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A Westward Extension of the Tropical Pacific Warm Pool Leads to March through June Drying in Kenya and Ethiopia



Open-File Report 2010–1199

U.S. Department of the Interior
U.S. Geological Survey

Cover. Failed crop in southeastern Kenya, June 2005. Photograph from USDA FAS/FEWS NET Crop Assessment Tour.

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A Westward Extension of the Tropical Pacific Warm Pool Leads to March through June Drying in Kenya and Ethiopia

By A. Park Williams¹ and Chris Funk²

Background

An estimated 14.3 million people are currently (July 2010) food insecure in Kenya and Ethiopia, and the U.S. government has spent more than \$972 million on food aid in these two countries since 2009 (USAID, 2010). This insecurity stems from recent drought and rapid population growth that has outpaced agricultural development (Funk and others, 2008; Funk and Brown, 2009). Previous work by Funk and others (2005, 2008) and Verdin and others (2005) has linked drought conditions in Kenya and Ethiopia with warm sea surface temperatures (SSTs) in the Indian Ocean. Recent work has shown that Indian Ocean SSTs substantially affect rainfall in this region from March through June (Funk and others, 2008; Funk and Verdin, 2009). This season is known as the ‘long rains’ in Kenya and the ‘Belg’ rains in Ethiopia.

Trends in Long Rains

Long-rains precipitation has declined in much of Kenya and Ethiopia in the past 30 years. These rainfall declines have been particularly strong in central and eastern Ethiopia and Kenya, with rainfall totals declining by 35–45 percent of the 1950–79 mean rainfall throughout much of the area south and east of the Ethiopian Highlands as shown in figure 1. The long rains of 2009 were the driest in at least 60 years throughout much of this region (Funk and Verdin, 2009).

This trend toward March–June dryness contrasts starkly with projections of increased rainfall in eastern Africa by the Intergovernmental Panel on Climate Change, or IPCC (Christiansen and others, 2007). The climate models that make projections of increased precipitation in this region probably do so because the model results generally forecast more ‘El Niño-like’ conditions globally in coming decades. El Niño conditions historically have been associated with increased

rainfall in eastern Africa. The link between El Niño indices and long-rains precipitation, however, is weak.

Trends in Tropical Indian and Pacific Ocean Climate

Although there are many processes that cause variability in the timing and magnitude of the long rains, it is suggested that rapid warming in the Indian Ocean and subsequent changes in atmospheric circulation are the underlying drivers of the downward trend in rainfall. The specific process that causes rainfall declines may be a westward extension of the tropical Pacific warm pool that has occurred because of rapid warming in the Indian Ocean and much slower warming in the central tropical Pacific. The equatorial Indian Ocean has warmed approximately twice as fast as the central tropical Pacific since 1900 (see fig. 2A, and Funk and others, 2008). This lopsided warming trend is clear among all the observational records evaluated and is shown in figure 2B. All models used by the IPCC predict that as global temperatures increase, Indian Ocean SSTs should increase faster than central Pacific SSTs (fig. 2B).

A principal components analysis (PCA) indicates that, since at least 1948, this lopsided warming trend has been responsible for more year-to-year variability in tropical Indian and Pacific Ocean surface temperatures (fig. 3A, D) than the well known El Niño–Southern Oscillation (ENSO; fig. 4A, D). As temperatures have increased in the tropical Indian Ocean, convection and precipitation have greatly increased in the region. In addition to the trends in surface temperatures, these trends are indicated in a PCA as the most important modes of variability in tropical climate datasets of precipitation and vertical velocity across the tropical Indian and Pacific Ocean region (fig. 3C, E). Just as in the SST analysis, climate variability associated with these trends toward increased

