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SATELLITE REMOTE SENSING AND THE SAHEL

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AND THE SAHEL

BY

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FOREWORD

The author is not a remote sensing expert; he has obtained his information from some thirty interviews with initiates, and from reading the many documents he was able to gather, with their help and the help of the specialist organizations. These documents are listed in the bibliography at the end of the report.

The author wishes to thank all those who have helped him in his task. Special thanks are due to: J.L. Domergue and P. Bouland of the French Ministry of Co-operation; Mr. Gilles Hervio of the EEC Office of Statistics, Mr. Clarence Sakamoto of NOAA-NESDIS, Messrs. Z.D. Kalensky and J.V. Hielkema of the FAO Remote Sensing Center, Mr. B. Guillot of ORSTOM (Lannion Center for Satellite Meteorology), Messrs. Lambergeon and Thierry Nègre of the Regional AGRHYMET Center, Niamey; Messrs. Ouattari and Delorme of the EEC Renewable Resources Project; Mr. J. Malacamp of SPOT Image and Mr. de Suremain of SCET-AGRI-BDPA.

As the reader will see, our study is studded with technical information and points of view on the many aspects of remote sensing (RS)* and satellite products, most of them borrowed from the reports, memoranda, conference papers and books listed in the bibliography at the end. It is possible that in some instances passages from these texts have not been correctly attributed to their authors; I hope the authors in question will forgive any such lapse.

Similarly, although several months were spent on the study it cannot pretend to be exhaustive, especially the inventory of research activities and projects; there are a great many of these, despite the short time RS has been in operation in the Sahel.

The aim of the report, as requested by the Club du Sahel, is to provide a fairly full status report on the RS situation, and evaluate the application of satellite techniques in the CILSS member countries.

Paris, May 1988

Roger Pons

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* For the sake of convenience, remote sensing will be referred to as RS throughout.

ABSTRACT

Remote sensing as applied to the Sahel has its supporters and its detractors. These techniques are still fairly new and relatively few genuinely operational products have been produced, although the human and material resources required, both inside and outside the Sahel, are considerable. Annual costs amount to between 12 and 15 million dollars - the equivalent of the entire AGRHYMET program. Research work proliferates, with a wide range of energetic agencies involved. Opinions, both for and against, are often very firmly held.

The Club du Sahel thought it would be useful to draw up an inventory and make a full appraisal of RS projects and programs. This is the aim of the present report.

Part One of the report deals with the basic characteristics of RS: its **technology and products**. The material and human requirements are described, to give the reader an idea of the respective constraints, potential and limitations of the different satellites, sensors and data processing systems employed. The ground stations and major operators are also introduced in this part of the report, and the products are then analyzed according to their function: measurement of rainfall, temperature, evapotranspiration, vegetation index, land area under crops, crop type, hydrology, forests, etc.

Besides their intrinsic qualities and reliability, these satellite products are looked at in terms of their end use: precipitation, water balance, vegetation conditions, crop and rangeland monitoring, yield forecasts, crop prediction and monitoring, floodland cropping, desertification, locust hazard, etc.

Part Two is an inventory of RS activities, i.e. projects and operations that involve the application of RS to the benefit of the CILSS countries.

It seemed worthwhile in drawing up this inventory to examine the part played by each of the main actors in the field: the USA, Europe, FAO, UNDP, CILSS (essentially the AGRHYMET program); projects like the CRTO and ACMAD; and Senegal, a country where there are a number of projects based on RS from space.

Part Two ends with two synoptic tables showing the multifarious operations, classified first by topic, then by promoter or operator, and finally by country.

Part Three is an assessment of the utility of these satellite products and techniques to the Sahel countries. The

contribution of these techniques is compared with competing or complementary techniques based on conventional data.

Several key ideas emerge from the study:

It is too early to judge how worthwhile remote sensing is in the Sahel; the techniques are developing rapidly and major breakthroughs could be made between now and the end of the century;

Certain limitations are emerging, however: atmospheric phenomena seem to lend themselves better to RS than do ground-level features; RS seems to be very useful in climatology, indispensable in pluviometry, less useful in crop monitoring, although here vegetation indices are of some utility. Its utility in yield forecasting seems still more uncertain, and crop forecasting runs into major technical and economic difficulties in attempts to measure cropland acreage and discriminate between crop types;

Utilization of satellite RS data should improve in the near future: RS techniques in general are expanding fast, and progress is expected in the Sahel both on the operational environment side (high resolution picture transmission receiving stations for NOAA data at the regional AGRHYMET center in Niamey, telecommunications, micro-computers, etc.) and on the operations management side (training of specialists, on the job or through outside courses);

The spin-off from RS will primarily benefit national and regional early warning systems, decision-makers in cropping and livestock sectors and, to a lesser extent, the agricultural statistics services. Nor should more specific applications be overlooked: floodland cropping, environment, locust control and forest clearance are all fields in which satellite techniques are often the only ones practicable on the scale required for the Sahel's vast open spaces;

It is not wise to try to use either RS or ground-based methods exclusively. More often than not the two techniques must be combined. The optimum role of each has yet to be established, however, and this demands experimentation and real co-operation between all those involved. Fortunately, some of the research projects now under way have been designed with this in mind.

The conclusion of our report contains a number of recommendations aimed at improving the productivity of the many efforts made to apply RS to the Sahel countries:

- **Coordinating experimental and research programs and projects** so as to avoid pointless competition between them. On the initiative of the CILSS Executive Secretariat and the Club du Sahel, a joint body (CILSS countries and foreign bodies or

countries promoting this work) could organize **periodical consultative meetings** (yearly meetings, for example) through which the harmonization that is lacking at present would gradually develop;

- **Creation, within the CILSS framework and on the initiative of the Executive Secretariat, of a more directive type of body to co-ordinate existing RS operations at both the national and regional levels.** This would mean ensuring that tasks are judiciously shared between the regional AGRHYMET center, the CILSS Member States, the CRTO, ACMAD and the receiving or data processing stations (CRODT, UTIS, etc.) so as to avoid waste, duplication of effort and errors in choice of equipment. The body would be run by the regional AGRHYMET center, while the major foreign donor agencies and foreign organizations giving technical co-operation in RS (eg. FAO, Lannion CSM*) would enjoy observer status;

- Some have advocated gradually bringing together most of the existing RS resources and operations of the Sahel at the RAC** in Niamey. This would probably lead to a degree of synergy at the regional level, besides a saving in staff and equipment. But it would be difficult to bring about, for both technical and political reasons.

* * *

RS is still a very recent venture in the Sahel. It has developed somewhat piecemeal in many different sectors, particularly through its many and varied research projects. This new technology is already making a significant contribution. While one must recognize its limitations in some fields where expectations had been higher, RS and its products are welcomed by some of those involved in early warning systems, crop and rangeland monitoring, and of course climatology. Moreover, major advances are expected in the medium term.

But the cost of RS is high for the modest budgets of Sahelian agriculture, statistics and livestock services. RS demands sophisticated equipment with highly skilled staff to operate it. All this sometimes arouses reservations and apprehension, which do not help build the vital co-operation between those on the ground and those "in space". This inevitable opposition ought little by little to diminish, provided care is taken to bring all concerned together in mixed, theme-oriented teams, for research projects and standard operations alike.

There are two major errors to be avoided, equally mistaken and dangerous: (i) the assumption that RS can replace most of the

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* Center for Satellite Meteorology, Lannion, France. "Lannion CSM" in this text.

**Regional AGRHYMET Center, Niamey, Niger. "RAC" in this text.

conventional methods and (ii) the view that it is, on the contrary, a costly, superfluous and more or less useless technology.

The Sahel is ill-endowed by nature, and its problems are well known. But the countries of the CILSS have at least had the good fortune to host some major initiatives in RS. These have already brought a significant contribution to the Sahel, and one that is likely to grow in the near future.

There are two imperatives, however:

(i) Remote sensing experts must make every effort to co-ordinate their activities, avoid unnecessary expense, adapt their products to the real needs of the Sahel and fit in harmoniously with existing provisions in the region;

(ii) Those connected, in whatever capacity, with the future of the CILSS countries (regional and national leaders, decision-makers in the co-operation agencies or international bodies), must not allow themselves to react unthinkingly against RS.

INTRODUCTION

"The technician inserted a diskette bearing digital information transmitted by a satellite somewhere. Then he straightened up, his eyes on the VDU screen, his hand lightly tapping out a few commands. Instantly a multitude of multicolored signs appeared, shifted about the screen, then fell into order. A perfect map, a many-colored mosaic, settled on the screen. The technician gazed at it, satisfaction in his smile. More than satisfaction: excitement. He could recognize the village where his survey had begun, the road that led to the hill ... his familiarity with the elements of the scene made it a special pleasure to see it for the first time as one whole ... he felt the completeness of it ... the picture he had produced showed him something all those weeks of travelling the area could not. ... The program was running faultlessly. He gently pressed another key and the inkjet printer began to reproduce, faithfully though in paler tones, the colored map on the screen ..."

From Télédétection: techniques
et applications cartographiques.

In the autumn of 1957, when an astonished world learned of the launching of the Sputnik by the USSR, not even the most enlightened observers could imagine the consequences of this technological feat.

Countless applications of space science have developed over the past thirty years: telecommunications, television, navigation aids, meteorology and Earth observation with all its many civilian and military spheres of application. One hundred and twenty-seven launches took place in 1987, and the 3,000th satellite is due to go into orbit soon.

The spin-offs have come fast in these short first years of the space age, aided by simultaneous advances in other fields of science and technology - telecommunications, new materials, information technology, etc.

Exploration of the cosmos forges on towards very distant horizons; probes move out towards remote stars, while the first men stood on the moon in 1969. But until new spin-offs emerge, the stars are still chiefly a matter for scientists.

For Planet Earth, however, while we cannot yet say we have completely mastered space applications, we have accumulated a great deal of knowledge of satellite operation, over the past two decades especially. In several sectors it is genuinely operational, though there is still a wide margin for progress, and research and experiment must continue alongside operational work.

Earth observation is one of these space activities. This is still a very young field; the first satellite designed for the purpose was launched only in 1972, a mere sixteen years ago. But remarkable progress has been made, not only in launching and positioning the satellites but also in payload sensors,

telecommunications and data processing and utilization facilities. These advances have led to growing use of remote sensing from satellites.

These new techniques, by their nature, involve very modern and powerful technological means; upheavals are inevitable in sectors where such new techniques are applied. This is so even in the advanced industrial countries, and is doubly true in developing countries, particularly the Sahel countries where there is such a drastic lack of advanced technology and research.

Be that as it may, there is no stopping progress. The promoters of space science applications vie in enthusiasm with research workers in the scientific community; space science attracts them as it does many young African researchers and decision-makers.

Experiments and research projects in remote sensing soon began in **Sahelian Africa** and, as projects reached the pre-operational stage, applications followed.

In the CILSS countries, as we shall see, research and experimental activities are far more widespread than activities one could regard as fully operational. The main operational activities are those of the AGRHYMET program, particularly at the Niamey RAC*.

The remote sensing operations covered by the present report are those that primarily concern the agriculture, livestock, hydrology and environment sectors and are run under the aegis of Sahelian States, the CILSS Executive Secretariat, or other agencies, donors and NGOs working to improve food requirement satisfaction rates, protect the environment or contribute to rural development generally in the countries of the Sahel.

Although meteorology does not strictly speaking fall within our purview, it is a field that overlaps with both agrometeorology and agroclimatology, and one in which RS plays an important part, especially south of the Sahara; for this reason we shall be exploring this field as well.

Space-borne RS must not be allowed to overshadow such older forms of remote sensing as aerial photography. Our analysis of RS projects under way in the Sahel shows that this technique is still in use, in combination with satellite methods and all the other means required for good observation of the Earth's resources.

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* RAC: Regional AGRHYMET Center.

The reader will also see how much ground-based work satellite RS demands if it is to be effective. Satellite data cannot be utilized without correlating, verifying and adjusting them to yardstick readings or ground samples.

Lastly, one must not overlook the crucial importance of the data processing and communications equipment required by any RS operation. This equipment is not only costly in its own right, it also demands very highly skilled operators, and this in turn often means heavy recurrent training and operating costs. Outside involvement is therefore essential if the necessary technology, human resources and funds are to be obtained. The CILSS countries clearly cannot provide such resources on their own.

In view of all these factors it is not surprising that RS projects aimed at the Sahel should have sprung up more or less spontaneously, without any real co-ordination. The research teams are used to a certain independence of action; the taste for discovery arouses competition and even rivalry, sometimes exacerbated by nationalism or insularity. The agencies specializing in satellite operation and everything connected with it are not entirely insensitive to the industrial and commercial aspects of their activities. Nor are the engineers and technicians who operate the equipment or work in the programs - programs that are all the more exiting for their newness - wholly immune to the lure of up-to-the-minute equipment, and this of course inflates their estimates and budgets.

Nor is it surprising that the enthusiasm RS arouses, in the Third World even more than elsewhere, should sometimes leave no room for the legitimate questions healthy management and good sense would dictate: "What is it for, and how much does it cost?" We must not be beguiled by scientific terminology into forgetting that these countries are desperately short of resources, and that the agencies and government services responsible for monitoring the agricultural year are short of many things, even the most elementary, for carrying out their task - whereas RS can perform these tasks only very imperfectly and at great cost.

From another standpoint, the Sahel's open spaces offer excellent subject matter for remote sensing since, by its very nature, RS covers a vast land area at usefully frequent intervals. Back on Earth, however, there is a shortage of ground observation stations, communications resources and data collation facilities.

The possibilities of Earth resource observation from space are by no means exhausted. The potential for progress is immense, at least in certain applications sectors.

The price of RS is high, certainly; but, there again, a new technology invariably becomes cheaper over time, and has an impact on the technical skills of those who use it.

Lastly, applied research is bound to involve a certain disruption in the beginning; this is the price of the spirit of competition that enables rival teams to advance faster and achieve new successes.

In this situation, and in view of the questions about RS that have been raised by both Sahelian decision-makers and somewhat puzzled donors, the Club du Sahel felt it would be helpful to commission a report on the state of affairs in this field.

The aim of this report is above all to enable the non-initiate reader to form an opinion about what remote sensing is, what contribution it can make to the CILSS countries, what are the completed or ongoing projects and activities and their utility to rural development (early warning, crop and livestock improvement and monitoring, land management, environment, hydrology, etc.). The contribution of remote sensing will be assessed not only in its own right but also in comparison to the results and costs of the other, more traditional, rival methods.

The document therefore includes:

- A first part entitled **"Technology and products"**, divided into two chapters, the first of which covers means (satellites, sensors, data processing) and operators, and the second the products that may be of use to the countries of the Sahel,

- A second part, an **"Inventory of RS activities in the Sahel"**, which lists over thirty projects by operator and analyzes each in turn, looking at objectives, methods, actors, results, origin, funding, etc,

- A third part, **"The contribution of remote sensing to the Sahel"**, in which this contribution is appraised in comparison with that of the more conventional methods wherever RS seeks to replace these, and in its own right wherever the two complement each other,

- A **Conclusion**, which sets out the **comments, criticisms and suggestions** that emerge from the observations in the report.

PART ONE

THE BASIC CHARACTERISTICS OF REMOTE SENSING

Remote sensing is, strictly speaking, observation of a target by a device situated some distance away. In practice, it refers to all the airborne or satellite techniques employed to obtain data on Earth phenomena from a distance, and also the techniques needed to process the information so obtained and work up the physical measurements, maps or statistics required for application of the data to a given subject.

While aerial photography dates back quite a way, satellite-based remote sensing is a very new technology; dating from the launching of the first weather and Earth observation satellites, it has developed in just past fifteen years.

The gigantic strides taken over the past few decades in electronics, information technology, optics, miniaturization and telecommunications, new materials, data processing and space technology all combine to explain the tremendous advances made in remote sensing since its birth, recent though that is. It is hard to say whether this pace of progress can be sustained, or if the growth curve will flatten out. This unknown factor is an important one, as we shall see below, when it comes to assessing the future of the many experiments and research projects on the Sahel currently under way. Since we do not know what potential for improvement RS techniques (and hence their results) may have between now and the year 2000, we cannot usefully assess the short- or medium-term probability of these experimental results finding widespread application - especially since these results are, at the present time, often far from conclusive.

Another major characteristic of RS is that, since it involves such a high technological level, it demands highly skilled operators, as well as equipment and an environment that are both sophisticated and costly. So it is hardly surprising that RS is practiced in the most advanced industrialized countries, while the very modest RS establishments set up so far in the Third World constitute technological island outposts, dependent on equipment and experts from the advanced countries.

On the other hand - and this is a point we shall be returning to a number of times - as a result of the vast open spaces of many developing countries and a very low density of ground observation stations or resources, these countries are often especially well suited to remote sensing applications. The Sahel is a case in point.

This new instrument, now in the full flush of its development, has not only aroused the enthusiasm of all those who use it, be they technicians, operators, research workers or scientists; it has also aroused the interest of decision-makers in development projects, particularly in the Third World.

It must be said that not only is RS advancing by great strides, it also covers a vast and varied field. It has become one of the main means of obtaining information for inventorying and managing the Earth's natural and developed resources and for planning development. It helps in topographical or thematic mapping, geology and mineral prospecting, hydrology, meteorology, oceanography, agronomy, and environmental and land-use planning and development.

To be able to gauge the utility of RS, one needs to know something about it in terms of the resources required for it to function and the range of products it provides.

This preliminary look at the facts will not be energy wasted. It will prove invaluable when we come to consider the remote sensing projects that concern the Sahel and compare the contribution this technology makes with those of the traditional methods in use in the CILSS countries for early warning, crop and rangeland monitoring, yield forecasting, hydrology, etc.

Chapter 1

THE TECHNOLOGY (*)

The uninitiated sometimes think the magnificent maps and images produced through remote sensing come directly from the satellite sensors, as if operated like giant cameras.

In fact, these representational records and the exploitable data are the fruit of a complex set of operations using a series of sophisticated methods.

The system basically consists of:

1) **Satellites** or aircraft (as stated above, we shall be considering only the first of these) and satellite **sensors** taking measurements from space and transmitting the data directly to ground stations or temporarily stocking some data;

2) **Data reception and/or processing stations** on the ground; some of these are specifically set up to complete the basic system, while others belong to specific users; the latter are generally close to the sites under observation.

1. The satellites and their sensors

Satellites differ quite widely according to the particular purpose of their mission, and they fall into several different categories. Among satellites orbiting the Earth, the first navigational spacecraft, TRANSIT 1, went into orbit in April 1960; TELSTAR, the first communications satellite, was launched in July 1962; and LANDSAT 1, regarded as the first operational Earth observation satellite, went up in July 1972.

It should be borne in mind that during that period and increasingly since then, countless spacecraft have been launched. There are several hundred orbiting the Earth and others voyaging out into the cosmos, like the probes currently heading for Mars, Mercury and Venus. The first manned flight around the Earth, of course, was Yuri Gagarin's in 1961, and the Americans Neil Armstrong and Edwin Aldrin made the first moon landing in 1969.

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* Most of the information contained in this chapter has been taken from the excellent publication by Mr. Fernant Verger titled "L'Observation de la Terre par les Satellites".

The Earth's artificial satellites can be classified according to their function; our interest lies with those whose task is to observe Earth resources (LANDSAT and SPOT) and, still more, with those designed for environmental and meteorological observation (METEOSAT, NOAA). Indeed it was for weather observation that observation satellites were first used: polar orbit satellites up until 1966, and geostationary satellites afterwards.

We shall consider the satellites according to their astronomical characteristics, as it is these, combined with the type of sensing equipment carried in the payload, that determine a satellite's observation capabilities.

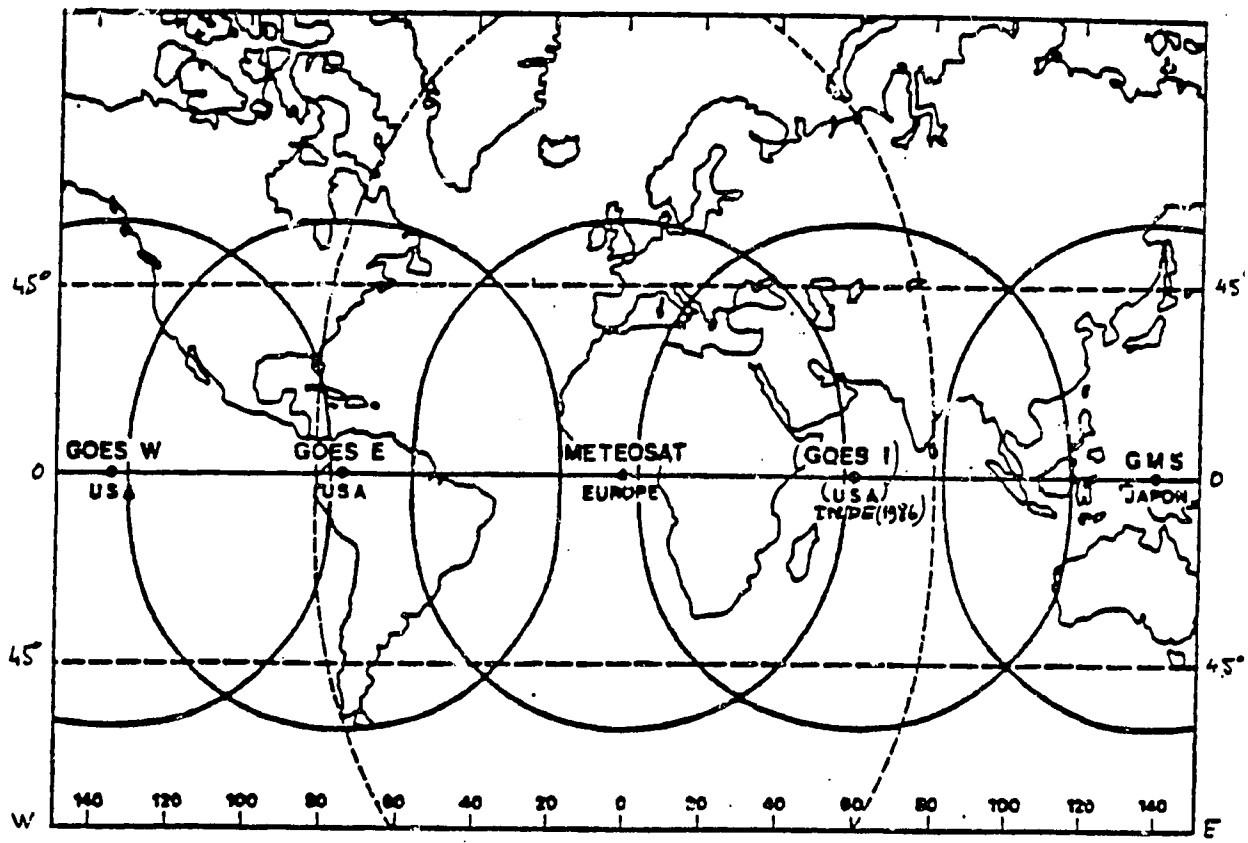
From this standpoint there are two main categories of artificial Earth-orbiting satellite:

- geostationary satellites;
- polar orbit satellites.

Geostationary satellites appear as stationary above one point on the Earth's surface. To achieve this they must have an angular speed and direction equal to those of the Earth's rotation following a circular orbit in the same plane as the equator. They thus describe a huge circle every day. These characteristics demand an altitude of about 36 000 km, and determine the potential field of vision. From the satellite, our planet is viewed within a cone having an apex angle of 17°. The same part of the Earth's surface, amounting to 42% of the total, can be seen at all times. The resulting projection system gives increasingly deformed images the further one goes from the nadir (i.e. the vertical projection from satellite to Earth) towards the outer edge of the observable zone. No observation of the polar regions is possible by these means.

Frequent measurements can be taken from a geostationary satellite. This easy repetition of observations is a precious asset, as it enables close monitoring of the development of atmospheric phenomena. However, the picture element (or pixel) at the center of the image is a large square whose sides measure several km. The land area covered by one pixel, and the form of the pixel deteriorate progressively as one approaches the horizon. Lastly, as we shall see below, the sensitivity of the radiometers (the sensors) aboard these satellites high above the Earth, is not such as to give high spectral resolution - i.e. fine-grade measurement of the electromagnetic radiation coming from the multitude of points that make up the ground scenes observed is not possible.

Geostationary or geosynchronous satellites are generally used for communications and meteorology. It is useful to note that as they are always vertically above the same point on the

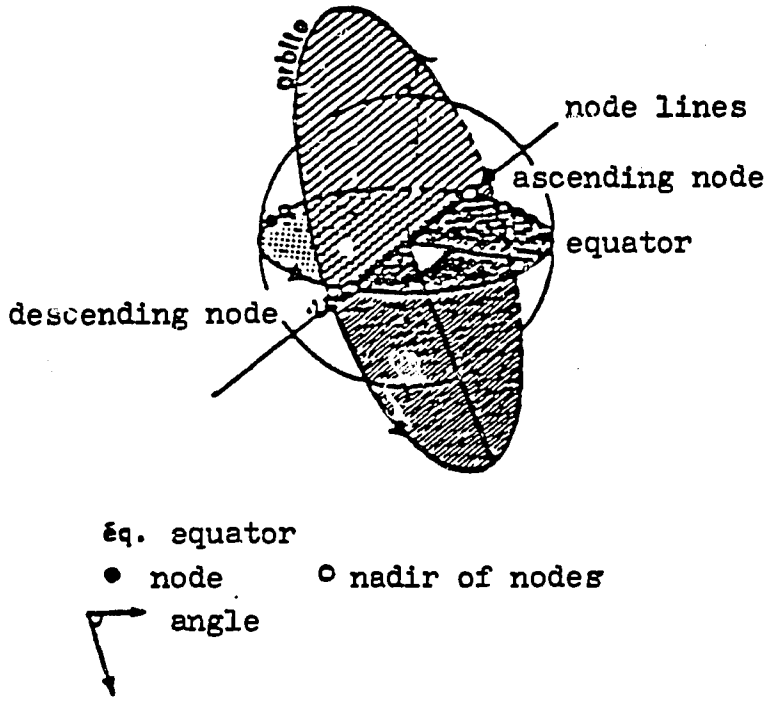


Effective areas of geostationary satellites of the Expérience Météorologique Mondiale (source: European Space Agency).

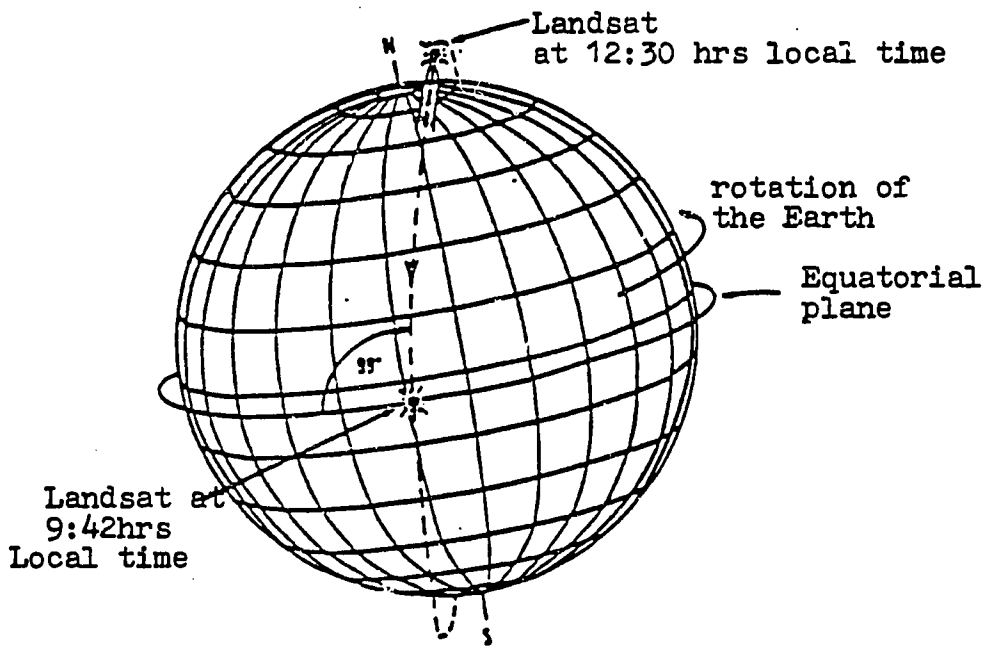
For METEOSAT, the visible area is also shown. Within this visible area, radio communications between the earth and the satellite are possible.

The presence of several satellites allows for constant observation of a complete zone at low and medium latitudes, but polar latitudes are constantly out of the observation area of geostationary satellites.

Source: Fernand Verger 1982 (see bibliography)



- Nodes and angle of satellite orbit
(F. Verger, 1982)



- Angle of Landsat orbit for sun-synchronous orbit. Source PAO N° E-6174-35

AGENCE SPATIALE EUROPEENNE ESA.SP.1073 (1-1985)

SOURCE : E.S.A (LOOKING DOWN – LOOKING FORWARD)

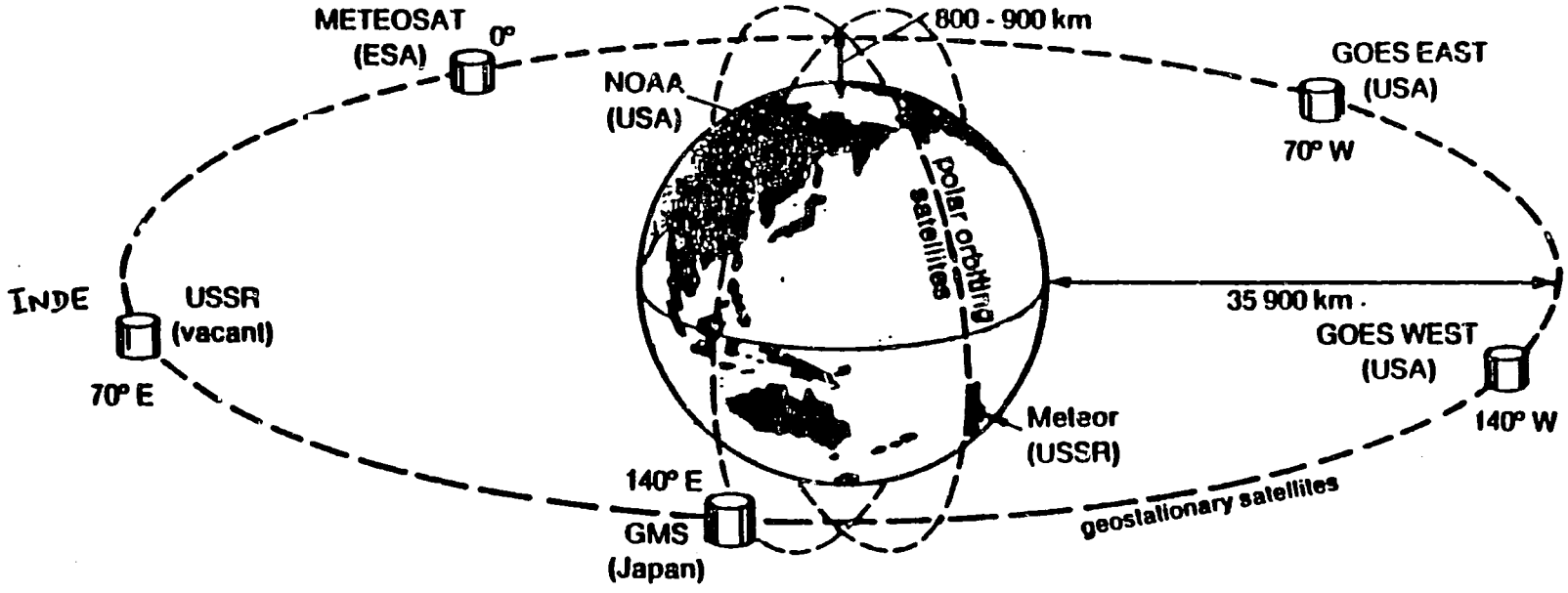


Figure 3 The World Weather Watch global observation satellite system.

Nota: Le satellite géostationnaire prévu par l'URSS à 70°Est a été remplacé par un satellite indien en 1986.

Earth's surface, they observe it throughout its diurnal course, by day, by night, in sunlight and in darkness.

The Global Atmospheric Research Program (GARP), launched in the early 1970s, was designed to put five geostationary satellites into orbit to provide continual observation of the greater part of the Earth's surface. Alongside two American satellites there was to be one Soviet satellite, one Japanese, and one European: METEOSAT, run by the European Space Agency (see below). All were launched between 1974 and 1978, though the one over the Indian Ocean was launched by Europe and the United States instead of the USSR and was replaced in 1986 by an Indian satellite.

Polar orbit satellites: unlike the geostationary satellites, these do not stay above the same point on the surface of the globe but travel across it at about 7 km per second.

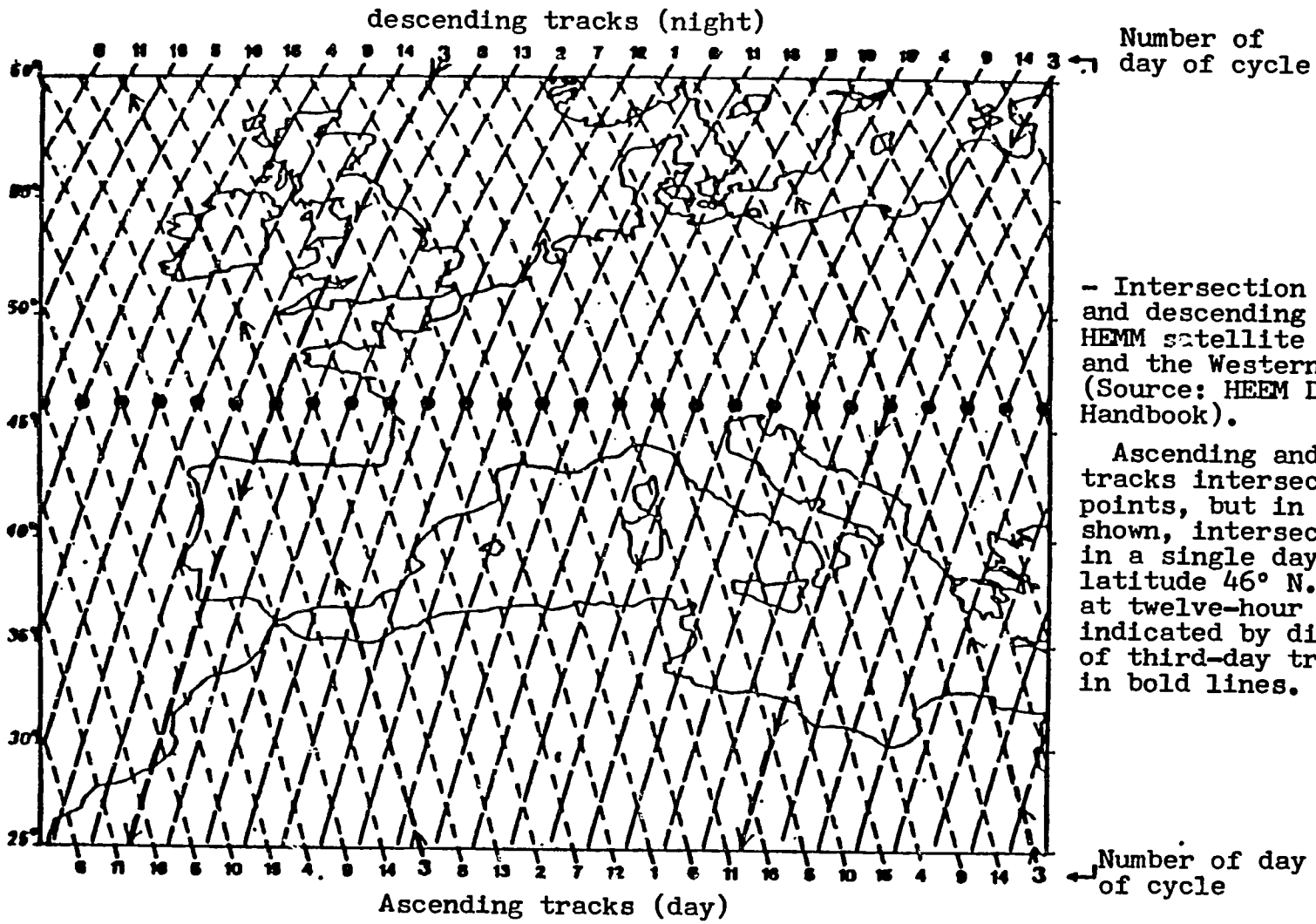
To provide correct observations they are generally launched into a circular orbit, or a very slightly eccentric one, at an altitude of a little under 1,000 km. Their period - i.e. the time they take to complete one orbit round the Earth - is fairly short: 1 h 40 minutes. on average, up to just under 2 hours.

The orbital inclination, i.e. the angle between the plane on which the satellite moves and that of the Earth's equator, is variable. The smaller the angle below 90°, the smaller the ground area covered by the observation. Only those satellites with an orbital inclination of 90° - i.e. those that move on a plane containing the Earth's polar axis, perpendicular to the equator - can cover the entire globe. Those used for observation, which are the ones that concern us here, have angles of inclination of between 98° and 102°.

Orbital inclination and altitude determine the precession of the nodes (= intersections between the satellite's trajectory and the plane of the equator); in other words they determine the progress of the orbital plane around the polar axis. With the nodes correctly conjugated one can obtain a sun-synchronous or constant sunlight orbit. This will precess in the same direction and at the same angular speed as the movement of the sun around the Earth (a little less than one degree per day).

The advantage of this type of orbit is that the satellite passes over each node at the same time, local time, on each orbit. For a given inclination, the time difference between satellite passes on either side of the equator depends only on latitude. At each passing of the satellite over the same site the light is nearly always the same, the position of the sun changing only with the seasons, not according to the time of day.

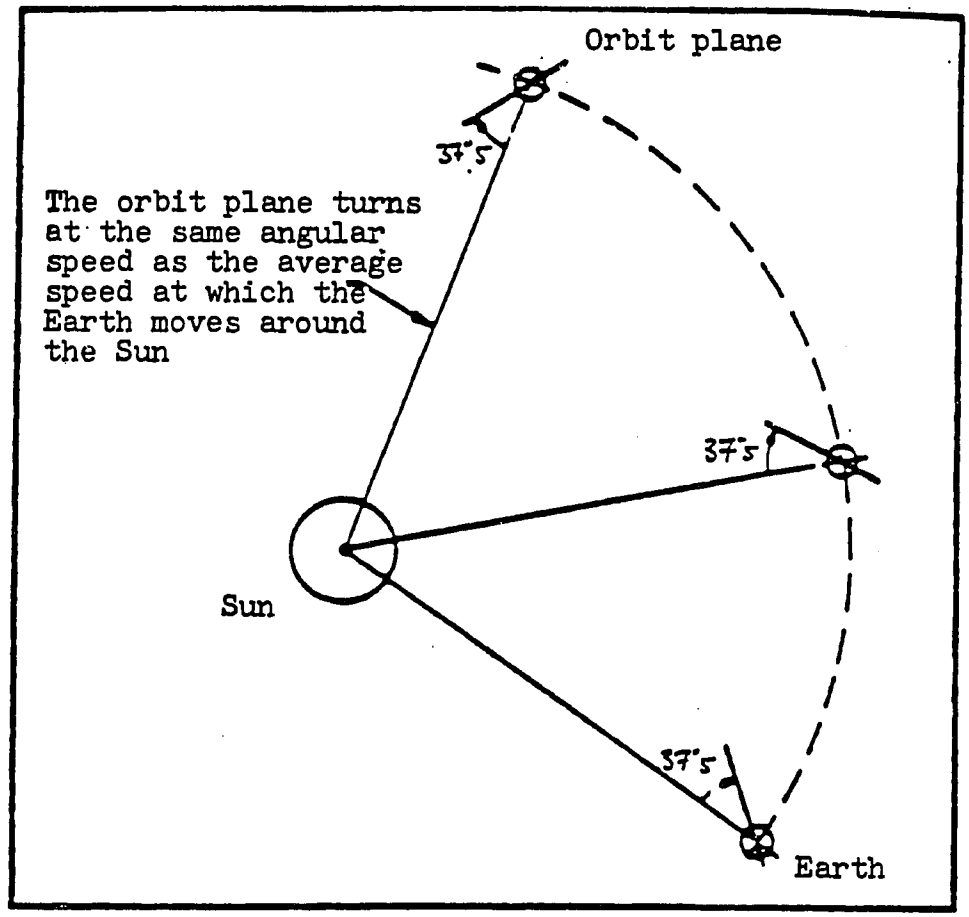
Given the 1 h 40 minutes. average orbital period of the satellites that concern us (NOAA, LANDSAT and SPOT), about



- Intersection of ascending and descending tracks of the HEMM satellite over Europe and the Western Mediterranean (Source: HEEM Data Users' Handbook).

Ascending and descending tracks intersect at numerous points, but in the region shown, intersections occuring in a single day are all at latitude 46° N. Intersections at twelve-hour intervals are indicated by disks. Examples of third-day tracks are shown in bold lines.

Source : Fernand Verger, 1982
(see Bibliography)



LANDSAT sun-synchronous orbit (Source: NASA LANDSAT Data Users' Handbook, PAO E-6175-35)

The angle between the orbit plane and the direction of the sun to the earth is constant throughout the year. The satellite is thus over the same regions of the earth at the same times (local times).

fourteen orbits are completed daily. If a satellite's passage at zenith over a given point on the equator at a given time is recorded, subsequent passes will show a westward shift; the satellite will pass vertically above a series of equidistant points progressing westward along the equator. As the circumference of the Earth is not an exact multiple of the distance of shift observed at each passing of the satellite, after 24 hours the satellite will pass near the site it passed the previous day but with a slight shift. In the case of LANDSAT 1, for example, this shift was 159.66 km to the west, and only after eighteen days, on its 251st orbit, did its path coincide with that of the first day. This orbital cycle varies according to the satellite's astronomic characteristics. Such cyclic regularity is a great advantage in Earth observation.

From a satellite with a low polar orbit, the instantaneous field of view - the land area visible at any one moment - is naturally very limited compared to that from a geostationary satellite: 6% of the Earth's surface as against 42%. It is also viewed from a much wider angle: 122° as against 17°. Detection is poor around the scene edges for such satellites as NOAA 9 or 10, whose sensors scan virtually the whole field, unlike LANDSAT 5 or SPOT 1.

This notion of instantaneous field of view (IFOV) is relative, since the usable field is by no means always explored in its entirety. What counts in fact is the field of the sensors employed, as we shall see when we consider the characteristics of the NOAA satellites on the one hand and LANDSAT and SPOT on the other, two very different satellite groups from this point of view (field, picture element, etc.)

The sensors are devices carried in the satellite payload, through which the basic data required by the mission are remotely sensed. Before looking at the different types of sensor, we need to see what they have in common and describe what it is they measure and how they measure it.

The primary information on which satellite RS systems are based is the amount of electromagnetic energy reflected or emitted by a body on the surface of the Earth.

Electromagnetic radiation is measured in two ways: by its wavelength, expressed in microns (1 Ì = one thousandth of a millimeter), and by its power, or flux, expressed in Watts.

A sensor measures the amount of energy brought to it by electromagnetic radiation in a given angle of field and a given part of the spectrum.

The only waves that can be used for Earth observation are those from parts of the electromagnetic spectrum ("windows") in which atmospheric transmission is adequate.

As shown in the diagram below, besides the characteristics of the observation satellite sensors, RS can be classified according to the wavelength channel characteristics of the

radiation it is designed to measure. There are two main channels:

- **The "visible" channel,** which includes the waveband visible to the human eye (0.4 to 0.7 micro) and the "near-infrared" band (0.7 to 1.1 micro). The source of radiation is reflected sunlight (direct sunlight lies in the 0.4 to 2 micro band). This can be sensed by day, provided there are no clouds between the sensor and the land area under observation;

- **The "thermal infra red" channel,** with wavelengths from 7 to 25 micro. This is radiation emitted by objects on the ground. This type of radiation transfers the object's heat, and wavelength depends on temperature. It can be sensed by day or by night provided there is no cloud cover.

