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THE USE OF THE NGM FOUS TEMPERATURE IN THE LOWEST MODEL LAYER (T1) AS A PREDICTOR FOR MAXIMUM TEMPERATURE AT PROVIDENCE, RHODE ISLAND

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(Editor's Note: The verification methodology employed for this study relies on hindcasts, and is therefore biased in favor of the T1 forecasting technique. As such, it is not possible to infer that the T1 approach is capable of producing temperature forecasts that are better than those produced by the MOS prediction system. However, the general approach to forecasting espoused by the author is sound and worthy of consideration by field personnel.)

1. INTRODUCTION

The temperature is an important element that any meteorologist must consider when preparing a forecast. Currently, two statistical guidance products provide surface temperature forecasts at various locations throughout the United States. These are the Model Output Statistics (MOS) guidance from the Limited-Area Fine-Mesh (LFM) model and the Nested Grid Model (NGM). The LFM-MOS and NGM-MOS (National Weather Service 1985a and 1990, respectively) are objective forecast tools, which were developed for use in all possible meteorological situations.

This study presents a maximum temperature forecasting technique for Providence, Rhode Island (PVD), which can also be applied to almost any meteorological situation. The technique requires an examination and evaluation of the NGM forecast fields, after which a series of forecast decisions regarding the anticipated state of the atmosphere are made. The NGM FOUS temperature in the lowest model layer (referred to as T1 for the remainder of this paper) is used as a predictor for maximum temperature during the period from June 1990 through May 1991. T1 has already proven to be quite useful in precipitation type forecasting during the winter (Ronco 1988). This paper will show that T1 can also be used as a reliable maximum temperature predictor.

2. METHODOLOGY

The NGM FOUS provides T1 forecasts for various locations around the United States. Providence (PVD) is not an NGM FOUS station, so Boston (BOS) and LaGuardia (LGA) were used to represent PVD for this study. An average of the T1 forecasts between BOS and LGA, taking the maximum T1 during the 1800-0000 UTC period for both stations, was used to represent the T1 forecast for PVD. BOS is 60 miles northeast of PVD, and LGA is located about 180 miles to the southwest. Hence, the average of the T1 forecasts between BOS and LGA should yield similar results compared to using interpolation in the estimation of T1 for PVD.

T1 represents the NGM FOUS temperature in the lowest model layer, which is model layer 1. The mid-layer pressure at model layer k is equal to the product of a fixed function of sigma(k) with the model forecast of surface pressure. For practical purposes, the variability of surface pressure for each model forecast was ignored and replaced with the normal model value of surface pressure (National Weather Service 1985b).

Mid-Layer pressure at model layer 1 = sigma(k=1) x normal model value of surface pressure

Table 1a lists the terrain height and normal model surface pressure for BOS and LGA valid during the period of study. Also listed (Table 1b) are the current values of terrain height and normal model surface pressure, which were implemented in August 1991. The model surface pressure for BOS is 992.07 mb, and for LGA it is 992.37 mb. These pressure values were rounded off to the nearest whole number, so 992 mb was used as the normal model surface pressure for BOS and LGA. The fixed value of sigma for model layer 1 is 0.982. Thus, the mid-layer pressure at model layer 1 for BOS and LGA is equal to (0.982) x (992 mb), or 974 mb.

By application of a Skew T, Log P thermodynamic diagram, pressure can be converted to height in the standard atmosphere. The height of the 974 mb level in the standard atmosphere is approximately 1000 ft. Therefore, the average height of T1 for BOS and LGA (which is used to represent T1 for PVD) is 1000 ft above mean sea level. PVD is close to sea level, so T1 is about 1000 ft above the surface at PVD. Based on the dry adiabatic lapse rate of 10°C/km, which also equals 3°C/1000 ft, a parcel of air at PVD will warm by approximately 3°C if it is allowed to descend dry adiabatically to the surface from the T1 level. With no other factors being considered, T1 + 3°C was used as a first approximation in forecasting the maximum temperature at PVD, after the average T1 between BOS and LGA was determined.

3. CONSIDERATIONS

The T1 technique requires a forecaster to make a series of decisions regarding the anticipated state of the atmosphere (cloud cover, precipitation, winds). Figure 1 is a decision tree, which makes use of several of these factors to arrive at a maximum temperature forecast for PVD based on T1. It should be noted that the verification results for the T1 technique were not determined in a pure forecast mode; rather, the results were obtained by using hindsight. Also, for verification purposes, T1 was not adjusted for model error. Therefore, the success of the T1 technique is dependent on the ability of the forecaster to anticipate the future weather conditions. This requires an examination and evaluation of the forecast synoptic and mesoscale environment. The quality of the NGM forecasts (and subsequently, the T1) must also be evaluated. If the forecaster can recognize a situation when the NGM (e.g., T1) may be in error, the necessary adjustments can be made to ensure a better maximum temperature forecast.

