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Recent Drought Tendencies in Ethiopia and Equatorial Subtropical Eastern Africa

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Vulnerability to Food Insecurity:
Factor Identification and Characterization Report

Number 01/2005

Recent Drought Tendencies in Ethiopia and Equatorial-Subtropical Eastern Africa



This work represents a collaborative effort of FEWS NET Team members at the UCSB Climate Hazard Group, USGS National Center for EROS, and Chemonics International.

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Synopsis

Chronic and increasing food insecurity

- The average number of Ethiopians requiring food aid is growing by more than half a million people per year.
- These chronic and increasing aid requirements may soon extend beyond the capacity of early warning systems.

Recent declines in rainfall in water-insecure eastern and southern Ethiopia

- In some dry or heavily populated regions in the east and south water supplies and food production may be increasingly inadequate.
- Pastoral and agro-pastoral livelihoods may be hardest hit.
- *Belg* rainfall in the east and southeast exhibit the largest percent reductions.
- Many areas have experienced and may continue to experience post-1997 precipitation reductions.
- Southwestern Ethiopia has seen a long-term post-1960s downward trend in rainfall.
- Declines in *Belg* rains may impact long cycle crop production.

Steady rainfall in western highlands provides opportunity for water management

- Ethiopia receives large amounts of water, poorly distributed in space.
- Extremely high population densities in portions of the southwestern highlands are creating critical shortages of water.
- Water management in the western highlands, combined with effective agriculture, transportation and market systems could alleviate Ethiopian food insecurity.

A warming Indian Ocean may decrease long rains

- Positive temperature anomalies in the southwestern Indian Ocean may increase oceanic precipitation and decrease rainfall over eastern Africa, especially during March-May.
- Changes in the monsoonal circulation may be linked to poor rains in parts of eastern Tanzania, Kenya, Somalia, Ethiopia, Djibouti and Eritrea.

August 2nd 2005*

Introduction

This report presents an analysis of Ethiopian rainfall from 1960 through 2004, based on 186 gauges in Ethiopia and 373 gauges from surrounding countriesⁱ. Substantial post-1997 declines in March-September rainfall have been observed in the northeast, southeast and southwestern portions of the country, a result corroborated by several independent data sourcesⁱⁱ. The observed rainfall reductions have been accompanied by an increase in millions needing food aid (Figure 1).

The greatest percent decrease has occurred during the *Belg* (March-May) season, though *Kiremt* (June-September) rains have also diminished in many areas. This recent dryness may be linked to a warming tendency in the southern Indian Oceanⁱⁱⁱ, and is likely to impact densely populated and/or water-insecure regions of southern and eastern Ethiopia. These areas face declines in rainfall and increasing demands on land, water and agriculture. Recent dryness, dropping coffee prices, rising population and land degradation combine to create mounting destitution that must be countered with innovative planning and policies^{iv}.

This report is organized as follows. Section 1 provides context for our results by summarizing recent trends in food aid, precipitation and the regional climate. Section 2 quantifies the water availability situation by analyzing potentially available runoff. Section 3 describes the results of our historical rainfall analysis. Section 4 relates the observed rainfall variations to circulation and sea surface temperature patterns in the Indian and Pacific Oceans. Section 5 briefly summarizes our results.

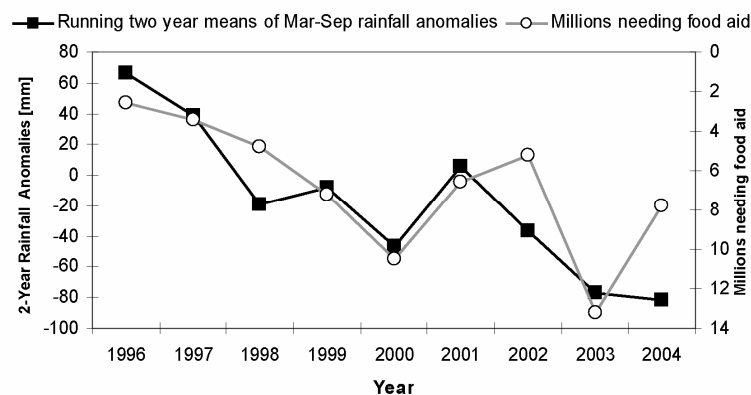


Figure 1. Running 2-year March-September rainfall anomalies (left axis) with millions needing food assistance (right axis, inverted). While the two time series show a good correspondence ($r^2=0.62$) many factors influence food aid needs.



Figure 2. Shaded regions indicate weather-related food insecurity hotspots for 2003-04, as defined in the FAO State of Food Insecurity Report for 2004. Ethiopia is shown with a dark border. The rectangle encloses the equatorial and subtropical eastern African nations.

1.0 Introduction – food insecurity in equatorial and subtropical eastern Africa and Ethiopia

In many developing nations coping with hydrologic extremes is equivalent in cost and potential outcome to war (Kates, 2000). The stakes are escalating. The average supply of water per person world-wide is expected to drop by 33% over the next 20 years, with between 2 to 7 billion people facing water shortages by 2050 (UN, 2003). At present, 825 million people face malnutrition each year, 5 million children die, and the number of African food crises per year has tripled from the 1980s to 2000s (FAO, 2004). The majority of these crises occur in equatorial and subtropical eastern Africa (ESEA, 23°N/S, 21-52°E, Figure 2). Many nearby nations (Swaziland, Lesotho, the Democratic Republic of Congo, Chad, Niger, Angola, and Zambia) currently face dramatic food shortages as well.

Of the ESEA countries, Ethiopia faces the largest food insecurities. The past ten years have seen declines in rainfall (Figure 1, black line with rectangles) and an average annual increase of about 0.5 in millions needing food aid (Figure 1, gray line with circles, y-axis on right, inverted).

1.1 Certainly more people and possibly less rainfall

Many factors over the last ten years compound food insecurity in Ethiopia. Outbreaks of Rift Valley Fever have limited livestock exports. Declining coffee prices have reduced cash cropping in highland areas. Population growth alone, if not mitigated by other factors^v, will create an additional 1.5-2 million individuals per year without food (Funk et al., 2003).

Ethiopia's population of 74 million will double in fewer than 25 years, potentially leading to erosion, deforestation, and the loss of soil nutrients; meanwhile less than 8% of the sexually active population uses family planning (Reuters, June 21, 2005). Unless checked, this growth will undermine development efforts. Adding to these concerns are reports that less rainfall (Funk et al. 2003) may be becoming more sporadic (Steffen et al, 2003).

