Climatology Note

NOTE ON A DEFINITION OF NORMAL WEATHER

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ABSTRACT

This paper clarifies the distinction between abnormal weather, and above and below average weather, using standard statistical analyses. Abnormal maximum and minimum temperatures are defined as requiring at least two standard deviations from the mean; otherwise even though they could be above or below average, the weather is still "normal." July and January maximum and minimum temperatures for Denver, New York, Los Angeles, Miami, and Bismarck are presented as examples of this analysis.

1. INTRODUCTION

It happens frequently on radio and television. The newscaster or weather broadcaster reports "the high temperature today is much above normal." But what is "normal"? Was the temperature actually anomalously high, or just "above average but within the normal range of expected values."

This paper discusses the concept of normal weather using maximum and minimum daily temperatures for July and January at several selected U.S. cities (Denver, New York, Los Angeles, Miami, and Bismarck).

2. METHODOLOGY

A consistent procedure to define normal temperatures is to apply the concept that observed temperatures are distributed according to a Gaussian probability density function. Thus if the temperatures fall within some bound of the average, i.e. one or two standard deviations (σ or 2σ), the observed temperature can be considered normal. Beyond that range, the weather could be considered abnormal.

The mean and standard deviation of temperature for a site can be calculated from daily observations over a long period of record for a specific month. We have chosen, however, an alternative procedure using monthly average maximum and minimum temperatures which are easier data to obtain.

The N-year mean, monthly average maximum and minimum temperatures for N years of record, can be calculated from

$$\hat{T} = \sum_{i=1}^{N} \overline{T}_i/N \qquad (1)$$

where T refers to either maximum or minimum temperature, $\overline{T}_i$ refers to the average for the month in the year denoted by the subscript, i, and $\hat{T}$ is the N-year average.

The standard deviation from (1) is computed by

$$\hat{\sigma} = \frac{1}{N-1}\sqrt{\sum_{i=1}^{N}\left(\overline{T}_i - \hat{T}\right)^2} \qquad (2)$$

Values of $\overline{T}_1$, $\overline{T}_2$, etc. were obtained from

$$\overline{T}_i = \sum_{j=1}^{n} T_j/n \qquad (3)$$

where n is the number of days in a chosen month. T_j is the temperature on day j. The standard deviation from (3) for a given month in a given year could be computed from

$$\sigma_i = \frac{1}{N-1}\sqrt{\sum_{j=1}^{N}\left(T - \overline{T}_j\right)^2} \qquad (4)$$

if the data were readily available. Over the period of record, the daily average standard deviation could then be calculated from

$$\sigma = \sum_{i=1}^{N} \sigma_i/N \qquad (5)$$

In lieu of using (4) and (5), Madden (3), and Madden and Shea (4) suggest a procedure to convert values of (2) to estimates of (5) using the equation

$$\tilde{\sigma} = \sqrt{n\hat{\sigma}^2/\left[1 + 2\left(1 - \frac{1}{n}\right)a + 2\left(1 - \frac{2}{n}\right)a^2 + 2\left(1 - \frac{3}{n}\right)a^3 + \ldots\right]} \qquad (6)$$

where a is a measure of the day-to-day correlation in temperature. The values of a vary geographically and with season.

Madden (3), and Madden and Shea (4) present maps of the characteristic time in days between effectively independent samples of temperature (reproduced here as Fig. 1), which along with Table 1 of Madden (3) permit an estimate for "a" anywhere in the contiguous United States.

Using (6), $\tilde{\sigma}$ is used as an estimate of σ in (5).

Table 1. Maximum and minimum temperature evaluations at five U.S. cities. (Temperatures in °F.)

