à renforcer les réseaux et le partenariat avec les autres structures qui ont un intérêt pour les questions de changement climatique. Certaines organisations de financement et de développement (Banque Mondiale, Banque Africaine de Développement) devraient être des partenaires privilégiés dans le cadre de la coopération. A ce niveau, aussi bien la BAD, le Club de Sahel, le CILSS, etc. disposent tous de banque de données individuelles. Il serait donc souhaitable que l'une des activités de la nouvelle institution soit d'intégrer ces données au bénéfice des décideurs et des utilisateurs de sorte à faciliter la planification locale et régionale. Le problème n'est probablement pas au niveau de la connaissance de son dépositaire et surtout de comment l'obtenir et l'utiliser.

Le partenariat devrait être la pierre angulaire que le forum devrait développer avec les autres Institutions, notamment celles impliquées dans la recherche dans la Sous-région. En particulier, le nouveau forum devrait permettre une meilleure implication des organisations non gouvernementales dans les actions tendant à mieux intégrer le système climatique et les variabilités climatiques dans le processus de développement.

5. Pour la Concertation

Le nouveau forum devrait s'appuyer sur le concept de la concertation qui est conçue comme un ensemble d'opportunités d'échanges devant permettre aux Etats membres d'harmoniser leurs politiques et programmes sur la gestion des variabilités climatiques. Elle se ferait à travers les rencontres formelles entre les Etats membres et les partenaires au développement pour débattre des problèmes d'intérêt commun d'ordre scientifique, technique, juridique ou financier.

La structure devrait s'atteler à mettre ce précepte en jeu :

- rencontre des techniciens ;
- réunions des ministres ;
- réunions des responsables et administrations
- réunions des organismes techniques (concertations avec les Institutions – spécialisées des Nations Unies et autres Institutions de l'Union Européenne et de l'O.U.A., etc.) ;
- réunions des Bailleurs de Fonds Partenaires au Développement ;;
- rencontres conjointes Décideurs - Communauté Scientifique ; etc

6. Au plan de la Coordination

La coordination scientifique, technique, juridique et réglementaire se ferait sur la base des règles élaborées par les parties prenantes, permettant ainsi à la nouvelle institution de jouer un rôle de chef d'orchestre dans les actions relatives à une meilleure connaissance du climat et des impacts sur les ressources et les activités de production économique.

Plusieurs hypothèses sont possibles pour cette structure :

- organisation intergouvernementale ;
- association ;
- organisation sous tutelle ;
- structure privée faisant de la prestation de service.

Pour le financement, le concept de base de gestion du nouveau forum devra s'inspirer d'exemples de structures similaires qui sont légères et peu budgétivores. Il faudrait qu'elle puisse générer des ressources propres et bénéficier de ressources de diverses sources. En tout état de cause, son fonctionnement ne devrait jamais être tributaire de ressources provenant uniquement que des Etats.

7. En conclusion

Mesdames, Mesdemoiselles et Messieurs, j'ai pu présenter succinctement en bref aperçu de nos connaissances en matière de changement climatique pour cerner la problématique de ce forum du point de vue de décideur. Cela m'a permis de relever quelques points relatifs à l'état de nos connaissances en relevant le vide institutionnel actuel. Par rapport à cet état de fait, je me suis attelé à vous apporter quelques éclairages sur nos besoins pour aider à une meilleure prise de décision au bénéfice de nos ressources que sont l'eau des activités aussi importantes que l'agriculture dans les économies de nos pays.

Voici présentées assez brièvement les quelques idées que m'a inspirées le traitement du thème que le Secrétariat a bien voulu me confier : "**Point de vue du décideur relatif à la nécessité de la collecte et de la dissémination de l'information climatique dans la planification des ressources au niveau national et régional.**" La finalité d'une telle réflexion est de promouvoir les actions de sécurité alimentaire dans notre Sous - région.

Je voudrais en vous quittant que vous méditiez sur certaines questions lors de vos travaux :

1. le contexte actuel est-il favorable à la mise en place d'une structure unique ?
2. ce forum doit - il être logé dans des structures déjà existantes ou bien faudrait - il plutôt qu'il soit autonome et indépendant (ACMAD, etc.) ?
3. quelle devrait être le mode de financement qui permettrait de pérenniser une telle structure ?
4. quel seraient les besoins actuels des décideurs et utilisateurs des informations potentielles collectées par un tel forum ?
5. quelles serait la valeur ajoutée de la création d'une telle structure dans le contexte actuel ?
6. quel serait le statut d'un tel forum ?

C'est sur cette note que je voudrais, encore une fois, remercier le Dr Hassan Virji, Directeur exécutif de START, de m'avoir donner l'occasion de m'adresser à vous.

Naturellement, les idées développée ici ne sont que des orientations qui devraient être analysées d'avantage pour en ressortir une substance de base qui servirait à poursuivre le débat.

Je vous souhaite plein succès dans les travaux et espère pouvoir, comme les décideurs de notre Sous-région, m'appuyer sur les orientations de votre rencontre pour mieux comprendre le cadre dans lequel une telle structure devrait évoluer.

Je vous remercie

Seasonal Forecasting of African Rainfall: Prediction, Responses and Household Food Security

Thomas E. Downing
Environmental Change Unit, University of Oxford

Richard Washington
School of Geography, University of Oxford

1. Introduction

Devastating droughts are etched on the history of Africa. As 1997/8 reminded the world, floods can be equally devastating, although less frequent on a widespread scale. Clearly African resources are sensitive to climatic variability, as seen in assessments of agriculture, water resources, ecosystems, and health (for example, see Ominde and Juma, 1991; Hulme, 1996; Watson *et al.* 1998; Martens, 1996).

Rainfall variability and long term drought, such as in the Sahel, make African geophysical time series some of the most striking on the planet. Clearly, the ability to predict rainfall variability a season in advance could have major impacts on the fragile economies of Africa.

More than a century has passed since some of the earliest scientific efforts at understanding the variability of tropical and subtropical rainfall (Blanford 1884). Following this, Walker (1930) and Walker and Bliss (1930, 1932) made extraordinary progress in uncovering what are still today the three largest known modes of interannual atmospheric variability, including the non-oceanic component of the El Niño/Southern Oscillation (ENSO). Despite this promising grounding, seasonal forecasts of rainfall have only become operational in the last ten years or so (see Hulme *et al.* 1992). This is largely because the modern era of meteorology set the limits to the successful forecasting of future states of the atmosphere to about six days.

Recently, a revolution from deterministic to probabilistic forecast schemes, has extended predictability of climate to several months ahead for large parts of the globe. With its marked record of droughts, high interannual variability of rainfall and its largely agricultural economy, Africa is a prime potential benefactor of seasonal forecasting.

This paper reviews recent developments in both climate prediction and the use of climate forecasts in promoting household food security. We outline the process of compiling and distributing seasonal forecasts. Components of operational seasonal forecasts for Africa are examined. The utility of climate forecasts is described against the background of household vulnerability and strategies to cope with food insecurity.

Climate forecasts may indeed revolutionise resource management in Africa. Yet, their utility ultimately depends on the linkages between geophysical, economic and social science insights as well as global linkages between institutes that provide and distribute forecasts and those responsible for responses, ultimately the vulnerable households throughout the world.

2. Seasonal Forecasting

Daily weather forecasts of specific rainfall events, associated with explicit synoptic rainfall producing systems, are only accurate to about five days. In contrast, probabilistic forecasts of monthly or seasonal rainfall totals, usually expressed in categories ranging from very wet to very dry, are being issued for several parts of the world.

The process of deriving a seasonal forecast is shown in Figure 1. As for any climatological analysis, data preparation and evaluation of key relationships require significant resources and expertise. For a thorough regional analysis, global data sets are required, even for relatively simple multivariate statistical analysis. These data should be continuously updated in order to monitor performance of the prediction model. Technical problems can arise if the time series are not homogeneous, if underlying trends are present or due to missing data.

Methods for climate prediction began with statistical analysis of rainfall periodicity. Most predictions are now based on multivariate empirical approaches, while numerical methods are seen as the basis for future schemes.

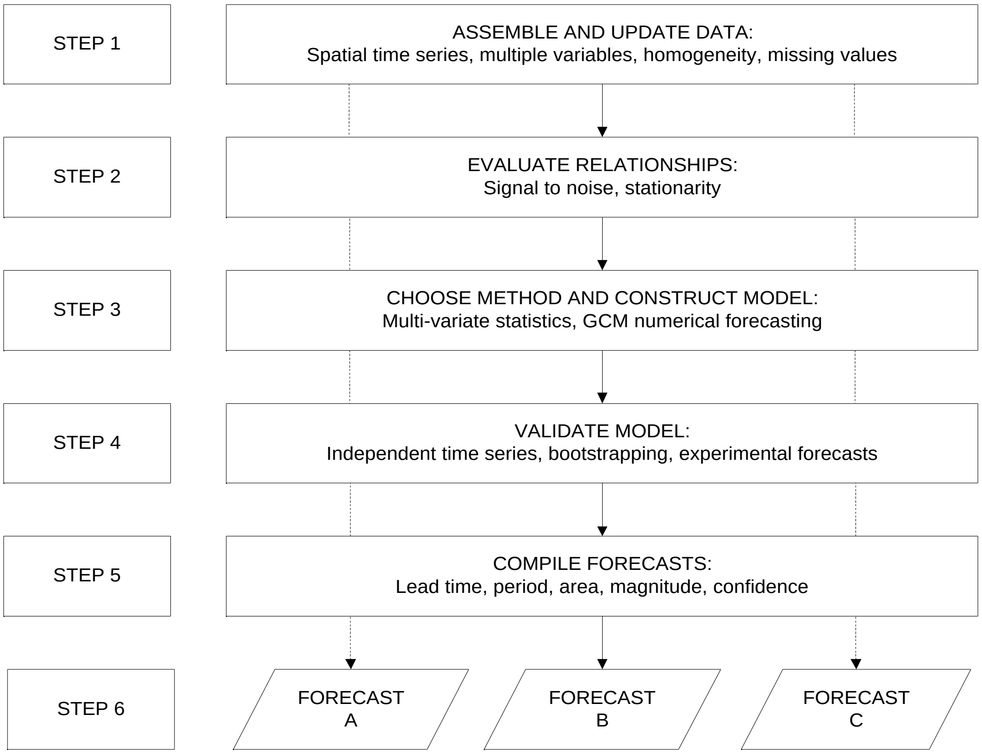
Once a predictive model has been constructed, it needs to be validated. Only then, can reliable operational forecasts be issued. These steps are duplicated in every forecast centre. The result is a range of forecasts based on different assumptions and methods.

Next we review seasonal forecast methods used to predict African rainfall.

2.1 Statistical Analyses of Rainfall

Seasonal rainfall forecasts have been based simply on the analysis of the rainfall time series of a region alone, without linking rainfall variability to the atmospheric circulation or underlying physical mechanisms. In these instances the time series of rainfall typically displays marked multi-annual variability so that wet or dry conditions persisting for several years are recognisable in the form of pronounced autocorrelation or significant low frequency spectral peaks in the time series.

OPERATIONAL SEASONAL FORECASTS



Southern Africa, for example, experiences a large component of quasi bi-decadal variability (Tyson, 1986) which accounts for a little under 30% of the total rainfall variability. Future projections of this signal were used to warn of the drought of the early 1980s (Tyson and Dyer, 1978, 1980). While the largest ENSO event of the century in 1982/83 no doubt helped to secure the veracity for this particular forecast, such endeavours remain bold when the physical mechanisms for the underlying variability have not been properly understood. This is particularly so when other variables in the climate system, such as temperature, are non-stationary. In this sense, purely statistical methods are the most basic of the seasonal prediction approaches.

2.2 Numerical Approaches

Numerically based forecasts entail the integration of General Circulation Models (GCMs), usually with sea surface temperature (SST) forcing, typically over a period of 50 or more days. Such approaches usually feature multiple runs of the GCM, each initialised with different starting conditions (corresponding to different states of the atmosphere). A set of these integrations is known as an ensemble. If all ensemble members (i.e., each of the time series of rainfall for a particular region for each of the integrations) are similar, then the forecast confidence for the forthcoming season would be regarded as very high, since the model indicates that the atmosphere is insensitive to the nature of its starting conditions given the nature of SST forcing. The SSTs would then be acting to impose a signal on the atmosphere regardless of the nature of that overlying atmosphere. In reality this is seldom the case. Some of the ensemble members may show similarity, but this does not mean that the emergent evolution of the real atmosphere will necessarily assume any one of the clustered trajectories.

Forecasts based on this broad method are undertaken by several research groups such as the United Kingdom Meteorological Office (UKMO) (Harrison, personal communication). This method is dependent on the ability of GCMs to simulate accurately the regional climatology of the target area, which, in turn, depends on factors such as the model resolution, the degree of topographical diversity of the target area and the sophistication of the model parameterisation, particularly that of the convective scheme. For some models and some areas, this level of accuracy is excellent (e.g. North East Brazil in the UKMO HADAM2B model), whereas for other regions the model rainfall climatology is poor (e.g. the Asian Monsoon region in UKMO HADAM2B). On the whole GCMs appear to be oversensitive to initial conditions and under represent the amplitude response of SST forcing, but it is generally accepted that this route to seasonal forecasting offers the largest potential for future improvement.

2.3 Multivariate Empirical Approaches

The ability to predict seasonal rainfall totals several months in advance is due to the exchanges of energy between the oceans and the atmosphere, which includes the weather systems that produce rainfall. Mass, momentum and heat are readily exchanged between these two fluids. Rain falling into the ocean and evaporation of water from the ocean constitute the mass flux, wind stress on the ocean surface from near surface wind forms the momentum exchange; heat transfers occur as either latent or sensible heat flux both into and out of the ocean.

Latent heat flux is given by:

$$Q_e = L P_a\,(0.622\,/\,P) C_e V (e_o - e_z)$$

Sensible heat as:

$$Q_h = C_p P_a C_t V (T_w - T_a)$$

where:

Q_e and Q_h are latent and sensible heat transfer
T_w and T_a are sea and air temperature respectively
e_o-e_z is saturation vapour pressure connected with the sea and air temperatures
C_t and C_e are transfer coefficients
L is latent heat of evaporation
V is wind speed
P_a is air density
P is atmospheric pressure

Both these forms of heat flux are difficult to calculate accurately (e.g. Gulev, 1995). In practice, quantification of the interaction between the ocean and atmosphere in empirical studies typical of those which lead to forecasting schemes, is assumed to be represented by sea surface temperature anomalies (SSTAs) alone. This assumes, for example, that large positive anomalies will be associated with enhanced flux of sensible heat, even though the temperature gradient between the atmosphere and ocean is not explicitly calculated.

Sea surface temperatures evolve very slowly compared with the atmosphere, owing to the much larger mass and heat capacity in the oceans. Seasonal forecasts based on the impact of the current condition of the ocean surface on the atmosphere retain accuracy through the persistence in the sea surface temperatures.

This approach to seasonal prediction therefore rests on several important factors:

a) Existence of tolerably accurate SST data sets with good spatial and temporal coverage of the globe.
b) SSTAs that are spatially coherent and temporally persistent so that broadscale modification of the overlying atmosphere occurs.
c) SSTAs are of sufficiently large amplitude to impact on the overlying atmosphere.
d) Mechanisms in the atmosphere deliver the signal imposed by the anomalous heat flux over distances that may be much larger than the individual synoptic or mesoscale systems which generate rain.

For much of the last 50 years, factors (b-d) were not thought to occur in reality. SSTAs were thought to be too small and too spatially incoherent to impact the atmosphere in an organised way. Thus Gilchrist (1986) warned that the “uncertain scientific base of the subject has undoubtedly been a deterrent to attempts to present it in an optimistic light”.

> The problem appeared to lie in the remote delivery of the SSTAs imposed signal: “it is reasonable to expect the atmospheric anomalies to last as long as the ocean anomalies, but when it concerns teleconnected effects it implies a determinism about the consequences of one specific form of forcing that is at variance with our general understanding of the limitations of the deterministic evolution of the atmosphere” (Gilchrist, 1986).

We now know that Gilchrist (1986) was wrong about the lack of determinism, at least in much of the tropical atmosphere. While the nature of ocean-atmosphere interaction in the Pacific Ocean (Bjerknes, 1966, 1969), as well as the mechanisms which were likely to drive the interaction (Wyrtki, 1973), had been identified by the early 1970s, adding to the work of Walker some 40 years previously, it took a few more decades to appreciate that events on one side of the planet, in the Pacific, could have an impact on rainfall half way round the world in Africa (Lindesay, 1988, van Heerden, *et al* 1988).

An important part of the empirical route to seasonal forecasting therefore lies in determining the location of SSTAs that show the best statistical relationship with rainfall for an area of interest. The starting point for this is a data set of both rainfall and SST. Several global SST data sets are available (e.g. COADS, GISST) which provide monthly historical anomalies at resolutions between 2 x 2 ° and 5 x 5 ° latitude-longitude. Similarly, global rainfall data sets are available, such as Hulme (1994) which provides monthly totals at 2.5 ° x 3.75 ° latitude-longitude resolution.

Empirical seasonal forecasting requires the identification of lagged statistical associations between SST indices and rainfall indices. This may be achieved through any one of the following methods:

a) correlation
b) multiple regression (e.g. Ward and Folland, 1991)
c) canonical correlation (e.g. Landman, 1995)
d) discriminant analysis (e.g. Folland et al. 1991)
e) neural networks (e.g. Hastenrath et al. 1995)

Correlation is the simplest of these techniques. It measures the matched variance (specifically, the standardised covariance) between two time series. The rainfall, y, and the SST, x, are, at the simplest level, time series at a single location. Problems result from the number of time series involved. In the case of evaluating the correlation between a single index of rainfall and global SSTs, several hundred correlation coefficients need to be calculated.

Figure 2 shows a typical way of displaying these statistics. Here rainfall from a single grid box (overlying southeastern Namibia) for the season January to March (JFM) has been correlated with global January to March SSTs at a 10 x 10 degree resolution for the years 1950-1993. The locally significant (95% level) correlation coefficients have been mapped to the location of the SST used to calculate the coefficient. Significant negative correlations between rainfall at this location and SSTs are found across the tropical eastern and central Pacific. Warmer (cooler) than normal SSTs in this region are therefore associated with drier (wetter) conditions in the southern Kalahari. The strongest correlations reach $r = -0.55$ near 120 ° W in the southern tropical Pacific. Weak negative correlations are also found in the northern tropical Atlantic and tropical Indian Ocean. A clear ENSO signal is apparent in the Pacific SSTs, although positive correlations are absent over the western Pacific. Reasons for this might lie in the small variance of the SSTs in the Indonesian warm pool but point to the utility of the SSTs in the central and eastern Pacific in the seasonal forecasting process, particularly if the rainfall-SST correlations maintain significance at several months lead time. It is interesting to note that the largest correlations between Namibian rainfall and SST occur half way round the planet.

When a single rainfall grid box is used in the calculations described above, the signal to noise ratio in the rainfall time series is often low. This may be improved by generated area averages or weighted area averages using techniques such as Empirical Orthogonal Functions (EOFs). Figure 3 (a) shows the weights of a rotated rainfall EOF for JFM. In essence this EOF may be used to calculate an objectively derived area index of rainfall representing much of southern Africa. This particular EOF, which is derived from a set of Africa-wide rotated EOFs, represents the variability of JFM rainfall over Namibia and northwest southern Africa. Correlations between the EOF time coefficients and JFM SST (Figure 3b) confirm that southern African rainfall in JFM tends to be enhanced (deficient) when JFM SSTs in the eastern and central Pacific are anomalously cool (warm). The correlations in the Atlantic Ocean shown in Figure 2 are absent when a large area of southern Africa rather than a small region of Namibia is used as the rainfall index. In addition, the strength of the correlation coefficients increases when an area average (EOF) is used. Figure 3c shows the correlations between the EOF time coefficients and JFM sea level pressure. Moderate to strong positive correlations are evident in the central and eastern tropical Pacific. Correlations are negative over much of the south Atlantic and Africa as well as the western Pacific. Figure 3d shows the correlations between the EOF time coefficients and October to December (OND) SST, with the SSTs leading the rainfall by one season. At a season lead, the SST correlations compare well with the simultaneous values shown in Figure 3b, in some cases even strengthening. Likewise, correlations with OND sea level pressures (SLPs) (Figure 3e) show much the same form as the simultaneous correlations.

Figure 2: Correlations X 100 between JFM rainfall in southeastern Namibia and JFM sea surface temperatures, 1950-1993. Only correlations locally significant at the 95% level are shown.

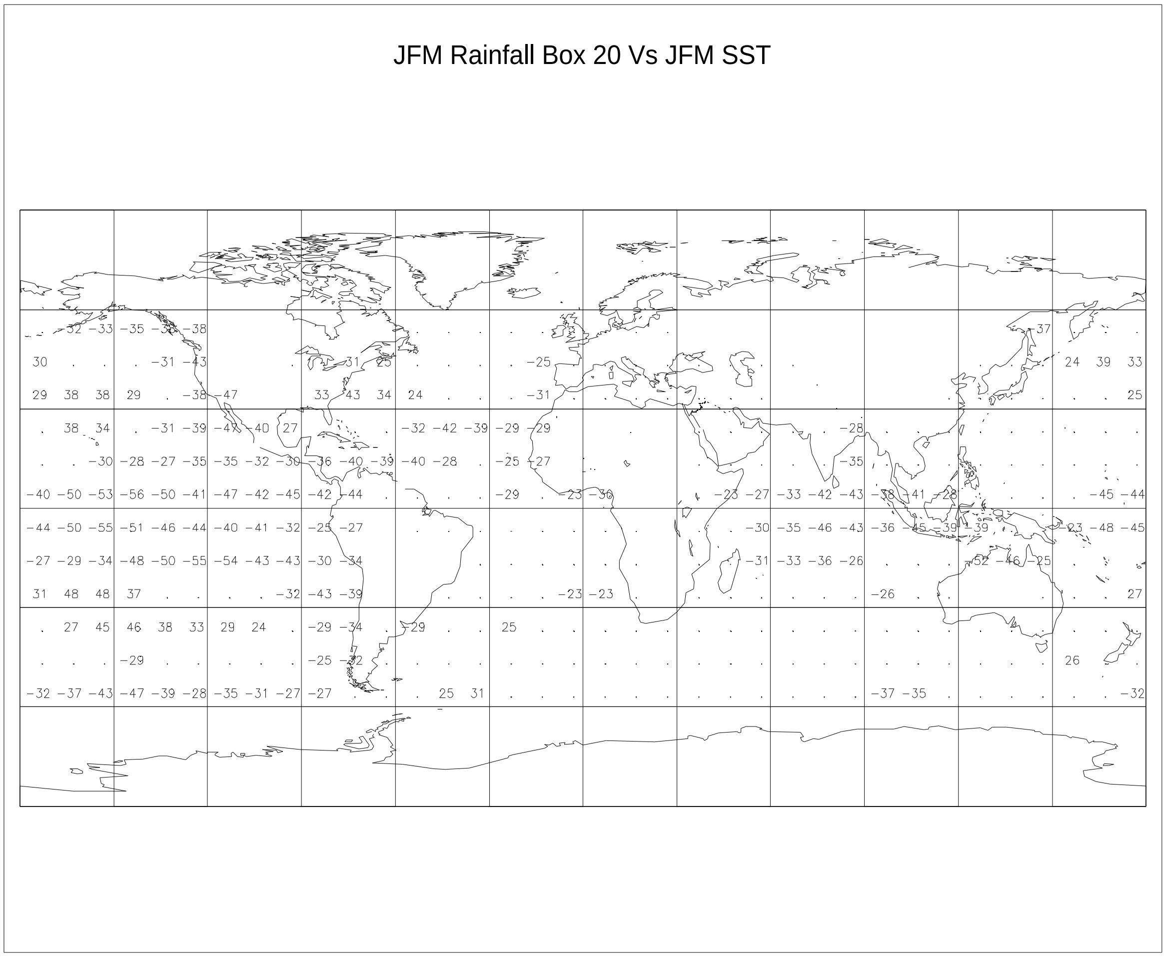


Figure 3a January to March (JFM) Varimax rotated rainfall EOF3 for 1900-1996. The values indicated are the correlation form of the EOF X 100. Data is from the Hulme (1994) precipitation data set at a resolution of 2.5 x 3.75.

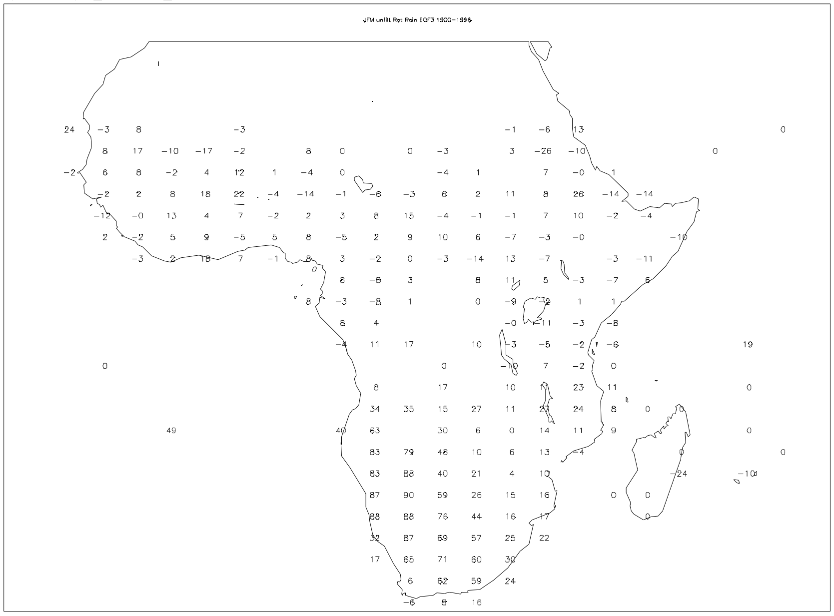


Figure 3b Correlation coefficients (x 100) between Varimax rotated rainfall EOF3 and JFM SST for the period 1950-1993. Rainfall data are from Hulme (1994) and SST data from the UKMO GISST data set. Only correlation coefficients locally significant at the 95% level are shown.

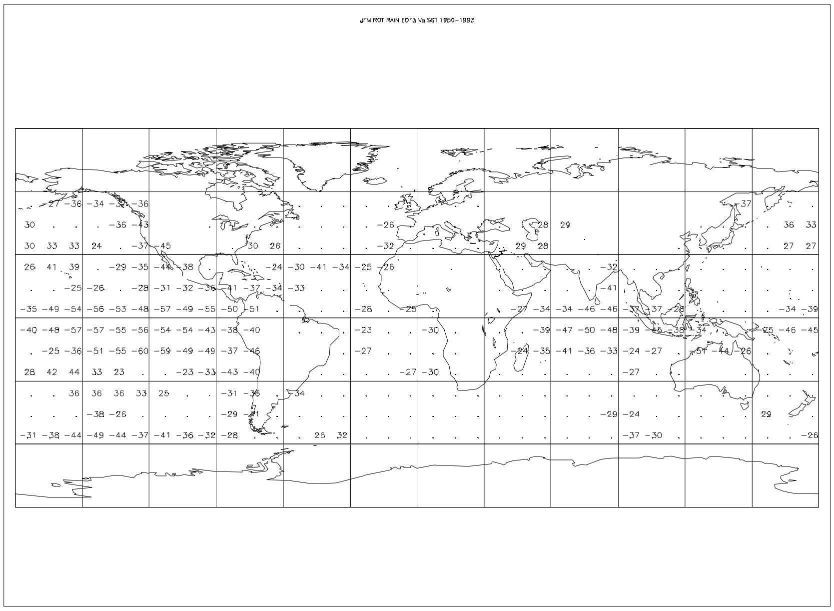


Figure 3c Correlation coefficients (x 100) between Varimax rotated rainfall EOF3 and JFM sea level pressure for the period 1950-1993. Rainfall data are from Hulme (1994) and SLP data from the UKMO GMSLP21F data set. Only correlation coefficients locally significant at the 95% level are shown.

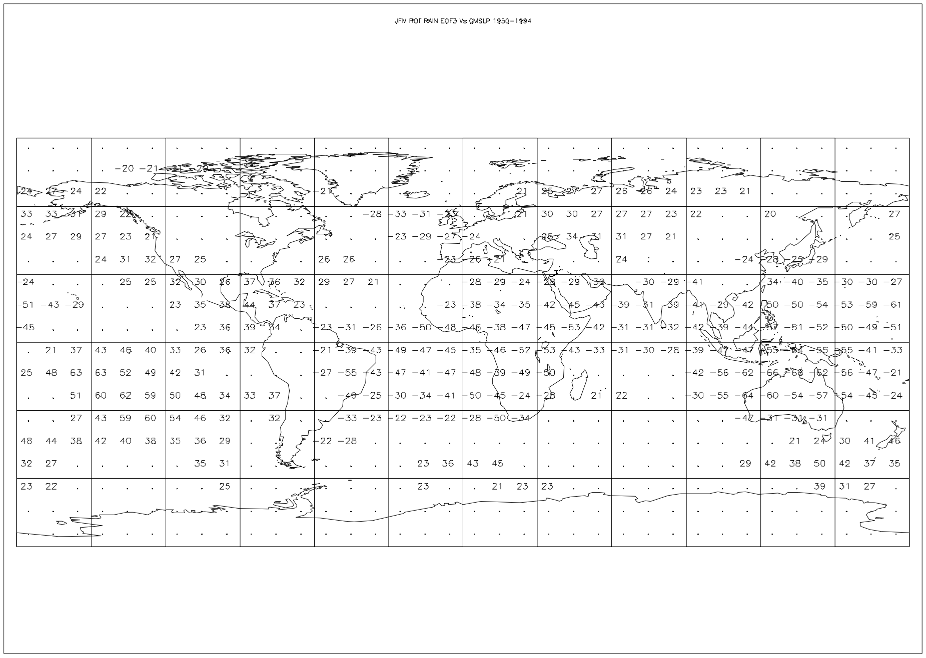


Figure 3d Correlation coefficients (x 100) between Varimax rotated rainfall EOF3 and previous October to December (OND) SST for the period 1950-1993. Rainfall data are from Hulme (1994) and SST data from the UKMO GISST data set. Only correlation coefficients locally significant at the 95% level are shown.

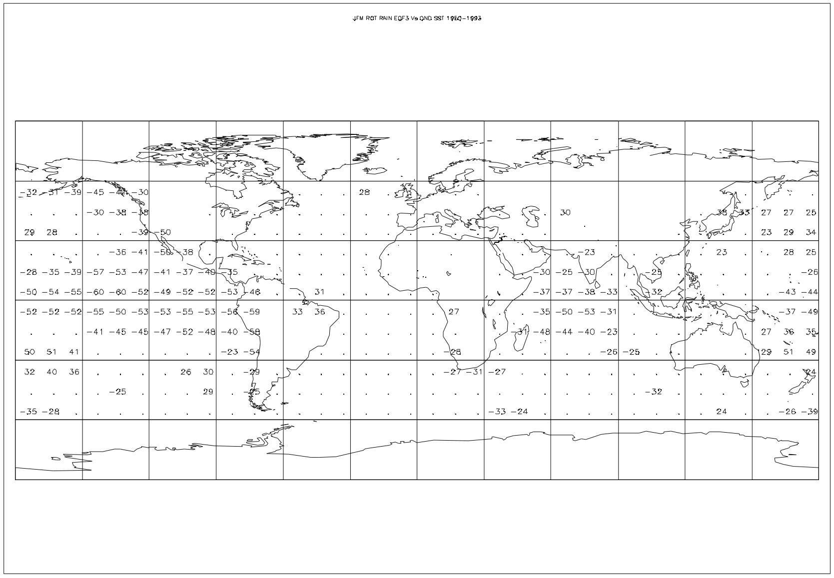
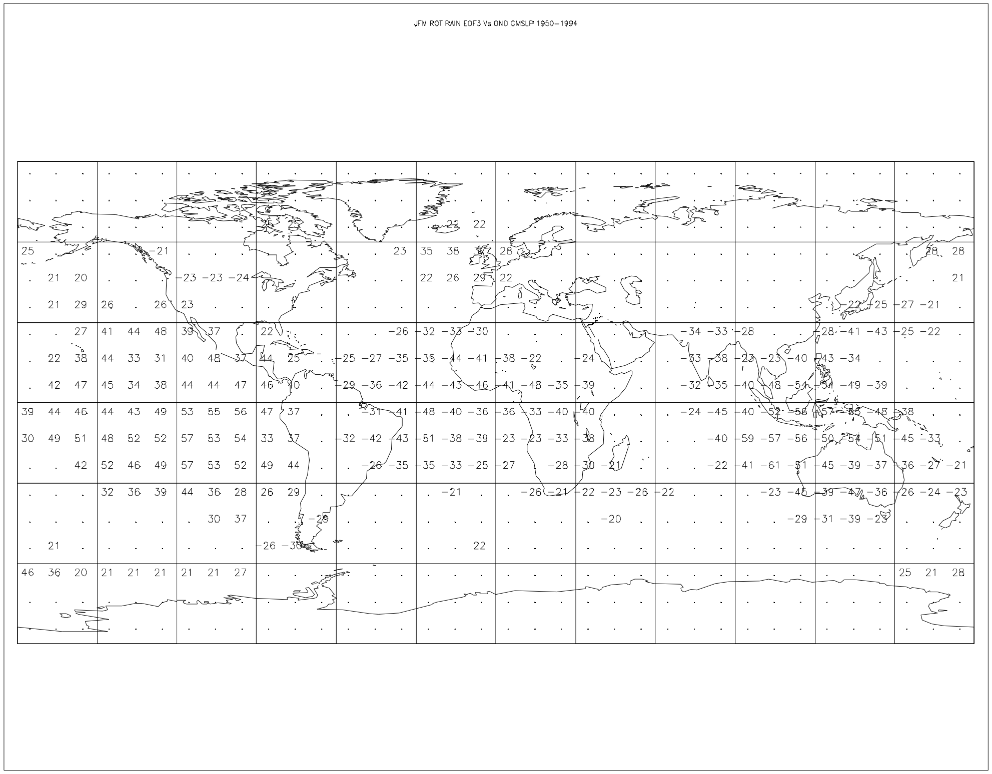


Figure 3e Correlation coefficients (x 100) between Varimax rotated rainfall EOF3 and OND SLP for the period 1950-1993. Rainfall data are from Hulme (1994) and SLP data from the UKMO GMSLP21f data set. Only correlation coefficients locally significant at the 95% level are shown.



Correlation is a useful ‘first look’ at the location of SST and SLP anomalies which relate to rainfall of a particular region. The results considered here suggest that rainfall over the Kalahari and Namib arid regions contain some useful predictability. Predictive models, however, cannot be built from correlation alone.

A multiple regression model offers direct statistical predictive ability:

$$Y' = A + B_1X_1 + B_2X_2 + \ldots + B_kX_k$$

Where:

Y' is the estimated value for Y

A is the y intercept

B_i are the regression coefficients

In this case there is one predictand and several predictors. However, where SSTs are being used as the predictors, there is a clear need to reduce the dimensionality of the data set. If interpolated to 10 x 10 latitude-longitude resolution, some 400 boxes cover the domain 55^o N to 55^o S. Submission of so many predictors to a multiple regression would lead to a false perfect fit. The number of predictors may be reduced by creating simple area averages of the predictors (such as the Nino3 SST region). EOFs offer a useful means of reducing the number of variables to a few indices without losing important signals in the SST data set (e.g. Folland et al. 1991). At the same time the EOFs would indicate those regions which might contribute a minimal signal to the area average. A problem with multiple regression is that the predictors are modelled against one predictand, in this case a single time series of rainfall.

The canonical correlation (CCA) model is given by:

$$U_r = a_1X_1 + a_2X_2 + \ldots + a_iX_i$$
$$V_r = b_1Y_1 + b_2Y_2 + \ldots + b_iY_i$$

where

the linear combination of Y_i in V_r and X_i in U_r are such that the correlation between U_r and V_r is maximised. Here X and Y may represent time series of area averaged rainfall and SST respectively.

CCA is conceptually similar to multiple regression, except that the method involves more than one predictand. A combination of rainfall indices is related to a combination of SST in such a way that the two combinations have maximum correlation. This feature makes canonical correlation an ideal method in the empirical seasonal problem.

Discriminant analysis involves the training of predictor variables such that their combination, linear or multiplicative, optimises the distinction between target classes of predictor variables, in this case rainfall. The discriminant functions are of the form:

$$D_i = d_{i1}Z_1 + d_{i2}Z_2 + \ldots + d_{ip}Z_p$$

where

D_i is the score on the discriminant function i
d_{ip} is the weighting coefficients
Z_i is the standardised values of the p discriminating variables used in the analysis.

In practice, the skill of multiple regression and discriminant analysis in linking predictors to a target rainfall index is comparable.

Neural networks likewise train sets of predictor variables in order to optimise relationships between groups of variables. Use of this technique has been confined to only a few studies (Hastenrath *et al.*, 1995), but is theoretically promising.

Regardless which of the statistical methods are employed, it is generally accepted that the relationship between predictor and predictand should be developed over an independent period of time. This is referred to as the training period. The statistical models developed from this training period are then used to ‘forecast’ (in reality to hindcast!) values for another independent time period, but for which the observed rainfall values are known. These time slices may be made up of either (a) two blocks of years, for example a training period from 1900-1949 and a later period from 1950-1991 or (b) randomly selected years from a single time slice (jack knife technique). Of these the former is more desirable since it provides truly independent periods, whereas the latter may not be truly independent owing to the high degree of interannual persistence in some rainfall and SST time series.

Forming relationships on the basis of truly independent periods may be problematic owing to the non-stationarity of the climate system throughout the twentieth century. This problem besets the calculation of SST EOFs in particular, which are sensitive to the length of the time period and the region for which they re calculated. If calculated over the entire globe, the leading EOF is a climate change signal, indicating the general warming of SSTs in most locations across the global oceans. The sub division of the SST record into two separate periods is thus problematic since the first EOF is often a mixture climate change and some other mode of variability in the SST data such as ENSO (Folland *et al.* 1997).

Thus far SSTs have been stressed as examples of predictor variables. The paradigm within which much of the seasonal forecasting is currently practised rests on the notion that heat fluxes between the ocean and the atmosphere pre-condition the atmosphere and determine the nature of the broadscale flow within which rainfall systems may (or may not) develop. An important addition to this idea is that the condition of the atmosphere into which that forcing is delivered may have a crucial impact on the outcome of such forcing. In other words, the atmosphere may or may not be susceptible to the SST forcing, depending on the atmosphere’s state at the time of the forcing. Atmospheric variables are thus often built into the statistical associations, which have been described above. These typically include the strength and direction of near surface, upper tropospheric and stratospheric winds and the location and strength of important standing eddies such as the sub-tropical anticyclones. Such circulation variables are generally available only from 1950 onwards, being particularly scarce for non-surface parameters. Difficulties result from the few degrees of freedom available to develop statistical models when using such data and the added problem of truly independent testing and training periods.

2.4 Numerical and Statistical Approaches

Success in predicting future states of the tropical Pacific Ocean through numerical modelling (Cane and Zebiak, 1985), have opened new opportunities for seasonal forecasting schemes whereby the empirical models of the sort discussed above may benefit from the predictions of SST from numerical modelling. The assumptions of persistence of SSTs ahead of the forecast delivery date are therefore no longer needed in the case of forecasts which use Pacific Ocean SST. Much then rests on the skill of the models used to predict the SSTs.

3. Operational Forecasts in Africa

Table 1 shows a selection of operational forecasts for several regions in Africa. Most of these appear in the NOAA Experimental Long-Lead Forecast Bulletin. All employ empirical methods. The regions for which seasonal forecasts are available depend on the following factors:

1. Marked component of interannual rainfall variability which is coherent over a large region
2. History of research into the mechanisms associated with the rainfall variability
3. Success in statistically linking predictors such as sea surface temperature with rainfall
4. Economic incentive to generate the forecast

Seasonal forecasting in Africa has focused on the Sahel and the region directly to the south (Sudan), the Guinea Coast, East Africa and southern Africa. Empirical relationships between sea surface temperatures and rainfall exist for all these regions in the rainfall seasons is indicated in Table 1. In addition, each region has experienced crippling droughts during recent years. We consider the general nature of these forecasts, concentrating on southern Africa.

3.1 Sahel

Seasonal forecasts of Sahel rainfall have been issued for over a decade. The UKMO forecast (Folland *et al.* 1991) and the CSU forecasts (Landsea *et al.* 1993) are examined here. UKMO forecasts use the Hulme (1994) rainfall data set and the GISST SST data set (Parker and Folland, 1995). Area averages of rainfall are used to develop an historical time series against which the predictors are trained. Reduction of the SST dimensionality is achieved through the calculation of global SST eigenvectors of which EOF3, showing an interhemispheric contrast in temperature, is a key predictor. In addition, local SSTs in the Guinea coast region and ENSO serve as further inputs. Regression and discriminant analysis are both used as the statistical link between the rainfall and SST predictors. The training period used is from 1946-1992 and the hindcast period 1901-1945.

Table 2 shows the independent hindcast skill (temporal correlation between

Table 1 Selected operational seasonal forecasts for Africa

Area	Institute	Months	Method	Inputs
East Africa	**UKMO**	**Oct-Dec**	**Regression**	**SST**
East Africa	**Univ.of Wisconsin**	**Sept-Dec**	**Neural Nets**	**SST+A**
East Africa	**NOAA**	**Oct-Dec**	**CCA**	**SST**
Sahel	**NOAA**	**Jul-Sep**	**CCA**	**SST**
Sahel	**CSU**	**Jul-Sep**	**Regression**	**SST+A**
Sahel	**UKMO**	**Jul-Sep**	**Regression+LDA**	**SST**
Sthn Africa	**Univ.of Witwatersrand**	**Jan-Mar**	**Regression**	**SST**
Sthn Africa	**Univ. of Zululand**	**Oct-Mar**	**Regression**	**SST+A**
Sthn Africa	**Univ. of Wisconsin**	**Jan-Mar**	**Neural Nets**	**SST**
Sthn Africa	**South Africa Weather Bureau**	**Jan-Mar**	**CCA**	**SST**

Notes: U.K. Met. Office (UKMO), National Oceanic and Atmospheric Administration (NOAA), Colorado State University (CSU). Cononical Correlation Analysis (CCA), Linear Discriminant Analysis (LDA), sea surface temperature (SST), other atmospheric variables (A)

Table 2. Skill (given by correlation coefficients between forecast and observed rainfall) of the UKMO forecasts for the Sahel and the Guinea coast.

			Sahel	Guinea
Forecasting	**1901-45**	**Using**	**.51 (.10)**	**.44 (.02)**
Forecasting	**1946-92**	**Using**	**.68 (.66)**	**.53 (-.33)**

forecasts and observations) in forecasting two of the four North African rainfall regions.

Sahel rainfall forecasts issued by Colorado State University (Landsea *et al.* 1993) divide the region into central and western zones. Predictors include the Quasi-Biennial Oscillation (QBO), previous North African rainfall and surface temperature data, Atlantic ridge and sea surface temperatures, the state of ENSO and Caribbean SST, wind and SLP. The predictors are linked through Least Absolute Deviations (LAD) regression with the model developed over a 1950 to 1995 training period. This forecast model is thus an example of an empirical forecast that includes both SST and atmospheric predictors.

The skill indicated by hindcast testing of the early June regression models for the years 1950 to 1995 is for 58% of the variability in the West Sahel (for four predictors), 59% for the Central Sahel (for five predictors), and 58% for the Guinea Coast (for seven predictors). Recent tests suggest that the true skill (against independent data) would be on the order of 43%, 44% and 41%, respectively (Mielke *et al.* 1996). In contrast, persistence yields skills of 20%, 28% and 0% for the three regions, respectively.

3.2 East Africa

East Africa has two main rainfall seasons. The Long Rains fall from March to May and the Short Rains from October to December (Washington *et al.* 1997). Although the Long Rains produce more rainfall, the post-Monsoon season from October to December is characterised by more spatially coherent rainfall and more widespread correlations with SST. It is likely that the boreal Monsoon reversal, particularly in the Indian Ocean during the Long Rains, disrupts the Walker Circulation in the Indian Ocean, breaking the links with ENSO (Washington *et al.* 1997).

Note: The skill of persistence forecasts is shown in parentheses (after Coleman *et al.* 1997).

Correlations between an area index of East African rainfall and global satellite derived rainfall (using the Xie and Arkin, 1996 data) over the period 1979-1995 for the two rainfall seasons March-May and October-December are shown in Figure 4 (a) and (b) respectively. Two important points are apparent:

1. The region of coherent rainfall in March-May over East Africa (measured as high correlations of rainfall area index with gridded rainfall) is small and confined to East Africa. During the October-December season the region of coherent rainfall is large and extends across the tropical Indian Ocean.
2. Relationships between East African rainfall and rainfall over Indonesia and the eastern tropical Pacific is weak and incoherent in March-May compared with October-December. The structure of the Walker Circulation is clearly evident in October-December. Enhanced rainfall over East Africa is associated with enhanced rainfall in the central and eastern tropical Pacific but suppressed rainfall over

Indonesia. An ENSO-like structure is only very weakly evident in March-May and the sign of the correlation is reversed.

Figure 4a Correlation between an area index of East African rainfall and global rainfall for MAM 1979-1995. Data is the Xie-Arkin satellite rainfall data set at 2.5 by 2.5 resolution. Correlations with a modulus larger than 0.38 are locally significant at the 95% level.

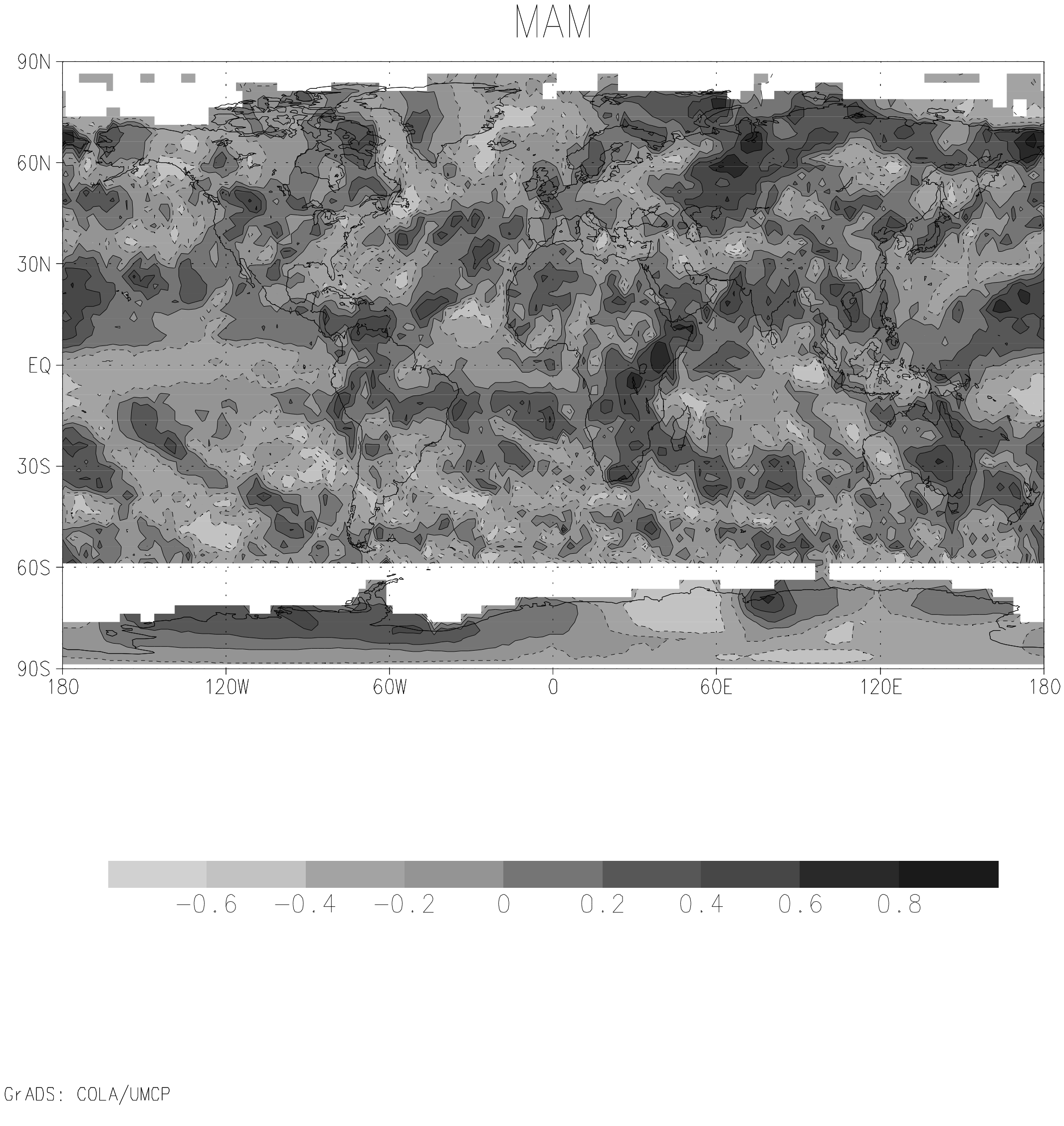
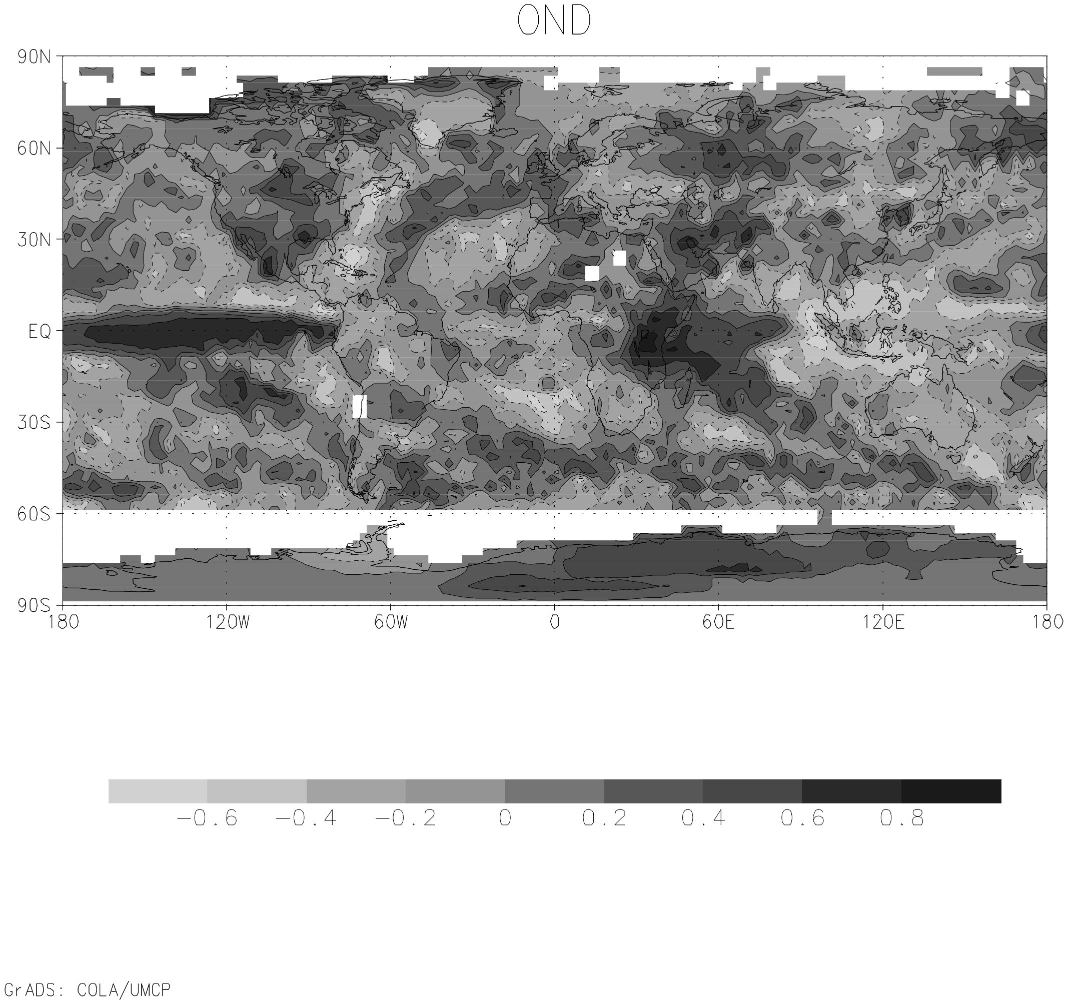


Figure 4b Correlation between an area index of East African rainfall and global rainfall for OND 1979-1995. Data is the Xie-Arkin satellite rainfall data set at 2.5 by 2.5 resolution. Correlations with a modulus larger than 0.38 are locally significant at the 95% level.



Efforts at empirical forecasting of East African rainfall have relied on fundamental research relating to ocean-atmosphere dynamics in the Indian Ocean (Hastenrath and Greischar, 1993; Hastenrath *et al.* 1993) which have shown that equatorial Indian Ocean wind direction is a key parameter relating to rainfall. Greischar and Hastenrath (1997) use neural networks as the statistical tool linking the near surface equatorial wind with rainfall. Persistence in the wind field from the pattern set in the previous seven years is the basis of the link.

3.3 Southern Africa

The rainfall season in southern Africa runs from October to March, but the late summer (January-March) includes rainfall of tropical origin which is generally thought to be more predictable than rainfall of midlatitude origin (Harrison, 1984, Tyson, 1986; Barnston et al., 1996). Work on southern African rainfall and circulation variability in late summer is extensive (see reviews in Tyson, 1986 and Mason and Jury, 1997). Southern African rainfall has been shown to respond directly to SST (Walker, 1990; Jury and Pathack, 1993; Jury *et al*., 1994; Mason, 1995; Mason, 1997). Seasonal forecasts in southern Africa have been developed and co-ordinated by the recently founded South African Long-Lead Forecast Forum (SALIF).

The seasonal forecasts issued by Jury (1996) are considered here. This seasonal forecasting scheme is an example of a multiple regression scheme with numerous predictors from both the atmosphere and ocean. These include Niño3 SST, Southern Oscillation Index, tropical Atlantic 200 hPa winds, Indian Ocean SSTs, near surface tropical Indian Ocean winds, convection near the equatorial African coast, SW Atlantic Ocean SST and SSTs of the coast of NE Brazil. Data used in this scheme originates from COADS and GISST, CPC, ECMWF. Data reduction has been achieved through rotated EOFs (SST) and area averages. Owing to the satellite outgoing longwave radiation (OLR) indices, all model training periods were limited to 1971-1993.

A mean hindcast r-squared of 65% (assuming 17 degrees of freedom) shows a high model skill. Several multiple regression equations, each relating to rainfall of a number of sub regions had a mean hindcast r-squared fit of 69%. Jury (1996) notes that a partial validation of the model skill was undertaken using a jack-knife technique, where each year was held out in turn and the predictor term coefficients (but not the choice of predictors) were determined from the remaining years and used to forecast the withheld year. Mean correlations between observed and model predicted values were 0.73 for early summer and a somewhat higher 0.79 for late summer models.

3.4. Problems in Seasonal Forecasting

The role of ENSO in modulating African rainfall variability has been stressed throughout this paper. ENSO imparts a significant signal to most of the core areas of operational forecasts in Africa. Clearly, changes to the ENSO system would have important implications for the veracity of the operational forecasts. Such changes are not unprecedented in the twentieth century record.

Figure 5 (a) and (b) shows the secular variability of the Southern Oscillation Index for the austral summer (January to March). This has been calculated by means of a 15-year running standard deviation of the SOI of both observed standardised Tahiti-Darwin sea level pressure (a) and the standardised Tahiti-Darwin equivalent from a century long integration of the UKMO GCM (HADAM2A) (b). The collapse in variability of the SOI, corresponding to a reduced number of intense ENSO events, is apparent in both the model and the observed data. Until this feature of global climate variability is better understood, seasonal forecasts which rely on ENSO as their main predictor may be subject to unacceptably low levels of predictability were the current phase of ENSO activity to wane. Indeed, much of the early work of Walker and Bliss

(1932) lost favour owing to the demise of ENSO events following the publication of his pioneering work.

3.5 Decadal Variability

The importance of the low frequency component of southern African rainfall has long been known (Tyson, *et al.* 1975). Although bi-decadal variability explains less than 30% of the total rainfall variability, the underlying oscillation has been used to predict the prolonged southern African drought of the 1980s (Tyson and Dyer, 1980), to infer climates of the Last Glacial Maximum (Cockroft *et al.* 1987), the late Holocene (Tyson and Lindesay, 1992; Cohen and Tyson, 1995) and those of the next century (Tyson 1993). Physical mechanisms to explain this bi-decadal rainfall variability have, however, remained elusive.

Figure 6, which shows the relationship between low frequency southern African January to March rainfall and the January to March component of global low frequency SST EOFs, suggests that much of the rainfall variability is associated with SSTAs in the southern central Pacific (5 - 15° S) and the southern Indian Ocean, (25 – 45° S) (r=0.59 p=0.05). The southern African droughts of the 1980s, 1960s and 1920s, together with the wet spell of the 1970s and 1950s, are in phase with modulation of these SST EOFs. The relationship degrades between the years 1925 and 1945 (Figure 6), corresponding with the broad period of low variability in the SOI shown above. An important question thus surrounds the utility of rainfall forecasts which are issued on multi-annual timescales. That such skill exists is beyond doubt.

4. Responses to Seasonal Climate Forecasts

The preparation of operational seasonal forecasts results in multiple forecasts from different model centres (
). Successfully using and responding to the seasonal climate forecasts depends on how the forecasts are disseminated, reviewed and acted upon (Figure 7). In some cases, there may be efforts to reconcile the various predictions and provide a composite forecast. For instance, the International Research Institute for climate prediction have initiated forecast panels to review the predictions and discuss issues of how the forecasts should be used (IRI, 1998).

With or without reconciliation, the forecasts are disseminated through a wide variety of channels. The traditional mode is through the World Meteorological Organisation's network of national meteorological centres (NMCs). In contrast to hierarchical and official channels, widespread access to the Internet has accelerated the speed of communication. Many organisations are intermediaries, as well as responding in their own way. For example, NMCs might act on a warning to inform a governmental drought preparedness working party at the same time as passing on the warning to the public.

Local users, in terms of farmers and resource managers are the ultimate beneficiaries of forecasts. Figure 7 explicitly highlights vulnerable socio-economic populations as a separate beneficiary. To prevent famine, forecasts much reach and benefit such populations. But, this is far from a necessary response to issuing climate forecasts.

Each decision-maker must decide how to respond. Confirmation of the forecast is often achieved by checking with other official and informal sources. Clear environmental signals may be required to confirm the formal prediction based on remote statistical techniques. Specific responses are subject to diverse forms of analysis, ranging from formal cost-benefit analysis to collective, precautionary behaviour. Initial responses are specific adjustments to the expected conditions. Over the longer term, as forecasts prove reliable this information may be included in strategic management decisions.

The next section focuses on aspects of household food security that influence the utility of climate forecasts. Our particular concern is with vulnerable populations and responses that promote food security in Africa.

5. Household Vulnerability and Coping strategies

This section presents concepts of vulnerable food systems, with a focus on household strategies for coping with climatic variations. The final section relates progress in climate prediction to household vulnerability and coping strategies.

Conceptions of food security have evolved over the past few decades, and it has increasingly been recognised that “much more was involved in food security than just climate.” (Glantz 1997). Since the World Food Conference in 1974 there have been three major shifts in food security thinking: changing scale from global to household and individual; broadening the focus from food alone to long-term resilience of livelihoods; and diversifying from objective indicators such as target levels of consumption to more subjective perceptions of security (Maxwell 1994).

A rich literature now exists on coping strategies, capacity to withstand shocks and stress, and more generally vulnerability (see IDS 1991 and Downing 1991 for famine early warning systems; Downing 1996 in relation to climate change; and the special issue of the Internet Journal for African Studies (e.g., Glantz 1997) for recent papers on climate prediction).

Vulnerability can be defined as the “degree of loss resulting from a potentially damaging phenomenon” (UNDHA 1993, p63) or “the insecurity of the well-being of individuals, households, or communities in the face of a changing environment” (Moser 1996, p2).

Critical questions are: What determines the relationship between a hazard and its effects? Who are vulnerable? Why? These require a broader analysis of vulnerability. This amplification of vulnerability stems from the literature on development and livelihood security (for example, see Chambers 1989; Dow and Downing 1995) rather than the more circumscribed work on disaster relief. As such, it begins to place vulnerability in the wider structures of political ecology.

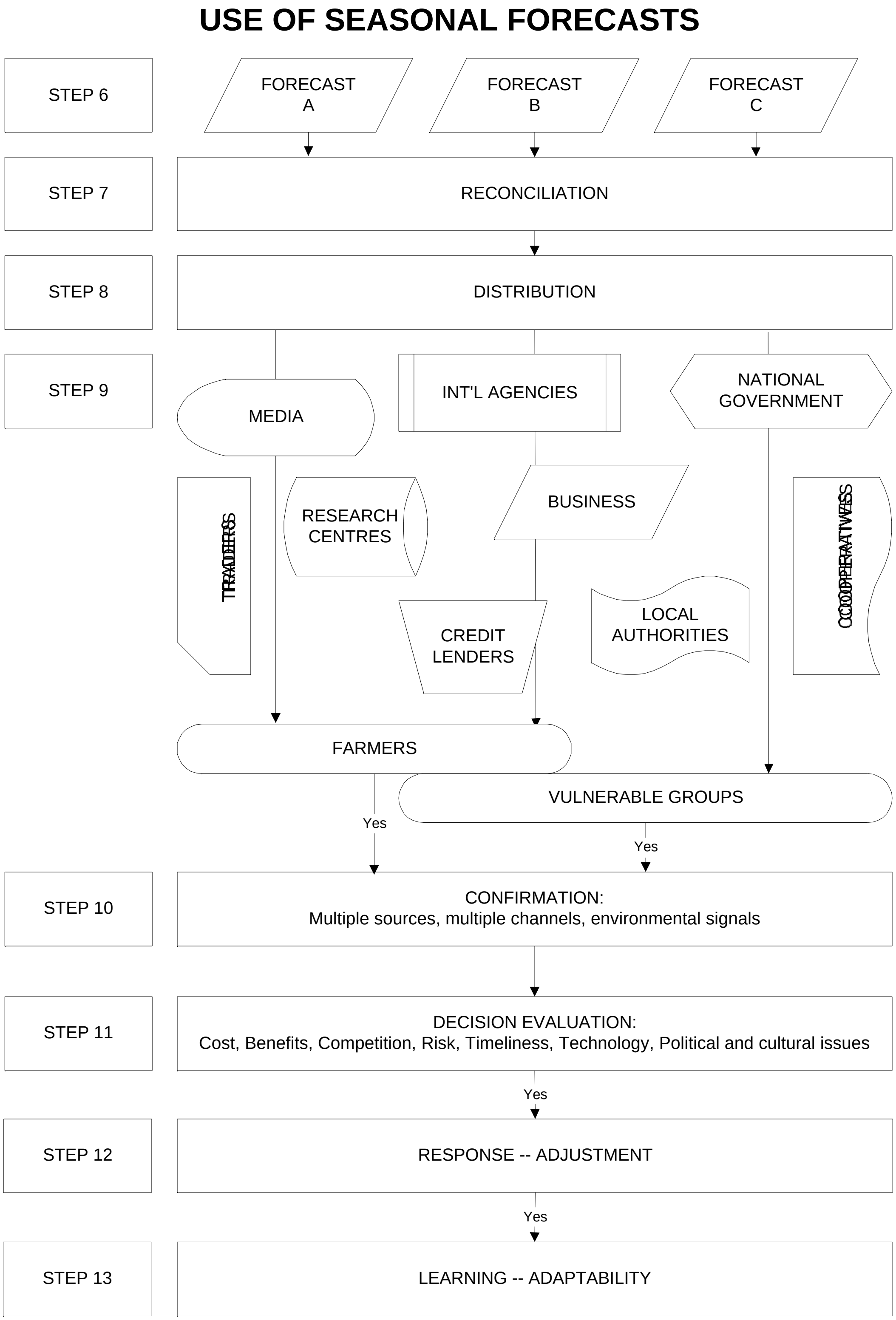


Figure 7. Use of seasonal forecasts.

Particular vulnerabilities are the conjuncture of social, economic and political structures. Anderson and Woodrow (1989) chart vulnerability and capability related to physical/material resources, social/organisational relations, and motivational/attitudinal aspects. Bohle *et al.* (1994) suggest a tri-partite causal structure of vulnerability (Figure 8) based on the human ecology of production, expanded entitlements in market exchanges, and the political economy of accumulation and class processes. Vulnerability *per se* is best viewed as "an aggregate measure of human welfare that integrates environmental, social, economic and political exposure to a range of harmful perturbations" (Bohle *et. al.* 1994: 37-38). In one of the fullest treatments of vulnerability and disasters, Blaikie *et al.* (1994) regard vulnerability as a product of such characteristics as ethnicity, religion, caste membership, gender and age that influence access to power and resources. One application of the concept of vulnerability is in the US Famine Early Warning System, which monitors food crises in Africa (Figure 9).

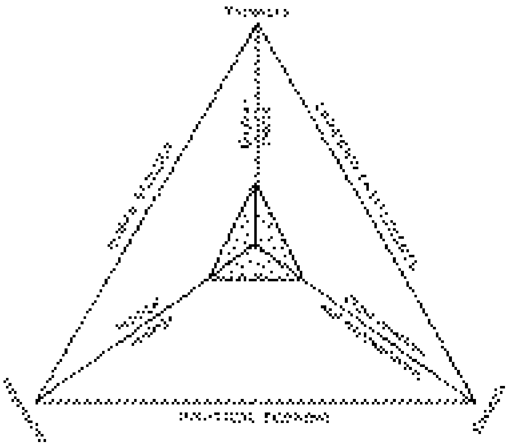


Figure 8: Three dimensions of vulnerability. The fundamental processes that determine vulnerability are implied in the conjuncture of the human ecology of production, exchange entitlement and political economy. Vulnerable groups can be located in different sectors of the triangle. For instance, subsistence farmers would be more dependent on their land and labour resources than on market exchanges. The destitute and refugees are closely tied to the political economy of aid. The urban poor are dependent on what they can earn in informal markets. Source: after Bohle *et al.*)

Regardless of the nuance of vulnerability frameworks, key concepts are:

- Vulnerability is a relative measure. The analyst, whether the vulnerable themselves, external aid workers, or society in broad terms, must define what is a critical level of vulnerability.
- Everyone is vulnerable, although their vulnerability differs in its causal structure, its evolution, and the severity of the likely consequences.

- Vulnerability relates to the consequences of a perturbation, rather than its agent. Thus, people are vulnerable to loss of life, livelihood, assets and income, rather than to specific agents of disaster, such as floods, windstorms or technological hazards. This focuses vulnerability on the social systems rather than the nature of the hazard itself.
- The locus of vulnerability is the individual related to social structures of household, community, society and world-system. Places can only be ascribed a vulnerability ranking in the context of the people who occupy them.

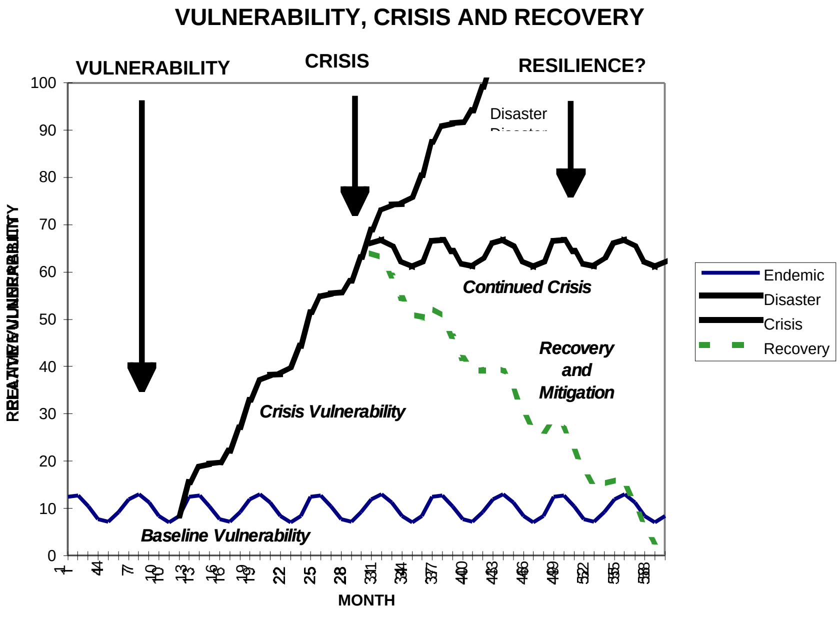
These concepts of vulnerability shift the focus of vulnerability away from a single hazard to the characteristics of the social system. Vulnerability is explicitly a *social* phenomenon related to a human value system.

Figure 9: Vulnerability Matrix for the U.S. Famine Early Warning System. Vulnerability is portrayed as a progression from slightly vulnerable to famine. At each level of vulnerability, households pursue different strategies—from production to survival. Consequently, different forms of intervention are warranted for different levels of vulnerability, from targeted development assistance to supporting coping strategies and ultimately emergency food relief. Source: U.S. Famine Early Warning System (FEWS) (1992)

Level of Vulnerability	Conditions of Vulnerability	Typical Coping Strategies and/or Behaviours	Interventions to Consider
MODERATELY VULNERABLE	**Drawing-down Assets**	**Assets/resources/ wealth**: coping measures include drawing down or liquidating less important assets, husbanding resources, minimising rate of expenditure of wealth, unseasonable "belt-tightening" (e.g., drawing down food stores, reducing amount of food consumed, sale of goats or sheep)	**Mitigation and/or Development: Asset Support** (release food price-stabilizatio stocks, sell animal fodder at "social prices", community grain bank, etc.)
	Maintaining Preferred Production Strategy	**Production strategy**: only minor stress-related change in overall production/income strategy (e.g., minor changes in cropping/planting practices, modest gathering of wild food, inter-household transfers and loans etc.)	
SLIGHTLY VULNERABLE	**Maintaining or Accumulating Assets**	**Assets/resources/ wealth**: either accumulating additional assets/resources/ wealth or only minimal net change (normal "belt-tightening" or seasonal variations) in assets, resources or wealth over a season/year. i.e., coping to minimise risk	**Development Programs**
	Maintaining Preferred Production Strategy	**Production Strategy**: any changes in production strategy are largely volitional for perceived gain, and not stress related	

HIGHLY VULNERABLE	**Depleting Assets**	**Assets/resources/ wealth**: liquidating the more important investment, but not yet "production", assets (e.g., sale of cattle, sale of bicycle, sale of possessions such as jewelry)	**Mitigation and/or Relief: Income and Asset Support** (Food-for-work, Cash-for-work, etc.)
	Disrupting Preferred Production Strategy	**Production Strategy**: coping measures being used have a significantly costly or disruptive character to the usual/preferred household and individual life-styles, to the environment, etc. (e.g., time-consuming wage labour, selling firewood, farming marginal land, labour migration of young adults, borrowing from merchants at high interest rates)	
EXTREMELY VULNERABLE **Or**	**Liquidating Means of Production**	**Assets/resources/ wealth**: liquidating "production" resources (e.g., sale of planting seed, hoes, oxen, land, prime breeding animals, whole herds)	**Relief and/or Mitigation: Nutrition, Income and Asset Support** (food relief, seed packs, etc.)
AT-RISK	**Abandoning Preferred Production Strategy**	**Production strategy:** Seeking non-traditional sources of income, employment, or production that	
FAMINE	**Destitute**	**Coping Strategies Exhausted**: no significant assets, resources, or wealth; no income/production	**Emergency Relief** (food, shelter, medicine)

Figure 10: Dynamic vulnerability during a food crisis. Source: after Bohle (1993).



Vulnerability changes over time incorporating social responses as well as new rounds of hazardous events. Bohle (1993) captures the dynamic nature of vulnerability (Figure 10). In this illustration, vulnerability begins to increase at the end of the first year, reaching a crisis at 30 months. Here the outcome of the crisis is uncertain. In a resilient society with appropriate interventions, recovery and mitigation can bring vulnerability back down to baseline (or lower) levels. Unmitigated, or in conjunction with another event such as civil strife following drought, the crisis may become a disaster. Or, some groups and communities may continue in crisis, on the edge of disaster. Social groups vary in the structure of their vulnerability. For example, the rural landless (without non-agricultural incomes) are typically more sensitive to food shortages, with less on-farm storage and buffering capacity than smallholders. So, the trajectories shown here may be sharper and the outcome different for different groups, even in the same region.

Specific groups of vulnerable peoples can be defined. While the precise boundaries of vulnerability vary between cultures and environments, the common catalogue often starts with the characteristics of individuals:

- Women, especially those with special nutritional needs during and after pregnancy
- Children, who are less resilient in terms of nutrition or who may already be malnourished
- Elderly, who may suffer from a lack of mobility and less mental awareness
- Disabled and disease-stricken, who have special needs and require routine assistance for survival

At the household level, vulnerability may be delineated by socio-economic class and means of securing a livelihood: In rural areas:

- Smallholder agriculturalists may be resource-poor with limited access to land and labour, in marginal lands, with varying degrees of empowerment and access to emergency and development assistance.
- Pastoralists often have little empowerment to recurrent development resources, yet operate in regions with pronounced climatic hazards. However, they often attract international assistance during a disaster.
- Landless labourers relying on casual employment are often at the margin of poverty with little ability to accumulate savings or to invest in more productive activities.
- Destitute peoples have been forced out of productive activities, often due to ill health and old age in addition to being impoverished through natural disasters and other causes. Where the destitute migrate to urban centres, they may have more opportunities for assistance and work, although this depends on the nature of the receiving society.

In urban areas:

- The unemployed and destitute in urban areas may be incorporated into social welfare systems (often informal), but suffer significantly in times of disaster if the numbers become too large and if relief fails to target their pressing needs.
- Underemployed poor people, comparable to landless labourers, are on the margins of survival. A slow deterioration in the economy can affect this group, often leading to a major but largely hidden crisis.

- Refugees are the most visible vulnerable population, usually swelling in numbers after a disaster. They may also be vulnerable to further hazards, for instance while attempting to return to their homes and occupations or in camps with inadequate protection against floods, heat and frost, among other hazards. Yet, this group tends to benefit from its visibility and various formal channels of assistance.

Finally, community characteristics may be enumerated that place vulnerable social groups at risk from specific types of hazards. Such vulnerability includes, for example:

- Building location, design and standards that determine the resilience of homes, work places and community meeting places.
- Occupancy patterns and who is in substandard buildings, when, for how long, etc.
- Transport and mobility, for example the pathways between home and work may cross hazardous regions and access to safe areas such as cyclone shelters in Bangladesh.
- Health, water, power and communication infrastructure that sustain life as well as provide channels for relief assistance.

6. Coping and climate prediction

How does the broad range of vulnerability and capacity in Africa relate to emerging skills in climate prediction? On the one hand there are tremendous opportunities.

Climate, and particularly drought, affects a wide range of activities beyond just crop yields: land quality; on-farm storage; water supplies; labour migration; rates of urbanisation and rural population growth; use of inputs such as fertiliser; farm income; farmers' skill and experience and so forth (Glantz, 1996: p.145-148).

Seasonal forecasts have been used in some parts of Africa, for example in predicting maize yields in Zimbabwe (Cane *et al.*, 1994). Several studies have analysed costs of El Niño events, for example, and predict considerable savings could be made if accurate warnings of the onset of the phenomenon could be used (see Glantz *et al.*, 1997). The 1991-1992 El Niño-related drought in southern Africa was estimated to cost the US government $800 million in responses to the phenomena (Farmer 1997).

For agriculture and water resource management the benefits could be quite extensive, altering the entire basis of economic planning in Africa. The utility of reliable long-range forecasts, therefore, could be enormous, not just for earlier warning of need for emergency aid. Policy- makers and farmers alike should benefit.

Beyond the immediate concerns of an individual season, the process of developing climate prediction and response capabilities could have substantial benefits. Long-term learning and partnership between climatologists, agriculturalists and decision-makers should heighten awareness of information needs and focus development. An open process of information access, as in the case of forecasts distributed over the Internet, could assist development of efficient and equitable agricultural and food marketing systems. An ultimate goal is to reduce uncertainty and risk in investment in drought-prone areas.

Making the best use of climate predictions will not be without problems. As for both climate prediction and vulnerability, a considerable volume of literature addresses the use of weather prediction, but mostly from a developed country perspective (see Easterling 1986; Sonka *et al.* 1987; Changnon 1992; Nichols, 1996;). Issues of particular interest in Africa include:

1. Targeting users. The potential users of climate forecasts vary, from the local to global, from producers to consumers, from the at-risk to those with a general interest in the state of the world (Table 2). Each has different needs for information, and different potential benefits. Common concerns are type of weather event, forecast lead time and precision (Table 3).
2. Reaching vulnerable livelihoods. Beyond "decision-makers" or "users", the context of vulnerability conditions the utility of climate predictions in preventing famine and ameliorating poverty. The vulnerable may not receive predictions through timely and reliable channels, and may distrust official warnings. They are likely to have fewer resources to respond to predictions; land and land tenure, labour for planting, credit for inputs, storage of surplus, and access to markets already hinder agricultural development among the rural poor. Additional information may not be the major constraint to ameliorating vulnerability.
3. Generalising spatial and temporal information. Climate predictions may enter the process with clear spatial and temporal resolution, bands of uncertainty, and even colour maps and visualisation techniques. As the predictions work their way through various dissemination channels, predictions are likely to be generalised. Warnings at a regional scale will be taken as true for each locale within the region. Projections for local conditions (such as the semi-arid maize growing region of southern Zimbabwe) are likely to be extended to similar zones elsewhere and adjacent geographic regions, even though they may experience wetter conditions on average. Forecasts for specific time periods, such as the start of the rains, may be interpreted as true to the entire season. The generalised message may well be more extreme than intended, as appears to have been the case in southern Africa in 1997/98.
4. Lag between forecasts and dissemination. Working through the forecast process and dissemination channels takes time. The original message and subsequent revisions will not be current for any user. For some users, perhaps most critically for the vulnerable populations, this delay may be significant. Where organisational rules resist change, an early planned response may be inappropriate in light of new information. For example, a prediction of good rains following drought may not be sufficient to reduce food aid operations, which have long lead times in planning, ordering, shipping and distribution. The long lead times also allows messages to be distorted (#3), in contrast to short-term forecasts which quickly expire.
5. Maladaptive responses. Not all responses to predictions will be beneficial to every user. Information is not a public good; and climate predictions should be seen as part of competitive and institutional processes that may be maladaptive. Smallholder agriculturalists, for instance, compete in a mixed commodity/subsistence farming system. During a drought, without irrigation, they may be relatively worse off if commercial producers can maximise production and control markets. In South Africa, credit organisations apparently reduced credit to

smallholders during 1997, in response to the early warning of delayed rains and a poor season (Schulze, personal. comm., 1998). Lower yields in this sector may reflect this institutional risk management rather than poor rains (which turned out to be wetter than the initial forecast suggested). The urban poor may be particularly susceptible to rising prices, perhaps in anticipation of shortages as a consequence of climate forecasts.

