

Warming increases the risk of civil war in Africa

Marshall B. Burke^{a,b,1}, Edward Miguel^c, Shanker Satyanath^d, John A. Dykema^e, and David B. Lobell^b

^aDepartment of Agricultural and Resource Economics and ^cDepartment of Economics, University of California Berkeley, Berkeley CA 94720; ^dDepartment of Politics, New York University, New York, NY 10012; ^eSchool of Engineering and Applied Sciences, Harvard University, Cambridge MA 02138; and ^bProgram on Food Security and the Environment, Stanford University, Stanford CA 94305

Edited by Robert W. Kates, Independent Scholar, Trenton, ME, and approved October 14, 2009 (received for review July 16, 2009)

Armed conflict within nations has had disastrous humanitarian consequences throughout much of the world. Here we undertake the first comprehensive examination of the potential impact of global climate change on armed conflict in sub-Saharan Africa. We find strong historical linkages between civil war and temperature in Africa, with warmer years leading to significant increases in the likelihood of war. When combined with climate model projections of future temperature trends, this historical response to temperature suggests a roughly 54% increase in armed conflict incidence by 2030, or an additional 393,000 battle deaths if future wars are as deadly as recent wars. Our results suggest an urgent need to reform African governments' and foreign aid donors' policies to deal with rising temperatures.

civil conflict | climate change

More than two-thirds of the countries in sub-Saharan Africa ("Africa" hereinafter) have experienced civil conflict since 1960 (1), resulting in millions of deaths and monumental human suffering. Understanding the causes and consequences of this conflict has been a major focus of social science research, with recent empirical work highlighting the role of economic fluctuations in shaping conflict risk (2). Combined with accumulating evidence on the potentially disruptive effects of climate change on human enterprise, such as through possible declines in global food production (3) and significant sea level rise (4), such findings have encouraged claims that climate change will worsen instability in already volatile regions (5–7).

Despite a growing research effort, however, linkages between climate change and conflict remain uncertain, however. Most existing studies linking the 2 variables have focused on the role of precipitation in explaining conflict incidence, finding past conflict in Africa more likely in drier years (2, 7). Given that African countries remain highly dependent on rain-fed agriculture for both employment and economic production, with agriculture accounting for more than 50% of gross domestic product and up to 90% of employment across much of the continent (8), this focus on precipitation is understandable. But such a focus bears uncertain implications for changes in conflict risk under global climate change, as climate models disagree on both the sign and magnitude of future precipitation change over most of the African continent (9). This uncertainty confuses efforts aimed at building a more comprehensive understanding of the human costs of climate change, and planning appropriate policy responses.

While global climate model predictions of future precipitation vary widely, predictions of future temperatures are more uniform, particularly over the next few decades. With recent studies emphasizing the particular role of temperature in explaining past spatial and temporal variation in agricultural yields and economic output in Africa (10, 11), it thus appears plausible that temperature fluctuations could affect past and future conflict risk, but few studies have explicitly considered the role of temperature. An analysis of historical climate proxies since 1400 C.E. finds that long-term fluctuations of war frequency follow cycles of temperature change (12); however, the relevance of this to modern-day Africa is uncertain.

We provide quantitative evidence linking past internal armed conflict incidence to variations in temperature, finding substantial increases in conflict during warmer years, and we use this relationship to build projections of the potential effect of climate change on future conflict risk in Africa. To explore the direct role of climate in explaining the historical risk of conflict, we use a panel regression of climate variation and conflict events between 1981 and 2002 (see *Methods*). Our model relates country-level fluctuations in temperature and precipitation to the incidence of African civil war, defined as the use of armed force between 2 parties, one of which is the government of a state, resulting in at least 1,000 battle-related deaths (13). Consistent with previous studies (2, 7), and to capture the potentially delayed response of conflict to climate-induced economic shocks (due to, e.g., the elapsed time between climate events and the harvest period), we allow both contemporaneous and lagged climate variables to affect conflict risk.