3.1 Sky cover

During days with greater than 70 percent sunshine, the heating of the ground often causes a superadiabatic lapse rate near the ground (e.g., the lowest 1000 ft) resulting in heating beyond the adiabatic warming of 3°C. This extra warming was empirically determined to be 2°C, so T1 + 5 was used as an initial forecast for days with greater than 70 percent sunshine. The initial forecast for partly sunny/mostly cloudy days with 30-70 percent sunshine was T1 + 4. In this case, the extra warming was less than for sunny days, but enough to allow for an increase of 1°C over the adiabatic warming. Cloudy conditions with less than 30 percent sunshine yielded a forecast of T1 + 3. The limited amount of sun with cloudy days was insufficient to produce much heating of the ground; thus, only the adiabatic warming of 3°C was considered with less than 30 percent sunshine.

The other sky condition to consider was low clouds (ceiling 1000 ft or less) and fog and/or steady precipitation falling for much of the day. During this situation, the lapse rate from the surface to the T1 level was much less than dry adiabatic, and likely was close to isothermal or exhibited a weak inversion. Thus, T1 was used as the forecast for rainy/snowy days and/or days with low clouds and fog.

3.2 Wind

During the spring and early summer, a south wind from 160° to 180° of 10 mph or more, acts to cool the air at PVD. This cooling effect is called a bay breeze, since a south wind at PVD blows directly from Narragansett Bay. The bay breeze is usually most pronounced during the spring when the air-water differential is greatest. The bay breeze has a stabilizing effect in the lowest 1000 ft, thus producing a lapse rate less than dry adiabatic. A decrease of 2°C from the adiabatic warming, which was empirically derived based on observation, was used to account for the cooling during bay breeze events. Thus, the occurrence of a bay breeze during the spring and early summer cooled the temperature forecast to T1 + 3 for sunny days, T1 + 2 for partly sunny days, and T1 + 1 during cloudy days. A south wind during the fall and winter seasons was considered to have little or no influence on the temperature forecast.

3.3 Snow cover

Snow cover, like the bay breeze, works to cools the air. Snow, with its high albedo, reflects some of the incoming solar radiation. Some of the remaining solar radiation is used to melt the snow, leaving much less energy to heat the ground and the air. This scenario also results in a lapse rate that is less than dry adiabatic in the lowest 1000 ft, accounting for a 2°C decrease from the adiabatic warming. Thus, the temperature forecasts for sunny, partly sunny and cloudy days with snow cover were considered to be the same as those with a bay breeze. (Snow cover was defined as at least 2 inches of snow on the ground.)

3.4 Season

During the months of December through February, the T1 at 1800 UTC resulted in better high temperature forecasts than using the maximum T1 for the 1800-0000 UTC period. During this time of year, the maximum temperature usually occurs early in the afternoon. Hence, T1 at 1800 UTC, which is usually lower than T1 at 0000 UTC, was more appropriate.

4. DATA

The maximum temperature forecasts for PVD given by the T1 technique, LFM-MOS and, NGM-MOS were verified against the observed temperature from June 1990 through May 1991. The T1 and LFM-MOS forecasts were compared during four, 3-month periods corresponding to the seasonal stratification of the LFM-MOS. The periods were June to August 1990 (summer), September to November 1990 (fall), December 1990 to February 1991 (winter), and March to May 1991 (spring).

The NGM-MOS is stratified into two, 6-month seasons. The warm season is from April to September and the cool season is October to March. The T1 and NGM-MOS forecasts were compared during the 1990-91 cool season (October 1990 to March 1991), and for the period from June to September 1990. The months of April and May 1990 were not available for the warm season comparison between the T1 technique and NGM-MOS.

Both the 0000 and 1200 UTC model runs were used for the comparison between the T1 technique and LFM/NGM-MOS forecasts. Comparisons were made during three forecast periods. The first period was the 12-24 hour maximum temperature forecast from the 0000 UTC run. The second period corresponded to the 24-36 hour maximum temperature forecast from the 1200 UTC run, and the third period was the 36-48 hour forecast from the 0000 UTC run.

The mean absolute error was calculated for the T1 technique and LFM/NGM-MOS forecasts. The mean algebraic error was also used for verification of the T1 technique to determine forecast biases. Both the mean absolute and mean algebraic errors were calculated for different paths of the decision tree to validate the appropriate modifications to the T1 forecast for each condition.

5. RESULTS

The verification results for the T1 technique and LFM-MOS during each season are illustrated in Figures 2a-d. These results show that the T1 technique, under the restrictive conditions imposed for this study, outperformed LFM-MOS during each forecast period of each season. The mean absolute error for the T1 technique was generally 0.5 to 1.5°F lower than the LFM-MOS for each forecast period during the summer, fall, and winter seasons. The gap between the two forecasts was nearly 2°F for each period during the spring season.

The performance of the T1 technique was best during the summer and fall with mean absolute error generally less than 2°F for each forecast period. In fact, the T1 technique came within 3°F of the observed temperature 89 percent of the time during the summer season, and 84 percent during the fall. During the spring, the mean absolute error was around 3°F for each period. The frequency that the T1 technique was within 3°F of the observed temperature during the spring was 67 percent.

