Biases in MOS Forecasts of Maximum and Minimum Temperatures at Phoenix, Arizona

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ABSTRACT

The biases of objective forecasts of maximum and minimum temperature for Phoenix are evaluated relative to the observed temperatures. The temperature forecasts were calculated from regression equations that had been derived from model output statistics (MOS). During the analysis period, from October 1982 through September 1984, significant cold biases, of ~1.5–2.5°F (0.8–1.4°C), were determined for the MOS minimum temperature forecasts at 24, 36 and 48 h. The maximum temperature forecasts had warm biases < 1.0°F (0.6°C) that were significant only at 24 h. The minimum and maximum temperatures from the most recent 30-year normals (1951–80) were, respectively, ~5°F (3°C) and 1°F (0.6°C) colder than the observed temperatures during the analysis period. The difference between the climatological and observed minimum temperatures is significant at the 1% level and suggests that a local or regional change in weather conditions may be an important factor in explaining the MOS biases.

1. Introduction

The dry desert climate of the southwestern United States is attracting many new residents. As a result, the population of metropolitan Phoenix, Arizona, increased from 150 000 residents at the end of World War II to 1 800 000 in 1984. There is evidence that the population increase may be affecting the local weather. For example, Balling and Brazel (1986) showed that the average summertime minimum temperature in Phoenix rose steadily ~7.7°F (4.3°C) from 1948–49 to 1980–84.

Such a rapid rise in the average minimum temperature, regardless of its cause, may affect the accuracy and skill of the temperature forecasts for Phoenix if forecasting procedures do not account for the apparent change in the local climatology. To determine whether the forecasts are biased, this study examines the objective forecasts of maximum and minimum temperatures that are produced operationally by the National Weather Service (NWS) for Phoenix. The objective forecasts were computed with regression equations using the model output statistics (MOS) procedure that is described by Glahn and Lowry (1972). At the time of the study, the limited-area fine-mesh model (LFM) of NOAA's National Meteorological Center supplied the data that went into the development sample for the regression analysis and produced the circulation forecasts that were used operationally in the regression equations.

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2. Analysis procedures

The MOS maximum/minimum temperature forecasts are calculated twice each day from the forecasts of the LFM, which is initialized with data from the standard observing times of 0000 and 1200 GMT. The MOS temperature forecasts are disseminated a few hours after 0000 and 1200 GMT and serve as guidance for the subjective temperature forecasts that are issued by local NWS offices at approximately 1000 and 2200 GMT. The MOS temperature forecasts are computed for four 24 h periods. The maximum and minimum temperature forecasts corresponding to the 0000 GMT observation time (1700 MST) include the maximum temperature for the next calendar day (local time), the minimum temperature for the second calendar day, the maximum temperature for the second calendar day, and the minimum temperature for the third calendar day (not used in this study). Similarly, forecasts from the 1200 GMT observation time (0500 MST) include the minimum temperature for the following calendar day, the maximum temperature for that same day, the minimum temperature for the next calendar day, and the maximum temperature for that same day (not used in this study).[1] For the sake of convenience, the three MOS temperature forecasts for each forecast cycle examined in this study are referred to as the 24, 36 and 48 h forecasts, respectively.

The MOS temperature forecast equations (Dallavalle et al., 1980) are available for four seasons: spring

[1] In November 1985, the NWS changed the maximum and minimum temperature forecast system to predict daytime highs and nighttime lows.

