African Famine Early Warning from Satellite Data

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Satellite data obtained from the NOAA series of meteorological satellites and the METEOSAT geostationary satellite are operationally used in near-real time to provide objective assessment of famine early warning for Africa. Advantages of the use of time-series satellite data are timeliness and consistency. When combined with ground-collected socioeconomic information, an integrated assessment of distributed agricultural potential is possible at a fraction of the cost of traditional inventories. This is the approach taken by the U. S. Agency for International Development's Famine Early Warning System (FEWS) and by the United Nation's Food and Agriculture Organization's Food Security program. In addition to providing spatially continuous and objective information in a timely fashion for a complete continent, these satellite-based early warning systems enable famine relief resources to be directed to those areas most affected at a fraction of the cost of previous methods of relief allocation for Africa. In addition, recent work relating El Nino Southern Oscillation events to African vegetation dynamics suggests that famine early warning in selected areas of Africa may be directly related to sea surface temperature anomalies in the tropical Pacific.

Background

Large areas of Africa have experienced serious droughts resulting in agricultural shortfalls in recent years. This has been most evident in Sahelian and Sudanian Africa, where a run of deficient precipitation years beginning about 1970 has occurred with 1984 being the driest year this century (fig. 1). The reasons for this curious and persistent run of year after year of below average rainfall are not understood. Suggested climate system forcings or explanations include large-scale land surface modification from overgrazing and tree cutting, increases in atmospheric dust from anthropogenic causes, and unusual Atlantic and Indian Ocean sea surface temperature conditions. Whether this is natural or/and anthropogenic in nature, the Sahelian rainfall situation since the late 1960's is rather unusual and warrants detailed study. However, it is important to note that a high degree of within-year variability also exists, as will be shown later.

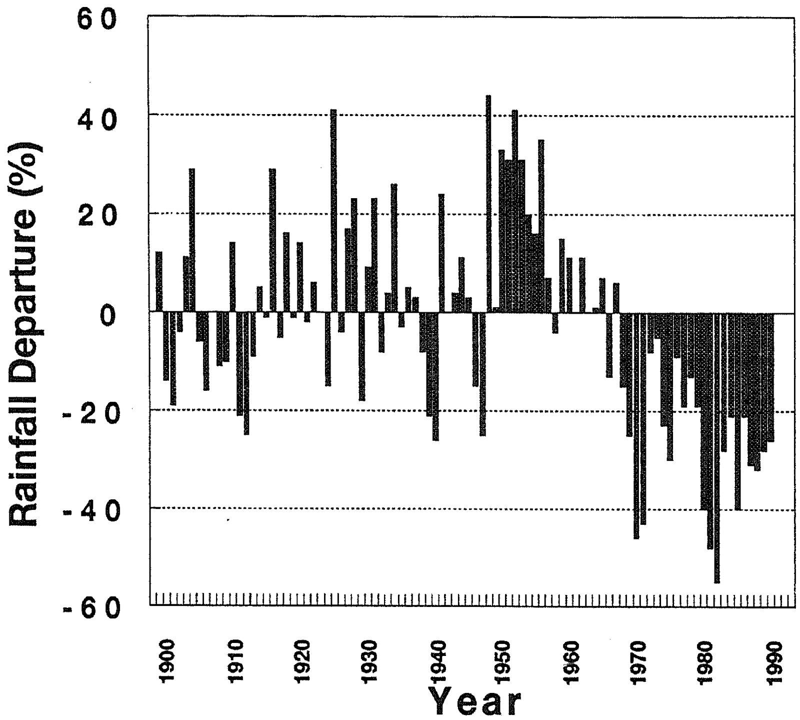

Figure 1. Sharon Nicholson's rainfall departure for Sahelian Africa from 1900 to 1992. Note the unusual run of drier years from the late 1960's to the present.

