WEATHER 'RECORDS' AND CLIMATIC CHANGE

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Abstract. Much recent popular opinion indicates more weather records are being established now than in the past or what one would expect by chance. The theory of extremes as applied to weather records is reviewed and then compared to the actual frequency of weather records established in the United States. It is concluded that fewer extremes of temperature are being set in recent years contrary to the popular view. Precipitation records are occurring at the normal theoretically expected rate.

1. Introduction

In the popular literature one sees frequent reference to weather records. In recent years some references to weather records have taken rather alarming viewpoints. For example, in the last few years, the following quotes have appeared in the popular literature:

"Droughts, floods, heat waves, and sudden chills unprecedented in living memory afflicted people used to an agreeably mixed climate whose fluctuations had hitherto been so constant that real change had passed almost unnoticed." (Tickell, 1977).

"Hottest, driest, longest, wettest, coldest – more weather records have been broken in the past decade than ever before in recent memory." (DeNevi, 1978, quote from book cover)

"Record low temperatures reported with increasing frequency in many parts of the United States." (Bryson and Murray, 1977, quote from book cover)

Extreme weather events can certainly be memorable but until a statistical test has been performed to test the statements above, it is legitimate to ask whether the popular viewpoint is real or is a delusion. The objective of this brief note is to provide an introduction to weather records and their meaning for climatic change. The subject of extremes in weather has a long history in meteorology. Court (1952) provides a good introduction to many facets of weather extremes and a bibliography of some of the earlier work. Gumbel (1942, 1958) performed some of the pioneering work in this field. The problem of the frequency of recent weather records has apparently not been addressed except in the most subjective way.

2. Theory of Extremes

Weather records are extremes of one sort or another. Extreme high temperature at a particular location for a given day of the year or given month are typical records. Ex-

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treme low temperatures, high or low precipitation, or high winds are further examples. More exotic records include extreme cold spells of 2, 3, 4, or more days duration or number of tornadoes in an area in a 24 hr period. In this study we limit ourselves to extremes of temperature or precipitation for a particular time interval such as a month because these weather records are the most commonly reported.

Consider a chronological sequence of observations such as temperature. Early in the chronology it is probable that a sampled temperature will exceed all the previous values and establish a new record temperature. As the chronology becomes longer the probability of establishing a new record becomes less and less. The first observation is a record high temperature. The second observation has a 50% chance of either being a new record or being lower. The third observation can either be a new high record, a new middle value, or a new low. Since the sampling is assumed to be entirely random, the probability of establishing a new high record on the third observation is 1/3 or 33%. Continued random sampling as a number X_n has a probability of establishing a new record (X_r) inversely equal to the number of samples (n) or

$$P(X_n > X_r) = 1/n. \tag{1}$$

Thus after 10 measurements or ten years of observation, the probability of establishing a new record is 10%. After 100 yr, the probability is 1%. For n arbitrarily large, there is always a finite probability of establishing a new record. This result is true provided we are randomly sampling from any symmetric distribution. The one standard deviation uncertainty in the above probability is $\sqrt{1/n - 1/n^2}$ (e.g., Glick, 1978).

The probability of establishing a new record is independent of the standard deviation of the measurements because the probability of a sample occurring in the wings of the distributions does not depend upon how broad or sharp the distribution is. Equation 1 is strictly true only if one is sampling from a white noise type of time series. If the time series has long-term oscillations so as to make it red, the probability of establishing a new record can be either systematically low or high because one is not sampling with equal probability all the possible values. Such a red series is characteristically said to be non-stationary.

3. Observations

The quotes at the beginning of this note suggested that for recent weather more extreme values are occurring than if one were randomly sampling from a symmetric distribution. Do the observations support the hypothesis that more weather records are occurring than one would expect by random sampling?

To test this hypothesis we used the monthly mean temperature and precipitation amounts for each of the 48 U.S. states given by Diaz and Quayle (1978). Each of the 48 states and 12 months plus yearly mean were searched for record minimum and maximum values. The number of records found at a time n since the beginning of the series was divided by the total number of possible records (624) of that type. Thus one obtains a measure

