Trends and Triggers: Climate, Climate Change and Civil Conflict in Sub-Saharan Africa

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Trends and Triggers: Climate Change and Civil Conflict in Sub-Saharan Africa

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ABSTRACT:

The conventional discourse relating climate change to human security focuses on long-term trends in temperature and precipitation that define ecosystems and their subsequent impact on access to renewable natural resources. Because these changes occur over long time periods, however, existing operationalizations of resource scarcity, such as measures of land degradation and desertification, are mostly stationary, and as such perform poorly in capturing the proximate factors that may "trigger" conflict. We argue that this conventional discourse may overlook one of the key findings emanating from the global climate models on which these predictions are based: increased variance around mean temperatures and precipitation.

We approach this question from two perspectives. First, we estimate the impact of both long-term trends in climate (operationalized as climate zones and land degradation) and short-term climatic variance (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. More temperate, fertile climates are associated with a decreased likelihood of conflict. Moreover, negative changes in rainfall are associated with an increased likelihood of conflict in the following year. However, an analysis of marginal effects leads us to conclude that interannual variability matters more than the specter of changes in overall means and climate, which take place over long periods of time. Second, we assess the outlook for the future based on our analysis of predicted changes in precipitation means and variance generated by NCAR-PCM3, a coupled global circulation model (CGCM) of precipitation over the period 1980-2059. We find that future total annual precipitation shows a positive linear trend, whereas no statistically significant trend is found in intra-annual or interannual variance, suggesting that monsoon patterns in Africa are unlikely to be affected by expected changes in climate. This leads us to conclude that strategies for managing risks to human security must focus on breaking the direct dependence of subsistence agriculturalists on rainfall as a source of crop water, even as the variability of access to this resource is not predicted to increase in the future.

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1. Introduction

As the predominant form of political violence today, civil wars occupy a position of infamy in the hierarchy of threats to human security. Civil wars kill, maim and displace human beings of all ages, cause emigration across and within borders, increase exposure to disease, and send poverty spiraling—all well documented threats to human security (Commission on Human Security 2003). Though directing their comments primarily to its economic effects, the World Bank working group on civil conflict could just as easily have been referring to the human costs when they described civil war as “development in reverse” (Elliott *et al.* 2003).

More recently, the notion of human security has been expanded to include threats emanating from a changing global environment. The independent Commission on Human Security identifies three broad sources of threats: consumption of fossil fuels and increased pollution in urban environments, land degradation due to overuse, erosion, and desertification, and finally the buildup of greenhouse gases that “threaten widespread climate change” (Commission on Human Security 2003, 17). However, the specific nature of the threats that might attend climate change is left unmentioned.

This oversight is curious, as there is a small but influential conflict literature that has sought to establish links between environmental scarcity and conflict, with a particular emphasis on renewable resources such as fresh water and arable land (Homer-Dixon 1994, 1999; Hauge and Ellingsen 1998, de Soysa 2002). This literature is essentially concerned with the neo-Malthusian notion of a monotonically dwindling resource pool. As natural resources become increasingly degraded due to overexploitation and global warming, it is argued, rising human populations will be forced to migrate internally or cross borders and distributional conflicts will arise as populations compete for pieces of an ever-dwindling pie. Thus conflict is perceived as the outcome of long-term, linear climatic changes in global mean temperature that will lead inexorably to less a less plentiful resource base in the future.

An alternate perspective, based on another central finding emanating from the climate change literature, is that increasing variability of climate around changing global means may lead to conflict. The consequences of this increased variance are several: a decline in the predictability of natural systems, instability, and increased incidence of extreme events such as tropical storms (IPCC 2001). More to the point, this increased variance may predict also increased interannual variation in precipitation, a factor that has been demonstrated to affect the onset of conflict (Miguel, Satyanath and Sergenti 2004). 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 for sustenance.

We approach this literature from two complementary perspectives. The first approach is to argue that the effects of climate change on the onset of conflict must be conceived of in terms of 1) long term trends that lead to a higher baseline probability of conflict in a state, and 2) short term “triggers” that affect the interannual variation in that probability. We then test whether changes in climate means and interannual variability affect the onset of conflict. We estimate the impact of both long-term trends (operationalized as climate suitability for agriculture and land degradation) and short-term climatic variance (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 endogenous indicators typical of the conflict literature. More temperate, fertile climates are associated with a decreased likelihood of conflict. Moreover, interannual changes in rainfall are negatively associated with an increased likelihood of conflict in the following year; that is, as precipitation rises relative to the previous year’s value, conflict becomes less likely. An analysis of marginal effects leads us to conclude that interannual variability matters more than the specter of changes in overall means and climate, which takes place over long periods of time.

The second approach involves assessing the outlook for the future based on our own analysis of predicted changes in precipitation means and variance generated by NCAR-PCM3, a coupled global circulation model (CGCM), and a critical review of the significant findings of the downscaled literature on climate change in Africa. Analyzing predicted values for precipitation over the period 1980-2059, we find that total annual precipitation shows a positive linear trend, whereas no statistically significant trend is found in either intra- or interannual variances, suggesting that monsoon patterns in Africa are unlikely to be affected by expected changes in climate.

These findings point to two conclusions. The first is that the future for Africa is not necessarily one defined by increasingly erratic rainfall, constant drought, and reduced food security. While we acknowledge that gains in this respect may be offset by loss of fertile lands due to rising sea levels, without sounding too pollyannaish, our analysis indicates that with respect to rainfall, the future is not so dark for Africa. The second regards policy. One clear implication of our analysis is that conflict may be mediated by reducing the dependence of subsistence agriculturalists on rainwater for agriculture, even as variability is not predicted to increase over time. Clearly, this is a task few governments in Sub-Saharan Africa, most of which are deeply in debt, will be able to accomplish without assistance.

The paper proceeds as follows. Section two presents a review of recent attempts to link environmental change and conflict and some issues that surround using existing models of conflict for predictive purposes. Section three develops the argument that increases in interannual rainfall variability may be more significant in triggering conflict than more long-term processes of desertification and land degradation, and derives an empirical model for testing these competing hypotheses. Section four summarizes our choices of instruments and tests the model. Section five extends our discussion into the future, assessing predictions derived from the NCAR-PCM3 CGCM. Section six concludes with a summary of significant findings, suggestions for future extensions and modifications to the model, and a discussion of the limits of using exogenous factors to explain political phenomena.

2. Literature Review

2.1. Resource Scarcity and Conflict: An Overview

The conventional discourse relating climate change to human security focuses on long-term change to the climatic means that define ecosystems and their subsequent impact on access to renewable natural resources. The eight atmospheric-oceanic global climate models that form the core findings of the Intergovernmental Panel on Climate Change predict increases in mean global temperature between 1.4 and 5.8 degrees Celsius over the next seventy years (IPCC 2001). As mean temperatures rise, the models predict also increased incidents of droughts, desertification and severe precipitation events (i.e. hurricanes and typhoons).

This discourse has its roots in neo-Malthusian notions of carrying capacity. Neo-Malthusians believe 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 and Ehrlich 1990; Homer-Dixon 1999). Moreover, the promise of technical innovation as a solution to these problems (Simon 1981) is unlikely to be realized due to lower stocks of human capital and therefore latent innovative capacity (Boserup 1965), which ultimately produces an ingenuity gap between technologically innovative and stagnant societies that exacerbates existing asymmetries of access to resources (Homer-Dixon 2000).

This perspective, embodied in the work of Goldstone[1] (1991) and Homer-Dixon and his students, has been criticized on both theoretical and empirical grounds (Gleditsch 1998, de Soysa 2002). Gleditsch has argued that the causal mechanisms are too elaborate (operating through multiple paths of causality and several layers of intervening variables) and fail to take account for the effects of differing levels of economic and political development on resource consumption and conflict—that is, highly developed economies and polities may experience lessened instances of conflict over resources even as their demand for them increases. Moreover, de Soysa (2002) rightly notes that Homer-Dixon's research design looks only at instances of resource conflict, selecting on the dependent variable and therefore likely overestimating the centrality of environmental degradation to conflict.

