Of Climate Change and Crystal Balls

The Future Consequences of Climate Change in Africa

Joshua W. Busby, PhD*
Jay Gulledge, PhD
Todd G. Smith, JD
Kaiba White

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—the continent that has contributed least to human-induced alteration of the global climate—is

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*Dr. Joshua Busby, who holds a PhD in government from Georgetown University, is an assistant professor at the LBJ School of Public Affairs at the University of Texas–Austin and the Crook Distinguished Fellow at the Robert S. Strauss Center for International Security and Law. One of the lead researchers on a $7.6 million Department of Defense–funded grant on Climate Change and African Political Stability through the Strauss Center, he has written extensively on climate and security for such venues as *Security Studies*, the Brookings Institution, the Council on Foreign Relations, the German Marshall Fund, and the Woodrow Wilson International Center for Scholars. He served as an outside reviewer for the 2008 National Intelligence Assessment on climate change and US national security. The 2011 Defense Science Board report on this topic cited his work. Prior to coming to the University of Texas, Dr. Busby was a Research Fellow at the Center for Globalization and Governance at Princeton University's Woodrow Wilson School, the Belfer Center for Science and International Affairs at Harvard University's John F. Kennedy School of Government, and the foreign policy studies program at the Brookings Institution.

Dr. Jay Gulledge is the senior scientist and director for science and impacts at the Center for Climate and Energy Solutions, a nonresident Senior Fellow at the Center for a New American Security, and a Next Generation Fellow of the American Assembly at Columbia University. A certified senior ecologist, he has two decades of experience teaching and conducting research in the biological and environmental sciences. His scientific research examines the biological mechanisms and social drivers of greenhouse gas exchange between ecosystems and the atmosphere. After 16 years in academic research, Dr. Gulledge shifted his focus to the science/policy interface, informing policy makers, business leaders, the public, and the press about the science and impact of global environmental change and approaches for managing the associated risks. After earning a PhD at the University of Alaska–Fairbanks, he was a Life Sciences Research Foundation Postdoctoral Fellow at Harvard University, subsequently holding faculty posts at Tulane University and the University of Louisville. In 2011 he received the American Geophysical Union's Charles S. Falkenberg Award and was nominated for George Mason University's Climate Change Communicator of the Year.

perhaps the region most vulnerable to climate change. However, model projections of the physical effects of climate change in Africa remain highly uncertain, particularly at the national and subnational spatial scales at which political processes operate. Because of Africa's almost complete dependence upon rain-fed agriculture, the uncertainty of future precipitation patterns raises special concern.[1]

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 "threat multiplier" with the potential to contribute to conflict and state failure.[2] Since most of political science concerns itself with explaining the past rather than predicting the future, scholars have looked to historic data on rainfall variability, disasters, temperature change, and human migration (all expected effects of climate change) to try to get traction on the causal connections between climate phenomena and security outcomes.

Such an approach assumes climatic "stationarity" (discussed below), a concept necessarily rejected by analysts of climate impacts as a guide to future outcomes. Two complementary approaches used by this community include 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 broader security implications of climate change; however, uncertainties in the underlying climate projections remain, and a mismatch exists between the spatial and temporal scales of available climate change projections and the questions posed by political scientists.

Using Africa as a regional focus, this article attempts to reconcile the scientific community's approach to analyzing the effects of climate change

A PhD student at the LBJ School of Public Affairs, Todd G. Smith previously worked with Médecins sans Frontières in Ethiopia and China, and with the Impumelelo Innovations Award Trust in South Africa, where he was primary author of the 10th volume in Impumelelo's Series of Best Practice, which examined environmental programmes. He holds a JD from Emory University and an MA in public affairs from the LBJ School.

Kaiba L. White is a former research associate on the Climate Change and African Political Stability program at the Robert S. Strauss Center for International Security and Law. Her professional and academic work has addressed climate change, renewable energy, and geographic information systems. She holds an MA in environmental policy and planning from Tufts University.

with the emerging approaches in political science for assessing the future security consequences of such change. It presents georeferenced maps of subnational climate vulnerability in Africa, using past exposure to climate-related hazards, population density, household and community resilience, and governance as well as political violence. The article couples this approach with projections of future climate change, employing an ensemble of five general circulation models and suggesting that maps of chronic vulnerability which incorporate a variety of indicators provide a helpful advance for international relations scholars. Specifically, such maps are less reliant on heroic assumptions about changes in political and economic systems than either forecasting or scenario analysis.

The article's first section summarizes what we know about climate change, and the second what we know about climate change in Africa. The third section discusses the limits of three strategies that 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 georeferenced maps of subnational climate vulnerability in Africa. By incorporating maps of future climate change from general circulation models, we build on our previous work that used historic incidence of climate-related hazards and a variety of indicators of population density, household and community resilience, and governance and political violence.

What We Know about Climate Change

For the purposes of this article, 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, climate determined where and how we lived. Homo sapiens emerged sometime within the past half million years, during the great Ice Age that had gripped the earth for the previous 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 12,000 years and counting, the Holocene has lasted longer than most of the previous interglacials, and humans have capitalized on this extended period of global warmth.[4]

During the Holocene, the global average temperature has varied little, and there is no evidence that the earth as a whole has been warmer than today during this time.[5] The sea level rose rapidly for thousands of years as the last glaciation ended and then stabilized between 7,000 and 3,000 years ago, offering permanent seaside locations to build fishing ports and trading centers that would become great cities.[6] Atmospheric circulation settled into consistent patterns that created breadbaskets where glaciers once stood. After more than 100,000 years of nomadism, humans began to put down roots. Within a few millennia, we transformed from nomads to modern industrialists.

Our modern societies are fortresses of security from the elements, and our survival strategy now calls for withstanding the weather in all its fury rather than retreating to more comfortable climes. The modern systems we have constructed to provide personal and economic security are largely based on the past century 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 one for our modern society precisely because we have invested in optimizing social systems to it.[7] Our great cities are near sea level; we produce our food in the breadbaskets; and we have designed our building codes, water utilities, and power plants to resist familiar weather extremes. As sea levels change, as atmospheric circulations shift, and as climate extremes intensify, society as it now exists is no longer optimized for the climate. For this reason, and as a guide to decision making about climate-sensitive systems, water and climate specialists recently declared in *Science* magazine that "stationarity is dead."[8]

Stationarity assumes that the range of climate conditions for a given area occurs within a static envelope of variability defined by past extremes. However, climate change means that future climate averages and extremes will differ from those in the past. The past, therefore, is likely to be a poor indicator of how climate risks may interact with social factors to determine future risk of social instability, conflict, and state failure. Analysts of climate impacts necessarily reject stationarity as a guide to future outcomes.

Uncertainty of Climate Projections

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 agreement among models erodes as spatial scales become smaller (fig. 1).[9] Moreover, they may systematically underestimate the responsiveness of various components of the climate system to the warming that has occurred so far.[10] Some aspects of climate that are changing more rapidly than models project include the rise of globally averaged sea level, loss of Arctic sea ice, intensification of precipitation, poleward expansion of the dry tropics, and loss of land-based ice from mountain glaciers and the Greenland and Antarctic ice sheets.[11]

Several sources of uncertainty in model projections have been summarized in detail previously.[12] First, the amount of greenhouse gases that

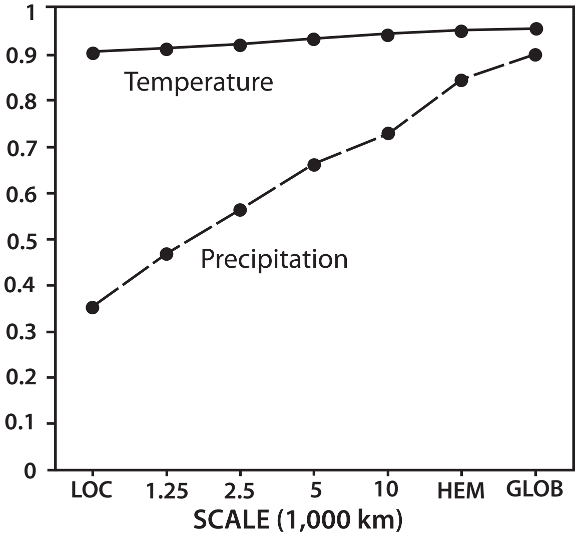

Figure 1. Relative agreement among models at different spatial scales among 21 global climate models used in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. (Adapted from Gerald A. Meehl et al., "Global Climate Projections," in *Climate Change 2007: The Physical Science Basis; Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. S. Solomon et al. [Cambridge, UK: Cambridge University Press, 2007], 806, fig. 10.27, http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter10.pdf. Note that LOC = local scale; HEM = hemisphere scale; and GLOB= global scale.)

humans will emit into the atmosphere in the future is unknown. Climate analysts have developed socioeconomic scenarios based on plausible alternative futures, but these are essentially elaborate guesses about what the future might hold—it is not possible to ascribe probability to any scenario (though business-as-usual scenarios appear likely for some years to come). Changes in other future climate forcings also remain unknown. The amounts of light-shading particles and methane in the atmosphere, volcanic eruptions, and changes in solar activity are unpredictable. Large differences in greenhouse gas emissions and other climate forcings among socioeconomic scenarios account for much of the spread in model projections.[13]

"Response uncertainty," another important contributor to uncertainty in model projections, refers to disagreement among models resulting from "the limited knowledge of how the climate system will react" to a given emissions scenario.[14] The IPCC's 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 intermodel spread among projections from 1990 to 2100 for any given emissions scenario is on the order of 2°C (i.e., the difference between the two models producing the lowest and highest projections). Considering that the G-8 (Group of Eight) has 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 about 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 produces a full uncertainty range for projected warming to 2100 of 1.1–6.4°C, with a "likely" range of 1.8–4°C.[15] The fifth assessment, scheduled for completion in 2013/2014, may well amplify the range of expected uncertainty since its models will include natural carbon cycle feedbacks in response to human-induced warming.

