Historical El Niño/Crop Production Relationships in Southern Africa

United States Geological Survey/Famine Early Warning System Special Report

Issued September 21st, 2002[1]

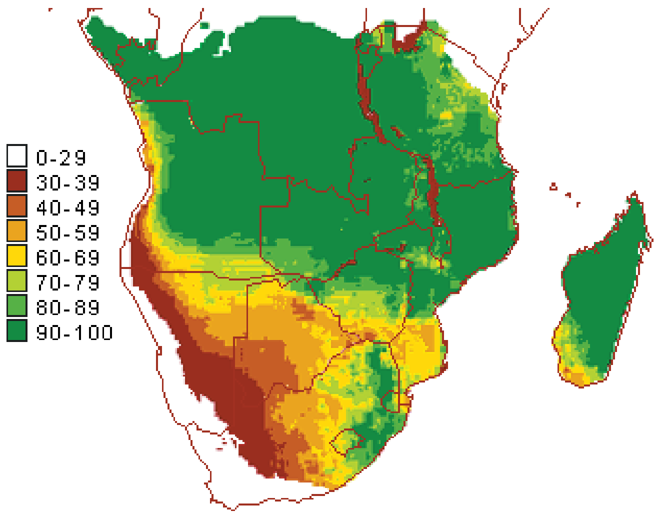

Figure 1. Long term average end-of-season WRSI values (1962-2001)

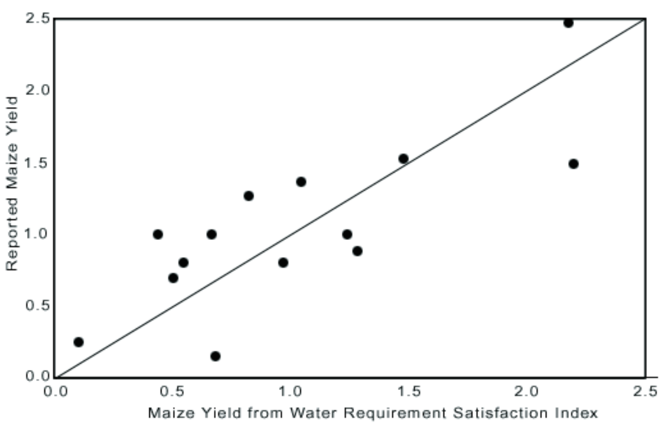

Figure 2. Quality controlled ground based yield estimates compared with the corresponding WRSI yield estimates for 14 communal lands in Zimbabwe. Correlation 0.8. From Verdin and Klaver, 2002.

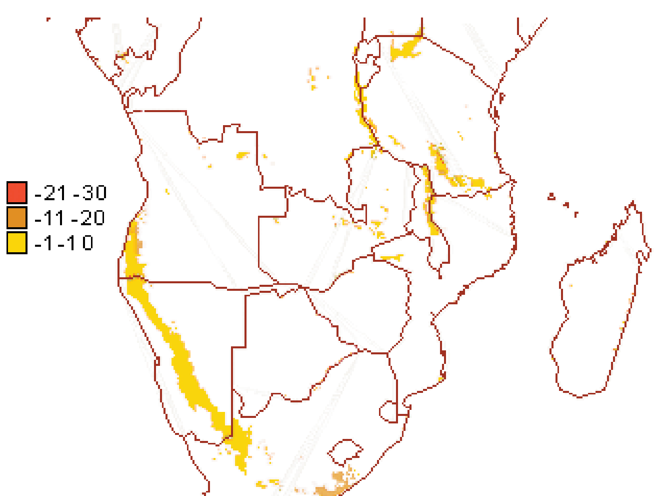

Figure 3. Statistically significant WRSI anomalies for weak El Niño years (α=0.05).

Introduction

Several countries in Southern Africa face dramatic food insecurity crises. In Zimbabwe nearly 5.6 million people (41% of the national population) face inadequate food supplies[2]. Malnutrition there is on the rise, and the cost of living continues to soar[3]. In Malawi 3.2 million people (>25% of the population) will likely require food aid this year[4]. In Zambia 20% of the population (~2 million people) are in need of assistance with food access being a greater problem than food availability. A recent position paper by FEWS/NET states that these three countries are under a real threat of famine[5]. Adding to present concerns are recent forecasts of El Niño, a condition historically linked to drought in Southern Africa. These forecasts generally call for a weak to moderate El Niño event[6] with sea surface temperature anomalies in the eastern Pacific of between 0.5 and 1.0 degrees. This report quantifies the likely impacts a weak or moderate-to-strong El Niño event might have on southern Africa crop production. *Our results show that the crop water satisfaction outlook under conditions of weak-El Niño is very similar to long term average conditions. If a moderate-to-strong El Niño develops, however, history suggests that crop yield reductions of 20-40% for several regions of Zimbabwe, eastern Botswana, southern Mozambique and Lesotho are likely. Zambia has historically had WRSI yield reductions of around 10% during El Niño years. Malawi is not likely to be affected.*

