Regional Climate Change and National Responsibilities[a,b]

6 July 2020

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Global warming of about 1.6°F (0.9°C) over the past half century "loads the climate dice." Fig. 1 updates the "bell curve" analysis of our 2012 and 2016 papers[1,2] for Northern Hemisphere land, which showed that extreme hot summers now occur noticeably more often than they did 50 years ago. Our 2016 paper showed that there are strong regional variations in this bell curve shift, and that the largest effects occur in nations least responsible for causing climate change.

In the United States the bell curve shift is just over one standard deviation[c] in summer and about half a standard deviation in winter (Fig. 2). Measured in units of °F (or °C) the warming is similar in summer and winter in the U.S., but one practical implication of Fig. 2 is that the public in the U.S. is more likely to notice the warming in the summer. Summers cooler than the average 1951-1980 summer still occur, but only ~19% of the time. Extreme summer heat, defined as 3 standard deviations or more warmer than 1951-1980 average, which almost never occurred 50 years ago, now occurs with frequency about 7% in the U.S. and 19% in China.

Warming in Europe (see paper) is moderately larger than in the U.S. In China (Fig. 2) warming is now almost two standard deviations in summer and more than one standard deviation in winter, a climate change that should be noticeable to people old enough to remember the climate of 50 years ago. Bell curve shifts in India (see paper) are slightly larger than in China.

The Middle East and Mediterranean summer bell curve shifts are almost 3 standard deviations (Fig. 2). Every summer is now warmer than average 1951-1980 climate, and the period with "summer" climate is longer. Given that summers were already hot in this region, the change affects livability and productivity as noted below. Bell curve shifts in the tropics, including central Africa (see paper) and Southeast Asia (Fig. 2), which also was already hot, are now two to three standard deviations and extreme hot spells can occur in multiple seasons.

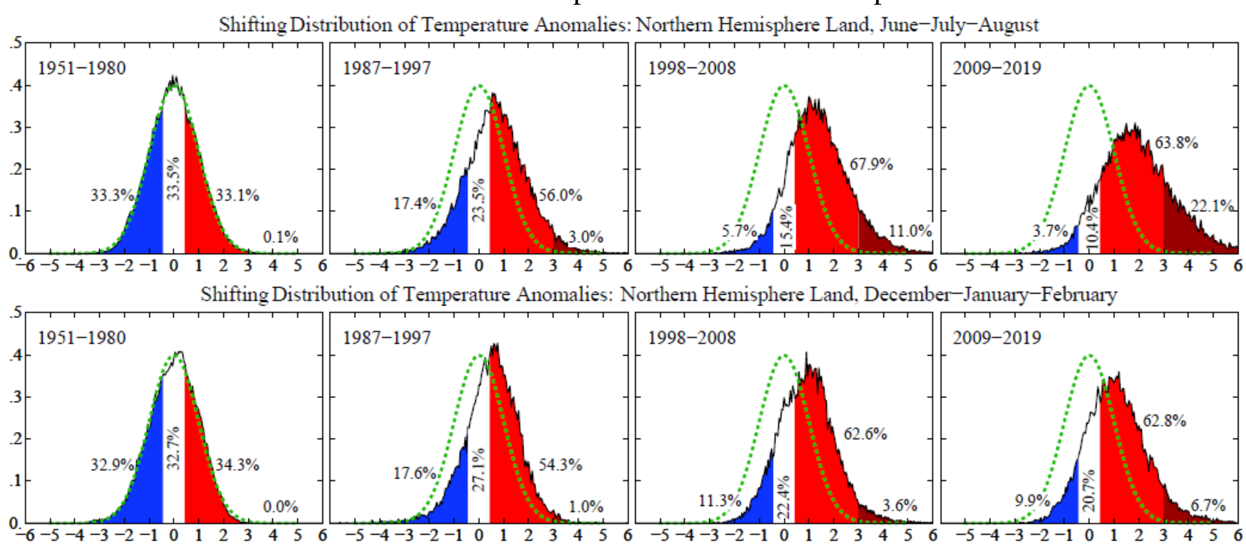

Fig. 1. Frequency of occurrence of local temperature anomalies (relative to 1951-80 mean) divided by local standard deviation (horizontal axis) for Northern Hemisphere land. See our 2012 and 2016 papers.