Motivated by these concerns, we have compiled and analyzed a large number of quality controlled station data from Ethiopia and eastern Africa⁴; this report presents these results.

1.2 A warming Indian Ocean and recent drought in ESEA

While a full climate analysis is beyond the scope of this report, we do present results suggesting that warming sea surface temperatures (SSTs), especially in the southwest Indian Ocean (SWIO), may be linked to decreasing rains across ESEA. This link was first identified in research performed by the Ethiopian National Meteorological Services Agency (Shanko and Camberlin, 1998). Shanko and Camberlin found that tropical storms over the SWIO led to lower than normal rains in Ethiopia, primarily during the *Belg* season, through reductions in available moisture, upper-level easterly wind anomalies, and a northward shift of the subtropical westerly jet. SWIO cyclonic activity played a role in the devastating drought of 1984, and its terrible human toll of 400,000 to a million deaths.

Recent research has identified an increase in rainfall over the southern hemisphere Indian Ocean (Hurrell et al., 2004, Hoerling et al., 2004) and there is an emerging consensus that Indian Ocean SSTs play a key role in African rainfall (Nicholson, 2003; Goddard and Graham, 1999). ENSO-Indian Ocean teleconnections can help explain the negative impact of El Niños on Ethiopian rainfall (Haile, 1987; Wolde-Georgis, 2001).

The circulation patterns associated with increased SWIO rainfall anomalies are likely to be associated with increasing aridity and descending air over southern Africa and the northern Indian Ocean (Hoerling et al., 2005), consistent with the atmospheric response to off-equatorial latent heating (Gill, 1982). These changes can both weaken onshore flows from the Indian Ocean and reduce the occurrence of rain-bearing westerly winds (Okoola, 1999) from the Congo/Zaire basin (Camberlin and Phillipon, 2002; Camberlin, 1997). It thus seems plausible that warming and increased convection in the southern Indian Ocean has played a role in creating current food insecurity crises in the ESEA countries. If so, then global warming may be lowering average rainfall conditions in these countries.

2.0 Water availability: areas at-risk and opportunities for improved water management

Figure 3-top panel shows the spatial distribution of the net surface runoff that might be used for crop production (Senay and Verdin, 2004). This map factors in average precipitation, actual evaporation, and population density to estimate the potential available runoff per family at a regional scale. Food balance considerations can be used to interpret these runoff values from a food security perspective^{vi}.

In Figure 3 top panel, light orange regions would typically provide enough crop and biomass to support an average family in an average year. Dark-orange and red regions will typically face chronic water shortages. Blue and green regions typically have excess potential runoff. Appropriate water management and agricultural practices could utilize this water. Note the extremely large spatial differences: areas with the most available net surface runoff receive 20 times more than the least water-secure regions. The at-risk areas can be further subdivided into **A** semi-arid regions facing increasing water shortages and **B** wet areas with very high population densities. Regions with more than 6,000 m³ of potential runoff can be considered as areas with a potential 'water-surplus'. These areas are primarily in the northwest, and denoted with a **C** in figure 3.

We briefly discuss regions A, B, and C.

2.1 The semi-arid and water-limited east - A

Our rainfall analysis suggests that many of the water scarce areas in **A** have experienced reduced rainfall since 1997, as well as poor rains in 2002 and 2004. We consider these regions to be high-risk areas, since a combination of climate, health, and population factors lead toward increasing vulnerability. In agro-pastoral and pastoral midland and lowland areas, rainfall totals may drop below levels sufficient to support livestock. In the eastern highland areas, reduced *Kiremt* and *Belg* rains may affect short and long cycle crops, as well as coffee production.

2.2 The wet and water-limited southwest - B

Another somewhat surprising result presented in Figure 3 is the extremely low potentially available surface water per family found in central portions of the southwestern highlands. In Sidama and Hadiya – population densities of greater than 200 person/km² (Figure 3-bottom) lead to available runoff values of only 500 m³ per family. This region has been experiencing a “green famine” in recent years. Since the 1960s this region has also experienced a long-term drying trend. Thus even though this area is very wet, the combination of population pressure and decreasing rainfall warrants concern.

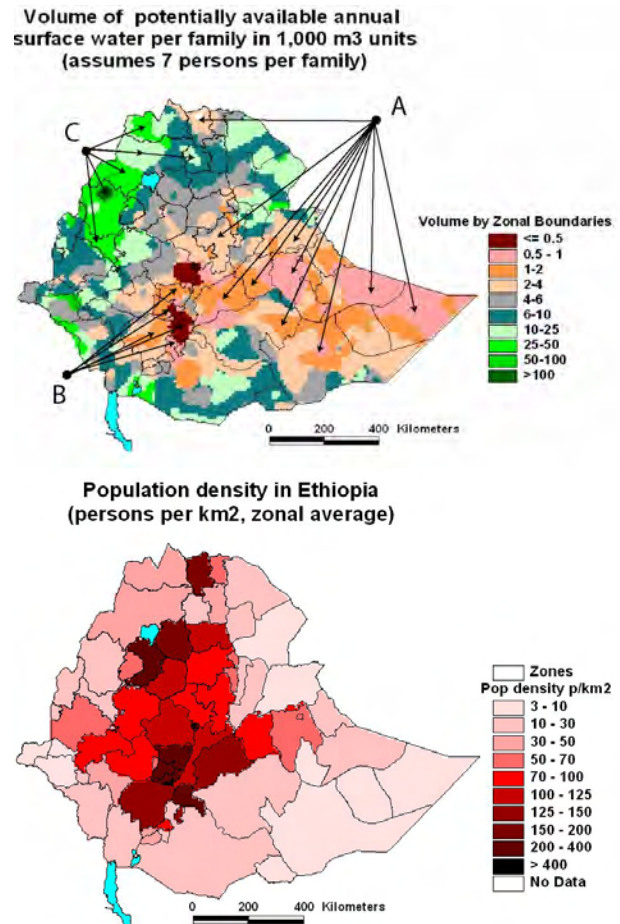


Figure 3. Top - Volume of potentially available annual surface water per family in 1,000 m³ units (assumes 7 persons per family). Bottom – population density of Ethiopia, persons per km².

2.3 Areas with surplus water - C

Blue and green areas in the top panel of Figure 3 will tend to have adequate water supplies. Population pressure, however, could result in land degradation and eventual productivity loss, as is known to have happened in parts of northeast Ethiopia

Soil and water resource utilization and management should be given a high priority in these fragile environments. If efficient techniques of agricultural intensification were combined with effective means of transporting and selling crops in less water-secure areas, excess runoff could alleviate food shortages in other parts of Ethiopia.