The phrase "full uncertainty range" is a misnomer since emissions and physical model response are not the only factors contributing to uncertainty. Another aspect of scientific uncertainty that has not been fully explored—equilibrium climate sensitivity—quantifies the amount of warming that would result from a doubling of the amount of carbon dioxide (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 "likely" lies within the range of 2.0–4.5°C and is "very likely" larger than 1.5°C.[16] All of the IPCC models calculate climate sensitivity internally. Consequently, it is not possible to use these models to perform a true risk analysis in which, for any given model, one varies the climate sensitivity to see what would happen to any or all climate variables.

Another form of uncertainty not included in projection ranges—"model structural uncertainty"—covers a host of unknown processes that may simply be missing from the models.[17] For example, some potential amplifying (positive) or dampening (negative) feedbacks are too poorly understood for inclusion in models. Take for example the potential release of billions of tons of CO_2 and methane from frozen soils (permafrost) in the Arctic.[18] As the planet warms, these soils begin to thaw, releasing additional greenhouse gases to the atmosphere and amplifying the warming trend.[19] At present, we cannot predict how much and how quickly they will release their stores of carbon. Another positive feedback not completely integrated into models involves the potential for plants and oceans to take up less CO_2 from the atmosphere in a warmer world. Negative feedbacks may also be missing from models, but the climate system appears particularly endowed with positive feedbacks, which entails heightened risk from a security assessment perspective.[20]

Climate Extremes—Not Averages—Responsible for Most 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 effects on the local climate. Although changes in local average climate conditions are important, 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, the amount of precipitation in the heaviest rain events increases more than the annual average precipitation.[21] 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 (i.e., an upper-five-percentile event) that happens only once in 40 years to every six years. Moreover, the new one-in-40-year event would be more intense (fig. 2).[22]

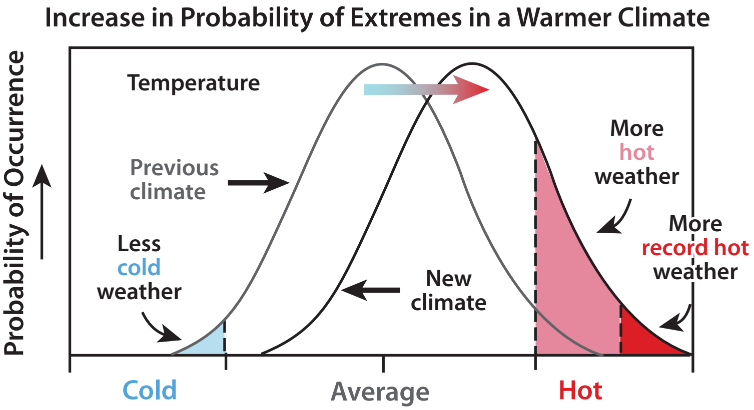

Figure 2. Simplified depiction of the changes in temperature in a warming world. (Reprinted from Thomas R. Karl et al., eds., *Weather and Climate Extremes in a Changing Climate: Regions of Focus; North America, Hawaii, Caribbean, and U.S. Pacific Islands*, Synthesis and Assessment Product 3.3, Report by the US Climate Change Science Program and the Subcommittee on Global Change Research [Washington, DC: US Climate Change Science Program, June 2008], 19, http://downloads.climatescience.gov/sap/sap3-3/sap3-3-final-all.pdf.)

For example, model experiments by Thomas Knutson and Robert Tuleya found that the most intense categories of hurricanes (categories four and five) became more frequent while weaker categories became less frequent in a modeled world with 750 parts per million (ppm) atmospheric CO_2 (fig. 3).[23] Knutson summarizes the findings of these and related studies as follows:

- Anthropogenic warming by the end of the 21st century will likely cause hurricanes globally to be more intense on average (by 2 to 11% according to model projections for an IPCC A1B scenario). This change would imply an even larger percentage increase in the destructive potential per storm, assuming no reduction in storm size.
- There are better than even odds that anthropogenic warming over the next century will lead to an increase in the numbers of very intense hurricanes in some basins—an increase that would be substantially larger in percentage terms than the 2–11% increase in the average storm intensity. This increase in intense storm numbers is projected despite a likely decrease (or little change) in the global numbers of all tropical storms.
- Anthropogenic warming by the end of the 21st century will likely cause hurricanes to have substantially higher rainfall rates than present-day hurricanes, with a model-projected increase of about 20% for rainfall rates averaged within about 100 km of the storm center.[24]

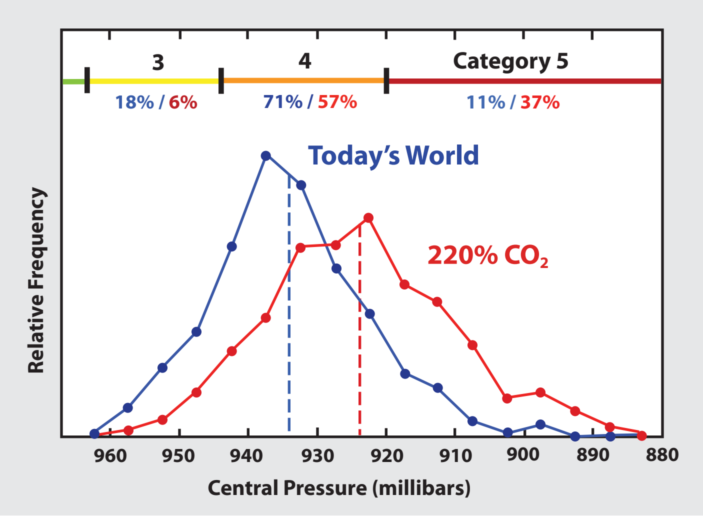

Figure 3. Frequency distributions of hurricane intensities from a climate model under "present-day" (i.e., around 1990) CO_2 concentrations (about 350 ppm) and under CO_2 increased by 220 percent (about 770 ppm). (Adapted from Thomas R. Karl et al., eds., *Weather and Climate Extremes in a Changing Climate: Regions of Focus; North America, Hawaii, Caribbean, and U.S. Pacific Islands,* Synthesis and Assessment Product 3.3, Report by the US Climate Change Science Program and the Subcommittee on Global Change Research [Washington, DC: US Climate Change Science Program, June 2008], 107, http://downloads.climatescience.gov/sap/sap3-3/sap3-3-final-all.pdf.)

What We Know about Climate Change in Africa

Climate impacts analysts broadly agree that "Africa is likely to be the continent most vulnerable to climate change."[25] Low adaptive capacity, 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.[26] The African continent warmed by about 1°C over the past century, and it is clear that human-induced climate change is well under way there, as in most other parts of the world. However, several common misconceptions about climate change in Africa limit a full understanding of the problem:

- Like other low-latitude regions of the earth, Africa has warmed less than more northern latitudes, including Europe and the Arctic. However, natural and human systems in Africa are adapted to a relatively small range of historical climate variability compared to more northerly locations. Consequently, those systems are likely to be sensitive to small changes in temperature and precipitation.[27]

- Africa has so many problems not directly caused by climate change that the latter can seem unimportant. However, it has the potential to exacerbate many of Africa's more traditional, high-priority problems, including insecurity regarding disease, water, and food.[28]
- Though often ignored, drivers of climate change other than greenhouse gases are important in much of the developing world. These include aerosols from burning wood, dung, and coal that alter atmospheric hydrology and block incoming solar radiation, thus changing the land-surface hydrology. From the standpoint of the effects on climate as well as preventing and adapting to them, these drivers of climate change are as significant as greenhouse gases and contribute strongly to current climate trends in Africa and Asia—much more so than in Europe and the Americas.[29]
- Unlike the situation for other continents with more developed economies, very little climate data exists for Africa.[30] As a result, some important climate trends in Africa have been attributed primarily to local changes in land cover but are more likely linked to large-scale climate phenomena, such as human-induced global warming and related changes in sea-surface temperatures in the North Atlantic or Indian oceans. Several scientific studies link drought intensification in the western and eastern Sahel and in southern Africa to human-induced warming of the Indian Ocean.[31] In another example, the rapid loss of glacier mass from Mount Kilimanjaro's ancient ice cap in recent decades has often been attributed to extensive deforestation around the mountain's base.[32] However, research by Thomas Mölg and colleagues found that deforestation could account for less than 20 percent of Kilimanjaro's ice loss.[33] The authors argue that changes in large-scale climate dynamics remain the best explanation for alpine glacier wasting both on Kilimanjaro and globally.
- Climate data for Africa are particularly sparse in terms of observed impacts. One can mistake the lack of data for a paucity of climate-

