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Trends and triggers: Climate, climate change and civil conflict in Sub-Saharan Africa

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Abstract

The conventional discourse relating climate change to conflict focuses on long term trends in temperature and precipitation that define ecosystems and their subsequent impact on access to renewable resources. Because these changes occur over long time periods they may not capture the proximate factors that trigger conflict. We estimate the impact of both long term trends in climate and short term climatic triggers on civil conflict onset in Sub-Saharan Africa. We find that both operationalizations have a significant impact. Climates more suitable for Eurasian agriculture are associated with a decreased likelihood of conflict, while freshwater resources per capita are positively associated with the likelihood of conflict. Moreover, positive changes in rainfall are associated with a decreased likelihood of conflict in the following year. We also assess the outlook for the future by analyzing simulated changes in precipitation means and variability over the period 2000–2099. We find few statistically significant, positive trends in our measure of interannual variability, suggesting that it is unlikely to be affected dramatically by expected changes in climate.

Keywords: Africa; Climate change; Civil conflict; Development; Precipitation; Environment

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Introduction

The study of international security is expanding to include threats from a changing global environment. The Independent Commission on Human Security identifies three sources of threats: consumption of fossil fuels and increased pollution in urban environments; land degradation due to overuse, erosion, and desertification; and the buildup of greenhouse gases that ''threaten widespread climate change'' (Commission on Human Security, 2003, 17). The causal link between climate change and threats to security, however, is not specified.

This oversight is curious, as a growing literature relates environmental scarcity to conflict, emphasizing the role of renewable resources such as freshwater and arable land (Hauge & Ellingsen, 1998; Homer-Dixon, 1994, 1999; de Soysa, 2002; Urdal, 2005). This literature is based on the neo-Malthusian notion of a monotonically dwindling resource pool. As natural resources become degraded due to overexploitation and global warming, it is argued, rising human populations will be forced to migrate internally or cross borders (Gleditsch, Nordås, & Salehyan, 2007) and distributional conflicts will arise as populations compete for pieces of an ever-dwindling pie.

An alternate perspective is that increasing climatic variability may lead to conflict. The environmental consequences of greater variability are declines in system predictability and stability, and increase in extreme events such as tropical storms (IPCC, 2001), all of which may affect access to resources. Because the effects of resource scarcity are mediated by existing asymmetries of access and wealth, these effects are especially threatening to Sub-Saharan Africa, the population of which is primarily rural, poor, and dependent on forests for fuel and rain-fed subsistence agriculture.

We investigate these arguments from two complementary perspectives. First, the effects of climate change on the onset of conflict must be conceived of as (1) long term trends that may lead to a higher baseline probability of conflict, and (2) short term triggers that affect the interannual variability in that probability. We estimate the impact of both long term trends (operationalized as climate suitability for Eurasian agriculture, land degradation, and freshwater availability per capita) and short term triggers (operationalized as the lagged percent change in annual rainfall) on the onset of civil conflict in Sub-Saharan Africa. We find that both operationalizations have a significant impact on the likelihood of conflict onset, even in the presence of controls typical of the conflict literature. An analysis of marginal effects leads us to conclude that interannual variability matters more than the specter of changes in overall climate that takes place over long time periods.

Second, we assess the outlook for the future based on an analysis of predicted changes in precipitation means and variability generated by NCAR-PCM,[1] a general circulation model (GCM). Using simulated values for precipitation over the period 2000–2099, we find that total annual precipitation flux is expected to increase in western Africa and the Sahel while decreasing in southern Africa. Moreover, few significant trends are found in our measure of interannual variability throughout the region.

These findings point to two conclusions. The first is that the future for Africa is not necessarily one defined by increasing interannual variability in rainfall, the most significant climatic variable in our analysis of conflict onset. The second regards policy. Our findings suggest that

[1] National Center for Atmospheric Research Parallel Climate Model. A more detailed description of the model can be found at http://www.cgd.ucar.edu/pcm/.

reducing dependence on rainwater for agriculture may mitigate conflict, even as rainfall variability is not predicted to increase over time.

The article proceeds as follows. Section two presents a review of attempts to link environmental change and conflict. Section three develops the argument that increases in interannual rainfall variability may be more significant in triggering conflict than more long term processes of land degradation and climate change, and presents hypotheses. Section four covers our identification strategy, summarizes our choices of variables and tests the model. Section five extends our discussion into the future, analyzing simulations derived from the GCM. Section six summarizes our significant findings and concludes.

Literature review

The conventional discourse linking climate change to conflict focuses on long term changes in the climatic means that define ecosystems and their subsequent impact on access to renewable natural resources. The 18 GCMs that form the core findings of the Intergovernmental Panel on Climate Change (IPCC) project increase in mean global temperature between 1.8 and 4.0°C over the next 100 years (IPCC, 2007). As mean temperatures rise, the models project increased incidents of droughts, desertification and severe precipitation events. Human populations will experience decreased land productivity and freshwater availability.

This discourse has its roots in neo-Malthusian notions of carrying capacity. Neo-Malthusians argue that human population growth, coinciding with increases in affluence and per capita rates of consumption, will cause exponentially increasing demands on natural resources, leading inevitably to shortages, land and water degradation, and distributional conflicts (Ehrlich, 1969; Ehrlich & Ehrlich, 1990; Goldstone, 1991, 2002; Homer-Dixon, 1999). The potential of technological innovation as a solution to these problems (Simon, 1981) is considered remote due to lower stocks of human capital and therefore latent innovative capacity (Boserup, 1965), which ultimately produces an ingenuity gap between innovative and stagnant societies that exacerbates existing asymmetries of access (Homer-Dixon, 2000).

This perspective is criticized on theoretical and empirical grounds (Gleditsch, 1998; Nordås & Gleditsch, 2005; de Soysa, 2002). Gleditsch argued that the causal mechanisms are too elaborate (operating through multiple paths of causality and several layers of intervening variables) and failed to account for differing levels of economic and political development on resource consumption and conflict—that is, highly developed economies and polities may experience lessened conflict over resources even as demand increases.

Even assuming the conventional causal mechanisms are valid, neo-Malthusian analysis does not identify short term causes that trigger the outbreak of conflict. It does predict conflict over access to resources, but the causal mechanisms are so complex, and the environmental changes so gradual, that identifying theoretical or empirical thresholds that trigger violence once crossed is difficult. Hauge and Ellingsen (1998) concluded that countries subject to environmental damage, including deforestation and land degradation, were more likely to experience internal and external conflict. However, their coding of these variables was subjective and based on somewhat arbitrary cut points for collapsing continuous variables into dichotomous variables, and all their environmental measures were stationary. Moreover, a recent reanalysis by Theisen (2006) found that the study could not be replicated. Esty et al. (1998) found no relationship between environmental degradation and various types of state failure, including civil conflict.

