Warming increases the risk of civil war in Africa

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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).

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Table 1. Regression coefficients on climate variables, with civil war as a dependent variable

Variable	Model 1 Coefficient	Model 1 SE	Model 2 Coefficient	Model 2 SE	Model 3 Coefficient	Model 3 SE
Temperature	0.0447**	(0.0218)	0.0430*	(0.0217)	0.0489*	(0.0275)
Temperature lagged 1 year	0.00873	(0.0210)	0.0132	(0.0233)	0.0206	(0.0298)
Precipitation			−0.0230	(0.0519)	0.0165	(0.0848)
Precipitation lagged 1 year			0.0250	(0.0489)	0.0278	(0.0811)
Per capita income lagged 1 year					−0.0266	(0.0258)
Political regime type lagged 1 year					−0.000538	(0.00576)
Constant	−1.514	(0.923)	−1.581*	(0.854)	−1.872	(1.254)
Observations	889		889		815	
R^2	0.657		0.657		0.389	
RMSE	0.193		0.193		0.241	

Coefficients represent effect of temperature (°C) and precipitation (m) on civil war in Africa, 1981–2002. All regressions include country fixed effects to control for time-invariant country characteristics; Models 1 and 2 include country time trends to control for time-varying country characteristics. Model 3 includes lagged income ($1,000) and political regime type [score from least democratic (−10) to most democratic (+10)] as controls, and includes a common time trend. Standard errors are robust and clustered at the country level. Asterisks indicate coefficient significance level (2-tailed): ***, $P < .01$; **, $P < .05$; *, $P < .10$.

To predict changes in the incidence of civil war under future climate change, we combine our estimated historical response of conflict to climate with climate projections from 20 general circulation models that have contributed to the World Climate Research Program's Coupled Model Intercomparison Project phase 3 (WCRP CMIP3). We focus on climate changes and associated changes in conflict risk to the year 2030, both because the host of factors beyond climate that contribute to conflict risk (e.g., economic performance, political institutions) are more likely to remain near-constant over the next few decades relative to mid-century or end of century, and because climate projections themselves are relatively insensitive to alternate greenhouse gas emissions scenarios to 2030.

The left panel of Fig. 1 shows the range of climate model projected changes in growing season precipitation and temperature for 5 African regions and the continent as a whole for 2020–2039 relative to 1980–1999, for the 18 climate models running the A1B emissions scenario. Projections of temperature change for the continent average around +1 °C, with some models projecting as much as +1.6 °C and some as little as +0.7 °C. Precipitation projections are more variable, with climate models disagreeing on both the sign and magnitude of