Results

Temperature variables are strongly related to conflict incidence over our historical panel, with a 1 °C increase in temperature in our preferred specification leading to a 4.5% increase in civil war in the same year and a 0.9% increase in conflict incidence in the next year (model 1 in Table 1). Relative to the 11.0% of country-years that historically experience conflict in our panel, such a 1 °C warming represents a remarkable 49% relative increase in the incidence of civil war.

Despite the prominence of precipitation in past conflict studies, this temperature effect on conflict is robust to the inclusion of precipitation in the regression (model 2 in Table 1) and also robust to explicit controls for country-level measures of per capita income and democracy over the sample period (model 3 in Table 1)—factors highlighted by previous studies as potentially important in explaining conflict risk (1, 14–16). We also find the effect of temperature is robust to various alternative model specifications, including models with and without lags (Table S1); specifications using alternative transformations of climate variables, such as first differences or deviations from country trend (Table S2); the use of alternative climate data sets (Table S3); models including climate leads as well as lags (Table S4); models using conflict onset rather than incidence as the dependent variable (Table S5); and alternate specifications using the income and democracy controls (Table S6). Following the agricultural impact literature (3, 11), we also explore whether climate variables averaged over agricultural areas and during growing-season months provide a better signal, finding mixed results (Table S7). Finally, we find little evidence of nonlinear effects of climate variables on conflict incidence (Table S8).

Author contributions: M.B.B., E.M., S.S., J.A.D., and D.B.L. designed research, performed research, analyzed data, and wrote the paper.

The authors declare no conflicts of interest.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

¹To whom correspondence should be addressed. E-mail: marshall.burke@berkeley.edu.

This article contains supporting information online at www.pnas.org/cgi/content/full/0907998106/DCSupplemental.