Skeptical of the neo-Malthusian position, de Soysa (2002) tested similar hypotheses against an alternate (yet still stationary) operationalization of resource abundance and found that resource-rich areas were less likely to experience conflict, suggesting that resource scarcity led to greater resource strain and an increased likelihood of conflict. Contrarily, de Soysa also found that resource wealth was associated with lower economic growth rates and thus higher incidence of conflict. Therefore, the impacts of resource abundance and scarcity on conflict were both direct and indirect. The joint impact of population growth and resource degradation was studied by Urdal (2005), who found only weak support for the hypothesis that increased resource scarcity led to conflict.

More recent contributions to the study of environmental conflict depart from the extant literature in two main ways. First, these studies make use of temporally variant measures of natural resource scarcity. Miguel, Satyanath, and Sergenti (2004) estimated the effect of economic shocks on the likelihood of civil conflict in Sub-Saharan Africa. Because the region is agrarian and irrigation is not widely practiced, they contended that rainfall was a plausible instrument for economic growth. Using data on rainfall variability, they found that increased rainfall had a positive impact on income growth and a negative impact on the likelihood of conflict, mediated by its effect on economic growth. The relationships between rainfall and other measures of environmental resource scarcity, however, were not addressed.

Second, several recent studies disaggregate the unit of analysis, departing from the traditional country-year research design and focusing instead on sub-national, geographically defined units. Raleigh and Urdal (2007) and Levy, Thorkelson, Vörösmarty, Douglas, and Humphreys (2005) represent two such analyses, applying geo-referenced data to small geographical units. Raleigh and Urdal found that freshwater availability had a negative impact on the likelihood of conflict. Moreover, they found this relationship was compounded by higher population densities and therefore more competition for resources. Applying a similar approach, Levy et al. found that when rainfall was significantly below normal, the likelihood of conflict outbreak was higher the subsequent year. While their study made use of economic and political control variables, the state-level resolution at which these data were available was a limiting factor. The conflict-mitigating effects of freshwater availability are examined (and partially contradicted) in the literature on interstate conflict by Gleditsch, Furlong, Hegre, Lacina, and Owen (2006), who found that shared river basins increased the likelihood of conflict between neighboring countries.

Ultimately, our analysis makes use of time-variant measures of resource scarcity but does not disaggregate geographically. Disaggregation allows the testing of many arguments in the conflict literature that reference geographic features like rough terrain (Gates & Buhaug, 2002) and resource endowments (Buhaug & Lujala, 2005) that are non-constant across the territory of a state, relatively immobile, and for which precise data are available. In contrast, insurgent and state forces are relatively mobile and, more importantly, strategic about where they choose to prosecute their war aims. Without detailed knowledge about the leadership and personnel of the various movements, disaggregated analyses might lead to inferences that mistake strategic decisions about where rebels organize and fight for the grievances or opportunities that motivate them. At this point, the relative strengths and weaknesses of country level, on one hand, and geographically disaggregated analyses, on the other, are varied enough to justify competitive coexistence.

Thus framed, we address two open questions in the literature. The first is how to combine stationary trend measures with temporally variant trigger measures in order to model the environmental conditions that lead to conflict. The second regards the neo-Malthusian tendency to assume (a) that resources are dwindling and (b) that fewer resources lead inexorably to conflict.

The argument and hypotheses

The argument

Much of the economic literature on civil war explains participation in rebellion as the result of rational cost–benefit analysis. This logic is rooted in Becker (1968) and Ehrlich (1973), who argued that the propensity to commit crime (in this case, the crime of rebellion) was a function of the payoffs and punishments associated with criminal activity.[2] This literature focuses on the costs authorities can impose on would-be criminals, defined as the benefit of criminal activity minus the expected severity of punishment, adjusted for the expected likelihood of apprehension. A second branch of this literature focuses on the opportunity cost to wages in the legal economy. Collier (2000) and Collier and Hoeffler (2002, 2004) contended that the gap between the expected economic returns from joining the rebels relative to those from conventional economic activity drove the empirical relationship between low income and the onset of civil war. Miguel et al. (2004) interpreted their findings regarding rainfall and conflict in these terms precisely. A particularly good year of rain increased the expected returns to participation in farming. Conversely, as agricultural productivity declined due to diminished rainfall, the opportunity cost to violence diminished.

Viewed from this perspective, we can generate hypotheses regarding the effects of land degradation, climatic conditions, and freshwater abundance on the likelihood of conflict. Land degradation refers to processes that negatively affect land productivity. If productivity is defined as the expected benefit per unit of effort, then we expect higher levels of land degradation to be associated with lower returns to agriculture and therefore a higher likelihood of conflict, *ceterus paribus*.

Climatic conditions may also affect conflict. Gallup, Sachs, and Mellinger (1999) estimated that tropical agriculture suffered from a productivity gap of upto 50% compared with agriculture in more temperate zones. They argued that the mechanisms linking tropical climates to lower agricultural productivity were the unsuitability of tropical soil to large-scale, Eurasian agriculture and increased disease burden. We therefore expect climates less suitable for Eurasian agriculture to be associated with lower economic returns to agriculture and therefore a higher likelihood of conflict, *ceterus paribus*.

Finally, freshwater resources may have an impact on expected returns to participation in agriculture, though the nature of this relationship is potentially complicated. One might suspect that larger stocks of freshwater resources would be associated with greater returns to agriculture. Therefore, the hypothesized relationship would be negative. However, large stocks of freshwater may be found in tropical zones that receive large amounts of rainfall but are also characterized by poor soil quality. As such, the hypothesized relationship between freshwater availability and conflict may be positive. We test both hypotheses.

The preceding interpretations ignore the fact that land degradation and climate change occur over long time spans, and, as such, represent trends to which human beings have proven remarkably adaptive. Conflict is one possible outcome of increased resource scarcity, but it

[2] This would appear to be the implicit position of Fearon and Laitin (2003), who argued that the most significant determinant of civil war onset is the ability of the state to dissuade potential rebels. Wealthier, more politically consolidated and less geographically challenged states are less prone to conflict because potential rebels expect the likelihood of apprehension and therefore costs to rebellion to be high.

is hardly the only conceivable one. Observed solutions to persistent problems of land degradation and scarcity include the adoption of new agricultural technology, income diversification through participation in the wage-based economy, and internal migration (Reardon & Taylor, 1996).

The problems associated with long term changes in land quality are also present in response to interannual variability in climate. However, short term variability leads to changes in income that leave less time for adaptation. Household studies of income diversification in Sub-Saharan Africa suggest that short term variability presents very different problems for agriculturalists, and that the negative effects of economic downturns are felt primarily by those at the lowest end of the economic spectrum operating in areas with few non-agricultural or agriculturally linked alternate sources of income. These individuals are typically young men with low levels of social status—those most likely to take up arms.

