Of Climate Change and Crystal Balls: The Future Consequences of Climate Change in Africa

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Abstract: Given its geographic location and the low adaptive capacity of many of its governments and economic systems, Africa is perhaps the most vulnerable region to climate change. However, model projections of the physical effects of climate change in Africa are highly uncertain, particularly at the national and sub-national spatial scales at which political processes operate. Against this backdrop of great social vulnerability and physical climate uncertainty, political scientists and the policy community have begun to explore the potential security consequences of climate change, describing it as a stressor or a threat multiplier with the potential to contribute to conflict and state failure. Since most of political science is focused on explaining the past rather than predicting the future, scholars have looked to historic data on rainfall variability, disasters, temperature change, refugee movements (all expected effects of climate change) to try to get traction on the causal connections between climate phenomena and security outcomes. Such an approach is rooted in the assumption of stationarity—the concept that the range of climate conditions for a given area occurs within a static envelop of variability that is defined by past extremes. The past, however, may be a poor indicator of how climate risks are likely to interact with social factors to generate disasters, instability, and conflict. Scholars of climate impacts have sought to understand such departures from historic patterns through the use of forecasting and scenario analysis. Using Africa as a regional focus, this paper employs a different approach: vulnerability mapping. This paper presents geo-referenced maps of sub-national climate vulnerability in Africa, using projections of future of climate vulnerability from the National Center for Atmospheric Research (NCAR) as well as indicators of past disaster incidence, household/community vulnerability, governance and political violence as well as demographic information. We suggest that maps of chronic vulnerability incorporating a variety of indicators provide a helpful advance for international relations scholars, as they are less reliant on heroic assumptions about changes in political and economic systems than either forecasting or scenario analysis.

Climate change is a novel problem. Never before has the human species had the capacity to alter the planet's basic life-sustaining functions in as fundamental a way as it does now. Given its geographic location and the low adaptive capacity of many of its governments and economic systems, Africa is perhaps the most vulnerable region to climate change. However, model projections of the physical effects of climate change in Africa are highly uncertain, particularly at the national and sub-national spatial scales at which political processes operate. With Africa almost entirely dependent on rainfed agriculture, the uncertainty of future precipitation patterns is of special concern.

Against this backdrop of great social vulnerability and physical climate uncertainty, political scientists and the policy community have begun to explore the potential security consequences of climate change, describing it as a "stressor" or a "threat multiplier" with the potential to contribute to conflict and state failure.[1] Since most of political science is focused on explaining the past rather than predicting the future, scholars have looked to historic data on rainfall variability, disasters, temperature change, refugee movements (all expected effects of climate change) to try to get traction on the causal connections between climate phenomena and security outcomes.

Such an approach is rooted in the assumption of stationarity—the concept that the range of climate conditions for a given area occurs within a static envelop of variability that is defined by past extremes. However, as pronounced in a 2008 issue of the journal *Science*, "stationarity is dead": future climate means and extremes will be different than in the past.[2] The past, therefore, may be a poor indicator of how climate risks are likely to interact with social factors to generate disasters, instability, and conflict. Climate impacts analysts necessarily reject stationarity as a guide to future outcomes. Two complementary approaches used by this community are deterministic climate forecasts generated by complex physical models, and plausible "if-then" scenarios of future climate conditions upon which a range of plausible impacts scenarios can be developed. Some political scientists have begun adopting similar approaches to assessing the broad security implications of climate change, but the uncertainties in the underlying climate projections remain and there is a mismatch between the spatial and

[1] (CNA Corporation 2007; Campbell et al. 2007).
[2] (Milly 2008).

temporal scales of available climate change projections and the questions political scientists pose.

Using Africa as a regional focus, this paper attempts to reconcile the scientific community's approach to climate change impacts analysis with the emerging approaches in political science for assessing the future social and political consequences of climate change. This paper presents geo-referenced maps of sub-national climate vulnerability in Africa, using projections of future of climate vulnerability from the National Center for Atmospheric Research (NCAR) as well as indicators of past disaster incidence, household/community vulnerability, governance and political violence as well as demographic information. We suggest that maps of chronic vulnerability incorporating a variety of indicators provide a helpful advance for international relations scholars, as they are less reliant on heroic assumptions about changes in political and economic systems than either forecasting or scenario analysis.

The *first* section summarizes what we know about climate change, the *second* what we know about climate change in Africa. The *third* section discusses the limits of three strategies political scientists have used to understand the significance of future climate change: historical analogues, forecasting, and scenario analysis. The *fourth* section presents our approach based on geo-referenced maps of sub-national climate vulnerability in Africa. By incorporating maps of future climate vulnerability from NCAR model output, we build on our previous work that used historic incidence of natural disasters and a variety of indicators of social, political and demographic vulnerability.

Section 1: What Do We Know About Climate Change

For the purposes of this paper, three important aspects of our knowledge of global climate change are important, including challenges to the notion of stationarity, the uncertainty of climate projections, and the importance of changes in the incidence of extreme weather events.

'Stationarity is Dead'

For most of human existence, the climate determined where and how we lived. *Homo sapiens* emerged sometime within the past half million years, during the great ice age that has gripped the Earth for past two million years.[3] Our species has mostly known a cold existence, punctuated by geologically brief warm periods (interglacials) every 100,000 years. Until a few thousand years ago, humans were perpetual nomads, moving and adapting their simple lives to dramatic climatic variations that occurred over decades to millennia. Then came "The Long Summer," the current warm interglacial that geologists call the Holocene. At 16,000 years and counting, the Holocene has lasted much longer than most of the previous interglacials, and humans have capitalized on this extended period of global warmth.[4]

Over the past 10,000 years, the global temperature has varied by only ±1°C around the long-term average.[5] Sea level rose rapidly for thousands years as the last glaciation ended, then stabilized between 6000 and 3000 years ago, offering permanent seaside locations to build ports and trading centers that would become great cities. Atmospheric circulation settled into consistent patterns that created breadbaskets where glaciers once stood. After two million years of nomadism, humans began to put down roots. Within a few millennia, humans transformed from nomads to modern industrialists. Our cities are permanent fortresses of

[3] (McHenry 2009).
[4] (Fagan 2004).
[5] (Jansen 2007).

security from the elements. Our survival strategy now is to withstand the weather in all its fury rather than retreat. The modern systems we have constructed to provide personal and economic security are largely based on the past century or two of experience with the weather, a period of relative calm. We have forgotten the millennia of dramatic climate variability that our more mobile ancestors survived. The climate we have known for the past century is the ideal climate for our modern society precisely because we have invested in optimizing social systems to that climate.[6] Our great cities are sea level, our food is produced in the breadbaskets, and our building codes, water utilities, and power plants are all designed for familiar weather extremes. If sea levels change, atmospheric circulations shift, or climate extremes intensify, society will no longer be optimized for the climate. For this reason, water and climate specialists recently declared in *Science* magazine that “stationarity is dead.”[7]

Stationarity is the assumption that the range of climate conditions for a given area occurs within a static envelop of variability that is defined by past extremes. However climate change means that future climate means and extremes will be different than in the past. The past, therefore, may be a poor indicator of how climate risks are likely to interact with social factors to generate social instability, conflict, and state failure. Climate impacts analysts necessarily reject stationarity as a guide to future outcomes.

Climate Projections are Uncertain

Although global climate models do a good job of mimicking the magnitude and gross spatial distribution of observed global temperature change on subcontinental to global scales, their performance is not as good for precipitation and performance generally degrades as

[6] (Rockström 2009).
[7] (Milly 2008).

spatial scales become smaller.[8] Moreover, they may be systematically underestimating how responsive various components of the climate system are to the warming that has occurred so far.[9] Some aspects of climate that are changing more rapidly than models project include sea level rise, loss of Arctic sea ice, intensification of precipitation, poleward expansion of the dry tropics, and the loss of land-based ice from mountain glaciers and the Greenland and Antarctic ice sheets.[10]

There are several sources of uncertainty in model projections. First, the amount of greenhouse gases that humans will emit to the atmosphere in the future is unknown. Climate analysts have developed socioeconomic scenarios based on plausible alternative futures, but these are essentially elaborate guesses at what the future might hold and it is not possible to ascribe probability to any scenario. The range of greenhouse gas emissions scenarios employed is broad and accounts for much of the spread in model projections.[11] Changes in other future forcings are also unknown, such as the amounts of light-shading particles and methane in the atmosphere, volcanic eruptions, and changes in solar activity are unpredictable.

Another important contributor to uncertainty in model projections is the "response uncertainty," which refers to disagreement among models resulting from "the limited knowledge of how the climate system will react" to a given emissions scenario.[12] The IPCC Fourth Assessment report (AR4) employed around 20 global climate models in its projections of future climate. For a given climate-forcing scenario (i.e. a given amount of greenhouse gas emissions, solar activity, etc.), the inter-model spread among projections is large. For example, the uncertainty range of projected global warming from 1990 to 2100 for any given emissions

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[8] (Meehl 2007).
[9] (Engelhaupt 2007). See also (Füssel 2009).
[10] (Gulledge 2008b; Seidel 2008).
[11] (Meehl 2007).
[12] (Meehl 2007).

scenario is on the order of 2°C (i.e. inter-model standard deviation of approximately ±1°C). Considering that the G-8 have agreed on the aspirational goal of stabilizing the climate at not more than 2°C above the average preindustrial global temperature, an uncertainty range of ~2°C is significant. The quantified uncertainty range for model projections is simply based on the spread among different climate models across a range of emissions scenarios. Combining emissions uncertainty and response uncertainty, the full uncertainty range for projected warming to 2100 is 1.1–6.4°C, with a "likely"[13] range of 1.8–5.4°C.[14]

The phrase "full uncertainty range" is a misnomer, since emissions and physical model response are not the only factors contributing to uncertainty. Another aspect that has not been fully explored is the equilibrium climate sensitivity, which quantifies the amount of warming that would result from a doubling of the amount of CO_2 in the atmosphere. The best estimate is about 3°C, but it could be as low as 1°C or it could be more than 10°C; the correct value is *likely*[15] to lie within the range of 2.0-4.5°C.[16] Because global climate models are almost always run with each model's best estimates of equilibrium climate sensitivity, the uncertainty for this parameter is not included in the uncertainty range for climate projections. Another form of uncertainty that is not included in projection ranges is "model structural uncertainty," which covers a host of unknown processes that may simply be missing from the models. For example, there are potential amplifying (positive) or dampening (negative) feedbacks that are too poorly understood to be included in models. One example is the potential release of billions of tons of carbon dioxide and methane from frozen soils (permafrost) in the north.[17] As the planet warms, these soils are beginning to thaw, releasing additionally greenhouse gases to the atmosphere

[13] The IPCC defines "likely" as greater than 2:3 odds.
[14] (CCSP 2008).
[15] The IPCC defines "likely" as greater than 2:3 odds.
[16] (Meehl 2007, Box 10.2).
[17] (Walter et al. 2006).

and amplifying the warming trend. How much and how quickly they will release their stores of carbon is presently unpredictable. Another positive feedback that is not completely integrated into models is the potential for plants and oceans to take up less carbon dioxide from the atmosphere in a warmer world. There may also be negative feedbacks that are missing from models, but the climate system appears to be particularly "blessed" with positive feedbacks, which entails heightened risk from a security assessment perspective.[18]

Climate Extremes Cause Damage

Changes in average global temperature are useful to scientists who study the physics of the global climate system, but they are virtually useless for understanding local climate impacts. Rare, intense weather events cause most local damage. A general feature of climate projections is that global warming causes local extremes to increase more than local averages. For example, heat waves warm up more than the average temperature, and the amount of precipitation in the heaviest rain events increases more than the annual average precipitation.[19] If the frequency distribution of a local climate variable (e.g., daily high temperature or daily precipitation) were normally distributed, a one-standard-deviation increase in the average would increase the frequency of an extreme event that happens only

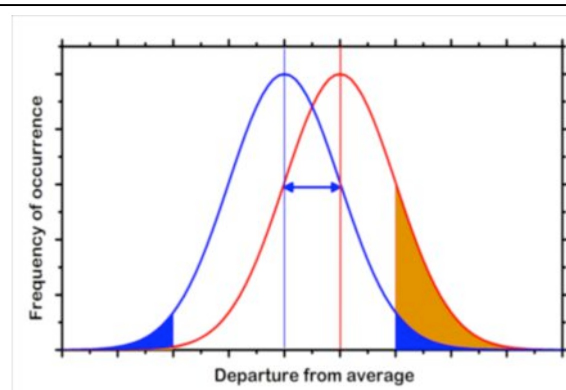

Figure 1. Simplified depiction of the changes in temperature and precipitation in a warming world. (SOURCE: Adapted from CCSP, 2008)

18 (Gulledge 2008b).
19 (Meehl 2007, Box 10.2). For similar discussions, see (Tebaldi et al. 2006)

once in 40 years (a five-percentile event) event to every six years. Moreover, the new 1-in-40 year event would be significantly more intense (Fig. 1).[20]

For example, model experiments by Knutson and Tuleya (2004)[21] found that the most intense categories of hurricanes (cat. 4 &5) became more frequent, while weaker categories became less frequent, in a modeled world with ~750 ppm atmospheric CO_2 (Fig. 2). The authors concluded: “Although we cannot say at present whether more or fewer hurricanes will occur in the future with global warming, the hurricanes that do occur near the end of the 21st century are expected to be stronger and have significantly more intense rainfall than under present day climate conditions.”

