Rainfall in Darfur prior to the conflict of 2003

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Abstract: Data on rainfall patterns only weakly corroborate the claim that climate change explains the Darfur conflict that began in 2003 and has claimed more than 200,000 lives and displaced more than 2 million persons. Rainfall in Darfur did not decline significantly in the years prior to the eruption of major conflict in 2003; rainfall exhibited a flat trend in the thirty-years preceding the conflict (1972-2002). The claim that climate change explains the conflict rests on the observation that rainfall in Darfur has declined when comparing the present thirty-year period of 1972-2002 with earlier periods. This is strongly evident for El Fasher and El Geneina but less clear for the more southerly rainfall stations. Rainfall is basically stationary over the pre- and post-1972 sub-periods. A theory linking climate change around 1972 with an outbreak of conflict in 2003 has no compelling supporting evidence at present.

"Darfur, at its core, is a conflict of insufficient rainfall."
Jeffrey Sachs

Introduction

Influential voices such as those of United Nations Secretary-General Ban Ki-moon, former Vice President of the United States Al Gore, the United Nations Environment Program, Columbia University professors Jeffrey Sachs and Mahmood Mamdani, and popular commentators such as Stephan Faris writing in *The Atlantic Monthly*, have recently proclaimed or insinuated the idea of the Darfur civil war as a climate crisis (Gore 2006; Sachs 2006; Faris 2007; Mamdani 2007; Moon 2007; United Nations Environment Program 2007). The contention is that climate change has led to declining rainfall and land degradation. These changes have intensified violent struggles over water, pasture and farmland. These struggles then erupted into full-blown war in 2003. As Mamdani (2007) put it, "With the drought that set in towards the late 1970s, co-operation turned into an intense struggle over diminishing resources." Sachs (2005) played to the peanut gallery: "Two things have happened. First, the population has doubled in the last generation, and second, the rainfall has gone down sharply. These are very hungry, crowded people, and now they are killing each other." The Stern report on the economics of climate change was more circumspect (2007, p. 112): "Long periods of drought in the 1970s and 1980s in Sudan's Northern Darfur State, for example, resulted in deep, widespread poverty and, along with many other factors such as a breakdown in methods of coping with drought, has been identified by some studies as a contributor to the current crisis there." While non-environmental causes of the conflict are noted, the thrust of this emerging narrative of the Darfur crisis seems to be that if there had been more rain there would not have been war and consequent human catastrophe.

Careful attention should be paid to examining this explanation of the emergence of violence in Darfur, one of the world's most significant conflicts. The fighting began in earnest in 2003, has led to over 200,000 excess deaths, and has forced over two million people to flee their villages for the comparative safety of refugee camps. The government of Sudan, which organized much of the violence perpetrated by the irregular militia known in Darfur as the *janjawid*, has since the beginning claimed that the conflict was a local, tribal conflict caused by environmental change.

The commentators suggesting a climate change explanation for the Darfur conflict usually present little data to validate their claims, instead relying on a general understanding that Darfur is part of the Sahel, that rainfall has declined in the Sahel, that rainfall decline in the Sahel is partly attributable to changing ocean temperatures, that changing ocean temperatures are partly the result of global warming, and so therefore climate change may be the culprit of the Darfur conflict.

This paper presents analysis of several sources of data on rainfall in the Darfur region. As we show, data on Darfur rainfall patterns only weakly corroborate the claim that climate change explains the conflict. The emphasis here is on exploring the hypothesis that change in climate explains the conflict, as opposed to the broader more general question of whether climate explains conflict generally. The emphasis here also is on change in rainfall, and not on the causes of the change in rainfall. In other words, we address the question of whether a change in rainfall can reasonably be viewed as the cause of the Darfur conflict. We do not address the question of what causes changes in rainfall in Darfur, nor the question of whether tropical regions with low rainfall such as Darfur are more prone to large-scale violence than other tropical regions with higher rainfall.

Rainfall in Darfur did not decline significantly in the years immediately prior to the eruption of major conflict in 2003. Short-term but significant droughts in 1984 and 1990 did not provoke wide-spread conflict. Rainfall in Darfur exhibited a flat trend, with normal variability, in the thirty-years preceding the conflict (1972-2002). These observations would seem to obviate the possibility of an explanation for the conflict as due to a short-run downturn or steady decline in rainfall generating a disruption or decline in the livelihoods of those poorer Darfurians at the median or lower-quintiles of the income and asset distribution. To be precise: there was no decline in rainfall in the period 1972-2002 that can reasonably be construed as the cause of the conflict.

Moreover, some recent studies of satellite imagery of vegetation over the past twenty-five years have found a greening trend in Sahelian Africa, including Darfur, suggesting that farmers, herders and local ecosystems not been in a downwards spiral of lower biomass production.

The claim that rainfall change explains the conflict rests instead on the reduction in average rainfall in Darfur that occurred around 1970, compared with previous decades. The data suggests that the lower average rainfall of the 1970-2003 period was not general to Darfur but rather restricted to the northerly rainfall records from the stations at El Geneina and El Fasher in northern Darfur. More southerly rainfall stations in Darfur and neighboring Kordofan exhibited no lower mean.

The rainfall patterns of Darfur are similar to those of Sahelian Africa more generally. While semi-arid conditions of low rainfall with high variability, both temporally and spatially, are tough environments for humans, there is much evidence that Sahelian societies have coped through evolving strategies such as income diversification, agricultural intensification and migration, rather than large-scale violence. Life is not peaceful: there are endemic low-level struggles over resources, particularly between herders and farmers. However, conflict has not erupted into warfare because regional institutions and central governments have by-and-large projected their authority into Sahelian hinterlands and arrested violent situations before they have intensified. Other Sahelian sub-regions that have developed wide-spread conflict on the scale of Darfur, such as the long-lasting civil conflicts in Chad and the various wars in Ethiopia and Eritrea, are only implausibly linked to climate change. Sahelian West Africa has seen no outbreak of larger-scale conflict.

What makes Darfur different from West Africa and similar to Chad, Ethiopia and Eritrea? The answer is straightforward: an elite ruling the country from Khartoum that has preferred to exclude peripheral populations from genuine participation in political processes. In response to threats from peripheral regions, the elite has repeatedly revealed a willingness and ability to use large-scale violence, particularly against civilian populations. In Sudan, this willingness to use large-scale indiscriminate violence was evident in the civil wars encompassing Southern Sudan and the Nuba Mountains. Individuals who constitute the present military regime in Sudan are being indicted or are being considered for indictment by the International Criminal Court, and the defense that they were reluctantly embroiled in a local conflict induced by climate change has little merit.

Data sources

Darfur, the westernmost province in Sudan, like most of arid and semi-arid Africa, is marked by a good deal of climatic variability. It spans several environmental zones, ranging from Saharan Desert in the far north of the province to African Sahel and Savanna regions further south. Rainfall is characterized by marked seasonality with a long dry season and shorter wet season from June to October. Rainfall increases from north to south, with Saharan regions receiving low and intermittent rainfall, Sahelian regions ranging between 100-400mm per year, and Savanna regions ranging from 600-1000mm per year. The wet season exhibits much variability within years, between years, and across short distances.