The next section relates rainfall tendencies to water availability. The semi-arid east has seen a decline in post-1997 rains, the wet southwest has experienced a slow decline since the 1960s, and the relatively water-secure northwest has seen little change in rainfall patterns over the last 45 years.

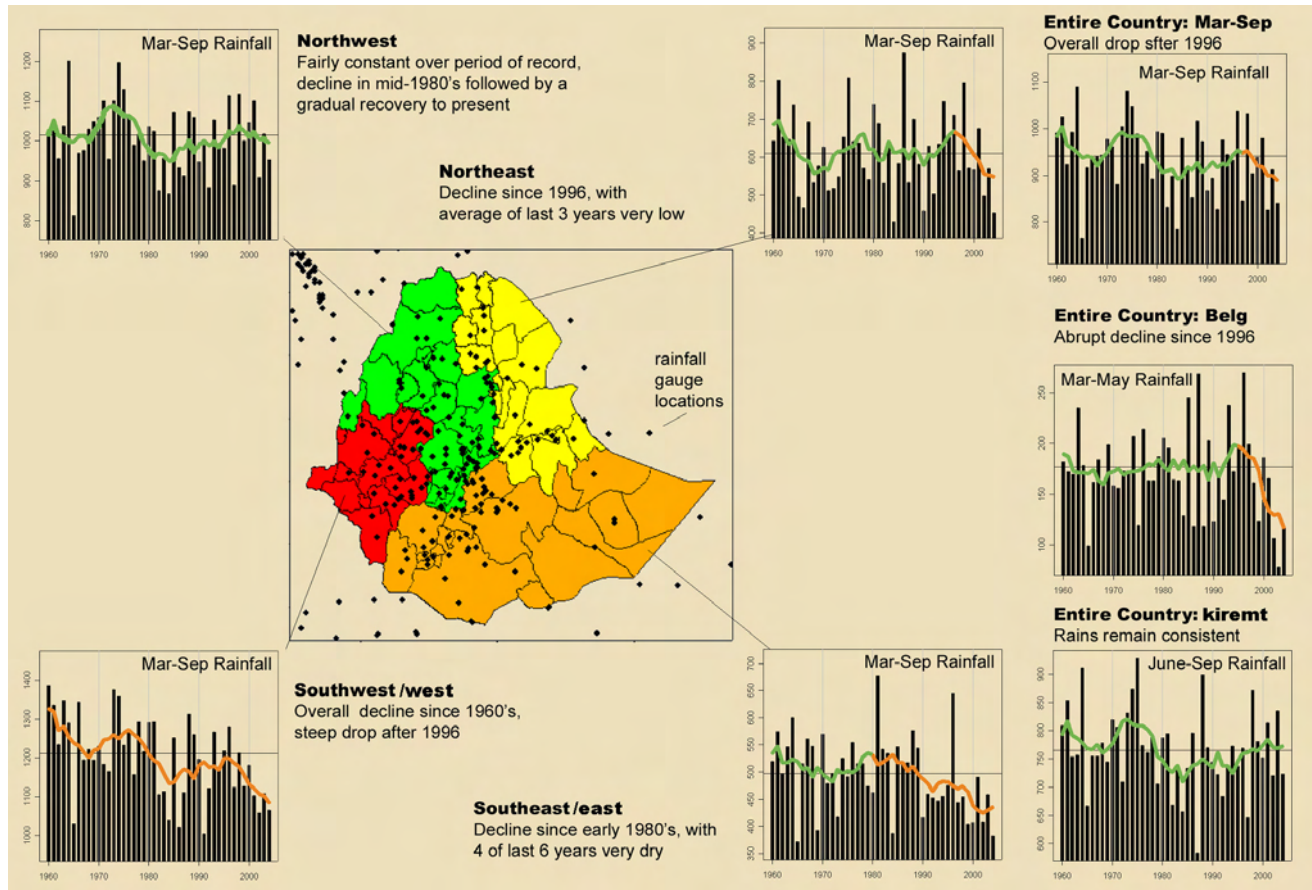


Figure 4. Time series of March-September rainfall at a national scale (right column) and for four regions (left and center). Black bars show seasonal rainfall. Heavy colored lines show running 7-year means. Colors have been added to describe long-term variation patterns. Orange lines denote rainfall tendencies likely to increase food insecurity.

3.0 Observed variations in regional and national precipitation

The seven time series shown in Figure 4 summarize our analysis of Ethiopian station data¹ for the March-September period. The colored map in the center of the image shows four regions (red, yellow, orange, green) of homogeneous variation from year to year. Dots on this image also show the locations of station data used in this study. Our sub-national analysis is simple – we are especially concerned about water-insecure areas (Figure 2) that may be experiencing reduced levels of rainfall (Figure 3).

Please note that the topography and climate of Ethiopia are very complex; we can only discuss broad aspects of its rainfall variability in this report.

The four panels on the left and center present the average March-September rainfall for four regions (the northeast, southeast, southwest and northwest). The three panels on the right show the national average precipitation for the March-September, *Belg* (March-May), and *Kiremt* (June-September) time-periods. Running seven-year means have been added to each plot. Orange lines indicate negative rainfall tendencies that may increase food insecurity.

3.1 National trends

On a national scale the March-to-September rainfall totals (upper-right) exhibit a 20-year variation (wet in mid-70s, mid-90s, dry in mid-80s, mid-00s). Of most concern at the national scale may be the recent increase (1990-1996) and then decrease (1996-present) appearing in the *Belg* rainfall totals.

3.2 Regional analyses

Regional time series suggest variations from this pattern. In northwest (green, Figure 4) Ethiopia the rainfall has been fairly constant over the period of record, with a decline in the mid-1980s followed by gradual recovery to the present. In the southwest an overall decline since the 1960s is found, with a steep drop occurring after 1996.

Of most concern from a food security perspective is the post-1980 decline found in the March-September southeast/eastern rainfall and the post-1996 decline in the northeast. In the southeast/east 4 out of the last 6 seasons appear very dry, and in the northeast the average of the last 3 years is very low.

3.3 Rainfall declines in low water availability regions

It is very important to realize that the recent rainfall declines found in the northeast and southeast regions (Figure 4) correspond to areas with low water availability (Figure 3, A). The long-term downward

trend in the southwest/west may also be of concern in densely populated regions with low potential runoff.

