# The Impact of Increasing Summer Mean Temperatures on Extreme Maximum and Minimum Temperatures in Phoenix, Arizona

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28 November 1989 and 31 May 1990

ABSTRACT

Over the past few decades, heat-island related temperature increases in Phoenix, Arizona have been similar to the temperature increases predicted in a number of greenhouse simulation experiments. In this investigation, we use the Phoenix climate record to assess how increasing summertime mean temperatures are related to changes in the extreme maximum and minimum temperatures. Generally, rising mean temperatures are associated with substantial changes in the occurrence of extreme minimum temperatures (e.g., fewer days of extreme low minimum temperatures and more days of extreme high minimum temperatures). However, while the rising mean temperatures strongly influence the occurrence of moderately high maximum temperatures, they are weakly associated with the occurrence of extreme maximum temperatures. The results suggest that considerable caution should be used in predicting the occurrence of extreme temperatures from projected increases in mean temperature levels.

## 1. Introduction

A number of climate models have projected significant increases in global, hemispheric, and regional temperatures as "greenhouse" gases are added to the atmosphere (e.g., Washington and Meehl 1984; Wetherald and Manabe 1986; Schlesinger and Mitchell 1987; Wilson and Mitchell 1987; Hansen et al. 1988). In most of these models, the changes in temperature correspond to the *mean* temperatures on the monthly, seasonal, and annual time scales. However, a given adjustment in the mean temperature may result in a variety of changes in diurnal temperature patterns (Karl et al. 1984, 1986, 1987; Rind et al. 1989) and/or changes in the frequency of extreme events (Mearns et al. 1984; Hansen et al. 1988; Waggoner 1989).

In this investigation, we use the observed increasing temperatures in Phoenix, Arizona to determine the empirical link between known warming and the frequency of extreme maximum and minimum summer temperatures. Although the increasing temperatures in Phoenix are far more related to heat-island processes (Balling and Brazel 1986, 1988) than to any greenhouse effect, the increasing summer temperatures in Phoenix may serve as a valuable analog for potential greenhouse warming. The observed mean summer (July and August) linear temperature increase is on the order of 0.7°C per decade with more warming in the minimum as opposed to the maximum temperatures (Fig. 1). These daily maximum and minimum temperature records may be analyzed to determine the influence of rising mean seasonal temperatures on the frequency of extreme highs and lows.

## 2. Methods and results

Daily maximum, minimum, and mean temperatures were collected from a readily available computer database for July and August from 1948–1988. The observations were taken at the National Weather Service Forecast Office located at the Phoenix Sky Harbor Airport; only minor station moves occurred through the study period and no missing data are contained in the record. For each season, 18 variables were determined including: the seasonal (two-month) mean temperature; seasonal average maximum temperature; seasonal average minimum temperature; the number of days with a maximum temperature $\geqslant$ 42°, 43°, 44°, 45°, and 46°C; the number of days with the minimum temperature $\geqslant$ 28°, 29°, 30°, 31°, and 32°C; and the number of days with the minimum temperature $\leqslant$ 20°, 21°, 22°, 23°, and 24°C.

Analysis of these data indicate the following:

1) Average summer temperatures in Phoenix are rising at a rate of 0.07°C $\mathrm{yr}^{-1}$ (Fig. 1); the rate of in-

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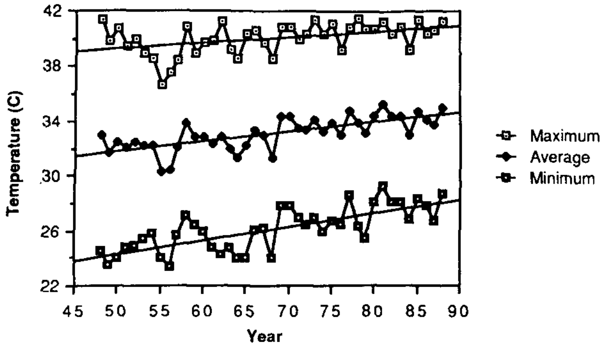

FIG. 1. Plot of July–August seasonal temperatures over the 1948–88 study period in Phoenix, Arizona.

crease in the seasonal average minimum temperature (0.10°C $yr^{-1}$) is twice as large as the rate of increase in the average maximum temperature (0.04°C $yr^{-1}$).

