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Earlier Famine Warning Possible Using Remote Sensing and Models

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Remote sensing allows scientists to detect slowly evolving natural hazards such as agricultural drought. Famine early warning systems transform these data into actionable policy information, enabling humanitarian organizations to respond in a timely and appropriate manner.

These life-saving responses are increasingly important: In 2006, one out of eight people did not have enough food to eat and 22 million more people became sufficiently undernourished to require intervention, prompting 22 countries to provide $6.5 billion in food aid. Since their inception in the mid-1980s, the combination of monitoring and mitigation systems has dramatically reduced the number of famines caused by biophysical hazards, such as floods, drought, and pests, that destroy food crops [*Murphy and McAfee*, 2005]. Yet despite this notable achievement, many countries, mostly in Africa, face chronic and increasing food insecurity.

The motivation is strong therefore to increase the effectiveness of food aid, and to ensure that the assistance arrives sufficiently early to ward off human and economic catastrophe. Remote sensing information that is properly interpreted reduces the influence of politics in determining the amount and location of aid delivered, ensuring that the aid goes only where it is needed.

This article briefly reviews three recent contributions that Earth observations have provided to famine early warning: trend identification, increasingly accurate forecasts of food security conditions, and enhanced integration of biophysical and socioeconomic data.

Famine Early Warning Systems Network

In this article, we present work that grows out of our ongoing efforts through the U.S. Agency for International Development's (USAID) Famine Early Warning Systems Network (FEWS NET). The network monitors food security in 20 African countries, three Central American countries, Haiti, and Afghanistan. Because these countries experience significant variability in interannual rainfall and food production, spatial data with regional coverage are essential [*Verdin et al.*, 2005]. Thus, quantitative vegetation and rainfall data obtained from satellite remote sensing are used extensively by FEWS NET due to the data's timeliness and ability to identify change. The success of famine early warning is determined by FEWS NET's ability to apply these data to complex decision-making processes that are often conducted during crises.

This section reports on new products and methods being developed to improve the ability of early warning systems to identify hazards to food security early enough so that political and budgetary decisions can be made in a timely manner. It often takes more than 6 months from the time that assistance is approved by donors for the food to begin to arrive in the affected areas. This means that budgetary decisions that precede humanitarian action often must be made months before the outcome of the harvest is known and before official production figures are available in the region in question. Information on hazards can generally be provided on timescales of years (multiannual trend analyses), seasons (forecasts of climate conditions), and months (midseason harvest assessments). Earth observations can contribute to each of these efforts, saving human lives.

Satellite vegetation indices [*Brown et al.*, 2006], lake levels, and interpolated station data [*Verdin et al.*, 2005] suggest substantial declines during the past three decades in annual rainfall within southern and eastern Africa (http://www.fews.net/resources/gcontent/pdf/1000929.pdf). Blends of Global Precipitation Climatology Project precipitation and dense gauge observations [*Funk et al.*, 2007], for example, show 10–30% reductions in January–June rainfall in southern Africa from 1991 to 2005 compared with the 1979–1990 average. These declines are probably related to anthropogenic increases in Indian Ocean sea surface temperatures [*Barnett et al.*, 2001], which tend to reduce December–June rains in southern [*Hoerling et al.*, 2006] and eastern [*Funk et al.*, 2005; *Verdin et al.*, 2005] Africa, adversely affecting the food security of millions of Africans [*May*, 2005].

In semiarid regions along Africa's eastern seaboard, these declines have combined with increasing population pressures, HIV/AIDS, malaria, poor land management, limited investments in agriculture, and economic and social marginalization to produce alarming increases in malnutrition and