Even assuming the conventional causal mechanisms are valid, neo-Malthusian analysis does not provide traction on identifying short-term causes that "trigger" the outbreak of conflict. Neo-Malthusian analysis predicts conflict over access to resources, but the causal mechanisms are so complex and environmental changes so gradual that determining theoretical or empirical thresholds that, once crossed, trigger violence is extremely difficult. Hauge and Ellingsen (1998) attempted the first large *N* test of the various causal mechanisms emanating from the neo-Malthusian school. Hauge and Ellingsen concluded that countries experiencing various types of environmental degradation, including deforestation and land degradation, are more likely to experience internal and external conflict, although their model is not one of conflict onset. However, their coding of these variables is impressionistic, based on somewhat arbitrary cutpoints for collapsing continuous variables into dichotomous variables, and all environmental measures are stationary.

De Soysa (2002) tests similar hypotheses against an alternate yet still static operationalization of natural resource wealth and finds that resource-rich areas are less likely to experience conflict, suggesting that a paucity of resources leads to greater resource strain and an increased likelihood of conflicts. However, de Soysa finds also that resource wealth is associated with lower rates of economic development, which predicts higher incidence of conflict. Therefore, the impact of resource abundance on conflict is complicated, exerting both direct and indirect effects.

Finally, an alternate perspective linking resource scarcity to conflict is that offered by Miguel, Satyanath and Sergenti (2004). They estimate the effect of economic shocks on the likelihood of civil conflict in Sub-Saharan Africa. Because the region is largely agrarian and irrigation is not widely practiced, the authors contend that rainfall is a plausible instrument for economic growth. Using data on rainfall variation, they find that increased rainfall has a strong positive impact on income growth and a negative impact on the likelihood of conflict, mediated largely by its effect on economic growth.

2.2. Conflict Models: Some Issues in Predicting Rare Events

Global models of civil conflict onset have performed notoriously poorly at prediction. Ward and Bakke (2005) undertake a reanalysis of three state of the art models (Fearon and Laitin 2003, Collier and Hoeffler 2004, King and Zeng's (2001) reanalysis of the State Failure Project's (2000) data) and find that, using the standard cut point of 0.5 regarding predicted probabilities, only the State Failure model has any real predictive power, correctly predicting about a third (37 of 114) of state failures within the population. The Fearon and Laitin and Collier and Hoeffler models returned zero and three correct predictions respectively

Ward and Bakke explain the lack of predictive performance as a result of two flaws in research design. The first is a general emphasis on statistical significance and hypothesis testing, rather than prediction, as the decision rule for including independent variables in flagship specifications. Second, they argue that estimating models based on the universe of cases, rather than samples, encourages over fitting of the data that reduces predictive power.

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[1] To be fair, Goldstone's argument focuses more on institutionally determined asymmetries of access. However, the engine of causality in his model is unprecedented population growth.

To the reasons cited by Ward and Bakke, we add three: a reliance on stationary variables, a global rather than regional emphasis, and finally a reliance on endogenous variables. First, these models utilize variables that do not, in many instances, vary. This criticism is especially applicable to the Fearon and Laitin model. Fearon and Laitin conclude that GDP *per capita* and rough terrain (operationalized as the percentage of mountainous terrain in a country) are the most robust predictors of conflict onset. Yet these two variables are virtually perfectly autocorrelated, with first-order autocorrelations of 0.9969 and 1, respectively (the mountainous terrain variable being based on a single observation[2]). Given that Indonesia, the country with the most onsets in their sample, is still modally non-eventful (fifty negative observations versus six positive (onset) observations), it is clear that models reliant on stationary variables are likely to perform poorly in this role.

Second, the global perspective of the models may hinder predictive power. Table one presents observed and predicted baseline probabilities of conflict onset by region as generated by the Fearon and Laitin model. Clearly, the model performs best with respect to Asia but less well with respect to North Africa and the Middle East, Sub-Saharan Africa and Latin America. Because of the centrality of economic development to the model, their analysis drastically under-predicts the incidence of conflict in the most economically developed "region": the Western, industrialized democracies and Japan. While global theoretical models may achieve the most desirable balance between parsimony and inclusiveness, they do not deal well with the possibility that conflicts in more homogeneous subsets of states (in our case, Sub-Saharan Africa, which is predominately poor, ethnically fractionalized, and authoritarian) may operate according to distinct political and economic logics. Moreover, as Miguel, Satyanath and Sergenti (2004) have noted, a regional focus may facilitate the use of econometric identification strategies that would be inapplicable in other circumstances.

Table One: Observed versus Predicted Rates of Onset by Region (Fearon and Laitin 2003)

Region	*N*	Rate of Onset	Baseline Predicted Rate of Onset	Percent Difference
Asia	1096	0.03011	0.0304	0.96%
Eastern Europe and former USSR	646	0.02012	0.01713	-14.86%
Latin America and Caribbean	1210	0.0124	0.01341	8.15%
North Africa and Middle East	910	0.01868	0.01511	-19.11%
Sub-Saharan Africa	1593	0.02134	0.01983	-7.08%
Western Democracies and Japan	1155	0.00173	0.00466	-169.36%
Totals	6610	0.01724	0.01675	-2.84%

Finally, these studies tend to rely on endogenous variables, specifically economic development (Fearon and Laitin 2003, Collier and Hoeffler 2004, Hegre and Sambanis 2004), natural resource dependence (Sørli 2002, Fearon and Laitin 2003, Humphreys 2003, de Soysa 2002, Humphreys 2003, Lujala, Gleditsch and Gilmore 2003, Snyder and Bhavnani 2003, Collier and Hoeffler 2004) and strength of political institutions (Ellingsen and Gleditsch 1997, Hegre *et al.* 2001, Fearon and Laitin 2003, Smith 2004) as predictors of onset. Typically, researchers use lagged values of endogenous variables in order to address the potential for reverse causality. However, this methodology has been criticized on at least two fronts. The first is that this approach assumes that actors do not anticipate the onset of conflict and adjust their behavior (Miguel, Satyanath and Sergenti 2004). This problem is

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[2] Four of the eleven variables in Fearon and Laitin's model do not vary (mountainous terrain, noncontiguous territory, ethnolinguistic and religious fractionalization). Five others (GDP *per capita*, oil dependence, POLITY2 score, and the dummy variable *anocracy*) are autocorrelated at r=.85 or higher.

likely to be significant since the effect of coding conflict onsets according to battle deaths may cause us to overlook the effects of lower intensity conflicts on these indicators.[3]

The second is that these indicators are not only potentially endogenous to conflict, but to other explanatory variables as well. Setting aside the various and well-documented problems of endogeneity that arise from the interplay of political institutions, patterns of economic development and resource dependence (see Sachs and Warner 2001, Acemoglu, Johnson and Robinson 2001, Rodrik, Subramanian and Trebbi 2004), Hendrix has found these variables to be endogenous to other exogenous explanatory variables, specifically various measures of rough terrain and ecology (Hendrix 2005). For these reasons (and the obvious—our inability to accurately forecast patterns of democratization, economic development and the like into the future), our identification strategy will focus primarily on exogenous explanatory variables.

Thus framed, we must address two open questions in the literature. The first regards what we have been calling neo-Malthusianism and the tendency to assume a) that resources are indeed dwindling, and b) that dwindling renewable resources will lead inexorably to conflict. The second is how to begin to use temporally variant yet exogenous explanatory variables in order to model the mechanisms that may trigger the onset of conflict in already conflict prone states. The next section addresses these mechanisms in greater detail.

3. The Argument and Hypotheses

3.1. Trends, Triggers and Opportunity Costs

Much of the economic literature on civil war explains participation in rebellion as the result of rational cost-benefit analysis. This logic has its intellectual roots in the work of Becker (1968) and Isaac Ehrlich (1973), who were among the first to argue that the propensity to commit crime (in this case, the crime of rebellion) is a function of the payoffs and punishments associated with criminal activity. Much of this literature focuses on the potential 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. This would appear to be the implicit position of Fearon and Laitin (2003), who argue 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 therefore less prone to conflict because potential rebels expect the likelihood of apprehension by state forces to be high.

A second branch of this literature focuses on indirect costs: the opportunity cost to wages in the legal economy. Collier and Hoeffler (2002) contend that the purported gap between the expected returns from joining the rebels relative to those from conventional economic activity is what drives the empirical relationship between low income and the onset of civil war. Miguel, Satyanath and Sergenti (2004) interpret their findings regarding rainfall and conflict in precisely these terms. A particularly good year of rain increases the expected returns to participation in farming. Conversely, as agricultural productivity declines due to drought or diminished rainfall, the opportunity cost to violence diminishes. Thus, negative economic shocks, in the form of negative changes in rainfall relative to the previous year, are associated with a higher incidence of conflict.

