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Intra-seasonal NDVI change projections in semi-arid Africa

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Abstract

Early warning systems (EWS) tend to focus on the identification of slow onset disasters such famine and epidemic disease. Since hazardous environmental conditions often precede disastrous outcomes by many months, effective monitoring via satellite and in situ observations can successfully guide mitigation activities. Accurate short term forecasts of NDVI could increase lead times, making early warning earlier. This paper presents a simple empirical model for making 1 to 4 month NDVI projections. These statistical projections are based on parameterized satellite rainfall estimates (RFE) and relative humidity demand (RHD). A quasi-global, 1 month ahead, 1° study demonstrates reasonable accuracies in many semi-arid regions. In Africa, a 0.1° cross-validated skill assessment quantifies the technique's applicability at 1 to 4 month forecast intervals. These results suggest that useful projections can be made over many semi-arid, food insecure regions of Africa, with plausible extensions to drought prone areas of Asia, Australia and South America.

Keywords: Early warning; Africa; Food security; NDVI; Precipitation; Rainfall; Malaria; Rift valley fever; Pastoral livelihoods

1. Introduction

In areas with limited in situ data, NDVI and satellite rainfall estimates are routinely used to identify areas prone to drought related crop failure and poor pasture conditions (FEWS, 2000; Field, 1991; Hutchinson, 1998), malaria (Hay et al., 1998) and Rift Valley Fever (RVF) (Linthicum et al., 1999), and damaging pests such as locusts (Hielkema et al., 1986; Tucker et al., 1985). These satellite observations are routinely used by development organizations working in semi-arid regions where agriculture and pastoralism are the primary livelihood strategy (Maxwell, 1996; Watts, 1987; Webb & Rogers, 2003). By monitoring environmental and social conditions, governments and international, national and local organizations have been able to respond rapidly to food crises. This paper describes a statistical approach for making intra-seasonal projections of vegetation change, thereby providing the potential for earlier early warning of these events.

The enhanced integration of remotely sensed vegetation and precipitation products has an immediate and interested audience, with the ability to inform policy and emergency response agencies and governments. One way of leveraging the substantial human investment in the environmental monitoring of vegetation (Eklundh, 1996; Hielkema et al., 1986; Kawabata et al., 2001; Prince & Justice, 1991; Tucker et al., 1986), precipitation (Adler et al., 1994; Arkin et al., 1994; Huffman et al., 1995, 1997; Love et al., 2004; Xie & Arkin, 1996) and atmospheric conditions (Kalnay et al., 1996) is to use *observed* environmental conditions to make predictions of future land surface properties.

Many studies have described the dependency of vegetation on variations of rainfall and temperature (Davenport & Nicholson, 1993; Lotsch et al., 2003a; Nicholson et al., 1997; Richard & Poccard, 1998; Tucker & Nicholson, 1999). The Normalized Difference Vegetation Index or NDVI from NOAA's Advanced Very High Resolution Radiometer (AVHRR) instrument has been used to assess climate in semi-arid zones where rainfall records are scarce or difficult to obtain in a timely fashion (Davenport & Nicholson, 1993; Zhou et al., 2003). A month lead-time can prove critical in

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minimizing the impacts of these hazards. This paper demonstrates one way in which the lagged relationship between rainfall and NDVI can be used to estimate vegetation response to current conditions, helping to make early warning systems earlier. We refer to these statistical estimates of NDVI change as 'projections' to differentiate them from climate-based forecasts of NDVI (Anyamba et al., 2002; Verdin et al., 1999). The approach described here is distinct from and compatible with climate-modeling approaches. Our focus is on the direct use satellite-observed precipitation as a basis for forecasting NDVI.

2. Data

The following sections describe the datasets that were used in the model: 1° monthly precipitation fields from the Global Precipitation Climatology Project (GPCP), 0.1° monthly precipitation fields from NOAA's Climate Prediction Center, relative humidity fields from the National Climatic Diagnostics Center's reanalysis, and 1° and 0.1° monthly AVHRR NDVI data from NASA's Global Inventory Monitoring and Modeling Systems group (GIMMS).

