Temperature Forecast Biases Associated with Snow Cover in the Northeast

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ABSTRACT

The sensitivity of temperature forecast biases to the presence or absence of snow cover is investigated for the December–March periods of 1985–86 and 1986–87 at ten stations in the northeastern United States. Forecast biases are consistently "warmer" for snow-covered (defined here as ⩾2″) versus open conditions in situations where the MOS forecast equations do not include snow cover as an explicit predictor. The differences are most often statistically significant for the forecasts of minimum temperature. However, this aspect of forecast performance is superimposed on a general cold bias for both maximum and minimum temperature forecasts, and the two effects tend to cancel for snow-covered conditions. No significant differences in forecast bias between snow-covered and open conditions are found for the few cases where snow cover is included explicitly as a predictor in the MOS forecast equations.

1. Introduction

Ground-surface conditions affect surface temperatures, and therefore forecast errors for surface temperature, both in dynamical forecast models (Peterson and Hoke 1989; Walsh et al. 1985) and statistical guidance forecasts (Dallavalle et al. 1985; Jacks et al. 1990; Maglaras and Carter 1986). Limited samples of statistical daytime temperature forecasts have been found to be too cool if soil moisture is abnormally low (McCarthy 1984) or if normally present snow cover is absent (Murphy and Dallavalle 1984), and too warm given snow cover at a normally snow-free location (Curran and Ostby 1974; Dewey 1977).

Systematic forecast errors (biases) under such anomalous surface conditions might be expected to be most pronounced when the relevant variable is not included explicitly in the forecasting procedure. Of particular interest in this study, it is often the case that the multiple-regression equations underlying model output statistics (MOS) temperature forecasts from both the LFM (Dallavalle et al. 1985) and NGM (Jacks et al. 1990) do not include snow cover as one of the predictor variables. Rather, the presence or absence of snow cover influences the temperature forecasts implicitly. This is to say that temperature forecasts are specified in a manner consistent with the predominant snow-cover conditions that prevailed during the period for which the forecast equations were developed, so that the forecasting procedure is "tuned" to locally typical surface conditions.

The alternative, used occasionally for the 12–24-h projection in the LFM-based MOS forecasts, is to include observed snow cover as a binary or "dummy" predictor: this predictor variable takes on a value of either zero or one, depending on whether the snow cover is above or below a specified threshold. When this is done, absence of snow cover results in the forecast temperature being increased by a constant, location-specific amount. Thus, the rationale is that, hopefully, explicit inclusion of snow cover would reduce, if not eliminate, biases resulting from anomalous surface snow conditions.

It is sometimes recommended that human forecasters consider the biases anticipated to be present in the objective guidance, and compensate when making their own subjective forecasts (Dallavalle et al. 1985; Maglaras and Carter 1986). For this and other reasons the error characteristics of the MOS guidance in particular situations are of interest to forecasters who use the guidance. The present work seeks to 1) investigate and document the nature of temperature forecast biases associated with anomalous snow cover in the Northeast, 2) compare the effects of explicit versus implicit treatment of snow cover on forecast biases, and 3) examine the extent to which forecasters may have compensated for these biases.

2. Analysis

Examined here are LFM-MOS and corresponding subjectively formulated public (FP) maximum and

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minimum temperature forecasts taken from the NWS Public Weather Verification Data Archive (Carter and Polger 1986). Also included in this dataset are the verifying observed temperatures. The time period considered here consists of the two "snow seasons" (December–March), 1985–86 and 1986–87, representing the period of record currently available to us since implementation of the current LFM-MOS forecast equations, on 25 November 1985 (Dallavalle, personal communication). Separate analyses are presented for December–January–February and for March, since "winter" and "spring" prediction equations are used for the two time periods, respectively (Dallavalle et al. 1985).