> driven effects but should take care not to confuse the lack of detection for the absence of impacts.[34]

Several of Africa's key vulnerabilities to climate change lie in the areas of food security (agriculture, grazing, and fisheries), water availability, health, and coastal zones.[35] The IPCC also identified several systems and sectors typical of, but not specific to, Africa as "especially affected" by climate change: Mediterranean-type ecosystems, tropical rain forests, 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 little adaptive capacity. No wonder, then, that the IPCC describes Africa generally and its heavily populated river deltas as regions especially affected by climate change.[36]

Food Security

According to the IPCC, "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."[37] Africa already struggles with food insecurity and depends heavily upon rain-fed agriculture. Although projections indicate that the main crop-producing region of Africa will receive increased average annual rainfall as a result of global warming, year-to-year temperature, precipitation, and drought extremes will likely increase as well, resulting in more variable crop yields. Elevated flooding and storm intensity together with longer and severer periods of drought are likely as larger amounts of precipitation fall in fewer, more intense events.[38] Higher temperatures alone will likely reduce crop productivity in Africa, even in areas with sufficient rainfall.[39] At low latitudes, crops already grow near or above their temperature optima, and further warming in the absence of adaptive changes to cropping systems would reduce their growth. Similarly, milk and meat production are expected to decline with further warming due to increased heat stress on livestock. Barring adaptation, decreased agricultural production will not only increase hunger but also reduce the incomes of crop and livestock producers and raise food prices, further boosting the threat of hunger.[40]

In 2007 the IPCC's AR4 stated 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."[41] Although weak evidence supported this conclusion at the time, several recent peer-reviewed studies provide stringent support for the general notion that African crop yields face substantial risk due to climate change.[42]

The European Union's ClimateCost study used IPCC climate projections to drive the ClimateCrop model to estimate country-level crop productivity changes in 2080 for maize, wheat, and rice.[43] Under a "business-as-usual" climate change scenario in which greenhouse gas concentrations rise to 712 ppm carbon dioxide equivalent (CO_2e) in 2080, model output showed net declines in crop yield of 17–42 percent in 30 African countries. The largest declines occurred in northern Africa, the Sahel, the Horn of Africa, and southern Africa. For those 30 countries, optimization of both water and fertilizer inputs (i.e., adaptation) reduced the average yield decline from 24 percent to 7 percent. In the absence of adaptation, a lower greenhouse gas concentration (498 ppm CO_2e in 2080) reduced the average loss from 24 percent to 10 percent. Combining adaptation with the lower greenhouse gas concentration lowered the average loss to 2 percent.

The threat of climate change to Africa's agriculture is not relegated to the distant future. Growing seasons have already become shorter in the Sahel, lowering crop yields.[44] A recent climatological 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 Millennium Development Goals."[45]

Other studies confirm substantial risks to African food security from climate change early this century. Available projections of climate change risks to African agriculture are relatively insensitive to time in the future, with agricultural productivity changes of plus or minus 50 percent possible by the 2030s (fig. 4). Because of this high sensitivity and large range of uncertainty, Christoph Müller and colleagues suggest that "guidance for policy can best be drawn from a risk management perspective, studying specifically the probability of high-impact scenarios."[46] Attention to the

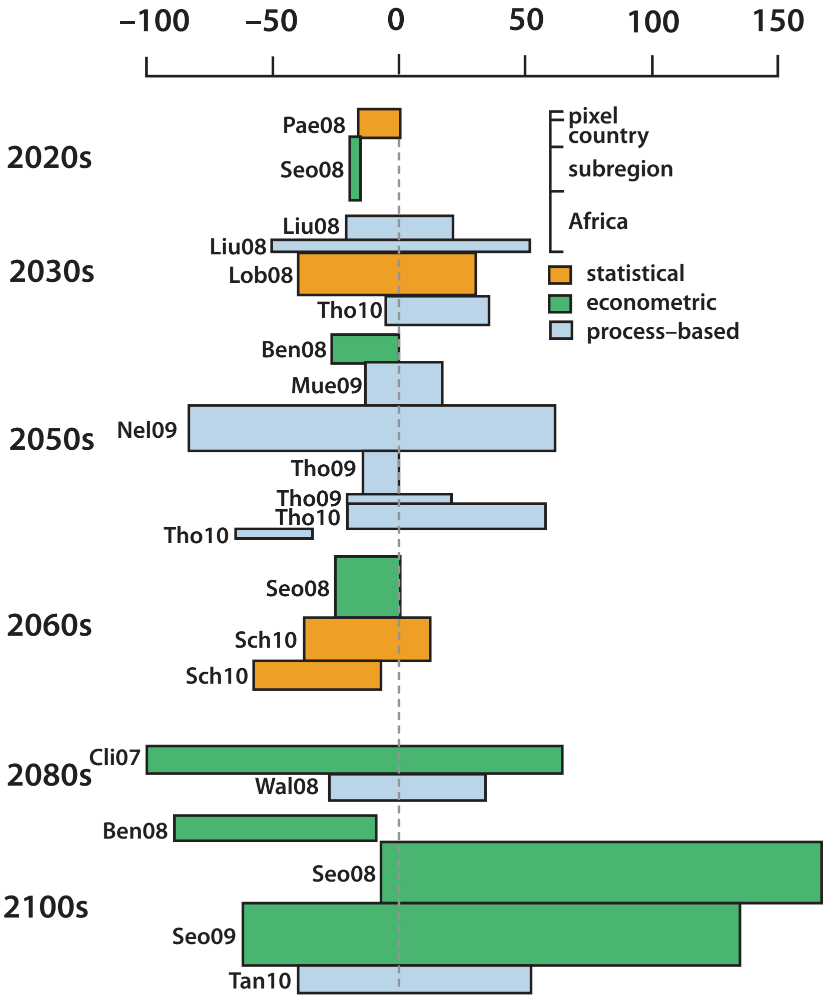

Figure 4. Various published projections of relative (percentage) changes in African agriculture from present conditions. (Reprinted from Christoph Müller et al., "Climate Change Risks for African Agriculture," *Proceedings of the National Academy of Sciences*, 28 February 2011, 2, http://www.pnas.org/content/early/2011/02/23/1015078108.full.pdf.)

Note: The width of each bar is proportional to the spatial scale covered by each projection, and colors represent different assessment methods, as shown in the legend. See Müller et al. for source studies noted in the figure.

full range of uncertainty is essential if we wish to understand how serious the risk of food insecurity might be for African societies due to near-term climate change. Thomas Hertel, Marshall Burke, and David Lobell found much larger climate change effects on food prices and poverty by 2030 than did previous studies that focused only on central tendencies or medium-impact scenarios.[47]

A large fraction of Africans rely on fish as their primary source of protein, and fisheries serve as a major source of income to coastal communities as well as those situated around inland lakes.[48] The number of fish caught is declining already as a result of overfishing, pollution, and other stresses that degrade aquatic systems. Hence, small changes in climate that alter aquatic ecosystems will likely have a deleterious effect 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 Tanganyika.[49] Once again, the effects of climate change are not limited to the distant future.

Other Impacts

Water availability and flooding. By 2050, northern, southern, and parts of western Africa will likely see moderate to extreme decreases in stream flow (runoff) (fig. 5).[50] The area of southern Africa experiencing water shortages could increase from 9 percent today to 29 percent by 2050. Reduced flow is projected for the Nile River, which supplies water for the irrigation of virtually all crops in Egypt and its neighbors. One should bear in mind that 2050 is an arbitrary marker—not the beginning of problems. Crop irrigation experiences disruption when the Nile water flow drops by 20 percent, a condition that has a 50 percent chance of becoming persistent by 2020.[51] The IPCC projects that water stress will affect 75 to 250 million Africans by 2020.[52]

Eastern Africa could see moderate to extreme increases in stream flow by 2050 (fig. 5). Greater precipitation could lead to more wet-season flooding without enhancing dry-season water availability because of expectations that the added rainfall will 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 probably will disappear by the middle of the century.[53] These glaciers have been present since the last ice age, and east African civilization has developed around the water resources they provide. Loss of these

