ECONOMICS

Asylum applications respond to temperature fluctuations

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International negotiations on climate change, along with recent upsurges in migration across the Mediterranean Sea, have highlighted the need to better understand the possible effects of climate change on human migration—in particular, across national borders. Here we examine how, in the recent past (2000–2014), weather variations in 103 source countries translated into asylum applications to the European Union, which averaged 351,000 per year in our sample. We find that temperatures that deviated from the moderate optimum (~20°C) increased asylum applications in a nonlinear fashion, which implies an accelerated increase under continued future warming. Holding everything else constant, asylum applications by the end of the century are predicted to increase, on average, by 28% (98,000 additional asylum applications per year) under representative concentration pathway (RCP) scenario 4.5 and by 188% (660,000 additional applications per year) under RCP 8.5 for the 21 climate models in the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP).

The European Union (EU) has seen an unprecedented wave of immigration in 2015 (*1*) as part of a larger surge in migration across the Mediterranean Sea that began in 2014. Many of the migrants flee war-torn countries such as Syria, Afghanistan, or Iraq, and there is an active debate as to whether a change in climatic conditions has contributed to, and will amplify, such migration flows. For example, a 2015 study has shown that the unrest in Syria was preceded by a record drought that led to lower agricultural yields and forced farmers to migrate to urban areas (*2*). Although that study does not attribute the Syrian conflict to the drought, the authors argue that it added another stressor. These arguments have gained traction outside the academic literature. For instance, the Pentagon calls climate change a "threat multiplier" (*3*). However instead of looking at individual countries, we take a step back and investigate the role of weather shocks in global distress-driven migration to the EU in 2000–2014; i.e., preceding the recent crisis. Asylum applications to the EU from the 103 source countries in our sample totaled 1.5 million in 2015; that is, more than 4 times the average in our sample. Previous studies had found a relationship between weather variations and migration (*4*, *5*, *6*), but ours is the first to focus on distress-driven migration (as measured by asylum applications) on a global scale. Two centuries ago, the "year without a summer" (1816), following the volcanic eruption of Mount Tambora in Indonesia, saw massive crop failures throughout the Northern Hemisphere, caused by the aerosol-obscured atmosphere and unseasonal climate. It triggered sizeable migrations as peasants deserted their fruitless farms (*7*). Here we provide quantified evidence of a similar phenomenon taking place in the present day, whereby weather shocks on agricultural regions in 103 countries around the globe directly influence emigration, now toward the EU.

The relationship of international migration decisions to economic situation in both the source and destination country has been extensively documented. Migration's response to income or wealth corresponds in an inverted U shape: Positive income shocks in the home country enable individuals to overcome liquidity constraints and finance migration costs (*8*). Richer households are not liquidity-constrained and show a negative migration-income relationship as improving conditions at home make it less desirable to leave (*9*). [See supplementary text sections 1 and 2 for a more detailed review and discussion (*10*).] Migration barriers have been described as one of the biggest distortions in the global economy (*11*).

Causes of migration are not limited to the desire for better economic opportunities: humans flee persecution and war. We investigate how exogenous weather fluctuations affect one facet of migration: asylum applications, which equal roughly 1/10 of the overall migration flows over our sample frame. Our sample included the 103 non–Organisation for Economic Co-operation and Development (OECD) source countries that reported asylum applications to the EU in each year between 2000 and 2014. It covered, on average, 351,000 asylum applications per year, the majority (140,000) coming from the 31 Asian countries, including Afghanistan and Iraq, each of which supplied ~25,000 applicants. The 46 African and 11 non-EU countries in Europe accounted for ~100,000 applicants each, whereas 16 countries in the Americas accounted for the rest (tables S7 to S9). For example, 55,943 people from Serbia applied for asylum in the EU in 2000. Applications from all source countries average 378,000 per year—that is, our sample covered 93% of all applications to the EU. Recent research (*12*) suggests that, in agricultural production areas, there should be a negative relationship between economic conditions and conflict, which then translates into asylum applications.