	Denver		Bismark		Los Angeles		Miami		New York	
	Jan.	July	Jan.	July	Jan.	July	Jan.	July	Jan.	July
$\hat{T}_{max}$	43.0	87.9	18.3	84.4	65.3	75.5	74.8	88.4	36.8	82.9
$\hat{T}_{min}$	16.0	58.8	− 3.5	56.5	47.3	62.9	59.0	76.4	25.4	68.1
$\hat{\sigma}_{max}$	5.5	2.3	6.9	2.9	3.0	2.3	2.5	1.5	4.3	1.7
$\hat{\sigma}_{min}$	4.8	2.2	7.4	2.5	2.5	1.9	4.8	1.2	4.2	1.7
$\bar{\sigma}_{max}$	19.8	10.0	25.5	11.7	12.1	7.1	10.7	8.5	23.5	13.7
$\bar{\sigma}_{min}$	17.3	9.8	27.2	10.1	10.1	5.9	20.6	7.0	23.2	13.2
$\hat{T}_{max} + 2\bar{\sigma}_{max}$	82.6	107.9	69.3	107.8	89.5	89.7	96.2	105.8	83.8	110.3
$\hat{T}_{min} + 2\bar{\sigma}_{min}$	50.6	78.4	50.9	76.7	67.5	74.7	100.2	90.5	71.8	94.5
$\hat{T}_{max} - 2\bar{\sigma}_{max}$	3.4	67.9	32.7	61.0	41.1	61.3	53.4	71.9	−10.2	55.5
$\hat{T}_{min} - 2\bar{\sigma}_{min}$	−18.6	39.2	−57.9	36.3	27.1	51.1	17.8	62.3	−21	41.7
Record max	72	101	*72	*109	*95	*103	86	96	65	104
Record min	*−25	43	−25	*35	28	54	31	70	− 1	55
a	0.73	0.675	0.725	0.70	0.70	0.78	0.69	0.61	0.62	0.51
Years of record used to obtain $\bar{\sigma}$	(1951–1985)		(1951–1985)		(1951–1985)[1]		(1960–1985)[1]		(1951–1985)	
Years of record for max and min temperatures	(1941–1978)		(1941–1978)		(1941–1978)		(1941–1978)		(1941–1978)	

[1]Jan. 1983 data was missing.

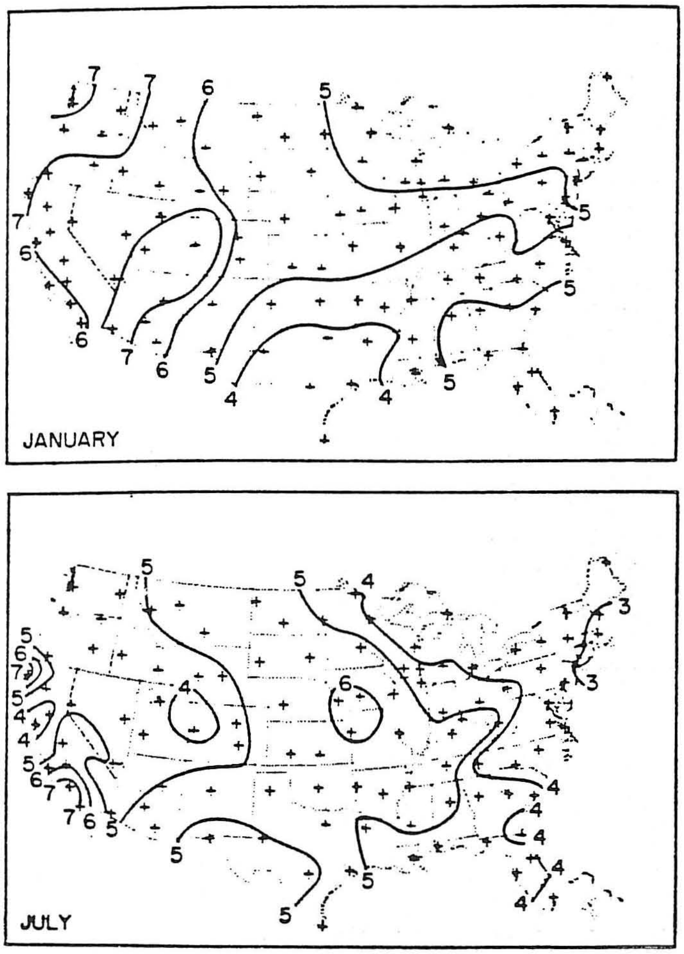

Fig. 1. Characteristic time in days between effectively independent sample values (from Madden and Shea, 4).