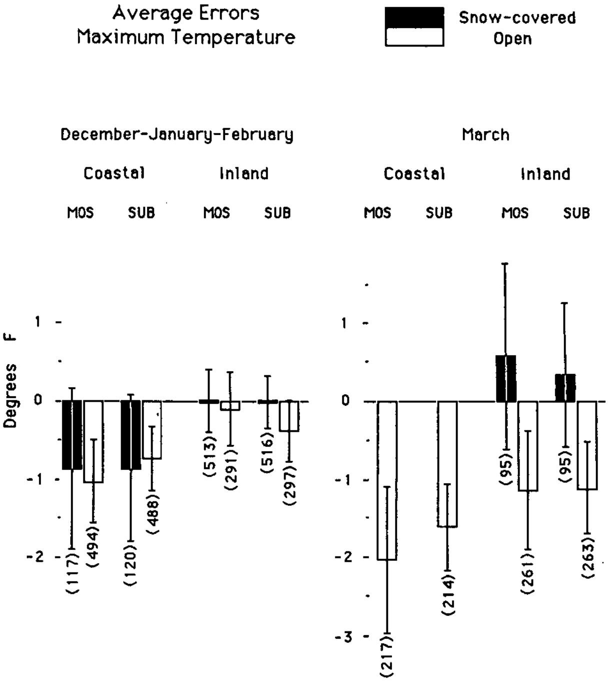

FIG. 2. Average forecast errors (bias) for MOS and subjective human (SUB) maximum temperature forecasts, for cases where snow cover is not an explicit predictor in the MOS equations. Data are for the 12–24-h projection during 1985–86 and 1986–87. Results are stratified according to snow-cover condition at verification time, with a 2-inch cutoff. Error bars denote 95% confidence limits. Sample sizes are given parenthetically.

The ten northeastern stations for which 1985–87 archived forecasts are available are indicated in Fig. 1. Also indicated in this figure are relative frequencies of snow cover for the 1977–78 through 1983–84 seasons, corresponding to the developmental period for the current LFM-MOS equations (Maglaras and Carter 1986). For example, a relative frequency of 0.5 for DJF indicates that half the daily observations during December–February of these years indicated snow cover. The daily snow data have been taken from the TD-3200 summary of the day (described in National Climatic Data Center 1990). The threshold for classifying a day as "snow covered" is snow depth ⩾ 2 inches, with this cutoff being chosen on the basis of results from Baker et al. (1991). The stations are subjectively grouped geographically using these snow-cover frequencies, as indicated in the figure, into an "inland" (higher snow-cover probability) group and a "coastal" (excluding Portland, Maine) group. Since very little snow occurs in April or May, the spring (March–May) *seasonal* climatology for snow-cover probability in the developmental sample for the LFM-MOS spring equations is approximately one-third of the values plotted in Fig. 1 for March. Note also that while these groupings are convenient for the present analysis, separate prediction equations for each of the ten locations are used in the MOS system (Dallavalle et al. 1985).

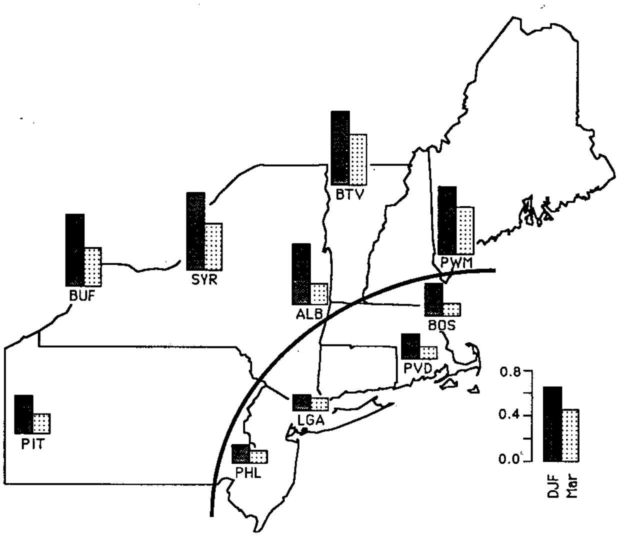

FIG. 1. The ten stations for which temperature forecasts are investigated. Bar graphs show relative frequency of at least 2 inches of snow cover for the period December 1977 through March 1984, which constitutes the developmental period for the MOS forecasts examined here. Heavy line indicates subjective geographic grouping made on the basis of the snow-cover frequencies.