Our baseline regression links annual asylum applications from each source country outside the OECD to any EU member state. We use a panel analysis with source-country and year fixed effects, which is equivalent to a joint demeaning of all variables and accounting for common annual shocks. In other words, we link anomalies in log applications to weather anomalies once common annual shocks are absorbed (e.g., the global financial crisis in 2008). Our specification examines whether hotter-than-normal temperatures will increase or decrease asylum applications from a given source country. Because our dependent variable is in logs, we estimate relative impacts, which is preferable as the number of applications differs greatly among source countries in absolute terms. We allow the effect to vary by the average weather variable: Hotter-than-usual temperatures can reduce asylum applications for cold countries and increase them for hot countries. Our model includes both average temperature and precipitation. The coefficients and standard errors are given in table S1.

We find a statistically significant relationship between fluctuations in asylum applications and weather anomalies: Applications are lowest for average temperatures around 20°C and increase if the weather is too cold or too hot. We choose to focus here on the EU because it receives the largest share of asylum application and, despite having a high rejection rate, remains a major provider of international protection (*13*); other target ensembles are considered in the sensitivity checks. Colder countries in Europe outside the EU are predicted to account for fewer asylum applications in a warming world, whereas hotter countries, especially in Asia and Africa, are expected to see sizable increases in a warming world (tables S7 to S9).

The coefficients on temperature are displayed in Fig. 1. We show a quadratic response function (dashed brown line), as well as flexible restricted cubic splines (solid brown line). Both use the contemporaneous average temperature in the source country, averaged over the maize growing area and season. These models correspond to columns (1a) and (3a) of table S1, respectively. Each line gives the point estimate and is normalized so that the minimum of the response function is zero. We find a highly significant relationship ($P < 0.01$ for joint significance) between logged asylum applications and average temperature over the maize growing area and season for the 103 source countries in our sample. If we average the weather on the basis of population in a grid cell (table S2), the P value becomes 0.14 and the temperature variables are no longer significant, which suggests that weather shocks over the agricultural area are the crucial channel. The use of different weather data sets yields comparable results for seasonal averages (table S3). Including data on political conflicts as controls

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(table S4) produces important predictors of asylum applications, but the estimated relationship with temperature only slightly weakens, suggesting that they either pick up other forms of aggression or persecution because our conflict measures are limited to certain continents and actors or that the conflict data has measurement error.

The average temperature for which asylum applications are lowest is 21.4°C for the quadratic model and 19.9°C for the spline model. These values correspond to the optimal temperature range for agriculture (*14*). Countries that are currently warmer than the optimal temperature would thus be predicted to produce an increase in asylum applications under a warmer climate. The range of observed average temperatures over our 15-year panel is depicted as green horizontal lines in Fig. 1, and green "x" symbols denote the average over all 15 years. [A map of the current average climate over the maize growing season is provided in fig. S2, whereas fig. S3 shows the average temperatures over all months of the year and all grid cells in a country.] Because the regression is in log points, a y value of 1 implies an increase of 100 log points, or a $e^1 = 2.72$-fold increase in the number of applications.

Although the quadratic specification lends itself easily to interpretation of the regression coefficients and allows for some nonlinearity, it remains restrictive by assuming symmetry around the optimum. The more flexible model using restricted cubic splines with five evenly spaced knots between 15° and 35°C (supplementary text section 2.2) enables us to relax this symmetry assumption, as well as the forced linearity in the marginal impact. The discovered relationship is slightly asymmetric, which suggests that temperatures above the optimum level are more harmful than those below this level.

Total precipitation, on the other hand, is not an important predictor of migration, consistent with previous research on conflict that indicates that temperature, as opposed to precipitation, is a stronger predictor of conflict (*15*). Moreover, the relative changes in temperature under future climate change scenarios translate into larger changes in yields than do precipitation changes (*16*). When we exclude precipitation from the regression [column (2a) of table S1], we obtain similar results.