False alarms. Reliability is often seen as a major constraint in climate prediction. The effect of a false alarm, or misleading forecast, can taint an emerging system. This is a major concern for weather offices, which regularly measure their skill. It is more difficult to demonstrate skill in climate prediction since there are far fewer independent events for validation (perhaps only two per year). The effect of false alarms will vary for each user. Few will use climate predictions as the sole criteria for decisions; all are accustomed to risk in decision-making

Type of User	Potential Application of Forecast			Benefits
	Multi-year Forecasts	Seasonal Forecasts	Within-Season	
Commercial Producers	Capital and land investment	Acreage planted; Planting dates; Crop/variety selection; Water management	Water management; Application of inputs; Harvest dates	Increased certainty and reduced risk; Improved financial viability; Long-term survival; Enhancement of comparative advantage
Subsistence Producers	Limited, possibly diversification and off-farm savings	Planting dates; crop/variety selection	Limited	Improved food security in poor years; Improved marketable surpluses in good years
Agricultural Support Services	Plant and capital investment; Research and development priorities; Location decisions; Production strategies	Product selection; Sales forecasts; Pricing policy	Adjustments to marketing strategy	Improved financial viability; Ability to respond better to farmers' requirements; Recovery from drought
Agricultural Extension Services	Promotion of drought mitigation strategies; Development of improved extension advice	Preparation of dynamic, climate specific extension advice to subsistence and smallholder producers	Specific adjustments to earlier extension messages and advice	Better extension service to subsistence and smallholder producers

Source: after Gibberd *et al.* (1996).

Weather	Farm Type			Decision	Required Lead Time	Required Precision/ Accuracy
	Subs.	Trans.	Comm.		months	%
Drought	✓	✓	✓	Plant or not plant; Choice of crops and tillage; Contingency plans for livestock and water	3	90
Overall quality of the rainy season	✓	✓	✓	Choice of crops, crop varieties and tillage; Irrigation planning to use impounded water efficiently; Arrange seasonal credit	3	80
Onset of planting rains	✓	✓	✓	Timing of field operations; Expectation of yield where correlated to planting date	0.5-1	80
Nature of early rains	✓	✓	✓	Whether to risk dry planting, depending on frontal, widespread rainfall or convective, isolated, discontinuous rainfall	0.5	80

Beginning of mid-season drought		✓	✓	Choice of variety and planting date	3	80
Length of mid-season drought		✓	✓	Choice of crop	3	60
Severity of mid-season drought		✓	✓	Preparing to divert grain crops to fodder	3	60
End of rainy season	✓	✓	✓	Timing of harvest operations; Possibility of late catchcrops; Planning post-harvest tillage	2	80
Amount of winter rains		✓	✓	Plan summer crops for optimum winter cereal crop; Possibility of other winter crops	6	80
Distribution of winter rains		✓	✓	Level of inputs to invest in winter crop	1	60
First frost date	✓	✓	✓	Planting date for late planted crops; Cut-off planting date for frost-sensitive crops	6	80
Last frost date			✓	Date of winter cereal planting to avoid frost at anthesis; Planning spring plantings under irrigation	6	80
Frost frequency over winter			✓	Preparedness for frost on winter horticultural crops	1	40
Dry season severity	✓	✓	✓	Off season farm capital development; Livestock management	1	40
Dry season length	✓	✓	✓	Disposal of crop residues; Fodder rationing to livestock; Livestock mobility and sales	1	40
Above normal summer temperatures			✓	Precautions in dairying and horticulture	3	6
Below normal winter temperatures			✓	Precautions in small stock and horticulture	3	40

Notes: Types of farmers are subsistence, transitional (or emerging) and commercial. Precision/accuracy: 100% = completely reliable, 0% = same as no forecast.
Source: based on Gibberd, *et al.* (1996)

6. Conclusions

Droughts in 1983-4 and 1991-2 were both described as unusual or the worst to affect the subcontinent in the 20th Century (Downing *et al.*, 1989; Rook 1997). It is remarkable that, despite serious reductions in harvests, widespread hunger was averted in 1991-92, largely attributed to the rapid responses instigated by regional early warning systems. In early to mid- 1997, prediction of drought (in southern Africa) and flood (in eastern Africa) raised the question of whether improvements in climate predictions would be able to improve household food security (see the IJAS 1997, especially papers by Buckland, Callear, Cane, Dilley, Farmer, Nicholls, Ogallo and Wolde-Georgis).

The effects of climate, and in particular climatic hazards, depend very much on the vulnerability of the population. The use of climate predictions is also related to vulnerability, both in terms of direct effects and in terms of how easy it is for a given group to access climate predictions and respond to them. Building institutional capacity to provide medium-term climate forecasts to enhance adaptive resource management in Africa would be a major step forward both in achieving present development aims and in preparing for climate change. Research on how to disseminate information, and ensure it is applicable at a household level is crucial.

Would better forecasts have altered the outcomes of diverse African food crises over the past decade or longer? The answer depends on how the political economy would have adapted to widespread dissemination of forecasts (and other data on climate and production). Good forecasts, in each case, would not have been sufficient to ensure early responses, to bolster sustainable livelihoods and to prevent vulnerable populations from being displaced. "There is frequently a danger that forecasting can become an end in itself, detached from many of the social processes that give rise to hunger and starvation" (Tapscott 1997).

7. Ackowledgements

This paper draws upon a paper presented to the START Workshop on Climate Variability Prediction, Water Resources and Agricultural Productivity: Food Security in Sub-Saharan Africa and Downing and Stowell (1998). RW acknowledges gratefully acknowledges support from the Doe and from the Univ. of Oxford Research Committee. Thanks to Brad Delp and Tom Scholz.

References

Anderson, M. B. and P. J. Woodrow (1989). Rising from the Ashes: Development strategies in times of disaster. Boulder CO, Westview Press.

Barnston, A. G., Thiao, W. & Kumar, V., 1996. Long-lead forecasts of seasonal precipitation in Africa using CCA. Journal of Climate, 11, 506-520.

Bjerknes, J. 1966: A possible response of the atmospheric Hadley Circulation to equatorial anomalies of ocean temperature, Tellus, 18, 820-829.

Bjerknes, J. 1969: Atmospheric teleconnections from the equatorial Pacific, Monthly Weather Review, 97, 163-172.

Blaikie, P., Cannon, T., Davis, I. and Wisner, B. (1994). At Risk - Natural Hazards, People's Vulnerability, and Disasters. London, Routledge.

Blanford, H.F. 1884 On the connection of Himalayan snowfall and seasons of drought in India. Proc R Soc London, 37, 3-22.

Bohle, H. G. (1993). The geography of vulnerable food systems. Coping with Vulnerability and Criticality. Bohle, H. G., Downing, T. E., Field, J. O. and Ibrahim, F. N. Saarbrucken, Verlag Breitenback: 15-29.

Bohle, H. G., Downing, T. E. and Watts, M. J. (1994). "Climate change and social vulnerability: towards a sociology and geography of food insecurity." Global Environmental Change **4**(1): 37-48.

Callear, D. (1997). "Can we get policymakers to take notice of information on drought and imminent food shortages?" Internet Journal of African Studies(2): www.dir.ucar.edu/esig/ijas/ijasno2/callear.html.

Cane, M. A. (1997). "ENSO and its prediction: How well can we forecast it?" Internet Journal of African Studies(2): www.dir.ucar.edu/esig/ijas/ijasno2/cane.html.

Cane, M. A., Eshel, G. and Buckland, R. W. (1994). “Forecasting Zimbabwean maize yield using eastern equatorial Pacific sea surface temperature.” Nature **370**: 204-205.

Cane, M.A. and Zebiak, S.E. 1985: A theory for El Niño and the Southern Oscillation, Science, 228, 1085-1087.

Chambers, R. (1989). “Vulnerability, coping and policy.” IDS Bulletin **20**(2): 1-7.

Changnon, S. A. (1992). “Contents of climate predictions desired by agricultural decision makers.” Journal of Applied Meteorology **31**: 1488-1491.

Chen, D., S. E. Zebiak, et al. (1995). “An improved procedure for El Niño forecasting: implications for predictability.” Science **269**: 1699-1702.

Cockcroft, M.J., Wilkinson, M.J. and P.D. Tyson 1987: The application of a present-day climatic model to the late Quaternary in southern Africa. Climatic Change 10(2), 161-181.

Cohen, A.L.; Tyson, P.D. 1995: Sea-surface temperature fluctuations during the Holocene off the south coast of Africa: implications for terrestrial climate and rainfall. Holocene. 5(3), 304-312.

Colman, A.; Davey, M.; Harrison, M.; Evans, T. and Evans, R. 1997: Multiple Regression and Discriminant Analysis Predictions of Jul-Aug-Sep 1997 Rainfall in the Sahel and Other Tropical North African Regions, Experimental Long Lead Bulletin, June 1997.

Davies, S., Buchanan-Smith, M. and Lambert, a. R. (1991). Early Warning in the Sahel and Horn of Africa: The State of the Art. Brighton, UK: Institute of Development Studies.

Dilley, M. (1997). “Warning and intervention: What kind of information does the response community need from the early warning community.” Internet Journal of African Studies(2): www.dir.ucar.edu/esig/ijas/ijasno2/dilley.html.

Dow, K. and Downing, T. E. (1995). “Vulnerability research: Where things stand.” Human Dimensions Quarterly **1**(3): 3-5.

Downing, T. E. (1991). Assessing Socioeconomic Vulnerability to Famine: Frameworks, Concepts, and Applications., Brown University.

Downing, T. E. and Stowell, Y. (1998). Household food security and coping with climatic variability in developing countries. Handbook of Weather, Climate and Water. Glantz, M. H. New York, McGraw-Hill**:** forthcoming.

Downing, T. E., Ed. (1996). Climate Change and World Food Security. Heidelberg, Springer.

Downing, T. E., Gitu, K. W. and Kamau, C. M., Eds. (1989). Coping with Drought in Kenya: National and Local Strategies. Boulder, Lynne Rienner.

Downing, T. E., Ringius, L., Hulme, M. and Waughray, D. (1997). “Adapting to climate change in Africa.” Mitigation and Adaptation Strategies for Global Change **2**: 19-44.

Easterling, W. E. (1986). “Subscribers to the NOAA Monthly and Seasonal Weather Outlook.” Bulletin of the American Meteorological Society **67**: 402-408.

Famine Early Warning System (FEWS) (1992). Vulnerability Assessment. Arlington, VA, FEWS/Pragma Office.

Farmer, G. (1997). “What Does the Famine Early Warning Community Need from the ENSO Research Community?” Internet Journal African Studies(2): http://www.dir.ucar.edu/esig/ijas/ijasno2.

Folland, C.K., Owen, J., Ward, M.N., Colman, A. 1991: Prediction of seasonal rainfall in the Sahel region using empirical and dynamical methods. J Forecasting, 10, 21-56.

Folland, C.K., Parker, D.E., Colman, A.W., Washington, R. 1998: Mulit-decadal variability of the global oceans, in Decadal Climate Variability, ed. Navara, A. in press.

Gibberd, V., Rook, J., Sear, C. B. and Williams, J. B. (1996). Drought Risk Management in Southern Africa: The Potential of Long Lead Climate Forecasts for Improved Drought Management. Chatham Maritime, Natural Resources Institute.

Gilchrist, A. 1986: Long-range forecasting. Quarterly Journal Royal Meteorological Society. 112(473), 567-592.

Glantz, M. (1997). “Summary: ENSO/FEWS discussions.” Internet Journal of African Studies(2): www.dir.ucar.edu/esig/ijas/ijasno2/summary.html.

Glantz, M. H. (1996). Currents of Change; El Niño’s Impact on Climate and Society, Cambridge University Press.

Glantz, M. H. (1997). “Eradicating famines in theory and practice: Thoughts on early warning systems.” Internet Journal of African Studies **1**(2): http://www.dir.ucar.edu.esig.ijas.ijasno2/glantz.html.

Glantz, M., Betsill, M. and Crandall, K. (1997). Food Security in Southern Africa: Assessing the Use and Value of ENSO Information. Boulder, Environmental and Societal Impacts Groups, National Center for Atmospheric Research.

Greischar, L. and Hastenrath, S. 1997: Neural Network to Predict "Short Rains" at the Coast of East Africa for Boreal Autumn 1997. NOAA Experimental Long Lead Bulletin**,** June 1997.

Gulev, S..K 1995: Long-term variability of sea-air heat transfer in the North Atlantic Ocean. International Journal of Climatology. 15(8), 825-852.

Harrison, M. S. J., 1984. The annual rainfall cycle of the central interior of South Africa. South African Geographical Journal, 66, 47-64.

Hastenrath, S. , Greischar, L. and van Heerden, J. 1995: Prediction of the summer rainfall over South Africa. Journal of Climate, 8, 1511-1518.

Hastenrath, S. and Greischar, L. (1993) The monsoonal current regimes of the tropical Indian Ocean: Observed surface flow fields and the geostrophic and wind-driven components. Journal of Geophysical Research 96 (C7): 12,619 - 12,633.

Hastenrath, S., Nicklis, A. and Greischar, L. (1993). Atmospheric-hydrospheric mechanisms of climate anomalies in the Western Equatorial Indian Ocean. Journal of Geophysical Research 98 (C11): 20,219 - 20,235.

Hulme, M. 1994: Validation of large scale precipitation fields in general circulation models, in Debois, M. and Desalmand, F. (eds.) Global Precipitations and Climate Change, Springer Verlag, Berlin.

Hulme, M., Biot, Y., Borton, J., Buchanan-Smith, M., Davies, S., Folland, C., Nicholds, N., Seddon, D. and Ward, N. (1992). “Seasonal rainfall forecasting for Africa. Part I: Current status and future developments.” International Journal of Environmental Studies **39**: 245-256.

Hulme, M., Ed. (1996). Climate Change and Southern Africa: An Exploration of Some Potential Impacts and Implications for the SADC Region. Norwich and Gland, Climatic Research Unit and WWF International.

International Research Institute (IRI) for climate prediction (1998). Web site:, www.ogp.noaa.gov/IRI/.

Jury, M. R., 1996. Regional teleconnection patterns associated with summer rainfall over South Africa, Namibia and Zimbabwe. International Journal of Climatology, 16, 135-153.

Jury, M. R. & Pathack, B. M. R., 1993. Composite climate patterns associated with extreme modes of summer rainfall over southern Africa: 1975-1984. Theoretical and Applied Climatology, 47, 137-145.

Jury, M.R.; McQueen, C.; Levey, K 1994: SOI and QBO signals in the African region. Theoretical and Applied Climatology. 50(1-2), 103-115.

Landman, W. A., 1995, A canonical correlation analysis model to predict South African summer rainfall. Experimental Long-Lead Forecast Bulletin., 4, 4, 23-24.

Landsea, C.W., W.M. Gray, P.W. Mielke, Jr., K.J. Berry, 1993: Predictability of seasonal Sahelian rainfall by 1 December of the previous year and 1 June of the current year. Preprints of the 20th Conference on Hurricanes and Tropical Meteorology, San Antonio, AMS, 473-476.

Lindesay, J. A., 1988. South African rainfall, the Southern Oscillation and a Southern Hemisphere semi-annual cycle. Journal of Climatology, 8, 17-30.

Martens, W. J. M. (1996). Vulnerability of Human Population Health to Climate Change: State-of-Knowledge and Future Research Directions. Maastricht, Dutch National Research Programme.

Mason, S. J., 1995. Sea surface temperature - South African rainfall associations, 1910-1989. International Journal of Climatology, 15, 119-135.

Mason, S. J., 1997. Recent developments in seasonal forecasting of rainfall. WaterSA, 23, 57-62.

Mason, S. J. & Jury, M. R., 1997. Climatic change and inter-annual variability over southern Africa: a reflection on underlying processes. Progress in Physical Geography, 21, 24-50.

Maxwell, S. (1994). Food Security: A Post-modern Perspective, Institute of Development Studies.

Mielke, Jr., P. W., K. J. Berry, C. W. Landsea, and W. M. Gray, 1996: Artificial skill and validation in weather forecasting. Wea. Forecasting, 11, 153-169.

Moser, C. O. N. (1996). Confronting Crisis: A Summary of Household Responses to Poverty and Vulnerability in Four Poor Urban Communities. Washington D.C., World Bank.

Nichols, J. M. (1996). Economic and Social Benefits of Climatological Information and Services: A Review of Existing Assessments. Geneva, World Meteorological Organization.

Ogallo, L. A. (1997). “Validity of the ENSO-related impacts in eastern and southern Africa.” Internet Journal of African Studies(2): www.dir.ucar.edu/esig/ijas/ijasno2/ogallo.html.

Ominde, S. H. and Juma, C., Eds. (1991). A Change in the Weather: African Perspectives on Climatic Change. Nairobi, ACTS Press.

Parker, D.E. and Folland, C.K. 1995 Correction of instrumental biases in historical sea surface temperature data. Quarterly Journal Royal Meteorological Society.. 121(522), 319-367.

Rook, J. M. (1997). "The SADC Regional Early Warning System: Experience Gained and Lessons Learnt from the 1991-92 Southern Africa Drought." Internet Journal of African Studies(2): http://www.dir.ucar.edu/esig/ijas/ijasno2.

Solway, J. S. (1994). "Drought as a 'Revelatory Crisis': An Exploration of Shifting Entitlements and Hierarchies in the Kalahari, Botswana." Development and Change **25**: 471-495.

Sombroek, W. G., H. M. H. Braun, et al. (1982). Exploratory Soil Map and Agroclimatic Zone Map of Kenya., Nairobi: Kenya Soil Survey.

Sonka, S. T., Mjelde, J. W., Lamb, P. J., Hollinger, S. E. and Dixon, B. L. (1987). "Valuing climate forecast information." Journal of Climate and Applied Meteorology **26**: 1080-1091.

Stewart, M., Clark, C. E., Thompson, B. and Lancaster, S. (1996). Workshop on Reducing Climate-Related Vulnerability in Southern Africa, 1-4 October, Victoria Falls. Washington, Office of Global Programmes, National Oceanic and Atmospheric Administration.

Tapscott, C. (1997). "Is a Better Forecast the Answer to Better Food Security? To Better Early Warning? To Better Famine Prevention?" Internet Journal of African Studies(2): http://dir.ucar.edu/esig/ijas/ijasno2.

Trenberth, K.E. and Hurrell, J.W. 1994: Decadal atmosphere-ocean variations in the Pacific. Clim Dynam, 9, 303-319.

Tyson, P.D. 1986: Climate Change and variability in southern Africa, OUP Cape Town

Tyson, P.D. 1993: Recent developments in the modelling of the future climate of southern Africa, S A Journal Science, 89, 494-505.

Tyson, P.D. and Dyer, T.G.J. 1978: The predicted above - normal rainfall of the seventies and the likelihood of droughts in the eighties in South Africa, S A Journal of Science, 74, 372-377.

Tyson, P.D. and Dyer, T.G.J. 1980: The likelihood of droughts in the eighties in South Africa, S A Journal Science, 76, 340-341.

Tyson, P.D. and Lindesay, J.A. 1992: The climate of the last 2000 years in southern Africa. The Holocene, 2 (3), 271-78.

Tyson, P.D., Dyer, T.G.J. and Mametse, M.N. 1975: Secular changes in South African rainfall: 1880 to 1972, Q J Royal Met Soc, 101, 817-833.

Van-Heerden, J.; Terblanche, D. E.; Schulze, G. C , 1988: The Southern Oscillation and South African summer rainfall. Journal-of-Climatology. 8(6), 577-597.

Walker, G.T. 1930: Seasonal forecasting Quart J Royal Met Soc, 56, 359-364.

Walker, G.T. and Bliss, E.W. 1930: World Weather IV Mem Roy Met Soc, 3, 81-95.

Walker, G.T. and Bliss, E.W. 1932: World Weather V Mem Roy Met Soc**, 4,** 53-84**.**

Walker, N. D., 1990. Links between South African summer rainfall and temperature variability of the Agulhas and Benguela Current Systems. Journal of Geophysical Research, 95, 3297-3319.

Ward, M.N. and Folland, C.K. 1991: Prediction of seasonal rainfall in North Nordeste of Brazil using eigenvectors of SST. Int J Climatology, 11, 711-744.

Washington, R.; Rowell, D., Ininda, J. 1997: East African Rainfall, comparison of Long and Short Rains, Int J Climatology, in review.

Watson, R. T., Zinyowera, M. C. and Moss, R. H., Eds. (1998). The Regional Impacts of Climate Change: An Assessment of Vulnerability. Cambridge, Cambridge University Press.

Wolde-Georgis, T. (1997). "El Nino and drought early warning in Ethiopia." Internet Journal of African Studies(2): http://www.dir.ucar.edu/esig/ijas/ijasno2/georgis

Wyrtki, K. 1973: Teleconnections in the equatorial Pacific Ocean, Science, 180, 66-68.

Xie, P.; Arkin,-P.A. 1996: Analyses of global monthly precipitation using gauge observations, satellite estimates, and numerical model predictions. Journal-of-Climate**.** 1996. 9/4, 840-858

Food Security Issues in Sub-Saharan Africa

E. U. Nwa
University of Ilorin,Nigeria.

Abstract

Food security indicators such as per capita food supplies and GDP per worker, among several others, place Sub-Saharan Africa as the most disadvantaged region of the world. Raising agricultural productivity was seen as the key to food security for the sub-region. Fortunately, the tremendous gap between the potential land and water resources and the current level of exploitation of these resources presents enormous opportunities to intensify and expand agricultural production in the sub-region.

With particular reference to the climate / water / land agricultural system, four major constraints to increased agricultural production were identified as: drought; water use; pests, diseases and weeds; and land and environmental degradation. It was envisaged that four major approaches could be used to overcome these constraints. The four approaches include the development of more reliable drought forecast strategies and drought mitigation programmes; the development of integrated pest, disease and weed control strategies; the development of land maintenance and degraded land restoration strategies; and irrigation improvement and expansion.

It is recommended that specific research activities be identified and undertaken within the four approach areas above. Special attention was drawn to the use of the holistic and integrated watershed analysis and management approach to the problem of land maintenance and degraded land restoration. Attention was also to be focussed on the inland bottom lands and the fadama lands as a means to improve and expand irrigation in Sub-Saharan Africa. Tenaciously pursued, these approaches will make tremendous contributions to the food security situation in the sub-region.

1. Introduction

Food security is defined as access by all people at all times to enough food for an active, healthy life (World Bank, 1986). This definition may appear simple, but the implications are enormous. Not only must there be enough food in quantity and quality but each individual must have an assured access to the food. The definition further makes demands on social services such as health, water supply, among others, calls for advisory services - in nutrition for example - and demands economic and employment opportunities for the individual.

However, because this workshop is concerned largely with an attempt to understand the integrated climate / water / agricultural systems, this paper will restrict itself to the supply aspect of food security. Restrictive as this may appear, it is nevertheless very important because agriculture is the most important resource base of Sub-Saharan Africa which can stimulate the growth of other sectors of the economy which in turn could contribute to the national, community, household and individual food security.

Unfortunately, agricultural production in Sub-Saharan Africa has been declining. The per capita food production in Africa as a whole dropped by 20 percent over the last two decades. While the population of the continent continues to grow at an average rate of 3 percent per annum, food production has managed to grow only at an average rate of 2 percent per annum (OAU, 1996). The situation is definitely worse for Sub-Saharan Africa. Yet, the region must raise its food production if its people are to escape from widespread poverty and food insecurity.

This paper highlights some of the causes of food insecurity in Sub-Saharan Africa and draws the attention of the scientific community to a few areas through which it can contribute to the food security of the people in the sub-region.

2. Location, Population and Climate

As the name suggests, Sub-Saharan Africa refers to the part of the African continent generally south of the Sahara Desert or more precisely, south of 20°N latitude. As defined above, the sub-region contains 48 countries and covers 2960 million hectares of land or about 80 percent of Africa, and has a population of 520 million people (INRA, 1995). The ecological zones of Sub-Saharan Africa with some climatic characteristics are indicated in Table 1.

Table 1. Ecological zones of Sub-Saharan Africa with some climatic characteristics (Source: FAO, 1986.)

Ecological zone	Length of growing season (days)	Annual rainfall (mm)	Mean monthly temperature $^{\circ}$C		
			Max	Normal	Min
1. Arid	1-74	100-400	42	33-35	15
2. Semi-arid	75-119	400-600	40	22-33	13
3. Dry sub-humid	120-179	600-1200	39	21-31	12
4. Moist sub-humid	180-269	1200-1500	37	23-30	14
5. Humid	270-365	>1500	37	26-30	18
6. Very humid	270-365	>1500	33	24-28	21
7. Montane	-	1400-2000	36	14-29	5

3. Some Indicators of Food Insecurity in Sub-Saharan Africa

Table 2 gives some indicators of food insecurity in Sub-Saharan Africa. Although items 7-10 in the table refer to Africa as a whole, it should be noted as previously indicated, that 48 out of 53 African countries are found in Sub-Saharan Africa. The situation would be slightly worse if the 5-remaining countries are eliminated from those items (7-10).

Table 2. Some indicators of food insecurity in Sub-Saharan Africa

- About 37% of the population remain chronically undernourished.
- In 1996, about 800 million people in the developing countries were chronically undernourished. By the year 2010 about 700 to 800 million persons worldwide are expected to be chronically undernourished, and more than 300 million of them would be in Sub-Saharan Africa.
- Per capita food supplies for direct human consumption for developing countries as a whole would continue to grow from the 2,520 calories / day by the year 2010, but for Sub-Saharan Africa, the expected very low value of 2,170 calories / day of 2010 will not be much different from the low value of 2,040 calories / day of 1990-92.
- The GNP in Sub-Saharan Africa declined from 1.9% in 1969 to 1.2% in 1989.
- The global trade in the sub-region declined from 3.8% in 1970 to 1.0% in 1989.
- The GDP per worker in the sub-region is still the lowest in the world.
- In 1996, 82 member states of FAO were considered as Low Income Food Deficit Countries (LIFDC's); of the 82, 44 are in Africa, i.e out of 53 Africa countries, only 9 are not members of LIFDC's.
- Out of 52 Low Food Supply countries where there was improvement in the supply situation between 1969-71 and 1990 - 92 only 19 came from Africa. But out of 34 Low Food Supply Countries where the situation deteriorated during the above period, 23 came from Africa.
- In 17 African countries, 2 or 3 out of 5 people do not have adequate food.
- Protein energy malnutrition affects 40% of African children under 3 years of age.

Sources: FAO, 1996a, b, c; INRA, 1995.

4. Potential for Intensification and Expansion of Agriculture in Sub-Saharan Africa

Raising agricultural productivity is the key to food security for Sub-Saharan Africa. It is a well known fact that the majority of the population of the sub-region depend on agriculture for their employment and income. Agriculture also stimulates other sectors of the economy, all of which contribute to the food security of the people.

In spite of the gloomy picture painted in Table 2 above, hope is not lost. There is considerable potential for the intensification and expansion of agriculture in the sub-region. In Africa as a whole, only 26 percent of the arable land is often cultivated and only about 6 percent of the cultivated land is irrigated. The crop yields obtained are usually between 1/4 and 1/3 of those from experimental plots (OAU, 1996 and INRA, 1995). Although Africa is not as well endowed with water resources as the other continents, only about 3 percent of the water resources was being used for all purposes in 1994 (FAO, 1996d).

Thus, the tremendous gap between the potential land and water resources and the current level of exploitation of these and other resources presents enormous opportunities to intensify and expand agricultural production in Sub-Saharan Africa.

5. Major Constraints to Increased Agricultural Production

There are very many constraints that hinder agricultural production in Sub-Saharan Africa. For Africa as a whole, OAU (1996) has listed at least 15 important constraints which include hinderances such as national agricultural policies, trade, and political and civil strife, among several others. However, from the point of view of the scientific community and with particular reference to the climate/water/land/agricultural system, this paper has identified four leading constraints to increased agricultural production in Sub-Saharan Africa. These are:

. drought;
. poor and limited water use;
. land and environmental degradation; and
. pests, diseases and weeds.

5.1 Drought

The definition of drought depends on the objective of the definition. Drought could be defined in the context of meteorology, hydrology or agriculture, among others. For example, in meteorology, drought occurs when rainfall is below normally expected values. In agriculture, which is our interest here, drought occurs when the water supply is insufficient to meet livestock or crop water requirements.

The Sahel, the area between latitudes 14°N-18°N, has suffered four major droughts during this century. These occurred during the periods of 1910-1914, 1940-1945, 1969-1976 and 1982-1985 (Faure and Gac, 1981; Nwa, 1993). Faure and Gac (1981) and Sonuga (1977) have indicated that drought maximum seems to occur after approximately every 30 years with one drought occurring approximately every 10 years. However, they were quick to add that the period of measured data (76 years) is too short to establish a firm cyclicity in the drought appearance. The annual minimum daily water level of Lake Chad at one of its measuring stations (Bol), which also reflects the rainfall pattern in the Sahel, is shown in Figure 1.

Since the early 1960's, there has been a steady decline in the total annual rainfall throughout the Sahel, stretching from Senegal to Ethiopia, and this has led to the progressive increase in the occurrence of drought. The result has been repeated crop and livestock losses over the last two decades to the detriment of food security in the region. The declining rainfall trend in the Sahel is illustrated in Figure 2 (FAO, 1992).

The patterns of rainfall in West, East and Southern Africa are different and sometimes uncorrelated. However, the worst drought on record is said to be that of 1910, and it affected East and West Africa alike (FAO, 1996d).

Because droughts are frequent and severe in Sub-Saharan Africa, programmes that lead to more reliable forecasts and those that are aimed at the mitigation of their effects will make excellent contributions to food security in the sub-region.

5.2 Poor and Limited Water Use

In 1995, the irrigation potential of Sub-Saharan Africa was put at approximately 42.10 million ha of land while the total irrigated area (all types) was about 8.34 million ha (FAO, 1995). The gap between the potential irrigable and the actual irrigated area was about 33.76 million ha of land. Since the estimation of irrigation potential took into account the availability of water, it means that there was enough water to irrigate the 33.76 million ha that was not irrigated. Using the ratio of the actual irrigated area to the potential irrigable area, it means that only about 20 percent of water available for irrigation was actually used for the purpose. This explains the concept of limited water use. If more water is used in this sense then more food would be produced, and food security would be enhanced.

Although the total area under irrigation in Sub-Saharan Africa is quite small in comparison to other regions, there are indications of inefficient (poor) use of water at a number of locations. Waterlogging in irrigation projects is often caused by over-irrigation and seepage from the transport canals. Rising water table, waterlogging and salinization have been reported in Ethiopia and South Africa (FAO, 1996e) and in Nigeria (Nwa, 1982). The usual effect of these conditions is a decrease in crop production to the detriment of food security.

5.3 Land and Environmental Degradation

According to INRA (1995):

> The term "land" refers to the complex of soil, climate and biotic resources within major terrestrial ecosystems, and "land use" to systematic application of human know-how to

> harness the desired benefits. Land quality implies the capacity of all the components to produce economic goods and services depending on the land use and management. Land degradation refers to the loss of "intrinsic qualities of land," and involves natural or human-induced degradative processes that decrease the current or future capacity to support life-sustaining functions. Land degradation leads to adverse changes in intrinsic qualities of its components (i.e. soil, water, vegetation, fauna and climate) causing reduction in productivity and environmental regulatory capacity.

Land degradation processes include water and wind erosion, chemical and physical soil degradation. Human-induced land degradation are caused principally by inappropriate agricultural activities, overgrazing, over-exploitation and deforestation which is also a major cause of depletion of genetic resources.

The greenhouse effect is one of the adverse environmental impacts of land degradation. This is because land degradation leads to the emission of carbon from the soil to the atmosphere. Land degradation has resulted in drought, desiccation, aridification and desertication. It is a major factor in food insecurity. Solving the problem of land degradation is one of the ways of providing food security to the people in Sub-Saharan Africa.

5.4 Pests, Diseases and Weeds

Pests, diseases and weeds constitute serious constraints to agricultural production in Sub-Saharan Africa. The integrated pest, disease and weed management approach to solving the problem is preferred. The approach requires a good understanding of the climatic variables for several species of organisms.

6. Some Approaches to Increased Agricultural Production and Food Security in Sub-Saharan Africa

6.1 Drought Forecasting and Drought Mitigation Strategies

The devastating effect of drought on food security in Sub-Saharan Africa has already been discussed. What is left to repeat here is that research programmes that lead to more reliable drought forecasts and those that are aimed at the mitigation of their effects will make enormous contributions to food security in the sub-region. The mitigation programme could include, among several others:

- the development of drought resistant and short duration crop varieties, and
- the study, evaluation and use of indigenous food plants; at least 2,000 of these are said to be lying unappreciated in scattered parts of the sub-region.

6.2 Pests, Diseases and Weed Control Strategies

The incidences of pests, diseases, and weeds are closely related to the climate. It has been established that some crops such as tomato and other vegetables usually give higher yields during the dry season in the humid and moist sub-humid zones of Sub-Saharan Africa. One of the reasons given for this development is that the incidences of some crop pests and diseases are much less during the dry season. A good understanding of the relationship between pests and diseases, and climate will make it possible to develop better integrated pest, disease and weed control strategies that will reduce their constraint on agricultural production.

6.3 Land Maintenance and Degraded Land Restoration

In spite of the serious situation of land degradation in Sub-Saharan Africa, it is heartening to note that it is technically feasible to restore degraded lands. One approach suggested by the Institute for Natural Resources in Africa of the United Nations University is the use of the holistic, integrated watershed analysis and management approach (INRA, 1995). This approach is very attractive and recommends itself especially as the interest of this workshop concerns integrated climate / water / land / agricultural systems.

A watershed includes agriculture, forestry, soil and water conservation, as well as socio-economic and cultural activities, among others. Good results of a research approach that was designed to manage this complex system which includes the climate, will definitely lead to sustainable development and food security for the people. Interestingly, this is the approach also advocated recently by the International Irrigation Management Institute (IIMI) in its "Water Basin" approach to irrigation management (IIMI, 1996):

> IIMI uses the term "water basin" to refer to a region consisting of all the catchment areas linked by a common drainage system. "Water Basin" is a holistic term in two sense: it includes the upper and the lower areas of a basin, as well as its groundwater; and it includes socio-technical, economic, cultural and human dimensions in a systems perspective. Efforts to improve the productivity of water in irrigation systems must be carried out in the context of the entire water basin within which the irrigation system operates, and must consider both "on" and "off" site impacts of operations and interventions.

6.4 Irrigation Improvement and Expansion

Irrigation improvement and expansion are definitely some of the most important means of promoting food security in Sub-Saharan Africa. It was indicated that about 33.76 million ha of land remains to be exploited for irrigation in the sub-region. According to FAO (1996e) about one-sixth of all cultivated land worldwide is irrigated, and it provides 40 percent of food production. In Sub-Saharan Africa, irrigation of 19 percent of all rice growing land accounts for 32 percent of rice production. It is no wonder that FAO (1996e) sees irrigation improvement and expansion as a challenge to food security in Africa.

The following approaches to irrigation improvement and expansion have been discussed by FAO (1996e):

. irrigation policy review and reform,
. rehabilitation and new schemes,
. large-versus small-scale schemes,
. irrigation management transfer,
. reduction of irrigation development costs,
. irrigation extension system and extension support services,
. reform of land tenure system,
. private sector irrigation,
. reduction of health hazards in irrigation project areas,
. new techniques in irrigation technology, and
. irrigation research.

The above list shows that the improvement and expansion of irrigation in Sub-Saharan Africa are very complex. Each item on the list requires attention if sustainable irrigation systems are to be developed in the sub-region. However, the discussion of one or two ideas within the last three items on the list - reduction of health hazards in irrigation project areas, new techniques in irrigation technology, and irrigation research - will be sufficient for our purposes here.

There are no reliable estimates of the size of the inland valley bottom lands in Sub-Saharan Africa i.e. the baatis in Sierra Leone, dambos in southern and eastern Africa, mbugas in Tanzania, matoro in Zimbabwe, bas-fonds in the Sahelian and sudanian zones, wadis or khors in Sudan and Eritrea, vleis in South Africa, and the fadama in Nigeria. An estimate of 20-50 million ha was made for West Africa, 3.5 - 11 million ha for Zambia, and 1.2 million ha for Zimbabwe (FAO, 1996e). What can be said is that a vast resource exists, and presents an opportunity to characterize, classify and develop methods of using the enormous climate/water/land/ agricultural systems for sustainable food security in Sub-Saharan Africa.

In the Nigerian fadama for example, washbores (very shallow boreholes usually < 6m) and tube-wells (shallow boreholes, usually <12m) are used for irrigation. In some other areas, small pumps (3-5hp) are used to pump surface water for irrigation while in others the conjunctive use of surface and shallow groundwater are applied for irrigation. Unfortunately, the relationship between the surface water, the shallow and deep groundwater, has not yet been determined to establish whether or not the shallow groundwater irrigation system is sustainable.

What level of drought can these systems withstand? This and several other questions must be answered to be sure that the systems can provide sustainable food security for the people.

Water based disease such as schistosomiasis, and water vectored diseases such as malaria and onchocerciasis, the three most important diseases prevalent in irrigated areas, are still posing serious health hazards to irrigation farmers and other persons in the project areas. Chemical, biological and environmental control measures to reduce the vector densities or vector lifespan can minimize the health hazards and enhance agricultural production and food security.

7. Summary and Recommendations

This paper reviewed the food security situation in Sub-Saharan Africa, which contains 48 out of 53 African countries and has a population of 520 million inhabitants occupying 2960 million ha of land or about 80 percent of the African continent. Food security indicators such as per capita food supplies and GDP per worker, among several others, place Sub-Saharan Africa as the most disadvantaged region of the world.

Raising agricultural productivity was seen as the key to food security for the sub-region. In Africa as a whole, only 26 percent of the arable land is cultivated and only about 6 percent of the cultivated land is irrigated. At the worldwide level only one-sixth of all cultivated land is irrigated and yet this land provides 40 percent of the food produced. In Sub-Saharan Africa, 19 percent of all rice growing land accounts for 32 percent of rice production. The average crop yields in the sub-region are usually between 1/4 and 1/3 of those obtained in experimental plots. Thus, the tremendous gap between the potential land and water resources presents enormous opportunities to intensify and expand agricultural production in the sub-region.

With particular reference to the climate/water/land/agricultural system, four major constraints to increased agricultural production were identified as drought; water use; pests, diseases and weeds; and land and environmental degradations. Four major approaches to overcome these constraints and increase agricultural productivity and food security were suggested. These are:

- the development of more reliable drought forecast strategies and drought mitigation programmes;
- the development of integrated pest, disease and weed control strategies;
- the development of land maintenance and degraded land restoration strategies; and
- irrigation improvement and expansion.

To raise agricultural productivity as a means of ensuring food security in Sub-Saharan Africa in the context of climate variability and change, it is recommended that specific research activities be identified and undertaken in the following general programme areas.

1. Drought forecasting and drought mitigation
2. Integrated pest, disease and weed control
3. Land maintenance and degraded land restoration
   Research activities involving the holistic, integrated watershed analysis and management approach is particularly recommended. A pilot project in this area could be quite rewarding.
4. Irrigation improvement and Expansion

Research efforts focussing on the inland valley bottom lands and the fadama lands are highly recommended. This is particularly important since the International Irrigation Management Institute (IIMI) has not yet turned its attention to this vast resource for irrigated agriculture.

References:

FAO. 1986. AFRICAN AGRICULTURE THE NEXT 25 YEARS: ATLAS OF AFRICAN AGRICULTURE. FAO, ROME.

FAO. *1992. Nigeria: Irrigation Sub-Sector Review. FAO, Rome*

FAO. 1995. Irrigation in Africa in figures. Water Reports No. 7 FAO, Rome.

FAO. 1996a. Nineteenth FAO Regional Conference for Africa. Report on FAO Activities in the Region, 1994 - 95. FAO, Rome.

FAO. 1996b. Nineteenth FAO Regional Conference for Africa. World Food Summit: Policy statement and Plan of Action. FAO, Rome.

FAO. 1996c. Food Security Assessment. WFS 96/TECH/7. FAO, Rome.

FAO. 1996d. Food Production: The Critical Role of Water. FAO, Rome.

FAO. 1996e. Nineteenth FAO Regional Conference for Africa. Irrigation Improvement and Expansion: A Challenge to Food Security in Africa. FAO, Rome.

Faure, F; and Gac, J. 1981. Will the Sahelian drought end in 1985? Nature 291: 475-478.

IIMI. 1996. The New Era of Irrigation and Water Management: Medium Term Plan for 1998 - 2000. International Irrigation Management Institute, Colombo, Sri Lanka.

INRA. 1995. Land Restoration and Integrated Watershed Management in Sub-Saharan Africa: A Project Proposal. Institute for Natural Resources in Africa of the United Nations University,Accra, Ghana.

Nwa, E. U. 1982. Grounwater problems of the Kano River Irrigation Project of Nigeria. Fourth Afro-Asian Regional Conference of the International Commission on Irrigation and Drainage, Lagos, Nigeria. Vol. II, Publ. 10: 123-137.

Nwa, E. U. 1993. Irrigation in competition for water: The case of the Lake Chad basin. 15th Congress of the International Commission on Irrigation and Drainage. Special Session R. 9: 115-127.

OAU. 1996. African Common Position of Food Security and Agricultural Development. Organization of African Unity, Addis Ababa, Ethiopia.

Sonuga, J. O. 1977. Hydrological aspects of the drought event in Nigeria, 1972-1973. Hydrological Sciences XXII(4): 487-502.

World Bank. 1986. Poverty and hunger: issues and option for food security in developing countries. World Bank, Washington, D.C.

Water Resources and Agricultural Management at Strong and Potentially Increased Climate Variability

Prof. Hartmut Grassl
World Climate Research Programme

Abstract

After the introduction of the clear relationship between agricultural yield and climate parameters (like mean temperature, area-averaged rainfall and run-off for a tropical and a mid-latitude area), observed strong climate variability, as expressed especially by amount and timing of rainfall, will be given for the Sahel and Tropical West Africa. Part 2 of the paper describes two new tools needed for better agricultural management when it reacts to climate variability: (1) seasonal rainfall predictions and (2) modelling of yield given these predictions. Part 3 discusses the way forward, creating conditions for the better use of climate information and variability predictions in agricultural decision-making. In the final section, the development of global change research programmes, taking into account potential changes in climate variability (new extreme events), will be outlined together with the networks needed for the application of research results that facilitate the approach to sustainability.

Numerical Simulation of Intra-seasonal, and Inter-decadal Climate Variability over Africa

Fredrick H. M. Semazzi
WMO/CLIPS Office

The National Center for Atmospheric Research (NCAR) Regional Climate Model (RegCM2) is employed to investigate the physical mechanism, which govern the autumn seasonal rains of eastern Africa. The model employs the Mercator conformal projection, with a domain of 5580 km x 3700 km centered at 31oE, 4oS, and a horizontal grid point spacing of 60km. At this resolution, the main features of the bottom topography are well resolved. The simulation period is October-December 1988 and the model initial and lateral boundary conditions re taken from ECMWF data.

In our study of intra-seasonal variability associated with the autumn rains (short rains) we examined the model simulations for the period October through December of 1988. Systematic analysis of surface water balance reveals that evapotranspiration is a major sink in the water budget over the regions where precipitation is moderate and small, while the roles of runoff and drainage become important over the regions when precipitation is abundant. The model simulations also suggest that the precipitation variability over the regions with heavy precipitation is primarily dictated by the non-local factors (e.g. large-scale circulation).

In another suite of simulations, we employed RegCM2 to simulate the interannual variability of the short rains (autumn rains) over central and eastern Africa over 12 years (1982-1993). The model reproduces the observed interannual variability of the precipitation for most of the years. The results show that the external factors play a more important role in determining the precipitation anomalies than the internal factors.

We find that increase of precipitation over the Congo Basin is associated with the intensification of the rising branch of the equatorial Hadley Cell over Africa. Positive SST anomalies over the southern Atlantic Ocean basin and strong southerly flow pattern are responsible for the increase in water vapor transport over the Congo Basin, and subsequent increase in precipitation.

We note strong positive correlation between the simulated interannual variability of rainfall over Lake Victoria, the Turkana channel, the western Kenya highlands, and most of Tanzania, with ENSO, and it corresponds well to observed variability. The response to ENSO is more directly related to the SST anomalies over the Indian and Atlantic Ocean basins than the remote teleconnection with the Pacific Ocean. Interannual rainfall variability over the eastern Kenya Highlands is not directly related to El Nino events. Strong warm SST anomaly conditions over the western Indian Ocean basin are associated with wetter years over the eastern Kenya Highlands.

The 30-60 day oscillation is evident over the Democratic Republic of Congo (DRC) and northern Angola plateau in the model simulation. The onset of rains may be related to the 30-60 day oscillation. Although a strong El Nino signal is evident in the wet minus dry SST composite, the SST anomalies over the Atlantic and the Indian Oceans appear to play a more important role in modifying the precipitation over DRC.

In a related study the NCAR, GCM, CCM-1, was employed to investigate the role of global SST anomaly forcing in promoting the extreme climatic conditions that prevailed in Africa during the years of 1950s and 1970s. In the 1950s abundant rainfall was observed over tropical Africa, particularly over Sahel and Southern Africa. By contrast, in the 1970s, this rainfall anomaly pattern was characterized by the opposite phase, with most of the continent experiencing severe droughts.

CCMI successfully simulates the primary features of the seasonal mean climate conditions and anomalies over Sahel and Southern Africa. The authors attribute this to the ability of the model to simulate the annual harmonic oscillation realistically. A weaker annual cycle comprising the annual mean (non-oscillating component) and annual harmonic oscillation in the 1973 (representing the 1970s) run relative to the 1950 (representing the 1950s) experiment provides a viable explanation for the synchronous climatic anomaly conditions that prevailed in Northern and Southern Africa during these two years. Investigation of the relative role of the GCM's internal variability and the SST externally forced variability during the rainy season over tropical Africa yields valuable insight into the reasons for the observed anomalous climatic behavior. Over Sahel and Southern Africa, where the annual harmonic oscillation is relatively large, SST forced variability dominates over internal variability in explaining the drier conditions in 1973 relative to 1950.

Further simulations were conducted in which the NASA, GEOS-2, GCM was employed to investigate the role of geographically fixed lower boundary forcing (especially large-scale topography) in establishing the link between global SST anomaly forcing and the Sahelian drought. The results show that in the absence of orographic forcing, the Shelian droughts nearly vanish in the case of the GEOS-2 GCM.

Acknowledgements: These research projects were supported by ACCP/NOAA, CD/NSF and START/HDP-IGBP-WCRP.

Interannual to decadal variability of rainfall in West Africa: Diagnosis and Modeling

Luc Le Barbé[1], Thierry Lebel[2]
[1]Groupe CATCH/PRAO, ORSTOM- Direction de l'Hydraulique, BP 385, Cotonou, Bénin
[2]Groupe CATCH/PRAO, ORSTOM- LTHE, BP 53, 38041 Grenoble Cedex 9, France

Abstract

The drought suffered by West Africa for the past twenty-five years is a well-established fact which illustrates the variability of rainfall in that region at the decadal scale. The average difference in the seasonal rainfall between the period 1950-1970 and the period 1970-1990 is around 180 mm for the whole region. In the Sahel, the difference is smaller (100 - 120 mm), but it represents a decrease ranging from 15 to 25% and a displacement of the isohyets 1° in latitude southward. West African rainfall is also notoriously unreliable at the seasonal scale, with large fluctuations in space for a given season and equally important fluctuations of the average seasonal rainfall from one year to another. The EPSAT-Niger experiment, for instance, has led to the recognition that, in the Sahel, spatial gradients of the seasonal rainfall in the order of 200 mm over a distance of less than 20 km are not uncommon, creating large patches of low millet yield even in places where the average crop is fair.

It is thus essential to characterise and model this variability in a way that allows the assessment of its impact on water resources and agricultural productivity. It is also important to simulate scenarios that have not yet been observed and which may be of lesser or larger severity than that of the current drought. Most studies devoted to the analysis of the West African rainfall variability to date were based on the analysis of raw data at the 10-day, monthly or seasonal scales. In the study presented here, use is made of a comprehensive daily data set, collected by ORSTOM in connection with the operational meteorological services of West African countries, in order to obtain a more accurate vision of the drought, both in space and in time. A model is proposed that allows the retrieval from these daily data of information characterising the rainfall regime at the scale of the rainy events associated either to mesoscale convective systems or to monsoon rain.

Based on this model, the average number of rainy events and their average magnitude is computed over a 15°x12° window running from Guinea to West Nigeria and from the coast to northern Sahel. It appears that the main factor explaining the drought is the decrease of the number of rainy events, which is general over the region, and especially well-marked (average decrease of 20%) in the Sahel during the core of the rainy season. By comparison, the

changes in the average event raindepths are much smaller, except on the coast. A decrease is observed north to the 14°N parallel, while a light increase is observed between 10°N and 12°N.

A climatic interpretation of these findings is then presented, whereby it is argued that some concepts about the installation and retreat of the rainy season in West Africa should be revised. Some consequences for the agriculture are also mentioned. In the Sahel, the length of the rainy season has not changed much during the dry years, and it is rather the probability of dry periods during the core of the rainy season that has increased. In the South, the second rainy season ends earlier during the dry years than during the wet years. Therefore, crops able to resist unusual dry sequences during their vegetative cycle should be promoted in the Sahel, whereas crops less sensitive to a shortened length of their cycle should be looked for in the South.

1. Rainfall Variability and Hydrological Impact in West Africa

The rainfall series of West Africa are characterised by notorious variability at the interannual and decadal scales. An example of this is given in Figure 1, where the normalised rainfall index proposed by Lamb (1985), and computed here from Sahelian stations, is plotted for the period 1921-1994. The most striking feature of this series is the succession of two opposite periods extending over the last 45 years. From 1950 to 1964, the Sahelian rainfall index is generally positive. It starts to fluctuate between positive and negative values over the next 5 years, before remaining permanently negative until 1993, except for one year in 1975. The average global deficit of the period 1970-1990, with respect to the period 1950-1970, is over 150 mm, which corresponds to a relative decrease of 30%, or more, in the north of the region and to a 1.5° southward shift of the interannual isohyets. A comparable deficit has been observed more to the South. Its timing and amplitude have been less studied, probably because the immediate impact of the drought has been more severe in the Sahel where the water resources are scarce.

The average rainfall deficit between the wet and the dry period for the region studied here, extending from the coast to the Northern Sahel, is about 180 mm. The influence of this deficit on the river flows is a reality all over West Africa. The mean annual discharge of the river Niger at Niamey has decreased from 1060 m^3/s over the period 1929-1968 to 700 m^3/s over the period 1969-1994, a diminution of 34%, and the average of the minimum daily flows in period of low waters has dropped from 64 m^3/s to 11 m^3/s over the same periods (Bechler *et al.*, 1997). In 1984 at Niamey, the Niger River stopped flowing, a phenomenon never before observed, at least since the foundation of the town at the beginning of the century. In the Soudanian zone, the average river flows have dropped by 40% in Benin. Situations of food penuries have become common in the Sahel and would have devastating consequences, were it not for the international aid. Several exporting crops, such as the oil palm in Benin, are no longer profitable. A number of hydraulic works have not performed as anticipated when they were designed, based on current rainfall conditions. In 1984, almost all of the hydroelectric dams of the Soudanian region went totally dry, causing a general deficit of energy that had not been imagined as even possible.

The question today is not to discuss the overall statistical significance of this generalised drought. Whether occurring in a stable or changing climate, the drought has to be considered as a fact which must be analysed at all levels from its causes, lying in the atmospheric circulation and ocean temperatures (see e.g. Lamb, 1978a and 1978b; Folland *et al.*, 1986; Janicot and Fontaine, 1993, for a review of ideas about the links between the Sahelian rainfall and the atmospheric and oceanic factors), to its impact on the hydrological cycle. Here we propose to identify where and when the last great decadal rainfall fluctuation occurred. We also propose to analyse the manifestations of this deficit in terms of rainfall regime and not only by looking at global statistics. In our opinion, this is a primordial step that should help scientists working on the identification of the physical causes of these fluctuations. In addition, it is important to be able to simulate scenarios of different levels of droughts, which have not been necessarily observed up to now but are nevertheless *possible*, so as to be able to study their possible impact.

To that end, a dynamical stochastic model will be used which allows the retrieval of the rainy event regime from daily rainfall data, the only data for which long series are available in West Africa. As a matter of fact, despite an overall abundance of the rain during a season, it is the chronology of the rainy events which affects the water balance and the agricultural productivity over a region.

2. Data and model

2.1 Data

To carry out the required analysis, the information used must be, as far as possible, homogeneous both in space and time. Based on a comprehensive data set collected from the operational meteorological services of the various countries of the region, it was found that reaching that goal was possible by working on a window extending from 10°W to 5°E and from 4°N to 16°N over the period 1951-1990. Currently there exists 2067 rainfall stations operating in 13 West African countries (excluding Liberia and Sierra Leone). The oldest station has been observed since 1881. The data set used for this study is made of 2,049 stations totaling 53,268 station-years.

In the following, we will focus on the analysis of the differences between the rainfall regime of the wet period 1951-1970 and the rainfall regime of the dry period 1971-1990. This means that the decadal scale is privileged over the interannual scale. The reason for that choice is that the impact of the interannual variability is comparatively smaller. Furthermore, it appears from the EPSAT-Niger experiment that at the interannual scale and below, extreme spatial gradients are dominant. Lebel *et al.*, (1997), for instance, have recorded repeated seasonal rainfall gradients of more than 200 mm over 20 km (or less). This variability cannot be studied from the data of the meteorological services for the operational networks are too scarce and made of daily reading gauges only.

2.2 The dynamic stochastic model

The selected model belongs to the family of the Compound Poisson Processes (CPP). Its basis is thus relatively simple and well established. Such models have been used under different forms in many applications involving some rainfall process modeling. The hypotheses of the version used here are the following:

1. The occurrence of a rainy event is independent of the occurrence of the preceding events, that is, the number of events is Poisson distributed, whatever the length of the period considered.
2. The storm (or event) rain depth does not depend on the number of the preceding events, nor on their associated rain depths.
3. The event rain depth distribution is exponential but its average varies during the rainy season. It is thus a dynamic model, taking into account the non-stationarity of the rainfall process.

Since only daily data are available, they do not allow for making out the diurnal cycle. The rainfall regimes are thus described by two vectors of 365 daily values, one for the mean number of rainy events per day, l_j, and one for the mean event rainfall, m_j. The expectation, h_j, and standard deviation, s_j, of the rainfall of a given day of year j are computable from these two parameters as:

$$h_j = l_j x m_j$$
$$(s_j)^2 = 2\ l_j x (m_j)^2$$

The computation and interpolation in the 2D geographical space of these two vectors provide a full account of the rainfall regimes, at least in terms of the classical indicators used to that end. It also allows, through Monte-Carlo procedures, for the numerical simulation of rainy event series conforming to the hypothesis of the model. Finally, and this is what is of interest to us in this presentation, it is possible to compare the daily fields for each parameter and two different periods, with the aim of determining the dates and locations of the excesses and deficits characterising the wet and dry periods.

A full description of the model and its inferences is available in Le Barbé and Lebel (1997) and Tapsoba (1997). The basic hypothesis of the Poisson representation of the rainfall regime were validated, over a few sub-regions of West Africa (e.g. Le Barbé and Lebel, 1989; Le Barbé and Tapsoba, 1994; Le Barbé and Lebel, 1997; D’Amato and Lebel, 1997).

2.3 Calculation of regional grids

Over the study area, 336 stations have been considered as correctly observed during the wet period 1951-1970 and 388 during the dry period 1971-1990 so as to be able to estimate for each period and for each day of the year, the two parameters of the dynamic stochastic model. The variance of these estimates are also available. Using a kriging approach taking into account the uncertainty of the interpolated parameters (Delhomme, 1976), a 0.1° spaced grid is computed for each parameter and each period.

3. Analysis of the changes in the rainfall regimes

It is not possible in a short paper to give a detailed account of all the results that can be retrieved from a systematic analysis of the station profiles and of the regional grids. Therefore, we will limit ourselves to providing here a general overview of these results. A more comprehensive account is available in the French version of this paper and a full paper, to be submitted to an international journal is in preparation.

3.1 Analysis of the profiles at individual stations

Shown in Figures 2 and 3 is the evolution of the mean number of events per day and of the mean event rainfall for the wet period (black curves) and the dry period (grey or red curves). The six stations of Figure 2 are located to the North of 11.5°, at various longitudes ranging from 9°W (Bamako) to 2°E (Niamey) and are representative of the Sahelian zone in the traditional classification used to describe the climate of West Africa. The three stations of Figure 3 are located to the South of 10° N, in the Soudanian area.

At first glance, the profiles of Figure 2 are similar, or at least they are much more similar to each other than to the other profiles shown in Figure 3. A striking fact is that, while the curves representing the mean event rainfall show little difference between the wet and the dry periods, there is a significant decrease of the mean number of events when shifting from the wet to the dry period. A quick computation shows that more than 90% of the total rainfall decrease between the two periods are caused by the decrease of the mean number of events. This decrease is especially pronounced during the core of the rainy season, where the decrease amounts to about 20% to 30%. It is worth noting that the relative value of the decrease is not so different from North to South, while, at the same time the overall climatological gradient is well visible: during the wet (resp. dry) period, the mean number of events per day increases from a maximum of 0.4 (resp. 0.28) in the North (Niafunke) to a maximum of 0.78 (resp. 0.62) in the South of the area (Hounde). This exemplifies the fact that the south-to-north gradient of rainfall over West Africa is linked both to a shortening of the rainy season (which is itself caused by the migration of the ITCZ) and to the number of rainy events decreasing to the North, event at the peak of the rainy season. By contrast, at the peak of the rainy season, the mean event rainfall is somewhat equal at all stations (that is, whatever their latitude within the Sahelian zone).

In that respect, the change in the rainfall climatology between the wet and the dry period **is not** assimilable to a general southward shift of the rainfall patterns. The curves of Figure 2 show that both the mean event rainfall and the length of the rainy season (defined by the number of events curve) are basically unchanged. The only variable that changes significantly and systematically at all stations is the number of events. This likely contradicts the assumption that the rainfall decrease of the present period is linked to an average shift of the ITCZ southward.

Looking at the curves of Figure 3, it is clear that coastal or close to the coast stations (Ndouci, Abidjan) have to be distinguished from stations located more to the North (Kafolo, 10°N). The main difference between this latter group and the former resides in the mean event rainfall curves. Similarly to what happens in the Sahelian zone, the mean event rainfall does not change much between the wet and the dry periods at Gaoua and Kafolo. On the opposite, there are significant differences between the curve of the wet period and that of the dry period at Abidjan, Ndouci, as well as at Cotonou (not shown). The mean event rainfall appears to be larger during the wet period for the first rainy season and smaller during the second rainy season. Also, there seems to be a time shift: the decrease of the mean event rainfall initiating the “little” dry season occurs earlier during the dry period, which is also the case for the second increase associated to the second rainy season. Both patterns are significant of the different changes affecting the rainfall regimes when moving from the coast to the Sahel.

The mean number of events curves are also significant of such differences. For Ndouci and Abidjan, they show a similar decrease all along the two rainy seasons. It seems that on the coast, the decrease of the mean event rainfall and of the mean number of events are equally responsible for the overall rainfall decrease of the first rainy season. During the second rainy season, the increase of the mean event rainfall balances the decrease of the mean number of events, so that the overall rainfall change is weak as compared to what is observed during the first rainy season or during the unique rainy season in the Sahel. There are two main differences between the interior stations of Kafolo and Gaoua (not shown) and the coastal stations: i) the distribution of the number of events has only one mode; ii) the mean event rainfall does not change between the wet and the dry periods, which is a common feature with the Sahelian stations. Another common pattern shared by Gaoua and Kafolo and the Sahelian stations is the decrease of the number of events during the peak of the rainy season. Nevertheless, there are some distinct features as well, the most interesting being the “sill” observed in June on the number of events curve. The increase of the number of events stopped for one month, then restarted. Such a phenomenon is not consistent with the description of the rainfall regime in the Sudanian area being driven only by the northward migration of the zone of convective systems associated to the ITCZ. It has to be noted at that point that the station of Hounde, shown in Figure 2, and located almost two degrees north of Kafolo displays the same phenomenon, whereas it is not observed at Goualala, located half a degree south of Hounde.

3.2 Towards a new partitioning of the West African rainfall climate

Between the Sahelian and the Coastal climates, there seems to exist two intermediate climates that can be distinguished by concentrating on the curve summarizing the change of the number of rainy events between the wet and the dry periods. In Figure 4, these curves have been drawn and grouped into four families. From the criterion of the rainfall regimes, as analysed here, the southern limit of the Sahelian climate lies between 12°N and 13°N. Between 8°N and 13°N lie what will be called here the intermediate and the Soudanian climates. Their separation is not zonal. The intermediate climate extends from 10°N to 13°N in the western part of our study area. Its characteristics are driven by the presence of the mountains of Guinea that shield the region from the monsoon rains of the first part of the rainy season. During the second part of the rainy season, the rainfall regime is Sahelian, and characterised by the predominance of mesoscale convective systems, as was shown by Laurent (1996) from satellite imagery. The Soudanian climate extends from 8°N to 12°N, covering mostly the eastern part the study area, with the exception of the region shielded from the monsoon influence by the Atakora mountains of Northern Benin and Togo. This Soudanian climate is a progressive transition from the coast to the Sahel. This transition is indeed very progressive in areas devoid of any orographic influence. Places like Kafolo (10°N) and Bouake (8°N) are very similar in Figure 4. They define a zone where the overall rainfall deficit of the dry period has been the smallest.

3.3 Regional analysis

The various results analysed above on a station by station basis are summarised in Figure 5. To draw this figure, zonal averages of the 0.1°x0.1° grids have been computed. Then the grids of the mean number of events and of the mean event rainfall of the dry period have been subtracted to the corresponding grids of the wet period. The colour table has been chosen so as to obtain the same colours for comparable relative changes of each variable. The dominant changes of the mean number of events, as compared to those in the mean event rainfall are obvious. There is only one area of increase in the mean number of events (negative values in blue), centred on the beginning of August and with a maximum in the southern part of the Soudanian climate. At the opposite, the greatest deficit is recorded in the Sahel over the month of August, and then in the northern part of the coastal climate in October.

With regard to the mean event rainfall, it is seen that it varies little, the areas of increase roughly compensating those of decrease, except during the little dry season on the coast, where a strong increase is observed. A finer dynamical analysis has also been carried out that has implications for the characterisation of the rainfall climate of West Africa. The reader is referred to the extended French version of this paper, or to a future paper in preparation, for further details.

4. Impact on the Water resources

The deficit of the yearly rainfall that characterises the current dry period over West Africa is relatively uniform when studied from the means and at the yearly scale. However, it has many distinct features both in space and time when considering finer time scales and more relevant parameters such as those produced by our dynamic model. Despite the presence of a variety of situations in the South, there is a main opposition between the Sahel and the remaining of the area studied. This has some impact on the water resources and on the agriculture that will be quickly mentioned in this section.

4.1 The Sahel

The length of the rainy season has not been reduced significantly. The decrease of the number of rainy events is rather uniform over the study area, ranging from 0.15 to 0.2 events per day at the peak of the rainy season, the period of the year where this decrease is at its maximum.

The frequency of the stress supported by the crops due to a lack of water, especially at the stage of grain formation, has considerably increased during the recent dry years. This is probably a major reason for the decline of the millet productivity in this region. Since the length of the rainy season does not seem to have been reduced it would be of little help to look for varieties characterised by a shorter vegetative cycle. The solution seems to be looking for varieties with better resistance to that kind of stress.

4.2 From the Sahel to the Coast

In this region, the timing of the first rainy season is unchanged after 1970, but its intensity has decreased significantly. Conversely, both the timing and the intensity of the second rainy season change after 1970. The second rainy season starts everywhere earlier during the dry years and its propagation southward is more rapid, which involves first a diminution of the dry season and then a diminution of the rainy season itself. Its intensity decreases as well, although less markedly than that of the first rainy season.

In this region, it is thus reasonable to think that the decrease of the length of the second rainy season and its early onset are key factors responsible for the reduction of the crop productivity. By contrast with the Sahel, it may be that using varieties with a shorter vegetative cycle and adapting the culture schedule prove efficient tools to fight the drought.

A yearly rainfall global deficit of about 180 mm has been recorded over the study area between the recent wet (1951-1970) and dry (1971-1990) periods. A dynamical modeling of the rainfall regimes of each of these two periods over West Africa has led to the identification of complex patterns of deficits in both the mean number of rainy events and mean event rainfall. The decrease of the mean number of events is by far the predominant cause of the overall rainfall deficit of the dry period. However, it seems that both the orography and the succession of two rainfall regimes during the rainy season introduce a variety of intermediate situations between that of the Sahel, characterised only by the sharp decrease of the number of convective systems during the core of the rainy season, and that of the coast, where both the number of events and the mean event rainfall have changed when shifting from the wet to the dry periods. Some consequences of the current drought on agriculture have been mentioned, showing the interest of characterising the changes that happen in the rainfall regimes and not only the modifications of global statistics. An extension of this work to a more global appraisal of the impact of the drought on the water resources of the region is under way. A climatic survey has been set up in Benin to that end (Depraetere et al., this conference). As part of this survey, specific hydro-meteorological measurements are added to the operational networks of Benin. It is also believed that more insight into the mechanisms conditioning the rainfall fluctuations over West Africa could be gained from a detailed analysis of the results produced by the model. Investigations on this topic are continuing.

References:

Bechler, N., M. Lamotte, H. Korou Motcho, M. Mietton, 1997. Les étiages du fleuve Niger : risque de pénurie en eau pour l'agglomération de Niamey. In ***Sustainability of Water Resources under Increasing Uncertainty*** (Actes du symposium de Rabat, Avril 1997). IAHS Publ. n°240, 67-74.

D'Amato, N. and T. Lebel, 1997 : On the characteristics of the rainfall events in the Sahel with a view to the analysis of climatic variability. ***International Journal of Climatology***, Accepted.

Delhomme, J.P., 1976 : Application de la théorie des variables régionalisées dans les Sciences de l'eau. Université Pierre et Marie Curie, France, 152 p.

Depraetere, C., A. Afouda, G. Alé, L. Le Barbé and T. Lebel, 1997. Vers une meilleure evaluation de l'impact des variations climatiques en milieu tropical par le developpement des modeles hydrologiques continentaux, this symposium.

Folland, C.K., Palmer, T.N. and Parker, D.E., 1986. Sahel rainfall and worldwide sea temperature 1901-1985. Nature, 320, 602-607.

Janicot, S. et Fontaine, B., 1993. L'évolution des idées sur la variabilité interannuelle récentes des précipitations en Afrique de l'Ouest. La Météorologie, Ser. 8, 1, 28-53.

Lamb, P.J., 1978a. Case studies of tropical Atlantic surface circulation patterns associated with Subsaharan weather anomalies: 1967 and 1968. Monthly Weather Review, 106, 482-491.

Lamb, P.J., 1978b. Large scale tropical surface circulation patterns associated with Subsaharan weather anomalies. Tellus, 30, 240-251.

Lamb, P.J., 1985 : Rainfall in Subsaharan West Africa during 1941-1984. Preprints, ***Third conference on climate variations and symposium on contemporary climate***, Los Angeles, January 1985. 1850-2100.

Laurent, H., 1996. Life distribution of mesoscale convective clouds over Africa. Preprints, ***Seventh conference on mesoscale processes (AMS, RMS)***, 9-13 Septembre 1996, Reading, UK, 178-180

Le Barbé, L. and T. Lebel, 1989 : Analysis of regional precipitation patterns in Western Africa based on the law of leaks. Preprints, ***Fourth International Meeting on Statistical Climatology***, Rotorua, New zeland,AMS Publ., 273-277.

Le Barbé, L. and D. Tapsoba, 1994 : Une méthode de caractérisation des fluctuations pluviométriques interannuelles du Sahel- L'exemple du Burkina Faso. In: ***Interactions Surface Continentale/ Atmosphère : l'expérience HAPEX-Sahel, (***Actes des***10eme journées hydrologiques de l'ORSTOM)***, Montpellier, France, septembre 1994, ORSTOM Ed., 383-400. Paris

Le Barbé, L. and T. Lebel, 1997. Rainfall climatology of the HAPEX-Sahel region during the years 1950-1990. ***J. Hydrol***, 188-189, 43-73.

Lebel, T., J.D. Taupin and N. D'Amato, 1997. Rainfall monitoring during HAPEX-Sahel: 1. General rainfall conditions and climatology. ***J. Hydrol.***, 188-189, 1-4, 74-96.

Polcher, J., 1995. Sensitivity of tropical convection to land surface processes. ***J. Atmos. Sci.***, 52, 3143-3161.

Tapsoba, D., 1997. Caractérisation événementielle des régimes pluviométriques Ouest Africains et de leur récent changement. Thèse de doctorat d'Université, Paris XI, 109 p.

Summary of Lessons Learned from Climate Predictions for Southern Africa in 1992-95

Wassila Thiaw
Climate Prediction Center, NOAA, Camp Springs, Maryland, USA

[Ed. Note: Figures for this paper were not available.]

1. Introduction

Rainfall fluctuation in southern Africa has been a focus of scientific research for several decades. Frequent droughts, particularly the severe 1991-92 drought, and the need for a sustainable development in Africa, have called for improved global and regional climate monitoring and prediction. The possibility of forecasting climate anomalies in southern Africa well in advance is of considerable interest, as droughts can have serious agricultural and economic impacts. Southern Africa is among the several major target regions of the tropics, where promising leads in seasonal forecasting have developed over the past few years (Hastenrath, 1995). It has been demonstrated that some regions in southern Africa are influenced by El Niño / Southern Oscillation (ENSO) (Ropelewsky and Halpert, 1987 and 1989). ENSO represents the largest natural climatic variability on the interannual time scale (Philander, 1990). Thus, it affects the climate and the economy of various regions of the world. Efforts have been made during the past decade to predict ENSO events. Good prediction of an ENSO event can give some indication of the climatic conditions that will prevail during the next few seasons, even in areas such as southern Africa. However, southern Africa climatic conditions have also been shown to be sensitive to fluctuations of sea surface temperature over the Indian Ocean and the Atlantic Oceans (Mason et al., 1990). Several forecast techniques have been developed during the past decade. Those include statistical and dynamical models.

This report describes recent developments in climate prediction over southern Africa and the lessons learned from them. Here, we focus only on prediction tools that are available and those cases where forecast skills were assessed. Section 2 of this summary describes the importance of ENSO in long-lead prediction of southern Africa seasonal rainfall. In section 3, we discuss the status of seasonal rainfall prediction over southern Africa. Finally, a summary of the lessons learned is given in section 4.

2. Importance of ENSO in Predicting Southern Africa Seasonal Rainfall

2.1 ENSO Relationship to Rainfall Variability in Southern Africa

Interannual rainfall variability in southern Africa has been demonstrated to be modulated by ENSO (Ropelewski and Halpert, 1987 and 1989; Hastenrath, 1995; Lindsay and Vogel, 1990). A schematic representation of ENSO-related precipitation based on an analysis of composites (Ropelewski and Halpert, 1987) is shown in Figure 1. Drought is noted through much of southern Africa, including Zimbabwe, during an ENSO event (from November through April). The 1991-92 drought over southern Africa, considered one of the most severe droughts during this century, was preceded by and ENSO episode which started evolving about March 1991 (Matarira and Unganai, 1995). During a strong ENSO episode, the rainfall during the October-November-December season tends to decrease across the whole southern Africa. Cane *et al.* (1994) found that warm El Niño episodes are moderately well-related to rainfall and maize (corn) yield in Zimbabwe, with correlation coefficients of 0.64 and 0.71, respectively. However, extending the Cane *et al.* study to South Africa and Zambia, Lecomte and Thiao (1995) found the corn yield in South Africa dropped sensitively during the 1982083 and 1991-92 warm events.

2.2 Long-Lead Predictability of ENSO

NOAA’s Climate Prediction Center has been issuing a quarterly Experimental Long-Lead Forecast Bulletin describing the most current long-lead forecasts one season or more in advance. The bulletin is mostly intended for the US surface climate, but forecasts of ENSO and surface climate of other parts of the world, including the tropics, are also included.

The Prediction of ENSO has been the focus of many research groups during the past decade. Hastenrath (1995) reviewed the current status of long-lead forecasting in the low latitudes, including ENSO. Barnston *et al.* (1994), in their evaluation of the status of long-lead seasonal forecasting, focused on five promising ENSO prediction systems that are currently or potentially operational: 1) the Lamont-Doherty Earth Observatory simple coupled model, commonly known as the Cane-Zebiak model, 2) the Scripps-MPI hybrid coupled model, 3) NCEP’s comprehensive coupled model, 4) the CPC’s statistical CCA model, and 5) the CPC’s empirical constructed analog model. These models deal with the equatorial Pacific (5°N-5°S), but with slightly different longitude bands. While NCEP’s coupled model and the CPC’s CCA and analog models focus on the Niño-3 region (90°W - 150°W) and Central Pacific (140°W - 180°W), respectively. Figure 2 illustrates the good agreements between forecasts and observed SST anomalies for the five models. In particular, all five models predicted the strongest ENSO episodes relatively well, especially for the 1986-87 event. However, the models did not perform equally well. Fore example, the Lamont model predicted quite accurately the 1986/87 cold event, while the Scripps/MPI model was the best for the 1988/89 event. However, the latter performed poorly for the spring warming of 1993 when CCA predicted the event somewhat better.

Figure 3 shows the ENSO forecasts experimentally issued during 1995 by four of the five models discussed above, including: the CPC CCA model, the Lamont model, the NCEP coupled model and the Scripps/MPI model. The Cane-Zebiak model described slightly below normal ENSO conditions up to three seasons lead and almost normal SST at four seasons lead. The CPC CCA model also indicated slightly below normal SST anomalies up to two seasons lead and near normal to slightly above normal conditions at three and four seasons lead, respectively. This picture was almost similar for the NCEP coupled model which also indicated normal to slightly below normal SST anomalies for one to nine month lead forecasts. The Scripps/MPI forecasts suggested an intensification of below normal SSTs along the equator through the fall and early winter 1995. However, the model predicted that warming near the dateline would spread eastward and intensify over the following six months. A large fully-mature El Niño, comparable in magnitude to the 1982-83 event was predicted to be in place by the end of spring 1996.

Overall, the first three models described neutral ENSO conditions. This was the case at least through the spring of 1996 for the NCEP coupled model, and through the summer of 1996 for the CPC CCA and Lamont models, while the Scripps/MPI model predicted significant cooling through the winder of 1995-96, then a return to warm ENSO conditions by late spring 1996. These differences in the forecasts illustrate the imperfection in the skills of the models.

3. Experimental Prediction of Southern Africa Seasonal Rainfall

The predictability of Africa seasonal rainfall has been investigated by several research groups. The experimental forecasts that have been posted in the CPC Long-Lead Forecast Bulletin included empirical methods used by Greischar and Hastenrath (1994, 1995), Landman (1994, 1995), and Thiao and Barnston (1996).

3.1 Multiple Linear Regression, Linear Discriminant Analysis and Neural Networking

Greischear and Hastenrath (1994) used stepwise multiple linear regression (SMR), linear discriminant analysis (LDA) and neural networking to predict December-January-February rainfall in the Transvaal region expressed as a precipitation index referred to as TVR. TVR is believed to be representative of a large area in southern Africa. It is positively correlated with the Southern Oscillation Index (SOI) and negatively correlated with the 50 mb zonal wind (U50) over Singapore, and indication of the phase of the quasibiennal oscillation (QBO). In other words, rainfall is enhanced by cold ENSO conditions two seasons earlier and by an easterly QBO phase one year earlier. The predictors, based on empirical-diagnostic analyses, include (1) July-August-September values of the SOI, (2) the preceding January-February-March U50, (3) an index of the October-November surface westerlies along the Indian Ocean Equator called UEQ, and (4) an index of November SST in the southwestern Indian Ocean called

UKT. The most skillful result was found using a neural networking model that utilized u50 and SOI information through the end of September 1994, in which 62% and 50% of the TVR variance were explained for the periods 1979-90 and 1979-93, respectively. For stepwise multiple regression, only 26% of the TVR variance was explained.

As an example of the Greischar-Hastenrath Forecast schemes, we describe the determination of the forecast for South Africa summer rainfall during 1994-95 and 1995-96.

During 1994, the SOI value for July-August-September was -1.03 hpa, compared with a mean value of 1.7 hpa. This was thought to tend to suppress rainfall. The U50 value for January-February-March 1994 was 7.53 m/s, compared with a mean of -1.5 m/s. This also would tend to suppress the forecast rainfall. Thus, a forecast was issued as follows: negative rainfall anomalies of 71 mm and 46 mm were predicted using SMR and Neural Networking, respectively. The forecasts were comparable to what occurred in the summers of 1981-82, 1984-85, 1985-86, 1989-90, and 1992-93.

During 1995, the July-August-September SOI was 2.17 hpa, compared with mean and standard deviation values of 1.74 and 1.50 mb, respectively. This would tend to enhance rainfall. The U50 value for January-February-March 1995 was 3.77 m/s, compared with mean and standard deviation values of -1.49 and 13.01 m/s, respectively. This would tend to suppress the rainfall forecast. The resulting forecast for TVR rainfall for December-January-February 1995-96 was as follows: negative rainfall anomalies of 4 mm and 27 mm were predicted using SMR and Neural Networking, respectively. The forecasts were comparable to what occurred in the summers of 1959-60, 1960-61, 1965-66, 1976-77, and 1979-80, and 1987-88.

Although the models predicted negative anomalies during 1994-95, the forecasts underestimated the severity of the drought. Negative anomalies between 100 and 300 mm were observed in the TVR region. The 1995-96 forecast did not verify. This season was one of the wettest in record, with positive anomalies between 200 and 400 mm for the period November 95 - March 96. The verification anomalies for 1994-95 and 1995-96 are based on the 1961-90 climatology and were computed from the Global Telecommunication System (GTS) reports available at CPC.

3.2 Canonical Correlation Analysis

The canonical correlation analysis (CCA) has been widely used in the last few years for ENSO prediction (Barnston and Ropelewski, 1992), and for US surface climate prediction (Barnston, 1994). It includes a cross-validation design to obtain uninflated estimates of the forecast skill. More recently, it has been used operationally by the Research Group for Statistical Climate Studies (RGSCS) of the South Africa Weather Bureau and by the African Desk of the US Climate Prediction Center.

3.2.1 The research Group for Statistical Climate Studies

Thirteen South African regions having homogenous rainfall climates are defined. The predictors include SSTs in the equatorial Pacific (11°N-11°S, 120°E-85°W), the Indian Ocean (20°N-38°S), and the Atlantic Ocean (7°N-38°S). Fore each region, one or more of the three oceans are used as predictors, depending on which set resulted in the highest cross-validated skill. Fore example, a predictor period of September-October-November 1994 was used to predict each of the individual summer months from December to May 1994-95. Figure 4 shows the categorical forecasts for January and February 1995. The farther above the change rate of 33, the higher the forecast skill.

The forecasts called for near normal January rainfall in the northeast portion of southern Africa, with above normal rainfall in a band stretching from north of East London northwestward toward Upington. The forecast for February indicated favorable rainfall except for the northeastern portion. During January 1995, parts of southern Africa, including northeastern South Africa, received about 150% of normal rainfall (based on GTS reports, 1961-90 climatology). However, dry conditions prevailed during February in most locations.

Using the same methodology, the forecasts for the 1995-96 summer season called for favorable rainfall conditions over the central and western interior in January, followed by drier conditions from February through March in the southwestern Cape and especially in the central and eastern portions of South Africa. During 1996, according to GTS reports, rainfall was well above normal over the eastern half of South Africa, and normal to slightly below normal over the central and southern parts.