(March–May), summer (June–August), fall (September–November) and winter (December–February). In this study, the biases in the MOS temperature forecasts for Phoenix were computed for the cool season from October through March and the warm season from April through September. The verification data are the calendar day values of maximum and minimum temperatures that were observed by the NWS at Phoenix. The biases in the MOS forecasts were compared with the most recent climatological values of the daily maximum and minimum temperatures, which are based upon the observed temperatures from 1951 to 1980. The significance of the biases was determined by using the null hypothesis (that the bias falls within the variability of the temperature observations) and computing the test statistic z [$z = (\overline{T_F - T_{OBS}})(\sigma^2/N_E)^{-1/2}$], where T_F is either the MOS forecast of the maximum or minimum temperature or the appropriate climatological value of the temperature, T_{OBS} is the observed maximum or minimum temperature, the overbar is a sample average, $\overline{T_F - T_{OBS}}$ is the sample bias, and σ is the standard deviation of $T_F - T_{OBS}$; N_E is an estimate of the effective independent sample size.[2] It accounts for serial correlation in the time series of $T_F - T_{OBS}$ and is considerably smaller than the sample size in this study. Values of $|z| \geqslant 1.96$ are significant at the 5% level and values of $|z| \geqslant 2.57$ are significant at the 1% level.

3. Results

The MOS temperature forecasts were analyzed from October 1982 through September 1984. The verification statistics are summarized in Tables 1 and 2. Table 1 shows that the MOS minimum temperature forecasts had cold biases of ~1.5°F (0.8°C) in the cool season and ~2.5°F (1.4°C) in the warm season. All of the biases are significant at the 1% level. The biases of the minimum temperature forecasts made from the 0000 (36 h forecasts) and 1200 (24 and 48 h forecasts) GMT observation times are about the same order of magnitude. There does not appear to be any tendency for the biases to decrease or increase with the length of the forecast. The climatological minimum temperatures were >5°F (3°C) colder than the observed minimum temperatures in both seasons. This difference is quite large and is significant at the 1% level.

The MOS maximum temperature forecasts had warm biases of ~0.5°F (0.3°C) in both seasons (Table 2); however, only the 24 h MOS temperature forecasts had significant biases. At 24 h, the cool and warm season biases were significant at the 1% level. As with the minimum temperatures, the biases for the maximum temperature forecasts do not increase or decrease with the length of the forecast. Instead, in both cool and warm seasons, the biases of the maximum temperature forecasts made from 0000 GMT (24 and 48 h forecasts) are larger than those from the 1200 GMT (36 h forecasts); however, the differences between the biases are not significant. The climatological maximum temperatures were colder than the observed temperatures. Although the bias in the climatological maximum temperatures was ~1.0°F (0.6°C), the bias was significant at the 5% level only during the warm season.

TABLE 1. Verification statistics for the 24, 36 and 48 h MOS minimum temperature forecasts at Phoenix. The 24 and 48 h MOS forecasts were made from the 1200 GMT LFM forecasts and the 36 h MOS forecasts were made from the 0000 GMT forecasts. The total number of cases for the cool season is 365 and for the warm season is 366.

Forecast	$\overline{T_F - T_{OBS}}$ (°F)	σ (°F)	N_E	z
		Cool season		
24 h	−2.1	3.2	165	−8.43
36 h	−1.5	3.3	167	−5.87
48 h	−1.5	3.9	168	−4.99
Climatology	−5.4	5.5	173	−12.91
		Warm season		
24 h	−2.5	3.6	168	−9.00
36 h	−2.0	3.7	168	−7.01
48 h	−2.6	3.7	170	−9.16
Climatology	−5.1	5.5	174	−12.23

4. Concluding discussion

Tables 1 and 2 show that significant biases occurred in the MOS minimum temperature forecasts at 24, 36 and 48 h and maximum temperatures at 24 h during the cool and warm seasons at Phoenix. The biases might be explained by modifications to the LFM physics that were implemented after the time period of the dependent data used in the development of the MOS equations. Alternatively, the biases may be the result of changes in local or regional weather conditions. The dependent samples for the development of the 24, 36 and 48 h MOS temperature forecast equations include, respectively, the periods from December 1972–February 1980, June 1975–February 1980, and March 1976–February 1980. MOS equations do not account for increases or decreases of temperature that might have occurred after the time period of the dependent sample. The average annual maximum and minimum temperatures at Phoenix for the calendar years of the development sample and the average maximum and minimum temperatures at Phoenix during the two years of this study are shown in Table 3. The changes

[2] The procedure for estimating the effective independent sample size was suggested by Charles J. Neumann (personal communication, 1985) and is adapted from Siegel (1956). Each continuous sequence or run of numbers above (R_a) and below (R_b) the median of a time series is counted. Then, the number of observations above (N_a) and below (N_b) the median is calculated. In this notation the expected number of runs is $E = 2N_aN_b/(N_a + N_b) + 1$ and $N_E = N(R_a + R_b)/E$. Since, by definition, $N_a = N_b$, then $E = N/2 + 1$. For large N, $E \sim N/2$ and $N_E \sim 2(R_a + R_b)$.