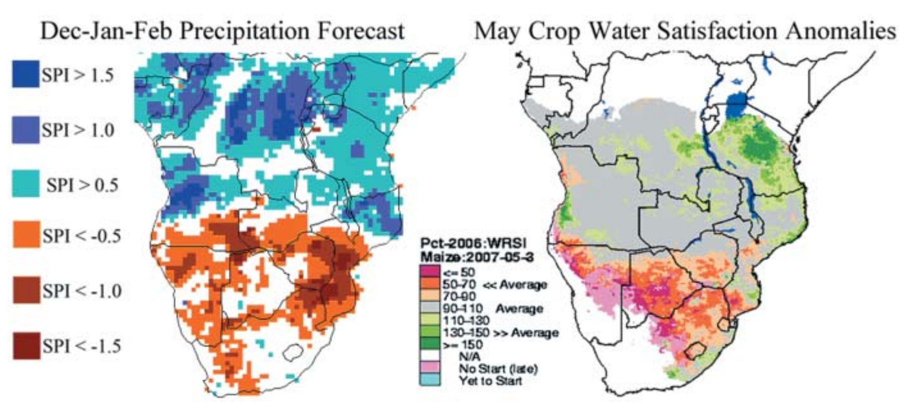

*Fig. 1. (left) Standardized Precipitation Index (SPI) rainfall forecasts [*Funk et al., *2007], based on November observations of sea surface temperatures, precipitation, and wind fields. (right) A common index of crop performance: end-of-season maize Water Requirement Satisfaction Index (WRSI) anomalies, which show areas that needed more water.*

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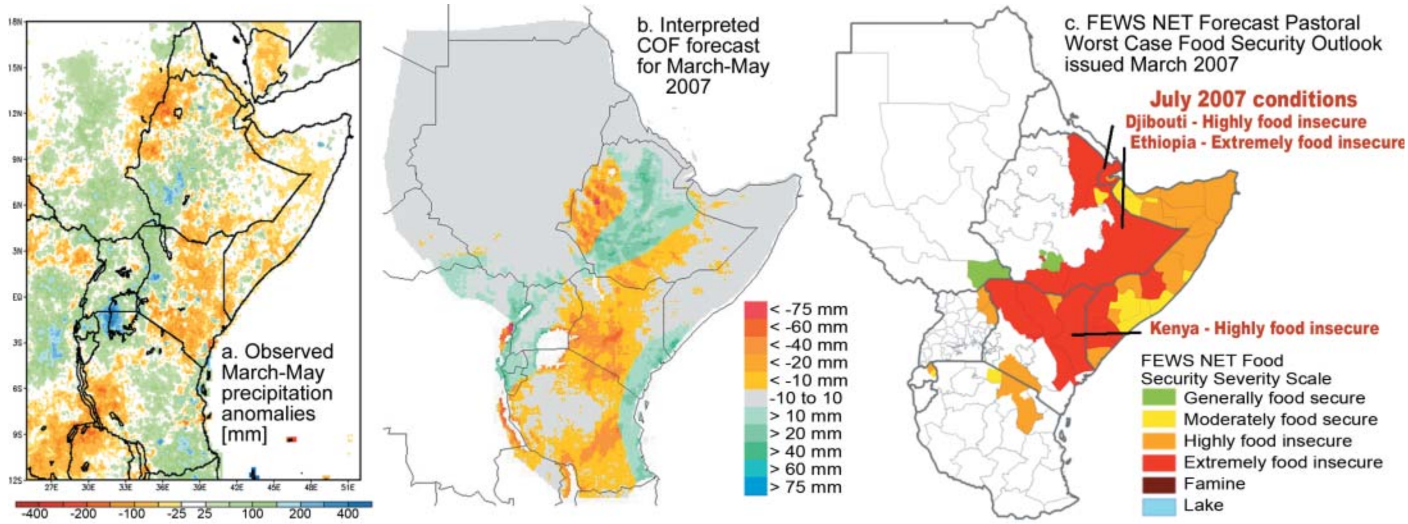

Fig. 2. (a) Observed rainfall. (b) Climate Outlook Forum forecast precipitation anomalies. (c)Worst-case rangeland food security outlook. Text in orange indicates July 2007 FEWS NET watch and emergency locations for eastern Africa.

undernutrition, especially among children. While these trends are disturbing, our expanding satellite observation systems and modeling capacity often enable scientists to make effective food security forecasts for this region [*Funk et al.*, 2007]. One such recent forecast (http://www.fews.net/resources/gcontent/pdf/1001190.pdf), for example, correctly anticipated the wet-dry north-south rainfall dipole that visited southern and eastern Africa during the 2006–2007 boreal winter and produced drought in some regions and floods in others, the latter leading to Rift Valley Fever outbreaks (Figure 1).