This discussion suggests that a better identification strategy might focus on short term changes. Rainfall is one well-documented source of interannual variability. Therefore, we expect that higher levels of rainfall relative to previous years will be associated with higher returns to agriculture, and therefore lower risk of conflict, *ceterus paribus*.[3]

Hypotheses

H1: Measures of land degradation are positively associated with the risk of civil war onset.
H2: Measures of climate suitability for Eurasian agriculture are negatively associated with the risk of civil war onset.
H3: Measures of freshwater availability are negatively associated with the risk of civil war onset.
H4: Measures of freshwater availability are positively associated with the risk of civil war onset.
H5: Contemporaneous measures of increased (decreased) rainfall are negatively (positively) associated with the risk of civil war onset.
H6: Lagged measures of increased (decreased) rainfall are negatively (positively) associated with the risk of civil war onset.

In addition to these hypotheses, we investigate whether the effects of changes in rainfall are amplified by existing resource scarcity. Returning to the opportunity cost analogy, if expected wages are already low and alternatives scarce, negative changes in rainfall will affect to a greater extent those operating in already marginal lands or less suitable climates.

H7: The interaction of increased (decreased) rainfall and land degradation should be negatively (positively) associated with the risk of civil war onset.
H8: The interaction of increased (decreased) rainfall and climate suitability for Eurasian agriculture should be negatively (positively) associated with the risk of civil war onset.
H9: The interaction of increased (decreased) rainfall and freshwater availability should be negatively (positively) associated with the risk of civil war onset.

[3] Of course, this relationship cannot be purely linear; too much rainfall may cause flooding and massive soil erosion. However, we were unable to identify such threshold effects (results not shown) in our analysis.

Data, estimation, and results

The dependent variable: civil conflict onset

The dependent variable is the onset of civil war in a given country-year in Sub-Saharan Africa. We rely on the coding developed by the PRIO/Uppsala Conflict Data Project (Gleditsch, Wallensteen, Eriksson, Sollenberg, & Strand, 2002). The variable is coded as 1 for the year of onset only and 0 for all years thereafter. Though the data now cover the time period 1946–2006, we restrict our analysis to the period 1981–2002 due to availability of explanatory variables. Onset years make up 9.6% of all country-year observations.[4]

The independent variables: trends and triggers

Trends

The primary operationalizations of trends are measures of land degradation, overall ecological suitability for Eurasian agriculture, and renewable freshwater resources per capita. Land degradation is defined as the temporary or permanent reduction in the productive capacity of land as a result of human action (Bot, Naechtergaele, & Young, 2000). We use the negative of the total percentage of land degraded, which has a mean value of −0.283 and a standard deviation of 0.266, bounded on the lower end by South Africa, the Sudan, Mauritania, Côte D'Ivoire, Zimbabwe, Zambia and Guinea (appreciable degradation 0) and Kenya on the higher end (−1). Therefore, the expected sign on the coefficient for total degradation will be negative, rather than positive, as the hypothesis suggests. We do this in order to facilitate the construction and interpretation of the interaction terms. Unfortunately, these values are static within countries. The data are available from the Food and Agricultural Organization (FAO) Terrastat Web site (http://www.fao.org/ag/agl/agll/terrastat/); for a detailed discussion of variable construction, see Bot et al. (2000).

We also include a measure of climate suitability for heavy grass agriculture of the type that typifies the Eurasian land mass. The variable, climate scale, is similar to that used by Hibbs and Olsson (2004) and is measured on a four-point scale, ordered in ascending value: 1 for dry tropical (desert) and highland, 2 for wet tropical (rainforest), 3 for temperate humid subtropical and temperate continental, and 4 for dry, hot summers and wet winters. This scale is based on the Köppen–Geiger climate system, which classifies climate according to mean annual precipitation and temperature, and is calculated by summing these values weighted by the proportion of national territory falling within these categories. The mean value is 1.79 with a standard deviation of 0.68, bounded on the lower end by Ethiopia (1) and on the higher end by the kingdom of Lesotho (3.989). Sub-Saharan Africa as a region has the second lowest mean value for this measure, with only the Sahara-dominated region of North Africa and the Middle East being less suited to agriculture. These values, while also static within each country, are a closer approximation to the concept of climate change induced by global warming, as land degradation is by definition endogenous to land use.

Finally, we operationalize freshwater availability as total renewable water resources (in thousands of cubic meters) per capita. The data have a mean value of 24.12 with a standard

[4] We utilized Fearon and Laitin's coding for civil conflict onset as a robustness check and to investigate whether smaller and larger conflicts operate according to similar causal logics. Due to its much higher casualty threshold (1000 versus 25), onset years make up only 2.9% of observed country-years.

deviation of 55.9, and are highly skewed (the median value is 5.44). It is bounded on the lower end by Rwanda (0.63) and the higher end by the Republic of Congo (432.9). Data are available at 5-year intervals from the FAO Aquastat Web site (http://www.fao.org/ag/agl/agll/aquastat/).

Triggers

Miguel et al. (2004) coded percent change in rainfall from the previous period from the Global Precipitation Climatology Project (GPCP) database of annual rainfall estimates. The data are available at a resolution of 2.5° by 2.5° and cover the time period 1979–1999. Their method of coding nodes as ‘‘belonging’’ to a country was whether the exact node fell within national borders, and as such lacks some of the precision of our alternate coding (see Appendix 2). We update Miguel et al.’s data through 2002 using the newest version of GPCP data (Adler et al., 2003).

Our operationalization of an environmental trigger is the percent change in annual rainfall in country i in year t from the previous year, henceforth rainfall trigger. This measure controls for cross-country variation in average levels of rainfall and captures interannual variability, a measurement may expect to increase with future increases in atmospheric levels of greenhouse gases. We also generate dummy variables to identify changes that are greater than ± 1 and ± 2 standard deviations from mean rainfall.

Control variables

Most of the control variables used here (GDP per capita, oil producer, percentage of mountainous terrain) are taken from the Fearon and Laitin (2003) data set on civil conflict and have been updated through 2002. Other control variables are taken from Miguel et al. (2004) and the World Development Indicators 2005 CD-ROM. Descriptive statistics for all variables used in this article can be found in Appendix 1.

Estimation and results

Our analysis indicates that both short and long term climatic factors affect conflict, though their effects are present only when other political, economic and geographic factors are included. Specifically, we find the lagged rainfall trigger and climate scale measures to significantly predict onset. Table 1 reports maximum-likelihood logit models of conflict onset and resource scarcity, alternately specified in terms of long term trends and short term triggers. The equations follow the general functional form

$$\Pr(\text{Onset}_{it}) = \frac{e^{a+bX_{it}+cY_i+dZ_{it}}}{1+e^{a+bX_{it}+cY_i+dZ_{it}}} + \varepsilon_{it} \qquad (1)$$

where $\Pr(\text{Onset}_{it})$ is the probability of conflict onset in country i and year t, X_{it} is the rainfall trigger (both current and lagged with respect to the year of onset), Y_i is the measure of land degradation, climate scale, and/or freshwater resources per capita in country i, Z_{it} is a matrix of lagged control variables, and ε_{it} is an error term. The coefficients of interest are b and c, the effect of short term climatic triggers and long term climatic trends on conflict onset. We use Huber–White robust standard errors because we expect observations are not independent within countries.