This interpretation is a common one in studies of criminal activity. Gould, Weinberg and Mustard (2002) find that criminal activity, particularly crimes against property, increases as the wages of

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[3] One well known example of this problem is evident in coding the Cuban Revolution, which is coded in the COW dataset as having begun in 1958 (1957 according to the PRIO/UCDP), even though Castro had been organizing his 82-man fighting force in Mexico since 1955 and the first battle of conflict (the landing at Playa Las Coloradas on December 2) occurred in 1956. An even more egregious example is that of the Nicaraguan Revolution, coded in both datasets as having begun in 1978 even though the primary rebel group, the FSLN, had been constituted in 1961.

unskilled laborers decline. More to the present point regarding violence in primarily agrarian societies, Mehlum, Miguel and Torvik (2004) estimate the effect of rainfall on rye prices in 19th century Bavaria and find that higher rye prices, the most common staple grain of the time, were associated with higher incidence of property crimes. The link here is more complex: rising food prices reduced real wages (as food purchases ate up a larger and larger share of wages), thereby diminishing opportunity costs to criminality.

Viewed from this perspective, we can generate hypotheses regarding the effects of land degradation and deteriorating climatic conditions. Land degradation refers to a human-induced process that negatively affects its productivity. If productivity is defined as the expected benefit per unit of effort, then it is clear that we should 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 also have been demonstrated to affect agricultural productivity. Gallup, Sachs and Mellinger (1999) have estimated that tropical agriculture suffers from a productivity gap of up to 50 percent compared with agriculture in more temperate zones. They argue that the mechanism linking tropical climates to lower agricultural productivity are the unsuitability of tropical soil to large-scale agriculture and the increased burden of disease on humans and plant species. The impacts, of course, are differential according to the type of tropical climate. While tropical deserts do not suffer from these problems of disease, average annual rainfall tends to be below the widely accepted lower limit of 500 millimeters/year for sustaining rain-fed agriculture. Based on this discussion, we expect climates more hostile to agriculture to be associated with lower returns to agriculture and therefore a higher likelihood of conflict, *ceterus paribus*.

The main problems with these interpretations are two-fold. First, the preceding argument suggests that expectations regarding returns to effort in the legal economy and returns to violence are not endogenous to expectations regarding the productivity of natural resources. In the vast majority of cases where “lootable” resources such as alluvial diamond deposits are not in play, whether the returns to violence are significant enough to offset the very real likelihood of dying or being apprehended by state forces is at best an open question. The simple fact that many of the rebel combatants in African civil wars have been kidnapped child soldiers calls into question the idea that modeling the decision to join the rebel army as a purely economic one.

Second, this argument ignores 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. The nature of this adaptation has been overwhelmingly technological relative to minor physical differences that have evolved. Conflict may be one possible outcome of increased resource scarcity, but it is scarcely the only conceivable outcome. Societies with more democratic political institutions may respond differently to shortages. Sen (1987, 1999) has argued that large-scale famines do not occur in democratic societies with free presses because the office-seeking behavior of elites will require them to affect changes in the distribution of resources in response to widespread hunger. Moreover, the adoption of new agricultural technology and income diversification through participation in the wage-based economy and internal migration are two obvious ways in which Sub-Saharan African agriculturalists have met the potential problems of long-term land degradation and climate change (Reardon and Taylor 1996).

The putative problems associated with long-term changes in land quality and environment are present also in responding to interannual variability in climate. However, the difference with short-term variation is that changes in income occur on a much shorter time scale. Also, the potential investment of effort in non-agricultural activity must be weighed against expected returns to agriculture in the future. Household studies of income diversification in Sub-Saharan Africa suggest that short-term variation (operationalized as droughts) present 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 potential sources of income. These individuals are typically young men with low levels of social status, or, as was said of the Sierra Leonean rebels, "semi-literate village school drop-outs"—those most likely to take up arms (Bangura, quoted in Miguel, Satyanath and Sergenti 2004).

This discussion suggests that a better identification strategy might focus on short-term changes. One well-documented source of interannual variation is rainfall. Miguel, Satyanath and Sergenti argue that rainfall is a reasonable proxy for economic growth in the primarily agricultural economies of Sub-Saharan Africa. If this is the case, we would expect that higher levels of rainfall would be associated with higher returns to agriculture, *ceterus paribus*.[4]

3.2. Hypotheses

H_1*: Measures of climate-induced land degradation should be positively associated with the risk of civil war onset.*
H_2*: Measures of agriculturally induced land degradation should be positively associated with the risk of civil war onset.*
H_3*: Contemporaneous measures of rainfall abundance should be negatively associated with higher risks of civil war onset.*
H_4*: Lagged measures of rainfall abundance should be negatively associated with higher risks of civil war onset.*

In addition to these hypotheses, we are interested in investigating whether the hypothesized effects of changes in rainfall are amplified by existing resource scarcity. Returning to the opportunity cost analogy, if expected wages are already low and labor market mobility is low as well, negative changes in rainfall should affect those operating in already marginal lands or hostile climates to a greater extent.

H_5*: The interaction of total rainfall and land degradation should be negatively associated with higher risks of civil war onset.*

4. Data, Estimation and Results

4.1. The Dependent Variable: Civil Conflict Onset

The main dependent variable is the onset of civil war in Sub-Saharan Africa, 1981-1999. Two codings of this variable will be used: that used by Fearon and Laitin (2003), and that developed by the PRIO/Uppsala Conflict Data Project (Gledistch *et al.* 2002) . Fearon and Laitin define insurgency as:

1. The presence of groups who seek either to take control of a government, take power in a region, or use violence to bring about a change in government policies.
2. A conflict that killed or has killed at least 1000 over its course, with a yearly average of at least 100.
3. At least 100 of the dead are on the side of the government (including civilians attacked by rebels).

PRIO/UCDP defines conflict as a violent incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state, results in at least 25 battle-related deaths. In both cases, the variable is coded as 1 for the year of onset only and 0 for all years thereafter. Largely due to the lower casualty threshold, PRIO/UCDP includes many more conflicts, with onsets representing 2.9 percent of observations in Fearon and Laitin's data, but 9.3 percent using the PRIO/UCDP coding. Both operationalizations will be used in order to check the robustness of the model, and to investigate whether more and less deadly conflicts operate according to separate causal logics.

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[4] Of course, this relationship cannot be entirely linear; too much rainfall may cause flooding and massive soil erosion. This subject will be covered at greater length in section five.

4.2. The Independent Variables: Trends and Triggers

Trends

The primary operationalizations of what we have termed trends are measures of land degradation and overall ecological suitability for sustaining agriculture. Land degradation is defined as the temporary or permanent reduction in the productive capacity of land as a result of human action (Bot, Nachtergaele and Young 2000). The aggregate measure of land degradation, percent of total area degraded, can be broken down according to land degradation due to deforestation, overgrazing, overexploitation of vegetation and industrial activities (what we will call non-agricultural degradation), and improper agricultural management (what we will call agricultural degradation). The mean value for non-agricultural degradation is 17 percent, with a standard deviation of 20.26, bounded on the lower end by South Africa, the Sudan, Mauritania, C'ote D'Ivoire, Zimbabwe, Zambia and Guinea (all with no non-agricultural degradation) and Kenya on the higher end (100 percent degraded). The mean value for agricultural degradation is 10.89 percent but highly skewed, with half the countries showing no degradation due to agriculture and two countries, Burundi and Nigeria, with 65 and 75 percent degradation, respectively. Unfortunately, these values are static within countries. The data is available from the Food and Agricultural Organization (FAO) Terrastat website[5]; for a more detailed discussion of variable construction, see Bot, Nachtergaele and Young (2000).

In order to capture the effects of long-run ecological change, we include an instrument for how favorable conditions are to agriculture. The variable, *climate scale*, was developed by Hibbs and Olsson (2004) and is measured on a four point scale, ordered in ascending value: 1 for dry tropical (desert), 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 well-known Köppen-Geiger climate system, which classifies climate according to average annual precipitation and temperature. The scale is calculated by summing these values weighted by proportion of national territory falling within these categories. The mean value for all countries in the sample 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 mountain kingdom of Lesotho (3.989). It bears mentioning that 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 having a climate 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 human behavior.