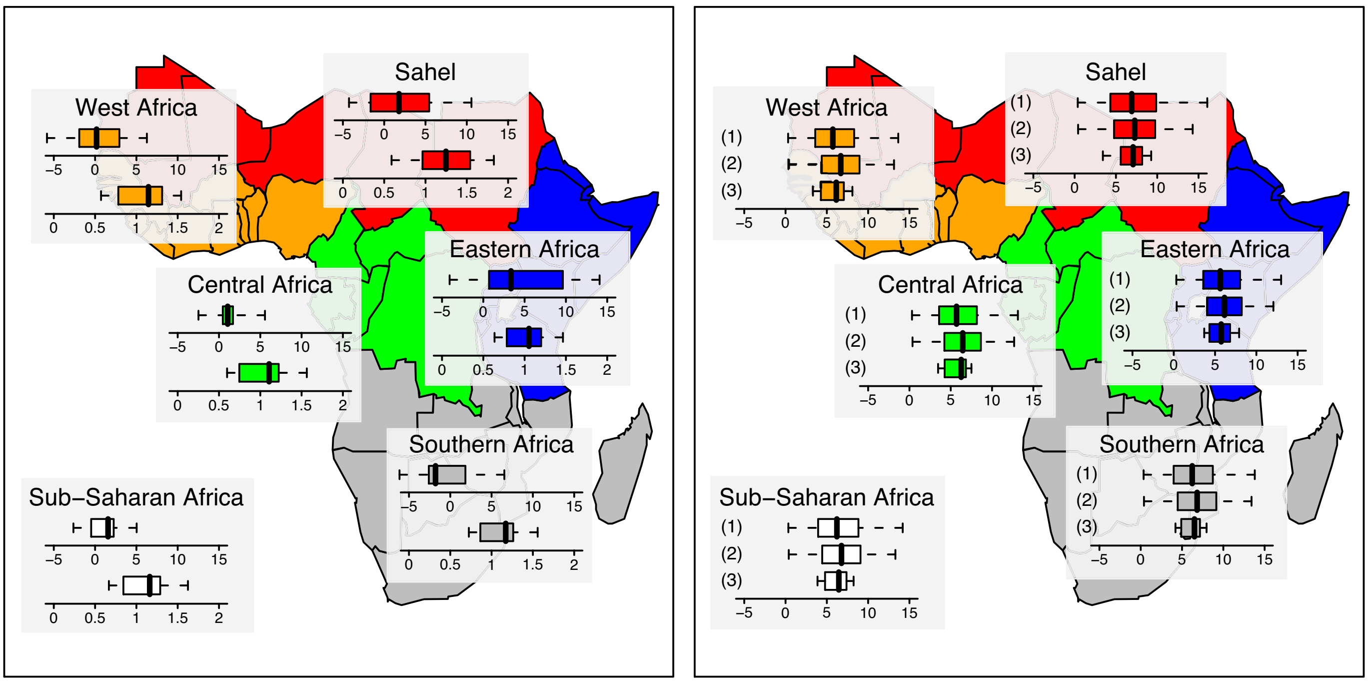

Fig. 1. Projected changes in climate and conflict to 2030. (*Left*) Projected changes in climate to 2030 for 5 sub-Saharan Africa subregions and the region as a whole. Boxplots show the range of model ensemble projected changes for precipitation (% change, *Top*) and temperature (°C, *Bottom*), for 2020–2039 minus 1980–1999, based on the 18 models running the A1B scenario, with the dark vertical line representing the median, the colored boxes showing the interquartile range, and the whiskers indicating the extremes. (*Right*) Projected percentage point change in the incidence of civil war for the same period and regions, based the same climate model projections and a 10,000-run bootstrap of model 1 in Table 1. For each region, boxplot 1 represents projections including uncertainty in both climate model projections and in conflict response to climate, boxplot 2 represents uncertainty only in conflict response to climate, and boxplot 3 represents uncertainty only in climate projections. Dark vertical lines represent median projection, colored boxes show the interquartile range, and whiskers indicate the 5th–95th percentile of projections.

Table 2. Projected changes in African civil war incidence to 2030, by emissions scenario

	Median % change	% increase in civil war relative to baseline	5th–95th percentile observations of projected % increase	% of observations < 0
A1B				
Model 1	5.9	53.7	6.2–119.4	3.0
Model 2	6.1	55.8	2.7–128.8	4.1
A2				
Model 1	5.2	47.4	5.4–101.8	3.0
Model 2	5.4	49.2	2.3–109.8	4.2
B1				
Model 1	4.8	43.4	5.0–99.4	3.0
Model 2	5.0	45.1	2.0–107.1	4.2

Projections are for all of sub-Saharan Africa for 3 emissions scenarios, based on 10,000-run bootstrap of models 1 and 2 in Table 1, which combine uncertainty in climate model projections and in the responsiveness of conflict to climate. Eleven percent of the country-years in the 1981–2002 baseline experienced civil war.

future changes, with the median projected precipitation change near 0.

The right panel of Fig. 1 shows projections of changes in African civil war incidence to 2030, accounting for uncertainty in both climate projections and conflict response to climate. The projections are built from model 1 in Table 1, with the uncertainty of conflict response to climate derived from 10,000 bootstrap runs of the model, and climate uncertainty determined by evaluating the set of bootstrap runs across each of the 18 individual climate models running the A1B scenario, giving each model equal weight (17) (see *SI Text*). Thus, the resulting distributions represent 180,000 predicted impacts, of which the 5th–95th percentiles are displayed.