3.4 Corroborating evidence

The magnitudes of the post-1996 changes shown in Figure 4, especially in the March-May season, are dramatic. They are substantiated by other independent climate observations. Figure 5 shows 1996-2004 anomalies for three different precipitation time series. Rainfall from two (similar) enhanced-satellite datasets, the Global Precipitation Climatology Project (GPCP) and the Xie-Arkin CPC Merged Analysis of Precipitation (CMAP) time series are shown, along with global climate model precipitation estimates. These images were calculated by taking the average of consecutive 1996-2004 seasons, and subtracting from them the 1979-2000 mean.

While the climate model reanalysis appears to exaggerate the recent dryness, all three datasets depict substantial dryness across most of eastern Africa during the *Belg* rains. Tanzania, Rwanda and Burundi, Kenya and Ethiopia all appear to have experienced rainfall deficits ranging from 50 to 150 mm per season. These values are consistent with our analysis shown in Figure 4. Dryness during the *Kiremt* (June-September) season appears more limited to southwestern and southeastern Ethiopia.

3.5 Possible implications for long cycle crops

In our previous report (Funk et al., 2003) we discussed the importance of slowly maturing long cycle crops to *Meber* crop production. *Meber* crops are typically harvested in September or October. Short cycle maize and sorghum are typically planted between April and July. Long cycle crops are planted during the *Belg* season and harvested following the *Meber* in late fall. These slowly maturing varieties of sorghum and maize are well suited to high elevations. Given sufficient agricultural inputs they are often substantially (1.5-2.5 times) more productive than short cycle varieties planted during the *Meber* season. Long cycle crops contribute approximately 50% of national production, compared to 40-44% for 'short-cycle' (June-September) varieties.

Crop water balance models suggest that long cycle crops depend on April-May rains; rainfall totals for these months explain 50% of the variance of end-of-season crop water satisfaction indices. Thus, the March-May declines shown in Figure 4 could adversely affect long cycle production – amplifying the recent tendency for poor *Belg* rainfall performance by diminishing yields recorded in late fall. A time series of March-September rainfall anomalies for 1960-2004 averaged over the long-cycle crop growing regions (Figure 6) exhibits both a long-term downward trend and a substantial decrease since the mid-1990s. While 1984 stands out as a terrible year, 1997, 2002 and 2004 also experienced poor rainfall.

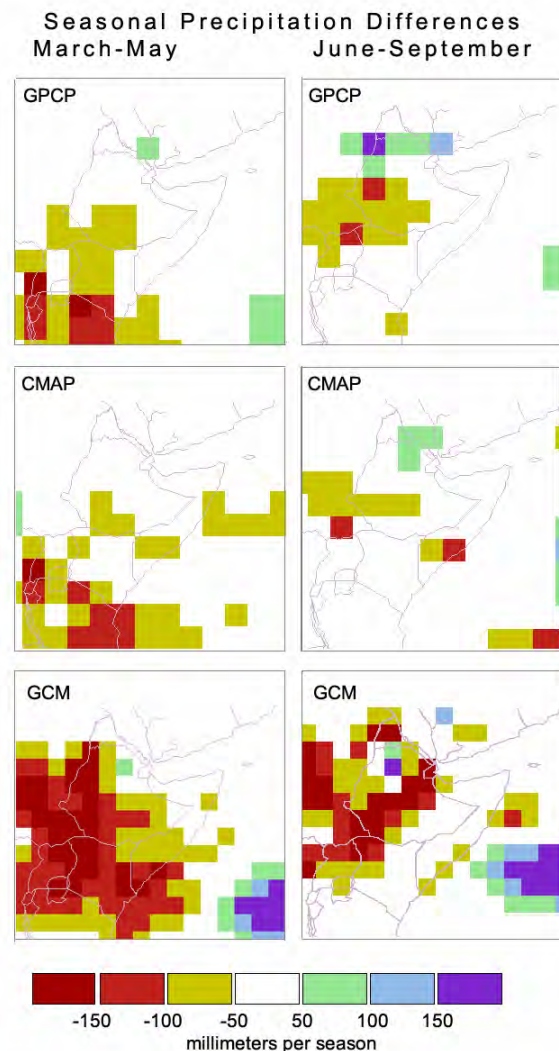


Figure 5. 1996-2004 GPCP, CMAP and GCM (NCAR/NCEP Reanalysis) precipitation anomalies in mm per season for the March-May (left) and June-September (right) seasons^{vii}

3.6 Recent changes in timing of the rains

Figure 7 shows monthly rainfall values for four representative administrative-level 3 zones: West Hararge in the eastern highlands, Bale in the central south, Zone 1 of the Afar regions, and Illubabor in the southwestern highlands. Note that these values are averages for the zones, within each zone higher-altitude areas will tend to be wetter and lower-altitude areas will tend to be drier. These four zones were selected because they had reasonable station densities (Figure 4) and high population densities with low water availability (Figure 3).

The y-axis on these figures represents years, and the x-axis denotes months, so reading across the image shows the 12 months of rainfall for a given year. Recent variations and can be summarized as follows. In West Hararge, Bale and Afar Zone 1, fairly good rains were received during the *Belg* season between the late 1980s up through 1997. These regions have also



March-Sep Rainfall Totals for Long Cycle Regions

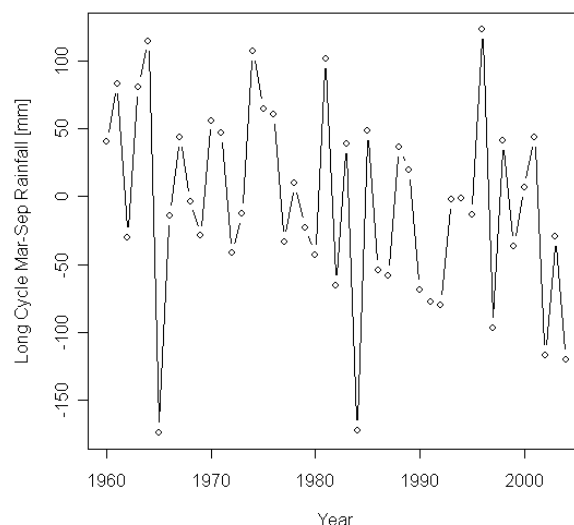


Figure 6. Long cycle crop growing regions of Ethiopia and the associated March-September rainfall anomalies in mm.

received very low rains over the past several *Belg* seasons, with very low May rainfall. The recent dryness, following a decade of above-average rainfall, will impact increasingly vulnerable populations that already stretch available water resources (Figure 3).