Large long-term fluctuations in climate are an inherent feature of climate in Sahelian regions. Interdecadal and interannual variability are the norm (Hulme 2000). Nicholson ( ) finds that during the 1820s and 1830s dry conditions prevailed with many lakes drying up. Rainfall then returned to higher levels, but the first decades of the 20th century, particularly the 1910s and 1920s, again experienced low rainfall. Sahelian rainfall increased to high levels during the 1930s-1960s. The late 1960s-1990s saw lower rainfall (Foley, Coe et al. 2003). The evidence of the 1990s is of mean rainfall levels above the 1960-1991 average. As noted above, indices of vegetative cover also suggest improvements in the last decade of the 20th century (Prince, Wessels et al. 2007).

This paper makes use of three data sources with measures of rainfall from Darfur and other relevant regions. Rainfall station data appears to have been only collected in the three main towns of El Geneina, El Fasher, and Nyala. Prof. David Lister, of the Climate Research Unit of the School of Environmental Sciences, University of East Anglia, kindly provided us with rainfall station records for Sudan for the period 1881-2006. The Darfur rainfall station data begins in 1917 for El Fasher, in 1928 for El Geneina, and in 1920 for Nyala. For comparison we also include the station of En Nahud, in western Kordofan, the province neighboring Darfur.

The second source is the rainfall estimates of the Global Precipitation Climatology Project (GPCP), a blending of estimates from satellite and rain gauge measures (Adler, Huffman et al. 2003). The formal name for the dataset is "GPCP Version 2 Combined Precipitation Data Set." These precipitation estimates are available for nodes of a 2.5°x2.5° latitude--longitude global grip array, and start in 1979. The data for the Sahelian nodes were obtained through an interactive website that enables users to obtain time series for GPCP (http://disc2.nascom.nasa.gov/Giovanni/tovas/rain.GPCP.2.shtml)

A third source is the historical monthly precipitation dataset for global land areas from 1900 to 1998, gridded at 2.5° latitude by 3.75° longitude resolution, created by Hulme (1998) for the Climate Research Unit of the University of East Anglia.[1] This data uses various techniques to average rainfall station data into grids.

Figure 1 is a Google Earth image that shows the locations of the rainfall stations and the GPCP nodes. The Hulme dataset nodes are similarly situated.

[1] 'gu23wld0098.dat' (Version 1.0) constructed and supplied by Dr Mike Hulme at the Climatic Research Unit, University of East Anglia, Norwich, UK. The work was supported by the UK Department of the Environment, Transport and the Regions (Contract EPG 1/1/85). Downloaded from http://www.cru.uea.ac.uk/~mikeh/datasets/global/

Short-term drought as a precipitating factor in the Darfur conflict

Did a short-term rainfall decline precipitate the large-scale violence in Darfur in 2003? Sachs has interpreted the paper by Miguel, et al. (2004) as suggesting that short term declines in rainfall precipitate conflict, and implied that Darfur experienced such a short-term decline in rainfall. In one interview, Sachs (2005), remarked that "… Africa is living so much on the edge that a recent paper [presumably Miguel, et al.], published last year, proved statistically that when the rains fail, the probability of war soars." Writing in *Scientific American*, Sachs (2006) observed that "… studies have shown that a temporary decline in rainfall has generally been associated throughout sub-Saharan Africa with a marked rise in the likelihood of violent conflict in the following months."

The Miguel, et al. (2004) study used change in rainfall as an instrumental variable in estimating how change in GDP per capita might influence conflict. They were clear that only as rainfall changes were mediated via incomes would there be a reasonable empirical basis for linking rainfall to conflict (p. 745): "While it is intuitively plausible that the rainfall instruments are exogenous, they must also satisfy the exclusion restriction: weather shocks should affect civil conflict only through economic growth." The focus on how rainfall affects GDP and how GDP affects conflict is presumably a compromise for the more relevant but basically unmeasurable relationship between rainfall and consumption or rainfall and assets. A place that exhibited large swings in rainfall, from low to high to low to high, might reasonably be expected to have adapted to the fluctuations with savings mechanisms for storing surplus from the good years so that consumption would not decline in the bad years: the short term decline in rainfall would then be viewed by residents as a lamentable but normal part of the ecosystem, and would not provoke large-scale violent conflict. People would be richer were rainfall higher, but they might not necessarily feel themselves to be impoverished when rainfall is low.

For Darfur, there has been limited research on how robust livelihood outcomes are to changes in rainfall. De Waal (1989), for example, argued that Darfur populations were quite resilient to extreme drought, and provoked a lively and continuing debate (Gray and Kevane 1993). Parallel research in West Africa has been assessing the adaptive capacity of Sahelian populations to drought conditions (Mortimore 1989; Mortimore and Adams 2001; Raynaut 2001), concluding that Sahelian populations are far more adapted in terms of maintaining incomes and livelihoods than many commentators imagine. As we see below, rainfall declined only in northern Darfur, and the population of northern Darfur is highly mobile. Northerly populations may not be that vulnerable to local drought. Reardon, et al. (Reardon, Matlon et al. 1988) noted some time ago the paradox that populations in more northerly Sahelian ecosystems in Burkina Faso, where rainfall means were low and variability high, experienced more stable incomes in the event of droughts than more southerly Sahelian populations.

In any case, rainfall data shows no evidence of short-term decline in Darfur preceding the conflict; the years leading up to the crisis are not out of the norm of variability for the thirty year period prior to the crisis. Figure 2 shows data for the period 1972-2002 for the four rainfall stations relevant to the situation in Darfur (El Geneina, El Fasher, Nyala and En Nahud). Figure 3 shows data for the four locations in Darfur that are nodes for the rainfall estimates of the Global Precipitation Climatology Project (GPCP). As is clear from the charts, there was no significant decline leading up to the conflict of 2003. Instead, some of the locations and sources suggest substantial declines in 1984 and 1990. These declines did not provoke large-scale conflict, even though by they generated considerable population displacement.[2] Figure 4 presents the distribution of monthly rainfall for the four GPCP nodes, comparing 2002, the rainy season that preceded the large-scale conflict that erupted in the dry season of January 2003, to the drought years of 1984 and 1990. Rainfall was comparatively high in 2002 and evenly distributed, suggesting that if there was a proximate drought event that could have triggered a large-scale outbreak of violence, it would have been in 1984 or 1990.

The evident lack of a linear trend in the 30 year period 1972-2002 for the rainfall station data and the 23 year period 1979-2002 for the GPCP data is not an artifact of the starting date. For all ten starting dates over the period 1965-1974 and for all four rainfall stations, the estimated coefficient on the variable YEAR is not statistically significant in a regression explaining rainfall totals over 30 year periods. A similar result obtains for the GPCP data when estimating a linear trend for each span of years ending in 2002 and starting with 1979 and continuing through 1988. The coefficients on YEAR are not significant, with the exception of the period 1988-2002 in the northwestern node, where there is a positive trend. (These results are available upon request.)

The rainfall data thus suggest there was no short-term decline in rainfall that precipitated the conflict of 2003. Neither was there a statistically significant trend decline in rainfall for the thirty year period prior to the outbreak of the conflict.

Long-term rainfall: Trend decline or structural break?

Estimating trends

At one time it was thought that rainfall in Darfur was declining rapidly (Eldredge, Khalil et al. 1988). As seen above, there has been no trend in rainfall in Darfur for the thirty year period 1972-2002. For longer period of time, say 50 year periods, there is also limited evidence of a decline. Table 1 reports the coefficients on the variable YEAR in regressions explaining rainfall totals over 50 year periods. Since the starting date used in estimating a trend might generate a spurious trend (if the start date was an outlier year of high rainfall), we estimate the trend coefficient for every start date. Each time period is fifty years or, for those where fifty years would go beyond 2002 (the end date of interest), the number of years included in the time period is 2002 minus the starting year.