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[a] This Communication updates our 1 March 2016 Communication, which is based on our 2012 and 2016 papers.
[b] A brief Communication, essentially a cover note to this one, is available at Hunky-Dory.
[c] The standard deviation is a measure of typical year-to-year fluctuation of seasonal-average temperature.

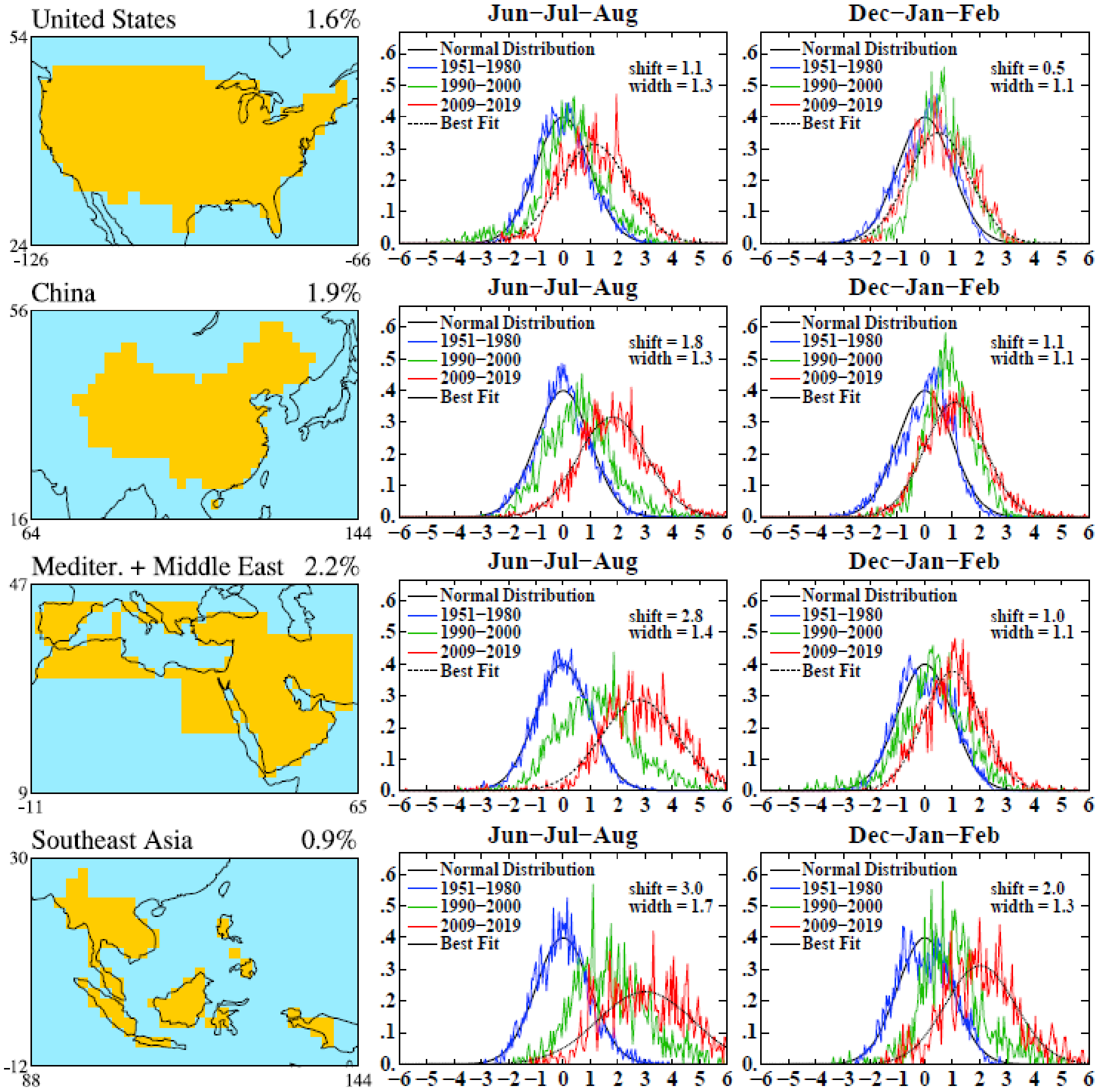

Fig. 2. Frequency of occurrence of local temperature anomalies (relative to 1951-80 mean) divided by local standard deviation (horizontal axis) for land areas shown. Numbers above map are percent of globe covered by selected region. "Shift" refers to dashed curve fit to 2009-2019 data relative to base period.

The tropics and the Middle East in summer are in danger of becoming practically uninhabitable by the end of the century if business-as-usual fossil fuel emissions continue, because wet bulb temperature could approach the level at which the human body is unable to cool itself under even well-ventilated outdoor conditions.