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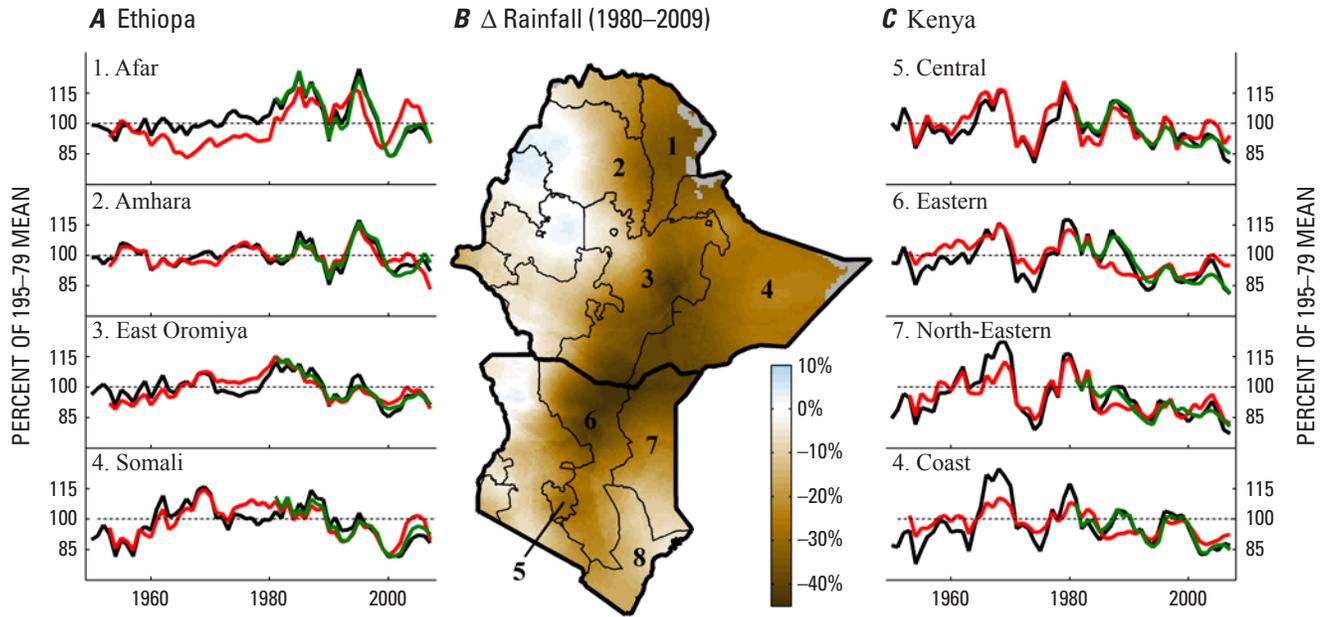


Figure 1. Plots (A and C) show March–June rainfall within various divisions of Ethiopia and Kenya relative to the 1950–79 mean. Analysis only represents areas where mean March–June precipitation was greater than 100 millimeters.