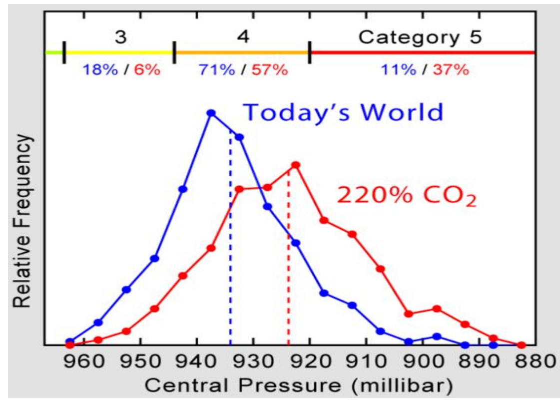

Figure 2. Frequency distributions of hurricane intensities from a climate model under present-day CO_2 concentrations and under CO_2 increased by 220% (about 750 ppm). (SOURCE: adapted from CCSP, 2008)

Section II: What do We Know About Climate Change in Africa

Assessments of the regional impacts of climate change widely agree that the most vulnerable countries and societies are in Africa. Weak governments and institutions, rapid population growth, widespread water stress, prevalence of malaria and diarrheal diseases, reliance on rain-fed agriculture, a large fraction of economic productivity occurring in climate-sensitive sectors, and the climate change that has already occurred combine to make African societies very vulnerable to climate change.[22]

[20] (CCSP 2008).
[21] (Knutson and Tuleya 2004).
[22] (IPCC 2007a; Niang, Nyong, and Clark 2007).

Africa's key vulnerabilities to climate change are in the areas of water availability, food security (agriculture and fisheries), health, coastal zones, and natural ecosystems and biodiversity.[23]

The African continent warmed by about 1°C over the past century (Fig. 3), more warming than occurred globally. It is clear, therefore, that human-induced climate change is well underway in Africa, as it is in most other parts of the world. However, there are several misconceptions or confusions about climate change in Africa:

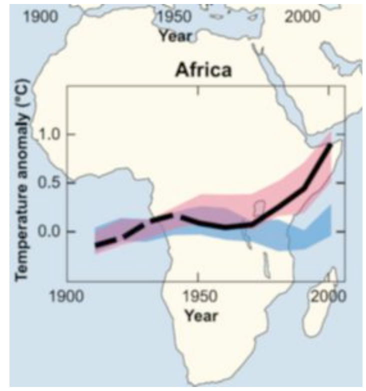

Figure 3. During the 20th century Africa warmed by about 1°C (black line), larger than the global trend. The warming trend falls within the pink shaded area, which shows the results of climate models driven by both man-made (greenhouse gases and aerosols) and natural (solar radiation and volcanic aerosols) climate divers. The blue shading includes only the natural drivers and does not match the observed trend. Source: IPCC 2007, p. 40.

- Because there are some regions where warming is much greater than in Africa (e.g., the Arctic), some people think that Africa is not particularly vulnerable to near-term climate change. In reality, Africa is extremely vulnerable to small changes in temperature and precipitation because its ecosystems and societies are adapted to a small range of historical climate variability.[24]
- Africa has so many dire problems that are not directly caused by climate change that the latter can seem unimportant by comparison. However, climate change exacerbates many other problems. Those who seek to eradicate disease, increase access to water, resolve conflict, etc. need to understand that climate change makes the problems they care about more intractable.

[23] (Niang, Nyong, and Clark 2007).
[24] (Baettig, Wild, and Imboden 2007).

- Drivers of climate change other than greenhouse gases are often ignored yet are important in Africa and much of the developing world. These include aerosols from burning wood and coal that alter atmospheric hydrology and block incoming solar radiation, changing the hydrology of the land surface. From the standpoint of climate impacts and preventing and adapting to them, these drivers of climate change are as important as greenhouse gases and are contributing strongly to current climate trends in Africa and Asia—much more so than in Europe and the Americas.
- Unlike for other continents with more developed economies, there is very little climate data for Africa. As a result, some important climate trends in Africa have been attributed to regional land use change only, but are likely tightly linked to large-scale climate phenomena, such as changes in sea surface temperatures or atmospheric aerosols. Increased Sahel drought is one such trend.[25] Climate data for Africa are particularly sparse in terms of observed impacts. The lack of data can be mistaken for a lack of climate-driven impacts, but obviously these are not the same and one should take care not to confuse the lack of detection for a lack of impacts.[26]

The IPCC also identified several systems and sectors that are typical of Africa as being "especially affected" by climate change: mediterranean-type ecosystems, tropical rainforests, coastal mangroves and salt marshes, coral reefs, water resources in the dry tropics, lowland agricultural systems, low-lying coastal systems, and human health in populations with low adaptive capacity. It is no wonder, then that the IPCC also identified Africa generally and Africa's heavily populated river deltas as regions "especially affected" by climate change.[27]

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[25] (Engelhaupt 2007).
[26] (Rosenzweig, Karoly, and Vicarelli 2008).
[27] (IPCC 2007a).

Food security

The IPCC states that “Sub-Saharan Africa is … currently highly vulnerable to food insecurity. Drought conditions, flooding and pest outbreaks are some of the current stressors on food security that may be influenced by future climate change.” Given that Africa already struggles with food security, it will not take much in the way of increased stress from climate change to undermine current development goals. There is a striking correspondence between population density and areas currently suitable for rain-fed agriculture in Africa. The amount of temperature and precipitation change projected by models for this region is large compared to the historical range of variability.[28] Because African societies are heavily dependent on rain-fed agriculture, they are more sensitive to climate changes in this region than wealthier societies that irrigate their crops. On average, the crop-producing region of Africa is projected to receive increased rainfall as a result of global warming. At first blush this projection would appear to be beneficial. Unfortunately, one of the most robust features of model projections is that year-to-year temperature, precipitation and drought extremes are likely to increase strongly, resulting in unpredictable crop yields from year to year. Increased flooding and storm intensity is likely, and even longer and more intense periods of drought are likely to occur in spite of the overall increase in precipitation, which is likely to fall in fewer, more intense events.[29]

Higher temperatures alone are likely to reduce crop productivity in Africa, even in areas with sufficient rainfall. At low latitudes, crops already grow near or above their temperature optima, and further warming would reduce their growth. Similarly, livestock are sensitive to heat and milk and meat production are expected to decline with further warming. Barring

[28] (Baettig, Wild, and Imboden 2007).
[29] (IPCC 2007a).

adaptation, decreased agricultural production will not only increase hunger, but also decrease incomes of crop producers and raise food prices, further increasing the threat of hunger.[30]

The threat of climate change to Africa's agriculture is not relegated to the distant future. Growing seasons have already grown shorter in the Sahel, lowering crop yields.[31] Moreover, a recent study concluded that "late 20th-century anthropogenic Indian Ocean warming has probably already produced societally dangerous climate change by creating drought and social disruption in some of the world's most fragile food economies" in eastern and southern Africa. According to the study's lead author, Chris Funk, "rainfall declines, combined with tremendous levels of rural poverty and vulnerability, produce undernourishment, malnutrition, child stunting and social disruption, hindering progress towards Millenium Development Goals."[32] By 2020, the IPCC projects that "in some [African] countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised."[33]

A large fraction of Africans rely on fish as their primary source of protein and fisheries are a major source of income to coastal communities and those situated around inland lakes.[34] Fish catch is declining already as a result of over-fishing, pollution, and other stresses that degrade aquatic systems. Hence, small changes in climate that alter aquatic ecosystems are likely to have deleterious effects on protein supply and income in Africa. In fact, climate change has already been linked to a well-documented decrease in the ecological productivity of Lake

[30] (Niang, Nyong, and Clark 2007).
[31] (IPCC 2007c).
[32] (Kalaugher 2008).
[33] (IPCC 2007a).
[34] (Niang, Nyong, and Clark 2007).

Tanganyika.[35] Hence, once again, the effects of climate change are not relegated to the distant future.

Water availability and flooding

By 2050, northern, southern, and parts of western Africa are likely to see moderate to extreme decreases in surface water flow (runoff) (Fig. 4).[36] Projections are highly variable and less certain for the white areas in Fig. 4. The area of southern Africa experiencing water shortages could increase from 9% today to 29% by 2050. Decreased flow is projected for the Nile River, which supplies water for irrigation of virtually all crops in Egypt and its neighbors. One should bear in mind that 2050 is an arbitrary marker and is not the beginning of problems. Crop irrigation is disrupted when Nile water flow drops by 20%, a condition that has a 50% chance of becoming persistent by 2020.[37] The IPCC projects that 75 to 250 million Africans will be exposed to water stress by 2020.[38]

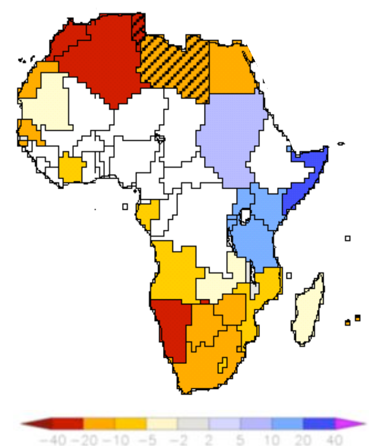

Figure 4. Projected percentage change in annual runoff in 2050 relative to the 1900-1970 average. Any color indicates more than two-thirds of models agreed about the direction of change; hatching indicates more than nine-tenths of models agreed. Yellows and browns indicate decreases and blues indicate increases. Source: Updated from Milly et al. (2005).

Eastern Africa could see moderate to extreme increases in runoff by 2050 (Fig. 4). Increased precipitation in eastern Africa could lead to more wet-season flooding without

[35] (O'Reilly et al. 2003; Rosenzweig, Karoly, and Vicarelli 2008).
[36] (Milly 2008; Niang, Nyong, and Clark 2007).
[37] (Niang, Nyong, and Clark 2007).
[38] (IPCC 2007c).

enhancing dry-season water availability because the increased rainfall is expected to occur during the monsoon. Events such as the severe flooding in Mozambique in 2000 could become more common. Tropical glaciers of East Africa are retreating rapidly and are expected to be gone by the middle of the century. These glaciers have been present since the last ice age and East African civilization has developed around the water resources they provide.[39] The loss of these resources over the next few decades will have serious implications for the sustainability of East African societies. The increased rainfall anticipated for this region will only be of use if expensive adaptive measures are taken to capture and store seasonal monsoon rainfall.