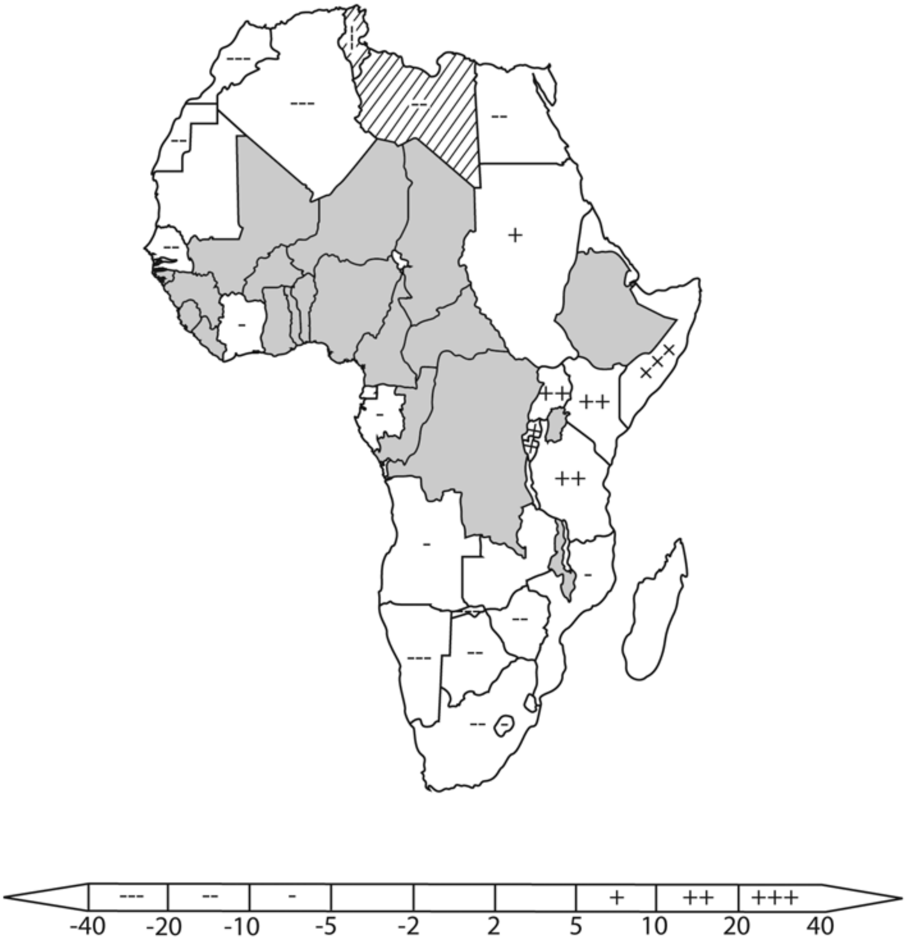

Figure 5. Projected percentage change in annual runoff in 2050 relative to the 1900–1970 average (median value from 12 climate models). (Updated from P. C. D. Milly et al., "Stationarity Is Dead: Whither Water Management?," *Science* 319, no. 5863 [1 February 2008]: 574.) A plus or minus sign indicates areas where more than two-thirds of the models agreed about the direction of change; shading indicates that fewer than two-thirds agreed; hatching indicates that more than nine-tenths of the models agreed. Minus signs indicate decreases, and plus signs indicate increases.

resources over the next few decades will have serious implications for the sustainability of east African societies. The more abundant seasonal monsoon rainfall anticipated for this region will prove useful only if it is captured and stored in reservoirs, a process requiring expensive, adaptive measures.

Health. Climate-sensitive diseases are likely to respond to climate change and may already be doing so. Malaria, cholera, and meningitis—major diseases in Africa—represent the main causes of mortality induced by climate change in Africa during the year 2000, as estimated by the World Health Organization. According to this estimation, Africa already has the highest rate of such mortality in the world, with sub-Saharan Africa the hardest hit.[54] By 2030, diarrheal diseases could increase by an additional 10 percent as a result of climate change.[55] Evidence links a current resurgence of malaria in east Africa with climate change although sparse data makes it difficult to separate various drivers of the disease.[56]

Coastal impacts. Africa has many densely populated agricultural deltas and coastal megacities. A rise in sea level, saltwater intrusion into freshwater supplies, and intensified coastal storms with higher storm surges probably will affect coastal Africa in the coming decades. Almost certainly, current models significantly underestimate a future rise in sea level.[57] Experts generally consider plausible a rise of one meter or more by the end of this century.[58] However, approximations of consequent damage and loss of life as well as associated increases in the height of storm surges use lower model-generated estimates of a rise in sea level, systematically biasing these estimates to the low side. One such estimate includes 0.5 to 17 percent of the total population of Africa's coastal countries at risk of damage, with economic damages of 6 to 54 percent of gross domestic product by the end of the twenty-first century.[59] By 2050, permanent flooding would cost Guinea 17 to 30 percent of its rice fields, assuming current projections for sea level rise and no adaptation. Given the high probability of systematically underestimating a rise in sea level, favoring the upper end of these estimated ranges seems reasonable.[60]

Analogues, Forecasts, and Scenarios in Climate Security

From these diverse and still only partially understood physical consequences of climate change, scholars seek to understand the likely effects on human health and livelihoods. Social scientists and policy analysts attempt to assess the potential security consequences of climate change, focusing mostly on the likelihood of armed conflict. They try to evaluate the security dimension by employing a variety of strategies, including historical analogues, forecasting, and scenario analysis. Although 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 examining the future consequences of climate change. 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 pitfalls.

Analogues

Political scientists, largely through quantitative studies, take the anticipated effects of climate change (such as drought, rainfall variability, disasters, temperature changes, and migration) and look for historical analogues to find correlations between those climate indicators and the onset of violent conflict, including forms of social strife such as riots and strikes. They also explore a variety of causal mechanisms by which climate effects might give rise to security outcomes and the empirical support for them. These scholars ask such important questions as whether scarcity, abundance, or variability of resource supply act as drivers of conflict and inquire about the role played by extreme weather events and the movement of environmental migrants in sparking conflict.[61]

Given the tendency in the policy and advocacy community to link climate change and security outcomes through conjecture and anecdotes—often regarded as environmental determinism—the rigor of these quantitative studies is important.[62] However, most of them can do little more than use the past and present as a guide to the future. Though optimistic about the potential for more rigorous research on the causal connections between climate and security, Ragnhild Nordås and Nils Petter Gleditsch conclude that "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."[63] That said, past exposure to droughts, floods, and other climate-related hazards may not be a good guide to future climate outcomes, as indicated by our earlier discussion of nonstationarity.[64] As Halvard Buhaug, Ole Theisen, and Gleditsch 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."[65]

The effects of climate change have historical antecedents, but 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 more convincingly than others.

Forecasting/Projections

The discipline of political science largely concentrates on the explanation of past events, employing prediction and projection more sparingly, although there are some prominent examples. Models of US presidential elections, for instance, have sought predictive power using a few key variables.[66] Bruce Bueno de Mesquita is renowned for generating predictions of international political developments for private clients, using somewhat proprietary models.[67]

In the climate security arena, a couple of studies have attempted to make more precise projections of future implications based on historical analogues. We 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.[68] Here, we reference forecasting in a narrower sense to encompass quantitative models of the future. One finds at least two notable examples of such work in the climate security arena.

First, in a special issue of the journal *Political Geography* in 2007, Cullen Hendrix and Sarah Glaser, like their peers, use historical analogues—rainfall totals and rainfall change from the previous year—to determine whether or not those variables historically have been correlated with the onset of violent conflict in sub-Saharan Africa. The implication is that if climate change leads to alterations 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. However, they found statistical support only for their "trigger" variable of rainfall change correlating with conflict onset in the period 1981–2002 rather than their "trend" variable of rainfall totals. Hendrix and Glaser extended their research by using 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 twenty-first century. Recognizing that their findings might reflect the particular operationalization of rainfall variability, they conclude that "our inability to detect widespread significant trends in rainfall triggers does not suggest a future increase in civil conflict in Sub-Saharan Africa resulting from our measure of interannual rainfall variability."[69] In their article, they merely seek to understand the potential direction of future change; unlike other approaches discussed below, they shy away from estimating the magnitude of effects on the future incidence of armed conflict.

As we note in the section on vulnerability assessments and Africa, below, this nonfinding may arise from Hendrix and Glaser's use of annual rather than seasonal rainfall data as well as the idiosyncrasies of the particular global circulation model they employ from the National Center for Atmospheric Research, which may be less accurate for Africa and possess less region-specific spatial resolution than desirable. Their work points to the challenges of extrapolating from uncertain physical models of climate change the future security consequences of such 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 inter-annual rainfall variability reflects 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 the incidence of future conflict resulting from climate change. For example, in their econometric work on temperature and conflict incidence/onset in sub-Saharan Africa, Marshall Burke and colleagues 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 subcontinent would experience a 54 percent rise in armed conflict by 2030 under their model specifications. They then suggest if the death rate of future civil wars is the same as that of historic civil wars, the conflict-specific mortality from these future conflicts would amount to a cumulative 393,000 battle deaths by 2030. In so doing, they make a number of assumptions about future states of the world in terms of nonclimatic indicators known to contribute to conflict, such as regime type and economic dynamics—namely that per capita economic growth and democratization increase linearly at the same rate as during the period 1981–2002.[70] Future rates of civil war mortality may depart dramatically from historic rates, and democratization and economic growth may not change as uniformly as the authors project.

Although one can question the likeliness of these assumptions, scholars have registered other criticisms about the approach with respect to their argument, the historical evidence, and the correlation between temperature change and the onset of civil war. As Buhaug argues, the findings may not be robust to alternative specifications of the statistical model. Extending the model beyond the study's time frame would likely yield different results since the number of conflicts in Africa declined after 1999 (with a temporary and slight uptick after 2005). In addition, 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—factors that might confirm or refute the explanation by Burke and others of the causal link between climate change and conflict. Moreover, the authors attribute the connection to the effects of agriculture on economic welfare, but the causal chain from temperature increase to declining agricultural yields to economic decline to conflict onset remains fuzzy.[71] A stronger defense of the argument would examine some country cases in their data set to show that the implicit causal chain actually reflects a series of events that precipitated conflict.[72] Although 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 and others more difficult to defend.