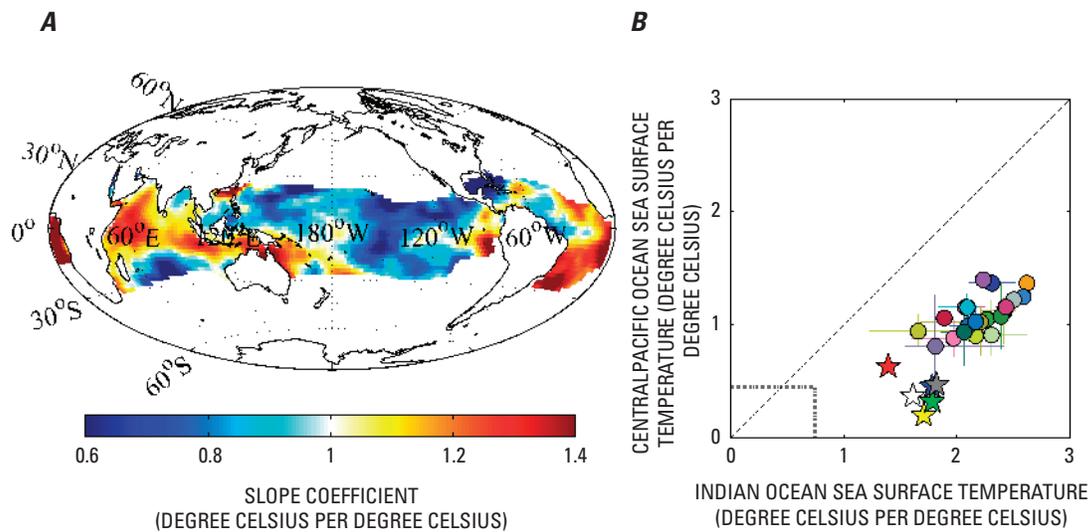


Figure 2. (A) Slope coefficients from the regression of 5-year running mean (March–June) NOAA extended sea surface temperatures (SSTs) against 5-year running mean March–June Goddard Institute for Space Studies (GISS) global temperature from 1900–2009, where mean 1951–81 (March–June) SSTs were above 24 degrees Celsius, for the Indian Ocean and central Pacific Ocean. (B) The same slope coefficients as in (A), but contrasting the (y-axis) central Pacific Ocean versus the (x-axis) Indian Ocean. Coefficients in (B) were calculated using observed (stars) and Intergovernmental Panel on Climate Change (IPCC) modeled (circles) climate datasets.

