A recent and abrupt decline in the East African long rains

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[1] The successive failure of the East African short rains (typically October-December) and subsequent long rains (March-May) in 2010–11 plunged much of the region into severe drought, impacting millions of people and triggering a humanitarian crisis. While poor short rains in 2010 were generally anticipated given linkages with La Niña, the subsequent long rains do not exhibit similar predictability. Here we show the long rains failure in boreal spring of 2011 is consistent with a recurrent large-scale precipitation pattern that followed their abrupt decline around 1999. Using observations and climate model simulations, we show the abrupt decline in long rains precipitation is linked to similarly abrupt changes in sea surface temperatures, predominately in the tropical Pacific basin. Citation: Lyon, B., and D. G. DeWitt (2012), A recent and abrupt decline in the East African long rains, Geophys. Res. Lett., 39, L02702, doi:10.1029/2011GL050337.

1. Background

[2] The failure of consecutive rainy seasons in East Africa presents a major climatic shock to the region, as witnessed by the resulting humanitarian crisis in 2011 [FEWS NET, 2011; United Nations Organization for the Coordination of Humanitarian Affairs, 2011]. While the East African short rains (the terms “short rains” and “long rains” are used to broadly describe a typically bimodal rainfall season across East Africa; the seasonal cycle of rainfall has notable regional variations and differing terms to describe them) have been studied extensively, exhibiting a robust relationship with El Niño-Southern Oscillation (ENSO) on the seasonal to interannual time scale [Mason and Goddard, 2001], climate scientists have focused considerably less attention to the long rains season. Attempts to link interannual variability of the long rains to large scale climate patterns such as ENSO and tropical Atlantic or Indian Ocean sea surface temperatures (SSTs) have met with limited success [Camberlin and Philippon, 2002; Indje et al., 2000] or revealed relationships that only apply to the early, or late, stages of the season [Camberlin and Philippon, 2002; Camberlin and Okoola, 2003]. On longer timescales, total precipitation received during the long rains season has been reported to be in decline in recent decades [e.g., Williams and Funk, 2011]. This decline has been attributed to a contemporaneous, upward trend in SSTs in the south-central Indian Ocean and west Pacific Ocean. The suggested physical link is that increasing SSTs in this region favor a local enhancement of precipitation with the resultant latent heating altering regional wind and moisture flux patterns, ultimately reducing long rains precipitation in East Africa [Williams and Funk, 2011; Funk et al., 2008].

2. Recent Rainfall and Sea Surface Temperature Changes

[3] An intriguing aspect of the failure of the long rains in 2011 is the associated large-scale, anomalous precipitation pattern (departure of March-May (MAM) 2011 rainfall from a 1979–2009 base period average; shaded in Figure 1a) based on the “CAMSOPI” merged analysis of station rainfall observations and satellite estimates [Janowiak and Xie, 1999]. Below average rainfall in East Africa was accompanied by drier than average conditions across much of southwest Asia, the central and southern Indian Ocean and the west-central tropical Pacific. Precipitation was concurrently well above average in the western tropical Pacific and in a zonally-elongated band extending across the northern Indian Ocean from the west Pacific westward to the Arabian Sea. Was this precipitation pattern a singular event, associated only with the most recent long rains failure?

[4] Figure 1c displays time series of MAM precipitation anomalies averaged across land areas of East Africa (10°S to 12°N, 30°E-52°E; red box in Figure 1b) taken from three datasets: “GPPC” [Rudolf and Rubel, 2005], “GPCP” [Huffman et al., 2009] and again, CAMSOPI). While precipitation in East Africa shows a high degree of spatial variability given the region’s complex terrain [Hession and Moore, 2011], the area-average emphasizes the bulk behavior of the long rains. A clear decline in precipitation is evident in the time series since the 1980s. However, the decline is seen to be associated with an abrupt decrease in precipitation after 1999. Indeed, for GPCP the mean MAM precipitation for the period 1999–2009 is more than 15% less than that for 1979–1998, with the difference in means statistically significant (p < 0.01) based on a two-tailed t-test. The largest monthly departures (not shown) were observed to occur during April and May. An independent analysis of rainfall data from over 180 observing stations across Ethiopia shows a similar, abrupt decline in MAM rainfall when evaluated for the entire country [Funk et al., 2005]. What has the large-scale precipitation pattern looked like for this season during the post-1999 period? Figure 1b displays anomalous (1979–2009 base period) MAM GPCP precipitation and 850hPa vector wind (from National Centers for Environmental Prediction Reanalysis (NCEP) data [Kalnay et al., 1996]) averaged from 1999–2009. Only statistically significant values (p < 0.10 based on a t-test) are shown. The 11-year average rainfall anomaly pattern is remarkably similar to that observed during the 2011 long rains. In addition, anomalous southerly 850hPa winds off the east coast of Africa become westerly across the northern Indian Ocean.
Ocean. We note that MAM rainfall anomalies in this region (from GPCP) are not significantly correlated with local SSTs (see contours in Figure 1a) but they are significantly correlated (p < 0.05) with anomalous, low-level zonal flow (see auxiliary material). Thus, we hypothesize the enhanced rainfall in the northern Indian Ocean is a dynamical, regional response and not just a direct result of increasing, local SSTs. The leading mode (explaining 16.3% of total variance) from an empirical orthogonal function (EOF) analysis of GPCP MAM precipitation anomalies has a loading pattern (Figure 2a) with similar spatial structure to Figure 1b. The associated principal component (PC) time series (Figure 2b) shows an abrupt jump in 1999, with generally positive values afterwards. This time series is negatively correlated with our East Africa rainfall index (r = −0.50, p < 0.01). While Figure 2 does not necessarily indicate abrupt shifts in precipitation occurred across the entire domain in 1999, a shift in the overall large-scale pattern is clearly evident.