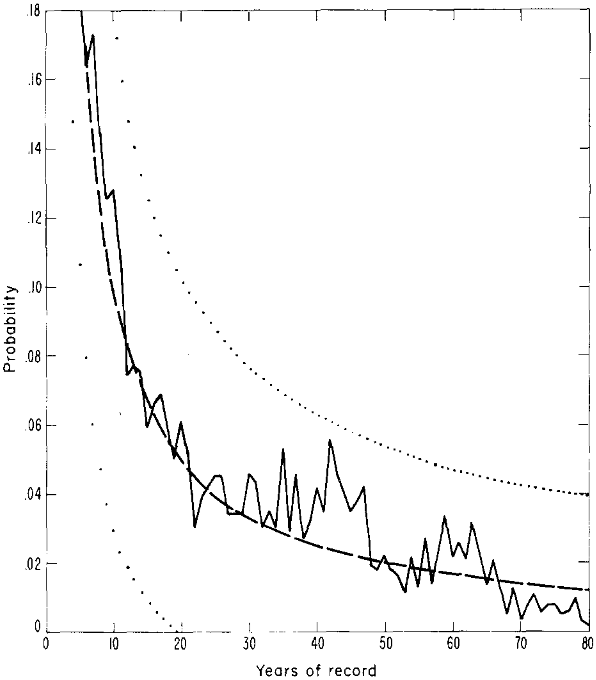

Fig. 1. Measured probability of record maximum monthly and yearly temperatures for states (solid line) and the theoretical probability (dashed line) with its 95% confidence limits (dotted lines). The 95% confidence limits are chosen for 72 degrees of freedom, a larger number than is probably actually the case, so the confidence limits to test for white noise are conservatively narrow.

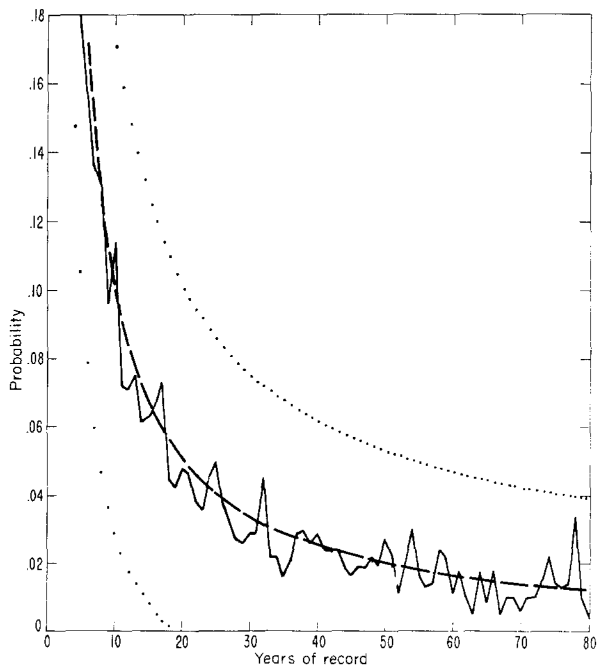

Fig. 2. The same for record minimum temperature.

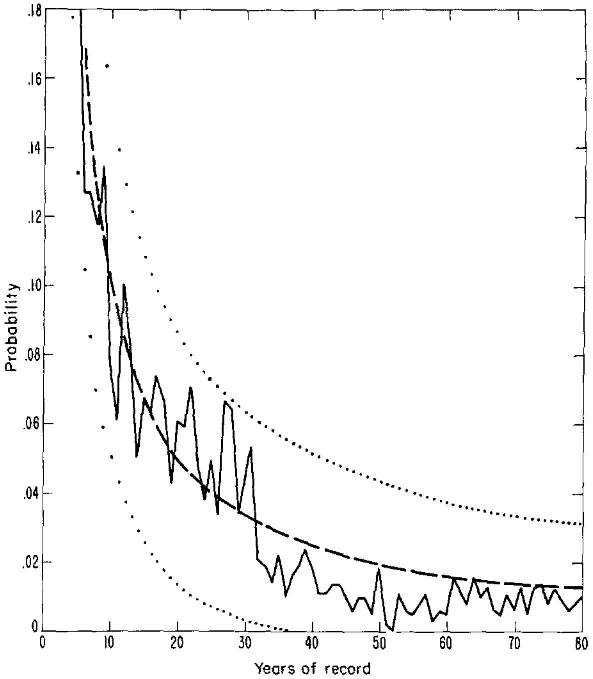

Fig. 3. The same for record maximum precipitation. 144 independent time series are assumed in calculating the confidence limits.