2) For all frequencies of extreme maximum and minimum temperatures examined (Table 1), the standardized coefficients of skewness and kurtosis, $z_1$ and $z_2$, were computed to determine selected characteristics of the distributions. Given the 41 years of records, absolute values of $z_1$ or $z_2$ above 2.02 indicate a significant departure from normality at the 0.95 level of confidence used throughout this study. The results indicate that the more extreme maximum or minimum temperatures have frequency distributions dominated by positive, and significant, skewness and peakedness. The lack of normality in the frequency distribution of the extreme values of such meteorological data is in agreement with the findings of other investigators (e.g., Gumbel 1958; Tabony 1983; Katz, 1985) working with extreme value statistics.

3) Several statistics were used to establish the relationship between average summer temperature and the frequency of extreme maximum temperatures. The Pearson product-moment correlation coefficient and the associated linear slope were determined; recognizing the lack of normality in some of the temperature distributions, the Spearman rank-order correlation coefficient was also computed. Absolute values of these correlation coefficients above 0.31 are statistically significant. In each case, the results show that the number of days with maximum temperatures exceeding the selected high values (42°–46°C) increases significantly with rising seasonal mean temperatures (Table 1). Specific examples show that while a 1°C climb in seasonal temperature increases the number of 42°C maximum temperatures by over four days, the impact of the 1°C seasonal temperature rise dwindles to an increase of less than one day in the number of 45°C maximum temperatures (Fig. 2). Although this increase in the number of 45°C maximum temperatures is approximately one additional day in three years, the value represents a 52% increase in the number of days with a 45°C temperature. It is worth noting that despite the rapid rise in seasonal temperatures in the Phoenix area over the past few decades, the record maximum temperature of 47.8°C (118°F) observed at the airport location in 1958 was not equalled or exceeded between 1959 and 1988.

Due to the nonnormal distributions in some of the arrays, and given the apparent nonlinear relationship between the frequency of extreme temperatures and mean seasonal temperature, a variety of nonlinear curves were substituted for the trend lines. In no case did the nonlinear analysis produce a statistically significant increase in the $r$ values describing the rela-

TABLE 1. Statistics describing the relationship between mean seasonal (July and August) temperature and the occurrence of extreme maximum and minimum temperatures in Phoenix, Arizona.

| Variable | $\bar{X}$ | $s$ | $z_1$ | $z_2$ | $r_1$ | $r_2$ | $B$ |
|---|---|---|---|---|---|---|---|
| Max ⩾ 42°C | 15.46 | 7.15 | −0.33 | −0.95 | 0.71 | 0.73 | 4.34 |
| Max ⩾ 43°C | 8.34 | 4.73 | 0.27 | −1.15 | 0.69 | 0.68 | 2.68 |
| Max ⩾ 44°C | 2.85 | 2.50 | 2.76 | 0.87 | 0.60 | 0.49 | 1.03 |
| Max ⩾ 45°C | 0.73 | 1.18 | 4.98 | 4.48 | 0.44 | 0.38 | 0.38 |
| Max ⩾ 46°C | 0.41 | 0.80 | 5.29 | 4.33 | 0.40 | 0.33 | 0.22 |
| Min ⩾ 28°C | 16.39 | 13.58 | 1.70 | −0.98 | 0.92 | 0.89 | 10.10 |
| Min ⩾ 29°C | 9.22 | 10.04 | 3.15 | 1.40 | 0.89 | 0.85 | 7.12 |
| Min ⩾ 30°C | 4.32 | 5.63 | 3.53 | 1.78 | 0.93 | 0.83 | 3.88 |
| Min ⩾ 31°C | 2.56 | 3.94 | 4.54 | 2.91 | 0.86 | 0.74 | 2.43 |
| Min ⩾ 32°C | 0.49 | 1.00 | 6.97 | 10.73 | 0.61 | 0.48 | 0.40 |
| Min ⩽ 20°C | 1.54 | 2.66 | 6.02 | 6.83 | −0.73 | −0.63 | −1.41 |
| Min ⩽ 21°C | 2.17 | 3.16 | 4.49 | 3.15 | −0.77 | −0.75 | −1.99 |
| Min ⩽ 22°C | 4.27 | 5.08 | 2.52 | −0.39 | −0.74 | −0.76 | −3.21 |
| Min ⩽ 23°C | 8.71 | 8.07 | 2.14 | −0.49 | −0.81 | −0.80 | −5.40 |
| Min ⩽ 24°C | 15.34 | 11.19 | 1.10 | −1.36 | −0.83 | −0.84 | −7.80 |

Note: $\bar{X}$ is the mean number of days ⩾ or ⩽ a threshold temperature in July and August, $s$ is the standard deviation (in days), $z_1$ and $z_2$ are the standardized coefficients of skewness and kurtosis, $r_1$ is the Spearman rank-order correlation coefficient for the relationship between the mean seasonal temperature and the number of occurrences ⩾ or ⩽ selected temperatures, $r_2$ is the Pearson product-moment correlation coefficient for the relationship between the mean seasonal temperature and the number of occurrences ⩾ or ⩽ selected temperatures, and $B$ is the slope associated with the linear relationship (number of days per 1°C change in seasonal temperature).

tionship between the seasonal temperature and the frequency of an extreme maximum temperature. Nonetheless, the lack of a strong relationship between the seasonal temperatures and the more extreme daily temperatures is related, in part, to the low number of observations of the extreme temperatures.