A coherent large-scale precipitation anomaly pattern thus appears to have accompanied the abrupt decline in long rains precipitation and this pattern has been a recurrent feature of MAM precipitation during the post-1999 period. Is there evidence for coherent, large-scale changes in the state of the global oceans since 1999? Figure 3a shows the standardized, MAM SST anomalies (1971–2000 base period) averaged over the period 1999–2010 obtained from the “ERSSTv3b” dataset [Smith et al., 2008]. Interestingly, across much of the eastern North Pacific SSTs have been below average while in the western Pacific they have been exceptionally high (average anomalies as much as 1.5 standard deviations above the long-term mean for the 13-year period). Tropical Indian and Atlantic Ocean SSTs have also been well above average for the period. Of course, the SST anomalies in Figure 3a contain contributions from variability occurring on many time scales, including interannual, decadal, and long-term trends. For example, a shift towards a warmer tropical Atlantic is reported to have occurred in 1995 [e.g., Trenberth and Shea, 2006] and there is some evidence that decadal variations in the Pacific have resulted in a cooler eastern Pacific SSTs since 1998 although indicators monitoring this low frequency behavior have not been consistently negative over the period [Bond et al., 2003].

An EOF analysis of the MAM SST anomaly field for the period 1950–2011 (globally, from 30°S to 30°N) was performed based on the ERSSTv3b data. The leading EOF (Figure 3a), explaining over 33% of total variance, is associated with a long-term trend (Figure 3d) in SSTs across much of the tropics (with large loadings over the central Indian Ocean). The second mode (Figure 3c), explaining over 15% of total variance, has oppositely-signed loadings

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1Auxiliary materials are available in the HTML. doi:10.1029/2011GL050337.
in the east and west Pacific. Loadings over the Indian Ocean are comparatively smaller in magnitude. The PC time series for the second mode (Figure 3e, multiplied by $/C0_1$ for clarity) indicates an abrupt shift in 1999. A similar result is obtained when limiting the EOF analyses to encompass only the Pacific basin and for different SST datasets (e.g., the Kaplan dataset [Kaplan et al., 1998] and the Optimally Interpolated SST data from Reynolds et al. [2002]). Each GCM simulation run began in January 1950 and was initialized with slightly different atmospheric conditions to create a 24-member ensemble for each model. The average MAM precipitation anomaly (computed in each model relative to a 1979–2009 base period) across all 72 runs for the period 1999–2009 is shown in Figure 4a (only statistically significant values plotted based on a t-test and $p < 0.10$). Drying across East Africa and the western Indian Ocean is clearly evident, and with the exception of the central Indian Ocean where the models tend to generate too much precipitation generally (see auxiliary material), the overall large-scale precipitation anomaly pattern is quite similar to observations (c.f. Figure 1b).

To see the contribution of SSTs from individual ocean basins a set of experiments was conducted using the ECHAM5 forced with the average observed MAM SSTs from 1999–2010 for selected basins (delineated by dashed lines in Figure 3a) while holding SSTs to their 1971–2000 climatological values elsewhere. The basin SST anomalies were added to the seasonally varying, climatological SST in each experiment, which was then integrated for 31 years, using initial atmospheric conditions from January 1950. Only the last 30 years were used in the analysis, representing 30 “ensemble members.” Anomalies in model fields were computed by subtracting 30-year average values from a control run using climatological SSTs globally. Statistically significant (based on a t-test, $p < 0.10$) precipitation and 850 hPa vector wind anomalies for runs forced with just the tropical Indian and Pacific Oceans are shown in Figures 4b and 4c, respectively. Indian Ocean SST anomalies lead to enhanced precipitation over much of the basin, with wide-scale drying over the western Pacific and central and western Africa, reminiscent of the model response to idealized Indian Ocean forcing during February-May by Hoerling et al. [2006]. Anomalous 850 hPa winds show westerlies along coastal East Africa, largest south of the equator. The ensemble average anomalies from the Pacific-only runs (Figure 4c), however, capture the observed pattern remarkably well, including the observed drying across East Africa and much of the western Indian Ocean not simply the result of ENSO variations or changes in the Pacific decadal oscillation.