Serious droughts in Africa were not limited to Sahelian and Sudanian Africa during the 1980's and 1990's. In 1982-1983 Southern and Eastern Africa experienced significant precipitation shortfalls; similar droughts also occurred in the late 1980's and in 1991-1992. It unfortunately seems to be the case that serious drought is frequently present somewhere in Africa, with the attendant consequences of famine if external food relief is not supplied.

As much of Africa is based on subsistence agriculture, serious droughts often result in widespread famine, sometimes exacerbated by political instability and even civil war. Donor-country relief activities to prevent famines from developing have been complicated by lack of quantitative information describing actual conditions and that famine could not be anticipated. Frequently, traditional information describing famine magnitude and spatial extent is incorrect or highly contradictory.

Furthermore, in times of serious drought it is not uncommon for many areas to overstate the magnitude of their food requirements to maximize donor relief for their specific areas, in the process perhaps denying donor relief for truly deserving areas. These factors led the Food and Agricultural Organization of the United Nations (FAO) and the U. S. Agency for International Development (USAID) to begin famine early warning programs based, to a large extent, upon NOAA advanced very high resolution radiometer (AVHRR) and METEOSAT satellite data in 1983. This topic has previously been reviewed by Hutchinson (1991).

Two satellite techniques are used in famine early warning for Africa: Normalized difference vegetation index (NDVI) measurements derived from daily advanced very high resolution radiometer (AVHRR) data from the National Oceanic and Atmospheric Administration (NOAA) series of polar-orbiting meteorological satellites (NOAA-7, NOAA-9, NOAA-11, NOAA-9, and now NOAA-14); and cold cloud duration rainfall estimates derived from METEOSAT geostationary satellite data. While both satellite data types are used in famine early warning, I will focus largely on the NOAA AVHRR normalized difference vegetation index measurements.

NOAA AVHRR Satellite Data

The NOAA-series of sun-synchronous polar-orbiting meteorological satellites orbit at an altitude of ~850 km and have a daytime overpass time of ~ 1430 hours local solar time. The AVHRR sensor scans ~55° from nadir and complete coverage of the earth is available twice daily at a spatial resolution of ~5.5 x 3.3 km at the satellite subpoint. Daily data from channels 1 (0.55-0.70 μm), 2 (0.72-1.1 μm), and 5 (11.5-12.5 μm) were used with a scan angle of 40° or less, processed to produce a vegetation index of (2-1)/(2+1), and formed into 10-day maximum value composites after Holben (1986). Channel 5 was used as a cloud filter where every pixel cooler than 12°C was labeled as a cloud. Holben (1986) and Holben and Fraser (1985) have shown that maximum value vegetation index composites simultaneously minimize scan angle, atmospheric effects, clouds, and all other degrading effects upon the vegetation index. Every 7.6 km grid-cell has ~ 6-7 potential data values to choose from every 10-day period. The NOAA AVHRR data are processed into three "10-day" composite images every month: from day 1 to day 10; from day 11 to day 20; and from day 21 to the end of the month. A monthly composite is also produced.

The normalized difference vegetation index is a non-destructive estimate of the photosynthetic potential or capacity of the area measured after Sellers (1985, 1987). Consequently, when normalized difference vegetation index measurements are made over time they provide information on the time history of the photosynthetic potential or capacity which has been shown to be highly related to total biomass production. This assumption has been tested in the Sahelian zone of West Africa where Tucker et al. (1985) and Prince (1991) have shown multi-temporal NOAA AVHRR normalized difference vegetation index data to be directly related to herbaceous above-ground biomass production.

Biomass production and green vegetation density are usually closely related to precipitation in grasslands and savannas. Precipitation ceases to be the primary factor in primary production when the rainfall is greater than ~700-800 mm/yr (Lamotte and Bourliere, 1983; Le Houreou and Hoste, 1977; Nicholson et al., 1990). The relationship of precipitation to green vegetation density and biomass or primary production depends upon the amount and timing of the rainfall, evapotranspiration and runoff, soil infiltration, and the ability of vegetation to respond to rainfall.