2.1. Global and operational contexts

In this study, the data were used at two spatial resolutions: 1°/quasi-global (50 N/S, 180°W to 180°E) and 8 km African (40° N/S, 20°W to 55°E) data re-projected to the Plate Carree or geographic 0.1° resolution. The 1° data provides global validation with low signal-to-noise ratios for the inputs. The 0.1° scale recreates the operational context used in weekly monitoring by FEWS NET.

2.2. Precipitation data

This analysis used two sources of precipitation: the global GPCP Version 2 Combined Precipitation Dataset (Huffman et al., 1995, 1997) and the African 0.1° Rainfall Estimate or RFE climatology. The GPCP is a 2.5° merged analysis incorporating precipitation estimates from low-orbit-satellite infrared data and rain gauge observations. This study used 1° monthly gridded area-mean rainfall totals and error estimates over the January 1979 to January 2001 period (GPCP, 2001). For Africa, NOAA's Climate Prediction Center's African RFE Climatology (ARC, Love et al., 2004) provides a unique resource for studying rainfall variability. The CPC's ARC dataset is similar in spirit to climate reanalysis projects. A fixed algorithm, the RFE 2.0 method (Xie & Arkin, 1996; Xie et al., 2002) is applied consistently to a long homogeneous set of 0.1° three-hourly Meteosat infrared and Global Telecommunications System rain gauge data. While the ARC estimates lack additional satellite inputs used in the operational RFE 2.0 estimates, it has much longer period of record (1995–present as opposed to 2001–present). The ARC data is used operationally by USAID's Famine Early Warning System, and is available for download from www.fews.net.

2.3. Relative humidity data

This study has used surface relative humidity (the 0.995 sigma level) fields from the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) reanalysis. These fields are at a 2.5° resolution and are available from January 1948 to present. Atmospheric fields in the reanalysis are derived from solutions to the primitive equations for vorticity, divergence, virtual temperature, logarithm of surface pressure and specific humidity on a T62 spectral grid with 28 unequally spaced sigma levels (Kanamitsu, 1989; Kanamitsu et al., 1991; Sela, 1980). The data were resampled to a 1.0° and a 0.1° resolution using cubic convolution.

Moisture related parameters in the reanalysis are considered much less reliable than temperature, pressure or wind fields, which are constrained by observations. Despite the approximate nature of these fields, both our previous efforts modeling rainfall in Africa (Funk & Michaelsen, 2004; Funk et al., 2003b) and the ongoing use of statistically corrected climate forecast models (Landman & Goddard, 2002) have demonstrated that climate models can provide useful information regarding atmospheric moisture conditions. 'True' relative humidity varies more smoothly in space and time than rainfall, making the use of reanalysis based on relative humidity plausible.

7. Conclusion

Because food insecurity typically results from a combination of climate events and societal vulnerabilities, crises almost always arise in areas with limited in situ data. Satellite information is thus the first line of defense for many of the world's millions of food insecure. Information on the progress of the growing season as measured by meteorological satellites combined with extensive social science and livelihood information provides actionable guidance and early warning of food security crises (Mathys, 2005). These assessments are often needed for deadlines imposed by the budgetary cycle of large international donor organizations such as the US Agency for International Development or the UN World Food Program. Early assessments of large potential crop losses are key to finding the funds and to sending local assessment teams to trouble spots and for arranging for early and adequate shipments of food aid to regions in need. These practical timing and budgetary considerations are the impetus of this research and define the user community for new products.

The study results presented here are quite promising, suggesting that useful projections can be made over most semi-arid regions of Africa, with potential extensions to drought prone areas of Asia, Australia and South America. These projections will be integrated into existing early warning systems, allowing for the advance identification of climate impacts affecting agricultural and pastoral regions. As monitoring activities expand into new regions, the extended model may become an important tool for protecting the lives and livelihoods of agricultural communities in semi-arid zones throughout the world.