TABLE 2. Verification statistics for the 24, 36 and 48 h MOS maximum temperature forecasts at Phoenix. The 24 and 48 h MOS forecasts were made from the 0000 GMT LFM forecasts and the 36 h MOS forecasts were made from the 1200 GMT forecasts.

Forecast	$\overline{T_F - T_{OBS}}$ (°F)	σ (°F)	N_E	z
		Cool season		
24 h	0.6	3.0	165	2.57
36 h	0.3	3.4	165	1.13
48 h	0.5	3.9	166	1.65
Climatology	−0.7	6.5	168	−1.40
		Warm season		
24 h	0.7	3.1	166	2.91
36 h	0.2	3.4	166	0.76
48 h	0.4	4.0	167	1.29
Climatology	−1.0	6.6	170	−1.98

in the average maximum and minimum observed temperatures from the dependent samples (the three rows in part b of Table 3) to the study sample (row c in Table 3) are on the order of 0.0°F (0.0°C) for the maximum temperatures and ~2.5°F (1.4°C) for the minimum temperatures. The magnitudes of the changes are approximately equal to the magnitudes of the MOS biases and the increase in the observed minimum temperature is consistent with the negative values of the MOS biases in Table 1. This comparison suggests that changes to the LFM physics between the time that the MOS equations were developed and the period of this study had a minimal effect on the biases in the forecasts at Phoenix. It appears, therefore, that local or regional changes in weather conditions are the major factors that account for the MOS biases.

Significant MOS biases are likely to have occurred at other locations where the observed temperatures in 1982–84 increased or decreased significantly from the temperatures that were observed in the dependent sample for the MOS equations. Although this study did not calculate MOS biases at other locations, recent trends in the average annual maximum and minimum temperatures were examined at four other Arizona locations with observing stations operated by the NWS. Figure 1 shows the locations of Phoenix and Flagstaff (FLG), Tucson (TUS), Winslow (INW), and Yuma (YUM). Table 4 contains departures of the mean annual maximum and minimum temperatures from the 30-year normal that were averaged from 1972–75, 1976–79 and 1980–84. Temperatures from the calendar years 1976–79 correspond closely to the time periods for the dependent samples of the 36 and 48 h MOS equations. From 1976–79 to 1980–84, the average annual minimum temperature increased by ~1–2°F (0.6–1.1°C) at three of the four stations. The minimum temperature increases at these stations are similar to the increase at Phoenix. From 1976–79 to 1980–84, the average annual maximum temperature changed very little at all of the stations, except Yuma, where it increased by 1.6°F (0.9°C). The trends in the average annual maximum and minimum temperatures must be viewed cautiously because there were changes in the observing procedures at some of the stations. Flagstaff and Winslow became automatic observing stations in the late 1970s, and the observational responsibilities at Yuma were transferred from NWS to the United States Marine Corps in 1979. The maximum and minimum temperatures at Flagstaff and Yuma, however, are recorded by NWS personnel who follow the pro-

TABLE 3. Observed values of minimum and maximum temperatures at Phoenix for (a) the average annual temperature from 1972 to 1984, (b) the approximate average temperatures for the dependent samples of the MOS equations, but calculated from the average temperatures for the calendar years most closely corresponding to the dependent sample, (c) the average temperatures during the time of this study, and (d) the 30-year normals from 1951 to 1980.