There is usually a strong and direct relationship between precipitation and the normalized difference vegetation index (figure 2). Similar, but slightly different, relationships have been reported from other arid and semi-arid grassland settings in Africa and elsewhere, although factors such as temperature, type of precipitation, timing, intensity, etc. are also important (Lauenroth, 1979; Nicholson et al., 1990; Rutherford, 1979; Seely, 1978). Figures 2 and 3 show the reasons why NOAA AVHRR normalized difference vegetation index data are so useful in famine early warning detection--they are directly linked to precipitation and hence primary production.

The data set presently in use from July 1981 to the present is a 7.6 km grid cell size equal-area projection NDVI product for Africa. In early 1996, this data set will be replaced by a 6-km grid cell size data product comprised of the NDVI, associated channel values, pixel angular information and day of acquisition, and cloud mask overlays. As soon as each "10-day" composite image is produced, it is transmitted to U.S. AID's Famine Early Warning Office for analysis.

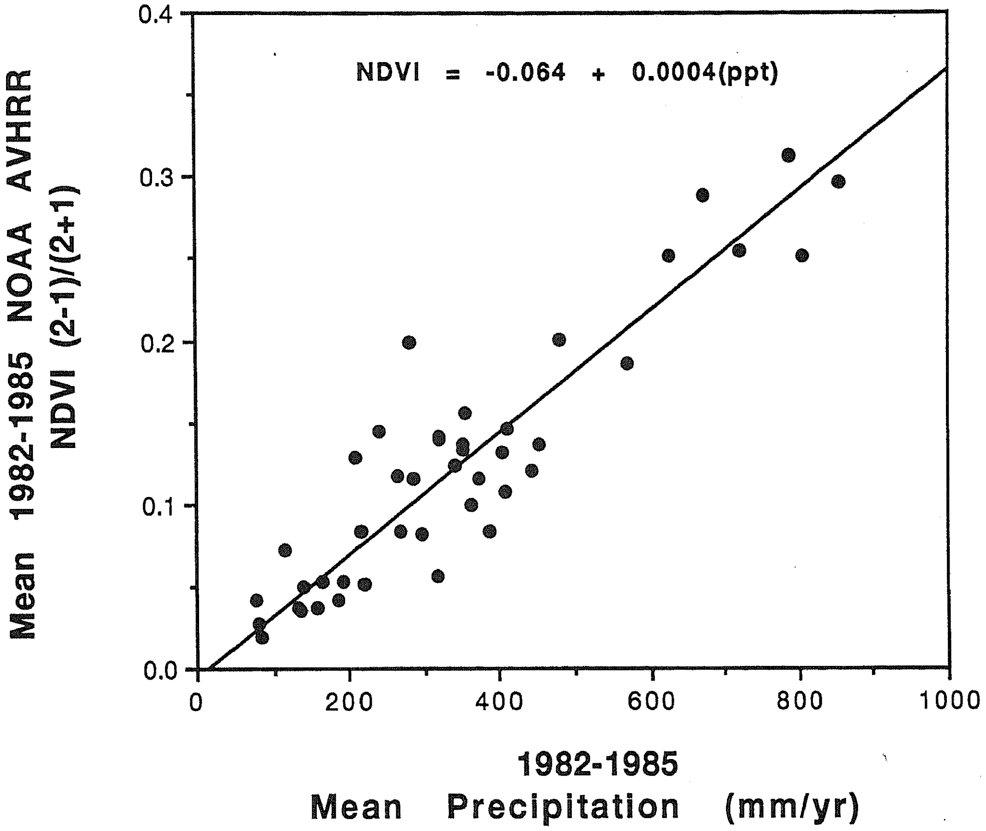

Figure 2. Correlation between the average 1982-1985 normalized difference vegetation index and the 1982-1985 station precipitation at specific reporting meteorological stations. Note the high degree of correlation between these two variables (from Tucker et al., 1991).