All models predict increased conflict incidence across all regions for this 5th–95th percentile range, with a 5.9% median projected increase across the continent. Again given the 11% of country-years in our panel that experience conflict, this increase corresponds to a 54% rise in the average likelihood of conflict across the continent (Table 2). If future conflicts are on average as deadly as conflicts during our study period, and assuming linear increases in temperature to 2030, this warming-induced increase in conflict risk would result in a cumulative additional 393,000 battle deaths by 2030 (see *Methods*). Given that total loss of life related to conflict events can be many times higher than direct battle deaths (18), the human costs of this conflict increase likely would be much higher.

Because uncertainty in projections of conflict incidence appear driven more by the uncertainty in the climate–conflict relationship than by climate model projections (Fig. 1, *Right*), we reran the all-Africa projections for various alternative specifications of model 1. Estimates of the median and range of projected increases in conflict remain remarkably consistent across specifications of how civil war responds to climate (Fig. 2, *Top*), including whether war is assumed to respond to levels of climate variables or year-to-year changes in those variables, whether or not potential response to precipitation in addition to temperature is included, and the use of alternative climate data sets. Alternative emissions scenarios (A2 and B1) also give very similar projections of the median and range of increases in conflict risk (Table 2).

In addition, because nonclimate factors that affect conflict risk also could change over time, we include 2 projections of 2030 civil war incidence taking into account the combined effects of projected changes in climate, economic growth, and democratization (Fig. 2, *Bottom*). Using a 10,000-run bootstrap of model 3 in Table 1, we evaluate 2 scenarios: (i) a "linear extrapolation," in which future per capita economic growth and democratization are assumed to proceed at the same rate as in 1981–2002 (using the average over our African sample countries), and (ii) an "optimistic scenario," in which the annual per capita economic growth rate is 2% and the increase in democracy is the same as during 1981–2002, a period of substantial democratic reform in Africa (see *Methods*). We find that neither is able to overcome the large effects of temperature increase on civil war incidence, although the optimistic scenario reduces the risk of civil war by roughly 2% relative to the linear extrapolation, corresponding to a 20% relative decline in conflict (Fig. 2, *Bottom*).

Discussion

The large effect of temperature relative to precipitation is perhaps surprising given the important role that precipitation plays in rural African livelihoods and previous work emphasizing the impact of falling precipitation on conflict risk (2). In fact, precipitation and temperature fluctuations are negatively correlated ($r = -0.34$) over our study period, suggesting that earlier findings of increased conflict during drier years might have been partly capturing the effect of hotter years. The inferred precipitation effect is stronger in the current study when using the same precipitation dataset as in ref. 2 (Table S3), suggesting that the role of precipitation remains empirically ambiguous, perhaps because the high spatial variability of precipitation is less well captured than temperature variability by the relatively coarse climate data. Nevertheless, the temperature signal is robust across datasets and is consistent with a growing body of evidence demonstrating the direct negative effects of higher temperatures on agricultural productivity and the importance of these fluctuations for economic performance (10, 11, 19).

Temperature can affect agricultural yields both through increases in crop evapotranspiration (and hence heightened water stress in the absence of irrigation) and through accelerated crop development, with the combined effect of these 2 mechanisms often reducing African staple crop yields by 10%–30% per °C of warming (3, 11, 20). Because the vast majority of poor African households are rural, and because the poorest of these typically derive between 60% and 100% of their income from agricultural activities (21), such temperature-related yield declines can have serious economic consequences for both agricultural households and entire societies that depend heavily on agriculture (10). Finally, because economic welfare is the single factor most consistently associated with conflict incidence in both cross-country and within-country studies (1, 2, 14–16), it appears likely that the variation in agricultural performance is the central mechanism linking warming to conflict in Africa. Yet because our study cannot definitively rule out other plausible contributing factors—for instance, violent crime, which has been found to increase with higher temperatures (22), and nonfarm labor