3. RESULTS

Values of $\hat{T} \pm 2\bar{\sigma}$, $\hat{T}$ and a for the daily maximum and minimum temperatures at Denver, New York, Los Angeles, Miami and Bismarck are presented in Table 1. Also shown are the observed record maximum and minimum temperature for a long period of record obtained from Bair and Ruffner (5) and the Gale Research Company (6).

In New York City, the average minimum temperatures in January and July between 1951–1985 were 25.4°F and 68.1°F, with standard deviations of 4.2°F and 1.7°F, respectively. The average maximum for the same period were 36.8°F and 82.9°F, with standard deviations of 4.3°F and 1.7°F. The smaller deviations in July reflect that there is less variability during the summer. Using the criteria that a temperature within $\pm 2\sigma$ defines "normal" weather, a daily maximum in January as high as 71.8°F, for instance, would still be considered *normal*, although the temperature is *above average*.

Other definitions of normal temperatures for the five selected cities are presented in Table 1. Using the criteria that $\hat{T}_{max} + 2\bar{\sigma}_{max}$ and $\hat{T}_{min} - 2\bar{\sigma}_{min}$ bracket normality, the record maximum and minimum denoted by the asterisk indicate values which exceed these limits. Interestingly, only about 6 of the 20 record values exceed the limits, which suggests that a number of new records should be expected in these cities before too much more time has passed.

4. DISCUSSION

This paper presents a definition of normal range of expected temperatures in five major U.S. cities, and relates the limits of normality to record observed temperatures. Normal temperatures can be either above or below average but are not anomalous. The use of statements such as "unseasonably warm" or "above normal weather" are not consistent unless temperatures are above an accepted threshold such as two standard deviations above the mean.

Other meteorological variables could also be examined using this approach, such as snowfall. For example, in Fort Collins, Colorado, the average for the 20-yr period of 1966–67 to 1984–85 was 53.2″. From official snowfall recorded on the Colorado State University campus in Fort Collins, the standard deviation for the 20-yr average 1965–66 to 1985–86 was 21.5″. Therefore, using one standard deviation to represent what we could refer to as normal, a winter snowfall of anywhere from 76.3″ to 33.3″ is "normal" for Fort Collins. A two standard deviations from the mean would be 96.4″ and 21.8″. Record snowfall observations in Fort Collins for the period 1889–1985 were 8.5″ (1945–46) and 107.4″ (1979–80). Therefore, if Fort Collins receives a winter snowfall of 70″ this winter, this would be an above average snowfall, but not by this definition, an abnormal one.

So, the next time the weather broadcaster on a television or radio refers to a low in January of − 15°F in Denver as below normal, remember he/she should say "below average." A low of − 15°F in Denver is "normal."

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NOTES AND REFERENCES

1. Roger A. Pielke is a Professor of Atmospheric Science at Colorado State University in Fort Collins, Colorado. His research focuses on mesoscale meteorology and climatology, and on developing improved techniques for weather forecasting.

2. Nicki Waage is a high school student at Poudre High School in Fort Collins. She participated in this research as part of a Partners program sponsored by the Fort Collins Chamber of Commerce.

3. *Madden, R. A., 1979: "A Simple Approximation for the Variance of Meteorological Time Averages,"* J. of Appl. Meteor., *18, 703–705.*

4. *Madden, R. A. and D. J. Shea 1978: "Estimates of the Natural Variability of Time-Averaged Temperatures over the United States,"* Mon. Wea. Rev., *106, 1695–1703.*

5. *Bair, F. E. and J. A. Ruffner 1974:* The Weather Almanac, Gale Reseach Co.

6. Gale Research Company 1981: Weather of U.S. Cities, *Vols. 1 and 2.*