Triggers

Miguel, Satyanath and Sergenti (2004) coded the data from the Global Precipitation Climatology Project (GPCP) database of annual rainfall estimates. This data is available at a resolution of 2.5 by 2.5 degrees and covers the time period 1979 to 1999. Their method of coding nodes as "belonging" to a country is whether the exact node fell within national borders, and as such lacks some of the precision of our alternate coding (see Appendix 1).

Our preferred operationalization of environmental trigger is the percent change in annual rainfall in country *i* in year *t* from the year previous, by country. This measure is attractive because it effectively controls for cross-country variation in average levels of rainfall and operationalizes interannual variability, a measurement calcuated to increase with future increases in atmospheric levels of greenhouse gases. We generate also dummy variables to identify changes that were greater than one and two standard deviations from the mean, both positive (increases in rainfall) and negative (decreases in rainfall).

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[5] Terrastat can be accessed at http://www.fao.org/ag/ti/agll/terrastat/.

4.3. Control Variables

Most of the control variables used here (GDP *per capita*, oil producer, percentage of mountainous terrain, and whether or not an ongoing the country was experiencing an ongoing civil war) are taken from the Fearon and Laitin (2003) dataset on civil conflict. Various other control variables (GDP growth, rural population density, percentage of rural population) are taken from the World Development Indicators 2004 CD-ROM. Finally, data on average caloric intake *per capita* (to be discussed later) was taken from the FAO online database. Descriptive statistics for all variables used in this paper can be found in Appendix 2.

4.4. Estimation and Results

Table two reports logistic regressions of conflict on resource scarcity, alternately specified in terms of long-term trends and short-term triggers. The regressions follow the general functional form

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

where Pr(Onset) is the probability of conflict onset in country i, year t, X_{it} is the percent change in precipitation relative to the previous year (either current or lagged), Y_i is the measure of land degradation and/or ecological suitability in country i, Z_{it} is a matrix of control variables, and ε_{it} is an error term. The primary coefficients of interest will be b and c, the effect of short-term climatic triggers and long-term climatic trends on conflict onset. Because we expect that observations may not be independent within countries, we use Huber-White robust standard errors adjusted for clustering on countries.

Table Two: Logit Models of Climate Change and Civil Conflict Onset in Sub-Saharan Africa, 1981-1999

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dependent Variable	F&L coding	UCDP coding	F&L coding	UCDP coding	F&L coding	UCDP coding
Explanatory Variable						
%Δ Rainfall	-0.001	0	-0.001	0		
	0.002	0.001	0.002	0.001		
%Δ Rainfall $_{t-1}$	-2.791*	-1.529**	-2.663*	-1.495**	-2.439*	-1.478**
	1.458	0.756	1.433	0.751	1.344	0.721
Agric. Degradation	-0.006	0.012	-0.001	-0.001	-0.003	-0.004
	0.013	0.008	0.013	0.007	0.014	0.007
Non-Agric. Degradation	-0.002	0.014**	-0.001	0.01	-0.003	0.007
	0.01	0.007	0.011	0.006	0.01	0.006
Climate Scale	-0.644	-0.17	-0.441	-0.493**	-0.722	-0.6828***
	0.419	0.253	0.391	0.233	0.454	0.264
Ongoing Conflict$_{t-1}$	-1.01	1.8898**				
	0.652	0.314				
GDP *per capita* $_{t-1}$	-0.421	-0.246	-0.325	-0.469*	-0.433	-0.492
	0.454	0.214	0.41	0.241	0.534	0.31
GDP growth $_{t-1}$	-0.034	-0.01	-0.022	-0.029*	-0.012	-0.023
	0.031	0.016	0.028	0.017	0.028	0.017
log(Population) $_{t-1}$	0.011	-0.163	0.003	-0.085	0.104	0.011
	0.247	0.144	0.241	0.141	0.26	0.151
ln(% Mountainous)	0.294*	0.031	0.209	0.209**	0.209	0.165
	0.175	0.108	0.168	0.098	0.235	0.131
Oil Producer	0.472	1.065**	0.286	1.257***	0.208	1.3348***
	0.924	0.418	0.863	0.429	0.934	0.472
Rural Pop. Density					0.002	-0.003
					0.001	0.018
Percent Pop. Rural					-0.019	0.002***
					0.032	0.001
Constant	-2.335	-1.506	-2.845	-0.754		
	2.535	1.436	2.451	1.425		
N	704	704	704	704	694	694
Brier Score	0.0284	0.0798	0.0285	0.087	0.0288	0.0848

* Significant at p<.1, ** Significant at p<.05, *** Significant at p<.001

Huber-White robust standard errors below coefficient estimates.

Models 1 and 2 include all our hypothesized variables of interest plus controls for level of economic development (GDP *per capita*), economic growth (GDP growth), population, whether the country was an oil producer, the logged percentage of mountainous terrain, and finally whether the country was already experiencing another, ongoing civil conflict. All of the time-variant indicators were lagged in order to (partially) address issues of endogeneity, with the obvious caveat regarding threshold effects having been addressed in the literature review. These controls were selected for their prominence in the literature and usual robustness to changes in model specification (see Hegre and Sambanis 2004). Models 3 and 4 are identical, save for the exclusion of the lagged ongoing war variable.

Models 5 and 6 represent an alternate perspective on the factors that might mitigate or increase the baseline likelihood of conflict. The new variables, percentage of rural population and rural population density, operationalize two potential circumstances. The first is that primarily rural populations will be more susceptible to changes in rainfall and climate, as a larger share of the national population's income is dependent on agricultural productivity. Alternately, the measure for rural population density operationalizes the potential degree of resource scarcity emanating from more intense use of existing lands. While the coefficient on rural population density is not significant, the percentage of rural population was significant and in the hypothesized direction. Interaction terms (these measures interacted with our percent change in rainfall measure), however, were not significant.

At first glance it is clear that our identification strategy is much better suited to explaining the onset of smaller scale conflicts (the PRIO/UCDP coding) than more deadly ones. Aside from our lagged measure of percent change in rainfall relative to the previous year, only the lagged percentage of mountainous terrain ever achieved significance, and only in the first model, with respect to the Fearon and Laitin coding.

The evidence regarding the effects of long-term patterns of land degradation and climate was not robust. Neither measure of land degradation was consistently significant, nor was the sign consistently in the hypothesized direction. Our measure of climate, *climate scale*, was highly significant in specifications four and six, with the sign always in the hypothesized direction. Regarding the hypothesized short-term, trigger mechanism, the lagged percent change in rainfall relative to the previous year was significant and in the hypothesized direction in all specifications. This is consistent with the findings of Miguel, Satyanath and Sergenti (2004). However, the contemporaneous measure of percent change in rainfall relative to the previous year was not remotely significant under any specification. Moreover, none of our dummy codings for positive or negative changes one or two standard deviations from the mean variance were significant in any of the codings, suggesting that the finding regarding precipitation is truly linear. Taken together, this lends a good deal of support to hypothesis four.

None of the interaction terms between lagged percent change in rainfall and our trend measures, climate scale and the two measures of degradation, approached significance in any of the specifications (regression results not reported). Therefore, our hypothesis regarding the potential for magnified effects of changes in rainfall in countries characterized by degradation or ecological hostility to agriculture was not substantiated.

In order to demonstrate the marginal effects of changes in our variables of interest, we present the counterfactuals regarding Senegal in 1997 in table three. The baseline model predicts the probability of conflict onset for that country year at 0.0826, which is in the 50th percentile for all predicted probabilities of onsets. Using CLARIFY, developed by King, Tomz and Wittenberg (2001), we estimate that a one standard deviation negative change in percent change in rainfall from the previous year increases the likelihood of onset by 33.78 percent. On the other hand, a one standard deviation positive change in the climate scale variable decreases the likelihood of onset by 24.45 percent. Looking at concurrent changes in both variables, a one standard deviation increase in lagged rainfall coupled with a one standard deviation increase in our measure of suitableness of land for large-scale agriculture predicts a decline in the probability of onset of almost 50 percent.