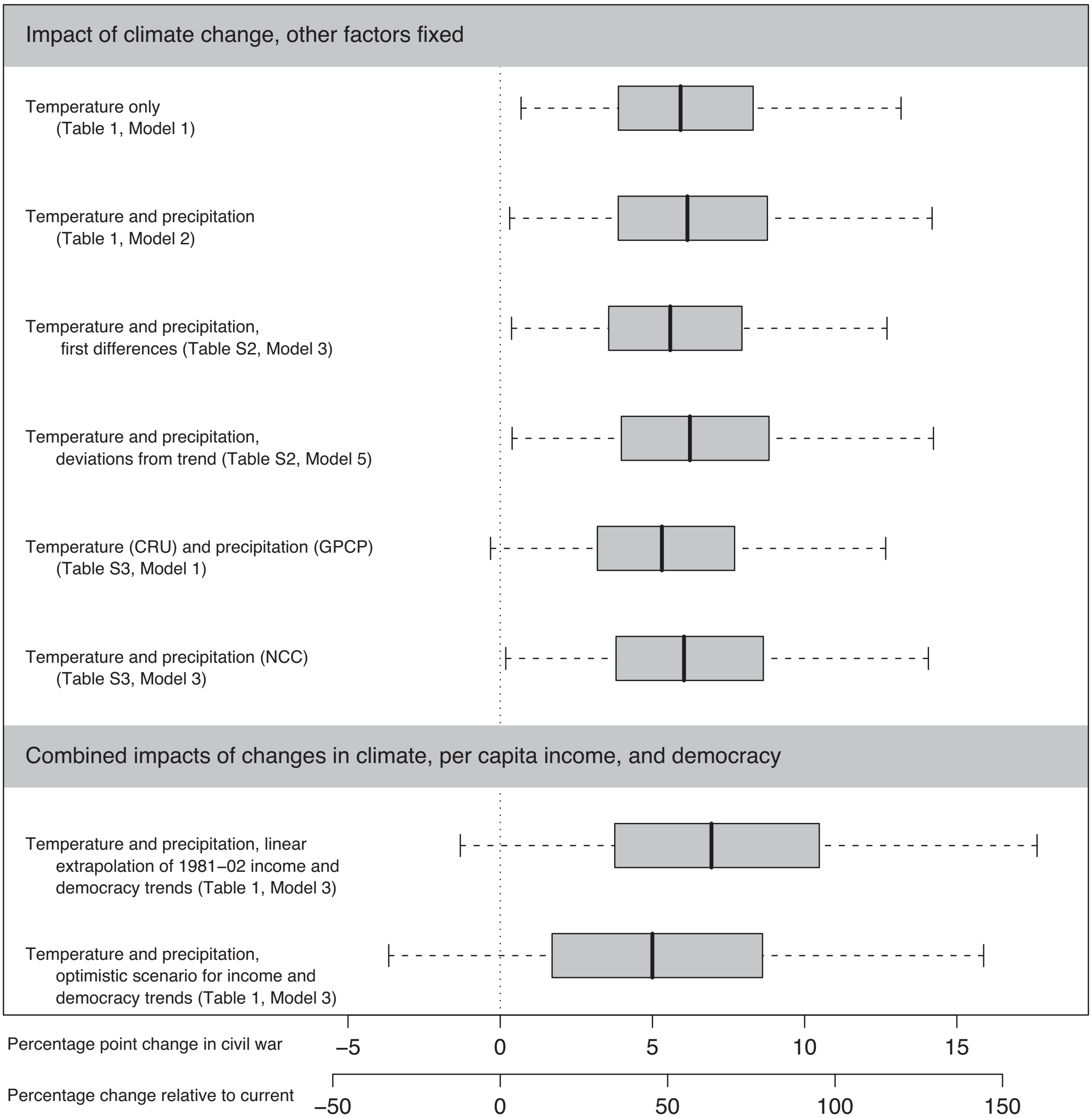

Fig. 2. Projected percent changes in the incidence of civil war for all of sub-Saharan Africa, including both climate and conflict uncertainty as calculated as in Fig. 1. (*Top*) Projections based on alternative specifications of the relationship between climate and conflict, with other factors fixed. (*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,

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

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 $d_i year_i$ 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).

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