In Bale recent September-November rains, however, appear to be quite good. The same situation (low March-May, higher September-November) rainfall appears to hold for Illubabor. Note the high variability in the onset and intra-seasonal distribution of these rains.

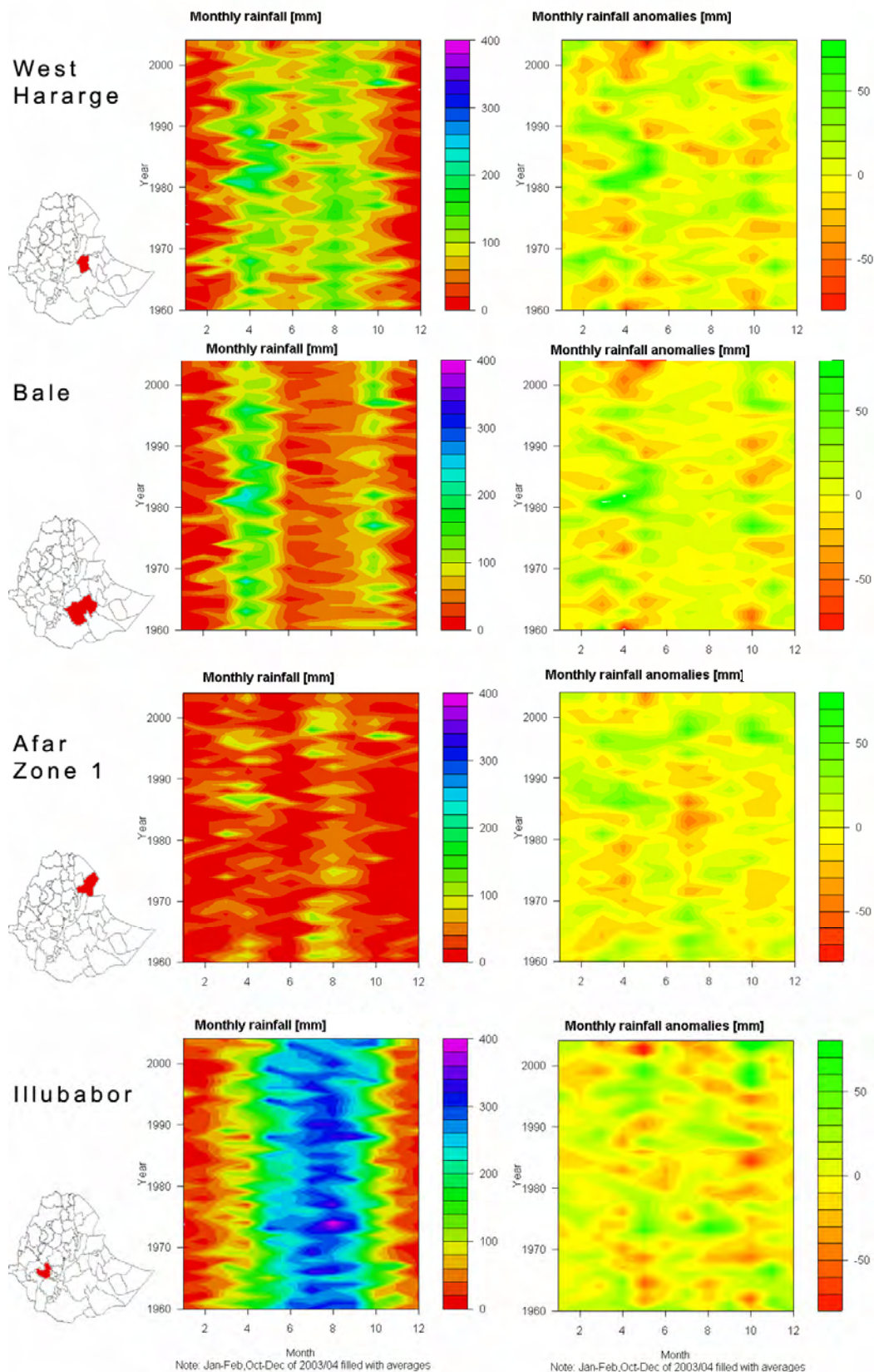


Figure 7. Monthly rainfall displayed by year (y-axis) and month (x-axis) for 4 selected zones: West Hararge, Bale, Afar Zone 1, and Illubabor.