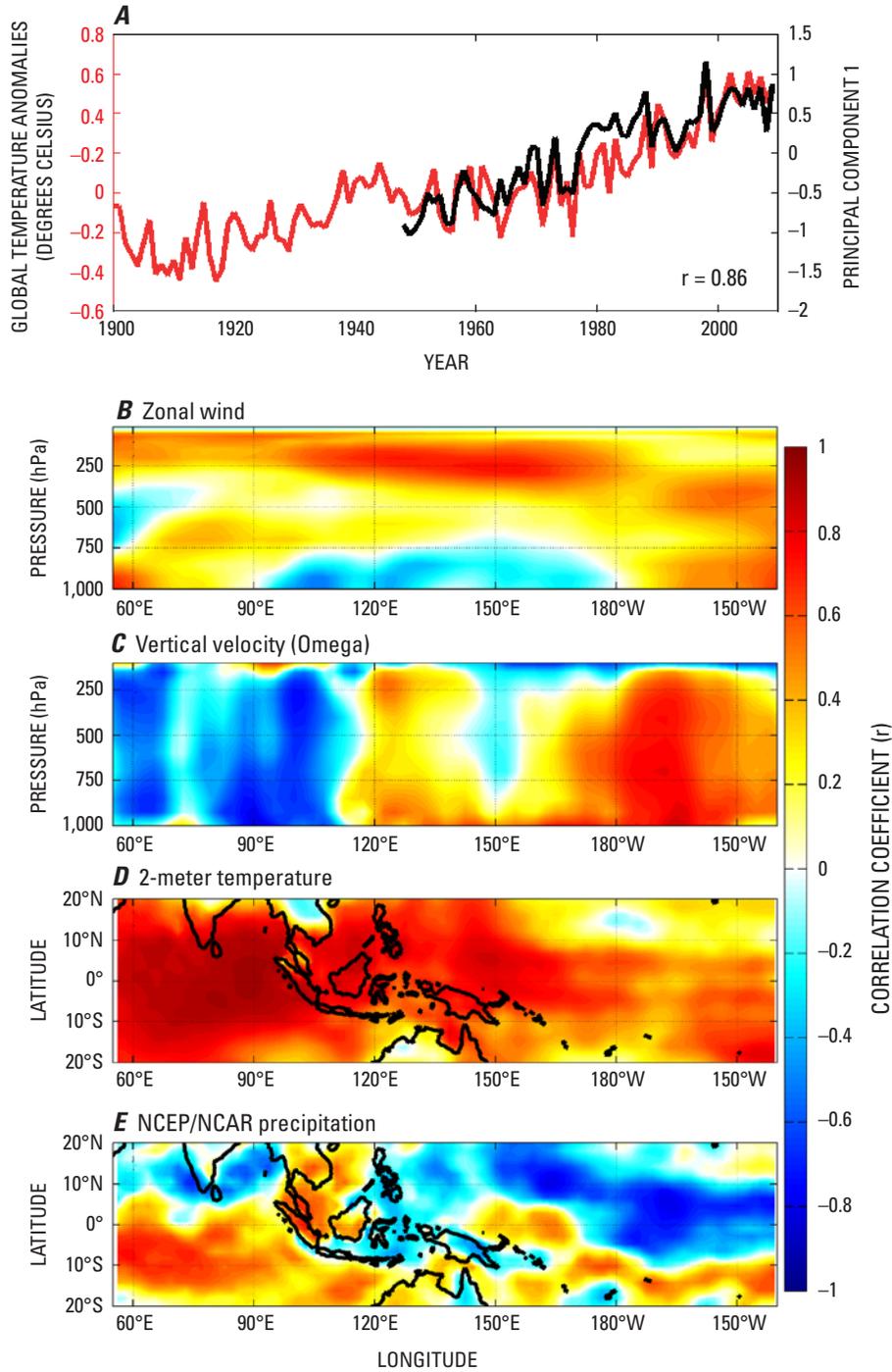


Figure 3. (A) time series of principal component 1 (PC1, black) and mean March–June Goddard Institute for Space Studies (GISS) annual global temperature anomaly (red). Lower 4 panels: Correlation maps for regression of annual March–June climate on the Principal Component 1 time series from (A). Climate variables include (B) mean zonal wind profile between 20°N and 20°S, (C) mean vertical velocity profile between 20°S and 20°N, (D) mean March–June temperature 2 meters above sea level, and (E) National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) total precipitation.

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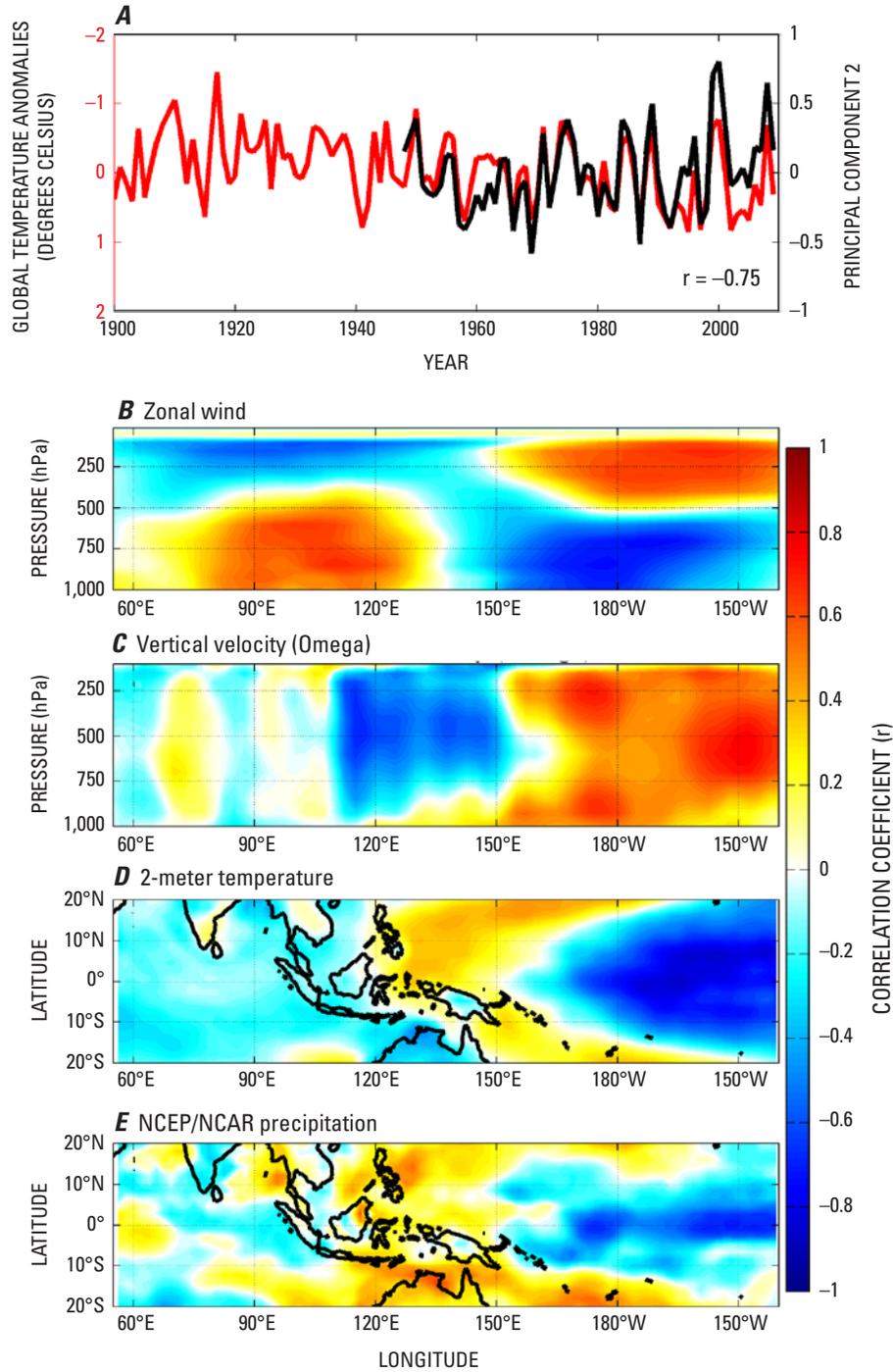