Having established a consistent and robust U-shaped relationship between the weather in a source country and asylum applications—that is, temperatures that are too low or too high will lead to higher asylum applications—we now turn to simulations of how these applications will be altered under global climate change. We present both the response to hypothetical uniform temperature increases ranging from 1° to 5°C, as well as the predicted changes under the 21 global climate models in the NEX-GDDP (NASA Earth Exchange Global Daily Downscaled Projections) CMIP5 (Coupled Model Intercomparison Project phase 5) archive that estimate spatially heterogeneous warming scenarios. The U-shaped migration-temperature relationship suggests that colder source countries will experience a reduction

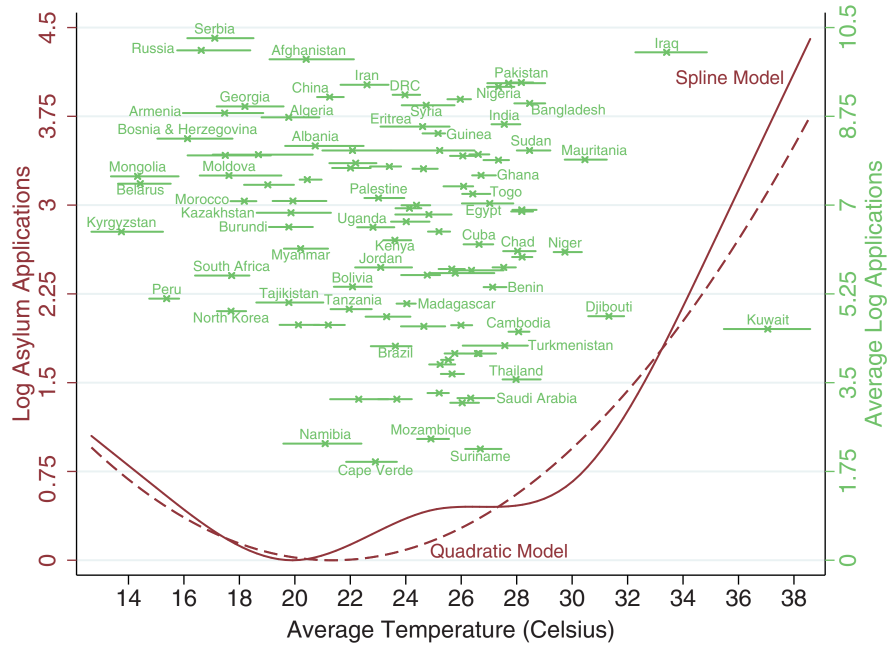

Fig. 1. Response of asylum applications to the EU with respect to the annual average temperature over the maize growing season. The quadratic response function is shown as a dashed brown line, whereas the restricted cubic spline is shown as a solid brown line (knots at 15°, 20°, 25°, 30°, and 35°C). Standard errors for the coefficients are given in table S1. Because the models are in logs, the left y axis indicates the relative impact of changing temperatures on asylum applications. Each model controls for a quadratic function in season-total precipitation, as well as source-country and year fixed effects. The mean of the 15 annual average temperatures and log asylum applications (right y axis) for each source country are denoted by green "x" symbols. Because the models use weather anomalies in the identification, the green lines display the variation in annual average temperature in each country, ranging from the lowest to the highest observed value in the 15-year period.