Building on the utility of these forecasts, recent research has focused on reformulating forecast information in formats compatible with satellite observing systems. For example, statistical models of vegetation dynamics [*Funk and Brown*, 2006] can be used to combine satellite observations with rainfall forecasts [*Funk et al.*, 2007] to predict future vegetation extremes. This research takes advantage of vegetation persistence while accounting for the differential rainfall-vegetation growth relationships. A user, such as a food security analyst, is presented with a single product (for example, a satellite-derived normalized difference vegetation index time series across a growing season) that combines observations and predictions seamlessly in a more usable format. These results can be immediately incorporated into operational analyses of food security. With funding from NASA's Applied Sciences program, these projections will be operational in the FEWS NET program by 2009.

Climate Outlook Forums and Food Security Outlooks

Regional Climate Outlook Forums provide another important mechanism for formulating and disseminating seasonal climate forecasts. These meetings bring together climate scientists, operational forecasters, and climate information users to formulate a consensus model-based forecast and to discuss the implications of probable climate outcomes for climate-sensitive sectors such as agriculture and ultimately food security. Since 1996, the NOAA Climate Programs Office, USAID, and the United Nation's World Meteorological Organization have supported these meetings in Africa and in other regions. During this time, seasonal forecasts have significantly improved, particularly in years with a strong signal from the El Niño–Southern Oscillation.

FEWS NET participates in and helps to fund the forums, and through the work of its scientists transforms the probabilistic forecasts into rainfall projections using the Forecast Interpretation Tool. Developed by FEWS NET, the tool incorporates historical rainfall climatologies that enable a translation of climate model output [*Husak et al.*, 2007] to historical rainfall climatologies [*Funk et al.*, 2003] in order to transform forecast probabilities into rainfall anomalies. These anomalies are then used to drive models describing crop yields and pastoral conditions. The predicted yields then are combined with information about the ways the local population make a living and socioeconomic monitoring data to estimate the food security situation of a region for the next 6 months. These estimates are used to support contingency and response planning efforts in a food security outlook, which is a new planning product of USAID.

Figure 2 shows the results of using the FEWS NET's Forecast Interpretation Tool to translate the March 2007 Regional Climate Outlook Forum forecast into estimates of expected rainfall anomalies [*Husak et al.*, 2007]. FEWS NET analyzed sector-specific consequences of the forecast to determine climate's potential impact on the food security situation in pastoral, agropastoral, and agricultural zones. This analysis correctly anticipated food security problems in eastern Africa.

Integrating Biophysical and Socioeconomic Data Sets

Accurate projections of biophysical parameters provide the opportunity to improve indicators of food access as well as food production. Through the implementation of a new economic model that links variations in commodity prices to weather-related variations in local production, it is possible, for the first time, to provide commodity price projections and regional price maps [*Brown et al.*, 2007]. These data can enhance food security by providing price data to small- and medium-sized food traders and brokers in African countries, thereby increasing the efficiency of food distribution in market systems.

FEWS NET is beginning to adopt this price modeling approach in order to better inform policy makers about future variations in food access, a key component of food security, particularly in regions with a high percentage of the population reliant on markets instead of agriculture for their food.

Earlier and Better Early Warning

Current food security problems are often monitored using remote and local observations of food security conditions. These observations are used to develop immediate food aid need requirements and therefore need a very high accuracy.

In the past 5 years, however, contingency planning and preparedness for crises, particularly in regions that experience problems frequently, have increased in importance. Clearly, anticipating future problems allows for better integration with humanitarian aid sources that require lengthy negotiation, early purchasing, mobilization, and shipping of food aid.