The more southerly rain stations of Nyala and En Nahud exhibit no trend at all for these 50 year periods. The northern rain stations are mixed. For El Geneina a negative trend is estimated if the starting year is in the 1940s or early 1950s. These were periods of above average rainfall in El Geneina, and so using them as the start date to estimate a trend results in a statistically significant negative trend. But after 1954 there is basically no trend. For El Fasher there is no long term trend when starting in the earliest years. But there is a strong negative trend

[2] A digression is warranted here: in 1991 a former Islamist stalwart originally from Darfur , Daoud Bolad, resurfaced as commander of a Darfur branch of the Sudan People's Liberation Army (SPLA), which was fighting the military Islamist regime in Khartoum. Bolad was captured, tortured and executed. His threatened Darfur rebellion, if successful, may well have been attributed by future analysts to the poor rainfall of 1990. The sad circumstances of his death (and that of his comrades in arms) reveal a major shortcoming in cross-country and cross-regional analyses of conflict: they typically count as conflict only successful conflicts (ones that turn into large-scale conflicts). One may well imagine that years of low income do not stimulate conflict at all, but rather weaken a central army's ability to overcome a rebellion at a very early stage. Bad rainfall, in this logic, does not cause conflict, but rather enables successful conflict (from the point of view of the rebels). Given that most African regimes are illegitimate dictatorships, perhaps one should be hoping for less, rather than more, rain?

when starting the time period in the 1960s, years of high rainfall in El Fasher. (None of the rainfall stations have statistically significant trends when the start date is in the period 1965-71.)

Figure 5 shows the rainfall levels measured at El Fasher rain station for the period 1917-2002. A simple regression of rainfall on year for the full period yields a coefficient that is statistically significant, and suggests a gradual decline in rainfall over the 80 year period, on the order of .4 mm decline per year.

The downwards trend over the long durée is also apparent using the Hulme 2.5x3.75 dataset. Figure 6 gives the data for four nodes. The node located at 12.5° latitude and 26.25° longitude is approximately 150 km to the southeast of El Fasher. The rainfall levels estimated in this dataset are higher than those of the El Fasher rain station, presumably because the interpolation is using rain stations that all lie to the south of the El Fasher station, the northernmost in Darfur. The slope of the rainfall trend for the full time period for this 12.5° latitude and 26.25° longitude node is a decline of .70 mm per year. The other nodes exhibit similar patterns, though the western nodes do not have statistically significant trends.

Deviations from 30-year mean

Comparing 30 year means is a common data presentation technique in climatology. Figure 7 shows the rainfall in Darfur for the period 1970-2002 when presented as a deviation from the 30 year mean of the 1961-90 period, the current World Meteorological Organization reference period. For El Fasher, the fifteen years prior to 2002 were almost invariably lower than average rainfall, with 1998 the very worst year. For En Nahud, just across the Darfur border in the neighboring region of Kordofan, rainfall had been above average the reference mean for the decade previous to 2002.

Figure 8 presents for El Fasher the deviations from the 1961-90 mean, but now for the entire time series. It is clear that the period 1970-2002 is lower rainfall compared with the earlier 1940-1970 year period, though the difference is largely due to the 1960-70 period of high rainfall. Going back further in time one finds that the 1950s were very similar to the 1980s and 1990s.

Structural breaks

The notion of gradual decline in the northern Darfur area is misleading. Instead, what seems to have happened to rainfall in El Fasher and other Darfur regions is a break around the late 1960s or early 1970s in the basically stationary time series of rainfall. For the period 1917-1971, rainfall fluctuated around a mean level of 176 mm per year in El Fasher. For the period 1972-2002, rainfall fluctuated around a mean level of 148 mm per year. The variance of rainfall is the same for both time periods. As noted above, there had been no trend decline in rainfall in El Fasher for thirty years prior to the outbreak of major conflict in 2003. If the two time periods are treated separately, simple regression analysis indicates no statistically significant trend for either time period.

The same situation holds for the other locations. As an exercise, we run regressions for the four Hulme nodes and for the four rainfall stations. One regression estimates a linear trend, the other estimates rainfall using a simple dummy variable taking on the value 1 for years after 1971 and 0 otherwise. For the four Hulme nodes, the R-square is higher for the simple break in intercept model, by a large amount (the R-square for the trend regressions are around .05, for the break models they are around .20). For the rainfall station data, neither coefficient for En Nahud, the break model is better for El Geneina and El Fasher, and the trend model fits better for Nyala.

So for six of the eight series, a structural break in 1972 provides a better fit than a linear trend. In only one case does the trend perform better.

In order to determine the timing of the structural break for the relevant Darfur nodes, we run the non-parametric test of Pettitt (1979). The test statistic is give by $K=\max|U_k|$ where

$$U_k = 2\sum_i^k (Rank_i) - k(n+1).$$

That is, the rainfall totals are ranked, and then for possible break years the sum of ranks of years before the break year is calculated, and from this is subtracted the break year times n+1. A break in the series is statistically significant if the statistic is larger than the appropriate cutoff from the distribution under the null hypothesis of no break or change.

As seen in Table 2, the results suggest that breaks in rainfall to lower mean rainfall occurred in 1971 for El Fasher, and around that date for the other rainfall stations and nodes. The findings are similar to other studies. Mahe, et al (2001), for example, find a change point around 1970 for Sahelian rainfall in West Africa .

Summary: Structural break in 1972 and no long-term trend decline

To summarize the longer-term data, the characterization of rainfall in Darfur as "declining", with the implication of rainfall getting lower and lower, fluctuating around a declining mean, is misleading. The rainfall evidence suggests instead a break around 1972. This is apparent for El Fasher and El Geneina but less clear for the more southerly rainfall stations. Rainfall is basically stationary over the pre- and post-1972 sub-periods.

Structural shift in rainfall in the early 1970s as an explanation of conflict in Darfur

The evidence of a structural break in northern Darfur as opposed to a declining trend is discordant with some of the narratives of Darfur as a climate crisis alluded to in the introduction. Those suggesting that rains sharply declined in the years preceding the conflict seem to have little merit. Those suggesting conflict erupting from an implacable decline in rainfall that began several decades previously are misleading.

An explanation of Darfur as a climate crisis would then have to explain how the structural shift towards lower mean rainfall in the early 1970s might over time generate increasing tension that would boil over into war. Unfortunately, the explanations of Darfur conflict as erupting from a long-period of drought are very muddled. Sachs (2007), for example, places the explanatory burden on another variable: "Rapid population growth - from around 1 million in 1920 to around seven million today – has made all of this [rainfall decline causing environmental degradation] far more deadly by slashing living standards." Other commentators point to changed migration patterns, or more permanent resettlement from northern to southern regions.

As a modeling exercise, a structural shift towards lower mean rainfall can produce many different plausible time paths for the probability of large-scale civil conflict. With lower mean rainfall, there may be increased vulnerability and more chronic extreme poverty for some segments of the population, especially for herders. This would be more likely is the production technology of the farmers and herders exhibited some form of threshold, so that if household production assets fell below the threshold then the household income would be significantly lower, making it difficult to save to acquire the asset. It would also have to be the case that local economic institutions were such that asset recovery was difficult, and moral hazard in labor markets meant that laborers earned less income working with the assets of employers than working with their own assets, or were rationed out of the labor market. The thesis of steady impoverishment relies on an assessment that the lower level of mean rainfall meant that the deviations below mean hurt more, and deviations above mean helped less, than in the past. This possibility is intuitive and reasonable, a kind of eroding sandbars theory of livelihoods- big storms carry more sand away, and regular currents are no longer strong enough to replenish.