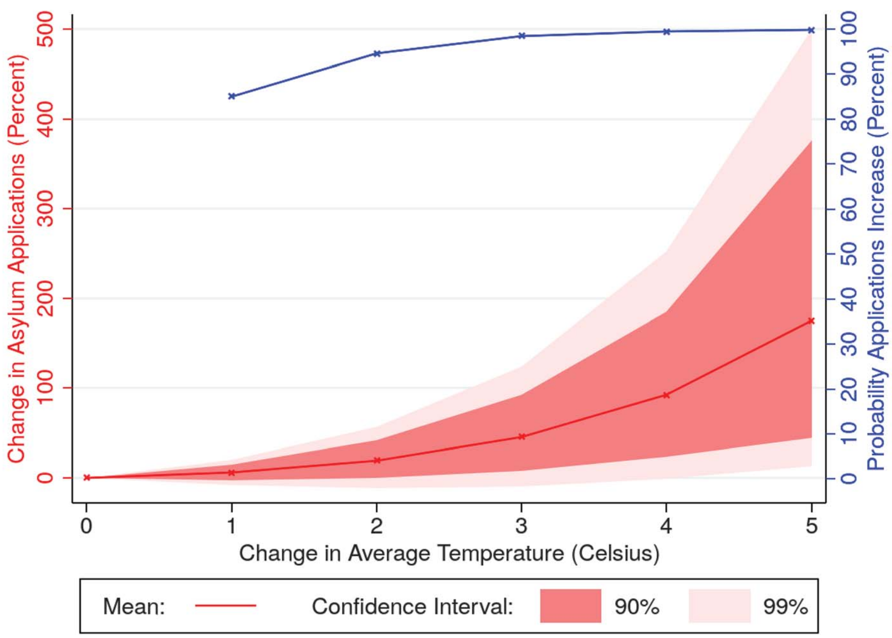

Fig. 2. Predicted changes to asylum applications under uniform climate change scenarios. We used 1000 samples drawn from the joint distribution of the model parameters (solid brown line in Fig. 1) to repeatedly predict the change in the percentage of total asylum applications filed in the EU. The solid red line shows the predicted change in percent, whereas the shaded areas illustrate the 90% and 99% confidence intervals. The blue line (right y axis) indicates the probability that asylum applications increase.

in asylum applications to the EU under warmer temperatures, whereas warmer countries will see an increase thereof, as they lie to the right of the temperature that minimizes applications.

When we simulate the aggregate effect of a uniform 1° to 5°C warming, we compare the extrapolated number of asylum applications to the predicted applications under the historic observed weather in 2000–2014. Figure 2 accordingly illustrates the predicted changes in total applications to the EU by using the restricted cubic spline model [solid brown line in Fig. 1 or column (3a) from table S1], as well as the probability that they increase compared with the baseline. We prefer the cubic spline specification because the model is better at capturing nonlinearities within the observed range of temperatures and is more conservative in out-of-sample predictions, as the relationship is assumed to be linear above the highest knot whereas the quadratic model assumes increasing rates. Truncating the response function and forcing it to become flat outside the observed range does not substantially affect the overall results (figs. S6 and S7). The results are comparable if we use the quadratic specification, as shown in the first row of Fig. 3. The likelihood of an increase in applications is shown as a blue line in Fig. 2 (right y axis) and ranges from 85% under +1°C warming to 99% under both +4° and +5°C warming. The change in the volume of applications is highly nonlinear: A 1°C warming results in a relative modest 6% increase in applications, but a 5°C warming leads to a 175% increase. The predicted mean change is positive in all models and under all warming scenarios.

Asylum applications are also forecasted using temperature data from the 21 climate models in the NEX-GDDP archive (supplementary text section 3.4) for the medium term (2030–2059) as well as the end of the century (2070–2099). We compare them to an analogous 30-year historic baseline (1976–2005) in the NEX-GDDP data. The mean estimate and the confidence intervals are constructed using the same sample from the parameter distribution as for the uniform temperature increases and are shown in figs. S8 and S9. Asylum applications are predicted to increase, on average, by 28% under representative concentration pathway (RCP) scenario 4.5 and 188% under RCP 8.5 by the end of the century, but there is large heterogeneity among countries (tables S7 to S9), with some colder countries seeing declines as they become warmer and closer to the optimal temperature.

These predictions are ceteris paribus. On the one hand, they might overstate the responsiveness, as the model uses historic weather shocks to identify the relationship while we apply it to a permanent warming scenario in which countries can engage in adaptive responses (e.g., shifting the growing season). On the other hand, these predictions might also be underestimates, as historic weather shocks are small enough in size that they likely do not capture disruptive events (such as major civil unrest) in case of continuous warming.

There are several likely mechanisms behind the sensitivity of fluctuations in asylum applications to temperature anomalies. First, there is a strong nonlinear relationship between agricultural yields and temperature (*14*, *17*, *18*). Moderate temperatures (i.e., in the lower 20°C range) over the growing season are ideal, with both hot and cold temperatures reducing yields. Second, gross domestic product (GDP) growth rates have been found to be very sensitive to temperature, even on the nonagricultural components of the GDP and even in industrialized countries (*19*, *20*). For both yields and GDP, being too hot is worse than being too cold. An improvement in agricultural output or GDP will help producers and workers (if they are paid their marginal product, which increases) in those regions, reduce the incentive to join criminal activity, and lead to less conflict (*12*). Third, the same sign in the relationship with weather is found for aggressive behavior, which increases with temperatures that have been shown to reduce output (*21*). This relationship holds consistently across several spatial and temporal scales (*22*). The first two mechanisms are a priori conducive to increased distress-driven migration in the event that weather deviates from the moderate optimum, and all three predict that increases in very warm locations are likely to be associated with higher asylum applications.