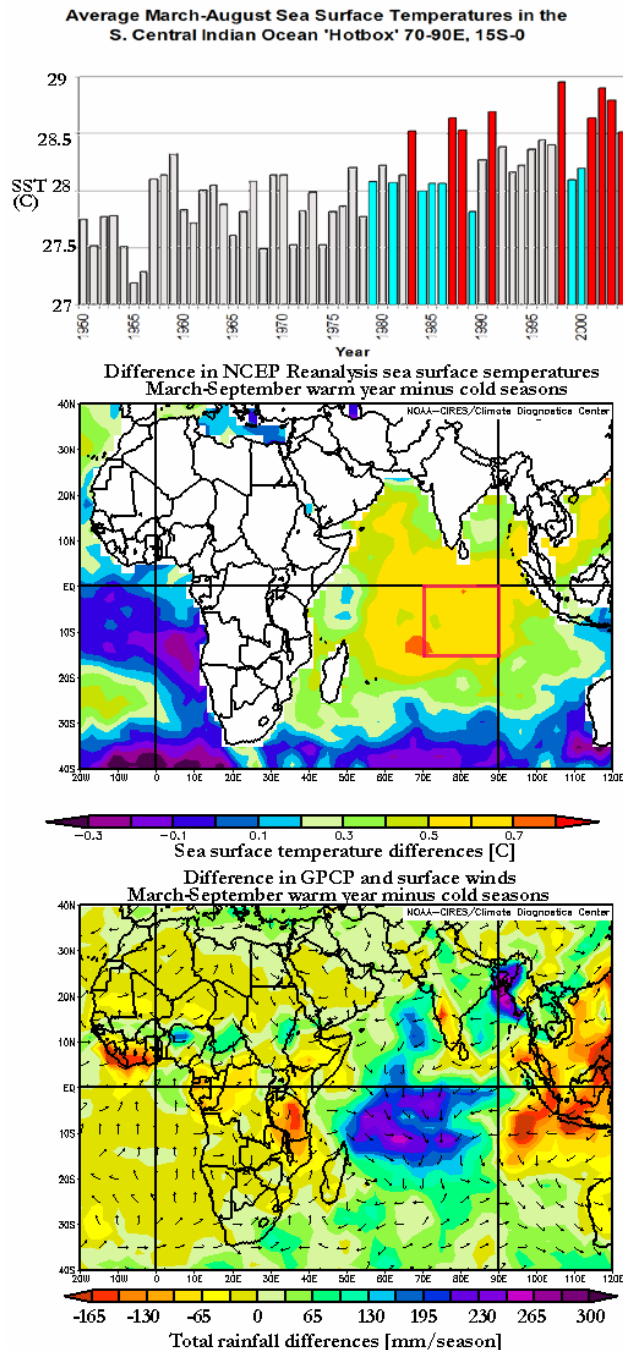


Figure 8. These figures show (top) a time series of March-September sea surface temperatures in the south-central Indian ocean (70-90°E, 0-15°S). Red bars denote 'warm' seasons (83, 87, 88, 91, 98, 01-04); blue bars depict 'cold' seasons (79, 81, 84, 85, 86, 89, 99, 00). The middle panel shows the difference in SSTs between warm and cold seasons. The bottom panel shows the difference (warm minus cold seasons) for GPCP precipitation fields and surface (1000 mb) winds.

4.0 Recent warming in the Indian Ocean and dryness in eastern Africa

This section briefly examines regional SSTs and climate fields^{viii} in conjunction with composites of the GPCP time series. Our concern is that warming in the southern equatorial Indian Ocean (Figure 8, top & middle) may be linked to reduced precipitation over eastern Africa via changes in atmospheric circulations over the western Indian Ocean.

The top panel of Figure 8 shows the warming SSTs averaged over 0-15°S and 70-90°E. Red bars in this panel denote relatively warm seasons (83, 87, 88, 91, 98, 01-04) while blue bars mark relatively cold seasons (79, 81, 84, 85, 86, 89, 99, 00). The trend in this time series is representative of temperatures across the basin as a whole. The center panel of Figure 8 shows the SST differences for warm minus cold seasons. The red box identifies the area averaged to produce the time series shown in the top panel.

The magnitudes of the SST differences shown are substantial given that the tropical Indian Ocean is generally less variable than the tropical Pacific, and that the SSTs are already very warm. Note that many of these warm and cold seasons are associated with El Niño and La Niña, respectively, which tend to synchronize Indian Ocean sea surface anomalies with those in the central eastern Pacific (warm during El Niño, cold during La Niña).

When very warm waters grow warmer, evaporation and precipitation can increase. This precipitation influences the atmosphere. The apparent effect, over the March-September season, draws surface winds away from the surrounding landmasses and into areas of increasing rainfall in the southern Indian Ocean (Figure 8, bottom). Note that parts of Northwestern Ethiopia are *not* linked to decreased GPCP rainfall. This is consistent with the upper-left panel of Figure 4.

Time series of satellite measurements of lake levels (Figure 9) exhibit this same pattern. Following a large ENSO-related jump in 1998, levels in Lake Tanganyika, Victoria and Turkana have been dropping. Lake Tana, on the other hand, shows little trend, except perhaps for a recent drop in 2002-04. This is again consistent with relatively low rainfall in 2002-04, shown in the upper-left panel of Figure 4.

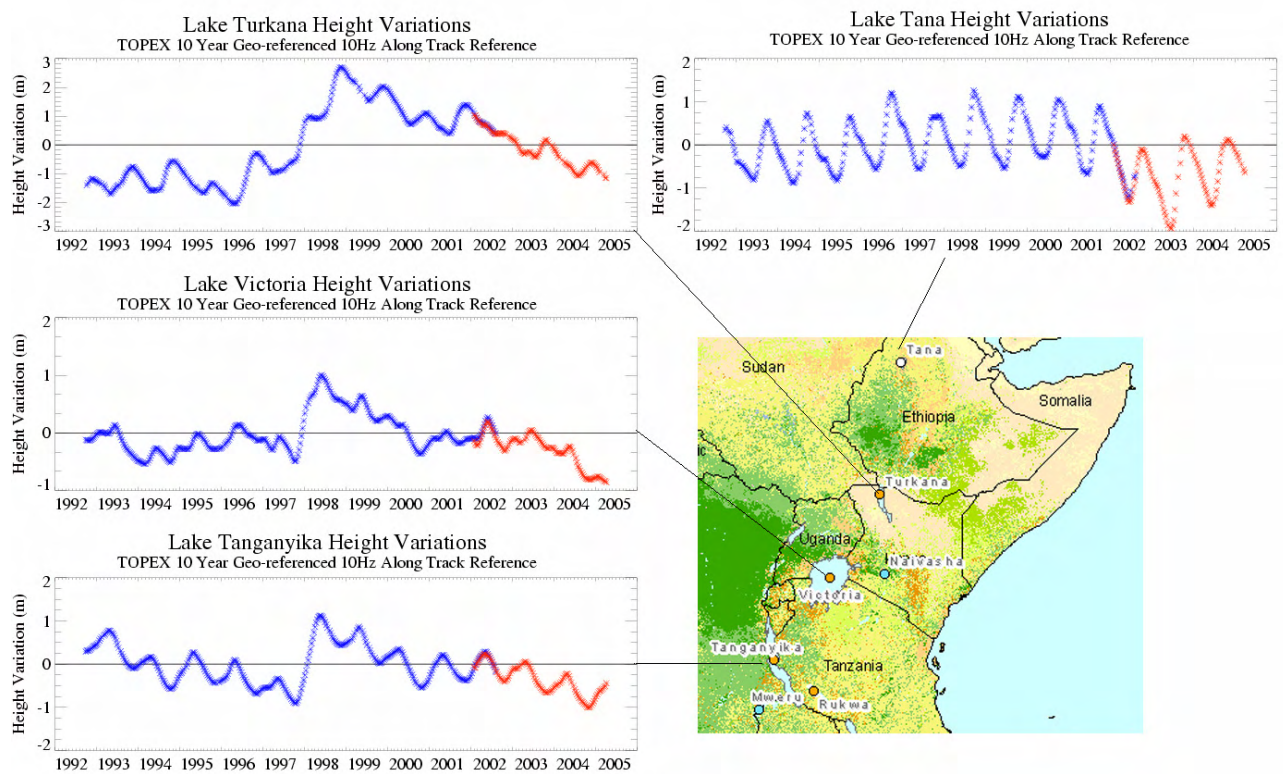


Figure 9. Topex Poseidon/Jason 1 Lake levels for five lakes in eastern Africa. Time series and imagery obtained from the USDA PECAD crop explorer: www.pecad.fas.usda.gov/cropexplorer/global_reservoir/