Health

Climate-sensitive diseases are expected to respond to climate change and may already be doing so. Malaria, cholera, and meningitis are major diseases in Africa and are all sensitive to climate, and are the main causes of climate change-induced mortality in Africa in the year 2000 as estimated by the World Health Organization. According to this estimation, Africa already has the highest rate of climate change-induced mortality in the world, with sub-Saharan Africa being hardest hit.[40] By 2030, diarrheal diseases could increase by an additional 10% as a result of climate change.[41] There is some evidence that a current resurgence of malaria in East Africa is linked climate change, although it is difficult to separate various drivers of disease based on sparse data.[42]

Coastal zones

[39] (Niang, Nyong, and Clark 2007).
[40] (Patz et al. 2005).
[41] (Niang, Nyong, and Clark 2007).
[42] (Patz et al. 2005).

Africa is a coastal continent with densely populated agricultural deltas and many coastal megacities. Sea level rise, saltwater intrusion into freshwater supplies, and intensified coastal storms with higher storm surges are likely to impact coastal Africa in the coming decades. Sea level rise is almost certainly significantly underestimated by current models.[43] A rise in sea level of one or two meters by the end of this century is generally considered plausible by experts.[44] However, estimates of damage and lost lives resulting from sea level rise and associated increases in storm surge heights use lower model-generated estimates of sea level rise, systematically biasing these estimates to the low side. One such estimate includes 0.5 to 17 percent of the total population of the coastal countries at risk of damage from sea level rise, with economic damages of 6 to 54% of GDP by the end of the 21st century. By 2050, 17 to 30 percent of Guinea's rice fields would be lost due to permanent flooding, assuming current sea level rise projections and no adaptation. Given the high probability that sea level rise has been systematically underestimated, it seems reasonable to favor the upper end of these estimated ranges. In Nigeria, about 6000 km^2 of agricultural land and hundreds of oil fields worth billions of dollars would be inundated by 1 meter of sea level rise. Barring protective measures, sea level rise will inundate coastal wetlands, negatively impacting fisheries.

Section III: Analogues, Forecasts, and Scenarios in Climate Security

From these diverse and still only partially understood physical consequences of climate change, scholars have sought to understand the likely affects on human health and livelihoods. From these impacts, social scientists and policy analysts have tried to assess the potential security consequences of climate change, focusing mostly on the likelihood of armed conflict.

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[43] (Rahmstorf 2007; Rahmstorf et al. 2007).

[44] (Gulledge 2008a; Rahmstorf 2007).

They have sought to gain traction on the security dimension through a variety of strategies, including historical analogues, forecasting as well as scenario analysis. While the use of historical analogues is most clearly suited to traditional empirical research in the discipline of political science, it may have limited utility in addressing the future consequences of climate change. Predictive, forecasting models and scenario analysis have less standing in the discipline but are attractive in that they directly address the limits of historically based research for novel problems. However, as this section notes, they too have their problems.

Analogues

Political scientists, largely through quantitative studies, have taken the anticipated effects of climate change (such as drought, rainfall variability, disasters, temperature changes, and migration) and looked for historical analogues to find correlations between those climate indicators and the onset of violent conflict. They have also explored a variety of causal mechanisms by which climate effects might give rise to security outcomes and the empirical support for them. Among the important questions asked by these scholars is whether scarcity or variability of resource supply is the more likely driver of conflict, as well as what role extreme weather events and the movement of environmental migrants could have in sparking conflicts.[45]

Given the tendency in the policy and advocacy community to link climate change and security outcomes through speculative conjecture and anecdotal information, the rigor of these quantitative studies is admirable. However, most of them can do little more than take the

[45] For good examples, see (Raleigh and Urdal 2007; Hendrix and Glaser 2007; Nel and Righarts 2008; Thiesen, Holtermann, and Buhaug 2009; Levy et al. 2005). For a critique of the policy literature and IPCC references to climate and security, see (Nordås and Gleditsch 2009). For a discussion of climate change, migration, and conflict, see (Raleigh and Jordan 2008; Gleditsch, Nordås, and Salehyan 2007).

present as a guide to the future. While optimistic about the potential for more rigorous research on the causal connections between climate and security, Nördas and Gleditsch concluded, "Unfortunately, the precision in conflict prediction remains at the stage where meteorology was decades ago: the best prediction for tomorrow's weather was the weather today."[46] That said, past climate change may not be a good guide to future climate outcomes as the previous discussed indicated.[47] As Buhaug et al. note in their capable summary of the state of the empirical literature on climate and conflict: "Since rapid climate change is still mostly a feature of the future, empirical research of historical associations (or lack thereof) may be of limited value."[48]

While the effects of climate change have historical antecedents, the uncertainty surrounding the physical effects of climate change, particularly in Africa, makes it difficult to extrapolate the social and political effects and security outcomes of interest, including but not limited to conflict. Those challenges have not stopped a number of scholars from trying, some with more success than others.

Forecasting/Projections

The discipline of political science largely focuses on explanation of past events. Prediction and projection have been employed more sparingly, though there are some prominent examples. Electoral models of U.S. presidential elections, for example, have sought predictive power using a few key variables.[49] Bruce Bueno de Mesquita is renowned for

[46] (Nordås and Gleditsch 2007, 633).
[47] (Busby 2008). See also (Busby 2009a, 2009b; Buhaug, Gleditsch, and Theisen 2008).
[48] (Buhaug, Gleditsch, and Theisen 2008, 36).
[49] For example, see the special issue of PS from October 2008 which featured pieces on the 2008 U.S. presidential election.

generating predictions of international political developments for private clients using models that are somewhat proprietary.[50]

In the climate security arena, a couple of studies have sought to make more precise projections of future implications of their work based on historical analogues. I group these studies under the label of forecasting/projections, recognizing that scenario analysis, discussed below, is also sometimes bundled under the broader label of forecasting.[51] Here, I reference forecasting in a more narrow sense to encompass quantitative models of the future. There are at least two notable examples of such work in the climate security arena.

The first is the 2007 piece by Hendrix and Glaser in the special issue of *Political Geography.* Like their peers, they use historical analogues—rainfall totals and rainfall change from the previous year—to determine whether or not those variables have historically been correlated with the onset of violent conflict in sub-Saharan Africa. The implication is that if climate change leads to changes in total rainfall and/or rainfall variability (and those have been found to be correlated with the onset of violent conflict), then climate change would make violent conflict more likely. As it is, they only found statistical support for their "trigger" variable of rainfall change being correlated with conflict onset in the period 1981-2002, rather than their "trend" variable of rainfall totals. The interesting extension Hendrix and Glaser made was to use climate models to ascertain the direction of future interannual rainfall variability as well as projected trends in long-run rainfall by the end of the 21st century. Recognizing that their findings may reflect the particular operationalization of rainfall variability, they conclude: "Our inability to detect widespread significant trends in rainfall triggers does not suggest a

[50] For a profile of Bueno de Mesquita, see (Thompson 2009).
[51] The website forecastingprinciples.com defines forecasting as "The field of forecasting is concerned with approaches to determining what the future holds. It is also concerned with the proper presentation and use of forecasts. The terms 'forecast,' 'prediction,' 'projection,' and 'prognosis' are typically used interchangeably." See the frequently asked questions.

future increase in civil conflict in Sub-Saharan Africa resulting from our measure of interannual rainfall variability."[52] In their piece, they merely sought to understand the potential direction of future change; unlike other approaches discussed below, they shied away from estimating the magnitude of effects on the future incidence of armed conflict.

As I discuss in *section 4*, this non-finding may be a result of their use of annual rather than seasonal rainfall data as well as the idiosyncrasies of the particular global circulation model they employed from NCAR that may be less accurate and possess less region-specific spatial resolution than would be desirable. Their work points to the challenges of extrapolating from uncertain physical models of climate change the future security consequences of climate change, even in a general sense of an up or down indicator in the incidence of conflict. In this case, their conservative judgment that they could not find strong patterns of future interannual rainfall variability reflected an appreciation of the uncertainties in the physical models of climate change as well as conflict models.

Other scholars have issued more specific quantitative projections of future conflict incidence resulting from climate change. For example, in their econometric work on temperature and conflict incidence/onset in sub-Saharan Africa, Burke et al. find a correlation between historic increases in temperature and conflict incidence/onset, over the period 1981-2002. Using projections of future temperature increases, the authors calculate that the sub-continent will experience a 54% increase in armed conflict by 2030. They then suggest if the rate of future civil wars is as deadly as historic civil wars have been, then the conflict-specific mortality from these future civil wars is likely to be 393,000 battle deaths. In so doing, they make a number of assumptions about future states of the world in terms of other indicators that are known to contribute to conflict. For example, they make assumptions about regime

[52] (Hendrix and Glaser 2007, 710).

type and economic dynamics, namely that per capita economic growth and democratization increase linearly at the same rate as during the period 1981-2002.[53]

While this piece was provocative and garnered a number of headlines, the research is subject to methodological criticism. The finding may not be robust to specification. Extending the model beyond the study time frame would likely yield different results, as the number of conflicts in Africa actually went down in the period after 1999 (with a temporary and slight uptick after 2005). With temperatures rising and conflict decreasing, this suggests a basic evidentiary flaw, notwithstanding the correlations the authors found. Moreover, the model includes few of the political and economic controls that the wider field of armed conflict typically employs such as inflation, measures of ethnic political marginalization, rough terrain, and distance from the capital city. Perhaps the weakest element in this short piece is the thin causal account to explain the apparent correlation. While they attribute the connection to the effects on agriculture, the mechanism by which you get from declines in agricultural yields to armed conflict is under-specified. They suggest that the effects go through economic welfare, which is noted as one of the main contributors to conflict, but the causal chain from temperature increase to declining agricultural yields to economic decline to conflict onset remains fuzzy. The authors need to show in at least some of the country cases in their dataset that the implicit causal chain actually reflects a series of events that precipitated actual conflict.[54]

For the purposes of this paper, the projections for conflict incidence and mortality are most salient.[55] While the paper notes that climate models have not yet converged around a

[53] (Burke et al. 2009). While the authors employ a fixed-effects model to account for some invariant attributes of ethnicity, colonial past, geography, there are other political developments that likely changed during the study period that their model cannot account for.
[54] This section has been informed by some unpublished critiques of the Burke et al. piece from Halvard Buhaug and Jack Goldstone.
[55] Because their calculations assume no adaptation, the authors take pains to describe their work as "projections" rather than "predictions" (Burke et al. 2009, 20673).

common set of findings for precipitation across the continent, the authors seek to obviate this difficulty by noting that there is more consistency across model specifications for temperature predictions.[56] The problem is that the strongest empirical findings in the climate security literature, including the Hendrix/Glaser paper, another by Levy et al., as well as an earlier by Burke co-author Edward Miguel piece, are based on a precipitation indicator as the important driver of conflict.[57] Just because the existing climate models cannot capture with a high degree of confidence future precipitation patterns does not mean that these are indicators of unimportant processes. In a sense, the Burke et al. piece elevates the significance of temperature just because the data is better. However, extrapolating from temperature increases to conflict incidence to battle deaths requires us to be believe in the initial causal connection as well as the models assumptions about economic growth, democratization, and future casualty rates. While space forbids a more exhaustive review of all three of these assumptions, any of them appears problematic on its own. For example, it is unclear that the assumption of a historic rate of civil war mortality, about 40,000 deaths per year, is well-grounded. As the 2007 Human Security Project project noted (see Figure 6), deaths from state-based battle deaths in sub-Saharan Africa have not been stable, declining from historic highs in the mid 1980s, with a bump in the early 1990s and then a large spike in 1998, following by precipitous decline in the early 2000s.[58] Extrapolating a baseline mortality rate from such disparate historic data does not appear to be especially well-motivated.