The results of our baseline regression suggest that suboptimal weather (namely, temperatures that are too cold or too hot) increases asylum applications to the EU. One might

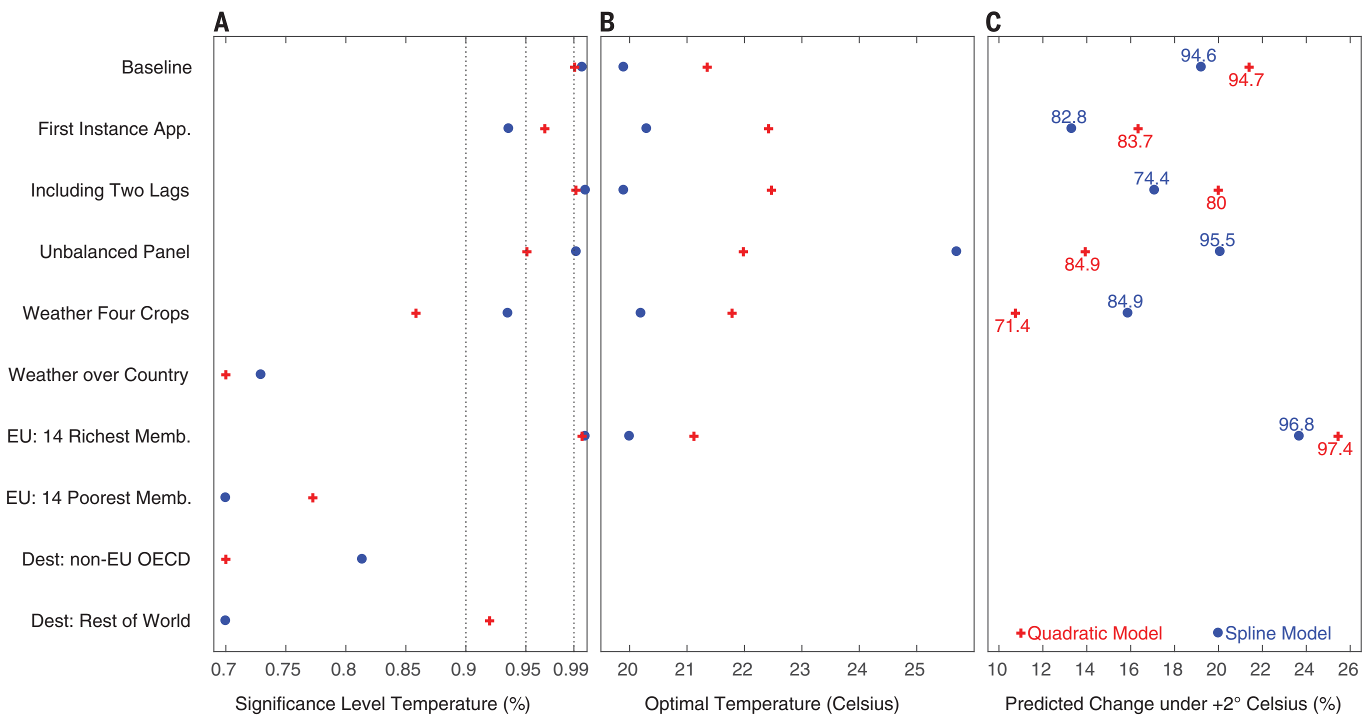

Fig. 3. Sensitivity checks to various modeling assumptions. Each row represents a separate model. (**A**) *P* value for joint significance of the temperature variables (values below 0.7 are shown as 0.7). (**B** and **C**) For cases in which there is a significant link between temperature and asylum applications (average significance level above 0.9 for the quadratic and spline model), (B) shows the temperature that minimizes asylum applications, and (C) illustrates the predicted change in applicants (x axis) as well as the probability that a +2°C uniform warming will lead to an increase in applications to the EU (number next to the estimate).

wonder whether these additional applications are caused by heightened persecution or just by changing economic conditions, with both being credible intermediates in a causal chain linking weather anomalies and demand for asylum. To clarify this issue, we examine the numbers of accepted applications per year between a source country and the EU. We do find that the weather-induced spikes in applications translate into roughly three times higher acceptance rates in the following two years (see supplementary text section 2.4 for more detail), suggesting that destination countries classify the additional cases as more deserving than the average applicant and see them as refugees and not economic migrants.