Average forecast errors (i.e., forecast bias), stratified according to location and season as described previously, are presented in Fig. 2 for maximum temperature, and in Fig. 3 for minimum temperature. In each case, the bias is calculated as

$$\bar{B} = \frac{1}{N} \sum_{i=1}^{N} (F_i - O_i), \qquad (1)$$

where F_i is the ith forecast, O_i is the corresponding observation, and N is the sample size. Only results for the 12–24-h projection are presented, and the plotted data include only those cases where snow cover is treated implicitly in the MOS forecast equations. These cases constitute the majority of the data, since of the stations considered here only the December–January–February 12–24-h projection equations for maximum

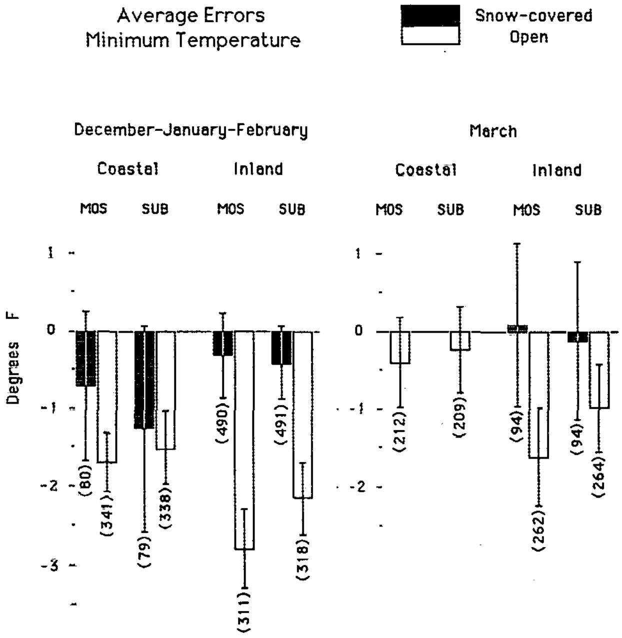

FIG. 3. As Fig. 2, for minimum temperature forecasts.

temperature at Buffalo, and minimum temperature at Philadelphia and Syracuse, use snow cover as an explicit predictor (Dallavalle, personal communication). A particular forecast is classified as pertaining to a snow-covered or open period according to presence of snow on the ground on the calendar day on which the verification period begins, again using the ≥2″ threshold. Similar results (not shown) are obtained using snow-cover cutoffs of trace, 4 inches, and 5 inches.

Also shown in Figs. 2 and 3 are error bars depicting the 95% confidence intervals pertaining to the biases (1). These are calculated according to

$$CI_{\bar{B}} = \bar{B} \pm 1.96\left[\left(\frac{1+\rho_1}{1-\rho_1}\right)\left(\frac{\text{MSE}-\bar{B}^2}{N-1}\right)\right]^{1/2}, \quad (2)$$

implicitly assuming that the biases follow Gaussian distributions. Here MSE denotes the mean-squared forecast error

$$\text{MSE} = \frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2, \quad (3)$$

which range approximately from 15° to 45°F^2. The parameter ρ_1 is the lag-1 autocorrelation of the forecast bias, calculated using

$$\rho_1 = \frac{\sum_{i=1}^{M-1}(B_i - \bar{B})(B_{i+1} - \bar{B})}{(M-1)(\text{MSE} - \bar{B}^2)}, \quad (4)$$

which pertains to the day-to-day correlations of like (max to max, and min to min) forecast variables for each projection. Here $M - 1$ is the number of nonmissing consecutive forecast pairs for each forecast variable and projection, without regard to the presence or absence of snow. While the autocorrelations are relatively small, averaging about 0.1, this is sufficient to inflate the variance of the mean bias [the quantity inside the square brackets in (2)] on average by 22% (Katz 1985). In both (2) and (4) the variances of the forecast biases have been expressed in terms of the MSE and the biases themselves (using the fact that MSE equals variance plus squared bias) in order to more clearly relate these statistics to parameters describing the forecast performance.