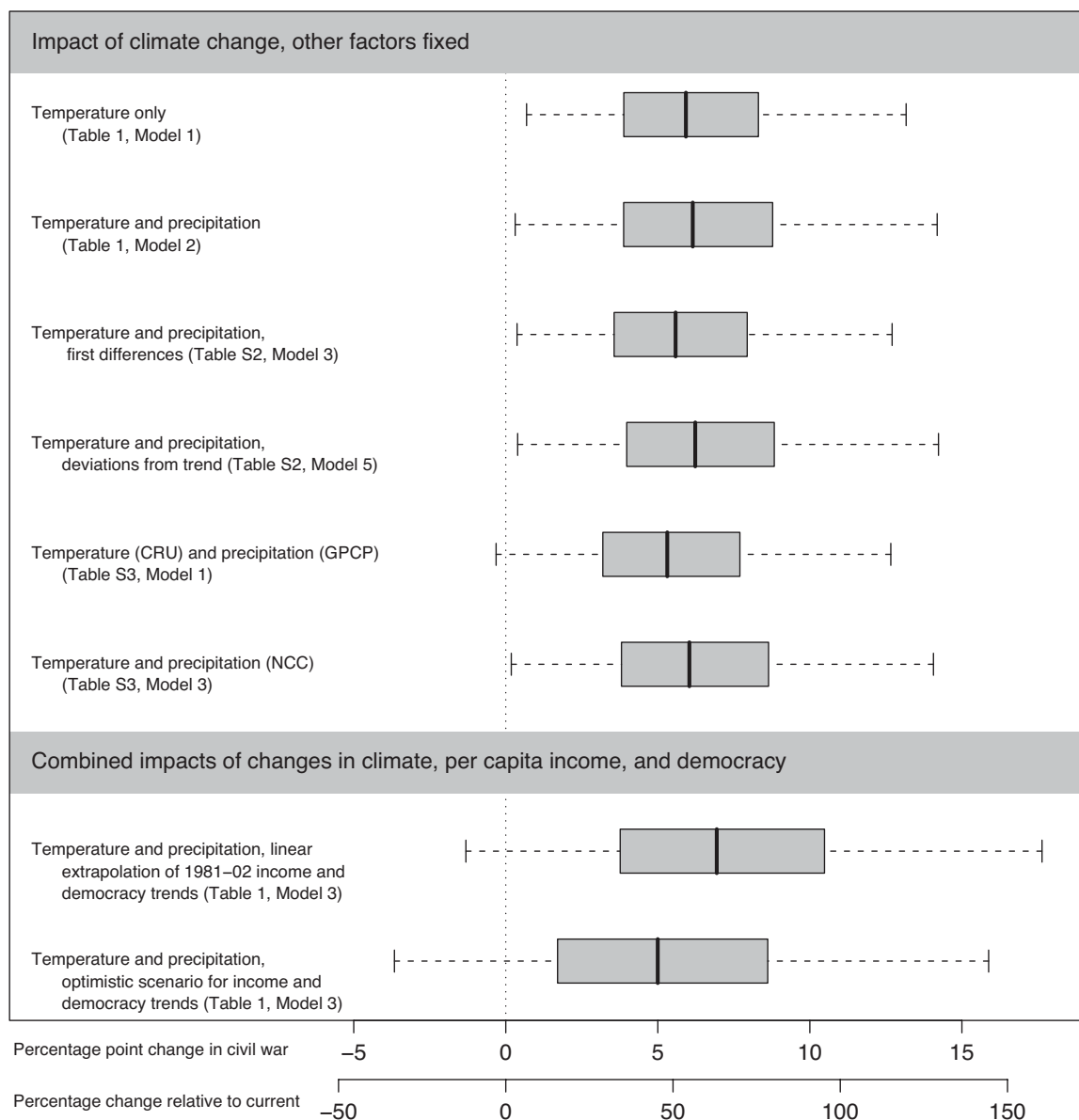


Fig. 2. Projected percent changes in the incidence of civil war for all of sub-Saharan Africa, including both climate and conflict uncertainty as calculated as in Fig. 1. (*Top*) Projections based on alternative specifications of the relationship between climate and conflict, with other factors fixed. (*Bottom*) Projected combined effects of changes in climate, per capita income, and democracy. Dark vertical lines represent the median projection, colored boxes show the interquartile range, and whiskers indicate the 5th–95th percentile of projections, using climate projections from all climate models for the A1B scenario, such that each boxplot represents 180,000 projections. Each specification includes the variables listed on the left (contemporaneous and lagged for the climate variables) in addition to country time trends and country fixed effects.

productivity, which can decline with higher temperatures (23)—further elucidating the relative contributions of these factors remains a critical area for future research.

Nevertheless, the robustness of the reduced-form relationship between temperature and conflict across many alternative model specifications argues for a large direct role of temperature in shaping conflict risk. When combined with the unanimous projections of near-term warming across climate models and climate scenarios, this temperature effect provides a coherent and alarming picture of increases in conflict risk under climate change over the next 2 decades in Africa. Furthermore, the adverse impact of warming on conflict by 2030 appears likely to outweigh any potentially offsetting effects of strong economic growth and continued democratization. We view this final result with some caution, however, because economic and political

variables are clearly endogenous to conflict; for example, conflict may both respond to and cause variation in economic performance (2) or democratization. Consequently, credibly identifying past or future contributions of economic growth or democratization to civil war risk is difficult. We interpret our result as evidence of the strength of the temperature effect rather than as documentation of the precise future contribution of economic progress or democratization to conflict risk. Similarly, we do not explicitly account for any adaptations that might occur within or outside agriculture that could lessen these countries' sensitivities to high temperatures, and thus our 2030 results should be viewed as projections rather than predictions.

The possibility of large warming-induced increases in the incidence of civil war has a number of public policy implications. First, if temperature is primarily affecting conflict via shocks to

economic productivity, then, given the current and expected future importance of agriculture in African livelihoods (24), governments and aid donors could help reduce conflict risk in Africa by improving the ability of African agriculture to deal with extreme heat. Such efforts could include developing better-adapted crop varieties, giving farmers the knowledge and incentives to use them, and expanding irrigation infrastructure where feasible (25).

Second, implementing insurance schemes to protect poor societies from adverse climate shocks also could help reduce the risk of civil war in Africa. One possibility is the expansion of weather-indexed crop insurance, which has shown promise in many less-developed countries (26). Another variant would be making the provision of foreign aid contingent on climate risk indicators—“rapid conflict prevention support” (27)—to bolster local economic conditions when the risk of violence is high. Our findings suggest that the need for such mechanisms in Africa will become increasingly urgent as global temperatures continue to rise.