Figures 3a-b show the verification results for the T1 technique and NGM-MOS. As expected, the T1 technique also displayed an improvement over NGM-MOS for each forecast period during the 1990-1991 cool season and the 1990 warm season (excluding April and May). The mean absolute error for the T1 technique was just under 1°F lower than NGM-MOS for each forecast period during the warm season. The difference was a bit less during the cool season, slightly over 0.5°F for all three periods.

One must keep in mind that the results of the T1 technique were based solely on hindsight. No forecast decisions regarding anticipated weather conditions were made. The modifications from the forecast decision tree were made after the maximum temperature for the day was reached. This was necessary to develop, test and evaluate the T1 technique. Improvement to the LFM-MOS and NGM-MOS could be expected if subjective modifications of cloud cover and precipitation were made, but this was not reflected in this paper because the purpose of this study was only to develop and present a new approach for forecasting maximum temperature at PVD.

The mean absolute error and mean algebraic error for the T1 technique for the most frequent conditions of the decision tree are shown in Figures 4a-d. The T1 technique had an overall cold bias of -0.7°F for those cases with greater than 70 percent sunshine during June 1990 to May 1991. The bias was zero during the fall, but there was a substantial cold bias of -1.6°F during the spring. This cold bias could likely be attributed to the sunny and unseasonably warm spring at PVD in 1991. The combined average temperature for April and May was around 5°F above normal along with much above normal sunshine. A warm bias between 0.5 and 1°F was present in three of the four seasons for 30-70 percent sunshine (Figure 4b). Overall, for the entire period, the T1 technique exhibited a minor warm bias of 0.4°F.

Figure 4c shows that for those cases with less than 30 percent sunshine (independent of low clouds/precipitation), the T1 technique displayed a warm bias for all four seasons. The overall warm bias was 1.3°F. These results may indicate that the lapse rate in the lowest 1000 ft is slightly less than dry adiabatic during cloudy days. This would explain why there was a warm bias greater than 1°F for three of the four seasons. The spring had the most significant warm bias (1.9°F), which was coupled with a mean absolute error over 4°F. The high frequency of easterly flow events during the spring, normally accompanied by clouds, was the likely cause for the poor performance by the T1 technique.

The T1 technique displayed an overall warm bias of 0.8°F for days with low clouds and/or precipitation as shown in Figure 4d. A cold bias existed during the summer and fall, along with mean absolute error around 1.5°F. However, during the winter and spring, the mean absolute error increased to over 3°F, and warm biases dominated. Precipitation events during the cold season are normally caused by overrunning in which colder air is trapped near the ground, resulting in a low level inversion or isothermal lapse rate. This could explain why the forecast given by the T1 technique was too high since the T1 temperature was used as the forecast during rainy/snowy days.

Figure 5 shows the performance of the T1 technique for bay breeze and snow cover events independent of sunshine. There were 33 total bay breeze cases and 18 snow cover cases. The results for each sky condition were not displayed due to very small data sets. Further study would be necessary to obtain meaningful results for bay breeze and snow cover events for each sky condition.

The performance of the T1 technique for all conditions combined is displayed in Figure 6. The results indicated the overall bias was near zero for the entire period from June 1990 to May 1991. The seasonal bias scores were also impressive. Only a slight warm and cold bias existed during the summer and spring seasons, respectively, while the bias was near zero during the fall and winter.

6. CONCLUSIONS

The results of this study show that T1 is a reliable predictor for the maximum temperature at PVD. However, this assumes that a thorough examination and evaluation of the NGM forecast fields is made, along with an accurate forecast of the anticipated weather conditions. The results presented here assume a perfect prog is made by the local forecaster.

The mean absolute error for the T1 technique for each season of each condition was mostly under 3°F, except for days with less than 30 percent sunshine during the spring. The overall bias scores for the most frequent conditions of the decision tree validated the modifications made to the T1 forecast. The only exception was that the dry adiabatic assumption for less than 30 percent sunshine needs to be adjusted downward. Also, additional data would be necessary to determine if the modifications that were made to bay breeze and snow cover events improved the forecast.

The T1 technique worked best during the summer and fall most likely because the lapse rate is closest to dry adiabatic during this time of year. The technique did not perform as well during the winter and spring, especially for rainy/snowy days during the winter and early spring, and for cloudy days during the spring with easterly flow. Easterly winds at PVD have a stabilizing effect on lower levels of the atmosphere with cool, marine air dominating the lowest 1000 ft, resulting in a lapse rate that is less than dry adiabatic. Also, cold shallow airmasses and overrunning precipitation events during the winter and early spring normally prevent mixing of the air down to the surface from the T1 level.

This forecasting approach could be applied to other locations. By using the normal model pressure to determine the height of the lowest sigma level for the station in question, and applying the dry adiabatic lapse rate to the station elevation, an initial forecast could be derived. This value would then have to be modified for sky cover and other possible climatic effects. It should be noted that the terrain height and normal model pressure values have been changed as of August 1991. Thus, before applying this technique to another station, the new model pressure values must be used. The new version of TPB 351 is not yet available, but the updated values are available in Eastern Region Staff Notes of November 1992.