[3] Lesser warming can still make life more difficult and reduce productivity in these regions, because temperatures are approaching the limit of human tolerance and both agricultural and construction work are mainly outdoor activities. Middle latitude countries have a near optimum average temperature for work productivity, while warmer countries such as Indonesia, India and Nigeria are on a steep slope with rapidly declining productivity as temperature rises (see Fig. 2 of Burke et al.[4], 2015).

Warming and climate effects are not uniform within the regions that we illustrate. In the U.S., e.g., warming is largest in the Southwest, consistent with expected amplified warming in dry subtropical regions.[5] Similarly summer warming is amplified in the Mediterranean and Middle East region, where at minimum it intensifies drought conditions such as those of Syria in recent years, if not being a principal cause of the drought.[6]

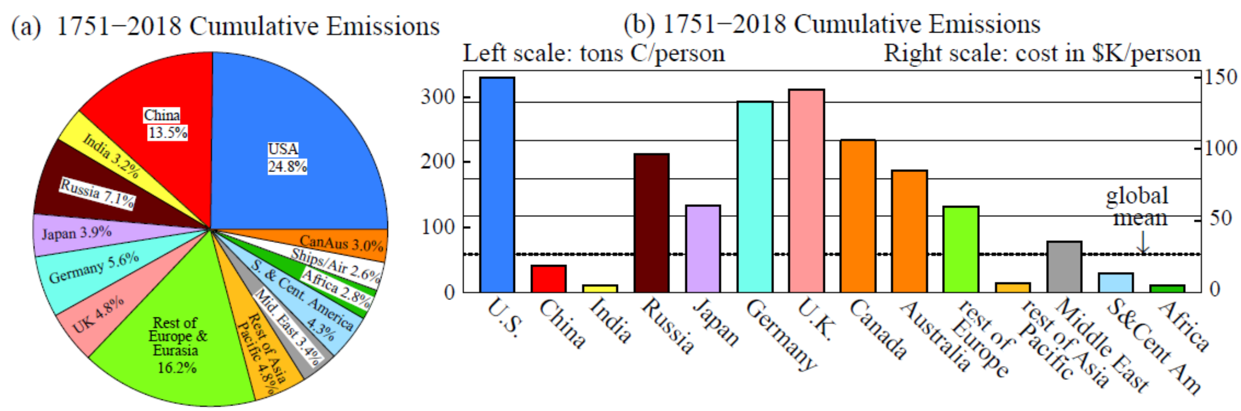

Fig. 3. Cumulative fossil fuel CO_2 emissions by national source (a) and per capita (b). Results for additional individual nations are available at www.columbia.edu/~mhs119/CO2Emissions/. The per capita cost of extracting from the air the national emissions of CO_2 is shown on the right scale, based on an estimated cost of $123 per ton of CO_2, which can be scaled for alternative cost rates.[7]