4) The rising seasonal temperatures appear to have a much stronger impact on the number of days of extreme minimum temperature (Table 1). Selected examples (Fig. 3) show that a 1°C increase in the seasonal temperature results in ten additional days with ≥28°C for the minimum temperature, while the same 1°C seasonal increase generates just over two additional days of ≥31°C for the minimum temperature. Similar patterns are determined for the frequency distributions of extreme, low minimum temperatures (Table 1).

## 3. Discussion and conclusions

The analyses presented in this study indicate that rising mean seasonal temperatures will increase significantly the number of days with high maximum and minimum temperatures and decrease the number of days with extreme low minimum temperatures. In terms of actual occurrences, the impact of rising seasonal temperatures appears to be greatest on the more moderate maximum and minimum temperatures. For example, a 1°C rise in seasonal temperature produces four more days of 42°C temperatures in July and August; yet, that same 1°C rise will produce fewer than one additional day of temperatures above 45°C (nonetheless, a 50% increase).

In attempting to estimate frequencies of extreme temperatures given projected greenhouse warming, Hansen et al. (1988) simply shifted the frequency distribution of daily maximum and minimum temperatures by the amount of warming suggested for the mean temperatures. Mearns et al. (1984) used a more complex scheme involving changes in the mean, variance, and/or autocorrelation in the time series. Both Mearns et al. (1984) and Hansen et al. (1988) concluded that relatively small changes in the mean could produce substantial changes in the frequency of extreme events. Based on our analyses of the Phoenix data, the more simplistic scheme of Hansen et al. (1988) appears to overestimate the frequencies of extreme high temperatures. For example, based on the calculated linear slope, a 1°C rise in seasonal temperature would increase the number of 43°C days from 8 to 11 days (Table 1). However, a simple shift in the frequency distribution would suggest an increase from 8 to 15 days. Instead of increasing the number of 43°C days by 2.68 as suggested by the slope, the shift in frequency distribution increases the number of 43°C days by over 7 days. However, the two schemes produce similar results for some of the extreme minimum temperatures.

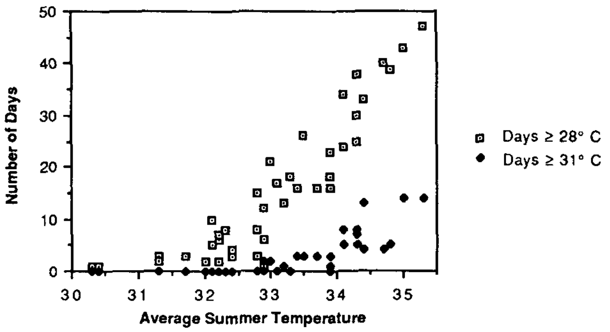

FIG. 3. Same as Fig. 2 except for selected minimum temperatures (≥28°C and ≥31°C).

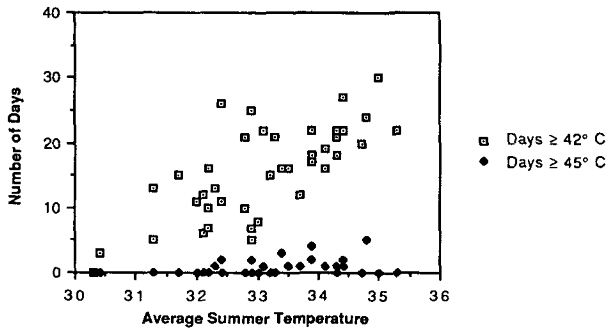

FIG. 2. Scatter diagram showing the relationship between occurrence of selected maximum temperatures (≥42°C and ≥45°C) and average summer (July and August) temperature in Phoenix, Arizona (1948–88).

Based on these findings, we must suggest that caution be exercised in predicting distributions for extreme maximums and minimums from projected increases in mean monthly or seasonal temperatures. Future research should focus upon the changes in the characteristics of the frequency distributions that may be associated with higher average temperatures. Special attention should be placed on how various forcing mechanisms impact the tails of the frequency distributions. The findings of this study are based upon warming induced by strong heat-island effects in a desert setting; large-scale forcing associated with any greenhouse warming may produce vastly different results in other parts of the planet.

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