Increasing Climate Extremes and the New Climate Dice

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Abstract. We address questions raised about our study "The New Climate Dice" by using longer base periods that include the 1930s. We show that the 2012 summer heat wave in the United States (June-July data) exceeds any that occurred in the 1930s. We reconfirm our conclusion that the increasing extremity of heat waves and the area covered by extreme events is caused by global warming. The location and timing of weather extremes depends on many factors and to a large degree is a matter of chance. Changing climate can be described, usefully and realistically, by the combination of "climate dice" and a shifting, broadening "bell curve", an approach that we believe can be appreciated by the general public.

Our recent paper (1), popularly described as "The New Climate Dice" although the publishers eliminated that phrase from the paper's title, showed that rapid global warming during the past three decades is driving a large increase in extreme heat waves with important consequences. Our paper was greeted with enthusiasm by many scientists. A perceptive review and discussion by Karl and Katz of the changing "bell curve", which we use to quantitatively describe local temperature anomalies, will appear soon in the journal that published our paper (2).

In addition, a few media outlets included strong criticisms of our study. First, it was stated that our study goes back only to the 1950s ignoring heat waves of the 1930s "which dwarf what we have now" (3). Second, it was stated that we offer no proof of our conclusion that the extreme heat waves are a consequence of climate change (4). Both statements are wrong. The support critics offered for their assertions was that the 1951-1980 base period that we used to define climate anomalies was biased. Here we repeat our analysis with alternative base periods, reconfirming and strengthening our conclusions, and we add further information.

1. Base period for analysis and standard deviation

Studies of climate change generally use some base period to define an average climate and calculate "anomalies" relative to that average, i.e., climate anomalies are the deviations from that average climate. In our papers (1, 5, 6) we used 1951-1980 as the base period.

Global temperature change over the past century (Fig. 1) helps us discuss possible effects of the choice of base period. Our choice of 1951-1980 as a base period has several merits:

1) The period 1951-1980 is prior to the large warming of the past few decades. If we wish to examine the effect of that global warming on climate, we must compare with the climate that existed prior to that warming.

2) The 1951-1980 period has the best global data coverage and can best characterize climate variability. Spatial coverage of data was poorer at earlier times.

3) 1951-1980 was the base period used by the National Weather Service and other researchers when we made our first analyses of observations and climate simulations (5). For comparison with these early analyses and climate simulations we should use the same base period.

4) Many of today's adults, baby-boomers, grew up during 1951-1980, so it is recent enough for many people to remember what the climate was like.

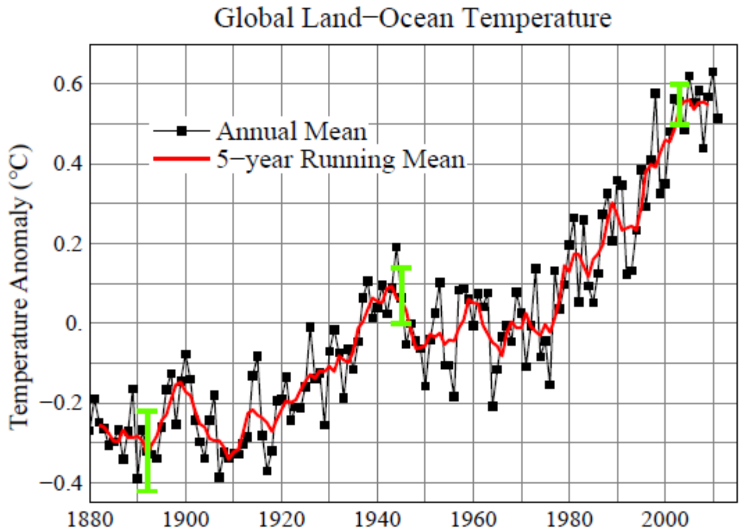

Fig. 1. Global surface temperature anomaly relative to 1951-1980 mean; update of (6).

Use of 1951-1980 as the base period did not prevent us from comparing recent climate with the 1930s and other times; indeed, our study (1) included comparisons with the 1930s. However, quantitative details can be influenced by the base period. Specifically, a longer base period is likely to encompass a larger range of temperature variability. Our study concerns the climate observed by a person on the ground at any given location, including comparison of current unusual climate anomalies with anomalies that occurred in the past. We know that some regions, notably the Midwest U.S. in the 1930s, experienced large climate anomalies prior to 1950. Such large anomalies can increase the size of the standard deviation (σ) of local temperature.[1]

Figure 2 compares standard deviation of seasonal-mean surface temperatures for 1931-1980 and 1951-1980, calculated relative to average 1931-1980 and 1951-1980 temperatures, respectively. Standard deviations are similar for the two periods, but, there are noticeable increases for the longer period, especially in the U.S. Midwest in summer. We also made calculations for 1921-1980, with the results very similar to those for 1931-1980. Because the data coverage in Africa, South America, and Asia is poor for 1921-1930, we use base period 1931-1980 below.