Famine Early Warning Analysis

When the time series of AVHRR normalized difference vegetation index data are available, simple comparisons among years serve to identify areas within Africa experiencing drought and hence the potential for subsequent famine. For example, within the Sahelian zone (broadly defined as the long-term 200 to 400 mm/yr precipitation zone immediately south of the Sahara), AVHRR normalized difference vegetation index data from 1980 to 1994 identify marked differences among three geographic subdivisions of this ecological or climatic zone (fig. 3).

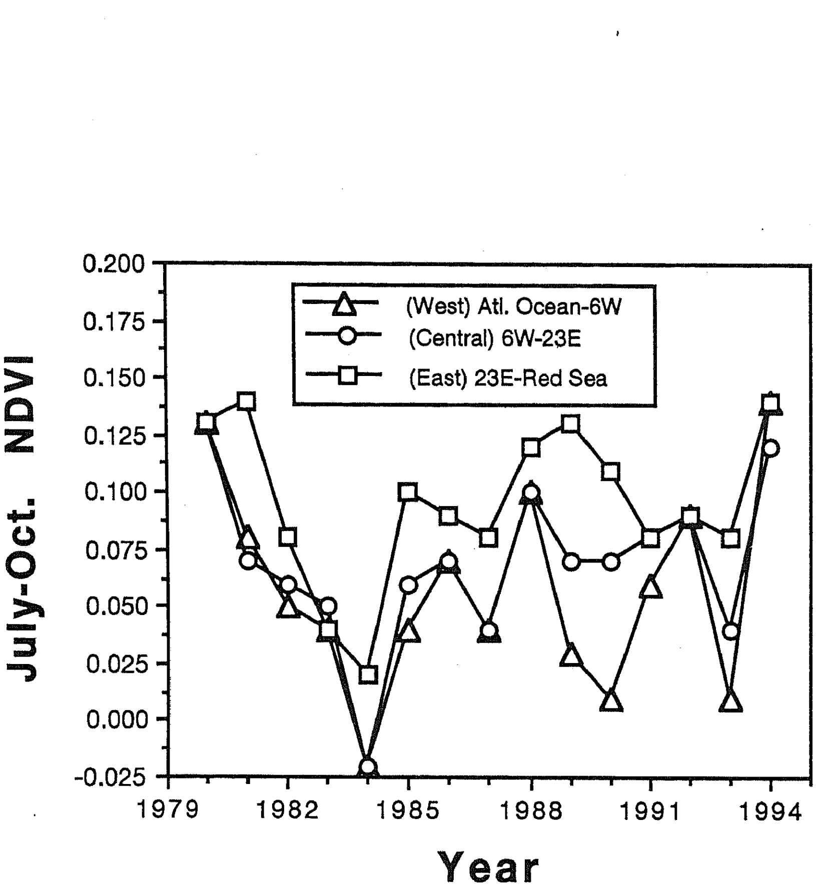

Figure 3. The average growing season normalized difference vegetation index for the Sahel Zone is disaggregated in a western component (the Atlantic Ocean to 6^{o} W), a central component (6^{o} W to 23^{o} E), and an eastern component (23^{o} E to the Red Sea). The Sahel Zone is defined as the long-term 200-400 mm/yr precipitation zone (see also Tucker et al. 1991).

For example, very similar normalized difference vegetation index values were found for the Western, Central, and Eastern portions of the Sahelian Zone from 1980 to 1983 and in 1992 to 1994. In contrast, from 1989 to 1990 and again in 1993, the Eastern Sahel exhibited higher normalized difference vegetation index values than the Central Sahel, which in turn was higher than the Western Sahel (fig. 4). NOAA AVHRR normalized difference vegetation index data from 1981 to 1995 (and continuing) enable comparisons to be made pixel by pixel, district by district, country by country, and region by region which readily identifies changes in surface conditions directly related to primary production. When combined with historical socioeconomic information, a much better understanding will emerge regarding the agricultural potential for the area(s) in question.