Scenarios

Though sometimes grouped under the broader rubric of forecasting, scenario analysis offers 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. 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 seem especially helpful for problems characterized by high uncertainty. Unlike forecasting and projection models, scenario analysis depends much less on numbers, relying more on expert opinion about the most plausible possibilities for future states of the world. Given a narrative and set of assumptions, participants in a scenario-planning exercise typically explore questions 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 make the institution more responsive to this and other problems. In other settings, the participants themselves generate scenarios. For example, different groups—often four of them—frequently receive derivatives of a single scenario, with alterations in the assumptions, leading to disparate sequences of events. The participants are asked to suspend their disbelief about the nature of the assumptions and simply react to the scenario they have before them, as if it could have happened.[73]

Scenarios have limited acceptance in political science but wider acceptance in the business community. They are ubiquitous in the climate science realm, where projections of future climate change are predicated upon different assumptions about economic growth and greenhouse gas emissions over the course of the twenty-first century. In the climate security community, scenarios have some limited application, particularly in the policy world. In a widely cited piece commissioned by the Defense Department's Office of Net Assessment, Peter Schwartz and Doug Randall try to assess the consequences for US national security in the event of abrupt climate change. Scientists consider this class of phenomena low-probability events that could possibly occur to switch off or slow down circulation of the Gulf Stream and induce the onset of another ice age, accompanied by likely plummeting of European temperatures.[74]

Jay Gulledge, one of the authors of this article, participated in another effort by the Center for a New American Security and the Center for Strategic and International Studies that examined three future scenarios to assess the security consequences of expected or severe climate change by 2040 or catastrophic climate change by 2100. In that study, "plausibility" rather than "probability" made a scenario worth considering: "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."[75] The National Intelligence Council's 2020 Project provides a third application to the climate security arena, specifying four future states of the world, several of which had to do with climate change and energy systems.[76]

Scenario analysis supplies 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 George Wright and Paul Goodwin point out, a scenario may not actually shake people out of current mind-sets but merely reinforce them. Moreover, scenarios may fixate the minds of participants on those situations to make them appear more likely than they actually are.[77] Moreover, as Josh Busby, another of the authors of this article, has pointed out, scenarios that rely on the most uncertain and least likely effects of climate change to build a case for security connections may prove 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 when critics still question the basic science of the problem, then the question becomes a matter of whether it is better to overstate or understate the significance of a problem.[78] In terms of assessing the probable security consequences of climate change, ways of judging the quality of competing narratives remain unclear. Having taken part in a number of scenario exercises, we have found that participants often have trouble suspending their disbelief and spend much of the time questioning the likelihood that we will end up in the scenario's state of the world.

Vulnerability Assessments and Africa

Vulnerability assessments, another approach to evaluating the potential security consequences of climate change, allow analysts to map the sources of vulnerability spatially. Frequently identified with susceptibility to losses, vulnerability, according to the IPCC's AR4, is "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."[79] 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 Hurricane Katrina or the Haitian earthquake of 2010. In this section, we review the rationale behind vulnerability assessments and briefly explain our methods before discussing the results.

Why Vulnerability Assessments?

In our approach, we capture a static snapshot of long-run vulnerability, approximating what Jericho Burg called "chronic vulnerability" rather than emergent, dynamic processes.[80] Other organizations, like the Famine Early Warning Systems Network, the World Food Programme, and the United Nations, have parallel efforts to document and map emergent vulnerability to drought and famine. 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.[81]

We see a different value added by our approach, which utilizes several baskets of sources of vulnerability—physical, demographic, household/community resilience, and governance and political violence.[82] 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 goal is not simply to show that Ethiopia, for example, is vulnerable to climate change at the country level, but to indicate which parts of Ethiopia are vulnerable and why. Because our work has a specific climate security focus, we emphasize a particular sort of vulnerability—the likelihood that large numbers of people may die because of exposure to extreme weather events. We are somewhat agnostic about what form the security consequences might take; these may include but are not limited to violent conflict.[83] Our approach uses a weighted index of four baskets to spatially represent subnational climate security vulnerability using the mapmaking tools of ArcGIS software. Doing so enables analysts to identify "hot spots" of long-term vulnerability and thereby narrow the areas of concern, both for "ground-truthing" the maps (during which analysts conduct field work to compare the validity of vulnerability maps developed in the computer lab with local expert opinion) and for guiding policy interventions to the priority areas of key concern.

Survey of Methods

Like the historical analogue work, our vulnerability assessments in their first incarnation largely relied on historical data—on the incidence of exposure to climate-related hazards, on population density, on household and community resilience (using health and education indicators), and on governance and political violence (using statistics from the World Bank and other outlets). We weighted each basket equally, and each one had a number of subindicators indicative of underlying phenomena that we thought relevant to a country's overall vulnerability based on a review of the literature and deductive logic (see the table below).

Although subnational-level data were not available for every indicator, we aimed for broad representation of diverse sources of vulnerability and natural routes of response to the physical manifestation of climate change, beginning at the individual and community level and proceeding to the governmental level where the severity of the climate event overcomes local capacities for self-protection. To make these indicators and baskets comparable, we converted each one into a quintile of relative vulnerability and compared countries and subnational units in Africa against all values for that given indicator in Africa. Consequently, a country or subnational unit might appear secure because it ranks highly within Africa even though its status relative to the rest of the world might remain poor. Our composite of

Table. Index of vulnerability to climate change

Basket of Climate-Related Hazard Indicators		
Hazard Type (weight)	**Data Source**	**Years of Data Used**
Cyclone Winds (.16)	United Nations Environment Programme / Global Resource Information Database (UNEP/GRID)–Europe	1975–2007
Floods (.16)	UNEP/GRID–Europe	1999–2007
Wildfires (.16)	UNEP/GRID–Europe	1997–2008
Aridity (Coefficient of Variation) (.16)	UNEP/GRID–Europe	1951–2004
Droughts (.16)	Global Precipitation Climatology Center	1980–2004
Inundation (Coastal Elevation) (.16)	Digital Elevation Model from the US Geological Survey	1996
Population-Density Basket		
Indicator (weight)	**Data Source**	**Years of Data Used**
Population Density (.25)	The population density indicator utilized the LandScan (2008) High Resolution Global Population Data Set copyrighted by UT-Battelle, LLC, operator of Oak Ridge National Laboratory under contract no. DE-AC05-00OR22725 with the United States Department of Energy.	2008

Table (*continued*)

Basket of Community and Household Resilience Indicators			
Variable (weight)	**Indicator (weight)**	**Data Source**	**Years of Data Used**
Education (.25)	Literacy rate, adult total (% of people ages 15 and above) (.125)	World Development Indicators (WDI)	2008; 2007 for Burkina Faso; 2006 for Algeria, Egypt, Mali, and Senegal; 2005 for Niger; no data for Djibouti, Republic of the Congo, or Somalia
	School enrollment, primary (% gross) (.125)	WDI	2006–9; 2004 for Gabon
Health (.25)	Infant mortality rate adjusted to national 2000 United Nations International Children's Emergency Fund (UNICEF) rate (.125)	Center for International Earth Science Information Network (CIESIN)	1991–2003
	Life expectancy at birth (years) both sexes (.125)	WDI	2008
Daily Necessities (.25)	Percentage of children underweight (more than two standard deviations below the mean weight-for-age score of the National Center for Health Statistics / Centers for Disease Control and Prevention / World Health Organization international reference population) (.125)	CIESIN	1991–2003
	Population with sustainable access to improved drinking water sources (%) total (.125)	US Agency for International Development Demographic and Health Surveys; UNICEF Multiple Indicator Cluster Surveys; WDI	Department of Human Services 2000–2008; Multiple Indicator Cluster Survey 2005–6; WDI 2008 for Algeria, Botswana, Cape Verde, Comoros, Eritrea, Mauritius, and Tunisia; WDI 2005 for Equatorial Guinea; WDI 2000 for Libya
Access to Health Care (.25)	Health expenditure per capita (current US dollars) (.125)	WDI	2007; 2005 for Zimbabwe; no data for Somalia
	Nursing and midwifery personnel density (per 10,000 population) (.125)	WDI	2004–8; 2003 for Lesotho; 2002 for Kenya

Basket of Governance and Political Violence Indicators			
Variable	**Indicator (weight)**	**Data Source**	**Years of Data Used**
Government Responsiveness	Voice and accountability (.2)	World Governance Indicators	2007, 2008, 2009
Government Response Capacity	Government effectiveness (.2)	World Governance Indicators	2007, 2008, 2009
Openness to External Assistance	Globalization index (.2)	KOF Index of Globalization	2009
Political Stability	Polity variance (.1)	Polity IV Project	1999–2008
	Number of stable years (as of 2008) (.1)	Polity IV Project	1855–2008
Presence of Violence	Battles and violence against civilians (.2)	Armed Conflict Location and Events Data Set	1997–2009

climate vulnerability yielded a map that brings the confluence of all four baskets together and shows a number of hot spots of high climate-security vulnerability, including parts of Somalia; South Sudan; the Democratic Republic of the Congo; and pockets in Ethiopia and Chad, among other areas (fig. 6).