Table Three: Presenting the Counterfactual

Pr(Onset) in Senegal 1997

	Actual Value	-1 SD %Δ Rainfall $_{t-1}$	+1 SD Climate Scale	+1 SD Climate Scale & %Δ Rainfall $_{t-1}$
%Δ Rainfall	-.0548	-.0548	-.0548	-.0548
%Δ Rainfall $_{t-1}$	-.0108	-19.67	-.0108	.1972
Agric. Degradation	0	0	0	0
Non-Agric. Degradation	39	39	39	39
Climate Scale	1.273	1.273	1.957	1.957
GDP *per capita* $_{t-1}$	1117	1117	1117	1117
GDP growth $_{t-1}$	5.141	5.141	5.141	5.141
log(Population) $_{t-1}$	9.054	9.054	9.054	9.054
ln(% Mountainous)	0	0	0	0
Oil Producer	0	0	0	0
Predicted Probability	.0826	.1105	.0624	.047
Percent Change from Pr(Onset)SGL 1997	0	+33.78	-24.45	-43.1

In sum, the most significant results of our retrospective analysis are three-fold: first, the lagged percent change in rainfall is significant with the expected sign in all specifications, and was robust to a variety of other specifications not reported. Second, it appears that measures of contemporaneous climate and climate change do not explain the onset of larger conflicts. This is evidenced by the lower level of statistical significance attained by the lagged percent change in rainfall variable and the failure to attain significance of the various operationalizations of climatic trends. Indeed, none of the control variables were significant in any of the models when applied to the Fearon and Laitin coding.

Finally, the results from our models suggest that the marginal effects of interannual variability in rainfall are much greater than the marginal of changes in climate. This point is drawn into relief if we remember the time periods over which climate change is expected to take place, a topic we address further in the next section. Given that no model of climate change predicts anything nearing a one standard deviation change in the suitability of climate for large-scale agriculture on a year-to-year basis, we are less confident making predictions about the marginal impact of climate without turning to its effects on other determinants of economic development and political consolidation, a topic that is beyond the scope of this paper (see Hendrix 2005).

5. Looking to the Future

Thus far, we have demonstrated that short-term variability in precipitation (to a greater extent) and long-term trends in the suitability of climate for agriculture (to a lesser extent) affect the onset of civil conflict. This model was generated using data from a time period, 1981-1999, during which much of Africa experienced significant droughts, especially in the Sahel region (Nicholson 1993). We now turn to a preliminary analysis of model-predicted changes in Sub-Saharan African climate in order to make inferences regarding expected future onsets of civil conflict.

5.1 Background

The increasing use and validation of coupled ocean-atmosphere global circulation models (CGCMs) has significantly improved understanding of global climate and facilitated predictions of climate change decades into the future. The Intergovernmental Panel on Climate Change (IPCC) recommends and makes available[6] data from seven CGCMs produced by various research institutions from around the world. CGCMs are highly complicated thermodynamic mass balance models that use both physical first principles and statistical relationships to describe oceanic and atmospheric interactions, known climate patterns, and global teleconnections. Models promoted by the IPCC (as well as the majority of others) are forced by increases in atmospheric levels of greenhouse gases; primarily, an increase in CO_2 of 1% per year resulting in a doubling of atmospheric CO_2 concentrations by 2070, is standard (Washington *et al.* 2001, IPCC 2001).

CGCMs describe and predict changes in many climatic parameters such as surface air temperature, sea surface temperature, precipitation, cloud cover, terrestrial hydrological parameters such as streamflow and runoff, and ice cover. While results vary between models, all seven IPCC models predict an increase in globally averaged surface air temperature of between 1.4 and 5.8 ºC accompanied by an increase in the total global precipitation through the 21st century (IPCC 2001). In addition to the IPCC Third Assessment Report (IPCC 2001), many independent comparisons of CGCM results and validations between CGCM data and observed climate data demonstrate these same patterns (e.g., Rowell 1998, Gonzalez-Rouco *et al.* 2000, Douville *et al.* 2002, Landman and Goddard 2002, Srinivasan 2003, Bartman *et al.* 2003).

An important result from these models is the impact of increasing greenhouse gas concentrations on climatic variability (Washington *et al.* 2000). Climate change will be manifest in the global

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[6] See the IPCC Data Distribution Center online at http://ipcc-ddc.cru.uea.ac.uk/

hydrological cycle as changes in intensity and frequency of precipitation events (Gonzalez-Rouco *et al.* 2000). While absolute changes in the magnitude of climate variables are themselves key findings of these models (e.g., rises in sea level as a consequence of ice cover melt), concurrent increases in variability of climate factors are also of great importance. Increased interannual variability in temperature and precipitation on a global scale may result in increased extreme events such as flooding, drought, or storm activity (Rowell 1998, IPCC 2001).

Generally, CGCMs predict an intensification of the global hydrological cycle resulting from an increase in atmospheric water vapor and greater equatorial convection (Rowell 1998, Washington *et al.*2000, Gonzalez-Rouco *et al.* 2000, Douville *et al.* 2002, Landman and Goddard 2002, Srinivasan 2003, Bartman *et al.* 2003). Increased precipitation in wintertime is predicted for mid- and high latitudes. Results are more variable in summertime: precipitation increases in some regions while decreasing in others and expected changes in monsoonal conditions are model dependent (IPCC 2001). Total global precipitation is expected to increase by 0.15 mm/day throughout the 21st century, an increase three times greater than what would be expected if trends over the past three decades continue unaltered (Douville *et al.* 2001). The mechanism behind this increase in precipitation is well understood: increasing global temperatures will increase surface evaporation and atmospheric water holding capacity, ultimately resulting in increased water content of the atmosphere (IPCC 2001, Douville *et al* 2001). Terrestrial systems respond to increased precipitation with region-specific decreased rates of evaporation, increased soil moisture, and/or increased streamflow and runoff (Nijssen *et al* 2001).

Many uncertainties are inherent in these model data: global results are generally robust, but on the regional scale parameter sensitivity and local variability result in differences between observed data (such as rainfall) and model predictions. (In our sample, real rainfall 1981-1999 and model predicted rainfall were correlated at 0.6). Runoff and other soil and land hydrology parameters are difficult to estimate accurately with CGCMs (Douville *et al.* 2002), making terrestrial predictions more uncertain than the atmospheric component of the hydrologic cycle. Furthermore, differences between CGCM predictions are more significant for precipitation than temperature, and there is significant disagreement between models in the magnitude of change in precipitation on the regional scale. These uncertainties arise from the spatial resolution of CGCMs, typically several degrees of longitude by several degrees of latitude. Statistical downscaling methods provide higher resolution spatial data and are preferred for regional analyses, but these models are computationally very intensive, complex and well beyond the scope of this paper.

Despite uncertainty in the country-level details, several studies comparing results obtained from CGCMs and downscaled regional models demonstrate that CGCMs accurately replicate observed patterns in rainfall variability (Rowell 1998, Gonzalez-Rouco *et al.* 2000, Landman and Goddard 2002, Srinivasan 2003). Despite some discrepancies between CGCMs and with observed data, then, CGCMs accurately simulate large scale features of global climate, can reproduce climatic teleconnections, and, relevant to this study, replicate patterns of interannual variability.

The African continent experiences important climatic teleconnections that link global climate change to regional changes in precipitation: ocean forcing 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 and Cook 2001). Consequently, CGCMs are useful for analyzing large-scale changes in African climate. Validations of CGCMs with regional downscaling techniques specifically demonstrate that large-scale structure and variability of precipitation patterns in Sub-Saharan Africa are well simulated by CGCMs (Bartman *et al.* 2001, and Landman and Goddard 2002, Paeth 2004). Models predict an increase in summer rainfall in Southern Africa, an increase in summer monsoonal precipitation, a strong increase in surface evaporation, a significant increase in soil moisture retention, and a slight increase in runoff (Bartman *et al.* 2001, Landman and Goddard 2002, Douville *et al.* 2002, Paeth 2004). Precipitation maxima are located over Cameroon, Ethiopia, and the West Coast of Africa.