Errors for both MOS and subjectively (SUB) formulated FP forecasts are shown in Figs. 2 and 3, with solid bars denoting snow-covered conditions and open bars denoting open conditions. No snow-covered results are shown for coastal stations in March as there are insufficient numbers of cases for analysis. Sample sizes for plotted cases are shown parenthetically. Two features of the temperature forecasts stand out most strongly in Figs. 2 and 3. The first of these is that overall these forecasts exhibit a negative (cold) bias, regardless of the geographical grouping, and regardless of the presence or absence of snow cover. All cases for which the biases are significantly different from zero (where the confidence interval does not include zero) are open ground-surface conditions.

The second prominent feature in these figures is that, with a single exception, forecast errors under snow-covered conditions exhibit a lesser cold bias than the corresponding cases verifying on days with less than 2 inches of snow on the ground. Significance levels (p values) for each of the snow versus open comparisons can be calculated using the test statistic

$$z = \Delta \cdot \left[\left(\frac{1+\rho_1}{1-\rho_1}\right)\left(\frac{\text{MSE}_S - \bar{B}_S^2}{N_S - 1} + \frac{\text{MSE}_O - \bar{B}_O^2}{N_O - 1}\right)\right]^{-1/2}, \quad (5)$$

which will approximately follow the standard normal distribution under the null hypothesis of no difference in bias between snow-covered and open conditions. Here the subscript S denotes presence of snow, the subscript O denotes open conditions, and

$$\Delta = \bar{B}_S - \bar{B}_O \quad (6)$$

is the difference in bias between snow-covered and open conditions.

Table 1 shows differences in bias (6), the test statistic (5), and corresponding p values for each comparison. The p values are one sided, which is the appropriate choice given the a priori hypotheses that either snow cover at a usually open location leads to forecasts being too warm, or absence of snow cover at a usually snowy location leads to forecasts being too cold. In both of these cases Δ should be positive. The bias differences

TABLE 1. Differences in bias between snow-covered and open conditions, Δ (6), with corresponding *z* statistics (5) and one-tailed significance levels (*p* values). Results are for the 12–24-h projections with no explicit MOS snow-cover predictor. NS indicates *p* value greater than 0.10.

	DJF					
	MOS		SUB		March	
	Coastal	Inland	Coastal	Inland	MOS Inland	SUB Inland
Maximum temperature						
Δ, °F	0.17	0.10	−0.13	0.37	1.70	1.44
z	0.287	0.323	−0.249	1.456	2.349	2.586
p value	NS	NS	NS	0.0727	0.0094	0.0049
Minimum temperature						
Δ, °F	0.99	2.49	0.26	1.73	1.70	0.87
z	1.884	6.554	0.368	5.086	2.743	1.457
p value	0.0298	0.0000	NS	0.0000	0.0030	0.0726

(with one exception) are indeed positive, which is consistent with the hypothesis. It is primarily the results for minimum temperature forecasts and results for March that are statistically significant, with differences for maximum temperature forecasts in winter being either not significant or marginally significant.