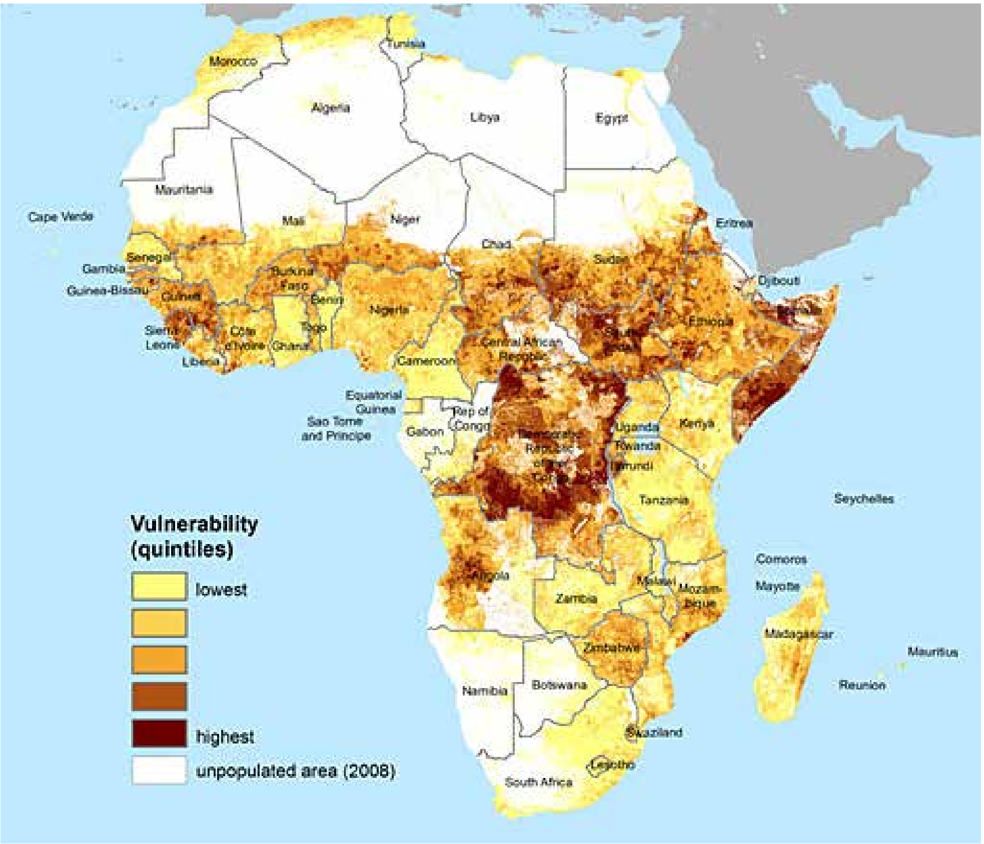

Figure 6. Composite vulnerability in Africa: Climate-related hazard exposure, population density, household and community resilience, and governance and violence. (Data from World Bank Governance Indicators; Polity IV Project: Political Regime Characteristics and Transitions; KOF Index of Globalization; Armed Conflict Location and Event Data; World Health Organization; World Development Indicators; Food and Agriculture Organization of the United Nations Food Security Statistics; UNICEF Multiple Indicator Cluster Survey; Demographic and Health Surveys; United Nations Environment Programme / Global Resource Information Database–Europe; Global Precipitation Climatology Center; Digital Elevation Model from the US Geological Survey; LandScan; and Center for International Earth Science Information Network. Map by Kaiba White, Climate Change and African Political Stability Program, August 2011.)

The challenge of such vulnerability work lies in assessing the external validity of the model weights. Our vulnerability model is not based on an underlying econometric model.[84] Data availability issues have complicated a research strategy based on statistical modeling. Our indicators combine national and subnational data, with different indicators from different years. In addition, our model seeks to identify hot spots of climate-security vulnerability, including but not limited to conflict. Thus, even if data were available to create a data set (and we are actively developing one), we would have some difficulty identifying the appropriate dependent variable.

To address questions about the adequacy of our approach, we have undertaken a variety of strategies to assess the validity of the model, including (1) fieldwork to ground-truth our maps with local expert opinion, (2) sensitivity analysis to see how our maps change with different model weights, (3) demonstration of the value added by additional baskets and indicators through the use of difference maps, (4) comparison of our findings of historic vulnerability with climate model projections of future exposure to climate change, and, data willing, (5) development of an econometric model to test the validity of our model weights.

Our composite vulnerability work already reflects the input based on fieldwork in southern and eastern Africa. In particular, we added an indicator of chronic water scarcity (the coefficient of variation) to capture arid lands that have historically proven quite vulnerable to changing weather conditions, in a way that our drought indicator—based on the Standardized Precipitation Index—simply did not capture. Elsewhere, we have presented sensitivity analysis reflecting changes in model weights as well as difference maps that show the value added by household and governance indicators compared to simpler maps of physical exposure and population.[85] The econometric model is a work in progress.

The extension in this article explicitly encompasses future climate change by using ensemble averages from five global climate models. We wish to compare the incidence of historical climate-related exposure with projections of future climate change to see how our representations of future vulnerability differ from those of the past. To the extent that areas vulnerable historically remain so in the future, we can have more confidence in where to guide fieldwork and resources. As was the case with our previous research, we see this effort as a proof of concept to be refined with better data and methods as the work progresses.

In this article, we intended to make use of readily available data from existing global climate models to assess whether or not historical incidence of exposure to climate hazards overlaps with areas likely to experience changes in rainfall. These models suffer from a number of limitations. For large parts of Africa, significant disagreement exists among climate models about the probable consequences of climate change. Most global climate models have trouble replicating climate patterns at more fine-grained resolution because of problems with taking into account local variation in topography, bodies of water, and so forth, that may create microclimates. For this reason, we have partnered with climate modelers from the University of Texas to develop a regional climate model for Africa that does a better job of validating the continent's weather patterns—that is, a model which, with minimum error, can replicate historical climate patterns in terms of annual precipitation and the seasonality and location of major rainfall events.[86] Like the econometric model, this effort is a work in progress.

In the meantime, our partners provided data for five global climate models that they considered reasonably valid for Africa: CGCM3.1, ECHAM5_MPI-OM, GFDL-CM2.0, MIROC3.2_MEDRES, and MRI-CGCM_2.3.2. Each included data from 1981 through 2000 for the 20c3m (the "20c" is for 20th century) experiment and data from 2041 through 2060 for the IPCC A1B emissions scenario.[87]

To demonstrate the promise of this approach, we generated continent-wide projections for seasonal precipitation change for the A1B emissions scenario for the year 2050, compared to that for 1990 (both 2050 and 1990 rely on 20-year rolling averages—2041–60 and 1981–2000, respectively). Whereas Hendrix and Glaser assessed changes in total rainfall, comparing contemporary rainfall patterns with those in 2100, we focused more on short-term projections, based on time horizons that policy makers might consider more relevant. Moreover, our coverage is continent-wide rather than confined to sub-Saharan Africa. In addition, we computed our precipitation totals based on only the months with the most rainfall, which vary by region (fig. 7). We did this to try to evaluate changes in rainfall during the growing season as currently known. The start date and duration of planting seasons change, so it is important to know if the rains are projected to fall in the same quantities during the growing season. If we used annual data and if rainfall went up in some months and down in others, the annual average over the course of the year might remain unchanged. We believe that changes in rainfall during the planting season will be more disruptive to agricultural planning and food security than annual variations in rainfall.

Figure 7. Historical seasonal rainfall regions in Africa. (Data from US Geological Survey Global Geographic Information System Database: Digital Atlas of Africa [monthly precipitation data]. Map by Kaiba White, Climate Change and African Political Stability Program, August 2011.)