	Minimum (°F)	Maximum (°F)
(a) 1972	58.8	86.1
1973	58.0	85.9
1974	59.3	86.9
1975	57.0	84.9
1976	60.2	85.4
1977	62.1	87.6
1978	60.9	86.3
1979	58.8	86.0
1980	61.6	86.4
1981	64.0	88.0
1982	61.8	85.0
1983	62.7	85.3
1984	61.8	86.4
(b) 24 h equations (~73–79)	59.5	86.1
36 h equations (~75–79)	59.8	86.0
48 h equations (~76–79)	60.5	86.3
(c) Study average	62.3	86.0
(d) 30-year normal	57.3	85.1

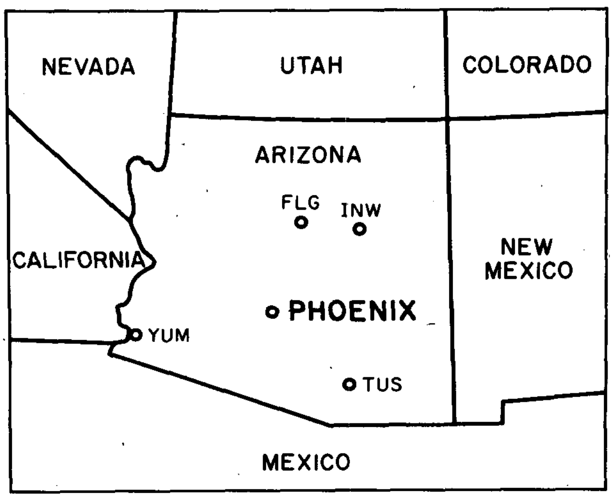

FIG. 1. The locations of Flagstaff, Phoenix, Tucson, Winslow and Yuma.

TABLE 4. Departure of the average annual minimum and maximum temperatures (°F) from the most recent 30-year normal for the specified years at five Arizona stations and the change of the average annual minimum and maximum temperature in 1980–84 relative to 1976–79.

	Flagstaff	Phoenix	Tucson	Winslow	Yuma
		Minimum temperatures			
1972–75	−1.4	1.0	−1.1	−0.5	−0.5
1976–79	0.2	3.2	1.6	−0.1	0.9
1980–84	2.4	5.1	0.8	1.8	2.1
(1980–84)–(1976–79)	2.2	1.9	−0.8	1.7	1.2
30-year normal 1951–80	30.0	57.3	54.2	39.1	59.8
		Maximum temperatures			
1972–75	−0.2	0.6	−1.2	−0.4	−1.5
1976–79	0.5	1.2	−0.1	0.2	−0.7
1980–84	0.4	1.1	0.0	−0.2	0.9
(1980–84)–(1976–79)	−0.1	−0.1	0.1	−0.4	1.6
30-year normal 1951–80	60.8	85.1	81.7	70.6	87.8

cedures that were used in the 1970s. Thus, the magnitude of the minimum temperature increases after the time of the development sample at Flagstaff, Winslow and Yuma suggest that the MOS minimum temperature forecasts for these stations may have had significant biases.

Balling and Brazel (1986) argued that the upward trend in summertime minimum temperature from 1948–84 at Phoenix was a result of urbanization. This hypothesis may be an important factor in explaining the increasing minimum temperatures, but Table 4 shows that, since 1972, minimum temperature increases similar to that at Phoenix also were reported at Flagstaff, Tucson, Winslow and Yuma. While greater Tucson has a population > 500 000, Flagstaff and Yuma have populations < 50 000 and the population of Winslow is <10 000. Local urbanization is not likely to be a major factor in the increase of the minimum temperature at Winslow. In view of the increases in the average annual minimum temperatures since 1972 at Flagstaff, Tucson, Winslow and Yuma and the changes in observing procedures of the maximum and minimum temperatures at Winslow, additional studies of temperature trends in Arizona are needed before it can be concluded that urbanization is the only factor in the minimum temperature increase at Phoenix.

Regardless of the explanation for the temperature increase, the MOS equations used operationally from 1982 to 84 were not able to compensate for changes in the average temperature that occurred after the equations were developed. Consequently, the MOS temperature forecasts for Phoenix had significant biases.

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