5.2 The Coupled Global Circulation Model

For our analyses, we chose the most recent version of the United States Department of Energy National Center for Atmospheric Research Parallel Climate Model (NCAR-PCM3) available online through the IPCC Data Distribution Center.[6] This model was chosen primarily because it has the highest spatial resolution (2.8° x 2.8°) and because data were available for comparison from three different future scenarios[7] (A1B, A2, and B2). Furthermore, the NCAR-PCM3 model simulates not only increases in CO_2 but also other greenhouse gases, something that only two of the seven models accomplish. The NCAR-PCM3 model includes sophisticated land surface schemes representing the interactions between vegetation and surface energy and moisture budgets and may therefore be more realistic than several of the other CGCMs that use only "bucket"-style topographical structures (Srinivasan 2003). In studies comparing a selection of IPCC-recommended CGCMs, NCAR-PCM3 produces hydrographic results similar to three other CGCMs (HCCFR-CM2, HCCPR-CM3, and ECHAM4) (Nijssen *et al.* 2001). Furthermore, calibrations of this model to real data show that NCAR-PCM3 performs well replicating precipitation patterns in Sub-Saharan Africa (Srinivasan 2003).

5.3 Data Analysis

Data are available as monthly mean precipitation values for a given latitude and longitude coordinate from 1980-2099. A significant difficulty is introduced when combining physical data with socio-economic data: the former adhere to geographic boundaries, while the latter represent political boundaries. Given limitations imposed by spatial resolution described above, as well as uncertainty associated with using CGCMs at the regional scale, we chose to limit analysis to methods that would describe general trends and patterns, and limited analysis to annual means over the period 1980-2059. This captures the broadscale patterns of variability that CGCMs are capable of reproducing without demanding unreasonable temporal extension or resolution from globally derived data. For country-specific analyses, precipitation data nodes were assigned to a country given geographic coordinates and weighted according to the percentage of the 2.8° x 2.8° box that resided in a given country (see Appendix 1 for details).

We recognize and accept the considerable limitations associated with making predictions about future climate change on a country-by-country basis using data from a CGCM. However, many studies have shown considerable agreement between CGCMs, downscaled regional models, and empirical data when predicting patterns of variability in precipitation (Srinivasan 2003, Paeth 2004). We therefore proceed by looking solely at measures of future variability and simple measurements of trends, namely regression of time series. Data were analyzed in the following ways:

1. Total annual precipitation for a given latitude-longitude coordinate, and for a given country (aggregated coordinates), were calculated for the available future scenarios (A1B, A2, and B2). Intra-annual variance was calculated from monthly data for a given year at both spatial scales of analysis. Simple linear regressions were performed on these time series to look for temporal trends in total annual precipitation and intra-annual variance.
2. Percent change from the prior year, an operationalization of interannual variation, was found above to be a significant predictor of (lagged) onset of conflict. This measurement was calculated for future years (2006-2059) using data from scenarios A1B, A2, and B2. Values were calculated at a spatial scale of 2.8 x 2.8 degrees (i.e., not aggregated at the country level). Percent change from the prior year was calculated as [(precipitation at time *t* - precipitation at time *t-1*)/ precipitation at time *t-1*].

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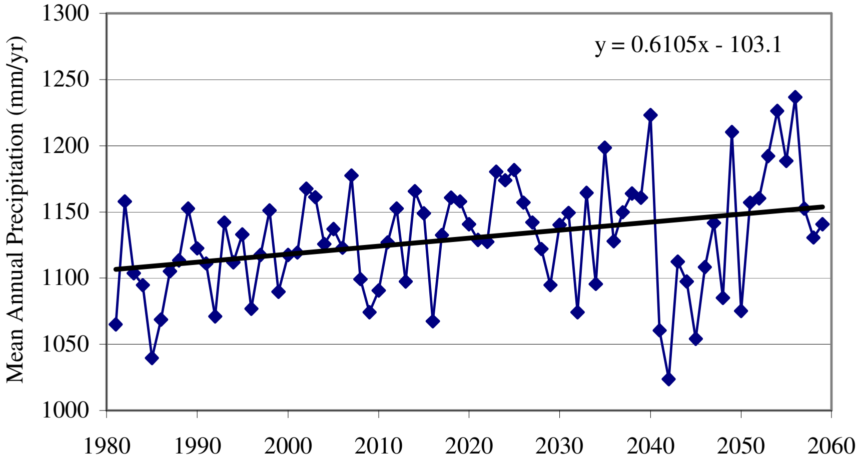
[7] The IPCC Third Assessment Report outlines 4 major scenarios (A1B, A2, B1, and B2) under which future climate conditions may evolve. Each scenario involves different assumptions regarding levels of economic growth, conservation measures, and other factors that could affect rates of greenhouse gas emissions.

3. Total variance (σ^2) across all years, another indicator of interannual variation, was calculated at the country level of aggregation and used to rank countries. This was done for both real (GPCP) data from 1981-1999 and for CGCM data for 2006-2059 for the three scenarios.
4. Future shocks were calculated as +/- 2 standard deviations from the mean. Although this variable was not found to be a significant predictor of onset of civil war in Sub-Saharan Africa, it provides a useful means of classifying future patterns of precipitation events.

5.4 Results and Discussion

Our results agree with those found by other researchers for general trends in precipitation[8]. Mean total annual precipitation (averaged over the entire Sub-Saharan region) increases by 0.6 mm/year over the period 1980-2059 (figure one). Statistical analyses were performed on all three future scenarios. All three scenarios show a positive linear trend in rainfall over this time period (A1B, $p < 0.005$; A2, $p < 0.005$; B2, $p < 0.05$). However, regression analyses of intra-annual variance (σ^2, monthly data) for the three scenarios were not significant. That is, no linear trend in intra-annual variance is demonstrated by the model data.

Figure One: Time evolution of mean annual rainfall in Sub-Saharan Africa predicted by NCAR-PCM3.



Interannual variance was operationalized as percent change in precipitation from prior year, total variance for a given country and the resulting relative ranking, and number of precipitation shocks. For the first operationalization, regression analyses of time series from the three scenarios show no significant linear trends. In the case of relative ranking of total variance, model data were compared with observed data as a means of comparing the relevance of model data to our earlier analysis of GPCP data. The model data do a significant job replicating the ranking a country received using the observed variance (Spearman rank correlation = 0.51, d.o.f. = 38, $p < 0.05$.). In this case, there are no significant changes in ranking of a country's interannual variance from observed (1981-1999) data to predicted (2006-2059) data (Table four). Countries with low interannual variation in precipitation maintain low variances into the mid-21st century, and countries with high variation maintain similar patterns.

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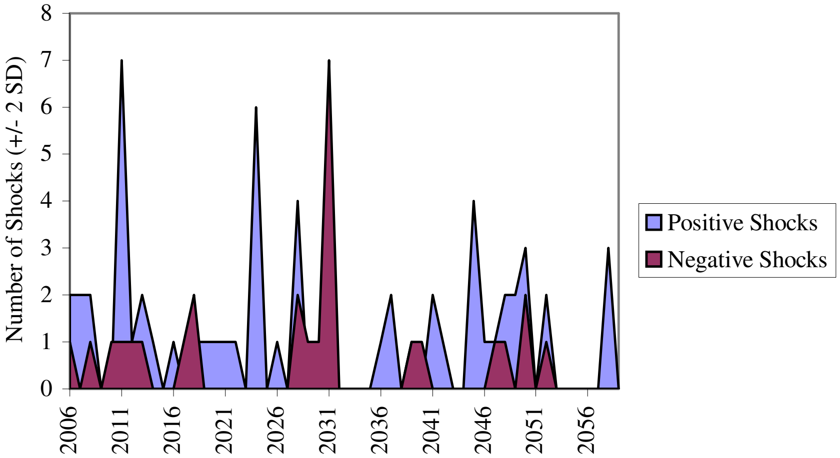
[8] Initially we intended to compare the results from the three different scenarios (A1B, A2, and B2); however, given the coarse level of analysis and simple statistical tests used, there were no significant differences in trends between scenarios. Consequently, we report results for scenario A2 only, the scenario we find most plausible.

Table Four: Country-specific interannual variance in annual total precipitation from observed data (GPCP) and model data (NCAR-PCM3) in Sub-Saharan Africa. Rankings are used to compare the observed (1981-1999)and model (2006-2059) data where 1 = lowest variance and 39 = highest.