Variability of seasonal temperature tends to be dominated by year-to-year fluctuations rather than long-term temperature change, as reaffirmed by Fig. 2. The large inter-annual "noise" is what makes it difficult for the public to recognize that climate is changing. Specifically for that reason we introduced the concept of "climate dice" (5), hoping in that way to combat the tendency of the public to interpret the latest interannual climate fluctuation as the long-term climate trend.

[1] The standard deviation is a measure of the typical deviation of a quantity about its average value. Deviations of most physical quantities about their average value can be approximated well by a simple "bell curve". Small deviations from the average are common and very large deviations are more rare, so a graph of the frequency of occurrence of different deviations has a bell shape. For example, the average height of American men is 5' 10" and the standard deviation (σ or "sigma") is 3". If the probability distribution of heights were a perfect "bell curve" or "gaussian distribution", then 68% of men will have height within 1-sigma of the mean, that is a height between 5' 7" and 6' 1". 95% will be within 2-sigma of the mean and 99.7% will be within 3-sigma, i.e., in the range 5' 1" to 6' 7". Thus 3-sigma anomalies, deviations of more than 9" shorter or taller than average, are very rare Only 1 or 2 men out of a thousand will have a height exceeding 6' 7". This idealized bell curve is quite accurate in this and many cases.

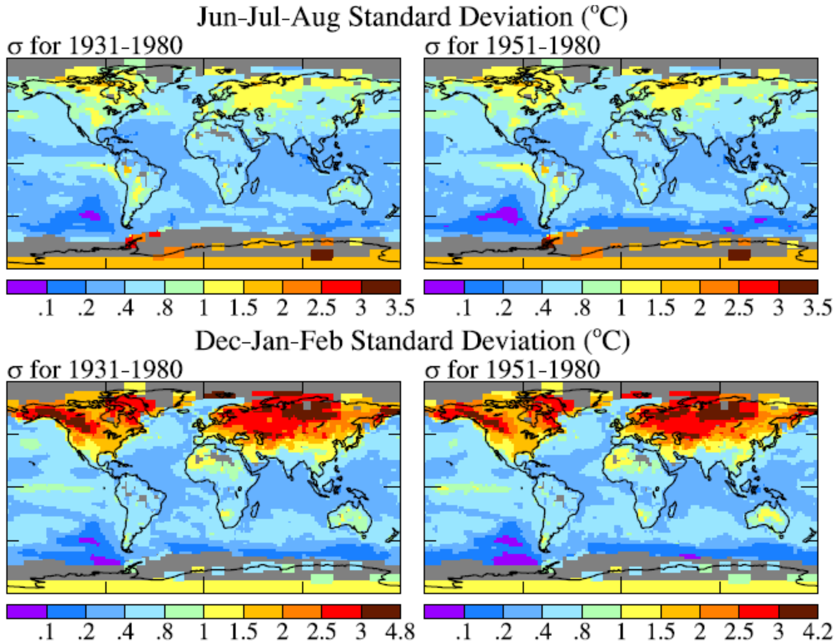

Fig. 2. Standard deviation of seasonal mean surface temperature for two periods.

The fact that the standard deviation is larger for base period 1931-1980 than for base period 1951-1980 causes the anomalies in any given year to be smaller when plotted in units of the standard deviation. However, 1930s temperature anomalies are, of course, reduced by exactly the same factor as the temperature anomalies of recent years.

Figure 3 shows Northern Hemisphere[2] summer temperature anomalies relative to the base period 1931-1980. The upper part of Fig. 3 is for six consecutive years in the 1930s including the years with the greatest 1930s summer heat in the United States and the lower part is for the most recent six years that have data for the entire summer. Fig. 3 can be compared with Figs. 6 and S2 of our published paper (1), which uses base period 1951-1980.[3]

It is noteworthy that there are almost no areas in the 1930s that achieve +3-sigma heat, if the standard deviation (σ or "sigma") is calculated for the 1931-1980 base period. For these six years (1931-1936) the Northern Hemisphere land area with summer heat exceeding +3σ is 0.4% for 1931-1980 standard deviations. The six years 2006-2011, in contrast, have 10% of the land area with anomalies exceeding +3σ for 1931-1980 standard deviations. This 10% result compares with 12% when 1951-1980 standard deviations are employed (1). For either choice of base period, the hemispheric land area with extremely hot temperature anomaly (> +3σ) is more than a factor of 10 larger in recent years than in the 1930s.