WRSI Time series

This analysis begins with a forty-one year (1961-2001) time series of gridded 10 day rainfall estimates. The Collaborative Historical African Rainfall Model (CHARM) covers the years between 1961 and 1995 by synthesizing interpolated gauge data[7], reanalysis precipitation fields[8], and a model of orographic rainfall[9]. Recent (1996-2001) satellite-based estimates produced by the Herman[10] and Xie-Arkin[11] techniques were provided by the Climate Prediction Center (CPC). These precipitation fields were in turn used to drive a grid cell based implementation of the Water Requirement Satisfaction Index (WRSI) developed by the USGS FEWS NET[12,13]. The WRSI estimates the percent of the water requirement met by a crop at each pixel from the onset of rains to the end of the season. Pixels with 100% WRSI values received all the water they needed during the season. Pixels with WRSI values of less than 30 are assumed to have failed. Crop parameters for 120 day maize were used in this analysis. Figure 1 shows the climatological end -of-season WRSI values for southern Africa. Gridded WRSI maps have been shown to be useful tools for monitoring drought[14], and a comparison with yield estimates from quality controlled districts in Zimbabwe have a correlation of 0.8 (Figure 2).

WRSI Composite Anomalies

WRSI anomalies, defined as the difference between the end-of-season WRSI and the long term mean (Figure 1), show how well a given season's crop water requirements were met. Averaging anomalies from similar years allows us to make WRSI anomaly composite maps that show historical crop water satisfaction conditions during El Niños. This study examined two WRSI anomaly composites - one for weak and one for moderate-to-strong El Niños. The first composite contains years designated as 'weak' by the NOAA Climate Prediction Center (CPC) during January-February-March. These correspond to the six growing seasons ending in 1970, 1978, 1980, 1988, 1991 and 1993. January-February-March eastern equatorial Pacific (NINO3.4) sea surface temperature anomalies for these years ranged from 0.6 to 0.8 C. The second group of 8 years were moderate-to-strong El Niños: 1966, 1969, 1973, 1983, 1987, 1992, 1995 and 1998. January-February-March eastern equatorial Pacific (NINO3.4) sea surface temperature anomalies for these years ranged from 1.1 to 3.3 C. Ignoring potentially important controls in

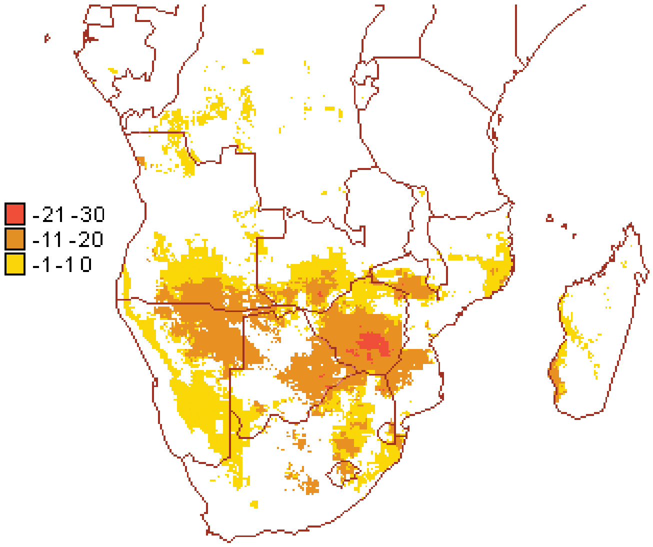

Figure 4. Significant WRSI anomalies for moderate-to-strong El Niño years (α=0.05).

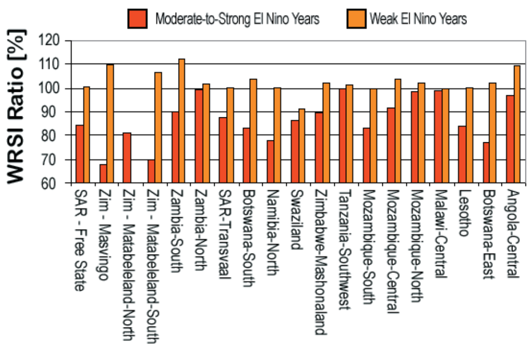

Figure 5. Average WRSI during weak and moderate-to-strong El Niño years divided by long term average WRSI, by crop growing region.