While changes in forecast bias according to the snow-cover condition in Figs. 2 and 3 follow the hypothesized pattern (positive values for Δ), only some of the results for the inland stations in winter conform to the notion that forecast errors for the climatologically "typical" (snow-covered, in this case) ground condition will be near zero, with cold bias for the anomalous (open) cases. In the other cases, where the climatologically usual ground condition is open (i.e., coastal stations in winter and all stations in March), forecast biases for open conditions are generally significantly negative. Here the apparent warm bias for snow-covered conditions serves to debias the forecasts to some extent. That is, the underlying cold bias is compensated by the warm bias attributable to the anomalous snow cover at verification time.

Figure 4 presents the available results for cases where snow cover has been included as an explicit predictor in the MOS forecast equations. In strong contrast to the results shown for implicit treatment of snow cover, there is no consistent trend in the direction of the sign of the forecast bias difference (6). Table 2 presents significance tests of the bias differences (6) for the MOS forecasts shown in Fig. 4. These are shown in the first row, with asterisks. Only the difference for the Syracuse minimum temperature forecasts is even weakly significant. Note that in both Fig. 4 and Table 2 the snow versus no-snow classifications have been made according to the same criteria used in the MOS forecasts, which are different in each case.

Table 2 also compares differences in forecast bias for the other stations in the respective geographic groups, for which there are no explicit snow-cover predictors in the MOS equations. Most striking are the comparisons between bias differences for winter minimum temperature forecasts at Syracuse with those for the other inland stations. Here there seems to be a clear improvement in forecast performance attributable to inclusion of the snow-cover predictor. For Philadelphia winter minimum temperature forecasts, the signs of the bias differences indicate improvement in relation

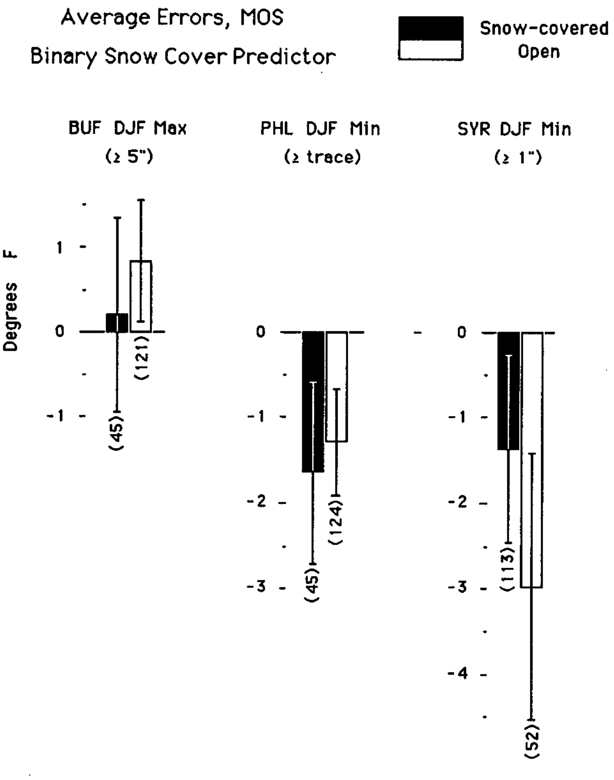

FIG. 4. Average MOS forecast errors (bias) for the period December–February 1985–1987, in cases where snow cover is included as an explicit predictor in the MOS equations. Results are stratified according to snow cover at verification time, with the cutoff (indicated in each case) consistent with the binary predictor threshold used. Error bars denote 95% confidence limits. Sample sizes are given parenthetically.

TABLE 2. Comparisons between the three cases (all DJF) where an explicit MOS binary snow-cover predictor is used and other stations in the same region. Asterisks indicate the stations for which explicit snow-cover predictors are used in the MOS equations. Shown are differences in bias Δ (6), z statistic (5), and p values (two-tailed for cases with explicit snow-cover predictors and one-tailed otherwise), for the differences in MOS forecast bias between snow-covered and open conditions. NS indicates p value greater than 0.10. In all cases the snow vs open classifications have been made according to the thresholds used by the MOS, indicated parenthetically.