We report results for three models. Model 1 includes only the hypothesized variables of interest. Model 2 adds controls for level of economic development (GDP per capita), economic growth (GDP growth), population, the logged percentage of mountainous terrain, and whether the country derives over 33% of its export revenue from oil. We select these controls for their prevalence in

Table 1
Logit analysis of climate, climate change, and civil conflict onset, 1981–2002

Explanatory variable	Model 1	Model 2	Model 3
Rainfall trigger	−0.026	0.129	0.135
	0.513	0.632	0.630
Rainfall trigger$_{t-1}$	−1.927***	−2.055***	−1.743
	0.560	0.617	2.167
Total degradation	−1.079	−0.739	−0.818
	0.707	0.570	0.551
Climate scale	−0.340	−0.588**	0.565**
	0.264	0.255	0.253
Freshwater resources	0.003*	0.008***	0.008***
per capita	0.002	0.002	0.002
GDP per capita$_{t-1}$		−1.655***	−1.654***
		0.412	0.414
GDP growth$_{t-1}$		−0.023	−0.022
		0.017	0.017
ln(Population)$_{t-1}$		−0.278*	−0.272*
		0.163	0.164
ln(% Mountainous)		0.243**	0.245**
		0.107	0.106
Oil producer		1.363**	1.357**
		0.586	0.59
Trigger$_{t-1}$ × total degradation			−2.108
			1.955
Trigger$_{t-1}$ × climate scale			0.478
			0.769
Trigger$_{t-1}$ × freshwater			−0.002
			0.005
Constant	−2.078***	3.894	3.249
	0.530	2.905	2.783
n	816	814	814
Pseudo log-likelihood	−247.002	−225.890	−226.883
Wald chi^2	13.48	62.29	80.83
Prob > chi^2	0.019	0	0

*Significant at $p < 0.1$, **Significant at $p < 0.05$, ***Significant at $p < 0.001$.
Huber–White robust standard errors below coefficient estimates.

the conflict literature and their robustness to changes in model specification (see Hegre & Sambanis, 2006). We lag all time-variant indicators on period in order to mitigate potential endogeneity. Model 3 includes interaction terms between the lagged rainfall trigger and the various trend variables (land degradation, climate scale, and freshwater resources per capita).[5]

The results in Table 1 suggest four main findings. First, our trend and trigger measures are not associated with the onset of conflict in the absence of economic, political and demographic control variables. Only the lagged rainfall trigger is significant in Model 1. This finding suggests two inferences. The first is that the political effects of climate and freshwater availability

[5] Results for robustness checks using the Fearon and Laitin coding are not reported. Our model proves better suited to explaining the onset of smaller conflicts than larger ones. While all three models using the lower coding threshold are significant (p-value for the $\chi^2 < 0.05$), only Model 3 was significant with respect to the higher casualty threshold coding. Only GDP per capita, the most robust covariate in the empirical literature on conflict, and freshwater resources per capita are significant across the two specifications, with comparable signs on the coefficients and point estimates.

are not apparent absent control variables typical of the civil conflict literature. The second, and more interesting inference from a developmental perspective, is that these endogenous control variables are not fully determined by exogenous factors such as climate (see Acemoglu, Robinson, & Johnson, 2001; Gallup et al., 1999; Hendrix, 2006; Rodrik, Subramanian, & Trebbi, 2004). Were that the case, we would expect the effect of climate and rainfall variability to swamp the effects of our economic, political, and demographic indicators.

Second, the evidence regarding the effects of our long term trend variables is not consistent. Total land degradation is not significant under any specification, though the relationship is positive, as hypothesized. Our measure of climate suitability for Eurasian agriculture is highly significant and negative in Models 2 and 3, lending support to Hypothesis 2. Freshwater resources per capita is highly significant and positive in Models 2 and 3, suggesting that greater availability of freshwater resources per capita is associated with a higher likelihood of conflict.

Third, the lagged rainfall trigger is significant in two of three specifications, with the sign always in the hypothesized direction. This is consistent with the findings of Miguel et al. (2004). However, the contemporaneous measure of rainfall trigger is not remotely significant under any specification. In addition, none of the dummy codings for ± 1 or ± 2 standard deviations from the mean are significant in any of the models (results not shown). Taken together, this lends a good deal of support to Hypothesis 6.

Fourth, none of the interaction terms between lagged rainfall trigger and our trend measures approaches significance in any of the specifications, though their inclusion in the models did affect the significance of their constituent variables. Therefore, the hypothesized potential for magnified effects of rainfall triggers in countries with differing levels of degradation, ecological suitability for Eurasian agriculture, and freshwater availability are not substantiated. Rather, the impacts of interannual variability in rainfall are consistent across countries with different ecological realities and natural resource endowments.

We present the marginal effects of changes in our variables of interest in Figs. 1–3. Using CLARIFY (King, Tomz, & Wittenberg, 2000), we estimate that moving from the 25th to 75th percentile values for lagged rainfall trigger decreases the predicted probability of conflict onset by an average of 34%. The marginal effect of a commensurate quartile-to-quartile change in the climate scale is virtually identical, decreasing the predicted probability of conflict onset by an average of 32%. Quartile-to-quartile shifts in both variables generate a decline in the predicted probability of conflict onset of 55%. This is comparable to the average 51% decrease in the predicted probability of conflict onset produced by a quartile-to-quartile shift in GDP per capita—the most powerful covariate of conflict in the literature. Results suggest that the marginal effects of interannual variability in rainfall are much greater than the marginal effects of changes in climate. This point is underscored by the time periods over which climate change is expected to take place. Given that no model of climate change projects anything near a one standard deviation change in the suitability of climate for large-scale agriculture on a year-to-year basis, we are less confident drawing conclusions about the marginal impact of this variable without turning to its effects on long term economic development and political consolidation, topics beyond the scope of this article (Hendrix, 2006). Similar quartile-to-quartile analysis of the renewable freshwater resources per capita variable yields a change in the predicted probability of onset of only 5%.