The approach presented here is another tool which can assist the forecaster with the maximum temperature forecast at PVD. However, it should not be used alone, but in conjunction with the LFM-MOS, NGM-MOS, and other available guidance. If used properly, the T1 technique, in most cases, can offer a reliable and accurate maximum temperature forecast at PVD.

7. ACKNOWLEDGEMENTS

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National Weather Service, 1985b: FOUS Messages from the RAFS. NWS Technical Procedures Bulletin No. 351, NOAA, U.S. Department of Commerce, Washington, DC, 7 pp.

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Ronco, J.A., 1988: A Procedure for Forecasting Precipitation Type Using NGM Low-Level Temperatures and LFM-MOS Frozen Precipitation Probabilities. Eastern Region Technical Attachment No. 88-2, NOAA/NWS, Bohemia, NY, 6 pp.

Table 1a. RAFS model terrain height and normal surface pressure valid through August 5, 1992 (from National Weather Service 1985b).

	HEIGHT (METERS)	PRESSURE (MB)
BOS	175.85	992.07
LGA	175.31	992.37

Table 1b. RAFS model terrain height and normal surface pressure valid August 6, 1992 (from NWS Eastern Region Staff Notes, November 1992, Volume 92-11).

	HEIGHT (METERS)	PRESSURE (MB)
BOS	103.22	1000.9
LGA	124.80	998.3

MAXIMUM TEMPERATURE FORECAST DECISION TREE FOR PVD

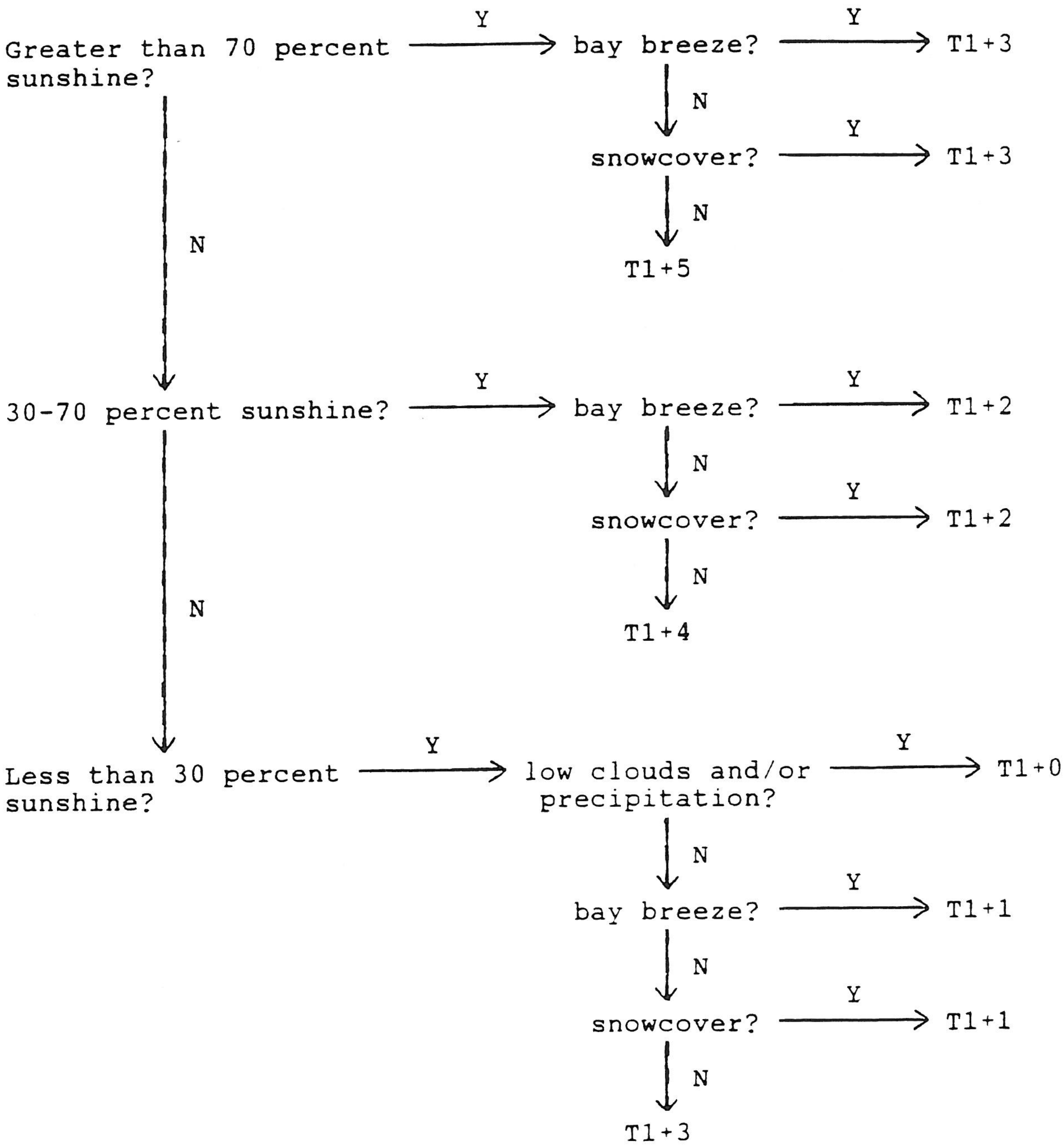

Figure 1. Decision tree for maximum temperature forecasting at PVD based on T1.