3.2.2 The African Desk/CPC

The African Desk established at the Climate Prediction Center (CPC) of the NWS/NCEP has been experimenting with African seasonal forecasting in collaboration with the Prediction Branch of CPC. Rainfall data extracted from the 2.5° by 3.75° lat.-long grid-box global rainfall database developed by Hulme (1994) and quasi-global SST data between 40°S and 60°N derived from the COADS dataset and interpolated in grid boxes of 10° by 10° (Barnston, 1994) were used during the training period 1995-1994. Africa has been divided into three major homogeneous regions, including southern Africa. CCA has been used to study the predictability of southern Africa seasonal rainfall using global SST as a single predictor. The technique has been described in Barnston (1994) and Barnston, Thiao, and Kumar (1996). Several experiments have been performed. The best skill for southern Africa was obtained for the summer rainfall at four seasons lead, with an average skill of 0.23 (fig. 5). Modest to moderate skill between 0.3 and 0.5 was found along the east coast of southern Africa from Mozambique southward to South Africa and across central South

Africa westwards to southern Namibia. The skill levels were low (0.10-0.30) across much of the subcontinent and in the Cape region of South Africa. However, the diagnosis produced by CCA indicated the development of a moderate cold ENSO event associated with a tendency for above-normal rainfall. Given the linearity of CCA, a warm ENSO event would coincide with a tendency for below-normal rainfall. A forecast based on this research will be issued in early November for southern Africa summer rainfall.

4. Summary and Lessons Learned

Severe and recurrent rainfall deficits across Africa during the past two to three decades have been detrimental to the economy of the African nations. Thus, policy makers and funding agencies often fact tough challenges in developing relief plans. There clearly is a need for forecasts of short-term climate fluctuations, such as for seasonal rainfall anomalies for one or more seasons in advance. However, climate prediction is still experimental. The techniques used may be capable of roughly estimating the climatic conditions that will prevail during the next few seasons. While numerical approaches are being considered, work so far has focused more on statistical methods. These purely statistical methods, while lacking insight into the atmospheric circulation mechanisms, sometimes outperform the numerical modeling approaches. However, Hastenrath (1995), in his review of recent advances in tropical climate prediction, proposed that the parallel pursuit of a general circulation-based empirical approach and numerical modeling offers insight into the atmosphere-ocean mechanisms of climate anomalies and therefore should be encouraged.

In addition, emphasis should be put on diagnostic studies to better understand the physical mechanisms of climate variability. The Southern Oscillation accounts for only part of the variability in southern Africa rainfall. Thus, more predictors should be identified and used in a forecast scheme to achieve increased accuracy in the forecasts.

One big challenge that most scientists face when dealing with climate prediction, especially in Africa, is the sparsity of the raingage network and the unreliability of the historical data. CCA Experiments performed using filtered station data (Barnston, Thiao, and Kumar, 1996) and gridded data extracted from the Hulme data set (Thiao and Barnston, 1996) showed improved skills in parts of Africa having sparser data when using the latter dataset. This could be explained by the fact that gridded data are developed using stations that have major gaps during some periods, while the station data set completely excluded such stations. Furthermore, an independent experiment was run for South Africa using area average rainfall over 80 districts. The spatial distribution of the skills at one month lead for South Africa summer rainfall were different from the one for southern Africa as a whole (see above). Higher skill between 0.3 and 0.5 were observed in the western half of South Africa, while skill levels were lower in the eastern portion. This discrepancy could result from the differences between the construction of the two data sets. This calls for the need to maintain and update routine databases for use in climate prediction. Enhanced quality control and dissemination with shorter delay times would be major assets to further development of tropical climate prediction on a real-time basis (Hastenrath, 1995).

Attention should also be given to skill evaluation and verification of forecast performance. The accuracy of long-range climate prediction is low for most of southern Africa. However, it usually exceeds that of a random forecast. Thus, it is often assumed that economic decisions should be based upon the actual forecast rather than upon the climatological state. In reality, however, the lower the forecast accuracy, the higher the loss can be in the cast of complete reliance on the forecast, whereas it could be more advantageous to be guided mainly by the climatological data. One of the advantages of using CCA in long-range prediction is that the forecast is damped toward climatology in proportion to its lack of skill.

Finally, the publication of long-range forecasts, and in general the distribution of the information to consumers should be encouraged, but not only when the information contains data on the expected accuracy of the forecast. Information on the accuracy of the forecasts in critical to the users for the decisions they would have to make through careful analyses with regard to the economic value of the forecasts. The provision of skill level is a prerequisite for any long-lead forecast to be accepted for publication in the CPC Experimental Long-Lead Forecast Bulletin.

References

Barnston, A.G., W.Thiao, and V. Kumar, 1996: Long-Lead forecasts of seasonal precipitation in Africa using CCA. *Accepted, Weather and Forecasting.*

_____ et al., 1994: Long-lead seasonal forecasts - where do we stand? *Bulletin of the AMS, 75, 11, 2097-2114.*

_____, 1994: Linear statistical short-term climate predictive skill in the Northern Hemisphere. *J. Climate, 7, 1513-1564.*

_____, and C.F. Ropelewski, 1992: Prediction of ENSO episodes using canonical correlation analysis. *J. Climate, 5, 1316-1345.*

Barnett, T. et al., 1995: Dynamically based forecasts for (1) Tropical Pacific SST through spring 1996 using a hybrid coupled ocean-atmospheric model, and (2) summer 1995 US surface temperature using a two-tiered approach. *Exp. Long-Lead Bulletin, 4, 2, 1-3.*

Cane, M. et al., 1994: Forecasting Zimbabwean maize yield using eastern equatorial Pacific seas surface temperature. *Letters to Nature, 370, 204-205.*

_____ et al., 1986: Experimental forecast of El Niño. *Nature, 321, 827-832.*

Greischar, L. and S. Hastenrath, 1995: Prediction of summer rainfall over eastern South Africa using empirical methods, *Exp. Long-Lead Bulletin, 4, 4, 27-28.*

_____ and S. Hastenrath, 1995: Prediction of summer rainfall over eastern South Africa using empirical methods, *Exp. Long-Lead Bulletin, 3, 4, 24.*

Hastenrath, S., 1995: Recent advances in tropical climate prediction. *J. Climate, 8, 1519-1531.*

_____, and L. Greischar, 1995: Prediction of summer rainfall over South Africa. *J. Climate, 8, 1511-1518.*

Ji, M. et al, 1994: An experimental coupled forecast system at the National Meteorological Center some early results. *Tellus, 46A (1994), 4, 398-418.*

Landman, W., 1995: A canonical correlation analysis to predict South African summer rainfall, *Exp. Long-Lead Bulletin, 4, 4, 23-24.*

_____, 1994: A canonical correlation analysis to predict South African summer rainfall, *Exp. Long-Lead Bulletin, 3, 4, 25-26.*

Lecomte, D. and W. Thiao, 1995: SST anomalies in the equatorial Pacifica and their relationship to corn yield in southern Africa. *Presented at the International Symposium on African Drought, July 31-August 4, Trieste, Italy.*

Lindsay, J.A. and C.H. Vogel, 1990: Historical evidence for southern oscillation Southern African rainfall relationships. *Int.J. Climatol., 15, 199-135.*

Mararira, C.H. and L. Unaganai, 1995: A rainfall prediction model for southern Africa based on southern oscillation phenomena. *Technical Hand Book, SADC/FAO Early Warning System, pp. 41.*

Ropelewski, C.F. and M.S. Halpert, 1989: Precipitation patterns associated with the high index phase of the southern oscillation. *J. Climate, 2, 3, 268-284.*

_____, and M.S. Halpert, 1987: Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. *J. Climate, 115, 8, 1606, 1626.*

Thiao, W. and A. Barnston, 1996: Prediction for Sahel rainfall in Jul-Aug-Sep 1996. *Exp. Long-Lead Bulletin, 5.2.29.-32.*

_____, A.G. Barnston and V. Kumar, 1995: Teleconnections and seasonal rainfall prediction in Africa. *Proceedings of the 20th Climate Diagnostics Workshop, October 23-27, Seattle, WA, 413-416.*

Zebiak, S. and M. Cane, 1995: Forecasts of Tropical Pacific SST using a simple coupled ocean-atmosphere dynamical model. *Exp. Long-Lead Forecast Bulletin, 4, 2, 7-9.*

LA PRÉVISION SAISONNIÈRE DU CLIMAT POUR L'AFRIQUE

Jean-Claude ANDRÉ

Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CERFACS)
F - 31 057 TOULOUSE Cedex 1 (France)

ABSTRACT

Climate prediction is a crucial issue for Africa. The key scientific question is however to determine to what extend there exists predictability skill, at which temporal scales (monthly, seasonal, annual, interannual) and for which parameters (temperature, precipitation,..). This review paper discusses evidence of seasonal skill, based on actual coordinated research programmes conducted between African and European groups: the El Masifa project between Algeria, France, Marocco and Tunisia, and the PROVOST project between many European groups coordinated by ECMWF. Examples are given concerning predictability scores for precipitation prediction, as well as for some other meteorological parameters.

RÉsumÉ

La prévision climatique est un sujet de première importance pour l’Afrique. La question scientifique principale est de déterminer si le climat est prévisible, et si oui à quelle échéance temporelle (mensuelle, saisonnière, annuelle, interannuelle) et pour quels paramètres (température, précipitations,...). Cet article de synthèse traite des éléments relatifs au potentiel de prévisibilité tel qu’évalué à partir des résultats des programmes de recherche conduits en coopération entre des groupes africains et européens, comme le projet El Masifa entre l’Algérie, la France, le Maroc et la Tunisie, et le projet PROVOST entre de nombreux groupes européens et coordonné par le CEPMMT. On donne des exemples concernant les scores de prévisibilité pour les précipitations, ainsi que pour d’autres paramètres météorologiques.

1. Quelle PrÉvisibilttÉ pour le climat en Afrique ?

Le climat fluctue à toutes les échéances, et ses variations mensuelles, saisonnières, inter-annuelles, décennales, et même à plus long terme, présentent toutes une grande importance vis-à-vis des grands secteurs socio-économiques, et, en particulier en Afrique, pour la production agricole. La première question qui se pose est donc : ces variations sont-elles prévisibles ? Et si oui quelles sont celles d'entre elles qui présentent une "prévisibilité" suffisante pour que l'on puisse effectivement réaliser des prévisions possédant un certain degré de fiabilité ?

Les dix dernières années ont vu les connaissances scientifiques liées à l'oscillation australe et au phénomène El Nino (ENSO) progresser de façon spectaculaire, laissant présager de la possibilité de mettre en place des méthodes de prévision de cette oscillation et des fluctuations climatiques induites à l'échéance inter-annuelle. Les pays bordant l'océan Pacifique et les pays de l'hémisphère sud sont ceux pour lesquels le potentiel prédictif associé à l'ENSO est le plus important : les méthodes de prévision de cette interaction océan - atmosphère se développant dans la ceinture intertropicale, qu'elles soient basées sur des modèles dynamiques couplés, ou bien qu'elles soient construites en tirant tout le parti possible d'approches à caractère plus statistique, ont commencé à se mettre en place. La question importante qui nous préoccupe ici est de savoir si le potentiel prédictif de ces méthodes s'étend au continent africain.

Halpert et Ropolewski (1992) ont montré que l'oscillation australe (ENSO) se traduisait par des anomalies climatiques de moindre importance en Afrique : le signal sur l'Afrique de l'Ouest est toujours extrêmement faible, très difficilement discernable parmi les fluctuations à plus court terme. Seule une partie de l'Afrique de l'Est et l'Afrique australe connaissent des fluctuations climatiques partiellement explicables par les différentes phases de l'oscillation australe. Ceci est confirmé par les analyses météorologiques opérationnelles réalisées au Centre Européen de Prévision Météorologique à Moyen Terme (CEPMMT, 1997) : en moyenne, la différence entre deux situations aussi contrastées que, d'une part, l'hiver 1986-87, avec développement du phénomène El Nino, et, d'autre part, l'hiver 1988-89 avec développement de la phase opposée de l'ENSO (phénomène La Nina), ne se traduit sur l'Afrique que par des différences de géopotentiel à 1000 hPa au plus égales à 1 dam, alors que ces mêmes variations peuvent atteindre des valeurs plusieurs fois supérieures dans les autres régions du globe (Figure 1b). Les simulations climatiques réalisées dans les mêmes conditions au CEPMMT (1993) montrent de plus que ces faibles fluctuations sont difficilement reproductibles par le modèle (Figure 1a).

La prévisibilité des fluctuations climatiques est-elle donc plus importante pour les échéances plus rapprochées? Les prévisions expérimentales à caractère statistico-dynamique réalisées de façon systématique par le service météorologique britannique (UKMO) semblent le montrer. En effet les simulations rétrospectives de Rowell et al. (1992), basées sur des intégrations du modèle du UKMO avec une température de surface océanique (TSO) prescrite, montrent une capacité intéressante pour prévoir les précipitations tant sur la zone sahélienne que plus au sud dans le Golfe de Guinée (Figure 2).

L'objectif principal de cet article de synthèse est donc de caractériser plus spécifiquement les capacités prédictives à l'échéance saisonnière (c'est-à-dire jusqu'à 3 ou 4 mois), et de présenter les résultats de prévisions mises en place de façon systématique avec certains pays d'Afrique et en coopération européenne.

2. La prÉvision saisonniÈre

On définit ici la prévision saisonnière comme la prévision à l'échéance de 3 à 4 mois, pour laquelle la TSO joue un rôle prépondérant, sa connaissance permettant en effet de caractériser les fluctuations de la circulation atmosphérique que ses anomalies induisent.

Un ensemble de laboratoires européens s'est engagé dans l'exploration systématique de la prévisibilité et de la prévision saisonnières, en grande partie sous l 'égide du CEPMMT à travers un projet, dit "PROVOST", regroupant de nombreux centres climatiques comme le Hadley Center (UKMO), le Centre National de Recherches Météorologiques (CNRM, Météo-France), et la Direction des Etudes et Recherches d'Electricité de France (EDF/DER). De façon analogue, et toujours avec l'aide des programmes de la Commission de l'Union Européenne, s'est mis en place un programme relatif à la prévision climatique pour les pays d'Afrique du Nord, dit "EL MASIFA", réalisé en collaboration entre les services météorologiques algérien, marocain et tunisien et le CNRM. Nombre des expériences de prévisibilité et de prévision numérique saisonnières réalisées à l'occasion de ces deux programmes sont étroitement coordonnées, ce qui permet une meilleure compréhension et une meilleure utilisation et valorisation des résultats.

Une des différences principales entre les expériences de prévision saisonnière réalisées dans les programmes PROVOST et EL MASIFA concerne la façon dont la prévision de l'évolution de la TSO est réalisée. Si dans les expériences de prévisibilité la TSO est prescrite conformément à son évolution observée, dans les expériences de prévision cela n'est évidemment plus possible. Dans le projet EL MASIFA, la méthode utilisée pour prévoir l'évolution de la TSO sur les 3 à 4 mois nécessaires est relativement simple, et utilise un processus auto-régressif pour, à partir de la TSO observée à l'instant initial, prévoir les grandes lignes de son évolution. Cette méthode présente un avantage certain de qualité statistique des résultats par rapport à la méthode la plus simple qui consisterait à considérer que le champ spatial de TSO reste constant pendant les 3 à 4 mois de prévision, tout en conservant une simplicité de mise en œuvre très attractive. Par contre, dans la partie prévisionnelle du programme PROVOST, la TSO sera prédite grâce au schéma de prévision lui-même, qui associera de façon couplée un modèle atmosphérique et un modèle océanique initialisé de façon plus ou moins élaborée. Les résultats des prévisions avec le modèle couplé ne sont malheureusement pas encore disponibles, cette partie du programme venant d’être lancée seulement récemment.

La figure 3 montre que la prévisibilité à 3 mois pour les hivers de l’hémisphère nord est réelle, mais reste variable d’une année à l’autre. Si elle est particulièrement importante pour l’hiver 1982/83 (année où a été observé un fort phénomène El Nino), avec des coefficients de corrélation d’anomalies très souvent supérieurs à 0,4, elle est sensiblement moins élevée pour la moyenne des 5 hivers de 1978/79 à 1983/84, avec des coefficients de corrélation d’anomalies restants positifs mais de valeurs moins élevées. Une variable plus directement intéressante pour la prévision climatique en Afrique est représentée à la Figure 4, où sont portés les résultats d’expériences de prévisibilité pour les années 1987 (où la pluviométrie sahélienne a été très nettement déficitaire) et 1988 (où cette même pluviométrie s’est révélée proche de sa valeur climatologique) : la différence entre ces deux années semble tout à fait prévisible, quelle que soit la méthode d’initialisation retenue pour le modèle atmosphérique.

Si la prévisibilité saisonnière sur l’Afrique semble bien avérée, même pour des paramètres aussi difficiles à prévoir que le sont en général les précipitations, il reste à vérifier que la prévision que l’on peut effectivement mettre en place, tant dans les conditions présentes (méthode auto-régressive du projet EL MASIFA) que dans les conditions futures (modèle couplé océan-atmosphère du projet PROVOST), peut atteindre une partie significative de cet objectif.

La figure 5 montre les coefficients de corrélation d’anomalies comparés pour les expériences de prévisibilité PROVOST et pour les expériences de prévision EL MASIFA, pour l’altitude du géopotentiel à 850 hPa: on y constate que de façon systématique la prévision n’atteint pas les scores que laisse espérer la prévisibilité, mais que la prévision permet toutefois d’atteindre des scores assez élevés dans la bande intertropicale (de l’ordre de 0,5 sauf pour les premières années de la décennie 90), de même que dans l’hémisphère nord (bien que les scores y soient moins élevés, seulement de l’ordre de 0,2 à 0,3). Ces résultats s’appliquent de façon très semblable pour la température à 850 hPa (Figure 6), avec des scores à peine moins élevés. De façon encore beaucoup plus encourageante, les précipitations totales au cours d’une saison sont, elles aussi, assez bien prévues dans la bande intertropicale, avec des scores de 0,2 par rapport à un objectif de 0,3 pour les expériences de prévisibilité, et des scores très proches de ceux de la prévisibilité pour l’hémisphère nord, bien que ces scores soient plus faibles et surtout plus variables d’une année à l’autre (Figure 7).

3. Perspectives

Les premières conclusions qui peuvent être tirées des ces expériences coordonnées entre l’Europe et l’Afrique sont au nombre de trois :

- tout d’abord, nombre de paramètres climatiques apparaissent prévisibles à l’échéance de 3 à 4 mois, même parmi ceux qui traditionnellement sont les plus délicats à prévoir, comme les précipitations. Bien entendu la prévisibilité est d'autant meilleure que la zone de prévision est plus étendue : si la bande intertropicale en tant que telle présente de bonnes perspectives du point de vue de la prévisibilité, des régions moins étendues (comme l'Europe) présenteront des scores assez nettement moins élevés ;

- **ensuite, les méthodes simples qui peuvent être mises en œuvre dès à présent, comme par exemple la prévision à partir de températures de surface océanique prévues par auto-régression, permettent d'atteindre une fraction significative des scores que laissent espérer les expériences de prévisibilité ;**

- enfin, la mise en œuvre ultérieure de méthodes basées sur des modèles couplés océan-atmosphère plus performants peut permettre de rapprocher les scores atteints en prévision de ceux que laissent espérer les études de prévisibilité.

Il paraît donc du plus grand intérêt d'étendre à l'ensemble de l'Afrique, sinon à certaines de ses sous-régions principales, le type d'expérimentation systématique qui vient d'être décrit pour l'Europe et l'Afrique du Nord.

Remerciements

Je tiens à remercier les chercheurs des projets PROVOST et EL MASIFA pour la communication de nombre de leurs résultats avant publication. L'aide de M. Déqué a été particulièrement appréciée pour rassembler ces éléments.

Références bibliographiques

CEPMMT, 1993: "Proceedings of the Workshop on monthly and seasonal forecasting". ECMWF, 7-9 Dec. 1992.

CEPMMT, 1997: "Annual research progress report on long-range forecasting, September 1995 to Augusta 1996". In "Long-range forecasting progress report for 1995/1996",, WMO/TD, **800**, 21-49.

Déqué, M., et J.P. Piedelièvre, 1997 : Communication privée.

Halpert, M.S., et C.F. Ropolewski, 1992: "Surface temperature patterns associated with the Southern Oscillation". J. Climate, **5**, 577-593.

Rowell, D.P., C.K. Folland, K. Maskell, J.A. Owen et M.N. Ward, 1992: "The influence of global sea surface temperature on the variability and predictability of seasonal Sahel temperature". Geophys. Res. Lett., **19**, 905-908.

The use of satellite data in monitoring rainfall and riverflow forecasting in large river basins of sub-Saharan Africa

D.I.F. Grimes and M. Diop
TAMSAT, Dept of Meteorology, University of Reading, Reading, RG6 6BB, U.K.

1. Introduction

For the past 30 years, there has been concern about decreasing rainfall in Sahelian Africa and whether this is linked to anthropogenically-induced climate change. Unfortunately, accurate assessment of the situation on any but the coarsest spatial and temporal scales is hindered by the sparseness of the rain gauge network. In the last decade, the situation has improved with the development of satellite technology. In particular, imagery from the Meteosat satellite is now used routinely in many areas to provide operational rainfall data. The advantage of this is that area estimates can be made in real time and at low cost over the whole region. As well as giving valuable information about long-term variability, the data are available for immediate applications such as drought monitoring and river flow forecasting. The main disadvantage is that estimates generally rely on calibration against ground-based data, and the calibrations vary spatially and temporally.

2. Rainfall estimation methodologies

Most operational rainfall monitoring systems in Africa use Thermal Infra Red (TIR) imagery from the Meteosat satellite because of its high repetition rate and the link between rainfall and cloud top temperature. Low temperatures identify cumulonimbus clouds associated with convective storms and the duration of the clouds colder than a given threshold temperature T_t (the Cold Cloud Duration or CCD) may be used to provide a quantitative estimate of rainfall (Arkin, 1979). There are a number of variants on this theme and this paper will describe two of which are in operational use. The first was developed by the TAMSAT group at the University of Reading in the United Kingdom, and the second is the EPSAT-Lannion method developed by the ORSTOM group based in Dakar, Senegal.

In the TAMSAT method (Milford *et al.*, 1990), which was originally devised for drought monitoring, TIR data are used to construct CCD images which represent the number of hours each pixel is colder than T_t in a 10 day interval or dekad. A linear relationship is assumed to exist between the rainfall (P) and the CCD (D) of the form:

$$P = a_0 + a_1 D \qquad \text{for } D > 0 \qquad (1)$$
$$P = 0 \qquad \text{for } D = 0$$

The values of the threshold T_t and the parameters a_0 and a_1 are determined by comparing available rain gauge measurements with the CCD values of the pixels containing the gauges. For calibration purposes, northern Africa is divided into a number of zones (Figure 1) and a set of parameters is calculated for each zone and month. The parameters thus obtained are assumed to be applicable to all years, so calibrations may be carried out with historic data. Although this is a slightly dubious assumption, it has the advantage of simplicity and means there is no need for real-time gauge data.

The EPSAT technique also uses a linear relationship between rainfall and CCD to derive dekadal estimates but takes into account the effect of surface temperature and latitude. The algorithm is of the form:

$$P = aD + bT_{max} + cL + d \qquad \text{for } P > 0 \qquad (2)$$
$$P = 0 \qquad \text{for } P = 0$$

Where, T_{max} is the mean of the maximum surface temperatures in the two pentads making up the dekad and L is the latitude. In this case, T_t is set at -40^0 C and the calibration is carried out using available, real-time rain gauge data.

Two comparisons of the methods have been reported recently (Arnaud *et al*., 1996 and Laurent, 1996). Both studies conclude that the EPSAT method gives slightly more accurate results, particularly at high rainfall values. This is mainly due to the use of contemporaneous rain gauge data for calibration, which may be a complicating factor in operational terms. Figure 2 (reproduced from Arnaud et al.) compares the two algorithms for the time period 1990 to 1994 at a spatial scale of 10,000 km^2 using the EPSAT-Niger rain gauge dense network for validation. Both approaches are adequate for monitoring the progress of the rainy season, identifying regions at risk from drought and predicting likely harvests.

Some of the variance in the regression of satellite-pixel values and gauge measurements is explained by the fact that the gauge measurement is an imperfect estimator of the pixel area average rainfall. This has been investigated by Flitcroft *et al*., 1989, who used a geostatistical approach to quantify the errors associated with using a single point value to estimate an area rainfall. As an illustration of this method, Figure 3 shows the mean gauge value for each of the TAMSAT zones and mean estimate for the pixels containing the gauges for June to October, 1991. The error bars, computed according to Flitcroft take into account the spatial structure of the rainfall (via its correlogram), and the number of gauges used in the calculation, allowing a realistic assessment to be made of the accuracy of the satellite estimates.

Several conclusions can be drawn from Figure 3. Firstly, for zones 1 to 4 and 7 and 8, the satellite estimates are reasonably accurate and follow closely the shape of the season. The good agreement in Zones 7 and 8 is quite surprising as it might be expected that orography and coastal effects would degrade the results. Secondly, peak rainfall tends to be underestimated, confirming the results of Arnaud *et al.* and Laurent. Thirdly, the estimates are worst in zone 5 and particularly in zone 6 where the bimodal pattern of the season is not replicated. This is almost certainly due to the effect of maritime air near the coast producing rain from relatively warm clouds. Figure 3 emphasises the fact that the reliability of satellite based rainfall estimates depends on whether the climatic assumptions built into the algorithm are being met. Where these assumptions are valid, the estimates give valuable information in real time with complete area coverage.

3. Applications to hydrology

The availability of real-time area rainfall estimates has obvious applications in the field of hydrology which are as yet underexploited. The rainfall data can be used as input to a surface hydrological model which forms the basis of riverflow management and flood warning systems. The use of satellite data allows the modelling of remote and ungauged catchments and opens up the possibility of monitoring the surface water budget on a regional scale which could be very useful in climate change simulations. This study uses the Pitman model (Pitman, 1976). This is a conceptual model which calculates river flow from catchment average rainfall and potential evaporation (E_p). Here, it has been applied to the Oualia and Dakka Saidou catchments of the Senegal (Figure 4) and the Kafue Hook catchment in the Zambezi basin. For hydrological purposes, a separate calibration was carried out for each catchment and rainfall estimates were calculated on a daily basis.

The problem of interannual fluctuations in calibration parameters calculated from a limited data set was found to cause variations of up to 30% in estimated annual rainfall. In order to disentangle this problem from the ability of the estimates to successfully predict the detailed flow, the calibrations for this study are based on contemporaneous rain gauge values. This will show the potential of the method, but eventually it may be possible to achieve the same results without real time rain gauge data.

The method of estimating evaporation is also an important consideration. This is particularly so in semi-arid regions where more than 90% of rainfall may be evaporated. For the Kafue Hook, available pan evaporation data were used as estimates for E_p. However, this was not possible for the Senegal, so climatological monthly mean E_p values were substituted. In the original Pitman model, actual evaporation E is calculated from E_p as a linear function of soil moisture. In a seasonally arid catchment, the extent of vegetation is obviously of critical importance. This has been addressed by making use of NDVI estimates derived from the NOAA AVHRR data to estimate the fraction of the catchment covered by vegetation. Evaporation is then calculated using an algorithm suggested by Serafini and Sud (1987) which applies different models to vegetated and non-vegetated areas. The modified evaporation model made a significant improvement to the results in Oualia, where there are marked seasonal changes in vegetation and little difference in the other catchments, and has therefore been adopted as the standard model. This is more fully described in Bonifacio *et al.*, 1996. For each catchment, satellite rainfall estimates and rain gauge data were used as input and the results assessed by comparison with the measured river flow. This was achieved both by visual inspection of the simulated and actual hydrographs and by calculation of an objective function O

$$O = 1 - \sum_i \left(Q_{oi} - Q_{si}\right)^2 \Big/ \sum_i \left(Q_{oi} - Q_m\right)^2 \qquad (3)$$

where Q_{oi} is observed flow, Q_s is simulated flow and Q_m is the mean daily measured flow. Model parameters were calibrated by maximising O for one year, then running with the same calibration for subsequent years.

Results for the three catchments are summarised in Table 1 and specimen hydrographs are shown in Figure 5. The calibration year is indicated by an asterisk.

Table 1.

Catchment	Area per gge/km^2	Year	O_{CCD}	O_{gge}
Oualia	7000	1987	0.76	-0.58
	7000	1988*	0.85	0.62
Dakka Saidou	2000	1986*	0.91	0.82
	2000	1987	0.80	0.89
	2000	1988	0.70	0.66
Kafue Hook	8000	1992/3*	0.97	-
	8000	1993/4	0.82	0.59

In general, the performance of the rain gauge data depends on the density of the network within the catchment. The satellite estimates consistently give better results than the gauge estimates, with the exception of Dakka Saidou, the most densely gauged catchment, in 1987. The satellite estimates generally give a good match both to the long-term baseflow characteristics and also to individual peaks. This is particularly so for the Kafue Hook catchment in 1992/3. The fit overall is very good considering the simplicity of the model and the poor quality of evaporation data and well demonstrates the potential application of satellite data to hydrological modelling providing the interannual stability of the calibrations can be improved.

4. Use of weather analysis information in rainfall estimate calibration

It is likely that at least some of the variability in the relationship between CCD and rainfall should be due to the prevailing weather regime. In order to investigate this, we have compared the relationship between CCD and rain gauge values with weather conditions in the Oualia catchment derived from analyses from the European Centre for Medium Range Weather Forecasting (ECMWF) in Reading. Results presented here look at the effect of Africa Easterly Waves on the calibrations and are discussed in more detail elsewhere (Diop *et al.*, 1996).

African Easterly Waves are westward propagating waves that occur around 15° N with a wavelength of 1500-4000 km, a phase speed of 5 - 7° of longitude / day and a lifetime of 2.5-5.5 days. There is some controversy about the rainfall associated with them, though most studies have associated the trough with heavier rainfall. In this work, we have analysed the waves for July-September 1988 and 1989 on a daily basis using the ECMWF initialised data. The waves were identified by carrying out streamlines/isotachs analyses on the 700 mb chart. The waves were divided into 6 phases numbered as follows: 1-ahead of the ridge; 2-in the ridge; 3-behind the ridge; 4-ahead of the trough; 5-in the trough; and 6-behind the trough. Phase 7 indicates no wave activity. Days in the study period are classified according to their agreement with the gauge data. A ‘good’ day is any day for which the mean catchment rain gauge falls into the interval [SRE-*e*, SRE+*e*] mm where SRE is the satellite rainfall estimate and the value of *e* is the mean of the standard errors of the individual calibrations. For this study, *e* = 4 mm. An ‘underestimate’ is a day for which the mean rain gauge is higher than this range; an overestimate occurs when it is lower. Table 2 summarises the accuracy of the rainfall calibration with regard to the phase of the wave affecting the catchment. Overall the calibration is good when the catchment is affected by a ridge (phases 1 and 2) or if no wave is detectable. However, the calibration coefficients are not significantly different for the ridge, trough or ‘no wave’ situations. In general, the least stable calibrations correspond to the wave phases associated with deep convection.

Table 2.

Phase	1-2	3-6	7
No. of days	20	61	89
Under %	10	33	10
Over %	5	10	13
Good %	85	57	76

5. Merging of satellite estimates of rainfall data

The EPSAT technique described in Section 2 improves the reliability of the rainfall estimates by the use of contemporaneous rain gauge data in the calibration. An alternative approach is to merge available rain gauge information with the satellite estimates. Again, one must overcome the problem that gauge data are point measurements whereas the satellite estimates are area averages. Once more, a geostatistical approach is appropriate. If the spatial structure of the rainfall can be determined by computing a variogram, rainfall estimates and associated errors can be computed for any area. This allows maps to be constructed giving the best rainfall estimate from the available set of rain gauges for each pixel-sized area. If an error is also assigned to the satellite estimates (which as a first guess may be spatially invariant), a weighted average may be used to compute a 'best' estimate for each pixel as

$$P = \frac{e_g}{\sqrt{\left(e_g{}^2 + e_s{}^2\right)}} p_s + \frac{e_s}{\sqrt{\left(e_g{}^2 + e_s{}^2\right)}} p_g \qquad (4)$$

where e is the error value and subscripts s and g refer to satellite and gauge estimates respectively. Figure 6 shows this approach applied to the EPSAT dense rain gauge network in Niger for one day in August 1992. The pixel estimates from the gauges and associated error values are shown together with the satellite estimates and the error estimates for each pixel for the gauge data. It can be seen that the smallest error values are associated with the most closely spaced gauges.

6. Future directions

The challenge for the future is to improve the rainfall estimates both in terms of resolution and reliability. There are many possibilities as satellites increase in number and the ability of computers to manipulate and store the data continues to develop rapidly.

6.1 The use of data from other satellites

The use of passive microwave imagery for rainfall estimation has been well researched, particularly since the increased availability of data from the SSM/I sensor. However, poor spatial resolution and low overpass frequency limit the applications. In addition, the quality of the estimates over land is degraded by the variation of the background signal due to changes in vegetation and soil moisture. Nevertheless, microwave imagery is a useful additional source of information, and the challenge is to find optimum ways of combining this information with the Meteosat derived estimates. Work in this direction is being carried out by a number of organisations (e.g., Arkin and Xie, 1995).

Synthetic Aperture Radar (SAR) (e.g., from ERSI) is already being used to monitor soil moisture. The launch of the TRMM mission in 1997 will provide the additional capability of using radar to monitor cloud processes. This could be a major step forward in developing physically-based approaches rather than empirical algorithms for rainfall estimation.

6.2 Novel computational approaches

Improvements in computer technology mean that even more sophisticated data analysis methods can be applied to extract the maximum information from the available data. Neural network techniques are finding a range of applications in GIS data analysis and are of particular relevance here. It should be possible to use these methods to identify cloud and weather types from a combination of satellite imagery and weather analysis products and use these to select appropriate algorithms for rainfall estimation (Pankiewicz, 1997).

7. Conclusions and recommendations

Satellite-based estimates of rainfall are of great potential benefit both for investigating long- term, regional changes in rainfall and in real time monitoring of surface water budgets with relevance to agriculture and hydrology. Current developments imply improved accuracy and reliability in the future. As of yet, this methodology is not used to its full capability. In order to improve this situation, the following actions are recommended:

5. cataloguing existing data sets of rain gauge, evaporation and hydrological information for the whole of the sub-Saharan region and development of a regional database of rain gauge, evaporation and hydrological data, satellite imagery and weather analysis products;
6. collaborative research projects developing estimation techniques appropriate to the sub-Saharan region; and
7. funding fellowships to stimulate collaborative projects and to provide training for local scientists.

References

Arkin P.A.; 1979; The relationship between fractional coverage of high cloud an rainfall accumulations during GATE over the B-scale array. Mon. Weather Review, **107**, 1382-1387.

Arnaud Y., Taupin J.D., Laurent H.; 1996 Validation de deux methodes d'estimation des pluies par satellite; in *Validation Problems of Rainfall Estimation by Satellite in Intertropical Africa*; Guillot B. ed.; Orstom, Paris.

Bonifacio R. Diop M., Dugdale G. and Grimes D.I.F.; 1996; Use of Meteosat and NOAA AVHRR data in the hydrological modelling of a semi-arid catchment in W. Africa; in *Progress in Environmental Remote Sensing*: Research and Applications; E. Parlow ed. Balkema pub.

Diop M., Dugdale G., Grimes D.I.F.; 1996; The influence of easterly waves on satellite rainfall calibration on a Sahelian catchment; presented at the 2nd International Meteorology Society Conference, Morocco, 1996.

Flitcroft I., Dugdale G., Milford J.R.M.; 1989; Relating point and average area rainfall over the Sahel; Proc. Int. Workshop on Precipitation Measurement, 4-7 Sept., 1989, St Moritz, Switzerland; WMO, IAHS, ETH.

Laurent H.; 1996; Validation des estimations de precipitation a grande echelle in *Validation Problems of Rainfall Estimation by Satellite in Intertropical Africa*; Guillot B. ed.; Orstom, Paris.

Milford J.R., Dugdale G.; 1990; Estimation of rainfall using geostationary satellite data; in *Applications of remote sensing in agriculture*, J.A. Clark & M.J.Steven (ed.), London, Butterworth.

Pankiewicz G.S. 1997; Neural network classification of convective air masses for a flood forecasting system; Int. J. Rem. Sens., **18**, No. 4, 887-898.

Reed, R.J. (1978) The structure and behaviour of easterly waves over west Africa and the Atlantic. In Meteorology over the tropical oceans, Shaw, D.B. (Ed). Royal Meteorology Society.

Serafini Y.V., Sud Y.C.; 1987; The time scale of soil hydrology using a simple water budget model *Climate*, **7**, 585-591.

Xie P. and Arkin P.A.; 1996; Analysis of Global Monthly Precipitation Using Gauge Observations, Satellite Estimates and Numerical Model Predictions; Journal of Climate; **9**, p840-858.

Acknowledgements

We gratefully acknowledge data and assistance provided by the following organisations: national met. services of Zambia, Mali and Guinea, the Zambezi River Authority, ZESCO, ORSTOM and OMVS.

Modelling the Daily Rainfall in West Africa

S.G.K. Adiku[1], N. Van de Giesen[2] and G.N.N. Dowuona[1]

(1) Department of Soil Science, University of Ghana, Legon, Ghana.
(2) West Africa Rice Development Association (WARDA), 01 BP 2551, Bouake, Cote D'Ivoire.

Abstract

We have evaluated the performance of the stochastic daily rainfall model of Adiku *et al.* (1997) at eight sites, covering a variety of ecological zones in West Africa. The simulation of the number of rainy days in any given month at each site agreed quite well with the observed ($R^2 = 0.93^{**}$). Also, when the daily rainfall was aggregated to monthly rainfall, the agreement between the simulated and observed at the various sites was quite good ($R^2 = 0.93^{**}$). Thus, the model captures both the temporal (month-to-month) and spatial variations of the rainfall quite well. In its current form, however, the model has some limitations. For example, the total number of rainy days in a given month can be simulated but not the manner in which these rainy days are distributed in the month. In some months at certain sites, rainfall is clustered to some part of the month rather than randomly distributed, as the model output suggests. Furthermore, there seems to be a considerable increase in the year-to-year variations in the West African rainfall especially over the last two decades. The model in its current form is unable to account for such short-term changes in rainfall patterns. Some suggestions have been offered in the text as to how the model could be improved to take account of these limitations.

1. Introduction

The significance of rainfall to the productivity of rainfed agriculture in West Africa is generally known. However, water management and rainfed agriculture is hampered by the spatial and temporal distribution of rainfall (Fig. 1). Agronomic research conducted under rainfed conditions at a given site within the region often leads to results that tend to be site and time specific, thus, limiting the scope of extrapolation of research findings (Nix, 1968; McCown, 1973).

The most commonly employed approach to overcome these limitations is the establishment of multi-location trials conducted over long periods of time. This approach, however, is not only time consuming but can be very expensive. What should constitute the minimum number of locations or time remains a subject of controversy and will not be discussed here any further. On the other hand, it has become evident that crop modelling techniques provide a feasible alternate approach for testing and assessing the successes/failures of a variety of agrotechnologies in different environments.

A host of crop models which have been developed within the last few decades has been listed by Ritchie (1991). These models are currently used as decision support tools for the evaluation of the effects of a variety of cultural practices such as planting density, fertilizer levels, planting dates, etc. on crop productivity. Most crop models operate on a daily time scale and require an input of daily climate variables for execution. For the West African sub-region, rainfall appears to be the most important and most variable climatic factor. Although rainfall data are commonly available at many sites in the region, the long-term records of the daily rainfall are not always readily available in digital form, and even where they do occur, climate data are often entered as tables, which is inconvenient when simulations involving entire seasons need to be repeated for several locations (Fernandez, 1992).

Furthermore, there is also the problem of missing values. Thus, the use of historical data with crop models is cumbersome and is not without problems, hence the need for weather generating models. The need for a daily rainfall simulation model becomes even more important considering the realization that a set of historical rainfall patterns may not repeat itself in exactly the same manner in future (Van Tassel, 1990). As also noted by Fernandez (1992), the flexibility of crop models would be greatly enhanced if such models have the ability to generate the required climate data.

The aim of this study is to evaluate the performance of a stochastic rainfall simulation model (developed and tested for two sites in Ghana by Adiku *et al.*, 1997) at other rainfall sites in the West African region. Limitations of the model and the possible improvement opportunities will be discussed.

2. Material and Methods

2.1 Sites

In this study, eight sites within West Africa were selected from the various ecological zones of the region (Fig. 1). The sites include Accra and Tamale (Ghana), Abidjan, Yamoussoukro, Bouake and Korhogo (Côte d'Ivoire), Niamey (Niger) and Ouagadougou (Burkina Faso). Except for Accra, rainfall generally decreases from the southern coastal zones to the nothern zones of the region.

Also, rainfall within the southern zones is bimodal with peaks in June and October, whereas the rainfall within the northern zones is monomodal.

2.2 Data analysis and modelling

The daily rainfall data covering a period of nine years (1987-1995) were obtained on CD ROM for each of the stations. The data were used to derive the values of the input parameters required by the model. The details of model development and input requirement are given elsewhere (Richardson and Wright, 1984; Adiku *et al.*, 1997).

However, briefly, two sets of parameters are required: (i) parameters that define the rainfall state of a day (wet day = *W*; dry day = *D*) and (ii) parameters that describe the distribution of the daily rainfall. The rainfall state of the day is described in terms of transition probabilities of a first-order Markov chain for four categories, namely: the probability of a dry day followed by a dry day (P(*D/D*), the probability of a dry day following a wet day (P(*D/W*)), the probability of a wet day following a dry day (P(*W/D*)) and the probability of a wet day following a wet day (P(*W/W*)). The distribution of the daily rainfall at each site for any month is assumed to follow a two-parameter gamma distribution. The transition probabilities values as well as the rainfall distribution parameters were also assumed to remain unchanged for a given month.

Having obtained the input parameter values, the rainfall model which was essentially based on Markov chain Monte-Carlo simulation techniques as per Richardson and Wright (1984) and was executed for 1000 realizations at each site. The main output of the model included the number of rainy days in a month and the total monthly rainfall, which was obtained by aggregating the daily rainfall values for the month. Comparisons of simulated and observed data were undertaken and the degree of agreement assessed on the basis of R^2 (the coefficient of determination).

3 Results and Discussion

3.1 Number of rainy days in a month

Table 1 summarizes the simulated and the observed number of rainy days in some months for two sites: Abidjan and Niamey that fall in different rainfall zones (Fig. 1). Both the simulated and the observed data follow similar trends in each case, although the model slightly overestimated the number of rainy days from August to October at Abidjan and in September at Niamey. The month-to-month variations are also well captured. Figure 2 shows the plot of the simulated versus the observed number of rainy days in each month for all the study sites.

Table 1. Simulated and observed number of rainy days in a month at two sites in different ecological regions.

	Abidjan		**Niamey**	
Month	Simulated	Observed	Simulated	Observed
May	11	11	5	5
June	14	14	8	7
July	7	7	11	11
August	7	6	14	14
September	6	5	8	7
October	13	11	4	4

The generally good agreement ($R^2 = 0.93^{**}$) indicates that the model was capable of generating data that has similar statistical properties as the observed.

3.2 Total monthly rainfall

Figure 3 shows block diagrams of the simulated and observed mean monthly rainfall for three sites in Cote d'Ivoire (Abidjan, Yamoussoukro and Bouake). Abidjan (Fig. 3a) and Yamousoukro (Fig. 3c) show bimodal rainfall pattern which is also reflected in the simulated monthly rainfall pattern. Furthermore, the model also correctly simulated lower rainfall values for Yamousoukro than for Abidjan.

However, there is an apparent discrepancy between the simulated and observed monthly rainfall in May and September at Yamoussoukro. Given that the number of rainy days in a month was generally well simulated (Fig. 2), the apparent discrepancy here seems to be more due to difficulties in sampling the correct daily rainfall amount from the gamma distribution. We may note that the estimation of the gamma parameters in this study was based on simple expressions of the mean and variance. Using more powerful computer software could provide better estimates of these parameters.

In the case of Bouake, rainfall is generally low until a main peak in August-September and thereafter, there is a sharp fall in rainfall in October. The simulated monthly rainfall also follows the observed trends. Thus, in general, there was a good agreement between the simulated and observed in terms of month to month and site to site variations.

Figure 4 shows the plot of simulated versus the observed monthly rainfall for all sites. Except for a outliers, the agreement between the simulated and observed data was quite good ($R^2 = 0.93^{**}$). This signifies that the rainfall model in its current state is capable of simulating rainfall at each station is quite good. The model has generally performed quite well under the limited testing undertaken in this study.

3.3 Further research

Despite the apparent satisfactory performance of the rainfall model, some issues require further research attention: (i) how does the simulated distribution of the rainy days in a month compare with the observed and (ii) how can the model take account of the year-to-year variations of rainfall, which have become so evident in West Africa?

The first limitation relates to the model assumption that rainfall parameters determined for a given month remain unchanged (Richardson and Wright, 1984; Adiku *et al.*, 1997). In reality, rainfall within some months can be clustered. An analysis of the daily rainfall at Accra, for example, indicates that about 44% of the rainfall events occurred during the first half of the months of March, April, May, June and July; the percentages of rainfall events were 44%, 40%, 47%, 50% and 60% respectively. Hence, more of the rainfall events occurred in the latter parts of March, April and May while the opposite was the case in July. Of interest then, is the question, when (at what time during the month) is it more likely for rainfall to occur? Answering this question implies a re-examination of some of the model assumptions. It seems reasonable that for those months where rainfall appears to be structured, the rainfall parameters may have to determined for even shorter time intervals, perhaps, on the basis 15 days rather than on monthly basis. The model in its present form assumes a random distribution of rainfall events within a month. Using the model in this present state for agricultural advice, especially on the choice of planting dates, etc., may thus lead to erroneous conclusions. This aspect requires further research in order to improve the model.

The second issue relates to the non-stationarity of rainfall parameters with time. It appears that, unlike the temperate regions where rainfall patterns and hence rainfall variables remain constant over time, there is increasing evidence that this is not so in the West African tropics (Adiku and Stone, 1995). Indeed, the work of Adiku *et al.* (1997) shows that the transition probability values computed for Accra and Tamale over four 5-year periods from 1970 to 1989 were different from those computed from the entire twenty-year period (1970-1989). This indicates that there is some danger in using parameter values derived from short-term rainfall records for long-term simulations. Our proposal for a solution is to recognise that changes in rainfall trends may be due to a number of reasons including physical phenomena such as atmospheric circulation patterns. Adiku and Stone (1995) observed that rainfall along the southern coast of Ghana is influenced by the Southern Oscillation Index (SOI). Also, Opoku-Ankomah and Cordrey (1994) found significant correlation between the SST (Sea Surface Temperatures) of the Atlantic and rainfall in many parts of Ghana. In an analysis of sources of moisture for rainfall in West Africa, Gong and Eltahir (1996) observed that a substantial part of the rainfall in the region is from water vapor advected from central Africa and from the Atlantic. Hence, atmospheric circulation obviously plays a role in determining rainfall patterns.

Thus, a pure stochastic rainfall model which does not consider the influence of other physical effects of rainfall patterns may have limitations for general applicability in the West African tropics. It will be desirable to develop a hybrid rainfall model that considers both stochastic and physical elements.

4. Conclusion

We have evaluated the performance of a rainfall simulation model at eight sites in the West African region. Model performance in terms of simulating the number of rainy days of each month at each site was quite good ($R^2 = 0.93^{**}$). Also, when the daily rainfall was aggregated to monthly rainfall, the agreement between the simulated and observed mean monthly rainfall at the various sites was quite good ($R^2 = 0.93^{**}$). Hence, the general patterns of rainfall in the region (monomodal, bimodal, etc.) can be reproduced.

However, some limitations of the model were identified. The model was not able to reproduce the observed distribution of rainy days within the month, although the total number was well simulated. Furthermore, for real-time simulations, trends and cycles in rainfall have to be considered in modeling rainfall.

References

Adiku, S.G.K. and Stone, R.C., 1995. Using the Southern Oscillation Index (SOI) in improving rainfall prediction and agricultural water management in Ghana. Agric Water Management, 29:85-100.

Adiku, S.G.K., Dayanada, P.W.A., Rose, C.W. and Dowuona, G.N.N. 1997. An analysis of the within-season rainfall and simulation of the daily rainfall in two savanna zones in Ghana. Agric. and Forest Meteorology (in Press).

Fernadez, C.J. (1992). Simulation of normal annual and diurnal temperature oscillations in non-mountainous mainland United States. Agron. J. 84:244-251

Gong, C. and Eltahir, E. 1996. Sources of moisture for rainfall in west Africa. Water Res. Research, Vol 32 (No. 10): 3115-3121.

McCown, R.L. (1973). An evaluation of the influence of available soil water storage capacity on growing season length and yield of tropical pastures using simple water balance models. Agric. Meteor., 11: 53-63.

Nix, H.A. (1968). The assessment of biological activity. pp 77-78. In: A.G. Stewart (ed). *Land Evaluation*. MacMillan Pub. Sydney, Australia.

Opoku-Ankomah, Y. And Cordrey, I. 1994 Atlantic sea surface temperatures and rainfall variability in Ghana. J. Am Meteorol. Soc., 7: 551-557.

Richardson, C.W. and Wright, D.A. 1984. WGEN: A model for generating daily weather variables. USDA-ARS. US-Govt. Print Office. Washington DC.

Ritchie J.T. (1991). Specificatios of the ideal model for predicting crop yields. In: Muchow, R.C. and J.A. Bellany (eds). *Climatic risk in Crop Production: Models and Management for for Semi-Arid Tropics and Subtropics*. CAB International, Wallingford.

Van Tassel, L.W. 1990. Simulation of meteorological data for use in agricultural production systems. Agric. Syst. 34: 319-336.

Contribution to the Study of Interannual Variability of Rainfall in Senegal

Abdoulaye SARR * & Siméon FONGANG

Laboratoire de Physique de L'atmosphère (L.P.A) ESP B.P. 5085 Dakar-Fann Sénégal.

Abstract

This study is an attempt to explain interannual variability of rainfall in Senegal from 1980 to 1996. During these years, the distribution of rainfall is irregular. Rainfall situations more often differ from those observed in close areas at the same latitude. This means that other elements act out of the global ones in the behaviour of the rainy season according to the geographical position of Senegal.

In a first step, dynamic and thermodynamic effects which hamper or favour the movement of the more rainy disturbances is shown. Data used are analysis from the European Centre for Medium Range Weather Forecast (ECMWF) and radiosonde data for Dakar.

Cloud coverage for different temperature thresholds are studied from Meteosat images in the infrared channel (IR), while the activity and positions of dynamic High Pressure Centres that are Azores (AA), Saint-Helena (ASH) and Libya (AL) are followed by images in the water vapour channel. The importance of the meridional ridges from the anticyclones that act on the latitudinal positions of the Inter-Tropical Front (ITF) and the Inter-Tropical Converge Zone (ITCZ) is illustrated. Less activity of Algerian thermal low, corresponds to frequent merging between zonal ridges from AA and AL over Algeria.

The study shows that for dry years (1982, 1983, 1984, 1991 and 1992), the direction of rainfall deficits, which can be East / West, South / North and vice versa, vary and depend more often on the behaviour of dynamic High Centres. This was shown by former studies by Janicot (1990) and Citau (1992). We often notice an excess of rainfall compared to the normal 1951-1980 considered in this study and which include some wet years (before 1969) and a dry period after that date. This classification into dry and wet years is not homogenous over the Sahel in general and bordering countries in particular. Within Senegal, differences are noticed in the distribution of wet and dry years. The influence of Sea Surface Temperature (SST) is studied by considering monthly data in three oceanic areas:

- the coastal zone which lies from the Equator to the coast of Morocco 00° to 30° North and from 15° West to 30° West;

- the North Atlantic zone between 05° and 20° North and from 30° to 60° West; and
- the South Atlantic zone (SA) between 00° to 20° South and from 10° East to 30° West.

The analysis of SST anomaly diagrams shows differences between dry and wet years and particularly years where the rainy season is better? in the west of the country. Positive anomalies over the North Atlantic correspond to a rainy season in the western part of Senegal and frequent formation of tropical depressions, which can became cyclones. They are in general, “Dakar Systems” (DS), as they were named by Frank (1971). At the beginning, these anomalies are mobile disturbances over the continent and then became tropical depressions over the sea, sometimes turning into cyclones later. The years 1989, 1995 and 1996 provide typical examples of high positive SST over the North Atlantic Ocean and near the western coast in which Dakar represents the most advanced continental area. Many DS were observed and some of them became thereafter cyclones which reached the Caribbean region and the southern United States. This work showed the sub-regional features and differences. They must take into account in the interpretation and the analysis of seasonal forecast over West Africa, particularly in Senegal. The observed tendency in Senegal reveal that a global seasonal forecast over the western Sahel must be analysed by taking into account local factors. During the 16 years of the study, at least 10 of them according to our criteria (percentage of the total amount per station compared to the normal 1951-80 and the spatial distribution of near or above normal ones) are considered satisfactory.

1. Introduction

Since the severe drought of the 1970s over the Sahel, many papers were published about the physical mechanisms that monitor the interannual variability of rainfall in this area (Krauss 1977, Krishnamurti 1978, Janicot 1985, 1990, Palmer 1986). Many hypotheses were emitted to explain this variability.

Descriptive studies of the long rainfall series, such as those of Nicholson (1979, 1981, 1986) have shown that from a spatial point of view, the rainfall variability belongs to a wider domain than the Sahel and can be extended to all of western Africa. In a general view of western Africa, many studies explained the physical causes associated with deficits of rainfall. Newel and Kidson (1979), Kanamitsu and Krishnamurti (1978), Lambergeon *et al.* (1981), have shown that a rainfall deficit in the Sahel is associated with a reinforcement of African Easterly Jet (AEJ) and a weakening of the Tropical Easterly Jet (TEJ). Hastenrath (1989) shows for the Atlantic near the West African coast that the position of the Inter-Tropical Front (ITF) -- an area where the meridional wind is zero -- from 1945 to 1983 goes from 12°N to less than 10°N after 1970. Concurrently in the same area, after 1970, the zonal component of the wind is about -1 m/s and its meridional component about -2 m/s.

The remote connection between SST anomalies above oceans is also studied by many authors (Lamb 1978, Hastenrath 1984, 1987, 1990, Folland 1986, Palmer 1986, Semazzi *et al.*, 1983, 1996, Duyan 1991, Ward 1992, Janicot *et al.*, 1996). The interannual variability of long-term precipitation over the Sahel was associated with warmer than normal SSTs over the Southern Atlantic, South Pacific and Indian Oceans and cooler than normal SSTs over the Northern Atlantic and Northern Pacific Oceans (Folland *et al.*, 1986). Simulations on the impact of SSTs on the Sahelian rainfall were also studied by others authors (Ropelewski 1990, Semazzi 1996, Branston *et al.*, 1994, 1996).

The hopeful results have led since 1980 to an increasing interest in seasonal prediction about the quality of the coming rainy season mainly in Africa. These forecasts are very important for Sahelian countries where agriculture holds a central role in the economy. These forecasts give an indication as to the behavior of coming season, which is of great interest for the management of the agricultural season.

Meanwhile, according to the high spatial variability of rainfall, these tendencies provided by specialized centers on climate prediction needs readjustment and local adaptation following climatic specific realities. We know that more than 75% of rainfall in the Sahel is provided by mobile disturbances called squall lines.

This work is limited to Senegal and follows the logic of introduction of local conditions. We try to show the rainfall tendency in Senegal from 1980 to 1996 by determining the direction of deficits (and/or excesses). Marginal factors related to rainfall in neighboring areas in the same latitude as Senegal and sub-regional differences within Senegal are also studied.

As a first step, we present the area of study and meteorological circulation observed predominantly during the northern summer. The second part of the paper focuses on data and methods of analysis, while the last part is devoted to results and discussions.

2. Area of Study and Meteorological Circulation

The focus of this study is the interannual variability of rainfall in Senegal, a country located in the western Sahel (fig.1). Senegal is located between 12°18’N and 16°42’N latitute and 11°30’W and 17°32’W longitude. All of its western part is maritime and Dakar is the most protruded area into the ocean. The river by the same name runs along its Northern and Eastern borders. The isoyhetes decrease from South to North and lap from 1,300 mm in mean in the South to 300 mm to the North with a high degree of variability. Significant rainfall deficits have been reported since the early 1970s (Nicholson, 1980). The relief elevation is low with the exception of some elevations, and generally do not exceed 150 meters.

Rainfall season in Senegal lasts from June to October, following the northward movement of the Inter-Tropical Front (ITF), which follows the apparent movement of the sun with a delay of six weeks (Garnier, 1979). The main Dynamic Action Centers (DACs), which interact in the movement of the ITF, are the Anticyclones of Azores (AA), Libya (AL) and Saint-Helena (ASH). The ITF, also called Meteorological Equator, is located inside the Tropical Depression (fig.2) and presents a 'bell structure' with the edge located in the central Sahara in Algeria. The western branch slopes southward under the action of the ridge from AA.

We must add to these DACs the thermal depressions over Algeria and Mauritania. The first one is active and is present as a vortex located in the neighborhood of Hoggar Mountain (Viltard *et al.*, 1989). Its presence causes a northward movement of the ITF in the area. The most western vortex is located in the thermal trough, which separates the AA and AL ridges (Viltard *et al.*, 1989). Because of the mountain's presence, the vortex of Hoggar is almost stationary. The topography of that region can favor the circulation of air masses from two different hemispheres. The DACs mentioned above act mainly from their meridional and zonal ridges, which sometimes merge. In general, the cases observed are the merging of ridges from AA and AL, ASH with AA. The depth of the monsoon layer is also important in the precipitation process. This was shown by Viltard *et al.* (1989) by comparing the summers of 1981 and 1985. During 1981, a northerly wind of 850 hPa prevailed between 05°N and 10°N, while during 1985 in the same area, the wind was from the south, showing the difference in the importance of the monsoon in the two years. The monsoon layer was deeper in 1985 than in 1981.

3. Data and Analysis Methods

3.1 Data

In this study, we use rainfall data in Senegal, radiosonde data of Dakar at 00 and 12 UTC, SST, satellite data in the infrared and water vapor channel and ECMWF analysis.

The rainfall data over Senegal are from 1980 to 1996 at daily, decadal, monthly, and annual time scales. We have selected rainfall stations belonging to various rainfall zones of Senegal. Sea Surface Temperatures (SSTs) used in this work are monthly (isotherms and anomalies) on the Northern Atlantic (NA) (05°N and 20°N from 60°W to 30°W), South Atlantic (SA) (0° and 20°S from 30°W to 10°E), the Global Tropic (10°S and 10°N from 0°, to 360°), the Atlantic Western Coast (AWC) (0° to 30°N from 15°W to 30°W) (fig.1) and over the Pacific, the niño1+2 (between 0 and 10°S from 90°W to 80°W).

3.2 Analysis Methods

The first step is the determination of new tendencies from simple statistical parameters such as the mean (M), the standard deviation (σ), and the coefficient of variation ($CV = \sigma/M$). These tendencies are compared to the results of Nicholson (1988) and the normal 1951-1980 which include a wet period before 1969 and a dry period after that date. The zonal and meridional components of the wind at many levels allow for a comparison of the atmospheric dynamics at Dakar during a rainy and dry decade.

The state of the atmosphere is also analyzed using the Moist Static Energy (MSE) (Sarr *et al.*, 1995), which is a conservative convection indicator comparable to the Equivalent Potential Temperature. This indicator is given by the following formula:

$$MSE = gZ + CpT + LQ$$

where Z is the height in kilometers, T = the temperature in Kelvin, Cp = the specific heat coefficient of the air at constant pressure, L = the latent heat of vapor condensation, Q = the specific humidity, and G = the acceleration of gravity.

Sea Surface Temperature (SST) data are used as isotherms and anomalies. Anomalies are deviations from the normal behavior. They are positives for values higher than normal and negatives for values below normal. The synoptic situation is studied from surface and upper level chart analysis of Meteorological Center of Dakar.

The evolution of rainy clusters are analyzed and followed by Meteosat (cold top clouds images of in the IR channel). The images represent monthly means and are used to compare years of different rainfall amounts. The water vapor channel allows us to follow the position of the DACs and the Equatorial depression.

4. Results and Discussions

We first computed for all stations of the study area the percentage of annual rainfall amount, which departs from the normal during 1951-1980. A classification was done from the number of stations in the year with a cumulative total showing the rainfall as a deficit, normal or excess. The criteria used to quantify the year's rainfall departure from the cumulative total (CT) are:

- year very dry (YVD)	$CT \leq 50\%$
- year of deficit (YD)	$50\% \leq CT \leq 75\%$
- normal year (NY)	$75\% \leq CT \leq 100\%$
-year of excess (YE)	$CT > 100\%$.

The 16 years in the period are classified into the four classes mentioned above: YVD (1983, 1991, 1992), YD (1982, 1984, 1990), NY (1985, 1986, 1993, 1994), and YE (1981, 1987, 1988, 1989, 1995, 1996). The spatial interpolation of the percentage shows the areas of deficit or (excess) (fig.4 and 5). According to the latitudinal distribution of the isoyhetes, this interpolation for all of the years does not indicate a prevailing North / South deficit. This is presumed to be the particularity of Senegal where rainfall distribution is often not the same as in neighboring countries at the same latitude. Former studies by Nicholson (1988), Janicot (1990), and Palmer *et al.* (1990) also made this observation. Palmer, by comparing the rainy seasons 1987 (dry) and 1988 (humid) over West Africa, noticed that towards the western coast, mainly over Senegal, the rainfall field was reversed compared to the rest of the Sahel as shown in fig.3.

The classification of data shows that 10 out of 16 years are normal for Senegal. This distribution is not homogenous over the rest of the Sahel, and within Senegal, we notice certain variability. In an earlier study, Sarr *et al.* (1995) have shown that some of the disturbances spotted east of Senegal are not evident on the coast. There is an area of decay and scission of squall lines between 40 and 160 kilometers east of Dakar. During the third week of August 1995 (except the 27th and 30th), the weather was rainy every day in Dakar, especially the 23rd, 25th and 29th with 68.7, 41.5 and 60 mm. of rain, respectively. The first week of September was the opposite, very dry with only 12.6 and 7.2 mm of rain for the 3rd and the 10th, respectively.

The analysis of chronological profiles of zonal and meridional winds for the two weeks (fig.6), indicates that in the lower layers, a northern trade wind prevailed over Dakar during this period when the ITF reaches its northernmost position. The dry days correspond to the northern trade wind. During strong eastern winds (above 18 m / s) between 700 and 600 hPa, we observed no or weak rainfall. The values of wind shear given by the difference between zonal wind at 200 hPa and 850 hPa are important for rainfall as shown by Dhonneur (1980). The values of wind shear in August are lower than that for the month of September.

From the moist static energy (MSE), differences between chronological profiles for the two months mentioned above are shown. We notice that the structure of August is more homogenous than the structure of September (fig.7).

Many minimums are observed in the lower altitudes, and days of weak MSE values are less rainy. A disturbance in these conditions can decay or degenerate. These kinds of structures could explain rainfall deficit observed in the west's departure from the east certain years. Deficit in the northern areas is in general linked with southward retreat of the ITCZ. This situation happens when the ridge from AA is very active over the near Atlantic and over Mauritania. That was the case in 1992 and is illustrated by the cold cloud top mean maps, which are not presented here.

During the wet year of 1995, an area of little deficit is noticed in the southern portion of the country (fig.5). The more plausible explanation should involve the tracks and positions of disturbances. Clusters at lower latitudes moved northwestward while disturbances formed to the north and followed a western and a southwestern path. This might occur when the ITF maintains a well-marked northern position, as was the case in 1995. An important role is played by certain cyclonic disturbances west of Senegal. They are in general associated with a surface and lower layers of depression around Dakar. These cyclonic disturbances generate significant amounts of rain which are discontinuous and can last for many days (fig. 8).

The cumulated amount of rain can reach or exceed 100 mm. The structure of the rainfall intensity distribution curves differ from those of squall lines (fig.9) which generate a maximum at the beginning followed by residual rains due to the stratiform area. Over the ocean, these disturbances more often became tropical depressions or cyclones, as was the case of the disturbance of the 17th of August 1995.

During many years (1989, 1993, 1995, 1996), cyclonic disturbances called "Dakar-Systems" (DSs) by Frank (1971) were frequent and generated a significant amount of rain west of Senegal. Before continuing their path over the ocean, these DSs generated long discontinuous rain in the western area, mainly Dakar. One of them -- which later became the cyclone, Hugo -- in August 1989 produced 113 mm of rain in Dakar from the 24th to the 26th (fig.9).

An area more often with excess is observed in the area surrounding Linguere in north-central Senegal. This must be due to a refilling in water vapor of disturbances when they cross over the Senegal River.

Figure 10-a shows that since the year 1980, the variation coefficient remains high in the North (42% and 39%) at Podor and Saint-Louis, respectively and to the West (33% and 32%) at Dakar and Linguere. For the rest of the country, this coefficient varies between 13% at Kolda and 28% at Matam. Nevertheless, we notice a remarkable decrease of the variation coefficient compared to those calculated by Nicholson (fig. 10-b). These results seem to prove a new positive tendency emerging over Senegal, as attested by the last three years of 1994, 1995 and 1996.

From 1980 to 1986, the cumulated annual rainfall in Senegal has rarely reached the normal for the years of 1951-1980. The years of 1980 to 1986 was a period with deficits during which we notice few years with the average normal, namely 1971, 1984 and 1985. The driest year of the period of study is 1983. In contrast, from 1987 to 1996 (except 1991), the cumulated annual rainfall amounts are in means normal with a good spatial distribution. The 1983 and 1989 seasons represent extremes with opposite signs. The first year is very dry in Senegal and the rest of the Sahel. The year 1983 is marked by high positive anomalies of SSTs over the niño1+2 area in all months. The SST anomalies over the NA, SA, and the Global Tropics (GT) are negative.

By way of contrast, 1989 is very humid over all of the Sahel, and particularly over Senegal, where it is preceded by two wet years, 1987 and 1988. For 1989, the SSTs over niño1+2 and the SA are negative while the SST anomalies are positive in JASO over the NA and GT. Over the West African coast, the SSTs are warm in JAS with a northern extension. The ITCZ position is around 20°N over Mauritania with a high number of cold clouds occurrence (CCO).

The years of 1980, 1988, 1993, 1994 and 1995 have a better cumulated annual rainfall (equal to or above normal) to the north of Senegal. During these years, the northern limit of the ITCZ is 20°N and sometimes above over Mauritania. The SST anomalies over the NA, SA and GT are positive (fig.11). The years during which the deficit is located to the west of Senegal (1981, 1986, 1990, 1992, 1993, and 1994), the SST anomalies are in general negative. When we analyze mean images of CCO percentage (Lahuec *et al.* 1994), (not shown here) we notice that the southern limit of the Azores ridge over the near Atlantic Ocean is between 13°N and 15°N. The position of ridges and DACs can also be shown through the mean water vapor images. The positions of the SHA during the wetter years as shown by Debois *et al.* (1988) could explain the minor deficit observed over the south of Senegal in 1995. Two dry years (1983, 1984) and two wet years (1985, 1989) are compared from the monthly mean water vapor images in JAS. For that, we have analyzed the evolution of temperatures (numerical counts) through four longitudes (27°W, 17°W, 08°W and 03°E) between 30°N and 30°S. The high temperatures correspond to the areas of maximum of subsidence that are the location of anticyclones and weak temperatures depict the ITCZ band (Debois *et al.* 1988). During the two wet years, temperatures over the area of SHA are higher than those of dry years on the most western axes. Over the ITCZ band, the variation between temperatures are weak but the ITCZ band is wider in wet years and its position is more towards the north (fig.12).

The ridge from AA over the nearest Atlantic is more marked in 1984, 1985 and 1983. During the years with the humid parts in the center and the west of Senegal (1985, 1987, 1988, 1995 and 1996), we notice positive SST anomalies over the west Atlantic coast and the NA with the ITCZ over Mauritania. The years 1982 and 1990, during which the ITCZ was in mean over 20°N and the ridge in the nearest Atlantic developed, are very humid around Linguere. The niño1+2 is negative and SST anomalies slightly positive over the NA.

5. Conclusion

Using rainfall data of different scales, the spatial and temporal variability of rainfall in Senegal is studied. The spatial orientation of deficits (or excesses) is specified for the years 1980 to 1996, and differences with neighboring countries at the same latitudes shown. The tendency in Senegal is not the same as in the others countries of the western Sahel.

The study shows the impact of SSTs on the rainfall regime in Senegal, based on the global tendencies as the ENSO phenomenon which cause disorder in the atmospheric circulation at a larger scale. The study shows that the years with positive SST anomalies over the NA and the west Atlantic coast coincide with good rainfall in the west of Senegal plus generation of numerous cyclonic disturbances. By comparing the variation coefficients with those calculated by Nicholson, we have shown a stabilization of the coefficient in the eastern and southeastern parts of Senegal and a slight decrease in the rest of the country. This decrease can signify an improvement of rainfall tendency in Senegal after the period of high deficit. The role of dynamic and thermodynamic parameters on rainfall activity of convective systems is illustrated.

This work is an introductory step for a next phase in which elements found in this study might be specified and quantified by using a longer set of data. Such work will lead to local adaptation of seasonal forecast issued from specialized climate prediction centers.

Acknowledgements

This work was carried out by a financial support of "AIRE Developpement". We thank DMN of Senegal, ASECNA, UTIS and ORSTOM for their cooperation. We are also grateful to Dr. Wassila Thiao of the African Desk of NOAA CAC for his valuable contribution.

References:

Albergel J. *et al.* 1985 : Secheresse au Sahel veille Climatique Satellitaire, n°7, 18-30.

Branston, A. G., 1994 : Linear Statistical Short-term climate predictive skill in the Northern Hemisphere. J. Climate, 7, 1513-1564.

Branston, A. G., Thiao, W., Kumar, V., 1996 : Long-lead forecasts of seasonal precipitation in Africa. Wea. And Forecasting, 11, 4, 506-520.

Citeau , J., 1992 : Les Satellites Météorologiques, une Approche Nouvelle de la connaissance du climat du Sahel ; Thèse de Doctorat Université Paul Sabatier , 110 pages.

Desbois M., *et al.*, 1988 : Characterization of some elements of the Sahelian climate and their interannual variations for July 1983, 1984 and 1985, from analysis of METEOSAT ISCCP Data, J. Climate, 1-9, 841-878.

Druyan, L., 1989 : Advances in the study of sub-saharan drought, International Journal of Climate, 9, 77-90.

Folland C. K. *et al.* 1986 : Sahelian Rainfall and Worldwide Sea Surface Temperature ; 1901-1985 Nature, 320, 602-607.

Frank, N., 1971 : Atlantic Tropical Systems of 1970 . Mon. Wea. Rev., 99, 281-85.

Fontaine, B., Janicot, S., 1996 : Sea surface temperature fields associated with west African rainfall anomaly types. J. of Climate, 9, 11, 2935-2940.

Hastenrath S. 1984 : Interannual variability and annual cycle : mecanism of circulation and climate in the tropical Atlantic sector. Mon. Wea. Rev., 109, 137-147.

Hastenrath S. *et al.* 1987 : The southern oscillation in the tropical Atlantic sector. Contib. To Atmosp. Physics, 4, 447-463.

Hastenrath S. 1990 : Decadal scale changes of the circulation in the tropical Atlantic sector associated with Sahel drought. Int. J. Climatol., 10, 459-472.

Kanamitsu M., Krisnamurti T. N.1978 : Northern summer tropical circulation during drought and normal rainfall months. Mon. Wea. Rev., 106, 331-347.

Krauss E. B., 1977 : Subtropical drought s and cross equatorial energy transport. Mon. Wea. Rev., 105, 1009-18.

Lahuec and Guillot, B., 1994 : Satellite monitoring of the climate - climatic-monitoring atlas :1986-1994 (Africa and the Tinter tropical Atlantic) 91 pp.

Lamb, P. J., 1978 :Case studies of tropical Atlantic surface circulation patterns during recent sub-saharan weather anomalies : 1967 and 1968. Mon. Wea. Rev., 106, 482-491.

Nicholson S. E. 1979 : Revised rainfall series for the west African subtropics . Mon. Wea. Rev., 107, 620-623.

Nicholson S. E. 1981 : Rainfall and Atmospheric circulation during drought periods and wetter years in West Africa. Mon. Wea. Rev., 109, 2191-2208

Nicholson S.E., Kim J. and Hoopingarner J., 1988 : Atlas of rainfall and its interannual variability. Department of Meteorology, Florida State University,237 pp.

Palmer, T. N., 1986 : Influence of the Atlantic, Pacific and Indian Oceans on Sahel Rainfall. Nature, 322, 251-253.

Palmer, T. N., *et al.*, 1990 : Modeling Interannual Variations of Summer Monsoon. ECMWF Seminar Proceedings « Tropical extra-tropical interactions » 10-14 Sept 1990, 283-285.

Picon, L, 1991 : Utilisation de l'imagerie Meteosat pour l'étude des variations à court terme du climat Africain. Thèse de doctorat d'état, Université Pierre Marie Curie, 210 pages.

Sarr, A., Fongang, S., Sauvageot, H., 1995 : Etude d'un indice énergétique de prévision de lignes de grains à Dakar. Journ. Sécheresse, n°4, Vol. 6 :337-46.

Semazzi F. H. M. *et al.* , 1996 : AGCM Study of the Teleconnections between the Continental Climate of Africa and Global Sea Surface Temperature Anomalies. J. of Climate 9, 10, 2480-97.

Viltard, A., Laurent, H, DE Felice, P., 1990 : Lower-Tropospheric Cyclonic Vortices in Northern Africa in Summer. Mon. Wea. Rev., 118, 818-823.

Wayler P. R. *et al.*, 1996 : Interannual Variability of Monthly Precipitation in Costa Rica. J. of Climate 9, 10, 2606-13.

Tools for the Assessment of Regionalized Climate Change Impact Studies in Agricultural Production and Hydrological Responses.

Roland E. Schulze
Department of Agricultural Engineering
University of Natal, Pietermaritzburg
South Africa

Abstract

On a seasonal scale, much of Africa periodically experiences a "reversible" type of climate change with its sometimes devastating consequences through the El Niño phenomenon. On a decadal scale, however, the essentially "ineversible" consequences of anthropogenically induced climate change threaten to render large parts of the continent both drier and warmer.

In order to assess the impacts of both variants of climate change at regional and local scales, one needs "present climate" baselines against which comparisons can be made. For South Africa, two such baseline databases have been established.

The first is a "static" database at 1 minute of latitude and longitude spatial resolution with gridded values of expected monthly rainfall, monthly means of daily maximum and minimum temperatures, reference potential evaporation, frost descriptors and heat as well as chill units.

The second is a "dynamic" database in which 1946 relatively homogeneous response zones have been delineated in South Africa, and for each, a 45 year record of daily rainfall has been established as well as information on other climate parameters and soils.

These databases can be used with perturbations of regional climate scenarios, both in "forecasting mode" (i.e. one season ahead, for example El Niño) and in "prediction mode" (i.e. with decadal scale change). For both modes of scenarios, methods of temporal downscaling are required.

This paper describes the development of these databases, some methods of temporal downscaling employed and illustrates the potential for assessing regional differences in agricultural and hydrological responses at both seasonal (El Niño) and decadal (global warming) scales over South Africa.

A Strategy for Monitoring, Forecasting, early warning System and Integrated Pest management in the Soudano-Sahelian Zone

Baba Mallam Wali
North East Arid Zone Development Programme

[*Ed.Note: Figures for this paper were not available.*]

Abstract

Grasshoppers, especially *Oedaleus senegalensis* and *Kraussaria angulifera* , are important economic pests in the northern part of Nigeria. They cause, in some instances, almost total destruction of many crops, especially millet, sorghum and cowpea. They have proved to be serious pests because they rapidly build up populations; feed gregariously on plant material, consuming their own weight of food every 24 hours; and migrate long distances, about 100 km in a day.

This paper examines the strategy adopted by the North East Arid Zone Development Programme (NEAZDP), an Integrated Rural Development Programme in Yobe State, Nigeria, on Integrated Pest Management (IPM) especially the monitoring and early warning system for grasshopper pests in the area. The strategy involves use of a grasshopper survey, a Geographic Information System (GIS) and the Agricultural Extension Service. Over the last four years, the advance information provided by the programme has assisted communities and local governments plan ahead and concentrate resources in areas where outbreaks are expected.

Effective control has been achieved and crop losses reduced. It is suggested that the methods used for IPM, currently operational in NEAZDP areas and presented in this paper will benefit areas with similar problems.

1. Introduction

An insect pest is one that is judged by man to cause harm to himself, his crops, animals or his property. In agronomy an insect is classified as a pest if the damage it causes to a crop or to livestock is sufficient to reduce the yield and/or quality of the harvested product by an amount that is unacceptable to the farmer (Dent, 1991).

Grasshoppers and locusts are destructive pests causing substantial damage to crops worldwide. *Oedaleus senegalensis Krauss*, the sahelian grasshopper, has in recent years (1974-1993) proved to be the most destructive grasshopper within the Arid Zone of Nigeria North of 10°N latitude (NEAZDP 1994).

In 1985 and 1986, grain losses due to grasshoppers was over 30% in Borno State and 40% in Kano State (Ibid). In 1990, millet crops in some villages in northern part of Yobe State were totally destroyed by grasshoppers, and farmers abandoned their fields.

In West Africa, *O.senegalensis* occurs in the zone between 10°N and 17°.50 N latitude and isoyets 150 - 850mm. It is associated with cultivations of millet which is its preferred food plant. The seasonal movement of the pest is associated with that of the Inter-Tropical Front (ITF). Migrations are northward during May to early September/October and southwards October through November following the movements of ITF. (Launois).

The life cycle of *Oedaleus* appears to be synchronised with the vulnerable stages of millet crop. Under natural conditions, the development of eggs in diapause begins when rain saturates the soil to depth of about 6-8 cm. Similar soil conditions favour the germination of millet and grass seeds, thus providing food for the emerging nymphs. Development from egg to adult to egg, i.e. one generation, takes between 30-35 days. *Oedaleus* generally produce three generations a year. A fourth generation may be produced when the rainy season extends into October. When populations of the grasshopper exceeds one million per hectare, total destruction of crops may occur.

Kraussaria , on the other hand, is a large yellowish grasshopper species which is common in abandoned farmlands in the Soudano-sahelian zone. It is a gregarious pest of local importance. It feeds on cereals throughout the growing phase and on cowpeas. It is univoltine, i.e. producing only one generation in a year, and it passes the dry season in egg diapause just like *Oedaleus*. Eggs hatch in late July or early August and the emerging young bright green nymphs are found on the weeds and undergrowth on edges of millet farms. Older nymphs change to adult colours and move to feed on millet and cowpea. In October/November, the adults lay egg, which enter into diapause to survive the dry harsh season.

2. Study Area

2.1 General Description

The North East Arid Zone Development Programme (NEAZDP) area covers 22,860 km^2 (2,286,091 hectares) within the nine northern local government areas of Yobe State between latitudes of 11° 50' - 13° 25' and longitudes of 9° 40' - 12° 25'. It is bordered the Niger Republic in the north, Jigawa State in the west and Borno State in the east. It is one of the driest regions in Nigeria.

Physiographically, the programme area is part of the Lake Chad Basin. The topography is flat or very gently sloping towards Lake Chad to the east. Sandy soils cover 90% of the land. The other 10% belong to the floodplain of the Komadugu Yobe and Komadugu Gana Rivers, seasonally flowing from west to east.

