BREAKING GLOBAL TEMPERATURE RECORDS AFTER MT. PINATUBO

GILBERT W. BASSETT JR. and ZHIYONG LIN

Department of Economics(m/c144), University of Illinois at Chicago, Box 4348, Chicago, Il 60680-2451, U.S.A.

Abstract. The probability of setting global temperature records is reconsidered in light of cooling due to the Mt. Pinatubo eruption. The cooling 'resets' temperature by moving it away from the top of its 100-year range. Depending on the statistical model for temperature, this 'reset' can lead to a much lower probability for a record in the next few years. The exercise illustrates how record setting depends on the underlying model, the current record value, and – if there is serial correlation – the current temperature.

1. Introduction

It was shown previously that the probability of a global temperature record in the years following the warm 1980's could be high even without an increasing trend (Bassett, 1992). This was due to (i) serial correlation of global temperature in which a warmer than normal year makes it more likely that subsequent years will also be warmer than normal and (ii) in the late 1980's global temperature was already near its historical maximum value. Positive correlation in a time series makes a clustering of records much more likely than when there is independence. Combined with the warm temperatures of the 1980's, which put the series near the top of its 100-year historical range, it was found that a jump to a new record would not be a rare event. In fact, a new record high temperature occurred in 1990. The intent of the exercise was not to produce an exact, realistic numerical value for the probability of a record, but to show that different models could lead to different and sometimes surprising record breaking probabilities.

In this paper we reconsider the record setting question in light of changed circumstances. The June 1991 eruption of the Mt. Pinatubo volcano in the Philippines has lowered global temperatures due to large quantities of aerosols ejected into the atmosphere. As a result global temperature has moved away from the top of its historical range and this can change record probabilities from those reported previously.

Based on the models that were used previously, we recompute record probabilities taking account of the cooling due to Mt. Pinatubo. We again focus on the probability that a new record will be set within three years.[1] This probability is

[1] The reason for originally considering a record within three years was the widely reported Hansen wager in which, 'Climate expert James Hansen ... told a group of climatologists last week that his confidence that the greenhouse effect has arrived is even higher than it was in 1988, when he testified before Congress that he believed the global warming of recent decades was driven by gases produced by human activity. So sure is he now of this conclusion that he said he'd bet even money that one of the next 3 years will be the hottest in 100 years. ...People aren't going to believe such an 'incredible' and scientifically outrageous prediction, Hansen said" (Science, 1990).

Climatic Change **25**: 179–184, 1993.

expressed as a function of the 1992 temperature value, which is now known to have been almost 0.3 °C cooler than recent years. The probability expressed as a function of 1992 temperatures permits comparison of record probabilities over a range of alternative 1992 temperature values including one in which 1992 is as warm as recent years, as if the 1992 cooling had not occurred. We are thus able to see how much the probabilities decrease as a result of the cooling due to Mt. Pinatubo.

The next section presents a brief description of the statistical models that are used to represent temperature and that are the basis of the probability calculations. This is followed by presentation of record probabilities under alternative model specifications.

2. Temperature Models

Global temperature values, denoted by $c(t)$, are expressed as the deviation in degrees Celsius from the 1950–1979 average. The temperature values are assumed to be realizations of random variables $C(t)$ that are described below. The temperature values for $t = 1880, \ldots, 1992$ are known and the maximum temperature value of 0.46 °C occurred in 1990; see Figure 1.[2] The temperature of 0.39 °C for 1991 would have been higher except for a cooler second half of the year that has been attributed to Mt. Pinatubo.

Record probabilities are obtained for a range of alternative 1992 temperatures. By computing the probabilities for a range of values we are able to compare probabilities as a function of 1992 values and assess the impact of the Mt. Pinatubo cooling on the probability of a record.

Temperature values are assumed to be generated by:

$$C(t) = \mathrm{a} + \mathrm{b}t + e(t); \tag{1}$$

where a and b are parameters. The random variables $e(t)$ are assumed to follow the first-order autoregressive process

$$e(t) = \rho e(t-1) + v(t) \tag{2}$$

where the $v(t)$'s are independent with a common normal distribution that has mean zero and variance $\sigma^2(v)$. The ρ parameter is the correlation between successive $e(t)$'s. The variance of $C(t)$ is $\sigma^2(C) = \sigma^2(v)/[1 - \rho^2]$.