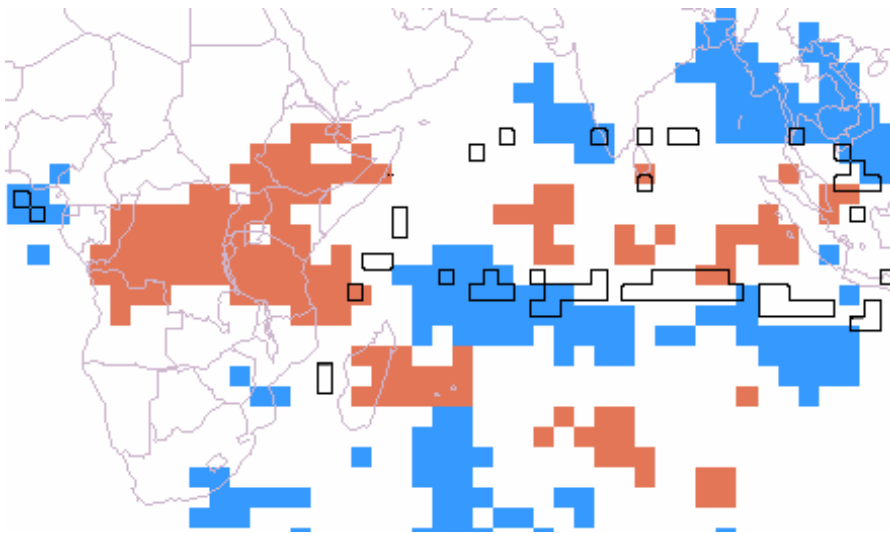


Figure 10. Regions with recent warm March-May SSTs and substantial March-May GPCP precipitation differences. The black rectangles enclose regions that had average of SSTs of **less than** 29°C over the 1980-1996 period, and **more than** 29°C over the 1997 and 2004 period. Blue areas denote regions in which seasonal precipitation differences (1980-1996 seasonal averages minus 1997-2004 seasonal averages) were greater than 50 mm. Red areas indicate regions in which these seasonal differences were between -50 and 150 mm.^{vii}

Note that four distinct sources of information (climate model analyses, satellite rainfall estimates, interpolated station data, and lake levels) converge on post-1996 dryness in eastern Africa.

4.1 Focus on the 1997-2004 March-May rainy seasons

This section examines briefly the post-1996 decrease in March-May rains. This was the most alarming tendency found in Ethiopian rainfall (Figure 4). The March-May long rains are critical for the eastern African region and have been quite poor in recent years (Figure 5).

Since 1997, the southern Indian-Pacific has seen expansions of the pool of very warm ($>29^{\circ}\text{C}$) surface waters. The Indian Ocean is particularly warm in the March-May season when the basin is relatively cloud free and winds are light. Warming of these warm waters can trigger enhanced convection over the ocean. Analyses of recent (1997-2004) March-May SSTs and precipitation fields do show new areas of very warm water (Figure 10, black rectangles) and increased convection (Figure 10, blue areas) across the southwestern Indian Ocean. These rainfall anomalies, in turn, can drive changes in circulation patterns that reduce rainfall over eastern Africa (Figure 10, red areas).

Our premise is that warm SST anomalies in the southern equatorial Indian Ocean produce an anomalous circulation that reduces rainfall over parts of eastern Africa. The associated climate pattern would

have a surface low to the immediate west of the heat source, eastward wind anomalies near the equator, and vertical circulations that bring hot dry descending air down over eastern Africa and the northwestern Indian Ocean. Observed climate fields seem to support this hypothesis, as does previous research (Shanko and Camberlin, 1998).

In Figure 11 we compare SST and east-west (zonal) wind anomalies in the Indian Ocean as a function of latitude and season. This figure examines the hypothesis that increasing SSTs in the southern Indian Ocean (as shown by the dark gray polygon in Figure 10) might be related to changes in moisture bearing winds along the western edge of the Indian Ocean. If a warming and increasingly rainy southern Indian Ocean is related to changes in low level winds, then this should be apparent in a visual comparison of the SST and wind anomalies (Figure 11). In this figure, March-May SST anomalies have been averaged across the basin (45° - 105°E), while the wind anomalies have been averaged over the western rim (45° - 60°E). The x-axis denotes successive seasons (1960-2004). The y-axis represents different latitudes. SST anomalies are shown with a filled contour plot. Wind anomalies are shown with arrows, with the upper-right direction defined as a north-eastward anomaly.

The tendency towards increasing SSTs, especially south of the equator is apparent. These warm anomalies are generally (but not always) associated with eastward surface wind anomalies. The post-1997 shift in wind anomalies at 0° and 10°N is quite apparent.