The climate of the NEAZDP area has varied in cycles over the years. Rainfall is seasonal, concentrated in the three months of July, August and September. Since the early 1970s, the trend has been towards a drier climate. The current annual rainfall (400 mm in the southwest, 250 mm in the north-east) has decreased by some 15 to 20% over the last 25 years.

Occupations and land use in the NEAZDP area reflect the low rainfall and its pattern of seasonal distribution. Rainfed farming for millet and sorghum is the primary source of income for most families. But soil fertility has decreased and drought has increased over recent years, making dryland farming increasingly marginal. The limited areas of the floodplain are more fertile and produce higher value crops of rice and vegetables. But floodplain farmers also face difficulties as levels in rivers are lower and more variable than they were 25 years ago.

The livestock sector supports a smaller number of people than crop production, although grazing land covers a greater area. Almost all animals are raised under the conventional open access grazing system, many of them adapting traditionally to the seasonal pattern of water and fodder availability through migrations. In the NEAZDP area, as in other regions of northern Nigeria, the drying climate and competition for resources has led to a trend of marginalisation of the livestock sector. Many migratory pastoralists have settled over the last 25 years because they can no longer support their families through their herds alone. Others have moved out to the east and south.

A very important trend in the NEAZDP area is the rise in human population, estimated at a steady 2.25% per annum and leading to a doubling in numbers every 30 to 35 years. In other parts of northern Nigeria, population increase has meant that all spare land is now occupied, and rural people have to deal with the ever-pressing problem of obtaining more from the same land and water resources through intensification of production. In the NEAZDP area, this point is approaching, very rapidly in some places, a little less so in others.

The physiographic and climatic conditions enumerated above makes agriculture a very risky business with many food security implications, especially to the subsistence farmers. This is compounded further by almost endemic problem of grasshopper outbreak in the area.

3. Forecasting Grasshopper Outbreak

The most reliable method for forecasting grasshopper outbreak in a given area is through grasshopper eggpods survey. Eggpod surveys are conducted to demarcate areas where emerging populations of grasshopper nymphs will be great enough to cause economic losses to crop seedlings. The number of viable eggpods in a given area determines the degree of destruction that likely will be caused by emerging nymphs to crops. Migration of adults and hoppers from other locations could change the expected level of damage. There are records of migrations of nymphs of *Oedaleus* into crops with low eggpod density, and seedlings have been destroyed.

However, as areas of high-density eggpods are identified, remedial action can be carried out immediately not only to forestall the migration of the hoppers to new areas, but also to prevent emerging nymphs from destroying crops in the areas identified.

3.1 Grasshopper Eggspod Surveys

The eggpods surveys were carried out in northern part of Yobe State covering nine local government areas in the state. The area, for administrative convenience, is divided by NEAZDP using local government development areas into 18 development areas. The development areas are administrative areas concretised by NEAZDP with a resident male and female Development Area Promoters (DAP). From 1994 to 1997, the Northeast Arid Zone Development Programme (NEAZDP) commissioned three eggpods surveys. A survey was not conducted in 1995. Each year a random sample of at least 50 villages was used to conduct the surveys. The procedure of the survey is as follows:

4. Site Selection

4.1 Terrain

Notice is taken of the terrain and crops cultivated. The preferable terrain is open flat or undulating expansive area where millet was cultivated in the previous year.

4.2 Vegetation

Fallow fields are also identified around the village for the presence of the following species of wild plants as they are preferred breeding places of grasshoppers, especially *K. augulifera*. These are: *Cenchrus biflorus*, *Aristida pallida*, *Dactyloctenium aegyptium*, *Eragrostis ciliaris*, *Andropogon gayanus*, *Balanite*s *aegyptica*, and *Ziziphus sp.*

4.3 Previous Grasshopper Activity:

Farmers, village dwellers and pastoralists were also asked about presence / absence of grasshopper damage to crops during the previous season. Other enquiries include: species of grasshoppers seen in the previous seasons; crops attacked; level of losses; directions of migration; and concentrations of grasshopper populations.

4.4 Observations taken on site:

The survey team also recorded the following parameters:

a) Soil type; sandy, silty etc.

b) Examination of dry stalks of millet left in the field to record presence / absence of grasshopper damage.

c) Examination of harvested panicles to record level of damage by grasshoppers to grains.

d) Examination of loose top soil near millet stumbles for density of grasshopper frass (faecal pellets)

e) Area of contiguous field cultivated to millet to provide information in planning magnitude of control operation.

5. Sampling Techniques

5.1 O. senegalensis

Within the selected millet farm, the first sample plot was marked out at least 10 m away from the road or path. The second sample was taken 50 m north or south of the first. The third and fourth samples were taken 50 m apart west or east depending upon the orientation of the farm.

5.2 Exposing Eggpods

a) A plot size measured 2 m x 2 m (=4 m^2). Loose top soil 1-2 cm deep was removed using a shovel to expose a compact soil surface.

b) Remaining thin layers of dust were blown off using a motorized blower while keenly inspecting any exposed objects.

c) The action by the jet of wind exposed tips of eggpods which were then marked with thin stalks of grass.

d) Each eggpod was carefully excavated and removed using a matchet or any sharp implement.

e) In the field eggpods were examined and classified as follows:

(i) Alive - all eggs present were viable.

- Predator/Parasitized - marked by presence of coleopterous or dipterous larva inside the eggpod.

(iii) Dead - eggpods with incomplete walls and containing no eggs or few shrivelled eggs. Parasites or predators when observed near such eggpods were recorded.

All materials collected from one sampling site of four plots were put into labelled plastic bags for detailed study in the laboratory.

5.3 K. angulifera

Eggpods of *Kraussaria* are found in soil about 10 cm deep beneath some sahelian saplings, trees and shrubs. Eggpods are aggregated and occur near lateral roots and have been found, associated with *Gweria* sp., *Guiera* sp., *Acacia* sp. *Balanites* sp., *Combretum* sp., and tussocks of *Andropogon gayanus* and *Hyparrhenia rufa.*

Survey procedures were as follows:

a) Surveying for *Kraussaria* eggpods was undertaken in any fallow area adjacent to the millet field surveyed for eggpods of *O. senegalensis.*

b) An area about 60 x 60 cm surrounding the base of shrub/tree selected was marked out. The soil was loosened to a depth of about 10 cm using a shovel. Large crumbs were broken up.

c) The mist blower was then used to blow away the loose soil and any eggpods exposed in the process were collected. Blowing was continued to a depth of 15 cm. On each site, four sampling plots about 60 m apart were examined.

d) The eggpods collected were put into labelled plastic bags for further study in the laboratory.

6 Results of Surveys

6.1 Oedaleus senegalensis

Seventy-three sample villages each were surveyed in 1994 and 1996, and fifty-four in 1997. In 1994, a total 519 eggpods were collected, 522 in 1996 and 181 in 1997. Out of the eggpods collected in 1994, 48.2% were alive and 40.7% destroyed by predators and / or parasites. The results for 1996 were 44.9% alive, 10% parasitised and 44.65% dead. For 1997, the alive eggs accounted for 24%, 29% parasitised and 47% dead.

The density of the eggpods for *Oedeleus* is shown in Table 1. The result for the three years shows that 1996 had the highest eggpod density. This can be attributed to the lack of control measures in 1995, which resulted in the build up of grasshopper populations. However, because of joint control measures carried out in 1996 with assistance from communities and local governments, the eggpod densities and the threat of grasshopper outbreak in 1997 was low.

6.2 *K. angulifera*

The eggpod densities of *K. angulifera* were very high in many sectors during 1994, 1996 and 1997 (See Table 2). *Kraussaria* produces only one generation a year. Eggs laid in late September / October enter into obligatory diapause for 6-7 months and hatch in July the following year. The grasshopper, *K. angulifera* , is a voracious feeder of local interest, adding their weight to damage caused by *Oedeleus*. All sites that have eggpods exceeding 100 / ha are potential areas for the hatch development of threatening populations of *Krausaria* in the coming season.

The above results are imputed into GIS data file for production of maps showing areas of various levels of threat to crops by both *Oedaleus* and *Kraussaria*. The results for 1997 are shown in Tables 1 & 2.

7 Control of Grasshoppers through Integrated Pest Management (IPM)

Integrated Pest Management (IPM) is a pest management system that in the context of the associated environment and the population dynamics of the pest species, utilises all suitable techniques and methods in a compatible a manner as possible and maintains the pest population levels below those causing economic injury (Dent, 1991). The emphasis of IPM is on the use of a combination of methods aimed at providing economic, but long-term reliability with the minimum of harmful side effects. This means that there is concern and support for a more ecologically-oriented approach that would incorporate the use of control techniques based on an understanding of the biology and life history of the pest.

The management of grasshoppers is carried out by NEAZDP using the IPM approach. The initial stage is using the grasshopper eggpods survey on an annual basis as described in the previous section of the paper. This provides the necessary information on where control measures can be taken through the various extension methods. The following approaches are applied:

8 Information Dissemination

The results of the surveys are made known to both farmers and government officials through a discussion forum in the villages. In addition, a workshop is held at the Programme headquarters for policy-makers, mainly for state and local government officials. In the villages, the results of the surveys are made known to the communities through the village development association and through a weekly radio programme. The communities are then informed of the dangers the grasshoppers pose to the crops. Cultural measures are discussed as well and then mitigation efforts are organised. With respect to the state and local governments, officials are invited for a one-day workshop after the survey is completed to inform them of areas where an outbreak might be expected, so that necessary preparations can be made to purchase insecticides.

Table 1. Grasshopper egg pod population per ha., *Oedaleus senegalensis*

DEV. AREA	1994 density/ha	1996 density/ha	1997 density/ha
Balle	2411*	2000	1250
Futchimiram	208	1563	00
Degeltura	625	2125	00
Kanamma	938	875	208
Yunusari	625	1000	417
Dapchi	5469	1563	313
Gumsa	625	625	00
Karasuwa	3250	11250	417
Kaska	2344	750	781
Yusufari	1250	2125	00
Dumburi	2083	1042	00
Gwio Kura	1250	1250	208
Muguram	2750	781	208
Gorgoram	1875	250	208
Dagona	2917	7500	833
Wachakal	00	3750	833
Bulangwa	2000	2031	1667
Machina	3482	1875	1250

* One eggpod contains 24 viable eggs.

Table 2. Grasshopper egg pod population per ha., ***Kraussaria angulitera***

DEV. AREA	1994 eggpod density / ha	1996 eggpod density / ha	1997 eggpod density / ha
Balle	5250*	35875	00
Futchimiram	5625	129,688	179,792
Degeltura	15208	28625	19583
Kanamma	6563	2125	2708
Yunusari	2708	11875	78750
Dapchi	29583	61875	2031
Gumsa	55000	27708	17083
Karasuwa	7321	1250	3958
Kaska	5833	1750	00
Yusufari	5000	27625	15781
Dumburi	13375	39844	1250
Gwio Kura	19063	11458	1250
Muguram	14219	7656	00
Gorgoram	00	1750	00
Dagona	00	6667	5000
Wachakal	382,500	12500	1250
Bulanguwa	19531	1563	625
Machina	5268	19750	6667

* One eggpod contain about viable 110 eggs.

9 Control Measures by Communities

9.1 Shallow Cultivation

Farmers were advised to dry cultivate their fields to expose the eggs to desiccation and physical damage (Stinner and Home, 1990). Exposed eggs fall easy prey to their natural enemies, predators and parasites. In the two grasshoppers pests discussed above, Amotabi *et al.* (1988) noted that cultivation is known to affect the number of eggs and nymphs present by exposing the eggpods to desiccation by reducing the level of food, shelter and vegetation available and by making the soil rough and unsuitable for egg laying. However, it has been difficult to convince poor, small-scale farmers to dry cultivate their farms due to the additional costs in involved in their farming operations.

9.2 Drive Hoppers into Trenches

At the beginning of rainy season when the grasshoppers are at the nymph stage, farmers were encouraged to dig trenches about 70 cm deep, 50 cm wide to trap migrating nymphs, where they are destroyed by fire. These trenches are dug at regular intervals depending on the population of the nymphs. Lights and water traps are also effective for adults and nymphs. Several farming communities have experience in using these methods.

9.3 Use of Neem Kernel Extract

Use of neem kernel extract is also popular in areas where the problem is very localised. This practice is also popular in Borno where local cowpea growers use aqueous extracts to ward off grasshoppers from their crops during the dry season (Jackie, 1993). Neem leaves are soaked overnight and the solution is sprayed on cowpea plants using a shaped tree branch or broom. Presumably, the effect on the grasshoppers is a result of phagodeterence or the presence of nutrional/toxic factor (Jackie, Ibid, NEAZDP 1996).

10 Role of Government

Apart from the cultural practices enumerated above, areas of high eggpod density require chemical control, which the villagers cannot afford. Local government and state officials use the results of eggpod survey to control hoppers by spraying with insecticides, mainly Fenitrothion 96% ULV at 0.5 - 1 lit/ha.

The surveys have assisted local government officials to know where areas of grasshopper concentration are located and thereby reduce crops losses. From 1994, the various communities and local governments have jointly carried out with the NEAZDP various control operations. The control measures have substantially reduced populations of grasshoppers in the programme areas.

11 Conclusion

Agriculture, especially upland farming in the programme area, is a risky business. This is due to reduce soil fertility, pest outbreak and erratic rainfall patterns. Grasshoppers have over the years have been the most important pest to crops, causing much damage to millet, sorghum and cowpea crops. Forecasting the incidence of grasshopper outbreak through eggpod surveys is an important essential first step in forestalling the problem of grasshopper outbreak in an area. The surveys provide timely information to farmers and government departments so that remedial action can be organised to protect farmers’ crops. However, this requires commitment on the part of extension staff to organise and inform farmers of the actual situation on the ground and organise them to take the action necessary to control the grasshoppers, especially at the nymph stage. It also requires commitment from the various governments to control the grasshoppers on a wider scale by organising control teams and using insecticides. These actions could protect farmers from loosing their crops to grasshoppers and enhance food security for their families and the nation in general.

The methods discussed here are not particularly elaborate or sophisticated; are non-capital intensive; and are well within the capabilities of the small-scale farmer. Areas having similar problems of pests within the semi-arid zone are invited to give the methods a trial.

REFERENCES

1. Amatebi G. Apeji S.A and Oyidi O. (1988) - Effects of Farming Practices on populations of two Grasshopper Pests (Kraussaria angulifera Krauss and Oedaleus Senegalensis Krauss (Orthoptera Acoiddeau) in Northern Nigeria - Tropical Pest Management 34 p173 - 9.

2. Dent, David (1995) - Insect Pest Management CAB International, Wallingtord Oxon Ogio SDE U.K.

3. Jackie L.E.N (1993) - Use of Neem in controlling Cowpea Pests, IITA Research No.7, Sept 1993 p5 - 10.

4. North East Arid Zone Development Programme (1996) - Field Guide for Integrated Management of Major Pests, Diseases and Weeds in the NEAZDP operational area - Rural Extension Manual No. 2.

5. North East Arid Zone Development Programme - Management Report Summary Revised, February 1997.

6. North East Arid Zone Development Programme (1995) Natural Resources Inventory Management and Use.

7. North East Arid Zone Development Programme (1994) Grasshopper Eggpods Survey and Pest Forecast in 18 Development Areas of NEAZDP, Yobe State.

8. North East Arid Zone Development Programme (1996) - 1996 Grasshopper Eggpods Survey in the NEAZDP Area - Final Report.

9. North East Arid Zone Development Programme (1997) - 1997 Grasshopper Eggpods Survey in the NEAZDP Area - Final Report.

10. Oyidi Oba (1985) - The Breeding Systems of some Grasshoppers and Locusts in Northern Nigeria - Samaru Miscellaneuos Paper 105.

11. Sctinner, B.R. and G.J. House (1990) Anthropods and Other Invertebrates in Conservation - Tillage Agriculture, Annual Review of Entomology 35, p299 - 318.

On Sahelian Disturbance Line Characteristics and Tropospheric Structure: A Climate Perspective from Daily Observations

Peter J. Lamb, Michael A. Bell, and Jonathon D. Finch
Cooperative Institute for Mesoscale Meteorological Studies and School of Meteorology,
The University of Oklahoma, Norman, Oklahoma 73019

Abstract

This paper will review the variability of the characteristics of Sahelian Disturbance Lines on decadal, seasonal, and interannual time-scales for the last half of this century. The relations between this Disturbance Line variability and the behavior of the distinctive West African tropospheric wind field will also be presented. Those analyses will, in addition, be used to assess the predictability of the start of the Sahelian rainy season with a 1-3 month lead time. The above investigations will be based on unique sets of daily rainfall totals and individual rawinsonde soundings for the Sahel.

1. Introduction

Since the 1950s, there has been a progressive and widespread decrease in annual rainfall totals in Sahelian West Africa, resulting in almost continuous drought conditions since the early 1970s, with shorter periods of particularly extreme dryness (Lamb, 1982; Ropelewski *et al.*, 1993). Almost all rainfall in the region is produced by westward-moving disturbance lines (DLs) that are generally oriented north to south, have much larger north-south (102-103 km) than west-east (10-102 km) dimensions, and occur during the June-September monsoon season (Hastenrath, 1991). Therefore, a better understanding of the variability of these rainfall systems should lead to a better understanding of what has caused the decline in monsoon season and annual rainfall totals. The DLs receive their moisture from the low-level southwesterly monsoon flow and are steered westward by the easterly flow above the monsoon layer in which their bases are embedded. The most prominent features of that easterly flow are the African Easterly Jet (AEJ) near 700 mb and the Tropical Easterly Jet (TEJ) near 200 mb. Indices that describe the horizontal extent and intensity of the DLs have been previously developed, and this paper reviews how these DL characteristics have varied on the interannual and decadal time scales. This paper will also discuss the possibility of predicting the seasonal onset of agriculturally sufficient rains in the Sahel, based upon the pre-rainy season evolution of AEJ-related shears and their relation to the intraseasonal variation of DL size and intensity. Although the results presented here extend only to 1987, the work is ongoing and the findings for 1988-97 will also be shown at the Conference.

2. Data and Methods

Disturbance line characteristics were inferred from a daily rainfall data set supplied by Dr. M. V. K. Sivakumar for 1951-90 that includes records from ~530 stations in Senegal, Mali, Burkina Faso, and Niger. Data for June-September were used to generate DL-related time series for four square catchments, each approximately 440 km by 440 km and centered upon Dakar, Senegal (14° 44'N, 17° 25'W; 64 possible stations), Bamako, Mali (12° 38'N, 8° 02'W; 70 possible stations), Kindi, Burkina Faso (12° 26'N, 2° 02'W; 109 possible stations), and Niamey, Niger (13° 30'N, 2° 08'E; 39 possible stations). The catchments and rainfall stations are located in Fig.1. Square catchments were used in order to accommodate the linear nature of the westward-moving DLs, and were centered on rawinsonde stations (except for Kindi) to facilitate comparison of their rainfall statistics with closely associated tropospheric wind characteristics.

Two basic DL index time series for 1951-87 were developed for each catchment from its daily rainfall totals, to use as a basis for characterizing the DLs. The Daily Disturbance Extent Index (DDEI; Bell and Lamb, 1994) is simply the percentage of available stations within a given catchment that received rainfall above a trace for each day from June to September in each year. The DDEI thus represents the horizontal extent and/or degree of organization of the DLs. Several DL-related statistics were then generated from the 1951-87 DDEI time series for each catchment: (a) number of days per season when DDEI ≥ 70% (frequency of large and/or well-organized DLs), (b) number of days per season when 0% < DDEI ≤ 30% (frequency of small and/or poorly organized DLs), (c) number of days per season when DDEI = 0% (frequency of total DL absence), and (d) average non-zero DDEI value per season (average DL size).

The Daily Disturbance Intensity Index (DDII) is defined for each day with rainfall above a trace from June to September 1951-87, as follows:

$$\mathrm{DDII}_j = \frac{1}{\mathrm{N}_j} \sum_{i-1}^{\mathrm{N}_j} \frac{r_{ij} - \bar{r}_i}{\sigma_i} \qquad (1)$$

where r_{ij} is the daily rainfall value (>trace) on Julian day j at station i in a particular season, $\bar{r}_i$ is the long-term (1951-90) mean of the five-day moving average daily rainfall value for the period centered on Julian day j at station i, σ_i is the 1951-90 standard deviation of the five-day moving average rainfall value on Julian day j at station i, and N_j is the number of available rainfall stations within the catchment that received rainfall (>trace) on Julian day j. The DDII is thus not defined on those days when all available stations within a catchment did not receive rainfall above a trace, and so the index is a true measure of intensity. Standardized anomalies were used because of the strong south-north seasonal rainfall gradient in the region. This index does not include the seasonal cycle. Several DL-related statistics were then generated from the DDII time series for each catchment: (a) number of days per season when DDII ≥+0.4s _(frequency of strong disturbance lines); (b) number of days per season when DDII≤ -0.4s _(frequency of weak disturbance lines); and (c) average DDII value per season (average DL intensity).

The Daily Disturbance Intraseasonal Intensity Index (DDIII) is defined (Finch, 1998) for each day with rainfall above a trace from June to September, 1951-87, as follows:

$$\mathrm{DDIII}_j = \frac{1}{\mathrm{N}_j} \sum_{i-1}^{\mathrm{N}_j} \frac{r_{ij} - \left[\bar{r}_i\right]}{\left[\sigma_i\right]} \tag{2}$$

where r_{ij} is a daily rainfall value (>trace) on Julian day j at station i in a particular season, [r $_i$] is the long-term (1951-90) mean of all available June-September daily rainfall values (>trace) at station i, [_$_i$] is the 1951-90 standard deviation of all available June-September daily rainfall values (>trace) at station i, and N_j is the number of available stations within the catchment that reported rainfall (>trace) on Julian day j. For each day from June-September in each season, the DDIII represents the catchment averaged standardized rainfall anomaly with respect to the long-term (1951-90) average and standard deviation of all rain day amounts from June-September at the individual stations. Like the DDII, this index is defined only on those days that received rainfall above a trace. In contrast to the DDII, this index retains the seasonal cycle and is used to trace intraseasonal variations in rainfall intensity.

Two sets of daily rawinsonde data were also utilized in this study. Both data sets were kindly provided by Dr. D. L. Cadet. The first data set includes up to 4-times-daily mandatory level geopotential height, wind, temperature, dewpoint depression, and mixing ratio data, with values between the mandatory levels interpolated every 25 mb for Dakar (1950-51, 1953-55, 1957-61, 1964-69, 1971-78), Bamako (1967-79) and Niamey (1950-51, 1953-79). The second data set includes once- or twice-daily significant, standard, and mandatory level geopotential height, wind, temperature, dewpoint depression, and mixing ratio data for the same locations for 1980-84.

Moncrieff & Miller (1976) and several other authors (e.g., Frank, 1978; Weisman *et al.*, 1988; Rowell & Milford, 1993) have suggested that there is a crucial dependence of tropical squall line development and longevity upon the environmental vertical wind shear. Omotosho (1990) developed environmental wind shear criteria (associated with the African Easterly Jet) for the lower and middle Sahelian troposphere that were considered to be critical for the occurrence of convective storms at Kano in northern Nigeria. Based upon these shear criteria, Omotosho (1990) suggested a scheme to predict the onset of significant convective rainfall—i.e., the start of the rainy season—several weeks in advance. The prediction scheme—has the following steps— (a) on a daily basis, calculate the differences in the u-component wind between the surface and 700 mb (ΔU_L) and between 700 mb and 400 mb (ΔU_M), (b) average each of these shears over successive seven day periods; and (c) when the two 7-day average shears simultaneously meet the following conditions:

$$-20 \le [\Delta U_L] \le -5 \text{ and } 0 \le [\Delta U_M] \le 10 \text{ m/s}$$

for three continuous weeks, rainy season onset is predicted to occur five to six weeks after these conditions were first met.

Following the work of Omotosho (1990), in an initial effort to test the applicability of his predictive scheme across the entire Sahel, u-component wind data from 400 mb, 700 mb, and the surface (for 1980-84) or 950 mb (for 1950-79) were used to examine the development of ΔU_L and ΔU_M before the rainy season onset and during the course of the subsequent monsoon season. Seven-day and ten-day averages of these shear values were calculated for each year, and then averaged over the available record length at each of the three rawinsonde stations. The annual cycles of the 1951-87 averages of the seven- and ten-day mean values of the DDEI and DDIII were compared to the long-term average of the seven- and ten-day mean ΔU_L and ΔU_M values, respectively, to see what relationship exists between the rainfall and shear characteristics on this long-term average basis. It was considered important to test the Omotosho (1990) prediction scheme in this long-term climatological mode as a step towards validating it on the interannual time-scale.

3. Results

The results obtained from the time series of DDEI and DDII characteristics for the present square catchments (Fig. 1) were quite similar to those found for circular catchments (with the same ìdiameterî) in Bell and Lamb (1994). Specifically, it was found that the dramatic decline in seasonal rainfall totals in the West African Sahel after 1950 was the result of: (a) a pronounced and progressive zone-wide decrease (increase) in the frequency of large and well-organized (small and/or disorganized) DLs throughout the period (see Fig. 2); (b) a post-1965 increase in the frequency of DL absence (see Fig. 3); (c) a general zone-wide increase in the frequency of weak DLs for the period as a whole, but with considerable interannual variability (see Fig. 4); (d) a general decrease in the frequency of strong DLs throughout the period for the extreme westernmost (Dakar) and easternmost (Niamey) catchments, whereas this decrease reversed after the early-1970s for the two central (Bamako, Kindi) catchments (Fig. 4); and (e) pronounced and progressive zone-wide decreases in the seasonal average DL size and DL intensity throughout the period (Fig. 5). Note that there is an overall positive relationship between DL size and intensity from daily to interannual time scales, as illustrated in Figs. 6 & 7.

Fig. 8 compares the annual cycles of (a) the long-term average 10-day mean ΔU_L and ΔU_M shears and (b) the long-term average 10-day mean DDEI and DDIII values for the Dakar, Bamako, and Niamey catchments. These curves show that, in a long-term average annual cycle sense, the tropospheric low-level shear (ΔU_L) strengthens (becomes more negative) until the end of June at all three stations, and then begins to slowly weaken. Towards the end of June, the size and intensity of DLs begins to quickly increase. Near the center of the mid-rainy season ΔU_L weakening, there is a slight temporary strengthening of the ΔU_L which coincides at all three stations with a drop in the DDEI, and at least a plateau, if not a drop, in the value of the DDIII. After this mid-season strengthening, the low-level shear weakens again slightly, and then strengthens once more (except at Dakar) as the DDEI and DDIII values fall at the end of the rainy season. After the DDEI and DDIII have diminished greatly by the end of the rainy season, the low-level shear again weakens through the end of the year. Finally, Fig. 8 suggests that the above shear criteria of Omotosho (1990) work well, on a long-term average annual cycle basis, in diagnosing when the size and intensity of DLs begin to quickly increase. This is particularly true of the Bamako and Niamey catchments. Therefore, it appears possible that these shear criteria could have predictive value for rainy season onset on a seasonal basis across much of the Sahel. The Conference presentation will examine this issue in greater depth than is possible at this time.

Acknowledgments

This research was supported by NOAA Grant NA67RJ0150.

References

Bell, M. A., and P. J. Lamb (1994) Temporal variations in the rainfall characteristics of disturbance lines over subsaharan West Africa: 1951-90. In Proceedings of theInternational Conference on Monsoon Variability and Prediction, Trieste, Italy, May, 1994, 35-41.

Finch, J. D. (1998) Variability of tropospheric airflows over subsaharan West Africa. MSc thesis, University of Oklahoma, Norman, Oklahoma, USA.

Frank, W. M. (1978) The life cycles of GATE convective storms. J. Atmos. Sci., 35, 1256-1264.

Hastenrath, S. (1991) Climate Dynamics of the Tropics, Kluwer, Dordrecht, 488 pp.

Moncrieff, M. W., and M. J. Miller (1976) The dynamics and simulation of tropical cumulonimbus and squall lines. Quart. J. Roy. Met. Soc., 102, 373-394.

Omotosho, J. B. (1990) Onset of thunderstorms and precipitation over northern Nigeria. Int. J. Climatology, 12, 369-382.

Ropelewski, C. F., P. J. Lamb, and D. H. Portis (1993) The global climate for June to August 1990: Drought returns to Sub-Saharan West Africa and warm Southern Oscillation episode conditions develop in the central Pacific. J. Climate, 6, 2188-2212.

Rowell, D. P., and J. R. Milford (1993) On the generation of African squall lines. J. Climate, 6, 1181-1193.

Weisman, M. L., J. B. Klemp, and R. Rotunno (1988) Structure and evolution of numerically Simulated squall lines. J. Atmos. Sci., 45, 1990-2013.

The WMO Climate Information and Prediction Services (CLIPS) Project

Professor Fredrick H. M. Semazzi
WMO/CLIPS Project Office

Abstract

The Twelfth World Meteorological Congress in June 1995 recognized that important advances had been occurring in science and climate services including the important scientific outcome of the World Climate Research Programme. The Congress asserted that provision of climate information and prediction will improve economic and social decision-making and will support the goal of sustainable development. The Congress therefore decided upon the establishment of the WMO Climate Information and Prediction Services (CLIPS) project and included it in the WMO Fourth Long-term Plan for 1996-2005.

The primary objective of the CLIPS Project is to develop the capacity of the National Meteorological and Hydrological Services (NMHSs) to take advantage of the recent advances in the science of climate and in the processing and delivery of climate information, and to pass on the benefits of the improved climate services to the user community.

The CLIPS Project builds on past decades of successful atmospheric and oceanographic research, such as the Tropical Ocean and Global Atmosphere (TOGA) project, and on established operational meteorological and hydrological networks involving international and regional centres as well as the NMHSs. At the same time, it builds on a developing capability to predict climate on monthly, seasonal and inter-annual time scales.

In the final analysis, the CLIPS Project should stimulate the use of sector-specific information, in an ongoing, iterative process of dialogue between the producers of climate information and the multitude of users in government, academia, private industry and the media. It is envisaged that this process will be based on established technical cooperation arrangements between WMO and regional and sub-regional inter-governmental bodies, especially through the WMO Regional Associations (RAs).

The CLIPS Project office is established within the WCP Department of the WMO Secretariat with responsibility for the implementation of the project. This arrangement also allows CLIPS to maintain relations with WMO partners in the activities under Thrust 2 of the Inter-Agency Climate Agenda Framework, Climate Services for Sustainable Development.

Following the planning phase, which included formulating of the CLlPS project concept and expert missions, the project moved into the implementation phase with the launching of activities within the project's components. The paper presents an outline of the strategies for the implementation of the CLIPS Project.

3. Introduction

In recent years, major advances have been made in the monitoring and analysis of climate information and the ability to exchange it rapidly and efficiently. Promising scientific results have been obtained concerning the prediction of climate on the time scales from seasonal to inter-annual. Therefore it has become feasible to take a new step in the development of an enhanced range of operational climate services.

Many National Meteorological and Hydrological Services (NMHSs) have long experience in preparing various climate products for use in socio-economic activities and decision-making. The implementation of the WMO CLIPS Project should ensure that this experience is shared among the NMHSs. Consequently, the capacity of NMHSs to deliver climate services and meet the expectations and needs of customers - national, regional or international - must be built. The capacity building initiative, as proposed through the WMO CLIPS Project, will strengthen the role of NMHSs and ensure the provision of better climate services to their respective governments and other national users.

4. The CLIPS Project Concept and Objectives

A vision for climate information and prediction services on which the development of the project was based, and the project objectives, were outlined in the booklet, "Climate Information and Prediction Services" published earlier by the WMO (WMO-No. 832, 1995).

The ultimate goal of the WMO Climate Information and Prediction Services (CLIPS) project within the WMO World Climate Applications and Services Programme was defined as "to provide the best possible climate information, including expectations of future conditions, to improve economic and social decisions, which will reduce risks and improve economic vitality as well as the quality of life". The project is intended to build on the many successful WMO data collection and research programmes to provide important new services and fulfill the promise of years of investment in these programmes.

The main objectives of the project were formulated as:

(I) Demonstrate the value and eventual socio-economic benefits of climate information and prediction services.

(ii) Provide an international framework to enhance and promote climate information and prediction.

(iii) Encourage the development of operational climate predictions.

(iv) Facilitate the development and strengthening of a global network of regional national climate centres.

An important feature of the CLIPS Project which was stressed in the brochure and in the planning process was that the climate services developed with the assistance of the project would be derived from both analysis of the past and contemporary climate and near future climate predictions.

The beneficial application by users of the outcome of climate services should be achieved through a set of stages beginning with data collection and management and ending with an interface with users on the utilization and assessment of climate information and prediction (see figure below). The CLIPS Project acts mainly within Stages 3 and 4.

<u>User Applications and Benefits Derive from a Set of Stages</u>

STAGE 1	**STAGE 2**	**STAGE 3**	**STAGE 4**	**STAGE 5**
Data Input	**Climate Diagnostics and Predictions**	**User Oriented Products**	**User Interface**	**User Applications Benefits**
GCOS, WWW, etc.	*Anomalies, SOI, ENSO, SST, etc.*	*Rainfall probabilities, frost risk assessments.*	*Outreach, credibility, marketing, media, etc.*	*Increased yie better decisio improved pr less loss, et*
Research and Development Process **CLIMATE SCIENCE APPLICATIONS**				
Assessment and Feedback Process				
Training Process				

(CLIPS activities expected to be mainly in shaded stages)

The project objectives and modalities of its implementation were refined by taking into account results of sectoral support missions undertaken from the end of 1995 through 1996. This missions programme, which is planned to continue, has covered countries in RA I, RA II, RA V (ASEAN countries), and RA III. Each mission visited several countries in the respective region. The post-mission evaluations and subsequent communication between the CLIPS Project office and the NMHSs are being used to prepare proposals for submission to donor programmes, such as VCP, to initiate pilot projects in Member countries.

5. CLIPS Project Components

CLIPS Project implementation comprises a suite of complementary components. The strategies, rationale and the steps in their implementation respond to the urgent need to enhance application of climate services. Also, a geographical balance of activities is being pursued to ensure that the project responds adequately to the priorities of the social-economic needs in all WMO Regions.

There are four major components of the CLIPS Project:

a. Training
b. Demonstration / pilot projects
c. Liaison with research programmes
d. Networking

The attributes and implementation plans for these components are described below.

3.1 Training Component

The following categories of training events are planned:

a. *Initial training seminars/workshops*

Training seminars and workshops (usually one week in duration) are designed to promote awareness among the staff of national climate services of applications and services involving modern climate products such as climate forecasts, and how to use these products.

b. *Advanced training workshops*

These are of a broader and more advanced scope than the initial training seminars / workshops. Advanced workshops of 2-3 weeks in duration should review recent climate research developments and the use of climate information to assist decision-making and sectoral management. The major foci of the advanced training workshops are to provide the participants with the opportunity to gain hands-on experience in handling various CLIPS application tools and also to be trained to conduct awareness raising training seminars in the member countries.

c. *Roving seminars*

These seminars are organized through visits of experts in CLIPS activities to selected countries to provide on-the-spot training of NMHS staff. They also provide a platform for spreading information about successful implementation experiences.

The goal is to hold at least one training event in each Region, every year. Depending on the sector priorities in each region, special considerations will be added to the workshops on relevant topics such as public weather services, agro-meteorological applications and water resources management. Proceedings of the training workshops will be published and disseminated widely.

Advanced training focuses on the development of methodologies for applying climatological information and tailoring seasonal-to-inter-annual climate predictions to practical use by decision-makers in agricultural planning, water resources management and other socioeconomic sectors. Participants will be required to bring observational data from their countries and/or regions to initiate pilot projects.

Each training workshop will have a theoretical and a practical component, with participants assisted by the instructors in familiarizing themselves with a network of dedicated PC computers available for their exclusive use. For example, participants will be introduced to climate information applications software such as Climlab to gain hands on experience in using modern climate information processing tools.

Prior to the training event, participants will receive printed material about the data requirements and applications software to be used. This will allow the participants to be aware of techniques to be employed and become prepared to initiate a Pilot Project.

3.1.1 Responsibilities of training workshop participants

(i) Serve as a nucleus for initiating country specific demonstration projects,
(ii) Facilitate links with CLIPS Project international network,
(iii) Serve as a resource for developing national climate information policy,
(iv) Promote feedback to the research community, and
(v) Promote national awareness of CLIPS Project benefits.

3.1.2 Attributes of Training Workshop Participants' datasets

- geographical information of major hydrological systems and/or agricultural production systems in the country or region;

- hydrological data such as monthly averages of river discharges, river stages,
- crop statistics, i.e. crop yields, crop production, or other agricultural data available, such as the environmental conditions needed for selected crops in the participants' home country;
- water resources systems data (reservoir characteristics, hydropower generation, etc);
- the longest possible records available on monthly averages of precipitation and temperature from selected weather stations on a regional scale; and
- any other information that the participant may consider important to evaluate the impact of extreme climate events such as droughts and floods on agriculture, water resources management, human and property loss, etc.

In 1997 (July - December), a programme of introducing the CLIPS Project and training will continue through related meetings on Climate Data Management focussing on CLTCOM / CLIPS / DARE for Regions I, III and IV; Newly Independent States in Regions II and VI; and a joint RA m / TV Expert Meeting on Climate Matters.

In 1998, an extensive programme of training workshops is planned with the goal to undertake one training workshop per Region. At the same time, roving seminars will be organized, initially in countries in Regions II and III.

In 1999, roving seminars / workshops on CLIPS will continue in Regions IV and VI, and it is expected that the second round of the workshops will be organized in conjunction with the meetings on the progress of pilot projects in the Regions (see below) which will contain a capacity building component. These workshops will be carried out on a more advanced basis than workshops to be held in 1998.

3.2 Demonstration/pilot Project Component

In this component, two categories of projects are envisaged.

a. *Demonstration projects*

These projects are organized through Members which have already gained experience in the provision of modern climate services. They are aimed at sharing this experience among NMHSs; normally, support through WMO would be limited to publication of reports and their distribution to Members.

b. *Pilot projects*

> These projects are organized mainly on a national and / or sub-regional scale and would normally require substantial external assistance using, for example, the VCP channels. Countries / sub-regions to be selected as participants in pilot projects are identified through expert missions, outcome of training events, requests by Members, and recommendations of the WMO constituent bodies.

The demonstration and / or pilot projects may deal with individual components of enhanced climate services, for example, aspects of the use of the Internet, down-scaling of information to regional- and national-scales, establishment and enhancement of user interaction, study of predictable climate signals, e.g. ENSO; or may consist of a suite of integrated topics, where each project is designed to evaluate a number of components of enhanced services.

Two different strategies for initiating and implementing pilot projects will be adopted depending on the level of preparedness, sectoral needs, carrying out support missions in the region of interest, as well as other considerations.

Strategy I for initiating pilot projects	**Strategy II for initiating pilot projects**
Expert mission report Identify target countries Propose priority sectors Identify counterparts Identify project leader and duration Identify project objectives Establish evaluation criteria Identify source of funding	Participants prepare data for training workshop Initiate pilot project at training workshop Consolidate pilot project after workshop Follow-up steps similar to those under Strategy I

While the first option may be adopted when preparatory work has been already undertaken, the second option is more appropriate where the degree of preparedness is inadequate and fact-finding missions have not been undertaken or the information is obsolete because of the long duration that has elapsed since they occurred. Under these circumstances, CLIPS advanced training workshops are used to initiate the pilot projects.

In 1997, a pilot project at ACMAD will continue and some pilot projects will be initiated using support submitted through the VCP channels. Demonstration projects will be initiated in conjunction with a training workshop for ASEAN countries in RA II and V.

In 1998, further proposals for pilot projects will be developed for submission for funding consideration. Workshops on the progress of pilot projects in countries in Regions II and V will be organized to be funded through extrabudgetary (possibly VCP) sources.

In 1999, this series of workshops will continue in countries in Regions I, III, IV, and VI.

3.3. Liaison with Research Programmes Component

This liaison is planned through Climate Outlook Fora and joint expert meetings.

a. *Climate Outlook Fora*

Proposed as regional/sub-regional workshops, researchers dealing with climate information and prediction and specialists in climate services will jointly develop consensus or consolidated climate outlook guidance together with guidance on their interpretation and dissemination to users. The participants of the fora are representatives of NMHSs and regional operational climate centres. The climate outlook fora are also designed to provide capacity building on creation and interpretation of climate predictions. They should draw together partners from various advanced climate prediction centres.

The plans already exist for outlook fora in Southern Africa for 1997-1999. A climate outlook forum in the Asia-Pacific region is planned for 1998.

- *Expert meetings*

These will be organized on specific topics requiring co-ordination of the CLIPS Project with research programmes such as CLIVAR.

3.4. Networking Component

This part of the project deals with studies of the feasibility of using telecommunication platforms, such as CTS and Internet, to disseminate climate products; consultant services may be required for this purpose.

Recognizing the high cost of organizing workshops, training seminars, and publication of reports, there is need to adopt the Internet as a CLIPS Project primary mode for information exchange. This will not be confined to the data products, but also will be used in performing other CLIPS Project functions, which involve exchange and sharing of information.

Internet platforms will enable NMHSs to share their experiences with others wishing to develop the same capability, and to take part in regional and international networks of countries exchanging information and experience in the provision of climate services. CLIPS Project promotes use of Internet to transmit climate data and information, and to facilitate exchange of knowledge between Members.

A study will be initiated to identify ways and means for exploiting the GTS, and on an experimental basis, a limited CLIPS Internet network will be established. Initially, the participating NMHSs will comprise a subset of Members involved in demonstration / pilot projects, which already have adequate connection speed to handle transfer and exchange of CLIPS products. The specific implementation actions will entail initiation of Internet-based exchange of CLIPS products, over a one-year test period among the selected NMHSs and research institutions.

EXPERIMENTAL CLIPS SERVICES OVER INTERNET

Distribute Climate Outlook to NMHSs
Distribute pilot project progress reports
Initiate an Internet newsgroup
Initiate online CLIPS training events
Provide feedback to the climate information providers

4. Publications

The four components of the project will be supported by publications related to the CLIPS Project, which include reports on training workshops, pilot projects, planning strategies, etc. With the help of consultants, several CLIPS publications will be prepared including reports on dissemination of climate products via GTS and Internet, annual manuals and related CLIPS demonstration / pilot projects reports. Education material on CLIPS should include a manual on methodologies for providing climate services with an emphasis on interaction with users.

The planned publications include:

(i) Publication of manual for CLIPS related training; 1998
(ii) Publication of manual on dissemination of CLIPS services via GTS and Internet; 1998
(iii) CLIPS demonstration / pilot projects (several reports; 1999)
(iv) Publication of manual on education in the provision of CLIPS services
(v) Methodologies in providing CLIPS services; 1999
(vi) Information package for use by educators; 1999

5. The WMO CLIPS Project in the context of the inter-agency climate agenda framework

The Climate Agenda -- an integrating framework for international climate related programmes sponsored by WMO, UNEP, UNESCO and its IOC, FAO, WHO, and ICSU -- is organized along four major thrusts:

- New frontiers in climate science and prediction.
- Climate services for sustainable development.
- Studies of climate impact assessments and response strategies to reduce vulnerability.
- Dedicated observations of the climate system.

The Inter-Agency Committee on the Climate Agenda (IACCA), established in April 1997, identified leading organizations to be responsible for coordination of the development of the Climate Agenda within each of the four thrusts. WMO is leading coordinating organization for Thrust 2 - Climate Services for Sustainable Development.

The CLIPS Project concerns many aspects of activities envisaged under Thrust 2 and, indeed, represents a major effort to achieve objectives of this Thrust formulated as follows:

- delivery of operational climate forecasts and assessment of trends in climatic variables;
- establishment of networks of national, regional and global climate services;
- provision of assistance to nations to help them to respond to climate extremes and climate-related calamities, especially drought and desertification.

Among the activities, which are to be undertaken to meet these objectives, some depend particularly on the implementation of the CLIPS Project. Table 1 shows the relationship of these activities to the CLIPS Project components.

Implementation of CLIPS Project requires a cooperative effort from many agencies, since there is abundant wealth of experience accumulated by sectors over the years to provide services to the users. The implementation of the CLIPS Project is taking advantage of the cooperation and connections through IACCA agenda partners to enhance interaction with the users.

Activities planned under the four components of the CLIPS Project are also related to a number of activities under other thrusts of the Climate Agenda, notably:

- development of seasonal to inter-annual forecasting techniques (Thrust 1);
- creation of regional networks of scientists and scientific institutions to facilitate access to advanced scientific knowledge available worldwide and within the region (Thrust 1);
- studies of the benefits from the application of climate information in, assessments of climate impacts and establishment of national response strategies (Thrust 3);
- dissemination of information on the socio-economic implications of climate variability and change to governments and the general public (Thrust 3);
- identification of possible mitigation and adaptation strategies (Thrust 3);
- encouragement of capacity building to develop technical skills for observations, analysis and product generation (Thrust 4).

The Climate Agenda Framework, strongly supported by WMO, enhances the opportunities for collective efforts of which the CLIPS Project will certainly be one of the most significant manifestations.

6. Launching of CLIPS Project Activities

The implementation of the CLIPS Project is planned in such a way that various activities would be evenly spread over Regions.

For example, in Region I, a package of important capacity building initiatives has been undertaken and coordinated during the formative phase of the CLIPS Project in the areas of training, development of climate outlook guidance, and initiation of pilot projects.

A seminar and training course was organized for representatives from eleven African NMHSs at ACMAD (October through December 1996). The seminar covered a wide spectrum of climate services, with emphasis on data management during the first two weeks (CLICOM), and on climate applications and prediction during the remainder of the course (CLIPS).

A CLICOM/CLIPS seminar was conducted in February 1997 for English-speaking countries in Lusaka, Zambia. Participants came from 11 SADC countries. The topics covered included overview of the CLIPS Project, operational CLIPS activities within the participants' services and from other regions, and the importance of CLIPS in RA I socio-economic sectors.

A CLICOM/CLTPS seminar was held for some of the French-speaking countries of RA I, in March 1997. Participants came from 12 countries, and a variety of instructors covered topics similar to those described for the Lusaka seminar.

A pilot project was launched, at ACMAD in Niamey, Niger, to improve the Climate Bulletin (CB), the Climate Watch-Africa (CW) publication, and the climate outlook for the contiguous regions of Africa.

A Climate Outlook Forum for Southern Africa (SADC countries) is being organized by the IRI, the CLIPS Project office and other institutions. The Climate Outlook will take place September 1997 in Harare, Zimbabwe. Part of the Climate Outlook Forum will be a capacity building component, including a tutorial on creation and interpretation of climate predictions and a short workshop on dissemination of the climate predictions to users in the SADC countries.

LIST OF ACRONYMS

ACMAD	African Centre of Meteorological Applications for Development
ASEAN	Association of South East Asean Nations
CLICOM	Climate Computing
CLIPS	Climate Information and Prediction Services
CLIVAR	Climate Variability and Predictability
DARE	Data Rescue
ENSO	El Niño Southern Oscillation
FAO	UN Food and Agriculture Organization
GCOS	Global Climate Observing System
GTS	WWW Global Telecommunication System (WMO)
IACCA	Inter-agency Committee on the Climate Agenda
ICSU	International Council of Scientific Unions
IOC	Intergovernmental Oceanographic Commission
NMHSs	National Meteorological and Hydrological Services
SADC	Southern Africa Development Community
SOI	Southern Oscillation Index
SST	Sea Surface Temperature
TOGA	Tropical Ocean and Global Atmosphere
UNEP	UN Environment Programme
UNESCO	UN Educational, Scientific and Cultural Organization
VCP	Voluntary Cooperation Programme
WCP	World Climate Programme
WHO	World Health Organization
WMO	World Meteorological Organization

Table 1. **Activities in Thrust 2 of the Climate Agenda as related to the CLIPS Project components**

Thrust 2 Activity	**Organizations/Programmes Involved**	**CLIPS Project Components**			
		Training	Pilot Demonstration Project	Liaison with research community	Netv
Enhance programmes for the organization of regional/sub-regional events (workshops and training courses/seminars) bearing in mind the needs of the developing countries.	WMO UNEP	1	3	2	
Support the training of relevant national personnel involved in the assessment of climate extremes and the development of national preparedness.	WMO UNEP FAO ICSU WHO	1	2	3	
Develop mechanisms and procedures for the provision and dissemination of quality controlled, user-oriented climate data and products	WMO GCOS	3	1	3	
Encourage better assessment of users' requirements and needs for climate information, analyses and predictions.	WMO	1	1	3	
Raise awareness on the benefits of climate services and the establishment of plans for preparedness for, and mitigation of, adverse effects of extreme climate events.	WMO UNEP FAO WHO UNESCO	1	1	3	
Promote and facilitate the exchange of acquired experience in serving various climate-sensitive sectors, and the natural disaster preparedness and reduction plans, including interaction with users and marketing the services provided.	WMO	2	1	3	
Develop a network of national, regional and global climate centres, in close coordination with, and taking advantage of, the existing infrastructures.	WMO ICSU FAO	3	2	2	
Stimulate the transfer of research methodologies for climate predictions into operational climate prediction services.	ICSU WMO	2	2	1	
Foster research into the application of climate products resulting form climate forecasts and analyses.	ICSU WMO	3	2	1	

1 - leading component(s)
2 - supporting component **3 -** other related components

ACMAD
CLIMATE INFORMATION PREDICTION AND SERVICES:
Present Activity and Future Development

Laban Ogallo
ACMAD Board of Governors

Abstract:

In carrying out its core demonstration project (CDP) for the period 1997-1998, ACMAD submitted an implementation plan for a medium range weather guidance and climate monitoring and prediction activity, consistent with WMO requirements. A coordination meeting was held in February 1996 in conjunction with the 8th and extraordinary session of the board of governors of ACMAD. The overall objective of the CDP is to enable ACMAD and its users, Africa's national meteorological services, to build suitable weather and climate services for the end users, i.e. agriculture, water resources, energy, tourism, environment, commerce, etc. One major part of the CDP is the evaluation of the service chain for data input, data analysis and ACMAD products. At the end of the chain, the product tailored by the national meteorological services for their end users. The paper describes the climate activity implemented at ACMAD as part of CDP, including the evaluation plan and future developments.

The main climate activity at ACMAD is the preparation of the African Climate Watch Bulletin, which contains information on climate monitoring and climate predictions over Africa. The monitoring section consists of monthly highlights of the major weather events and monthly climate summaries describing the state of the rainy season and its evolution. The prediction section provides an outlook of the upcoming rainy season for regions where significant skills in the prediction schemes have been demonstrated. These include Western Africa, the Horn of Africa, Southern Africa and Southwest Indian Ocean Islands. Recently, a special rain onset bulletin has been elaborated for Sahel Countries based on the empirical method developed by Professor Omotosho form the University of Lagos. This method has been implemented by using the SYNERGIE data integration system to extract wind data input from any grid point, and by using MS Excel software to monitor the thresholds and elaborate the prediction.

As for development, ACMAD established a plan for an experimental pilot project for the application of climate prediction in agriculture and water resource management. The project is being conducted with cooperation of ACMAD, the Nigerian Meteorological Service, the High Volta Water Authority of Ghana and the Côte d' Ivoire Meteorological Service. Another development axis is being developed for the implementation of a new climate monitoring and prediction

tool. This means that ACMAD will have, in house, an advanced climate prediction tool for better climate assessment.

Overview of modelling activities at ICRISAT*:

A case study of sorghum

R. Tabo
ICRISAT, Nigeria, Kano

Abstract

Despite the importance of sorghum as one of the most important staple foods for the people living in the semi-arid region of West and Central Africa (WCA), its productivity has remained low and unstable due to several constraints among which are drought and inherent poor soil fertility. In this paper, we attempt to review some of the work carried out by ICRISAT and its collaborators including the National Agricultural Research Institutes (NARS) and other research institutes aimed at alleviating the constraints to sorghum production. Emphasis is placed on the modelling efforts made so far to address these constraints. The Agricultural Production Systems Research Unit (APSRU)/ICRISAT collaborative initiative on modelling is discussed with reference to the improvement and stabilization of the productivity of sorghum and sorghum-based cropping systems in West and Central Africa as it relates to climatic variability and water availability. The need for a close collaboration between the International, Regional, and National Research Institutes in a multidisciplinary modelling project is also highlighted.

1. Introduction

Sorghum (*Sorghum bicolor* (L.) Moench) is the world's fifth most important cereal and the second most important food crop after millet in the semi-arid region of West and Central Africa (WCA). However its yield has remained low due to many constraints including erratic and low rainfall, poor soil fertility, biotic stresses and socio-econimic factors. Although the cropped area is expanding in Africa, where it grew 13 million hectares between 1979-81 and 1992-94, yields fell by 14% during the 1980s before rising once more in the early 1990s. Grain yields (1992-94 average) were 0.8 t/ha in Africa, 1.2 t/ha in Asia, over 4 t/ha in North America, and over 5t/ha in Europe (FAO and ICRISAT, 1996).

Sorghum is grown in areas that are characterized by droughts of variable duration and intensity. Growth, development and yield of sorghum are more adversely affected by the timing of evapotranspiration (ET) deficit than by the total seasonal ET (Howell and Hiler, 1975). To optimize water use, it is therefore essential to develop the capability to predict the quantitative effects of water stress. Crop simulation models based on soil conditions, climatic and management factors are effective management tools to predict the effect of drought on crop yields across a range of environmental conditions (Jordan and Sullivan, 1982). Sivakumar (1991) also reported that dry spell analysis could be used to explore alternatives to the present cropping patterns in West and Central Africa for greater productivity.

In this paper, we review some of the modelling efforts to address constraints on sorghum production. We also highlight the collaborative work of the Agricultural Production Systems Research Unit (APSRU)/ ICRISAT on systems modelling and the need for a multidisciplinary, international and regional modelling project.

2. Role of modelling in addressing constraints to sorghum production in the semi-arid tropics of West and Central Africa

In order to identify the major factors influencing growth, development and yield of sorghum, it is important to have a good understanding of the interactions between the environmental factors and the cultivars. This can be achieved through the conduct of multi-location field trials over many years to evaluate the different crop management practices in varying agroecological zones. This approach is time-consuming and costly.

An alternative approach is to evaluate the various technologies using crop simulation models along with historical long-term climatic data. Considering the wide variation in the maturity periods of different sorghum genotypes, it is essential that these genotypes are matched with the soil-moisture availability period so that increased biomass and grain yields are achieved. Crop growth models are a useful tool to integrate the information on crop growth and development with the environment factors influencing these processes.

However, modelling should not be a substitute for field experimentation, but a more rational basis for experimentation. Models should be considered primarily as research tools. There is a need for detailed, sound and comprehensive field experimentation as a basis for developing and validating these models.

2.1 Modified SORGF model

The SORGF model which was developed by Arkin *et al.* (1976) and modified by Huda *et al.* (1984) estimates growth and development of grain sorghum. They revised and validated several subroutines of the SORGF model using data collected from multi-locational field trials. In their revisions, the researchers have included the incorporation of a multi-layered soil water balance sub-model, cultivar-specific information on daylength and temperature relationships for determining phenology, radiation interception and dry matter accumulation relationship, and cultivar-specific information on dry matter distribution patterns. Table 1 lists some of the minimum data set requirements for the SORGF model.

Table 1. Input data required for Sorghum simulation model SORGF

Cultivar data

Leaf number-total number of leaves produced
Leaf area- maximum area of each leaf
Daylength and temperature relationship for phenology
Dry-matter distribution pattern

Agronomic data

Sowing date
Final plant population
Row width
Depth of sowing

Weather data (daily from sowing to maturity)

Maximum temperature
Minimum temperature
Solar radiation
Rainfall

Soil data

Available water-holding capacity
Initial available water content

Location data

Latitude

Source: Arkin *et al.* (1976)

Huda *et al.* (1987) tested the model using data from field experiments conducted at the ICRISAT Asia Center, Patancheru, India (17°32' N latitude, 78°16' E longitude) during the dry seasons of 1979/80 and 1980/81 on an alfisol. They concluded from their studies that observed and simulated data on phenology, drought-stress coefficients, Total Dry Matter (TDM) and grain yield showed that the model can accurately simulate the response of sorghum to drought stress. But they also suggested that there is a need for more quantitative information, particularly on the effects of drought stress occurring at specific growth periods. This is essential if appropriate strategies for water management practices are to be developed. This type of information would also lead into further improvement in the SORGF model.

2.2 CERES sorghum crop growth model

The CERES sorghum crop growth model operates on a daily time step to simulate crop development, water and nitrogen balance, growth and yield based on soil, climate, management and crop genetic inputs (Godwin, 1989; Alagarswamy *et al.*, 1989; Ritchie and Godwin, 1989). The CERES models have built-in procedures for simulating the uptake of nitrogen (N) and its subsequent utilization by the crop. These models allow the calculation of soil water balance for the evaluation of possible yield reductions caused by soil and plant water deficits. The following equation is used to evaluate the soil water balance of crop or fallow land:

$$S= P + I - EP - ES - R - D$$

where

S = the quantity of soil water;
P = precipitation;
I = irrigation;
EP = evaporation from plants;
ES = evaporation from soil;
R = runoff; and
D = drainage from the profile.

Some of the equation’s uses include:

- the definition of agroecological potentials for sorghum across some agroecological subregions;

- the estimate yield gaps which are defined as the difference between the agroecological potential of a crop and what the farmers actually realize in a given region. This enables a good characterization of the 'untapped potential ' and a definition of the 'opportunity' that can be exploited if all constraints are removed. Yield gap analysis is a powerful tool that can be used effectively to define priority research domains within a broad crop growing region;

- the evaluation of risks to dependable crop production using historical weather records; and

- the formulation of suggestions for using the techniques for priority-setting for sorghum research.

The CERES family of crop models contains several genetic coefficients which describe how the development of any genotype is influenced by environmental factors such as minimum and maximum temperatures, and daylength (Ritchie and Alagarswamy, 1989). The numbers and description of genetic coefficients used in CERES sorghum models for simulating phenology are:

P1 Thermal time (above the base temperature 8^0 C) during which the plants are not responsive to changes in photoperiod. The duration of this period is from seedling emergence to the end of the juvenile period.

P2O The threshold photoperiod above which the thermal time for panicle initiation (PI) will be influenced by photoperiod.

P2R Rate at which thermal time for PI increases for every hour increase in photoperiod beyond P2O.

2.3 RESCAP : A Resource Capture Model for Sorghum and Pearl Millet

This resource capture model emphasizes the role of leaves in relation to the interception of light, and the role of roots in relation to the uptake of water (Monteith *et al.* 1989). It is centered around two assumptions:

- the amount of dry matter produced per unit of radiation intercepted by foliage is effectively constant during vegetative growth when water is not a limiting factor; and
- the amount of dry matter produced per unit of water transpired is inversely proportional to mean saturation deficit constant whether water is a limiting factor or not.

This model was developed primarily to predict the growth and yield of sorghum and pearl millet, given an appropriate set of environmental variables and genetic coefficients.

3. Agricultural Production Systems Simulator (APSIM)

A collaborative activity is being developed in which the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the Australian CSIRO / QDPI Agricultural Production System Research Unit (APSRU) will adapt and apply a cropping systems model, APSIM, to research on cropping systems and mixed crop-livestock systems in the Semi-Arid Tropics (SAT) in India and Africa (McCown, 1996). This collaboration is known as CARMASAT (Collaboration on Agricultural / Resource Modelling and Applications in the SAT). Management of CARMASAT will be the responsibility of a team of two scientists -- one from ICRISAT and one from APSRU -- designated as co-managers.

The major objectives of this collaboration are:

- to develop and implement a program of collaborative systems research within ICRISAT that draws upon the experience and capability of APSRU in agricultural systems research and knowledge of the area of systems modelling. Other systems research groups may be involved also;

- to link this collaborative research program in simulation modelling to components of the ICRISAT Research Projects; to ecoregional research initiatives of the CGIAR system including the Desert Margins Initiative and the Rice/Wheat Initiative; and to aspects of the spillover in Africa and Asia of the results of the earlier Kenya studies by APSRU; and

- to develop the human, physical and technical capabilities of ICRISAT in the general area of simulation modelling to support the process of technology enhancement and adoption.

While simulation modelling is not new in ICRISAT, with this collaboration, ICRISAT is entering a phase of development which features simulation of production systems. This includes outputs in terms of production and the state of the soil resources (soil loss, organic matter change), in response to: (1) resources (soil, weather) and (2) management actions, e.g. crop choice, fertilization, rotations, intercropping, residue removal, etc.

While the collaboration involves some development of new models, it is mainly concerned with applications which enhance ICRISAT's achievements in its research projects.

As ICRISAT is working in a climatic zone with an extraordinary high spatial and temporal variability in natural resource constraints to agricultural production, this project represents an additional investment by ICRISAT to address an old challenge which has been exacerbated by the necessity to reduce the locations and duration’s of experimental programs. While models for these purposes have long been used in ICRISAT, the ICRISAT-APSRU collaboration takes new steps in simulation technology and methodology for application.

Simulation models are important in ICRISAT in at least three types of applications:

1. improved description of variability in natural climatic constraints;

2. evaluation of alternative farm management options; and

3. improved matching of genotypes and environment.

A key innovation is change from a core modelling concept of a crop responding to resource supplies to that of a soil responding to weather, management and crops.

4. Proposed uses of APSIM in West and Central Africa

- APSIM will be adapted and applied to our cropping systems research so that value can be added to the research results.

- Using information from the long-term trials and the characterization of production systems, APSIM will be used to explore the potential implications of the various improved sorghum-based cropping systems (sorghum-groundnut, sorghum-cowpea, sorghum-soybean and sorghum-pigeonpea) in farmers' fields.

- APSIM will be used to evaluate the technology options for improved water and nutrient (N and P) management in sorghum-based cropping systems so as to enhance the productivity and promote the sustainability of the systems.

- APSIM will be used to extrapolate the results from these trials to other similar agroecological zones in WCA and to predict the performance of these systems.

5. Need for Multidisciplinary and Multinational Modelling Approach

To develop suitable and appropriate crop production strategies for increased and sustained yields of sorghum in the diverse environments of West and Central Africa, there is a need to adequately understand the links between climate variability, water availability and use, and agricultural productivity. Various national, regional , and international institutions as well as the different networks operating in the region have generated a lot of useful information required for the understanding of these various processes, but this information is not available in an organized manner.

There is therefore a need for a more coordinated effort from the National Agricultural Research Systems (NARS), the International Agricultural Research Centers (IARCs), universities, development agencies and other similar institutions to assemble existing data into a more user-friendly form which would be accessible to all concerned. Where there are gaps, collaborative studies should be set up to fill in these gaps. Data from these joint experiments will also be used to validate some aspects of the proposed models which would then be more adapted to the agroecological conditions in the region. Furthermore, because of the variability of land use systems characteristics, it is essential to integrate disciplines and institutes in regional agricultural research efforts in order to target technologies to specific environments in West and Central Africa (Duivenbooden, 1995).

In conjunction with this, the different production systems in WCA should be characterized in detail using existing secondary data, field surveys and

Geographical Information Systems (GIS). Technologies will then be designed for and adapted to each production zone using the analysis of the effects of climatic changes on crop growth, development and productivity.

All these joint efforts would hopefully culminate into setting priorities and guiding research for the region; a more efficient use of scarce and limited resources for research work; and the development of appropriate and more adapted technologies aimed at improving and stabilizing the productivity of sorghum and sorghum-based systems.

REFERENCES

Alagarswamy, G., Singh, Upendra and Godwin, D.C. 1989**.** Modelling nitrogen uptake and response in sorghum and pearl millet. Pages 11-13 *in* Modelling the growth and development of sorghum and pearl millet. Research Bulletin No. 12 (Virmani, S.M., Tandon, H.L.S., and Alagarswamy, G. eds.). Patancheru 502324 Andhra Pradesh, India: International Crops Research Institute for the Semi-arid Tropics. 43 pp.

Arkin, G.F., Vanderlip, R.L. and Ritchie, J.T. 1976. A dynamic grain sorghum growth nodel. Trans. ASAE, 19: 622-626, 630.

FAO and ICRISAT. 1996. The world sorghum and millet economies; facts, trends and outlook. 68 pp.

Godwin, D.C. 1989. Simulation of nitrogen transformation in soil. Pages 8-10 *in* Modelling the growth and development of sorghum and pearl millet. Research Bulletin No. 12 (Virmani, S.M., Tandon, H.L.S., and Alagarswamy, G. eds.). Patancheru 502324 Andhra Pradesh, India: International Crops Research Institute for the Semi-arid Tropics. 43 pp.

Howell, T.A. and Hiler, E.A. 1975. Optimization of water use efficiency under high frequency irrigation: 1. Evapotranspiration and yield relationship. Trans. ASAE, 18: 873-878.

Huda, A.K.S., Sivakumar, M.V.K., Virmani, S.M., Seetharama, N., Singh, S. and Sekaran, J.G., 1984. Modelling the effect of environmental factors on sorghum growth and development. *in* Proc. Int. Symp. Agrometeorology of sorghum and millet in the semi-arid tropics, 15-20 November 1982. ICRISAT, Patancheru, A.P., India, pp. 277-287.

Huda, A.K.S., Sivakumar, M.V.K., Sri Rama, Y.V., Sekaran, J.G. and Virmani, S.M. 1987. Observed and simulated responses of two sorghum cultivars to different water regimes. Field Crops Research, 16: 323-335.

Jordan, W.R. and Sullivan, C.Y. 1982. Reaction and resistance of grain sorghum to heat and drought. *in* Sorghum in the Eighties: Proc. Int. Symp. Sorghum, 2-7 November, 1981, ICRISAT, Patancheru, A.P., India, pp. 131-142.

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P., and Freebairn, D.M. 1996. APSIM: a novel software system for model development, model testing and simulation in agricultural systems research. Agricultural systems 50: 255-271

Monteith, J.L., Huda, A.K.S. and Midya D. 1989. RESCAP: A Resource Capture Model for

Sorghum and Pearl Millet pages 30-34 *in* Modelling the growth and development of sorghum and pearl millet. Research Bulletin No. 12 (Virmani, S.M., Tandon, H.L.S., and Alagarswamy, G. eds.). Patancheru 502324 Andhra Pradesh, India: International Crops Research Institute for the Semi-arid Tropics. 43 pp.

Ritchie, J.T. and Alagarswamy, G. 1989**.** Genetic coefficients for CERES models. pages 27-28 in Modelling the growth and development of sorghum and pearl millet. Research Bulletin No. 12 (Virmani, S.M., Tandon, H.L.S., and Alagarswamy, G. eds.). Patancheru 502324 Andhra Pradesh, India: International Crops Research Institute for the Semi-arid Tropics. 43 pp.

Ritchie, J.T. and Godwin, D.C. 1989. Description of soil water balance. pages 14-16 *in* Modelling the growth and development of sorghum and pearl millet. Research Bulletin No. 12 (Virmani, S.M., Tandon, H.L.S., and Alagarswamy, G. eds.). Patancheru 502324 Andhra Pradesh, India: International Crops Research Institute for the Semi-arid Tropics. 43 pp.

Sivakumar, M.V.K. 1991. Drought spells and Drought Frequencies in West Africa. Research Bulletin no. 13. ICRISAT Sahelian Center, Niamey, Niger 181 pp.

van Duivenbooden, N. 1995. Land use systems analysis as a tool for land use planning, with special reference to North and west African agroecosystems. Ph.D. thesis Wageningen Agricultural University, Wageningen, the Netherlands 176 pp.

Opportunities and Constraints in Realizing Yield Potential of cassava across drought environments: Science & Realities

***Indira J. Ekanayake*[1] *and Shrikant Jagtap*[2]**

[1]Physiologist, Root and Tuber Improvement Program (TRIP), Crop Improvement Division (CID), and [2]Agroclimatologist, Crop Ecology and Modeling Unit, Resource and Crop Management Division (RCMD), International Institute of Tropical Agriculture (IITA), PMB 5320, Oyo Road, Ibadan, Nigeria

Abstract

Cassava (*Manihot esculenta* Crantz) is a major staple in the West African subregion where 60% of the total cassava production in Africa is cultivated. More than 50% of cassava-growing environments, both in the upland and hydromorphic inland valleys, are seasonally dry. Periodic and non-protracted or seasonal drought stresses associated with these environments are responsible for large reductions in cassava root yields. On-farm root yields can be improved two- to three-fold and the quality of fresh and processed products improved by the adoption of recently improved production technologies. Contributions of improved clones and agronomic practices to high root yields under low to severe drought conditions are analyzed. In addition to the use of improved early bulking and drought-tolerant cassava clones, on-farm drought mitigation measures through the use of other integrated management practices are reviewed as potential ways to minimize the savanna farmers' risk in cultivating cassava in a drought environment.

1. Introduction

Currently the African continent leads the world in cassava production, with an annual production of 82 million tonnes of fresh roots. Recent increases in production (Table 1) imply an increase in the area of production (Manyong and Oyewole, 1997) and to a lesser extent, an increase in root yield per unit area, and a shift in cassava cultivation from the traditional humid forest to the savannas. Therefore, cassava is increasingly grown in suboptimal environments. Recent observations on cassava distribution indicate that cassava is presently cultivated more regularly throughout the sub-Saharan region and outside its southern latiudinal limit (15°S) and northern limit of the Sahel (15°S).

Drought-prone agroecological zones for cassava are the forest-savanna transition, southern Guinea savanna, northern Guinea savanna, mid-altitude savanna and Sudan savanna zone. Drought is the most limiting factor for cassava

Table 1.

Region / Country	1993	1994	1995
World	*163*	*160.1*	*160.8*
Africa	*83.1 (50.98)*	*80.1 (50.03)*	*82.0 (50.99)*
Nigeria	29.9 (18.34)	31.0 (19.36)	31.4 (19.52)
Zaire	20.8 (12.76)	16.9 (10.55)	17.5 (10.88)
Ghana	4.2 (2.58)	6.1 (3.81)	7.2 (4.48)
Tanzania	6.8 (4.17)	5.2 (3.25)	4.4 (2.74)
Mozambique	3.5 (2.15)	3.3 (2.06)	4.2 (2.61)
Uganda	3.1 (1.90)	3.4 (2.12)	3.0 (0.80)
Madagascar	2.4 (1.47)	2.4 (1.50)	2.4 (1.49)

cultivation in these areas despite the well-known drought tolerance of the crop. According to COSCA data, about 5% of farmers in both humid and sub-humid agroecozones cite drought as a reason for decrease in cassava production. Low natural fertility and water holding capacity of the soils plus low input use by farmers contributes to low average root yields.

This paper examines drought-prone savanna environments and their constraints to cassava production and assesses the appropriateness of different technological interventions to improve cassava production. The stage is set for a regional approach to improve the predictive capabilities on cassava productivity in West Africa. This study also gives some insight into the efficacy of various mitigation measures to reduce the vulnerability of cassava and to improve productivity and food security in the face of climatic variability and change associated with global warming.

2. Distribution of cassava by environment

Cassava, in contrast to other staples, grows and produces marketable roots under favorable as well as marginal ecological conditions of rainfall or soil fertility. Optimum environmental characteristics for cassava are given in Table 2. Because of its multifaceted adaptability to various ecological and sociological conditions, cassava is distributed across a wide range of agroecozones and across ecological niches within a zone. Some of the production system information, i.e. proportion of land area under cassava cultivation in a sub-region, is given in Table 3.

Table 2.

8. Broad tropical adaptation (30º N to 30º S)
9. Temperature > 20º C; in Andean zone & subtropics 17º C
10. Mean annual rainfall 600 to 3000 mm
11. Tolerates > 6 months of drought
12. Altitude up to 1600 to 1700 m; in Andean zone up to 2300 m
13. Require fairly deep, open textured soils
14. Tolerates soil acidity (pH 4.4) and Al toxicity
15. Optimum soil temperature range of 25º to 29º C
16. No tolerance of alkalinity (> pH 8)
17. Soil depth restrictions, high clay soils and calcareous soils unsuitable
18. Sensitive to flooding
19. Sensitive to poor drainage

Flexibility in planting and harvesting, efficiency of land and labor use in terms of carbohydrate production, and vegetative propagation are conducive to cassava's widespread use. The classical niche of cassava is as the last crop in a long-fallow system, but in short-fallow shifting cultivation systems, it becomes the dominant intercrop. Cassava can be cultivated with either high levels of input per unit land area per unit time (intensive culture) or under low input levels (extensive culture). Morpho-physiological characteristics of cassava fit well with its culture.

Table 3.

	% Area under cassava	
Agroecological zone	**West Africa**	**Central Africa**
Northern Guinea savanna zone (NGS)	9.8	21.2
Southern Guinea savanna zone (SGS)	30.6	9.6
Derived savanna / coastal savanna (DS / CS)	77.2	25.8
Mid-altitude savanna (MAS)	78.9	18.9
Humid forest (HF)	69.5	57.8
Total	53.0	43.8

The dominance of cassava in the order of humid > sub-humid > dry climates is well established (COSCA data; Carter *et al.*, 1992). Furthermore, cassava's traditional dominance in humid and wetter parts of sub-humid lowland zones (211 ≥ 270 day growing period) rather than the semiarid zones is partly due to population distribution rather than ecological reasons (Carter *et al.*, 1992). More cassava is grown on soils with no restrictions and acidic soils (Carter *et al.*, 1992) than on restricted soils (Asadu *et al.*, 1997). The trend in soil fertility status (Table 4), from high to low, is in the order of non-humid > highland humid > sub-humid > lowland humid zone. Using base saturation as a major fertility index, lowland humid cassava soils is the least fertile (mean of 80% base saturation).

3. Cassava environments: systems of classification

Cassava growing environments are complex (Ekanayake, 1994).The agroecological zoning, as defined by IITA and TAC, uses rainfall distribution and potential evapotranspiration temperature issues for constraint free environments (IITA, 1992).

A consensus has been reached on a global edapho-climatic classification for cassava production by an overlay of IITA approach with the Cassava Atlas Classification (Carter *et al.*, 1992) which is now GIS formatted using evapotranspiration estimates to determine wet or dry months. The classes are derived from a set of climate conditions for cassava cultivation covering global cassava production. The dominant cassava ecology is the upland in West Africa. A minor cassava ecology is the inland valley swamp ecology.

4. Crop and systems approach to improved cassava production

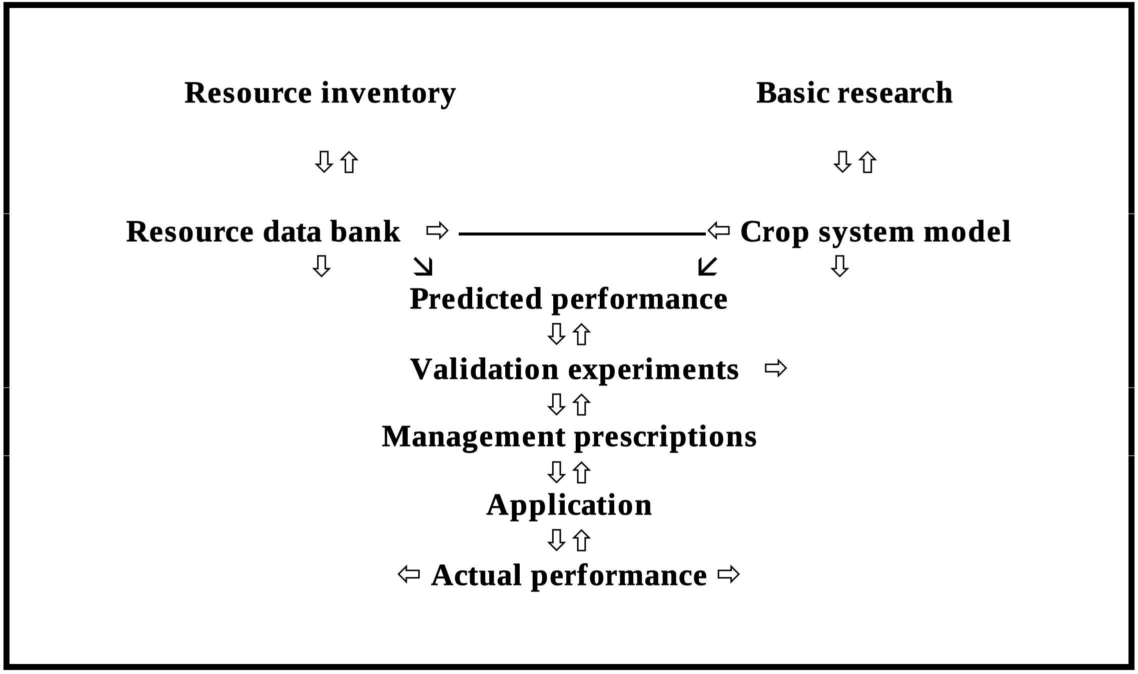
A complement of the reductionist and holistic approaches is needed to evaluate the consequences of the introduction of a new technology. Simulation techniques or modeling and field experiments designed to test model predictions are an answer to define the research strategies on the basis of a quantitative understanding of the role of various climatic factors and growth processes on variations in root yield. Components of a system research strategy are delineated in Figure 1.

Table 4.

Soil properties	**Lowland humid zone**	**Lowland sub-humid zone**	**Lowland non-humid zone**	**Highland humid zone**	**LSD (0.05)**
Clay (%)	19.2	16.7	25.2	22.5	2.1
Silt (%)	14.3	15.7	17.0	25.8	2.2
Sand (%)	66.5	67.6	57.9	51.3	3.1
Total N (%)	0.113	0.087	0.218	0.144	0.035
Organic matter (%)	2.15	1.52	4.20	2.89	0.404
Available P (ppm)	10.09	5.92	12.18	15.30	3.25
Total S (%)	0.042	0.039	0.034	0.044	0.011
C:N ratio	13.0	11.0	11.0	11.0	1.4
PH	5.8	6.0	6.5	6.3	0.17
Ca	4.55	3.57	12.86	7.38	1.22
Mg	0.98	6.28	6.50	1.48	1.22

K	0.27	0.21	0.36	0.53	0.05
Na	0.29	0.31	0.59	0.39	0.04

Figure 1. Components of a system research strategy for cassava



Several dynamic crop simulation models and decision support systems for cassava (Fukai and Hammer, 1987; Gutierrez *et al.*, 1988; Gray, 1997) were developed in the last three decades to predict cassava production and its agro-economic viability under various tropical and subtropical conditions and to improve our understanding and decision-making on use of water, soil, nutrients and other resources for cassava production. These models are aimed at predicting production levels under various growing conditions, while maintaining water resources and addressing nutrient depletion problems. The capabilities for predicting crop growth, pest and disease dynamics, root yield and quality and functionality of these models are highly different.

5. Improved cassava production technologies and their suitability

The fitness of an improved technological intervention to an environment depends on the extent to which it overcomes and provide answers to the limitations of that particular environment. An array of technologies “on the shelf” that can easily be adopted by small and marginal cassava farmers in savannas are discussed below. This list is not exhaustive, it does present some relevant data for each issue. Most of these practices are site-specific although the underlying physiological principles are basic. Therefore, recommendations and agronomic research are sub-regional and location-specific in effect.

5.1 Germplasm improvement and cultivar replacement.

Low input technologies for cassava have been developed, where the major element is newly improved and adapted clones. Several clones which combine good levels of resistance to CGM and other pests, low cyanogenic potential, and drought adaptation have been developed (Dixon *et al.*, 1994). The potential root yield range of some of these clones is 15 to 45 t/ha in the Sudan savanna zone. The actual yield range in farmers fields, however, is much wider (3-30 MT/ha), while the range on research plots is also large. Recent work in northern Nigeria clearly illustrates the potential for improving adaptation to abiotic stress constraints prevalent in semi-arid zones and the potential for using genetic diversity from elsewhere (i.e. north-eastern Brazil) to incorporate multiple resistances (Ekanayake *et al.*, 1994; 1996). There is scope for genetic improvement for specific abiotic stresses such as salt tolerance in cassava for saline areas using molecular techniques.