When we utilize this regional seasonal rainfall map to calculate projected changes in precipitation, we generate figure 8. This map suggests that north Africa, the western Cape, and parts of the Sahel are particularly likely to ex-

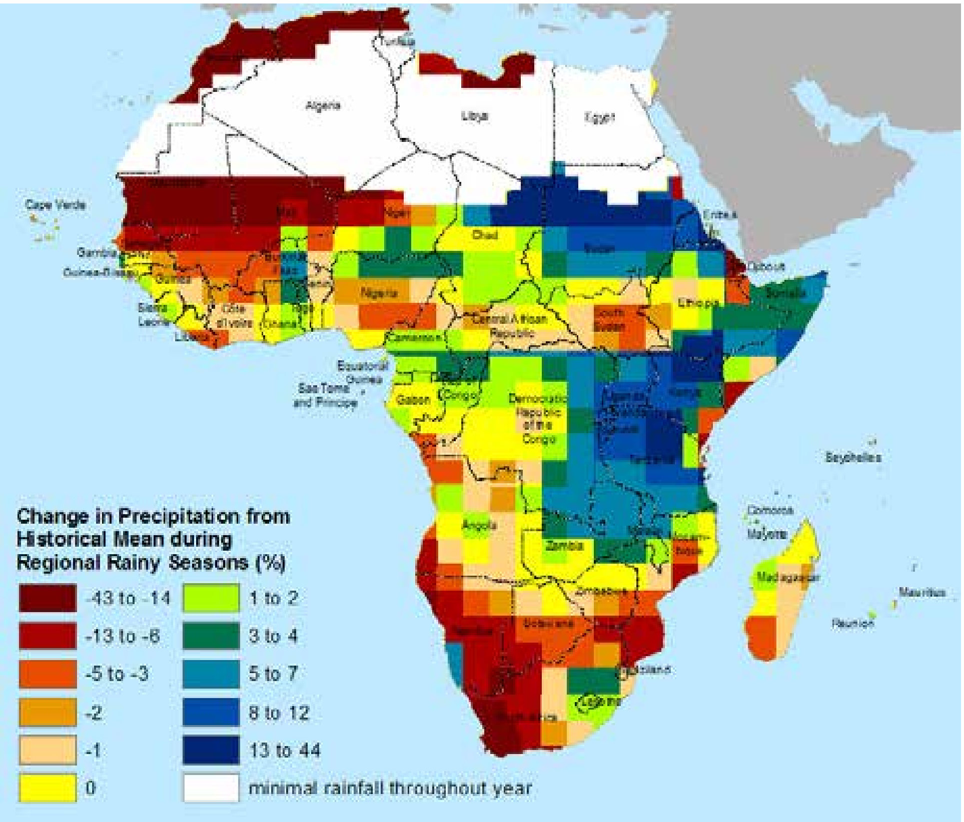

Figure 8. Projected change in precipitation quantities for seasonal rains in Africa (scenario A1B, 2041–60). (Data from five different Coupled Model Intercomparison Project, Phase 3 (CMIP3) IPCC AR4 atmosphere-ocean general-circulation models (AOGCM): CGCM3.1, ECHAM5_MPI-OM, GFDL-CM2.0, MIROC3.2_MEDRES, and MRI-CGCM_2.3.2. See "Historical seasonal rainfall regions in Africa" map [fig. 7] for rainy season timing. Map by Kaiba White, Climate Change and African Political Stability Program, October 2011.)

perience declines in rainfall, with much of east Africa as well as portions of west Africa experiencing an increase in the amount of seasonal rainfall.

We used these same data to map projected change in the variance of rainfall across the continent during the historical rainy months (fig. 9). This measure seeks to assess the volatility of future rainfall, based on the multi-model ensemble of projections for midcentury. The models project increasingly volatile rainfall across much of Sudan, parts of Somalia, Angola, Zambia, and Zimbabwe, while other areas—the Mediterranean coastline, pockets of west Africa, the Democratic Republic of the Congo, and much of South

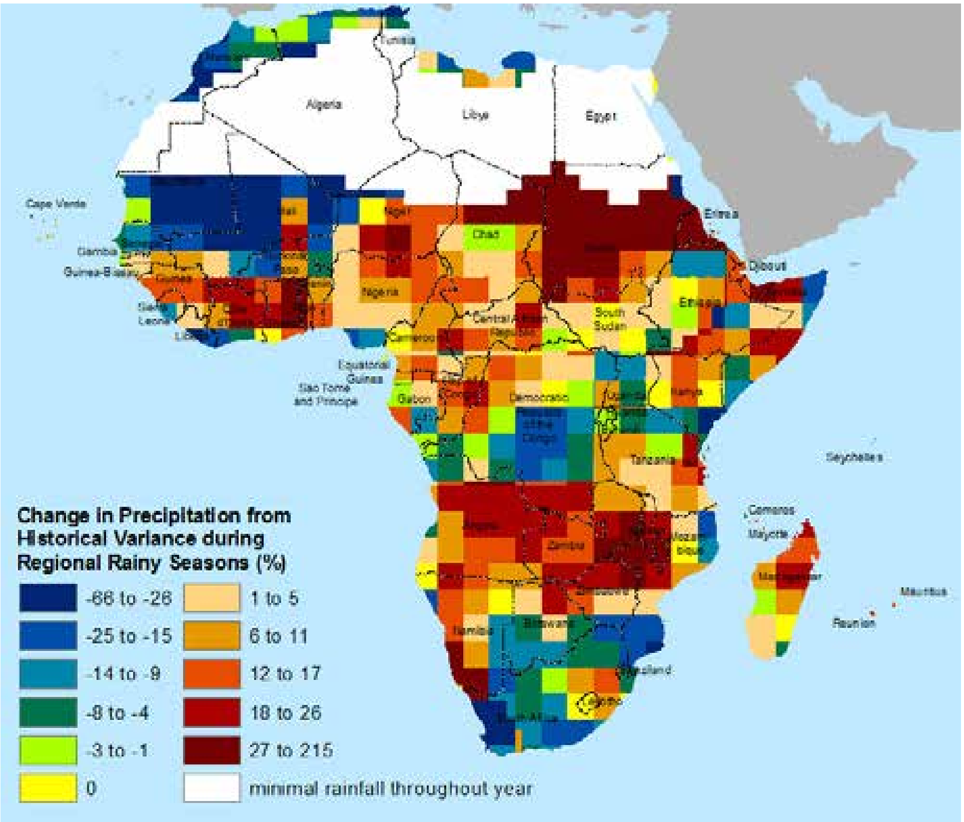

Figure 9. Projected change in precipitation variance for seasonal rains in Africa (scenario A1B, 2041–60). (Data from five different CMIP3 IPCC AR4 AOGCMs: CGCM3.1, ECHAM5_MPI-OM, GFDL-CM2.0, MIROC3.2_MEDRES, and MRI-CGCM_2.3.2. See "Historical seasonal rainfall regions in Africa" map [fig. 7] for rainy season timing. Map by Kaiba White, Climate Change and African Political Stability Program, October 2011.)

Africa—will experience less volatile rains, if these model projections are correct. This measure of seasonal rainfall is relatively crude and does not account for the possibility of changes in the seasonality of rainfall.

We consider these results provisional since they represent model output from five global climate models known to perform relatively poorly at the local level, especially in Africa. Our map of seasonal planting cycles, based on a preliminary review of the months of highest rainfall, is also fairly crude. Nonetheless, we are heartened that the results here mirror the regional patterns discussed in other studies, including the negative trend for rainfall in southern Africa in Hendrix and Glaser's study as well as the application of model output from a study by Claudia Tebaldi and colleagues using more multiensemble methods (figs. 10 and 11).[88] Consistent with the two other studies, our work also shows increased rainfall over much of east Africa.

How do our projections of future exposure to climate change compare to historical climate-related hazard exposure? Obviously, projected change in precipitation is but a single indicator and does not include the full suite of hazards in our climate hazard basket. Nonetheless, projections of significant negative percentage changes in rainfall most closely match our measures of drought (fig. 12) and the coefficient of variation (fig. 13). They are not perfect measures. More rainfall in some places could reflect increased likelihoods of floods rather than enhanced agricultural potential. In our collaborative work with climate modelers at the University of Texas, we are developing a variety of indicators that more closely approximate flooding, drought events, and heat-wave days. Regardless, for the purposes of this article, when we compare historical exposure to drought (measured by the Standardized Precipitation Index [SPI]) and areas of chronic water scarcity (captured by the coefficient of variation [CV]), we observe some areas of overlap.

Across all four maps (figs. 8, 9, 12, and 13), north Africa has a consistent profile. Climate models project declining rainfall in the future for this region, which has historically experienced significant episodes of drought and a chronic scarcity of water. In two of three maps (figs. 8 and 13), southern Africa has a similar profile in terms of climate projections of decreased precipitation during the rainy season and chronic water scarcity. Other regions show discontinuity. East Africa and the Horn experience chronic water scarcity but may benefit from additional rains with climate change. With the latter popularly identified as one of the major causes of the current drought in the Horn of Africa but with global climate models projecting increased rainfall over most of east Africa, this difference between historical exposure and projections bears further scientific scrutiny.

Rainfall changes on their own are not fully dispositive of water-access issues. A parallel vulnerability effort by Marc Levy and colleagues has performed similar analysis. Looking at projections of sea-level rise, an increase in aggregate temperature, and water scarcity, they incorporate a number of political/governance variables, including a country's crisis history, the degree

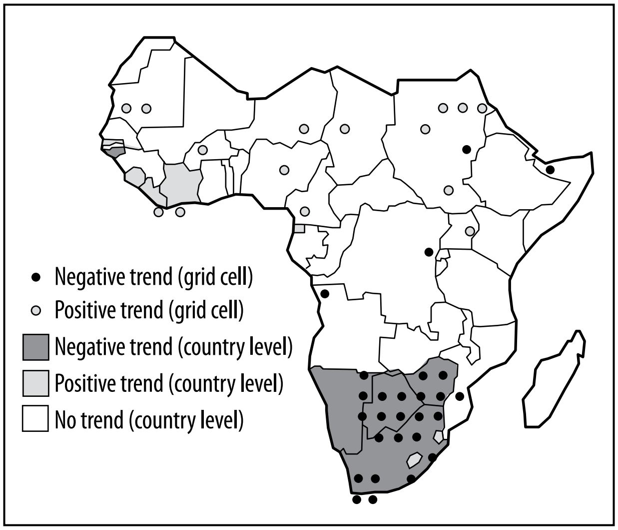

Figure 10. Hendrix and Glaser's rainfall trends projection: Effects of spatial aggregation on total annual rainfall estimates, 2000–2099, scenario A1B. (From Cullen S. Hendrix and Sarah M. Glaser, "Trend and Triggers: Climate Change and Civil Conflict in Sub-Saharan Africa," *Political Geography* 26, no. 6 [August 2007]: 710.)