It is also likely, however, that over time the likelihood of civil conflict might begin to fall, as farmers and herders adapted to the lower mean rainfall by pursuing more diversified livelihood strategies. After that point of diminishing likelihood of civil conflict is reached, it is reasonable to speak of the structural break as the cause of an outbreak of conflict? Do we think it reasonable for that point to extend thirty years past the break? Explaining the contemporary Darfur conflict by a rainfall shift that happened more than 30 years prior is a very weak sort of explanation. The rainfall change that happened around 1970 would have shaped the life experiences of Darfur inhabitants who were 50-plus years old in 2003. Every other adult in the region, including residents of El Fasher, has seen 30 years of stationary rainfall patterns, population increase, animal stock increase, technological change, and general economic change. It hardly seems compelling to argue that the quinquagenarians of Darfur went to war after thirty years of discrepancy between the golden age of their youth and their adult rainfall reality. Alternatively, the argument would have to be that institutions for managing land use were extraordinarily mal-adaptive and incapable of evolution to the post-1970s climate. The emerging narrative of Darfur as resulting from climate change presents no evidence that this was the case.

There is little longitudinal data on livelihoods in Darfur. No one can answer the general question of whether the population of Darfur has seen rises or declines in standards of living over the thirty years since the period of lower rainfall began, and whether living standards for the bottom deciles have worsened. Living standards obviously declined during the sharp and intense droughts of the early 1970s and 1984, but there is little evidentiary basis for a claim that living standards in general or at the bottom of the income distribution declined for the population of Darfur over the 1970-2000 period. More than likely, Darfur was no different from the rest of the Sahel: improvements on many dimensions of living standards (morbidity and mortality, education, migration opportunities, livelihood diversification) were coupled with increased vulnerability to market-mediated changes in terms of trade. Investments were made in schooling infrastructure, productive infrastructure (boreholes for watering holes, diesel pumps for market gardening), and market access infrastructure (railroad, telecommunications, air travel). The general economic development of Sudan (irrigated schemes, mechanized schemes, urbanization in central Sudan) offered increasing opportunities for farmers and herders in Darfur to sell more output at better prices, to purchase consumer goods (flashlights, plastic buckets), and to earn incomes through livelihood diversification (especially seasonal migration). Increasing integration into market society, and livelihoods changed by infrastructure investment did, however, add new sources of vulnerability. Households that were formerly largely self-sufficient increasingly came to see their standard of living determined by their choices about what productive activities to specialize in (become a mechanic? purchase a diesel pump?).

The set of income opportunities would generally have been expanding for most people in Darfur after the one-shot change in rainfall regime in 1972 because of economic change in central Sudan and the civil war. It is easy to imagine that growth stalled in the early 1980s, with the resurgence of civil war in 1983 and mismanagement of national economic policy and infrastructure. There seems to be consensus that Darfur society became much more weaponized during the 1980s with an influx of Chadian militias, Darfur residents joining the Sudan Armed Forces to fight against the SPLA, and encouragement of local militia groups in southern Darfur to raid southern Sudan). But the violence of the 1980s may have enriched Darfur at the expense of southern Sudan, rather than impoverished Darfur. Indeed, there are numerous accounts of how pastoralists from southern Darfur increased raids on Dinka cattle herders of southern Sudan after the drought of 1984. Likewise, Darfurian participation in the Sudan Armed Forces and allied irregular troops would have meant increased remittances back to Darfur.

The gist of this discussion is that there is little evidentiary basis for knowing how the shift in rainfall regime altered the incomes and expectations of farmers and pastoralists in Darfur.

Structural shifts in rainfall as explanation of conflict in sub-Saharan Africa

There is an alternative to direct examination of how the structural shift towards lower mean rainfall in Darfur affected the time path of assets and livelihood strategies in the region. This is to consider whether structural shifts generally are associated with increased outbreaks of conflict. Figure 9 suggests that all Sahelian countries experienced structural declines in the early 1970s such as that of Darfur. Given the relative absence of civil conflict in Mali, Burkina Faso and Niger, perhaps the structural decline in rainfall explains very little of the Darfur conflict.

We conducted an exercise to increase the sample size and use an agreed-upon measure of civil conflict. We calculated the break or change year in rainfall totals for every country in Africa, using the Hulme dataset, for time period 1940-1998. The country rainfall totals are simple averages of all nodes falling with the country borders. (For the moment small countries which do not encompass a node are not included, next round will interpolate a rainfall series for these countries.) The Pettitt test is used to determine the break year. For each country with a break year identified by the Pettitt test, we calculate the magnitude of the structural break as the difference between mean rainfall for the time period before the break and mean rainfall for the time period after the break. We then have a measure of the years since the break, and a measure of the magnitude of the break. We then use the Miguel et al.dataset of civil conflicts to test for an effect of a structural decline in rainfall on civil conflict. We calculate the number of years of conflict (any PRIO, serious PRIO, and Collier measures as used in Miguel et al.).

The results are in Table 3. Nineteen of thirty-seven countries experienced structural breaks, with 15 of the 19 breaks in the years 1967-1970. All saw declines except for Madagascar and South Africa. All of the Sahelian/West African countries saw structural breaks except for Ghana. The table makes clear that there is no obvious relationship between structural breaks and resulting conflict decades later. Of fifteen Sahelian/West African countries experiencing structural breaks, only two saw extended conflict during the 1980s. The same two (Chad and Sudan) continued with conflict in the 1990s, and were joined by a number of others. Country experts would be unlikely to ascribe those conflicts to declines in rainfall (e.g. Burkina Faso's short war with Mali and internal coup d'etat). For the non-Sahelian countries, there is a mix of cases of extended war and structural break. No pattern is evident.

Preliminary analysis, then, suggests little merit to the proposition that a structural break decades earlier is a reliable predictor of the outbreak of large-scale civil conflict. Too many other factors are at play.

Conclusion

We have considered and rejected the argument that Darfur's conflict is best thought of as a climate change conflict. There was no change in climate as a short-term trigger to the conflict. There is little evidence that the structural break in rainfall led to a downwards spiral for large fractions of the Darfur population. There is no evident cross-country pattern in the correlations between structural breaks in rainfall and incidence of conflict in later decades.