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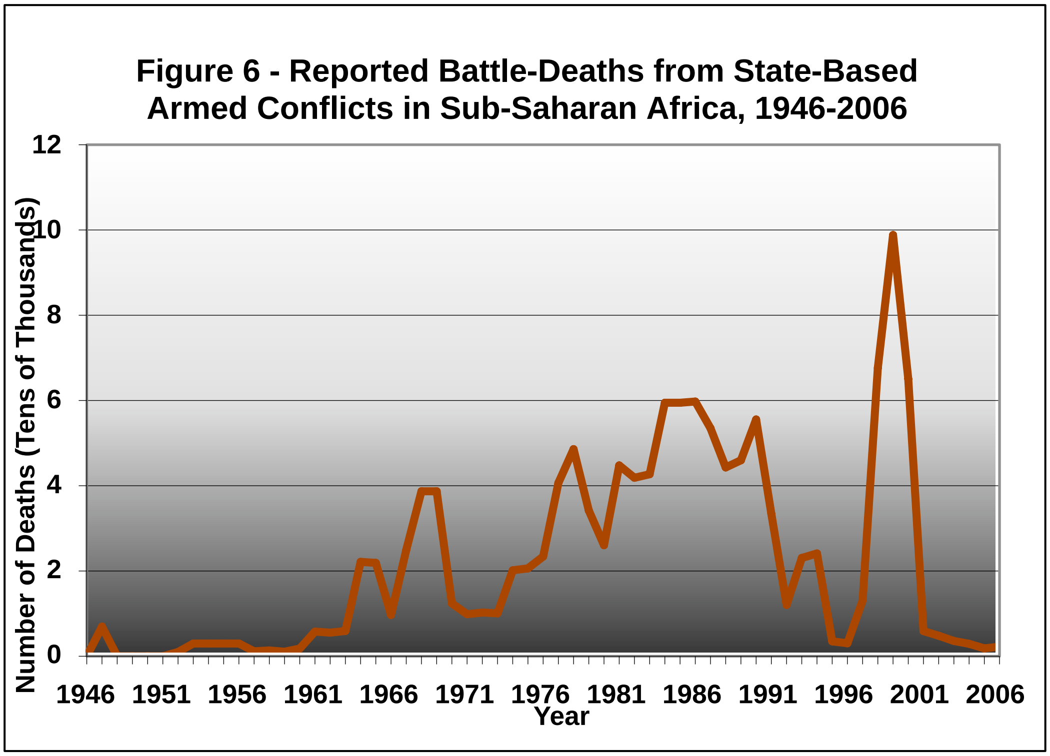
[56] General circulation models (GCMs, which are represented by the ensemble of 18 models in the Burke et al. paper) tend not to validate or replicate historic precipitation data very well, particularly compared to regional climate models (RCMs, which are created to mirror more locally specific weather phenomena). However, both GCMs and RCMs do tend to mirror each other in terms of temperature changes for Africa (Patricola and Cook 2009; IPCC 2007b; Cook and Vizy 2006).

[57] (Miguel, Satyanath, and Sergenti 2004).

[58] See figure 2.2 from the 2007 Human Security Report, http://www.humansecuritybrief.info/figures.html. Data are derived from the Battle Deaths datset from Lacina and Gleditsch. http://www.prio.no/CSCW/Datasets/Armed-Conflict/Battle-Deaths/

While predictive models for security outcomes remain an aspirational goal, the uncertainties of climate models, coupled with the poorly understood nature of the security consequences that could emanate from them, make the sorts of projections by Burke et al. potentially problematic.



Scenarios

Though sometimes grouped under the broader rubric of forecasting, scenario analysis provides an alternative approach for anticipating the future security consequences of climate change. Scenarios are narratives of a plausible future sequence of events, based on a set of assumptions. They are typically employed to force decision-makers in a corporate or policy setting to prepare for unexpected surprises that might not follow from current trends. They are thought to be especially helpful for problems characterized by high uncertainty. Unlike forecasting/projection models, scenarios analysis is much less numbers driven and relies more on expert opinion about the possible future states of the world that are worth contemplating. Given a narrative and set of assumptions, participants in a scenario planning exercise are typically asked about the driving forces that could have gotten them to that stage, how well their institution is designed to cope with such a situation, and what structural changes in the organization and broader policy environment might be facilitated to make the institution robust to this and other problems. In other settings, the participants themselves generate scenarios. In a group setting, different groups, often four of them, are frequently given derivatives of a single scenario, with alterations in the assumptions, leading to disparate sequences of events. The participants are asked to suspend disbelief about the nature of the assumptions and just react to the scenario they have before them, as if it could have happened.[59]

Scenarios have limited acceptance in political science, with wider acceptance in the business community. Scenarios are ubiquitous in the climate science realm, where projections of future climate change are predicted on different assumptions about economic growth and greenhouse gas emissions over course of the 21st century. In the climate security community, scenarios have some limited application, particularly in the policy world. Peter Schwartz and Doug Randall, in a widely cited piece that was commissioned by the Defense Department's Office of Net Assessment, tried to assess the consequences for U.S. national security in the event of abrupt climate change. This is a class of phenomena that scientists believe are low probability events that could possibly occur to switch off circulation of the Gulf Stream and induce the onset of another ice age, with European temperatures most likely to plummet.[60]

[59] (Garvin and Levesque 2005; Schoemaker 1991; Ogilvy and Schwartz 2004).
[60] (Schwartz and Randall 2003).

Schwartz is one of the leading exponents of scenario analysis, having pioneered the practice in the corporate realm for Shell.[61]

One of us was involved in another effort by the Center for A New American Security (CNAS) and the Center for Strategic and International Studies (CSIS) which examined three scenarios of the future to assess the security consequences of climate change in the event of expected or severe climate change by 2040 or catastrophic climate change by 2100. In that study, what made a scenario worth considering was "plausibility" rather than "probability." As Gulledge wrote in that piece:

> Given the uncertainty in calculating climate change, and the fact that existing estimates may be biased low at this time, plausibility is an important measure of future impacts. Under this umbrella of plausibility, potential changes that the IPCC or other assessments may characterize as improbable are considered plausible here if significant uncertainty persists regarding their probability…[62]

A third application to the climate security arena is provided by the National Intelligence Council's 2020 Report, which specified four future states of the world, several of which had to do with climate change and energy systems.[63]

Scenario analysis provides an important corrective to overreliance on contemporary states of the world for information and guidance about the future. Purposively identifying potential surprises and thinking through the consequences of unlikely events can help decision-makers prepare for rare, unlikely events. However, as Wright and Goodwin point out, a scenario may not actually shake people out of current mindsets and merely serve to reinforce them. Moreover, scenarios may fixate the minds of participants on those situations to make

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[61] See, for example, http://www.shell.com/home/content/aboutshell/our_strategy/shell_global_scenarios/what_are_scenarios/what_are_scenarios_30102006.html

[62] (Gulledge 2007, 35).

[63] See http://www.dni.gov/nic/NIC_2020_project.html

them appear more likely than they actually are.[64] Moreover, as Busby pointed out in his work, scenarios that rely on the most uncertain and least likely effects of climate change to build a case for security connections may be less useful than studies that take conservative estimates of the most probable consequences of climate change. If one can identify clear connections between climate change and security outcomes using restrictive assumptions where critics still question the basic science of the problem, then the question becomes is it better overstate or understate the significance of a problem.[65] In terms of assessing the likely security consequences of climate change, it is unclear how to judge between the quality of competing narratives. Having taken part in a number of scenario exercises, we have found that participants often have trouble suspending disbelief and spend as much time questioning the likelihood that we will end up in the state of the world in the scenario.

Section IV: Vulnerability Assessments and Africa

Vulnerability assessments are another approach to evaluate the potential security consequences of climate change, allowing analysts to map the sources of vulnerability spatially. Vulnerability is frequently identified with susceptibility to losses. According to the IPCC's Fourth Assessment, vulnerability is defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity."[66] Such a definition obscures the important social and political determinants of vulnerability that may dramatically exacerbate the human consequences of extreme weather or seismic events, like a

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64 (Wright and Goodwin 2009).
65 (Busby 2008).
66 (See Endbox 2 IPCC 2007c, 21).

Hurricane Katrina or the 2010 Haitian earthquake. In this section, I review the rationale behind vulnerability assessments and provide a brief review of our methods before discussing the results.

Why Vulnerability Assessments

In our approach, we capture a static snapshot of long-run vulnerability, what best approximates what Burg called "chronic vulnerability" rather than emergent, dynamic processes.[67] Other organizations, like the World Food Programme and the United Nations, have parallel efforts to document and map emergent vulnerability to drought and famines. Relying on near real-time data on precipitation, food supplies, crop yields, market prices, and other indicators, these vulnerability diagnoses have a shorter shelf-life and are used for short-term prediction and resource mobilization.[68]

We see a different value-added in our approach which utilizes a basket of sources of vulnerability—physical, household/community, governance and political violence, and demographic.[69] Rather than try to predict a narrowly defined security outcome—violent conflict—or create a suite of scenarios that observers may challenge as unlikely, we aim to identify the persistent sources of vulnerability from diverse perspectives that may make particular places less able to cope with climate change. The aim is not to just show that Ethiopia is vulnerable to climate change at the country level but which parts of Ethiopia are vulnerable and why. Our approach uses a weighted index of four baskets to spatially represent sub-national vulnerability using the map-making properties of ArcGIS software. We are somewhat

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[67] (Burg 2008).
[68] (World Food Programme 2009; United Nations 2009).
[69] This section is based on an 2009 conference paper by (Busby, Smith, and White 2009). See that piece for a full methodology.

agnostic about what form the security consequences might take; our approach enables analysts to narrow down the areas of concern, both for fieldwork to "ground truth" and test the sources of vulnerability developed from datasets as well as to guide policy interventions to the priority areas of key concern.

Brief Survey of Methods

Like the historical analogue work, our vulnerability assessments in their first incarnation largely relied on historic data – on disaster incidence, on household and community vulnerability (using health and education indicators), on governance and political violence (using statistics from the World Bank and other outlets), and on population. We weighted each basket equally, and each basket had a number of sub-indicators indicative of underlying phenomena that we thought relevant to a country's overall vulnerability (see Table I).