ENSO Cycle Anomalies and Famine Early Warning

Recently Cane et al. (1994) and Myneni et al. (1995) have reported that El Nino Southern Oscillation (ENSO) cycle sea surface temperature anomalies can highly influence African primary production and agricultural yield in specific areas. Cane et al (1994) have shown that ENSO cycle sea surface temperature anomalies are related to maize yield in Zimbabwe (figure 4). Mymeni et al (1995) have shown that ENSO cycle sea surface temperature anomalies seem to be related to precipitation patterns in other areas of Africa. Both of these types of ENSO cycle sea surface temperature anomalies as they affect African agriculture and natural vegetation are presently under detailed study to determine to what extent they exist and where within African they can be generalized.

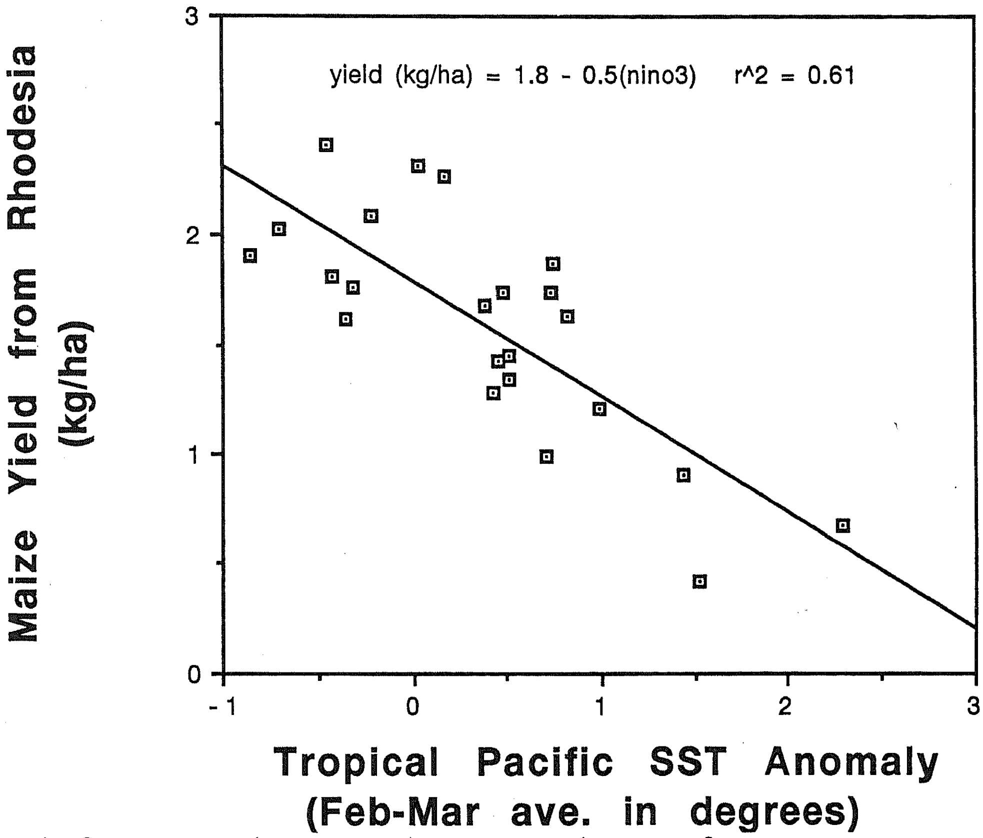

Figure 4. Comparison between February-March sea surface temperature and maize yield from Zimbabwe (Cane et al., 1994).

In summary, NOAA AVHRR data and other types of famine early warning satellite-derived information (sea surface temperature in the tropical Pacific and METEOSAT data) provide invaluable, very timely, cost-effective, and objective information which is be used to minimize the adverse effects of famine within Africa. This has resulted in tremendously reducing human suffering in a much more economical manner than is commonly realized. Without satellite data, this type of humanitarian work would not be possible.

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