Methods

Climate variables represent time series of temperature and precipitation from the Climatic Research Unit (CRU) of the University of East Anglia (28), averaged (for temperature) or summed (for precipitation) over all months at a given grid cell (0.5×0.5 degree in these data, or about 50 km at the equator), and then averaged over all cells in a given country. Our dependent variable is country- and year-specific civil war incidence (13), where $war_{it} = 1$ if there was a conflict resulting in $>1,000$ deaths in country i in year t and 0 otherwise.

Our regression equation links civil war to various measures of historical climate, x_{it} , conditional on country fixed effects and time trends,

$$war_{it} = f(x_{it}) + c_i + d_{year_t} + \varepsilon_{it},$$

where c_i represents country fixed effects accounting for time-invariant country-specific characteristics (such as institutional capacity) that might explain differences in baseline level of conflict risk, and d_{year_t} represents country-

specific time trends to control for variables that could be evolving over time (such as economic performance or political institutions) and altering conflict risk. In our baseline specification (model 1 in Table 1), climate is represented by levels of country-average temperature h in the current and previous year (29), such that $x_{it} = \beta_1 h_{it} + \beta_2 h_{it-1}$. Alternative panel specifications shown in Fig. 2 model x_{it} with contemporaneous and lagged precipitation included, with different transformations of climate (such as deviations from trend or first differences), with explicit controls for trends in country per capita income or democratization, or using alternative climate data sets (Tables S1–S8).

Per capita incomes are lagged annual values (in purchasing power parity, 1985 dollars), and political regime type is represented by the common Polity2 measure, where countries receive a yearly score between -10 (least democratic) and $+10$ (most democratic) (30) (see *SI Text*). These variables are lagged 1 year because both political regime type and economic growth are potentially endogenous to conflict (2), and using predetermined values reduces the most immediate endogeneity concerns. Projections of these variables to 2030 are based either on linear extrapolation of median 1981–2002 trends across sample countries (equal to $+0.1\%$ annual per capita income growth and a $+7$ -point increase in the Polity2 score) or on an optimistic scenario [equal to the same large increase in the Polity2 score and a $+2.0\%$ annual increase in per capita incomes, which is similar to the average African performance between 2000 and 2008 (31)].

Additional battle deaths related to warming are calculated using historical battle death data (32), and assume a linear increase in the conflict risk related to warming beginning in 1990 (corresponding to historical risk levels in our panel) and ending in 2030 (a 54% increase in risk). Cumulative additional battle deaths are then summed from the first year after the end of our panel (2003) through 2030, assuming a baseline annual battle death total equal to the average during our 1981–2002 study period (39,455 deaths/year).

ACKNOWLEDGMENTS. We thank W. Schlenker, P. Fordyce, R. Naylor, and W. Falcon for comments on the manuscript, and C. Tebaldi, W. Schlenker, and J. Zuberi for help with the data. We acknowledge the modeling groups, the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modeling (WGCM), for their role in making available the WCRP CMIP3 multimodel data set. Support for this data set is provided by the Office of Science, U.S. Department of Energy. M.B. and D.L. thank the Rockefeller Foundation for funding.