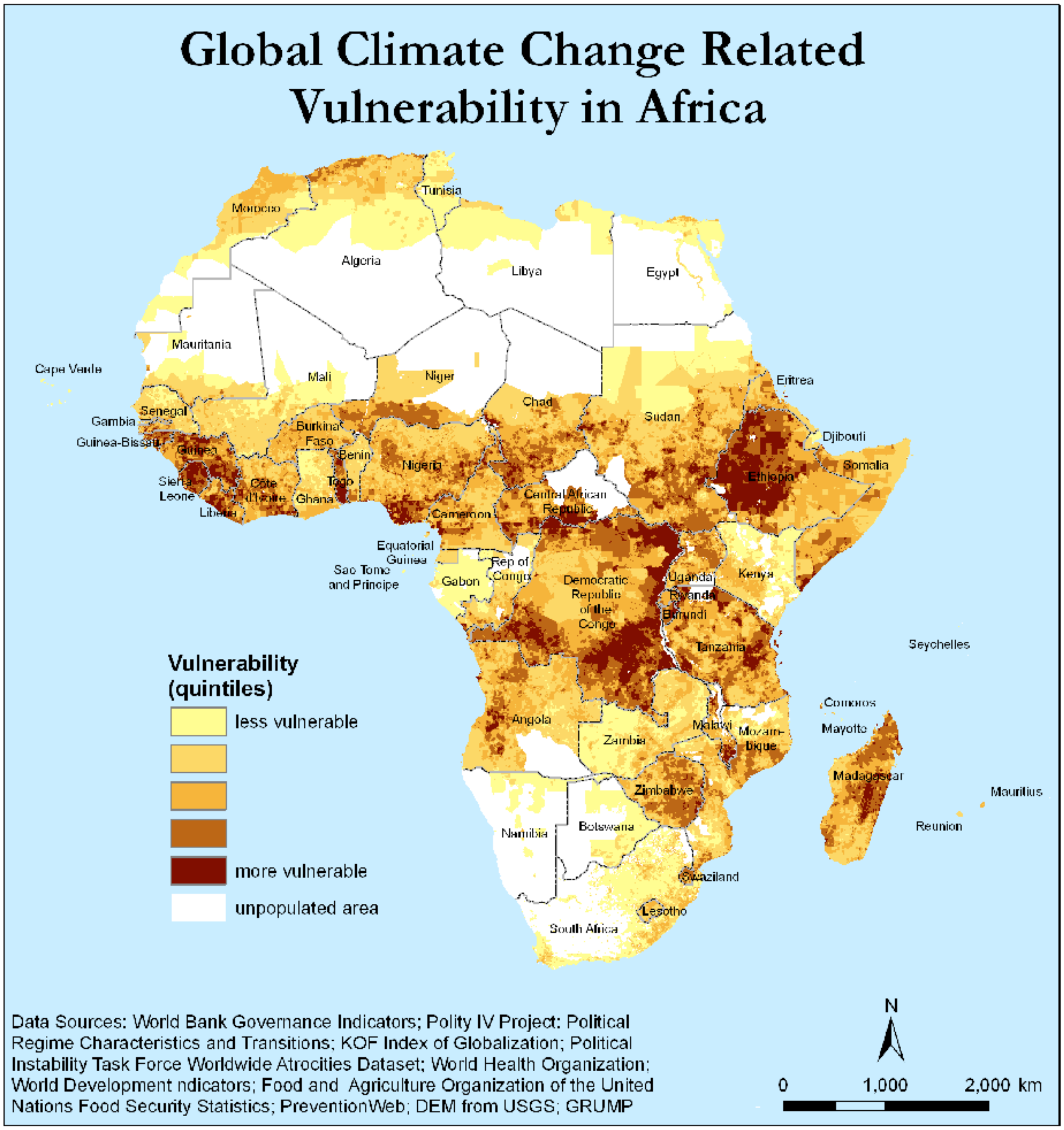
While sub-national level data was not available for every indicator, our aim was to be broadly representative of the diverse sources of vulnerability and the natural routes of response to the physical manifestation of climate change, beginning first at the individual and community level proceeding to the governmental level where local capacities for self-protection are overcome by the severity of the climate event. To make these indicators and baskets comparable, we converted each into quintiles of relative vulnerability, such that countries and sub-national units in Africa are compared against African averages. As a consequence, a country or sub-national unit might appear positive because it ranks highly within Africa, though its status relative to the rest of the world might still remain poor.

Table I: Index of Vulnerability to Climate Change

Basket	Indicators	Sources
Physical Vulnerability (25%)	•Disasters •Cyclone surge frequency •Cyclone wind frequency •Flood frequency •Drought frequency •Wildfires frequency •Future Vulnerability •Low-elevation coastal zones	Preventionweb US Geological Survey
Household Community/ Vulnerability (25%)	•Education •Literacy rate •School enrollment •Health •Adjusted Infant Mortality •Life expectancy •Daily necessities •Percent of children under 5 who are underweight •% access to clean water •Access to health care •Per capita spending on health •Nursing and midwifery density	World Development Indicators Center for International Earth Science Network World Health Organization
Governance and Political Violence (25%)	•Governance (80%) •Government Effectiveness •Voice and Accountability •Global Integration •Political Stability •Volatility in regime •Years since last major change •Political Violence (20%) •Atrocities	World Bank Polity IV KOF Index of Globalization Political Instability Task Force
Population (25%)	Population Density	GRUMP – Gridded Population of the World, Center for International Earth Science Network

Our first comprehensive maps of climate vulnerability yielded the following map (FIGURE 7):

FIGURE 7



The map shows Western Ethiopia, Madagascar, Zimbabwe, Somalia, parts of Nigeria, southern Sudan, the eastern parts of the Democratic Republic of Congo, parts of the Gold Coast, among other areas to be the most vulnerable, on the basis of historic and contemporary data.

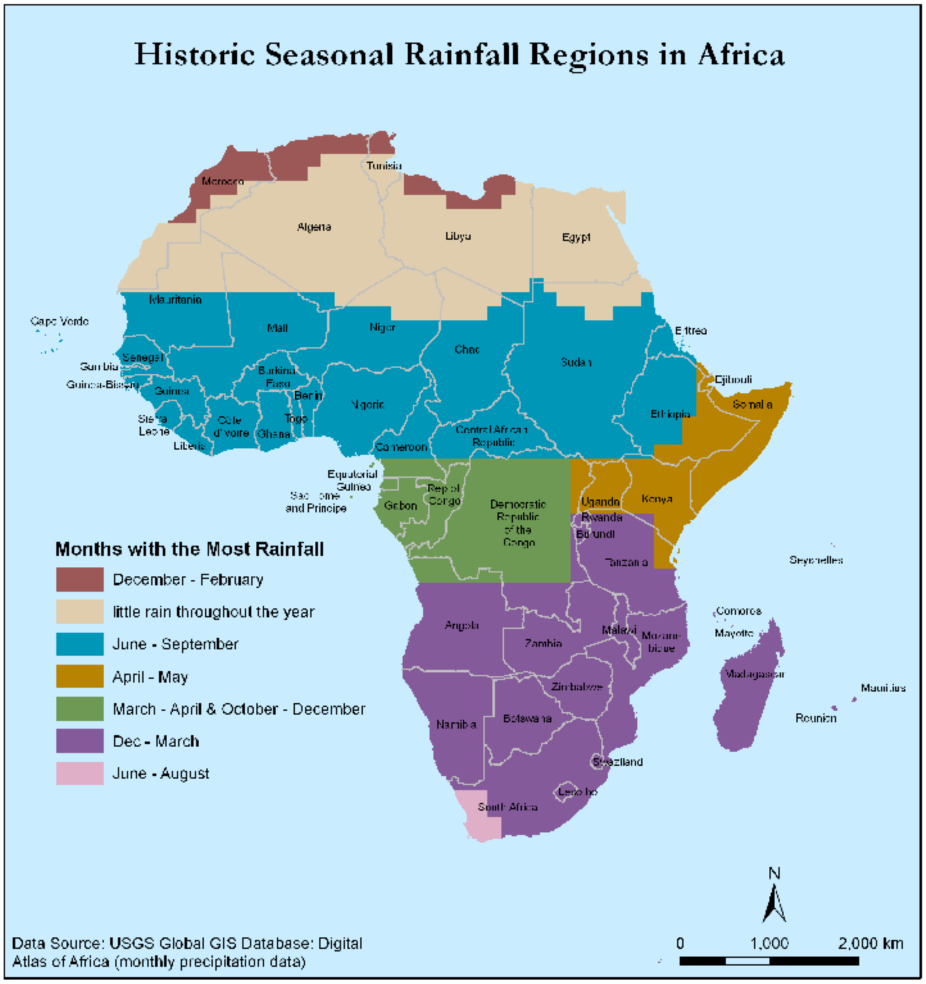
The extension for this paper, the first of many, explicitly encompasses future climate change by using model output that is available in ArcGIS. We aim to substitute the incidence of historic disasters with projections of future climate change to see how different our representations of future vulnerability are from the past. To the extent areas vulnerable historically are also vulnerable in the future, we can have more confidence where to guide fieldwork and resources.

Like our previous paper, we see both efforts as a proof of concept to be refined with better data and methods as time passes. Our aim in this paper was to make use of readily available data of predicted trends in climate indicators, seeking to discover whether or not historic disaster incidence overlaps with areas that are likely to experience changes in rainfall totals or rainfall variability. For this first iteration where we employ model output, we use NCAR data from a single global circulation model, the so-called CCSM-3 (Community Climate System Model) available from http://www.gisclimatechange.org/. Hendrix and Glaser also used model output from a single model, NCAR's PCM or Parallel Climate Model. Ideally, we would have multi-model ensembles like those used by Tebaldi as well as those employed by Burke et al. Unfortunately, we still require some data transformations to be able to incorporate other model specifications in to ArcGIS. More importantly, we aim to have a regional climate model that is designed specifically for model output for Africa.

In the meantime, to demonstrate the promise of this approach, we are able to generate continent-wide projections for seasonal precipitation change and rainfall variability for the A1B high growth emissions scenario for the year 2030, compared to 1990 (both 2030 and 1990 rely on twenty year rolling averages, 2020-2039 and 1980-1999 respectively). Whereas Hendrix and Glaser assessed changes in total rainfall, compared contemporary rainfall patterns with those in 2100, we sought more short-term projections, based on time horizons that policymakers might consider to be more relevant. We also extended our coverage continent wide rather than sub-Saharan Africa. In addition, we adjusted our rainfall totals to reflect the different zones of high seasonal rains (see Figure 8). This was important because to try to closely calibrate rainfall to the planting season as it is currently known. Even as the planting season changes in terms of start date and duration, it is also important to know if the rains are projected to be fall in the same quantities and the same interannual variation. If we were to use annual data, we might imagine that rainfall could go up in some months and down in others, potentially looking like a stable pattern over the course of the year. We believed that changes in rainfall during the planting season, either in terms of total quantity or variability, would be more disruptive to agricultural planning and food security, than annual rainfall data.[70]

[70] In Figure 10, we calculate the percent change between the seasonal variation in rainfall in the period 2020-2039 and the variation in the period 1980-1999. Variation here is calculated in terms of the sum of the squared seasonal deviations from the 20-year mean. The percent change in variation therefore can go up (less stable), remain the same, or go down (become more stable).

Figure 8



When we combine this regional seasonal rainfall map with projected changes in rainfall and rainfall variation, we generate two maps (Figures 9 and 10). (In figure 9, which depicts changes in total rainfall between 1990 and 2030, we exclude areas of North Africa below the Maghreb and above the Sahel that receive little rainfall).