We conduct several sensitivity checks of our baseline results that are summarized in Fig. 3 to rule out the possibility of our model picking up spurious correlations in the data. This figure includes three panels: Panel A shows the joint significance for all temperature variables. In cases for which there is a significant link between temperatures and asylum applications, panel B depicts the temperature that minimizes asylum applications, and panel C illustrates the predicted change in asylum applications under uniform +2°C warming, as well as the probability that applications will increase. Results displayed in panels B and C are generally robust.

The first row in Fig. 3 presents our baseline results for comparison. Results for the quadratic model are shown in red, whereas results for the model using restricted cubic splines are shown in blue (all models account for a quadratic function in season-total precipitation, but because they were not significant, the coefficients are not used when we evaluate climate impacts).

The second row limits asylum applications to case openings (rather than second instances, appeals, etc.). In principle, both first and subsequent applications could be influenced by weather, and the results are comparable when we limit the data to first instances. In our baseline regression, we simply added all instances.

The third row includes two lags of all weather variables. We show the combined results of the contemporaneous term as well as the two lags. Lagged variables might capture two opposite effects: (i) delayed increase of applications, accounting for cases when people apply the following year(s), as they might not be able or willing to flee right away, and (ii) forward displacement, whereby weather shocks induce the applications of individuals who were contemplating to leave in the next year(s) anyway, in which case the contemporaneous effect should be counterbalanced by coefficients of the opposite sign in the following years. Either these two effects are of small magnitude or they balance each other out, as the model with two lags produces similar predictions.

The fourth row uses a model that includes all source countries, even if they do not report applications for all of the 15 years, with little change (the optimal temperature in the spline model in panel B becomes a bit larger, but this has little effect on the predicted climate impacts in panel C).

The fifth row derives the weather not just over the maize growing area and season but also over the growing areas and seasons of the other three large staple commodities: wheat, rice, and soybeans. These four weather variables are then averaged using area weights. The temperature coefficients are no longer significant for the quadratic model, but the remaining results are robust to these changes.

The sixth row averages the weather over the entire country and year and no longer produces significant results. This suggests that the results are driven by events that happen in the agricultural (rural) areas during the time the crops are grown and is in line with the predictions that a significant result should mainly be observed for agricultural production areas (supplementary text section 2.1). We are not able to distinguish whether these events affect agriculture directly or other sectors in the same (rural) area at the same time of the year.

The seventh and eighth rows break the destination into two subgroups: the 14 richest and 14 poorest member states of the EU. Results are only significant for applications to the 14 richest member countries that absorb most of the applicants.

The last two rows examine applications to countries outside the EU, which we break into two subgroups on the basis of whether or not they belong to the OECD. There is no significant relationship with weather in the source country for the former, but these countries accept a small share of asylum applications (*13*). The rest of the world (non-EU, non-OECD) predominantly accepts applications from neighboring countries, but we observe only a marginally significant effect of the weather in the source country for the spline model.

Finally, we also tested for heterogeneity among source countries but generally did not find significantly different sensitivities to weather for various subgroups. The results, in which we split the sample into roughly equal halves based on (i) the corruption index of the source country, (ii) the latitude of the source country, (iii) the population of the source country, (iv) the share of the source countries' workforce that is employed in agriculture, or (v) the distance between the source country and the EU, are shown in tables S5 and S6.

In summary, we link annual asylum applications received by the EU member states to average temperature over the maize growing area and season in the source country and find a nonlinear relationship, especially for those applications filed into the richer EU member states. Moderate temperatures around 20°C minimize asylum applications. Both colder and hotter temperatures increase migration flows. Extrapolating those results, an increase in temperatures in source countries is predicted to lead to an increase in asylum applications to the EU as well, following a highly nonlinear response function. Our findings support the assessment that climate change, especially continued warming, will add another "threat multiplier" that induces people to seek refuge abroad. Weather impacts in low-income source countries will not be confined to those countries or regions but will instead likely spill over into developed countries through increased refugee flows.