[2] Data is shown separately for hemispheres in our paper (1) at the suggestion of the editorial board, who felt it was confusing to show winter and summer data in the same figure while the discussion focused on summer. Contrary to criticisms in the media, there is no attempt to hide data inconsistent with our analysis. Indeed, our paper includes Southern Hemisphere data in separate figures, with results similar to those in the Northern Hemisphere.

[3] Slight changes exist because our published paper (1) uses version 2 of NOAA's GHCN (Global Historical Climatology Network) data, while we use version 3 here. Version 2 was discontinued by NOAA after November 2011, so our analyses of 2012 summer data must be based on version 3. In our next publication we will illustrate that the changes are small for the periods in which both version 2 and version 3 data are available.

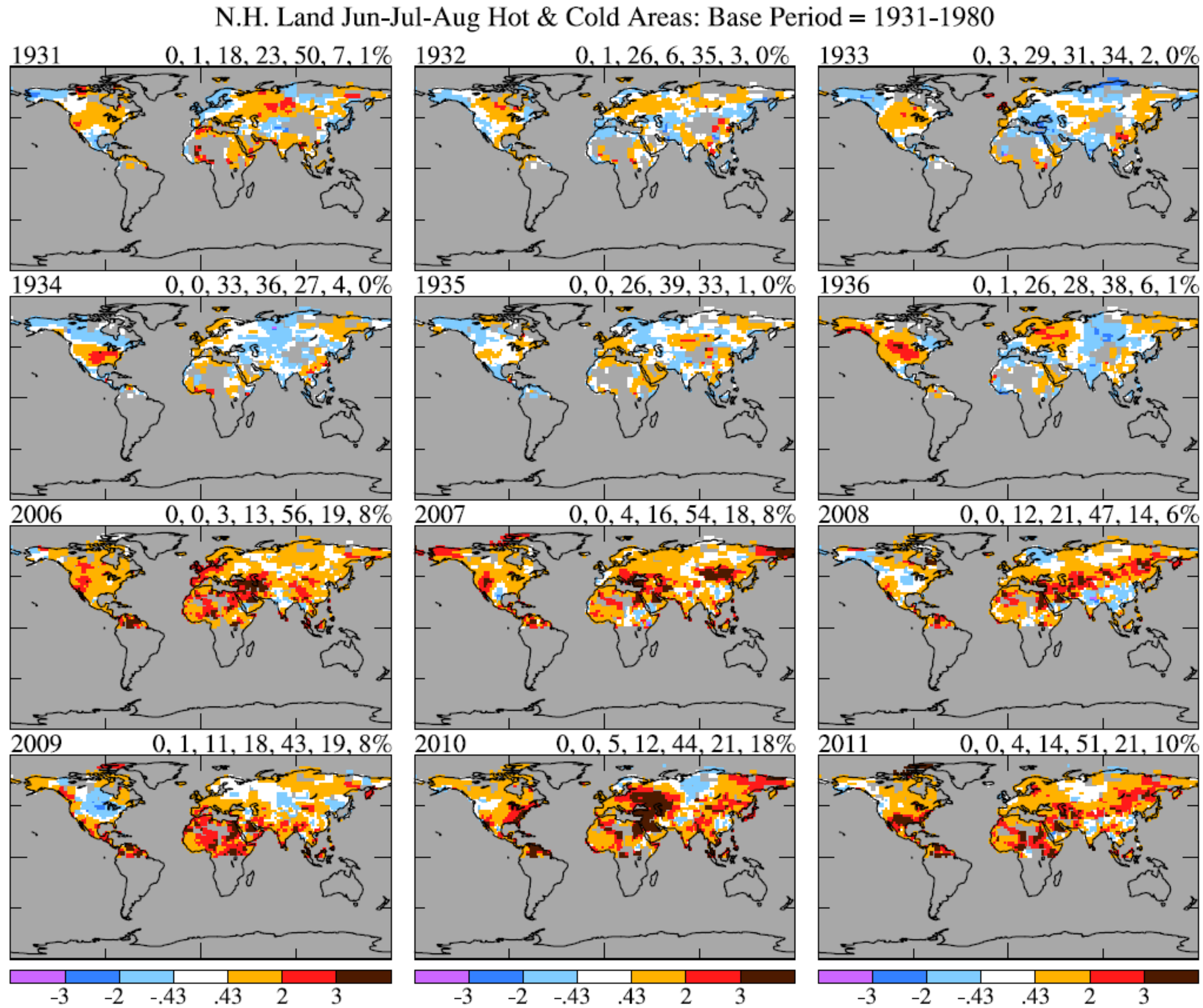

Fig. 3. June-July-August surface temperature anomalies over Northern Hemisphere land in 1931-1936 and 2006-2011 relative to 1931-1980 base period in units of the local 1931-1980 standard deviations. Numbers above each map are percent of area covered by each color bar category.