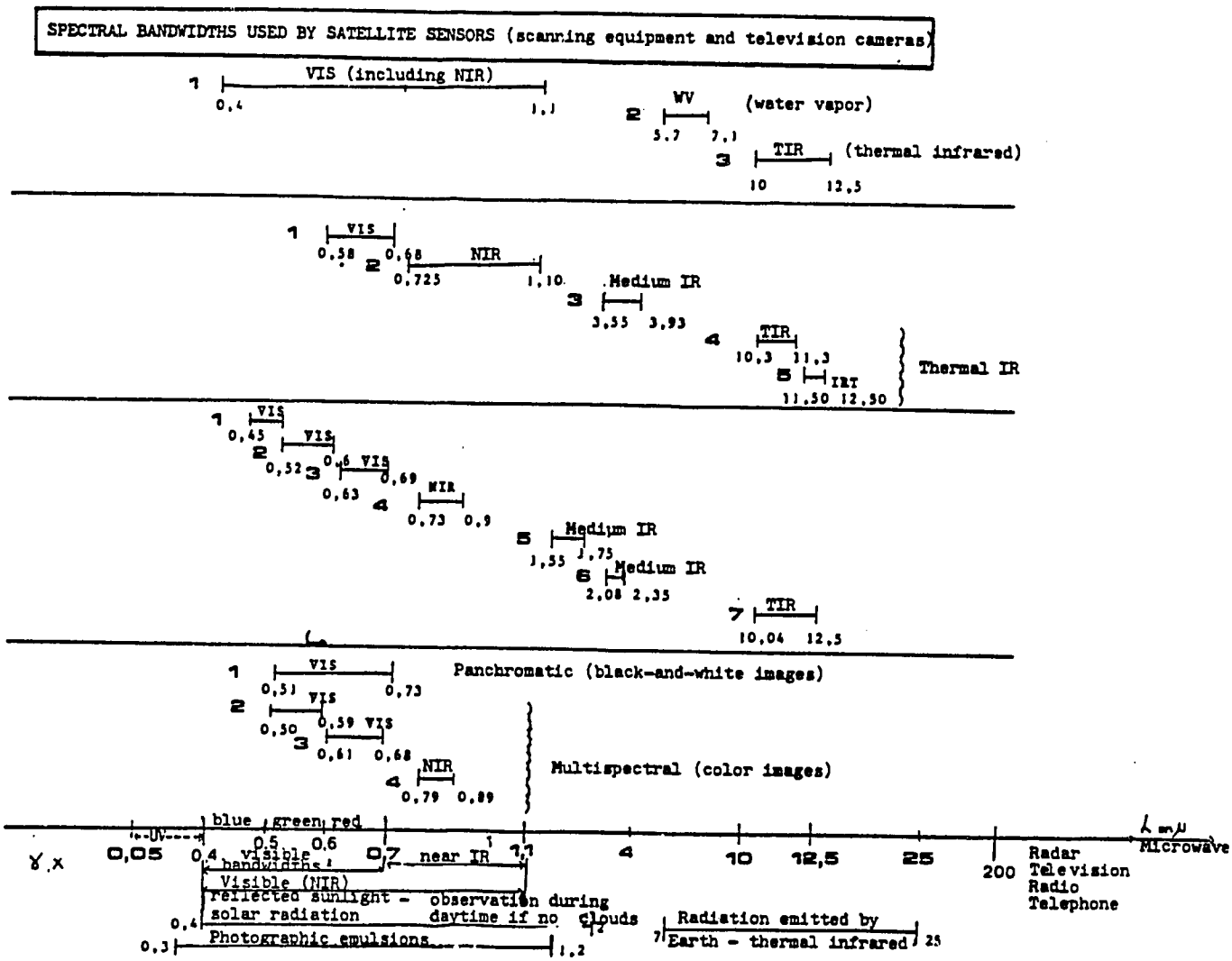
Some satellites also have radar in their payloads. Radar emits microwaves (200 micro and over), which are bounced back by objects on the ground. Microwaves are as yet little used for Earth observation (land or sea), but they can be sensed day or night and in all weathers.

Mainly in the visible region, experts often speak of the "spectral signature" of an object. This is its characteristic reflectance curve plotted in terms of wavelength. For example, the common characteristic of all vegetation is a reflectance curve that rises very sharply in the near-infra red range (near infra red can be seen as red on the usual color composites (false-color maps) and in infra red color photographs).

It should be remembered that the retina of the human eye is sensitive to light of wavelengths between 0.4 and 0.7 micro. It transforms energy received in the three primary colors (blue, green and red) into information, which the brain receives and re-combines, giving us the impression of shades of color. Photographic emulsions - the oldest remote sensing medium and still much used in RS - are sensitive to the wavelengths of a much wider band, from 0.35 to 1.2 micro, which includes the 0.7 to 1.2 micro wavelengths beyond the range of the human eye.

The sensors used in RS considerably extend our perception capacities. In the first place, they are highly sensitive and can measure radiation coming from the Earth at distances of up to tens of thousands of km. In the second place, they are sensitive to a very wide band of wavelengths, from 0.4 to 25 micro. This makes it possible to measure electromagnetic radiation from two different sources: reflected sunlight (the "visible" band and part of the mid infra red band) and radiation emitted by the Earth in the thermal infra red band.

Using wavelengths throughout the range but particularly in the "visible" band, these radiometric measurements express data which, collated and analyzed, provide a good deal of information about the nature and state of the objects observed - vegetation, for example.


SPECTRAL BANDWIDTHS USED BY SATELLITE SENSORS (scanning equipment and television cameras)
1 VIS (including NIR) 0,4 1,1
2 WV (water vapor) 5,7 7,1
3 TIR (thermal infrared) 10 12,5
1 VIS 0,58 0,68
2 NIR 0,725 1,10
3 Medium IR 3,55 3,93
4 TIR 10,3 11,3
5 IRT 11,50 12,50
Thermal IR
1 VIS 0,45 0,52
2 VIS 0,52 0,63
3 VIS 0,6 0,69
4 NIR 0,73 0,9
5 Medium IR 1,55 1,75
6 Medium IR 2,08 2,35
7 TIR 10,04 12,5
1 VIS 0,51 0,73
Panchromatic (black-and-white images)
2 VIS 0,50 0,59
3 VIS 0,61 0,68
4 NIR 0,79 0,89
Multispectral (color images)
blue green red
UV
visible
bandwidths
near IR
Visible (NIR)
reflected sunlight - observation during
solar radiation daytime if no clouds
Photographic emulsions
Radiation emitted by
Earth - thermal infrared
λ mμ
0,05 0,4 0,5 0,6 0,7 1,1 4 10 12,5 25 200
Radar
Television
Radio
Telephone
Microwave

It would be a long and complex process to describe the method and characteristics of the sensors used on RS satellites, with all their ancillary equipment for storing and transmitting information. Let us simply say that their capacities have been increasing very rapidly in several respects:

- spatial resolution, i.e. the size and observation qualities of the picture element or pixel. All else being equal, this factor varies widely according to nature of mission and type of satellite, as we have seen above;

- spectral resolution, i.e. the accuracy with which a sensor can distinguish neighboring wavelengths;

- radiometric resolution, i.e. the accuracy with which a sensor can identify the amount of energy transmitted, the limit being the slightest identifiable variation in energy.

The very high quality of spatial and radiometric resolution achieved makes it possible, among other things, to measure temperatures very precisely. The radiometer employed in all satellites of the NOAA Series since NOAA 6, launched in 1979, can detect temperature differences of 1/8 of a degree Celsius. The Advanced Very High Resolution Radiometer (AVHRR) carried by these satellites, including the currently operational NOAA 9 and NOAA 10, represents a major step forward from the VHRR, produced seven years earlier and used by the older satellites up to NOAA 5.

The temperature differences measurable with the AVHRR are five times smaller than with the VHRR, for the same spatial resolution, despite the fact that for a given technology, radiometric resolution can only be improved at the expense of spatial resolution. (In fact, in order to obtain a measurable amount of energy, it is advisable to have the largest IFOV possible).

To expand on this, although the comparison is somewhat crude, there are many analogies between a space-borne sensor and an ordinary camera. Both must take the same constraints into account, and their operators must often make the same kind of compromise between contradictory factors and imperatives. Where a photographer must strike a balance between depth of field and amount of light (aperture x exposure time), the remote sensor must balance spatial resolution against radiometric resolution. We could add many other such parameters to show the reader that the SPOT and LANDSAT satellites are to METEOSAT and NOAA, with their much wider angles of view, somewhat as telephoto lenses or zoom systems are to short focus or wide angle lenses.

METEOSAT 2*

Launch date: 19th June 1981
Engineers: European Space Agency (ESA) (EUMETSAT)
Type of orbit: Geostationary
Altitude: 36,000 km
Orbital inclination: 0.7° to plane of equator
Position of satellite in relation to Earth:
- Longitude 0°
- Latitude 0°

i.e. vertical to Gulf of Guinea (1,000 km west of Libreville, Gabon)
Period (time taken for one orbit): 1,411.5 minutes (23 h 52)
Number of orbits per day: 1
Coverage cycle: Half-hourly

Field covered:
42% of the Earth's surface, always the same part of the world, from the Arctic to the Antarctic and from the east coast of Brazil to the Arabian Peninsula and Madagascar.

Functions:
Earth observation, meteorology. The data established by the radiometer are received by the Odenwald Darmstadt processing station, FRG, which also uses the satellite as a space relay for re-transmitting raw or processed data to users. METEOSAT is also used as a relay to transmit measurements taken by ground stations.

Sensors:
The radiometer is equipped with three types of sensors, for three different channels in the electromagnetic spectrum:

. **The visible channel**, which allows pictures to be taken of that part of the Earth that is in sunlight. One sees the Earth the way one is used to seeing the Moon. The satellite's picture element is a square 2.5 x 2.5 km;

. **The water vapor absorption channel**, which gives an image of the water vapor content of the upper atmosphere;

* The new P2 METEOSAT satellite for weather forecasting was launched by Ariane 4 and put into orbit on June 15th 1988, on behalf of the ESA.

METEOROLOGIE NATIONALE
CENTRE DE METEOROLOGIE
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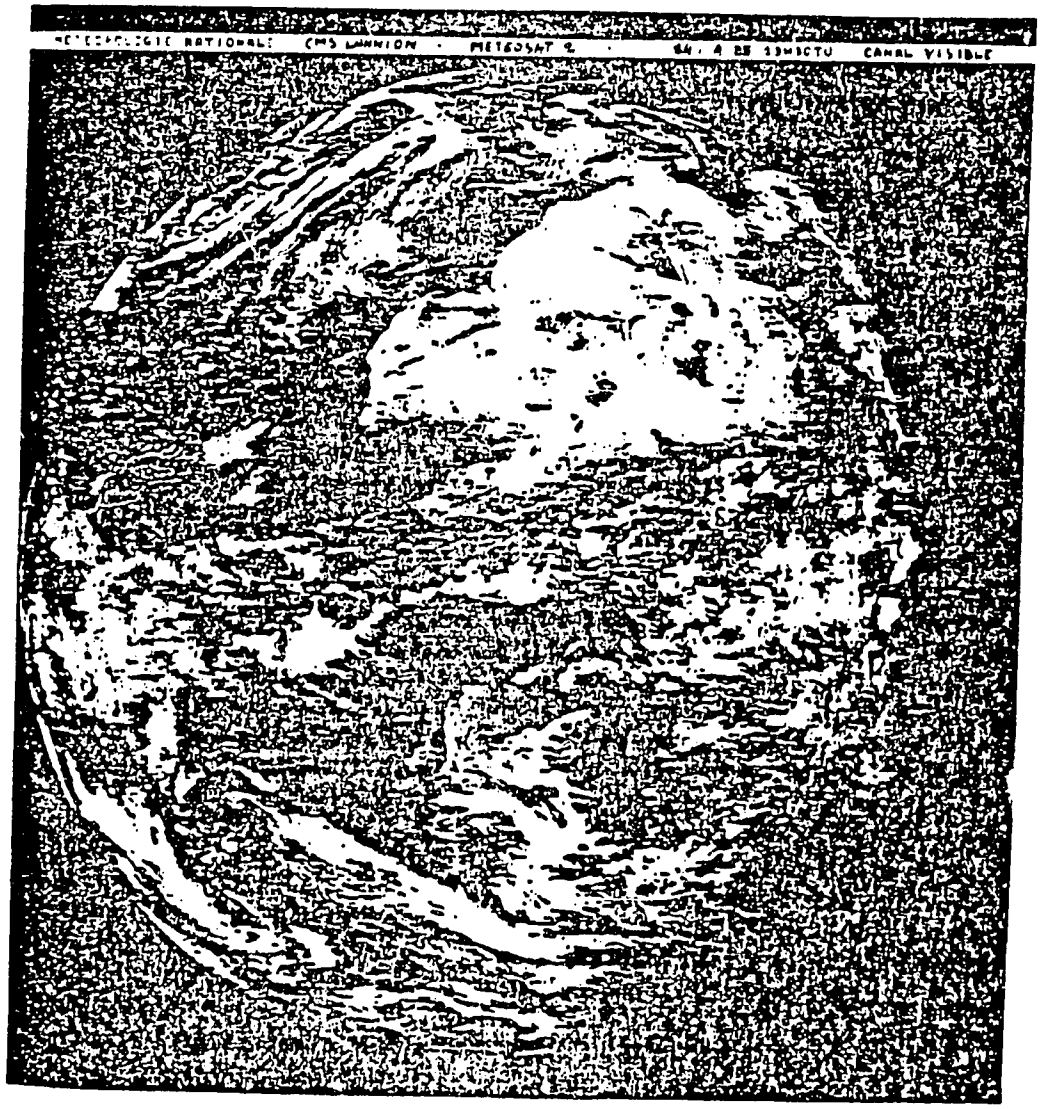
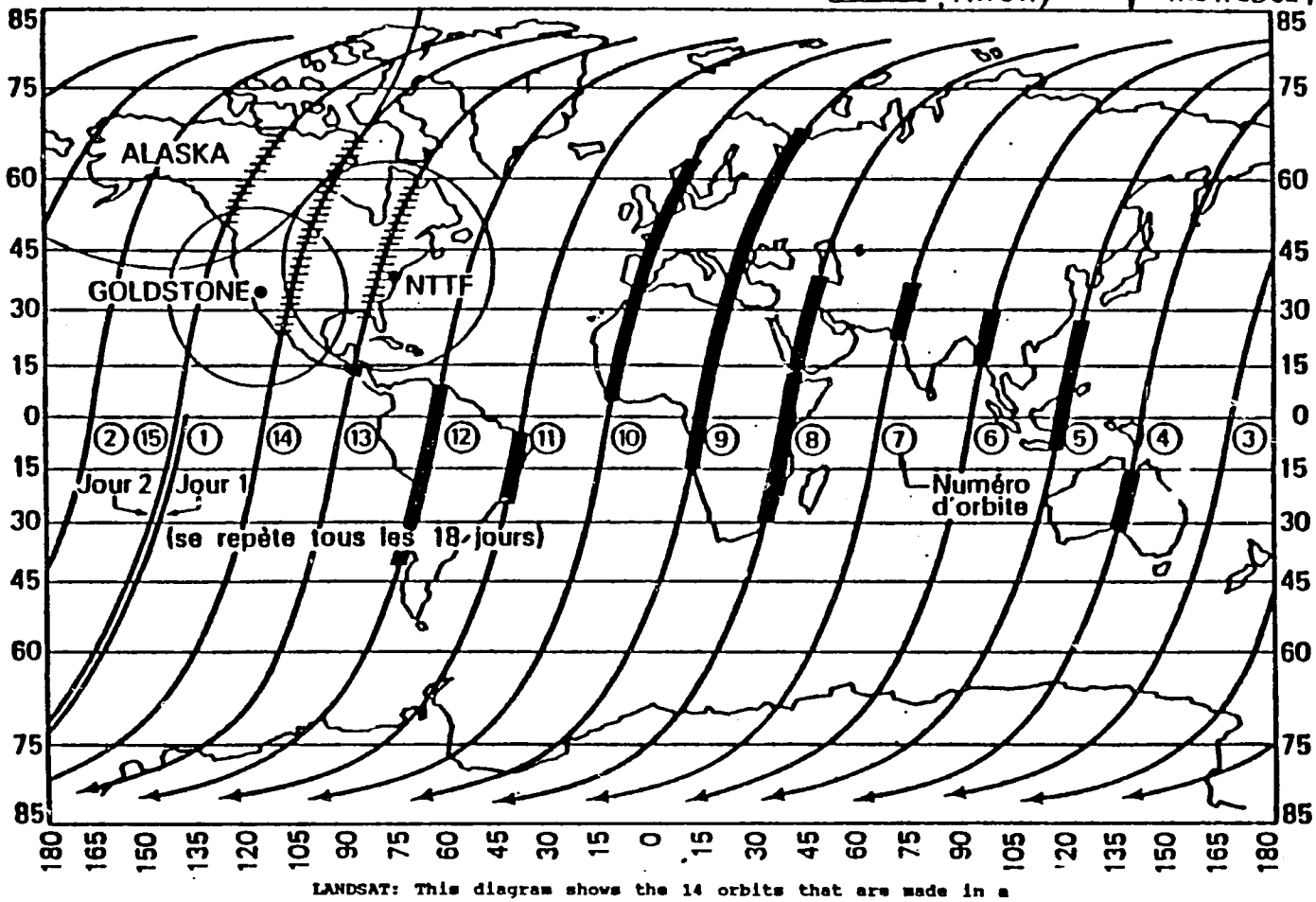
Ministère des Relations Extérieures — Coopération et Développement

VEILLE CLIMATIQUE SATELLITAIRE



MAI 1985

Source : NASA, citée par Alain Couzy (1981)



LANDSAT: This diagram shows the 14 orbits that are made in a single day at a distance of 2500 km from the equator. Orbit 15 - the first orbit the following day - is 160 km west of orbit 1. A possible NASA acquisition program is shown on these orbits: the parts shown in black would be recorded in memory and transmitted to an American earth station during the night; parts received in real time by earth stations are indicated by shaded areas.

NB: Since 1980, when this document was produced, other data acquisition stations have become operational, in particular the Mas palomas station (Canary Is.)

- **The thermal infra red channel**, which primarily senses the energy emitted by different points on the globe. This functions day and night, and after processing gives radiometric temperature maps on which cloud cover areas can be distinguished.

For the latter two channels, the picture element viewed from directly overhead is a square 5 x 5 km.

NOAA 9 SATELLITE AND AVHRR SENSOR

Launch date: December 1984
Engineers: National Oceanic and Atmospheric Administration (NOAA), US Department of ~~Trade~~ Commerce
Type of orbit: circular, polar, sun-synchronous
Altitude: 833 km
Orbital inclination: 99°
Number of orbits per day: 14.1
Time of passes over nodes: Ascending: 02.30 hours
Descending: 14.30 hours
Width of ground swath covered: 2,700 km

Main measurement instruments:

- TIROS Operational Vertical Sounder (TOVS), which measures atmospheric temperature and humidity (water vapor);

- Advanced Very High Resolution Radiometer (AVHRR), with sensors covering five bands: visible, near infra red, mid infra red, and two bands in the thermal infra red region. The recording field is 110.8° (55.4° on either side of the nadir).

Spatial resolution:
- at nadir: 1.1 km along the ground track, 1.1 km across.
- at outer edge of field: 2.5 km along the track, 7 km across.

Total area of ground scene: 2,000,000 km^2.

Data capture:
- Direct reading via High Resolution Picture Transmission (HRPT) as satellite passes, or, for about one-tenth of all records, delayed transmission after storage in payload memory as Local Area Coverage (LAC), at a resolution of 1.1 x 1.1 km.
- Delayed transmission after payload memory storage as Global Area Coverage (GAC), i.e. at a downgraded resolution of 4 x 4 km from a sample of 15 recorded data points at 1.1 x 1.1 km resolution.

Besides the HRPT and LAC data acquisition on the one hand and the GAC on the other, all of which are in digital mode, use all five spectral bands and require fairly well-equipped receiving stations, there is also an Automatic Picture Transmission (APT) system giving lower resolution, using data from only two channels on the AVHRR and providing analog data. Data are captured in many places around the world but give only summary pictures.

AVHRR measurements provide a way of observing the Earth by night as well as by day. By day AVHRR images show cloud cover, coastlines, and the extent of snow and ice. Night or day, data from channels in the thermal infra red window allow measurement of the temperature of any radiating surface (sea, land or cloud).

NOAA satellite data are in widespread use for the Sahel, for weather observation particularly (alongside METEOSAT) but also for crop monitoring (vegetation indices).

Did it, this report is Nov. 1988?

NOAA 11 is due to replace NOAA 9 in July 1988, when the latter will be deactivated and used as a reserve satellite.

NOAA 10 - AVHRR

The twin satellite, NOAA 10, launched in 1986 and also carrying an AVHRR radiometer, provides a well-matched complement to the NOAA 9 measurements. Passing over the ascending node at 19.30 hours it provides duplicate readings for each day's observations. Instead of coverage twice daily, there is a total of four daily readings of the same scene.

The products from the NOAA data are processed in ground stations in a number of countries: the United States (where the main one is the US Geological Survey's EROS Data Center near Sioux Falls in South Dakota, NASA-GFSC and the NOAA-NESDIS-CIAM data processing center at Colombia, Missouri); Spain (Mas Palomas); France (Lannion); and soon also Niger, with the AGRHYMET Center.

LANDSAT 5 Satellite - TM (Thematic Mapper) and MSS

Launch date: 1st March 1984
Engineers/Operator: Earth Observation Satellite Company (EOSAT), a private US company which took over from NASA in 1984.
Type of orbit: Polar, sun-synchronous (constant angle of 37.5° between orbital plane and Earth/Sun direction)

Inclination of orbit: 98°
Altitude: 705 km
Period (time taken for one orbit): 98 minutes
Number of orbits per day: 14 to 15 - average 14.7
Repetition rate: 16 days (same ground track repeated after 235 orbits)
Time of passage over node: (vertical to equator): 09.30 hours local time
Distance between two nodes (or more precisely two tracks at equator): c. 2,870 km
Width of swath covered by sensors: 185 km.
Area covered by one ground scene: 34,000 km^2

Sensors: Thematic Mapper (TM).
- Spatial resolution (pixel): 30 meters.
- Ground patch area: 900 m^2 or 0.09 ha.
- Number of channels: 7; 3 in the visible range, 1 in the near infra red, 2 in the mid infra red and 1 in the thermal infra red.
- Data: available either directly as satellite passes or using the Tracking and Data Relaying Satellite System (TDRSS); this has unfortunately been out of operation since the space shuttle accident in early 1986.

Given the long history of the LANDSAT satellite family (LANDSAT 1, or ERTS, was launched in July 1972), there is now a stock of fifteen years' medium-scale observation data, providing valuable hindsight on environmental changes.

LANDSAT 5 also carries a multi-spectral scanner (MSS) with four spectral bands in the visible and near infra red ranges and a resolution of 80 m. LANDSAT 4, launched in July 1982, also carries this MSS. The data from the LANDSAT 5 thematic mapper and the LANDSAT 4 and 5 multi-spectral scanners have been regularly received in recent years by the stations at Kiruna, Sweden, and Fucino, Italy. The Mas Palomas station in Spain (Canary Islands) only received MSS data in 1986.

SPOT 1 satellite

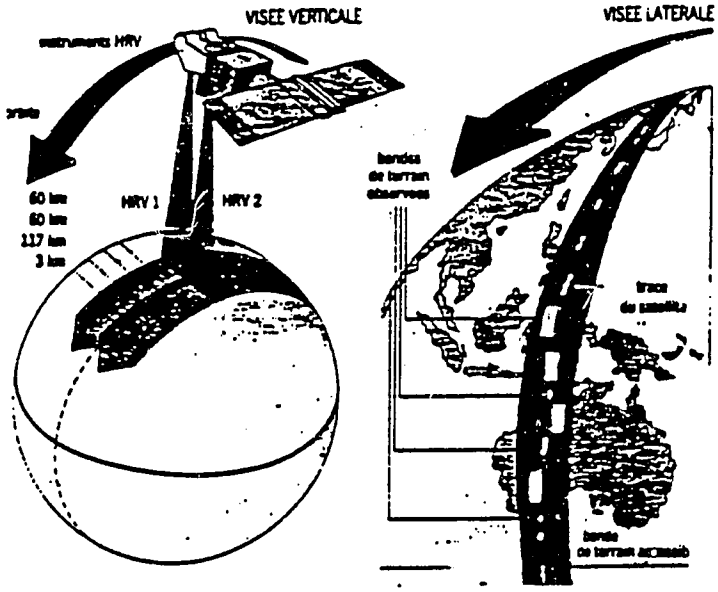
Launch date: SPOT 1, the "Satellite Probatoire d'Observation Terrestre", was launched on 22nd February, 1986
Engineers/operators: Centre National d'Etudes Spatiales (CNES), France, as part of a program decided on by the French Government in 1978 and jointly implemented with Sweden and Belgium.
Type of orbit: circular, sun-synchronous
Altitude: 832 km
Inclination of orbit: 98.7°
Descending node: 1039 h
Average period (time taken for one orbit): 101.4 minutes

SPOT.1

LES CARACTERISTIQUES DU SATELLITE

Imaging field

The two HRV instruments on board the satellite are identical and can be adjusted independently. Each instrument has a footprint 60 km wide. When the two HRVs explore adjacent areas on the earth's surface, the total footprint is 117 km wide.



Operating modes

SPOT offers two operating modes: multispectral and panchromatic.

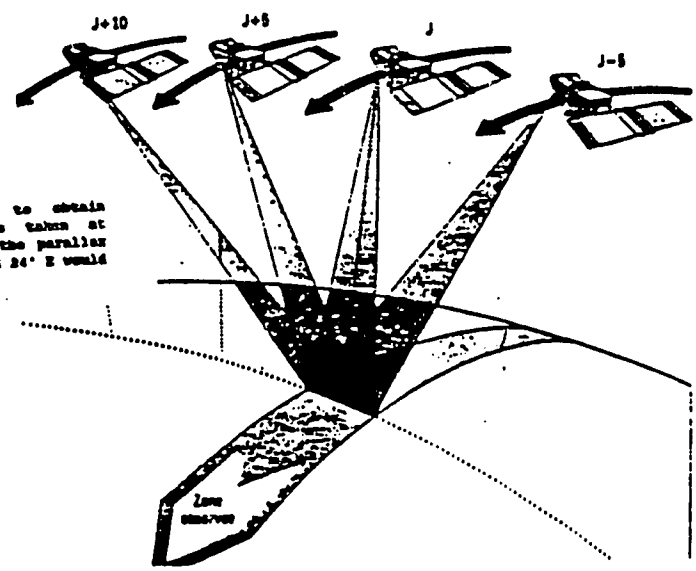
- In multispectral mode, observations are made in three spectral bandwidths with pixels of 20 m x 20 m:
  - a green band from 0.50 to 0.59 in
  - a red band from 0.61 to 0.68 in
  - a near infrared band from 0.79 to 0.89 in.
- In panchromatic mode, observations are made over a wide bandwidth (0.51 to 0.73) with pixels of 10 m x 10 m.

Vertical and lateral aiming possibilities

One of the salient features of SPOT is that it is fitted with an adjustable mirror that can be used for lateral observations. The line of sight can be directed eastwards or westwards up to +/- 27° from the vertical axis.

This feature makes it possible to observe zones inside the strip of the earth's surface either side of the satellite's ground track (strip width: 950 km), and is used to increase the frequency of observation of specific sites. For example, the same region on the equator can be observed successively 7 times during the 26 days of the orbital cycle, which is equivalent to 98 times per year and an average of one observation every 3.7 days. At 45° latitude, a given region can be observed 11 times during the orbital cycle, which is equivalent to 157 times per year and an average of one observation every 2.4 days (maximum interval: 4 days, minimum interval: 1 day).

Passage au jour:



Stereoscopy

Lateral observations also make it possible to obtain stereoscopic pictures by combining two images taken at different angles between -27° and +27°, through the parallax that is thereby created. Views taken at 24° W and 24° E would give a base/height ratio of 1.

COMPARATIVE PERFORMANCE OF SATELLITES AND PRINCIPAL FUNCTIONS

CHARACTERISTICS / SATELLITE	METEOSAT 2 *	NOAA 9 ET 10 AVHRR	LANDSAT 5 TM	SPOT 1
FOOTPRINT				
- width (km)				2 x 60 - 3 = 117 km spread over 950 km if required
- dimensions of scenes	42% of surface of globe (in fact + 50° L to -50°)	2 700 km	185 km	
- total surface area (in % of globe or km^2)		2 000 000 km2	34 000 km2	60 x 60 to 85 km = 3600 to 5100
CYCLE				
- repetition rate (days)	every 1/2 hour	twice a day	every 16 days	every 26 days in vertical observation and an average of 37 days in lateral observation for the Sahel
SPATIAL RESOLUTION (pixel)				
size of basic picture element				
- at satellite vertical (nadir)	2,5 x 2,5 km	1,1 x 1,1 direct acquisition LAC 4 x 4 km GAC	30 mètres	10 m N&B panchrom. 20 m color
- at extremities of scene		2,4 x 6,9 km	Idem	Idem
- minimum pixel area(1)	625 ha	120 ha	0,1 ha	0,01 ha panchr. N&B 0,04 ha color
DATA CAPTURE				
- radiometric resolution (sensitivity of radiation measurement)	-	1 024	256	256
	3	5	7	4 (1 panchrom. (3 multispectral
- number of spectral bands	0	3	4	4 (1 panchrom. (3 multispectral
MAIN FUNCTIONS				
- Precipitation (cloud, rain)	+	+	+	+
- Temperature, ETP	+	+	+	+
- Vegetation indices		+		
- Surface area measurement (zoning, urbanization, cropping)			+	+
- Forest fires, areas liable to flooding			+	+
COST OF COVERAGE per 1000 km2 (approx.) excluding cost of data analysis (which is generally proportionate to level of resolution)		0,05 $	129 $	400 à 1 100 $

Source: USAID, November 1986 (quoted by G. Nervio)

* principle role

(1) New weather-forecasting satellite METEOSAT P2 was placed in orbit by Ariane June 15, 1988

Orbital cycle: 26 days

Instruments: High Resolution Visible.
Two identical devices which can be aimed at an angle of up to 27° east or west of the orbital plane.

Width of ground track: 60 km for each device aimed vertically, i.e. 2 x 60 -3 = 117 km in all.
The ability to tilt the sensor's aim away from the vertical makes it possible to observe any area within a 950-km strip centered on the satellite's ground track.

Repetition rate: Increased as required by shifting aim of sensors to one side. Eg. at the equator it is possible to cover the same area seven times during the 26-day orbital cycle, or 98 times a year, once every 3.7 days on average. This potential frequency increases with latitude.

Spatial resolution: 1 pixel = 10 meters in panchromatic (black and white) mode, 20 meters in multispectral (color) mode.

Sensors: Push-broom system.

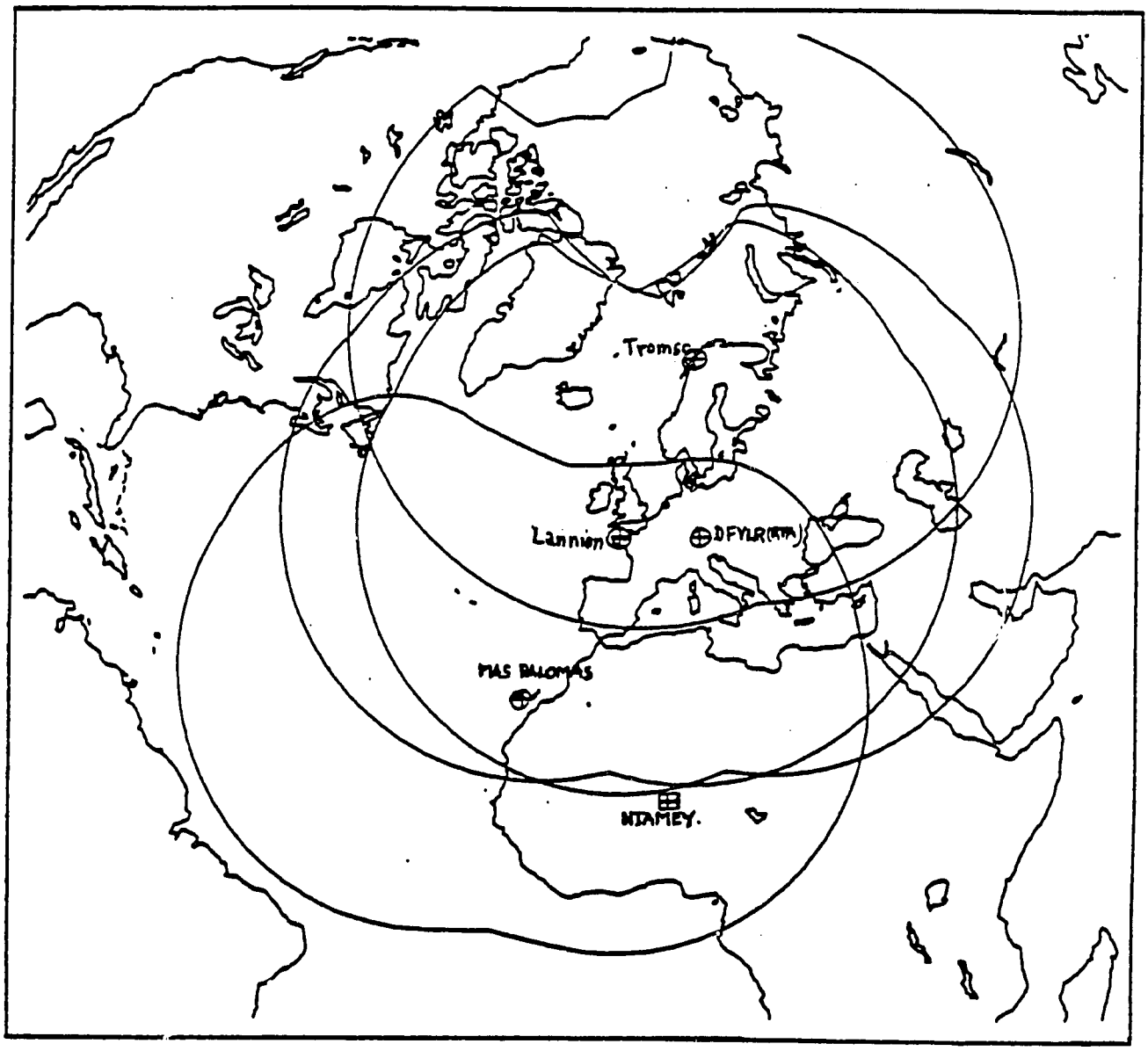
Spectral bands: 4 in the visible range (3 visible plus 1 near infra red). One of these is in panchromatic mode and three are in multispectral (green, red, near infra red). Measurements are taken only in sunlit regions.

Processing and distribution of data and products: The main stations are at "SPOT Image" in Toulouse (France) and Kiruna in Sweden.
Other direct-visibility receiving stations for this satellite: two in Canada, one in India, one in Spain (Mas Palomas, Canary Islands) and a number of others currently having equipment installed.
Time lag for obtaining products from SPOT Images and the world distribution networks: 1 to 4 weeks. This time-lag has been getting steadily shorter since summer 1987.
Levels of pre-processing of scene (60 x 60 km): 1A, 1B, 2, S.
Special products and by-products: computer-compatible tape; photographic products: film (full scene (60 x 60 km) or quarter scene, scale 1: 400,000 or 1:200,000); paper prints (full scene at 1:200,000 or 1:100,000; quarter scene at 1:100,000 or 1:50,000).
Possibility of stereoscopic products (relief maps) using side vision (ratio 1:1).

2 Data transmission and processing stations

Methods and equipment employed for data acquisition may involve still photography, video, film or, increasingly, scanner systems.

Apart from actual photographic film returned to Earth and recovered (only in the rare case of a manned satellite or recoverable module), all records, imagery and data gathered on



Source: Earthnet (ESA)

Direct acquisition areas for NOAA-AVHRR data using high-resolution HRPT mode (pixel: 1.1 km) for stations at Tromso (Norway), CMS Lannion (France), DRVLR Oberpfaffenhofen (FRG), Mas Palomas (Canary Is., Spain). The future HRPT reception station to be run by the regional AGRHYMET station at Niamey (Niger) will cover an area of similar dimensions and shape but centered on Niamey.

board observation satellites have to be scanned for transmission.

Measurements taken by sensors (now the commonest method) are expressed as electrical signals, proportional to the value measured - whence the term "analog". They can either be used in analog form, with continuous gradation of values, or they can be converted to digital signals, in which values are expressed as a series of numbers. This is referred to as digitization of data.

With such vast numbers of signs to be transmitted, digitization has an advantage in that it can use the great rapidity and huge throughput capacity of the most modern computers and data processing systems.

Some satellites transmit data in both forms. This is the case with METEOSAT, which sends WEFAX (weather facsimile) analog data and digital data that users capture according to the type of equipment they possess. The Regional AGRHYMET Center (RAC) in Niamey is equipped to receive WEFAX analog data from METEOSAT 2 by means of an SDUS (secondary data user station). The FAO's RS Center* in Rome also operates this way, but will soon also have, as part of the ARTEMIS project, a PDUS (primary data user station) to receive digital METEOSAT data. The future African meteorology center in Niamey (ACMAD project) also envisages installing a PDUS in a few years' time.

Data captured by satellite can be transmitted in real time, (i.e. transmitted as and when received) whenever the satellite is within sight of a receiving station. They can also be stored in memory for subsequent transmission to the ground when the satellite passes a receiving station. Finally, they can be re-transmitted via a relay satellite.

Repetition - the possibility of obtaining repeated data readings from a given geographical area and comparing them - is extremely useful. But many requirements have to be met even to acquire data once, on one pass over a given scene; and the necessary conditions are by no means always obtained, let alone repeatedly. It will depend on a number of factors:

- The nature of the orbit;
- Whether there is only one or several satellites of the same family available (eg. NOAA 9 and NOAA 10);
- Type of sensor (width of field, whether readings are being taken at 90° or off-center from the track, daytime or round-the-clock operation);
- Load factor;
- The time the shipboard equipment is available;
- Data storage and transmission capacity;
- Geographical location and functioning of the receiving stations;
- Also, for some sensors, weather conditions.

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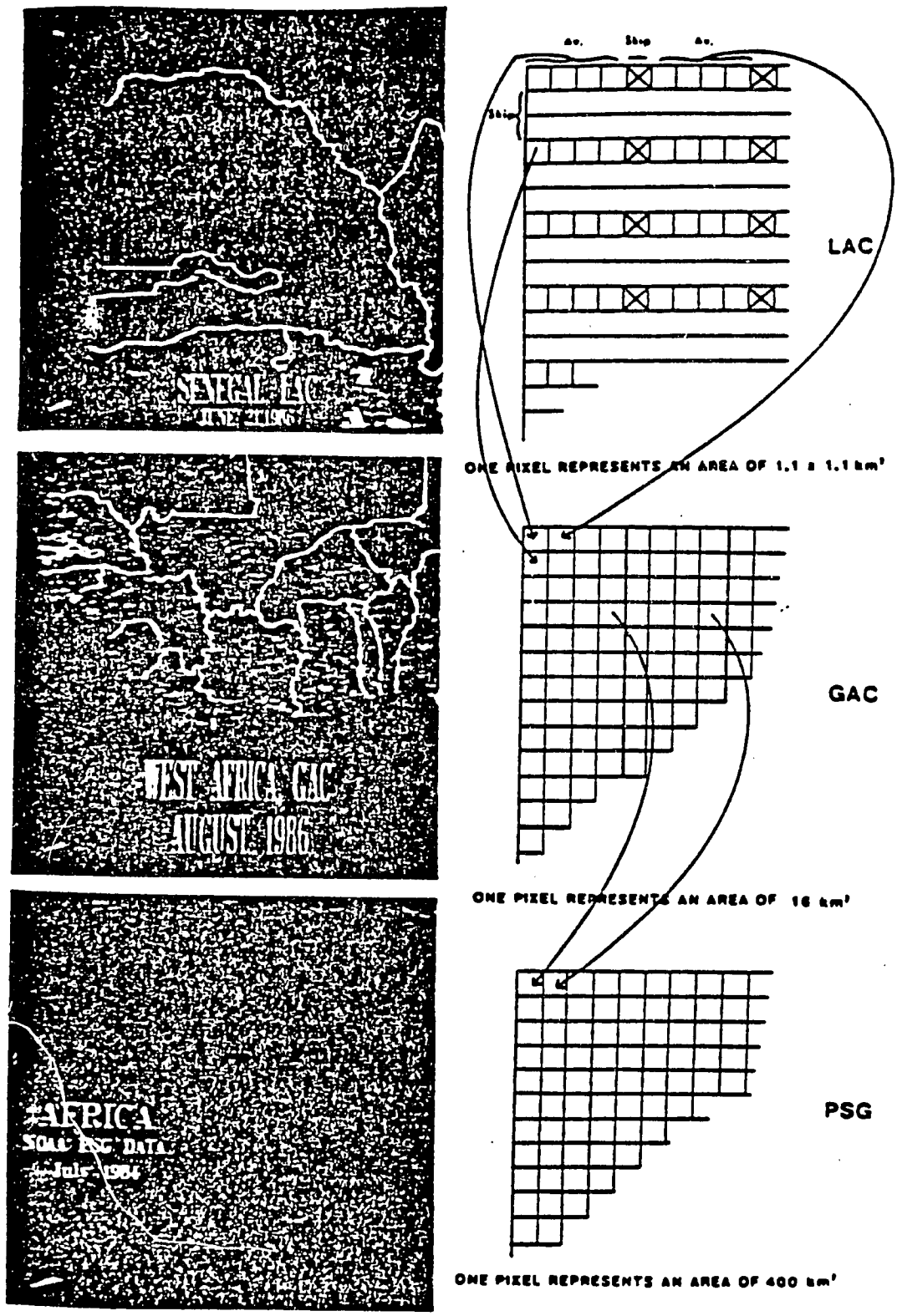
* FAO Remote Sensing Center, Rome. FAO RSC in this text.



The Relationship Between LAC, GAC and PSG Data

Source: GEOCARTO INTERNATIONAL (1) 1987.

This long list explains why for certain types of satellite it is quite difficult to obtain different, comparable sets of data on a given region within a short space of time. This is the case with LANDSAT and SPOT, both of which have narrow fields of observation, pass only infrequently over the same spot (this is especially true for LANDSAT), and record an enormous amount of data per scene, given their very high spatial resolution. The NOAA satellites, however, and to an even greater extent the geostationary METEOSAT, can provide frequent observations of the same ground scene, as shown in the comparative tables of satellite features.

Satellite data receiving and processing stations have multiplied around the globe as RS has expanded and the number of spacecraft circling the Earth has grown.

These stations differ from each other in many respects, and there are wide variations in size and capacity. In the first place, many are designed to receive and exploit data primarily from one type of satellite. Only well-equipped stations with sophisticated processing facilities and highly skilled, expensive labor can make full use of data from several types of satellite. There is a very wide gap between a basic ground station receiving low resolution data by delayed transmission, and one capable of fully exploiting high resolution information from several satellite types in real time.

Data from METEOSAT 2, the currently operational geostationary weather satellite of the European Space Agency (ESA) and EUMETSAT, is processed by the European station at Odenwald-Darmstadt, Federal Republic of Germany. This station uses the satellite as a space relay for re-transmitting raw or processed data to users. Many other stations of the sophisticated PDUS type or the more modest SDUS, process METEOSAT data. Among the primary stations, the one at Lannion in France deserves special attention. This space meteorology center houses a unit of ORSTOM, a scientific body that has a particular interest in the Sahel, and since the beginning ORSTOM and the Lannion SCM have carried out research work and experiments based on thermal infra red images in digital form. The Lannion center is now operational and regularly supplies both AGRHYMET and the CRODT in Dakar with processed weather data to complement the WEFAX data directly received through an APT receiver.