FIGURE 9

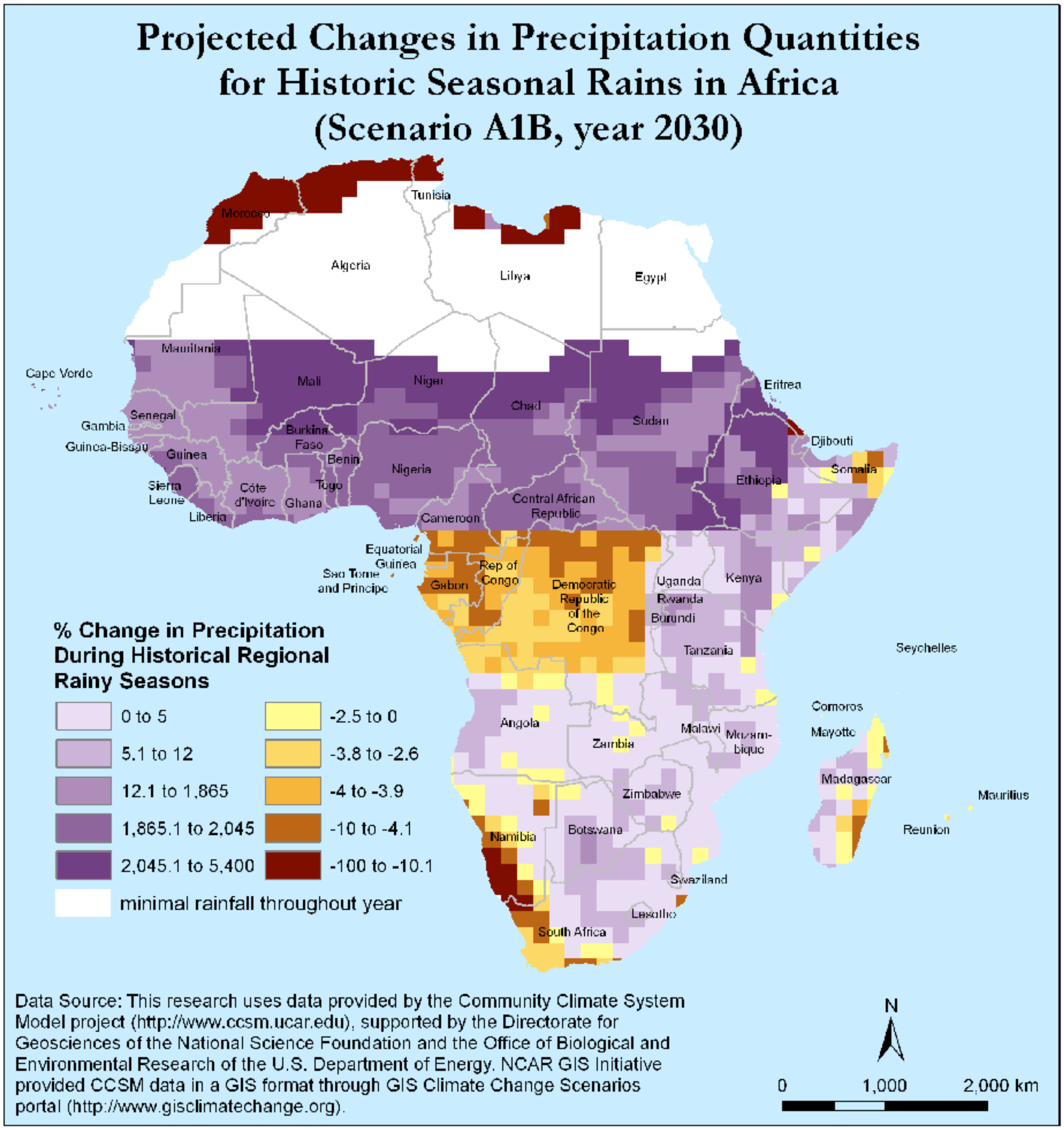
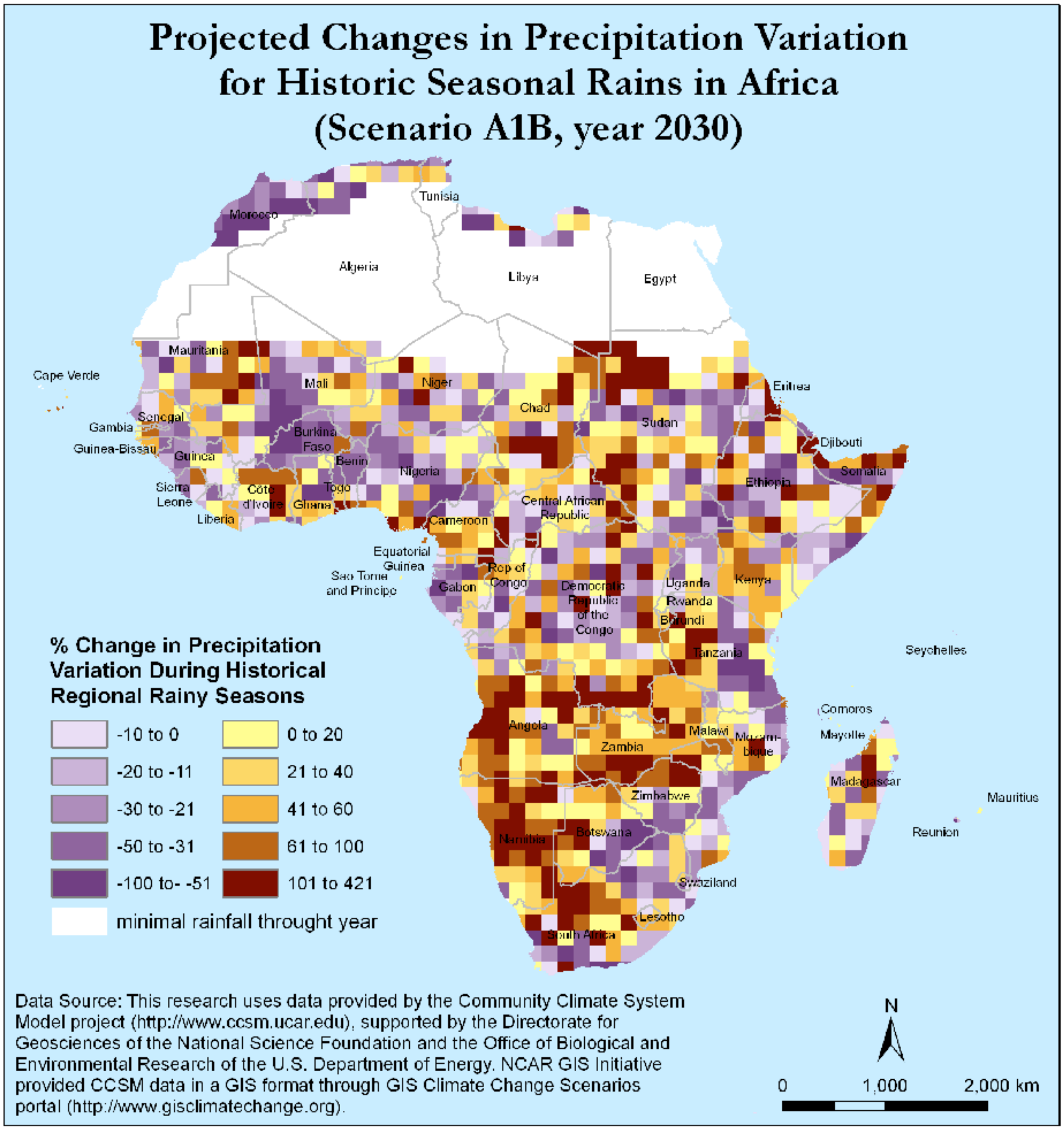

Projected Changes in Precipitation Quantities
for Historic Seasonal Rains in Africa
(Scenario A1B, year 2030)
Tunisia
Morocco
Algeria
Libya
Egypt
Mauritania
Cape Verde
Mali
Niger
Chad
Sudan
Eritrea
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Nigeria
Djibouti
Somalia
Ethiopia
Sierra Leone
Côte d'Ivoire
Ghana
Togo
Liberia
Cameroon
Central African Republic
Equatorial Guinea
Sao Tome and Principe
Gabon
Rep of Congo
Democratic Republic of the Congo
Uganda
Kenya
Rwanda
Burundi
Tanzania
Seychelles
Comoros
Mayotte
Angola
Zambia
Malawi
Mozambique
Madagascar
Mauritius
Zimbabwe
Reunion
Namibia
Botswana
Swaziland
Lesotho
South Africa
% Change in Precipitation During Historical Regional Rainy Seasons
0 to 5
5.1 to 12
12.1 to 1,865
1,865.1 to 2,045
2,045.1 to 5,400
minimal rainfall throughout year
-2.5 to 0
-3.8 to -2.6
-4 to -3.9
-10 to -4.1
-100 to -10.1
Data Source: This research uses data provided by the Community Climate System Model project (http://www.ccsm.ucar.edu), supported by the Directorate for Geosciences of the National Science Foundation and the Office of Biological and Environmental Research of the U.S. Department of Energy. NCAR GIS Initiative provided CCSM data in a GIS format through GIS Climate Change Scenarios portal (http://www.gisclimatechange.org).
N
0
1,000
2,000 km

FIGURE 10



Our changes in total rainfall map (Figure 9) suggests North Africa, the Congo Basin and the western Cape are particularly vulnerable to declines in rainfall, with the Sahel region experiencing an increase in the amount of seasonal rainfall as well as portions of east and southeast Afirca. Figure 10 suggests that central and southwestern Africa as well as northern

Sudan will experience the greatest degree of increased variation in rainfall. With rainfall variability associated with conflict in several previous studies, this provisional finding is disconcerting. We find that southeastern Africa is predicted to have more stable rainfall patterns, as are parts of the DRC, Western Africa and Morocco.

We view these results as extremely provisional, given that they represent model output from a single scenario and generate results that run somewhat counter to Hendrix and Glaser as well as the application of model output from Tebaldi using more multi-ensemble methods.[71] In this work, southern Africa is projected to be nearly uniformly drier than our findings would suggest (Figures 11 & 12).

FIGURE 11: Hendrix and Glaser Rainfall Trends Projection

C.S. Hendrix, S.M. Glaser / Political Geography 26 (2007) 695–715

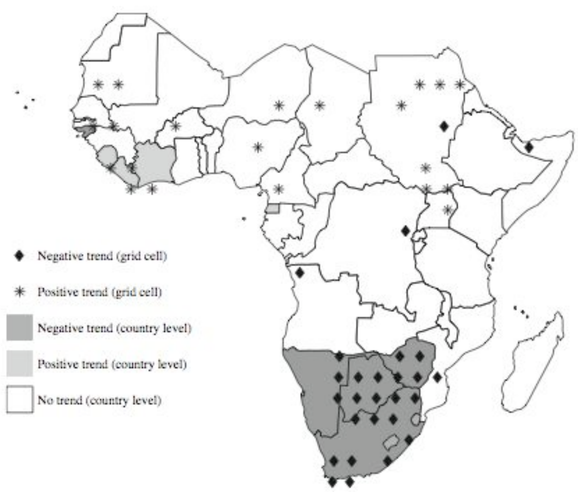
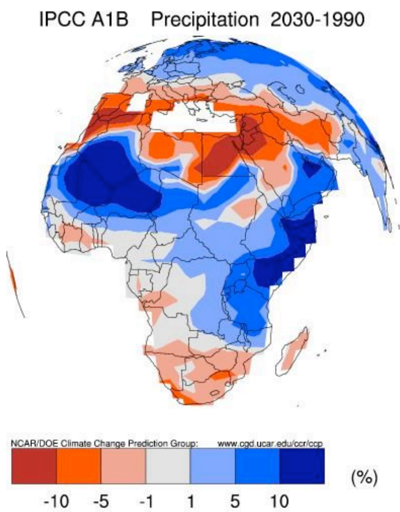


Fig. 4. Effects of spatial aggregation on total annual rainfall estimates, 2000–2099, Scenario A1B.

[71] The application of Tebaldi to a shorter time-horizon is from http://www.cgd.ucar.edu/ccr/climate_change_gallery_test/

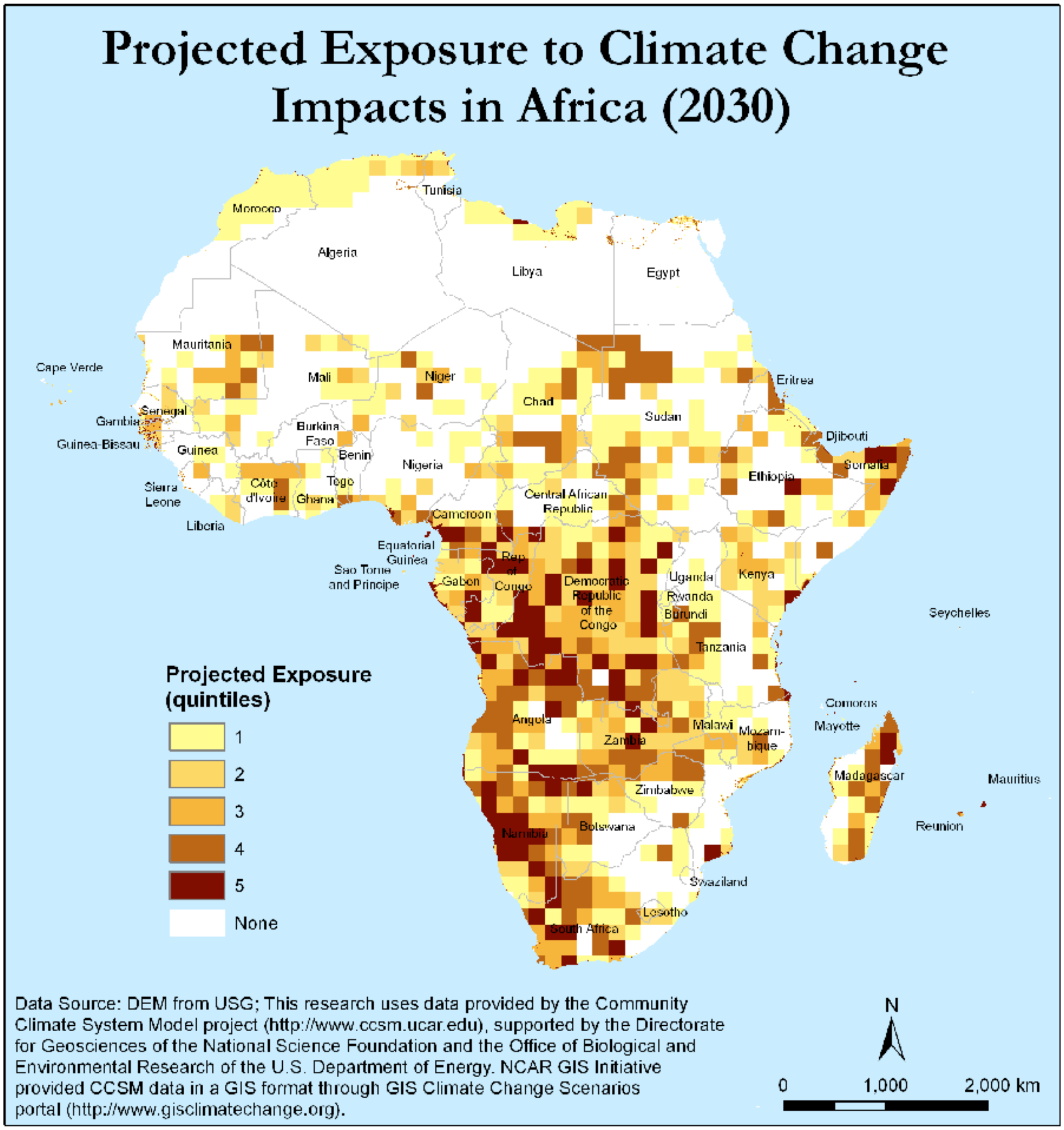
FIGURE 12: Tebaldi Rainfall Change Projection