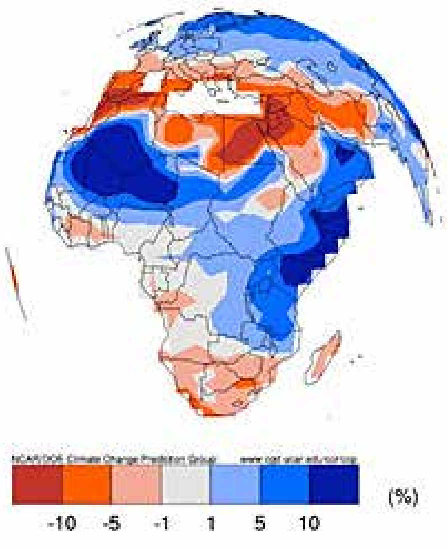

Figure 11. Tebaldi rainfall change projection: IPCC A1B, precipitation, 1990–2030. (From the National Center for Atmospheric Research / Department of Energy Climate Change and Prediction Group, http://www.cgd.ucar.edu/ccr/climate_change_gallery_test/pr.africa.htm.)

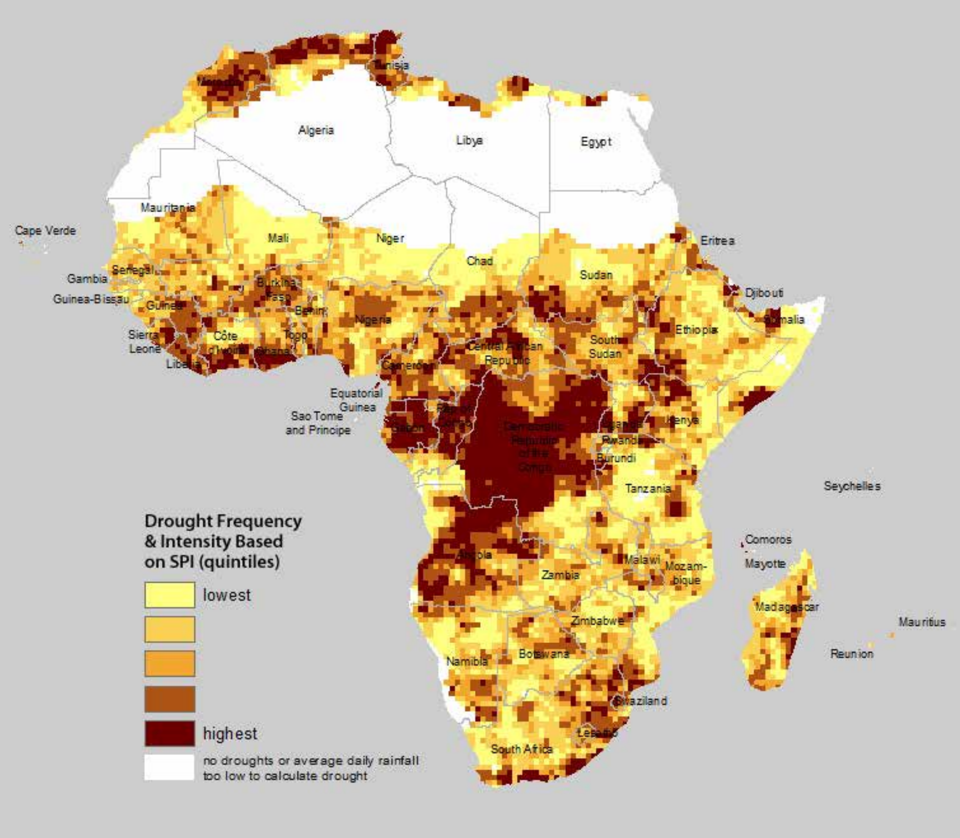

Figure 12. Drought frequency and intensity in Africa, 1980-2004. (Data from Global Precipitation Climatology Center. Map by Kaiba White, Climate Change and African Political Stability Program, November 2011.)

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 probably omit an area of high population and potentially high climate vulnerability.[89] We certainly need a corrective for Egypt with additional indicators of future climate vulnerability.

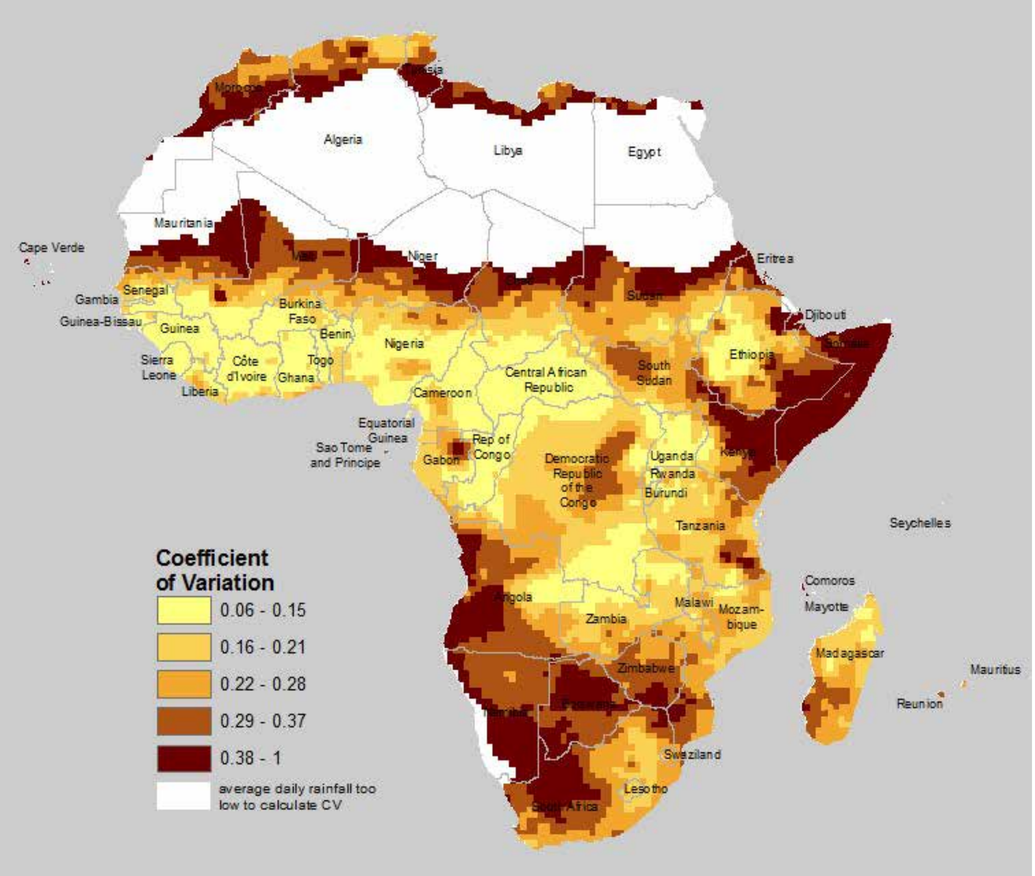

Figure 13. Precipitation coefficient of variation in Africa, 1951–2004. (Data from United Nations Environment Programme / Global Resource Information Database–Europe. Map by Kaiba White, Climate Change and African Political Stability Program, November 2011.)

Conclusion

To the extent that our vulnerability work is transparent about methods, including deficiencies in the sources of data, we seek to avoid some of the sharper criticism directed towards predictive models and scenarios. Our maps of complex vulnerability draw on historic physical exposure and diverse demographic, social, and political sources of vulnerability. By overlaying projections of future climate change, we have tried to identify the location and nature of the places within Africa most vulnerable to climate change in the future. We hope that our maps and methodology offer helpful spatial representations to guide considerations of climate and security in the scholarly community as well as among policy makers. Though hard to disentangle from other causes, the effects of climate change already are upon us, suggesting that we may soon have some additional evidence that allows us to evaluate the usefulness of our maps.

Notes

1. The contributions by Busby, Smith, and White are based upon work supported by, or in part by, the US Army Research Laboratory and the US Army Research Office under contract/grant number W911NF-09-1-0077.

2. CNA Corporation, *National Security and the Threat of Climate Change* (Alexandria, VA: CNA Corporation, 2007), http://www.cna.org/reports/climate; and Kurt M. Campbell et al., *The Age of Consequences: The Foreign Policy and National Security Implications of Global Climate Change* (Washington, DC: Center for Strategic and International Studies / Center for a New American Security, November 2007), http://www.csis.org/media/csis/pubs/071105_ageofconsequences.pdf.

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