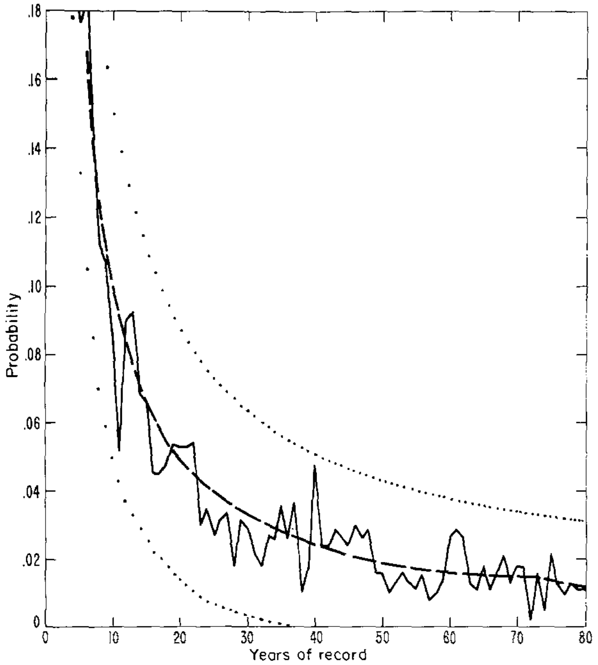

Fig. 4. The same for record minimum precipitation.

of the probability of establishing a record as a function of the number of years for which measurements were made.

Because there are fewer and fewer time series with continuous records beyond 80 yr in length, the plots in Figures 1-4 are stopped at 80 yr. The four plots show the probability of establishing monthly or yearly minima or maxima in either temperature or precipitation over a statewide area. The dashed and dotted lines in each figure show the theoretical probability of establishing a new record from Equation (1) and the 95% confidence limits for this theoretical probability, respectively. The confidence limits are established by assuming that, of the 624 times series only 72 are actually independent of each other in the statistical sense. From Diaz and Quayle's (1978) cross-correlation between regions we estimate there are no more than 6 independent regions in the United States. With the 12 monthly series, this gives 72 independent measurements (assuming the monthly values are uncorrelated). From Quayle (1981), 36 independent time series is probably a better estimate of the true number of independent time series, but choosing 72 gives us a very conservatively narrow estimate on the 95% confidence limits for white noise.

As one can see the empirically determined curves follow the theoretical curve quite well. There is a scatter about the theoretical curve because of the limited number of meteorological time series tested. However the scatter is not purely random since there are periods of time when one obtains more meteorological records than expected and other times one obtains fewer. This behavior is characteristic of a red noise type series. For example, the minimum temperature records occur more frequently than expected in the early years, less frequently in the mid-years, and a little more frequently again in recent years. Since many of the temperature records used here began in the 1890's, the deficit in the minimum temperature records in the mid-period arises primarily from the fact that the era around 1940 was comparatively warm. It is interesting to note that fewer than normal minimum temperature records are being established in recent years. None-theless the deviations from the model for white noise are not significant enough to conclude that we are not dealing with white noise in the establishment of new temperature records in the United States.

Precipitation throughout the entire period appears closer to being white noise than temperature. The lack of large spatial coherence in precipitation compared to temperature is probably the reason for the relative lack of temporal continuity in precipitation values which thus appear more nearly as white noise. This lack of spatial coherence also means we are dealing with more independent time series. The plotted 95% confidence limits are for 12 regions or 144 independent time series.

4. Conclusions

Contrary to the popular view expressed by the quotes at the beginning of this note, fewer temperature records are being established in the U.S. in recent years than one would expect if weather were white noise with a normal distribution. Recent studies by Chico and Sellers (1979), van Loon and Williams (1978) and Boer and Higachi (1980) indicate the standard deviation of temperature in the U.S. has decreased in recent years consistent with the results of this paper. There is a lack in the expected number of extreme temperature records in recent years. Climatic change in the U.S. over the last century has been sufficiently mild enough so that it can be modelled to a good first approximation as white noise in so far as the probabilities of setting new weather records is concerned. Williams (1978) and Madden (1977) reached similar conclusions for the similarity of precipitation and temperature to white noise.

One needs to be cautious in citing weather records as evidence of climate change. Because the probability of establishing a new weather record never drops to zero (Figures 1-4), then every year some region will establish a new temperature or precipitation record. Even in the warmest years on a global scale there will be some locations where a new monthly mean low temperature record will be set (e.g., Diaz, 1979).

Even in the coolest years, some locations will have periods of record warmth. Individual temperature and precipitation records by themselves tell us nothing about climatic change. Only if the number of new records established appreciably exceeds that which one would expect from a white noise series and does so for several years will one obtain any indication that a real climatic shift has occurred. Since there are approximately 95,000 stations now observing, it is not difficult to find locations where new records are being established. If one becomes aware of the new records, one may indeed falsely assume it is providing significant information about climatic change.

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