[7] MAM rainfall in the western Pacific warm pool region (120°E-155°E, 0°N-20°N) also exhibits an abrupt, upward shift in 1999 (Figure 3e), coinciding with the shift in SSTs. Rainfall there has been above the 1979–2010 average in all but one of the past 13 years, the exception being near-average rainfall during the 2009–10 El Niño event. By contrast, during MAM elevated SSTs over the south-central Indian Ocean since 1999 (Figure 3a) are not associated with a similar increase in precipitation (c.f. Figures 1b and 3a).

3. Results From Model Simulations and Experiments

[8] The influence of post-1999 observed MAM SST anomalies on the large-scale precipitation field was investigated more thoroughly by examining general circulation model (GCM) simulations (forced only with observed SST). Three models were utilized: the ECHAM4.5 [Roeckner et al., 1995], ECHAM5 [Roeckner et al., 2006] and the Community Climate Model version 3 (CCM3.6) [Kiehl et al., 1996]. Each GCM simulation run began in January 1950 and was initialized with slightly different atmospheric conditions to create a 24-member ensemble for each model. The average MAM precipitation anomaly (computed in each model relative to a 1979–2009 base period) across all 72 runs for the period 1999–2009 is shown in Figure 4a (only statistically significant values plotted based on a t-test and $p < 0.10$). Drying across East Africa and the western Indian Ocean is clearly evident, and with the exception of the central Indian Ocean where the models tend to generate too much precipitation generally (see auxiliary material), the overall large-scale precipitation anomaly pattern is quite similar to observations (c.f. Figure 1b).

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![Figure 3](image-url). (a) MAM SST anomaly averaged from 1999–2011, expressed as a standardized departure from a 1971–2000 mean. (b) Loadings for the first EOF of MAM SST based on an analysis for 1950–2011 and (c) second EOF. (d) PC time series for the first EOF mode. (e) Standardized time series of the PC for the second EOF (thick blue line, multiplied by $-1$ for clarity) and Pacific warm pool anomalous SST (precipitation) shown by red line (green line for GPCP, dashed black line for CAMSOPI).
with enhanced precipitation and anomalous westerly 850 hPa winds across the northern portion of the basin eastward to the western Pacific warm pool region and southerlies off the coast of East Africa.

4. Discussion

[10] Our analysis leads us to conclude that an abrupt decline in the East African long rains occurred around 1999 and it has been associated with a recurrent, anomalous large-scale precipitation pattern during boreal spring since that time. While previous work has shown a strong connection between Indian Ocean SSTs and variability in the East African short rains [e.g., Goddard and Graham, 1999], the long rains decline appears to be primarily forced by large scale SST changes mainly in the tropical Pacific (with abrupt changes in ocean temperatures in other regions near this time also observed [e.g., Cantin et al., 2010]). The observed shift in Pacific SSTs in the late 1990s does not appear to be closely related to previously identified patterns of decadal variability in the basin and is not explained simply by changes ENSO behavior [e.g., Merrifield, 2011]. What caused the shift is a currently unresolved question. Our analysis does not preclude decadal variability or the influence of anthropogenic forcing.

[11] Interestingly, the recent tendency for a cool eastern, and warm western, tropical Pacific is consistent with observational studies of global SST trends [Cane et al., 1997; Compo and Sardeshmukh, 2010; Williams and Funk, 2010] and somewhat reminiscent of theoretical studies of an ocean thermostatic control on SST under anthropogenic forcing [Clement et al., 1996]. It is noteworthy that over roughly the past three decades the difference in SST trends between observations and coupled model runs which include anthropogenic forcing is an ocean state reminiscent of La Niña. The climate models generate too much warming in the eastern Pacific in response to anthropogenic forcing [Hoerling et al., 2010; Cane et al., 1997; Clement et al., 1996] weakening the Pacific branch of the atmospheric Walker circulation [Vecchi and Soden, 2007]. While some observational evidence suggests the Walker circulation has shown some signs of weakening over the past century [Vecchi et al., 2006], the results here and of Merrifield [2011] suggest that, at least over the last decade or so, the Walker circulation may have intensified, or at least been modified.

[12] Overall, the persistence of the current SST anomalies we identify in the tropical Pacific suggests a continuation of poor long rain performance in East Africa (with implications for other regions as well) and also lends a measure of predictability. During La Niña years in particular, when the likelihood of drought during the short rains is enhanced, the likelihood of multi-season drought since 1999 has also been increased given the general lackluster behavior of the long rains since that time.

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