Looking to the future: precipitation in Sub-Saharan Africa

We have demonstrated that short term triggers in precipitation (to a greater extent) and long term trends in freshwater availability and suitability of climate for Eurasian agriculture

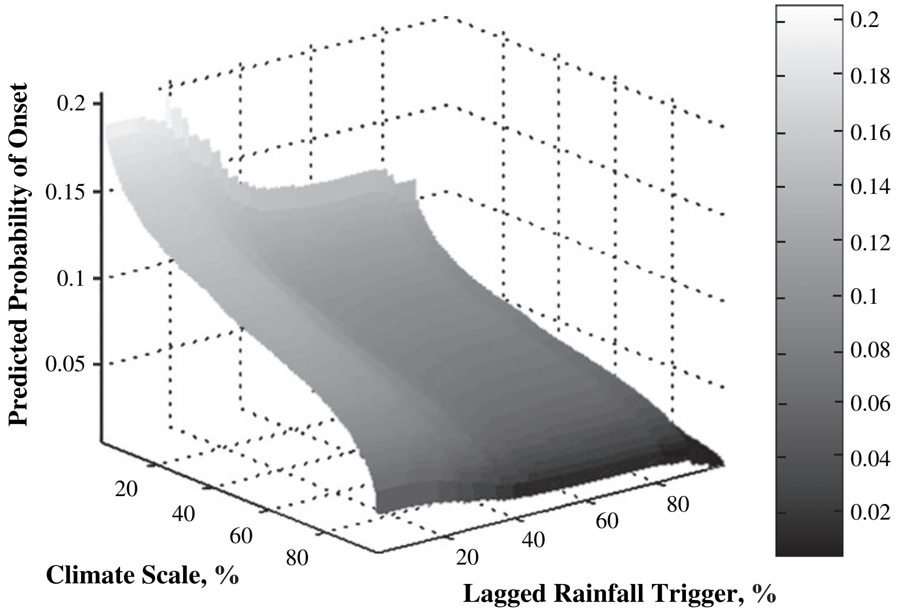

Fig. 1. Marginal effects of lagged rainfall trigger and climate scale on pr(onset), by percentile.

(to varying extents) affect the onset of civil conflict in Sub-Saharan Africa. Our political model uses data from 1981 to 2002, during which much of Africa experienced significant droughts, especially in the Sahel region (Nicholson, 1993). Should we expect future rainfall patterns to resemble those from this period? We now analyze simulated changes in Sub-Saharan precipitation to assess the potential for future conflict in the region; we further investigate the effect of spatial aggregation on our results.

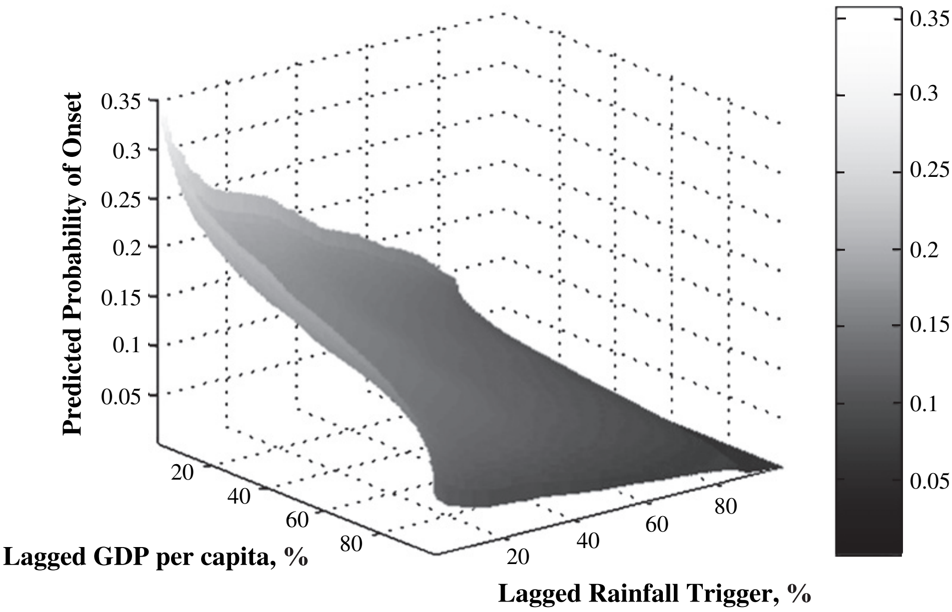

Fig. 2. Marginal effects of lagged rainfall trigger and lagged GDP per capita on pr(onset), by percentile.

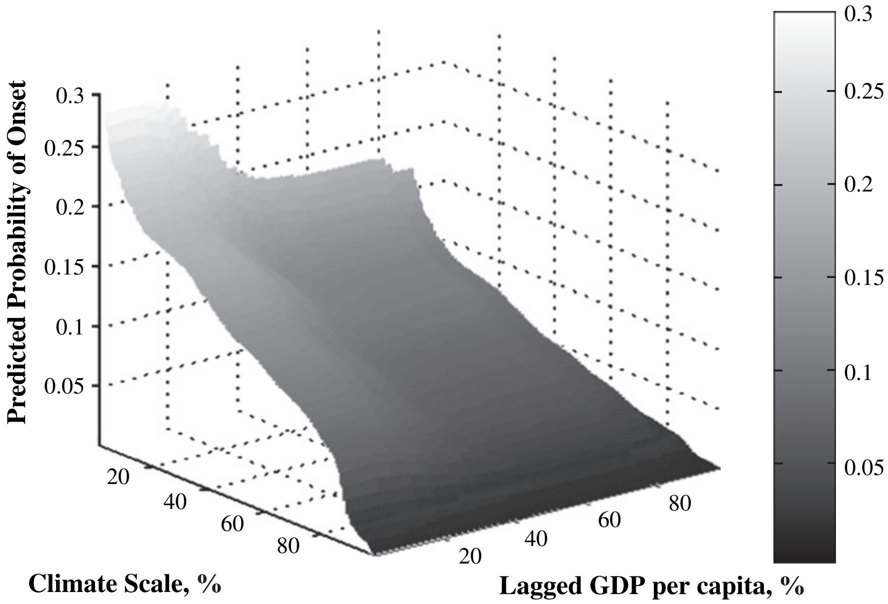

Fig. 3. Marginal effects of lagged GDP per capita and climate scale on pr(onset), by percentile.

Background

The increasing validation and application of coupled ocean–atmosphere general circulation models (GCMs) have enhanced understanding of global climate and improved projections decades into the future. The Intergovernmental Panel on Climate Change (IPCC) collects and analyzes data from 18 GCMs produced by various research institutions. These models are driven by increases in atmospheric greenhouse gases (primarily CO_2) and use balanced thermodynamic mass equations and statistical parameterizations to simulate changes in climatic and hydrologic parameters (IPCC, 2001; Washington et al., 2000). Models project an increase in globally averaged surface air temperature of between 1.8 and 4.0°C resulting from a doubling of atmospheric CO_2 through the 21st century (IPCC, 2007), patterns that have been validated by a host of studies (Bartman, Landman, & Rautenbach, 2003; Douville et al., 2002; Gonzalez-Rouco, Heyen, Zorita, & Valero, 2000; IPCC, 2001; Landman & Goddard, 2002; Rahmstorf et al., 2007; Rowell, 1998; Srinivasan, 2003). The IPCC Special Report on Emissions Scenarios (SRES) outlines a suite of future scenarios for comparative purposes; each scenario contains plausible trajectories for a plethora of social variables such as population size, economic growth, technological development, government regulations, and pollution emissions. Scenarios produce varying estimates of carbon production and hence different magnitudes of warming. This study analyzes three scenarios: A1B (medium warming), A2 (higher warming), and B1 (lower warming).