As already pointed out, the FAO's RS center in Rome, currently equipped with a secondary receiving station (SDUS), will by the end of 1988 have a primary station (PDUS) and the environment it will need for direct utilization of METEOSAT data.

NOAA's AVHRR data are of major interest to the CILSS countries, as indeed are METEOSAT data. Until very recently there was no direct-reception station to cover the Sahel region; this lack has now been remedied with the installation of the necessary equipment at Mas Palomas in the Canary Islands in July 1986. Better still, once installation of the HRPT (High Resolution

Picture Transmission) station at the RAC in Niamey is completed, the CILSS countries will have a unit capable of complete, direct acquisition and exploitation of NOAA data.

It should be pointed out in this regard that the satellite's MIRP processor handles data captured by AVHRR radiometer and transmits it in four different ways:

- Real time HRPT;

- Real time APT;

- Transmission of memorized data for Global Area Coverage (GAC) processing centers. GAC data characteristics are calculated so that one record covers a single complete orbit.

- transmission of memorized Local Area Coverage (LAC) data on areas selected in advance, for high resolution data processing centers. This can only be done for one 10-minute recording per 102 minutes.

Only data transmitted in real time to an HRPT station, or delayed transmission in the form of LAC data, provide a resolution of 1.1 x 1.1 km, i.e. a pixel of 1.21 km^2. Real time APT or delayed transmission GAC give a pixel of approximately 16 km^2, obtained by re-composition from a sample of 15 neighboring pixels. GAC definition is used by the EROS Data Center in the United States and the Goddard Space Flight Center (GSFC), which supplies preprocessed data to NOAA-NESDIS-AISC, the FAO and Price Williams. For the moment, in the absence of direct reception of NOAA pictures by the AGRHYMET HRPT station, it is GAC definition that is used for the NOAA-NESDIS images supplied to the Niamey AGRHYMET center.

Lastly, NOAA AVHRR data are also available by stereographic polar projection, which uses GAC data to produce a pixel with an average area of 400 km^2 (225 km^2 at the equator, 900 at the poles).

There are quite a number of **LANDSAT data receiving stations** around the globe. These can receive data in real time within their zone of visibility. For regions that are not covered, this satellite, like those in the NOAA series, has the necessary equipment to provide delayed transmission. In the United States LANDSAT data is in widespread use owing to the well-organized dissemination system that exists there. The State Department has put the US Geological Survey in charge of EROS, the Earth Resources Observation Systems program for resource inventorying and development; this has led to the creation of a major RS center, the EROS Data Center near Sioux Falls, South Dakota. Besides housing the records of LANDSAT and various other satellites, this institution has become one of the chief satellite data processing centers of the United States. It works in conjunction with NASA and handles data from the NOAA satellite among others.

Some years ago, NASA transferred the running of the LANDSAT program to a private company, the Earth Observation Satellite Company (EOSAT). EOSAT has been operating LANDSAT ever since, and also promotes the products' potential utilizations.

In Europe, the European Space Agency (ESA) launched the EARTHNET program in 1977. The aim of this program is to acquire pictures through a network of ground stations spaced out between northern Scandinavia and the Canary Islands, and distribute the products. In the beginning the network was gathering images mainly from US satellites, the LANDSAT series particularly. Since 1986, data from the LANDSAT 4 and 5 satellites have been marketed by a private consortium, Eurimages. Huge numbers of records are gathered and stored, especially by the stations at Kiruna in Sweden and Fucino in Italy; however, the most valuable from the Sahelian point of view are the records supplied by the Mas Palomas station in the Canary Islands. This station has been supplying data on West Africa, reaching as far as the Gulf of Guinea, since 1984. And as already mentioned, since 1986 Mas Palomas has been equipped with an HRPT receiving station for NOAA data. This station is to serve as a live model for its counterpart station at the RAC in Niamey, which is gradually being brought into operation and is in frequent contact with Mas Palomas.

Lastly, the FAO RS Center has built up a considerable collection of LANDSAT data records, which concern Africa in particular. Its reference system includes microfiches and microfilm of all LANDSAT imagery previously captured by NASA, as well as 70 mm transparencies.

Reception and processing of SPOT data: Decided upon by the French Government in 1978 and implemented in partnership with Sweden and Belgium, the SPOT program - Satellite Probatoire d'Observation Terrestre - was designed as an operational, commercial system. France's Centre National des Etudes Spatiales (CNES) is responsible for developing and operating the satellite. The structure chosen makes a clear distinction between the operating role of the CNES and the data distribution and user relations role allocated to the private company SPOT Image. SPOT data acquired and processed by the Toulouse station are disseminated, in the form of magnetic tape, maps or film, through a worldwide distribution network. The 60 x 60 km SPOT scenes are issued, on request, in multispectral (color) or panchromatic (black and white) form, processed to any of four image processing standards of increasing precision.

The ability to tilt the aim of either of the two sensors to either side of the satellite's track offers first and foremost a wide range of scenes within a 950 km wide swath, cutting the time required to cover a country, speeding up access to a given area, and considerably shortening the repetition rate (three and a half days for the Sahel as against the 26 days required with vertical aim only). But above all, with this original SPOT

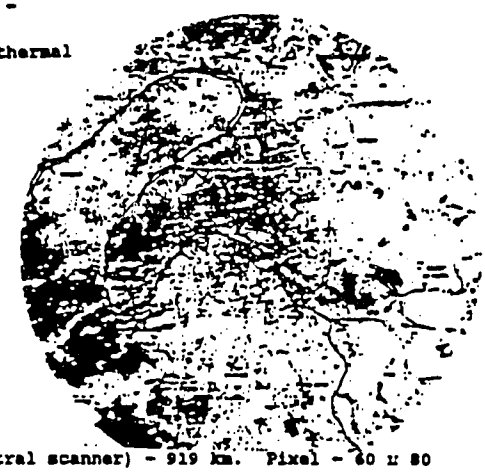
characteristic providing two observations of the same area taken from different angles, one can produce twin images from which one can show relief by photointerpretation, or plot altitude in a photogrammetric survey.

Lastly, it should be noted that the network of ground stations receiving data directly from this satellite is gradually expanding around the world, with stations in Canada, India, Spain, the Canary Islands, etc.

TRAITEMENT D'IMAGES DE SATELLITE

PROCESSING OF SATELLITE IMAGES

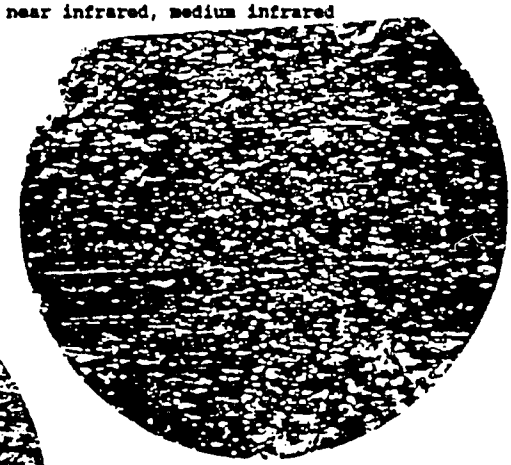
NOAA - 962 km. Pixel - 1.1 x 1.1 km. Approximate scale - 1:5,400,000.
Radiation - Visible, near infrared, medium infrared, thermal infrared.



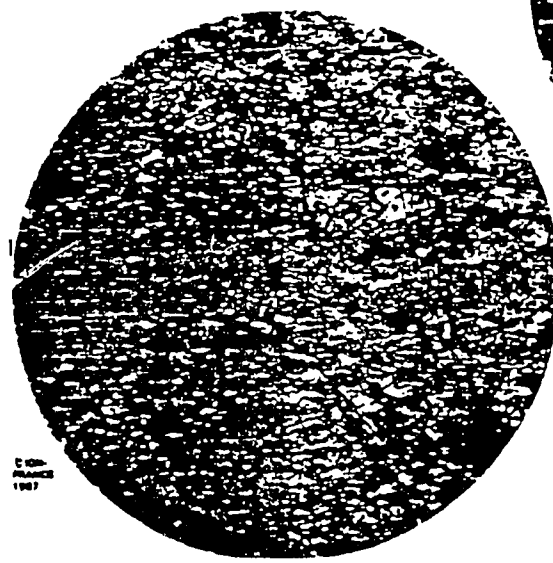
METEOSAT - 36,000 km. Pixel 2.5 x 2.5 km.
Radiation - Visible and thermal infrared.

LANDSAT MSS (Multispectral scanner) - 919 km. Pixel - 60 x 80 m. Scale - 1:100,000.
Radiation - Visible and near infrared

LANDSAT TM (Thematic mapper) - 705 km. Pixel - 30 x 30 m.
Scale - 1:100,000
Radiation - Visible, near infrared, medium infrared



SPOT - 832 km. Pixel - 10 x 10 m / 20 x 20 m. Scale - 1:50,000.
Radiation: visible, near infrared.



Source: Institut Géographique National, Paris

CHAPTER 2

THE PRODUCTS

1 Pluviometry

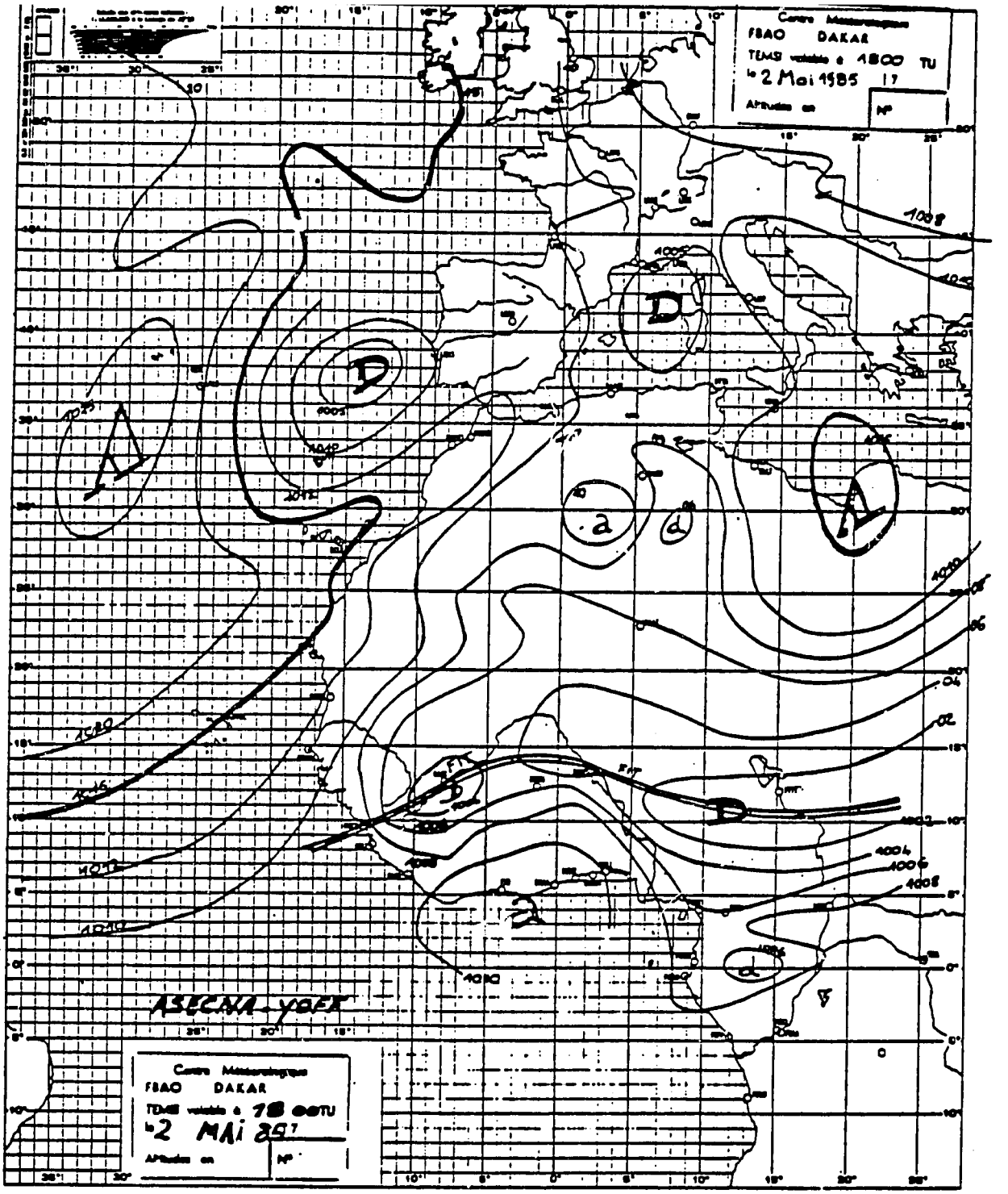
Rainfall is unquestionably the most crucial element in Sahelian life. So anything that will advance knowledge of it more rapidly will be making a major contribution. Unfortunately, the Sahel countries cannot establish the same density of observation stations as the countries of the North. What weather forecasting there is in the Sahel is still at the embryonic stage. But improved knowledge of the occurrence, location and intensity of precipitation would in itself be a great step forward, enabling many beneficial decisions to be made in the livestock, crop farming and agricultural monitoring fields especially.

Remote sensing is an indisputably valuable instrument in this respect for the Sahel countries, where ground observation stations are still too thinly scattered, some being inadequately equipped and having poor communications facilities.

In this section we shall examine the means, methods and results involved in RS research and applications for pluviometry in the Sahel.

Although this is the most fully operational RS "product", observation from space has by no means unraveled all the mysteries of precipitation. There is immense scope for research here, be it in perfecting results that are still imprecise and uncertain, or in trying to forecast further ahead and with the best possible chances of success. Alongside standard operations that are already supplying their share of very useful information, therefore, there is a whole range of research projects under way, as we shall see below. Many of these projects involve applied research, combining work in laboratories, universities and data processing stations with field work carried out jointly with researchers or technical staff from the CILSS countries.

Several different methods are employed to optimize utilization of available satellite data, supplementing rainfall information obtained in the field and extending rainfall data gathering in space. Some methods are based on cloud top temperature (or, in some cases, brightness) and others on ground surface temperature.



FIT = Intertropical front

Source: French National Meteorology Station - CMS Lannion
METEOSAT - 3/5/85 - 12:00 TU - Infrared channel

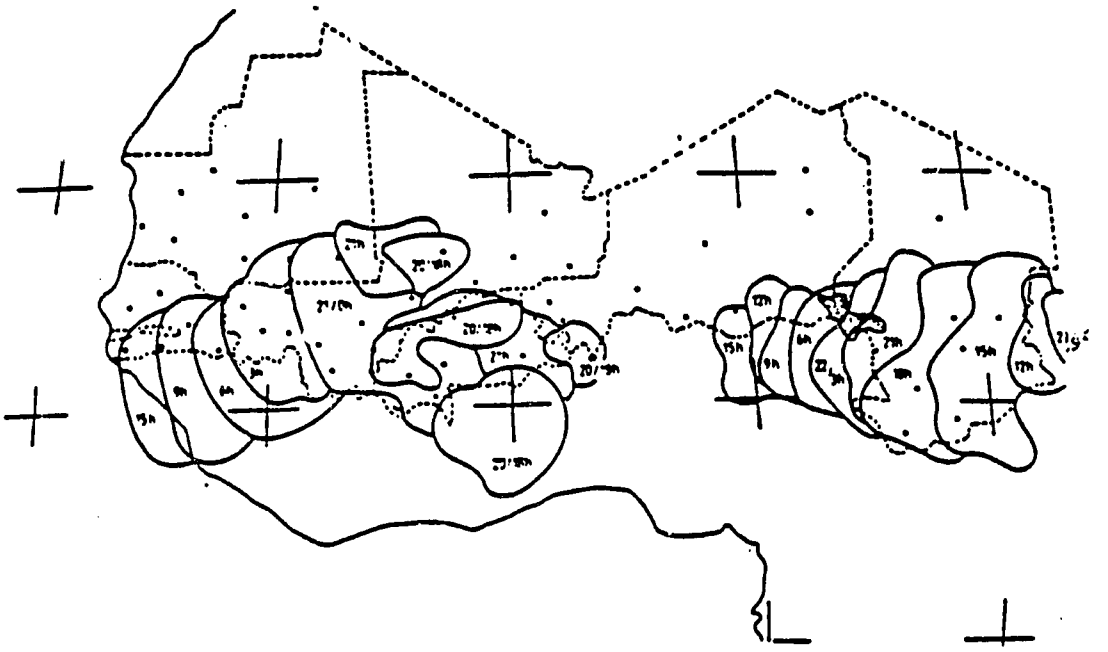


Figure 3: Monitoring of cloud masses affecting CILSS countries on July 20 and 21, 1986

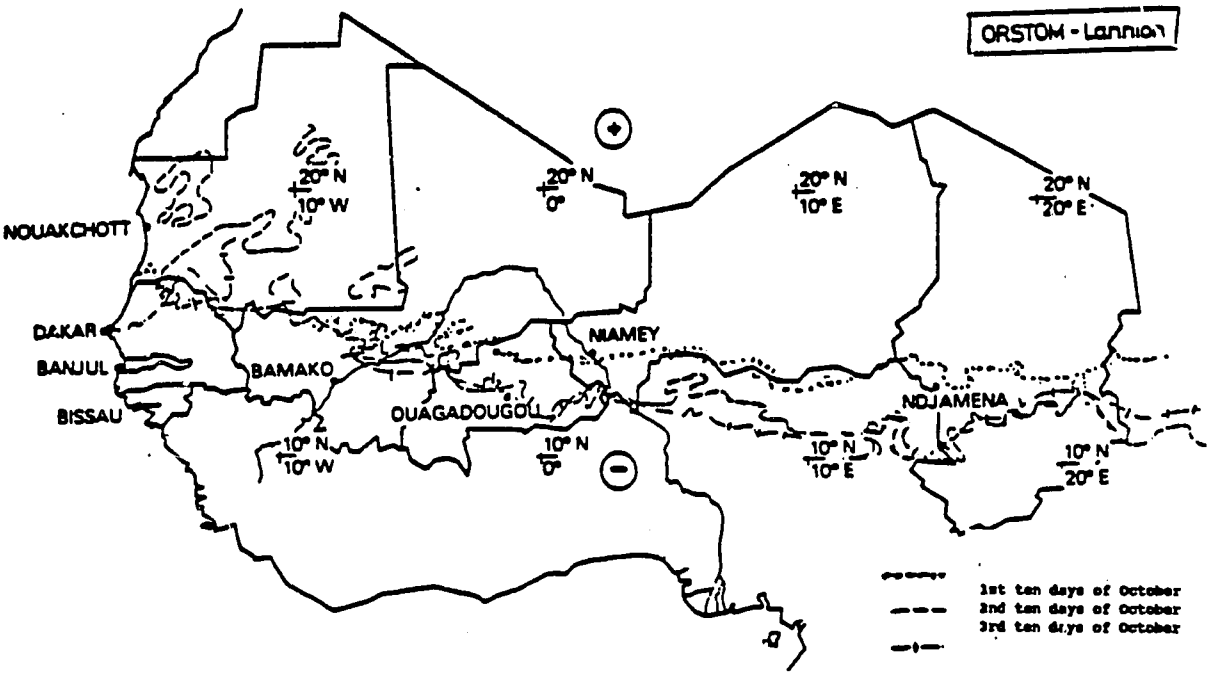


Figure 5 - Positions of isotherm + 39° over West Africa during October

Source : Dominique et Chaizy

Researchers are by no means unanimous as to opinions of the quality and reliability of the results obtained, particularly as regards time scale. Is it possible, at the present time, to make valid estimates for a ten-day period, a month, or the entire rainy season?

Should we, at this stage, regard these results as reliable (and hence operational) only in a qualitative sense, and postpone for the time being routine use of the quantitative rainfall estimates that are made?

What of research into rainfall monitoring on a much smaller timescale, day to day or even hour to hour? Some think this is a path worth exploring. It would mean coming down to the scale of actual precipitation occurrences, using satellite imagery to define an hourly convection index for each cloud cluster, and following the cluster as it moved across the globe.

Research and experimentation have taken off to a remarkable degree, especially over the past four or five years, carried out by a number of agencies in the United States, Europe and the Sahel itself. Involved in their initiation or implementation are such major bodies as NASA, NOAA and EARTHSAT in the United States, and in Europe the ESA, the Lannion CSM, ORSTOM, the French Ministry of Co-operation, the FAO RSC and Reading and Bristol Universities, not to mention the many projects carried out by a variety of other institutes or university laboratories less specialized in RS but nonetheless very active in this field. One has only to glance through the list of current projects or the bibliography (see end of document) to see the number and range of these research operations.

Keeping to essentials, the main focal points of research and development at the present time are the following:

- The Centre de Météorologie Spatiale, Lannion, France (the Lannion CSM), where an ORSTOM unit headed by B. Guillot has been carrying out and coordinating continuous and very worthwhile work, over the past four or five years especially;

- Reading University, United Kingdom, where Profs. Dugdale and Milford have developed a method which, after experimental work in the Sahel (the TAMSAT project), has been adopted by the FAO;

- Bristol University, United Kingdom, where Profs. Barnett and Power have explored and tested another method.

In the Sahel itself, the main centers for full-size experiments are naturally the Regional AGRHYMET Center in Niamey and the national meteorological services that are its correspondents in the CILSS countries. It should be noted that the RAC already exploits METEOSAT and NOAA data on an operational basis, either

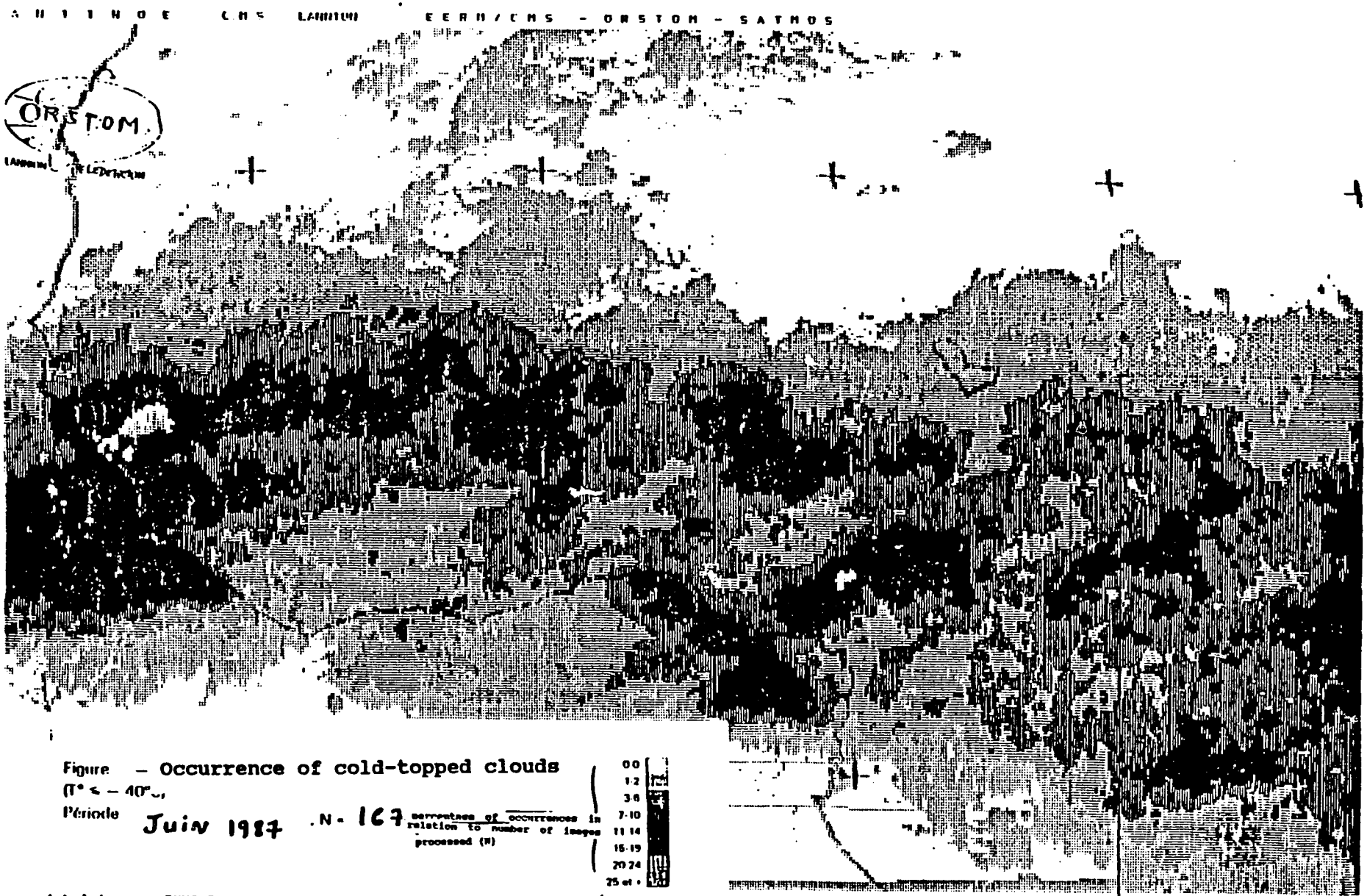


Figure – Occurrence of cold-topped clouds
(T° ≤ – 40°C)
Période Juin 1987 .N- 167 percentage of occurrences in relation to number of images processed (N)

Jabel image : CUNIMR somme mensuelle juin 87 167 images normalisé – lissé
échelle en POURCENTAGE d'occurence nuage à sommet froid

directly or from maps and other products acquired from the Lannion CSM in France.

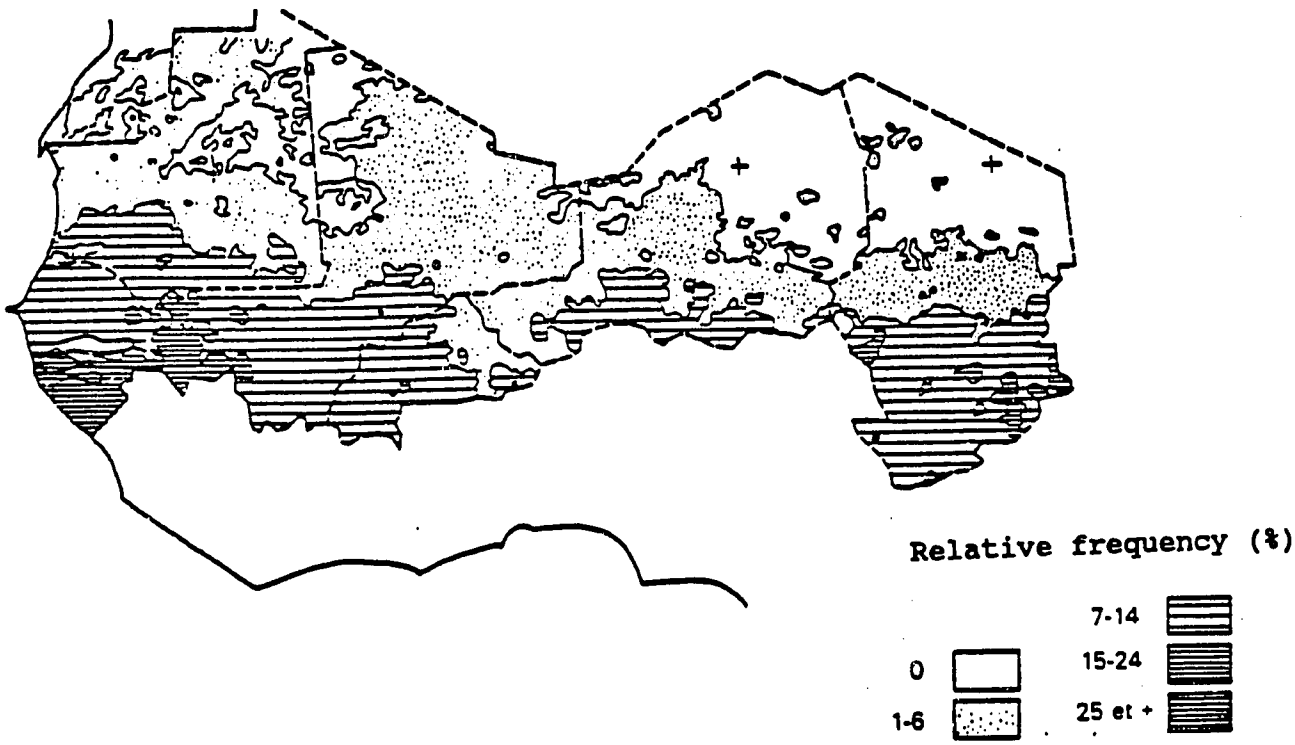
There are many projects currently under way in the CILSS countries, combining RS and ground readings in the drive to obtain better, earlier knowledge of precipitation during the rainy season. Over the past few years experiments have been carried out in every country concerned, but particular mention should be made of Senegal's Institut Senegalais de Recherche Agronomique (ISRA) and Centre de Recherches Océanographiques de Dakar-Thiaroye (CRODT). In their "Unité de Traitement d'Images Satellitaires" (UTIS), set up with the aid of ORSTOM, these two institutes already have considerable RS facilities with mixed teams of skilled staff. One example of the work going on in these centers is their monitoring of the Intertropical Convergence Zone, or ITCZ, and sea surface temperatures. This work has reached the stage of attempting rainfall probability forecasts for West Africa two or three months ahead. Geoffrey J. King, in his October 1987 report to the FAO, gives a status report on Senegal's many RS laboratories and projects (see bibliography).

The best results obtained to date towards improving knowledge of rainfall in the Sahel are essentially based on thermal infra red images from METEOSAT 2. The principle of the operation is identification of cold-topped clouds from a particular radiant temperature threshold (usually - 40° C). All clouds having a summit temperature less than or equal to this threshold are considered to be part of a rain-producing convection cell. It is generally agreed that 85 to 90% of rainfall in Sudano-Sahelian Africa is generated by such convection clouds. Given the frequency of METEOSAT imaging (upper limit: one map every half hour), cloud clusters can be monitored continuously throughout the rainy season.

Using one observation every three hours, these very tall cloud clusters are followed from the moment they form to the moment they disappear. It is easy to follow their movement if they are organized in squall lines (easterly winds).

By collating and synthesizing all these observations (cold-topped clouds, changes in convection, squall lines, etc.) over a ten-day period, one can produce an image that gives at least a qualitative glimpse of the structure and intensity of rainfall zones. One can then supplement this with ground readings and trace the isohyets in those areas where there is little or no rain-gauge data. The same observations repeated and compared throughout the rainy season give far more reliable quantitative information. The results are of little utility on a monthly basis but are very useful if the rainy season is taken as a whole; this has been especially true over the past year or two.

The other basic information item is radiant surface temperature, which is strongly affected by vegetation and soil



RELATIVE FREQUENCY OF COLD CLOUDS (TOP TEMPERATURE ≤ -40°C) ON 177 METEOSAT IMAGES OF WESTERN AFRICA TAKEN IN SEPTEMBER 1986

Source: J.L. Domergue and A. Chazy

moisture, and hence by the spatial and temporal distribution of rainfall. Rain produces a change in the immediate rate of evapotranspiration (PET), and this in turn has a direct impact on surface temperature.

Radiant surface temperature as measured by satellite, usually in the thermal infra red channel of METEOSAT, can therefore also be used as an indicator of rainfall. It is useful to map isotherms from readings taken at Lannion CSM, for example. Closely spaced isotherms indicate hot or cold fronts, and the position and alteration of these fronts indicate the arrival of the rainy season in the Sahel, its development, duration, etc. Furthermore, some methods, particularly the one being explored in Dakar, deduce some interesting qualitative and even quantitative rainfall information from this, in conjunction with the method based on cloud top temperature observations.

In Senegal, during the 1984-85 and '86 rainy seasons, an experimental study was made of the relationship between rainfall and surface temperature as measured in METEOSAT's thermal infra red channel. This showed that from 1st June onward mean temperature, corrected for air temperature, is a good indicator of cumulative rainfall over the same period.

M. Carn and J.P. Lahuec at Lannion CSM have thought up a simple and original method that combines the above two. From the number of occurrences of cold-topped clouds and the maximum radiant temperature, it gives satisfactory results over the season as a whole, but not for shorter periods when processing only six images a day. Verifications made in Niger in 1986 gave encouraging results for this new hybrid method. They showed that from July on, rainfall can be quantitatively estimated within a margin of error of less than 20%, and that a considerable advance on this is feasible in the near future.

The products described above are of great value to the Sahel, partly because of the crucial importance of rain and also because of the low density of recording and communications facilities in the field. At the same time, two other developments deserve attention. The first is the possibility of obtaining evapotranspiration (PET) indications from radiant soil temperature measured by satellite, and the second is an indication of the trend of the rainy season **before** it begins - though this not yet a very reliable indication, as the time perspective is still inadequate.

Measurements taken in METEOSAT's visible and thermal infra red channels also make a useful complement to real evapotranspiration of cropland as estimated on a regional scale from a combination of water balance and surface energy balance.

While it would be Utopian to dream of forecasting the rainy season in its entirety, it is nonetheless possible to assess climatic trends from the situations that have prevailed over the first months of the year, basing one's calculations on general circulation and ocean-atmosphere interactions.

Satellite observation has already been successfully used to draw useful correlations and establish certain relationships between, or at least the co-existence of, weather phenomena in the intertropical zone over the 1982-84 period (when anomalies occurred that were unrivaled since 1925), and other phenomena around the globe ("El Nino" in South America, Atlantic Ocean temperatures, etc.).

An attempt to forecast trends for the 1985 and 1986 rainy seasons met with some success. This type of forecast will of course have to be tested over a longer period before it can be properly appraised.

But there is no doubt that satellites and RS methods will play an important part in future research, which would in fact be impossible without them.

As regards the actual products that RS produces or helps to produce in the field of pluviometry and related data, in practical terms the main items to be considered are:

- In real time, the summary cloud formation maps obtained from METEOSAT and NOAA via APT automatic picture receiving stations;

- Products deriving from processing of digital data, mainly from METEOSAT and to a lesser extent from NOAA;

- Mapping of high-piled clouds, squall lines, hot and cold fronts, isotherms, isohyets and the intertropical convergence zone;

- Ten-day rainfall estimate maps or bulletins;

- Monthly rainfall estimate maps;

- Monthly maps of rainfall anomalies, in millimeters and percentages.

2 Vegetation index

Among the products specific to RS that are of use to the Sahel, the vegetation index is probably the most common, alongside the meteorological indicators proper (rainfall, temperature, etc.).

Although the vegetation index is beginning to achieve operational status and the RAC in Niamey has been using it regularly for a year or two now with the aid of NOAA-NESDIS services, it would seem worthwhile to give a brief outline of the technical characteristics of this indicator, and describe the various ways of calculating it. This will give an idea of the limitations of the product, for the Sahel particularly, and will show that this indicator too is in its initial application

stage. Research and competition are very intense in this field, as in so many others that make use of RS data.

In a study presented to the technical co-ordination meeting held at the Regional AGRHYMET Center in Niamey in June 1987, Mr. E. Bartholomé of the JRC compared the potential value of the different vegetation indices for identifying crop species in a Sahelian environment. Most of the information that follows has been borrowed from Mr. Bartholomé's clear, well-developed paper (see bibliography).

To try and qualify the state of the vegetation and monitor its development, one takes the capture of solar energy by chlorophyll on the one hand and water on the other. Measurement of the intensity of these two factors by satellite sensors gives a valuable indication of the plant's condition, since chlorophyll lies at the heart of photosynthesis and photosynthesis is the motive force in plant cell activity, whilst moisture readings show the plant's status with respect to this equally vital element.

The three figures below show the reflectance of the leaves of a variety of plants according to their chlorophyll and water concentrations.

These figures show that there is one band of the electromagnetic spectrum sensitive to photosynthesis activity (the red band, R, wavelengths 0.6 to 0.7 micro), and one band sensitive to moisture content (near infra red wavelengths, 0.7 to 1.1 micro).

The reflectance of a healthy plant is very high in the infra red and very low in the red, whereas senescence or water stress increases spectral response in the red and reduce it in the infra red, giving a spectral profile more like that of the soil.

The whole art of the researchers and experts working in this field lies in starting from these basic data and using vegetation reflectance differences to try and determine the state of the vegetation in a given area as seen from a satellite. From the radiation recorded in the red and near infra red channels, an index is calculated by one of a number of different methods: channel comparison, normalized difference index, perpendicular vegetation index, analysis of main components, soil/plant/water method.

In fact these methods are based either on a linear combination of channels or on the relationships between channels. None of these indices takes into account at the same time the possible disturbance of an object's spectral response by atmospheric attenuation, variations in brightness due to date and shadow, or soil variations. This preliminary comment already gives a hint of the difficulties this measurement entails and its relative lack of precision.

SPECTRAL RESPONSE - PLANT STATUS RELATION

a) effect of photosynthesis

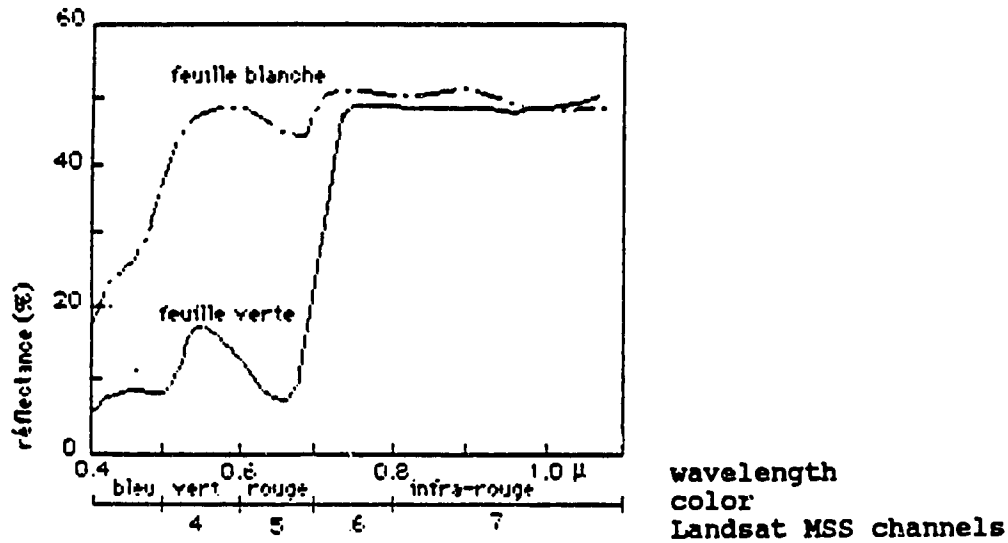


Figure 1: spectral response from geranium leaves to variegated leaves
(Knipling, 1970)

b) effect of water on the plant

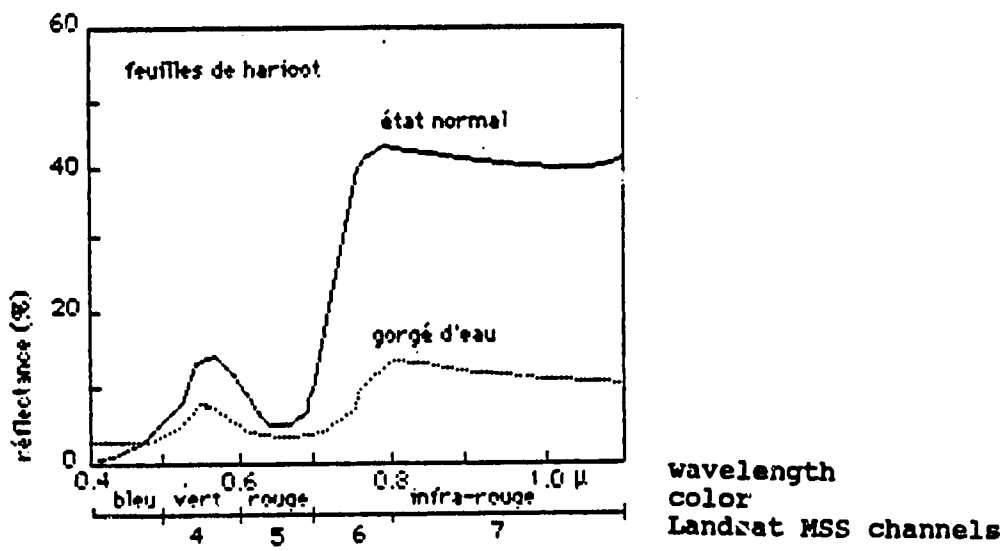


Figure 2: reflectance of bean leaves in a normal condition and when infiltrated with water after ground spraying (Knipling, 1970)

Source: E. BARTHOLOME: seminary on "Improvement of agricultural survey procedures by remote sensing", AGRHYMET Center, NIAMEY, 15-19 June, 1987

The most commonly used vegetation index is the Normalized Vegetation Index, or NVI, which combines reflectance measurements in the two channels as follows:

$$\frac{\text{red - infra red}}{\text{red + infra red}} \quad \text{or} \quad \frac{R - IR}{R + IR}$$

The satellite used for the measurements may vary (NOAA, LANDSAT or SPOT), but as their sensors give very different levels of spatial resolution, NOAA 9 and 10 are used most; their 1.1 x 1.1 km pixel is better suited economically to observation of vast areas of land, and they have the added advantage of passing far more frequently over a given area. SPOT or LANDSAT are used only for measurements from very limited areas, though they are better suited to taking measurements from yardstick areas and distinguishing between different crop species, as we shall see below.

What are the concrete ways in which the vegetation index can be utilized.

The products derived from it are generally based on data recorded at GAC resolution, in which one pixel is made up from an average sample of 15 AVHRR pixels and covers approximately 16 km^2. The vegetation indices are worked out from readings taken at each pass of the satellite over a ten-day period (at least with the NOAA satellites, which pass over the same region twice or three times daily). This series of observations is needed to eliminate areas of cloud cover. In the first stage, the indices are often combined or downgraded over an area covering 1° longitude by 1/2° latitude, called a grid cell. Each cell covers about 111 x 55 km, just over 6,000 km^2. This scale offers economic savings and allows rapid telegraphic data transmission, an important factor for crop monitoring in real time. Comparing these indices (shown visually by means of a computer graphics system) with those for the previous year, for example, one has an immediate and invaluable indication of drought-affected zones. This rather crude representation does have the merit of informing, at an early stage and in synoptic form, all those concerned by biomass developments at a given moment (leaders, decision-makers, farmers, pastoralists, donors, etc.). Informative comparisons can be made quickly, giving a first rough idea of the farming year as it progresses and allowing timely action to limit the consequences of disasters. These indices are particularly useful during the cropping season, from May-June to October in the Sahel.

The other product of vegetation indices is more developed and far more precise. It is a computer diskette, which can be used with an IBM-compatible microcomputer to display indices at GAC resolution on-screen or to produce photographic prints. These forms of data of course involve a certain time-lag, firstly in preparation time and secondly, above all, the time for delivery by mail or diplomatic bag. They are used to exploit vegetation

c) effect of senescence

Figure 3 shows the effect of senescence on plants: in green tissue, maximum absorption is in the red and spectral response is therefore low. In the infra-red, reflection is very high and the spectral response of dry leaves tends to homogenize and resemble that of the ground with a reflectance that tends to increase with the wavelength.