From these maps of rainfall changes and variation, we then generated new maps of overall vulnerability. Rather than make heroic assumptions about rates of change in health and education as well as patterns of governance and political violence, we take contemporary values for two of the three remaining baskets of vulnerability. We do not believe continent wide extrapolations for such processes are likely to be, at this stage, much more than speculation. Improvements in health and education are likely to be uneven within, let alone between countries. We thought it deeply problematic to try to impose a uniform set of assumptions about rates of change. For other phenomena, such as population, for which demographic information and models of change have an established track record, we were open to refinement, using projections from the GRUMP database.

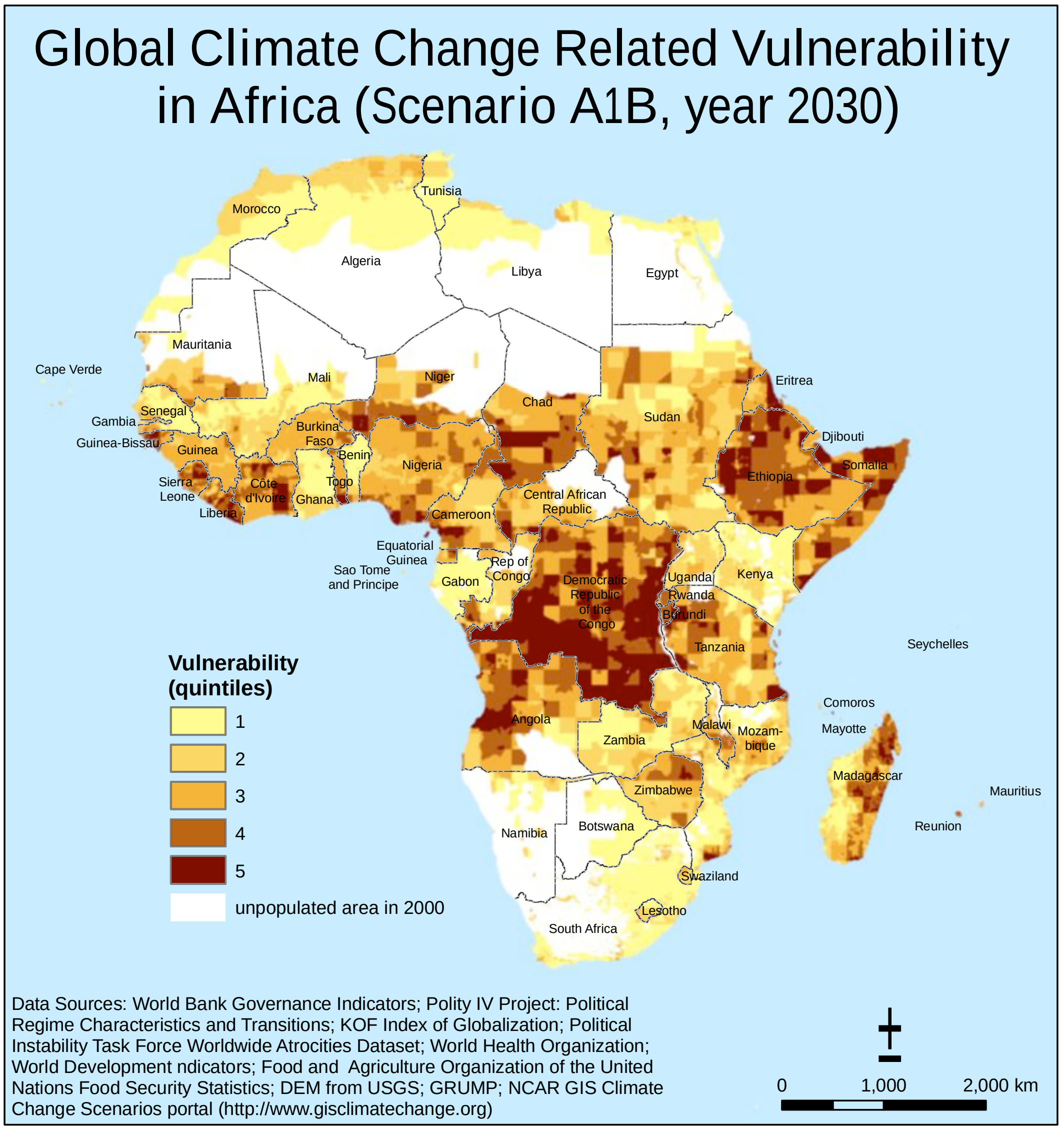
We calculated a new model of future physical exposure combining (1) low elevation coastal zones (2) changes in total rainfall and (3) changes in rainfall variation (Figure 13). We find that on the basis of these indicators generated by this particular climate model that the central western and southern part of Africa around the DRC is most vulnerable to climate change.

Figure 13



We then calculate total vulnerability by substituting the exposure data for the natural disaster data (Figure 14). In this context, the new map of overall vulnerability is not strictly comparable with Figure 7 since it only reflects a couple of indicators of precipitation and one for low elevation coastal zones. Nonetheless, the patterns for these particular indicators suggest future exposure will be concentrated in the DRC, Ethiopia, Somalia, Angola, and in pockets through West Africa.[72]

Figure 14



[72] The patterns, taking into account, projected future population density in 2015 are similar. Results upon request.

Conclusions

Rainfall deviations on their own are not fully dispositive of water access issues. A parallel vulnerability effort by Levy et al. has performed similar analysis. Looking at projections of sea-level rise, aggregate temperature rise, and water scarcity, Levy et al. incorporated a number of political/governance variables including a country's crisis history, the degree of violence in its neighborhood, and its capacity. Of particular interest is the final physical indicator, water scarcity, which would reflect the importance we might attach to countries like Egypt with low total rainfall but reliant on runoff or river systems with distant origins. Because our rainfall data excludes the low rainfall areas in the Sahara extending over to Egypt, we are likely to exclude an area of high population and potentially high climate vulnerability.[73] We certainly need a corrective for Egypt with additional indicators of future climate vulnerability.

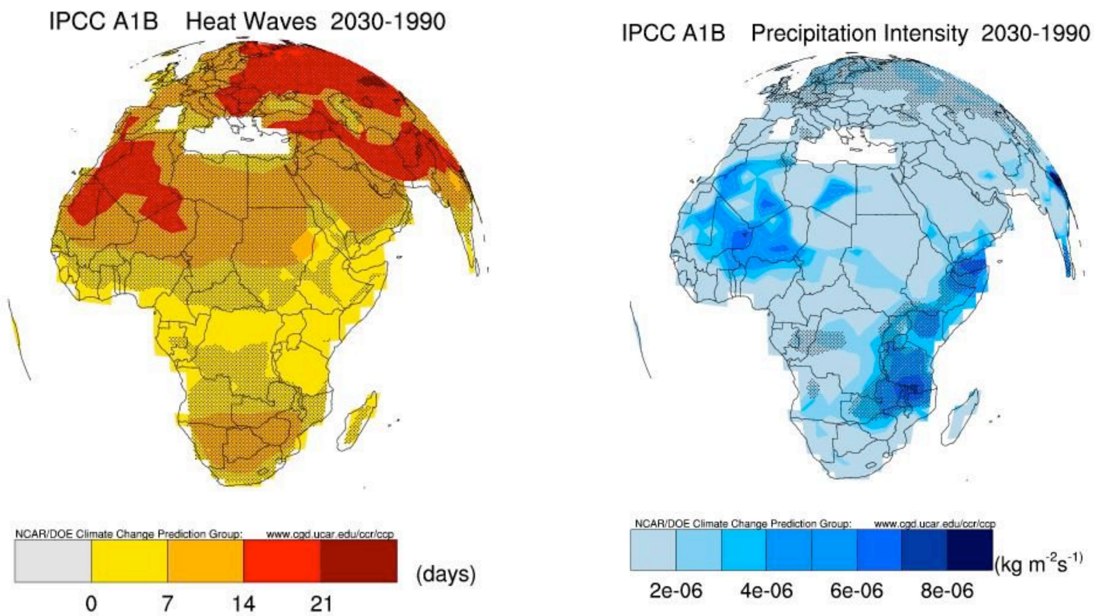
Other related refinements are likely important. For example, we classify countries that are projected to have the most negative rainfall change (and the greatest positive percentage change in variation) as the most vulnerable. However, a country that experiences an increase in rain above historic means may fare just as poorly as a country that gets too little rain. Beyond extension of this work to multi-model ensembles, river systems/water availability and more nuanced accounts of rainfall change, we therefore aim to collect data on extreme weather events.

Tebaldi has generated model output of extreme precipitation and temperature events for GCMs; this is an important template for the regional climate models we hope to develop.[74] Buja, based on Tebaldi's study, has represented a number of projections for 2030 for extreme weather events in Africa. While promising, these require, some manipulation to import into

[73] (Levy et al. 2008).
[74] (Tebaldi et al. 2006).

ArcGIS. Nonetheless, some of the patterns are striking. In Figure 15, two extreme weather event projections for 1990-2030 for Africa from Buja's visualization of Tebaldi's work are presented. These show concentrations of heat waves in West Africa along the Morocco coast with heavy precipitation events in the area as well as along the eastern coast of southern Africa.[75]

FIGURE 15: Heat Waves and Precipitation Intensity



In additions to these additions to our overall vulnerability approach are a host of others including incorporation of ethnic marginalization, expanded sub-national data on household and community vulnerability, as well as indicators of the strategic importance of particular places, based on the location of oil wells, mines, etc. Finally, we aim to subject this entire model to a range of sensitivity analyses to see how much the final maps change with different assumptions.