Cooling due to the volcano is represented by a decreased value for $v(1992)$; the $v(t)$'s, for $t = 1993$ and beyond, are assumed unaffected by Mt. Pinatubo. Hence,

[2] The data from 1880–1990 is from Trends '91, CDIAC, Oakridge National Laboratory and was compiled by James Hansen, Helene Wilson, and Reto Ruedy, NASA Goddard Space Flight Center. The four warmest years (temperature values) in this series occurred in 1990 (0.46 °C), 1991 (0.39 °C), 1981 (0.39 °C) and 1988 (0.33 °C). The series has been revised frequently in the past few years and this has resulted in some revisions in the years when records were set. 1988 is not a record year in the current series (the record broken in 1990 was set in 1981), but with the older series 1988 was a record year.

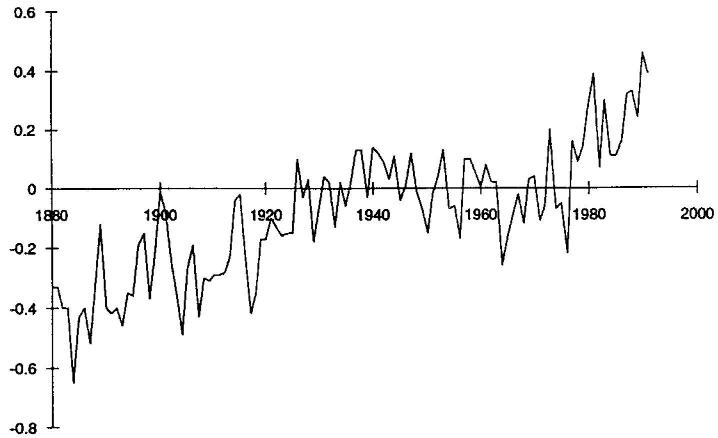

Fig. 1. Temperature 1880–1991.

the *direct* impact of the volcano is assumed to last only one year. (See Minnis *et al.* (1993) for a recent report on the impacts of the volcano). When ρ is assumed to be zero this means the volcano's impact is only felt in 1992. When ρ is positive there are indirect effects due to 1992 having been cooler than otherwise.

We consider four different models by restricting various parameters to be zero; unconstrained parameters are estimated from the historical data. The first two models are specified without serial correlation $\rho = 0$, while the third and fourth have a positive ρ that is estimated from the historical data. The estimated values of the free parameters used in the record probability computations are summarized in Table I.

3. Record Probabilities

We consider each model and its implied probability of a record; formulas used for the computations are the same as in Bassett (1992).

3.1. *No Linear Trend and Independence*

For this model b and ρ are restricted to be zero so that temperature is given by,

$$C(t) = -0.08620 + v(t);\ \sigma(v) = 0.219$$

(The negative mean is due to temperature being expressed in terms of yearly deviations from the 1950–1979). Temperature behaves in this model as if it were a drawing from an urn with values that do not change over time and where each drawing is independent of previous values.

Since there is no serial correlation there is no impact from Mt. Pinatubo, except that $c(1992)$ is lower than otherwise. In this case the probability of a record within

TABLE I: Parameter estimates based on 1880–1992 data (with $c(1992) = 0.13$)

	Model I	Model II	Model III	Model IV
a	−0.08620	−10.480	−0.08620	−10.389
b	0	0.005369	0	0.005320
ρ	0	0	0.7940	0.4262
$\sigma(v)$	0.219	0.131	0.134	0.119

three years after 1992 is 0.02.[3] For this model a temperature record within three years is a rare event; it is this model that Hansen was thinking about when he described his original prediction as 'outrageous'.

3.2. *Linear Trend and Independence*

Here ρ is restricted to be 0 and the b parameter is set as its estimated value,

$$C(t) = -10.480 + 0.005369t + v(t);\ \sigma(v) = 0.131$$

For this model there is a linear trend, but each year's temperature is independent of previous values. The estimate for b corresponds to the approximate ½ °C warming that has occurred over the past hundred years.

Since there is no correlation there is again no impact from the volcano and the probability of a record is 0.11.[4]

3.3. *No Trend and Serial Correlation*

This is the same as Model I except that deviations from average temperature follow a first-order scheme,

$$C(t) = -0.086 + e(t)$$

$$e(t) = 0.7940e(t-1) + v(t);\ \sigma(v) = 0.134$$

Under this specification there is no upward trend; the apparent global warming seen in Figure 1 is induced entirely by positive serial correlation. Positive correlation can produce apparent trends, which however will gradually dissipate over time.