Figure 1: Location of rainfall stations and GPCP nodes, Darfur, Sudan

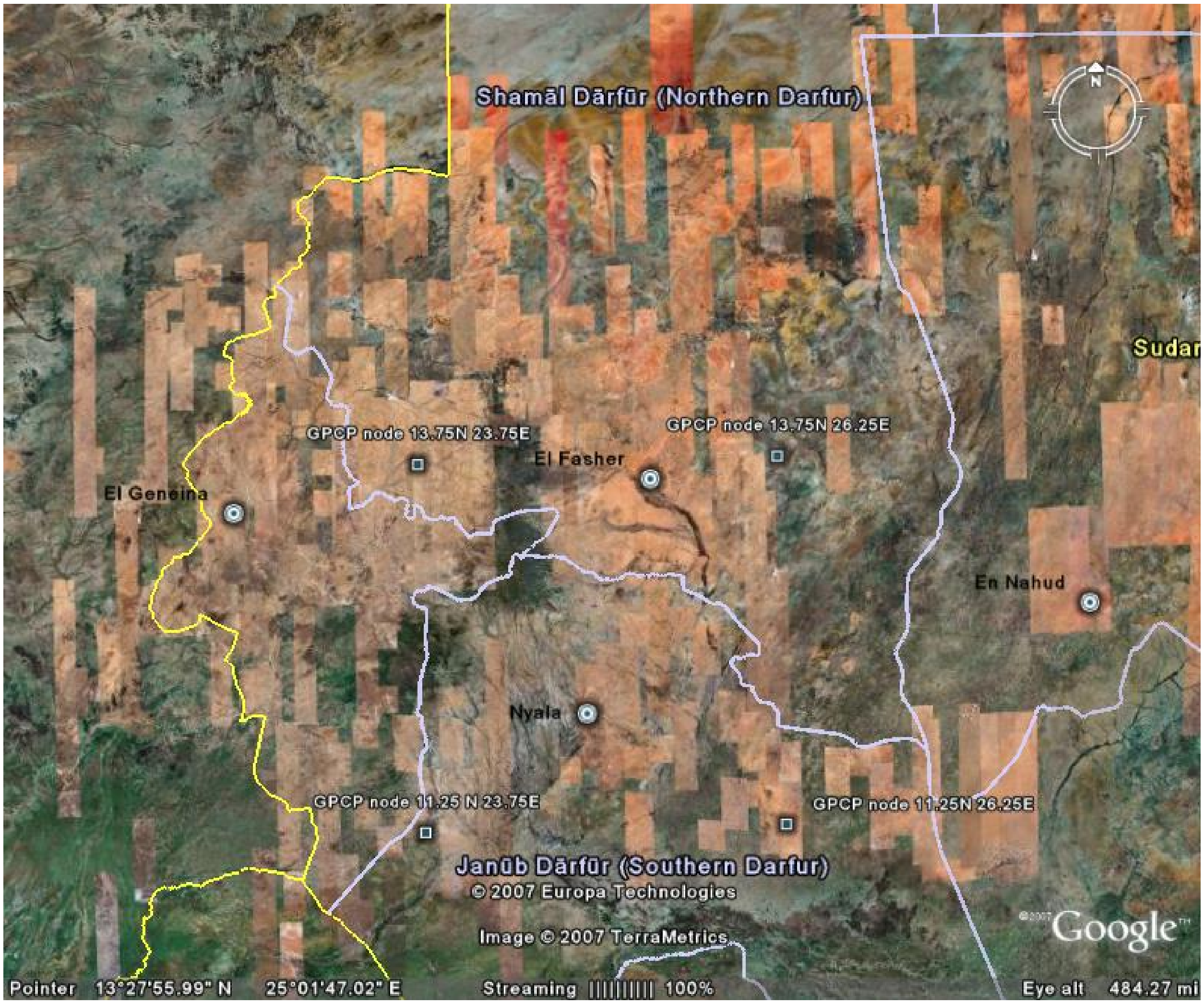
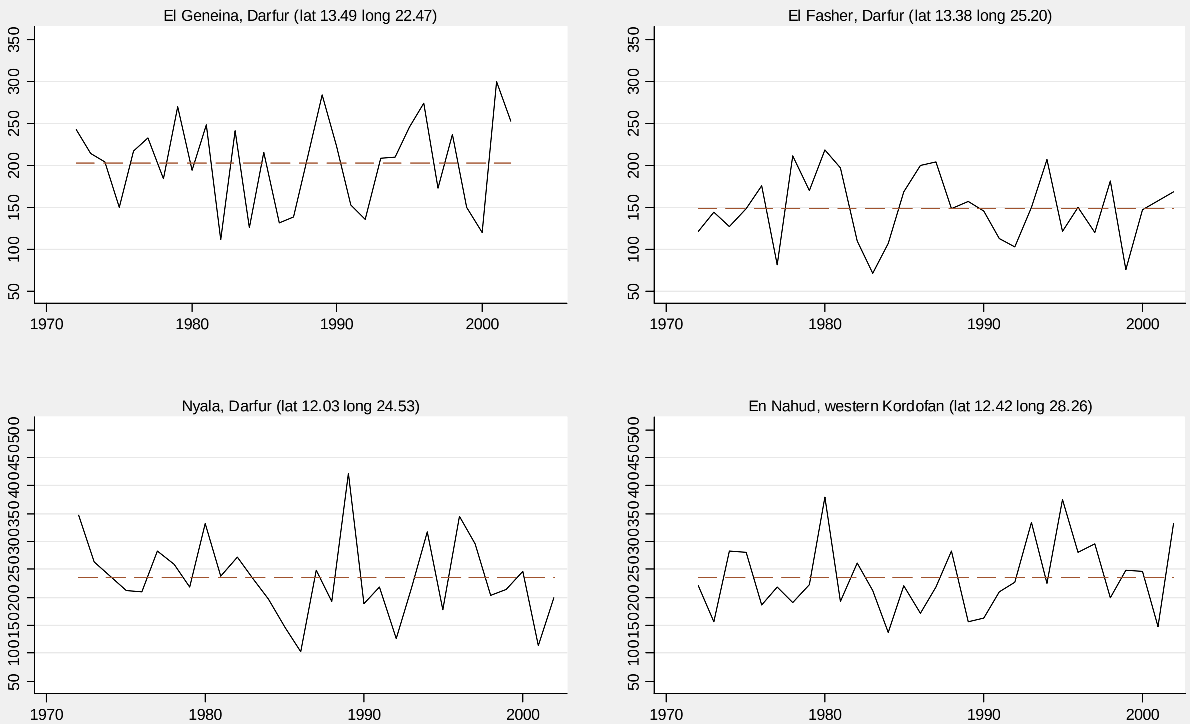


Figure 2: Rainfall (annual mm.) at four rain stations in Darfur area, 1972-2002

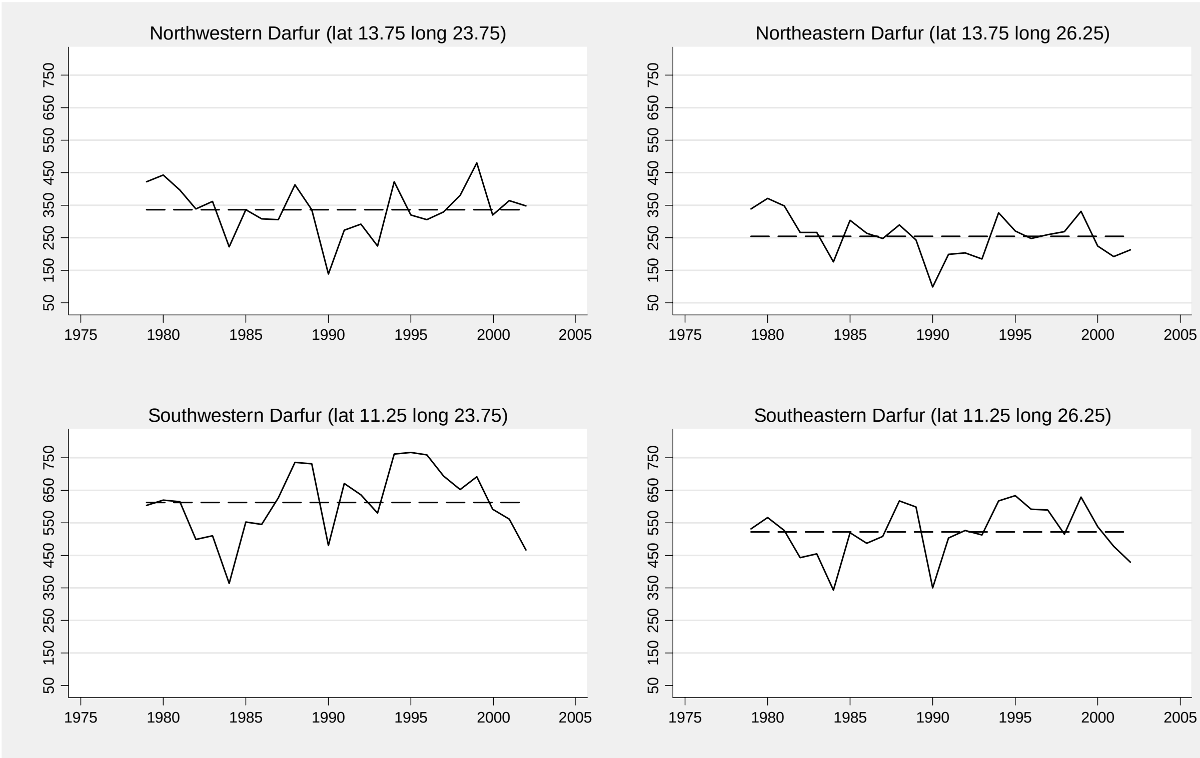
(dashed lines are 30-year means)