Figure 4. (A) time series of principal component 2 (PC2, black) and mean March–June mean Niño 4 temperature anomaly. Lower 4 panels: Correlation maps for regression of annual March–June climate on the PC1 time series from (A). Climate variables include (B) mean zonal wind profile between 20°N and 20°S, (C) mean vertical velocity profile between 20°S and 20°N, (D) mean March–June temperature 2 meters above sea level, and (E) National Center for Environmental Prediction (NCEP)/National Center for Atmospheric Research (NCAR) total precipitation.

convection and precipitation over the Indian Ocean is more substantial than the climate variability associated with ENSO (fig. 4C, E).

Linking Long-Rains Precipitation with Indian Ocean SSTs

The time series of principal component 1 (from hereon referred to as PC1), shown in figure 3A, represents the primary mode of variability in tropical Indian and Pacific Ocean climate since 1948. The trends toward more rapid warming of the Indian Ocean, and increased convection and precipitation in this region are interpreted as a westward extension of the western branch of the tropical Walker circulation. The western branch of the Walker circulation typically sits over the tropical Pacific warm pool region near the Malaysian and Indonesian Islands (hereon referred to as the Maritime Continent) and is characterized by rising air and high amounts of rainfall. Satellite-derived rainfall records since 1979 clearly indicate that, as the western branch of the Walker circulation has extended westward, rainfall over the Indian Ocean has also increased (fig. 5; Indian Ocean rainfall correlates well with PC1).

Well agreed-upon climate theory suggests an increase in condensation near the equator should cause a sizable release of energy approximately 5 kilometers above the earth's surface (Gill 1980, 1982). This release in energy should initiate two pulses of dry airflow in the middle and upper troposphere: one pulse flowing east, and the other flowing west. As the upward branch of the Walker circulation cell has extended westward in recent decades and caused increased condensation above the Indian Ocean, the reaches of the westbound pulse of dry air have increasingly extended over tropical eastern Africa.