5.2 Appropriate cutting selection, treatment, and multiplication

Techniques for overcoming physiological and pathological problems in planting material production have been developed (Ekanayake *et al.*, 1996). Clean planting material obtained from mature mother stock plants improves plant establishment, rapid growth, ability to withstand adverse stresses, and has a high yield potential. A method for rapid multiplication and easy distribution of healthy cassava planting materials has been used successfully in countries like Cameroon, Uganda and Malawi.

5.3 Appropriate land preparation and spatial arrangement

Over 90% of the farmers plant cassava along ridges, which are made approximately one-meter apart. Planting systems influence crop growth and productivity (Table 5). In both upland and lowland areas (IVs), inter-row spacing is adjusted based on the desired root size: one meter apart for large roots and 0.5m for slender roots. Inter-row spacing influences the growth pattern and crop architecture and affects light interception.

5.4 Appropriate planting time, planting method, and density

Adjusting planting/harvesting time is one means of optimizing use of restricted water from rainfall or ground water. The effect of the planting date on root yield in two Sudan savanna sites is given in Table 6. Time of planting cassava varies depending on the importance of cassava in the farming system. Where cassava is a dominant crop and is a staple, it is planted at the onset of rains. In cereal crop-based systems, cassava is planted later.

Table 5.

Planting system	**Cumulative leaf no./plant**		**Root yield (t/ha)**	
	TMS 91934 (improved)	***Dakata Uwariya (landrace)***	***TMS 91934 (improved)***	***Dakata Uwariya (landrace)***
Horizontal on furrow	502	502	5.1	5.6
Horizontal on ridge	808	463	7.6	5.7
Inclined on flat	523	408	5.1	5.6
Inclined on ridge	816	614	8.5	6.7
Vertical on flat	549	514	3.7	6.2
Vertical on ridge	588	484	7.3	7.5
Mean	631	498	6.3	6.2
SED	66	29	0.9	0.9

Table 6.

Treatment	**Seasonal rainfall (mm)**	**Seasonal evaporation (mm)**	**Root dry yield (g/m^2)**
Minjibir, Nigeria			
TMS 4(2)1425			1354
Dakata Uwariya			917
SED			103
PD 1: June 21	907	504	1422
PD 2: July 18	986	489	1385
PD 3: Aug. 18	764	521	839
PD 4: Sept. 12	238	543	895
SED			172
Ina, Benin			
TMS 4(2)1425			491
BEN 86052			916
SED			80
PD 1: June 17	546	576	634
PD 2: July 19	524	607	536
PD 3: Aug. 18	238	646	753
PD 4: Sept. 20	63	612	891
SED			143

5.5 Timely plant protection (IPM) and weed control measures

Broad level survey data fitted to GIS spatial analysis show that in cassava growing areas of West and Central Africa the risk of various cassava pests are high (Manyong and Oyewole, 1997). In addition, Manyong and Oyewole (1997) noted that physical factors such as LGP greater than 210 days, poor soil, and elevation greater than 800 m above sea level are associated with the severity of pest and diseases of cassava. Strategy by which these physical factors can be checked or controlled is through varietal improvement.

5.6 Biological control of introduced pests

Biological control of the cassava mealybug through use of a natural enemy, *Epidinocarsis lopezi* parasite, along with improved clones and agronomic practices, provide a cost-effective, sustainable and environmentally-friendly technology for cassava farmers. Wide-spread establishment and documented impact of exotic predatory mite species offer similar hopes on controlling CGM which has had devastating effects in farmers' fields. Table 7 shows the impact of improved technologies on sustaining root yields under natural CGM pressures.

Table 7.

Intervention technology	**3 months of age**	**6 months of age**	**9 months of age**
Chemical control (+ or - *T. aripo*)			
Dimethoate	339	1232	1562
Control	364	1320	1393
Permethrin	342	1003	1212
LSD (0.05)	73	138	245
Host plant resistance (Cultivar)			
92/0427	538	1582	2044
92/0326	479	1509	1720
91/02327	407	1494	1487
30572	330	1101	1185
TME2	212	935	1150
30001	123	488	745
LSD (0.05)	103	73	346

5.7 Use of mulching, irrigation and other water management practices

The effect of mulching to conserve moisture is a well-established technology although in practice, mulching is rarely practiced in drought environments since most of the crop residues are collected for other useful purposes, such as animal feed.

5.8 Use of organic manure or nutrient management

Although many farmers do not use mineral fertilizer for cassava, which is often grown at the end of the fallow cycle, incorporation of crop residues and manure are reported to be used at the farm level to increase soil organic matter content. Use of farmyard manure has been shown to increase the establishment and survival of cassava stakes in the Sudan savanna zone.

5.9 Appropriate cassava-based cropping systems and statistical tools

Cassava is widely intercropped with seasonal annuals and in multi-storey cropping systems of alley cropping and with fruit (bananas) or perennial trees (palm, coconut). These systems maximize solar radiation, moisture, and nutrient use efficiency, and reduce pest problems. The average yield advantage of TMS30572 (improved clone) was 4-5 t/ha or 35% of a local cultivar on farm with a residual fertilizer effect on cassava yield of 1-2 t/ha (Mutsaers *et al.*, 1995).

The use of fast and high capacity computers and more sophisticated statistical tools in data analysis has improved the efficiency of evaluating cropping systems data.

5.10 Other appropriate agronomic practices (crop rotation)

Farmers often obtain high root yields when improved clones are combined with better cultural practices. Crop rotation is advocated for maintaining soil fertility and to reduce soil-borne pests and diseases, nematodes in particular.

5.11 Postharvest technologies

Postharvest technologies are necessitated by the high perishability of cassava roots as shelf life of roots rarely exceeds two days. High cyanogenic potential also calls for the processing of roots. Women are responsible for 95% of cassava processing, and they are therefore an important target group. Storage and packaging technologies to extend root shelf life exist. Several types of processing equipment have been designed for use at farm and village levels in order to reduce postharvest losses, increase labor productivity, and improve product quality.

6. Realities of the challenge

The above discussion shows that the status of knowledge on cassava environmental limits and methods to overcome problems are considerable. An information base exists on a) yield-increasing technologies, i.e., shift to higher yielding improved varieties, use of yield-increasing inputs (fertilizer, manure, and bio-pesticides), introduction of additional crops in space and time (intercrops, relay and rotational crops); b) improved crop management practices not related to labor, i.e., cropping calendars and irrigation; and c) postharvest technologies.

The factors that are more likely to influence the sustainability of cassava productivity are supportive national agricultural policies, stability of adapted and high yielding cultivars, integrated pest and disease management, and development of product utilization. Shifts in favorable policy to encourage savanna farmers to adopt recommendations on improved technologies are helpful.

7. Conclusions

Cassava environments are diverse, ranging from humid to semi-arid zones. None of the sub-humid environments are inherently ideal for the crop. Considerable improved technologies are now available which can be properly targeted to achieve economic production levels. For example, early-bulking drought tolerant clones fit the 6-month cropping season after rice in inland valley culture. Drought-tolerant, 12-month bulking clones best fit the Sudan savanna upland ecology. A combinations of improved cassava clones and appropriate cultural practices increased the potential of cassava production in drought prone environments in West Africa.

Agroclimatic classifications suggest that the percentage of area considered as unsuitable to cassava can be decreased, by both genetic and cultural intervention. For example, the amount of water extracted by the root system of cassava can be increased by genetic means. Deep ploughing or increasing fertility, for example, are soil management practices which could be long-term goals. Biological constraints can be alleviated by similar means. Increased knowledge of physical and biological environments is useful for generating intervention technologies specifically targeted for distinct environments and systems modeling is potentially a high value tool.

References

Asadu, C.A., Nweke, F.I., & Ekanayake, I.J. 1997. The fertility status of soils grown to cassava in sub-Saharan Africa. *Soil Sci. Plant Analyses* (Draft). 20p.

Bieler, P., Ekanayake, I.J. & Dossou, R. 1997. Production of quality planting materials of cassava (*Manihot esculenta* Crantz) for the dry savanna. 1. Effect of planting date on crop growth. Field Crops J. draft.

Carter, S.E., Fresco, L.O., Jones, P.G., & Fairbain, J.N. 1992. *An atlas of cassava in Africa. Historical, agroecological, and demographic aspects of crop distribution.* Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. 86p, illus., maps.

Dixon, A.G.O. , Asiedu, R., Ekanayake, I.J. & Porto, M.C.M. 1994. Cassava improvement in Africa: contribution of the International Institute of Tropical Agriculture. In. Adipala, E., Bekunda, M.A., Tenywa, J.S., Ogenga-Latigo, M.W., & Mugah, J.O. (eds.). African Crop Science Conference Proc. Vol. 1. Pp. 466-469.

Ekanayake, I.J. 1994. Agroclimatological aspects that are important to classify cassava environments for better adaptation and maximized production. A paper presented at Genotype Environment interaction workshop, IITA, Ibadan, Nigeria. 16p.

Ekanayake, I.J., Asiedu, R. & Bieler, P. 1997. Production and delivery systems of good quality cassava planting materials in sub-Saharan Africa. In. Tropical tuber crops: Food security and Nutrition. Eds. Kurup, G.T., Palaniswamy, M.S., Potty, V.R., Padmaja, G., Kabeerathamma, S., & Pillai, S.V. Oxford & IBH Pub. Co., New Delhi, India (in press).

Ekanayake, I.J., Porto, M.C.M., & Dixon, A.G.O. 1994. Response of cassava to dry weather: potential and genetic variability. In. Adipala, E., Bekunda, M.A., Tenywa, J.S., Ogenga-Latigo, M.W., & Mugah, J.O. (eds.). *African Crop Science Conference Proc.* Vol. 1. Pp. 115-119.

Ekanayake, I.J., Dixon, A.G.O. &. Porto, M.C.M. 1996. Performance of various cassava clones in the dry savanna region of Nigeria. In. *Tropical tuber crops. problems, prospects, and future strategies.* Kurup, G.T., Palaniswamy, M.S., Potty, V.P., Padmaja, G., Kabeerathumma, M.S., & Pillai, S.V. (Eds.). Oxford and IBH press, New Delhi, India. pp. 207-215.

Ekanayake, I.J., Yaninek, J.S., & A.G.O. Dixon. 1997. Crop growth analysis of cassava affected by cassava green mite (*Mononychellus tanajoa* (Acari: Tetranychidae): 2. dry matter partitioning and root yield. *Crop science* (draft).

Fukai, S. & Hammer, G.L. 1987. A simulation model of the growth of the cassava crop and its use to estimate cassava productivity in Northern Australia. *Agric. Systems* 23:237-257.

Gray, V.M. 1997. A dynamic crop simulation model for assessing the yield potential of cassava under arid conditions in South Africa. In. Proc. Second all Africa Crop Science Congress, Pretoria, South Africa. in press.

Gutierrez, A.P., Wermelinger, B., Schulthess, F., Baumgaertner, J.U., Herren, H.R., Ellis, C.K., & Yaninek, J.S. 1988. Analysis of biological control of cassava pests in Africa. 1. Simulation of carbon, nitrogen, and water dynamics in cassava. *J. Appl. Ecol*. 25: 901-920.

IITA 1992. *Agroecological zones in Africa*. A map. Agroecological studies unit, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

IITA. 1996. Cassava in Africa: Review of constraints and opportunities. Paper presented as “IFAD global strategy for cassava development”. IITA, Nigeria & IFAD, Rome. 12p.

Manyong, V.M. & Oyewole, B. 1997. Spatial patterns of biological constraints to cassava and yam production in West and Central Africa: implications for technology development and transfer. African Journal of Root and Tuber Crops 2(1): 15-21.

Manyong, V.M., Smith, J., Weber, G.K., Jagtap, S.S., & Oyewole, B. 1996a. Macrocharacterization of agricultural systems in West Africa: an overview. Resource and Crop Management Research Monograph No. 22, IITA, Ibadan, Nigeria. 33p.

Manyong, V.M., Smith, J., Weber, G.K., Jagtap, S.S., & Oyewole, B. 1996b. Macrocharacterization of agricultural systems in Central Africa: an overview. Resource and Crop Management Research Monograph No. 22, IITA, Ibadan, Nigeria. 25p.

Mutsaers, H.J.W., Adekunle, A.A., Walker, P., & Paleda, M.C. 1995. The maize and cassava production system in southwest Nigeria and the effect of improved technology. On-farm trials in Alabata and Ayepe, 1985-1989. *RCMP Monograph No. 18.* IITA, Ibadan, Nigeria. 50p.

Evolution climatique au Tchad, ses conséquences sur les productions agricoles et les stratégies adaptées

Bekayo N. Derla

1. Situation géographique et climats

Situé entre les tropiques du Cancer au nord et celui du Capricorne au sud, le Tchad, pays continental, est caractérisé par un climat tropical. Trois zones agroclimatiques se distinguent du nord au sud :

- zone saharienne (0-200 mm de pluie) au-delà du 16ème parallèle ;
- zone sahélienne (200-600 mm de pluie) entre les 12ème et 16ème parallèle ;
- zone soudanienne (600-1.200mm) en dessous du 12ème parallèle.

Le régime pluviométrique est monomodal, avec une saison sèche allant de septembre à mai dans la zone sahélienne et d'octobre à avril dans la zone soudanienne.

2. Fluctuations de la pluviométrie

Pour se rendre compte de l'évolution du climat, des analyses pluviométriques ont été faites sur les données couvrant l'ensemble du territoire. Ces analyses ont été faites sur la base de trois normales ci-après :

- normale 1960 : données mensuelles de 1931 à 1960 (30 années) ;
- normale 1975 : données mensuelles de 1946 à 1975 (30 années) ;
- normale 1990 : données mensuelles de 1961 à 1990 (30 années).

L'analyse de ces trois normales montre une régression des isohyètes du nord vers le sud pendant la période 1960 à 1990 (voir cartes des isohyètes).

Dans la zone saharienne, l'isohyète de 200 mm qui s'arrêtait proche du 18ème parallèle en 1960, franchit cette zone en descendant et se situe entre les 17ème et 16ème parallèles en 1990 (voir normales 1960 et 1990). Cette régression des isohyètes s'observe également dans la zone soudanienne mais les fluctuations sont de moindre ampleur dans celle-ci. La tendance à la sécheresse du nord au sud du Tchad est donc une évidence.

Cette conclusion valable pour l'ensemble des pays sahéliens a été confirmée en septembre 1984 par le Colloque organisé à Dakar à l'initiative du

CIRAD-GERDAT et de l'ISRA et qui réunissait des chercheur de dix (10) pays africains dont le Tchad et ceux des pays américains et européens. Les participants à ce Colloque ont insisté sur la gravité de la sécheresse observée depuis 1968, avec une persistance plus longue que pour les périodes sèches connues entre 1909-1919.

Cependant, l'examen des séries chronologiques sur une période suffisamment longue (90 ans), donc 3 fois plus longue que la période conventionnelle d'observation (30 ans), ne permet pas de conclure à une tendance à l'assèchement du climat à l'échelle historique, car ces observations dont la 1/2 période apparente est d'environ 15 ans ne seraient que des «oscillations» d'années successives sèches et humides qu'il ne fallait pas confondre à la «tendance» sur une période de l'ordre du siècle.

De même l'analyse de rendements des céréales (sorgho et mil) sur une période de 1983 à 1996 (voir tableaux des rendements) n'a pas non plus confirmé une tendance à la baisse avec le temps. Mais cela peut être expliqué par l'utilisation des techniques culturales améliorées.

3. Travaux réalisés et technologies adoptées

Au niveau du Tchad et en particulier dans la zone cotonnière (zone soudanienne), des travaux ont été réalisés en vue de déterminer les zones à risque de sécheresse et de proposer des techniques culturales appropriés. Ces travaux réalisés dans le cadre du Réseau de la Recherche sur la Résistance à la Sécheresse (R3S) en zone intertropicale de la CORAF a concerné :

- le zonage des risques de sécheresse et leurs conséquences sur les systèmes de cultures ;
- les techniques de gestion du sol et l'alimentation hydrique des cultures.

Pour le zonage des risques de sécheresse, les données pluviométriques ainsi que les données ETP pour l'ensemble du Tchad couvrant la période de 1950 à 1987 ont été analysées. L'analyse fréquentielle de la pluviométrie annuelle de la zone cotonnière a permis de distinguer 5 régions :

1. région où la pluviométrie annuelle n'a pas ou peu évolué ;
2. région où la pluviométrie moyenne n'a pas ou peu changé mais où le risque d'années déficitaires s'est accru ;
3. région montrant une baisse relative de la pluviométrie moyenne conjointement avec une baisse plus importante de pluviométrie dans le temps (8 années sur 10);
4. région où la baisse de la pluviométrie est régulière mais relativement faible ;
5. région où la baisse de la pluviométrie est régulière et nettement plus accentuée.

Pour les travaux sur les techniques de gestion du sol et l'alimentation hydrique des cultures annuelles, il a été confirmé que les productions du sorgho et du coton sont bien liées aux conditions climatiques et que l'alimentation hydrique pendant le cycle cultural est déterminante.

Les travaux antérieurs réalisées sur des parcelles cultivées en coton ont permis d'identifier les techniques culturales qui favorisent l'alimentation hydrique de la plante en améliorant la longueur du pivot et en augmentant le nombre de racines secondaires. Il s'agit (voir graphique des divers traitements) surtout :

- du labour associé à une fertilisation organique et minérale suffisamment à temps ;
- du labour associé à une fertilisation minérale.

4. Conclusion

La sécheresse, déficience pluviométrique qui s'identifie par référence à une norme climatologique reposant, par convention, sur trois décennies d'observations est belle et bien constatée au Tchad. Elle est plus accentuée dans la zone sahélienne que dans la zone soudanienne. Pour limiter ses effets néfastes sur les productions vivrières (céréales pluviales en particulier), on a vulgarisé les techniques culturales visant à améliorer l'alimentation hydrique des plantes. Ce sont entre autres, le respect des dates de semis, les labours associés à la fertilisation minérale et organique suffisamment à temps pour que l'offre des éléments minéraux issus des engrais ou de la minéralisation de la fumure organique corresponde aux besoins nutritionnels de la plante.

L'utilisation des variétés tolérantes à la sécheresse, en particulier le riz pluvial, le mil, le sorgho et l'arachide est également une tentative avec plus ou moins de succès face au spectre de la sécheresse persistante au Tchad.

References

B. Djoulet, 1996 : Actes des Onzièmes Journées du CILSS, N'Djaména, 9-12 septembre 1996.

La sécheresse en zone intertropicale pour une lutte intégrée : Actes du Colloque «Résistance à la sécheresse en milieu tropical», Dakar, 24-27 septembre 1984.

Statistiques agricoles : sources ONDR, Direction de la Statistique Agricole 1983-1996.

Analyse des données climatologiques, source : DREM.

The United Nations University
Institute for Natural Resources in Africa (UNU/INRA)

Prof. A. Uzo Mokwunye
UNU/INRA

Africa is a continent richly endowed with diverse natural resources. The impact of the highest population growth rate (both humans and livestock) among the world's regions and of pressures from various sectoral development activities has been the rapid decline in the intrinsic properties of Africa's natural resources -- Africa's land, soils, waters, minerals and forest resources. Degradation of the natural resources base has resulted in increased poverty, reduced agricultural production and increased food insecurity. To stem this tide, exploratory studies were commissioned in 1981, followed latter by in-depth feasibility studies on establishing an institute to promote a more efficient management of natural resources in Africa. These studies and extensive consultations paved the way for the establishment of the United Nations University’s Institute for Natural Resources in Africa (UNU/INRA) in 1986.

The feasibility studies and consultations highlighted the necessity for holistic approaches to natural and environmental resources management as the basis for sustainable development in Africa. High priority was given to human resource development and institution building in natural resources conservation and management. The Institute's mandate thus foreshadowed the strategies and action programmes of the United Nations’ Conference on Environment (UNCED) and the key provisions of Agenda 21.

Mission of UNU/INRA

Reversing the degradation of Africa's natural resources base is the responsibility of Africans themselves. To accomplish this task calls for well-trained, well-equipped and motivated personnel capable of developing, adapting and disseminating technologies that promote the sustainable use of Africa's natural resources. **Building the needed indigenous capacity and strengthening national institutions constitute the mission of UNU/INRA.** The Institute's activities in research, training, and knowledge/information dissemination are targeted to ensure that African scientists, technologists, and institutions acquire the capabilities to generate, adapt and apply knowledge and technology to eradicate rural poverty, improve food security and promote more effective and efficient utilization of natural resources for self-reliant development.

For the short- to medium-term, the thrust of UNU/INRA's activities is on improving **food security** in Africa. The Institute's activities must be designed to meet the following criteria:

Relevance: Activities must reflect the priorities of African peoples and governments.

Empowerment: Rural people must become active "partners in development."

A golden rule is that we must adopt a holistic approach in tackling the complex problems faced by rural communities.

During the development phase of the Institute, several activities such as Institution Capacity Assessment and Field Surveys on Africa's soils and water resources as well as indigenous food crops and useful plans were conducted. Consultative meetings were held on such issues as Gender and Conservation and Management of Natural Resources in Africa, and the development of Genetic Resources agenda. Lessons from these activities have been useful in identifying three primary research, training and information dissemination programme areas:

Soil Fertility Restoration and Maintenance
Genetic Resources
Mineral Resources

Activities related to Gender and Natural Resources Management as well as Education and Training are cross-cutting.

A Modelling Approach Towards Crop Yield Assessment: A Case Study for Malawi Early Warning System for Food Security

G. K. Munthali
Meteorological Department, P.O. Box 2, Chileka, Malawi

Abstract

The activities of the Early Warning Unit for Food Security are mainly based on an information system at national and sub-national levels providing agroeconomic, agrostatistic and agrometeorological products. The information is used for the formulation and implementation of national and regional food policies and action programs. The agrometeorological component provides, among others, early crop yield assessment at a sub-national level normally referred to as the Agricultural Development Division (ADD).

This paper aims to review agrometeorological crop monitoring and forecasting techniques for estimating maize yield and production for local and hybrid varieties in Malawi. The approach is based on the Crop Specific Soil Water Balance Model from which models have been developed for eight ADDs. The assessment exercise will specifically cover the 1995/96 season. An attempt will also be made to compare the significance of the results generated by the model to those estimated by the Agricultural Development Divisions. A brief description of the methodology together with examples of the forecast prepared for the season will be provided, including an outline of the constraints associated with use of the model.

1. Introduction

1.1 Malawi: Geographical and Climatic Description

Malawi is a country lying between latitudes 9° and 17° South of the equator. Lake Malawi, which is part of the Great African Rift Valley, covers two-thirds the length of the country. The altitudes of different places of the country vary from near sea level to over 1,500 metres in plateau areas and up to 2,500 metres in mountainous areas.

There are two main seasons, namely the rainy season from November to April and the dry season from May to October. The climate is generally classified as tropical with hot, wet summers and cool, dry winters. The climate of Malawi depends on the Southern Hemisphere Sub-Tropical High Pressure belt which lies on the southern side of the country, approximately between 25° and 35° South throughout the year as well as on its topography (Torrence, 1972).

During the rainy season, a broad belt of maximum convective activity which marks the meeting point of northeasterly trade winds of the Northern Hemisphere and the southeasterly trade winds of the southern hemisphere, known as the Inter-Tropical Convergence Zone (ITCZ), invades the country from the north on its southward movement to its southern limit and on its way back to the north. This system is the main rain-bearing system and it migrates with the sun. The other system is the Zaire Air Boundary (ZAB), which marks the boundary between the Indian Ocean’s southeast tradewinds and the recurved South Atlantic air that reaches Malawi via Zaire. This system also brings widespread rains with it over the country which becomes heavy when it is associated with the ITCZ .

Occasionally the country is affected by tropical cyclones that originate in the Indian Ocean. Depending on its position over the southeast coast, a cyclone results in either a wet or dry spell in Malawi (Torrence, 1972).

Weather during the winter season is mostly influenced by the rapidly moving high-pressure cells further south of the country. A strong high-pressure cell over the South African coast draws cool moist southerly airflow into Malawi, resulting in rain and drizzle over the highlands and east facing escarpments along the lake-shore. Such weather conditions normally last for two to three days, after which clear weather sets in again to last several days.

With well-defined wet and dry seasons, Malawi enjoys abundant sunshine throughout the season. This is at a maximum in the rain shadow areas of the Shire Valley, southern lakeshore and over the western plateau areas. During the rainy season, the duration of sunshine in most areas is normally less than half the possible number of sunshine hours, and during some months of the dry season, certain areas in the southeastern part of the country are similarly affected. The sunshine hours are affected by the cloudiness over the particular station.

1.2 Maize Growing Areas

Maize is the staple food in Malawi and is grown in all the agroecological zones of the country as a rainfed crop. Administratively, the zones are normally referred to as Agricultural Development Divisions (ADD). Like in most rainfed agriculture, the level of maize production in Malawi depends largely on rainfall amount and distribution.

From a study by Nayava and Munthali (1992), the cycle length for local and composite maize varieties was taken as 120 days for areas that lie between elevation 0 and 800 metres above mean sea level. For areas higher than 800 metres above mean sea level, the cycle length was taken as 140 days. Similarly, the crop cycle length for hybrid maize variety was taken as 100 days for areas that lie between 0 and 800 metres above mean sea level and 120 days for those areas higher than 800 metres.

1.3 Food Security Monitoring

Malawi operates a National Early Warning System (NEWS) for food security, which is part of the Southern African Development Community (SADC), Regional Early Warning System (REWS) for food security whose activities are coordinated through a regional office in Harare, Zimbabwe.

The main objectives of NEWS are:

- to improve food security through the provision of advance information on the food and nutrition situation at national and sub-national levels for the formulation and implementation of national and regional policies and action programmes, and

- to consolidate and strengthen the existing Early Warning System to provide regular information on the food and nutrition situation in the country to policy/decision-makers. This system enables timely action to be taken to deal with food shortages or surpluses and problems associated with accessibility to food. It is also an integral part of the SADC early warning system.

Crop monitoring and yield forecasting is a major and essential activity of an early warning system for food security. In Malawi, just like in other SADC member states, such activity is done using agrometeorological methods. The information generated becomes an input into the overall food situation assessment in the country.

Nayava and Munthali (1992) developed simple linear regression models for local, composite and hybrid maize for each ADD. This is done by considering maximum yield (Model I) at ADD and national levels and weighted area (Model II) at the national level only for the period 1983/84 to 1991/92.

The independent variable in the models is the Water Satisfaction Index (WSI) computed through a crop specific soil water balance model proposed by Free and Popov (1986). The original water balance model or its variants are being used by many countries for crop assessments where rainfall amount and its distribution is assumed as the major constraint in crop production.

Generally, the yield models have provided satisfactory operational results. Their co-efficient of determination ranged from low to moderate, suggesting the possible existence of a nonlinear relationship between WSI and yield and/or the WSI may not be the only or most important yield-explaining variable, etc. as evident in a similar study by Lukando (1996). The forecasts for both local and hybrid maize produced at the end of February and March for ADDs in the southern and central parts of the country and those in the north, respectively are presented in Tables 1 and 2.

2. Objectives of Study

This paper makes an attempt to:

- present results of the yield forecast for the 1995/96 season;
- compare the yields based on the models and those estimated by ADDs; and
- suggest appropriate future research activities for further model improvements.

1. Methodology

In this study, crop forecasting models are developed using maize yield and an index of crop water satisfaction, respectively as the predicted and predictor variables. The data sources and procedures used to obtain these variables are described below.

3.1 Data Sources

3.1.1 Maize Yield

Maize yield data for the local and hybrid varieties were obtained from 1995/96 cropping season. This data is normally compiled by the planning division of Ministry of Agriculture and Livestock Development.

3.1.2 Crop and Soils Data

Information on maize and soil characteristics required for the water balance computation was supplied by the Department of Agricultural Research at the Ministry of Agriculture and Livestock Development.

3.1.3 Climatological Data

Climatological data was obtained from the Malawi Meteorological Services and dekadal rainfall covered 75 stations. The criteria for selection of the stations was based on long-term record availability, quality of data, minimum missing data, and the way it represents the ADDs.

3.2 Procedures

3.2.1 Water Requirement Satisfaction Index (WRSI)

The Water Requirement Satisfaction Index (WRSI) is an expression of the extent to which the water requirements of a crop have been satisfied in a cumulative way at any stage of the crop growing season. It is the ratio between actual and potential evapotranspiration of the crop.

The FAO Crop-specific Soil Water Balance Model proposed by Frere and Popov (1986), was adapted to the Malawi situation (Nayava and Munthali, 1992) and used to generate dekadal (10 day) WRSI for each of the 75 stations from planting to crop maturity. The computations were facilitated by the computer program called FAOINDEX developed by Gommes (1992).

Individual station indices were averaged by ADD to obtain simple ADD averages of WRSI.

3.2.2 Use of Planting Dates

Defining an element to mark the start of the rains is not easy, due to the intermittent and patchy nature of tropical rainfalls. The general deficit with three components, as used by Stern *et al.* (1981) with some modification by Munthali (1995), is as follows:

- the event, *D*, marking the start of the season is not considered at any station until the 1st day of November;
- an event, *E*, then indicates a potential starting date, defined as the first occurrence of at least 40 mm of rainfall cumulated over 10 days (1 dekad); and
- the potential start could be a false start if an event, *F*, occurs during the same month of November. F is defined as a dry spell of 10 days or more.

Mpata (1973), in liaison with the Ministry of Agriculture, designated a planting rain date as follows:

- a planting rain is a storm or close succession of rainstorms amounting to not less than 13 mm;
- this rainfall must not be followed by a drought period which is defined as any period of 10 days without rain early in the season (after 127 mm cumulative rain has fallen, this period may be extended to 14 days);
- a rainstorm is assumed to mark the young plant for as many days as there are tenths of 25 mm of rain recorded; and
- a dry day is therefore one with less than 3 mm of rain.

An average planting decade for a season and the area represented each rainfall station was established between October and December based on a combination of the methods described.

3.2.3 Maize Yield and WRSI Time Series and Scatter Plots

Time series and scatter plots of the yield from the Ministry of Agriculture and Livestock Development, and crop maturity stage WRSI were made for each ADD for the period 1986/87 to 1996/97 in order to:

- identify a meaningful relationship between the two variables;
- identify possible anomalies associated with the data; and
- have an indication of the probable functional relationship between the two variables.

Specifically, an analysis for the 1992/93 season by Munthali (1994) of plotting percentage of maximum yield for local maize against the Water Satisfaction Index indicated some linear relationship between the two variables. The same was true for a hybrid maize variety showing more variation in scatter diagram compared to local maize. This was attributed to greater sensitivity of hybrid maize to environmental conditions.

3.2.4 Assessment of Crop Yield for 1995/96 Season

Tables 3 and 4 give projected values of yield based on average WRSI at ADD level for both local and hybrid varieties. The figures of production are based on the area of the field as reported during the second round crop estimates meeting. A comparison of forecast yield against the final figures during third round crop estimates forum shows that the model overestimates yield for local maize (Table 5) for Blantyre, Machinga, Lilongwe, Kasungu Karonga ADDs . Conversely, the model underestimates the final hybrid maize yield in most ADDs.

The hybrid yield from final round estimates is over 2000 kgha-1. This figure represents that for all ADDs and takes into account the significant variations in the ADDs in terms of soil characteristics, weather patterns and management skills. The high yields for local maize achieved by Shire Valley ADD do need to be investigated further.

3.3 Proposed Models for Crop Yield Forecasting

The regression models were developed with the following common guiding principles in mind, also as reported by Sakamoto (1990):

- the sample size must be significantly larger than the number of independent variables;

- the independent variables should have reasonable agronomic relationship with the dependent variable. Additional variables should not be included with the objective to increase the coefficient of determination (r2); and
- the developed models should only be applied for the range of data used and for the location where the models were developed.

4. Discussion

The results generally show that the models are a useful tool with regard to crop yield assessment. A comparison exercise to validate the model, however is required as an on - going strategy to build up a quality-controlled historical yield database. There also needs to be an extended development of models to other cereal crops widely grown in Malawi such as rice and sorghum. In the long run, the actual time series yield database would be more useful compared to use of percentage of maximum yield. It also appears that the models are not sensitive enough to conditions where the crop is experiencing excess rainfall. A practical approach would be to reduce the amount of rainfall by an appropriate percentage attributed to losses due to run off.

There is also a need to explore the use of other independent variables, such as the Normalized Difference Vegetation Index (NDVI) and evapotranspiration, as a contribution to the validation exercise.

5. Acknowledgements

The author wishes to register a vote of appreciation to Messrs Nkhokwe, Munkhondia, Tamanga, Chavula and Nyirenda for their various contributions in producing this paper.1

References:

Frere, M. and G. F. Popov (1986) Early Agrometeorological Crop Yield Forecasting. FAO Production and Protection Paper No 73, FAO, Rome, 150 pp.

Gommes, R. (1992). FAOINDEX : FAO. Crop Specific Soil Water Balance Version 2.1 Remote Sensing Centre AGRT/FAO, Rome.

Lukando, M.F. (1996). Operational agrometeological maize yield forecasting for food security in Swaziland.

Mpata, S.B. (1973). Dates of planting rains, variability and probabilities in Malawi

Munthali, G.K. (1994). A modeling approach to crop yield assessment paper presented during the Land and Water Management Programme, Annual Science Conference, Windhoek, Namibia

Munthali, G.K. (1995). Development of Crop weather Models for determination of site specific effective planting rainfall decade for the production of maize, groundnuts and sorghum.

Nayava, J.L. and G. K. Munthali (1992). The Crop Specific Soil Water Balance for estimating crop yield in

Malawi.

Torrance, J.D. (1972). Climates of Malawi, Zambia and Zimbabwe. World Survey of Climatology, Elsevier Publishing Company, New York, pp. 409 - 460.

Sakamoto, C. (1990). The Water Satisfaction Index for estimating Crop Yield and harvested planted area ratio in Botswana. Department of Meteorological Services, Gaborane, Botswana.

Stern R.D., M.D. Dennett and I.C. Dale (1981). Analysing daily rainfall measurements to give agronomically useful results. I. Direct Methods.

Table 1: CROP YIELD ASSESSMENT BASED ON WATER REQUIREMENT SATISFACTION INDEX (WRSI)

CROP: Local Maize **FARMING SECTOR: Small Holder**

MODEL: Y= a+b* WRSI Where a = constant, b = x coefficient,
r^2 = coefficient of correlation

ADD	**a**	**b**	**r^2**	**STD Error Y (est.)**
NGABU	-65.01	1.679	0.80	14.289
BLANTYRE	-68.00	1.663	0.74	13.821
LIWONDE	-86.13	1.978	0.71	15.190
SALIMA	-128.30	2.444	0.72	13.652
LILONGWE	-114.10	2.275	0.79	10.452
KASUNGU	-80.40	1.909	0.66	11.68
MZUZU	-85.82	1.980	0.63	10.945
KARONGA	-140.85	2.583	0.71	13.004
NATIONAL	**-86.17**	**1.954**	**0.71**	**12.980**

Table 2: CROP YIELD ASSESSMENT BASED ON WATER REQUIREMENT SATISFACTION INDEX (WRSI)

CROP: Hybrid Maize **FARMING SECTOR: Small Holder**

MODEL: Y= a+b* WRSI Where a = constant, b = x coefficient,
r^2 = coefficient of correlation

ADD	**a**	**b**	**r^2**	**STD Error Y (est.)**
NGABU	**-57.68**	**1.645**	**0.80**	**21.652**
BLANTYRE	**-75.94**	**1.803**	**0.84**	**12.578**
LIWONDE	**-78.96**	**1.846**	**0.70**	**18.501**
SALIMA	**-172.70**	**2.776**	**0.82**	**11.675**
LILONGWE	**-107.00**	**2.065**	**0.87**	**7.960**
KASUNGU	**-48.17**	**1.47**	**0.50**	**14.710**

MZUZU	**125.20**	**2.304**	**0.82**	**7.196**
KARONGA	**-192.20**	**2.939**	**0.45**	**18.786**
NATIONAL	**-76.26**	**1.763**	**0.70**	**14.768**

TABLE 3: MALAWI EARLY WARING UNIT FOR FOOD SECURITY

CROP YIELD ASSESSMENT BASED ON THE WATER SATISFACTION INDEX (WRSI)

CROP: Local Maize **FARMING SECTOR: Small Holder**

YIELD: kg/ha WRSI: % AREA: hectares PRODUCTION: tonnes

90% CONFIDENCE INTERVAL: Y(est) +/- 1 (0,10)*Std.Err. of Y (est)

AREA BASED ON 2ND ROUND CROP ESTIMATES (FEBRUARY)

ADD	95/96 WRSI	95/96 YIELD	YIELD LOW	YIELD HIGH	95/96 AREA	95/96 PROD.	PROD. LOW	PROD. HIGH
SHIRE	90	779	551	1006	68855	53627	37955	69300
BLADD	90	874	620	1129	122250	106851	75738	137964
MADD	90	838	600	1076	193534	162170	116027	208314
SLADD	90	880	650	1100	71991	63213	46879	79547
LADD	91	1298	1050	1545	233257	302734	245028	360441
KADD	88	1254	970	1539	112139	140654	108749	172559
MZUZU	88	897	708	1086	61215	54897	43331	66463
KRADD	91	1146	856	1436	15407	17654	13190	22118
NATIONAL	**90**	**996**	**751**	**1240**	**878648**	**901801**	**686898**	**1116705**

TABLE 4: MALAWI EARLY WARING UNIT FOR FOOD SECURITY

CROP YIELD ASSESSMENT BASED ON THE WATER SATISFACTION INDEX (WRSI)

CROP: Hybrid Maize **FARMING SECTOR: Small Holder**

YIELD: kg/ha WRSI: % AREA: hectares PRODUCTION: tonnes

90% CONFIDENCE INTERVAL: Y(est) +/- 1 (0,10)*Std.Err. of Y (est)

AREA BASED ON 2ND ROUND CROP ESTIMATES (FEBRUARY)

ADD	**95/96 WRSI**	**95/96 YIELD**	**YIELD LOW**	**YIELD HIGH**	**95/96 AREA**	**95/96 PROD.**	**PROD. LOW**	**PROD. HIGH**
SHIRE	1405	2076	1410	2742	4201	8721	5923	11519
BLADD	2787	1753	1307	2200	89113	156246	116447	196045
MADD	3019	3133	1968	4298	59060	185024	116201	253848
SLADD	2355	3248	2369	4126	22588	73359	53611	93207
LADD	2355	2176	1801	2552	83947	182697	151191	214202
KADD	2242	2558	1772	3344	76311	195228	135236	255220
MZADD	2915	3157	2670	3644	21424	67641	57208	78074
KRADD	2561	1020	900	1951	10724	10942	9620	20923
NATIONAL	**2391**	**2395**	**1175**	**3107**	**367368**	**879858**	**646338**	**1123037**

TABLE 5: A COMPARISON OF YIELD FORECASTS AGAINST FINAL ESTIMATES FOR 1995/96 CROPPING SEASON

ADD	LOCAL MAIZE YIELD		HYBRID MAIZE YIELD	
	FORECAST KgHa^{-1}	FINAL KgHa^{-1}	FORECAST KgHa^{-1}	FINAL KgHa^{-1}
SHIRE VALLEY	779	1141	2078	2096
BLANTYRE	874	835	1753	2253
MACHINGA	838	794	3133	2659
SALIMA	880	1466	3248	2862
LILONGWE	1298	1030	2176	2348
KASUNGU	1254	1214	2558	2567
MZUZU	897	948	3157	2335
KARONGA	1146	849	1020	2446
NATIONAL	995.75	1035	2390	2446

Potential Increases in Agricultural Productivity through Irrigation Development in Sub-Saharan West Africa

J. Oladipo Adejuwon
University du Benin, Togo

Abstract

Using climatological data, reliable values of actual and potential primary biological productivity are computed for stations across the climatic profile from the coast to the Sahel. The values of potential productivity vary from about 110% of actual productivity in the coastal areas to over 450% in the most northerly parts. These indicate how much gain in agricultural productivity could be achieved through full irrigation in the various parts of West Africa. However, locally available water is rather limited to make full irrigation possible in the far north. Thus the areas of greatest potential for irrigation agriculture are in the Middle Belt.

1. Introduction

Our main concern in this paper is with small-scale irrigation schemes based on local water supply. Such small-scale projects, lacking the financial resources to conduct appropriate feasibility studies, can benefit immensely from the type of general information that this paper will make available. The paper is designed basically to assess how much, by way of increased primary biological productivity, and by implication, increased agricultural productivity (Okamoto et al., 1991) can be achieved through irrigation development within specific ecological locations across the West Africa landscape. This, it is hoped, can be adopted at individual farm levels, as one of the parameters for determining profitability.

The specific objectives of the paper are therefore to:

(a) document the magnitude and the areal pattern of rain - fed primary biological productivity (that is actual primary biological productivity) in West Africa.

(b) provide comparable values for irrigation-supplemented primary productivity (potential primary productivity).

(c) give comparable values for primary productivity that can be achieved with supplemented irrigation based on local conservation of water.

(d) indicate what proportion of the land can be fully irrigated to achieve the potential levels of primary productivity using only water saved locally from the previous rainy season surplus.

2. The Concept of Primary Productivity

Organic substances are introduced into the environmental system through basic biological production. The latter results directly from the photosynthetic, and in some cases, chemosynthetic activities of producer organisms, that is green plants. Part of the substances synthesized in this way is utilized by the producer organisms themselves in procuring energy for self sustenance and the balance, which is stored up in plant tissues is what is apparent as plant biomass. It is this balance or biomass that is made available to other living members of the ecological system as food and is usually referred to as Net Primary Production. It is the source of energy utilized in biological processes and functioning generally; and whenever the human element is included in the structure of the ecosystem, it as well yields the energy for the maintenance of the cultural and the economic circuits generated. In one particular case, primary biomass production becomes the basic agricultural production. This is where human intervention in the form of farming activities encourages and promotes the growth and development of specific plants that are useful to man.

Primary biological productivity, which is the rate at which plant biomass is accumulated, varies from place to place on the earth's surface in conformity with variations in certain environmental factors. The latter include solar radiation, atmospheric temperature, atmospheric moisture, soil moisture and the fertility status of the soil. Major (1963) observed that the actual evapotranspiration (AE) in a terrestrial environment is qualitatively related to the amount of vascular plant functioning. AE is the reverse of rain. It is the amount of water actually entering the atmosphere from the vegetation and the soil. Evapotranspiration requires sufficient energy to make the phase transfer of water from liquid to gas possible. Actual evapo-transpiration is therefore a measure of the simultaneous availability of water and solar energy in an environment during any given period of time. Since it is also the simultaneous availability of water and sunlight that limits biological productivity, obviously, AE is an environmental variable that could be used for the purpose of predicting biological productivity.

By assembling data on climate and productivity throughout the world, Rosenzweigh (1968) has been able to derive a formula connecting actual evapotranspiration and net primary productivity. Data on AE were derived using the formula suggested by Thornthwaite and Mather (1957). With this, AE is calculated from knowledge of the latitude of a place, its mean monthly temperature and its mean monthly precipitation. Both climatic and biological data were then transformed into common logarithms. Using the method of least squares, linear regression of productivity on AE was performed. The productivity prediction equation, including 95% confidence intervals for the slope and the intercept, is given as:

[--- Unable To Translate Box ---]

where AE is the annual actual evapotranspiration in millimetres, and NAAP is the net annual above-ground productivity in grams per square metre.

3. Net Annual Above-ground Productivity in West Africa

Using the equation given above and the data on water balance compiled by Thornthwaite *et al.* (1962), the annual productivity for each of twenty-five climatic stations across the climatic profile in West Africa was calculated. The results are depicted in Table 1. (Fig.1) The values of NAAP vary from 778 grams / m^2 / year at Nguru in the Sahelian ecological zone, to 4335 grams / m^2 / year at Port Harcourt, near the sea in the south. It is obvious from this pattern that the chief determining factor is climatic water supply, that is rainfall. The mean annual rainfall in Port Harcourt is about 3000 mm while that of Nguru is about 500 mm. On the other hand, the annual reception of solar radiation is inversely related to primary productivity being of the order of 110 kg - cal / cm^2 / year in Port Harcourt and 190 kg - cal / cm^2 / year at Nguru. (Davies, 1966).

However, the pattern of primary biological productivity corresponds closely with the distribution of the vegetation. A statistical testing of the degree of correlation was made following the suggestions of Robinson and Caroe (1967) on "the analysis and comparison of statistical surfaces." An arbitrary grid of thirty-eight points was imposed on the isopleth map of primary productivity in Nigeria. The value of productivity for each point was determined by interpolation. Keay's map of vegetation was also turned into an isarithmic map by ranking the boundaries such that the values 1, 2, 3, 4, 5... etc. were given to them as they follow one another from the Sahel through the various savanna zones and the forest zones to the coastal moist evergreen forests in the south. This is not a measure of the standing crop (that is the sum total of living tissues), but an indication of the direction of change of this important vegetation attribute. Using the same grid of 38 points, the vegetation value for each point was also determined by interpolation. Each grid point therefore has its own value for vegetation and biological productivity. The value of 'r' (representing the coefficient of correlation between the two variables) was calculated to be 0.9663, significant at 0.001 level. This should be regarded as a measure of the degree of reliability of the method being used to compute primary productivity. The central idea of this paper is based on Rosenzweig's regression equation. To demonstrate its reliability, we can compare the estimates based on this equation with independently measured values using the harvest method. According to Oyenuga (1971), unfertilized elephant grass (<u>Pennisetum purpuerum</u>) yielded an average annual above ground productivity of 3444 grams / m^2 / year at Ibadanan from 1953 to 1954. This value lies well within the limits set by the error terms for the computed values for Ibadan which is 3043 grams / m^2 / year. The annual rainfall amounts for Ibadan for 1953 and 1954 were 1180 mm and 1203 mm, respectively compared with the mean of 1210 mm on which the computed productivity estimates were based. Since the Oyenuga values were not included in the data used to derive the Rozenzweigh's equation, the close correspondence with the estimated values can be interpreted as conferring a high degree of acceptability on the equation.

4. Potential Primary Productivity

Actual evapotranspiration is essentially composed of evaporation and transpiration possible without irrigation. Potential evapotranspiration (PE) is the amount of evaporation and transpiration that will take place when soil water is constantly at, or above field capacity. Except in the perennially wet locations in southeastern Nigeria, such a soil condition could only be artificially created through irrigation. Under such a condition, AE would be equal to PE. Thus, a new level of biological productivity could be envisaged, based on the assumption that the fields would be irrigated to keep the soil water constantly at or above field capacity. This can be referred to as potential primary productivity. Using the Rosenzweigh's equation, but substituting PE for AE, the potential productivity values for the 25 climatic stations are estimated and depicted with the actual productivity value in Table 1 (column 'b'). The percentage increases in productivity resulting from full irrigation are included in column 'C'.

The pattern of distribution of potential productivity is quite different from that of actual productivity. The limiting factor is now available energy rather than available water. Thus areas of lowest potential primary productivity are the highlands, especially the Jos Plateau and the Foutadjalon Highlands. Potential primary productivity is highest in the Middle Belt in Nigeria, particularly in the Niger - Benue lowlands where values higher than 5000 grams/m^2/year are found. The belt of high productivity continues westwards through Burkina Faso, northern Togo and Benin Republic, northern Ghana and northern Ivory Coast, to reach the coast in the Republic of Guinea. In the wetter southern areas, values of potential primary productivity lie between 4000 and 5000 grams/m^2/year. North of the Middle Belt area, potential primary productivity is also generally between 4000 and 5000 grams/m^2/annum except in the highland areas.

5. Comparing Potential and Actual Productivity

Potential primary productivity is higher than actual productivity at each of the climatological stations. This means that application of irrigation water can enhance primary productivity throughout the sub-continent. Perhaps the more vital question at this stage centers on how much greater is potential than actual productivity. The answer to that question would determine the advisability or not to irrigate. The percentage increases in potential productivity over actual productivity varies from 11% in Port Harcourt to 435% at Nguru in the far north. In grams/m^2/year, the differences between potential and actual productivity vary from 584 at Port Harcourt to 4270 at Sokoto and 4350 at Yola.

The differences between actual and potential values of productivity can be used as measures of gains to be derived from full irrigation. In computing costs and benefits, these can be matched against the costs of supplying irrigation water. The conclusion therefore is that substantial gains in productivity can be achieved, especially in the northern areas, through full irrigation. It could be easily observed, however, that increases achievable in the coastal areas (Calabar, Warri, Port Harcourt and Benin City) may not be worth the costs of the installation of the irrigation facilities.

6. Increases Based on Conservation of Local Water Supply

It has been stated earlier, that our main concern in this paper is with small-scale irrigation schemes based on local water supply. In most parts of West Africa, rainfall is less than potential evapotranspiration. This means that full irrigation is not feasible without large-scale importation of water from other regions. Such large-scale importation of water calls for the investment of large sums of money which is now effectively beyond the means of most national governments. Moreover such large-scale projects can only benefit locations along the courses of the larger rivers such as the Niger and its major tributaries. Locations within the catchment areas of first-order to fourth-order streams which make-up more than 75% of the land area are completely ruled out as beneficiaries of such schemes.

Column 'd' in Table 2 depicts the maximum productivity to be expected from irrigation based on local water supply only. In the three forest ecological zones, there is no difference between this maximum productivity and the potential productivity. In other words, local water supply is all that is required to achieve full irrigation. In the Coastal moist evergreen rain forest zone, only an 11% increase in productivity can be mustered. However, in the Mixed moist evergreen rain forest belt and in the Drier semi-evergreen rain forest zone, the comparable increases are respectively of the order of 23% and 32%. Since the facilities for storing water for use during the short dry season are not likely to be expensive, highly profitable irrigation schemes directed towards the provision of vegetables and early season maize are indicated most especially at the drier margins of the forest zone. (See Fig.2)

For the Southern Guinea, Northern Guinea and Sudan savanna zones, the increases over actual productivity expected from the use of local water are, respectively 40%, 77% and 30%. These are sufficiently high to warrant the encouragement of widespread investment in small scale irrigation schemes. There is, however, still a wide deficit between estimated potential productivity and irrigated productivity based on local water supply. These are on the order of 1623 $gm/m^2/year$ at Bida (Southern Guinea Savanna), 2673 $gm/m^2/year$ at Bauchi (Northern Guinea Savanna), and 3917 $gm/m^2/year$ at Yola (Sudan Savanna). Even though full irrigation cannot be achieved with the limited local water supply, irrigation can still be profitably employed in mitigating the effects of delay in the onset of the rainy season; irregular, prolonged dry spells during the rainy season; and early termination of the rainy season.

The Sahel is completely ruled out of irrigation based on local water supply because of the absence of water surplus during the rainy season. Most of the rainfall is used to recharge soil water. By the time soil water is high enough to yield a surplus, the rainy season would have terminated. No irrigation is hence possible in the Sahel except along the flood plains of the large rivers where water imported from distant wetter areas is available.

7. Proportion of the land that can be fully irrigated to achieve the potential productivity level

It is common knowledge that in any catchment area, not all the land can be suitable for agriculture. Moreover, in a well planned rural landscape, some of the land needs to be allocated to non-agricultural rival claimants. Increases in agricultural productivity should therefore be estimated with this in mind. In other words, increases in agricultural productivity should be calculated relative to those areas normally used for agricultural productivity. The catchment area as a whole is used to collect rain water which is subsequently used to irrigate only a proportion of the land. Water saved from the non-agricultural areas could be used to increase productivity in the cultivated areas. Column 'f' in Table 2 gives the percentage of the land in each ecological zone that can be fully irrigated (that is to achieve the level of potential primary productivity) with the use of water saved on both agricultural and non-agricultural land. In the three forest zones, 100% can be fully irrigated with the available water surplus. This proportion falls rather precipitously to 42% in the Southern Guinea Savanna, 35% in the Northern Guinea Savanna and 10.5% in the Sudan ecological zone. Since there is no local stream-flow in the Sahel, no water can be saved and the proportion falls to 0%.

8. Conclusions

In conclusion, it is noted that agriculture could benefit from irrigation in most parts of West Africa. Irrigation as a strategy for increasing productivity is most highly indicated in the Guinea Savanna ecological zones where potential primary productivity is highest. Moreover, in the same zones, there is still considerable rainy season surplus that can be conserved and used during the dry season. Irrigation without massive importation of water from the wetter zones is virtually impossible in the Sahel. In the Sudan zone, only a 30% increase in productivity is possible and not more than 10% of the land can be fully irrigated using local water supply. In the coastal areas, increases in productivity achievable through irrigation may not be able to pay the cost of the necessary infrastructure. In the main forest zone, as much as 25% increase in productivity is possible.

Even in the Guinea zones, maximum increases in productivity can only be achieved with the adoption of appropriate farming systems and a careful choice of crops. Perennial field crops or successions of field crops with different planting and fruiting seasons are likely to be the most profitable. Such perennial crops include sugar-cane, cassava and pasture grass. A combination of early season crops such as yams, maize and other cereals with late season crops such as cotton and legumes could be adopted to make maximum utilization of irrigation.

References:

Davies, J.A. (1966), "Solar Radiation estimates for Nigeria". Nigerian Geographical Journal, Vol.9, pp. 85 - 99.

Major, J. (1963), "A climatic index to vascular plant activity" Ecology Vol. 43, pp. 485 - 498.

Okamoto, K. *et al.* (1991), "Influence of the Green House effect on yields of wheat, soyabeans and corn in the U.S.A. for different energy scenarios" Climatic Change Vol. 18, pp. 397 - 424.

Oyenuga, V.A. (1971), "Biological Productivity in West Africa". Journal of the West African Science Association Vol. 16, pp. 93 - 115.

Robinson, A.H. and Caroe, Lucy (1967), "On the analysis and comparison of statistical surfaces". Contribution in Quantitative Geography (eds. Garrison, W.L. and Marble, D.F.) Evanston.

Rosenzweig, M.L. (1968), "Net Primary Productivity of Terrestrial Communities: Prediction from climatological Data". The American Naturalist Vol. 102, pp. 67 - 74.

Thornthwaite, C.W. and Associates (1962), "Average Climatic water balance data for the continents: Africa" Lab Climatol, Pubn Climatol, Vol. 15, pp. 115 - 287.

Thornthwaite, C.W. and Mather, J. (1957), "Instructions and Tables for computing potential evapotranspiration and the water balance". Drexel Inst. Technol. Lab Climatol. Pubn Climatol., vol. 10, pp. 181 - 311.

Climatic Variability and Halieutic Productivity of Lake Nokue (Benin, West Africa): A Prospective Analysis

Professor Michel BOKO and
Wahab Amadou HOUADEGLA

Laboratoire de Climatologie. Université Nationale du Bénin
B.P. 03-1122, COTONOU, Rep. Of BENIN.

ABSTRACT

The Lake Nokue is located in the coastal plain of Benin. It extends over an area of 150 km^2. On September 21, 1885, an artificial channel was dug through the sandy strip to control the floods. Changed into fresh waterbody, the lake lost all the mangrove vegetation growing on its banks.

Sixty thousand people live on this waterbody, but almost ninety thousand people exploit it. The main economic activities are fishing, trade and tourism. The yearly production of fish varies between 14,000 and 20,000 tons, supporting 15,000 to 20,000 professional fishers. Variations in productivity are related to the number of fishers, fishing techniques used, and modifications in ecological parameters from one season to another as well as from year to year.

After we have analyzed the ecological parameters, all the climatic factors are selected by the principle of statistical independence of parameters to analysis. The regrouping of the modes of temporal variations of the climatic factors and physico-chemical parameters enable us to "create" eco-climatic types. The statistical analysis, processed in four steps, has allowed us to conclude that most of the lake’s fish species are particularly sensitive to eco-climatic conditions variations. These species include: *Cichlidae*, *Carangidae*, *Mugilidae*, *Portunidae*, *Clupeidae*, *Bagridae Gobiidae*, *Penaeidae* and others. Only species such as *Elopidae* and *Gerridae* seem to be able to survive whatever the eco-climatic conditions are. But the statistical series indicate low quantities of these species from September to November.

These outcomes could help to orientate research programmes on the impacts of climate change on the productivity of Lake Nokue and other lakes of Benin. The climatic evolution towards drier conditions will modify the faunistic stock of the waterbody completely, with the predominance of species such as *Cichlidae*, *Carangidae*, *Mugilidae* and other ubiquistic species (*Elopidae* and *Gerridae*).

1. Introduction

The southern fringe of Benin has perennial lakes and lagoons extending over 320 km^2 of which the most important is Lake Nokue (150 km^2, i.e. 50% of the whole extension of perennial waterbodies). This lake is located between the edge of plateaux of Terminal Continental series (Old Quaternary, indeed End Tertiary) and the ancient and recent coastal sandy strips. (Fig. 1) It was probably formed in the Quaternary Era during the Nuakchotian sea transgression, between 10,000 and 4,500 B.P.

About 90,000 people live on the waterbody and at its banks (among which more than 60,000 live on the lake itself). These people exclusively practice fishing and fish product trading. Annual production varies between 14,000 and 20,000 tons. Fish species are diversified (about ten species of fish and crustaceous). The yield is variable according to techniques used, e.g. cast net, lobster pots, "akaja" boughs, bottom lines, and also in linkage with the variations of hydroclimatic conditions of the waterbody.

Finally, the climatic parameters induce modifications of physico-chemical parameters on which the halieutic life depends (turbidity, pH, conductivity, dissolved oxygen, mineral salts). This study is carried out to assess the impact of climatic parameters, in order to grasp the future variations of fish production better in the context of a possible climate change.

1.1 Species and Variability of Yield

Numerous and different fish species live in the Lake Nokue, which is not too deep with detritic sedimentation and strong variations of salinity. Thus, the Lake Nokue is an original ecological domain. Its fauna was studied by many researchers (PLIYA J., 1980, DOSSOU C., 1981, VanTHIELEN and alii, 1987). These studies have highlighted a very exhaustive inventory of fish species in south Benin. The eco-biological characteristics allowed us to distinguish:

(a) Continental species: fresh water species which invade the lake at the beginning of high water period and after the flood period. *Chrysichtys nigrodigitatus (Bagridae)* is the most characteristic of them.

(b) Estuarian species adapted to salted water constitute a permanent species. They appear at many places. They are euryhaline species of which the typical representative is the *Cichlidae* species.

(c) Marine species are periodical, but some of them are permanent species in the lake, and only disappear during a short period of the flooding.

The production of the lake, estimated in 1959 at 15,000 tons, decreased to 8,000 tons in 1980 and increased to 14,000 tons in 1987 (Lagoonal Fishing Project, 1987). It is thought that this increase in 1987 was due to a modification in the data collection system as statistics of former years were based on estimations. However, statistical fluctuations occurred, showing the decrease of the productivity of this waterbody. For instance, the yield in 1988 is 2,813 tons less than in 1987 (i.e. -19%), and 4,623 tons less than in 1989 (i.e. -28%). The yield in 1987 decreases in 1,810 tons (i.e. -11%) in comparison with the yield in 1989.

To explain the variability of the production and to show the importance of the quantities of each species in every period of the year, we have classified, according to our observations in the field, a new calendar for fishing activities. This new calendar differs from the standard calendar (January - December), but fits the whims and realities of fishers on daily, monthly and yearly scales.

TABLE 1: Variability of Yield

YEARS		**1987**		**1988**			**1989**		
PERIODS	**LW**	**MRS**	**HW**	**LW**	**MRS**	**HW**	**LW**	**MRS**	**HW**
	Dec-Ap	May-Au		Dec-Ap	May-Au	Sep-Nov	Dec-Ap	May-Au	Sep-Nov
SPECIES									
CICHLIDAE	1084.92	1164.61	714.44	1334.7	1335.0	1176.6	2777.0	1665.6	1026.14
CLUPEIDAE	764.8	934.8	328.0	512.3	586.2	47.6	726.6	916.5	184.0
BAGRIDAE	441.5	377.0	199.5	123.3	152.5	227.8	232.2	204.7	219.0
MUGILIDAE	292.9	209.4	148.8	76.5	61.4	15.6	118.8	118.3	41.3
GERRIDAE	224.15	315.2	113.25	121.8	105.1	14.8	80.52	44.7	16.7
ELOPIDAE	71.8	109.13	80.44	70.6	42.5	16.1	72.31	58.63	31.1
CARANGIDAE	8.79	0.84	1.9	26.1	18.0	0.2	48.55	16.26	0.80
GOBIIDAE	10.85	14.8	6.29	43.2	72.4	102.8	87.94	102.21	164.98
PENAEIDAE	728.0	973.27	232.6	1013.3	795.3	28.5	1945.8	1524.6	91.7
PORTUNIDAE	1338.8	1681.9	560.96	1041.2	848.6	90.1	1737.8	1100.3	192.3
OTHERS	310.2	252.5	808.0	321.7	312.2	946.9	99.4	113.8	553.9
TOTAL	5276.7	5780.9	3194	4684.7	4329.2	2669.0	7927.0	5865.6	2522.0

Keys: LW: low water; MRS: major rain season; HW: high water. (Source: Lagoonal Fishing Project, LFP,1989. Cotonou)

Thus, Table 1 shows the evolution of species quantities during the period concerned. According to this table, the quantities of yield vary from one period to another during the year and from one year to the next. Yield totals also depend fishing techniques used as well as on ecological modifications during different periods of the year.

1.2 Factors of Yield Variation: Environmental Parameter Variations

A series of parameters, physical as well as chemical, characterize Lake Nokue and induce its specificity. One can put them into one of two categories: parameters related to water and meteorological parameters.

1.2.1 Parameters Related to Water

(a) Temperature

The best series of water temperature readings was recorded from 1987 to 1989 for the daily survey by the Lagoonal Fishing Project (1987). The mean values for these three years are shown in Table 2.

TABLE 2: Variations of mean monthly temperature (˚C) of air and water in Lake Nokue (1987-1989)

Month	Water	Air	Month	Water	Air
January	27.3	25.8	July	17.4	26.6
February	29.7	29.1	August	26.8	26.5
March	30.3	29.4	September	27.9	27.1
April	30.2	30.5	October	29.2	28.2
May	29.9	28.7	November	29.8	28.6
June	28.8	27.9	December	29.0	27.9

(Source: Data from LEP, Cotonou 1989)

The spatial variability of surface temperature is weak and does not exceed 3˚ C from one extreme to another within the lake, except waters under sea control which are a little cooler. The agreement between the variations of air temperature and water temperature could enable the study of the inter-annual variability out of the meteorological data.

(b) Salinity

Water salinity is directly linked with climatic conditions affecting the rhythm as well as the importance of water inflow. The alternate influences of floods and marine water determine important variations in the salinity of the lake. From the multi-daily records of LFP, data collected show the salinity varies from 0 to 38%.

These salinity variations reflect the complexity of exchanges between the lake and the ocean. According to COMARAF studies (1990), the salinity of the lake is affected by spatial variations linked not only with the ebb and flow of marine water and fresh water (So and Weme Rivers), but also with tidal motion. This allows characterization of higher salinity: in the western and central parts of the lake, where water shows a polyhaline tendency (26 to 38%), whereas Weme River's influence leads to mesohaline waters (10 to 18%) in the eastern part of the lake.

(c) pH

Like salinity, pH is a parameter of lake environment. The pH is linked with temperature values, dissolved oxygen and total mineralization. As noted by J. ARRIGNON (1985) "the range of pH values not directly fatal for fish species ranks from

5 to 9, but its effect on the fauna will be perceptible through its influence on the balance of other elements." The recorded values during three years of survey rank in that interval. If we adopt J. ARRIGNON's (1985) scale, we can establish the following table.

TABLE 3: pH Tolerance threshold in Lake Nokue (1987-1989)

PH Value	**Indications**	**Corresponding Periods According to seasonal fluctuations**
5 < pH < 9	bearable range for most fish species	all the year long
6 < pH < 7.2	optimal range for the reproduction of most species	about four months fluctuating with the lateness or the precocity of floods: July, August, September and October.
7.5 < pH < 8.5	optimal range for plankton productivity	major dry season and start of the rain season : November, December, January, February, March, April and May.

(Source: by the terms of J. ARRIGNON's table, modified and adapted to the ecology of Lake Nokue, according to LEP data.)

These pH values indicate not only the optimal range for the reproduction of most species, but also the optimal range for the plankton productivity. The fluctuations of pH values in the lake enable us to assign a place to the reproduction period of fish species (four months from July to October) when pH values vary in the range of 6 to 7.2. This period is not fixed as it is affected by climatic fluctuations linked with year to year temperature and rainfall variations and high water occurrence. The interval from 7.5 to 8.5 corresponds to the optimal productivity range of plankton. It corresponds also with the dry season in south Benin. During this period (December - March and sometimes April when dryness persists), the photosynthetic activity is at its highest. But, the pH values are very variable in the Lake Nokue because of multiple factors including place of sampling, hour of sampling, temperature, insulation, the intensity of photosynthetic activity, animals' breathing and metabolism of lower aquatic organisms. The variability is very great during the dry season, when pH values increase up to 8.5. During this period, all the factors of photosynthesis attain their highest values -- temperature : 30° C, insulation : 239 hours, etc.

(d) Dissolved Oxygen

Among all these environmental parameters which influence the yield-capacity of the lake, dissolved oxygen is one of those which plays the most important role in the biotic quality of water.

Dissolved oxygen was studied by ADITE (1989) in the Lake Nokue. The briefness of the study and the remote location of the sampling do not enable us to describe the dissolved oxygen variations precisely. In terms of Table 4 hereafter, we notice an evolution of the concentration of dissolved oxygen from February to August. The highest mean value is recorded in April at 7.6 mg/1 (110% of saturation). The highest absolute value (9.6 mg/1, 13% of saturation) was recorded in the same period.

TABLE 4 : Variations of Dissolved Oxygen in Lake Nokue (Salted water)

Month	Daily Mean Value		Maximum		Minimum	
	mg/l	%S	mg/l	%S	Mg/l	%S
February	6.9	92	8.1	110	6.2	82
April	7.6	101	9.6	131	5.8	77
June	7.2	92	8.1	104	5.9	74
August	6.8	84	7.6	95	5.9	73

(Source: A. ADITE; LFP; Cotonou. 1989)

This established fact covers up realities, which are different from one place to another. For instance, in the northern part of the lake during the same period, the rate of dissolved oxygen would be probably in the reverse order because of alluvial deposits in this part of the lake, the high turbidity recorded, and the increase of temperature related to water shallowness.

Beyond this chemical parameter which constitutes a favorable factor to halieutic activities, the transparence, the turbidity and the brightness play a less negligible role.

(e) Transparence, Turbidity and Brightness

These parameters condition the abundance or scarcity of the aquatic fauna. Indeed, fish species are adapted better to limpid water and develop well in it. This explains the high quantity of yield from December to April. This period corresponds then with the dry season when water is least turbid. On the contrary, during June and July, the turbidity goes on and reaches its summum in September and October, in high water period. It is also the period of low salinity and pH.

In addition to the turbidity, the wave action is due to running water. This wave action provokes the migration of fish species at one and the same time towards the central part of the lake and towards the surrounding marshes (SOEDE and CHABI, 1980).

As for the brightness, it acts in conjunction with the transparence to create favorable conditions to fauna and flora development, for it influences the photosynthetic activity.

1.2.2 Meteorological Parameters

(a) Air Temperature

For the period 1987-1989, the mean temperature was 27.6° C, and the annual amplitude weak (3.5° C) At an inter-annual time scale, the variability is not important. The highest and the lowest monthly average values were recorded respectively in April (30° C) and in August (25.5° C). As conditioning factors of the halieutic production, temperature and insulation are determinants in phytoplankton production.

(b) Duration of Insulation

The duration of insulation shows important variations from month to month and from year to year. The seasonal amplitude is very strong. The duration of insulation in August is only 60% of the average value in April. There are two peaks during the year. The first one occurs in April or May while the second one takes place in November. The lowest values occur in August and September.

(c) Wind Speed and Directions

The wind blows from south to west. At the station of Cotonou and during the period concerned (1987-1989), the frequencies are as follow:

67%	from the South-West
14%	from the South-South-West
19%	other 14 sectors

The mean annual wind speed is 3.9 m/s. The seasonal variations are very important, ranging from 2.6 m/s in December to 5 m/s in March. Calmness is more frequent from October to January. Wind speed induces currents and so contributes to define better the fishing seasons. It provokes surface currents, while bottom currents are linked with marine and particularly fluvial hydrology. The fundamental role of wind is that of mixing and oxygenation of the water. The turbulence of the water and its shallowness, added with wind friction, result in an important mixing of which the consequence is an appreciable aeration and, especially, a homogenous distribution of algae. So, the turbulence, which ensures the aeration, also ensures oxygenation in the lake system, which makes possible the existence of aquatic biocenosis.

(d) Rainfall

The lagoon zone of southeastern Benin is located in a region, which experiences a sub-equatorial climate. This zone records on average 1,400 mm per year. The major rainy season, extending from March to July, records 70.45% of the total precipitation.

The little rainy season, from September to November, records 20.36%. The rest is scattered among the other months.

The rainfall variations provoke sound modifications of the lagoon environment. The rise of lagoon levels during the high water period is one of the consequences of Weme River's flood, which occurs at the same time as the little rainy season in southern Benin. The temporal variations of rainfall enable us to notice three seasons:

(a) The dry season from December to April. The continental waterflow (drainage and precipitation) are negligible. The evaporation is at a maximum and the influence of marine water is preponderant. During this season, the lake receives the maximum level of salt water in February and March. Temperature and salinity are at the top levels.

(b) The rainy season from May - August. It is the time of heavy rainfall. Temperature decreases down to the minimum value.

(c) The high water season from September to November. The inflow of water from rivers, which drain the northern and central regions of Benin, perturbs the lagoonal ecology and the salinity rate is near zero. Temperature increases in October.

2. Methodology: Climatic Variability and Halieutic Production

From the assessments above, it is obvious that many factors of variation are linked directly (temperature, precipitation, insulation) or indirectly (turbidity, dissolved oxygen, salinity) with the climatic context of the region where the waterbody is located. The quantitative and qualitative relationships between production and climate could be analyzed in two manners:

(a) We can analyze statistically the relationships between production and meteorological parameters considered separately.

(b) It is also possible to combine the meteorological parameters into eco-climatic types or into bio-climatic indexes.

The so obtained indexes or eco-climatic types describe the synthetic value of parameters of which the influence seems to be preponderant. The range of variation corresponds to the intensity or the types of eco-climatic conditions. But, we can define the same types of eco-climatic conditions by computing the range of simultaneous variations of the main meteorological parameters.

The indexed variables which could a priori influence the production of lagoon species are:

(i) parameters related to water on the Lake Nokue
    (a) ambient temperature (MTA)

    (b) water temperature (MTE)
    (c) water salinity (MMS)
    (d) pH value (MPH).

(ii) parameters related to the atmosphere
    (a) air temperature under shelter (TMA)
    (b) insulation (INS)
    (c) wind speed at the ground level (VV)
    (d) rainfall amount (HP)
    (e) and duration of diurnal precipitation (DP)

After this catalogue of explanatory variables, we have to analyze the different correlation.

The detection of contingent linkages between the explanatory variables cited above would allow to save time and precision in following analyses. So, we notice with interest that:

5. insulation and ambient air temperature are positively correlated with a coefficient of linear correlation equals to 0.74, and

- ambient air temperature and water temperature are positively correlated with a coefficient of 0.90.

These two linkages result in fact in a positive correlation between insulation and water temperature. The coefficient of correlation is 0.73. It is due to the fact that insulation conditions, ambient air temperature in Tropics, and this one conditions water temperature. Among these three parameters, we will carry for further analysis ambient air temperature, recorded easier and more precisely by LFP, directly on the water body. The rainfall duration is strongly correlated with the amount of precipitation. The coefficient of linear correlation is 0.90. We will then carry the amount of precipitation for further analysis. Moreover, the salinity is positively correlated with pH. The co-efficient of correlation is 0.56.

In brief, we will carry in practice the following variables for the statistical study of the halieutic capacity yield of the Lake Nokue during the three years 1987, 1988 and 1989.

PARAMETERS RELATED TO ATMOSPHERE	**PARAMETERS RELATED TO WATER**
- ambient air temperature (MTA)	- salinity of water (MMS)
- wind speed at the ground level (VV)	- pH of water (MPH)
- rainfall amount (HP)	

We have processed by finding out statistical linkages between production (explained variables) and meteorological parameters (explanatory variables). For this purpose, we have used the methods of linear regression, principal components analysis, spectral analysis of points and factor analysis of agreements.

TYPE 1: Eco-climatic conditions are characterized by :

(a) high ambient air temperature: 30˚ C
(b) average wind speed: 3-4 m / s
(c) low cumulative rainfall amount: 106-295 mm
(d) high water salinity: 30%
(e) high pH of water: 8

This type is recorded from December to April or May. This characteristic conditions corresponds to the period of fall or dry season. During this period, the Lake Nokue experiences its lowest water levels. The rainwater contribution is weak. It is also the period of greatest water transparence and brightness. There is no turbidity, but dead calm (3 m / s) and scarce rainfall. The salinity and pH are increasing to the top values in April. So, the salinity rate is almost 35% and the pH is 8.5.

TYPE 2: Eco-climatic conditions are marked by :

(a) low ambient air temperature: 26˚ C
(b) high wind speed : 4-5 m / s
(c) high cumulative rainfall amount, 450 to 892 mm
(d) average water salinity: 20-24%
(e) relatively weak pH of water: 6-7

This condition is experienced from May or June to August. It is the period of the major rainy season in the southern region of Benin. This corresponds to a weather of high wind speed (about 5 m / s) which provokes turbulence in the water, generation of currents, and enables not only a good oxygenation and aeration of water, but also interferes in the spatial distribution of fish species. This type is characterized by a maximum rainfall in June. The pH and salinity are average.

TYPE 3: Eco-climatic conditions are marked by :

(a) low ambient air temperature: 25-26˚ C
(b) weak wind speed: 2-3 m / s
(c) average cumulative rainfall amount: 319 to 676 mm
(d) low water salinity: 0 to 10%
(e) and a low pH value of water: 5 to 6

This condition is recorded from September to November. It coincides with the little rainy season in south Benin, and with yearly high water of the Weme River. The ecological conditions of the lake are completely modified. They move from brackish to almost fresh water conditions. Some variables related to water and to the atmosphere are at very low levels. It is the period of high turbidity, because of an important income of sediments, mineral salts and other nutrients, which contribute to the chemical enrichment of the lake.

We can notice that the occurrence of the different types of eco-climatic conditions during the three years is linked with the timing and abundance of precipitation and high water.

3. Results

3.1 Linear Regression Method (LR)

One can notice that the abiotic factors induce pernicious consequences to the lagoon environment. Within the above defined eco-climatic conditions, only water-related parameters have a positive coefficient of correlation (salinity, r = 0.60 ; pH, r = 0.25). Meanwhile, this correlation is weak and positive with climate related parameters such as precipitation amount (r = 0.11), wind speed (r = 0.17), and negative with the other meteorological parameters (ambient air temperature, r = 0.73). The *Cichlidae* yield is correlated positively with water related parameters (salinity, r = 0.12 ; pH, r = 0.25) and negatively with parameters related to the atmosphere. The *Portunidtue* production is in positive correlation with parameters related to water (salinity, r = 0.60 ; pH, r = 0.23), in positive but weak correlation with rainfall amount (r = 0. 11) and wind speed (r = 0.17), but in negative correlation with ambient air temperature (r = - 0.73). The yield of *Penaeidae* is strongly linked with salinity (r = 0.68). This correlation remains positive with rainfall amount, pH, ambient air temperature and wind speed (with respectively r = 0.08, r = 0.47, r = 0.13 and r = 0. 14).

The types 1 and 2 of eco-climatic conditions are consistent with the ecology of *Penaeidae* (J. PLIYA, 1981). The yield of this species depends on climatic parameters, physical and chemical parameters related to water. The production of species included in the category called "OTHERS" is negatively linked with parameters related to the type 3 of eco-climatic conditions, except rainfall amounts with which the coefficient of correlation is positive (r = 0.22). The yield of *Bagridae (Chrysitchtys nirodigitatus)* is quite well correlated with some parameters related to eco-climatic conditions such as pH (r = 0.56) and ambient air temperature (r = 0.55).

Further statistical analysis, including principal component analysis shows that the different environmental conditions influence the production of every fish species in the same way from year to year. So, the type 1 is very favorable to the production of *Portunidae* and *Penaeidae*, and very unfavorable to "OTHERS" and *Gobiidae* species. The type 2 is particularly favorable to *Clupeidae (Ethmalosa)* and *Penaeidae* species; it influences negatively the yield of "OTHERS" species. The type 3 is essentially favorable to the yield of "OTHERS" and *Bagridae* species, but very unfavorable to *Clupeidae, Carangidae, Penaeidae* and *Portunidae.*

TABLE 5 – Influence of types on the production of each species during the three years 1987-1988-1989

Eco-Climatic Conditions	**1**			**2**			**3**		
Years	**87**	**88**	**89**	**87**	**88**	**89**	**87**	**88**	**89**
Species									
CICHLIDAE	-	-	+	-	+	-	-	+	+
CLUPEIDAE	+	-	-	+	+	+	-	-	-
CHRYSICHTHYS	+	-	-	+	-	-	+	+	+
MUGILIDAE	+	-	-	+	-	-	+	-	-
GERRIDAE	+	+	-	+	+	-	+	-	-

ELOPIDAE	-	+	-	+	-	-	+	-	-
CARANGIDAE	-	+	+	-	+	+	-	-	-
GOBIIDAE	-	-	-	-	+	+	-	+	+
PENAEIDAE	-	+	+	+	+	+	-	-	-
PORTUNIDAE	+	+	+	+	+	-	-	-	-
"OTHERS"	+	+	+	-	+	-	+	+	+

Keys + = Favorable - = Unfavorable

The accurate translation of all the influences are summarized in Table 5. We notice then an abundance of yield by the type 1. The type 2 corresponds to ecological conditions favorable to some species: estuarine species, and in a lesser quantity, marine species. The type 3 is favorable to the proliferation of species such as *Osteoglossidae (Heterotis niloticus), Channidae (Parachanna obscura), Mockokidae (Synodontis sp), Claridae (Clarias gariepinus)* and *Bagridae (Chrysichtys nigrodigitatus).*

To complete the spectral analysis, we have tested a factor analysis of agreements to confirm the outcomes above.

3.2 Factor Analysis of Agreements

This analysis aims at projecting on the principal plane the whole information contained in the table of contingence by crossing the eco-climatic types with fish species during the period 1987 - 1989. The factor analysis allows us to explain the linkages between the qualitative variables. From the outcomes (Table 6), it becomes clear that the percentage of inertia extracted from the two axes is about 91.6% (AXIS 1 = - 71.8%, AXIS 2 = 19.76%) which is considerable. We can, therefore, consider the projection of points on the plane as reliable enough.

TABLE 6: Percentage of intertia extracted from each axis

AXIS 1	AXIS 2	AXIS 3
71.87	19.76	4.26

The observation of Table 7 indicates that the category of "OTHERS" only has contributed in 56.1% to the positioning of the first axis. This category is followed by *Penaeidae* and *Portunidae.* These three species have contributed to the total in 83.6% to the positioning of this axis. Meanwhile, the three species are opposite on the projection plane: on one side, we have the category "OTHERS" with negative co-ordinates, and on the other side, *Penaeidae* and *Portunidae* with positive co-ordinates.