A key finding of GCM simulations is that climate change will be manifest in the global hydrologic cycle (Gonzalez-Rouco et al., 2000; Washington et al., 2000). Greater intra- and interannual variability in temperature and precipitation on a global scale may result in increased extreme regional events such as flooding, drought, or storm activity (Benestad, 2006; IPCC, 2001; Rowell, 1998; Tebaldi, Hayhoe, Arblaster, & Meehl, 2006). Rising temperatures will increase surface evaporation over the oceans and atmospheric water vapor holding capacity, ultimately resulting in increased atmospheric water content and precipitation (Bartman et al., 2003; Douville et al., 2002; Gonzalez-Rouco et al., 2000; IPCC, 2001; Landman & Goddard, 2002; Rowell, 1998; Srinivasan, 2003; Washington et al., 2000). Terrestrial systems will respond with decreased rates of evaporation, increased soil moisture, and/or increased streamflow and runoff (Nijssen, O'Donnell, Hamlet, & Lettenmaier, 2001).

Few studies analyze GCM results for Africa. Hulme, Doherty, Ngara, New, and Lister (2001) undertake a comprehensive comparison of results from seven GCMs under four SRES scenarios on the African continent. They calculate an increase in surface temperature of between 0.2 and 0.5°C per decade. While results are robust between models for temperature, the story is more varied for precipitation. Under scenarios of low warming (B1), equatorial east Africa experiences increases in rainfall in winter and decreases in summer, while the rest of Africa remains statistically stable. Under medium and high warming scenarios (A1, A2, and B2, respectively), winter precipitation decreases in southern Africa while increasing in equatorial east Africa. Summer precipitation decreases across the Horn of Africa while increasing in the central Sahel.

With these models, scale matters: global results are generally robust, but on the regional scale parameter sensitivity and local variability contribute to differences between observed data and model projections, as well as between models (Hulme et al., 2001; IPCC, 2001). Such uncertainties arise partially from the spatial resolution of GCMs, typically several degrees of longitude by several degrees of latitude. Statistical downscaling methods provide higher resolution spatial data and are preferred for regional analyses (Srinivasan, 2003), but these models are extremely computationally intensive. Herein lies a central difficulty combining physical and geopolitical data: the differing spatial scales (geographically referenced point estimates versus means aggregated at the nation level) complicate using both types of data in one model. For example, some nations may fall entirely within the resolution of the model grids (e.g., Lesotho), while others contain tens of point estimates. For this reason, we undertake analysis at three scales of spatial aggregation.

Despite these sources of uncertainty, studies comparing GCM results with downscaled models demonstrate that global models can replicate observed regional patterns in rainfall variability (Bartman et al., 2003; Gonzalez-Rouco et al., 2000; Landman & Goddard, 2002; Paeth & Hense, 2004; Rowell, 1998; Srinivasan, 2003). The African continent experiences important climatic teleconnections that link global climate change to regional changes in precipitation: ocean forcing (including the El Niño Southern Oscillation) is the dominant cause of variability in western Africa (Bartman et al., 2003) and global sea surface temperatures are strongly correlated with total precipitation in southern Africa (Vizy & Cook, 2001). We heed Hulme et al.'s (2001) caution about using GCM rainfall data for Africa; nevertheless, we agree with their conclusion that general circulation models can yield insights when various scenarios are analyzed in concert. We use the results from our political model to thus guide our analysis of rainfall projections.

The general circulation model

We analyze rainfall data from the United States Department of Energy National Center for Atmospheric Research Parallel Climate Model (NCAR-PCM), available online through the IPCC Data Distribution Center (http://www.ipcc-data.org/). This model was chosen because it has the highest spatial resolution (2.8° × 2.8°) and because data are available for three SRES scenarios (A1B, A2, and B1). Data are from model runs used in the IPCC Fourth Assessment Report (AR4). Calibrations of this model to real data show that NCAR-PCM replicates rainfall

Table 2
Number of time series, out of 290 grid cells or 41 countries, with significant linear trends ($p < 0.05$)

	Grid cell scale ($n = 290$)			Country scale ($n = 41$)		
	A1B	A2	B1	A1B	A2	B1
Total annual rainfall	48 (21)	73 (45)	9 (2)	11 (4)	12 (12)	4 (1)
Rainfall trigger	8 (3)	9 (6)	11 (10)	1 (0)	4 (2)	2 (0)

Parentheticals are the number of positive trends.

patterns in Sub-Saharan Africa (Srinivasan, 2003). In our sample, real rainfall (GPCP, 1981−1999) and model-simulated rainfall (NCAR-PCM, 1981−1999) are correlated at 0.6.

Data analysis

Data are obtained as monthly mean precipitation flux [kg/m^2/s] for a given 2.8° × 2.8° coordinate; we analyze the period 2000−2099. We investigate measures associated with rainfall that are significant covariates of conflict: overall freshwater availability (represented somewhat imperfectly by total annual precipitation flux) and rainfall trigger (percent change in rainfall from the previous year).[6] Linear time series regressions are employed at three scales of aggregation: a region-wide Sub-Saharan scale, the country scale, and the individual grid cell scale. This captures the broad patterns of variability that GCMs are capable of reproducing without demanding unreasonable spatial complexity from globally derived data. Time series are standardized to the seasonal (month specific) mean and standard deviation (mean of zero, standard deviation of one). To aggregate at the country level, precipitation data nodes are assigned to a country and weighted according to the percentage of the cell that resides in a given country (see Appendix 2 for details). In all cases, we compare the three SRES scenarios (A1B, A2, and B1).

Results and discussion

When averaged over the Sub-Saharan region, neither total annual rainfall nor rainfall trigger contain statistically significant trends. Significant trends do exist at the two higher resolution scales; Table 2 compares results for total annual rainfall flux and rainfall trigger at the country and grid cell scales. Rainfall trigger rarely increases under any scenario: at most, under scenario B1, 4% of grid cells have increases in variability, and only scenario A2 simulates increases in variability at the country scale. Total annual rainfall does contain significant trends under all scenarios. As expected, scenarios with medium and high warming also contain more grid cells and countries with changes in total precipitation. However, precipitation does not uniformly increase; about 50% of these time series contain decreasing trends, as do a significant number of countries. Table 3 lists countries that contain aggregated trends in both total annual rainfall and rainfall trigger.