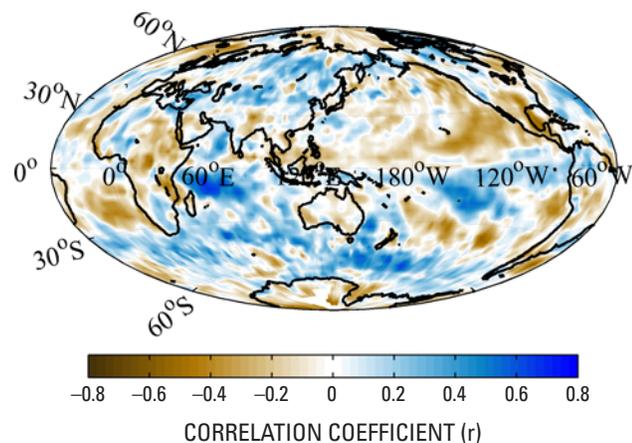


Figure 5. Correlation between Global Precipitation Data Project (GPCP) March–June rainfall totals and principle component 1 (PC1) from 1979 through 2009.

Enhanced easterlies aloft have stifled convection over Kenya and Ethiopia and caused declines in long-rains precipitation over the last 20 years. As the Indian Ocean has warmed, this reduction in long-rains precipitation has occurred in El Niño and La Niña years as shown in figure 6. This point is important because the IPCC projections of future climate in a warmer world are more ‘El Niño-like’, which presumably translates to increased precipitation in eastern Africa. It is instead proposed that increased Indian Ocean SSTs will continue to reduce long-rains precipitation in Kenya and Ethiopia, regardless of whether or not the projected trend in ENSO is realized. These results have important food security implications, from informing agricultural development, to environmental conservation, and water resource planning.

Summary

Global surface temperatures are strongly correlated with Indian Ocean sea-surface temperatures from March through June. As temperatures have increased, convection and precipitation above the Indian Ocean have increased and long-rains precipitation in Kenya and Ethiopia has declined. This decline has been particularly strong on the eastern flank of the Ethiopian Highlands in Ethiopia and across central Kenya. Climate theory suggests that the trends in convection over the Indian Ocean and drought in eastern Africa are dynamically linked. Increased release of latent heat over the Indian Ocean should elicit a westward pulse of dry air toward eastern Africa in the middle and upper troposphere, causing decreased convection over eastern Africa (Funk and others, 2008; Funk and Verdin, 2009). A similar process has been implicated previously as a possible cause of drought in the African Sahel (Giannini and others, 2003). Although most general circulation models simulate a shift toward a more ‘El Niño-like’ climate in tropical eastern Africa in response to increasing global surface temperatures there is no evidence of increased El Niño-like conditions (increased rainfall) for March–June in Kenya and Ethiopia in the last 40 years of observed anthropogenic warming. This is at odds with the most recent Intergovernmental Panel on Climate Change predictions of increased precipitation in tropical eastern Africa as a ‘likely’ response to anthropogenic global warming. Although El Niño events should still be expected to lead to wetter long rains than La Niña events, indications are that long-rains precipitation has steadily declined in the past several decades, regardless of El Niño–Southern Oscillation conditions. As this trend is associated with globally increasing temperatures, even a GCM-projected mild shift toward more ‘El Niño-like’ conditions is expected to be accompanied by an increased frequency of drought conditions in tropical eastern Africa because of reduced March–June rainfall. These findings are important for adaptation planning for the region. Wetter conditions in the century ahead are not to be expected, but rather continued drying.