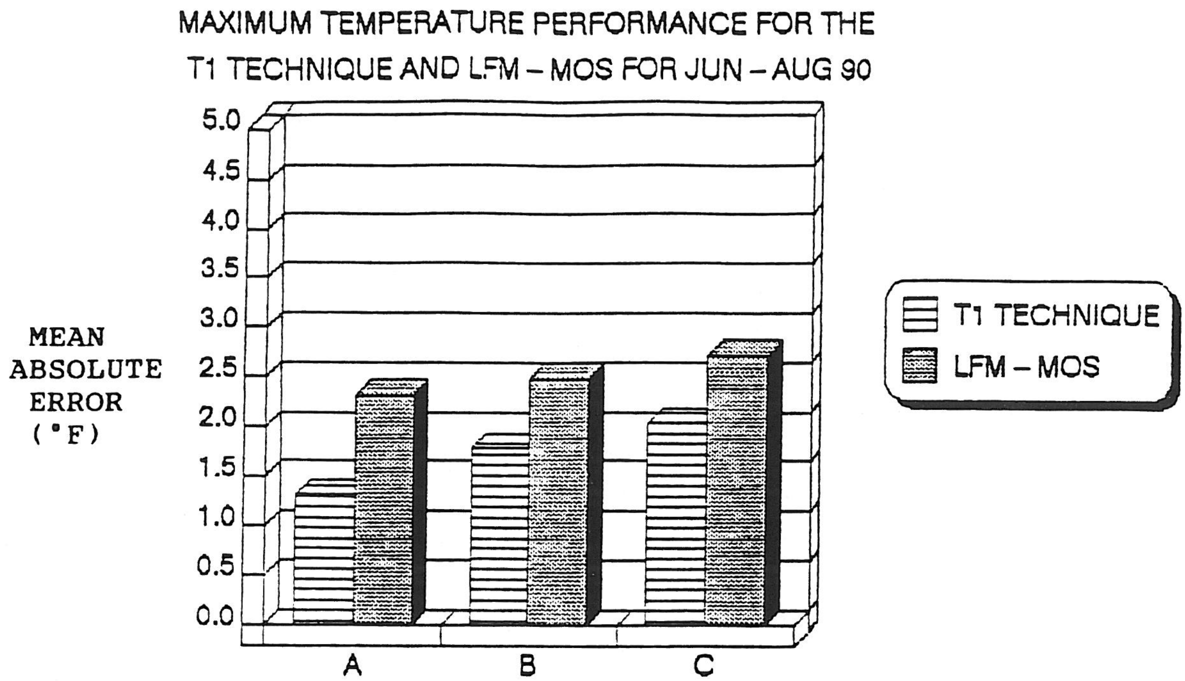

Figure 2a. Mean Absolute error (°F) for the T1 technique and LFM-MOS for (A) first period (12-24 hr) forecast from the 0000 UTC run, (B) second period (24-36 hr) forecast from the 1200 UTC run, and (C) third period (36-48 hr) forecast from the 0000 UTC run for Jun-Aug 1990.