- Blattman C, Miguel E (2009) Civil war. *J Econ Lit*, in press.
- Miguel E, Satyanath S, Sergenti E (2004) Economic shocks and civil conflict: An instrumental variables approach. *J Polit Econ* 112:725–753.
- Lobell DB, et al. (2008) Prioritizing climate change adaptation needs for food security in 2030. *Science* 319:607–610.
- Nicholls RJ, Hoozemans FMJ, Marchand M (1999) Increasing flood risk and wetland losses due to global sea-level rise: Regional and global analyses. *Global Environ Change* 9:S69–S87.
- CNA Corp (2007) *National Security and the Threat of Climate Change* (CNA Corp, Alexandria, VA).
- Barnaby W (2009) Do nations go to war over water? *Nature* 458:282–283.
- Hendrix CS, Glaser SM (2007) Trends and triggers: Climate, climate change and civil conflict in sub-Saharan Africa. *Polit Geogr* 26:695–715.
- World Bank (2009) *World Development Indicators 2009*. Available at: www.worldbank.org/data/. Accessed June 1, 2009.
- Christensen JH, et al. (2007) In *Climate Change 2007: The Physical Science Basis. Contribution of WG1 to the Fourth Assessment Report of the IPCC*, eds Solomon S, et al. (Cambridge Univ Press, Cambridge, UK), pp 847–940.
- Dell M, Jones BF, Olken BA (2008) Climate shocks and economic growth: Evidence from the last half-century. NBER Working Paper 14132, National Bureau of Economic Research. Available at <http://ssrn.com/abstract=1152673>. Accessed December 1, 2008.
- Schlenker W, Lobell DB (2009) Robust and potential severe impacts of climate change on African agriculture. Working paper, Program on Food Security and Environment, Stanford University, submitted.
- Zhang DD, Brecke P, Lee HF, He YQ, Zhang J (2007) Global climate change, war, and population decline in recent human history. *Proc Natl Acad Sci USA* 104:19214–19219.
- Gleditsch NP, Wallensteen P, Eriksson M, Sollenberg M, Strand H (2002) Armed conflict 1946–2001: A new dataset. *J Peace Res* 39:615–637.
- Fearon JD, Laitin DD (2003) Ethnicity, insurgency, and civil war. *Am Polit Sci Rev* 97:75–90.
- Collier P, Hoeffler A (1998) On economic causes of civil war. *Oxford Econ Papers* 50:563–573.
- Collier P, Hoeffler A (2004) *Greed and Grievance in Civil War* (Oxford Univ Press, Oxford, UK).
- Tebaldi C, Knutti R (2007) The use of the multi-model ensemble in probabilistic climate projections. *Phil Trans R Soc A* 365:2053–2075.
- Ghobarah HA, Huth P, Russett B (2003) Civil wars kill and maim people—long after the shooting stops. *Am Polit Sci Rev* 97:189–202.
- Schlenker W, Roberts MJ (2006) Nonlinear effects of weather on corn yields. *Rev Agri Econ* 28:391–398.
- Jones PG, Thornton PK (2003) The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environ Change* 13:51–59.
- Davis B, et al. (2008) *Rural Income-Generating Activities: A Cross-Country Comparison* (World Bank, Washington DC).
- Anderson CA, Bushman BJ, Groom RW (1997) Hot years and serious and deadly assault: Empirical tests of the heat hypothesis. *J Person Soc Psychol* 73:1213–1223.
- Hancock PA, Ross JM, Szalma JL (2007) A meta-analysis of performance response under thermal stressors. *Hum Factors* 49:851–877.
- Ravallion M, Chen S, Sangraula P (2007) New evidence on the urbanization of global poverty. Policy Research Working Paper 4199, World Bank. Available at <http://ssrn.com/abstract=980817>. Accessed June 1, 2008.
- World Bank (2008) *World Development Report: Agriculture for Development* (World Bank, Washington DC).
- World Bank (2005) *Managing Agricultural Production Risk: Innovations in Developing Countries* (World Bank, Washington DC).
- Miguel E (2007) In *Too Poor For Peace? Global Poverty, Conflict, and Security in the 21st Century* (Brookings Inst Press, Washington, DC).
- Mitchell TD, Jones PD (2005) An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *Int J Climatol* 25:693–712.
- Ciccone A (2008) Transitory economic shocks and civil conflict. CEPR Discussion Paper DP7081, Center for Economic and Policy Research. Available at <http://ssrn.com/abstract=1344640>. Accessed June 1, 2009.
- Marshall M, Jaggers K, Gurr T (2008) *Polity IV Project: Political Regime Characteristics and Transitions, 1800–2002*. Available at <http://systemicpeace.org/polity/polity4.htm>. Accessed August 24, 2009.
- Miguel E (2009) *Africa's Turn?* (MIT Press, Cambridge, MA).
- Lacina B, Gleditsch NP (2005) Monitoring trends in global combat: A new dataset of battle deaths. *Eur J Pop* 21:145–166.