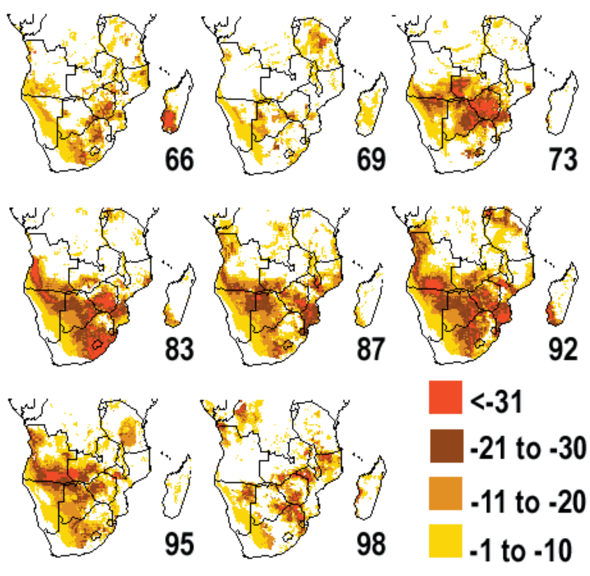

Figure 6. End-of-season WRSI anomalies for recent moderate-to-strong El Niño years. Years refer to the end of growing season.

the Atlantic and Indian oceans, these two scenarios - weak El Niño and moderate-to-strong El Niño - correspond, respectively, to a most likely and a worst case scenario for the upcoming season.

Significance Testing

Because nearby locations in the atmosphere and oceans tend to be similar, seasonal composites can produce coherent patterns that arise purely through chance. We can limit (but not remove) the influence of chance by only showing results which appear to be non-random. To do this we compared the weak and moderate-to-strong composite anomaly values at each pixel to 1,000 composite anomaly values comprised of six or eight randomly selected years. The resulting empirical sampling distributions allowed us to screen out anomalies which were not statistically significant (α=0.95). Maps of these significant anomalies can be used to explore the likely impact of the weak and moderate-to-strong El Niño scenarios.

WRSI Composite Anomaly Results

The WRSI composite anomaly maps for a weak El Niño year show no strong impacts (Figure 3). *Thus under conditions of a weak El Niño, crop prospects appear similar to long term average values. Moderate-to-strong El Niño events, however, have been historically related to reduced WRSI values in Zimbabwe, eastern Botswana, northern Namibia and Southern Angola* (Figure 4). The anomalies over most of these regions are between -11 to -20 WRSI, or between 15 to 35% of the long term mean WRSI. *Since the historical moderate-to-strong El Niño impacts coincide with some of the regions suffering food shortages this year, appropriate planning should include poor yields for these regions as a possible scenario.*

WRSI Ratio Results

In order to assess impacts on specific crop growing regions, the WRSI values were averaged by crop growing regions, kindly provided by the Regional Remote Sensing Unit in Harare. Dividing by the average WRSI value for all years provides a proxy measurement of rainfall-related yield ratios. WRSI yield ratios of 100% indicate average conditions (Figure 5). Under weak El Niño conditions all regions show yields ratios of near 100%. Under moderate-to-strong El Niño conditions the Matabeleland-South, Matabeleland-North, Masvingo, Eastern Botswana and Northern Namibia maize growing regions show yield reductions of 20% or greater, while regions in South Africa, Southern Botswana, Southern Zambia, Swaziland, Mashonaland, Southern Mozambique and Lesotho have historical WRSI yield reductions of between 10 to 20%.

WRSI Anomalies and the 1998 El Niño

Figure 6 shows the end-of-season WRSI anomalies for moderate-to-strong El Niño years. While not as widespread as other El Niño years, like the 1973, 1983 and 1992 seasons, 1998 did see zones of crop water deficits (as modeled by the WRSI). Many of these anomalies missed the important crop growing areas. Southern Zimbabwe, however, has received negative anomalies in every recent moderate-to-strong El Niño except for 1969. Northern Namibia seems similarly affected. *Thus while the effect of El Niño on the whole of Southern Africa has likely been over-estimated in the past, it still appears to be consistently linked to negative impacts in these specific regions.*

El Niño Impacts and Monthly Rainfall Anomalies

We found a strong correspondence between January rainfall deficits and WRSI reductions. Plots of statistically significant (α=95%) monthly rainfall composite anomalies for moderate-to-strong El Niño years (Figure 7) show that the strongest impacts are in January and March. The January anomalies, centered over Zimbabwe and south-central Mozambique contribute strongly to the negative WRSI anomalies for these regions. The January dry spell which occurred this year, with its detrimental impacts, may be typical of El Niño years as well.