The second axis is much influenced by *Cichlidae* species, followed by *Gerridae, Mugilide, Penaeidae* and *Gobiidae* species, with still an opposition between *Cichlidae, Gobiidae, Penaeidae* species (negative co-ordinates) and *Mugilidae, Gerridae* species (positive coordinates).

TABLE 7: Results of factor analysis: Species 1987-1989

	AXIS 1			**AXIS 2**			**AXIS 3**		
Eco-Climatic Conditions	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
SPECIES									
CICH	-0.160	0.360	3.8	0.213	0.640	24.4	0.003	0.000	0.0
CLUP	-0.289	0.792	4.9	0.123	0.143	3.2	0.083	0.065	6.8
BAGR	-0.292	0.503	2.3	0.196	0.226	3.7	0.214	0.271	20.6
MUGI	0.106	0.041	0.1	0.505	0.935	11.5	0.081	0.024	1.4
GERR	0.226	0.115	0.6	0.626	0.880	17.4	0.048	0.005	0.5
ELOP	0.045	0.016	0.0	0.338	0.939	2.9	-0.074	0.045	0.6
CARA	0.473	0.329	0.3	-0.572	0.483	1.5	-0.357	-0.188	2.7
GOBI	0.743	0.462	4.4	-0.592	0.294	10.2	0.540	0.244	39.5
PENA	0.456	0.819	16.9	-0.194	0.149	11.2	0.090	-0.032	11.1
PORT	0.328	0.815	10.6	0.156	0.184	8.7	-0.015	-0.002	0.4
OTHERS	-1.038	0.958	56.1	0.168	0.025	5.3	-0.137	0.017	16.4

In the same way (Table 8), on the first axis, we notice an opposition between type 3 on the one hand, and types 1 and 2 on the other hand for the period on concern. Type 3 has contributed at 74.5%, but it has negative co-ordinates. This axis may be considered as the axis of high water. The second axis sets over the three types in 1987 (opposite coordinates) against the three types of 1988 and 1989 (negative co-ordinates).

The co-ordinates of condition-points and species-points on the two axes defined above allow us for a visualization of the simultaneous representation of condition-lines and species columns (Fig.3). During the period of type 1, we notice a high production of *Penaeidae, Portunidae, Clupeidae* but a little production of *Cobiidae* and category "OTHERS" *(Parachanna, Clarias, Heterotis, Synodontis*, etc.), and an average yield of *Gerridae* and *Elopidae* species. Type 2 records an appreciable production of *Clupeidae, Penaeidae, Portunidae*, a little production of the category "OTHERS", of *Carangidae*, and a similar production of *Elopidae, Mugilidae* and *Gerridae* species. Type 3 records a high production of species of the category "OTHERS" (*Parachanna, Clarias, Heterotis, Synodontis*, etc.) and *Gobiidae, Bagridae* species, a very little quantity of *Carangidae, Gerridae, Penaeidae and Elopidae*, and a stable production of *Clupeidae and Portunidae.*

TABLE 8: Results of factor analysis: Eco-Climatic types 1987-1989

Eco-Climatic Conditions		**AXIS 1**			**AXIS 2**			**AXIS 3**		
		1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
87	1	0.199	0.233	2.1	0.309	0.565	18.2	0.125	0.093	13.8
87	2	0.314	0.553	7.5	0.256	0.367	18.0	0.043	0.011	2.4
87	3	-0.412	0.504	8.7	0.367	0.400	25.0	-0.155	0.071	20.7
88	1	0.186	0.605	1.5	-0.073	0.093	0.9	-0.112	0.221	9.6
88	2	0.112	0.426	0.6	-0.094	0.300	1.7	-0.005	0.001	0.0
88	3	-1.055	0.978	47.4	-0.115	0.012	2.0	-0.073	0.005	3.8

89	1	0.296	0.506	6.7	-0.266	0.410	19.6	-0.068	0.026	5.9
89	2	0.319	0.628	7.2	-0.198	0.240	10.0	0.020	0.002	0.5
89	3	-0.675	0.819	18.4	-0.17	0.056	4.6	0.253	0.115	43.4

Keys: Columns 1: co-ordinates
2: square of the correlation value to the axis
3: contribution to the axis

On the whole, the outcomes of data processing complete one another. The results of factor analysis have confirmed those obtained from spectral analysis.

4. Conclusion

Most of species are particularly sensitive to variations of ecological conditions induced by the variations of meteorological parameters of climate. Only *Elopidae* and *Gerridae* species seem to be able to survive whatever the eco-climatic types are. Unfortunately, they are not the most desired species; moreover, their productivity decreases notably during the period of high water. One may conclude that in the case of climate change, leading to precipitation decrease and ambient air temperature increase, fish production yields of the lake would be modified. Such a climate context will have certainly very important economic and social consequences on the lagoonal environment and fishermen.

References

ADITE (A.), 1989 - variations saisonnières de l'oxygène dissous dans les principaux plans d'eau du sud-Bènin. Direction des Pêches. Projet Pêche Lagunaire. 50 pages. Cotonu.

ARRIGNON (J.), 1985 - Aménagement écologique et piscicole des eaux douces. Collection Ecologie Foundamentale et Appliquée. Gauthier Villar. 340 pages. Paris.

BOKO (M.), 1990 - Problème de quantification des ambiances bioclimatiques en zone intertropicale. Application au rendement de la main d'oeuvre rurale. Troisième Partie: cas de la production halieutique. Climat et Santé, N° 3, pp. 23-33, GDR 102, CNRS. Dijon;

HOUADEGLA (W.A.), 1991 - Rythmes climatiques et productions halieutiques au Bénin: cas du lac Nokoué. Mémoire de maîtrise, UNB/FLASH/DGAT. 126+12 pages. Cotonou.

GBAGUIDI (A) et PFEIFFER (V.), 1988-1991 - Statistiques des pêches continentales. Version préliminaire. 70+91+135+128 pages. Direction des Pêches. Projet Pêche Lagunaire. Contonou.

KIMPE (P.de) et GIRAULT (P.), 1967 - La productivité primaire d'un milieu aquatique lagunaire tropical: le lac Nokoué. Bulletin IFAN, T.XXIX, Série A, N° 2, pp. 710-734. Dakar.

PLIYA (J.), 1980 - La pêche dans le sud-ouest du Bénin. Etude de Géographie appliquée sur la pêche continentale et marine. ACCT, 296 pages. Paris.

PROGRAMME COMARAF, 1990 - Atelier sous-régional de recherche conjointe sur le lac Nokoué, 20-25 juin 1990. Rapport Technique. 78 pages. Cotonou.

VAN THIELEN (R.) et al., 1987 - Guide de détermination des poissons et crustacés des lagunes et lacs du bas Bénin (non paginé). Projet Pêche Lagunaire. Cotonou.

Facteurs Climatiques et Ststeme Traditionanel de Stockage du Mais en Zone Tropicale Guineenne du Togo

Kwami G. KPAKOTE, Phillip SMITH,
Homa SMITH, Baba KAKABOU, Amen NENONENE
Université du Bénin

Abstract

In order to improve traditional maize granaries in the guinea tropical zone of Togo, scientific observations were taken to determine the technical and socio-economic performance of these structures.

The results of these studies emphasized the thermal and hydrous factor effects of the traditional granary function on stored maize. They displayed, in effect, the dryer role of this storage structure for the main foodstuff of the country.

In conclusion, the authors have indicated the effectiveness of the traditional storage system, by situating it position in the ecological, technical and socio-economic context.

1. Introduction

Parmi les denrées alimentaires produites au Togo, les céréales occupent annuellement 35 à 40% du tonnage, tandis que le maïs en représente 22 à 25%.

Le maïs occupe donc une place de choix parmi les cultures vivrières du Togo, et ce surtout dans la partie méridionale du pays. Il sert, dans la préparation d'une vingtaine de mets locaux, et constitue actuellement la céréale la plus utilisée dans l'alimentation de la population nationale.

En effet, dans la moitié sud du pays, le maïs est cultivé, depuis de longues dates, en deux campagnes agricoles par an. Dans les régions septentrionales qu'il est en train de conquérir au détriment du sorgho, il est produit en une seule campagne annuelle. De plus, il est à remarquer que, depuis une dizaine d'années, le maïs se cultive en relais avec le coton, alors qu'il est habituellement associé au manioc ou au niébé dans les régions non conquises au coton.

Au total, environ 90 à 95% du maïs stocké et consommé par les populations togolaises sont produits par les petits paysans. Cette situation incite peu à des investissements relativement importants. Aussi, recommande-t-on souvent, dans une première étape, l'amélioration des structures traditionnelles de stockage, en suite, dans une seconde étape, une intensification de la production du maïs et l'adoption de techniques plus modernes de conservation.

Par ailleurs, le stockage du maïs reste très tributaire du climat : par exemple, le silo traditionnel utilisé dans la partie septentrionale du pays n’est pas efficace dans la partie méridionale. Or, le stockage apparaît comme une spéculation très avantageuse pour le producteur. En effet, de la récolte en juillet - août à la période suivante de soudure en mai - juin, le prix de cette denrée augmente entre 175 et 325% suivant les années. En outre, le stockage est un moyen plus sûr pour les paysans de faire face à leurs besoins financiers, et le grenier semble remplir une fonction sociale relativement importante dans les communautés rurales.

La présente étude se donne pour objectif une meilleure maîtrise des principaux paramètres de stockage traditionnel du maïs en vue d’une sécurité alimentaire soutenue.

2. MatÉriel et Méthode

2.1. Cadre de l’étude

La zone couverte par les études du projet (figure 1) est strictement limitée à la moitié méridionale du pays, et ce pour deux raisons principales. D'abord, l'humidité relative de l'air y est constamment élevée, indiquant ainsi des risques sérieux de dégâts dans les greniers à maïs ; ensuite, c'est la zone de plus grande production de maïs.

Elle s'inscrit entre 6 et 8 20 de latitude Nord et 0 40' et 1 5' de longitude Est. D'une superficie totale d'environ 21.975 km^2, elle s'étend sur 40% de la superficie du territoire national. Alors que la moitié Nord du pays jouit d'un climat plus sec à deux saisons, la zone du projet est soumise au régime de climat tropical de type guinéen, avec une grande saison des pluies (de la mi - mars à la mi - juillet), une petite saison sèche (de mi-juillet à septembre), une petite saison des pluies (de septembre à mi - novembre) et une grande saison sèche (de la mi - novembre à la mi - mars).

A l'intérieur de cette zone, et sur la base des critères de relief et de microclimat, quatre régions microclimatiques sont identifiées.

(a) <u>Zone maritime</u> : elle correspond presque point par point à celle indiquée sous l’appellation de Région Maritime par la division administrative du territoire national, et représente toute l'étendue de superficie située à environ 70 km au nord de la mer. Elle compte les villages de Wogba, Agbatopé*, Gapé, Afagnagan*, Aklakou, Gboto-Vodoupé, Kévé*, Adabiam, Ferme (ESA-UB) Lomé, Mission-Tové et Batoumé.

Les autres régions définies dans la zone du projet correspondent administrativement à la Région des Plateaux avec des zones microclimatiques définies comme suit :

(b) Zone des montagnes : elle correspond à toutes les localités situées sur les hautes altitudes des plateaux de Dayes, des Monts Akposso et du Mont Agou, entre 800 et 1.000 m de hauteur. Elle concerne les villages de Doumé-Elavagnon*, Kedjan, Lalamila*, et Ikavi-kopé*.

(c) Zone des piémonts : elle correspond à l'ensemble des localités situées au pied des montagnes et à environ 500 - 600 m d'altitude. Elle comporte les villages de Adam-kopé*, Agbédougbé* et Gadjagan*.

(d) Zone des plaines : elle représente l'ensemble des localités s'étendant à l'est des régions des montagnes et des plateaux et sur une bande d'environ 180 km de large au nord de la Région Maritime. Les villages intéressés sont : Asrama, Akparé*, Tsagba*, Tététou et Atokodjè*[1].

2.2. Méthode d’étude des échanges thermiques circadiens entre greniers et air ambiant

Cette catégorie d’observations en station a concerné les variations thermiques nycthémérales de 4 types de greniers dont le grenier bas à fond plat, le grenier haut à fond creux, le grenier haut à fond plat et le crib rectangulaire. En tout 5 séries d'observations ont été enregistrées suivant le rythme d'une observation toutes les 4 heures, soit au total 7 observations par série allant de 6H d'un matin à 6H au matin suivant. Une série de mesures à donc couvert une journée de 24 heures.

Ces mesures indiquent la température au centre du grenier et les résultats expriment les valeurs moyennes des observations faites sous forme de graphiques (figures 3a et 3b).

2.3. Méthode d’étude de la variation microclimatique de la température de l’air ambiant et du grenier

En relation avec la température, les observations ont concerné 23 greniers in situ, répartis sur toute l'étendue de la zone couverte par le projet. En tout 14 observations ont été enregistrées sur chaque grenier entre le 3/12/84 et le 16/7/85 au rythme d'une observation tous les 14 jours.

Ces mesures indiquent la température au centre du grenier. Les résultats sont des valeurs moyennes des observations faites, et sont exprimés sous forme de graphiques (figure 4).

---

[1]* Villages dont les greniers ont fait l'objet de mesures de température et d'humidité relative qui ont servi aux estimations régionales des variations de ces facteurs physiques dans le temps.

2.4. Méthode d'étude de la variation de la teneur en eau des grains en cours de stockage

S'agissant de la variation de la teneur en eau des grains dans le grenier, les observations faites de la récolte à la fin du stockage ont porté sur 12 greniers in situ dont 3 par région microclimatique. En tout 14 observations ont été enregistrées entre le 3/12/84 et le 16/7/85 sur chaque grenier, et au rythme d'une observation tous les 14 jours.

Les résultats représentant la valeur moyenne de 3 greniers sont exprimées sur des graphiques.

- **Méthode d'étude de la variation microclimatique de l'humidité de l'air ambiant et des grains en cours de stockage**

En relation avec l'humidité, les observations ont été en effet réalisées sur des greniers in situ, c'est-à-dire auprès des paysans et sur des greniers regroupés en station à l'Ecole Supérieure d'Agronomie, Lomé. La zone couverte par le projet ayant été divisée en 4 régions microclimatiques, sur les 23 villages concernés par les études, 12 seulement ont été retenus pour le présent travail soit 3 villages par région microclimatique (Figures 5 a-d).

3. Resultats

3.1. Le grenier traditionnel à maïs : structure et typologie

3.1.1. La structure des greniers traditionnels

D'une façon générale [2], le grenier tradiditionnel, à moins que ce soit au plafond d'une cuisine, comporte quatre parties principales (figure 2).

- Le support ou système de pieux

Cette partie est généralement en bois (bambou, rônier ou autres espèces). Dans ce cas, elle est alors constituée d'au moins quatre piquets de taille allant de 50 à 200 cm du sol et disposés en carré, en rectangle ou en circonférence.

a) La plateforme de stockage

Elle est faite d'un ensemble de branchages ou de claies soigneusement attachées au support en respectant le schéma esquissé par le support.

La plateforme de stockage peut être plate comme elle peut être creuse. Dans ce dernier cas, la partie la plus basse de cette plateforme est généralement soutenue soit à l'aide de piquets de taille nettement inférieure à ceux mentionnés précédamment, soit à l'aide de gros cailloux.

- <u>La masse de produits stockés</u>

  Le grenier traditionnel ne sert qu'à conserver le maïs en spathes. Les épis entiers sont en général rangés suivant des couches concentriques autours d'une monticule de maïs non rangé.

  La masse de maïs stocké se présente extérieurement comme un cylindre attaché, à intervalles réguliers, par des lianes, de façon à la consolider.

  Dans le cas du grenier tressé, aucune précaution n'est prise pour le rangement du produit en son sein. Il en résulte que la densité du produit en son sein est nettement plus faible qu'elle ne l'est au niveau des autres types de greniers.

- <u>Le toit ou couverture</u>

  Généralement en pailles tressées, le toit est de façon conique au-dessus de la masse de produit, et prend appui sur un piquet de bois enfoncé dans la masse de produit stocké.

  Son rôle essentiel est de protéger le maïs stocké contre les pluies, ceci malgré la négligence relative affichée par certains producteurs de maïs dans sa confection.

3.1.2. Typologie des greniers traditionnels

A partir des observations que nous avons faites sur les greniers à maïs de la zone du projet, nous pouvons les classer en deux grandes catégories (figure 2):

- <u>les greniers fermés</u>

  Ce sont ceux qui cachent entièrement la masse de produit stocké. On y distingue les <u>greniers tressés</u> et les <u>greniers au plafond</u> des maisons, surtout des cuisines.

- <u>les greniers ouverts</u>

  Ce sont ceux qui sont susceptibles de laisser apparaître la masse de produit stocké, si celle-ci était importante. On distingue parmi eux :
    - les greniers bas (notés **Gb** sur les figures) pouvant avoir un fond plat ou creux (notés respectivement **Fp** ou **Fc** sur les figures),
    - les greniers hauts (notés **Gh** sur les figures) à fond généralement plat (notés **Fp** sur les figures)

Il est à remarquer que, les greniers hauts semblent être plus adaptés aux régions humides ; ils s'imposent dans le cas où le propriétaire choisi de pratiquer de l'enfumage pour assurer à son maïs une excellente conservation. Toutefois, tous les greniers hauts ne sont pas absolument sujets à l'enfumage.

3.2. Effet des facteurs climatiques sur le fonctionnement du grenier traditionnel.

Les études ont révélé que les principaux paramètres climatique en oueuvre dans le fonctionnement des greniers traditionnels sont d'ordre thermique et hydrique.

3.2.1. Effet du facteur thermique sur le mode de fonctionnement du grenier traditionnel

Cinq séries d'observations de température au sein et à l'extérieur de 4 types de greniers traditionnels dont le crib [3], indiquent les variations nycthémérales moyennes de la température au sein et à l'extérieur de 4 types de greniers traditionnels. Elles sont faites en station entre Décembre 1985 et Mai 1986 révèlent certains aspects de leur fonctionnement (figures 3a & 3b).

Ces observations aboutissent aux conclusions suivantes:

- Stabilité thermique du grenier traditonnel

  A l'examen des données d'observation, le grenier apparaît comme une enceinte résistant à des variations thermiques considérables. En effet, sur les 5 séries d'observations, et sur les 4 types de greniers concernés, les variations thermiques extrêmes ont été en moyenne de 28,0° et 29,6°C alors que la température de l'air ambiant a varié entre 25,9° et 30,3° C. D'une façon générale, la moyenne thermique journalière apparaît plus élevée dans les greniers (28,8°C) que dans l'air ambiant (27,9°C), et ceci quel que soit le type de greniers

- Les variations thermiques au sein des greniers en relation avec celles de l'air ambiant

  Suivant le tracé des courbes moyennes de variations thermiques pour l'ensemble des greniers et pour l'air ambiant (Figure 3a), on peut observer des déphasages constants entre la variation de température interne aux greniers par rapport à la variation de température de l'air ambiant. Cette observation indique également que les greniers réagissent avec un net retard (d'environ 3±1 heures) aux variations de température de l'air ambiant; le délai minimum de réaction reste cependant à préciser en augmentant la fréquence des mesures thermiques à 24 par exemple.

  Par ailleurs, la figure 3a révèle deux phases thermiques; une phase d'emmagasinement diurne de chaleur au niveau du grenier et une phase de refroidissement nocturne. Pendant la phase de réchauffement du grenier, la température de l'air ambiant est supérieure à celle prévalant au sein du grenier: une telle différence de température engendre un courant de transfert de chaleur se faisant donc de l'extérieur vers l'intérieur du grenier. Pendant la phase de refroidissement de la température interne du grenier, la température de l'air ambiant reste inférieure à celle prévalant au sein du grenier: le courant du transfert de chaleur se fait donc de l'intérieur du grenier vers l'extérieur. Ces observations complètent celles relatives à la variation de la température en fonction des positions verticales et radiales

- Relation entre types de greniers et variations thermiques en leur sein

Les résultats indiquent, entre les types de greniers (figure 3b), une distinction entre "greniers chauds" avec une moyenne thermique journalière de 29,3° à 29,7°C , et "greniers froids" avec une moyenne thermique journalière de 28,1° à 28,3°C , alors que la moyenne thermique journalière de l'air ambiant se situe entre 25,9° et 30,3°C .

Figure 3a : courbe moyenne des variations thermiques nycthémérales au sein des greniers traditionnels et dans l'air ambiant

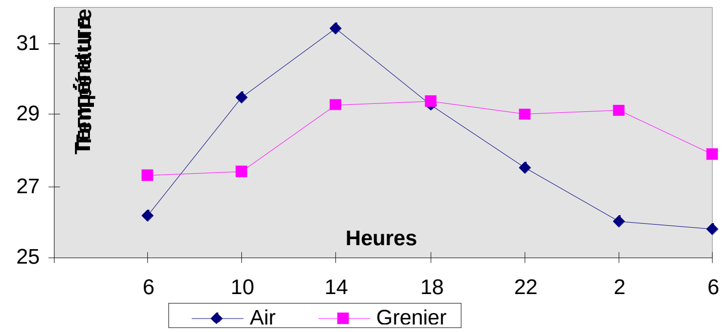
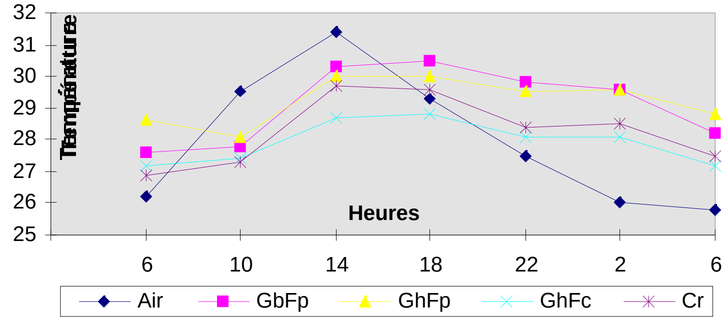


Figure N° 3b : Courbes moyennes des variations thermiques dans l'air ambiant et au sein de 4 types de greniers traditionnels



Les "greniers chauds" sont essentiellement des greniers à fond plat, qu'ils soient hauts ou bas. L'influence de la hauteur en faveur de l'élévation de la moyenne thermique du grenier, quoique apparente, ne paraît pas significative.

Malgré que les "greniers froids" aient des moyennes thermiques journalières relativement plus faibles que celles des "greniers chauds", ils entretiennent des moyennes thermiques journalières nettement plus élevées que la moyenne thermique journalière de l'air ambiant. En outre la phase de rechauffement des "greniers froids" apparaît nettement plus longue (environ 10 à 11 heures) que celle des "greniers chauds" (environ 4 à 5 heures). Dans le cadre de nos observations, sont considérés comme "froids" les greniers hauts à fond creux, de même que les cribs dont le fonctionnement thermique semble d'ailleurs trancher avec celui des greniers traditionnels proprement dits. Comparé au grenier haut à fond plat, le grenier haut à fond creux devrait son caractère "froid" à son fond creux, qui aurait tendance à exposer plus facilement la masse de maïs stocké aux conditions thermiques de l'air ambiant. Cette conclusion laisse prévoir que le grenier bas à fond creux serait également un "grenier froid".

- Conséquences pratiques des observations sur la variation de la température au sein du grenier traditionnel

  Le grenier traditionnel apparaît à la lueur de nos observations comme une enceinte relativement isolée capable d'emmagasiner de l'énergie solaire qu'il puise de la chaleur de l'air ambiant, et d'en céder partiellement lorsque la température de ce même milieu venait à devenir plus faible que la sienne. Et la stabilité thermique relative manifestée par lui incite à exclure toute idée d'une grande circulation d'air en son sein; le transfert de chaleur s'y opérerait essentillement par convection ou diffusion, au moins pendant une partie du temps de conservation : plus de précisions sur le phénomène seront apportées dans notre communication suivante.

  En définitive, par sa dynamique, le grenier apparaît plus qu'un simple entrepos à maïs : c'est **un véritable séchoir**.

  Sur un autre plan, les observations thermiques sur les greniers traditionnels semblent attribuer leur caractère "chaud" ou "froid" à la forme plate ou creuse de leurs plateformes : les greniers à fond plat seront plus "chauds" que ceux à fond creux ou concave. Ainsi, la concavité de la plateforme, recherchée pour acroître la capacité du grenier ne semble pas favoriser son efficacité.

3.2.2. Effet du facteur hydrique sur le mode de fonctionnement du grenie traditionnel.

La récolte précoce ou le stade de maturité du maïs peut présenter l'avantage de réduire, au moins partiellement, les dégâts dus aux oiseaux, aux rongeurs et aux insectes sur les épis avant leur récolte.

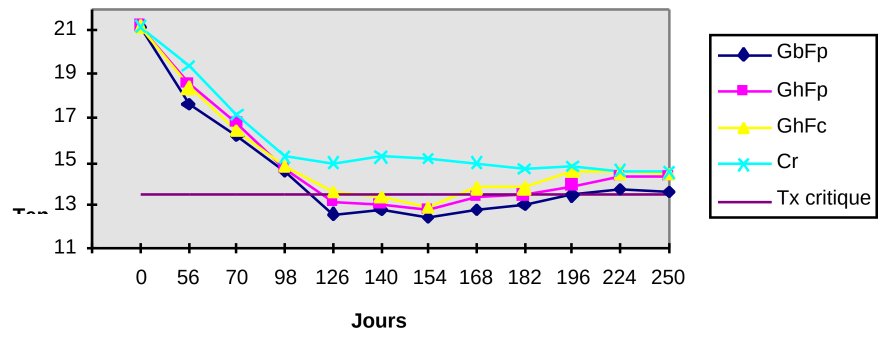
Les résultats d'observations [4] faites sur 12 greniers "précoces" et 12 greniers "tardifs" révèlent (figure 5) que dans nos conditions de travail, les teneurs en eau des grains à la récolte ont été de 25,1% pour le maïs récolté précocement contre 21,1% pour celui récolté tardivement. A 42 jours (soit 6 semaines) de la récolte, les teneurs en eau des grains se retrouvent au même niveau (15,4 et 15,3%) pour les 2 niveaux de précocité. A 56 jours (soit 8 semaines) de la récolte, les teneurs en eau des grains pour les 2 nivaux de précocité parviennent à 14% : à partir de là, elles fluctueront désormais entre 13 et 14%, du moins pour la période de l'année considérée par l'étude.

Si l'on considérait la récolte précoce, la perte de teneur en eau des grains s'est opérée au rythme moyen de 2% par semaine pendant les 4 premières semaines suivant la récolte, et de 0,5 à 0,75% en moyenne par semaine entre la fin de la 4ème semaine et celle de la 10ème semaine.

En prenant en compte la récolte tardive, tout se passe comme si, pendant les 2 semaines séparant la récolte précoce de la récolte tardive, le maïs devrait absolument perdre en tout 4% de sa teneur en eau, qu'il soit sur pied ou qu'il soit stocké dans un grenier; en d'autres termes, le grenier tel que nous le connaissons permet au produit récolté précocement de rattraper les deux semaines qui lui ont fait défaut par rapport au produit récolté plus tardivement.

En définitive, entre 8 et 10 semaines de la récolte, et suivant la précocité de celle-ci, le grenier traditionnel aurait permis au maïs de parfaire son séchage commencé pendant qu'il était encore sur pied. Ce phénomène, se produisant d'abord rapidement dans les premières semaines suivant la récolte, se poursuit lentement et progressivement jusqu'à un seuil d'équilibre avec l'humidité relative de l'air entre 13 et 14% atteint entre 10 et 12 semaines de la mise en grenier. Il est entendu que la teneur critique en eau des grains au-dessus de laquelle la conservation rencontre des difficultés est fixée à 13,5 % selon FAO (1983). Néanmoins, il est apparu dans nos travaux qu'une amélioration structurelle de ce grenier traditionnel pourrait accélérer la vitesse de séchage dès le début de l'entreposage.

Figure N°4 : Courbes de variation de la teneur en ea grains dans 4 types de greniers



Sur un autre plan, l'évolution de la teneur en eau des grains, mesurée sur 3 types de greniers traditionnels et un crib, confirme les conclusions sur les facteurs thermiques et partant l'efficacité supérieure du grenier haut à fond plat par rapport aux autres structures étudiées.

En définitive, les présentes observations confirment le fait que le grenier traditionnel n'aurait pas seulement la fonction d'un local servant à l'entreposage d'épis de maïs. De par sa structure, il a fonctionné également comme séchoir pour la masse d'épis de maïs stocké, surtout en période de forte teneur eau du maïs, du moins dans la phase finale du séchage des épis récemment récoltés et stockés.

3.3. Fonctionnement du grenier traditionnel en fonction des zones microclimatiques

3.3.1. Variations thermiques diurnes de l'air ambiant et des grains au sein des greniers traditionnels

Ce paramètre est exprimé sous forme de courbes moyennes des températures au sein et à l'extérieur de trois greniers in situ (Figure 5a-d) par région microclimatique. Selon ces résultats, deux catégories de régions se dégagent:

1. les régions à tendance régulière, c'est-à-dire celles des montagnes et des plateaux,

1. les régions à tendance irrégulière, c'est-à-dire la région maritime et celle des plaines.

Dans la catégorie des régions à tendance régulière, on observe un écart net entre la température au sein des greniers et celle à l'extérieur d'une part, et les courbes de ces températures se croisent peu pendant la durée de l'étude. D'une façon presque générale par ailleurs, la moyenne thermique diurne au sein du grenier apparaît supérieure à celle de l'air pendant les périodes de pluies, situation qui semble s'inverser aux périodes de sécheresse.

Dans la catégorie des régions à tendance irrégulière, l'écart entre les températures au sein du grenier et celles de l'air ambiant reste généralement faible sur toute la période couverte par l'étude ; la faiblesse de cet écart semble s'expliquer par le fait que les courbes des températures se croisent beaucoup plus souvent. La tendance à l'irrégularité apparaît plus marquée en région des plaines. Avec un peu moins de clarté que dans la précédente catégorie, il apparaît ici également que la moyenne thermique diurne au sein du grenier reste supérieure à celle de l'air ambiant pendant les périodes de pluies, situation qui s'inverse pendant les périodes de sécheresse.

Somme toute, cette anomalie thermique observé pendant les périodes de pluies au niveau des greniers traditionnels serait l'expression d'une perturbation fonctionnelle à leur niveau, et expliquerait ainsi la réhumidification des produits stockés pendant la saison des pluies.

3.3.2. Variations de l'humidité de l'air ambiant et des grains dans les greniers traditionnels

Il ne fait aucun doute qu'il existe une relation étroite entre l'humidité relative de l'air et la teneur en eau du maïs stocké [7] ; et les paysans eux-mêmes indiquent qu'à l' arrivée de la saison des pluies, la conservation du maïs rencontre les plus sérieux dégâts au niveau des greniers.

Selon 14 observations faites <u>in situ</u> entre le 03.12.84 et le 16/07/85 sur greniers par région microclimatique, on peut noter que, d'une façon générale, l'humidité relative de l'air de la saison sèche (Novembre-Mars) est plus faible que celle de la saison des pluies (Mars-Juillet).

D'une façon générale, la variation des courbes d'humidité relative des 4 régions paraît se calquer sur celle de leurs histogrammes des pluies (figure 6a).

Enfin, si l'on considérait que, sous nos conditions de milieu, l'isotherme d'absorption de la vapeur d'eau pour les céréales se situe à environ 70% d'humidité relative pour la conservation à une teneur en eau constante de 13,5% [1] la conservation du maïs commencerait à rencontrer des conditions d'humidité relative trop élevée à partir de la mi-Mars pour les régions microclimatiques de la zone du Projet (figure 6a).

Il apparaît intéressant de noter par ailleurs que le niveau critique de teneur en eau (Tc) des grains de 13,5% [1], est atteint en Avril pour la région des montagnes, et seulement vers Mai pour la région des plateaux (figure 6b). Malgré que l'ensemble de ces courbes accuse un léger pic en Mars, elles semblent indiquer que ce serait vers fin-Avril seulement que le niveau de la teneur en eau des grains stockés va dépasser franchement le seuil critique pour une bonne conservation.

Figure N°5a : Courbes des variations des paramètres stockage suivant les saisons et les régions microclimat Zone maritime

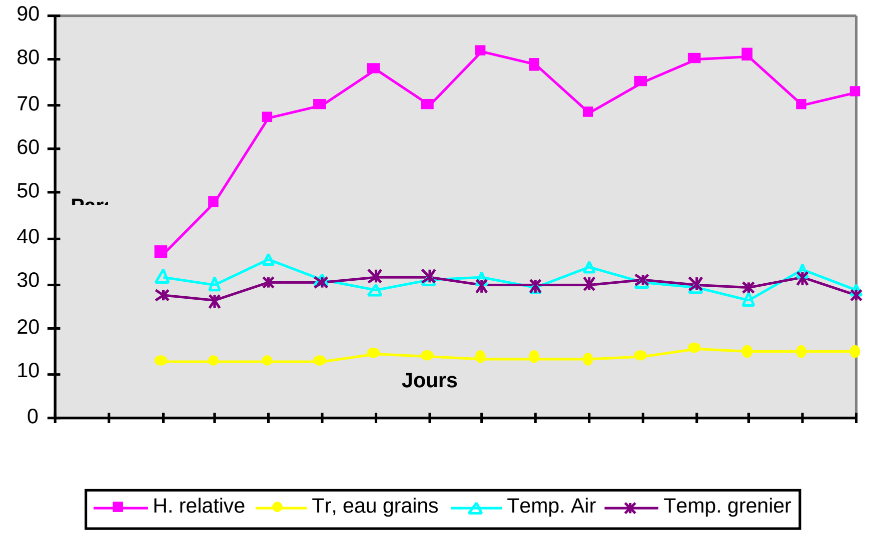


Figure N° 5b : Courbes des variations des paramètres de stockage suivant les saisons et les régions microclimatiques : Zone des piémonts

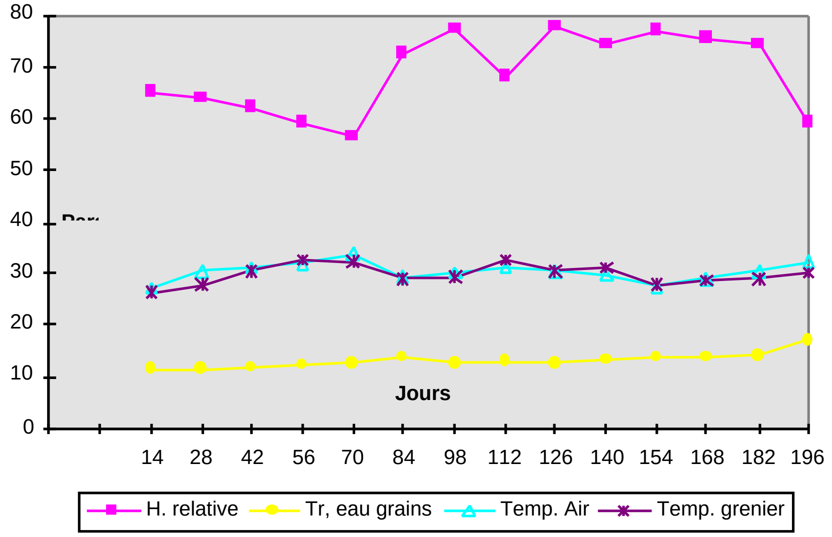


Figure N°5c : Courbes des variations des paramèt stockage suivant les saisons et les régions microclimatiques : Zone des plaines

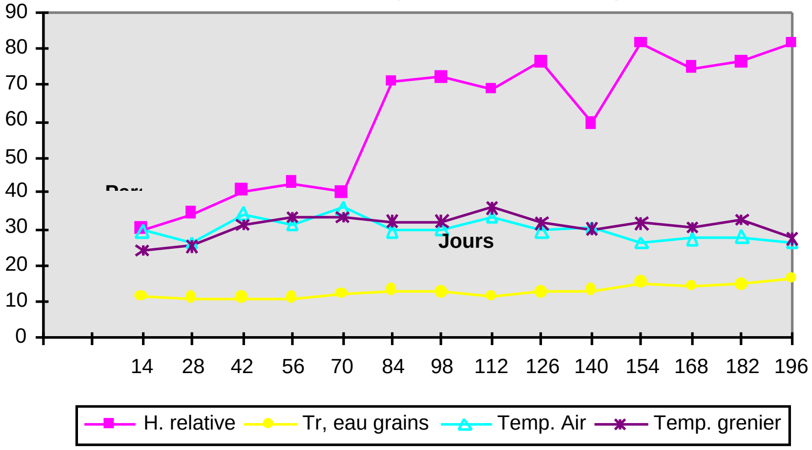


Figure N°5d : Courbes des variations des paramèt stockage suivant les saisons et les régions microclimatiques : Zone des montagnes

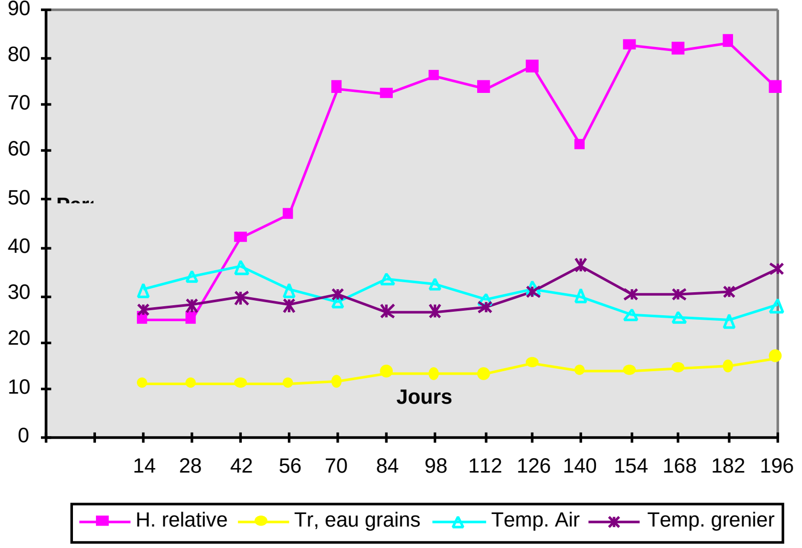


Figure N°6a : Courbe des variation de l'humidité relative dar zones microclimatiques

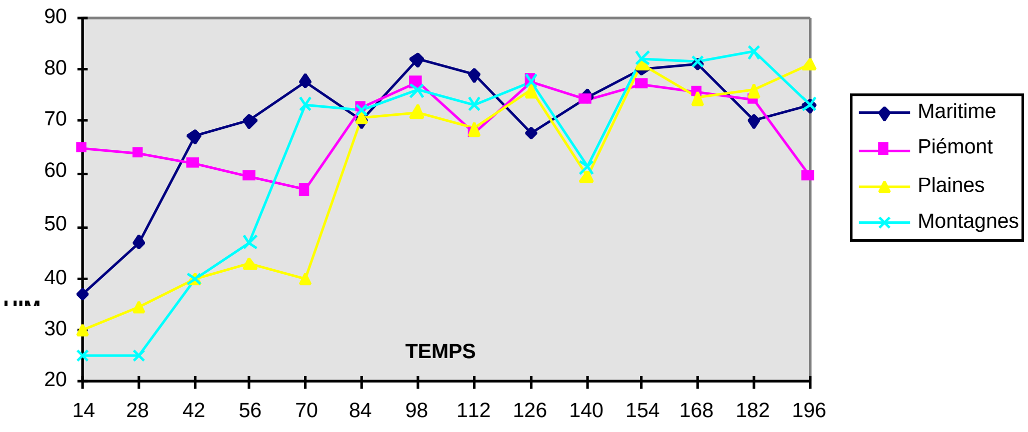
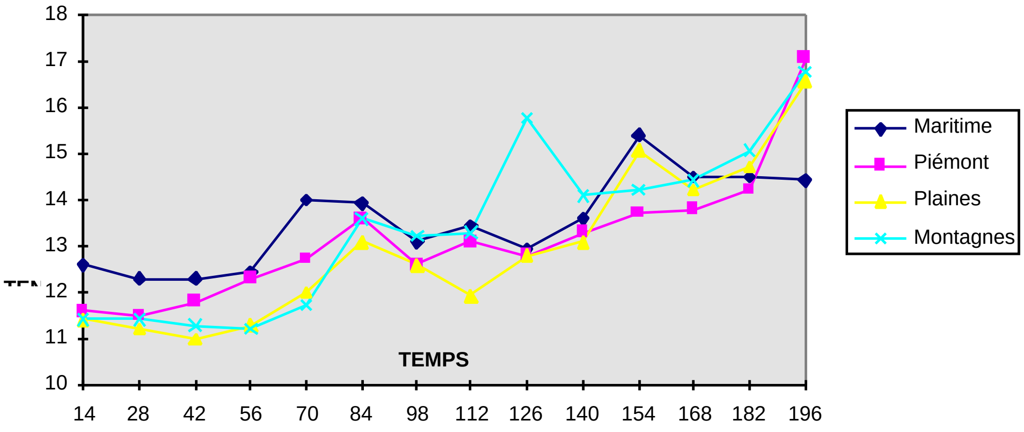


Figure N°6b : Courbe de teneur en eau des grains dans les microclimatiques



3.4. Conséquences des principes de fonctionnement du grenier traditionnel dans son cadre climatique et biologique.

Un accord apparaît entre les conclusions relatives aux observations sur les facteurs thermiques et celles sur les facteurs hydriques, et ce dans les 4 régions microclimatiques [5]. Il s'ensuit que la fonction de séchage très efficace entre Août et Février aussi bien dans les greniers traditionnels que dans le crib, se trouve handicapée par l'arrivée des pluies en Mars. Par ailleurs, l'apparition de **Prostephanus truncatus** réduit ce temps de conservation au début de Décembre, faute de quoi les pertes enregistrées deviennent très importantes.

Ces considérations donnent une indication des limites du grenier traditionnel, qui apparaît alors comme une structure intermédiaire ou structure-relai. En effet, celui-ci assure le séchage des produits stockés jusqu'à l'entrée dans la saison sèche. Ensuite, ces produits devront être conditionnés ultérieurement dans une autre structure susceptible de les protéger plus efficacement contre la réhumidification et les insectes. Cette autre structure de substitution qui pourrait être un silo, un magasin ou autre, ne saurait intervenir dès la récolte si aucun moyen de séchage n'est prévu.

Cette question prend d'autant plus d'importance que le maïs produit en deuxième campagne, représentant à peine 20% du total annuel, est récolté en saison sèche; c'est donc environ 80% de la production annuelle qui sont concernés. Ellle fait également appel aux contextes culturel, technologique et économique dans lesquels opèrent les producteurs de maïs.

4. Conclusion

Somme toute, la présente étude révèle l’adéquation du grenier traditionnel à maïs à son contexte écologique, technique, socio-économique et politique [6].

Au plan technique, le grenier traditionnel à maïs remplit de façon assez satisfaisante une double fonction: celle d'un séchoir et celle d'un entrepos. La fonction de séchoir semble obligatoire dans les conditions climatiques en vigueur à la récolte et dans le système d'exploitation dans lequel le maïs est produit. En définitive, l’efficacité de cette double fonction se trouve limitée par l’inefficacié des produits de traitement ou insecticides couramment vulgarisés, car inadaptés au type de stockage dans les greniers traditionnels à maïs de la zone guinéenne du Togo.

Au plan social, l'exploitant producteur de maïs entretient des liens privilégiés avec ses greniers à travers les rituels faisant intervenir ses ancêtres, et à travers le statut social que ses greniers lui confèrent au sein de la communauté.

Par ailleurs, au plan économique, le grenier assure une autosuffisance alimentaire et des revenus substantiels à son propriétaire.

Enfin, au plan politico-économique, le maïs représentant le produit alimentaire de basedu pays, l'amélioration et la promotion de cette structure endogène de stockage participeraient d'une stratégie sécuritaire alimentaire. En effet, soutenue par une organisation nationale efficace, cette structure pourra accroître les bases de la sécurité alimentaire nationale encore fragile par un rapprochement des stocks des utilisateurs potentiels par un déplacement des surplus d'une région excédentaire vers une autre en difficulté.

References

FAO (1983) - Food storage manuel - 2è Edit. 263 p.

Kpakote, K.G., Smith, H.S. & Smith, P.J. (1986) - Etudes togolaises de stockage de maïs en milieu rural : I - Les paramètres affectant la conservation traditionnelle du maïs à travers les avis des cultivateurs. Actes Conf. Intern. ANSTI/UNESCO ; Nairobi, 14 - 18 Avril 1986.

Kpakote, K.G., Smith, H.S. & Smith, P.J. (1988 a) - Etudes togolaises de stockage de maïs en milieu rural : III - Influence de la température sur le fonctionnement des greniers traditionnels in Food production & Agriculture in Africa.- Actes conf. Internat. Académie des Prof. Pour la Paix mondiale, Lomé : 06-10 Déc. 1986 - Edit. Adjangba, A.M. ; p. 201-214.

Kpakote, K.G., Smith, H.S. & Smith, P.J. (1988 b) - Etudes togolaises de stockage de maïs en milieu rural: IV - Influence du fonctionnement du grenier traditionnel sur l'humidité des grains en rapport avec l'humidité relative de l'air. in Food production & Agriculture in Africa.- Actes conf. Internat. Académie des Prof. Pour la Paix mondiale, Lomé : 06-10 Déc. 1986 - Edit. Adjangba, A.M. ; p. 215-223.

Kpakote, G.K. et al.(1994 a) - Performances des greniers traditionnels utilisés dans la zone tropicale guinéenne du Togo.- Journées tech. : expérience acquise en Afrique pour l'amélioration des tech. post-récolte. - Accra : 4 - 8 Juil. 1994.

Kpakote, G.K. et al.(1994 b) - Caractéristiques socio-économiques des systèmes traditionnels de stockage de maïs dans la zone tropicale guinéenne du Togo. - Journées tech. : expérience acquise en Afrique pour l'amélioration des tech. post-récolte. - Accra : 4 - 8 Juil. 1994.

Multon, J.L. (1982) - Conservation et stockage des grains et graines et produits dérivés: céréales, oléagineux. - Vol. 1, 576 p. Edit. Technique et Documentation Lavoisier.

Changement Climatique/Variabilite et Production Agricole

Alhassane A. Diallo
Direction de la Meteorologie Nationale

Abstract

Le communauté scientifique internationale en établissant un lien entre le changement climatique et les activités humaines a permis la mise en place de la Convention sur le changement climatique afin de parer au danger.

L'histoire du climate de la Terre nous reseigne que les changements climatiques ont toujours existé naturellement. Cependant, le climate se modifie plus rapidement à notre époque qu'il ne s'est transformé en dix millénaires et la planète découvre des conditions météorologiques extrêmes, inconnues jusqu'alors. Au cours des cent dernières années, la température de la terre a augmenté de 0,3 à 0,6°C et le niveau de la mer s'est élevé de 10 à 25 cm, ce qui est une menace sur la vie des populations des régions de faible altitude (les îles et les zones littorales de basse altitude).

D'ici la fin de siècle prochain on s'attend à une hausse de la température de 1 à 3°C et une élévation du niveau de la mer de 0,2 à 1 mètre.

Le dioxyde de carbone (CO_2) et les autres gaz à effet de serre en modifiant le bilan énergétique conduisent à un réchauffement de la surface du globe.

Par ailleurs, les nations présentent des degrés de vulnérabilité variables face au changement climatique et à la hausse du niveau de la mer. La vulnérabilité dépend de l'ampleur des changements environnementaux auxquels est confrontée une nation, de ses circonstance particulières et des ressources disponibles pour soutenir les stratégies d'adaptation.

Le changement climatique aura des conséquences tant sur la santé des populations que sur leur sécurité alimentaire. La situation du SAHEL est évocatrice: diminution tendancielle du régime des pluies donc une baisse de la production, (l'agriculture étant essentiellement pluviale).

L'impact du changement climatique sur l'agriculture varie selon les régions. Il sera porteur de plus de productivité dans certaines et au contraire entraînera une diminution de celle-ci dans d'autres régions.

Cette variabilité est liée à la disponibilité des ressources en eau et du comportement des plantes face aux fortes températures. Les nations sont obligées

d’adopter des stratégies de parade afin d’assurer la sécurité alimentaire de leurs populations.

Plusieurs voies sont utilisées dans les pays du SAHEL notamment au Burkina Faso.

La recherche agronomique s’oriente vers des techniques d’économie de l’eau, la création de variétés plus productives tout en étant résistantes à la sécheresse.

D’autres outils tels que les analyses agroclimatologiques en cue de définir des zones agroclimatiques les plus propices aux différentes cultures et la période de disponibilité en eau pour l’agriculture qui est essentiellement de type pluvial même si de grands efforts sount faits pour la maîtrise de l’eau en vue de l’irrigation. La connaissance parfaite du régime pluviométrique et l’utilisation de données de télédétection et de modèles agroclimatologiques permettent de mettre en place de façcon concomitante un système d’alerte précoce utile pour reseigner sur les risques et les difficultés recontrés au cours de la campagne agricole et un système de suivi agrométéorologique des cultures pour une estimation de la production assez précocement afin de prendre les décisions adéquates à temps.

Dans les pays du SAHEL cette expérience est opérationnelle depuis quelques années et permet d’assurer une politique de sécurité alimentaire.

1. Contexte et Definitions

Dans les années 80, les scientifiques en établissant une relation entre les émissions humaines de gaz à effet de serre et les changements climatiques mondiaux, suscitent l’inquiétude du public et appellent à concevoir d’urgence un triaté mondial afin de parer au danger.

En 1990, l’Assemblée Générale des Nations Unies met en place un Comité intergouvernemental de négociation qui rédige un project de Convention que sera adoptée le 09 mai 1992 à New York et ouverte à la signature en juin 1992, au Sommet de la Terre à Rio de Janeiro. Elle est entée en vigueur le 21 mars 1994 soit quatre-vingt-dix jours après la date du dépôt des instruments de ratification par le cinquantième Etat ou Organizme d’intégration économique régionale.

L’organe suprême de la Convention, **la Conférence de Parties (C.P.)** a défini un certain nombre de concepts pour la compréhension du phénomène, l’organisation, le fonctionnement de la mise en œuvre des différents éléments de la Convention:

1. **changements climatique:** des changements de climat qui sont attribués directement ou indirectement à une activité humaine altérant la composition de

l’atmosphère mondiale et qui viennent s’ajouter à la variabilité naturelle du climat observée au cours de périodes comparables;

2. **effets néfastes des changements climatiques:** les modifications de l’environnement physique ou des biotes dues à des changements climatiques et qui exercent des effets nocifs significatifs sur la composition, la résistance ou la productivité des écosystèmes ou sur la santé et le bien-être de l’homme;

3. **gaz à effet de serre:** les constituants gazeux de l’atmosphère, tant naturels au’antropiques, qui absorbent et réémettent le rayonnement infrarouge;

4. **système climatique:** un ensemble englobant l’atmosphère, l’hydrosphère, la biosphere et la géoshère, ainsi que leurs interactions;

5. **émissions:** la libération de gaz à effet de serre ou de précurseurs de tels gaz dans l’atmosphère au-dessus d’une zone et au cours d’une période donnée;

6. **réservoir:** un ou plusieurs constituants du système climatique qui retiennent un gaz à effet de serre ou un précurseur de gaz à effet de serre;

7. **puits:** tout processus, toute activité ou tout mécanisme, naturel ou artificiel, qui élimine de l’atmosphère un gaz à effet de serre, un aérosol ou un précurseur de gaz à effet de serre;

8. **source:** tout processus ou activité qui libère dans l’atmostphère un gaz à effet de serre, un aérosol ou un précurseur de gaz à effet de serre.

2. Comprehension du Phenomene

Le climat se modifie plus rapidement à notre époque qu’il ne s’est transformé en dix (10) millénaires et la planète découvre des conditions météorologiques extrêmes, inconnues jusqu’ici. Depuis le révolution industrielle, la température à la surface de la terre a augmenté de 0,3 à 0,6° et le niveau des mers s’est élevée de 10 à 25 cm au cours des cent dernières années, faisant peser une menace sur la vie des populations des régions de faible altitude.

Le Group Intergouvernemental sur l’Evolution du Climat (GIEC), a affiremé dans son deuxième rapport en 1995 que l’activité humain exerce effectivement une influence sur le climat global et que les concentrations accrues de gaz à effet de serre, largement atrribuées aux activités humains et plus particulièrement à l’utilisation de combustibles fossiles, à la modification de l’occupation des sols et à l’agriculture, ont provoqué une modification du bilan énergétique qui tend à réchauffer la surface du globe et à engendrer d’autres changements.

2.1 Rôle des gaz à effet de serre

- la plupart des consituants mineurs de l'atmostphère absorbent une partie du rayonnement infrarouge, mais ils le font à des degrés divers (il est donc malaisé d'établir une distinction bien nette entre les gaz dits gaz à effet de serre et les autres).

Quels sont donc les gaz qui importent réellement?

- la concentration dans l'atmosphère des gaz à effet de serre résulte de la differènce nette entre leur production par des «sources» et leur absorption par «des puits».

En renforçant les sources ou en affaiblissant les puits, l'homme peut contribuer à accroître la concentration.

- La vapeur d'eau est la gaz à effet de serre qui exerce la plus foret acton sur le climat présent. Sa concentration dans les basses couches dépend cependant de l'èquilibre naturel entre l'évaporation et les précipitations, donc non affectée directement par les activités humains.

- Le dioxyde de carbone ou gaz carbonique (CO_2), le méthane et les chlorofluorocarbures (CFC), émissions directement liées aux activités humaines, augmentent en concentration.

Le CO_2 rejeté dans l'atmosphère provient principalement de l'emploi de combustibles fossiles. En outre il peut y séjourner pendant de nombreuses décennies en retant chimiquement stable.

- Il existe un réseau complexe de puits naturels qui élimine une portion de CO_2 présent dans l'atmosphère (les Océans, les végétaux terrestres et les planctons).

- L'augmentation de la concentration de CO_2 dans l'atmosphère est le cycle complexe du carbone se modifie (causes: déforestation, rétroactions entre processus chimiques et biologiques dans les Océans et réchauffement de la planète).

2.2 Le Système Climatique

Le système climatique est complexe (Fig. 1: Sysème climatique). Le climat est gouverné par ce qui se passe dans l'atmostphère, les océans, la cyrosphèse (glaciers), la géosphère et la biosphère. Les interactions entre ces «sphères» ne sont pas totalement connues et les processus se passent à des échelles temporelles très différentes. Le temps de retour à l'équilibre de ces divers éléments du système climatique va d'un seul jour à plusieurs millénaires.

- Le système climatique tire pratiquement toe son énergie du rayonnement solaire;
- L'intensité du réchauffement produit par le rayonnement solaire est en partie subordonnée à la nature de la surface terrestre (dirrérence de réchauffement des océans et la terre ferme);
- Les océans influent foretment sur le climat présent;
- Les glaces renvoient dans l'espace une fraction importante du rayonnement solaire (albedo très élevé);
- Le comportement de la biosphère et de l'atmosphère n'est pas tout à fait élucider.

Le group de travail I du GIEC a publié en 1990, dans son rapport, les scénariôs régionaux d'évolution du climat pour cinq régions du globe, ce sont:

Sahel (10-20°N; 20-40°E)
Réchauffement de 1 à 3°C. Faible augmentation des précipitations moyennes sur la zones. Disparité des tendances à l'intérieur de la zone.

Sud de l'Europe (35-50°N; 10°W-45°E)
Réchauffement de 2°C en hiver et de 2 à 3°C en été. Augmentation possible des précipitations en hiver mais baisse de 5 à 10% en été.

Amérique du Nord - partie centrale (35-50°N; 85-105°W)
Réchauffement de 2 à 4°C en hiver et de 2 à 3°C en été. Augmentation des précipitations de 0 à 15fi en hivers, diminution de 5 à 10fi en été.

Asie du Sud (5-30°N; 70-105°E)
Réchauffement de 1 à 2°C sur l'ensemble de l'année. Faible changemnet de précipitation en hiver, augmentation de 2 à 15 5 en été.

Australie (12-45°C; 11°-115°E)
Réchauffement de 1 à 2°C environ en hiver.

2.3 Analyse de quelques paramètres météorologiques

Pour illustrer l'évolution du climat, nous analyserons la pluviométrie et la température dans trois localités situées au Nord, au Centre et au Sud du Burkina Faso (Dori, Ouagadougou et Bobo-Dioulasso), sous des climats tout à fait différents qui sont respectivement les climats sahélien, soudano-sahélien et soudano-guinéen (Cartes 1 et 2: respectivement réseau météorologique et zones climatiques du Burkina Faso).

Les séries chronologiques de la pluviométrie annuelle laissent apparaître très clairement une baisse tendancielle de la pluviométrie dans toutes les trois régions. (Cf. fig. 2 à 4).

De même la superposition des isohyètes pour les périodes 1961-90, 1971-80 et 1981-90 montre un net décroshage vers le Sud. (Cf. Cartes 2a à 3c). Il est de l'orde de 150 mm pour 100km au Nord et plus faible au Sud. Il y a donc un décrochage différencie entre le Norde et le Sud.

L'évolution des températures maximales et minimales au contraire indique que celles-ci augmentent partout. (Figures 5 à 10). La tendance de l'élevation des températures minimales est plus marquée que celle des températures maximales pour atteindre +1.3° en 1990 au Nord.

2.4 Variabilité du climat

La caractéristique essentielle du climat des régions semi-arides tropicatles est leur extrême variabilité. Les inondations et la sécheresse s'alternent. De même au niveau des températures, tant à l'échelle du jour qu'à celle de la siason, il y a des fluctuations d'une forte amplitude.

Afin d'ilustrer la variabilité du climat, deux paramètres seront étudiés: la pluviométrie et la température, parce que ces deux paramètres caractérisent bien le climat.

L'importance de l'écard type et du coefficient de variation montre bien la variabilité interannuelle de la pluviométrie au Burkina Faso (Tableau 1).

A cela il faut ajouter une distribution très irrégulière des pluies au cours d'une saison que la détermination des séquences de jour secs permet de mettre en évidence (Tableau II). De même il y a de forts contrastes entre les températures maximales et minimales. Ces variations sont tout aussi importantes au niveau journalier que saisonnier.

Autour des valeurs moyennes de la pluviomètrie ou des températures ces variations exprimées par le coefficient de variation, représentent quelques fois 30% de celles-ci. Les fluctuations donc sont très importantes.

L'apparition de conditions météorologiques extrêmes comme conséquence du changement climatique accentue le caractère variable du climat tropical. Ces situations sont observées de plus à travers le monde entier (en Europe, on a déjà enregistré des inondations en Asie (Japon), en Afrique Occidentale (Benin, Côte d'Ivoire).

La caractéristique essentielle du climat des régions semi-arides tropicales est leur extrême variabilité. Les inondations et la sécheresse s'alternent. De même

au niveau des températures, tant à l'échelle du jour qu'à celle de la saison, il y a des fluctuations d'une forte amplitude.

2.5 Conclusion

- l'évolution du climat est une réalité

- Les nations présentent des degrés de vulnérabilité variables face au changement climatique et à la hausse du niveau de la mer. La vulnérabilité dépend de l'ampleur des changements environnementaux auxquels est confrontée une nation, de ses circonstances particulières et des ressources disponibles pour soutenir les stratégies d'adaptation.

Il est aujourd'hui démontré que l'activité humaine, contribue à l'évolution du climat et les scénarios aboutissent à une élévation moyenne de la température de 1 à 3°C, et du niveau de la mer.

L'élévation des températures observée dans les trois localités va dans le même sens que les prévisions faites pour la région SAHEL.

Les dispositions contraignantes contenues dans la convention et ses annexes visent à stabiliser les concentrations de gaz à effet de serre dans l'atmosphere à un niveau qui empêche toute perturbation anthropique dangereuse de système climatique, et ce dans un délai suffisant pour que les écosystèmes puissent s'adapter naturellement aux changements climatiques et que la production alimentaire ne soit pas menacée tout en assurant un développement durable.

Sans aucun doute l'activité humaine contribue à une modification rapide du climat. Des instruments d'action ont été définis et il appartient au Politique d'en assurer la mise en œuvre. Cela exige la solidarité entre tous les Etats et une disposition des Etats développés à favoriser le transfert de technologies propres et à soutenir les pays en développement dans la définition et la mise en œuvre d'un développement durable face à la rapidité des changements environnementaux auxquels il n'ont pas toujours les moyens d'opposer une parade conséquente.

3. Production Agricole

L'agriculture est un activité humaine extrêmement sensible aux aléas du climat et des conditions météorologiques. Des phénomènes climatiques et météorologiques extrêmes telles que les fortes températures, les pluies excessives, les sécheresses, les inondations sont une menace sérieuse pour la production agricole au double plan quantitatif et qualitatif. Il importe donc de considérer le climat comme une ressource naturelle qui influe sur les animaux et les plantes lesquels réagissent de diverses façons aux éléments climatiques et à leur variations en fonction de leur aptitude physiologique.

La production agricole s'est adaptée au cours des générations aux conditions climatiques locales et l'Homme a développé des stratégies qui intègrent la dimension climat dans ses activités agricoles. Mais face aux changements rapides du climat mondial, les technologies, les techniques éprouvées et les stratégies développées pourraient ne plus être efficaces pour assurer une production agricole conséquente.

3.1 Impact des changements climatiques sur l'agriculture

Les conséquences du changement climatique global sont variables selon les latitudes, les saisons, la position géographicque de la région au sein d'un continent.

La production agricole dépend essentiellement de la disponibilité en ressources hydriques, de la température et de la fertilité des sols en dehors de toutes les autres considérations (travail du sol, apport d'engrais et de l'eau, utilisation de variétés plus productives et plus adaptées, emploi de pesticides).

L'accroissement des concentrations de CO_2 pourrait améliorer la productivité agricole par l'augmentation de l'intensité de la photosynthèse des plantes tels que le blé, le riz, et le soja (plantes en C_3), par contre pour les plantes comme le sorgho, le maïs, le mil, les graminées de pâturage et de fourrage, les résultants seraient moins spectaculaires (plantes en C_4). De même une élévation importante des températures pourrait avoir des conséquences sur le métabolisme des plantes. Une analyse fine des températures permet de daire un choix judicieux et des périodes de cultures et des espèces qui conviennent aux conditions de température (Tableaux III et IV).

Or, les changements climatiques vont modifier les régimes régionaux de précipitations, d'évaporation et de température.

Les zones agroclimatiques tendraient à se décaler vers les pôles face à l'évolution du climat avec un décalage plus pronouncé au niveau des latitudes élevées car on prévoit que les températures moyennes augmentaeraient plus fortement au voisinage des pôles qu'à celui de l'équateur. Il faut s'attendre donc à des conséquences importatntes sur la production agricole.

L'élévation du niveau de la mer va exposer certaines populations littorales aux inondations età la perte de terres par érosion: certains territoires pourraient devenir des déserts et, en régions tropicales et subtropicales, les conditions de l'agriculture sont appelées à se détériorer.

Les zones côtières africanes devront faire face à une accélération de l’érosion côtières, à des modifications de la répartition temporelle et géographicque de la pluviousité, à des dégâts aux écosystèmes.

La détériouration physicque et chimique des terres, la modification des régimes pluviométrique et l’élévation de la température vont perturber les systèmes de production agricole et pourraient aboutir à des drames si les pays en développement ne bénéficient pas de transfert de technologies appropriées respectueuses de l’environnement et de la forêt, de la part des pays développés. Ils devraient en outre mettre en place des programmes de recherches agricoles conséquents qui prennent en compte les projections de l’évolution du climat admises à ce jour.

Quelqu’un a dit ceci «les pénuries alimentaires résultant d’évolution des températures, d’une diminution de la pluviosité et même d’une augmentation des vents, constituent l’une des principales menaces qui pèsent sur l’Afrique».

Les pays en développement sont les plus menacés par les répercussions des évolutions climatiques et ne disposent pas de moyens financiers qui leur permettraient de s’adapter à ces situations nouvelles. Les pays en développement sont les plus menacés par les répercussions des évolutions climatiques et ne disposent pas de moyens financiers qui leur permettraient de s’adapter à ces situations nouvelles. Les pays africains désorganisés pour diverses raisons (guerre, maladies, catastrophes naturelles) et dépourvus de technologies et de techniques appropriées sont les plus vulnérables et pourraient payer un lourd tribut si la solidarité internationale ne les soutenait pas à forger des outils de parade. Or le défi consiste à faire en sorte que les actions d’amortissement de l’impact du changement climatique à long terme soient compatibles avec l’objectif de développement durable, objectif dont la noblesse n’a d’égale que l’importance de la tâche à accomplir.

Dans la plupart des pays africains, l’agriculture occupe la grande majorité de la population et est essentiellement tributaire de la pluviométrie, elle-même particulièrement fluctuante surtout dans les régions semi-arides.

La production agricole est surtout orientée vers la satisfaction des besoins alimentaires bien que le thé, le café, le cacao et d’autres cultures industrielles constituent une part importante de l’économie de nombreux Etats.

Les régions où la modification des régimes de précipitation et d’évaporation aboutiraient à une diminution des ressources en eau, connaîtront une production agricole précaire et des risques de crise alimentaire pourraient s’y installer.

Afin d’atténuer cette situation, deux options existent pour sécuriser la production agricole:

1. la maîtrise totale ou partielle de l’eau

Cette voie est trop onéreuse et ne peut concerner qu'une petite fraction de la population. De plus les sites aménageables ne représentent qu'une faible portion des terres fertiles.

Sa mise en œuvre demande des ressources hydriques et financières importantes dont les Etats ne disposent pas. Elle, reste néanmoins la voie sure pour sécuriser la production agricole et éviter des crises alimentaires. La recherche de technologie simples, maîtrisables et supportables par les producteurs devra être encouragée.

2. l'adaptation de l'agriculture pluviale aux conditions climatiques et météorologiques

Pour ce faire, en amont, la recherche agricole devra intégrer les aspects ci-après dans ses programmes de recherche:

- économie de l'eau par des techniques culturales (diguettes filtrantes, billons cloisonnés, brise-vent, etc.);
- détermination de zonages agroclimatiques pour les différents cultures, (Figure 4);
- création de variétés résistantes à la sécheresse et aux fortes températures;
- techniques de protection des terres contre les différentes formes d'érosion.

La sécurité alimentaire étant la question essentielle à résourdre pour la plupart des pays africains, plusieurs stratégies ont été développées. L'une des plus simples est l'élaboration de mécanismes que reseignent sur la situation agricole dès les début de la saison des pluis et de façcon précoce.

La sécheresse étant endémique, elle est la menace à combattre. Les techniques développées ont pour but de minimiser les conséquences de la sécheresse sur la production et la disponibilité en produits alimentaires.

3.2 Système d'alerte précoce

Le système d'alerte précoce est un instrument qui permet de mesurer les variations conjonturelles des facteurs déterminants de la situation nutritionnelle des populations, d'évaluer les conséquences de ces variations et d'identifier les solutions ponctuelles permettant d'éviter les crises alimentaires graves.

L'objectif est de produire et diffuser des informations précoces et fiables sur la situation alimentaire et nutritionnelle des populations adin d'apporter les aides nécessaires en temps untile.

Pour ce faire, il convient de surveiller en permanence les perspectives des récoltes et de la situation alimentaire et de présenter une synthèse des résultats aux Décideurs.

Pour ce systéme, il faut:

D´terminer les zones à risque pour les cultures céréalières pluviales.

1) Contexte général

Les facteurs qui affectent la situation alimentaire des populations d'une région sont la disponibilité et l'accessibilité des produits alimentaires.

La disponibilité alimentaire est déterminée par la production agricole.

La production agricole est essentiellement basée sur les cultures céréalières destinées à l'autoconsommation.

Donc les zone à risque alimentaire sont d'abord celles où la production agricole céréalière est déficitaire.

Quelles sont les zones à risque pour les cultures céréalières pluviales?

CE SONT ZONES OU:

2) Il y a une installation tardive des cultures

Pourquoi?

- un début tardif de la saison des pluies;
- un échec des premiers semis.

3) La Longueur de saison trop coutre pour le cycle des cultures

Concept du Système

Si la durée de la saison des pluies ne permet pas de satisfaire les exigeces phénologiques minimales des cultures, il n'y aura pas de production.

4) Méthodologie d'approche:

i) Première étape

Données utilisées

- analyse agro-climatiques (ICRISAT)
- images de l'indice de végétation NOAA (AGRHYMET)
- images des champs pluviométriques Météosat (AGRHYMET)

Détermination de la décade de semis: la première décade qui reçoit une quantité de pluie suffisante pour le semis de céréales (20 mm).

ii) Deuxième étape

Détermination des zones où les semis ont échoué: les zones où les précipitations cumulées des deux décades suivant le semis ne sont pas suffisantes pour les cultures.

Données utilisées

5. ETP cummulée sur 2 décades est 120 à 140 mm
5. ETM du mil pour les 2 premières décades du cycle sont 42 mm et 50 mm (Kc=0,35)
6. les semis ont échoué si la pluviométrie est inférieure à la montié de l'ETM soit 20 mm.

Les études agro-climatiques constituent la base de cette approche.

Elles permettent de cerner la pluviométrie, la température, l'évaporation, les paramètres climatiques et météorologiques influençant directement la production agricole.

L'analyse de la pluviométrie devra faire ressortir les résultats ci-après:

- analyse pluviométrie annuelle (moyenne, mini, maxi, écart type, coefficient du variation, étendue). (Cf. Tableau IV);
- analyse fréquentielle des pluies (Tableau V);
- détermination de périodes sèches pour différentes longueurs (Tableau II)
- détermination durée saison pluie (Tableau VI):
  - début des pluies + écart type
  - fin des pluies + écart type tableau.

Ces informations permettent de mettre en œuvre des strategies adaptées au climat et d'améliorer les actions tactiques opérationnelles en combinant les données climatiques et météorologiques.

Par exemple pour connaître la longueur d'une saison des pluies donnée à partir d'une date de début des pluies réelle.

On utilise la formule ci-après:

$$Z = (n-m)/\sigma \quad (1)$$

$$\mathrm{Prob}\,(>z) = t \quad (2)$$

m = durée moyenne de la saison tenant compte du début réel des pluies;
n = longueur de la saison à déterminer;
σ = écart type pour la date moyenne de la fin des pluies.

Exemple: Si les semis sount effectués le 29 mai à Niamey, avec la fin des pluies moyenne au 25 septembre, alors on a m = 119 jours. L'écart type est égal à 14.1 jours.

Pour une longueur de la saison des pluies n supérieure ou égale à 110 jours, on a:

Z = (110-119) / 14.1 = -0.6383

à partir de la table de distribution normale standard on montre que:

Prob (>-0.6383) = 0.70 ou 70%.

La méthode de calcul est basée sur deux hypothèse:

1. Les dates de la fin des pluies sont réparties normalement:;
2. Il n'existe pas de rapport entre les dates du début des pluies et la fin de la période de végétation.

Il en découle qu'un précoce des pluies occasionne une période de végétation plus longues à l'inverse les pluies tardives conduisent à une période de végétation beaucoup plus courte.

L'analyse statistique de la température de l'air permet d'évaluer les régimes thermiques pour la croissance des cultures, la vitesse de certains processus physiologiques liés à la température teles que l'initiation florale et l'expansion foliaire, la photosynthèse et la resperation. Les plantes se comportent différemment par rapport à la température. On siat que les plantes en C_4 (sorgho, mil, maïs, pâturages, fourrages, canne à sucre) sont plutôt sensibles aux basses températures alors que les plantes en C_3 (blé, riz, soja) présentent une assimilation optimale du CO_2 entre 10 et 25°C et un ralentissement de celle-ci au-delà de 25°C (Blak 1975).

Les indications sur les régimes thermiques d'une région reseignent sur les possibilités de cultures à y faire.

Le suivi et l'estimation précoce de la production est la suite logique d'un système d'alerte précoce. Plusieurs méthodes existent. L'une des plus facilement applicables par les services météorolgiques à budget modeste est le suivi agrométéorologique. Il y a également plusieurs écoles: il y a les techniques qui simulent le processus physiologique des plantes et celles, déterministes, qui s'appuient sur la relations qui existe entre le bilan hydrique des cultures et la productions de biomasse.

- les analyses agroclimatiques
- les caractéristiques hydrodynamiques du sol (RUM)
- l'évapotranspiration potentielle (ETP) ou l'évaporation…(ET)
- les besoins en eau des cultures (Kc)
- données agronomiques des cultures (phénologie, longueur des différentes phases du cycle, etc.)
- superficies emblavées.

La méthodologie suivie est la suivante:

$ETM_i = ETP_i * Kc_i$ (3)
si $P_i + S_{i-1} \geq ETM_i$ alors $ETR_i = P_i + S_{i-1}$
si $P_i + S_{i-1} < ETM_i$ alors $ETR_i = P_i + S_{i-1}$

Le calcul du bilan hydrique de la décade (D_{i+1}), s'appuie sur:

- * les besoins en eau des cultures pour la D_{i+1} soit ETM_{i+1}
- * la réserve en eau du sol disponible à la fin de la décade D_i. S_i

éventuellement la pluviométrie complémentaire nécessaire pour assurer les besoins en euq des cultures soit i+1. Elle est déterminé à partir de la différence entre l'évapotranspiration maximales des cultures à la décade I+1 et les stocks d'eau du sol disponible,

$Si; P_{i+1} = ETM_{i+1} - S_i$ (3')

L'analyse fréquentielle de la pluviométrie décadaire classée par ordre croissant permet de situer les chances d'avoir une quantité de pluie supérieure ou égale à P_{i+1} à la décade i+1.

$f_i = \underline{r}_{i*100}$ (4) où r_i = rang de p_i
n+1 n = nombre
d'annees

L'indice de satisfaction de besoins en eau (ISE) est le quotient entre l'évapotranspiration réelle et évapotranspiration maximale. Il traduit le degré de satisfaction en eau d'une culture à un moment donné.

$$ISEi\ (\%) = \frac{ETR_i}{ETM_i} \qquad (5)$$

Un indice appelé indice de rendement espéré est calculé:

$$I\ RESP_{(\%)} = \frac{ETR_i}{ETM_i}\ (\text{total}) * \frac{ETR_i}{ETM_i}\ (\text{phase sensible}) \qquad (6)$$

Par corrélation on estime le rendement de la production:

$$RDT\ (kg/ha) = A * IRESP + B \qquad (7)$$

et enfin la production,

$$PDT\ (\text{tonnes}) = RDT * C \qquad (8)$$

L’indice de rendement espéré (6) permet de prendre en compte le niveau de biomasse et la production potentielle de l’épis. Il est relié de manière significative aux rendements moyens du mil en milieu paysan (7).

Conniassant la Superficie emblavée en ha, C, obenue par diverses méthodes utilisées par les agents de l’agriculture ou à partir de la carte d’occupation des sols, on détermine la production (8).

En mi-Août, on est à la moitié de la saison et tenant compte du stade des cultures et s’appuyant sur les résultats d’analyses fréquentielles de la pluviométrie, il est possible de simuler le bilan hydrique jusqu’à la fin du cycle de la culture et d’arriver, à une estimation de la production agricole.

L’avantage est de connaître suffisamente à temps avant les récoltes, la production attendue. Ceci permet, éventuellement, d’enclencher les actions préventives pour approvisionner les régions déficitaires en produits alimentaires venant soit des régions excédentaires soit de l’extérieur (importation ou don).

Au sénégal, RDT (kg / ha) = 11.3 * IRESP - 128, avec $r^2 = 0.66$ (9),

la formule établie pour l’estimation du rendement du mil.

4. Conclusion

- Dans les conditions habituelles la production agricole est fortement influencée par les aléas climatiques et les conditions météorologiques;
- Les pratiques culturales et les espèves cultivées se sont adaptées aux différentes régions après un processus d’adaptation qui a duré plusieurs sièclesl;
- Les changements climatiques rapides et l’importance de leur amplitude perturberont sans aucun doute ce qui a été établi par plusieurs générations;
- La recherche de nouvelles technologies et pratiques comme une réponse aux conséquences de changements climatiques sur la production agricole est indispensable. Cependant, pour les pays africains, le soutien de la communauté internationale est requise pour la mise en œuvre de certaines technologies pour lesquelles ils n’ont pas les ressources humaines et financières nécessaires;
- L’intégration de la dimension «climat et météorologie» dans les stratégies de développement de la production agricole est incontrournable quelque soit les acquis dans le domaine de la recherche agronomique;
- Une culture de l’utilisation au quitidien de l’information agrométéorologique doit être promue auprès des producteurs.

Climate, Water and Agriculture in Zambia

M.R. Muchinda
Zambia Meteorological Department, Lusaka

Abstract

Drought frequently affects portions of Zambia and other southern African countries, and causes substantial economic losses, especially in the agricultural sector. Attempts to mitigate the impact of drought have largely presented short-term solutions, which have not adequately addressed the problem of food security.

Previous episodic events in Zambia point to the fact that, while a major drought is a 1 in 50 year phenomena and is difficult to guard against, frequent minor droughts especially in the southern zone of Zambia are to be expected. These droughts should be planned for, with or without global warming.

Current agricultural practices in Zambia do not sufficiently exploit wet seasons and much of the available water goes unutilized. It is shown that over the last 40 years or so, the southern zone of Zambia (the driest zone) is now significantly less able to support the varieties of maize grown in the region, due to a declining trend in rainfall.

There is need to re-introduce the traditional dietary staples, which are more drought-tolerant. However, changes aimed at improving agricultural productivity should not only be focused on increased production as has been the case. To produce a surplus of crop or animal products is not enough; someone must buy and use them. Successful agricultural development and the growth in incomes (and therefore, purchasing power) should open up opportunities in service activities and small-scale manufacturing. This, however, calls for major improvements in the output delivery channels (ODCs).

1. Introduction

The climatic factor of greatest economic significance in southern Africa and Zambia, in particular, is rainfall. However, recent experience in the region has been dominated by erratic rainfall regimes, resulting in droughts that have drastically reduced agricultural production in many countries. Studies show that the amount of water available annually to each person in the Southern Africa Development Community (SADC) region has been declining since 1950. The drought scourge is generally believed to be worsening.

Droughts, of course, cannot be controlled, but their impact can be mitigated, especially if agriculture is geared to making the best use of available rainfall, and if water is stored where this is economically and physically feasible. While a major drought is, on past experience a 1 in 50 year phenomena (JICA, 1995) and is difficult to guard against, frequent minor droughts are to be expected especially in semi-arid areas of southern Africa. These droughts should be planned for, with or without global warming.

Recurrent droughts in the SADC region have been a blessing in disguise, in the sense that they have often exposed weaknesses in water conservation and supply. The water-related problems currently being experienced by some localities in Zambia and other southern African countries are not so much due to scarcity, but rather because of a mismatch between availability and demand.

Many of the countries in the SADC region rely on hydropower generation for their electricity needs and a primary limiting factor is water availability. In the event of declining water resources in the major drainage basins due to climatic conditions or increases in consumptive use, the production potential of existing or new hydropower schemes is likely to be affected. Unfortunately, other sources of energy, e.g. solar and wind energy, are not cost-effective or sufficiently developed to offer a viable alternative.

The purpose of this paper is to illustrate the general declining trend in rainfall in Zambia and how this resource has affected water availability for major economic activities such as agriculture and food security.

2. Effect of Rainfall Changes on Agriculture

Studies of daily rainfall values available for the period from 1950-90 at 35 Zambian stations have shown that over the last forty years, significant change in the ability of the country to support maize (the main dietary staple) production has occurred in the most southern agro-ecological zone, AEZ I (Kruss et a1.,1992), while the two northern areas, i.e. AEZ II and III, remain basically unaffected.

The southern zone of Zambia (the driest zone) is now significantly less able to support the varieties of maize grown there, e.g. MM 501/2/4, MM 601/3/14 and MM 752, with the most rapid change occurring prior to the mid-1970s.