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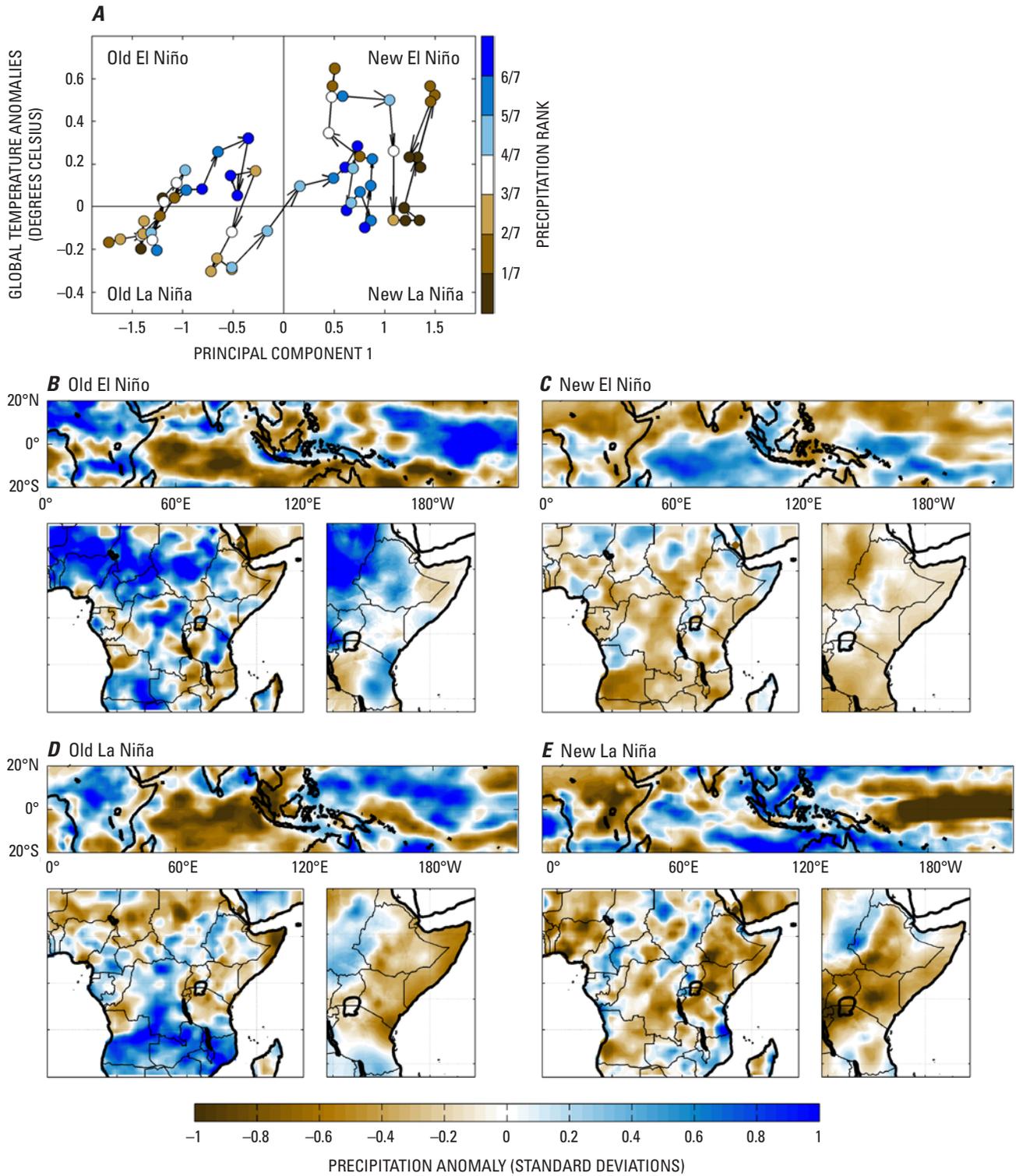


Figure 6. (A) Scatter plot of 5-year running NINO4 temperature anomalies versus standardized principle component 1 (PC1) values. Arrows indicate direction in time. Colors of circles represent the rank of 5-year running March–June rainfall in Kenya and Ethiopia. Maps show a comparison of precipitation anomalies during (B) old El Niño years (PC1 < 0, NINO4 > 0.25 degrees Celsius) versus (C) new El Niño years (PC1 > 0, NINO4 > 0.25 degrees Celsius) and (D) old La Niña years (PC1 < 0, NINO4 < -0.25 degrees Celsius) versus (E) new La Niña years (PC1 > 0, NINO4 < -0.25 degrees Celsius). Each set of three maps in B–E, were calculated using three different precipitation datasets to demonstrate consistency among datasets. Top maps: National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR), Bottom-left map: GPCC, Bottom-right map: CHG-CLIM.

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