Fig. 4 maps spatial patterns in changes in rainfall under the mid-range warming scenario A1B. At the grid cell scale, increases in total annual rainfall are scattered throughout western Africa, the Sahel, and equatorial Africa. At the country scale, significant increasing trends are

[6] We also analyzed time series of intra-annual variability and positive and negative rainfall shocks (± two standard deviations from the mean). Significant trends were not found. These operationalizations of rainfall variability were not significant predictors in our political model, and we therefore do not discuss them further.

Table 3
Countries in Sub-Saharan Africa containing significant trends (either increasing or decreasing) in two measures of precipitation: total annual rainfall flux [km/m^2/s] and rainfall trigger [interannual variability]

	A1B (medium warming)		A2 (high warming)		B1 (low warming)	
	Increasing	Decreasing	Increasing	Decreasing	Increasing	Decreasing
Total annual rainfall	Equatorial Guinea Ivory Coast Liberia Sierra Leone	Guinea Bissau Zimbabwe South Africa Namibia Lesotho Botswana Swaziland	Guinea Bissau Equatorial Guinea Ivory Coast Guinea Sierra Leone Ghana Togo Cameroon Nigeria Gabon Uganda Kenya		Equatorial Guinea	Guinea Bissau Ethiopia Eritrea
Rainfall trigger		Uganda	Ghana Zimbabwe	Namibia Swaziland		Togo Rwanda

Comparison is for three IPCC SRES scenarios of different relative degrees of carbon dioxide forcing.

restricted to western Africa (Table 3). Decreases in total annual rainfall are primarily clustered in southern Africa, and these grid cell patterns are reflected in the country scale aggregation as well. Our projected patterns are similar to those found by other researchers (Bartman et al., 2003; Hulme et al., 2001; IPCC, 2007; Landman & Goddard, 2002; Paeth & Hense, 2004; Tebaldi et al., 2006). Tebaldi et al. (2006) analyzed GCM simulations of extreme events in temperature and precipitation for 9 GCMs used in the IPCC AR4. They found increasing trends for various measures of rainfall variability such as consecutive dry days, days with rainfall greater than 10 mm, and maximum five day total, among others. While their measures of rainfall intensity are different from our measure of rainfall trigger, their results suggest that other operationalizations of rainfall variability may be a fruitful line of future investigation.

We are interested in investigating the effects of spatial aggregation on results because of recent growth in geographically disaggregated analysis (Levy et al., 2005; Raleigh & Urdal, 2007). The highest resolution available is the grid cell scale. Aggregating at the regional scale (averaging across the entire Sub-Sahara) clearly causes smaller scale patterns to be missed. Aggregating at the country level captures many of the patterns found at the grid cell scale: similar patterns emerge at both spatial scales in southern, central, and western Africa. However, some hotspots of changes in rainfall are missed by looking at country scale mean values. For example, under A1B, patterns of increasing total rainfall are seen in north-central and southern Sudan, northern Uganda, and western Mauritania but these patterns are lost at country scale aggregation (Fig. 4).[7] Under A2, Ghana and Zimbabwe show increasing rainfall triggers, while at the grid cell scale such results are not found. In our study, country scale aggregation captures the majority of significant patterns, but our results suggest that it is important to verify these patterns at multiple spatial scales.

[7] Some points are off-shore. The points describe a 2.5° by 2.5° square centered on the points, and as such the slightly off-shore points reference land area.

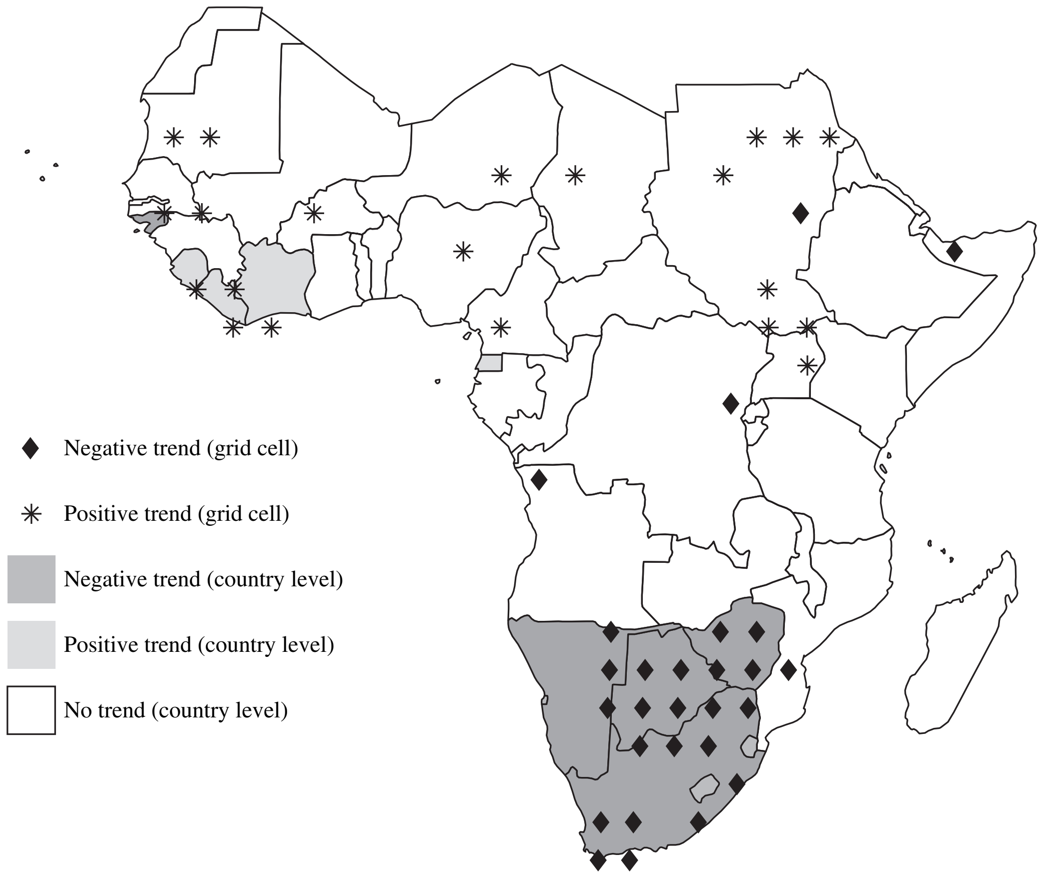

Fig. 4. Effects of spatial aggregation on total annual rainfall estimates, 2000–2099, Scenario A1B.