Until 1981, Zambia could meet most of its food requirements through its own agricultural production. The droughts, which affected the country in 1981/82, 1982/83, 1983/84 and 1986/87, caused a substantial drop in production, especially of maize and therefore necessitated maize imports. The decline in rainfall is also evident in Table 1, which clearly shows that 1981-90 was the driest of the four decades examined. If planted early, 70% of the growing seasons would have had adequate rainfall for varieties MM 504 and 60% for MM 604; but if planted at or after mid-December, 63% and 75% of seasons would have had inadequate rainfall. (Tiffen and Mulele, 1994) However, even with early planting, three out of ten seasons in AEZ I would have experienced maize failures. During the 1991/92 season, AEZ I suffered a 1 in 2.5 year drought.

Since there is generally a higher frequency of drought (3-5 dry dekads of <30 mm/dekad) in AEZ I and parts of AEZ II, during the growing period, the promotion of drought-tolerant crops, such as sorghum and millet, cannot be overemphasized.

3. Effect of the Drought on River Flow and Reservoir Volumes for Hydropower Generation

3.1 River Flow: Zambezi and Kafue Systems

River flows, like rainfall, have been experiencing a declining trend since 1980 and have continued to exhibit this downward trend.

Monthly runoff volumes recorded on Zambezi River at the Victoria Falls station and on Kafue River at the Hook Bridge station show the effect of the drought years on the flow volumes. When compared to the rest of the flow record, 1994/95 stands out as the driest on record on the Zambezi. (Mwasile and Lindunda. 1995)

3.2 Kariba Reservoir/Lake

Between 1981 and 1992, the lake level dropped from 487.5 m above mean sea level (maximum retention level - 488 m) to 475.9 m (minimum retention level - 475.5 m), a drop of about 1 km of water within a decade. The large drop in reservoir level has been due to a gradual decline in rainfall, coupled with the unclear reservoir operation scheme. (Mwasile and Lindunda, 1995)

3.3 Itezhitezhi/Kafue George Reservoir (ITT)

The full reservoir level at ITT guarantees 50% of the country's energy requirements under normal rainfall conditions. However, the ITT dam is a seasonal reservoir and, therefore, its effective management is problematic in the face of erratic rains and absence of operating guidelines or rules.

The utility company responsible for hydropower generation, the Zambia Electricity Supply Corporation (ZESCO), learned some valuable lessons from the 1991/92 and 1994/95 droughts and has put in place two major strategies:

- Lower Rule Curve method - This consists of a set of end-of-month reservoir levels below which, for safe operation, the reservoir levels should not fall. The Rule Curve method assists ZESCO in long-term power generation planning in the absence of knowledge of the rains and, hence, the flows expected in the next rainy season. In recent years, however, ZESCO has increasingly made use of ENSO forecast information from the Zambia Meteorological Department (ZMD), to help them plan their power generation more effectively.

b) HEC-3 Water Balance Simulation model - As a better way of managing the Kariba reservoir, this model has been employed to apportion on a month by month basis, the volumes of water for power generation, taking into account the driest years in the flow record. The results are then expressed in terms of reservoir levels at the end of each month for a selected generation target. (Mwasile and Lindunda, 1995)

ZESCO is also currently co-operating with the TAMSAT Group at Reading University and the ZMD in attempting to run a hydrological model using METEOSAT rainfall estimates as input to the model for a selected catchment, aimed at forecasting river flows.

3.4 Water for Agriculture

The regulation and management of river flows in Zambia is not only important from the standpoint of power generation but also for other water uses such as agriculture. It should be noted that agriculture in Zambia does only account for 26% of water demand, while domestic consumption accounts for 63% of total water demand (World Resources Institute, 1994).

It has been estimated that Zambia may experience a severe water shortage by the year 2000 if not matched with necessary infrastructure development. In the SADC region as a whole, water demand is projected to rise at almost 3% annually, equivalent to the region's average annual population growth rate until at least 2020. (SADC/IUCN/SARDC, 1996) Unless proper management strategies are put in place, much of the SADC region including Zambia could face severe water scarcity for agriculture, industry and domestic consumption.

4. Mitigation Measures to Reduce Vulnerability of Agricultural Productivity

4.1 Seasonal Cliamte Prediction

The development of objective climate prediction services (especially ENSO forecasts) presents a new opportunity for practical climate applications and services. There currently exists an opportunity for National Meteorological and Hydrological Services (NMHS's) to bring a technical product of climate predictions to the marketplace where it will be usefully applied. (WMO No.845)

In Zambia, organisations which have acknowledged the usefulness of ENSO forecasts in recent years include: Programme Against Malnutrition (PAM), Zambia National Farmers Union (ZNFU), FAO, Ministry of Agriculture, Food and Fisheries and UN agencies among others. Many agree that availability of ENSO information at all levels will increase economic benefits; reduce economic uncertainty; mitigate the adverse impacts of climate fluctuations; and generally improve food security, especially at household level.

Fortunately, much of the useful climate forecast information is rapidly disseminated through the international communication networks (e.g. Internet), but NMHS's must ensure that such information constitutes an immediate high-level signal to key government institutions (Office of the President, Ministry of Agriculture, Ministry of Finance, etc.) as well as non-governmental organisations and donor agencies.

4.2 Water Harvesting

During periods of heavy rainfall most of the water is left to flow downstream and finally to the sea unused. However, if impounded behind dams and reservoirs, this water could be used during periods of water scarcity. At the moment, wet seasons are still insufficiently exploited by many farmers in Zambia. There is little evidence of schemes to store water, plant trees or conserve soil; this occurs in spite of the fact that, in many localities, the amount of rainfall over the year is well below potential evapotranspiration.

In a region where water availability is anticipated to fall to 3,000 cubic meters per year per capita by the year 2000 and already well below the global average (SADC/IUCN/SARDC, 1996), the agricultural sector must be geared to making the best use of rainfall and water must be stored where this is economically and physically feasible. For instance, in Botswana where water has long been a precious resource for thousands of years, villagers often have their own water tanks, and water-conscious rural schools place tanks to harvest rainwater from the gutters (SADC/IUCN/SARDC, 1996).

Similarly, roof and rock catchment water harvesting methods are very popular in Zimbabwe and could prove useful in Zambia and other SADC countries where soil, climatic and socio-economic conditions are similar.

4.3 Irrigation

Africa, as a continent, has the lowest percentage of irrigated land. Seventy-five percent (75%) of Africa's irrigated areas can be found in just 5 countries: Egypt, Sudan, Morocco, South Africa and Malagasy. Each of these countries irrigates over 500.000 ha. In Zambia and elsewhere in Africa, there is little technological culture in irrigation. Most agriculture, therefore, is entirely dependent on the vagaries and uncertainties of rainfall. Notwithstanding the fact that Zambia possesses almost 45% of the water resources of the SADC region, the proportion of irrigated land (i.e., 0.9%) is much lower than the SADC average (7.2%).

Large-scale irrigation, however, is costly and only to be recommended where it can be employed cheaply and easily. It can usually be justified only for high value crops.

What Zambia and other developing countries need are simple irrigation systems, which are easy to construct and do not require high level management and maintenance. For instance, a recent innovation in Zambia is the "Clay Pot irrigation method" in which unglazed clay pots (tempered in fire to avoid swelling and shrinking) are buried into the ground with necks above ground. Water is poured into the pot and then slowly oozes into the surrounding soil to supply moisture to crops. The application efficiency is 100% and fertilizer can be applied directly into the pot to be later released as solute after dissolving. Vegetables, coffee and citrus are all well adapted to such a system.

4.4 Promotion of “Lost Crops”

The range of foods grown must definitely be broadened to improve food security. Included in such a strategy would be a number of "lost crops," such as sorghum, millet and cassava, which are more tolerant of drought conditions. In addition to re-introducing these "lost" dietary staples, there should be a deliberate move to increase the supply and variety of legumes. Legumes serve three main useful roles:

- balancing the diet,

6. improving soil fertility, and
7. providing by-products which can be important dry season animal fodder, e.g. groundnut hay.

The latter role is particularly significant. Food which is in excess to local demand can always be converted into livestock feed for an eventual increase in the supply of other products such as meat, milk and eggs. This is a major advantage of domestic food crops in comparison with export crops. Exports simply cannot be channeled into the livestock industry should a given country be unable to export all that it has produced.

The cry for promoting dietary staples to improve food security is not a new phenomenon. The idea has been on the agricultural agenda of most African countries for sometime now. What has been lacking are the following:

6. resources to help put in place the necessary mitigation and adaptation strategies;
7. coherent and integrated policy framework for the dietary staples (For instance, most African countries know almost nothing about sweet potatoes, not even the level of consumption.); and
- diversification of processing (milling and marketing) practices for the traditional staples.

4.5 Outtput Delivery System (ODS)

At a recent meeting in Dakar, Senegal, the Food and Agriculture Organisation (FAO) for the first time addressed food security from the point of consumption rather than production. This change is a reflection of FAO's recognition of imperfections in the Output Delivery Systems (ODSs) of many African countries. In Zambia today, even under a liberalized economy, weaknesses in the ODS are still more critical than weaknesses of the traditional production technology in limiting access to food. It is in the rural areas that the ODS tends to be weakest. The vital links in the food chain should include:

- local markets and purchasing points
- waterways including boats and bridges, railways, roads and vehicles together with the infrastructure to fuel and maintain them
- traders
- storage, processing and packaging facilities
- shops and other things necessary for final sale or export
- financial mechanisms necessary to operate and regulate an ODS .

Governments must therefore examine weaknesses in the ODS and institute corrective policy measures.

5. Conclusion

The crisis of food production in Africa relates at least partly to climatic variations, particularly the occurrence of prolonged drought episodes, leading to severe water shortages. In Zambia, it has been shown that over the last 40 years, significant change in the ability of the country to support maize production has occurred in the most southern agro-ecological zone.

The belief that good rains mean abundant resources has led to complacency in the management of an ever-dwindling resource, water, in Southern Africa. There is need for a reorientation of social attitudes, so that communities regard water as an economic good and appreciate that the resource base is finite. Unless meaningful mitigation measures (especially socio-economic policies) are put into place, crises due to water scarcity -- such as water rationing, electricity load-shedding, industry closures, food relief handouts and the like -- will be with us for sometime.

References

JICA, 1935. The Study on the National Water Resources Master Plan in the Republic of Zambia. Interim Report.

Kruss, P.D., Mukhala, E. and M.R. Muchinda, 1992. On trends the Zambian Precipitation Maize Crop Index: 1950-1990. of the Fifth International Meeting on Statistical Climatology, 115-115.

Muchinda, M.R., 1992. On Climatic Change. Bulletin 16. Department of Meteorology. Lusaka.

Mwasile C.B.and M. Lindunda, 1995. Electricity Generation and Distribution in Drought Conditions. Paper presented to the IUCN Workshop on Drought: 13-15 December 1995, Lusaka.

SADC, IUCN and SARDC, 1996. Water in Southern Africa. Eds. M.Chenje and P.Johnson.

Tiffen, M. and M.R. Mu lele 1994. The Environmental Impact of the 1991-1992 Drought on Zambia.

World Resources Institute. 1994. World Resources 1994-95: People and Environment. Oxford/New York.

Expérience de Prévision Saisonnière en temps réel des précipitations sur le Maghreb et le Sud-Est de la France

Jean-Philippe Piedelievre
Météo-France CNRM/GMGEC/EAC
42, Avenue G. Coriolis - 31057 TOULOUSE CEDEX (FRANCE)

Abstract

Since the beginning of July 1996, within the framework of the AVICENNA program, we are running a real-time experiment for the seasonal prediction of precipitation over the Mograbin countries (Algeria, Morocco and Tunisia), and the southeast of France. That experiment is done using the French GCM, “ARPEGE climat”, developed at Météo-France. The same model was already used for fifteen years in an *a posteriori* experiment (the PROVOST project) from 1979 through 1993. “Observed” data are taken from ECMWF analyses. SSTs anomalies are forecast by an auto-regressive scheme.

1. Introduction

Le projet PROVOST (projet UE(1) coordonné par ECMWF) a permis une évaluation des capacités de modèles numériques de simulation du climat à prédire les caractéristiques climatiques à l'échelle globale ; expérience à laquelle participent Météo-France, UKMO, ECMWF et EDF(2). Les résultats de ces prévisions sur la période couvrant les 15 années de la réanalyse ECMWF (1979-1993) aux échelles mensuelle et saisonnière (3 à 4 mois) sont en cours d'analyse et feront l'objet de publications de la part de la communauté scientifique pour les nombreux centres d'intérêts qu'une telle expérience suscite. Par ailleurs, nous sommes engagés, dans le cadre d'un autre projet scientifique financé par la Communauté Européenne, le projet AVICENNE, dans une expérience de prévision saisonnière en temps réel des précipitations (ELMASIFA : coordination MEDIAS-France) sur le Maghreb (Algérie, Maroc et Tunisie) et le Sud-Est de la France, dans sa partie méditerranéenne. Les deux projets ne sont pas liés, mais il est évident que le premier (évaluation des potentialités du modèle en matière de prévision saisonnière a posteriori) est un préalable très heureux pour le second, et sera notre référence en matière de climatologie numérique.

(1) **U**nion **E**uropéenne (2) **E**lectricité **D**e **F**rance

2. Dispositif expérimental

Le schéma du dispositif expérimental mis en œuvre pour l'expérience ELMASIFA est décrit en annexe. Il s'inspire de l'expérience PROVOST. Le modèle utilisé est ARPEGE climat (Déqué *et al.* 1994 ; Déqué et Piedelievre 1995), modèle atmosphérique dérivé du modèle spectral de prévision opérationnelle de Météo-France, ARPEGE-IFS développé conjointement par Météo-France et ECMWF. La résolution spatiale choisie est la résolution standard pour une simulation globale, T42, soit 2.8° x 2.8° ou encore une grille de 280 km. La discrétisation verticale se fait sur 31 niveaux, dont 2/3 sont situés dans la stratosphère. Les prévisions sont faites par la méthode dite de prévision d'ensemble. A chaque fois 3 simulations (9 dans le cas de PROVOST) sont réalisées à partir de situations initiales décalées de 24 heures. La prévision sera alors la moyenne des 3 simulations numériques. Les situations initiales sont élaborées à partir des analyses produites par ECMWF. Contrairement à PROVOST, expérience a posteriori, nous ne disposons pas des températures de la mer pour constituer les conditions aux limites du modèle atmosphérique.

3. Prévision des anomalies de la température de la mer

Une méthode statistique de prévision des anomalies de température de la surface de la mer autorise la prévision climatique en temps réel. Aux échelles de temps mensuelle et saisonnière, la variabilité de la circulation atmosphérique est étroitement liée à l'état thermique des surfaces marines dont les temps caractéristiques sont de cet ordre de grandeur. Une régression établie à partir des 15 années de réanalyse ECMWF, permet une prévision des structures d'anomalies les plus persistantes à partir des anomalies observées lors du mois précédant la période de prévision. Cette méthode privilégie les structures d'anomalies les plus durables en ignorant ce qui ne présente pas la persistance que l'on “ attend ” d'un facteur du climat. Une autre méthode consistera à coupler le modèle atmosphérique avec un modèle d'océan. Cette expérience est en préparation. C'est une démarche obligée pour le très long terme car les techniques statistiques basées sur la persistance ne peuvent espérer être utiles au-delà de 5 à 6 mois, par contre, il n'est pas certain, a priori, que le couplage soit “ mieux ” informatif pour des périodes allant de 1 à 4 mois.

4. Zonage du domaine géographique

Les prévisions numériques se font pour des groupes de points de grille du modèle que l'on identifie à des zones géographiques. La définition des zones géographiques a été décidée par chacun des services météorologiques nationaux des pays participants. L'expérience de prévision numérique du climat menée par le Centre National de Recherches Météorologiques (CNRM) à Météo-France dans le cadre du projet ELMASIFA s'accompagne de prévisions réalisées par des méthodes statistiques par les services homologues de l'ONM-Algérie, de la DMN-Maroc et de l'INM-Tunisie. Les études statistiques menées antérieurement par ces trois organismes ont permis de définir une régionalisation climatique (au sens des précipitations) que nous avons adoptée pour permettre une intercomparaison et une collaboration des diverses méthodes employées. Une cartographie du zonage ainsi décidé est présentée en annexe. L'Algérie a défini 10 zones, le Maroc 5, la Tunisie 4 et la France 1 zone correspondant approximativement au quart Sud-Est du territoire, région dont le climat est essentiellement à caractéristique méditerranéenne.

5.Diffusion de l'information

L'information prévue n'est pas la quantité de précipitation mais un indice dérivé de celle-ci. Les prévisions du modèle doivent être rapportées à la climatologie du modèle. L'expérience d'une simulation de 15 ans menée dans le cadre du projet PROVOST nous a permis d'évaluer 1) les erreurs systématiques du modèle, 2) sa variabilité interrannuelle. Les erreurs systématiques ont pour effet de décaler l'état moyen du climat simulé par le modèle numérique. Les déduire revient donc à recentrer les prévisions. La variabilité interannuelle permet de relativiser les quantités prévues de façon aux renormaliser selon une échelle de valeurs représentative de l'amplitude des variations de la quantité à prévoir dans le cadre d'une simulation réalisée avec le modèle. Enfin, ce qu'il importe de connaître c'est l'anomalie, l'écart à l'état moyen. Pour chacune des zones il est donc calculé un indice de précipitation qui est le rapport de l'anomalie à l'écart type. Les moyennes et les variances pour chacune des zones ont été calculées à partir des résultats obtenus dans le cadre de PROVOST. La diffusion de l'information se fait sous forme de messages dont on trouvera un exemple en annexe. Chaque service destinataire peut alors inverser les indices prévus en utilisant les climatologies (normale et écart type) observées en chacune des régions correspondant aux zones de prévision. Au sein d'une région il est possible de nuancer les prévisions en appliquant localement des statistiques connues sur des parties incluses (sous région, station).

6. Evaluation de la qualité des prévisions

L'évaluation de la qualité des prévisions est un important facteur de progrès. Il ne peut s'agir évidemment que d'une action a posteriori dont on se devra de tenir compte, avec un certain recul, pour améliorer le fonctionnement des dispositifs expérimentaux. On ne saurait juger d'une manière unique du niveau de réussite atteint par une prévision. La façon la plus sévère, objective, consiste à évaluer la proximité géométrique des prévisions et des observations. Cela se fait, par exemple, en calculant pour chaque zone un coefficient de corrélation des anomalies prévues et observées. La valeur de la corrélation spatiale des structures d'anomalies fournit le score (Skill score) de la prévision. Un point de vue un peu plus pragmatique sera, puisque nous effectuons des prévisions d'ensemble, d'évaluer, sous quelques hypothèses réalistes, les probabilités d’occurrence du dépassement de certains seuils d'anomalie. Dans le même ordre d'idée, il peut être profitable de savoir ce que les utilisateurs des prévisions ont retenu de l'information qu'ils auront ainsi reçue et le bénéfice qui estiment en avoir retiré. L'évaluation économique de ce type d'information probabiliste est un sujet de recherche en soi qui doit mettre en relation de longue durée les producteurs de prévisions et les utilisateurs du produit.

7. Conclusion

Le projet expérimental qui vient d'être décrit n'est pas un processus opérationnel. Il s'inscrit dans le cadre d'une recherche concernant l'évaluation des capacités d'un modèle numérique de simulation du climat à produire une information pertinente concernant, par exemple, la pluviométrie mensuelle ou saisonnière. L'analyse et, a fortiori, l'utilisation des résultats demandent avant tout un apprentissage de l'interprétation des prévisions en termes probabilistes. L'évaluation de la qualité des résultats de cette expérience par des utilisateurs “expérimentaux” peut permettre une appréciation de l'utilité économique de l'outil numérique. Les espoirs portés par de telles recherches sont grands mais la lucidité doit rester loi. Il ne peut être question de résoudre l'imprédictible de manière systématique. Il s'agit de faire mieux que le hasard, autrement dit, extraire, l'information pertinente du “bruit”. L'utilité d'une telle démarche ne peut se juger que sous la forme d'un bilan établi au terme de nombreuses expériences telles que celle-ci afin de démontrer la stabilité des résultats. Un tel bilan comptabilisera les succès mais aussi les échecs, en pondérant chaque événement selon l'importance que recouvrait la connaissance d'une prévision à l'époque où celle-ci fut délivrée. Autant la prévisibilité du climat varie selon la localisation géographique et la période, autant l'évaluation de l'utilité d'une prévision demande de la circonspection. Peut-être, en fin 1997, au terme de cette expérience, serons-nous aptes à porter un jugement de valeur sur notre tentative. Quels qu’en soient les résultats, nous apprendrons beaucoup.

Références

Déqué, M.,C. Dreveton and D. Cariolle, 1994: The ARPEGE/IFS atmosphere model: a contribution to the French community climate modelling. *Climate Dyn.*, **10**, 249-266

Déqué, M. and J.Ph. Piedelievre, 1995: High resolution climate simulation over Europe. *Climate Dyn.* **11**, 321-339

Palmer, T.N., and D.L.T. Anderson, 1994: The prospect for seasonal forecasting- a review paper. *Quart. J. Roy. Meteor. Soc.*, **120**, 755-793

Wavelet transform-obtained amplitude modulations of the annual and semi-annual rainfall cycles in the Congo-Gabon region and their connections with the SSTs

J.L. Melice (1), S. Bigot (2), and P. Vandergheynst (3)

- *ORSTOM, Intitut d'Astronomie et de Geophysique G. Lemaitre, Universite Catholiqu de Louvain, 2b chemin du Cyclotron, B-1348 Louvain-la-Neuve, Belgium*

- *Centre de Recherches de Climatologie (CRC), Universite de Bourgogne, Bat. Sciences Gabriel, BP 138, F-21004 Dijon Cedex, France*

- *Unite de Physique Theorique et de Physique Mathematique, Universite Catholique de Louvain, 2b chemin du Cyclotron, B-1348 Louvain-la-Neuve, Belgium*

Abstract

The high quality Centre de Recherches de Climatologie data bank of monthly rainfall data from 1951 to 1990 for 118 stations in Central Africa is analyzed with the empirical orthogonal function method. This produces an aggregation of the data in 8 coherent rainfall regions. The corresponding time series of one of these regions (the Congo-Gabon) is then investigated in the time-frequency domain with the continuous Wavelet Transform (WT) technique. This method is chosen for its unique capability of efficiently extracting the amplitude and frequency modulations of all deterministic periodicities hidden in the data. It is demonstrated that 55% of the rainfall information in the Congo-Gabon region is concentrated in the annual quasi 12 months and the semi-annual quasi 6 months cycles. The signatures of the two amplitude modulation series of these cycles in the global Sea Surface Temperature (SST) field is then obtained by correlating them with the United Kingdom Meteorological Office global set of SSTs. The amplitude modulation series of the semi-annual rainfall cycle is significantly correlated with SSTs located in the typical East-Pacific 'El-Niño' influenced zone while the amplitude modulation series of the annual cycle is significantly correlated with the SSTs located in the tropical Atlantic basin (the so-called Atlantic dipole zone). The remarkable efficiency of the multi-resolution WT technique allows, therefore, a high precision separation of the two main causative mechanisms (the SST anomalies in the East Pacific and in the tropical Atlantic) for the precipitation in the Congo-Gabon region. Moreover, as the SST impulses precede the rainfall amplitude modulations by 2-3 months, one may

consider the possibility of documenting the trend of the rainfall season 2-3 months ahead.

1. Introduction

It is well-known that the large scale variability of tropical rainfall is related to the slow evolution of the oceanic and continental boundary conditions owing to the weakness of thermal horizontal gradients in the tropical atmosphere (Hastenrath, 1988). From seasonal to decadal scales, climatic variability depends mainly on the Sea Surface Temperature (SST). An in-depth understanding of the links between SST variability and precipitation relies on the availability of globally reliable rainfall data. Such quality is not attained for the precipitation fields over sparsely populated and remote areas such as the Congo basin (Willmott *et al.*, 1994). To improve this situation, a new precipitation data bank of monthly rainfall gridded series for Central Africa for the 1951-1990 period (hereafter named CRC-Centre de Recherche de Climatologie) has been recently compiled (Moron *et al.*, 1995) and his quality compared with success to the Climatic Research Unit data bank (Hulme and Jones, 1990).

The purpose of this paper is to investigate the statistical dependence between interannual and seasonal rainfall variability in central Africa in order to get a better understanding of the relationships between temporal discontinuities of rainfall and SSTs. More precisely, we will: (i) construct from the high quality CRC rainfall dataset well defined coherent rainfall regions in Central Africa, (ii) question the corresponding time series of one of these regions (the coastal Congo-Gabon) in the time-frequency domain with the continuous Wavelet Transform (WT) technique, and (iii) investigate possible SST-precipitation teleconnections by comparing the WT-extracted information from the Congo-Gabon rainfall series to well-documented SST data sets.

First, a brief description of the rainfall data set and of the construction of homogeneous rainfall regions in Central Africa with the Rotation Principal Component Analysis (RPCA) method is given. The WT technique is then described stressing its advantages over classical Fourier Transform methods. Time-frequency characteristics of the Congo-Gabon rainfall series obtained with the WT technique are then presented, and the relations between the WT-extracted amplitude modulation series for the two main rainfall cycles and the SST of the United Kingdom Meteorological Office (UKMO) data set are described.

2. Aggregation of the CRC Central Africa rainfall data set in coherent rainfall regions

The CRC Central Africa monthly rainfall data bank consists of 118 stations (figure 1) and is available for the 1951-1990 period. There are less than 10% missing data per series. The equatorial data of Congo and Zaire has been collected locally by Sylvain Bigot with the ASECNA (Agence de Securite et de Navigation Aerienne) and African researchers. The data from Gabon was available from the National Meteorological Office.

The 118 stations are subjected to Rotation Principal Component Analysis (RPCA) using the Varimax rotation method. The purpose is to reduce the high spatial heterogeneity of the series and to aggregate them in few homogeneous series. Height coherent regions are obtained. The corresponding first 8 series extract 28% of the total rainfall information (figure 2). We will now focus our attention on the coastal Congo-Gabon region (region 6 in figure 2, 3.1% of extracted variance) as its rainfall series (figure 3 (top)) is demonstrated to give the most interesting results for the following analyses.

3. Continuous Wavelet Transform of the Congo-Gabon monthly rainfall (1951-1990) time series

Continuous Wavelet Transform (CWT) analysis (Lau and Weng, 1995; Meyers and O'Brien, 1994) is based on the convolution of a one dimensional signal $f(t)$ with a set of oscillatory form functions $\Psi(t)$ derived from the translations and dilatations of a mother wavelet $\Psi(t)$ where:

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{a}}\,\Psi\left(\frac{t-b}{a}\right)$$

and where a is the dilatation (scale) parameter and b is the translation parameter. The set of functions $\Psi_{a,b}(t)$, which also meets some other mathematical constraints such as zero mean, are called wavelets. The convolution of $f(t)$ with a set of wavelets is the Wavelet Transform (WT):

$$W_{a,b} = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} \Psi^{*}\left(\frac{t-b}{a}\right) f(t)\,dt$$

where * denotes the complex conjugate.

This last equation is called the Continuous Wavelet Transform (CWT) since a and b may be varied continuously. The dilatation or scale parameter a in $W_{a,b}$ corresponds to wavelength or period. The translation parameter b then corresponds to position or time. The WT expands a one-dimensional time series $f(t)$ into the two-dimensional parameter space (b,a) and yields a measure of the relative amplitude of local activity (over an interval proportional to a) at scale a and time b. This is in contrast to the Fourier Transform, which yields an average amplitude over the entire data set. It is clear that the WT coefficient $W_{a,b}$ will have a high value when the wavelet matches the signal. Thus, the WT allows the wavelets to be scaled to match most of the high-and-low frequency signals with optimal resolution. This ‘zoom in’ property is a unique characteristic of the WT that allows the localization of very short-lived high-frequency signals, while resolving the low-frequency variability in the time-frequency space accurately. In the transform shown in this paper, the Morlet wavelet (Morlet, 1983):

$$\Psi(t) = \exp\left(ic_\Psi t\right)\exp(-t^2/2)$$

where $c_\Psi = 5.4$, is used. This wavelet was chosen for its simple relation to the familiar Fourier modes. The energy density of a periodic function $f_0(t) = A\sin\left(\omega_0 t\right)$ is then $a^{-1}A^2\exp\left[-\left(a\omega_0 - c_\Psi\right)^2\right]$. For signals such as $f_0(t)$, a correspondence between scales of local transform maxima and Fourier modes is found analytically with the Morlet wavelet. The relation is given by (Meyers *et al.*, 1993)

$$\omega_0 = \frac{1}{2}\left(\frac{c_\Psi}{a_0} + \frac{\sqrt{2 + c_\Psi^2}}{a_0}\right)$$

where a_0 is the local maximum of the WT coefficient $W_{a,b}$.

Interpretation of a WT is often simplified by examining these local maxima and converting them to Fourier space. As an example, in the 2-D parameter space (b, a), the WT of a sine wave at constant frequency is a ridge (the local maxima) at constant scale a. Thus, by following the ridges in the parameter space, one can extract the amplitude and frequency modulations of the signal under investigation. The collection of ridges in the WT form the so-called skeleton of the WT. All deterministic information is preserved in this skeleton.

The CWT of the Congo-Gabon time series is presented in figure 3 (middle). Remarkably, the largest values of the modulus (amplitude) of the WT are confined at two main frequencies with corresponding periods centered at ~ 12 and ~ 6 months. These are the typical seasonal and semi-seasonal cycles of the rainfall in the tropical Africa region. These two periodicities concentrate, respectively 35% and 25%, of the variance of the total rainfall information and their modulated frequencies are always very close to the central frequencies. The amplitude modulations of the cycles are presented in figure 3 (bottom). They are obtained by following the local maxima of the two main ridges of the skeleton of the WT. A large variation in the amplitude is observed. As will be described later, the amplitude modulation at 1/6 cycles/month is probably related to a perturbation of the position of the Inter-Tropical Convergence Zone (ITCZ). The amplitude modulation at 1/12 cycles/month is probably linked to the input of water vapour originating from the South Atlantic.

4. Signature of the amplitude modulations of the Congo-Gabon annual and semi-annual monthly rainfall cycles in the SSTs

In this section, we investigate the spatial signature of the amplitude modulation series of the annual and semi-annual rainfall cycles of the Congo-Gabon region in the global SST field. The SST data set is the MOHSST version 4 (Bottomley *et al.*, 1990), compiled at the United Kingdom Meteorological Office on a 5x5 degrees grid. The amplitude modulation series are correlated to the monthly SST series (1951-1990) and the corresponding spatial distribution of the correlation coefficients are given in figures 4 and 5. The statistical significance levels at 99% are computed with Monte Carlo series having the same first order autocorrelation coefficients than the original series. Figure 4 presents the correlation between the Congo-Gabon semi-annual rainfall cycle amplitude modulation and the monthly SST field. Significant values appear in the East Pacific and they correspond to the typical Niño-influenced zone. Figure 5 depicts the correlation between the Congo-Gabon annual rainfall cycle amplitude modulation and the monthly SST field. The most significant results are obtained in the Atlantic zone. The corresponding signature is very close to the signature of the so-called Atlantic dipole.

The first mode of SST variability is generally referred to as the Global Tropical Mode (GTM). It is obtained, for example, in Moron *et al.* (1995) with the help of RPCAs. The GTM has a signature (not shown here) in the global SST field that is very similar to the signature of the above-mentioned semi-annual cycle amplitude modulation series. The two corresponding series are plotted in figure 6. Note that the GTM impulse precedes the Congo-Gabon rainfall semi-annual cycle amplitude modulation by about 2-3 months. The second mode of SST variability is referred to as the North Atlantic mode while the third one is the South Atlantic mode. These two modes form roughly what is called the Atlantic dipole. The Atlantic dipole has a signature (not shown here) in the global SST field that is very comparable to the signature of the Congo-Gabon annual rainfall amplitude modulation series. In the Congo-Gabon, the water vapour originates from the South Atlantic and is highly dependent on the SST variability. This probably explains the modulation of the annual cycle and its signature in the South Tropical Atlantic. Moreover, the precipitation mechanism is probably perturbated by the anomalies of the position of the ITCZ. This could explain the amplitude modulation of the 6-month cycle in the precipitation data. As we are only here presenting statistical results, it is beyond the scope of this paper to analyse the mechanism linking the anomalies of the SSTs in the Pacific to the perturbation of the ITCZ.

5. Conclusion and Discussion

The very efficient Wavelet Transform technique allows the extraction of the amplitude modulation laws of the annual and semi-annual cycles for the rainfall in the Congo-Gabon region. The two corresponding series have two distinct causative mechanisms. The semi-annual cycle is modulated by the impulse of the SSTs in the tropical Eastern Pacific Ocean while the annual cycle is modulated by the impulse of the SSTs in the tropical Atlantic Ocean. These impulses precede the amplitude modulations by a few months. As a consequence, one may put forward the possibility of predicting the trend of the rainfall season in the Congo-Gabon region a few months ahead. This may be realized by forcing a General Circulation Model (GCM) with these well-localized SST anomalies. The corresponding GCM-generated gross-climate parameters outputs would then serve as boundary condition inputs for a regional mesoscale model taking into account regional characteristics as the sea-breeze mechanism. Finally, we stress here the importance of the availability of globally reliable rainfall data in Central Africa. As seen in this paper, rainfall data are indeed a unique opportunity for the identification of the precipitation-producing mechanisms. In figure 7, the time-evolution of the operational rainfall stations that are used in the CRC Central Africa data bank is presented. The number of operational stations decreases dramatically between 1980 and 1990.

References

Bottomley, M., Folland, C.K., Hsiung, J., Newell, R.E. and Parker, D.E.: 1990, 'Global ocean surface temperature atlas (GOSTA)', *United Kingdom Meteorological Office*, Bracknell.

Hastenrath, S.: 1995, 'Recent advances in Tropical climate prediction', *J. Climate*, 8, 1519-1532.

Hulme, M. and Jones, P.D.: 1993, 'A historical monthly precipitation data set for global and land areas: applications for climate monitoring and climate model evaluation', in: Analysis methods of Precipitation on a Global Scale', Report of a GEWEX workshop, 14-17 September 1992, WMO/TD-No. 558, *World Meteorological Organization*, Geneva, pp. A/14-A/17.

Lau, K.M. and Weng, H.: 'Climate signal detection using wavelet transform: how to make a time series sing', *Bull. of the American Met. Soc.*, vol. 76, No 12, 2391-2402.

Meyers, S.D., Kelley, B.G. and O'Brien J.J.: 1993, 'An introduction to wavelet analysis in oceanography and meteorology: with application to the dispersion of Yanai waves', Mon. Wea. *Rev.*, 121, 2858-2866.

Meyers, S.D. and O'Brien, J.J.: 1994, 'Spatial and temporal 26-day SST variations in the equatorial Indian Ocean using wavelet analysis', *Geoph. Res. Lett.*, 21, 9, 777-780.

Morlet, J.: 1983, 'Sampling theory and wave propagation', *NATO ASI series*, FI, Springer, 233-261.

Moron, V., Bigot, S. and Roucou, P.: 1995, ‘Rainfall variability in Subequatorial America and Africa and relationships with the main SST modes (1951-1990)’, *Int. J. Climatol*.., 15, 1297-1322.

Willmot, C.J., Roberson, S.M. and Seddena, J.: 1994, ‘Estimating continental and terrestrial precipitation averages from rain-gauge networks’, *Int. J. Climatol*., 14, 403-414.

Variations hydroclimatiques en Afrique de l’Ouest et Centrale

Brou KouamÉ, Jean Emmanuel Paturel, Eric Servat (1),
Hélène Lubès, Jean Marie Fritsch (2), and
Jean Marie Masson (3)

(1) ORSTOM, Programme FRIEND AOC, 06 BP 1203, Cidex 1, Abidjan 06, Côte d'Ivoire

(2) ORSTOM, Programme FRIEND AOC, BP 5045, 34032 Montpellier Cedex, France

(3) Laboratoire Géofluides-Bassins-Eau, URA-CNRS 1765, Université Montpellier II, Place Eugène Bataillon, 34095 Montpellier Cedex, France

Résumé

Cette étude s'intéresse aux manifestations, en Afrique de l'Ouest et Centrale non sahélienne, d'une variabilité climatique en phase avec ce qui a pu être étudié plus au nord au Sahel. Un ensemble de représentations cartographiques et de méthodes statistiques de détection de ruptures est utilisé pour analyser les séries chronologiques de précipitations annuelles et de débits moyens annuels. Les ruptures sont généralement localisées à la fin des années 1960 et au début des années 1970, en accord avec ce qui est observé au Sahel. On met ainsi en évidence une baisse généralisée de la pluviométrie de l'ordre de 20%. Les déficits d'écoulement atteignent, quant à eux, environ 45%, et ponctuellement plus de 60%. Dans bon nombre d'endroits les volumes écoulés ont donc diminué de près de moitié, ce qui ne va pas sans conséquences en terme de gestion de ressource.

1. Introduction

La sécheresse observée depuis plus de 20 ans au Sahel y a de sérieuses conséquences. Des études ont situé l’apparition de ce phénomène vers la fin de la décennie 60 et au début de la décennie 70 (Hubert et Carbonnel, 1987; Sircoulon, 1987 ; Hubert et al, 1989 ; Demarrée, 1990). Cependant, plus au sud, dans des régions au climat plus humide, il semble que ce phénomène soit également ressenti (Sutcliffe et Knott, 1987 ; Nicholson et al, 1988 ; Mahé et Olivry, 1991 ; Olivry et al, 1993). Ce sentiment est partagé par la population des pays riverains du Golfe de Guinée. qui appartiennent, avec d'autres, à ce que l’on appelle communément "l’Afrique humide". Il peut donc sembler paradoxal d'y parler de "sécheresse" car les conséquences d’un tel phénomène y sont moins sévères et moins dommageables. Toutefois, la diminution de la pluviométrie et la baisse des écoulements sont telles qu’à elles peuvent y pénaliser de nombreux projets de développement.

L’étude présentée ici, menée dans le cadre du thème "Variabilité climatique" du projet FRIEND Afrique de l’Ouest et Centrale de l’UNESCO, a pour but d’identifier et de mesurer les conséquences de cette variation climatique supposée en Afrique de l’Ouest et Centrale non sahélienne. L’analyse des données de 16 pays (du Sénégal à la Centrafrique et du Mali au Cameroun) a permis d’effectuer ce travail dans un cadre régional couvrant les zones non sahéliennes au sens large et donc limité au nord par le 14ème parallèle. Variabilité pluviométrique et variabilité des ressources en eau de surface ont été successivement abordées.

2. Données et méthodes

Les données utilisées proviennent de la Banque de données du Projet FRIEND AOC. L'étude a principalement concerné la période 1950-1989. L’information pluviométrique y est importante et bien répartie sur l’ensemble de la zone d’étude (près de 200 postes de mesure). L’information débitmétrique est, quant à elle, moins dense, tant dans l’espace que dans le temps.

Des outils d’interpolation et de cartographie, ainsi que des méthodes statistiques de détections de ruptures au sein de séries chronologiques ont permis l’exploitation de ces données. Rappelons ici qu'une "rupture" se définit comme un changement de la loi de probabilité de la série étudiée.

Des cartes d’isovaleurs de précipitations annuelles et d’indices pluviométriques annuels ont été établies. L’indice pluviométrique est une variable centrée réduite qui traduit une "intensité" d’excédent ou de déficit pluviométrique annuel dans le cas où la variable étudiée est la pluviométrie annuelle. Les méthodes statistiques de détection de ruptures retenues sont : test de corrélation sur le rang afin de déterminer le caractère aléatoire ou non de la série, et, pour détecter un changement de la moyenne dans les séries étudiées, test de Pettitt, statistique de Buishand, procédure bayésienne de Lee et Heghinian et procédure de segmentation de Hubert. Ces méthodes font l’hypothèse d’une stationnarité de la variance des séries et sont adaptées à la détermination d’une rupture unique (à l'exception de la méthode de segmentation de Hubert).

3. Variabilité des régimes pluviométriques

La figure 1 représente l'évolution des isohyètes durant les 4 dernières décennies. On observe que c'est le long des côtes que la pluviométrie annuelle est la plus importante. Cependant, entre la Côte d'Ivoire et le Bénin, le tracé des isohyètes est très irrégulier et les précipitations plus faibles. La présence de phénomènes d'up-wellings en mer à ce niveau stabilise les masses d'air et entraîne donc une pluviométrie plus faible. L'irrégularité constatée des isohyètes est habituellement reliée à la présence des Monts Togo prolongés, au Bénin, par la chaîne de l'Atakora ainsi qu'à l'orientation de la côte. Celle-ci est, par endroits, parallèle à l'orientation des flux de mousson et donc moins favorable aux précipitations (Eldin, 1971). Sur le reste de la zone, le gradient pluviométrique est pratiquement nord-sud. Plus à l'intérieur des terres, la distance à l'Océan Atlantique constitue un facteur primordial d'homogénéité des régimes des précipitations.

Au cours de ces quatre décennies, on note une tendance à la diminution de la pluviométrie. Toutefois, c'est durant la décennie 1960 que la pluviométrie moyenne annuelle a été la plus forte de la Côte d'Ivoire au Bénin. Durant les années 1980, tout le nord de la zone étudiée a une pluviométrie inférieure à 800 mm, ce que l'on n'observait pas durant la décennie 1950. Dans l'ensemble de la région, la tendance à la diminution de la pluviométrie moyenne annuelle semble débuter pendant la décennie 1970 et s'amplifier pendant les années 1980.

La figure 2 traduit des intensités de déficit ou d'excédent pluviométrique de chacune des décennies par rapport à la période de référence. Globalement, les décennies 1950 et 1960 sont excédentaires alors que les deux décennies suivantes apparaissent comme déficitaires. Les régions les plus touchées par cette baisse des précipitations se situent au nord et à l'ouest de la zone d'étude, c'est à dire dans les secteurs habituellement les moins et les plus arrosés. Vers l'est on observe le même phénomène mais avec une moindre ampleur.

Les résultats des tests de détection de rupture ont été reportés sur la figure 3. On note qu'il y a plus de postes à l'ouest qu'à l'est pour lesquels une rupture a pu être détectée. Ce phénomène apparaît donc bien, comme étant plus marqué en Afrique de l'Ouest qu'en Afrique Centrale.
En cas de rupture dans les séries chronologiques, les déficits calculés de part et d'autre sont généralement de l'ordre de 20%, mais parfois supérieurs à 25%. Les dates d'occurrence des ruptures détectées se situent autour de 1969-1970 (Servat et al, 1996 ; Paturel et al, 1996).

Un travail analogue a été mené sur des séries chronologiques de pluviométrie mensuelle. Quels que soient les mois ou les régions étudiés, on observe toujours une diminution de la pluviométrie. Seule exception, la zone à deux saisons des pluies (de la Côte d'Ivoire à certaines régions du Nigeria) qui connaît un mois d'août plus pluvieux qu'auparavant alors qu'il correspond, théoriquement, à la "petite saison sèche". Cette exception pourrait indiquer une réduction de l'extension spatiale de la zone à deux saisons des pluies au profit de celle à une saison des pluies unique.

Les différentes méthodes s'accordent donc sur la réalité d'une importante baisse de la pluviométrie sur l'ensemble de la zone non sahélienne d'Afrique de l'Ouest et Centrale. Si l'amplitude du phénomène, apparu aux alentours des années 1970, n'est pas uniforme, toutes les régions ont cependant été touchées. En saison sèche comme en saison des pluies, toutes les périodes de l'année ont subi cette diminution des précipitations. Cette variabilité est en tous points comparable à ce qui avait été décrit jusque là plus au nord dans le Sahel. Bien que la région étudiée soit qualifiée d'"humide", cette modification du régime pluviométrique ne peut qu'avoir des conséquences importantes sur la disponibilité des ressources en eau de surface.

4. Variabilité des régimes hydrométriques

En matière d'hydrométrie, l'information disponible n'est malheureusement pas aussi dense que pour la pluviométrie. On note, en particulier l'existence d'une forte hétérogénéité en matière de répartition spatiale, ce qui limite la pertinence et l'intérêt des représentations cartographiques. Les stations hydrométriques sélectionnées sont, cependant, suffisamment nombreuses pour traduire de manière significative, à l'échelle régionale, la réalité de la variabilité temporelle des ressources en eaux de surface. Comme pour la pluviométrie, un intérêt plus marqué a été porté à la période 1950-1989 qui correspond à une densité maximale de données disponibles.

Les premiers résultats obtenus concernent les modules annuels, ou débits moyens annuels, d'un ensemble de cours d'eau d'Afrique de l'Ouest et Centrale, représentatifs de la zone non sahélienne. Les bassins versants correspondants sont de superficies très variables (de 1 990 km_ à 600 000 km_). Néanmoins, comme le montrent, à titre d'exemple, les figures 4 et 5, sur la période 1950-1989 la quasi-totalité des stations étudiées fait état d'une nette diminution de l'hydraulicité depuis près de vingt cinq ans maintenant. En effet, depuis le début de la décennie 1970, à quelques rares exceptions près, toutes les années apparaissent comme ayant une hydraulicité inférieure à la moyenne, traduisant en cela une baisse des ressources en eau de surface.

Les indices représentés sur la figure 4 ont été calculés de façon analogue aux indices pluviométriques selon l'expression :

indice d'hydraulicité = $(X_i - \overline{X}) / s$ (1)

avec : X_i : débit moyen annuel de l'année i, en m^3/s ; à la station considérée ; $\overline{X}$: débit moyen interannuel calculé sur la période 1950-1989 en m^3/s, à la station considérée ; s : écart-type des débits moyens annuels, en m^3/s, à la station considérée.

Les séries chronologiques de débits moyens annuels ont été étudiées à l'aide des méthodes de détection de ruptures évoquées plus haut. Les résultats montrent que sur les 95 stations retenues à ce niveau de l'étude, 77 (soit légèrement plus de 80%) présentent une rupture. La grande majorité est localisée entre 1968 et 1972 comme en témoigne la figure 5. La précision de cette localisation dans le temps souligne le lien indiscutable qui existe entre la baisse de la pluviométrie et la diminution des écoulements de surface en Afrique de l'Ouest et Centrale non sahélienne.

De part et d'autre des dates de rupture dans les séries chronologiques, et sur la période 1950-1989, on atteint des différences importantes en ce qui concerne les débits moyens annuels. Elles sont rarement inférieures à 30% et parfois supérieures à 55% voire 60%. Le tableau 1 présente quelques valeurs moyennes de déficit pour certains grands fleuves et pays. Ces valeurs doivent être prises comme un ordre de grandeur car elles n'ont pas toutes été calculées dans les mêmes conditions : périodes de calculs parfois légèrement différentes et nombre de stations prises en compte très variable (de 2 sur le Fleuve Sénégal à 13 en Côte d'Ivoire). Néanmoins on constate, à l'examen du tableau 1, que la diminution des écoulements, et donc des ressources en eau de surface, est considérable dans ces régions situées au sud du Sahel. Le déficit d'écoulement atteint, en effet, près de 45% en général. C'est à dire que, dans cette région et à quelques exceptions près, les volumes qui transitent dans les cours d'eau ont diminué de près de moitié depuis le début de la décennie 1970, ce qui est considérable. Le décalage quantitatif qui semble exister entre les déficits pluviométriques et hydrométriques pourrait être lié à un déficit d'alimentation des cours d'eau par les nappes phréatiques (Mahé et Olivry, 1995). Les conditions pluviométriques persistantes, l'augmentation progressive des coefficients de tarissement et la dégradation continue du niveau des nappes ne permettant pas à la relation "nappe-rivière" de fonctionner comme avant 1970.

5. Conclusion

Comme on vient de le montrer, les régions situées au sud du Sahel ont également subi une variabilité climatique. Les régions dites "humides" d'Afrique de l'Ouest et Centrale ont vu leur régime hydrologique (pluie et cours d'eau) modifié depuis plus de vingt cinq ans maintenant.

Sur l'ensemble de la zone étudiée, les régimes pluviométriques ont subi d'importantes modifications qui se traduisent par des diminutions de hauteurs annuelles précipitées pouvant atteindre 20 à 25%. Cette baisse des précipitations affecte chaque mois qu'il soit de saison sèche ou humide. On constate également, dans bon nombre de zones de savane, une tendance à passer d'un régime climatique "guinéen" à un régime "soudanien" plus sec.

Les régimes hydrométriques ont également subi de profondes modifications. Dans toute la zone étudiée, les volumes écoulés ont considérablement diminué, cette baisse atteignant près de 45% en moyenne et plus de 60% par endroits. Une étude complète est actuellement en cours qui s'intéresse aux manifestations de ces modifications : basses eaux, hautes eaux, tarissement, etc.

Du point de vue de la ressource et de son utilisation, de telles modifications ne sont pas sans conséquences. L’agriculture, l’alimentation des retenues et la production hydroélectrique, entre autres, sont fortement pénalisées par cette diminution des ressources. Les conséquences de ce phénomène sont donc très inquiétantes en ce qui concerne le bon fonctionnement et la rentabilité des projets déjà réalisés ou envisagés. Si la carence pure et simple n’est pas à craindre dans ces régions situées au sud du Sahel, où les quantités précipitées restent importantes dans l’absolu, les effets de cette variabilité climatique peuvent, malgré tout, se révéler désastreux, en ce sens qu’ils modifient les données d’un équilibre déjà souvent mis à mal par ailleurs.

Remerciements

Les auteurs remercient MM. A. Aka, J.F. Boyer, B. Marieu, M. Ouedraogo et M. Travaglio pour leur contribution à la réalisation de cette étude.

Références

Demarrée, G. (1990) An indication of climatic change as seen from the rainfall data of a Mauritanian station. *Theor Appl Climatol*, 42: 139-147.

Eldin, M. (1971) Le climat, in *Le milieu naturel de la Côte d’Ivoire* (Avenard et al). Mémoires ORSTOM n°50. ORSTOM. Paris. 391pp.

Hubert, P. & Carbonnel J.P. (1987). Approche statistique de l'aridification de l'Afrique de l'Ouest. *J. Hydrol.*, **95**: 165-183.

Hubert, P., Carbonnel, J.P. & Chaouche, A. (1989) Segmentation des séries hydrométriques. Application à des séries de précipitations et de débits de l'Afrique de l'Ouest. *J. Hydrol.*, **110**: 349-367.

Mahé, G. & Olivry, J.C. (1991) Changements climatiques et variations des écoulements en Afrique occidentale et centrale du mensuel à l'interannuel. In: *Hydrology for the Water Management of Large River Basins* (Proc Vienne Symposium August 1991). IAHS Publ n°201, 163-172.

Mahé, G. & Olivry, J.C. (1995) Variations des précipitations et des écoulements en zafrique de l'Ouest et Centrale de 1951 à 1989. *Sécheresse* 1, **vol 6**: 109-117.

Nicholson, S.E., Kim, J. & Hoopingarner, J. (1988) *Atlas of African rainfall and its interannual variability*. Department of Meteorology, Florida State University, Tallahassee, Florida, USA.

Olivry, J.C., Bricquet, J.P. & Mahé, G. (1993) Vers un appauvrissement durable des ressources en eau de l'Afrique humide. In: *Hydrology of Warm Humid Regions* (Proc Yokohama Symposium July 1993). IAHS Publ. n°216, 67-78.

Paturel J.E., Servat E., Kouamé B., Lubès H., Ouedraogo M. & Masson J.M. (1996) Climatic variability in humid Africa along the Gulf of Guinea. Part two: An integrated regional approach. Accepté pour publication à *J. Hydrol.*

Servat E., Paturel J.E., Lubès H., Kouamé B., Ouedraogo M. & Masson J.M. (1996) Climatic variability in humid Africa along the Gulf of Guinea. Part one: Detailed analysis of the phenomenon in Côte d'Ivoire. Accepté pour publication à *J. Hydrol.*

Sircoulon, J. (1987) Variation des débits des cours d'eau et des niveaux des lacs en Afrique de l'Ouest depuis le début du 20ème siècle. In: *The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources* (Proc Vancouver Symposium August 1987). IAHS Publ n°168, 13-25.

Sutcliffe, J.V. & Knott, D.G. (1987) Historical variations in African water resources. In: *The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources* (Proc Vancouver Symposium August 1987). IAHS Publ n°168, 463-475.

Tableau 1: Ordres de grandeur (en %) de certains déficits d'écoulements annuels calculés depuis la date de rupture observée dans les séries chronologiques et sur la période 1950-1989.

Fleuve ou Pays	Déficit d'écoulement (%)
Fleuve Niger (stations du Mali et de Guinée)	40
Fleuve Sénégal (stations du Sénégal et du Mali)	60
Bénin	52
Burkina	48
Centrafrique	29
Côte d'Ivoire	47
Guinée	39
Tchad	47
Togo	44

Pluviometrie et Production Agricole: Exemple de la Production Cerealiere de la Region de Kolda (Senegal)

DACOSTA Honoré (1) & AKPO Léonard (2)
(1) Départ. Géographie, FLSH, UCAD, Sénégal
(2) Départ. Biologie Végétale, FST, UCAD, Sénégal

1. Introduction

La région de Kolda se situe au sud au Sénégal et correspond à la partie continentale de la moyenne et haute Casamance. L'agriculture est entièrement sous la dépendance des cycles pluviométrique dans des conditions de non maîtrise totale de la ressource en eau. Les productions agricoles sont donc sous l'emprise totale de la variabilité climatique face à laquelle les populations ne disposent d'aucun palliatif. La région dispose d'un réseau pluviométrique ancien (1905) avec des données de bonne qualité qui permettent d'analyser la variabilité de la pluviométrie et de la confronter aux statistiques de productions de productions agricoles disponibles depuis 1960.

2. Cadre géographique et contexte climatique

2.1 Le cadre géographique

La région de Kolda (fig. 1) a pour limite ouest le cours du Soungrougrou, au nord et sud les frontières gambienne et bissau-guinéenne et le cours de la Koulountou. Elle résulte de la reforme administre de 1984 qui a divise la région naturelle de la Casamance en deux entités dont Kolda à l'est. Elle a une superficie de 21 011 km et une population de 593 019 habitants (densité : 28 habitants/km) essentiellement constituée de peuls, mandingues, mancagnes et quelques autres minorités ethniques.

La région est drainée par le Soungrougrou, au nord, les cours moyen et supérieur de la Casamance, au centre, et la Kayanga à l'est. Il s'agit d'un réseau hydrographique assez lâche, dont les écoulements sont devenus intermittents suite à la sécheresse. Dans la partie ouest de la région, les cours de la Casamance et du Soungrougrou sont fortement influences par la remontée des eaux marines, par la marée. En effet, les altitudes sont faibles (maximum 51 m) et les pentes longitudinales et transversales avoisinent l’unité. La réduction des écoulements de surface et une forte évaporation ont eu pour conséquence l'inversion du fonctionnement normal de ces rivières, avec les plus fortes salinités en amont et les plus faibles en aval (estuaire inverse).

Sur le plan pédologique, on rencontre quatre grandes unités :

- Les sols ferrugineux tropicaux lessivés sur grès sablo-argileux. Ils occupent toute la partie est de la région jusqu'à la longitude 15° 15' ouest
- Les sols ferralitiques sur grès sablo-argileux : ils couvrent le reste de la région avec quelques poches de sols ferrugineux tropicaux à l'ouest de Sédhiou et sur le cours moyen du Soungrougrou.
- Les sols halomorphes sur alluvions argileuses se rencontrent sur les rives et les abords des rivières sous influence marine.
- Les sols hydromorphes se localisent dans les vallées et surtout dans la cuvette de la Kayanga dans l'extrême Est de la région.

Du point de vue végétation, les savanes très boisées (nord et sud), les forêts claires (centre) et les palmeraies (le long des cours d'eau) se partagent la région. Dans les parties soumises au flux et reflux, se localisent la mangrove et, à l'arrière plan, les tannes qui ont connu une grande extension sous l'effet de la sécheresse. Cette végétation a fortement subi les effets de la péjoration climatique combinée à ceux de l'action anthropique avec les défrichements abusifs, la coupe de bois de chauffe ou le charbonnage et la recherche de bois d'œuvre.

Kolda est une région rurale, les quelques villes existantes (Kolda, Sédhiou et Vélingara) sont des villes secondaires voire tertiaires dans la hiérarchie urbaine sénégalaise. La principale activité est l'agriculture, la région n'ayant aucune industrie digne de ce nom. La population se livre à la culture (mandingues et peuls sédentarisés) soit à l'élevage ou à la pêche artisanale sur la Casamance et le Soungrougrou.

2.2 Le cadre climatique

La région de Kolda appartient au domaine sud-soudanien (est et centre) et guinéen (ouest de Sédhiou au Soungrougrou) caractérise par l'existence de deux saisons bien marquées : (i) une saison sèche allant de novembre à mai, avec une circulation de composante principale Est, appelée harmattan ou alizé continental, chaud et sec; (ii) une saison des pluies, de juin à octobre, marquée par la prédominance des flux de composante principale sud-ouest, appelée mousson, très pluviogènique. Ce flux de mousson résulte en fait de l'alizé issu de l'anticyclone de Sainte Hélène et dévié par la force de Coriolis. Son influence se fait sentir sur l'ensemble de la région de juin à octobre et elle est responsable des précipitations enregistrées (Leroux M, 1983). La répartition des précipitations varie en diminuant du sud au nord et de l'ouest vers l'est de 1400 à 1000 mm.

3. Evolution de la pluviométrie

Les observations pluviométriques dans la région de Kolda ont commence en 1905 à la station de Sédhiou, 1919 à Kolda et 1930 à Vélingara pour les principales stations. Pour avoir une période commune d'analyse, les pluies annuelles disponibles ont été homogénéisées par la méthode du vecteur régional (Brunet-Moret, 1979) sur la période 1924-1995.

3.1 Variations de la pluviométrie annuelle

Elles sont illustrées par l'évolution en dents de scie des indices du vecteur régional qui représente la pluviométrie moyenne à l'échelle de la région considérée. La figure 2 montre que la période 1924-1994 peut se diviser en deux :

1924-1967:	une période globalement excédentaire malgré les courtes périodes sèches de 1930-31 et 1940-43.
1968-1994:	une période déficitaire dans ensemble, les seules années légèrement excédentaires ou moyennes étant 1975, 1978 et 1988.

Analysées à l'échelle stationnelle, on retrouve la même évolution de la pluviométrie mais une atténuation de l'ampleur des variations sur un gradient ouest-est (fig. 3) et nous avions considère comme l'estompement de l'influence océanique (Dacosta H., 1989).

La méthode des moyennes mobiles pondérées (Olivry, J. C., 1983) a été appliquée aux indices du vecteur et les pluies annuelles des trois stations. Cette moyenne mobile pondérée est inspirée des chaînes de Markov d'ordre 1 et considérée chaque indice ou pluie annuelle comme la somme d'une variable aléatoire et d'un polynôme représentant les effets de persistance des années antérieures. La courbe résultante illustre mieux les tendances de la pluviométrie annuelle dans la région.

L'application des tests rupture climatique (Lee & Heghinian 1977 ; Pettitt ; Hubert et al) aux stations de Sèdhiou, Kolda et Vèlingara montre que les chroniques des pluies annuelles dans cette région ne sont pas stationnaires. Ces différents tests situent la date probable de rupture 1967. Pour la station de Sèdhiou on a respectivement une moyenne 1426 et 1051 mm pour 1924-67 et 1968-95.

3.2 Les normales glissantes

Le calcul des moyennes pluviométriques interannuelles par normales climatiques (1931-1960, 1941-1970, 1951-1980,et 1961-1990) permet de mieux apprécier les fluctuations des précipitations annuelles pendant les sept dernières décennies (fig. 4).

Le tableau 1 montre une diminution progressive des moyennes interannuelles des normales climatiques qui montrent qu'en réalité la réduction de la pluviométrie dans le Sahel a été un phénomène progressif insensible depuis le début du siècle. Le décrochement observé partir de 1968 n'a été le révélateur d'une démarche progressive vers la sécheresse. Pour la normale 1961-1990 le déficit moyen se situe autour de 12 % mais pour des années particulières comme 1983 ce déficit a dépasse 20 à 25 % pour ces stations de la région (Dacosta). H., 1989). Le tableau 2 montre que le déficit est beaucoup important si on compare la série de 1968-95 ‡ la période antérieure (25 % de déficit) ou toute la série (18%).

4. Les productions céréalières

Les principales céréales produites dans la région de Kolda sont le mil, le sorgho, le riz et le maïs qui entrent dans l'alimentation de base des populations locales. Les statistiques de production disponibles portent sur la période 1960-1994. Le tableau 3 présente les valeurs synthétiques de ces chroniques de productions céréalières. La production de riz et de mil/sorgho varient d'environ 31% alors que celle de maïs connaît une plus grande fluctuation (62 %). L'importance de ces fluctuations témoigne du caractère très aléatoire de ces productions soumises à l'influence de la pluviométrie.

4.1 Variations des productions céréalières.

Les figures 5 et 6 montrent une variation en dents de scie de la production céréalières, une Evolution comparable ‡ celle de la pluviométrie régionale. Il apparaît une nette croissance de la production de 1960 ‡ 1967, la pluviométrie étant presque invariable. A partir de 1968, les fluctuations de la production céréalière sont calquées sur l’évolution de la pluviométrie et ce jusqu'en 1987. Après cette date on constate une nouvelle phase de croissance des productions.

Mais cette augmentation de la production est en étroite relation avec celle des surfaces emblavées (fig. 6). Si la période de sécheresse peut être un facteur explicatif de la forte variation de la production céréalière entre 1968 et 1987, il faut y ajouter les effets du "malaise paysan" de 1968 qui déstructure le monde paysan sénégalais avec l’arrêt de certaines subventions de l'Etat au monde rural. La figure 7 montre la corrélation entre production et surfaces emblavées qui explique 84 % de la variance de la production.

4.2 Variations des rendements

Si les productions ont connu une certaine augmentation, les rendements quant eux n'ont enregistre une croissance notable (fig. 8). De toute évidence le rendement de 1975 est erroné, car la pluviométrie très moyenne de cette annèe-là ne peut justifier une telle augmentation des rendements. Cette stagnation des rendements est-elle liée à un seuil de productivité en relation avec les capacités réelles du milieu ou à la persistance de pratiques culturales traditionnelles, au manque de réceptivité des paysans vis à vis des résultats de la recherche agronomique ou alors à la défaillance de la vulgarisation de ces résultats ? La question mérite d'être posée, car les surfaces à emblavées ne sont pas extensibles à l'infini et l'autosuffisance alimentaire passe inévitablement par l'amélioration des rendements des productions céréalières.

La figure 9 montre que la pluviométrie et les rendements connaissent une même évolution dans le temps ce qui semble logique. Mais cette relation est rendue plus diffuse par les caractéristiques pédologiques de la région. En effet les sols ici de types ferrugineux tropicaux lessivés ou ferralitiques formés de sable gréseux du Continental terminal. Il s'agit de sols très filtrants et profonds qui soustraient une grande partie de la pluie aux horizons superficiels du sol et la rendent indisponible pour les végétaux. La violence des averses, surtout en début de saison des pluies sur des sols souvent non protégés déclenche un important ruissellement de surface qui renforce le caractère précèdent.

4.3 Variations de la production de riz, maïs et mil/sorgho

Le riz, le maïs et le mil/sorgho constituent la base de l'alimentation des populations de la région. Les figures 10, 11 et 12 illustrent les variations de la production de ces trois céréales.

La culture de riz se fait essentiellement dans les bas-fonds en Casamance car il s'agit de la riziculture inondée, la culture de riz pluvial étant faible. L'évolution de la production de cette céréale obéit à la disponibilité suffisante de l'eau dans les bas-fonds et on constate que les années de forte production correspondent aux années à bonne pluviométrie. A partir de 1978, on a assiste en Casamance, d'une manière générale, à une diminution prononcée des pluies et à une hypersalinisation des sols de bas-fonds (Bassel M, 1993). Cette situation a grandement affecté la production de riz. La construction de nombreux barrages et digues anti-sel n'a que partiellement résolu le problème.

La culture de maïs est restée marginale pendant longtemps dans la région, d'où sa production jusqu'au début des années 80. Les possibilités de transformation et de consommation variée de cette céréale offerte par l'équipement des groupements de femmes en moulins ont contribué à la vulgarisation de sa culture. C'est ce qui explique la forte croissance de sa production depuis 1982 (fig. 9). La facilité de culture et la faible consommation en eau de cette culture est un facteur explicatif de son adoption.

Le mil et le sorgho sont de large consommation et leur culture est une tradition séculaire dans la région. Sa production, nettement plus élevée que celle du riz, fluctue également avec la pluviométrie. La promotion et valorisation des céréales locales, face ‡ l'augmentation sans cesse croissante du prix du riz et à la paupérisation du monde rural, ont beaucoup contribue à la relance de la production du mil et du sorgho.

5. Conclusion

L'évolution de la pluviométrie durant les quatre dernières décennies dans la zone soudano-sahélienne a eu des répercussions importantes sur les productions agricoles. L'analyse de l'évolution de la pluviométrie et des productions céréalières dans la région de Kola a montre l'existence d'une étroite dépendance à laquelle il faut ajouter les pratiques culturales et sociales qui sont des déterminants non négligeables. Il apparaît également que l'augmentation des contraintes à la production de riz a conduit à des mutations et l'adoption de céréales jusque-là marginales dans la consommation quotidienne des populations.

References

Brunet-Moret, 1979 - Le vecteur régional. Cah. ORSTOM, sér. , Hydrol. ,

Dacosta H., 1989 - Précipitations et écoulement sur le bassin de la Casamance. Thèse de 3Ëme cycle. Départ. De Géographie, FLSH, Univ., Cheikh Anta Diop, Dakar, 278 p.

Grouzis M., Albergel J., 1989 - Du risque climatique à la contrainte écologique. Incidence de la sécheresse sur les productions végétales et le milieu au Burkina Faso. In Eldin et Milleville (eds) : Le risque en agriculture. Coll. A travers champs, Orstom, pp. 243-254.

Hubert P., Carbonnel J.P. et Chaouche A., 1989 - Segmentation des séries hydrométéorologiques. Application à des séries de précipitations et de débits de l'Afrique de l'Ouest. Journal of Hydrology, vol. 110, pp. 349-367.

Lee A. F. S., Heghinian S. M.,1977 - A shift of the mean level in a sequence of independent normal random-A Bayesian Aproch-. Technometrics, vol. 19, n∞ 4, pp. 503-506.

Leroux M, 1983 - Le climat de l'Afrique tropicale.2 vol. , Edit. Champion

Olivry, J. C., 1983 - Le point en 1982 sur la sécheresse en Sénégambie et aux Iles du Cap-vert. Examen de quelques séries de longue durée (débits et précipitations). Cah. ORSTOM, sèr. Hydrol., Vol. , N° 1, : 47-69.

Pettitt A. N., 1979 - A non-parametric aproach to the change-point problem. Applied Statistics, 28, n° 2, pp. 126-135.

Variabilité Climatique et Comportement de la Cuvette Lacustre du Niger depuis le début du Siècle

F. BAMBA & G. MAHE
Hydrologues ORSTOM
B.P. 84 Bamako MALI

Resume:

A partir des années 70, les ressources en eau des bassins du fleuve Niger et de ses affluents n'ont cessé de diminuer (Bricquet et al.) , 1996 ; Mahé et al. , 1995, Olivry, 1993a). La Cuvette Lacustre du Niger qui est une zone dont les activités agro-pastorales et économiques sont très liées à la montée et à la descente des eaux de crues se trouve ainsi touchée par cette variation climatique.

Cette étude a pour but, de montrer le comportement de la Cuvette Lacustre du Niger depuis le début du siècle face à la variation climatique.

Pour réaliser cette étude, il a été procédé à l'évaluation des entrées et sorties de la Cuvette. Les entrées sont constituées par les débits du Niger à Ké-Macina et le Bani à Douna. Quant à la sortie, elle est constituée par l'écoulement du Niger à Diré. Comme les données de débits sur toutes ces stations ne sont disponibles qu'après 1951, il a donc été procédé à la reconstitution de leurs modules annuels depuis le début du siècle par des corrélations entre pluies annuelles et débits moyens annuels pour le Bani à Douna et le Niger à Diré. Quant au Niger à Ké-Macina, les modules d'avant 1951 sont reconstitués à partir des débits du Niger à Koulikoro. Les pluies, quant à elles sont déterminées automatiquement par la Méthode du Vecteur Régional (MVR) (Mahe et al.), 1994).

De cette étude, il ressort que la diminution de la superficie inondable ces dernières années serait liée en grande partie à la diminution des entrées constituées par les écoulements du Niger à Ké-Macina et du Bani à Douna. En effet, la plus grande partie des apports dans la cuvette est constituée par les écoulements entrants qui constituent 90% des eaux du delta central (LAË, 1994). Comme l'écoulement depuis le début du siècle a beaucoup plus varié que la pluviométrie sur la cuvette, ceci a entraîné une diminution très sensible (en rapport avec les écoulements) des surfaces inondables de la cuvette. Cela a eu pour cause, une modification des activités socio-économiques de la zone, caractérisée par une diminution des surfaces cultivables et de la production de poissons.

1. Introduction

Depuis les années 70, le continent africain est soumis à un déficit climatique sans précédent. Ce déficit a occasionné une baisse constante des eaux de surface et souterraines (Bamba F. et al.), 1996 Bricquet et al., 1996 ; Pouyaud, 1987 et entre autres). Malgré souvent un léger retour à la normale, force est de reconnaître que l'écoulement reste généralement presque toujours déficitaire. Ceci a entraîné une diminution de l'écoulement des fleuves Niger et Bani. La diminution des écoulements de ces fleuves et donc des apports de la Cuvette a provoqué une diminution des surfaces inondables de la Cuvette Lacustre du Niger, créant ainsi des problèmes chez la population de la zone qui vit au rythme de son remplissage et de sa vidange. En effet, la cuvette lacustre est alimentée essentiellement par ces deux cours d'eau, si bien que tout changement dans leur régime est directement ressenti dans la cuvette.

2. Cadre Physique

La zone que nous appellerons cuvette lacustre du Niger (et qui peut être aussi appelée Delta Central du Niger) est celle comprise entre les latitudes 12° N (Ké-Macina) et 16°20' N (Diré) et les longitudes 3° 00' et 6° 00' O (figure 1). C'est un immense delta intérieur dont la dynamique des eaux est très complexe. Elle est caractérisée d'une part par un élargissement brusque du lit du Niger et d'autre part par des pentes très faibles. La cuvette lacustre du Niger constitue une zone d'épandage pour les eaux drainées par les fleuves Niger et Bani. Son fonctionnement hydrologique dépend en grande partie :

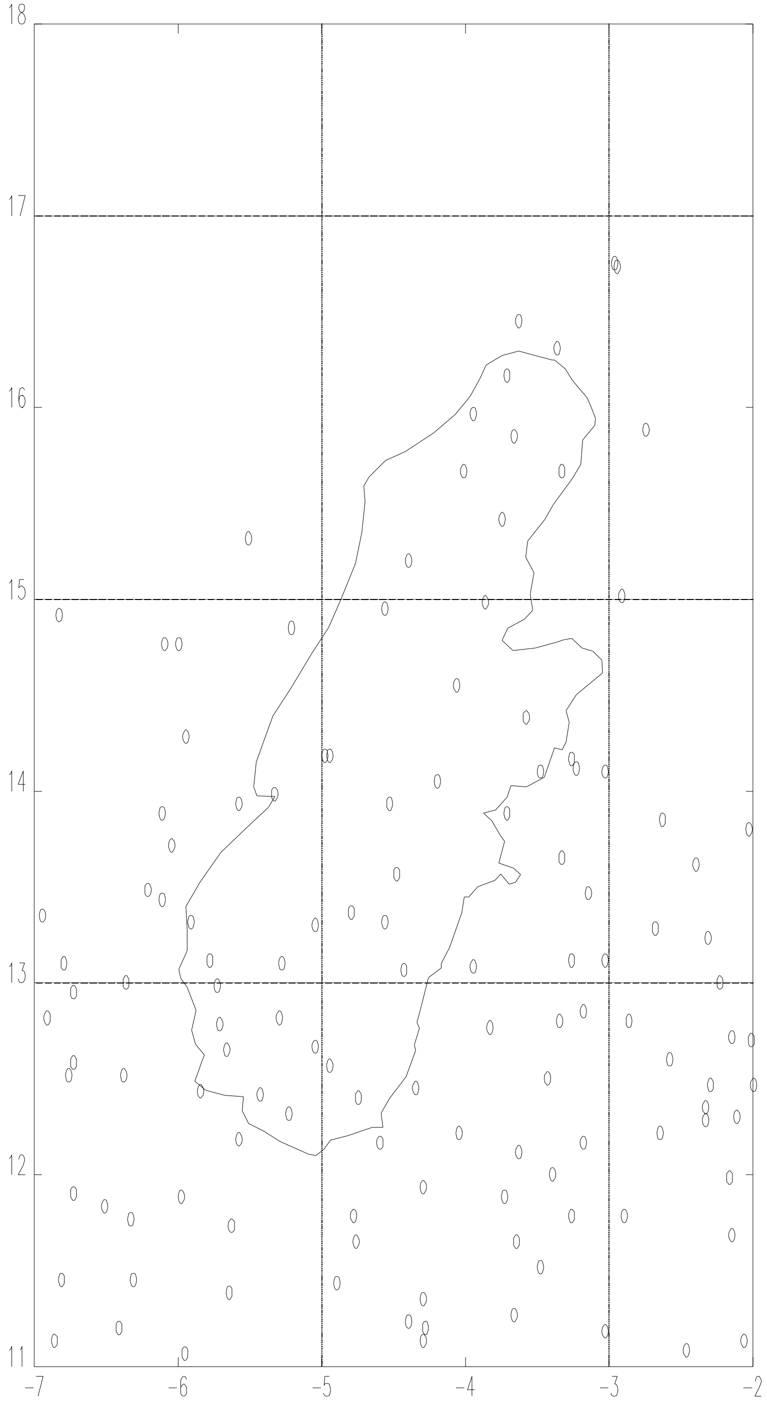
2. des régimes hydroclimatiques des fleuves Niger et Bani,
8. de l'évaporation et de l'infiltration dans la cuvette,
7. des conditions morphologiques du delta intérieur.

Les faibles pentes dans la cuvette entraînent des vitesses maximales du courant en surface n'excédant pas 0,3 à 0,6 m.s-1 dans les bras principaux (Olivry, 1993b).

Cette zone a une pluviométrie qui est de 600 mm au sud et de 150 mm au nord. Elle est caractérisée par deux régimes climatiques (Lamagat J.P. et al, 1996) :

3. le régime sahélien au sud. C'est la zone comprise entre les isohyètes 600 mm et 300 mm ; et
2. le régime subdésertique au nord. Cette zone est comprise entre les isohyètes 300 mm et 150 mm.

Figure 1: Situation géographique de la Cuvette Lacustre.



3. Bilan Hydrologique Depuis le Debut du Siecle (Eléments du bilan)

3.1 Pluviométrie

La pluviométrie moyenne sur la cuvette a été calculée par la méthode décrite par (Mahé, 1993; Mahé et al., 1994), sur la base de données annuelles observées sur la période 1901-1995. Ce ficher de données brutes annuelles (non homogénéisées) a été constitué par Soumaguel (1996).

Les résultats de ces calculs donnent une pluviométrie sur la cuvette égale à 555 mm sur la période 1907-1995 (tableau 1), avec une orientation des isohyètes allant du nord-ouest au sud-est. Pour la période, elles vont de 200 mm vers Diré (climat subdésertique) à 700 mm vers Ké-Macina et Douna (climat sahélien).

L'analyse des résultats du calcul de la pluviométrie dans la cuvette permet de constater que presque toutes les sept premières décennies, à savoir de 1907-1910 (3 ans) jusqu'en 1961-1970 ont une pluviométrie supérieure ou égale à la moyenne et les trois dernières, inférieures à la moyenne. En effet, en dehors de la décennie 1911-1920, toutes les autres de la période 1907-1969 ont une pluviométrie supérieure à la moyenne. Ceci permet de diviser la période 1907-1995 en deux : une première, humide, allant de 1907 à 1969 et une seconde plus sèche, de 1970 à 1995. La figure 2 montre le déplacement des isohyètes du sud au nord de la décennie sèche par rapport à celle humide.

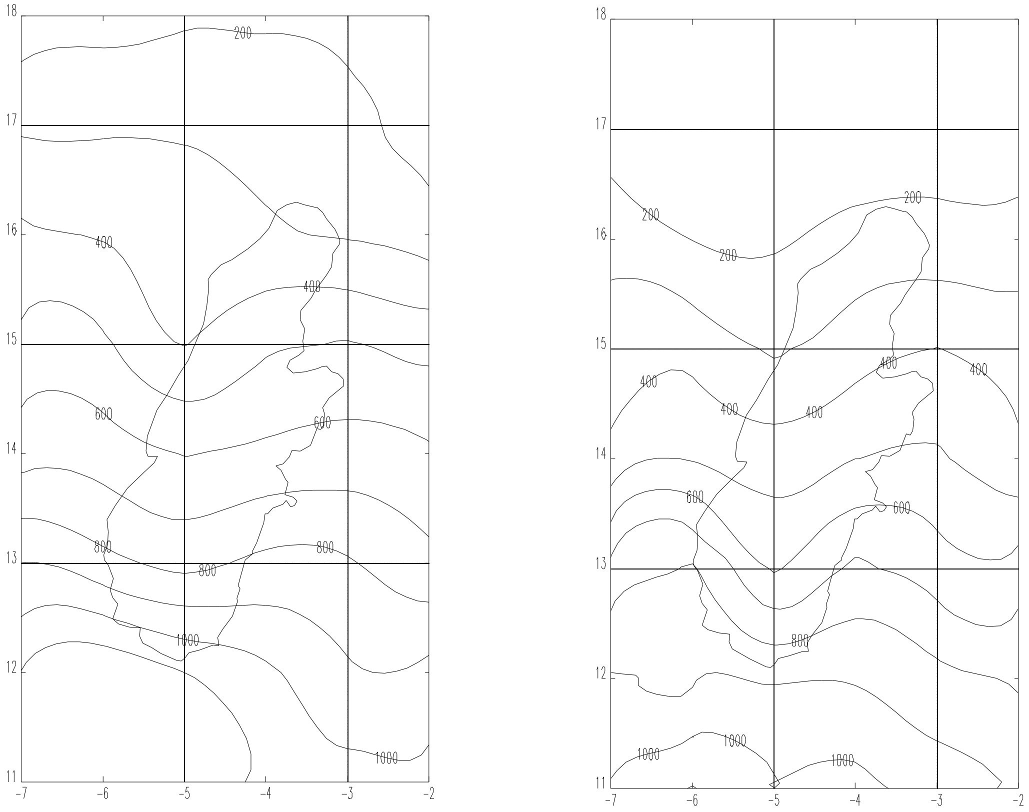
Après le calcul de la pluviométrie sur la cuvette, on a procédé à la détermination des autres éléments du bilan, à savoir les écoulements entrants et sortants de la cuvette.