Further, the necessary precision of the information needed for planning and forecasts of possible future food insecurity is far lower than that required to estimate current food aid needs. FEWS NET has recently begun to assess future changes in food security status due to biophysical and socioeconomic events through a twice-a-year projection of food security conditions. The food security outlook product has pushed forecasts and statistical projections of observations into the forefront of the early warning activity. Integrating projections with remote sensing observations will greatly improve the utility and integration of forecasts into operational networks.

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NEWS

Mixing and Stirring in the Southern Ocean

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The vertical and horizontal mixing of waters within the ocean affects the Earth's climate because it controls the poleward transport of heat and carbon within the ocean, the structure of the large-scale currents, and the character of water that upwells and interacts with the atmosphere. Particularly in the Southern Ocean, ocean general circulation models can show different behavior depending on the exact representation of mixing. To date, however, measurements of this mixing have not been available because of the remoteness and difficult working conditions in the Southern Ocean.

The Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean (DIMES) seeks to understand the regional importance of the Southern Ocean to global circulation by measuring large- and small-scale mixing processes. In the ocean, water moves primarily along surfaces of constant potential density (isopycnals), but it can also mix and change density between these surfaces in what is known as diapycnal mixing. This experiment, a joint effort between U.S. and U.K. scientists, will begin fieldwork in early 2009.

The experiment is motivated by the hypothesis that mixing in the Southern Ocean interior plays a controlling role in the dynamics of how the ocean circulates water on a global scale, a phenomenon called the meridional overturning circulation. Past studies of this circulation have often assumed that water travels southward in the ocean interior, upwells along isopycnals in the Southern Ocean, and is transformed by air-sea exchanges as it returns northward at the ocean surface, with negligible diapycnal mixing in the ocean interior. However, recent observational studies have called this view into question by suggesting that interior diapycnal mixing may be intense in some parts of the Southern Ocean, particularly where the Antarctic Circumpolar Current (ACC) encounters rough topography.

In the experiment, diapycnal mixing will be measured by tracking the vertical spreading of a tracer patch of 480 kilograms of trifluoromethyl sulfur pentafluoride (CF_3SF_5) that will be released at 60°S, 110°W near 1300-meter depth. At this depth, the tracer patch is expected to take about 3 years to advect into Drake Passage and through the Scotia Sea. High-resolution measurements of the vertical variations in the ocean (known as fine structure and microstructure) to be collected by U. S. and U.K. vertical (free-falling) profilers will provide instantaneous measures of diapycnal mixing. These measures will be augmented by floats that measure vertical velocity shear in the tracer layer and by electromagnetic Autonomous Profiling Explorer (APEX) floats that measure fine-scale shear and stratification year-round over the upper 1500 meters of the water column.

Isopycnal mixing and dispersion parameters will be determined from acoustically tracked isopycnal-following floats deployed in the same layer as the tracer, and also from the horizontal dispersion of the tracer patch. A mooring array in Drake Passage will measure the set of physical processes by which eddies and internal waves can interact. Hydrographic observations will be made during experiment cruises, and inverse modeling methods are planned to synthesize the observations. Finally, analysis of experiment data will take advantage of satellite altimetry in order to assess surface mixing processes and to evaluate how observations are distributed relative to the meandering dynamical features of the Southern Ocean. Models run at the Los Alamos National Laboratory (LANL), the National Oceanography Centre, Southampton (NOCS), and the University of East Anglia will be used to further guide the experiment and to interpret the results.

DIMES offers a range of opportunities for complementary work. The experiment's research cruises will visit remote parts of the southeastern Pacific, presenting opportunities for surface drifter and Argo float deployment. DIMES will deploy a major sound source array that could support ancillary float programs or permit the deployment of additional acoustically tracked Argo floats in the Antarctic Circumpolar Current region. Complementary efforts aimed at improving measurements and assimilation of meteorology and surface fluxes would be especially welcome. The experiment's research cruises also have the potential for biogeochemical measurements in a region of high importance, within a well-characterized physical environment.

Ultimately, results from the experiment should facilitate improvements in the representation of mixing in numerical models of the ocean and climate. While modeling efforts funded as part of the experiment