	$T_{\max}$, inland (≥5″)				$T_{\min}$, coastal (≥trace)				$T_{\min}$, inland (≥1″)		
	Δ	z	p value		Δ	z	p value		Δ	z	p value
BUF*	−0.64	−0.929	NS	PHL*	−0.036	−0.574	NS	SYR*	1.62	1.667	0.096
ALB	0.17	0.248	NS	BOS	1.15	1.564	0.0589	ALB	3.80	4.076	0.0000
BTV	−0.76	−1.150	NS	LGA	0.32	0.512	NS	BTV	4.02	3.658	0.0001
PIT	−1.10	−2.111	NS	PVD	0.54	0.671	NS	BUF	1.22	1.899	0.0288
PWM	−0.25	−0.346	NS					PIT	1.82	2.051	0.0201
SYR	0.54	1.193	NS					PWM	1.58	1.950	0.0256

to other stations in the region, but these are not generally significant (at least for the small samples analyzed here). Consistent with results in Table 1, inclusion of the binary predictor for inland winter maximum temperatures does not appear to significantly affect forecast bias differences. (Note that this does not imply that the predictor makes an insignificant contribution to overall forecast quality for Buffalo.)

Finally, it is of some interest to investigate whether there is evidence for forecasters having compensated for expected biases in the guidance, as has been recommended elsewhere (Dallavalle et al. 1985; Maglaras and Carter 1986). Differences in forecast bias between the MOS and subjective forecasts for snow-covered versus open conditions shown in Figs. 2 and 3 indicate that, with the exception of winter maximum temperature forecasts (where Table 1 shows differences in forecast biases to be not significant), differences are indeed narrower for the subjective versus the MOS forecasts. This result is consistent with a subjective correction having been applied. The narrowing of these differences in biases is strongest for the three minimum temperature forecast comparisons, although biases are still colder for open than snow-covered conditions, and an overall cold bias is still evident.

3. Summary and conclusions

The sensitivity of temperature forecast biases for the 12–24-h projection to the presence or absence of snow cover has been investigated for stations in the northeastern United States for December–March 1985–1987. Biases are significantly "warmer" for snow-covered versus open conditions in situations where the MOS forecast equations do not include presence or absence of snow cover as an explicit predictor. However, this aspect of forecast performance is seen to be superimposed on an overall cold bias for both maximum and minimum temperature forecasts, and the two effects tend to cancel for snow-covered conditions. The source of the underlying cold bias is not immediately clear, but does not seem to be attributable to unusual temperature conditions during the two years investigated here. Winter temperatures in the region were slightly below average for 1985–86, due primarily to December temperatures (Arkin and Janowiak 1987); while those for 1986–87 were slightly above average, again due mainly to December (Kousky 1987). March was moderately warm in the region in both 1986 and 1987 (Barnston 1987; Wagner 1987).

The few available cases where snow cover is included explicitly in the MOS forecast equations show a distinctly different pattern, with no significant differences in forecast bias for snow-covered versus open conditions. While the number of available predictors in the MOS maximum and minimum temperature forecast equations has been limited by the need to develop simultaneous forecast equations for 3-hourly temperatures and dewpoints (Dallavalle et al. 1985), the present results indicate that more routine use of explicit predictors for snow cover could be advantageous in development of future MOS packages. Of course, the MOS forecast equations are constructed over all forecast situations in the developmental sample, and snow-cover predictors will not always "make the cut" for inclusion in the final equations. In these cases, forecaster awareness of what has gone into the MOS seems especially important.

It should be emphasized that the results reported here are not comprehensive, as they treat only the northeastern United States for the 1985–86 and 1986–87 snow seasons. Of interest for future work would be examination of forecasts for the more recent winters, as well as a similar investigation for the north-central United States. Finally, only results from the LFM–MOS forecasts have been investigated here, and documentation of forecast biases in the newer NGM–MOS (Jacks et al. 1990) would be of use to forecasters as well.

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