Country	Observed Variance	Observed Rank	Model Variance	Model Rank
Mauritania	915.0	1	1192.4	1
Niger	2003.9	2	2781.5	3
Mali	2721.2	3	2660.5	2
Chad	3674.0	4	7594.5	7
Sudan	4307.7	5	11921.5	16
Namibia	4931.4	6	9283.6	9
South Africa	6382.9	7	7808.9	8
Senegal	7640.2	8	29810.6	31
Botswana	7646.8	9	18470.7	23
Central African Republic	8730.8	10	28892.7	30
Ethiopia	9981.2	11	10298.2	12
Burkina Faso	10106.9	12	20874.8	26
Cameroon	11671.5	13	19753.2	25
Benin	12398.1	14	13639.2	18
C'ote D'Ivoire	12413.3	15	4434.7	4
Somalia	12493.9	16	5870.8	5
Zimbabwe	15623.1	17	15124.3	20
Nigeria	16342.5	18	12740.3	17
Lesotho	16844.5	19	28624.2	29
Togo	19943.6	20	14658.1	19
Zambia	20077.2	21	23143.7	28
Uganda	21582.6	22	36136.9	34
Angola	23197.8	23	6916.4	6
Tanzania	23265.2	24	20916.1	27
Kenya	23922.5	25	11730.2	15
Republic of Congo	24076.3	26	35525.3	33
Madagascar	26504.0	27	11027.3	14
Mozambique	28142.6	28	16976.9	22
Burundi	28238.6	29	16664.9	21
Ghana	28839.4	30	10897.5	13
Rwanda	28891.7	31	43081.2	37
Gabon	31411.2	32	50212.0	38
Guinea Bissau	33864.7	33	30435.1	32
Liberia	34066.5	34	53532.4	39
Guinea	35763.5	35	9612.5	10
Malawi	38108.2	36	41813.7	35
Swaziland	38282.3	37	19356.4	24
Democratic Republic of Congo	45057.3	38	9641.4	11
Sierra Leone	92818.2	39	42134.8	36

Finally, there is no trend detected when analyzing time series of precipitation shocks (+/- 2 standard deviations from the mean). For the time period 2006-2059 over the entire Sub-Saharan region, there are 60 positive rainfall shocks and only 27 negative shocks predicted (figure two).

Figure Two: Total number of predicted precipitation shocks for Sub-Saharan Africa, estimated as +/- 2 standard deviations from the mean value.



The future increase in annual precipitation found for Sub-Saharan Africa is similar to patterns found by other researchers (Bartman *et al.* 2001, and Landman and Goddard 2002, Paeth 2004), a finding that suggests an optimistic future for onset of civil conflict related to climate change. Models (Douville *et al.* 2001) also predict that, for Sub-Saharan Africa, increased rainfall will translate into increased soil moisture as opposed to increased runoff, a further optimistic finding. If increased rainfall merely increased streamflow, runoff, and hence soil erosion, land degradation would increase. However, increased soil moisture bodes well for agricultural productivity. Our inability to detect a trend, either negative or positive, in intra- and interannual variance measurements suggests that rainfall variability in Sub-Saharan Africa will remain stable over the next five decades. This is not to say that variability will not exist: in fact, our analysis demonstrates 27 occurrences of negative shocks at the country level. In particular, the year 2031 will experience such a shock in seven different countries (figure two). We do not suggest that the specific year 2031 is a real prediction: the uncertainties in model data have already been discussed. Rather, our results suggest broadly that, while positive rainfall shocks are twice as likely in a given year than a negative shock, there is the possibility of a large negative rainfall shock that has spatial coherence in multiple countries. Finally, our ranking results demonstrate that countries that currently experience high levels of interannual variability will continue to do so into the future. In our case, Sierra Leone shows the highest levels of precipitation variability. In summary, as total rainfall is predicted to increase, accompanied by increased soil moisture, and measures of variability remain stationary, the impact of future climate change on precipitation in Sub-Saharan Africa is cautiously optimistic.

6. Discussion and Conclusions

This paper addresses the relationship between climate change and the onset of civil conflict from two complementary perspectives. The first is the elaboration of a model of conflict onset in which the significant variables of interest are measures of a) climate suitability for agriculture and land degradation, what we term climatic trends and b) interannual variance in rainfall, what we term triggers. Our findings, discussed in section four, suggest that interannual variability in rainfall is a more significant predictor of conflict than our measures of climate and land degradation. Admittedly, these results may be an artifact of 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 strong findings regarding the controls GDP *per capita* and GDP growth is interesting in its own right. While more rigorous empirical testing lies ahead, we broach two preliminary interpretations. The first, and one common in the literature on development, is that aggregate measures such as GDP *per capita* tend to be unreliable in highly stratified, primarily rural developing countries (Heston 1994). To the extent that this bias may be consistent (i.e. consistently over- or under-reporting), however, our substantive findings may not be impugned. The second, and more theoretically interesting, is that GDP *per capita* does not accurately capture the opportunity cost to participation in rebellion. Miguel, Satyanath and Sergenti (2004) address this possibility, arguing specifically that negative economic growth may lead to greater rural inequality, and that the distributive consequences of economic contraction drive participation.[9] 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 household income in Africa suggest that drought has significant, differential impacts on income across economic classes (Reardon and Taylor 1996, Reardon 1997). The problem with all of these conjectures, of course, is that good data is hard to find.

Our first cut at answering this question is presented in table five. Table five presents the output of a random effects, GLS model of annual *per capita* caloric intake with an AR(1) disturbance term. Oddly, linear increases in percentage change in rainfall relative to the previous year are negatively associated with caloric intake. However, this finding may be due to the inclusion and statistical significance of various cut-point operationalizations of the same variable; to wit, a two standard deviation negative shock in the previous period is associated with a 139-calorie drop in *per capita* intake. The estimate on climate scale, while in the right direction, is not significant. Moreover, the hypothesized relationships between rural population density and percentage of population living in rural areas, discussed in section four, are substantiated with regard to caloric intake. More agrarian societies, and societies marked by greater population pressures on rural land, are associated with decreased caloric consumption. This suggests that rainfall and resource scarcity have real impacts on the well-being of rural populations in Sub-Saharan Africa.

The second perspective involves assessing the outlook for the future based on our own analysis of predicted changes in precipitation means and variance generated by NCAR-PCM3, a coupled global circulation model (CGCM), and a critical review of the significant findings of the downscaled literature on climate change in Africa. We find that while overall levels of precipitation are expected to increase in the next fifty years, intra- and interannual variability are not expected to vary significantly from the actual levels of variability observed in the historical data. Indeed, our analysis predicts that positive rainfall shocks will outnumber negative shocks by a two-to-one margin. Furthermore, levels of ground moisture retention are expected to increase, which suggests that soil erosion will not countervail the positive effects of increased rainfall, as is predicted in other regions of the world such as Southeast Asia (Douville *et al.* 2001).

This finding is seemingly at odds with the conventional wisdom regarding global warming and the stability of climatic systems. We believe this counterintuitive finding to be open to three alternate interpretations. The first is that by focusing on a particular parameter, in this case, precipitation, we may be missing some important sources of overall climate variability. However, this possibility seems remote due to the centrality of the hydrological cycle to the definition of climate. The second is that in restricting our analyses to the time period 1980-2059, our regressions did not capture trends that may be predicted to lie further in the future. The third, and most interesting from our perspective, is that the cataclysmic predictions linking climate change and human security do not apply to Sub-Saharan Africa.

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[9] Interestingly, they do not address the possibility that economic growth may lead to increasing inequality. The essence of their microfoundational argument is that a paucity of legal economic alternatives drives young men to participate in rebellion. There are many reasons to believe, however, that positive income growth could lead to increased stratification of wealth, higher unemployment and lower wages (c.f. Dutch disease economics).

Table Five: Random Effects GLS Model of *Per Capita* Caloric Intake, 1981-1999

Dependent Variable	*Per capita* Caloric Intake
$\%\Delta$ Rainfall $_{t-1}$	-48.794*
	29.256
One SD Positive Δ_{t-1}	35.242**
	15.756
One SD Negative Δ_{t-1}	-24.533
	15.589
Two SD Positive Δ_{t-1}	3.865
	40.035
Two SD Negative Δ_{t-1}	-139.119***
	46.406
GDP *per capita* $_{t-1}$	113.175***
	29.031
GDP growth $_{t-1}$	2.345***
	0.822
Climate Scale	73.735
	52.804
Rural Pop. Density	-0.479***
	0.111
Percent Pop. Rural	-6.869***
	1.170
Interaction(% Rural & $\%\Delta$ Rainfall $_{t-1}$)	2.138
	2.216
Constant	2528.285***
	135.830
ρ	.736
N	651
R^2	.24

We attribute this non-finding to two unrelated sources. The first is the strength of oceanic teleconnections in regulating terrestrial precipitation in Sub-Saharan Africa. As oceans are known dampers of interannual variability, the fact that so much of Sub-Saharan Africa is bordered by the Atlantic, Southern and Indian Oceans may explain this finding. The second is the regional bias in the literature linking climate change and human security. In our review of the literature, we were able to locate only one study (Magadza 1994) that attempted 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 trend of widespread drought to the future (a method found to be faulty by current CGCMs). However, Magadza did not look at any predictive data. This stands in stark contrast to the comparatively massive literature regarding the impacts of global warming on future trends in precipitation in developed countries. Thus, it may be the case that our optimistic findings are out of synch with the general trend of climate science because of our regional focus.