Our inability to detect widespread significant trends in rainfall triggers does not suggest a future increase in civil conflict in Sub-Saharan Africa resulting from our measure of interannual rainfall variability. Other measures of rainfall variability may increase in the future (Benestad, 2006; Tebaldi et al., 2006), and this is a fertile area for future investigation. Moreover, as the spatial resolution and uncertainties associated with GCMs improve (IPCC, 2007), continued analysis of precipitation models, as well as the impact of scale aggregation, will enhance predictions of socio-political events.

Discussion and conclusions

This article addresses the relationship between climate and the onset of civil conflict from two complementary perspectives. The first is a model of conflict onset in which the variables of interest are measures of (a) trends: land degradation, climate suitability for Eurasian agriculture, and freshwater resources per capita and (b) triggers: interannual variability in rainfall. Our findings suggest that interannual variability in rainfall is a more significant determinant of conflict than our measures of climate, land degradation, and freshwater resources. Admittedly, these results may be biased due to stationarity in the trend measures, a problem addressed critically in section two but which ultimately proves insurmountable in our analysis due to constraints on available data.

The lack of a strong finding regarding GDP growth is interesting in its own right, especially in light of the centrality of economic concerns to our causal argument. We broach two interpretations. The first is that aggregate measures such as GDP tend to be unreliable in highly stratified, primarily rural developing countries (Heston, 1994). However, our finding regarding GDP per capita is strong and robust, indicating that the problem may not be the accuracy of our macroeconomic indicators. The second and more theoretically interesting interpretation is that GDP growth does not accurately capture the opportunity cost to participation in rebellion. While aggregate measures of income inequality have not been found to be significant correlates of conflict in the extant literature, disaggregated studies of drought and its effects on income in Africa suggest that drought has significant, differential impacts on income across economic classes (Reardon, 1997; Reardon & Taylor, 1996). The problem with all of these conjectures, of course, is that good data are hard to find.

The second perspective involves assessing the outlook for the future based on an analysis of simulated changes in precipitation means and variability. We find that while overall levels of precipitation are expected to increase in the next 100 years in western Africa and the Sahel and decrease in southern Africa, interannual variability is not expected to differ significantly from present levels, except for a few locales. This finding is seemingly at odds with the conventional wisdom regarding global warming and the stability of climatic systems, i.e., that variability is projected to increase. There are three possible explanations for our findings. The first is articulated by Hulme et al. (2001): because current generation GCMs do a poor job of replicating El Niño Southern Oscillation variability, simulations of interannual variability in African precipitation are suspect. The second is that we might find significant trends in variability if a baseline further in the past had been used. However, this is doubtful given the work of Hulme et al. (2001) who analyzed GCM data from 1900 to 2100 and found similar results. Third, the lack of greater interannual variability may turn out to be real in our specific measure of rainfall trigger, while other measures of variability (discussed in Results and discussion) may change in the future.

If there are established climatic results affirming the relative stability of Sub-Saharan African climate over the next several decades, why is the region characterized so negatively in the conventional wisdom? We believe this may be due to regional bias. We can locate only one study (Magadza, 1994) that attempts to predict the future likelihood of conflict in Africa related to climate change. Magadza describes an increase in conflict likelihood as a result of widespread drought conditions, a belief that extrapolated the then-current conditions to the future. However, Magadza does not look at any forecasted data. This stands in contrast to the comparatively massive literature regarding the impacts of global warming on future trends in climate in developed countries.

We broach two final observations. First, the neo-Malthusian expectation of a decreasing resource base may miss more theoretically interesting mechanisms leading to conflict in resource-scarce environments. Indeed, if the problem were simply availability of freshwater resources, rather than access, the positive finding regarding the impact of freshwater resources on the likelihood of conflict would be puzzling. Unequal access and ineffective distribution, which are central to explaining poverty in the midst of resource wealth (Sachs & Warner, 2001; de Soysa, 2002) have complex political and economic determinants that merit much closer analysis.

The second point is that the negative effects of interannual variability in rainfall may be mitigated if the relationship of direct dependence of African agriculturalists on rainfall can be broken. Even as rainfall triggers are not projected to increase over time, variability still remains, primarily in the form of rainfall shocks. Our analysis suggests that breaking this relationship of dependence on rain-fed agriculture will have positive effects for mitigating conflict.

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Appendix 1. Variable descriptions

Variable	*N*	Mean	Std. Dev.	Min	Max
A1B precipitation (kg/m^2/s)	347,420	3.5×10^{-5}	5.1×10^{-6}	0	3.6×10^{-4}
A2 precipitation (kg/m^2/s)	348,000	3.5×10^{-5}	4.9×10^{-6}	0	3.6×10^{-4}
B1 precipitation (kg/m^2/s)	348,000	3.6×10^{-5}	5.2×10^{-6}	0	3.1×10^{-4}
Climate scale	881	1.82	0.67	1	3.99
GDP growth	876	−0.38	6.56	−47.39	67.04
GDP per capita (in 1000s 1990 USD)	863	0.999	0.854	0.09	4.5
GPCP annual precipitation (mm/year)	855	1000.49	506.59	96.1	3016.01
Lagged percent change rainfall from previous year	846	0.01	0.21	−0.55	1.68
ln(% Mountainous)	881	1.59	1.43	0	4.42
ln(Population), lagged	881	15.73	1.16	13.24	18.68
Total degradation	881	−0.28	0.26	−1	0
Oil producer	881	0.12	0.32	0	1
One SD negative shock	846	0.17	0.37	0	1
One SD positive shock	846	0.17	0.37	0	1
Ongoing war	704	0.23	0.42	0	1
Onset (F&L)	704	0.03	0.17	0	1
Onset (PRIO/UCDP)	873	0.10	0.30	0	1
Percent change rainfall from previous year	846	0.02	0.21	−0.55	1.68
Two SD negative shock	846	0.02	0.12	0	1
Two SD positive shock	846	0.02	0.13	0	1

Appendix 2. Coding precipitation data

The GPCP data has a resolution of 2.5° by 2.5°. The NCAR-PCM climate model simulates values for temperature and precipitation at a resolution of 2.8° by 2.8°. At these resolutions, each data node references a land area of 77,000 and 96,000 km^2. While these resolutions are among the best returned by the GCMs distributed by the IPCC, many data nodes fall on or near national borders, meaning that coding mechanisms that assign data nodes to countries based on the location of the exact point of intersection will bias estimates.

In order to correct this bias, we divide each grid cell into four quadrants with the data node in the center. Each quadrant is then assigned to the particular country on the basis of majority: if a majority of the territory described by a quadrant fell within given national boundaries, that quadrant was assigned to the particular country even if the node fell across the border. This coding was done by hand using high-resolution maps generated in Matlab 7.0. When calculating annual precipitation based on averages across nodes, the value for each node is weighted according to the proportion of the national territory it describes. This coding method was also used to update the observed GPCP data.

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