3.2 Ecoulements entrants et sortants

L'écoulement entrant est constitué par les apports en écoulement du Niger à Ké-Macina et du Bani à Douna. Quant à l'écoulement sortant, il est pris celui du Niger à Diré. Ces écoulements doivent être déterminés sur la période 1907-1995. Mais comme les données de débits ne sont disponibles que sur la période après 1951, leurs reconstitutions s'imposent. Pour se faire, on a recherché des régressions linéaires entre les modules (ou entre modules et pluie). Si cette méthode donne de bons résultats pour le Niger à Ké-Macina (coefficient de corrélation égal à 0,98), elle donne de moins excellents mais acceptables résultats pour le Bani à Douna et le Niger à Diré (coefficient de corrélation étant respectivement égal à 0,63 et 0,68). Ceci s'expliquerait par le fait que pour le Niger à Ké-Macina, la régression a été faite entre les modules des stations de Koulikoro et de Ké-Macina. Pour le Bani à Douna, la corrélation a été réalisée entre les modules du Bani à Douna et la pluviométrie annuelle du bassin à cette station. Quant au Niger à Diré, la corrélation entre les débits moyens annuels à Diré et la pluviométrie annuelle à cette station n'a pas donné de bons résultats

Figure 2: Cartes des isohyètes de la Cuvette Lacustre pendant les périodes humides et sèches.

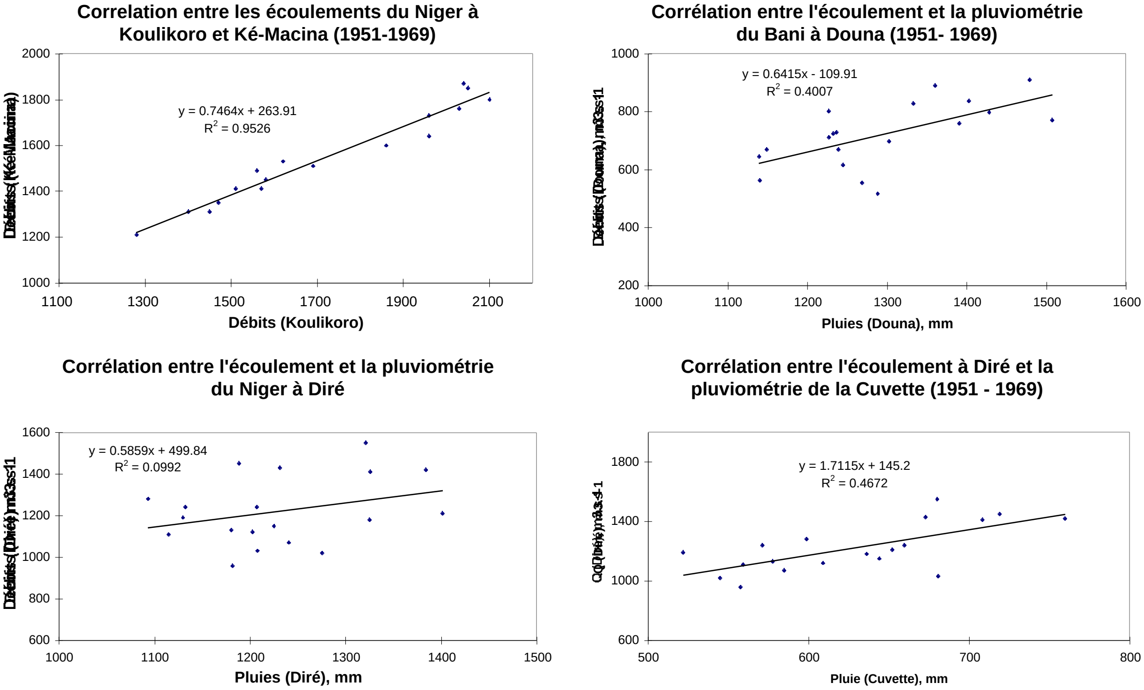
(coefficient de corrélation égal à 0,31). C’est celle entre les débits moyens annuels et la pluviométrie annuelle tombée dans la cuvette qui donne de résultats acceptables (coefficient de corrélation égal à 0,68) (figure 3).



Période humide

Période sèche

Figure 3: Régressions linéaires pour la reconstitution des débits moyens annuels.


Correlation entre les écoulements du Niger à Koulikoro et Ké-Macina (1951-1969)

Corrélation entre l'écoulement et la pluviométrie du Bani à Douna (1951- 1969)

Corrélation entre l'écoulement et la pluviométrie du Niger à Diré

Corrélation entre l'écoulement à Diré et la pluviométrie de la Cuvette (1951 - 1969)

4. Evolution des Apports et des Sorties de la Cuvette

Pour voir l'évolution des ressources en eau de la Cuvette Lacustre, on a déterminé quelques éléments de son bilan hydrologique. Parmi ces éléments, on peut citer l'écoulement entrant, constitué par les apports du Niger à Ké-Macina et du Bani à Douna, l'écoulement sortant qui est constitué par ceux de la station de Diré sur le Niger et la quantité de pluie tombée dans la cuvette. Ainsi, on a pu calculer l'apport dit total qui est constitué par les écoulements entrant plus la pluviométrie tombée dans la cuvette. Les résultats de ces calculs font l'objet du tableau 2.

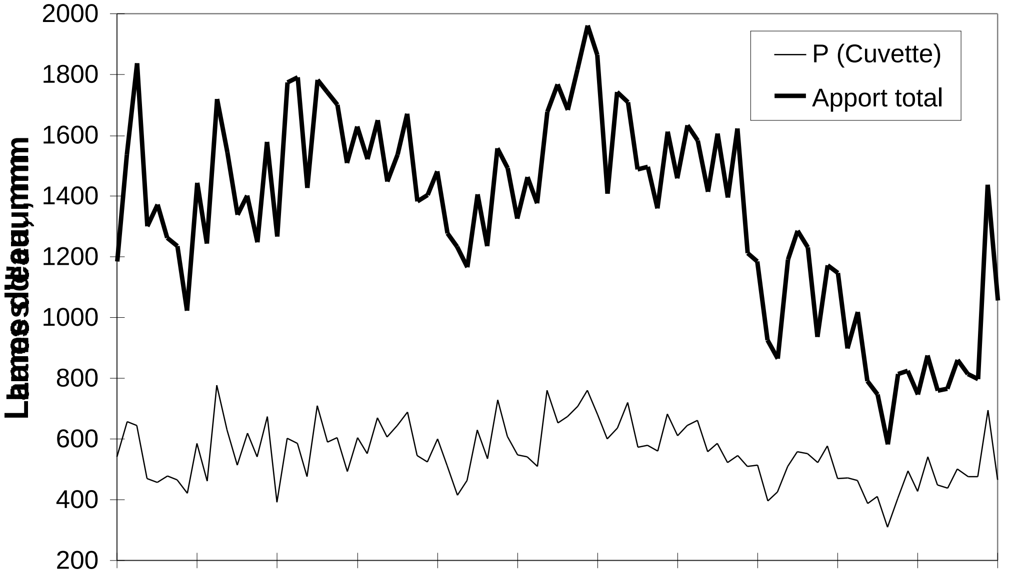
De ce tableau, on remarque que sur la période 1907-95, la lame écoulée entrant dans la cuvette fait 790 mm tandis que celle précipitée est de 555 mm. Ceci fait un apport total de 1345 mm. A Diré la lame écoulée est de 442 mm, ce qui fait une perte totale de 903 mm.

La représentation sur la période 1907-1995 des apports totaux et de la pluviométrie dans la cuvette montre leur baisse progressive (figure 4).

Tableau 1. Calcul des éléments du bilan hydrologique de la Cuvette Lacustre pendant différentes périodes.

Périodes	Lames écoulées (mm)		P, mm Cuvette	Apports (mm) Totaux
	Entrant	Sortant		
1907-1995	790	442	555	1345
1907-1969	918	497	587	1505
1970-1995	481	308	478	959
1907-1910	887	490	577	1465
1911-1920	818	462	540	1358
1921-1930	1015	481	566	1581
1931-1940	906	502	594	1500
1941-1950	820	487	573	1393
1951-1960	1036	575	658	1693
1961-1970	903	471	587	1490
1971-1980	584	366	499	1083
1981-1990	360	252	432	791
1991-1995	471	277	522	993

Figure 4: Comparaison entre les apports totaux dans la Cuvette Lacustre et la pluviometrie tombee sur sa surface.



Il est à remarquer que la plus grande partie des apports dans la cuvette est constituée par l'écoulement entrant. En effet, pendant la période 1907-1995 l'apport total en moyenne est de l'ordre de 1345 mm, dont 790 mm pour l'écoulement entrant, soit 59 % des apports totaux. C'est dire que le reste des 41 %, soit 555 mm provient de la pluie tombée sur la cuvette. Pendant la période humide (1907-1969) la cuvette a reçu 1505 mm d'apports totaux dont 587 mm de pluie tombée sur sa superficie. Pendant la période sèche (1970-1995), les apports totaux ont chuté à 959 mm dont 478 mm de pluie tombée. Ainsi, si l'écoulement entrant diminue de 1036 mm (moyenne de la décennie 1951-60) à 584 mm (moyenne de la décennie 1980-90), soit une baisse de 44 %, la lame d'eau précipitée sur la cuvette quant à elle diminue de 658 mm (moyenne de 1951-60) à 432 mm (moyenne de 1980-90), soit une baisse de 34 %. C'est dire que la plus grande cause de diminution des apports dans la cuvette est due à la baisse des écoulements du Niger et du Bani (figure 5).

5. Impacts de la Diminution des Apports dans la Cuvette sur les Activities Socio-Economiques de la Zone

La diminution des apports dans la cuvette ne se fait pas sans conséquences. En effet, cela a entraîné une diminution des surfaces inondables de la cuvette et perturbant du coup les activités socio-économiques de la zone. Le tableau 2, tiré de l’article de LAE, 1994 (La pêche dans le Delta Central du Niger) illustre non seulement la diminution des pertes en eau dans la cuvette mais aussi, celle des surfaces inondables.

La diminution des surfaces inondables pose le problème de productivité agricole. En effet, les surfaces utilisées pour les cultures de crue et de décrue se trouvent diminuées et cela entraîne une baisse de la production agricole. Ceci met en actualité le problème de changement dans les activités socio-économiques de la zone. Pour cela, le changement de variétés culturales demandant moins d’eau et à cycle court devient une nécessité.

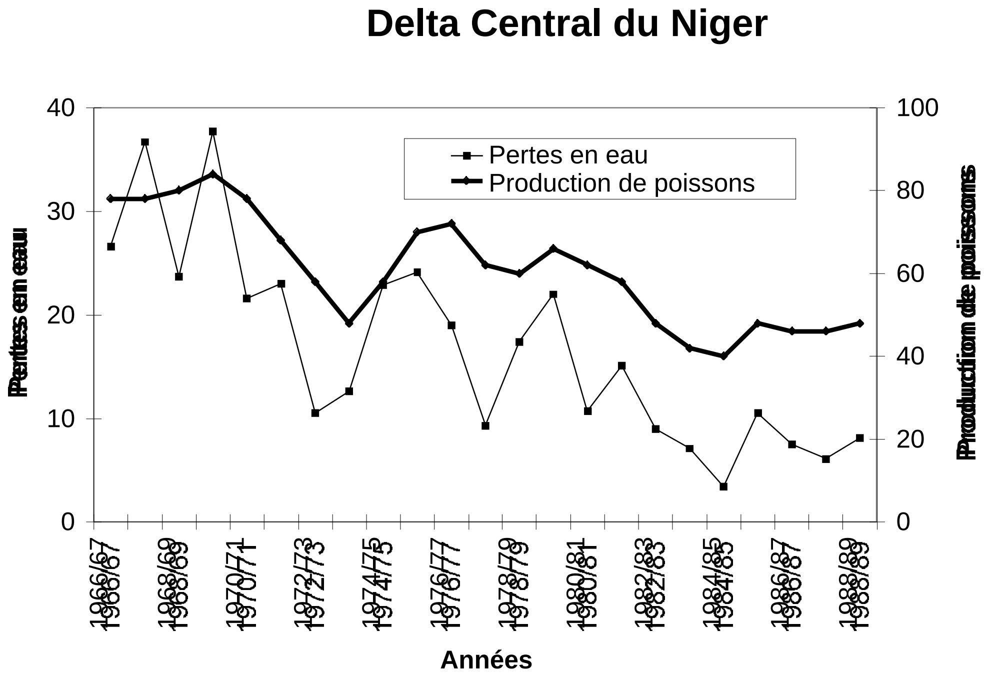
La figure 5, de la production de poissons et des apports d’eau dans le Delta Central du Niger de 1966 à 1989, tirée de l’article de LAE, 1994 montre une certaine concordance entre les pertes d’eau et la production de poissons. En effet, la baisse des apports dans la cuvette a entraîné une diminution de la production de poissons dans la zone. Ceci a eu pour conséquences la diminution du pouvoir d’achat de la population dont l’une des principales activités économiques demeure la pêche.

Tableau 2. Valeurs estimées des pertes annuelles en eau et des surfaces inondables dans le Delta Central du Niger (d'après LAE, 1994).

Années	Pertes en eau 10^9 m^3	Inondation km?
1966/67	26.6	25 300
1967/68	36.7	34 900
1968/69	23.7	22 500
1969/70	37.7	35 900
1970/71	21.6	20 600
1971/72	23	21 900
1972/73	10.5	9 600
1973/74	12.6	11 500
1974/75	22.9	21 800
1975/76	24.1	22 900
1976/77	19	18 100
1977/78	9.3	8 500
1978/79	17.4	16 600
1979/80	22	20 900
1980/81	10.7	9 800
1981/82	15.1	13 800
1982/83	9	8 200
1983/84	7.1	6 500
1984/85	3.4	3 100
1985/86	10.5	8 600
1986/87	7.5	6 800
1987/88	6.1	5 600
1988/89	8.1	7 400

N.B. : Il est à remarquer que l'estimation des surfaces inondables est donnée à titre indicatif. C'est dire qu'elle est imprécise (LAE, 1994).

Figure 5: Evolution des pertes en eau (en $10^9 m^3$) et de la production de poissons (en 10^3tonnes) dans le Delta Central du Niger de 1966 à 1989 (d'après LAE, 1994).



6. Conclusions

A l'issu de cette étude, on peut affirmer que de 1907 à 1995, les apports totaux dans la cuvette ont beaucoup chuté entraînant ainsi une diminution des surfaces inondables de la Cuvette Lacustre du Niger. Ceci ne va sans conséquences. En effet, cela a entraîné une perturbation des activités agro-économiques des populations de la zone qui a vu ses productions agricoles et de poissons diminuer. La baisse de la production agricole s'explique par la diminution des surfaces cultivables. Il est tout de même important de remarquer que dans la diminution des apports totaux, la grande part revient aux écoulements entrant dans la cuvette, à savoir ceux du Niger à Ké-Macina et du Bani à Douna. C'est justement cette baisse des écoulements entrants qui est la cause principale de la diminution des surfaces inondables de la cuvette lacustre. La diminution des écoulements entrants serait liée à l'amenuisement de la nappe phréatique qui s'est beaucoup vidée à cause des sécheresses des années 70 et 80 (Bamba et al., 1996).

References:

BAMBA F., MAHE G., BRICQUET J.P. & OLIVRY J.C. (1996) : Changements climatiques et variabilité des ressources en eau des bassins du Haut Niger et de la cuvette lacustre. XIIèmes Journées Hydrologiques de l'ORSTOM. 10-11 octobre 1996. Montpellier, 21p.

BRICQUET J.P., MAHE G., BAMBA F. et OLIVRY J.C. (1996) : Changements climatiques récents et modifications du fleuve Niger à Koulikoro (Mali). L'hydrologie tropicale : Géoscience et outil pour le développement. IAHS Publication no 238, pp. 157-166.

LAE R. (1994) : Modifications des apports en eau et impact sur les captures de poisson. ''La pêche dans le Delta Central du Niger'', Volume 1, Editions ORSTOM-KARTHALA-IER, Paris 1994, pp. 255-265.

LAMAGAT J.P., SAMBOU S. & ALBERGEL J. (1996) : Analyse statistique de l'écoulement d'un fleuve dans une plaine d'inondation : application aux côtes maximales du fleuve Niger dans la cuvette lacustre. L'hydrologie tropicale : Géoscience et outil pour le développement. IAHS Publication no 238, p 367-379.

MAHE G., DELCLAUX F. et CRESPY A. (1994) : ''Elaboration d'une chaîne de traitement pluviométrique et application au calcul automatique de lames précipitées (bassin versant de l'Ogooué au Gabon)'' Hydrologie Continentale, vol 9, n°2, 1993, pp.169-180

MAHE G. et OLIVRY J.C. (1995) : ''Variations des précipitations et des écoulements en Afrique de l'Ouest et Centrale de 1951 à 1989''. Sécheresse n°1, vol. 6 ; pp.109-117.

OLIVRY J.C. (1993a) : Evolution récente des régimes hydrologiques en Afrique Intertropicale, in « L'eau, la terre et les hommes, hommage à René Frecaut ». Madeleine Griselin Ed. Presses Universitaires de Nancy, pp. 181-190.

OLIVRY J.C. (1993b) : Fonctionnement hydrologique de la Cuvette Lacustre du Niger et essai de modélisation de l'inondation du Delta intérieur. Grands Bassins Fluviaux, Paris, 22-24 novembre 1993, pp. 267-280.

POUYAUD B. (1987) : Variabilité spatiale et temporelle des bilans hydriques de quelques bassins versants d'Afrique de l'Ouest en liaison avec les changements climatiques. In : The Influence of Climate Change and Climate Variability on the Hydrologic Regime and Water Resources (ed. par S. I. Solomon, M. Beran & W. Hogg) (Proc. Vancouver Symp., August 1987). IAHS Publ. no. 168.

SOUMAGUEL A (1996) : Elaboration des fichiers Opérationnels pour le calcul Régionalisé des pluies par la méthode du vecteur Régional (MVR) sur le bassin du Niger. Rapport d'activité FRIEND-AOC, Bamako, ORSTOM, Laboratoire d'Hydrologie, 35 p

Climate Variability and Water Resources Potentials in Nigeria

John A. Shamonda
Hydrology Department, Federal Ministry of Water Resources, Nigeria

Abstract

The paper offers a critical review of some of the available literature as well as a report of the recently concluded JICA2-assisted study for Nigeria on the Water Resources Master Plan. It is deliberately focused on climate variability and the subsequent effects on water resource potential in Nigeria.

Nigeria is located within the tropics. The landmass is of about one million square kilometres, and there is also an intricate drainage network of water resources. The southern part of the country is in the wet equatorial belt and the northern zone is bound by the semi-arid Sahel, which is gradually undergoing desertification.

Water scarcity, or desertification due to climate change or variability, is a growing concern for all the countries around the world, including Nigeria. The general consensus among scientists is that there has been a decline in rainfall in Nigeria, particularly over the last three decades. This decline is clearly manifested at some of the monitoring stations of major rivers in the country.

An appraisal of the climate variability is Nigeria and its effects on the nation's water resource potential is deduced from the record of hydrological data and information of about 30 years.

1. Introduction

Nigeria is located in the tropics and lies between the latitude of 4°10' and 13°50' North and the longitude of 2°15' and 14°45' East. It has a total land mass of about 923,800 km^2 and shares borders with the francophone territories of Benin, Cameroon, Niger and Chad. The country is bounded in the south by the coastline of the Gulf of Guinea in the Atlantic Ocean, running on a west-east axis to a total length of approximately 800 km.

---

2 JICA - Japan International Co-operation Agency

The geographic location, size and shape of Nigeria allow it to experience various forms of weather conditions, which can easily be classified into distinctive different types of climatic belts.

Like all the other countries along the West African coast, Nigeria records high temperatures all year round, with an annual mean for most stations in the country given as 27°C. The highest temperatures occur normally in the month of April in the northern part of the country, while the peak is recorded a little earlier in the year in the southern part.

The rainfall decreases both in duration and amount from the coast to the interior, except where there is altitudinal effect like in the Jos Plateau and in areas of the Cameroon Mountains. On the windward side of such relief features, rainfall is more and torrential.

The measured evaporation values are greater in the north than in the south since the dry season is much longer in the north.

The drainage density of Nigeria is very high with two international rivers, the Niger and the Benue, dividing the country into three parts. Most of the inland rivers drain into one of the two (Figure 1). On the basis of the relief features and the intricate drainage patterns, Nigeria is divided into eight Hydrological Areas. The total potential surface run-off and groundwater resources are estimated to be 267.30 billion m^3 and 51.93 billion m^3 respectively (Source: JICA-1995).

The annual surface runoff to the seas from the Niger, the watersheds of the southwestern littoral and the Cross River has been estimated to be 300 km^3.

2. Meteorological Services and Climate in Nigeria

Routine climate observations started in Nigeria in 1892 with the establishment of an agrometeorological station in Lagos, which was placed under the management of the Public Works Department (PWD).

In April 1949, a full-fledged Department was created for meteorological data collection and primarily to provide information for use in Aviation. The needs of other sectors of the economy were considered secondary. By 1960, before national independence, Nigeria had 115 rainfall stations, 41 agromet stations, 27 synoptic stations, 9 climatological stations and 9 upper-air stations otherwise known as aerological stations. By 1996, (Akeh et al., 1996) the network for each of the different grades of stations in the country had increased in greater proportion in the country to 224 rainfall stations, 167 agromet stations, 42 synoptic stations, and 13 climatological stations. However, there was a reduction in the number of upper-air stations to 5. These stations all provide meteorological data and information for the entire country.

Table I: Areal Mean Rainfall (1981-1989)

Table II: Mean Annual Pan Evaporation (1980-1989)

HA	Area (km^2)	Areal Rainfall (mm)	Range
1 - Niger North	131,600	710	400 - 900
2 - Niger Central	158,100	1,130	920 - 1,250
3- Upper Benue	158,900	990	570 - 1,850
4 - Lower Benue	73,000	1,300	1,300 - 1,650
5 - Niger South	53,900	1,990	1,300 - 2,800
6 - West Littoral	100,500	1,480	1,100 - 2,600
7 - East Littoral	59,800	1,810	1,500 - 2,200
8 - Lake Chad	188,000	560	400 - 1,300
Total	*923,800*	*1,080*	*400 - 2,800*

source: JICA NWRMP (1995) 3

HA	Nos. of Stations observed	Pan Evaporation (mm)
I	2	1,990 - 3,630
II	3	2,210 - 4,491
III	5	1,580 - 2,620
IV	2	1,520 - 1,900
V	1	2,450
VI	5	1,200 - 2,100
VII	3	1,660 - 2,210
VIII	2	4,470 - 5,220

source: JICA NWRMP (1995) 3

The Federal Department of Meteorological Services (FDMS), now under the Federal Ministry of Aviation, is the agency responsible for the collection of meteorological data and coordination of all efforts of other agencies and research institutions involved in climatic data collection in Nigeria.

A summary of the climatic situation in Nigeria, using the 8 Hydrological Areas for the classification, is provided in Tables I and II below:

3. Water Resource Potential in Nigeria

3.1 Surface Water

The river system in Nigeria is divided into five major drainage watersheds, namely the Niger, the Benue, the Cross, the Chad inland drainage, and the littoral of the southwestern zone. With the exception of the Chad system, almost all the rest of Nigeria's river systems drain into the Atlantic Ocean.

Through the division of the nation's watersheds, eight Hydrological Areas have been demarcated. Surface water resources in Nigeria are dominated by the Niger River and its tributaries which drain 63% of the country and bring water into the country from neighbouring Niger, Benin and Cameroon.

The international dimension to the water resource potential of Nigeria is reflected in the country's membership in a number of multi-national cooperative organizations with other nations in the regional inter-basins. Among the organizations in which Nigeria actively participates are: the Niger Basin Authority (NBA) which has nine member-states for control of River Niger; Lake Chad Basin Commission (LCBC) which was organized for the mutual use of the Lake Chad and its resources with four other member-states; and the Nigeria-Niger Joint Commission for control of the common hydrological/ hydrogeological basins along the international common boundaries.

3.2 Hydrogeology

About 60% of the country is underlain by crystalline rocks, 20% by consolidated sedimentary materials, and 20% by unconsolidated sedimentary materials. Static water levels range from zero in the coastal alluvium to 200 m in some sedimentary areas. In crystalline rock areas, well yields are unpredictable, and where sufficient depth of weathering exists, the well yields may be suitable for handpump operation (minimum yield is 10 litre/minute). Higher yields are available for the use of motorised pumps at specific locations where deep weathering and underlying fractures coincide.

In Nigeria, the flood plains, referred to as "fadamas," have not been fully exploited for irrigation, but they have also played a very important part in the regional economy where they have been used for dry season cattle grazing in the north and for fishing activities. There is considerable interest in new techniques to exploit seasonal groundwater in the fadamas for more extensive irrigation. A World Bank-funded project is currently going on in the states of Sokoto, Kebbi, Bauchi, Jigawa and Kano in the Sahel region on the water resource potential of the fadamas. Installation of facilities to monitor the response of the resource on intensive irrigation is in progress.

The water resource potential for each of the Hydrological Areas in Nigeria is provided in the Table III below.

Table III: Water Resources Potential of Nigeria

Hydrological Area	Surface Water Annual Yield [x10^9] (m^3)	Groundwater, Annual Yield [x10^9] (m^3)	Drainage Area (total area in Nigeria) - (km^2)
HA I	22.4	4.3	131,600
HA II	32.6	8.2	158,100
HA III	83.0	11.4	158,900
HA IV			73,000
HA VI	35.4	9.0	100,500
HA V	85.7	13.4	53,900
HA VII			59,800
HA VIII	8.2	5.6	188,000
TOTAL	267.3	51.9	923,800

Source: JICA NWRMP (1995)

4. Temporal and Spatial Variation in Climate in Nigeria

In the Table IV below, rainfall data for the 23 selected synoptic stations in Nigeria (Figures 2 & 3) over a period of 30 years were analysed and produced in a sequential and continuous 10-year series for three decades.

The presentation in this form removes the noises that could be produced from short-term fluctuations.

Using each decade as a unit of comparison, the annual mean rainfall during the decade of 1981-90 declined from that of the annual mean rainfall of the two previous decades. It is also very striking to note that the recorded data for the annual mean rainfall analysed for the decade of 1981-90 at all the chosen stations was remarkably less than the annual mean rainfall analysed for the entire period of the three decades (i.e. 1961-90).

Table IV. Rainfall Data

S/N	Station	Station Code	Hyd Area	Long (°)	Lat (°)	1961-1990 Mean R’fall (mm)	Mean R’fall (mm) **1961-70**	Mean R’fall (mm) **1971-80**	Mean R’fall (mm) **1981-90**
1	Sokoto	Sok	1	5.25	113.02	630	709	605	539
2	Yelwa	Yel	1	4.75	10.88	945	1057	929	845
3	Zaria	Zar	2	7.58	11.18	980	953	1013	945
4	Minna	Min	2	6.53	9.62	1193	1292	1227	1052
5	Mokwa	Mok	2	4.98	9.3	1216	1267	1257	936
6	Bida	Bid	2	5.97	9.05	1183	1257	1161	1083
7	Ilorin	Ilo	2	4.58	8.48	1244	1307	1179	1217
8	Lokoja	Lok	2	6.75	7.78	1200	1241	1174	1159
9	Bauchi	Bau	3	9.82	10.28	960	1031	987	864
10	Yola	Yol	3	12.47	9.23	901	938	892	842
11	Makurdi	Mak	4	8.62	7.68	1186	1248	1166	1140
12	Yandev	Yan	4	9.00	7.20	1297	1370	1268	1173
13	Ibadan	Iba	5	3.90	7.43	1315	1341	1305	1296
14	Ondo	Ond	5	4.78	7.07	1618	1666	1603	1601
15	Ijebu Ode	Ije	5	3.87	6.78	1466	1595	1451	1408
16	Lagos	Lag	5	3.40	6.45	1843	2126	1713	1596
17	Enugu	Enu	6	7.55	6.47	1706	1680	1795	1580
18	Port Harcourt	Por	6	7.17	4.67	2426	2596	2182	2478
19	Calabar	Cal	7	8.35	4.97	2772	2893	2877	2524
20	Nguru	Ngu	8	10.48	12.93	454	520	450	357
21	Kano	Kan	8	8.53	12.05	724	828	713	615
22	Potiskum	Pot	8	11.03	11.65	659	745	628	576
23	Maiduguri	Mai	8	13.08	11.85	570	653	602	438

Source: Jagtap, S.S. 2

5. Effect of Climate variability on water Resources in Nigeria

From the JICA Report, the trend in 30-year data (grouped by decade) for the mean annual flows of the Niger and Benue Rivers (monitored at Baro on the River Niger and Markurdi on the River Benue and at Lokoja, just downstream of the confluence), was studied.

Based on records in Table V below, the scenario shows a consistent decline in the mean annual runoff computed for one decade to the next at all the three stations. The systematic decline could generally be attributed to the consequential effect of the observed decrease in the amount of rainfall as shown in Table IV and effects of other climatic conditions due to changes noticed in climate phenomenon and the hydrological cycle.

Table V: Mean Annual Runoff of River Niger [Unit: 10^9 m^3]

Year	River Niger at **Baro** Station (total catchment area = 730,300 km^2)	River Benue at **Makurdi** Station (305,500 km^2)	River Niger at **Lokoja** Station (1,089,000 km^2)
1960 - 69	78	111	204
1970 - 79	57	84	166
1980 - 89	42	72	138

Source: JICA (1995) 3

6. Conclusion

In Nigeria, there are many action plans that are being implemented in a coherent and progressive manner in response to various climatic conditions of a complete hydrological cycle in a year and globally observed fluctuation in climate.

The newly released Water Resources Decree 101 of 1993 is set to ensure a rational and efficient use of available surface and underground water resources.

Studies on inter-basin water transfer within the country are part of the programmes of drought mitigation and water resources management, purposely with a view to transferring water from water surplus areas to water deficient basins. It is also a rational strategy of balancing the ecosystem in the entire country.

As a way of conserving the available water resources, the country power system depends on a mix of thermal and hydro power generating systems. The conservation strategy also includes construction of large and small earth dams to reduce losses into the sea and to create reservoirs for water use especially during the low flow period of the year.

Nigeria has entered into a number of bilateral and multi-lateral cooperative organizations with other African countries that share river basins for mutual use, development and management of the water resources in the common basins.

The creation of the Federal Environmental Protection Agency (FEPA) in 1990 in Nigeria with mandate to monitor and its mandate to manage the environment is a significant contribution to global efforts for sustainable development. The activities of the body seek to reduce land and atmospheric pollution and human activities that result in intensification of the greenhouse effect and the devastation of the environment.

References :

Akeh, L.E. et al. - (1996) "Trends and Prospects of the Growth and Development of the Nigerian Meteorological Services."

Jagtap, S.S. - (1995) "Changes in Annual, Seasonal and Monthly Rainfall in Nigeria During 1961-1990 and Consequences to Agriculture."

Japan International Co-operation Agency (JICA) - (1995) "National Water Resources Master Plan for Nigeria."

Proceedings of the Conference organised by NEPA (Nigeria) - (1995) "Global Climate Change - Impact on Energy Development," edited by Umolu, J.C.

Proceedings of the 1st Biennial Symposium of the Nigerian National Committee for UNESCO-IHP - (1990) "Hydrology in National Development."

Shamonda, J.A. - (1990) "Hydro-Niger Project for Flood Forecasting of River Niger and its Application for Regional Development"

World Bank/UNDP/ADE assisted study - (1992) "Sub-Saharan Africa Hydrological Assessment (West African Regional) Report."

Predicting climate variability in Southern Africa

Mark R. Jury

Climate Impact Predictions
Geography Dept, University of Zululand, KwaDlangezwa, South Africa

1. Background

The climate of Africa fluctuates widely, putting pressure on water resources and food security. At present, 17% of the population is undernourished. Within a decade, over 100 million people will face water scarcity (Petersen 1997). Rain-fed crops use over 80% of the available water and govern the economy of most African countries (Hulme *et al.* 1996). Good seasonal rains, which are essential to productivity, have been linked with regional sea surface temperature (SST) and the global El Niño-Southern Oscillation (ENSO). A reduction in economic and societal stress could be effected by reliable predictions of the coming seasonal rains. To enable prediction, climatologists must uncover signals which explain ocean-atmosphere coupling processes in the region (Hastenrath *et al.*, 1993; Mason *et al.*, 1996).

Analysis of monthly climatic data has highlighted the relationship between ENSO warm events and African drought (Ropelewski and Halpert, 1987; Janowiak, 1988). Upper westerly air flow increases during tropical Pacific warm events (figure 1) as sea temperatures in the tropical Indian Ocean rise in sympathy (Cadet, 1985; Jury and Pathack, 1993). During El Niño events, observations reveal that the Indian monsoon trough consumes the moisture intended for Africa (Jury, 1992; Jury *et al.*, 1994). Tropical warming events have also been identified in the Atlantic Ocean (Nicholson and Entekhabi, 1987), and impact rainfall over south-western Africa (Jury 1997) and the Sahel (Lamb *et al.*., 1986; Parker *et al.*, 1988; Janicot *et al.*, 1996) through the re-direction of moisture fluxes (Hirst and Hastenrath, 1983).

Each region of Africa has its own distinctive inter-annual climate anomalies and teleconnections (Semazzi *et al.*, 1988). The east and southern regions are dominated by the ENSO signal with opposite polarity, while the north and west regions respond to more localised environmental conditions. Sahelian rainfall corresponds with a N-S dipole pattern in Atlantic SST (Rowell *et al.*, 1992), whilst the North Atlantic (pressure) Oscillation (NAO) dictates a component of climate variance over the northern rim of the continent. ENSO-based predictability appears to be highest for southern Africa. To capitalise on this, research has commenced with statistical and numerical modelling efforts aimed at developing reliable predictions of seasonal rainfall.

2. Year-to-year predictability

In an effort to develop statistically-based, long-range forecasts for southern Africa, numerous teleconnection predictors have been assembled from the austral spring and include: global values for the Southern Oscillation Index and Quasi-biennial Oscillation, and tropical Atlantic upper winds; sea surface temperature (SST) pattern time series for the South Atlantic, Indian and Pacific Oceans; pressure, SST and surface winds in the tropical SE Atlantic and over the oceans to the south of Africa; pressure, SST, outgoing longwave radiation (OLR-cloud depth) and winds over the Indian Ocean. All predictors are available from 1971 to 1993, a 22-year statistical training period.

Multi-variate regression models are formulated in step-wise fashion so as to narrow down the predictors to an optimum mix of four. This preserves the statistical degrees of freedom and improves the subsequent ‘skill’ of the model in operational usage. Models have been developed for streamflow and crop yield in various regions of southern Africa where target data are available. Table 1 shows the algorithms and ‘fit’, and highlights the unique nature of each model. Skill validation tests indicate that reliable predictions of streamflow and crop yield are probable 70% of the time at a lead time of four months. Examples of validation tests for two models are given in Figure 2. Farmers, decision makers and others may take mitigation action on the basis of predictions for various targets in adjacent regions from different research groups, including numerical modelling products.

3. Operational products and summary

Models to predict streamflow and crop yields in southern Africa have been formulated, tested and implemented by the Climate Impact Predictions unit at the University of Zululand. Predictor inputs are tracked via Internet from NCEP, USA. Each September to November, long-range outlooks are provided on the Internet website to assist in planning the coming summer season: http://os2.iafrica.com/weather/forecast/cip_seasonal_outlook.html.

The predictability of streamflow and maize yield has been assessed and reliable statistical models have been developed for a number of targets. Southern Africa can anticipate drought and flood seasons and plan mitigation efforts aimed at improving the food security. It is expected that other regions of Africa can find similar tools to alleviate climate impacts in the near future.

Table 1:

	% fit	skill	four predictor algorithm
FS mz	= 74	80	+.45(oSTang)-.60(oSWv)+.24(aWCI-ABp)-.28(aAtlW)
SUG yd	= 84	86	+.85(oNIv)+.31(oSEolr)+.31(aATpc1)+.44(oSOI)
VICF	= 81	86	-.32(aMauRp)-.36(aArBst)-.37(oAtlW)+.73(oATpc2)
VAALr	= 78	84	-.48(oSIp)+.40(oPC4ag)+.39(aPC5ai)+.71(oPC9ai)
TEMP	= 80	85	+.92(aArBp)-.87(aColr)-.24(aMauRv)-.21(aPang)

Targets in order of appearance: central South Africa (SA) maize yield, Sugar cane yield (SA), Victoria Falls streamflow, Vaal River streamflow, Johannesburg area summer temperatures

References:

Cadet, D.L. 1985: The Southern Oscillation over the Indian Ocean. *Journal of Climate* 5, 189-212.

Hastenrath, S., Nicklis, A. and Greischar, L. 1993: Atmospheric-hydrospheric mechanisms of climate anomalies in the Western Equatorial Indian Ocean. *Journal of Geophysical Research* 98, 20219-20235.

Hirst, A.C. and Hastenrath, S. 1983: Atmosphere-ocean mechanisms of climate anomalies in the Angola - tropical Atlantic sector. *Journal of Physical Oceanography* 13, 1146-1157.

Hulme, M., Arntzen, J., Downing, T., Leemans, R., Malcolm, J., Reynard, N., Ringrose, S., Rogers, D., Chiziya, E., Conway, D., Joyce, A., Jain, P., Magadza, C., Markham and Mulenga, H. 1996: *Climatic Change and Southern Africa: an Exploration of some Potential Impacts and Implications in the SADC Region,* Report to WWF International, 104 pp.

Janicot, S., Moron, V. and Fontaine, B. 1996: Sahel droughts and ENSO dynamics. *Geophysical Research Letters* 23, 515-518.

Janowiak, J.E. 1988: An investigation of interannual rainfall variability in Africa. *Journal of Climate* 1, 240-255.

Jury, M.R. 1992: A climatic dipole governing the interannual variability of convection over the SW Indian Ocean and SE Africa region. *Trends in Geophysical Research* 1, 165-172.

Jury, M.R. and Pathack, B.M.R. 1993: Composite climatic patterns associated with extreme modes of summer rainfall over southern Africa: 1975-1984. *Theoretical and Applied Climatology* 47, 137-145.

Jury, M.R., McQueen, C.A. and Levey, K.M. 1994: SOI and QBO signals in the African region. *Theoretical and Applied Climatology* 50, 103-115.

Jury, M R, 1997, Southeast Atlantic warm events: composite evolution and consequences for southern African climate, *S African J Marine Science*, 17, (in press)

Lamb, P.J., Peppler, R.A. and Hastenrath, S. 1986: Interannual variability in the tropical Atlantic. *Nature* 322, 238-240.

Mason, S.J., Joubert, A.M. Cosijn, C. and Crimp, S.J. 1996: Review of the current state of seasonal forecasting techniques with applicability to southern Africa. *WaterSA* 22, 203-209.

Nicholson, S.E. and Entekhabi, D. 1987: Rainfall variability in equatorial and southern Africa: relationships with sea surface temperatures along the south-western coast of Africa. *Journal of Climate and Applied Meteorology* 26, 561-578.

Parker, D.E., Folland, C.K. and Ward, M.N. 1988: Sea-surface temperature anomaly patterns and prediction of seasonal rainfall in the Sahel region of Africa. In Gregory, S., editor, *Recent Climatic Change*, London: Belhaven Press, 166-178.

Petersen, M S, 1997, African water resources development and human needs, *Hydor Aulos*, 1, 2, 1-8

Ropelewski, C.F. and Halpert, M.S. 1987: Precipitation patterns associated with El Niño/Southern Oscillation. *Monthly Weather Review* 115, 1606-1626.

Rowell, D P, Folland, C K, Maskell, K, Owen, J A, and Ward, M N, 1992, Modelling the influence of global sea surface temperatures on the variability and predictability of seasonal Sahel rainfall, *Geophysical Res Letter*, 19, 905-908

Semazzi, F.H.M., Mehta V. and Sud, Y.C. 1988: An investigation of the relationship between sub-Saharan rainfall and global sea surface temperatures. *Atmosphere Ocean* 26, 118-138.

Climate Variability and Crop Failure: The Role of Ecosystem Biodiversity in Smoothing Household Consumption in the Northern Senegal Wetlands

John V. Magistro
Advanced Study Program Fellow
Environmental and Societal Impacts Group
National Center for Atmospheric Research

Abstract

Trends in global warming may prompt African authorities to adopt capital-intensive agricultural technologies that maximize crop output. Strategies of production intensification, however, often imply a simplification of cropping systems and a homogenization of agricultural landscapes. Such solutions may easily overlook smallholder farm livelihoods that rely on resource diversification and heterogeneity of the agroecological landscape as a means of mitigating risk in highly erratic, unpredictable tropical climates. This paper will explore smallholder production strategies in the middle Senegal Valley wetlands, and will highlight the role of ecosystem biodiversity in maintaining food security and smoothing household consumption throughout the year. The conclusion underscores the need for climate change experts and development planners to remain cognizant of the vital ecological function that biodiversity plays in maintaining smallholder food security in the context of an expanding human population, growing shift toward agricultural intensification, and anticipated increase in climatic variability.

1. Introduction

Current estimates on global warming under a *business as usual scenario* anticipate an increased severity and fluctuation of weather patterns throughout the tropics in the coming century. The IPCC 1990 report indicates that rising temperatures in semi-arid regions will result in increasing rates of evapotranspiration. It is this hydrological process, rather than temperature rise per se, that is postulated to be the critical factor affecting the tropical environment in sub-Saharan Africa. Increased evapotranspiration will most likely translate into greater moisture stress for tropical plants, necessitating, as one possible alternative, “a need for supplemental water supplies in response to decreases in soil moisture" (Glantz 1992:195). A more recent summary report by the Global Climate Change Information Programme cautions that "a shift in the global climate could bring about a change in the frequency and intensity of drought in already drought-prone regions," and that the consequences for soil erosion, crop productivity and food security could be of "great concern to the mainly marginal, subsistence farmers that crop these lands" (GCCIP 1996: 2-3).

Agriculturists will be required to adapt to greater interannual variability in wet and dry year extremes. If present general circulation models (GCMs) are even remotely accurate, it is anticipated that more frequent drought will be coupled with more intense wet years. Thus enhancements of the hydrological cycle producing higher intensity rainfall and flooding will only worsen conditions of soil erosion through increased intensity of runoff, amplifying present rates of crop land degradation and flooding of vital agricultural zones (Salinger 1994:134).

The ascendancy of GCMs in predicting a more precarious future climate will likely compel analysts and modelers of climate impact assessment to adopt maximization output parameters for food security. Under such a sanguine scenario, a proliferating world population in the tropical developing countries would most efficiently achieve levels of food self-provision via strategies of rapid agricultural capitalization that rely heavily on modern technological inputs of improved water management, seed, pesticides, and chemical fertilizers. Under current policy protocols calling for developing country studies on adaptation and mitigation to climate change, agricultural economists attempting to model future impact and response scenarios may likely utilize assumptions of production maximization as basic input-output parameters required to address projected food shortfalls, particularly in drought-prone environments such as the West African Sahel. Implicit in such models is a 'neo-green revolution' approach of improved high-yield varieties of maize, wheat and rice, and an assumed abundance of rural labor, ready access to credit, and adequate availability of fertilizer, fuel, and pesticides needed to boost production. Crop maximization models based upon capital and labor-intensive factor inputs, however, also frequently imply a simplification of cropping systems and a homogenization of agricultural landscapes (Altieri 1987; Srivastava *et al.* 1996, Thrupp 1997). Solutions that focus on maximizing agricultural productivity may easily overlook smallhold farm livelihoods that rely on resource diversification and heterogeneity of the agroecological landscape as a means of mitigating risk in highly erratic, unpredictable tropical climates.

Global climate change scenarios that model adverse environmental impact and that generate new economic models of agricultural productivity enhancement pose a major risk that could easily defeat the original purpose of environmental mitigation and improved food security. If not given careful consideration, the broader impact of such models could spell the loss of resilience of diversified agroecosystems under conditions of extreme climatic stress. A plausible outcome could be an increased likelihood of crop failure due to over-reliance on high-yielding, high-input monocrop regimes.

Historically, smallhold farmers have reduced the risk of crop failure and attendant declines in food supply and income by husbanding a diverse portfolio of crops and domestic animals, and by gathering off-farm wild foods (Richards

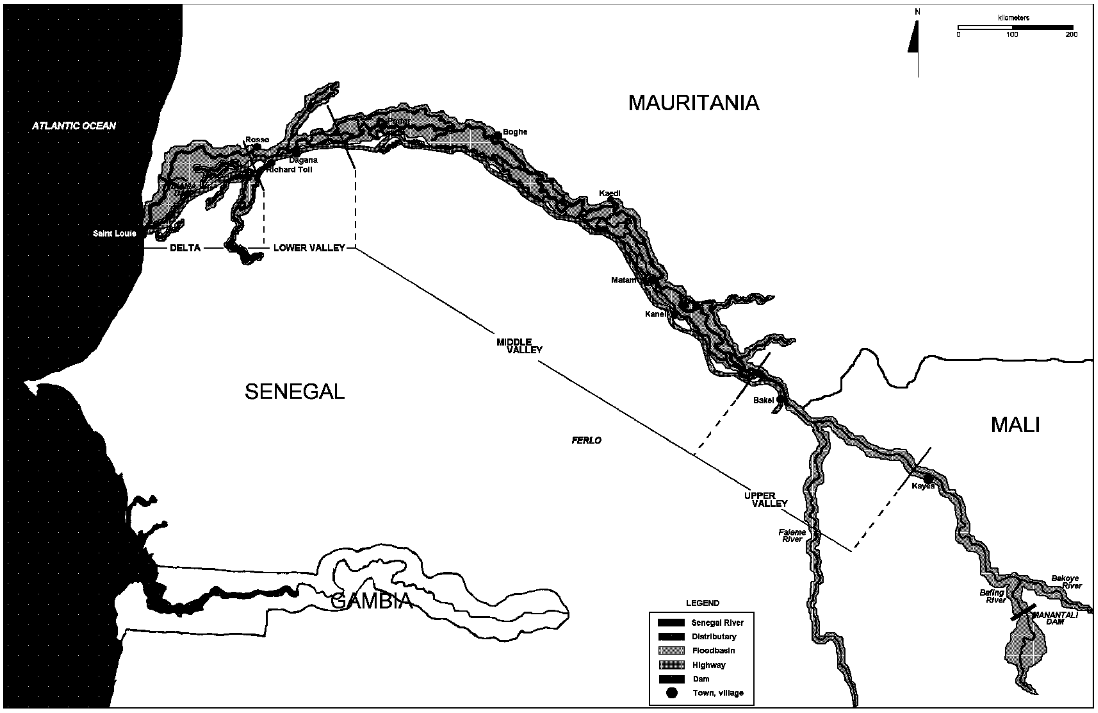
1985). This mixed repertoire of food and income resources has been particularly effective in smoothing household consumption patterns and providing a buffer against food scarcity during periods of high climatic stress such as long intervals between dry and wet seasons.

This paper will explore a contextually specific setting -- the middle Senegal Valley wetlands -- and highlight the key role of a biologically diverse landscape in maintaining food security and smoothing household consumption throughout the year. This ecologically rich mosaic is currently under threat by the management of two dams, one at Manantali, Mali and the other at Diama, Senegal, that propose to radically alter the downstream ecology of the Senegal River and maximize food production by introducing capital-intensive irrigated rice farming systems. Under a future scenario of regional and global-level climate change, local and national authorities will be under increasing scrutiny to adopt agricultural models, such as that currently being proposed in the northern Senegal region, which call for maximization of output via modern rice farming methods. This paper argues for caution and careful consideration of the implicit assumptions built into regional level climate change impact and assessment models by agricultural experts and economic planners. It is imperative that such professionals become cognizant of the vital ecological function that biodiversity plays in maintaining smallhold farmers' security in food and income in a world of expanding human population, increasing agricultural intensification, and ever-changing global climate.

2. Biophysical Features of the Senegal River Valley

The broad expanse of the Senegal River Valley stretches over 1,700 km from its highland source in the Fuuta Jalon region of Guinea to the northern Senegalese port city of St. Louis on the Atlantic Coast (Figure 1). It constitutes one of the largest wetland ecosystems in Africa (Grosenick *et al.* 1990:120), covering an estimated 289,000 km^2 and supporting a population estimated at 1.6 to 1.7 million inhabitants (Ndiame 1985:3; Van Lavieren and Van Wetten 1990:32).

Figure 1. The Senegal River Valley



The basin extends across a broad landscape that is characterized by three distinct zones: the upper basin of humid, tropical forests on the Guinea / Mali border; the middle basin of arid, semi-desert dunes and sandy uplands; and the lower basin of the river delta. The geomorphology, hydrology, and climate varies across the regions as does the range of subsistence livelihoods. Historically, each region has also supported distinct ethno-linguistic communities. The region of focus in this paper, the middle valley, is inhabited primarily by a sedentarized community of agropastoralists and fishers known as the Haalpulaar.

The key feature of the regional ecology is a distinct seasonal variation in rainfall and stream flow in the river basin. Precipitation falls intensively during a short two- to three-month period followed by a long, hot dry season. In an average year, rains begin in June, increase in intensity and duration by August and September, and subside in October. Annual runoff is distributed in a single peak, with most of the flow concentrated during the truncated wet season (Sir Alexander Gibb and Partners *et al.* 1987). The marked differential in runoff entering the river channels between wet and dry seasons creates a distinct 'pulse stable' ecosystem (Howard-Williams and Thompson 1985:219) in which low-lying basins adjacent to the main river channel are briefly flooded at the height of the rains.

3. Drought and Climatic Variability

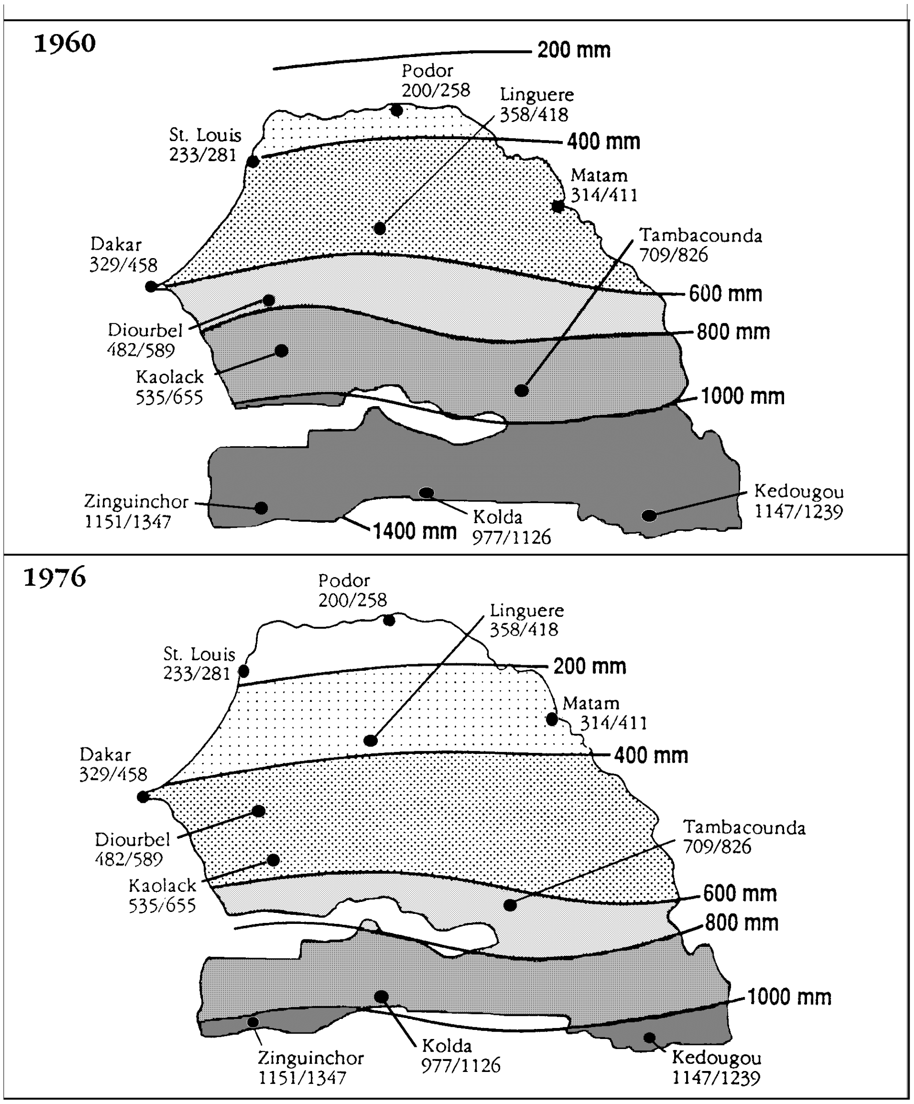
Historically, the region has been vulnerable to drought. Rural communities have traditionally engaged in a mix of farming, fishing, and herding activities, relying heavily on a customary form of recessional floodplain farming. However, they have not always met their subsistence needs through these customary livelihoods. Occasional shortages in rain and nominal flooding of the wetlands have caused food shortage and famine, forcing individuals to migrate temporarily out of the region, as was the case during the Sahelian drought of the late 1960s and early 1970s.

Sizable interannual variations in precipitation result from the particular atmospheric conditions of the Inter-Tropical Convergence Zone (ITCZ). The seasonal movement of the ITCZ north from March to October, and south from November to February creates an incremental range in wet and dry conditions in the valley according to the seasonal position of the ITCZ. The magnitude of drought conditions in the Sahel during the past decade is characterized by a shift of the isohyet marking the northern limit of cultivation southwards by approximately 120 kilometers to the Senegal-Mauritania border (OMVS, and Dames and Moore Intl. 1989:3-39). According to Michel (1985:114,116), isohyets in 1972 had drifted southward by more than 200 km in relation to a previous thirty year period, the 250 mm boundary falling slightly below the regional administrative center of Matam in the middle valley.

This phenomenon is illustrated in Figure 2 by showing the southerly shift of the isohyets in Senegal between 1960 and 1976. The reference to rainfall gradients here, by situating the Senegal River in its broader inter-regional context, calls attention to the episodic fluctuations of climate that have transpired in the region over the past century. A recent review of rainfall data from the region corroborates a secular drying trend in recent decades, indicating a reduction in average annual rainfall by more than 30 percent between 1930-69 and 1970-85 (Bass *et al.* 1995:492).

Enhanced fluctuations in decadal precipitation and increased drift in isohyet data may be anticipated in a future global warming scenario in which the range in climatic variance between wet and dry years will occur with increasing frequency.

Figure 2. Southward Shift of Rainfall in Senegal, 1960-1976. (SOURCE: Grosenick *et al.*., [1990:20])



The middle valley is characteristic of the arid sub-desert conditions of the Sahelo-Sudanian and Sahelian ecozones. The upper range in precipitation reaches 600 mm on the southeastern fringe at Bakel and drops continuously as one moves northward in the valley. At the upper Sahelian limits of the basin in Podor, rainfall approaches the northern limit of cultivation at about 250 mm per annum, seriously calling into question the agronomic viability of rainfed cultivation. As the river descends westward from Podor continuing its journey to the coast, rainfall conditions improve only slightly rising just above the annual mean for Podor.

A plethora of studies have measured the extent of climatic variability, particularly the abrupt regional perturbations of ecology and climate that ensued in the drought years of the 1970s and 1980s (Gannett Fleming *et al.* 1978; GERSAR-CACG *et al.* 1989; Grosenick *et al.*. 1990; Van Lavieren and Van Wetten 1990). These analyses draw from a large corpus of statistics, assorted figures, and varying time periods to persuasively illustrate the severity of drought in the past two decades. Bass *et al.*, (1995:488) note that average annual flow of the Senegal River over a 30 year period (1960-90) has experienced a statistically significant decline, suggesting a possible long-term departure from average annual norms. A comprehensive data set, assembled for the purpose of quantifying the hydrological deficits of the past century, has been undertaken by Hollis (1990a: 1990b). Drawing from both rainfall and river flow data, Hollis' analysis places the recent decade of prolonged drought in its proper longitudinal perspective. Rainfall averages from before and after 1972, a pivotal year marking the advent of two decades of drought, are listed for several major sites in the valley in Table 1. As Hollis (1990a:6) points out with regard to figures drawn from a GERSAR-CACG (1988) master plan for the river valley, "...the maximum annual rainfall for 1972 to 1978 rarely reaches the mean for the period before 1972." Table 1 illustrates with clarity the precipitous drop in rainfall recorded almost universally throughout the valley left bank.

River hydrology (as measured in annual volume of flow) as well may be convincingly used as a primary indicator of drought conditions. Hollis (1990a:6), for example, has rank ordered flow data for the Senegal River at Bakel during the past century to illustrate persuasively the severity of drought conditions in the 1970s and 1980s (Table 2). Hollis observes that "eight of the ten worst drought years this century occurred in the 1970s and 1980s. 1982 to 1986 saw the 7th, 2nd, 1st, [10th] and 8th worst droughts of this century in successive years" (Ibid.).

Historical research has confirmed the systemic nature of climatic variance in the Senegal Valley. Nicholson (1980), drawing from early geographical accounts of the region, notes that major drought periods can be traced back to at least the 16th century. The severity of drought during this century, particularly that of recent noted by Hollis above, is corroborated by another source who remarks:

> “The relatively dry conditions have persisted for approximately two decades and it now appears that this century may be the driest one in the West African region....in over 500 years. Annual flow data for Bakel since 1903 show that the recent drought has been longer and more severe than any drought since the beginning of the century.” (OMVS, and Dames and Moore Intl. 1989:3-36)

Table 1. Rank Order of Top Ten Drought Years in the Senegal River Basin.

Table 2. Mean Annual Rainfall Before and After 1972 in the Senegal River Basin (rainfall in mm)

Rank Order	Year	Flood Volume[a]
1	1984	4,958
2	1983	5,108
3	1913	6,207
4	1979	7,468
5	1972	7,610
6	1944	7,907
7	1982	8,096
8	1986	9,022
9	1985	9,578
10	1976	9,939
Average	1904-84	18,615

[a] Flood volume measured in 106m3 at Bakel from August to October.
SOURCE: Adapted from Hollis (1990a: 6).

Station	Average Before 1972	Average 1972-87	Percent Reduction	Minimum 1972-87	Maximum 1972-87
Dagana	320	184	43	58	328
Podor	317	176	44	66	304
Matam	526	298	43	175	477
Bakel	683	477	30	320	602

SOURCE: GERSAR-CACG *et al.*., (1988), in Hollis (1990a:7).

4. The Agroecological Context of Food Security in the Middle Senegal Valley

The ecology of the middle Senegal River Valley features a mix of habitats that collectively constitute a wetland mosaic. Discrete ecological zones, each with their own physical features and subsistence resource base, are dispersed in a transect extending laterally from the river across the valley floor (Figure 3). Livelihood patterns of farming, herding, and fishing are found within this transect and are practiced in varying combination according to the ecological features of each zone. Each one of these microenvironments has a distinct geomorphology, soil structure, ecology, and plant species composition contributing to the biological diversity of the region. Seasonal flooding of the bottomlands (*waalo*) enables occupants to exploit the floodplain intensively, undertaking a series of agropastoral and fishing activities that follow the calendrical ebb and flow of the river's flood cycle. At the beginning of the western African rainy season, runoff from local rainfall allows farmers to plant a variety of sorghum (*fela*) that is well adapted to the dry conditions of the high levee and floodplain *foonde*. This period also corresponds to the planting of finger millet (*suuna*) by farmers and herders dwelling in or near the upland *jeeri* zone. When the river floods, the *waalo* bottomlands also become the site of intensive fishing activity. Soon after the retreat of the floodwaters, intensive recession cultivation begins, first, in the heart of the floodplain where several varieties of sorghum (*samme*) adapted to varying soil conditions are planted. Second, planting begins on river garden *falo* plots, where inhabitants of riverine villages, particularly older women, practice mixed cropping of vegetables, legumes, grains, and fruit. Third, in years of ample flooding, farmers also exploit the high floodplain *foonde* adjacent to the riverine villages. Here, a rich polyculture of grains, vegetables, legumes, and fruits is planted; in years of low flooding, rainfall runoff still permits a sizable crop to be harvested in the *foonde*.

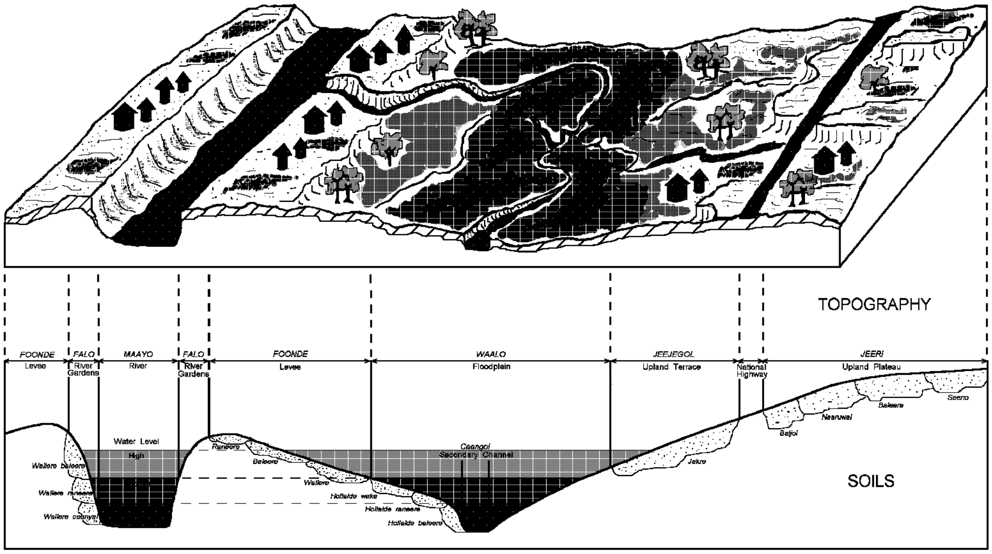


Figure 3. Agroecological Landscape of the Middle Senegal River Valley

The succession of farming and fishing activities and the completion of the wetland production cycle are brought full circle during the floodplain sorghum harvest, when FulBe livestock from the upland jeeri enter the bottomlands to graze the sorghum stubble. This mass migration of FulBe herds into the floodplain, known as the nyaangal, permits a rich nutrient exchange of cellulose and manure on the waalo bottomlands. The agropastoral dynamic of the floodplain enables the successful reconstitution of area herds during the harsh dry season while simultaneously allowing local farmers and fishers to benefit from enriched floodplain soils.

The Senegal wetland habitat provides a sequential spacing of crop harvests over the course of a year, thereby smoothing cyclical phases of crop surplus and shortage between wet and dry seasons and attenuating bouts of food scarcity. Riverine and flooplain gardens act as a relay cropping system (Adams 1985:295), providing vegetables and cereal grains for human consumption and fodder for small livestock between the rainfed jeeri harvest in November and the recession waalo harvest in March.

Since the early 1970s, this succession of cropping systems has been followed by an irrigated crop of garden vegetables that supplements local diets at a time when granary reserves are depleted. The staggering of garden falo and foonde harvests, particularly in the absence of a rainfed crop, acts as a food reserve, buffering against shortages well into the dry season until harvest of the recession bottomland sorghum crop.

5. Dams to Combat Drought and Food Insecurity

The risk of regional and national food scarcity, brought on by successive years of Sahelian desiccation, prompted the Senegalese government to embark upon an ambitious program of river basin development by the early 1970s. Policy measures were instituted to transform the northern valley wetlands into a regional rice bowl capable of provisioning the regional hinterlands and urban population centers. In 1972, a tri-state river basin commission, the OMVS (Senegal River Valley Development Authority), was established by the governments of Senegal, Mali, and Mauritania with multi-lateral donor assistance to transform the Senegal River Valley via a system of dams and capital-intensive irrigated rice schemes. The Diama and Manantali Dams were built primarily to generate hydroelectricity and to promote the development of irrigated rice farming. By stabilizing seasonal fluctuations in the river level with a controlled stream flow at the Manantali reservoir, a double crop season of rice harvests could be achieved.

In 1972, the Senegalese and Mauritanian governments began in earnest to develop rice irrigation perimeters on both sides of the river. As of 1988, an estimated 39,270 hectares has been developed in Senegal and another 16,856 hectares developed in Mauritania (Woodhouse and Ndiaye 1990:4). At present, a transitional phase involving the total conversion of area farmers to rice irrigation is being debated. This development strategy would wean local producers from customary forms of farming, fishing, and herding on the floodplain. The current focus, if reinforced by global climate change impact analyses that promote a policy of agricultural intensification and crop output maximization, will force resident smallholders to abandon customary livelihoods that emphasize risk mitigation and resource diversification, in favor of a less varied repertoire of agricultural activities placing the producer at greater financial and technological risk.

6. Consumption Smoothing and Resource Diversification

Research findings from two village sites are used here (Table 3) to illustrate in quantitative terms how a broad array of farming activities, based upon a diversified resource base, provide a greater level of food security to the smallhold producer than reliance on one agricultural system such as rice farming. Village A relies upon a mix of both customary and modern irrigated forms of agriculture, while village B depends almost exclusively upon irrigated rice farming.

A comparison of per capita crop harvests over the course of a year reveals a pattern of consumption smoothing and greater food security in village A. A temporal cropping sequence provides a modest but steady inflow of cereals and vegetables throughout much of the year. An annual per capita harvest of nearly 318 kg in village A favors positively in relation to the 207 kg harvest in village B. The monthly per capita inflow at village A is low for most of the year, and during the height of the dry season (May-July), a total rupture in harvest stocks occurs. Food supply rises at the end of the wet season in November, however, with the harvesting of rainfed millet in the upland jeeri fields and garden crops in the falo, foonde, and an irrigated perimeter (GIE). Grain reserves peak in March with a sizable bottomland sorghum harvest (233 kg/capita). This important reserve is then slowly drawn down during the height of the dry season.

The scenario of sequential crop harvests in village A contrasts sharply with the severe irregularity in food supply found in village B. Here, cultivators rely heavily on irrigated farming and a single rice crop harvest that occurs in December (190.5 kg/capita). This singular spike in food supply is hardly adequate in meeting consumption needs throughout the year, placing village households at great risk.

Table 3. Comparison of Per Capita Crop Harvests and Consumption Patterns.

	Village A			Village B		
Month	Grains (kg)	Vegetables (kg)	Total (kg)	Grains (kg)	Vegetables (kg)	Total (kg)
January	1.1	5.5	6.6	-	-	-
February	1.7	4.7	6.4	2.1	-	2.1
March	233.0	1.8	234.8	-	-	-
April	2.3	1.6	3.8	-	-	-
May	-	-	-	-	-	-
June	-	-	-	-	-	-
July	-	-	-	-	-	-
August	7.7	2.2	9.8	-	-	-
September	-	3.9	3.9	-	-	-
October	1.7	0.6	2.3	-	-	-
November	10.0	30.0	40.0	14.5	0.3	14.8
December	1.4	8.8	10.2	190.5	-	190.5
Total	258.9	59.1	317.8	207.1	0.3	207.4

Field data are based upon crop harvests weighed bi-weekly over a 12 month period (1989-1990) at two village sites and involving a random stratified sample of 15 households in village A and 9 in village B.

7. Conclusion: Policy Options to Mitigate Food Scarcity in the Context of a Changing Global Climate

Policy-makers in Africa will be hard pressed to resolve the growing needs of a burgeoning population to adequately feed itself in the coming century. As trends in global warming continue, we may anticipate increasing concern by national authorities to adopt modern agricultural strategies that rely heavily on capital intensification in order to meet the growing demand for food. Highly valued water resources, particularly unharnessed rivers in Africa, will become an increasingly attractive natural resource capable of provisioning nations with an abundant supply of food and electricity. In particular, irrigation agriculture may continue to be viewed as the 'silver bullet' technology that will bolster food output and resuscitate moribund rural economies from the depths of stagnation.

In the context of global warming, amplification of evapotranspiration and moisture stress is expected to occur at tropical latitudes. In the case of semi-arid regions such as the Senegal River Valley, this may exacerbate a growing problem already at hand in the drying of groundwater aquifers. Riverine communities dependent on hand dug wells for their potable water supply could be at increased health risk under such conditions, requiring huge investments of capital to install deep borehole wells throughout the region (Horowitz *et al.* 1991:32). Increased desiccation and moisture stress will also have deleterious consequences for a flood-dependent hardwood, *A. Nilotica*, that is one of the most highly valued multi-use tree species in the region. The adverse impacts anticipated from increased evapotranspiration suggest the need to maintain periodic flooding of the river basin for aquifer recharge and to mitigate the drying effects of moisture loss to crops and vegetation.

Moisture loss could also prompt heightened competition for a dwindling natural resource base. Suliman (1990) suggests that "a 1˚ C to 2˚ C increase in temperature coupled with a 10% reduction in precipitation could produce a 40-70% reduction in annual runoff. Conflicts between water users could deepen." (Suliman 1990:13-14, in Glantz 1992:195). This scenario has already begun to play itself out on the Senegal River where a transborder conflict between Senegal and Mauritania over productive land and water resources took place in 1989.

Four agricultural sources have been identified in the warming of the Earth's greenhouse gases: livestock, rice production, nitrogenous fertilizer use, and agricultural biomass burning (Salinger 1994:119). Each of these sources are integral components of the agropastoral complex found in the Senegal River Valley. The agricultural conversion of wetlands and fossil fuel burning have been identified as proximate causes of global environmental change, adding carbon and methane to the atmosphere (Stern *et al.* 1992:33). The large-scale conversion of wetlands to irrigated rice paddy in the Senegal River Valley will primarily produce methane as a final end product. Rice production is considered a primary agent of increasing methane emissions in the atmosphere, with some estimates ranging from 20% - 31% of the global methane budget. (Stern *et al.* 1992:48; Salinger 1994:119). While the relative global contribution of methane emissions from converted wetlands in the region may appear to be nominal, the impact in absolute terms of similar land transformation processes occurring on a global scale nonetheless should not be taken lightly and should be given further research attention.

In promoting policies of enhanced agricultural performance, a caveat is in store with regard to future development prescriptions that seek to maximize crop output. Such goals in and of themselves are highly laudible. However, perspectives on food security that may be driven by macroanalytical themes such as increased global warming and climate variability will require a process of 'groundtruthing' and complementary data sets at meso and micro levels. Contextually specific, multidisciplinary analyses merging both biophysical and social science data will be needed to provide an accurate, holistic view of the opportunities and impediments that African governments will face in adopting effective strategies of adaptation and mitigation to global climate change.

A case study has been presented here from the Senegal River Valley that illustrates how basic underlying assumptions about agricultural intensification and crop output maximization could have adverse consequences for ecosystem functioning, biodiversity, and food security. A micro analytical perspective, using the household and community as the key units of analysis, cautions against wholescale adoption of a future agricultural policy promoting production maximization at the expense of habitat loss and the erosion of customary forms of livelihood diversification. Resource diversification is a common adaptive response to precarious or unpredictable environments where climatic variability is a prominent feature of the physical landscape. Diversification mechanisms do not fare well with the objectives of modern commercial farming systems that emphasize monocropping regimes intended to maximize yields or profits. Customary farming systems such as those practiced in the Senegal River Valley, on the other hand, are designed to minimize crop loss and to even out the interannual yield variability that frequently occurs in such conditions of climatic uncertainty (Ribot *et al*. 1996:40). An optimal policy scenario would be to enhance and improve such customary farming regimes rather than dismantling them all together, while simultaneously promoting improved models of agricultural intensification (e.g., irrigated rice farming) for those individuals or groups who can absorb the financial risk. It is important for resource planners and climate change impact analysts to understand, therefore, that rural peasant communities are not homogenous socio-economic populations that can absorb risk uniformly. Thus, standard policy blueprints that prescribe general solutions to the problem of food security by means of large-scale technology adoption must be exercised with caution, and in many instances will most likely fail. A finer resolution or scale of agroclimatic planning should be promoted that takes into account regional and sub-regional parameters of biogeographical, socioeconomic, and ecological data:

- For agriculture there is a need to identify, by agroclimatic planning, the potential of and most suitable activities for an area. Greater diversity in farming systems spreads the vulnerability and reduces the dependence on one crop (Salinger 1994:134).

- A critical sociological lens is needed to better understand the physical, socio-economic, and political factors that shape producer behavior toward the environment. At present, Senegal farmers in the middle Senegal Valley are preoccupied with adopting risk averse measures such as resource diversification and agricultural strategies requiring low labor and capital investment to feed their families and to survive the moment. Living to the year 2050 and adopting agricultural methods that will assure their survival on a warmer planet, remains far beyond the immediate concerns of the middle Senegal Valley farmer.

Acknowledgments:

I wish to express my gratitude to Drs. Michael Horowitz and Muneera Salem-Murdock who supervised my research under a USAID funded cooperative agreement (SARSA), Drs. Peter Little and Michael Painter who served on my doctoral committee, and to the Institute for Development Anthropology and the Social Science Research Council for providing the financial support to carry out this study. I am also indebted to Dr. David Wilkie for his insightful comments on income and consumption smoothing, and to Dr. Michael Glantz and the National

Center for Atmospheric Research where I am currently in residence as an Advanced Study Program Fellow.

References:

Adams, William M., 1985. The Downstream Impacts of Dam Construction: A Case Study From Nigeria. Transactions of the British Institute of Geographers, New Series 10:292-302.

Altieri, Miguel A., 1987. Agroecology: The Scientific Basis of Alternative Agriculture. Boulder, CO: Westview Press.

Bass, Brad, H. Venema, and E. Schiller, 1995. Adaptation of Food Production to Drought in the Senegal River Basin. In Climate Change and World Food Security. T.E. Downing, ed. pp. 485-503. Berlin: Springer-Verlag.

Gannet, Fleming Cordrry and Carpenter, 1975. Assessment of Environmental Effects of the Proposed Developments in the Senegal River Basin. Partial Report for Fisheries. Dakar, Senegal: OMVS.

GERSAR-CACG, *et al.*.,1989 (December). Plan directeur de développement integré pour la rive gauche de la vallée du fleuve Sénégal: rapport d'(tape. New York, NY: PNUD / BIRD.

Glantz, Michael H., 1992. Global Warming and Environmental Change in Sub-Saharan Africa. In Global Environmental Change: 183-204.

Global Climate Change Information Programme (GCCIP), 1996. GCCIP Information: Climate Change and Its Impact on World Agriculture.

Grosenick, Gerold, Abdoulay Djegal, Jack W. King *et al.*., 1990. Analyse pour la Gestion des Ressources Naturelles du Sénégal: Rapport Final. (PDC-5517-I-13-7136-00). Washington, DC: Louis Berger International /Institute for Development Anthropology.

Hollis, George E., 1990 (August). Senegal River Basin Monitoring Activity: Hydrological Issues: Part I. Binghamton, NY: IDA (Institute for Development Anthropology). (Senegal River Basin Monitoring Activity I (SRBMA I) / IDA Working Paper No. 56).

Hollis, George E., 1990b (November) Senegal River Basin Monitoring Activity: Hydrological Issues: Part II - A report based on discussions and bibliographical work in Senegal, fieldwork around Matam and subsequent data analysis. Binghamton, NY: IDA (Institute for Development Anthropology). (Senegal River Basin Monitoring Activity I (SRBMA I) / IDA Working Paper No. 57).

Horowitz, Michael M.,1989. Victims of Development. Development Anthropology Network 7(2):1-8.

Horowitz, Michael M., Muneera Salem-Murdock, Curt Grimm *et al.*.,1991. The Senegal River Basin Monitoring Activity, Phase I: Synthesis Report. Binghamton, NY: Institute for Development Anthropology.

Howard-Williams, Clive, and Keith Thompson, 1985. The Conservation and Management of African Wetlands. In The Ecology and Management of African Wetland Vegetation. Patrick Denny, ed. pp. 203-230. Dordrecht: Dr. W. Junk Publishers.

IPCC (Intergovernmental Panel on Climate Change),1990. Climate Change: The IPCC Scientific Assessment. Report of the United Nations Environment Programme, Intergovernmental Panel on Climate Change (IPCC), Cambridge: Cambridge University Press.

Magistro, John, 1998. The Ecology of Food Security in the Northern Senegal Wetlands. A. Endre Nyerges, ed. In The Ecology of Practice: Food Crop Production in Sub-Saharan West Africa. Philadelphia: Gordon and Breach.

Magistro, John, 1994. Ecology and Production in the Middle Senegal Valley Wetlands. Unpublished PhD. dissertation, Binghamton University, NY.

Magistro, John, 1993. Crossing Over: Ethnicity and Transboundary Conflict in The Senegal River Valley. Cahiers d'Etudes Africaines, 130, XXXIII-2: 201-232.

Michel, Pierre, 1985. Sécheresse et transformation de la morphodynamique dans la vallée et le delta du Sénégal (Drought and Morphodynamic Process Transformations in the Senegal Floodplain and Delta). Revue de geomorphologie dynamique 4:113-130.

Ndiame, Fadel, 1985. A Comparative Analysis of Alternative Irrigation Schemes and the Objective of Food Security: the Case of the Fleuve Region in Senegal. M.S. Thesis, Michigan State University.

Nicholson, Susan E., 1980. Saharan Climates in Historic Times. In The Sahara and the Nile. M. A. J. Williams and H. Faure, eds. Pp. 173-200. Rotterdam: Balkema.

OMVS, and Dames and Moore International, 1989 (December). Senegal River Upper Valley Master Plan: Preliminary Report - Phase I (Policy and Planning Development Project 625-0621). Dakar, Senegal: OMVS / USAID.

Ribot, Jesse C., Antonio R. Magalhées, and Stahis S. Panagides, eds., 1996. Climate Variability, Climate Change and Social Vulnerability in the Semi-arid Tropics. Cambridge, UK: Cambridge University Press.

Richards, Paul, 1985. Indigenous Agricultural Revolution: Ecology and Food Production in West Africa. London: Hutchinson.

Salinger, M. J., 1994. The Effects of Agriculture and Forests on Climate. In Climate Variability, Agriculture and Forestry. pp. 119-122. Technical Note No. 196. Geneva: World Meteorological Organization.

Sir Alexander Gibb and Partners; Electricit(de France International; Euroconsult, 1987 Study of the Management of the OMVS Common Works: Summary Reports. Dakar, Senegal: OMVS.

Srivastava, Jitendra., Nigel Smith, and Douglas Forno,1996. Biodiversity and Agricultural Intensification: Partners for Development Conservation. Environmentally Sustainable Development Studies and Monographs Series No. 11. Washington, DC: The World Bank.

Stern, P. C., Young, O.R. and Druckman, D., eds., 1990. Global Environmental Change: Understanding the Human Dimensions. Washington, D.C: National Academy Press.

Suliman, M. ed., 1990. Greenhouse Effect and Its Impact on Africa. London: Institute for African Alternatives.

Thrupp, L. Ann, 1997 . Linking Biodiversity and Agriculture: Challenges and Opportunities for Sustainable Food Security. WRI Issues and Ideas, March 1997. Washington, DC: World Resources Institute.

Van Lavieren, B., and J. Van Wetten, 1990 (January). Profil de l'environnement de la vall(e du fleuve Sénégal. Arnhem, The Netherlands: Euroconsult / RIN (Institut National de Recherche pour la Conservation de la Nature).

Woodhouse, Philip, Ibrahima Ndiaye, 1990 (June). Structural Adjustment and Irrigated Food Farming in Africa: The "Disengagement" of the State in the Senegal River Valley. Milton Keynes, UK: Open University, DPP (Development Policy and Practice) Research Group, Technology Faculty. (Open University, DPP Working Paper No. 20).

†††† Young men have responded to the problem of food scarcity by migrating in search of waged income. Migratory remittances are essential in provisioning households with an adequate supply of purchased food stuffs throughout the year.

The policy implications of downstream ecosystem rehabilitation by means of a simulated flood release from the Manantali Dam are not examined in this paper but have been extensively addressed in previous work by this author and others who jointly conducted research in the region (see Magistro 1994, 1998; Horowitz *et al.*. 1991). For detailed assessment of this conflict see Horowitz (1989) and Magistro (1993).