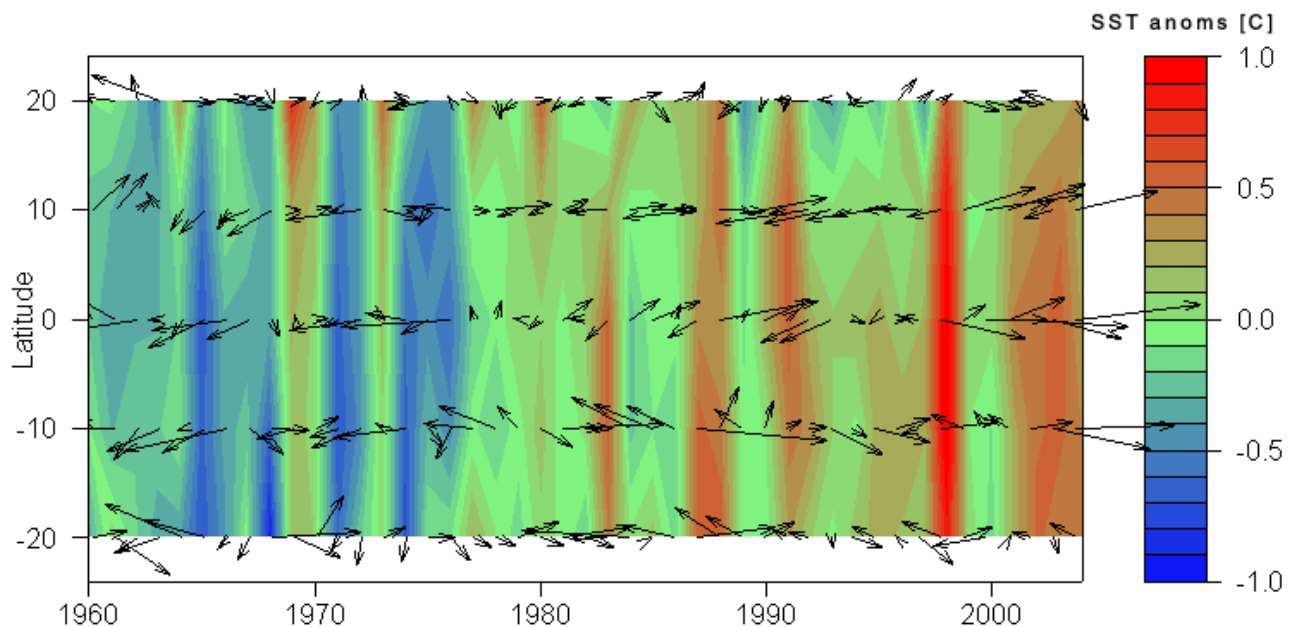


Figure 11. Latitude by season (March-May) plot of SST anomalies (red-blue shading) and reanalysis wind anomalies (arrows). All values averaged over the March-May season. SST anomalies were averaged across the Indian Ocean basin (from 45° to 105°E). East-west winds were averaged from 45° to 60°E . The direction of the arrows indicates the direction of the wind anomalies, with the upper-right denoting north-east anomalies. The maximum east-west wind anomaly was 1.3 meter per second. Note the westward flow at 10°N from 1991-1996. From 1997-2004 flows at the equator and 10°N have been increasingly eastward^{vii}.

Section 5: Summary

Multiple sources of evidence converge on a post-1997 tendency towards lower rainfall, especially during the *Belg* (March-May) season. This finding appears to hold for many parts of eastern Africa. Rainfall conditions have been stable in the relatively water-secure northwest of Ethiopia, and declining in parts of the water-insecure southeast, northeast and southwest of Ethiopia.

A combination of agricultural intensification, improved soil management, and enhanced transportation and market systems could allow grain surpluses in the west to be distributed to other regions. The recent decrease in *Belg* rains and a long-term tendency towards dryness in the long-cycle crop-growing regions may be threatening these slowly maturing crops. Vulnerable pastoralists and agro-pastoralists in the water-insecure southeast may have been strongly affected by low rainfall levels in recent years. It may become increasingly important for the early warning community to address the needs of these livelihood groups.

The observed climate fields (figures 8, 10 and 11), past analysis (Shanko and Camberlin, 1998) and recent modeling studies (Hoerling et al., 2004; Hurrell et al., 2004; Hoerling et al., 2004; Nicholson, 2003; Goddard and Graham, 1999) have all stressed the important impacts of the Indian Ocean on circulation patterns and African Rainfall. If the rapid warming (about 1°C in the last 50 years) of the Indian Ocean is related to reduced rainfall over eastern and southern Africa, then continuing precipitation deficits may be likely. Given the extreme food insecurity of the region, more research into this important topic would greatly benefit the food security community.

Chris Funk, Gabriel Senay, Alemu Asfaw, Jim Verdin, Jim Rowland, Joel Michaelsen, Gary Eilerts, Diriba Korecha and Richard Choularton contributed to this report. This work represents the collaborative effort of FEWS NET scientists at the UCSB Climate Hazard Group, USGS National Center for EROS, USAID/DCHA/FFP and Chemonics.

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Footnotes

ⁱ Most of the Ethiopian station data (162 stations) was kindly provided by the National Metrological Services Agency (NMSA). An additional 20 stations were obtained from the Global Historical Climate Network (GHCN) and 4 from the Food and Agricultural Organization (FAO). GHCN, FAO and FEWS NET archives were used to provide data for surrounding countries. The station locations are depicted with black circles in Figure 4.

Each station's monthly time series was carefully quality-controlled by visual comparison with surrounding stations. Block kriging was used to produce areal averages for administrative level 3 polygons shown in Figure 3. In Ethiopia the level 3 regions are referred to as zones.

A separate block kriging solution for each polygon provided a standard error estimate for each areal rainfall value. This enables us to quantify our confidence in each rainfall average. Comparing these standard errors to the interannual standard deviation allows us to quantify the uncertainty in our rainfall estimates. While accuracies varied by station distribution, most regions had standard errors of less than half their interannual standard deviation.

Thus if the interannual standard deviation in *Kiremt* rains was 50 mm/season, and our standard errors were around 25 mm, then we can detect a seasonal variation of about ½ a standard deviation – accurate enough to identify large variations and trends.

ⁱⁱ Spatial averages of rainfall were compared with stream gauge data, reanalysis precipitation and precipitable water fields, and satellite-based vegetation and precipitation time series, outgoing longwave radiation fields and eastern African lake levels.

ⁱⁱⁱ While we describe briefly some troublesome recent climate variations in the equatorial and subtropical eastern African countries, more research will be required to reject or confirm this hypothesis.

^{iv} Unless abated, this increasing chronic food insecurity could rapidly exceed the capacities of current food aid

systems. A simple (and simplistic) linear projection of Ethiopian food aid needs based on Figure 1 suggest that an annual aid requirements for around 17 million people might become typical by 2015. While we do NOT suggest that this simple calculation be used for planning, the tendency is alarming.

^v This value is based upon the approximate food balance calculation presented in our previous Ethiopia report.

^{vi} This map is presented with a reference unit volume of providing 1,000 m³ of water after considering evaporation and seepage losses from reservoirs. The 1000 m³ is suggested based on a reasonable amount of water that can be used to grow enough grain and biomass to support an average farm family in Africa. A general rule-of-thumb for equating water to grain is a factor of 1000, i.e., it takes 1000 tons of water to produce 1 metric ton of grain. Therefore, 1,000 m³ is expected to produce enough grain to sustain a family of 7 in times of difficulty for about 3/4th of the year according to the grain ration formula of WFP at the rate of 0.5 kg/person-day. Taking into account system inefficiencies, regions with less than 2-4,000 m³ may be labeled as highly vulnerable. Areas with 2-4,000 m³ units may be considered vulnerable.

^{vii} We have used NCEP/NCAR reanalysis climate fields and graphics provided by the Climate Diagnostics Center, Boulder, Colorado. The GPCP is a research quality set of rainfall estimates merging multiple satellite and gauge data.