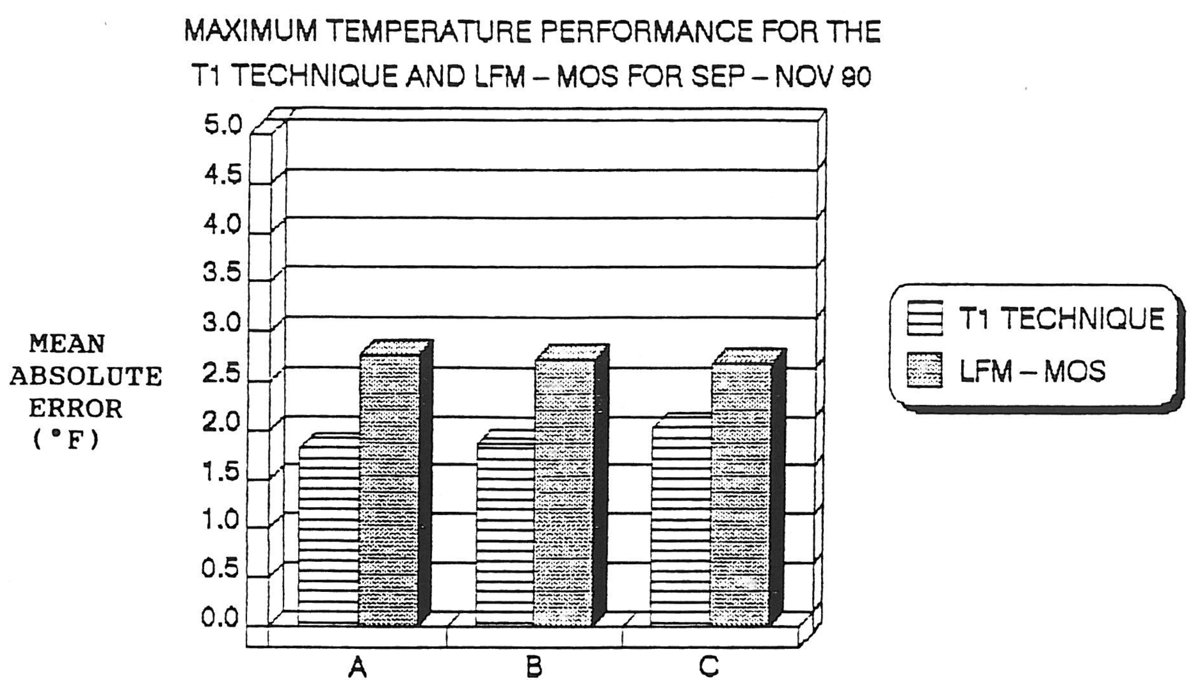

Figure 2b. Same as Figure 2a, except for Sep-Nov 1990.

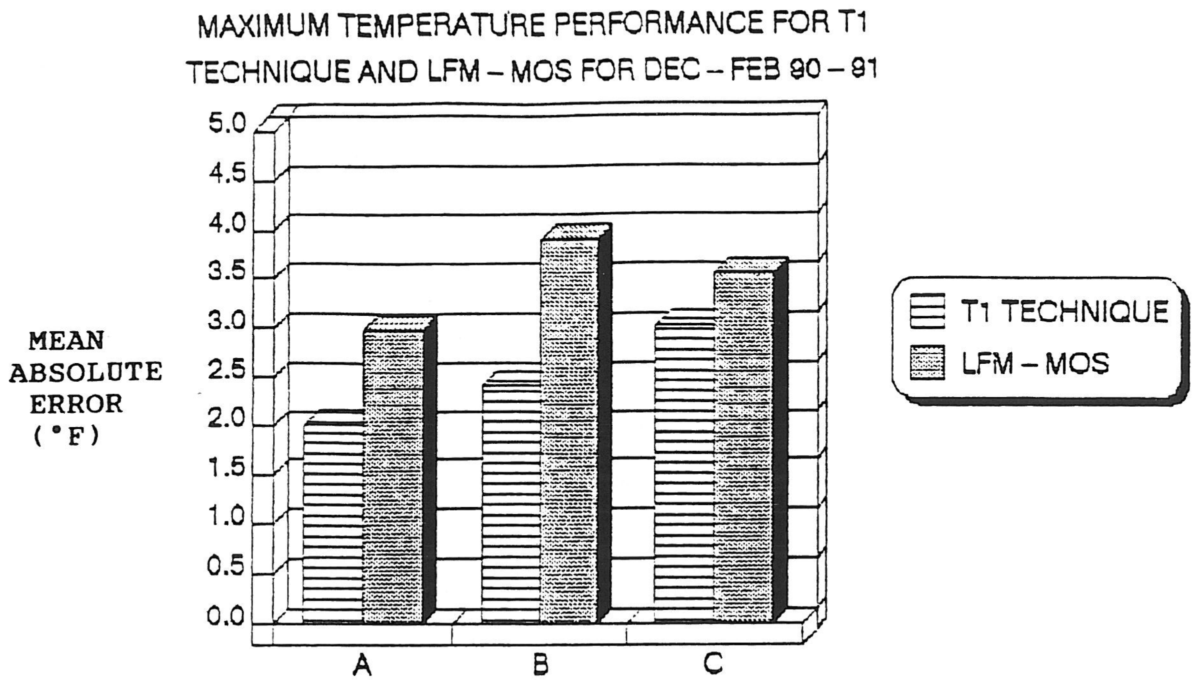

Figure 2c. Same as Figure 2a, except for Dec-Feb 1990-1991.