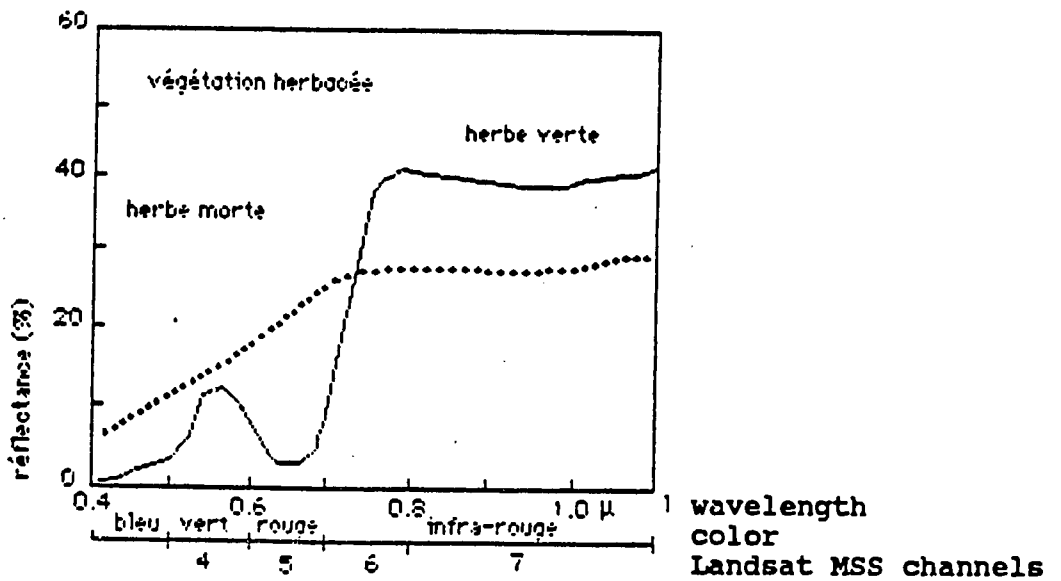


Fig. 3: spectral response of dead leaves in relation to healthy leaves

Source: E. BARTHOLOME: seminary on "Improvement of agricultural survey procedures by remote sensing", AGRHYMET Center, NIAMEY, 15-19 June, 1987

indices to the full, region by region or over time. With diskettes procured from the RAC in Niamey, for example, NOAA-NESDIS can deduce a variety of information from the indices. Besides false-color display on the Ambrosiak Color Co-ordinate System developed by NOAA-NESDIS, the RAC makes a full range of comparisons, over time and space, from the weekly indices.

These comparisons are made with a certain hindsight and, being based on GAC data, are more precise than any that can be made using 1° x 1/2° grid cells. One great step forward would be to have available in the Sahel itself, in real time, GAC (or better still LAC) data, and the means to process them. And this is about to happen, as a NOAA AVHRR receiving station is currently being installed at the RAC in Niamey and will be operational, along with its ancillary processing equipment, between now and 1989.

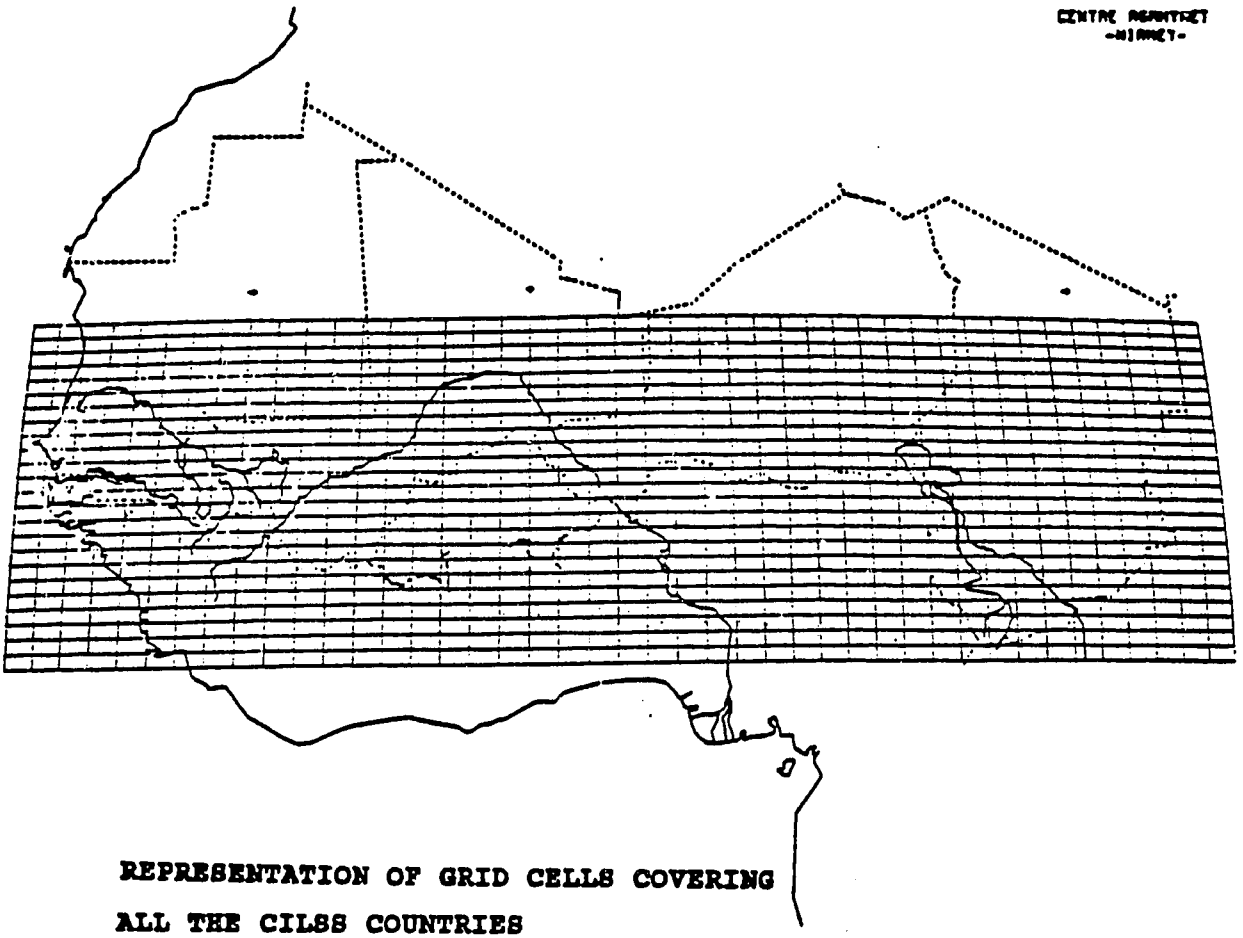
The maps, chronological graphs and miscellaneous tables based on the vegetation indices have, as we shall see when we look at current research and operational projects, given rise to quite a number of schemes by bodies involved in the Sahel, both Sahel-based bodies like the RAC in Niamey and outside bodies like NOAA-NESDIS, Columbia University and FEWS-NASA-USGS in the United States, ESPACE and SPOT Image in France, and ARTEMIS (FAO) in Rome, to mention only the most important.

We shall be looking at all the efforts made in this field and the various products and services supplied or on offer to the Sahel.

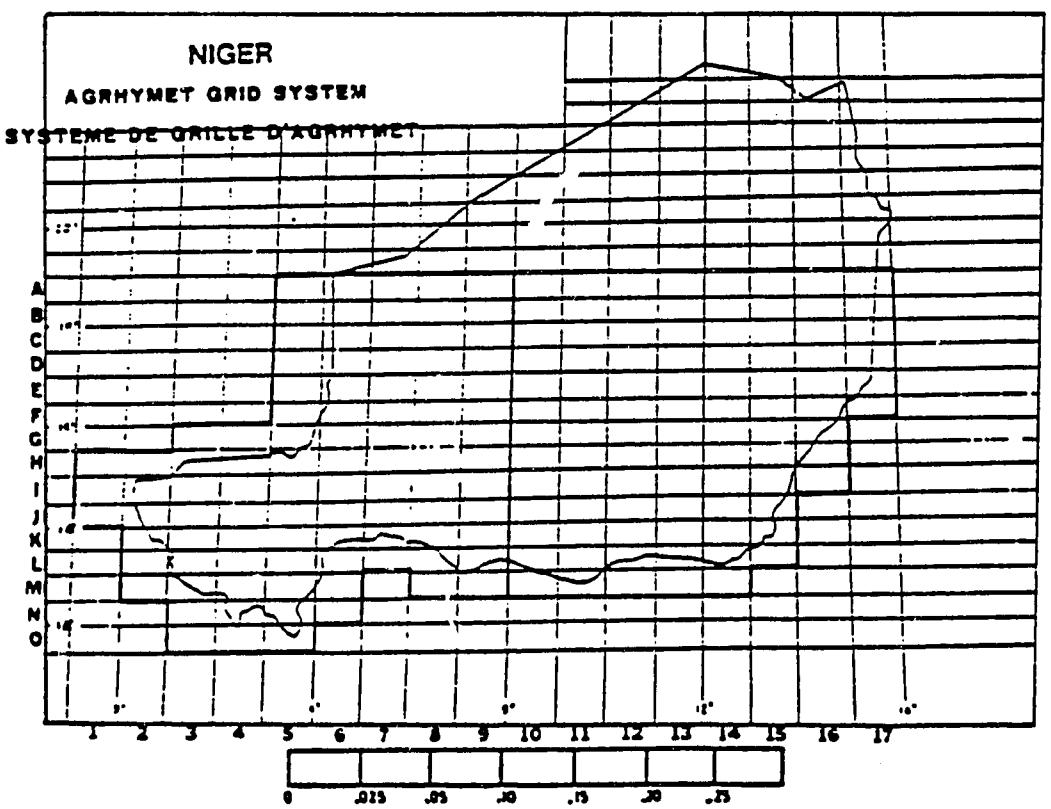
We shall also be returning to the question of vegetation indices when we come to assess the value of RS products and compare them with products obtained by conventional local methods.

At this point we would add that the initiators of vegetation indices in the US wanted to take as much advantage of these indices as possible. Over and above qualitative measurement of the biomass they have tried to estimate and forecast yields. However, even experiments on uniformly-sown maize fields in the US gave very low rates of correlation between yield and normalized vegetation indices. AGRHYMET, with the support of NOAA, attempted some estimates in 1986 but did not repeat the experiment in 1987. Yield forecasts from satellite data still seem very unreliable, especially in the Sahel, where growing crops are not at all homogeneous.

For the rangelands, on the other hand, the vegetation index is certainly more useful, giving a better basis for appraisal of this type of biomass, as we shall see below.



REPRESENTATION OF GRID CELLS COVERING ALL THE CILSS COUNTRIES

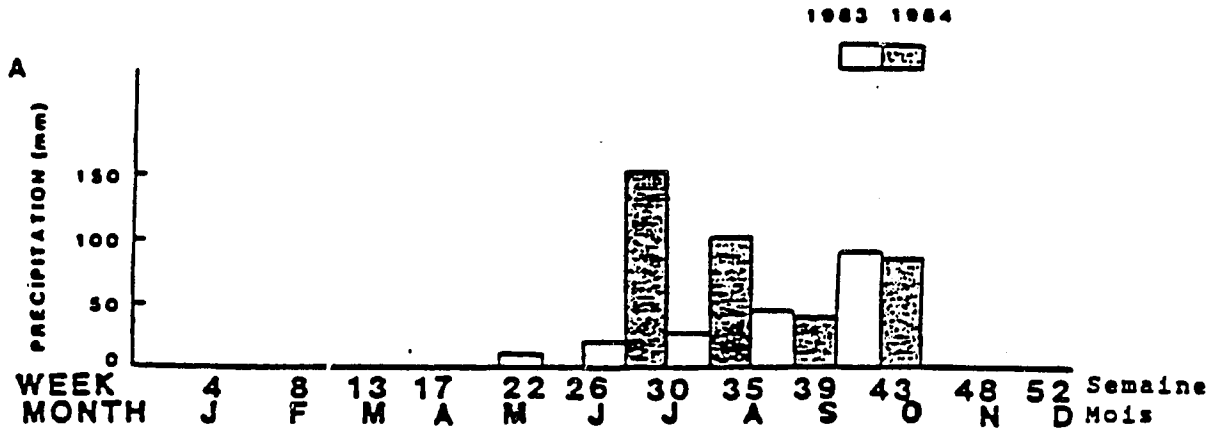


AGRHYMET GRID SYSTEM

Source: AGRHYMET

COMPARAISON DES DONNEES PLUVIOMETRIQUES ET DES INDICES DE VEGETAT
(Bruts et corrigés) pour 1983 et 1984 au SENEGAL.

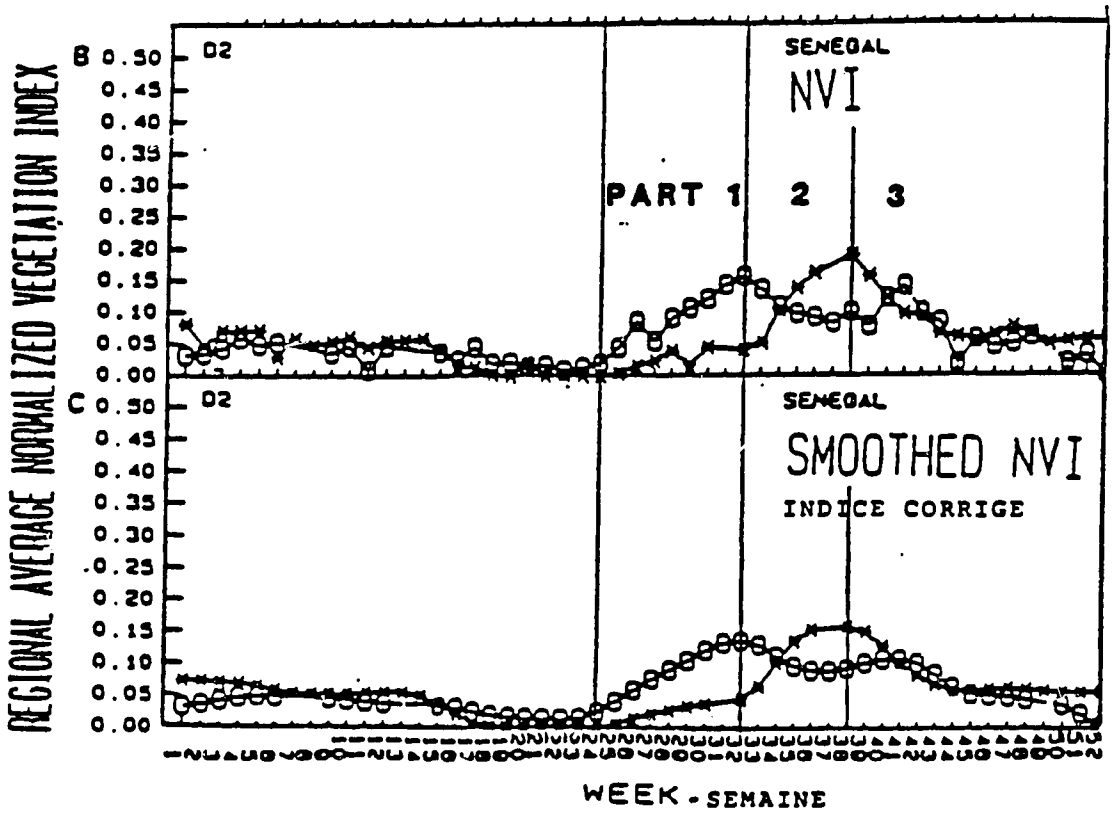
COMPARISON OF 1983, 1984 PRECIPITATION DATA (A)
TO NVI FOR 1983 AND 1984:
UNSMOOTHED (B) AND SMOOTHED (C) OF SENEGAL.



REGIONAL AVERAGE NORMALIZED VEGETATION INDEX

INDICE DE VEGETATION NORMALISE
(Moyenne régionale)

* = 1983
0 = 1984



Source: CM. SAKAMOTO
GEOCARTO INTERNATIONAL (1.1987)

3 Measuring cropland acreage

Monitoring rainfall and the other parameters that provide pointers on the moisture status of crops (real evapotranspiration, moisture balance, stress, etc.) and combining this data with the vegetation index, one will get a broad idea of the potential yield of growing crops, even if the picture lacks precision and is more qualitative than quantitative.

However, anyone familiar with the meager resources Sahelian countries possess for establishing their agricultural statistics will recognize the importance of finding a means, if not of filling the information gap, at least of supplementing the information and stimulating it with comparisons and extrapolation. RS has unquestionably aroused hopes in this sphere since in principle at least it provides a way of estimating the acreage under crops. So, for example, if satellite data led to a good estimation of the acreage for cereal cultivation, before harvest, this information could be combined with yield forecast information to provide a timely cereals crop estimate and enable all those concerned (decision-makers, observers, etc.) to take the necessary decisions in good time.

Measurement of grazing land acreage or areas along riverbanks usable for post-flood cropping; forest inventories; monitoring of areas under flood or liable to flood - all these could benefit from satellite-based acreage measurements.

As the reader will discover in the chapters on projects and operations in the Sahel, RS experts and promoters have staked a lot of hope on the benefits RS could bring in this sphere. They even thought they would be able to discriminate between different crops for the purposes of harvest forecasting. As we shall see, these hopes were dashed, and even acreage estimation has proved somewhat disappointing, at least until now.

And yet with the high resolution satellites - first LANDSAT and then, since its launch in February 1986, SPOT especially - we possess precision measurement instruments. Their spatial resolution (30 meters for LANDSAT TM, 20 and 10 meters for SPOT 1) ought to be sufficient to take valid readings of cereal crops.

Taking readings two or three times in the course of the season, one ought to get very valuable data on the acreage sown, then on growing crops, and finally on the fields of millet, sorghum or even rice, a few weeks before harvest.

In reality there are several obstacles to this scenario: some are technological or have to do with cost effectiveness, others are specific to the Sahel and its climatic, geographical, cultural and sociological particularities.

There is a remarkable study of the contribution of RS to agricultural acreage estimates for the Sahel countries, in the very thorough exposé on the use of RS to improve procedures for agricultural surveys prepared by Mr. Etienne Bartholomé of the EEC Joint Research Center (ISPRA) for the working meeting held at the Niamey RAC in June 1987.

The NOAA satellite, which supplies the vegetation indices, offers huge scenes, average pixel resolution and one or several takes daily. These can be used in assessing the state of vegetation and the biomass generally, and can also be used for measuring the geographical extent and intensity of grazing land.

Measuring cultivated areas, on the other hand, needs a far higher spatial resolution than NOAA's; it requires GAC or even LAC, so LANDSAT or SPOT must be used. But this means smaller scenes (34,000 km^2 for LANDSAT and 3,600 km^2 for SPOT). Moreover, these satellites have a long repeat cycle for coverage of a given area: 16 days for LANDSAT and 21 days, reducible to 4 on request, for SPOT. The small size of the scenes makes total coverage of any country prohibitively expensive. It would take forty LANDSAT MSS scenes, and 350 SPOT scenes, to cover just the usable agricultural areas of Mali. The cost of acquisition and processing would be beyond the present possibilities of the CILSS countries. Not even the leading developed countries get total coverage; they make do with test areas and "stratify" the land into classes, within which they extract typical samples from among the innumerable cultivated plots.

The long repeat cycle of the high resolution satellites is all the more inconvenient for the added problem of cloud cover. And of course the most valuable observations are to be made during the rainy season, when clouds are frequent.

Lastly, it has to be said that the time-lag involved in processing and delivery of images or interpretations is still quite long - often several weeks. What good is it to record data on cultivated land two weeks or a month before harvest if the final analysis is not available until a month or two later?

There are specific constraints in the Sahel apart from the above. In the first place, land is divided up in a very different way from Europe or North America. Fields are small and are often set apart from each other, laid out to suit a fairly irregular topography (hillside fields, for example). Plots are planted with trees such as mango, baobab or shea nut, the density and distribution of which is very variable.

Moreover, germination is not uniform, firstly because the seed is not uniform and also because of variation in soils. As a result crops, are not at all homogeneous - cereal crops in particular. Weeds increase the risk of confusion, especially early on in the season when they hide the cultivated plants.

Lastly, the growing period in the Sahel is the same for all plants. Whatever the species, plant growth starts at the same time, at the beginning of the rainy season; and the growing cycle often coincides with the duration of the rainy period, from May-June to October-November. Distinctions cannot be made, as they are in other parts of the world, between species or crop types with different seasons (eg. winter wheat and spring wheat in North).

Under these conditions, RS data follows the same curve throughout the year, independently of the spatial factor, and may be more significant for measuring biomass quantity and photosynthesis activity than for crop identification. As Mr. Bartholomé writes, distinguishing crop species by means of RS often seems to be a gamble.

As pointed out by Gilles Hervio in his report on early warning systems, written in late 1987, this view is shared by many specialist bodies: NOAA-NESDIS, EROS Data Center, the ISPRA JRC, AGRHYMET and the US Department of Agriculture.

That said, even for estimation of cultivated acreage and despite all the obstacles, RS is not without its uses. SCET-AGRI, a French firm specializing in rural development, has been running a useful experiment in Niger over the past three years with financial help from the French Ministry of Co-operation (see below the detailed description of the project and the lessons learned from it). SOSPAT, the Système d'Observation Statistique et de Prévision Agricole par Télédétection, tested in the field with officers of the Niger Ministry of Agriculture, is proving highly instructive. This trial - not yet completed - has combined ground surveys very closely with aerial photography and data from SPOT and NOAA, and has shown that cultivated acreage estimation is of some utility to the Sahel, though it falls far short of the hopes some people had placed in high resolution satellite imagery.

HR satellite imagery does provide information that is useful now and is likely to be more so in future, giving better spatial and radiometric resolution, faster product delivery, increased observation repetition rate through the addition of further satellites of the same family, etc.

But the Sahel countries' difficulties will continue for a long time, unfortunately, and in this sphere RS will mainly provide supplementary information for the statistical services or for the ground surveys which, at present all too often produce very unreliable results.

4 Other products

The high resolution satellites also supply other products. These concern hydrology, lakeside or riverine agriculture, forestry and the development of particular areas. SPOT 1 images

are particularly useful for the countries concerned. In the next section we shall be examining some projects of this kind: the forest inventory in Mali, evaluation of flooded areas along the Senegal River and floodland cropping.

Knowledge of grazing land. We know the part played by Sahelian livestock farming in the social and economic life of the CILSS countries. Although the livestock sector is currently going through profound structural changes, pastoralism, whilst undergoing a certain decline, will continue for a long time yet - very fortunately, since it covers huge stretches of rangeland and provides a livelihood for 1 to 2 million people. Rain is even more crucial here than in other sectors. Can RS ignore this issue? How can it help improve knowledge of grazing lands?

We have already mentioned the products that might be useful in this: rainfall and vegetation indices supply some very useful information on the intensity and extent of green biomass. Our examination of the projects under way in the Sahel (below) will illustrate current experiments in the application of RS to the Sahel's livestock sector. Several countries are involved in these schemes, mainly Senegal, Niger and Mali.

Considerable research has also been done in connection with **locust control** since 1975, with the FAO and its RS Center playing a leading part. The reproduction of the locust depends on rainfall amount and distribution in the arid and very arid zones of Saharan Africa, East Africa, the Middle East and Southeast Asia. Satellite observation is very useful for calculating and monitoring the growth and potential or actual migrations of this formidable pest, which can suddenly cause massive damage, as it did in the countries north of the Sahara during the first quarter of 1988.

The periodic documents and advice put out by the FAO and other bodies (the Regional AGRHYMET Center, FEWS, etc.) with the help of satellite data on rainfall, vegetation, etc. are appreciated by all those concerned by the locust hazard.

PART TWO

INVENTORY OF REMOTE SENSING ACTIVITIES

CHAPTER 1

THE CONTRIBUTION OF THE UNITED STATES AND CANADA

A. THE UNITED STATES

Because of the considerable resources and advanced technology the United States possesses in the space science sphere, and the great help it has given the Sahel in the form of food aid especially, US assistance in the remote sensing field is a phenomenon that is far from new.

Apart from a few very restricted one-off operations, it is USAID that has funded and run these programs. They have had the benefit of experimental results obtained in the US as early as 1974 in the field of satellite monitoring and inventorying of crops and agricultural resources more generally (the LACIE and AGRISTARS projects).

In 1977 the Assessment and Information Services Center (AISC), a branch of NOAA, began developing methods for assessing climatic impact in developing countries with a view to monitoring drought, cereals and food crops. But it was above all the terrible drought of 1984 that drew the attention of the Western countries to the fragile situation in the Sahel countries.

At a summit meeting in Bonn, Federal Republic of Germany, in 1985, the heads of state of the industrialized countries asked their experts to make a special case study of Africa. At the close of their meeting of September 1985 in Bonn, the experts recommended to the Summit members that the necessary efforts be made to establish the use of RS techniques in Africa for improving crop monitoring and early warning systems, south of the Sahara especially.

It is since this date that the advanced countries giving support to the Sahel have to a large extent geared the structure and emphasis of their RS activities to this region.

The United States is in the vanguard, acting through USAID with two main types of assistance:

- Support for the AGRHYMET program, especially the RAC in Niamey which has received equipment and regular supplies of data and satellite imagery, as well as training in the US for Sahelian and expatriate operators;

- The setting up of FEWS, a specific Famine Early Warning System, based in the US with representation in the Sahel states, to assist in early warning and monitoring of the situation in the Sahel countries.

By way of example, **vegetation indices**, which show the green biomass, have been in use in the US for nearly fifteen years now. As far as the Sahel is concerned, continual work has been done, commissioned by USAID, particularly as part of the African early drought warning program launched in 1985. Until now two means have been employed, both starting with the same NOAA images preprocessed by the Tucker method at the Goddard Space Flight Center. The first method is used by NOAA/AISC, in association with the University of Missouri at Columbia, at the Cooperative Institute for Applied Meteorology; the CIAM develops the products and sends them to the RAC in Niamey. The other is the FEWS (Famine Early Warning System) method, which uses vegetation indices developed under contract by a private firm, Price Williams and Associates.

1. Assistance to the AGRHYMET program

In 1985 and 1986, under a contract between USAID/Office of Foreign Disaster Assistance (OFDA) and NOAA/AISC, the latter body supplied estimates and various other products and data on the Sahel and the Horn of Africa.

This activity was centralized through the AISC office in Washington; it received a major contribution from the team at Colombia, Missouri, where NOAA staff and the University of Missouri are working within the CIAM (Cooperative Institute for Applied Meteorology). After the AISC's reorganization in 1987, the main activity, now financed by the USAID Bureau for Africa, was transferred to Columbia. In early 1988 it was not yet clear who would be in charge of this particular NOAA activity for the year.

It must be said that USAID, after a certain amount of reflection, had asked the National Research Council's Bureau of Science and Technology for International Development (BOSTID) to assess the validity of the NOAA program. The final appraisal was submitted in January 1987, and NOAA/AISC/CIAM produced their reply in May 1987. The reply is more positive than a mere plea for the defence, and is as interesting as the report itself. Between them the two documents give a complete insight

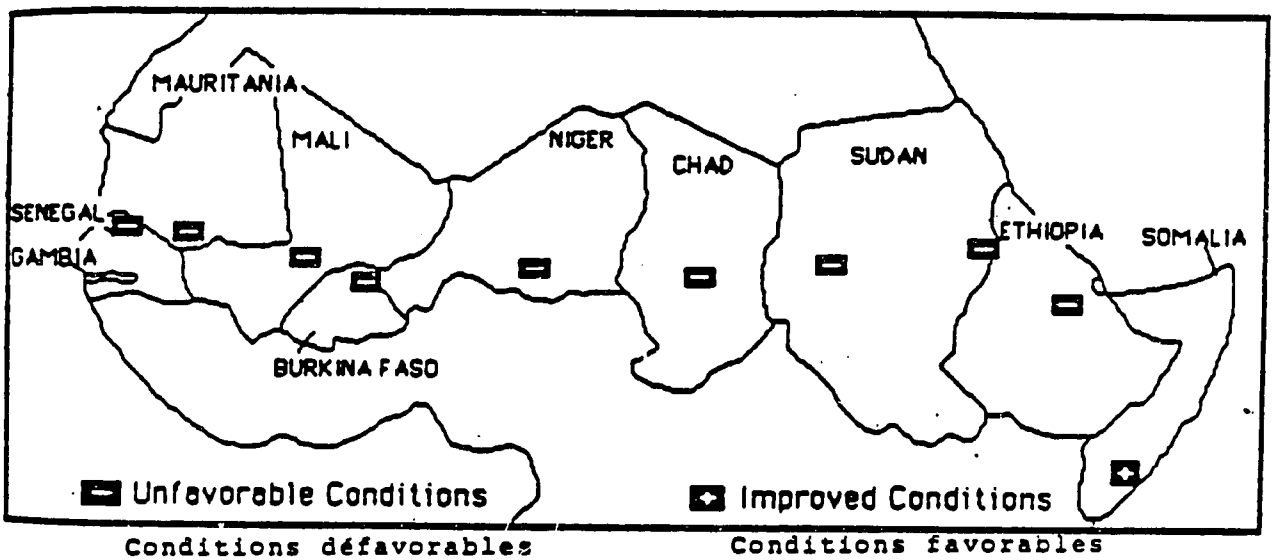
CLIMATE IMPACT ASSESSMENT

EVALUATION DES EFFETS DU CLIMAT.

SAHEL/HORN OF AFRICA

HIGHLIGHTS

FAITS MARQUANTS.



Conditions défavorables Conditions favorables

PREPARED BY

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (NOAA)
NATIONAL ENVIRONMENTAL SATELLITE, DATA AND INFORMATION SERVICE (NESDIS)
AND
COOPERATIVE INSTITUTE FOR APPLIED METEOROLOGY (CIAM)

FOR

THE UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT (USAID)
BUREAU FOR AFRICA

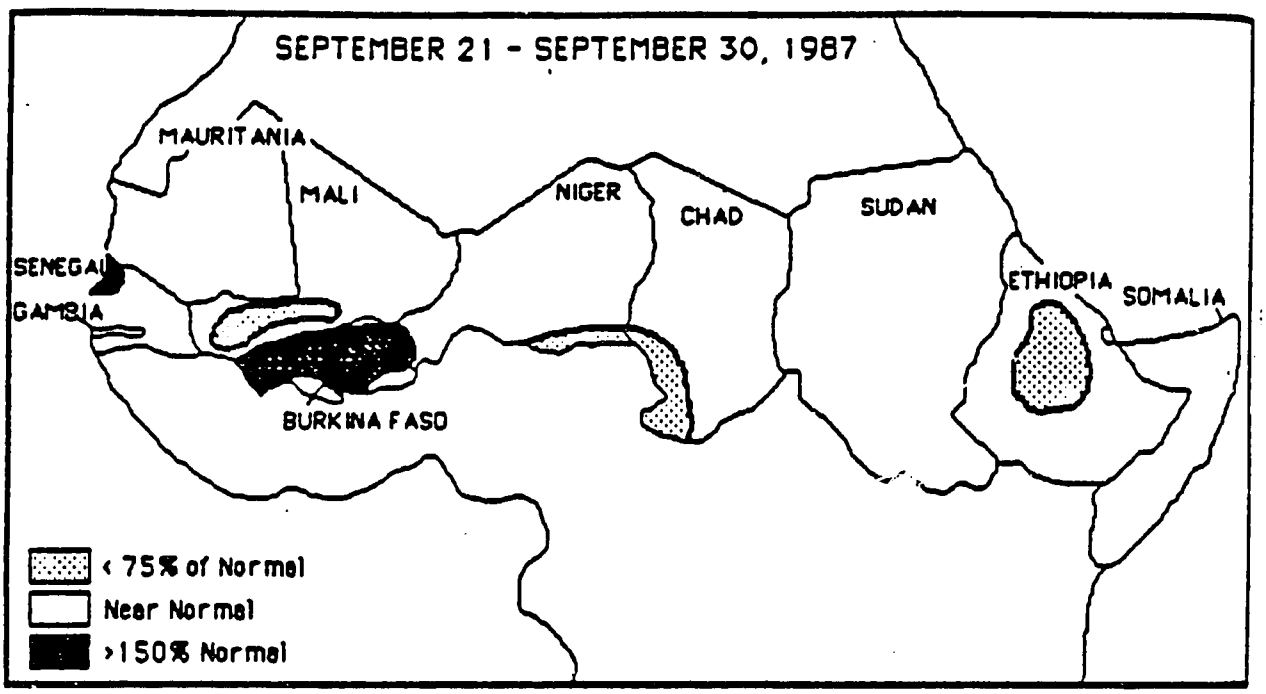
OCTOBER 1, 1987

Source: Bulletin décadaire de NOAA-NESDIS-CIAM. (Oct. 1. 1987.

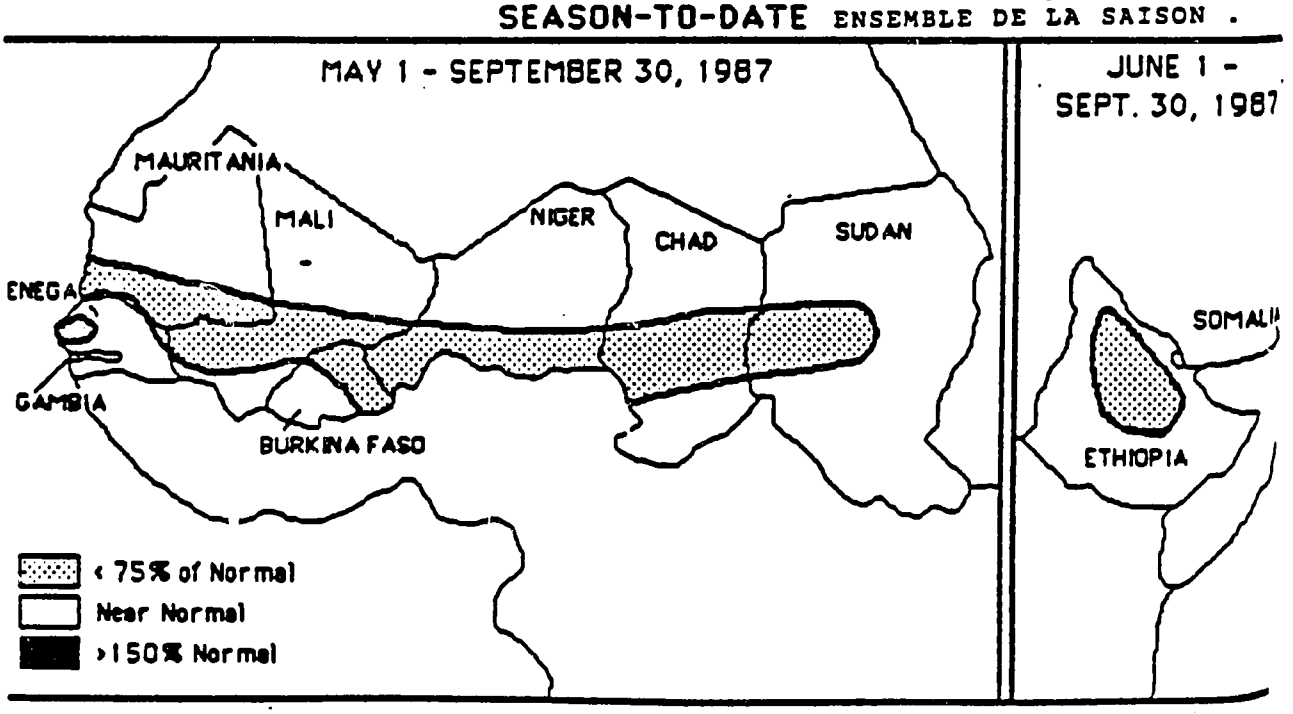
PRECIPITATIONS (En pourcentage de la normale)

PERCENT OF NORMAL RAINFALL

10-DAY JOURS



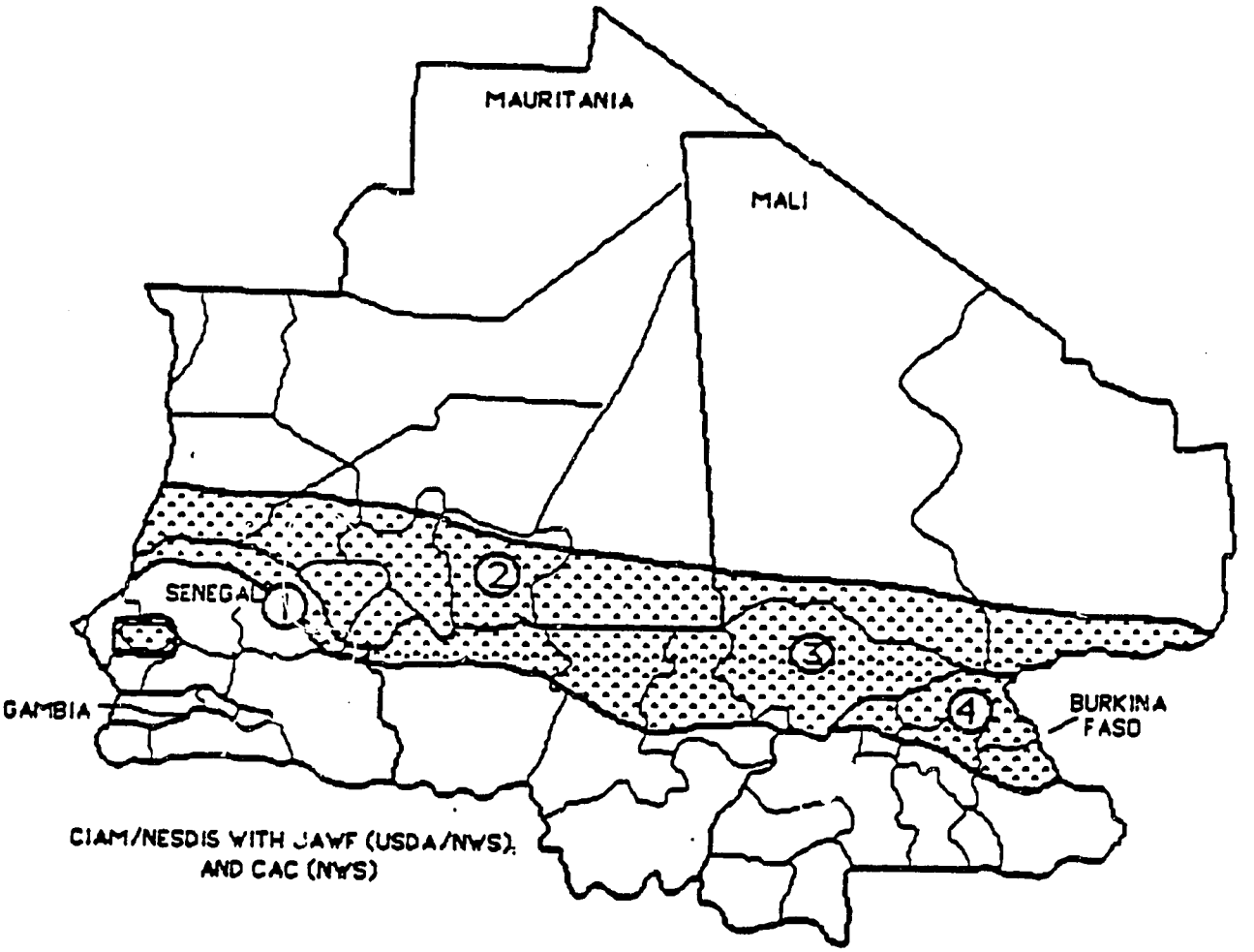
SEASON-TO-DATE ENSEMBLE DE LA SAISON .



Source: NOAA-NESDIS-CIAM.

SAHEL OCCIDENTAL

WESTERN SAHEL
OCTOBER 1, 1987



1 - Most of NORTHERN SENEGAL and a region centered around Bambey suffered from pluviometry well below the norm during most of the growing season. Yield prospects are low in these areas.

2 - In MAURITANIA, the rain that has fallen since mid-August has improved the condition of grazing land. The satellite images indicate that the biomass is superior to 1986. Conditions of the crops are, however mediocre due to the brevity of the rainy season.

3 - The below normal and unevenly distributed rainfall in the growing regions of Northern MALI will result in a reduced harvest.

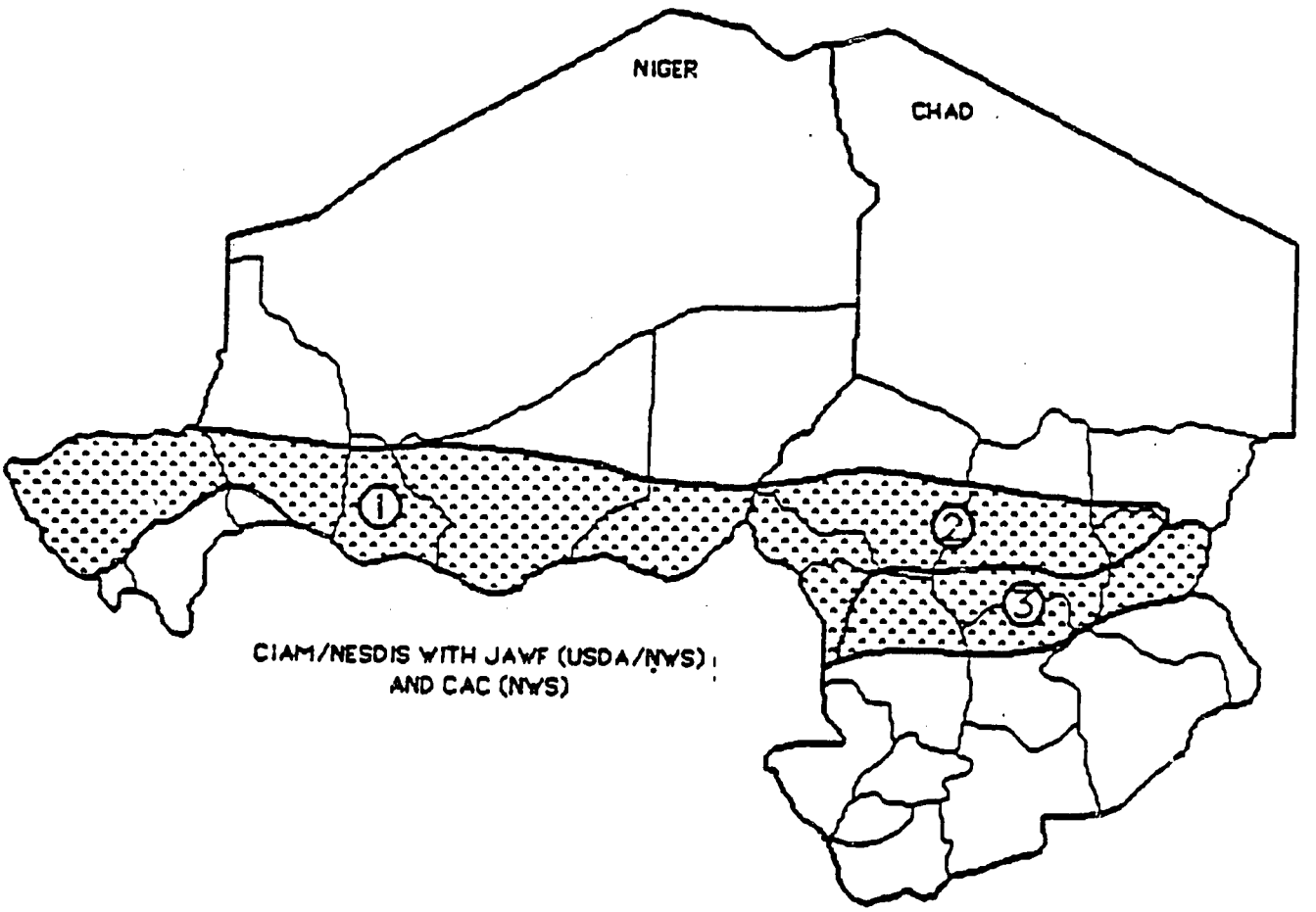
4 - The lack of precipitation in Northern BURKINA-FASO, particularly in the crucial growing period in August, will result in considerably reduced harvests.

The normal rainfall in other parts of the WESTERN SAHEL will result in normal harvests.