Early rains could pose transportation problems

During weak El Niños November rainfall has been significantly greater than average over portions of eastern and southern Zimbabwe and southern Mozambique (Figure 8). The magnitude of the composite anomalies in these areas (+40 mm/month) is similar to the climatological mean rainfall for November. This

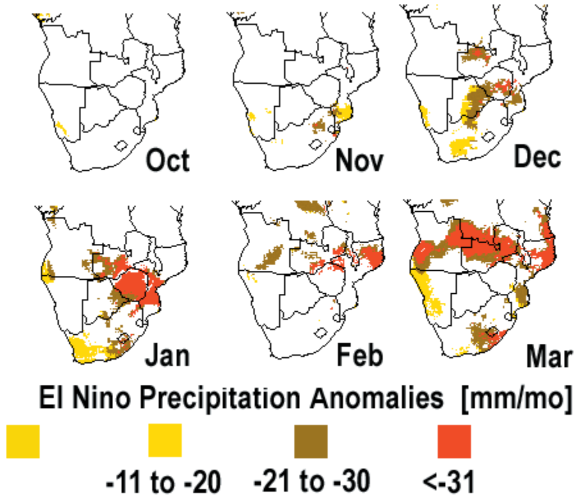

Figure 7. Statistically significant monthly precipitation anomalies for moderate-to-strong El Niño years (α=0.05).

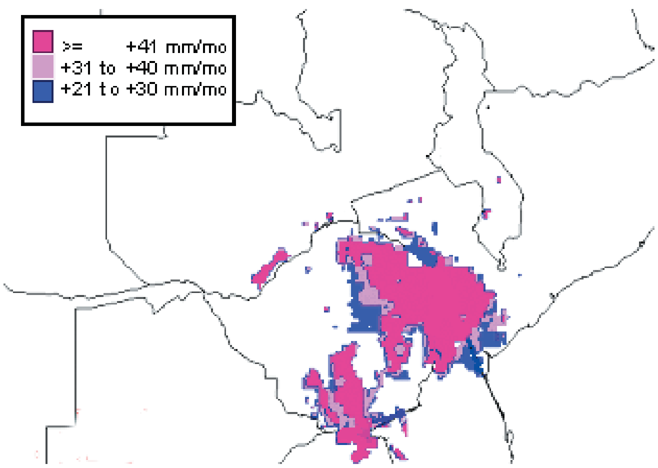

Figure 8. Statistically significant November precipitation anomalies for weak El Niño years (α=0.05).

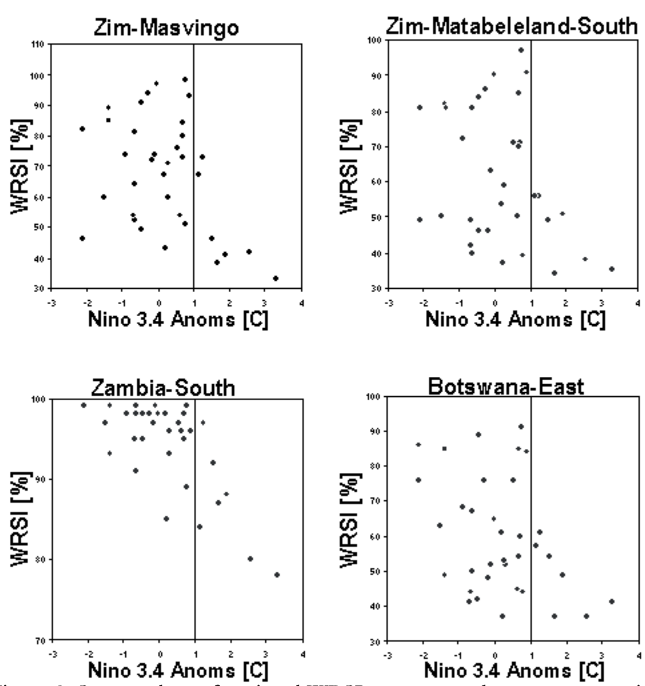

Figure 9. Scatter plots of regional WRSI averages and eastern equatorial Pacific (NINO3.4) sea surface temperature anomalies.

implies a potential doubling of the monthly rainfall. Early rains on unpaved roads in these regions could make food transportation more difficult.