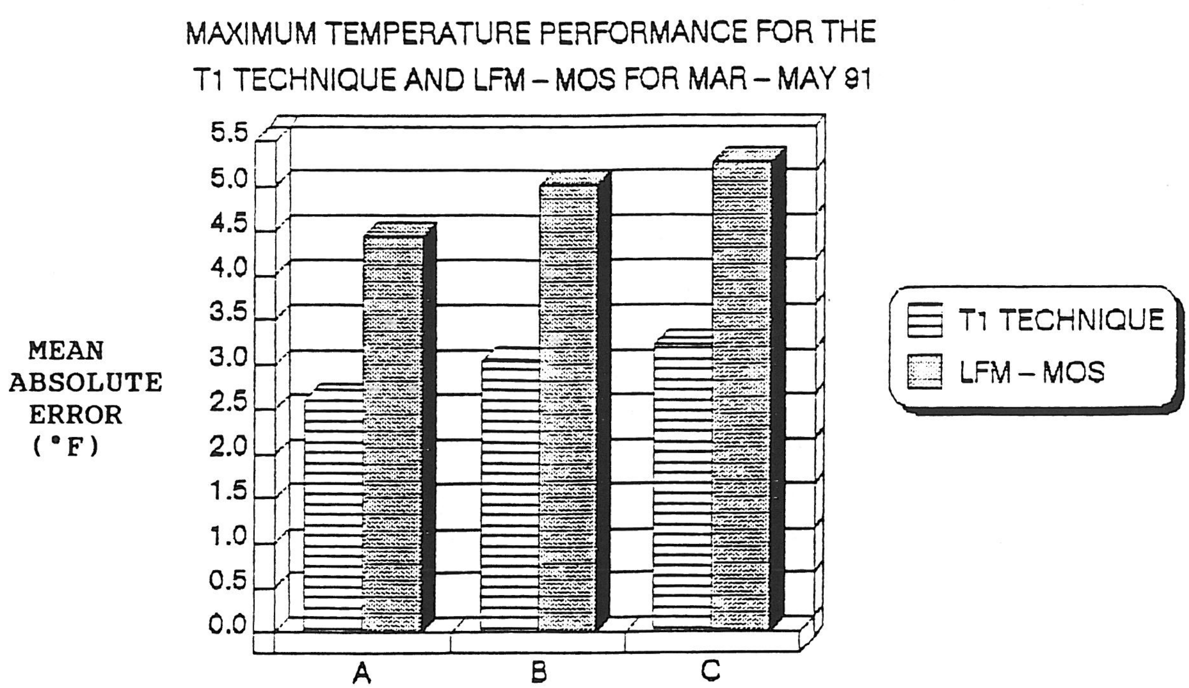

Figure 2d. Same as Figure 2a, except for March-May 1991.

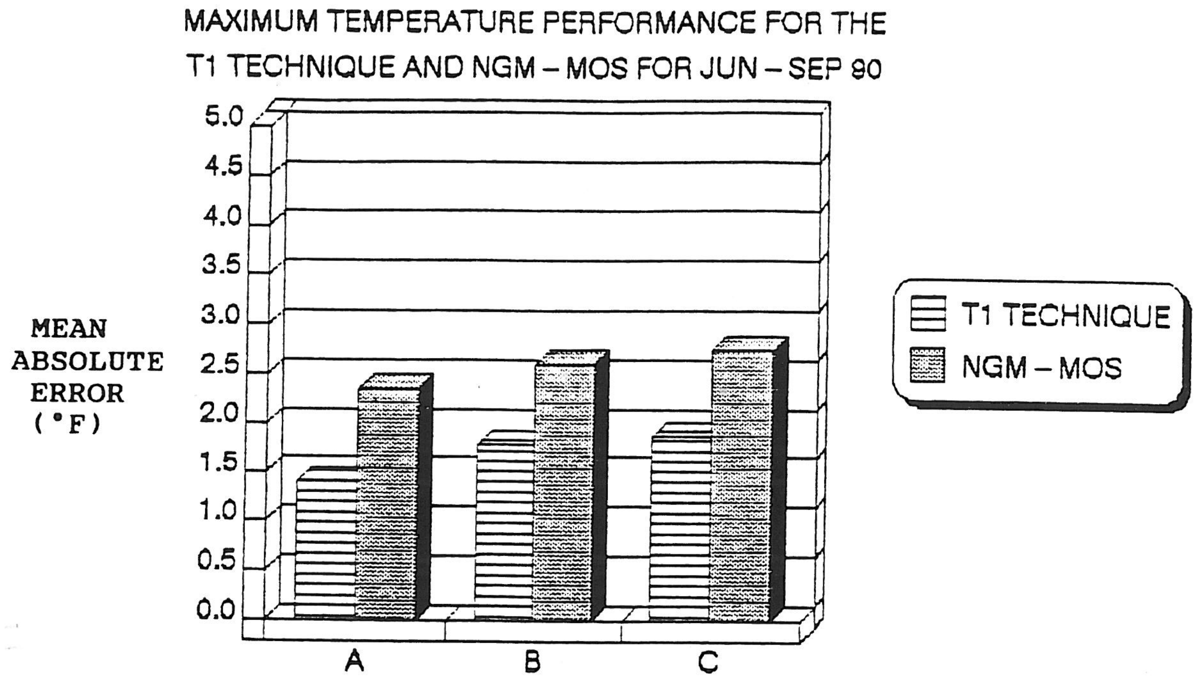

Figure 3a. Mean Absolute error (°F) for the T1 technique and NGM-MOS for (A) first period (12-24 hr) forecast from the 0000 UTC run, (B) second period (24-36 hr) forecast from the 1200 UTC run, and (C) third period (36-48 hr) forecast from the 0000 UTC run for Jun-Sep 1990.