At this point, we draw two final conclusions. The first is that our analysis does not indicate that, given the effects of climate on civil conflict onset, Sub-Saharan Africa is going to be worse off in the future; in fact, our analysis suggests that given the relationship between the region's reliance on agriculture and our findings regarding precipitation and expected soil moisture retention, Sub-Saharan Africa may witness increased agricultural yields in the future. Thus, the neo-Malthusian expectation of a monotonically decreasing resource base is unsubstantiated.

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. Although Miguel, Satyanath and Sergenti (2004) do not find differential impacts of changes in rainfall in countries with more developed irrigation systems (a finding we corroborate, regressions not shown), the fact that Sub-Saharan Africa on the whole is vastly under-irrigated biases our research design against a positive finding. Even as variability is not predicted to increase over time, variability still remains: our Spearman rank correlations suggest that countries characterized by high interannual variability will remain as such. Some of these countries include the most conflict prone and poor in the region, such as Democratic Republic of Congo, Sierra Leone, Liberia and Burundi. Our analysis suggests that breaking this relationship of dependence will have positive effects for both mitigating conflict and ensuring access to adequate nutrition.

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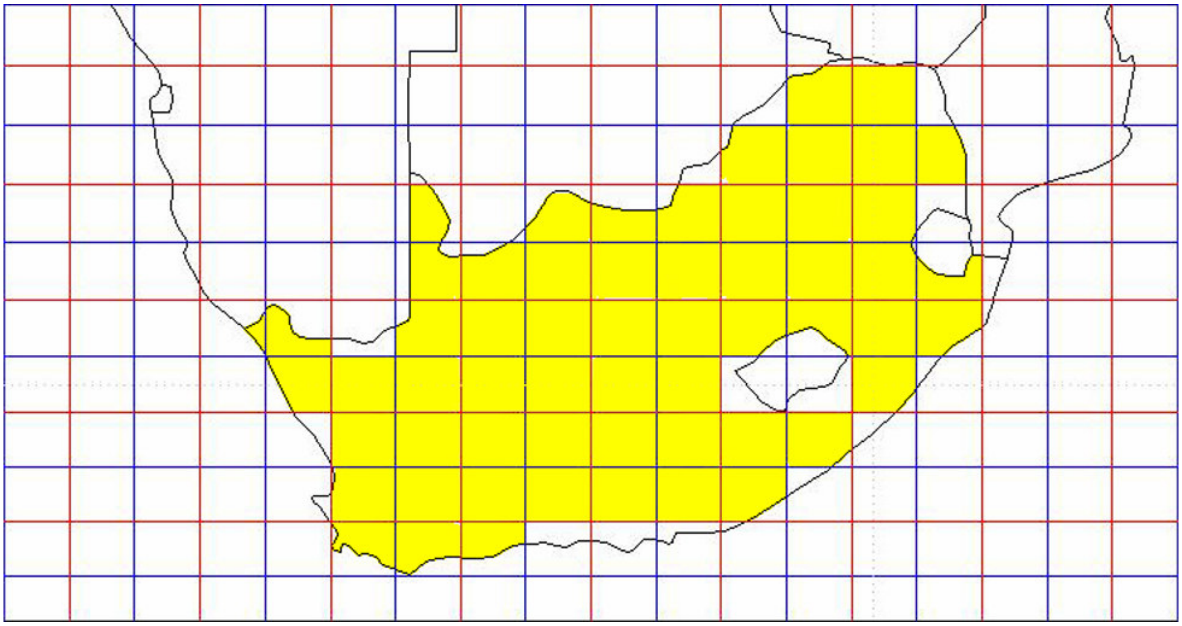
Appendix 1: Coding Precipitation Data

The NCAR coupled climate model generates predicted values for temperature and precipitation at a resolution of 2.8° by 2.8°. At this resolution, each data node "describes" a land area equivalent to 96,000 km^2, an area roughly twice the size of Lesotho. While this resolution is among the best returned by the benchmark GCMs recognized 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 are going to bias rainfall estimates.

In order to correct this bias, we divide each data node into four quadrants with the data node in the center. Each quadrant was 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 a assigned to the particular country even if the node fell across the border. This coding was done by hand using high-resolution maps generated by 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.

By way of example, we present the coding for South Africa, a larger African country. The points where blue lines intersect represent the actual data nodes; the red lines form a box around each node, indicating the four quadrants described by that data node. The quadrants filled in yellow indicate quadrants assigned to South Africa.



Country	Latitude	Longitude	Quadrants	% Total Area
South Africa	-34.8825	19.6875	2	0.030769
South Africa	-34.8825	22.5	1	0.015385
South Africa	-34.8825	25.3125	1	0.015385
South Africa	-32.0919	19.6875	4	0.061538
South Africa	-32.0919	22.5	4	0.061538
South Africa	-32.0919	25.3125	4	0.061538
South Africa	-32.0919	28.125	3	0.046154
South Africa	-29.3014	16.875	2	0.030769
South Africa	-29.3014	19.6875	3	0.046154
South Africa	-29.3014	22.5	4	0.061538
South Africa	-29.3014	25.3125	4	0.061538
South Africa	-29.3014	28.125	2	0.030769
South Africa	-29.3014	30.9375	3	0.046154
South Africa	-26.5108	19.6875	1	0.015385
South Africa	-26.5108	22.5	3	0.046154
South Africa	-26.5108	25.3125	3	0.046154
South Africa	-26.5108	28.125	4	0.061538
South Africa	-26.5108	30.9375	3	0.046154
South Africa	-23.7202	28.125	3	0.046154
South Africa	-23.7202	30.9375	3	0.046154

Appendix 2: Variable Descriptions

Variable	N	Mean	Std. Dev.	Min	Max
A1B Precipitation (mm/year)	3280	1140	34.73	135.13	3087.7
A2 Precipitation (mm/year)	3280	1133.6	33.52	140.8	3142.7
Agricultural Degradation	704	11.48722	17.60681	0	75
B2 Precipitation (mm/year)	2419	1142.8	36.3	123.2	3151.8
Climate Scale	704	1.832227	0.6840076	1	3.989335
GDP growth	704	2.530319	6.683136	-51.03086	38.85493
GDP *per capita*	704	1.074239	0.8335908	0.197	4.797
GPCP Annual Precipitation (mm/year)	704	1003.175	507.866	96.103	2587.637
Lagged Percent Change Rainfall from Previous Year	704	0.0113044	0.208155	-0.5498713	1.676975
ln(%Mountainous)	704	1.54268	1.451862	0	4.421247
ln(Population), lagged	704	8.769821	1.176022	6.336826	11.70567
Non-Agricultural Degradation	704	15.97017	19.68798	0	100
Oil Producer	704	0.1164773	0.3210245	0	1
One SD Negative Shock	704	0.1676136	0.3737884	0	1
One SD Positive Shock	704	0.1676136	0.3737884	0	1
Ongoing War	704	0.2286932	0.4202898	0	1
Onset (F&L)	704	0.0298295	0.1702378	0	1
Onset (PRIO/UCDP)	704	0.1022727	0.3032221	0	1
Per capita caloric intake	693	2152.063	277.4412	1510.2	2880.4
Percent Change Rainfall from Previous Year	704	0.0179221	0.2108449	-0.5498713	1.676976
Percent Rural	704	70.86527	13.52782	19.7	95.52
Rural Population Density	694	321.0866	193.7049	69.12092	986.5954
Two SD Negative Shock	704	0.015625	0.1241078	0	1
Two SD Positive Shock	704	0.0184659	0.1347245	0	1