Source: NOAA-NESDIS-CIAM

SAHEL ORIENTAL

EASTERN SAHEL
OCTOBER 1, 1987



1 - The harvest prospects for NIGER in 1987 are lower than in the two preceding years. The situation in certain regions, including Birni N'Knonni, Diffa, Magaria, Mainé-Soroa and Zinder, is as bad or worse than in 1984. The zone affected stretches southwards into Nigeria. The condition of the grazing land during the latest growing season has been poorer than last year. The biomass decreased over the last twenty days of September due to the approach of the dry season and the movement of the Intertropical Front.

2 - The condition of the crops and the grazing land is mediocre. Rainfall has been inadequate and the vegetation is regressing as the dry season approaches.

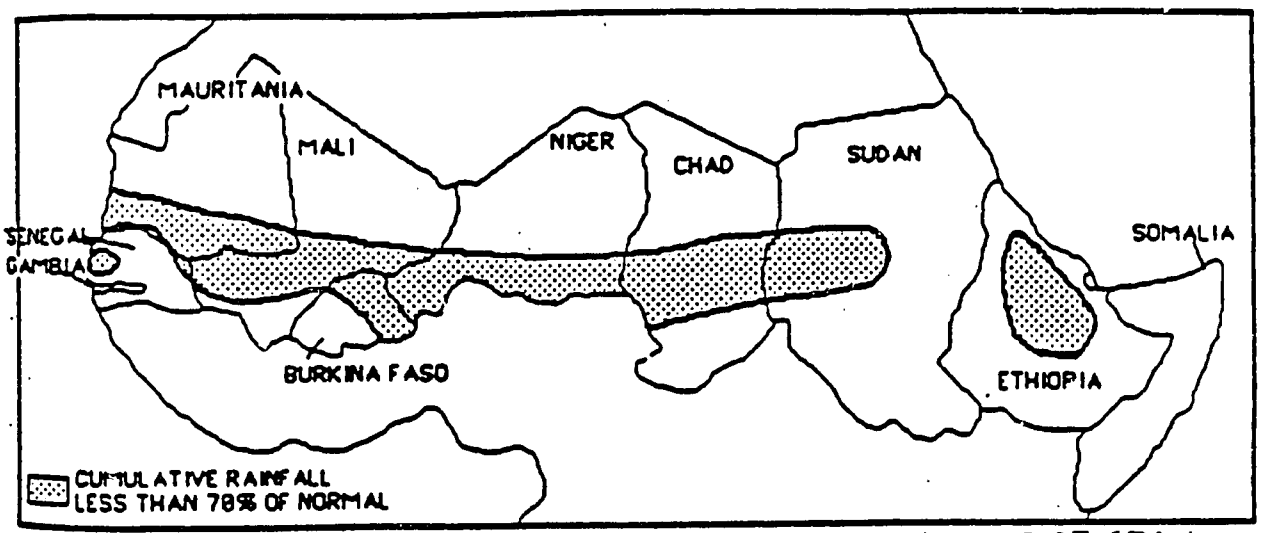
3 - The condition of the grazing land is generally satisfactory, but the second seedlings will probably not complete the vegetative cycle due to the inadequate rainfall.

The crops and grazing land in Southern CHAD are satisfactory and the plants have received sufficient water.

ANOMALIES PLUVIOMETRIQUES

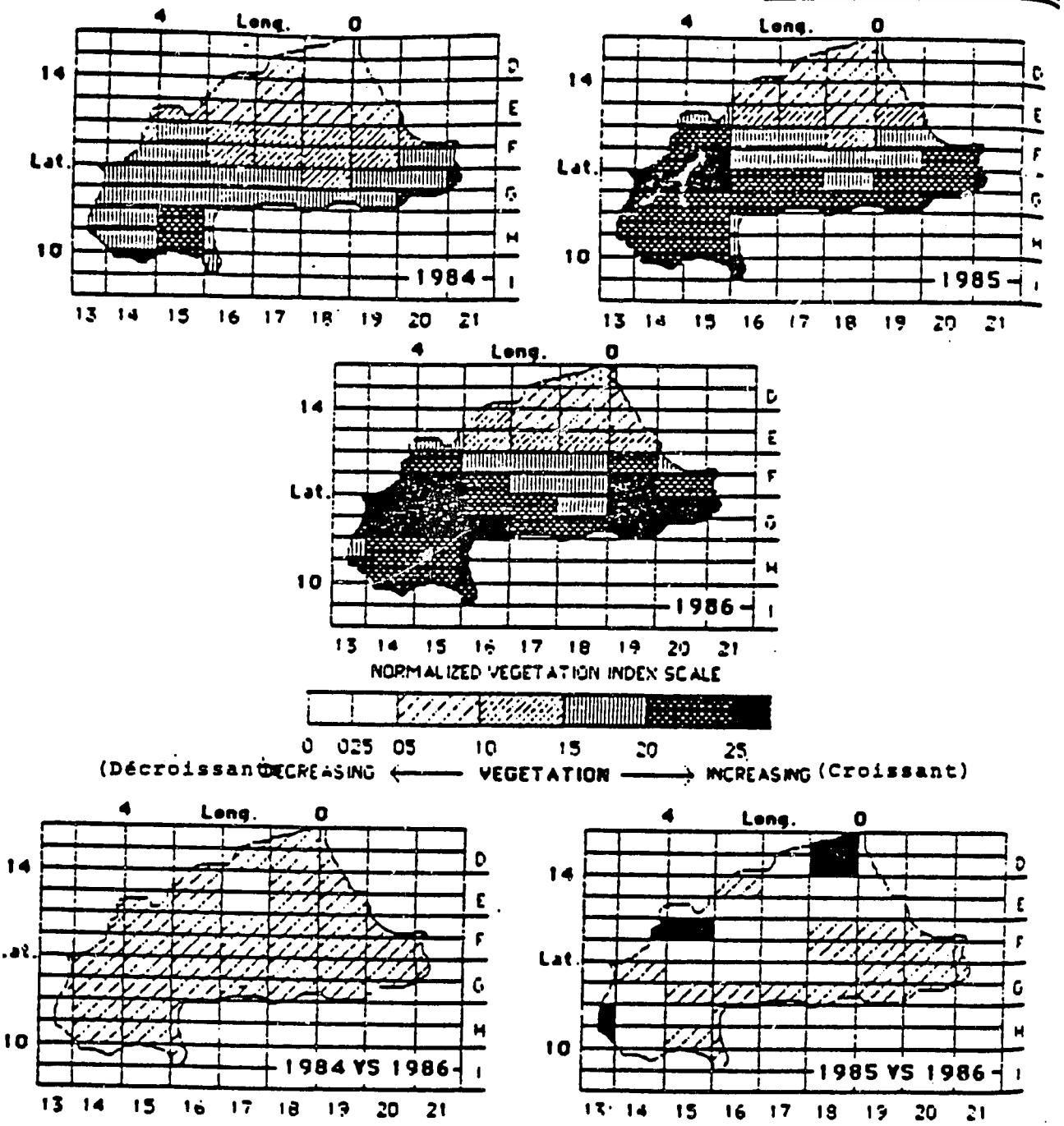
RAINFALL ANOMALIES

PREPARED BY NOAA/NESDIS/CIAM* RELEASE DATE: OCTOBER 1, 1987



Source: NOAA-NESDI-CIAM.

COMPARAISON DES INDICES DE VEGETATION DU BURKINA-FASO
POUR LES ANNEES 1984, 1985 ET 1986. (A la 3éme Semaine d'A



Part rapport à l'année antérieure
- 1986 LESS GREEN THAN PREVIOUS YEAR-Moins vert.
- NO DIFFERENCE FROM PREVIOUS YEAR -Sans changement.
- 1986 GREENER THAN PREVIOUS YEAR-Plus vert.

- NOAA Satellite Normalized Vegetation Index
Third Week of August - Burkina Faso
3é semaine d'août

Source C.M. SAKAMOTO. NOAA. NESDIS. GEOCARTO. INTERNATIONAL (4)

into the ongoing debate over the value of remote sensing. We shall be returning to them later, in the chapter on RS appraisal. But it is fitting at this stage to pay the homage due to the American Administration for its frankness on the issue. It seems to be an example worth thinking about: perhaps a similar debate on remote sensing in the Sahel ought to take place among all the major RS operators and other authorities concerned - the CILSS executive secretariat, AGRHYMET, the Club du Sahel, the famine prevention network, etc.

The main products and services NOAA supplies to AGRHYMET or the Sahel countries are as follows:

- Monthly information bulletins distributed through USAID;

- A weekly NDVI vegetation index on the Sahelian grid (1° longitude by 1/2° latitude), usually sent out by telex. With this index, a time series can be built up;

- Fortnightly analyses of rainfall and weather anomalies, transmitted to USAID;

- Diskettes and photographic prints, from which composite imagery can be viewed, using the Intensity Hue Saturation color co-ordinate system (ten-day vegetation index).

These products are sent by diplomatic bag, and involve a certain time-lag.

The means required for this technical assistance were estimated at eight full-time staff, use of an IBM/AT computer (not very costly), plus purchase of daily GAC data, and occasionally of LAC data, from the distribution Center. The contract between NOAA and USAID in recent years has involved approximately $2 million.

A further NOAA service has been the six-week training course it ran in Missouri in Spring 1986, attended by Sahelians and experts from the RAC in Niamey.

USAID brings assistance to AGRHYMET in Niamey itself, over and above the services supplied by NOAA, which has a permanent representative working at the Niamey RAC. Further USAID assistance includes provision of many items of equipment, computer hardware in particular (replacement of the existing computers is planned, at an estimated $2 million); sending of various experts on mission; and provision of software. These various services are estimated at $3.5 million for the next five years, or $700,000 a year, to which must be added the cost of the American personnel USAID plans to make available to the Niamey RAC to help with the installation and exploitation of the forthcoming NOAA receiving station (two full-time specialists plus technical staff on missions).

2. The FEWS project (Famine Early Warning System)

The FEWS project is a product of the 1984 drought. It concerns five of the CILSS countries - Mauritania, Mali, Burkina Faso, Niger and Chad - plus the Sudan, Ethiopia and Mozambique.

Its aim is to provide early warning of areas at risk - inland areas particularly. It therefore emphasizes socio-economic factors, health and nutrition especially. The resources for this project are concentrated in the United States, with just half a dozen representatives in the Sahel - one per country.

The FEWS method is to gather as much information as possible in the Sahel countries themselves and compare, combine and supplement it with data available in Washington, satellite data particularly.

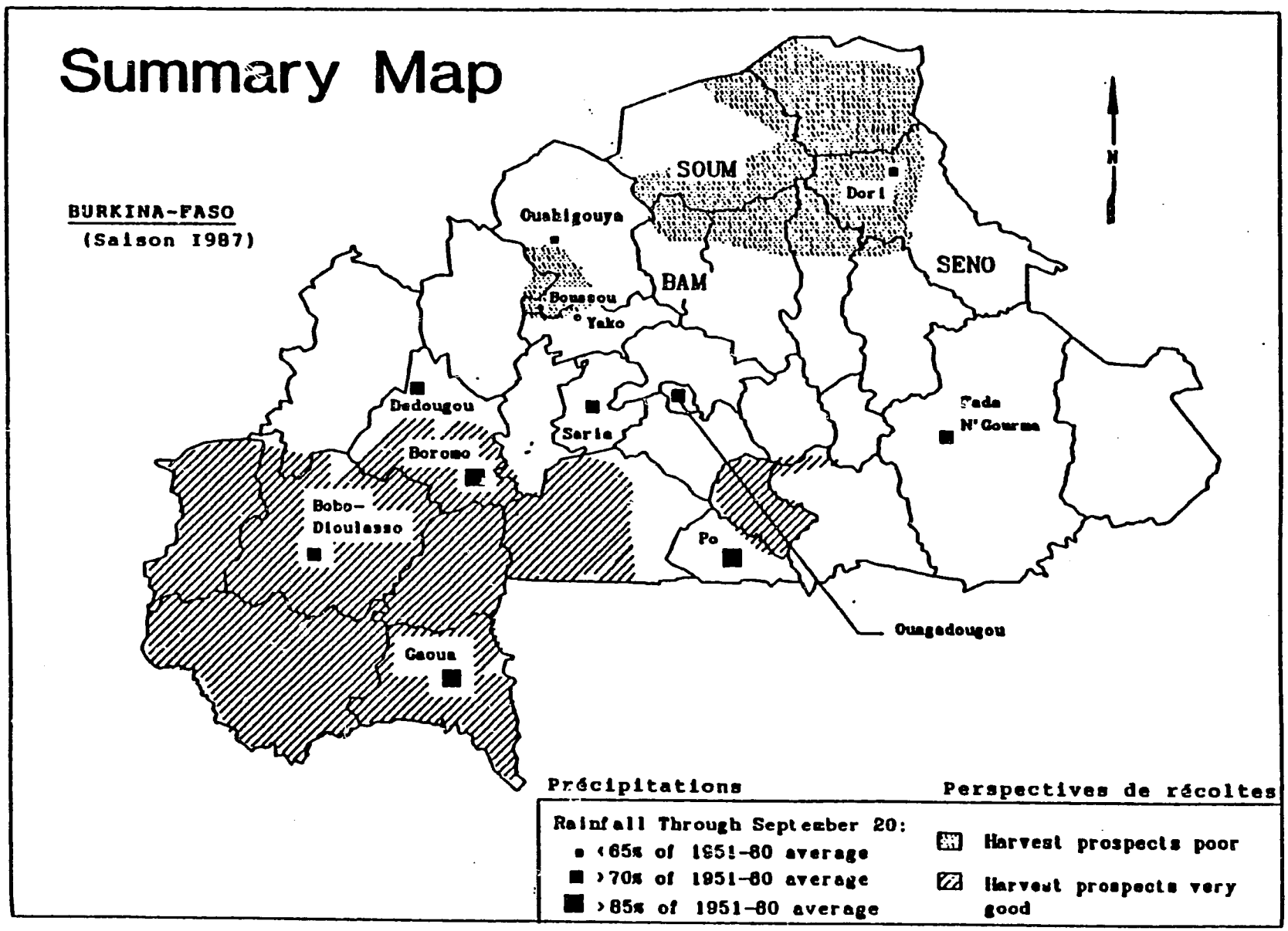
FEWS began in 1985; now, after an initial period when it was seen as a temporary project, it is becoming a permanent feature. It is headed by USAID; set up by the Office of Foreign Disaster Assistance (OFDA), it has since 1987 been the direct responsibility of the Africa Bureau, Technical Resources (AFR-TR).

For implementation, USAID calls on two organizations:

- The Department of Biostatistics and Epidemiology of Tulane University, where five people are responsible for the economic work and for recruiting the six Sahel-based representatives;

- Price Williams and Associates, who are responsible for data analysis and the writing and distribution of the FEWS bulletins. This involves six full-time members and four part-time.

The FEWS project went through three phases up to March 1988, the first two phases ending in 1987. Until that date rather more than $6 million had been spent, 2.5 million for Tulane University, 800,000 for Price Williams and 2 million for NOAA (see above). USAID have begun proceedings to provide for the next three years. An identification project has just been approved with a projected budget of $6 million - about $2 million a year. The project has still to be reshaped to take account of experience already gained and present-day imperatives in both the US and the Sahel. It should be said here while the Sahel countries benefit from the information gathered and processed, the aim of the FEWS is first and foremost to set up a system providing information for the US authorities and the many other US bodies concerned.



Source: FEWS country report (October 1987)

It appears that the instigators of the FEWS project, while not casting doubt on this aim, now wish to redirect the project with new aims:

- Broadening the scope of information to the entire economic life of the countries concerned, not only the social aspects;

- Total coverage of the countries concerned, not merely areas at risk. There is even talk of extending the project well beyond the Sahel and the Horn of Africa;

- Decentralization from Washington; an increased concern for co-operation with the African Governments, enabling them to improve their own early warning systems; and a desire to have the American services co-ordinate more closely among themselves (FEWS representatives in Africa will henceforth be members of their local AID mission) and with other donors;

- Improved use of remote sensing, especially for local utilization of vegetation indices.

Since May 1968, FEWS output has basically consisted of a monthly bulletin on each country (called the "blue bulletin"), which is distributed mainly in the United States and provides information on crop development, harvest prospects, rainfall and hazards of various kinds (population groups in difficulty, locusts, etc.).

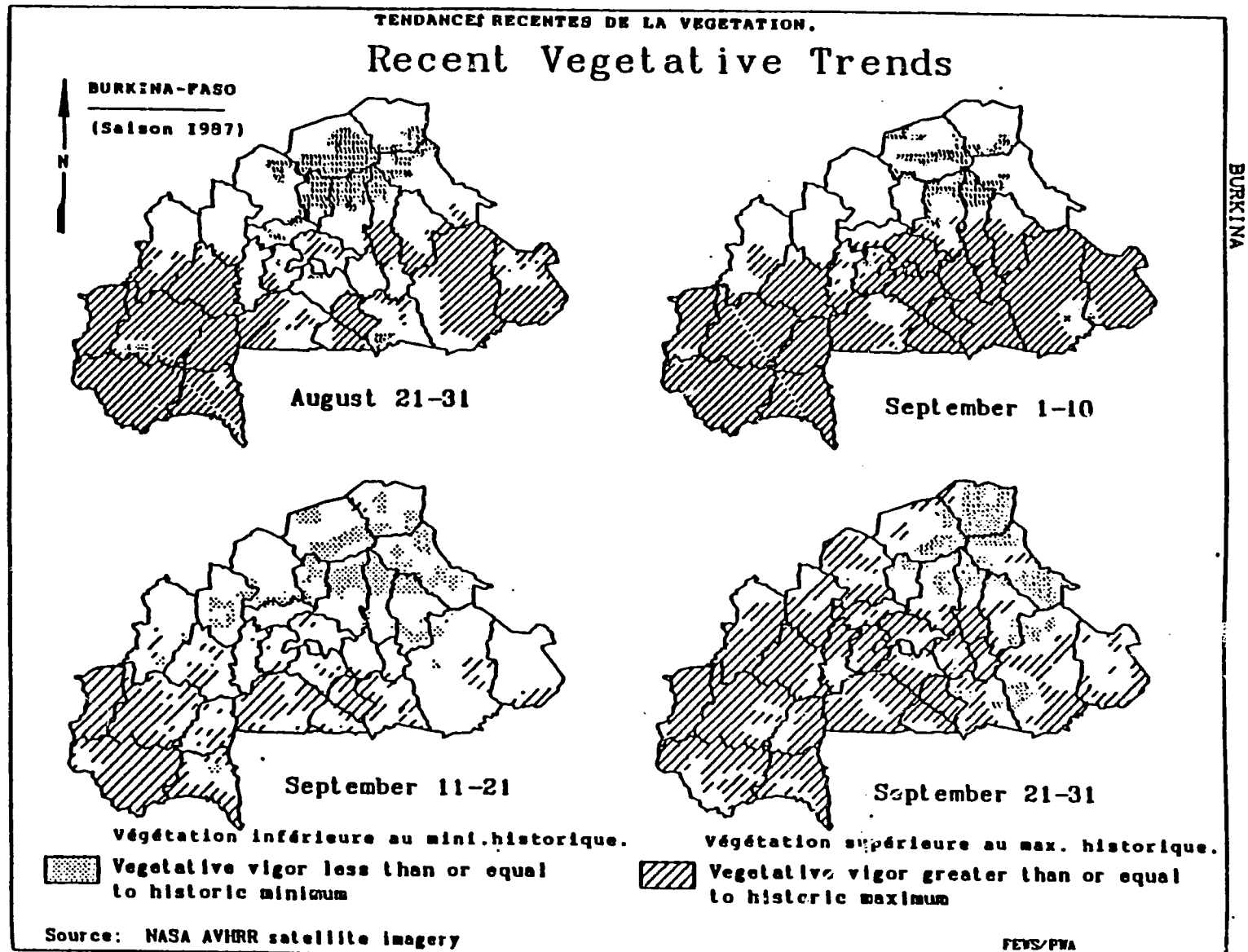
The bulletin is drawn up by Price Williams, which combines information gathered in the field by the FEWS delegates with data from other sources, especially the NOAA satellites.

RS thus plays a very appreciable part in the FEWS project. After turning to NOAA/NESDIS to obtain the vegetation indices in particular, USAID and their FEWS operator Price Williams decided to approach the NASA GSFC (a group headed by C.J. Tucker) to process the NOAA AVHRR data and work up the indices.

The US Geological Survey's EROS Data Center at Sioux Falls, Dakota also assists USAID, as regards methodology in general and the drawing up of vegetation maps for locust control purposes in particular.

The processing of a certain number of NOAA AVHRR products (weather data and agroclimatic data such as vegetation indices) is currently being transferred from the United States to the RAC in Niamey, and the future configuration of the FEWS project will probably have to take this into account.

With its NOAA image receiving station starting up gradually over the second half of 1988, the AGRHYMET network will have information available in real time, and often more precise information. For the vegetation index for example, the RAC will be able to capture data directly from the NOAA AVHRR satellite and process them <u>in situ</u> at GAC resolution (and even LAC if need be), whereas at present it only receives (by telex, and

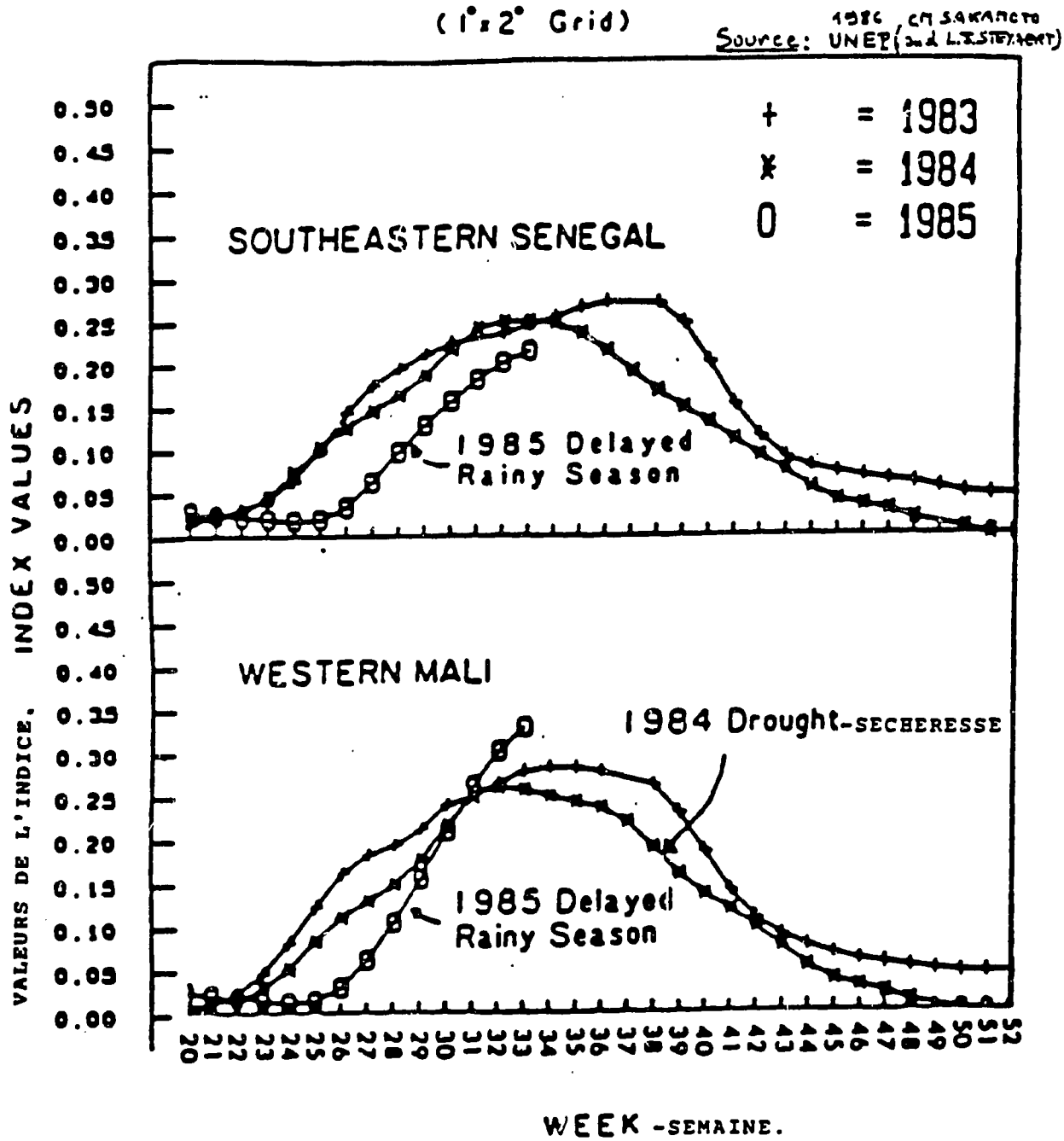


Source: FEWS Country report, October 1987

BURKINA

INDICES DE VEGETATION NORMALISES,CORRIGES,POUR LE SENEGAL SUD-EST ET LE MALI OCCIDENTAL EN I983,I984 ET I985.

Noter la diminution de la végétation en I984 et le retard dela saison des pluies en I985.



The smoothed normalized vegetation index for southeastern Senegal and western Mali in 1983, 1984, and 1985. Note the reduced vegetation for 1984 and the delayed 1985 rainy season.

with a time-lag of several days) the integrated index (1° x 1/2°) for the grid currently employed for the Sahel. The GAC diskettes reach Niamey a month or two months after the initial recording of the data.

The satellite imagery information which the FEWS project sends to the Sahel in its monthly bulletin will obviously arrive long after the products put out by the RAC in Niamey. One may well wonder whether USAID may not find it useful in future to turn to the RAC in Niamey for its vegetation indices, for example, once the RAC is operational in this field. This could mean an economic saving and greater efficiency, without depriving American readers of a rapid and regular source of information. This of course depends on RAC products from Niamey reaching Washington within a reasonably short time. It is true that the FEWS also concerns the Sudan, Ethiopia and Mozambique, three major countries which are beyond the geographical scope of AGRHYMET; but the reverse is true for Senegal and the small CILSS countries not covered by the FEWS project.

In fact it seems USAID decision-makers are considering this logical restructuring step. Some information suggests that USAID is planning to reduce its RS expenditure in this particular sector. $200,000 in credit has been made available to cover the cost of technology transfer from the EROS Data Center to AGRHYMET (software, interfaces, training), especially in connection with vegetation index methodology.

In this way 1988 will doubtless be period of adaptation for the FEWS project and for American assistance to AGRHYMET, as far as remote sensing is concerned.

3 Other US RS projects for the Sahel

Besides these two main US assistance projects, there are a few much smaller operations that are worthy of mention.

We shall mention two by way of example:

- **Joint pilot project between the Senegalese and Gambian Governments and the US Geological Survey,** (National Mapping Division, EROS Data Center).

  In 1986 and 1987, vegetation maps were produced from data gathered by the NOAA AVHRR. These covered the Gambia and Senegal, showing the vegetation index as calculated by the normalized difference (NDVI) method, correlating the quantity and vigor of green vegetation. Data based on a spatial resolution of 1 x 1 km are processed by the usual methods.

  These 1:100,000 scale maps were initiated and funded by the USAID Office of Emergency Operations;

- **Use of RS for estimating biomass production in the "integrated stock raising" project area in Tahoua, Niger.** This is one small part of a huge project, and is run by the University of New Mexico, Las Cruces. Its aim is to combine data gathered in this semi-desert pastoral region of northern Niger with NOAA AVHRR data, to determine what biomass is available, so that the Niger authorities can be informed of the availability of grazing from the end of one rainy season through to the next.

  The International Livestock Center for Africa (ILCA) provided the technical back-up for the remote sensing in 1985 and, after a period of data analysis in 1986 and 1987, a preliminary report on the 1988 rainy season is planned for the end of this year. As the "integrated stock raising" project comes to a close, it is probable that its remote sensing activities will also end.

B. CANADA

Canada was intending to take part in a program planned for the CRTO* in Ouagadougou, but the program in question never became a reality as the participants of the time were unable to come to an agreement.

More recently, at the French-speaking Summit held in Quebec in 1987, a future joint project was decided upon, between Canada and the French Technical and Cultural Co-operation Agency. The Canadian contribution (Can$250,000) is to be used for an RS application aimed at identifying suitable sites (in terms of their hydro-geology and forestry) for building small dams to irrigate land and produce fuelwood, charcoal and small-scale food crops. There are two objectives here: training Sahelian scientists in RS, and fostering integrated energy and agricultural resource development at village level.

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* CRTO: Centre Régional de Télédétection, Ouagadougou, Burkina Faso.

Chapter 2

EUROPEAN ASSISTANCE

Europe has been interested in the use of RS to benefit the Sahel ever since RS was first used for Earth observation. European assistance has taken many forms:

- EEC aid for projects, research and equipment;
- Technical assistance by the ESA (European Space Agency), through the METEOSAT satellites and the data processing ground stations at Darmstadt and Mas Palomas (see above);
- Bilateral aid from EEC member countries for research, equipment and projects.

The United States has made a major contribution to the Sahel in the remote sensing field, owing to the more advanced state of the science in that country and the fact that their satellite systems and RS activities are older than Europe's. But Europe has been catching up fast over the past few years.

European involvement is, as we shall see below, particularly intense in RS research as applied to the Sahel countries and their specific problems.

1. The Commission of the European Communities (CEC) and the ISPRA Joint Research Center (JRC)

As we have seen above, the experts of the JRC have taken an active part in various meetings on remote sensing applications for the Sahel. The writer of the present report has drawn heavily on papers by Mr. Etienne Bartholomé concerning vegetation indices, acreage measurements and other subjects.

The EEC has demonstrated its support by supplying equipment, including the METEOSAT data processing system supplied to AGRHYMET and the satellite imagery processing unit in Dakar referred to above. Similarly, with the major contribution it has made to the CILSS Diagnostic Permanent project, the EEC has indirectly been supporting the use of RS for harvest forecasting and improvement of agricultural statistics.

But above all, the EEC has launched one major project subdivided into seven smaller ones, each of which is run by one or several European laboratories.

Study of desertification on the edge of the Sahara, employing RS

This vast project, supported by Brussels through DG VIII, began three years ago. The various research projects it has led to have been entrusted to different European bodies chosen according to skills and nationality. Usually they are linked with counterpart institutes or bodies in the Sahel.

The seven sub-projects, now completed or under way, are as follows:

- **Monitoring of pastoral ecosystems and mapping of cloud cover and precipitation in the Sahel.** In conjunction with the FAO, the United Kingdom Universities of Reading and Bristol are responsible for testing methods of rainfall estimation from satellite data and establishing the relationship between the distribution, type and density of vegetation on the one hand and the quantity and distribution of rainfall on the other. The purpose is to be able to translate biomass type, distribution and quantity into viable grazing density;

- **Study of the regional water balance.** Phase One of this study was carried out in Senegal in 1985-86 with the Dakar satellite imagery processing unit (UTIS). A report on the work was issued in 1987. Phase Two began in October 1987 in Niger which, with the Niamey RAC, its NOAA station and the CEC coordinator, is better equipped technically.

  The project is being run by a group of French laboratories (INRA, IRAT, LERTS/CNES and the national weather service). The aim is (i) to establish what assistance METEOSAT and NOAA AVHRR thermal infra red data can bring to the monitoring of water conditions over the course of the rainy season in the Sahelian zone, and (ii) to draw up a quantitative map of real evapotranspiration of the vegetation cover, and from this deduce a rough estimate of yield at the end of the rainy season, using agroclimatic models connecting yield with the RET:MET ratio.

  Phase Two will continue up to 1990, and aims, more precisely, to map the real evapotranspiration of the vegetation cover from surface temperatures as measured by NOAA AVHRR;

- **Changes in the periurban environment of the big towns of the Sahel.** This sub-project is being run by the University of Louvain-la-Neuve, Belgium, which has taken Bamako in Mali as its sample town. SPOT data will be used for this trial study;

- **Methodology in the use of micro-computers to elaborate agroclimatic data and vegetation indices from raw satellite data.** This sub-project, while it is perhaps less spectacular than the others, is indispensable if the manipulation and processing of data is to be transferred to the Sahel

countries. The task has been entrusted to the University of Copenhagen, Denmark, which has made a specialty of this technology;

- **Search for underground water in the Adrar des Iforas, Mali,** by the Irish Laboratory for Environmental Resource Analysis and the Italian Geological Service;

- **Detecting hydrological indicators in the Senegal River basin, with a view to forecasting high-water flow.** This study is being carried out by the Institute for Lithosphere Geology in Milan, Italy;

- **Tree stand inventory and monitoring**, monitoring of changes, identification of areas affected by wind erosion. This sub-project is being run by the Universities of Reims, France and Berlin and Munich, Federal Republic of Germany.

Monitoring renewable natural resources in the Sahel.

This project, launched in 1983, is a continuation and expansion of an earlier project for "forecasting of agricultural production by RS in the Niger basin upstream of the central delta", which the ISPRA joint research center had been running in Mali and Guinea. The new program provides support for the AGRHYMET program and the Diagnostic Permanent project in their contribution to agro-pastoral monitoring and the early warning systems. Its main aim is to forecast cereals output in the Sahel by remote sensing, as a complement to the data conventionally used by the agrometeorology and statistics services.

Concretely, the project aims to:

- Develop an appropriate methodology that will enable RS to be used on an operational basis for cereal crop forecasting;

- Set up national structures in the CILSS countries with the equipment and training needed to use RS for this purpose.

For resources, this CEC project relies on the ISPRA joint research center, assisted by a French consultancy firm called SODETEG. There is a co-ordination unit at the Niamey RAC, where a small building has been constructed for the project. The Niamey team naturally provides the link with project correspondents in the countries concerned, and with the CILSS Executive Secretariat in Ouagadougou (home of the Diagnostic Permanent project financed by the European Fund).

The prime research subjects of the Sahel renewable natural resources monitoring project are as follows:
- building up a data base;
- training in the use of satellite data;
- implementation of the plan for improving agricultural statistics by the use of RS.

Rainfed cropping and floodland cropping are now receiving particular attention, irrigated rice growing no longer being a research priority. Other issues covered by present activities or proposals are hydrology, analysis of historical NOAA AVHRR data for vegetation monitoring, and stratification of (geographical) space into three levels: agricultural regions, soil type areas and sections (plot divisions).

An experiment in stratification of agricultural land using RS data took place in Mali in 1985 and 1986. An attempt was made to quantify the acreage of agricultural land in a 100,000 km^2 area reaching from Nara in the north via Bamako in the center to Bougoumi in the south, using LANDSAT imagery and, from 1986 onward, SPOT imagery as well. The improvements it was hoped to gain from exploiting the RS data concerned objective knowledge of the extent and location of agricultural land, stratification of the density of these areas, and synthesis and agro-ecological stratification, combining RS data with existing thematic maps. All these elements should provide ways of improving the sampling system of the agricultural statistics services which, in the Sahel at the present time, are based on administrative and socio-economic boundaries.

The second phase of the project (end-1989 to 1993) is already being prepared. In this phase the project is to be extended to cover every country in its entirety, whereas for the moment only pilot areas in four countries are covered. The project's promoters hope to reach the point of measuring agricultural land (i.e. cultivated acreage plus fallow land) and even to measure the cultivated acreage within this broader category.

The CEC has also supported other RS research projects for the Sahel. Examples are the study commissioned by Mauritania's SONADER from the BDPA and SCET-AGRI for the 1986-7 season, another on the use of SPOT images to evaluate flooded areas and floodland cropping around Lake R'Kiz, which connects with the Senegal River.

2. Bilateral contributions

Most European countries are giving their support to the development of RS in the Sahel. More often than not, they do so through financial participation in projects or by providing the services of specialist institutes and laboratories or individual experts.

We have already seen the part they play through the EEC, but there are also the bilateral projects. In this type of scheme France is in the lead, partly for historical reasons and partly because of that country's interest in satellite applications in the Sahel.

French co-operation

This takes the form of aid for satellite data receiving facilities and processing systems or equipment, user training in the appropriate African centers, and participation in or running of pilot application projects.

The coordinator and main provider of financial support for this program is the Ministry of Co-operation, which has a specialist unit to initiate, monitor and manage the schemes undertaken. The RS budget for the Sahel was over $2 million in 1988. Besides financial aid for projects, this budget provides support staff (two senior experts and two national service volunteers) and equipment for the AGRHYMET program, amounting to more than $0.6 million a year, and is also funding the HRPT receiving station for NOAA imagery ($1.5 million) and providing technical assistance (two senior experts) and equipment for the CRTO in Ouagadougou ($600,000 a year). In 1986 the Ministry also provided the CRTO with a mini data processing system and overhauled the one at Dakar University. Lastly, Paris does not seem to have abandoned the project of installing a SPOT receiving station at the CRTO; $5.5 million has been kept aside for this purpose in the reserve aid fund since 1987.

There are a great many French technical organizations and research bodies working on RS projects for the Sahel. The main ones are:

- The Centre Nationale d'Etudes Spatiales (CNES) and LERTS, the CNES laboratory specializing in satellite RS;
- SPOT Images;
- The Centre de Météorologie Spatiale, Lannion;
- ORSTOM, the French scientific research institute for cooperative development, whose specialist center in Bondy, France, and teams in Lannion and Dakar are well known;
- The Centre National de Recherche Scientifique (CNRS), with its two active and well-equipped data processing units, Imagéo and the Laboratoire de Météo Dynamique;
- The Institut de Recherche en Agronomie Tropicale (IRAT) in Montpellier;
- The Institut National de Recherche Agronomique (INRA) with its Montfavet center and laboratory;
- SCET-AGRI-BDPA;
- The Institut de l'Elevage et Médicine Vétérinaire Tropicale (IEMVT), whose experimental and research workers, in view of their mission, have a natural interest in the agricultural and pastoral applications of RS.

It would take too long to give a profile of every project to which these organizations contribute. We shall examine what seem to be the most important of those that have not already been mentioned, but it is first worth noting (i) that virtually all relate to applied research, (ii) that all are spread over several years (three or four on average), and (iii) that most of them cost between $200,000 and 400,000 a year each.

We have seen the part played by the Lannion center and its ORSTOM unit in climatology, both in applied research into rainfall and surface temperatures and at the operational level in supplying the RAC in Niamey and the CRODT* in Dakar with digital METEOSAT imagery. The Lannion center publishes a valuable newsletter entitled Veille Climatique Satellitaire, which is widely distributed.

Mention has also been made of the research undertaken by IRAT, INRA and the CNES LERTS laboratory as part of the big European project on desertification on the fringes of the Sahara; the

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* CRODT: Centre de Recherches Océanographiques de Dakar-Thiaroye

COMPARISON OF RAINFALL AND FREQUENCY

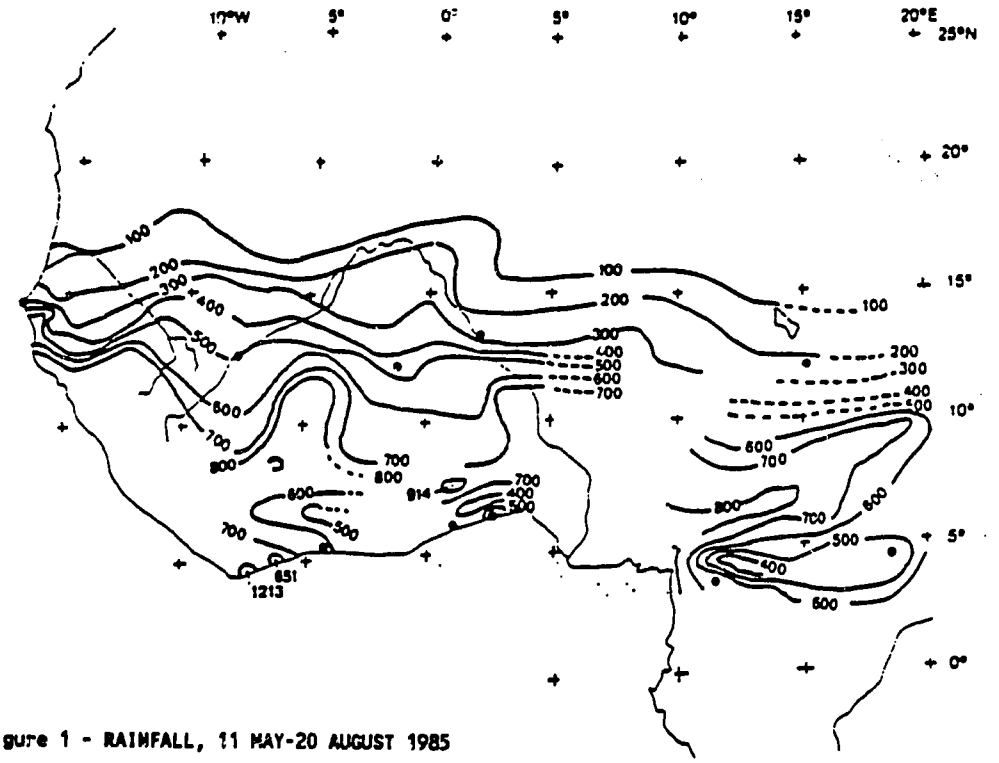


Figure 1 - RAINFALL, 11 MAY-20 AUGUST 1985

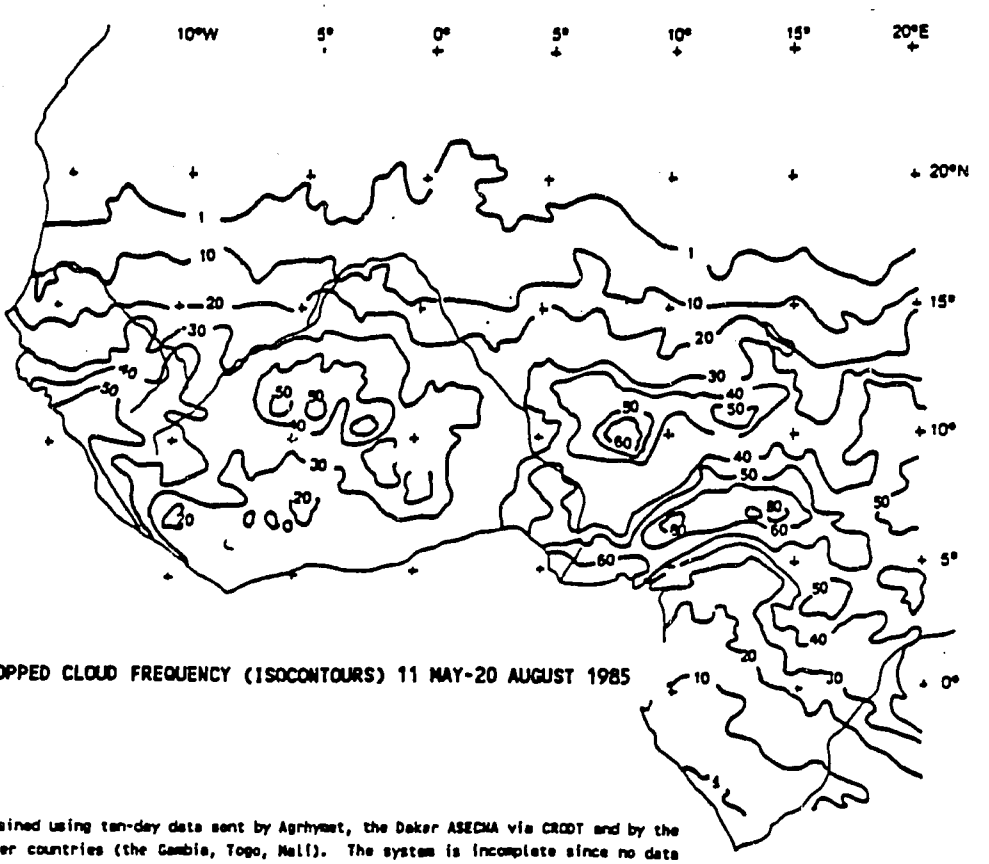


Figure 2 - COLD-TOPPED CLOUD FREQUENCY (ISOCONTOURS) 11 MAY-20 AUGUST 1985

The rainfall map was obtained using ten-day data sent by Agrhymet, the Dakar ASECNA via CRODT and by the national services of other countries (the Gambia, Togo, Mali). The system is incomplete since no data was received from the English-speaking countries and a few French-speaking countries (Guinea, Gabon, Congo).

