Perception of climate change

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AUTHOR SUMMARY

Should the public be able to recognize that climate is changing, despite the notorious variability of weather and climate from day to day and year to year? We investigate how the probability of unusually warm seasons has changed in recent decades, with emphasis on summer, when changes are likely to have the greatest practical effects. We show that the odds of an unusually warm season have increased markedly over the past three decades. Also the shape of the temperature anomaly distribution, describing the frequency of occurrence of local temperature anomalies, has broadened, making extreme hot summers much more likely.

We describe variability of observed seasonal-mean temperature as anomalies relative to the average temperature in the base period 1951–1980, which is an appropriate base period because global temperature was relatively stable and within the Holocene range to which humanity and other planetary life are adapted. In contrast, we infer that global temperature is now above the Holocene range, as evidenced by the fact that the ice sheets in both hemispheres are shedding mass (1) and sea level is rising at a rate by the fact that the ice sheets in both hemispheres are

An important change is the emergence of a subset of the hot category, extremely hot outliers, defined as anomalies exceeding \(+3\sigma\). The frequency of these extreme anomalies is about 0.13% in the normal distribution, and thus a typical summer in the base period climate would have only about 0.1–0.2% of the globe covered by such hot extremes. We show that during the past several years the portion of global land area covered by summer temperature anomalies exceeding \(+3\sigma\) has averaged about 10%, an increase by more than an order of magnitude compared to the base period. Recent examples of summer temperature anomalies exceeding \(+3\sigma\) include the heat wave and drought in Oklahoma, Texas, and Mexico in 2011 and a larger region encompassing much of the Middle East, Western Asia, and Eastern Europe, including Moscow, in 2010.

The question of whether these extreme hot anomalies are a consequence of global warming is commonly answered in the negative, with an alternative interpretation based on meteorological patterns. For example, an unusual atmospheric “blocking” situation resulted in a long-lived high pressure anomaly in the Moscow region in 2010, and a strong La Niña in 2011 may have contributed to the heat and drought situation in the southern United States and Mexico. However, such meteorological patterns are not new and thus as an “explanation” fail to account for the huge increase in the area covered by extreme positive temperature anomalies. Specific meteorological patterns help explain where the high pressure regions that favor high temperature and drought conditions occur in a given summer, but the unusually great temperature extremities and the large area covered by these hot anomalies is a consequence of global warming.

Our analysis is an empirical approach that avoids use of global climate models, instead using only real world data. Theories for the cause of observed global temperature change are thus separated as an independent matter. However, it is of interest to compare the data with results from climate models that are used to simulate expected global warming due to increasing human-made greenhouse gases.

Indeed, the “climate dice” concept was suggested in conjunction with climate simulations made in the 1980s (3) as

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a way to describe the stochastic variability of local temperatures, with the implication that the public should recognize the existence of global warming once the dice become sufficiently “loaded” (biased). Specifically, the 10 warmest summers (June-July-August in the Northern Hemisphere) in the 30-y period (1951–1980) defined the “hot” category, the 10 coolest the “cold” category, and the middle 10 the “average” summer. Thus it was imagined that two sides of a six-sided die were colored red, blue and white for these respective categories. The divisions between hot and average and between average and cold occur at $±0.43\sigma$ for a normal distribution.

Temperatures simulated in a global climate model (3) reached a level such that four of the six sides of the climate dice were red in the first decade of the 21st century for greenhouse gas scenario B, which is an accurate approximation of actual greenhouse gas growth [(4), updates at http://www.columbia.edu/~mhs119/GHG_Forcing/]. We find that actual summer-mean temperature anomalies over global land during the past decade averaged about 75% in the “hot category,” thus midway between four and five sides of the die were red, which is reasonably consistent with expectations.

Observed global warming has now been attributed with a high confidence to increasing greenhouse gases (5). We have shown further that the increase of extreme hot summer outliers is a consequence of the warming. These attributions are important, because we can infer reliably that the area covered by extreme hot anomalies will continue to increase during the next few decades and that even more extreme outliers will occur. The decade-by-decade shift to the right of the temperature anomaly distribution (Fig. P1) will continue, because Earth is out of energy balance, more solar energy absorbed than heat radiation emitted to space (6), and it is this imbalance that drives the planet to higher temperatures. Even an exceedingly optimistic scenario for fossil fuel emissions reduction, 6%/year beginning in 2013, results in global temperature rising to almost 1.2 °C relative to 1880–1920, which compares to a current level approximately 0.8 °C (7).

Practical effects of increasingly loaded climate dice are likely to occur via amplified extremes of Earth’s water cycle. Indeed, we suggest that the broadening of the temperature anomaly distribution that we have detected is related to interactions of warming with the water cycle. Extreme hot summer anomalies are usually in places experiencing an extended period of high atmospheric pressure, a condition that is amplified by global warming and ubiquitous surface heating from elevated greenhouse gas levels, thus favoring development of extreme regional temperature and drought. Yet global warming, by increasing the amount of atmospheric water vapor, also leads to an increase of heavy precipitation and floods, consistent with documented changes over Northern Hemisphere land and the tropics (8).