Close examination of Fig. 3 is revealing. The hottest summers in the 1930s were 1934 and 1936, when temperature anomalies were between $+2\sigma$ and $+3\sigma$ (using σ defined by the 1931-1980 base period) in much of the United States. The 2011 heat anomaly in Texas-Oklahoma exceeded $+3\sigma$ and the 2012 summer heat anomaly probably will exceed $+3\sigma$ in a larger portion of the United States (see below). Thus it seems that a substantial portion of the U.S. population will be able to assert that they lived through heat more extreme than that made famous in John Steinbeck's "Grapes of Wrath". However, the assertion will ring true only for those people who did not use air conditioning, which was not generally available in the 1930s.

Another important fact is hinted at by Fig. 3: temperature variability has increased in recent decades. The summers of 2008 and 2009 were unusually cool in parts of the United States. In the upper Midwest summer temperatures fell below -2σ in 2009, a time of high global temperature. The perception of increased climate variability is supported by global statistics, as we will show. This high variability needs to be appreciated by the public, if recognition of climate change is to be achieved as soon as possible.

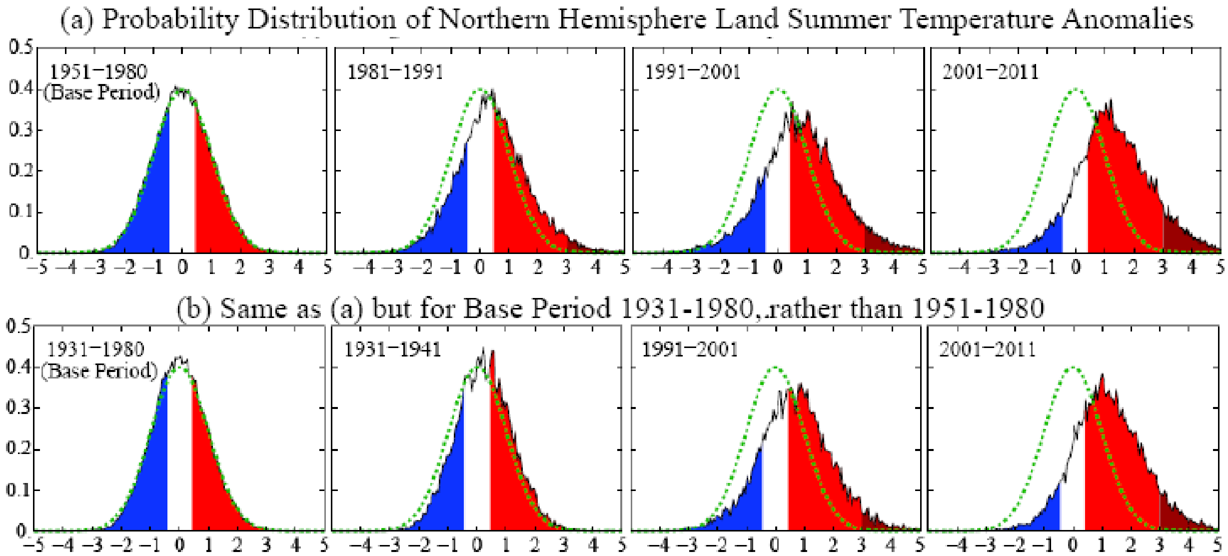

Fig. 4. Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies for Northern Hemisphere land in units of local standard deviation (horizontal axis). The normal (gaussian) distribution bell curve is shown in green.

The "bell curves" in Fig. 4 provide a powerful presentation of the temperature data. This presentation shows all data for Northern Hemisphere summer land temperatures. The graphs show the frequency of occurrence of temperature anomalies in units of the local standard deviation, with the standard deviation computed from either the 1951-1980 data (upper panel) or 1931-1980 data (lower panel).