Source: Sudan rain station data provided by David Lister, Climatic Research Unit, University of East Anglia

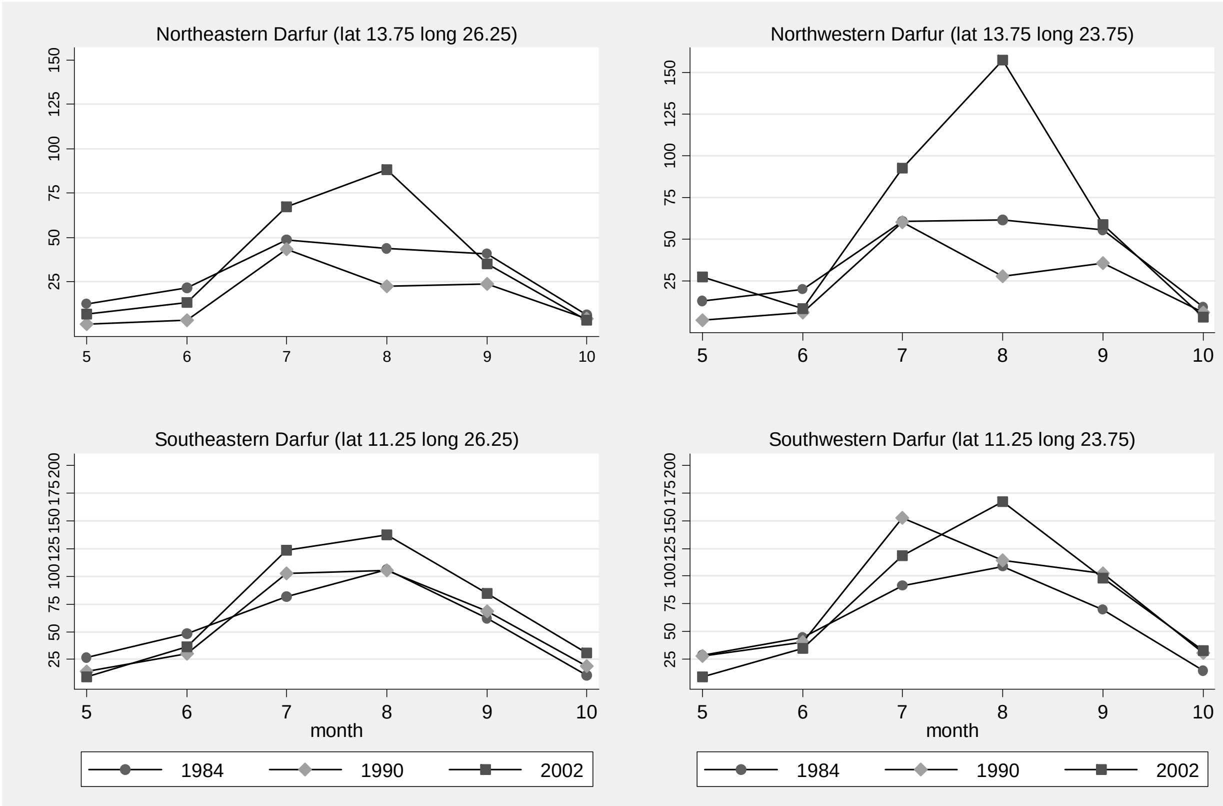
Figure 3: Rainfall at four latitude-longitude nodes in Darfur (annual mm.), 1979-2002

(dashed lines are 23-year means)



Source: GPCP 2.5x2.5 dataset

Figure 4: Distribution of monthly rainfall in Darfur in 1984, 1990 and 2002



Source: GPCP Version 2 Combined Precipitation Data Set

[redacted]