Robust Non-linear Teleconnections

The link between El Niño and the strongly affected crop growing regions appears to both robust and fairly non-linear. When eastern equatorial Pacific (NINO3.4) sea surface temperature anomalies are greater than +1C these regions always appear to have consistently below normal WRSI averages (Figure 9). This appears to hold for the southern Matabelbeland, Masvingo, eastern Botswana and southern Zambia regions (shown) as well as for the Free State, Transvaal, northern Namibia, Shonaland, northern Matabeleland, central and southern Mozambique, Lesotho and Swaziland (not shown). When the sea surface temperature anomalies are less than +1C there appears to be little relationship between the magnitude of the anomalies and the WRSI. Thus although the overall correlations between NINO3.4 sea surface temperatures and the WRSI time series are typically quite low, the link between reduced yields and El Niño appears quite strong during warm events. One likely interpretation of this result is that weather patterns are dominated by the Indian and Atlantic oceans during non-El Niño years.

Conclusion

If the current El Niño remains weak then this study suggests that it is unlikely to have a strong impact on southern African food production. There is some chance that greater than normal November rainfall could disrupt food distribution in rural areas. If a stronger El Niño develops, then yield reductions of between 15 to 35% percent for some agricultural districts appear likely, with Lesotho, eastern Botswana, Zimbabwe, northern Namibia and southern Mozambique being historically hit the hardest. Southern Zambia has historically had WRSI yield reductions of about 10% in moderate-to-strong El Niño years. Malawi does not appear to be strongly influenced by recent El Niño events. *Thus if present El Niño conditions intensify, history suggests that there is a real threat of repeat drought conditions arising in Zimbabwe and, to a lesser degree, Zambia*. It should be borne in mind that this study has neglected the impact of the Indian and Atlantic oceans, which also influence precipitation in southern Africa.

---

[1] Prepared by Chris Funk, Tamuka Magadzire, Gabriel Senay, Jim Rowland, Jim Verdin & Joel Michaelsen. Chris Funk has been supported by an EPA STAR fellowship.

[2] Vhurumuku, E., Butaumocho, B., 2002. Zimbabwe Food Security Assessment Report for 2002/03 Consumption Year, FEWS/NET, SADC Food Security Technical and Administrative Unit, Harare.
[3] UN, R.R.U., 2002. Zimbabwe Humanitarian Situation Report, United Nations, Harare.
[4] FEWS/NET, 2002. Food Security Warning: Food access crisis continues for many in Malawi, Famine Early Warning System Network
[5] FEWS/NET, 2002. Position Paper: Is a famine developing in Southern Africa?, Famine Early Warning System Network.
[6] See iri.columbia.edu/forecast and www.cpc.ncep.noaa.gov/products/forecasts/
[7] Willmott, C.J. and Robeson, S.M., 1995. Climatologically Aided Interpolation (CAI) of Terrestrial Air Temperature. International Journal of Climatology, 15(2): 221-229
[8] Kalnay, E., Kanamitsu, M., Collins, W., Deaven, D. and others, a., 1996. The NCEP/NCAR 40 Year Reanalysis Project. Bulletin of the American Meteorological Society, 77(3): 437-471.
[9] Funk, C., 1999. Orographic Precipitation in the Pacific Northwest. MA Thesis, UCSB, Santa Barbara.
[10] Herman, A., Kumar, V.B., Arkin, P.A. and Kousky, J.V., 1997. Objectively Determined 10-Day African Rainfall Estimates Created for Famine Early Warning Systems. International Journal of Remote Sensing, 18(10): 147-164.
[11] Xie, P. and Arkin, P.A., 1997. Global Precipitation: A 17-Year Monthly Analysis Based on Gauge Observations, Satellite Estimates and Numerical Model Outputs. Bulletin of the American Meteorological Society, 78(11): 2539-2558.
[12] Senay, G.B. and J. Verdin, 2001. Using a GIS-Based Water Balance Model to Assess Regional Crop Performance. UNESCO IAHS: Proceedings of the Fifth International Workshop on Application of Remote Sensing in Hydrology, October 2-5, 2001, Montpellier, France.
[13] Frere, M., Popov, G., Early Agrometeorological crop yield assessment, FAO Plant Production Paper 73, Food and Agriculture Organization of the United Nations, Rome, Italy, 144 p.
[14] Verdin, J., Klaver, R., Grid cell based crop water accounting for the Famine Early Warning System., Hydrological Processes, 16, 0-0, 2002.