Figure 2 shows the relationship between 1992 temperature and the probability of a record. The point A on the temperature axis at about 0.45 °C is the 1991 realized temperature and the point B at 0.13 °C is the actual 1992 temperature. The figure shows that the probability of a record decreases substantially as the 1992

[3] This is lower than the previously reported probability of 0.06. The lower value of 0.02 is due to the higher record value set in 1990 (the earlier paper was based on data through 1988).

[4] This differs from the value reported in the previous paper because of the higher record value set in 1990.

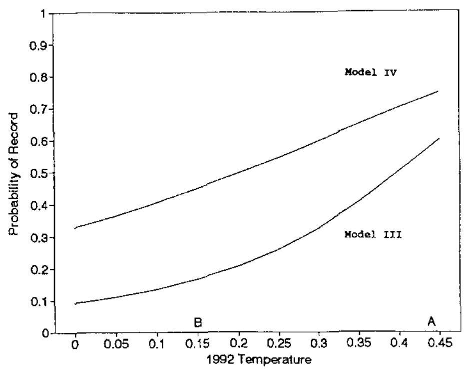

Fig. 2. Record probability as a function of 1992 temperature.

temperature falls. The cool 1992 moved the series away from the top of its historical range, thus decreasing the chances of a subsequent jump to a new record value.

The figure illustrates what happens if there had been no cooling. If 1992 temperature had been around point A in the figure the temperature series would have stayed near the top of its historical range. In this case it would have been better than 50–50 for a record within three years whereas when 1992 temperature is at point B the probability falls all the way to 0.15.

3.4. *Linear Trend and Serial Correlation*

In this model positive serial correlation is combined with an upward trend,

$$C(t) = -10.39 + 0.0053t + e(t);$$
$$e(t) = 0.426e(t-1) + v(t);\ \sigma(v) = 0.119$$

Figure 2 also shows the relation between 1992 temperature and the probability of setting a record for Model IV. The curve lies above the previous case because of the linear trend that is in this model. The figure shows that while the probability decreases with a decreasing 1992 temperature, it does not change by as much as in Model III. The upward trend in temperature means that there is a smaller change in record values as 1992 temperature decreases.

4. Conclusion

The probabilities of a record are summarized in Table II. It shows the probabilities for all four models at two different 1992 temperature values. The 0.45 °C case corresponds to what might have occurred without Mt. Pinatubo, while 0.13 °C is the much cooler temperature that actually occured in 1992.

TABLE II

	Case I	Case II	Case III	Case IV
Prob. of record: with Mt. Pinatubo eruption (1992 = 0.13 °C)	0.0189	0.1069	0.1508	0.4300
Prob. of record: without Mt. Pinatubo eruption (1992 = 0.45 °C)	0.0227	0.1340	0.5990	0.7451

The table shows that the probability of a record differs in the four cases. Models III and IV with positive serial correlation generate relatively high record probabilities. The table also shows the differences due to Mt. Pinatubo. With models I and II there is almost no change in the record probability due to the cool 1992 (the slight change comes from estimating the parameters with the alternative 1992 temperature values). This contrasts with the autocorrelation models where the 1992 cooling produces greatly diminished values for record probabilities.

The table shows that the probability of records depends on the model for temperature. Records are rare when there is no trend and little correlation. They become more likely when there is an increasing temperature trend and when temperature is positively correlated with past values. We also see that the Models III and IV produce very different results depending on the current temperature.

Finally, for the wagering purposes that motivated consideration of the original record breaking problem we find that cooling due to Mt. Pinatubo makes the Hansen wager, which says a record will occur in three years, much more lucrative for those betting against a record in the next three years.

Acknowledgement

We would like to thank James Hansen and a reviewer for their comments on an earlier version of the paper.

References

Bassett, G. W.: 1992, 'Breaking Recent Global Temperature Records', *Clim. Change* **21**, 303–315.
Hansen, J., Wilson, H., and Ruedy, R.: 1991, in *Trends '91*, Carbon Dioxide Information Analysis Center, Oakridge National Laboratory.
Minnis, P., Harrison, E. F., Stowe, L. L., Gibson, G. G., Denn, F. M., Doelling, D. R., Smith, W. L., Jr.: 1993, 'Radiative Climate Forcing by the Mount Pinatubo Eruption', *Science* **259**, 1411–15.
Science: 1990, May 4, 549.

(Received 30 November, 1992; in revised form 28 June, 1993)