Increasing temperature seems to have a significant effect on interpersonal violence and human conflict, as indicated by a body of empirical evidence in a rapidly expanding area of scientific study. In an assembly of 60 quantitative studies[8] covering all major world regions, it is found that interpersonal violence increases by 4% and intergroup conflict by 14% for each standard deviation increase of temperature. Such findings do not constitute natural laws, but they provide a useful empirical estimate of impacts of temperature change.

Human health is affected by higher temperature via impacts on heat waves, drought, fires, floods and storms, and indirectly by ecological disruptions brought on by climate change including shifting patterns of disease (see Chapter 11 of IPCC, 2014, and references therein). Vector-borne diseases, usually involving infections transmitted by blood-sucking mosquitoes or ticks, will spread to higher latitudes and greater altitudes as global warming increases.

National responsibilities for global warming can be assigned because fossil fuel CO_2 is the main cause of long-term warming. Deforestation and agricultural activities contribute to airborne CO_2, but restoration of soil and biosphere carbon is possible via improved agricultural and forestry practices and, indeed that is required if climate is to be stabilized. In contrast, fossil fuel carbon will not be removed from the climate system for millennia.[9] Other trace gases contribute to climate change, but CO_2 causes 80% of the increase of greenhouse gas climate forcing in the past two decades[10] and much of the other 20% is related to fossil fuel mining or fossil fuel use.

Climate change is accurately proportional to cumulative CO_2 emissions (Fig. 3a). The U.S. and Europe are each responsible for about a quarter of cumulative emissions, China for about 14% and India 3%. The disparity between developed and developing country emissions is even greater with consumption-based accounting of emissions.[11] Even without consumption-based accounting, the per capita emissions of the U.S. and Europe are an order of magnitude greater than most developing countries.

There is thus a striking incongruity between locations of largest climate change and responsibility for fossil fuel emissions. Largest bell curve shifts are in tropical rainforest, Southeast Asia, the Sahara and Sahel, where fossil fuel emissions are small. Climate change is also large in the Middle East, where emissions are large and rapidly growing, with several nations having higher per capita emissions than the United States[2].

Discussion. We conclude that continued business-as-usual fossil fuel emissions will begin to make low latitudes inhospitable. If accompanied by multi-meter sea level rise,[12] resulting forced migration and economic disruption could be devastating.

Even global warming as small as 2°C, sometimes called a safe guardrail, may have large effects. Bell curve shifts shown for 2009-2019 result from global warming of ~0.9°C relative to 1951-80. Thus 2°C warming relative to pre-industrial (1.7°C relative to 1951-1980) will result in bell curve shifts and climate impacts about double those that have occurred already. Global warming of 2°C is expected to cause eventual sea level rise of several meters,[13] and the potential sea level rise this century is clearly dangerous[11].

The message that climate science delivers to society, policymakers, and the public alike is this: *global* fossil fuel CO_2 emissions should be reduced as rapidly as practical. Country-by-country goals, the approach of the 21st Conference of the Parties[14] will not lead to rapid phasedown of fossil fuel emissions, if fossil fuels remain cheap. It is necessary to include a carbon fee that allows the external costs of fossil fuels to be incorporated in their price. Border duties on products from countries without a carbon fee would lead to most nations adopting a carbon fee.

Given the emission disparities, there is an obligation for developed countries to assist developing countries. Developing countries have leverage to achieve assistance, because their cooperation in improved agricultural and forestry practices is needed to store more carbon in the soil and biosphere and to limit trace gas emissions. International cooperation is also needed to develop more affordable carbon-free energies, because otherwise economic development in many nations will continue to be based on fossil fuels, despite pollution and climate impacts.

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