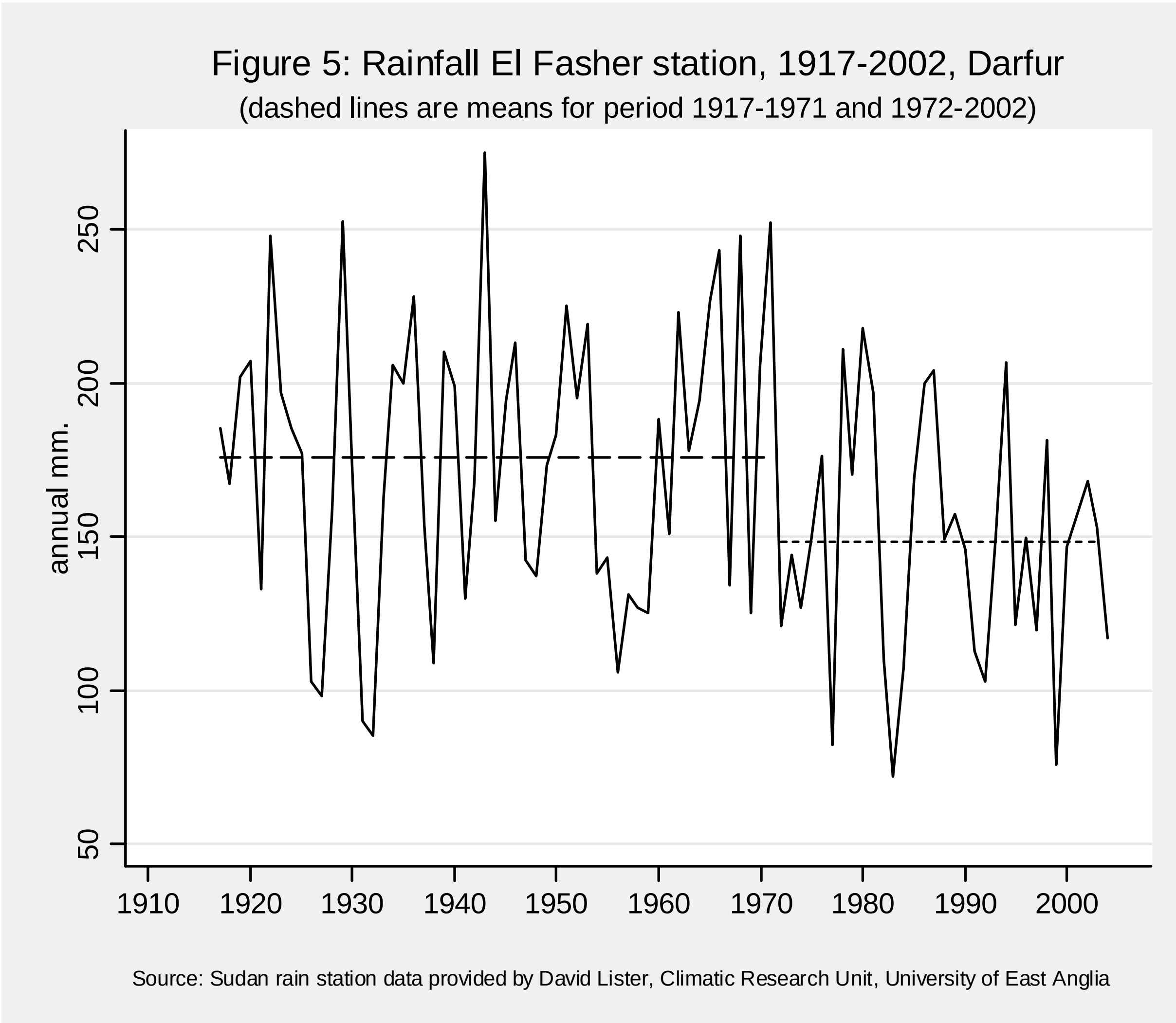
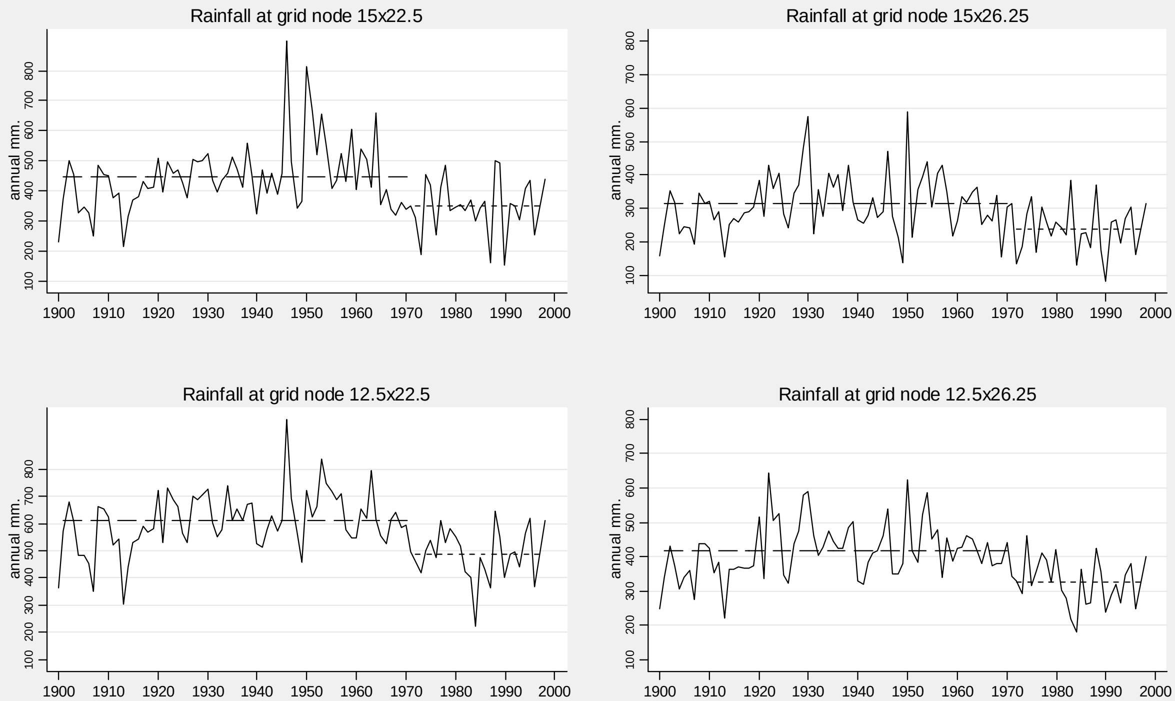


Figure 5: Rainfall El Fasher station, 1917-2002, Darfur
(dashed lines are means for period 1917-1971 and 1972-2002)
annual mm.
50
100
150
200
250
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Source: Sudan rain station data provided by David Lister, Climatic Research Unit, University of East Anglia

Figure 6: Rainfall in four latitude-longitude nodes in Darfur, 1900-1998

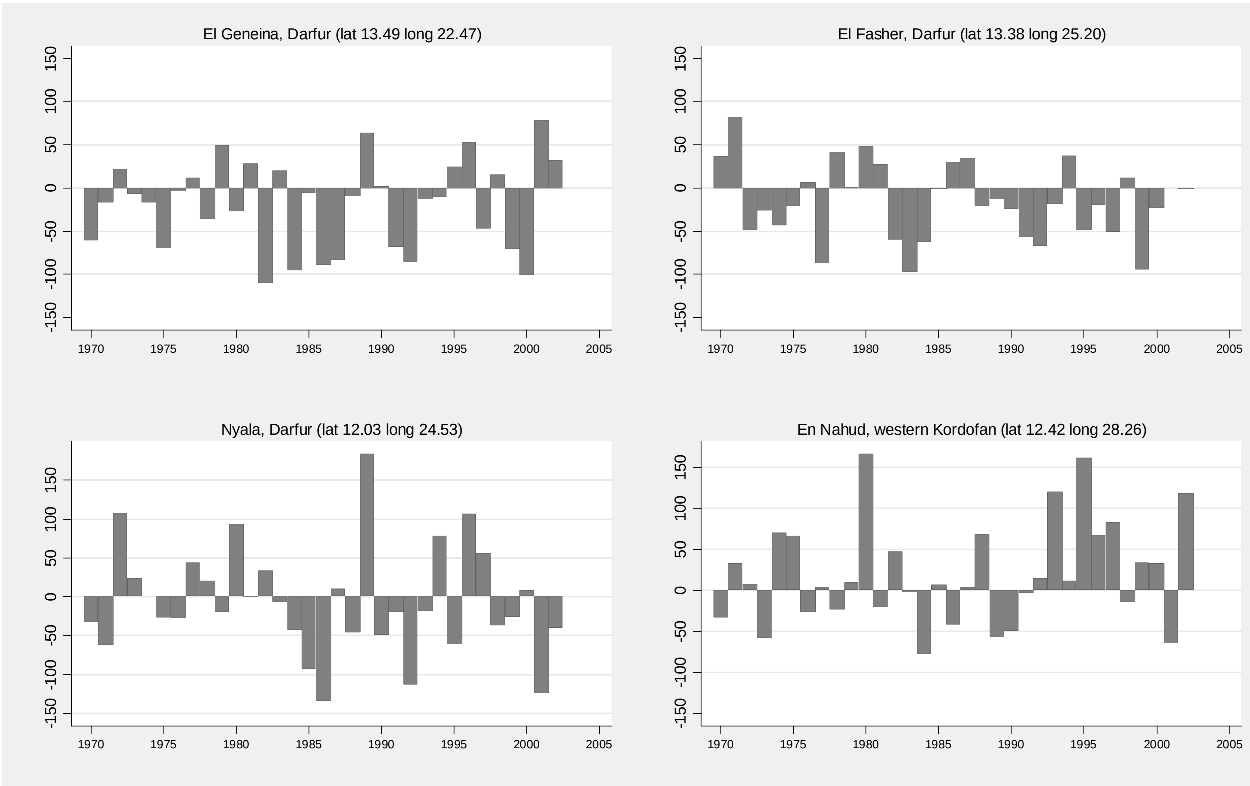
(dashed lines indicate mean levels for 1900-71 and 1972-1998)