The data concerning the cumulated frequencies over the ten ten-day periods studied (V.C.S. n°9 p.25) were smoothed on a Pericolor 2000 and used to draw up a frequency map of cold-topped clouds.

Comparing Figures 1 and 2 shows that rainfall and cloud frequency tend to coincide inasmuch as the curves describe the same axes, peaks and steep gradients.

work is aimed at establishing water balance (estimating and mapping RET [real evapotranspiration]) in partnership with Senegal and Niger.

The EPSAT project ("Estimation de précipitations par satellites"), jointly financed by UNDP, WMO and two French ministries, got under way in Burkina Faso (Ouagadougou degree square) in 1986 and has now begun in Niger, using a local radar for which the ancillary equipment is to be upgraded. The CNRS dynamic weather laboratory, ORSTOM Lannion and the Paris mining engineering school are all involved in this (see below).

Vegetation indices and crop moisture balances have since 1986 been the subject of some interesting work by IRAT/CIRAD in collaboration with the national weather services and agricultural research institutes, ISRA in Senegal and IER in Mali. The ESPACE project ("Evaluation et Suivi de la Production Agricole en Fonction du Climat et de l'Environnement": evaluation and monitoring of agricultural production in relation to climate and environment) has sought to develop a simple methodology for agrometeorological crop monitoring, with several aims in view:

- To contribute towards an early warning system (identifying drought areas from METEOSAT images);
- To give an estimate of crop emergence, provide indices of water requirement satisfaction during the growth cycle and draw up a preliminary balance sheet for the cropping season by early October;
- To establish indicators that take account of the moisture/yield relationship for different land and soil types.

At one point the ESPACE project looked like a French early warning system, but it has become a research operation in partnership with those being run by the RAC in Niamey. The ultimate objective is to help improve the forecasting instruments employed in West Africa. The RS aspects rely on NOAA and METEOSAT data.

Also worth mentioning is a scheme being run by the Institut de la Carte Internationale des Végétaux (Institute for the International Vegetation Map) (ICIV) in Toulouse. This is a study of the biological rhythms of sudano-sahelian vegetation (cycle of vegetation formations) in northwestern Burkina Faso and northern Côte d'Ivoire, using NOAA AVHRR, LANDSAT and SPOT imagery.

The relationship between rain, surface temperatures and vegetation indices has generated several other applied research operations aimed at improving the state of knowledge about the rangelands. ORSTOM (Montpellier/Dakar) and Paris XI University, with the help of ISRA/LNERV and the satellite imagery processing unit (UTIS) set up jointly with that body, have been closely involved in a project on the monitoring and functioning

of a pastoral ecosystem in Senegal, with a view to rangeland management for natural renewable resource conservation. This project is taking place at Ferlo in North Senegal, between isohyets 200 and 400, where extensive grazing on natural pasture is the main activity. The lands are now overgrazed, and the aim is to inventory and monitor the grazing, mainly by means of RS, so that it can be better managed. The operation under way for 1987 and 1988 is called "Sylvo-pastoral development in Ferlo", and is based around M'Biddi. The main data sources are METEOSAT and NOAA, with some SPOT data also being used. The project uses information gathered previously by the same teams and published in the Veille Climatique Satellitaire newsletter, particularly in issue No. 17, May 1987, Evaluation de la productivité primaire herbacée au Sahel sénégalais (saison de pluies 1986) ["Evaluating primary herbaceous output in the Senegalese Sahel (1986 rainy season)"].

Imagéo, the Paris RS laboratory of the CNRS, has been running an experiment in the pastoral regions of Mali since late 1984. The aim is to provide government and regional decision-makers in the Sahel with a way of managing rangelands at a time when pastoralism is in difficulties. Using available data, especially NOAA data received at Mas Palomas, this integrated study of the Sahelian pastoral ecosystems (entitled "Action incitative PICS Sahel") is concretely working towards production of a map at 1:1,000,000 (national level) and 1:500,000 (regional level), giving locations and biomass of Sahelian grazing lands.

This project, developed in Mali, aims to have its methodology operational by 1991 and transfer it to the regional AGRHYMET center for application to other Sahel countries where pastoralism is practiced. The Paris laboratory of Imagéo is well equipped for processing NOAA data - the radiometric and geometric quality of the images it produces are in no way inferior to those produced in the United States, for example.

Another methodological research project on RS evaluation of grazing resources, run by the IEMVT in partnership with Niger's agricultural research institute INRAN, has been under way in the South Tamesna area of Niger's sub-desert zone since 1984. Ground samples and radiometric measurements are taken and used in combination with NOAA and SPOT imagery to determine possible stocking density over a 100,000 hectare trial area. The aim is to be able to determine optimum stocking density two weeks after the rainy season. This experiment has given useful technical results, due particularly to the combination of SPOT and NOAA data (aggregate of SPOT images at a resolution of 20 m to cover one NOAA pixel of 1 x 1 km). However, there remains the problem of a fairly long time-lag (up to two months) before the necessary satellite images become available. Lead times of this order are incompatible with the project's goal, and it is

to be hoped that they will be very much reduced once the NOAA receiving station in Niamey is operational.

As this shows, to assess grazing resources over the whole of a country's pastoral zone, one needs a low-resolution (1 km) sensor with a wide field of view. As it is difficult to sample areas of 1 km^2 on the ground, SPOT 1 can here again be used as an intermediate scale to establish the biomass of a series of NOAA AVHRR pixels. This method is a valid interim measure until SPOT 4 is launched along with a "vegetation passenger" providing both scales of measurement.

As indicated in the first part of this report, RS applications for crop acreage measurement are being researched, especially by BDPA-SCET-AGRI with its agricultural statistics project in Niger (the SOSPAT project), run jointly with the Niger Ministry of Agriculture. This project began in 1985, and cost nearly $1 million for the first three years. It is working towards a method that will combine aerial photography, satellite RS (SPOT scenes and NOAA images) and ground surveys to estimate production (acreage and yield) of the staple crop, millet. Whatever conclusions this operation may lead to, it will be instructive. It is being conscientiously run and involves a combination of all the techniques concerned: ground readings, aerial photography and satellite data (see diagram).

At the outset, the project's promoters envisaged verification on a nation-wide scale in Niger, which would have required coverage of virtually all the country's agricultural land by means of 150 SPOT scenes. The method could then be extended to the rest of the Sahel. Updating would be necessary, roughly every five years; this would be done by monitoring a fairly large number of small areas (1/4 SPOT scene, which would reduce costs).

This target is still quite a long way off, and even if one may hope for progress in the future, especially through higher resolution, the experience of the past few years in attempting to discriminate between crops has proved very disappointing, as it has elsewhere in Africa. Work should be limited to distinguishing cultivated areas, and even here cloud cover is a major obstruction.

Other RS operations in the Sahel are funded by the FAC or through mixed SCET-AGRI-BDPA funding:

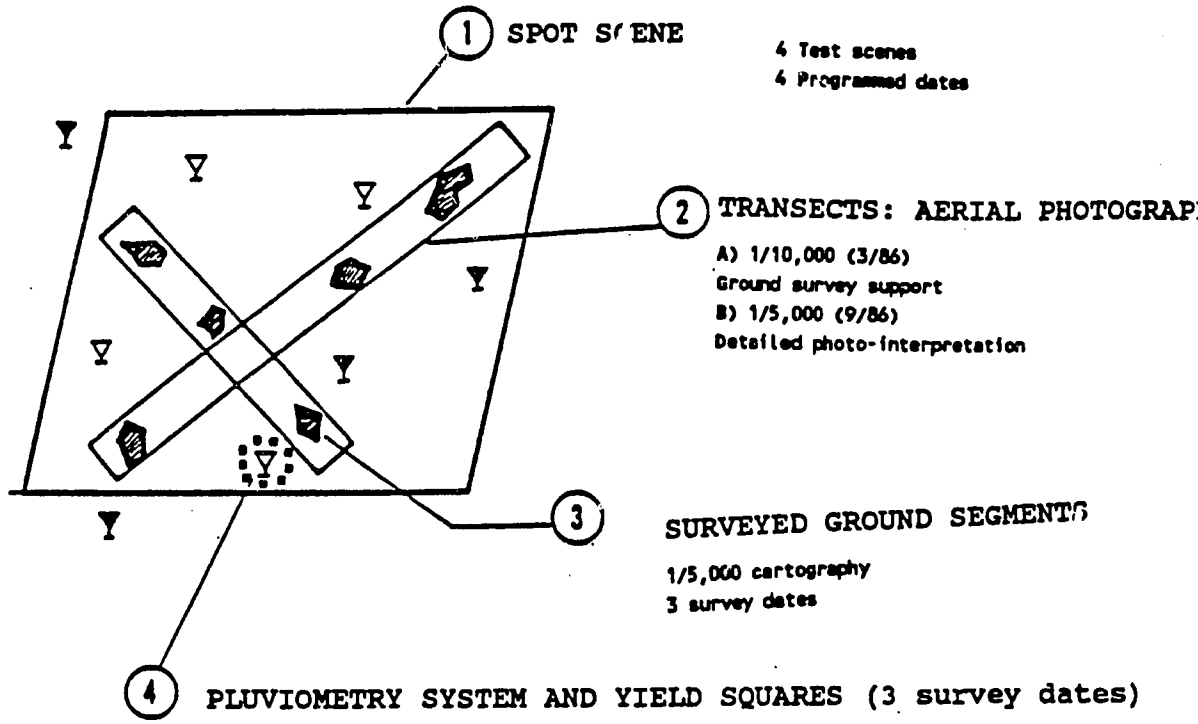
- Technical support for RS development under the aegis of the OMVS, whose objective is to use SPOT images to obtain a precise estimate of the extent of high-water flooding and alluvial floodland areas on the Senegal River, before the Manantali and Diama dams are flooded (see UNDP below);

- SPOT image simulation estimates on the AAVV agricultural zone in Bané, Burkina Faso, with a view to inventorying and monitoring crops in the Sudan zone.

PROJECT FOR AGRICULTURAL STATISTICS IN NIGER (SOSPAT)

Development of a method using remote sensing and ground surveys to estimate output (surface area, yield) of the major crop, millet.

PROJECTED SURVEY SYSTEM



REPRESENTATIVITY OF THE SURVEYED AREAS

(1) SPOT SCENES

60x60 km = 3,600 km^2
4 test scenes, i.e. 4% of AGRICULTURAL NIGER
Not a representative sample

(2) AERIAL PHOTOGRAPHS

Implanted transects using stratification
2 to 4 transects per scene (from 180 to 290 images)
12,000 to 24,000 hectares per scene in 1/10,000 (3.2-6.6%)
7,400 to 12,000 hectares per scene in 1/5,000 (2-3%)

(3) SURVEYED GROUND SEGMENTS

6 to 9 segments per scene
Average of 100 hectares per segment
750 hectares per scene, i.e. 0.2%

(4) PLUVIOMETERS AND YIELD SQUARES

Existing pluviometers: 20, i.e. 5 per scene
+ SOSPAT pluviometers: 12, i.e. 3 per scene
For 5 pluviometers per scene: survey per yield square (10 squares)

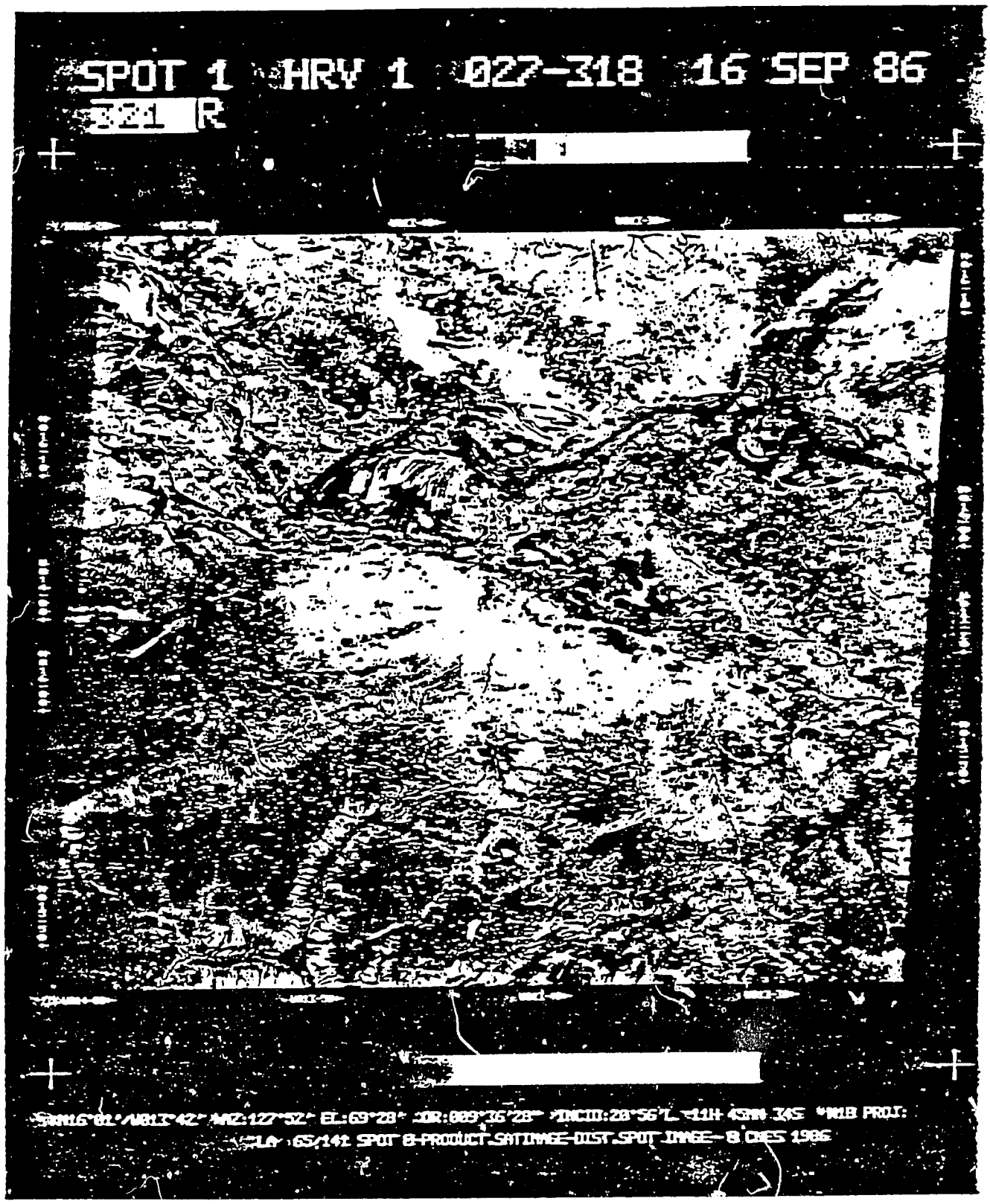
There have also been two French projects financed by the FAO (one which mapped the Niger delta for **locust control** purposes [see above], and one which mapped **the soils of the Senegal valley** for crop suitability) and one financed by the World Bank involving mapping of agricultural land for the East Senegal development plans (see below).

The FAC meanwhile is financing a project for which the BDPA, in association with the Centre Technique Forestier Tropical (CTFT) and on behalf of Mali's National Water and Forestry Department, has been responsible since 1985. This is the project entitled **"Continuous RS inventory and monitoring of the tree resources of Mali"**. The area concerned is the 600,000 km^2 of the country that lies south of the 16th parallel. Most tree stands in the Sahel are combined with agricultural land use and do not lend themselves to the traditional forest inventorying techniques, but RS has been used in recent years (LANDSAT, MSS and then SPOT) to supplement ground surveys and photointerpretation. This project is to draw up maps at 1:200,000 and 1:500,000, and must assess the suitability of RS for monitoring all of Mali's sensitive zones over a number of years.

In the sphere of cropping system assessment, mention should also be made of the operation that has been running in western Burkina Faso since 1986, with the aim of classifying surface states in this cotton-growing region. The project is jointly run by IRAT and the IRTC (Institut de Recherche sur le Coton et les Fibres Textiles).

ORSTOM, already mentioned in connection with livestock and climate monitoring, is very active in RS for Sahelian Africa. Based in Bondy near Paris, ORSTOM has for several years now been undertaking research in other directions as well, attempting to improve the application of RS to the problems of the Sahel. ORSTOM researcher J.M. Lamachère and his team, working on "Mapping of the infiltration and runoff capacities of the soils of a Sahelian drainage basin by SPOT image interpretation" in the Mare d'Oursi, Burkina Faso, have produced a 1:50,000 thematic map showing changes in surface states over the course of the rainy season.

Other groups of ORSTOM researchers have worked on a similar but broader and longer term study of "RS monitoring of changes in the Sahel's sensitive regions". This research subject involves a number of different operations with the common factor that they use satellite RS (mainly LANDSAT) to identify, locate and quantify environmental changes or deterioration in the West African Sahel. They include a study of dune organization and structures, and forms of denudation; research into soils and albedo; and acreage measurement of denuded village cropland. This is rather unrewarding work designed to fill a technical gap that began to be felt strongly three or four years ago: the lack of an adequate methodology for extrapolating from processed RS data to the great expanses of the tropical world, such as the Sahel and the Amazon.



SPOT SCENE, 16/09/86 showing the Senegal Valley in flood, the KAEDI rice-growing area (Mauritania), the dam and water storage facilities (top right) and the dry growing regions.
This 1/400,000 image can be enlarged to 1/50,000 for closer analysis in greater detail.

Lastly, the Institut National Géographique (IGN) plays an important technical role within the French technical co-operation system. Known throughout the world, the IGN has been looking at RS applications, in cartography especially, for a long time now. It has done a great deal of work for the benefit of the Sahel. In 1973, along with the CNES and then the BRGM, IFP and BDPA, the IGN founded the GDTA (Groupement pour le Développement de la Télédétection Aérospatiale), one of whose activities is to train technical staff, from developing countries especially.

Other European countries

The other European countries involved in RS application in the Sahel are mainly the United Kingdom, the Netherlands and Italy, although - as we have seen - most of the other countries are involved, for example, in analyzing the projects financed or undertaken by the European Communities Commission.

United Kingdom
The Universities of Reading and Bristol have for the past five or six years been carrying out some sustained and interesting experimental work on satellite pluviometry. We have already outlined the competing methods developed by Dugdale and Milford at Reading and Barrett and Power at Bristol, in connection with FAO projects and RS products in climatology. Reading University is in charge of the TAMSAT project, being well sited for the purpose with the Reading International Meteorology Center nearby. This work on rainfall and surface temperature has resulted in an operational method which the FAO's RS Center in Rome intends to put into practice in its ARTEMIS project.

The Netherlands
The Netherlands' contribution is primarily financial and technical support for the FAO, as we have seen above. Thanks to Dutch financing and the technical assistance of the National Aerospace Laboratory (NLR), the ARTEMIS program will be able to start work at the RSC in Rome in the second half of 1988.

It is true that the scope of the program will be Africa-wide and ultimately even wider, and that it will only be of partial benefit to the Sahel, as the Regional AGRHYMET Center will soon be developing products of an equivalent or superior kind more quickly than the RSC in Rome. However, the FAO's locust hazard information and the GIEWS early warning bulletin, both of which will owe much to the RS facilities being set up in Rome by the FAO with Dutch assistance, will still be very useful to Sahelians and donors alike.

Italy
Italy has been nurturing projects for some years now, to reinforce the AGRHYMET program and help equip national weather services. Besides supplying equipment, the activities planned include seminars on agrometeorology observation methods and instruments, to be held in Italy but designed for Sahelians from the CILSS countries. Some of the subjects for training and

study involve RS: thermal inertia of the soil in estimating evapotranspiration from METEOSAT data and the mapping of vegetation indices from NOAA images. In the latter field, a preliminary operation aims to gather data on two geographical areas, one in Italy and one in Mauritania.

Work has also begun on an image interpretation manual.

Chapter 3

THE CONTRIBUTIONS OF THE FAO, UNDP, WORLD BANK AND WMO

1 The United Nations Food and Agriculture Organization (FAO)

It was only natural that the role of the FAO should lead it to use remote sensing. Whether for early warning of famine, study of the effects of rainfall levels on crop farming and stock raising, or monitoring of areas threatened or already infested by the desert locust, the FAO was bound to use all the means at its disposal, including the most modern.

From the mid-1970s on it was doing precisely that, taking results obtained in the United States from the first Geostationary Operational Environmental Satellites (GOES) and the improved polar orbit satellites of the NOAA series, and using them to estimate rainfall. As far as Africa is concerned, this research has intensified since the ESA's launching of the first European geostationary environmental observation satellite, METEOSAT, in 1977.

Its fast-increasing use of RS led the FAO to set up an RS center in 1980 at its research and technological development division in Rome. The center has several functions: (i) to assist in the transfer of RS technology to the developing countries through training, advice and design of pilot projects, (ii) supporting the realization of projects in the field, (iii) monitoring rainfall and vegetation trends with the aid of satellite data in Africa and the Middle East, and (iv) coordinating and assisting RS activities undertaken by other divisions of the FAO.

Today, aided by its expanding resources, the center has gained experience in most RS fields. It is in contact with NASA, NOAA and EOSAT in the United States, and in Europe with the ESA, EARTHNET, SPOT-Image and the other European data processing facilities (Mas Palomas, Darmstadt, Lannion, Frascati, etc.)

During its first phase, the FAO's RS center had the facilities to carry out only certain observations itself. It had an SDUS station for analog (WEFAX) reception of METEOSAT data, plus all the ancillary computer equipment. Data from other satellites were procured either from NASA, as in the case of products relating to vegetation indices, or from the other agencies involved, eg. for recorded LANDSAT data. In this connection it should be added that the FAO has built up a very considerable

archive collection over recent years, especially of LANDSAT images.

For the rest, the RS center has expanded its research activities in conjunction with the Universities of Reading and Bristol in the United Kingdom (development of rainfall estimation methods) and with Swedish research workers. It has received considerable financial or material help from a number of countries, particularly the Netherlands, Italy and Japan.

In this way the FAO has become the executive agency for certain programs financed by donor countries, either through its own RS center in Rome or through facilities in other countries.

These are major programs, the chief ones involving Africa and the Rome facility. On issues affecting Africa, the FAO has for several years now worked in collaboration with the RS centers in Nairobi and Harare. Each of these centers (both very ill equipped until now) are to receive a PDUS receiving station for METEOSAT data before 1991. This project, totaling $2.7 million, will be implemented between 1988 and 1991 with Japanese funding, the FAO being responsible for implementation. The aim is to improve crop monitoring and early warning in southern and eastern Africa (SADCC project). The new products it will make available will be rainfall data and a vegetation index (which the FAO receives at present from the NASA GSFC in the United States, as part of a contract which the FAO and USAID jointly concluded with NASA.

The other main project involving the Rome RS center is ARTEMIS: Africa Real Time Environmental Monitoring Using Imaging Satellites. It involves a close partnership between the FAO's specialist services and the Netherlands National Aerospace Laboratory, the NLR, which designed and engineered the program. Financed by the Dutch Government, through a trust fund, to the tune of $3.5 million since 1984-5, the ARTEMIS system is soon to go into action. All equipment should be installed by mid-1988 and operational by the end of the year or early in 1989. Africa will be the beneficiary of the first operational phase; the Middle East and Southeast Asia will be covered at a later stage. The modest SDUS of today will be replaced by a PDUS with all its necessary accessories (a 3 meter diameter antenna, Hewlett-Packard A900 computer, etc.), allowing direct reception of METEOSAT data. (The RSC in Rome was host in 1983 and 1984 to an experimental PDUS, which the ESA made temporarily available to it).

The following data will be incorporated into the ARTEMIS system:

- Geographical and agroclimatic data (precipitation, potential evapotranspiration, type and duration of agricultural season);

- NDVI vegetation indices for the period 1980-88;

- Potential locust habitats.

The spatial resolution for all these data will be 7.6 km. The images will be in two formats (African continent, and Middle East and Southeast Asia).

The ARTEMIS system's products will be as follows:

- Main products: raw METEOSAT and NOAA AVHRR (GAC) data; ten-day and monthly composite NDVI vegetation index maps; ten-day and monthly estimated precipitation maps; estimated number of days of rain per ten-day period and per month;

- Thematic products: monthly map of estimated rainfall anomalies (in mm and in % of 30-year historic norm); ten-day potential locust reproduction factor; map of water availability for crops; miscellaneous maps.

The users of the ARTEMIS system are many and varied. First come the departments of FAO headquarters concerned (the global information and early warning system (GIEWS), the emergency center for locust control operations, the bureau of special assistance operations, the agrometeorology group, etc.). The second user group includes national and regional early warning projects; national and regional locust control organizations; and other UN agencies that may be interested.

So that the GIEWS and the locust control center can enjoy the full benefits of the ARTEMIS program's technical advances, and also in response to the need for better telecommunications, the executive staff at the RS center have designed a project entitled DIANA: Data and Information Available Now in Africa. This is a satellite telecommunications system costing an estimated $3 million, to be launched in a little under three years' time.

From this fairly full outline of the Rome RSC's activities, one can see (i) that the FAO is anxious to use this type of technique as fully as it can, and (ii) that its work is aimed primarily at Africa, where its main concern is monitoring of agriculture and the locust threat, with a view to timely response to food security needs. The FAO is naturally anxious to take measures against the desert locust, and its efforts in this field are continual. In recent years it has become the effective coordinator of locust control activities, and its RS center makes a full contribution, harnessing all the potential RS offers for surveillance of such isolated regions as the

Saharan massifs, and providing indicators (rainfall, vegetation indices) to identify migration areas or areas liable to give rise to a gregarious-phase populations.

In the beginning, RS activities were carried out pragmatically, in a variety of different ways, by the major departments of the FAO. The creation of the RSC in 1980 made it possible at an early stage to bring together most such operations in one place. Nonetheless, in 1987 the Director General deemed it necessary to improve co-ordination between RS-related activities within the FAO. RS users re-examined the question and put forward the main recommendation that a "Remote Sensing and Weather Data Users' Committee" should be set up, to improve links and stimulate the flow of information between the RSC and the other FAO units. The Chairman of this Committee is the head of the center, while its secretary is head of the agrometeorology group.

The benefits the Sahel draws from the FAO's RS activities are mainly indirect since, apart from the projects described below, which directly concern certain of the Sahel countries, and the locust alert measures which concern nearly all of them, it can be said that most of the FAO's satellite information is exploited in Rome by the FAO departments concerned.

Indeed, with the AGRHYMET program and its regional center in Niamey, the CILSS countries have a source of satellite information to which the FAO has little to add. This will be all the more true once the forthcoming NOAA data receiving station at the RAC is operational, and in a few years when the scheduled PDUS-grade METEOSAT receiving station is installed in Niamey (see below). This shows, in fact, how privileged the CILSS countries are compared with other African States, and explains why, to observers assessing their utility from the standpoint of the central or western Sahel, the FAO's existing and forthcoming facilities may seem rather superfluous.

In fact this assessment seems to be unfair, since the FAO's objective in the ARTEMIS project embraces the whole of Africa, the Middle East and Southeast Asia. The region covered by the CILSS states is small by comparison, even if some of its population groups are fairly vulnerable. Furthermore, the FAO provides training possibilities and a very valuable data bank, particularly for LANDSAT data. Lastly, the FAO is interested in making the most of satellite Earth observation (SPOT or LANDSAT) for estimating cropland acreage by stratification or zoning.

As regards users within the FAO itself, those with the keenest interest seem to be the GIEWS and all those working with it to produce periodical documentary information. Among the publications put out by the GIEWS, we should mention above all those that directly concern the Sahel. While they are drawn up from all the information sources available to the FAO, there is no doubt that satellite data contributes more and more. Using

such products as vegetation indices and rainfall records and estimates, the GIEWS can draw up synopses in Rome and distribute them fairly regularly and fairly fast throughout the Sahelian cropping season (May to October) and at the end of the season.

The maps below appear in the "Preliminary Assessment of 1987 Cereals Production in West Africa" drawn up by the FAO agrometeorology group and published by the GIEWS on 16th November in Rome. It is hard to say which or how many of the numerous parameters used to draw up these maps are taken from satellite data, but it would be surprising if they could be mapped without recourse to this type of information, especially as regards rainfall. Of the satellite data used, one would of course also have to distinguish between the data taken from bulletins and telexes released by the Niamey RAC and those from the FAO's RS center itself.

Be that as it may, the part played by satellite information in working out maps, graphs and reports is clearly greater at the beginning of and during the agricultural season than after harvest, when far more ground data is available and when, above all, one has a fairly precise idea of the abundance of the harvest and any areas under threat.

As well as climatic data (rainfall, temperature, etc.), since May 1983 the RS center has had at its disposal normalized vegetation indices worked out from NOAA 9 AVHRR data by the Goddard Space Flight Center in the United States. These images are produced every ten days, showing areas where conditions are above or below normal compared with the figures for the previous year. Unfortunately, a certain amount of time is needed for these documents to reach their destinations, delaying the release of the FAO bulletins and the dispatch of diskettes to those African countries that can use them.

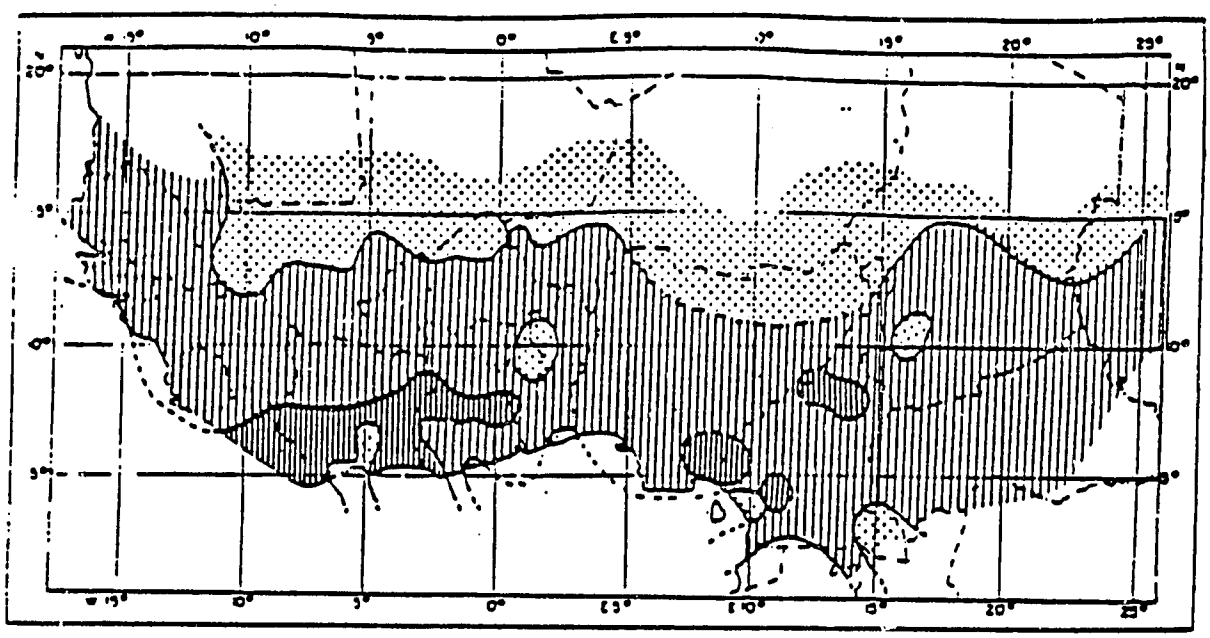
These technical conditions, and the widely varying state of technical progress in the developing countries as regards use of RS, are the reasons why the FAO focuses its African activities on the regions that could most usefully be equipped: Nairobi for East Africa, Harare for Southern Africa, and of course Cairo. The services that can be provided from the Rome headquarters are of interest to countries that are as yet only poorly equipped. This is not the case for the CILSS countries, though of course co-operation with AGRHYMET is to be encouraged, for experimental research or to fill certain information gaps. At any rate, it would be useful to have a minimum of co-ordination to avoid waste and duplication of effort.

Within the Sahel itself the FAO has supported or participated in the following projects:

- Quantitative estimation of precipitation, in association with the Universities of Reading and Bristol, United Kingdom. The aim of this project was to correlate ground truth

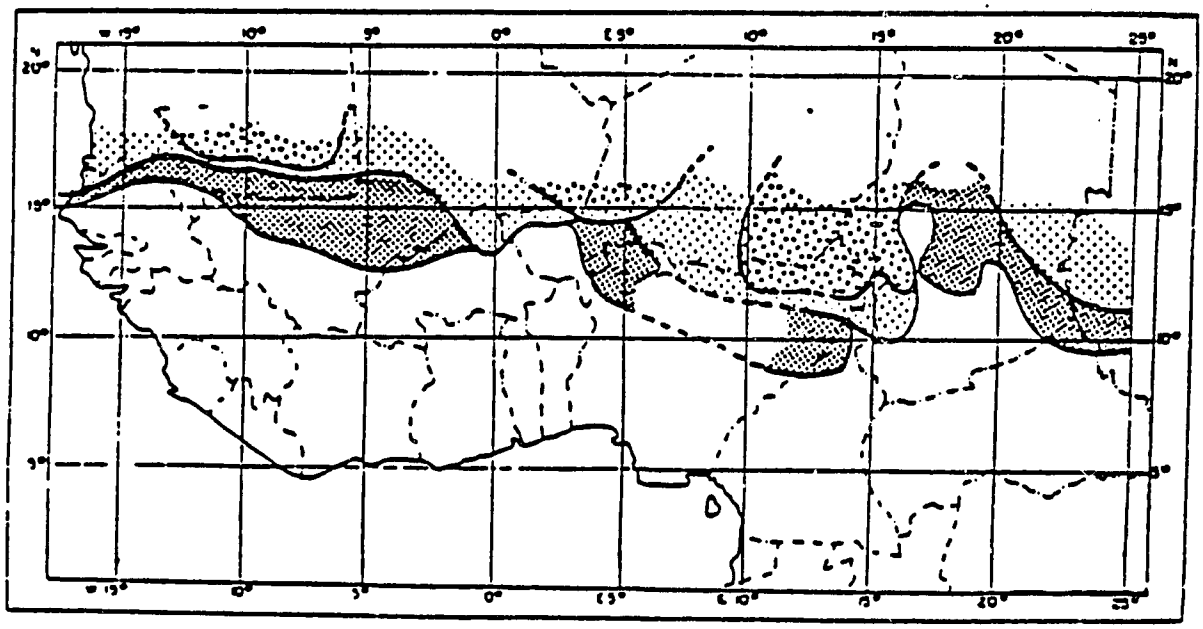
AGROMETEOROLOGICAL SUMMARY

MAP 1 - ACCUMULATED RAINFALL IN THE 1987 GROWING SEASON



Below normal Close to normal Above normal

MAP 2 - CONDITION OF CROPS



Overall failure Mediocre harvest Yield below normal

SOURCE: Agrometeorological Group of the FAO (AGP) - SMIAR bulletin, 16 November, 1987

measurements with satellite data elaborated by one of the competing methods proposed for PDUS stations using METEOSAT data: the TAMSAT method [put forward by Milford and Dugdale (1987), as opposed to the Bristol method invented by Barrett and Power (1987)]. This developmental research, carried out in the Sahel, was financed by the British Overseas Development Agency and the FAO;

- Pilot project for inventorying and continuous surveillance of Sahelian pastoral ecosystems: this joint FAO/UNDP/Senegal Government project began in 1979. Its operators were ISRA (the Senegalese Agricultural Research Institute) and the FAO. Its aim was to supply data in the form of maps, tables and reports on the current state of the rangelands in three sample regions of about 10,000 km^2 each;

- Mapping of the soils of the Senegal Valley with a view to crop suitability assessment. This project, involving Senegal only, was financed by the FAO with the French agencies BDPA and IRAT as operators;

- Cartographic inventory of vegetation tiers on the inland Niger delta, with a view to locust control. Country concerned: Mali. Financing: FAO. Operator: BDPA (France).

In addition to this, as part of the assistance given in setting up a crop forecasting and early warning system in Senegal, an FAO consultant, Mr. Geoffrey J. King, wrote a report on RS in Senegal after spending a month in that country in October 1987. This valuable document is a good illustration of the type of assistance the FAO supplies with its experts' missions; and we shall be mentioning Mr. King's conclusions when we come to assess the contribution RS has made to the Sahel.

2. The United Nations Development Program (UNDP)

The UNDP supplies a major part of the funding for the AGRHYMET program and various other development projects in the CILSS countries.

While it is difficult to give a figure, the UNDP contribution to AGRHYMET's RS budget has been considerable in the past.

Besides this vital though indirect help, there are RS-related schemes in the Sahel that have directly benefited from UNDP funding. These are:

- **The EPSAT project** for satellite estimation of precipitation, first in Burkina Faso and then in Niger, using the Niamey weather radar (see above). The aim is to determine precipitation with the help of METEOSAT images and rainfall data from the African network. The use of two time-scales, long-term (season or month) and short-term (rainfall event)

means that two networks must be set up: a loose network with one observation for every 100 km, and a tight one focused on a 1° square. The latter network, centered on Niamey, will be used to calibrate the local weather radar, digitalized for the purpose. This arrangement should lead to a first operational season in 1989 and so establish a link between the small-scale precipitation pattern and the satellite data;

- **Technical support for the development of RS in the OMVS** (Organisation pour la Mise en Valeur de la Fleuve Sénégal). As explained above, this project is working towards the use of RS on behalf of the OMVS monitoring and evaluation unit, estimating flooded areas and floodland crops in 1986-7 from SPOT images. This study, begun in May 1986 and jointly financed by the French FAC and the UNDP was carried out by SCET-AGRI-BDPA. In 1986-87 fifteen SPOT frames covering the Senegal Valley from the river mouth to Manantali (c. 700 km) were interpreted in order to monitor the high-water floods (September-October 1986) and the post-flood crops (February 1987). Since then, skilled staff have been trained in France, the RS contribution has been jointly appraised with users/decision-makers, and a program scheduled for several years has been set up to further assist the OMVS in its use of RS for monitoring land development;

- **Estimation of herbaceous biomass in northern Senegal at the end of the 1987 rainy season.** The ecological monitoring center (CSE or Centre de Suivi Ecologique) of the Senegal Ministry for the Protection of Nature has drawn up a map of herbaceous biomass in Ferlo, using 40 NOAA AVHRR images covering the period 1st July to 10th October 1987. The data were processed by the CSE itself with help from Copenhagen University's Institute of Geography.

  The methodology employed by the CSE differs from that used in the UNDP/FAO/ISRA pilot project based on localized sampling. The CSE method draws on joint work by NASA's GSFC and the ILCA, especially the work done in Mali. This involved three complementary sampling levels: ground level (18 monitoring stations), light aircraft (ICAR radiometer calibrated on NOAA AVHRR), and NOAA images obtained from the ESA facility at Mas Palomas, preprocessed in Copenhagen and finally presented in diskette form to give normalized differential vegetation indices (NDVI). Areas of bare earth, tree cover and the varying relative preponderance of fine or coarse grasses and legumes mean that this map must be used with caution. It overestimates biomass in the ferruginous Ferlo area and slightly underestimates it in areas with a high density of Cenchrus biflorus.

  There seem also to have been similar experiments carried out in Senegal over the past two years, on the herbaceous biomass of the North Ferlo region. These have been implemented by

different laboratories and Government departments with outside finance also coming from a variety of sources (see above).

3. World Bank

The World Bank is to be found everywhere in Africa, and in the Sahel particularly. Indirectly it has shown its interest in space applications a number of times, through large-scale projects aimed at Africa-wide co-ordination of existing national and regional resources in the meteorology and telecommunications fields. A preliminary project plan of which there was talk in early 1986 seems to have aborted. For the past year, however, there has been mention here and there in meetings of a new program entitled ICOMAH.

For the moment nothing concrete seems to be envisaged, let alone decided upon, and the World Bank is virtually absent from the RS field.

One modest, localized initiative ought to be mentioned, however. The World Bank has provided finance for an operation commissioned from France's BDPA to draw up an inventory of agricultural land in western Senegal by means of airborne and satellite RS, for development plan purposes. Mapping scales are 1:500,000 and 1:100,000.

4. World Meteorological Organization (WMO)

While it is not in direct charge of any RS project, the World Meteorological Organization is present wherever there is a Sahelian RS operation using meteorological information. It plays a crucial role, for example, through the continual assistance it gives the AGRHYMET program and, more generally, the entire structure of remote sensing work in the CILSS countries. As the reader will see from this study as a whole, the WMO is very active in the region. It is this agency, for example, that is handling the technical design of the future ACMAD center. Through its experts and its long years of experience in satellite imagery, the WMO provides valuable support for the development of remote sensing techniques in the Sahel.

Chapter 4

REMOTE SENSING IN THE SAHEL

1. AGRHYMET AND REMOTE SENSING (*)

The AGRHYMET program was set up in 1977, instigated and sponsored by the World Meteorological Organization. It was only natural that it should avail itself of the possibilities offered by remote sensing. The vast, region-wide CILSS agrometeorology and hydrology project has been especially endowed and structured for remote sensing.

The AGRHYMET program plays a major part in remote sensing. It has a large regional center equipped with modern computer and telecommunications facilities and run by a fairly large team of specialists. It lies at the center of a network interlinking all the national weather services of the member countries and, through these services, it has feelers in all the different regions of the Sahel. The Niamey RAC is the network's axis, its relay to the outside and to its branches, and its driving force; in future the role of the RAC will have to expand, as this technological centerpoint of the network acquires new attributes and remote sensing utilization grows.

AGRHYMET's functions (a contribution to early warning, monitoring of crops, rangelands, hydrology, etc.) make it the perfect operator and experimenter for running full-scale RS initiatives and testing them against real conditions in the Sahel, in direct contact with users.