The normal (gaussian) distribution (green curve) is used to define the blue, white and red areas, with $\sigma = 0.43$ yielding 33.3% of the distribution within each color category. Because the actual distribution of temperature anomalies is approximated well by the normal distribution in either base period, the $\sigma = \pm 0.43$ boundaries divide actual observations in the base period into three equally likely categories of cold, near-average, and hot conditions.

If dice are used to represent the chances of a cold, near-average, and hot season, two sides of a die would be blue, two sides white, and two sides red for the base period. The observed change in the frequency of temperature anomalies in recent years yields about one-half of a side blue for cold, one side white for near average, four sides red for hot, and one-half side red-brown for extremely hot, more than three standard deviations warmer than the base period average.

The most important observed climate change is the appearance of this new category of extreme heat, deviations more than $+3\sigma$, which practically did not occur in the base period. Remarkably several media reports had scientists asserting that we had not proven that the occurrence of these extreme heat anomalies was caused by global warming. The distributions in Fig. 4 contain all data points. The movement of the distribution to the right is global warming. Q.E.D.

United States summer temperature anomalies (Fig. 5) are particularly instructive. Despite the small area of the contiguous 48 states (covering only about 1.5% of the world's area), the effect of global warming during the past three decades is readily apparent. Only two of the past 15 summers have been cooler than either the 1931-1980 or 1951-1980 average. There is even a hint of the increased variability that the "bell curve" reveals more convincingly.

Fig. 5 is an alternative view of the concept that is being illustrated with the "loaded dice". In either case, it is important that the public understand that the anomalous warmth of 2012, even

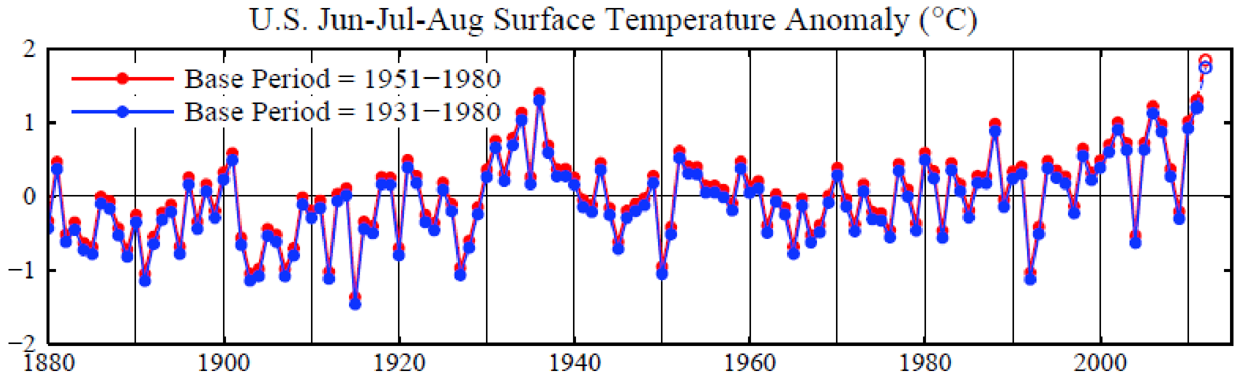

Fig. 5. Contiguous U.S. (48 states) surface temperature anomaly relative to alternative base periods. The 2012 data point is the average for June-July and may be reduced when August data are added.

though its extremity is caused by global warming, should not be assumed to represent a new norm. Climate will continue to be variable and there is still a significant chance of a season being cooler than the long-term average.

Fig. 5 also reveals that the 1930s heat was exceptional. It was not until 2012 that the 1936 extreme temperature was exceeded by a significant amount. However, Fig. 4 shows that the 1930s were not so exceptional on a hemispheric scale. As noted in our paper (1) analyses of the 1930s "dust bowl" in the U.S. suggest that it was probably related to the combination of Pacific Ocean temperature patterns favoring drought in the U.S. and exacerbation of the drought via effects of human-made plowing of the semi-arid Great Plains.

The important point that Fig. 4 makes is that such exceptional heat (relative to climatology, i.e., the long-term average) must now be expected to occur over an area of the order of 10 percent of the land. These extreme anomalies are important because their exceptional heat can and does drive exceptional wildfires, extreme drought, and dangerous heat.

The location of the extreme anomalies in any given year depends upon weather patterns, and is, to a significant degree, a crap shoot. Of course, in retrospect the location and timing of a given heat wave or drought can often be related to a specific weather pattern such as a "blocking high", to El Nino or La Nina atmospheric circulation patterns, or other meteorological situations. However, such meteorological situations have always occurred -- it is because of global warming that extreme conditions have become so much more pervasive.

References

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