REFERENCES AND NOTES

1. "Risk analysis for 2016" (Frontex, 2016); http://frontex.europa.eu/assets/Publications/Risk_Analysis/Annula_Risk_Analysis_2016.pdf.
2. C. P. Kelley, S. Mohtadi, M. A. Cane, R. Seager, Y. Kushnir, *Proc. Natl. Acad. Sci. U.S.A.* **112**, 3241–3246 (2015).
3. B. Obama, "Remarks by the President at the United States Coast Guard Academy Commencement" (United States Coast Guard Academy, 2015); https://obamawhitehouse.archives.gov/the-press-office/2015/05/20/remarks-president-united-states-coast-guard-academy-commencement.
4. P. Bohra-Mishra, M. Oppenheimer, S. M. Hsiang, *Proc. Natl. Acad. Sci. U.S.A.* **111**, 9780–9785 (2014).
5. R. Cai, S. Feng, M. Oppenheimer, M. Pytliková, *J. Environ. Econ. Manage.* **79**, 135–151 (2016).
6. C. Gray, E. Wise, *Clim. Change* **135**, 555–568 (2016).
7. J. Luterbacher, C. Pfister, *Nat. Geosci.* **8**, 246–248 (2015).
8. M. A. Clemens, in *International Handbook on Migration and Economic Development* (Edward Elgar Publishing, 2014), chap. 6, pp. 152–185.
9. S. Bazzi, *Am. Econ. J. Appl. Econ.* **9**, 219–255 (2017).
10. See supplementary materials.
11. M. A. Clemens, *J. Econ. Perspect.* **25**, 83–106 (2011).
12. E. McGuirk, M. Burke, "The economic origins of conflict in Africa," National Bureau of Economic Research (NBER) Working Paper 23056 (2017).
13. A. Missirian, W. Schlenker, *Am. Econ. Rev.* **107**, 436–440 (2017).
14. W. Schlenker, M. J. Roberts, *Proc. Natl. Acad. Sci. U.S.A.* **106**, 15594–15598 (2009).
15. M. B. Burke, E. Miguel, S. Satyanath, J. A. Dykema, D. B. Lobell, *Proc. Natl. Acad. Sci. U.S.A.* **106**, 20670–20674 (2009).
16. W. Schlenker, D. B. Lobell, *Environ. Res. Lett.* **5**, 014010 (2010).
17. D. B. Lobell, M. Bänziger, C. Magorokosho, B. Vivek, *Nat. Clim. Chang.* **1**, 42–45 (2011).
18. J. Tack, A. Barkley, L. L. Nalley, *Proc. Natl. Acad. Sci. U.S.A.* **112**, 6931–6936 (2015).
19. M. Dell, B. F. Jones, B. A. Olken, *Am. Econ. J. Macroecon.* **4**, 66–95 (2012).
20. M. Burke, S. M. Hsiang, E. Miguel, *Nature* **527**, 235–239 (2015).
21. A. S. Reifman, R. P. Larrick, S. Fein, *Pers. Soc. Psychol. Bull.* **17**, 580–585 (1991).
22. S. M. Hsiang, M. Burke, E. Miguel, *Science* **341**, 1235367 (2013).

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SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/358/6370/1610/suppl/DC1
Supplementary Text
Figs. S1 to S9
Tables S1 to S9
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Warming stresses developing countries

Weather-induced conflicts in developing countries spill over to developed countries through asylum applications. One approach to estimating the future impacts of climate change is to look at the effects of weather fluctuations. These transient shocks can be interpreted analytically as randomly distributed treatments applied to countries around the world. Missirian and Schlenker analyzed the relation between these localized shocks to agriculture and applications by that country's migrants for asylum in the European Union. When temperatures in the source country deviated from a moderate optimum around 20°C that is best for agriculture, asylum applications increased. Thus, the net forecast is for asylum applications to increase as global temperatures rise.

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