The RAC was already using RS in 1982, with the Bernard mission, and 1984, with the launch of the CEC renewable resources monitoring project and material assistance to the TAMSAT project - not to mention use of already-operational RS techniques in meteorology. But it was from 1985 on that RS really became established in the AGRHYMET program. At first, as we shall see below, it was primarily used in experiments that were, as usual, trial and error: digital METEOSAT data

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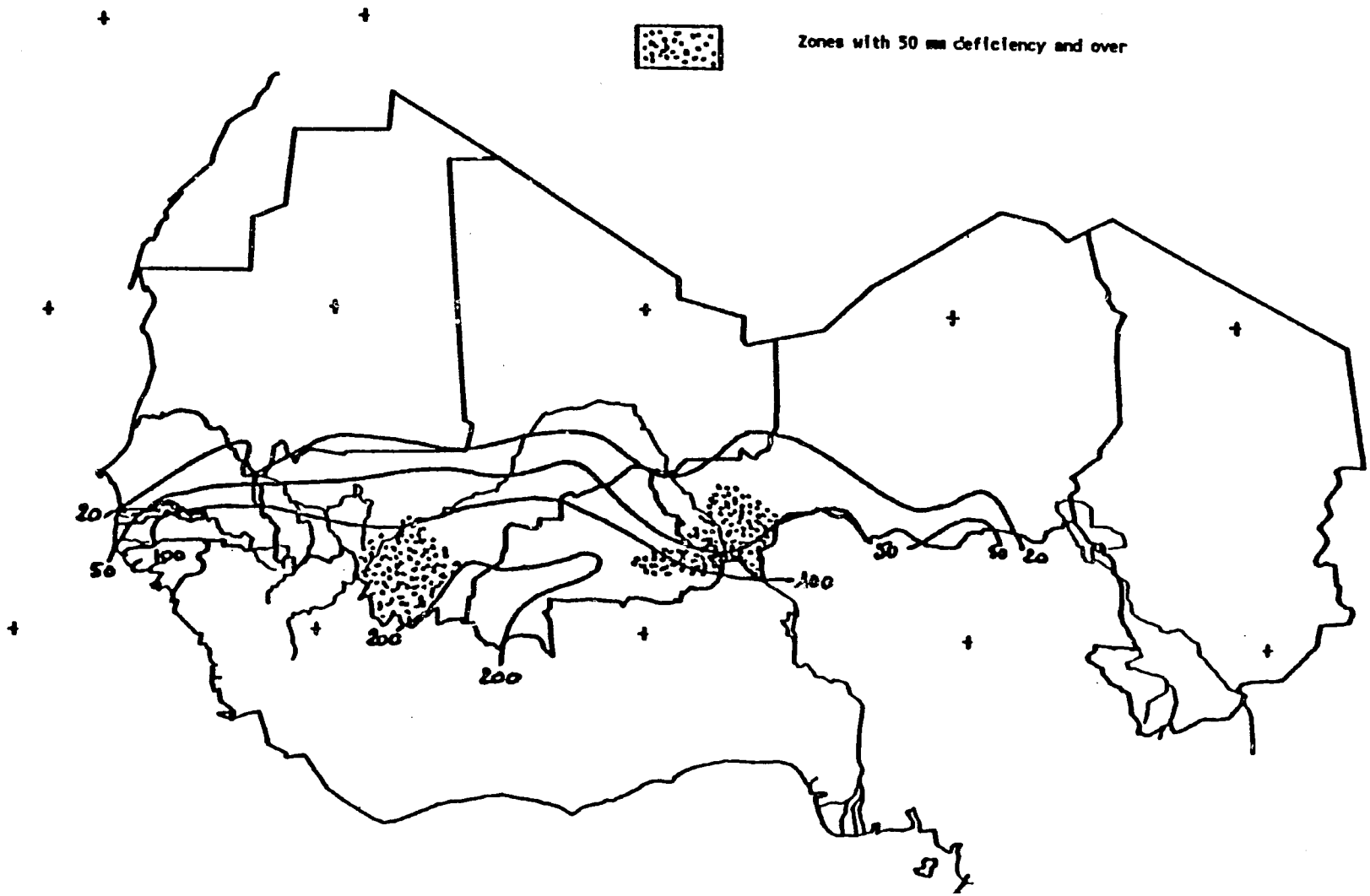
* Most of the information contained in this chapter has been taken from the excellent article by J.L. Domergue and A. Chanzy on "Les Outils satellitaires et les produits Agrhymet", published in February 1987 (refer to Bibliography), and from several interviews with M. Lambergeon, Director of Operations at the Agrhymet Regional Center.

CILSS
CENTRE AGRHYMET
NIAMEY

3rd ten-day period of June 1987
Map N°.1 : Pluviometry

Accumulated isohyets: 20, 50, 100 and 200 mm

Zones with 50 mm deficiency and over



CILSS
CENTRE AGRHYMET
NIAMEY

3rd ten-day period in June 1987
Map N°.2: Meteosat and NOAA satellite observations of Northern limit of cold-topped clouds during the ten-day period and changes in the vegetation index up to 25 June, 1987

No vegetation emergence

Biomass development identical to 1986

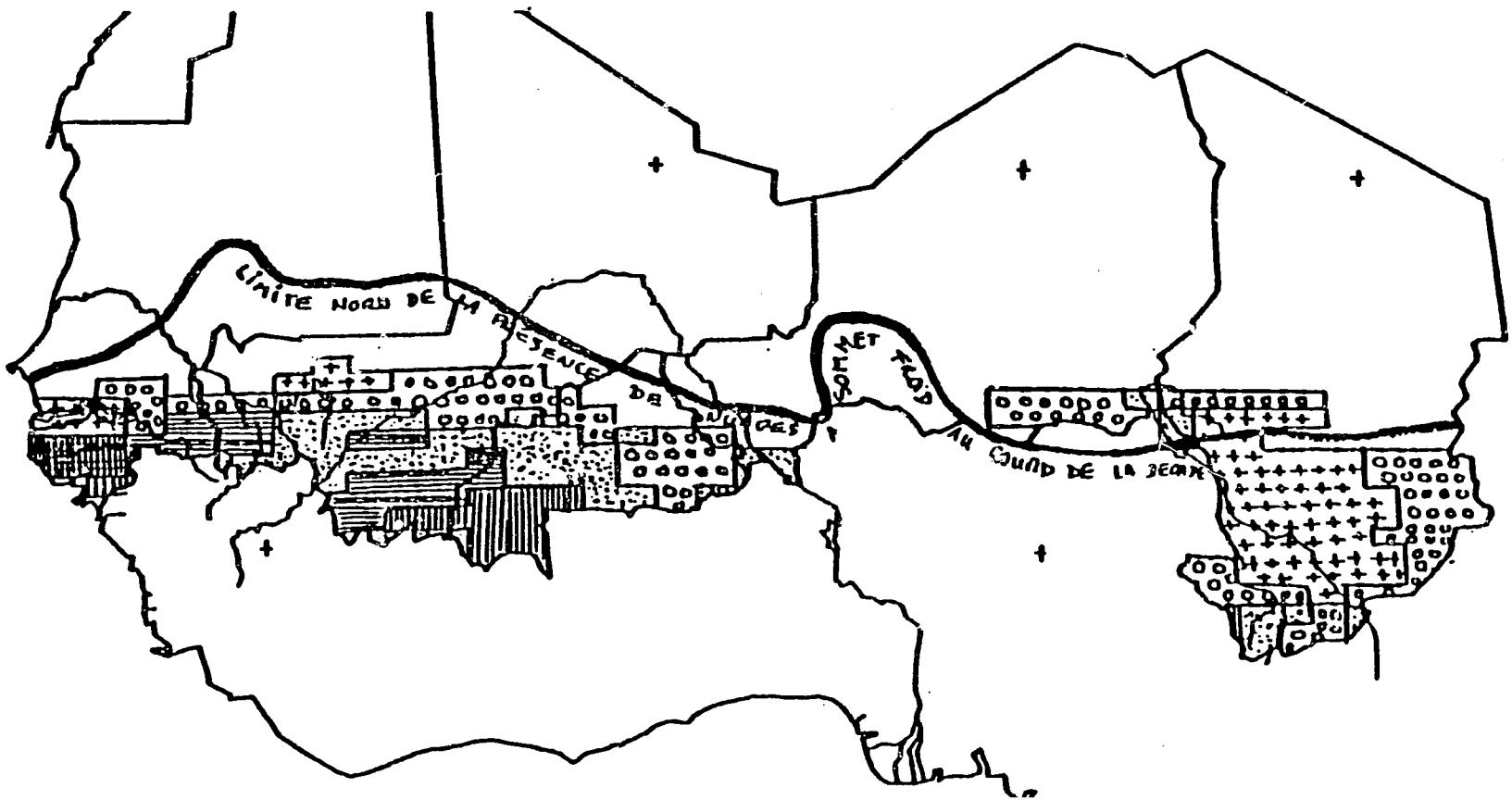
Biomass development superior to 1986.
Emergence of vegetation 2 to 3 weeks ahead and high growth of vegetation index.

Biomass development much higher than in 1986. Emergence 3 to 5 weeks ahead and very high growth of index.

Emergence of vegetation 2 to 3 weeks late.
High growth of vegetation index. Index on 25 June similar to last year.

Emergence of vegetation 2 to 3 weeks late.
Index on 25 June lower than last year.

Vegetation emergence much later than 1986 (up to 4 weeks).



processed by the Lannion CSM from 1985 on, vegetation indices communicated by NOAA/NESDIS/AISC. In March of that year, the French Co-operation Ministry initiated a seminar at the Niamey RAC on "Remote sensing at the AGRHYMET center"; one of its conclusions was that it would be opportune to install an HRPT receiving station for NOAA images.

Since then, events have moved very fast. RS occupies an important place in AGRHYMET's activities. It has become more and more operational, and although much progress remains to be made in this respect, it can be said that from the 1988 rainy season, and certainly from 1989, satellite data will be in widespread, everyday use.

Staffing and material resources have followed the same trend, helping in direct or indirect utilization of data from the NOAA or METEOSAT satellites. AGRHYMET's units in each country have hitherto been the beneficiaries of training by AGRHYMET specialists with a knowledge of satellite imagery interpretation. The weather services of the CILSS countries have also received the indispensable equipment for the basic operations. But, naturally enough, the main initiatives have concerned the RAC. First of all,the center acquired the basic APT equipment required for receiving analog data from space, with a small METEOSAT WEFAX system in particular. Next came all the ancillary computer hardware, software and imaging equipment.

RS operations were carried out by the RAC's ordinary staff, some of whom had got to know specific techniques while on training courses or primarily by self-training on the job. These operators were helped by experts on missions or permanently seconded to the center: Americans from NOAA, French military service volunteers.

The natural trend towards the growing and increasingly sophisticated use of satellite imagery has led AGRHYMET's decision-makers to try, little by little, to bypass the relays through which they have obtained METEOSAT and NOAA data to date, i.e. NOAA/NESDIS/AISC/CIAM and the Lannion CSM.

They are about to achieve this as far as NOAA data are concerned, as these will soon be received directly at the Niamey center by means of an HRPT receiving station financed by the French Ministry of Co-operation. But the PDUS request, in 1987 from the European Development Fund for direct acquisition of digital data from METEOSAT has been refused; AGRHYMET will have to make do with substitutes until the PDUS scheduled for the ACMAD Center is installed in Niamey some years from now.

The installation of the NOAA HRPT station is scheduled for June 1988; it should come on-line during the 1988 rainy season and be fully operational for the 1989 rains. Costing roughly $1.5 million, it will require a team of about ten skilled staff, operators included. France is to make available two engineers and two national service volunteers, plus experts on mission as

required. The United States will provide two engineers. USAID will probably continue to pay for processed NOAA data products in the interim; it has already sent the RAC the software and other elements required for the process.

The management and maintenance of the NOAA data PDUS have been costed at a little over $1 million a year. Half of these recurrent costs will be borne by the French Co-operation Ministry, a quarter by USAID and the remainder by the AGRHYMET program's ordinary budget.

Adding the other RS expenses (METEOSAT, document distribution, related equipment, general running costs), roughly estimated at an annual $500,000, one obtains a total annual RS cost of nearly $2 million for the Niamey RAC. A full estimate by the economic costing method would probably give a higher figure, with more like one third of the center's budget going to RS, a figure which does not look unreasonable once RS is making a real and appreciable contribution.

Products received or worked up by AGRHYMET to the benefit of the Sahel countries

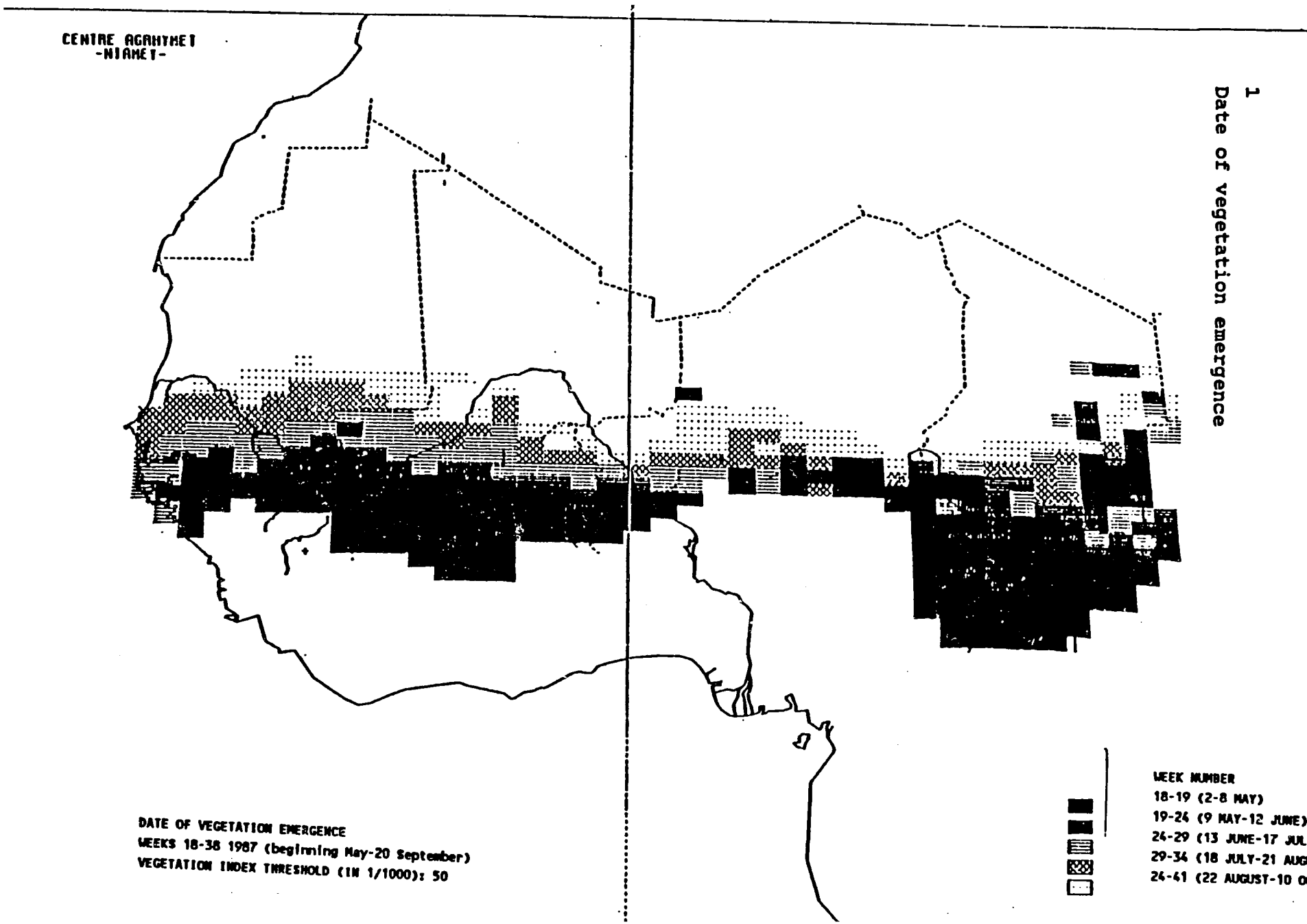
These break down into two major categories, the first relating to rainfall, soil moisture and plant moisture balance, the second to monitoring of crops and rangelands using vegetation indices. All these products are utilized and distributed either directly or indirectly, after different factors have been compared and combined. Bulletins are issued, daily, ten-daily and (for the most important) monthly or at the end of the season; telexes are sent out at varying intervals; and lastly, depending on their importance and where they can be utilized, documents are sent out to the CILSS member Governments and/or to other technical agencies concerned, in the Sahel itself or beyond. This is how the co-operation agencies, donors and RS specialists are kept informed of the data gathered or processed by the RAC. The part played by the CILSS member countries in sending information in to the RAC is an important one, for as everyone knows satellite RS without comparison and testing against ground data are barely utilizable. Moreover, satellite products usually only play a complementary part, insofar as they are designed above all to fill the information gap for the great Sahelian expanses where there are no means of observation on the ground.

Rainfall, soil moisture and plant moisture balance

The RAC uses METEOSAT 2 images for operational monitoring of cloud clusters in the region during the rainy season. Once every three hours - i.e. eight times a day - the APT receiver captures WEFAX analog images broadcast by the European center at Darmstadt, Federal Republic of Germany. From paper prints of these images one can monitor very deep cloud clusters and any squall lines they may form.

1

Date of vegetation emergence



The RAC also receives SYNOP weather messages from the regional network; these indicate, within 24 hours, the rainfall amounts recorded each day at pluviometry stations of West Africa. This information is automatically entered on a map base similar to a METEOSAT image, giving an immediate overall analysis of the cloud fields and the day's precipitation zones. Since 1985, the ten-day regional agrometeorological bulletin includes precipitation and squall lines.

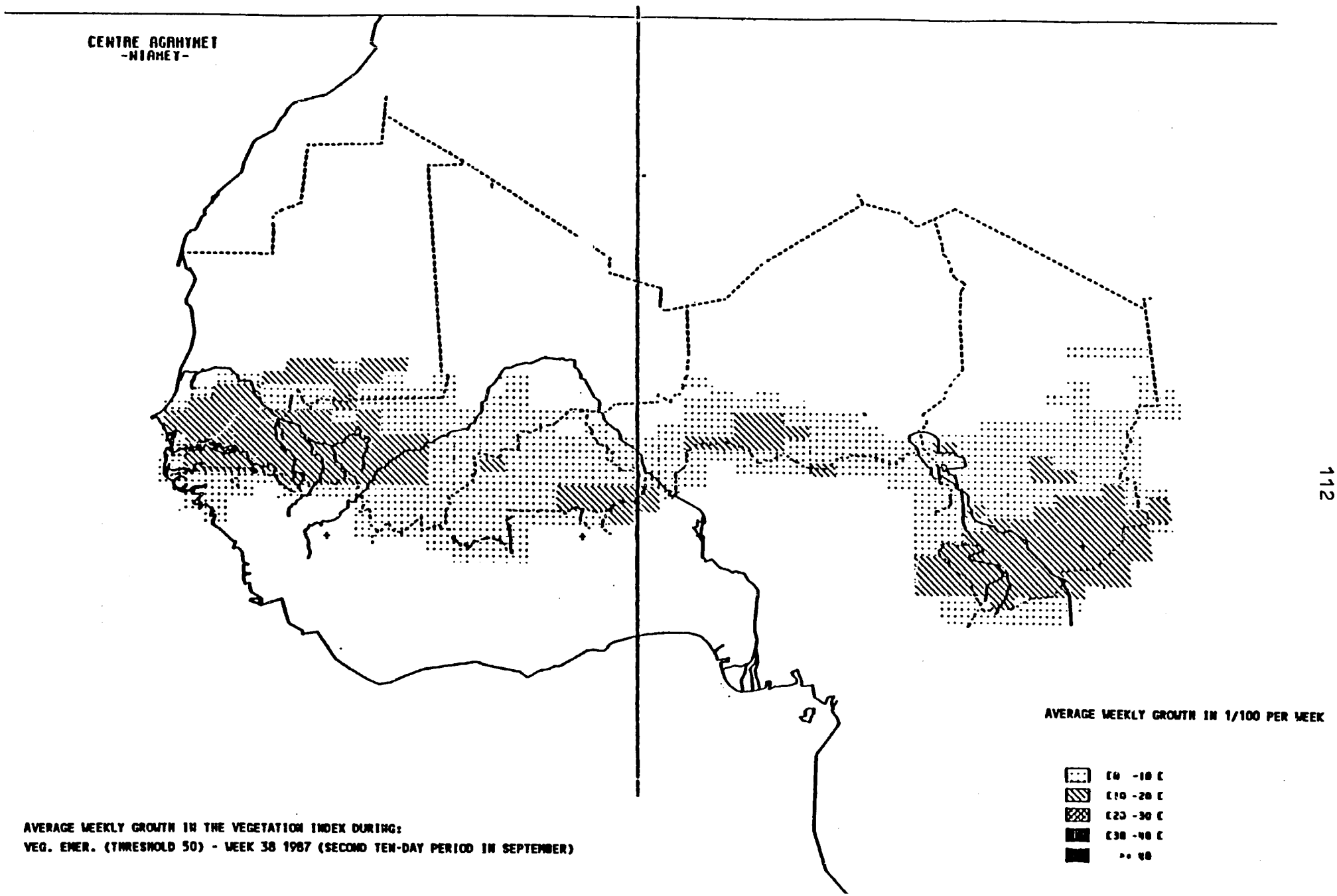
From the Lannion SMC in France, the RAC regularly receives an analysis of cold-topped clouds made from thermal infra red images received in digital form from METEOSAT 2. This analysis, made from six images per day over a ten-day period, is sent to the RAC by mail, in the form of an absolute-frequency map. The RAC uses it in its ten-day regional bulletin. The correlation between the occurrence of cold-topped clouds and rainfall is all the clearer over a longer period of the rainy season. These ten-day maps give only a qualitative glimpse of the structure of the rainfall zones, but they are enough to trace the isohyets in areas of low rainfall density. The Lannion center also supplies maps for a one-month period or for the whole rainy season, and these are more informative as to cumulative rainfall quantities.

The spatial and temporal distribution of rainfall and plant moisture status can be monitored by studying the radiant temperature of the earth as measured by satellite. Since 1985, the RAC has been using METEOSAT 2 satellite maps of the thermal range, supplied by the ORSTOM unit at the Lannion CSM every ten days. These false-color maps facilitate plotting of the isotherms. When the isotherms are compared, a steep temperature gradient reflects a hot or cold front. The experiment jointly run with the Lannion CSM in 1985 showed that by monitoring the +39° isotherm one could make a good assessment of the zonal progression of the arriving rainy season in the Sahel, its fluctuations during the season and the return of the following dry season. The false-color maps reach the RAC fast enough for an analysis to be made and published in the ten-day bulletin.

Monitoring of crop and rangeland condition: the vegetation index

Information transmitted by the AGRHYMET units in each country enable the AGRHYMET multidisciplinary working group to monitor the rainy season and draw up a "ten-day national agrometeorology bulletin". This information, gathered on the ground, is coded and then telegraphed to the Niamey RAC, which makes a regional synopsis. This kind of monitoring has its limitations: means are scarce, especially for good spatial distribution and for communications within each country; and it is not certain how representative or accurate the observations are.

Until 1985, the AGRHYMET system's monitoring of the state of the vegetation, and of crops in particular, consisted exclusively of ground observations. The idea of using RS to



AVERAGE WEEKLY GROWTH IN THE VEGETATION INDEX DURING:
VEG. EMER. (THRESHOLD 50) - WEEK 38 1987 (SECOND TEN-DAY PERIOD IN SEPTEMBER)

make up for the weaknesses of this system was based on the advantages of this new technology. From the time of the 1986 rainy season, vegetation indices calculated from NOAA satellite measurements were brought into AGRHYMET's already operational system.

Numerous earlier studies had shown that, using satellite data, one can differentiate the chlorophyll-bearing biomass of the Earth's vegetation cover from other types of Earth surface, such as surface water or bare soil.

It is known that chlorophyll-bearing biomass has a spectral response (reflectance in the various wavebands) which stands out sharply against those of other surfaces. Researchers proposed various combinations of several spectral channels to define a vegetation index, but it is the "normalized difference vegetation index" (NDVI) that has been adopted, as it minimizes atmospheric effects while remaining highly responsive to the amount of chlorophyll-bearing biomass and, above all, its moisture status. Applied at low resolution as it is at present in the Sahel, the index reflects the overall state of the biomass, combining areas of bare earth with areas of vegetation cover. Reflecting the quantity and vigor of the biomass as a whole, this vegetation index shows the general biomass context.

The vegetation index is well suited to monitoring grazing land, since it helps in measuring the quantity of biomass, and this is directly linked to grazing output. The RAC has used two methods. With the first, one takes a satellite scene and establishes the correlation between the vegetation index and the amount of dry matter on the ground; the correlation is close to 0.9, but one must readjust the models each season with fresh ground measurements. With the second method, one takes two chronological series: the ground truth adjustment procedure is simpler, but experiments still seem to be necessary to validate this method.

Much research has been done into crop monitoring, and it has followed two leads: yield estimates and forecasts on the one hand, and identification and measurement of cropland acreage on the other. The latter type of work is not within the scope of the AGRHYMET program, as we shall see below. As to crop yield, this is a more difficult subject than the rangelands. The connection between crop yield and the photosynthesis activity measured by the vegetation index is not a direct one, and this makes yield forecasting and estimation models far less precise. With the spatial resolution currently in use in the Sahel, vegetation indices can only be interpreted qualitatively. But even qualitative RS monitoring of crops and grazing land over the whole of the CILSS region is valuable.

The NOAA satellites were those best suited to vegetation index production (repetition rate, area covered, spatial resolution, data processing time). Until the NOAA receiving station is installed at the Niamey RAC (starting in mid-1988), vegetation

indices will continue to be procured for the RAC, as they have been since 1986, through collaboration between NOAA/NESDIS/AISC in Columbia, Missouri, and Washington, D.C., with USAID providing funds. USAID has made great efforts on AGRHYMET's behalf, especially in making NOAA products available to it.

The vegetation indices are gauged for a unit area of 1° longitude by 1/2° latitude (c. 6,000 km^2 grid cell). They reach the RAC each week by cable from the United States. The indices are elaborated in Columbia, Missouri, from preprocessed data purchased, since 1987, from the NASA GSFC, which in turn has acquired the raw data from NOAA (Suitland).

It takes about eight days from capture of data from a ten-day series to work-up and issue of the index. This is the time it will take, on average, for a CILSS country to have the cabled index at its disposal; computer transmission will come later. These countries can thus monitor the vegetation in real time, especially as they all have staff available who have been trained in vegetation index interpretation in the United States.

The RAC makes a regional synopsis of the results deduced from the NDVI and publishes them in its ten-day bulletin; at the same time it sorts the indices by country and sends them on within twenty-four hours.

The RAC also receives diskettes from Columbia. From these the vegetation indices can be displayed at GAC resolution (16 km^2) on the screen of an IBM-PC or compatible, or photographic prints can be made. The diskettes arrive by diplomatic bag within one to two months. This time-lag of course excludes vegetation monitoring in real time, but as this image is far more exact it is used to develop vegetation index interpretation methods, and constitutes a very useful record for researchers making comparative analyses over time or space.

With the NOAA receiving station, the AGRHYMET system's RS facilities will make a leap forward. It will be possible to capture NOAA data directly and so have information at a resolution of 1.1 x 1.1 km instead of GAC (4 x 4 km) as at present. The data will be processed and the indices produced with the help of the knowledge amassed by the RAC staff over past few years and the transfer of technology USAID has made possible (software, personnel). This technical advance will undoubtedly provide spin-off as regards precision of indices and the speed at which they become available. On both country and regional levels, the Sahel will be able to monitor crops and rangelands far more effectively.

The AGRHYMET program, then, is making ever-increasing use of RS, and products will improve. The RAC is becoming a major focus for the development of this technology in the Sahel, and even for Africa. But the situation is not perfect, and there are some questions that ought to be asked:

- Why does the RAC not concern itself with acreage measurement using the data available from LANDSAT 5 TM and SPOT 1?

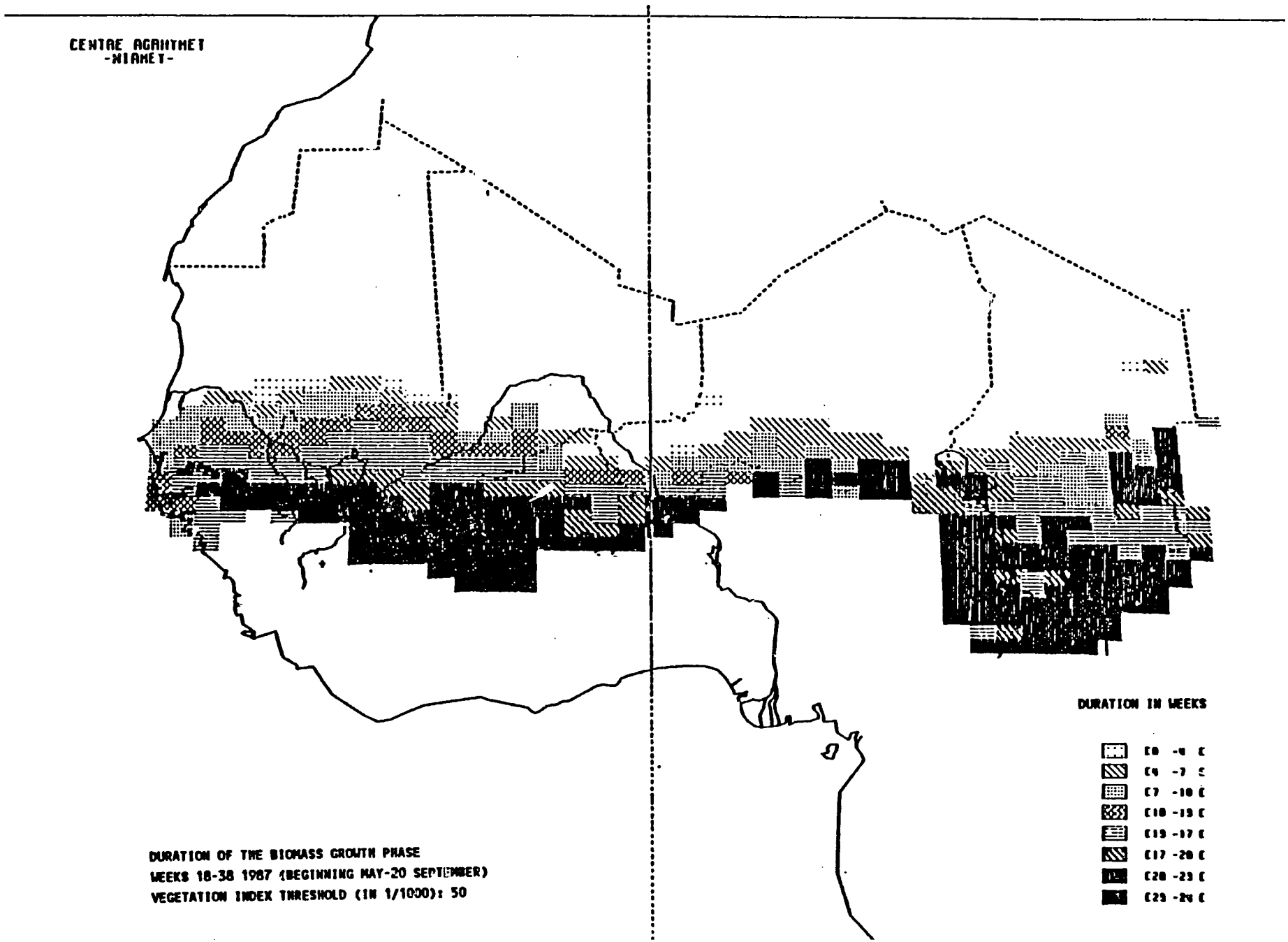
- How is the RAC going to coexist with the Africa-wide ACMAD centre planned for Niamey, especially in the RS field where co-operation is essential; for example, for the METEOSAT PDUS?

- How is duplication of effort to be avoided between the RAC and the FAO's remote sensing center in Rome?

It is natural that the impetus of developments should favor RS activities in the Sahel itself wherever possible; there are, however, some factors that work against this. It would be difficult, for example, to make the RAC in Niamey the site of all RS operations in the Sahel, as some circles concerned about optimum efficiency have suggested. The idea is attractive, but in reality there are already other projects, implemented through other structures than the CILSS (eg. CRTO and ACMAD), that have a different geographical scope and different decision-makers. It may be unfortunate, but it is a fact, and it would be far better to work towards operational co-operation and co-ordination between all these establishments. But tasks can get compartmentalized, internally as well as with respect to the outside. The AGRHYMET program has no responsibility for measurement of area; within the CILSS Executive Secretariat, this is the responsibility of the Diagnostic Permanent project, which also deals with crop forecasting. RAC specialists asked about this point add that reception, processing and utilization of SPOT and LANDSAT satellite data have little in common with those of NOAA or METEOSAT, and that the equipment is technically different.

These few queries show the need to accept that there are a number of different RS establishments in the Sahel, and that a great effort will be needed to co-ordinate them.

However, once the RAC has fully mastered direct reception and processing of NOAA images, the ESA may transfer this function from its Mas Palomas station to Niamey, as part of the ESA EARTHNET network. The RAC would then be making commercial use of RS, in a different and wider context than its initial CILSS framework.


CENTRE AGRHYMET
-NIAMEY-
DURATION IN WEEKS
DURATION OF THE BIOMASS GROWTH PHASE
WEEKS 18-38 1987 (BEGINNING MAY-20 SEPTEMBER)
VEGETATION INDEX THRESHOLD (IN 1/1000): 50

2. Remote sensing in Senegal

Research or development of RS projects have taken place in all the countries of the CILSS. Besides their normal participation in the standard operations of AGRHYMET, Diagnostic Permanent and other programs, these countries have become familiar with RS techniques, or at least with the techniques used in the Sahel itself, such as field techniques for obtaining data for correlation with the satellite data.

Our examination (below) of the fairly numerous research projects launched or implemented over the past few years will give the reader a glimpse of the RS activities in which Sahel countries and their experts have been involved.

One CILSS country deserves special mention, however, having hosted many activities and projects in this field. This country is Senegal.

For a variety of reasons (including its many advanced institutions and facilities and the fact that, though a Sahelian country, it also has access to the sea), Senegal has had the benefit of some major initiatives. Besides the projects we cover more fully below, there are other specialist RS agencies in Dakar, well equipped materially and with well-trained staff; in most cases the teams are a mixture of French and Senegalese, working closely with foreign research establishments, particularly the ORSTOM unit at the Lannion CSM in France and the ESA station at Mas Palomas in the Canary Islands.

Two institutes play a predominant part in RS activities in Senegal. They are not the only ones in the country, where university departments and research bodies are also trying their hand (one example being the national livestock laboratory LNERV, run by the Senegalese Institute of Agricultural Research - ISRA).

The Dakar-Thiaroye Oceanographic Research Center (CRODT, Centre de Recherches Océanographiques de Dakar-Thiaroye)

As its name suggests, all the work of the CRODT concerns sea observation: the measurement of sea water temperatures and all allied phenomena. Since around 1980 the research has been carried out in close collaboration with the ORSTOM unit at Lannion CSM, using mainly METEOSAT data.

French and Senegalese researchers very soon grasped the value of this field of observation for forecasting and monitoring weather phenomena above Sahelian Africa, so it was quite natural for the CRODT to extend the scope of its activity to the Sahel. Working together, the Lannion experts and those at Dakar-Thiaroye obtained some interesting results on the monsoon, the trend and timing of the rainy season, etc. They

have regularly published the lessons of their research in the bulletin "Veille Climatique Satellitaire" over the past few years (see bibliography).

The Dakar Satellite Imagery Unit (UTIS, Unité de traitement d'imagerie satellitaire)

This is a joint ORSTOM/ISRA structure. Many RS studies have been carried out under ISRA's aegis in the Ferlo region (using LANDSAT imagery, SPOT simulation, NOAA and METEOSAT images). Since 1986, the UTIS has been in a position to process raw data and work up finished products: processing the weekly METEOSAT synopses sent by Lannion, processing raw NOAA data captured by the Mas Palomas station into synoptic vegetation index maps for subsequent production of biomass maps. The UTIS is also capable of processing SPOT and LANDSAT data.

Following the first phase (1985-6) of the EEC RS-assisted study of "Desertification on the fringes of the Sahara", the UTIS has possessed an operational processing system for estimating and mapping rainfall comparable to the one the processing unit at the Niamey RAC is to be getting.

In addition, a basic Dundee model NOAA data receiving station will probably be installed.

This plethora of RS activities in Senegal reflects the energy of those research workers and institutes that can make use of satellite data. Most of them are carrying out applied research, but they are likely to gradually reach the operational stage, requiring increasing funds and increasingly costly equipment.

Here again, the time seems to be ripe for considering the need for co-ordination - country-wide first of all, then throughout the CILSS region - to avoid duplication of effort and lower-than-optimum efficiency. Greater awareness of this issue on the part of all concerned, including the associated organizations outside the Sahel, would improve the productivity of the whole system without having any negative impact on the research projects or on the full utilization of available facilities. FAO consultant Geoffrey King's report of October 1987 on RS in Senegal is very informative on the situation in this country (cf. bibliography).

3. The ACMAD project(African Center for Meteorology Applications for Development: CAAMD in French)

In line with a decision taken in April 1985 by the Conference of Ministers of the UN Economic Commission for Africa (ECA), an African Center for the Application of Meteorology for Development, ACMAD, is to be set up in Niamey, Niger, probably in 1989.

ACMAD has been designed with technical advice from the WMO, and its scope will cover the whole of Africa. Its long-term objective is to foster a balanced development of advanced meteorological techniques in the national weather services of African countries. The immediate aims are (i) to strengthen the capacity of national establishments (ii) to issue periodic climatological and meteorological data to the Government agencies responsible for early warning, to monitor crops in particular and help combat drought and desertification in general, and (iii) to increase the use and application of meteorological data.

The main products expected from the center once it is operational are:

- Short-term forecasts (up to three days), possibly medium-term forecasts (up to ten days), and seasonal forecasts for the whole of Africa;
- A watch system on meteorological and allied phenomena (drought, floods, cyclones, desert locusts);
- Practical methods for applying meteorology to agriculture;
- Training of scientific and technical staff;
- A weather data base for Africa;
- Research work;
- Regularly published climatic maps and forecasts;
- An information distribution network.

For the first two years of its existence, the ACMAD center means to avail itself of the resources already available in Niamey, the AGRHYMET center especially. In the next phase, ACMAD will receive AGRHYMET products in exchange for its own contribution: advanced technology and methodology; weather forecasts (short-term, medium-term and seasonal); hydrological, agrometeorological and meteorological data; and analyses of countries outside the CILSS.

To accomplish this range of tasks, the ACMAD center will have to make considerable use of RS. The kingpin of its RS facility will be a high resolution receiving station. For ACMAD to be able to supply services to all the agencies connected with it, the receiving station will have to be able to process data received directly in real time, either from the satellite's operators or from neighboring direct-capture stations.

Also planned is a direct-capture system allowing acquisition of data virtually in real time from high resolution weather satellites run by the ESA, India and the United States.

ACMAD is also scheduled to process data on Earth resources transmitted by the LANDSAT satellite in the United States and SPOT in France. The data would be obtained through an arrangement with the satellite's operator or with a neighboring direct-capture station.

Such a receiving station with its ancillary facilities could include three sub-systems: one for input, with an antenna and electronic equipment; one for processing, with a computer; and one for output, with a capacity for storage and duplication of the data transmitted and analyzed.

A preliminary estimate drawn up in late 1986 put the cost of such a station at $2.5 million, not including installation costs, operator training, or secondary expenses. The staff required to run the station could number as many as a dozen, while the ACMAD center as a whole would have about forty officers in all and an overall size similar to the Niamey RAC.

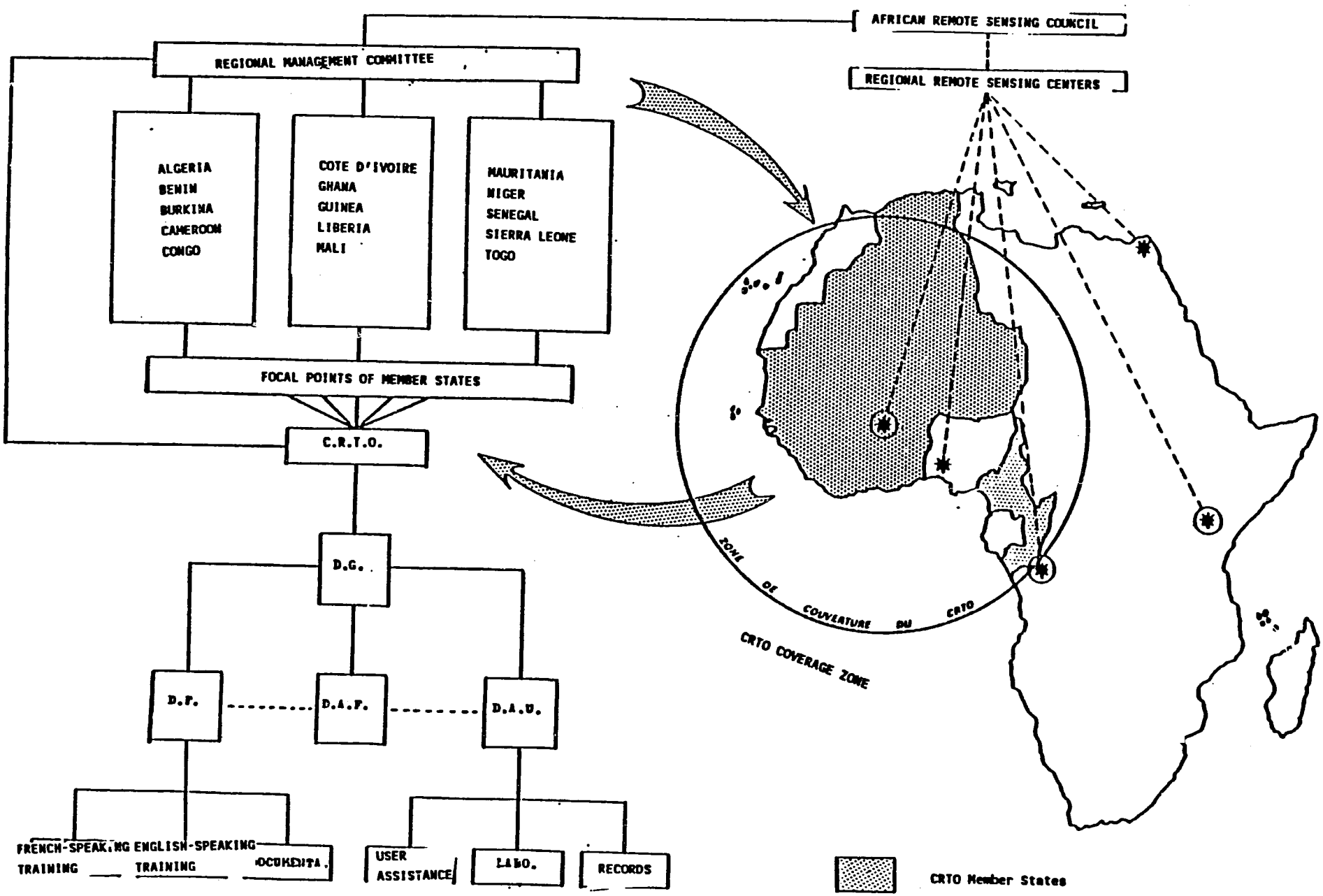
It is to be hoped that those responsible for the project, the ECA and WMO particularly, will take care not to duplicate the equipment already installed at the RAC or scheduled there. The RAC will soon have a receiving station for NOAA imagery, but with its present METEOSAT SDUS it can capture METEOSAT data only in analog mode (WEFAX system). It would seem reasonable, therefore, for the planned ACMAD RS center to confine itself to a PDUS for METEOSAT data, capturing directly in digital mode. As regards SPOT and LANDSAT data, a receiving station would cost far more and be far harder to justify.

Lastly, the main products ACMAD will supply in addition to those already available in the CILSS region will be weather forecasts (at first only short-term forecasts) and synopses for Africa as a whole. While up to now RS has been applied in the Sahel primarily in agroclimatology, weather forecasts should make it possible to utilize the agrometeorology potential to the full and supply farmers with timely information that will be useful in their work.

As regards desert locust surveillance, there is a danger of the work planned by ACMAD duplicating work already done, by the FAO in particular.

4. The Ouagadougou Regional Remote Sensing Center (CRTO, Centre Régional de Télédétection, Ouagadougou)

The CRTO, which covers West Africa as a whole, was set up following the Conference of Ministers of the UN Economic Commission for Africa (ECA) in Kinshasa in 1977; the Center was created in 1978. Four other remote sensing centers were also planned at this conference, in Kinshasa, Zaïre; Nairobi, Kenya; Cairo, Egypt; and Ile-Ife, Nigeria. Only the Cairo and Nairobi centers exist today in any real sense.



OUAGADOUGOU REGIONAL REMOTE SENSING CENTER
(C.R.T.O.)

Besides Burkina Faso, Mali, Mauritania, Niger and Senegal, the CRTO embraces Algeria and the coastal countries of West and Central Africa. Its main activity is training in RS. After modest beginnings, appreciable progress has been made in training over the past eight years, as the teaching staff has grown and better equipment has been acquired, photographic equipment particularly. Up to the end of 1985 the CRTO gave 206 Africans an initiation training in RS, and took 97 on to the application stage.

Since 1983, the activities of the Ouagadougou Center have fallen into three categories: contributions to outside projects (cf. table of projects), demonstration projects and training schemes.