To the extent that these models are transparent about methods, including the deficiencies in the sources of data, we hope to avoid some of the more sharp criticism that has

75 (Buja and Arblaster 2006).

been directed towards predictive models and scenarios. Given that predictive models (or projections) like the Burke et al. piece base their findings on global circulation models that may not adequately capture regional dynamics in Africa either historically or prospectively, we should question whether or not their future projections of temperature and precipitation are likely adequate. Moreover, since such approaches rely on assumptions about the rate of economic growth and political development for their estimates of conflict incidence and battle deaths, we should be particularly skeptical of specific numerical projections for security outcomes, particularly where the causal mechanisms are still only loosely fleshed out and are not accompanied by process-tracing of historical cases. In employing vulnerability assessments that get at the diverse sources of sub-national susceptibility to losses from climate change, we hope our maps and methodology prove to be useful spatial representations to guide considerations of climate and security in the scholarly community as well as among policymakers.

References

Baettig, M.B., M. Wild, and D.M. Imboden. 2007. A climate change index: Where climate change may be most prominent in the 21st century. *Geophysical Research Letters* 34:L01705.

Buhaug, Halvard, Nils Petter Gleditsch, and Ole Magnus Theisen. 2008. Implications of Climate Change for Armed Conflict World Bank.

Buja, Lawrence, and Julie Arblaster. 2006. A Climate Change Gallery: Changes in Key Climate Means and Extremes between 1990's and the 2030's. http://www.cgd.ucar.edu/ccr/climate_change_gallery_test/.

Burg, Jericho. 2008. Measuring populations' vulnerabilities for famine and food security interventions: the case of Ethiopia's Chronic Vulnerability Index. *Disasters* 32 (4):609-630.

Burke, Marshall B., Edward Miguel, Shanker Satyana, John A. Dykema, and David B. Lobell. 2009. Warming increases the risk of civil war in Africa *Proceedings of the National Academy of Sciences* 106 (49):20670-20674.

Busby, Josh. 2008. Who Cares About the Weather? Climate Change and U.S. National Security. *Security Studies* 17 (3):468-504.

Busby, Joshua. 2009a. Feeding Insecurity? Poverty, Weak States, and Climate Change In *Confronting Poverty: Weak States and U.S. National Security*, edited by S. Rice, C. Graff and C. Pascual. Washington, DC: Brookings Institution Press.

———. 2009b. The Climate Security Connection: What It Means for the Poor. In *Climate Change and Global Poverty: A Billion Lives in the Balance?*, edited by L. Brainard, A. Jones and N. Purvis. Washington, DC: Brookings Institution.

Busby, Joshua, Todd G. Smith, and Kaiba White. 2009. Locating Climate Insecurity: Where Are the Vulnerable Places in Africa? Paper read at Climate Change, Social Stress and Violent Conflict, November 19-20, at Hamburg, Germany.

Campbell, Kurt M., Jay Gulledge, J.R. McNeill, John Podesta, Peter Ogden, Leon Fuerth, R. James Woolsey, Alexander T.J. lennon, Julianne Smith, Richard Weitz, and Derek Mix. 2007. *The Age of Consequences*. CSIS/CNAS, November. Available from http://www.csis.org/media/csis/pubs/071105_ageofconsequences.pdf.

CCSP. 2008. Weather and Climate Extremes in a Changing Climate. Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. . edited by T. R. Karl. Washington, D.C.: Department of Commerce, NOAA's National Climatic Data Center, .

CNA Corporation. 2007. *National Security and the Threat of Climate Change* [cited July 8 2007]. Available from http://securityandclimate.cna.org/report/.

Cook, Kerry, and Edward K. Vizy. 2006. Coupled Model Simulations of the West African Monsoon System: Twentieth- and Twenty-First-Century Simulations *Journal of Climate* 19:3681-3703.

Engelhaupt, E. 2007. Models underestimate global warming impacts *Environmental Science & Technology* 41:4488-4489.

Fagan, Brian M. 2004. *The long summer : how climate changed civilization*. London: Granta Books.

Füssel, Hans-Martin. 2009. An updated assessment of the risks from climate change based on research published since the IPCC Fourth Assessment Report. *Climatic Change* 97:469-482.

Garvin, David A., and Lynne C. Levesque. 2005. A Note on Scenario Planning. Cambridge: Harvard Business School.

Gleditsch, Nils Petter, Ragnhild Nordås, and Idean Salehyan. 2007. *Climate Change and Conflict: The Migration Link*. International Peace Academy, May. Available from http://www.ipacademy.org/asset/file/169/CWC_Working_Paper_Climate_Change.pdf.

Gulledge, J. 2008a. Three plausible scenarios of future climate change,. In *Climatic Cataclysm: The Foreign Policy and National Security Implications of Climate Change*, edited by K. Campbell. Washington, DC: Brookings Institution Press.

Gulledge, Jay. 2007. Three Plausible Scenarios of Future Climate Change. In *The Age of Consequences*, edited by K. M. Campbell, J. Gulledge, J. R. McNeill, J. Podesta, P. Ogden, L. Fuerth, R. J. Woolsey, A. T. J. lennon, J. Smith, R. Weitz and D. Mix. Washington, DC: CSIS/CNAS.

Gulledge, Jay 2008b. Climate Change Risks in the Context of Scientific Uncertainty. In *The Global Politics of Energy* edited by K. M. Campbell and J. Price. Washington, DC: The Aspen Institute.

Hendrix, Cullen S., and Sarah M. Glaser. 2007. Trends and Triggers: Climate Change and Civil Conflict in Sub-Saharan Africa. *Political Geography* 26 (6):695-715.

IPCC. 2007a. *Climate Change 2007: Synthesis Report, An Assessment of the Intergovernmental Panel on Climate Change.* . Cambridge: Cambridge University Press.

———. 2007b. *Fourth Assessment Report -- Regional Climate Projections*. Contribution of Working Group I to the Fourth Assessment Report [cited July 8 2007]. Available from http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Pub_Ch11.pdf.

———. 2007c. Summary for Policymakers. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. v. d. Linden and C. E. Hanson. Cambridge: Cambridge University Press.

Jansen, E., et al. 2007. Paleoclimate. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller. Cambridge: Cambridge University Press.

Kalaugher, L. 2008. Warming of Indian Ocean threatens food supply. (July 10), environmentalresearchweb.org.

Knutson, T.R. , and R.E. Tuleya. 2004. Impact of CO2-induced warming on simulated hurricane intensity and precipitation: sensitivity to the choice of climate model and convective parameterization. *Journal of Climate* 17:3477-3495.

Levy, Marc A., Bridget Anderson, Melanie Brickman, Chris Cromer, Brian Falk, Balazs Fekete, Pamela Green, Malanding Jaiteh, Richard Lammers, Valentina Mara, Kytt MacManus, Steve Metzler, Maria Muñiz, Thomas Parris, Randy Pullen, Catherine Thorkelson, Charles Vorosmarty, Wil Wollheim, Xiaoshi Xing, and Greg Yetman. 2008. *Assessment of Select Climate Change Impacts on U.S. National Security*. Center for International Earth Science Information Network (CIESIN), Columbia University, July 1 [cited July 20 2008]. Available from http://www.ciesin.columbia.edu/documents/Climate_Security_CIESIN_July_2008_v1_0.ed.pdf.

Levy, Marc A., Catherine Thorkelson, Charles Vörösmarty, Ellen Douglas, and Macartan Humphreys. 2005. *Freshwater Availability Anomalies and Outbreak of Internal War: Results from a Global Spatial Time Series Analysis*. Human Security and Climate Change Conference [cited August 26 2006]. Available from http://www.cicero.uio.no/humsec/papers/Levy_et_al.pdf.

McHenry, H.M 2009. Human Evolution. In *Evolution : the first four billion years*, edited by M. Ruse and J. Travis. Cambridge, Mass.: Belknap Press of Harvard University Press.

Meehl, G.A. 2007. Global Climate Projections. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller. Cambridge: Cambridge University Press.

Miguel, E., S. Satyanath, and E. Sergenti. 2004. Economic shocks and civil conflict: an instrumental variables approach. *Journal of Political Economy,* 112 (4):725-753. .

Milly, P.C.D. 2008. Stationarity is dead: Whither water management? *Science* 319 (573-574).

Nel, Philip, and Marjolein Righarts. 2008. Natural Disasters and the Risk of Violent Civil Conflict. *International Studies Quarterly* 52 (1):159–185.

Niang, I., A. Nyong, and B. Clark. 2007. Vulnerability, impacts, and adaptation to climate change. In *Global Change Processes and Impacts in Africa: A Synthesis*, edited by e. a. L. Otter. Washington, DC: International START Secretariat.

Nordås, Ragnhild, and Nils Petter Gleditsch. 2009. IPCC and the climate-conflict nexus. Paper read at International Studies Association, February 15-18, at New York.

Nordås, Ragnild, and Nils Petter Gleditsch. 2007. Climate change and conflict. *Political Geography* 26 (6):627-638.

O'Reilly, Catherine M., Simone R. Alin, Pierre-Denis Plisnier, Andrew S. Cohen, and Brent A. McKee. 2003. Climate change decreases aquatic ecosystem productivity of Lake Tanganyika, Africa. *Nature* 424:766-768.

Ogilvy, Jay, and Peter Schwartz. 2004. Plotting Your Scenarios Global Business Network. http://www.gbn.com/consulting/article_details.php?id=24.

Patricola, Christina M., and Kerry H. Cook. 2009. Northern African climate at the end of the twenty-first century: an integrated application of regional and global climate models *Climate Dynamics*.

Patz, Jonathan A., Diarmid Campbell-Lendrum, Tracey Holloway, and Jonathan A. Foley. 2005. Impact of regional climate change on human health. *Nature* 438:310-317.

Rahmstorf, S. 2007. A semi-empirical approach to projecting future sea-level rise. *Science* 315:368-370.

Rahmstorf, Stefan, Anny Cazenave, John A. Church, James E. Hansen, Ralph F. Keeling, David E. Parker, and Richard C. J. Somerville. 2007. Recent climate observations compared to projections. *Science* 316:709.

Raleigh, Clionadh, and Lisa Jordan. 2008. Climate Change, Migration and Conflict Paper read at American Political Science Association, August 28-31, at Boston, MA.

Raleigh, Clionadh, and Henrik Urdal. 2007. Climate change, environmental degradation and armed conflict *Political Geography* 26 (6):674-694.

Rockström, J. 2009. A safe operating space for humanity. *Nature* 461:472-475.

Rosenzweig, C. , D. Karoly, and M. Vicarelli. 2008. Attributing physical and biological impacts to anthropogenic climate change. *Nature* 453:353-358.

Schoemaker, Paul J.H. 1991. When and How to Use Scenario Planning: A Heuristic Approach with Illustration *Journal of Forecasting* 10:549-564.

Schwartz, Peter, and Doug Randall. 2003. An Abrupt Climate Change Scenario and Its Implications for United States National Security. Emeryville, CA: Global Business Network.
Seidel, D. et al. 2008. Widening of the tropical belt in a changing climate. . *Nature Geoscience* 1:21 – 24.
Tebaldi, Claude, Katharine Hayhoe, Julie M. Arblaster, and Gerald A. Meehl. 2006. Going to the Extremes: An Intercomparison of Model-Simulated Historical and Future Changes in Extreme Events *Climatic Change* 79:185-211.
Thiesen, Ole Magnus, Helge Holtermann, and Halvard Buhaug. 2009. Drought, Political Exclusion, and Civil War. Paper read at Climate Change, Social Stress and Violent Conflict, November 19-20, at Hamburg, Germany.
Thompson, Clive. 2009. Can Game Theory Predict When Iran Will Get the Bomb? *New York Times*, August 12.
United Nations. 2009. *Global Impact and Vulnerability Alert System*. United Nations, July 6. Available from www.un.org/sg/GIVAS/backgrounder.pdf.
Walter, K. M., S. A. Zimov, J. P. Chanton, D. Verbyla, and F. S. Chapin III. 2006. Methane Bubbling from Siberian Thaw Lakes as a Positive Feedback to Climate Warming. *Nature* 443:71-75.
World Food Programme. 2009. Climate and Disaster Risk Solutions. World Food Programme.
Wright, George, and Paul Goodwin. 2009. Decision making and planning under low levels of predictability: Enhancing the scenario method *International Journal of Forecasting* 25:813–825.