Source: gu23wld0098.dat (Version 1.0), provided by Mike Hulme, Climatic Research Unit, University of East Anglia

Figure 7: Deviations from local 1961-1990 mean

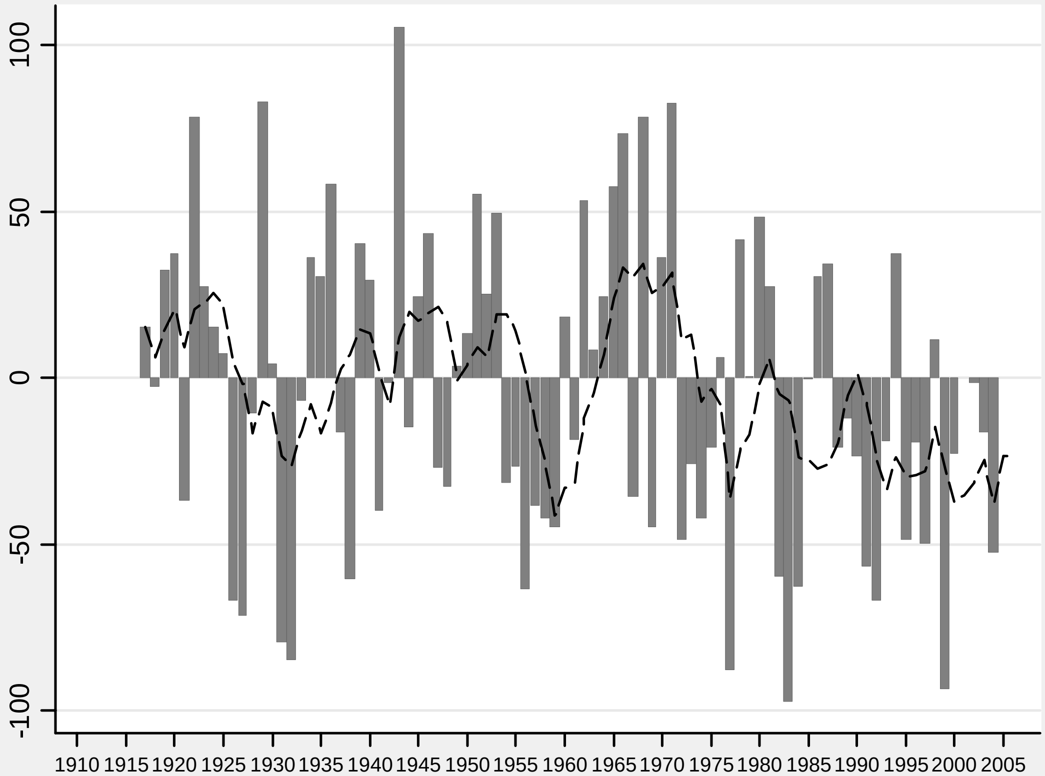
four rain stations in Darfur area, 1970-2002



Source: Sudan rain station data provided by David Lister, Climatic Research Unit, University of East Anglia

Figure 8: Deviations from 1961-1990 mean, El Fasher, Darfur

(dashed line is five year moving average of deviations)



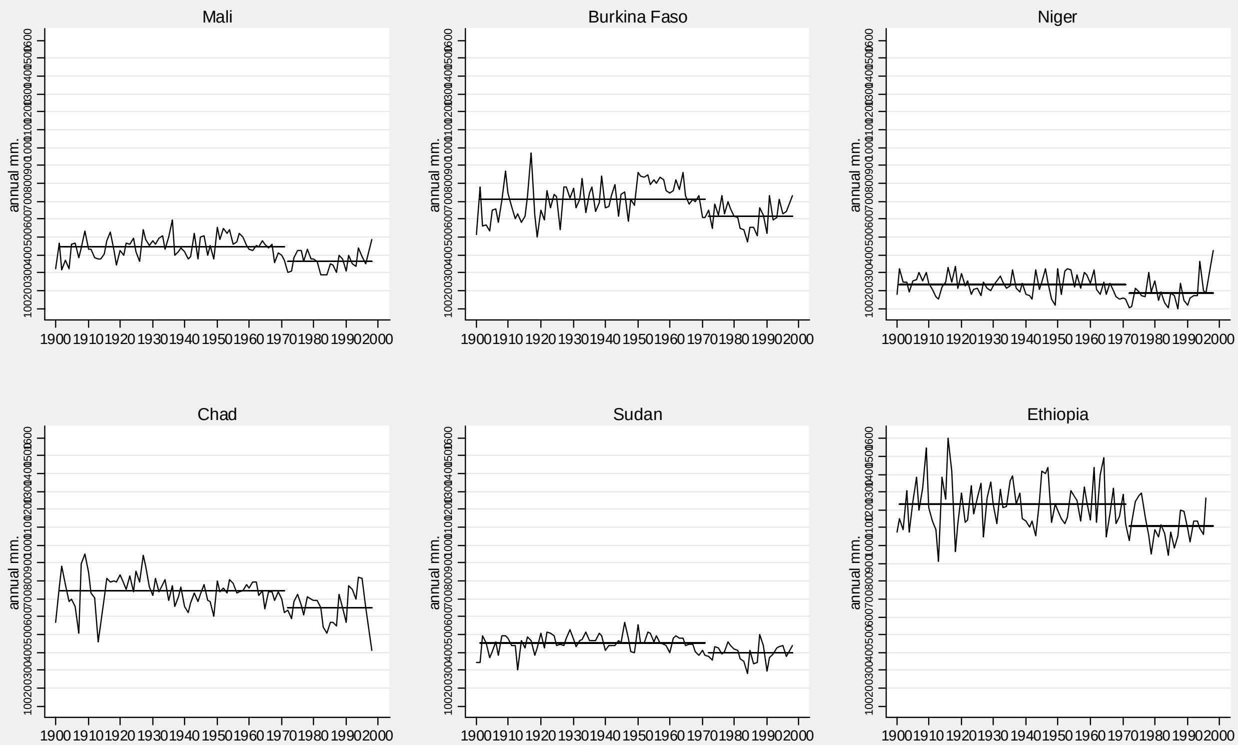
Source: Sudan rain station data provided by David Lister, Climatic Research Unit, University of East Anglia

Table 2: Pettitt test for change point in series of rainfall annual totals

Rainfall station	Value Uk	Critical K	Year of break
El Geneina	495	373	1968
El Fasher	381	365	1971
Nyala	157	356	
En Nahud	224	373	
Lat 15, Long 22	579	315	1964
Lat 15, Long 26	415	315	1968
Lat 12, Long 22	615	315	1970
Lat 12, Long 26	577	314.7965	1970

Sources: Lister and Hulme; Tests use observations 1940-2003 for rainfall stations and 1940-1998 for Hulme.

Figure 9: Rainfall in six Sahelian countries, 1900-1998
(dashed lines indicate mean levels for 1900-71 and 1972-1998)



Source: gu23wld0098.dat (Version 1.0), provided by Mike Hulme, Climatic Research Unit, University of East Anglia

[redacted]

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