The Center has been funded by its Member States ($440,000 in 1986) and two main donors: the United States to the tune of $3.375 million although they have now withdrawn, and France, which has contributed since the beginning and paid a total of $400,000 in 1986. The Center has had to face financial difficulties, as Member States' contributions have not always arrived on time.

During the second half of 1987 the UNDP gave $100,000 to finance a World Bank mission to strengthen and assess the CRTO.

The Center's ambition was to have a combined SPOT and LANDSAT ground station, which would enable it to work virtually in real time instead of having to rely on distant US or European sources for the supply of data and imagery. This hope has not yet been fulfilled, and the contribution of the CRTO, to the Sahel countries in particular, has been a very modest one compared to that of the Niamey RAC or even that of the specialist agencies in Dakar (CRODT, UTIS, etc.). It should be noted, however, that the French Ministry of Co-operation still has in its budget a program credit item for the installation of a SPOT image receiving station at the CRTO (a theoretical FF 30 million has been set aside since 1987). However, many people doubt that this project will become a reality in the near future.

In the first place, a station of this kind covering a 2,700 km circle around Ouagadougou would cost far more than this ($10 to 12 million for SPOT alone, $15 million to $18 million for SPOT and LANDSAT, plus $3 million for the processing system. Annual running costs would come to about $2 million or $3 million). In the second place, it is not a great disadvantage to use SPOT and LANDSAT images with a certain time-lag. Unlike the meteorological data from NOAA and METEOSAT, data from the Earth observation satellites can, as often as not, be perfectly well be utilized with a certain time-lag, especially for determination of cultivated acreage or attempts to discriminate between crop species on test zones. SPOT Image in Toulouse and EOSAT are now capable of supplying the necessary data or images within an acceptable space of time.

To conclude, despite its name, the CRTO in Ouagadougou is not a key element in the Sahel's RS system. Apart from training, the CRTO's contributions to projects on the ground are shown in the recapitulative tables of current operations (most of these are geared towards experimental research). Only if a SPOT receiving station is installed there - a possibility that is not to be ruled out, after all - will the CRTO become a truly operational center.

REMOTE SENSING PROJECTS FOR THE SAHEL

(See key at end of tables for main promoters)

SUBJECT AREA (Main field benefiting)	Date of origin	APPLIED RESEARCH OR OPERATIONAL PROJECT	OPERATOR	SATELLITES AND DATA PROCESSING	FUNDING, PROMOTERS	COUNTRIES BENEFITTING
AGROCLIMATOLOGY						
WEATHER MONITORING	1979	AGRHYMET Program (RAC and national weather services)	RAC + CILSS countries' ntnl. weather services	METEOSAT + Lannion CSM	States + CILSS AGRHYMET Prog. donors	CILSS
	1982 1987	Quantitative estimates of precipitation (Dugdale & Barrett or TAMSAT and Bristol methods)	Reading & Bristol Universities	METEOSAT	British ODA + EEC/FAO	CILSS
Rainfall, rainclouds, temperature RET	1986 1987	EPSAT (Estimation of Precipitation by Satellite) (Ouagadougou degree square) EPSAT (2nd phase in Niger: Niamey radar)	CNRS ORSTOM (Lannion + Mines, Paris + CNRS weather center, Palaiseau	METEOSAT 2	UNDP/WMO (Fr. Min. Coop + Min. Sci. Res.)	BURKINA + NIGER
	1985 to 1987	Determination of regional water balance:		METEOSAT (cf Assad thesis)	EEC (DG VIII)	SENEGAL NIGER
		(1) 1985-86, early 1987: rainfall estimation and mapping	UTIS (Senegal) IRAT + INRA + LERTS (CNES)	NOAA		
		(2) Oct. '87 water balance map (RET)	Idem	NOAA		
	1988	Italian project for Niamey RAC; Experiments in Italy and Mauritania and image interpretation	Italian weather service + AGRHYMET	METEOSAT NOAA	ITALY	CILSS
	1988	ARTEMIS (rainfall, vegetation index, locusts)	FAO (RSC)	METEOSAT LANDSAT/NOAA	FAO + NETHER-LANDS (NLR)	AFRICA (Phase 1)
	1986	ESPACE (estimation and monitoring of agricultural production according to climate and environment)	IRAT- AGRHYMET ISRA Senegal IER Agrométéo Mali, ORSTOM Mali	METEOSAT + NOAA Lannion CSM	French Min. Coop.	MALI SENEGAL
VEGETATION INDEX and crop monitoring	1986	Supply of NDVI vegetation indices since 1986 Telex + diskettes + training and permanent technical assistance from seconded staff	AGRHYMET RAC + CILSS States	NOAA/CIAT Columbia Univ.	USAID	CILSS
Rainfall, vegetation index, locust surveillance	1988	Equipment and supplies for HRPT NOAA receiving station at Niamey RAC + technical assistance thro' permanently seconded staff	French Min. Coop. + AGRHYMET RAC	NOAA AVHRR receiving station	French Min. Coop., FAC	AGRHYMET RAC

SUBJECT AREA (Main field benefiting)	Date of origin	APPLIED RESEARCH OR OPERATIONAL PROJECT	OPERATOR	SATELLITES AND DATA PROCESSING	FUNDING, PROMOTERS	COUNTRIES BENEFITTING
Contd. VEGETATION INDEX	1986	RS training in USA (Missouri) for Sahelian specialists	NOAA + Univ. Columbia (Missouri)	NOAA	NOAA	CILSS
and crop monitoring	1986	Study of Sudano-Sahelian plant biological rhythms (vegetation formation cycles)	ICIVT (Toulouse)	NOAA-AVHRR SPOT/LANDSAT TM		BURKINA (N-W) N. COTE D'IVOIRE
	1987	Joint pilot project between Senegalese & Gambian govts. and USGS: vegetation index	USGS/EROS Data Center	NOAA + AVHRR	USAID	SENEGAL GAMBIA
	1985	Processing of agroclimatological data and veg. indicators (methodology using microcomputers)	Copenhagen University	CHIPS image processing system	EEC	CILSS, esp. SENEGAL
PRODUCTION MONITORING, CROP FORECASTING	1985	Agricultural statistics by RS in Niger Système d'Observation Statistique par Télédétection (SOSPAT) Production estimating (acreage + yield) with ground surveys and aerial photographs	DDPA	SPOT + SPOT-Image (Toulouse)	FAC FF5 million end '87	NIGER
(Differentiating crops, cultivated acreage, yield forecasts)	1986	Cropping system assessment in cotton-growing region (cotton/corn plots); detailed classification of surface states	IRAT, IRCT	SPOT	French Min. Coop?	BURKINA (West)
	1986	Inventorying and monitoring of crops in Africa's Sudan zone, Bané scheme plots, differentiation of crops, vegetation index (secondary consideration)	DDPA CRTO-AAVV	SPOT	FAC + PEPS (SPOT prelim. evaluation prog.)	BURKINA (Bané)

SUBJECT AREA (Main field benefiting)	Date of origin	APPLIED RESEARCH OR OPERATIONAL PROJECT	OPERATOR	SATELLITES AND DATA PROCESSING	FUNDING, PROMOTERS	COUNTRIES BENEFITTING
PRODUCTION MONITORING, CROP FORECASTING contd.	1983	Monitoring of renewable natural resources in the Sahel Cereal crop forecasts (method + equipment + training for each CILSS State)	SODETEG JRC Regnl. coord. team (CILSS AGRHYMET RAC) natnl. units	LANDSAT and (occasionally) SPOT	EEC (EDF) (JRC)	CILSS (Experiment in MALI)
	1988	ARTEMIS (see above: Weather monitoring)	FAO	METEOSAT LANDSAT + NOAA	FAO	AFRICA, esp. CILSS (AGRHYMET)
LIVESTOCK	1985 1990 1991	1:500,000 mapping of biomass and location of Sahelian grazing land	CNRS/Imagéo	NOAA Mas Palomas + Imagéo Paris	CNRS + Fr. Min. Coop. F 1 m p.a., total FF5-6 m min.	MALI
Biomass vegetation index	1987 1988	Sylvo-pastoral development in the Ferlo (M'Biddi area). Rangeland management, extensive stockraising Senegal, monitoring of herbaceous layer in rainy season	ISRA/ORSTOM/ UTIS	METEOSAT + NOAA + SPOT	FF1.3 m with F 0.5 for RS	SENEGAL (Ferlo) M'Biddi grazing
	1984	Estimation of grazing resources by RS in South Tamesna, Niger	IEMVT + Niger Min. of Animal Resources and Higher Education Min.	NOAA + SPOT + LANDSAT	French Min. Coop.	NIGER (South Tamesna)
	1987 1988	Use of RS in estimating biomass production of Tahoua "integrated stockraising" project zones	Universities of New Mex. & TUFS	NOAA + AVHRR	USAID	NIGER (Tahoua Agadès region)
	1979	Pilot project: inventorying and monitoring of Sahelian pastoral ecosystems (rangeland maps of 3 regions, each 10,000 km²)	ISRA + FAO	LANDSAT	FAO + UNDP	SENEGAL
	1987	Estimating the herbaceous biomass of North Senegal at end of 1987 rainy season	Senegal Min. for Prot. Nat./Cent. de Suivi Ecologique (CSE)	NOAA/AVHRR + CSE CHIPS image processing system (with P-P at Copenhagen University)	UNDP/ OPE/UNSO	SENEGAL (North)

SUBJECT AREA (Main field benefiting)	Date of origin	APPLIED RESEARCH OR OPERATIONAL PROJECT	OPERATOR	SATELLITES AND DATA PROCESSING	FUNDING PROMOTERS	COUNTRIES BENEFITTING
HYDROLOGY	1985 1986	Monitoring and management of the Senegal Valley (run by OMVS)	BDPA	SPOT	FAC + UNDP	MALI, SENEGAL MAURITANIA
	1985	Search for underground water in the Adrar des Iforas, Mali	Analytical Lab. (Ireland) Geological Service (Italy)	LANDSAT	EEC	MALI
	1985	Hydrological indicators, Senegal basin, for forecasting of high-water flow	Inst. of Litho-sphere Geophysics Milan, Italy	LANDSAT	EEC	SENEGAL
	1986	Study of Lake R'Kiz: areas flooded, floodland crops	BDPA	SPOT	EEC	MAURITANIA
	1986	Mapping of soil infiltration and runoff capacity in a Sahelian drainage basin, by SPOT image interpretation (Mare d'Oursi drainage basin)	ORSTOM, Ouagadougou	SPOT	Fr. Min. Coop.	BURKINA
FORESTS	1985	Inventorying and monitoring of tree stands (wind erosion)	Universities of Berlin, Munich, Reims	LANDSAT	EEC	CILSS
	1985	Dynamics of interface between natural environment and forests (vulnerable areas)	ICIVT Toulouse			W. AFRICA
	1985	Forest inventory of Mali (south of 16th parallel)	BDPA + CTFT	LANDSAT, then SPOT	FAC	MALI

SUBJECT AREA (Main field benefiting)	Date of origin	APPLIED RESEARCH OR OPERATIONAL PROJECT	OPERATOR	SATELLITES AND DATA PROCESSING	FUNDING PROMOTERS	COUNTRIES BENEFITTING
MISCELLANEOUS	1986	Periurban environment of a big town in the Sahel: Bamako. Cf. Delorme report - Bamako test study	University of Louvain, Belgium	SPOT	EEC (DG VIII)	MALI (Bamako)
	1984	Inventory of agricultural lands: prodn. of development plans for Eastern Senegal	BDPA	LANDSAT	IBRD	Western SENEGAL
	1984	Soil mapping of the Senegal Valley and crop suitability	BDPA + IRAT	LANDSAT	FAO	SENEGAL
	1984	Inventory of vegetation tiers, inland Niger delta; locust control		LANDSAT	FAO	MALI
	1984	Provision of hardware (RAC + national weather services)	NOAA, NESDIS	NOAA/NESDIS/ AISC	USAID	AGRHYMET + CILSS states

COMMENTS:

1) This list does not include ongoing operations or initiatives carried out by the RS centers such as the Niamey RAC or the CRODT in Dakar, or the DRRSC in Ouagadougou or government departments in the CILSS countries. Nor does it mention ongoing technical assistance supplied by outside bodies, eg. WMO assistance to the AGRHYMET Program or more broadly ongoing assistance from satellite agencies or data processing stations.

2) The above table makes no claim to be an exhaustive list of recent or current RS projects and operations in the CILSS countries. It covers most of them, insofar as the author has been able to identify them.

KEY

USAID
CEC
FRANCE
UNDP
FAO
WORLD BANK

RS PROJECTS, BY PROMOTER AND FUNDING

I - MANAGEMENT AND GENERAL ASSISTANCE (for information only)

1) SAHEL: AGRHYMET: Program supported by the CILSS Secretariat and Government departments of the CILSS countries

- Assistance to CRTO

- DIAPER Project connected with research for improved agricultural statistics (crops acreage and forecasting)

- All CILSS member countries:

  . participation and assistance in ongoing research projects in the region
  . co-operation of national weather services in operations, AGRHYMET particularly.

- Senegal, CRODT/UTIS: Dakar center, processing station, numerous projects, particularly in association with ORSTOM, France

2) Donors to the AGRHYMET program: UNDP, USAID, Netherlands, France, Belgium, etc.

II - PARTICIPATION IN RESEARCH PROJECTS OR OPERATIONAL ACTIVITIES

- USAID and other US agencies (6):

. NOAA Program (METEOSAT equipment, one representative permanently seconded to the Niamey AGRHYMET Center

. NOAA vegetation index: AGRHYMET, CILSS countries

. Training in RS

. FEWS (Famine Early Warning System)

. Joint Senegal/The Gambia/USGS pilot project: The Gambia/Senegal vegetation index (image), May-June 1987 - NOAA-AVHRR/EROS Data Center

- Estimation of biomass production in "Tahoua integrated livestock project" zone - New Mexico University - NOAA-AVHRR

- **EEC (8):**

  - Surveillance of natural resources: CILSS
  - Regional water balance (Senegal rainfall map; Niger water balance [RET] map)
  - Vegetation index processing project; microcomputers; CILSS (particularly Senegal, CHIPS system)
  - Search for underground water in the Adrar des Iforas, Mali
  - Hydrologic basin indicators, Senegal basin, for predicting high-water flow: Senegal
  - R'Kiz lake study (area flooded, floodland crops): Mauritania
  - Tree cover inventory and surveillance (wind erosion): CILSS
  - Periurban environment of major towns: Bamako, Mali

- **WMO (3):**

  - Implementing agency, along with the FAO, of the AGRHYMET program
  - Technical advice and design of ACMAD center
  - Technical assistance for CILSS countries' weather services

- **UNDP (4):**

  - (+ WMO) - EPSAT project (precipitation): Burkina
  - (OPE-UNSO) Estimation of herbaceous biomass, North Senegal: Senegal
  - (+ FAC) - monitoring and management of the Senegal Valley (as part of OMVS): Senegal, Mali, Mauritania
  - UNEP + FAO up to 1979: pilot project for inventory and surveillance of pastoral ecosystems (3 x 10,000 km^2 rangeland map): Senegal

- **FAO (5)**

  . Soil mapping, Senegal Valley, and crop suitability: Senegal

  . Inventory of vegetation tiers: inland Niger delta; locust control: Mali

  . ARTEMIS: rainfall, vegetation index, crop monitoring, locusts

  . Rangeland maps: from 1979: Senegal (with ISRA and UNEP)

  . Implementing agency (with WMO) of AGRHYMET program

- **FRANCE (12):**

  . Installation of NOAA receiving station at RAC: CILSS (equipment + four expatriates, French Co-operation Ministry)

  . Study of plant biological rhythm (ICIV, Toulouse): Burkina

  . Evaluation of cropping system in cotton-growing area (IRAT + IRCT): Burkina (west) (cotton, corn)

  . Crop inventory and monitoring, Bané: Burkina (Co-operation Ministry, FAC)

  . RS statistical observation system (SOSPAT), BDPA: Niger (Co-operation Ministry; FAC)

  . ESPACE (agricultural production monitoring): Mali + Senegal (Co-operation Ministry)

  . Rangeland biomass mapping: Mali (Co-operation Ministry)

  . Sylvo-pastoral development in the Ferlo (M'Biddi): ORSTOM + ISRA (Senegal)

  . Evaluation of forage resources, South Tamesna: IEMVT (Co-operation Ministry)

  . Mapping of soil infiltration and runoff capability (Mare d'Oursi): Burkina (ORSTOM)

  . Dynamic interfaces between natural environment and forests (ICIV Toulouse): West Africa

  . Mali forest inventory (Min. Coop, FAC)

- **OTHER**

British Overseas Development Agency (ODA): precipitation (Dugdale & Barrett) CILSS (+ FAO)

Netherlands: cf. FAO (ARTEMIS) equipment + design + engineering

World Bank: eastern Senegal project; maps; BDPA

Italy: sending of material, training and experiment jointly in Italy and Mauritania

Canada: identification of hydro-geological and forest sites for establishing small schemes (irrigation, wood, food crops).

THEMATIC LIST OF RS PROJECTS IN THE SAHEL

I -	**AGROCLIMATOLOGY**			**16**
	Weather:			
	Weather forecasting & monitoring	1	4	
	Rainfall	3		
	Crop monitoring			
	RET	1		
	Vegetation index	5	12	
	Yield			
	Specialist RS training	1		
	Crop acreage	5		
II -	**LIVESTOCK**			**7**
III -	**HYDROLOGY**			**5**
IV -	**FORESTS**			**3**
V -	**MISCELLANEOUS**			
	Regional development + equipment			3
	Total projects			**34**

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RS PROJECTS IN THE SAHEL BY COUNTRY

CILSS 7	SENEGAL 9-10	MAURITANIA 2
	MALI 6	THE GAMBIA 1
	BURKINA 6	CHAD 0
	NIGER 4	

PART THREE

REMOTE SENSING AND ITS CONTRIBUTION TO THE SAHEL

Having inventoried existing projects and initiatives that use RS, we must now assess their results. This comes down to asking what benefit the Sahelian countries have drawn, or are likely to draw in the near future, from these modern technologies.

The future has to be taken into account, as space science and its allied technologies are developing so fast that significant breakthroughs can be made in the space of a few years. This should be borne in mind when trying to assess the merits of RS; assessments we may make of a given satellite product today are very different from those we would have made four or five years ago. Will this be equally true in the future? As a rule, of course, the curve of progress flattens out fairly fast, gradually slowing down as new ways forward are sought. But in many fields of RS application, there is doubtless still a wide margin for further advances between now and the end of the century.

We ought therefore to use some caution in our assessment of the different RS operations, their products and cost, for that assessment may prove short-lived. Caution is also called for when making comparisons with similar, more or less competing products born of more traditional methods applied in the field, in which the margin for potential progress is often quite narrow.

These considerations put forward, one must nonetheless make some assessment of RS in the applications or research experiments carried out so far on behalf of the CILSS countries. There are several possible approaches. The products can be assessed one after the other, but this has been done to a large extent in the product profiles in Part One of this report. An alternative approach is to look at the contribution RS has made from the standpoint of the users. Users are of course in a good position to judge a given product, be it a specifically RS product or one comparable to products that can be obtained without the use of RS, and in this way an assessment can be made of how valuable, indispensable, inexact, secondary or superfluous RS may be.

This latter approach seemed more instructive, as it would add to the points of view put forward by the promoters, donors and specialist operators. As we shall see below, there is no

shortage of opinions from any of these quarters. Not all the opinions are entirely disinterested, some coming from teams that are more or less in competition with each other, especially in the vast field of experimental research, or from big organizations or services whose work is in competition with RS and may even be hostile to change. Space technology is no more immune to professional coteries, corporatism, system loyalty and domination by large institutions than any other field. What is more, the introduction into an impoverished Sahel of such high technology and sophisticated hardware as RS involves, contrasting so sharply with the means at the disposal of the local services, inevitably arouses conflict, apprehension or rejection.

All this means that the opinions and assessments of different parties are of great utility, even if they must sometimes be toned down - which we shall do as and when appropriate.

A preliminary comment is called for in this connection. It concerns the fair criticism one sometimes hears, that certain promoters of RS products and equipment tend to overemphasize the gadgetry aspect of the technology. The introductory quotation at the beginning of this report is typical of this unfortunate tendency to present satellite images through impressive but costly equipment, which may or may not be necessary but is often premature in terms of the technological environment and priorities. This deviation not only concerns the Sahel - it is widespread since the birth of visual data processing technology.

Conversely, those accustomed to field work often have a hostile initial reaction to RS and everything connected with it. For them, the only way to salvation is through working directly from the real, the palpable - or indeed through conventional and often routine methods. Their systematic mistrust of satellite techniques is all the more awkward in that many of these people have important roles in the various Sahelian structures contributing to famine early warning, crop or rangeland monitoring, etc.

Fortunately, as time goes by the two sides get to meet each other, joint operations and experiments are run, and the gulf between them is gradually bridged. Better mutual understanding is developing; there is still, however much mistrust on both sides, and this is a problem that goes far beyond assessments of the value of satellite products for the Sahel.

Bearing all this in mind, we shall borrow widely from the opinions, suggestions and criticisms of commentators in the different groups involved. We shall take them according to types of objective.

* * *

Knowledge of pluviometry is essential for the Sahel. The ideal would be to know, at all times, the amount of rain that has fallen at any given site.

One glance at the ground observation stations on the map and their communications means shows what an immense gulf there is between this ideal and the reality. There is no need to stress how irreplaceable satellite observations are in this field. The real question is not **whether** RS should be used, but what kind of contribution it can make; at present it contributes much, but not as much as it potentially could.

In our earlier analysis of the products elaborated and distributed by the Niamey RAC, we saw in practical terms the usefulness of RS, on its own or in combination with other measurements from the West African weather network. The ten-day meteorological bulletin takes account of squall lines and precipitation events affecting the CILSS countries during the rainy season. The RAC, as we saw, monitors cloud clusters and daily rainfall zones virtually in real time. With maps and other products based on METEOSAT digital data sent by mail from the Lannion CSM, the RAC has ten-day information and a qualitative glimpse of the rainfall zones, from which it can plot isohyets in the low-rainfall zones. Lannion also provides maps based on radiant surface temperature, from which one can plot isotherms; these provide a wealth of information about the arrival of the rainy season in the Sahel, its fluctuations through the season, and the return of the dry season.

Most of these records are drawn up from METEOSAT data. The installation of a primary data user station (PDUS) to receive these data directly would enable the RAC to bypass the precious Lannion relay and save him a little time. A PDUS is planned for Niamey as part of the future ACMAD center. In the meantime the RAC may find a technical solution for direct capture and processing of METEOSAT data in digital mode at reasonable cost.

Even now, the products available in the pluviometry field in the CILSS countries are to a large extent derived from satellite data. It is to be hoped that in the near future, information on precipitation - which at present is often only qualitative - will gradually become quantitative.

Grasp of the spatial distribution of the rains will also improve, if only with the potential offered by the new NOAA imagery HRPT ground station to be installed at the RAC.

Weather forecasting should also make appreciable progress; the future ACMAD center, for example, has included this in its schedule. It will probably be five or six years before forecasts are available; when they are however, RS will have made it possible to consider giving the small farmers of the Sahel the benefit of rainfall predictions.

Many other agencies also make their contribution to the Sahel countries. Some, for example, produce records of a more or less

similar kind to those produced by the RAC, eg. Price Williams on behalf of USAID (FEWS project) and the FAO RS Center (ARTEMIS project). Many research institutes scattered about Europe (in France and the United Kingdom especially), and of course Sahelian institutes (primarily in Dakar), are working to improve and standardize satellite data on rainfall and weather phenomena in the Sahel and improve their interpretation. Certain experiments are considered interesting from the standpoint of long-term forecasting of the rainy season (see above studies by Lannion CSM and ORSTOM-CRODT Dakar). Others, perhaps less spectacular because less speculative, involve analysis of weather phenomena which, once they are better known, will facilitate further progress. All these activities are useful, provided they are not too scattered, and provided there is a minimum of co-ordination between them to prevent duplication of effort and that compartmentalization to which scientific research is subject now and then.

The state of the vegetation is another major preoccupation in the Sahel. The ability of local or central Government, co-operation agencies and donors to react in time in the event of famine depends on being able to monitor crops and grazing land. Besides rainfall data, it would be useful to know, earlier and more precisely for the whole of the Sahel, the factors that determine or reveal the state of the vegetation.

Whether one looks at evapotranspiration, soil moisture, the water balance, vegetation index, yield forecasts, or the extent and quality of grazing, RS has its contribution to make. This is rarely an exclusive contribution, as ground observations are, at least potentially, fairly numerous and helpful in these fields. But given the nature of the Sahel with its vast expanses and modest survey networks, and given the unarguable advantages of RS in this respect, satellite techniques are playing an increasing part in crop and rangeland monitoring.

Not all satellite data lead to products of equal precision, reliability and quality. The usefulness of the different indicators needs to be assessed with care.

Estimates of real evapotranspiration (RET) from satellite sensing of surface temperatures has been the subject of many studies. Some of these have shown that it is possible to use METEOSAT thermal infra red data to map RET, so complementing the agroclimatic data from the ground network. But the problems encountered in this field must not be overlooked. One experiment in Senegal showed that the problems lie on the one hand in the uncertainty of the surface temperature values, and on the other hand in assessing RET over areas of 5 x 5 km, using models of the water balance. Only with better-calibrated thermal infra red data and with two NOAA satellite channels might one find a practical answer to these problems. Moreover, while waiting for the new generation of METEOSAT satellites to come into operation, it seems more logical to reserve METEOSAT for monitoring rainfall events, and to consider using NOAA data

for mapping RET. More precise calibration is possible with NOAA thanks to its higher spatial resolution (1 km^2 as opposed to METEOSAT's 25 km^2).

Here again, the NOAA ground station in Niamey will put the RAC's Agrometeorology Applications Division in a good position to play its part in taking this type of satellite product through to the operational stage.

The vegetation index is a typical product of remote sensing. It was developed in the United States, and only appeared in the Sahel a few years ago, introduced by NOAA/NESDIS/AISC (USAID Program). It is a spectacular and alluring satellite observation product. Much research has been done on the subject in the United States, Europe and Africa - where there is particular need for such an index.

Since 1985, the AGRHYMET center has made increasing use of this index. Experimental at first, use of the index has now become operational, even though, once again, the technique has its limitations. With the forthcoming NOAA ground station, substantial progress can be made, both in spatial resolution and in lead times for utilization of the images. Good results may be expected in this field, and with the technology transferred to the Sahel the region will no longer have to rely on the United States to supply the vegetation index.

This product is a good indicator, as it gives an immediate reflection of the combined appearance and vigor of the vegetation. It is very useful to anyone wanting a broad idea, during the rainy season, of the areas where conditions are most favorable or least favorable, further advanced or more backward. From readings taken during the growing seasons of two successive years, some very instructive comparisons can be made.

However, one example will suffice to give a notion of the aberrant results that can be obtained if the vegetation index is too hastily employed. As it is based on the reflectance of plants, which in turn is a function of chlorophyll activity, one may get a high index after rain in a sub-desert area where an intensely green flush of very short grass will have emerged; but in an area of dense growth where no rain has fallen for some time, one will get a low index because the grass has yellowed, although it is still abundant. As one can see, then, this index reflects the greenness of the vegetation and green biomass rather than total usable biomass. This is an important point when it comes to monitoring rangeland or - to a lesser extent - crops. It shows yet again the need to correct satellite information and combine it with the other available data (type of region, date in relation to the season, vegetation type, etc.). Lastly, it will be remembered that the nature of the Sahel in itself adds to the lack of precision (non-uniform crops, soil effects, etc.)

But all in all, provided the satellite vegetation index is judiciously used, it is a very useful instrument. Its is recommended for monitoring vegetation with a view to early warning and monitoring of the cropping and grazing seasons. However, the hopes that had been nurtured in recent years - that one could use the vegetation index to deduce yield estimates and forecasts - are still a long way from fulfillment.

AGRHYMET, with the support of NOAA, attempted to estimate yields in 1986. The experiment was not repeated in 1987, despite NOAA's conviction that it was feasible.

The problem is that the correlation between yield and vegetation index is by no means established. The vegetation index enables one to monitor natural vegetation as a whole, but the state of crops does not vary in exactly the same way as the natural vegetation; crops are more sensitive to drought and intermittent rain than is natural herbaceous growth. Measurement of the state of health of the natural vegetation can be a good indicator during a period of severe drought; but if the vegetation in general is in good condition, this does not necessarily point to good crop growth. The US National Research Council experts' appraisal report on the NOAA/CIAT products (January 1987) considers that the vegetation index worked out for the Sahel is not based on a valid method. They conclude, on the subject of quantitative yield forecasts for the Sahel and the Horn of Africa, that it is beyond the scope of the technology and data employed, especially in view of the grid cell (1° x 1/2°). This assessment is disputed by the NOAA/CIAT operators in their reply of May 1987, however. Furthermore, some of the NRC's arguments will be obsolete once the NOAA ground station at the Niamey RAC is operational (higher spatial resolution and faster utilization of data).

For grazing land, the vegetation index is more reliable, and despite possible aberrations such as those cited in the example above (dense yellow grazing versus short green grazing), once combined with other data such as place, season, soil type, etc., it gives a fairly good idea of the state of the herbage at a given moment and even, in many cases, of the quantity of biomass available.

All in all, then, the vegetation index is a very useful additional tool, provided one does not ask more of it than it can provide and provided it is judiciously used, along with the various traditional indicators of the state of the vegetation. These are as a rule quite varied and fairly accessible, facilitating good comparisons and correlations with the satellite index.

Estimating cropland acreage and predicting harvests

Great hopes for harvest estimates for the Sahel were raised by the launching of the LANDSAT family of satellites and then, in February 1986, SPOT 1 with its even higher spatial resolution (10 meters in black and white, 20 meters in color). It was thought that RS would now be of considerable assistance to the statistical services. The indicators examined above (rainfall, RET, vegetation index) already constitute appreciable complements to traditional information resources, or substitutes for them. The possibility of measuring cropland acreage and even distinguishing different crop types or species by the use of such precise sensors (which would be rather like a zoom lens compared to those of the other satellite families, NOAA and METEOSAT) looked real; if one could measure the areas for cereal cultivation in the Sahel, one could combine these figures with estimates of yield from sample areas, and produce a harvest estimate. One can well see the value of such an operation for the CILSS countries, which otherwise have very limited means of making harvest forecasts and estimates. To be able to make such an estimate for the whole region, in real time, from space, looked like a way of filling a serious gap in agricultural statistics and forecasting.

It is still a little early to give a definite reply on this issue. There are several experiments under way, but these are not yet completed; and they will not give the last word on the matter, since breakthroughs are expected in the coming period. However, several obstacles have been revealed, which enthusiastic operators and researchers had perhaps sometimes underestimated.

The first problem is that, by their very nature, high resolution sensors cannot cover a very large scene. Their use is thus obviously restricted to sample areas, since the cost of covering the whole of the region's cropland would be exorbitant. This test area method calls for field studies and laboratory work to stratify the cropland.

Another problem is to cover a given area in acceptable conditions. The LANDSAT and SPOT satellites have repetition cycles of 16 and 21 days respectively (which with SPOT can be cut to 4 days on request). This is a much lower coverage capacity than METEOSAT's or NOAA's, and is further limited by the fact that LANDSAT and SPOT use bands in the visible part of the spectrum, and therefore cannot observe the Earth's surface if it is hidden by cloud cover. But the Sahel would want cereals acreage measurements several times during the growing period which, naturally enough, coincides with the rainy season when cloud cover is at its maximum.

Lastly, as the LANDSAT and SPOT data receiving and processing stations are at Mas Palomas (Canary Islands, Spain) and Toulouse (France), there is a considerable time-lag involved in

the dispatch and receipt of satellite images and data for the Sahel countries.

Applied research work undertaken (especially over the past two years) to find ways of discriminating between crop species has proved very disappointing. Despite the excellent resolution of the SPOT image and its small scene size, it has not always been possible to avoid the same stumbling blocks we have mentioned in relation to NOAA vegetation indices for the Sahel. It has not been possible to distinguish between crop species - eg. millet and sorghum - and many specialists now seem reserved on the issue, or indeed pessimistic.

As to measurement of cropland acreage, so indispensable to any crop forecast or estimate, this is clearly not practicable on a large scale for the same cost-related reasons as given above; it is not even very convenient for use on test areas, owing to the technical limitations of satellite observation per see.

It is too early to say whether hopes of using satellite data for these purposes must be abandoned. It is hard to imagine what technical innovations and advances the next generation of satellites and sensors will bring. Between now and the end of the century we may look forward to even better spatial and radiometric resolution (i.e. sensitivity of reflectance measurements). And it is not impossible that during this period a SPOT or LANDSAT receiving station will be installed in the Sahel, at the CRTO in Ouagadougou for example; this would cut lead time and allow image records to be kept over long periods.

But for the next few years, it does seem that crop forecasts and estimates for the Sahel will have to be based mainly on traditional, local methods and resources. Satellite data will be used to back up the surveys, but only in specific instances, on a modest, experimental basis rather than the grander uses that had been hoped for.

This undeniable disappointment is due to shortcomings in space technology itself - but we must not overlook the fact that the Sahel is also desperately short of the resources to make good use of satellite products. Some such shortcomings were revealed at a technical co-ordination meeting of June 1987, held in Niamey and organized by the EEC's CILSS-EDF project for renewable natural resource monitoring in the Sahel. The regional co-ordination team for the project pointed to (i) overlap between research and operational application; (ii) inadequate resources and staff in the "national units" which, in the best of cases, had only one or two staff trained in the use of RS; (iii) problems of co-ordination and personal sensitivities at the national level; (iv) difficulties in setting up data bases in some member countries; and so on.

As we have seen, high resolution satellites make other useful contributions, in hydrology, the measurement of likely flood areas and floodland crops, woodland acreage measurement, or planning and development (for the big towns especially). Their

use is increasing in the Sahel itself, although often in the form of experimental applications or applied research.

* * *

Although they are so recent, satellite remote sensing techniques are already bringing the CILSS countries a very wide range of assistance. This fast-growing contribution has by no means reached its peak, if only because it is based on a technology that is itself developing very fast and unevenly.

Our list of projects, products and applications shows this very specific character of RS quite clearly. In all the CILSS countries, there are fully operational applications, experiments and applied research projects, all going on simultaneously, not to mention the programs being implemented in developed countries running satellites and ground stations.

From the point of view of Sahelian decision-makers, the merits of remote sensing must be judged by its usefulness in the drive to meet the great needs of their countries.

The EWS (early warning systems) gain most from remote sensing. They make widespread use of satellite data such as rainfall and vegetation index, to complement or compensate for local information. RS is a valued aid because of its rapidity and the fact that it gives a general picture for the whole of the region. Logically, the role of RS should increase in the coming period. Satellite imagery provides irreplaceable indications in case of drought; it has enabled the Sahelian authorities to know, at an early stage, the trend of the rainy season, areas at risk, locust hazards, the approximate trend of the coming harvest, and the state of the rangelands.

Quantitative crop forecasting, as we have seen, is likely to remain a job for field survey services for some time, as RS is not yet capable of measuring acreage per crop type or forecasting yield on an economic or operational basis. The technique is of little help, therefore, in the various attempts at early determination and quantification of the cereals harvest. This is unfortunate, as those responsible for these questions in the food aid, national planning and agricultural statistics services would have welcomed remote sensing as a data source. Perhaps this will be possible one day, as progress continues.

Those responsible for stock raising in the Sahel and, to a far lesser extent, the pastoralists themselves already benefit from rangeland information from satellite sources. With the aid of experiments carried out in Senegal, Mali and Niger, and particularly the aid of the forthcoming NOAA station at the AGRHYMET center, satellite data will reach a far more operational and efficient stage. Information will be coming fast from different branches of the RS system. But for pastoralists and farmers to make full use of this information,

a major training drive and much extension work will be required; and in that sphere it is the CILSS Governments that will have to take steps.

Lastly, much has been said in recent years about agrometeorological applications within the AGRHYMET program. Advice to farmers is one of the highest priorities among the projects envisaged. And what the farmers want above all is the possibility of knowing the weather in advance. In other words, if Sahelians had weather forecasts in the near future, RS would make a massive contribution: leaders, extension workers and farmers would be able to take the necessary steps to optimize their chances of crop success (sowing the right seed, ploughing, sowing and hoeing at the right moment, etc.).

The ACMAD African weather center project intends to start making short-term forecasts within a few years; let us hope that in the meantime the necessary structures will have developed far enough in CILSS countries to enable farmers, or at least the most advanced sections of the farming community, to reap the benefits of the new forecasts. And let us hope that communications resources will be capable of bringing the forecast to the farmer.

To end our review of the contribution RS is making to the Sahel countries, we must stress **the importance of training**, if satellite techniques are to be accepted, utilized and correctly applied. A number of establishments are attempting to prepare the necessary technical staff and specialists; most experimental projects involve Sahelian staff alongside foreigners; and there are Africans working alongside expatriates in RS activities that have attained operational status.

As we have already pointed out, the two establishments organizing preparatory training in satellite techniques are the CRTO at Ouagadougou, which is initiating young Africans into photointerpretation in particular, and the AGRHYMET center. Some of the specialists trained by the RAC with financial and technical assistance from the United States were also able to attend courses in Columbia, Missouri in 1986. The RAC also acts as a data host, receiving satellite data and redistributing to each of the CILSS countries by cable. Through the national and regional bulletins it publishes every ten days during the rainy season and the other products it sends out to Government departments and all those in the region who may be concerned, the AGRHYMET network is a vital structure for promoting satellite techniques. Used as an integral part of the agrometeorological analyses, which they illustrate with better and better maps, diagrams and graphs, RS techniques are shown to good advantage in the work of AGRHYMET, and many people get to know them by this channel.

CONCLUSIONS AND RECOMMENDATIONS

While remote sensing brings an undeniable contribution to early warning systems, crop and rangeland monitoring and climatology in general in the Sahel, it must be said in all honesty that it arouses genuine reservations in many, Sahelians and non-Sahelians alike. This includes decision-makers in the CILSS Executive Secretariat and in Sahelian Government agencies, usually those whose work should normally lead them to co-operate with the remote sensing world.

There is of course disagreement and compartmentalization in other fields too; co-operation between the national weather, agriculture or agricultural statistics authorities is not always easy, as we have seen in the past with early warning systems. Outside the Sahel, many donors too have reservations about remote sensing.

Our long examination of remote sensing is not exhaustive; it is virtually impossible to make a really full inventory of RS-based research work and experiments carried out in or on behalf of the Sahel. However, it can be seen from our appraisal that this new technology is already providing many welcome products. Satellite imagery is replacing or supplementing traditional means with greater and greater effectiveness. Above all, there should be significant breakthroughs in the coming years. As pointed out above, RS is of great utility in the pluviometry field; it is of real and probably increasing value in vegetation monitoring (crops and rangelands); but it is of uncertain utility in yield forecasting and harvest estimation, as results so far have been disappointing in cropland acreage measurement and discrimination between crop types. Satellite imagery also has specific useful applications in hydrology (areas under flood, floodland crops), in forestry, in environmental protection or development schemes, and in locust control.

Notwithstanding criticisms and reservations, RS has undeniable advantages. In view of their size and the inevitably sparse distribution of their ground observation resources, the CILSS countries are particularly well suited to certain RS applications, and have much to gain from their use. In other fields, however, such as harvest estimates and cropland acreage measurement, the Sahel is handicapped in comparison to regions like Europe or the Unites States that have large, uniform areas of cropland.

For early warning systems, as Gilles Hervio argued in his report of October 1987, satellite data are useful for several reasons. They provide a cartographic view of the region,

incomparably richer than the very local data gathered on the ground, from which it is difficult to extrapolate. They provide early indications of the areas undergoing the severest stress. And they are a way of measuring changes in the state of vegetation from year to year. According to Gilles Hervio, LANDSAT and SPOT data already provide a basis for stratifying land areas, which should improve the precision of statistical surveys appreciably. The writer concludes: "Satellite information is thus a valuable source of information, but it would be a mistake to expect too much from this technology. The hope of obtaining estimates of agricultural acreage per crop seems a long way off, and yield forecasts seem very dubious and unreliable".

* * *

To end this report, it may be helpful to suggest some **steps towards resolving misunderstandings and making up for the shortcomings of the present arrangements.** Below is a set of recommendations aimed at improving productivity in the many current attempts to apply RS to the countries of the CILSS:

- **Co-ordination of research and experimentation projects and programs to avoid unnecessary competition.** The Executive Secretariats of the CILSS and Club du Sahel could set up a joint body (CILSS countries, outside agencies and countries promoting the schemes) which could organize periodical consultative meetings (yearly, for example) through which the harmonization that is lacking at present would gradually develop. This would mean harmonization not only between participants but also internally, whereas we have seen throughout this study, co-ordination is sometimes very weak;

- **Creation by the CILSS Executive Secretariat of a more "directive" body to improve co-ordination of standard RS operations at both national and regional levels.** It would have to divide tasks between the regional AGRHYMET center, the CILSS member States, the CRTO, ACMAD and the receiving and processing stations (CRODT, UTIS, etc.) in such a way as to avoid waste, duplication of effort, and errors in choice of equipment. This body would be run by the RAC, and the main foreign donor organizations and agencies providing technical co-operation (FAO, ESA, Lannion CSM, etc.) would have observer status.

  Specific encounters organized at the RAC, such as the meeting on meteorology and surface states held in Niamey by the ISLCP (24th - 28th April, 1988) and the encounter on the utilization of NOAA data planned for this autumn, are useful. But real co-ordination can only come about through **plenary** meetings at which all parties are present.

The idea aired by some people, of gradually concentrating most of the standard RS operations for the Sahel at the RAC in Niamey is an attractive notion. It would certainly provide a genuine synergy, and savings in staff and equipment. But apart from the fact that it is the Diagnostic Permanent project, not AGRHYMET, that is responsible for agricultural statistics, harvest forecasting and cropland acreage measurement, it would seem that compatibility between different technical systems is very poor (between the data processing systems and receiving stations for NOAA on the one hand and SPOT and LANDSAT on the other, for example). Furthermore, at the political and institutional level, the establishments involved must be distributed among the CILSS countries geographically; and some of the agencies in question (CRTO, ACMAD) depend on other bodies than the CILSS, bodies whose membership and geographical scope are different from those of the CILSS.

* * *

Remote sensing has only appeared in the Sahel over the past few years. The techniques are being applied rather piecemeal in many different sectors, mainly through a wide range of research projects; and they are already making a significant contribution. Even if there are certain limitations in fields where greater things had been hoped for, the value of remote sensing is much appreciated by those concerned with early warning, crop and rangeland monitoring, and of course climatology.

But the cost of RS is high in terms of the modest budgets of the Sahelian agriculture, agricultural statistics and livestock services. Sophisticated equipment and highly skilled staff are required. These factors sometimes arouse apprehension and reservations, discouraging co-operation between those "on the ground" and those in the RS world. This inevitable opposition should gradually diminish, provided care is taken to bring all those concerned into mixed, theme-oriented teams, in research projects and, above all, in standard operations.

It is vital to avoid two major errors, both of which are particularly dangerous: (i) the assumption that remote sensing can replace traditional techniques in most cases, and (ii) the view that the technology is over expensive, superfluous and virtually useless.

The Sahel has been ill endowed by nature, and its problems are well known. It has at least had the good fortune to have given rise to some major RS initiatives; the technology has already made a major contribution, and there will probably be breakthroughs in the near future.

There are two imperatives, however:

- Those working with RS must make a great effort to co-ordinate their activities, avoid unnecessary expense, adapt their

products to the real needs of the Sahel, and find a way of fitting harmoniously into the existing arrangements;

- Those connected with the future of the CILSS countries in whatever capacity (decision-makers at national and regional level and in the co-operation agencies and international organizations) must not allow themselves to react unthinkingly against RS.

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