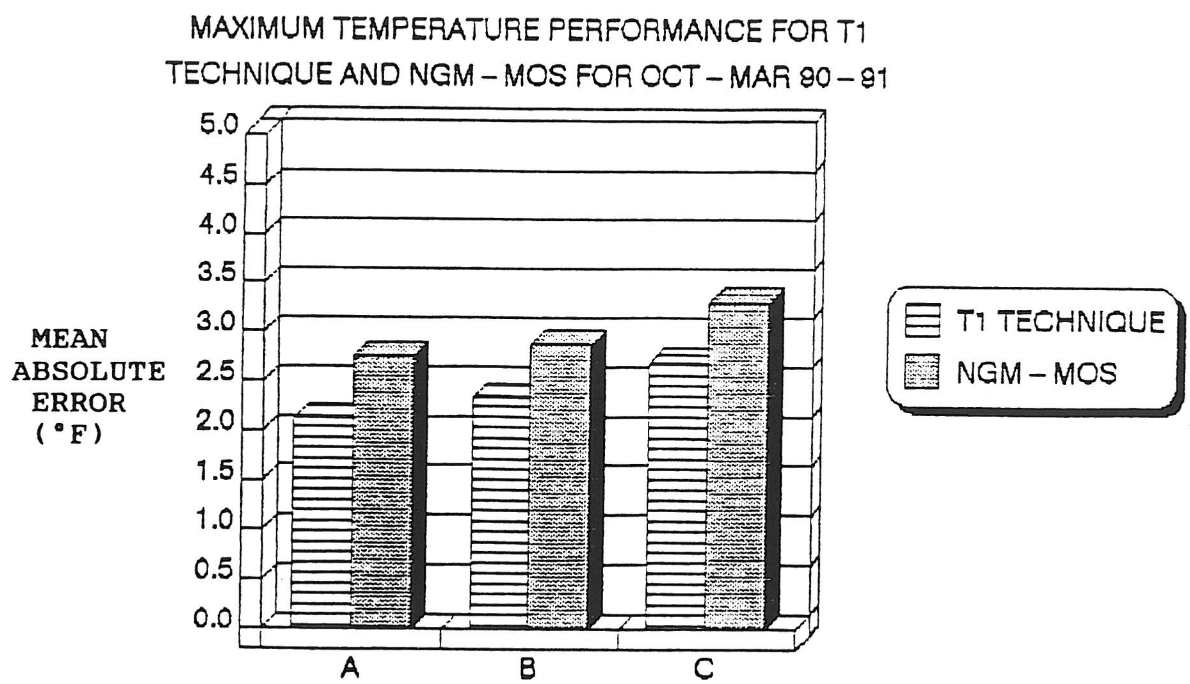

Figure 3b. Same as Figure 3a, except for Oct-Mar 1990-1991.

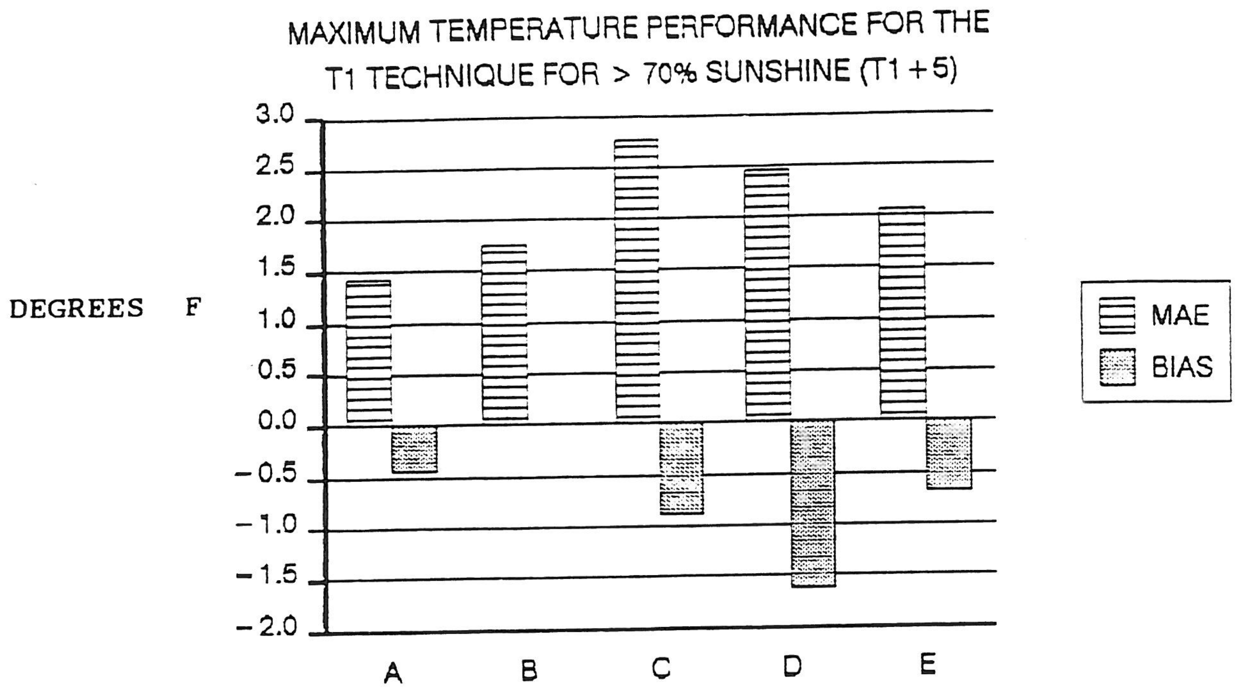

Figure 4a. Mean absolute error (MAE) and mean algebraic error (BIAS) for the T1 technique for greater than 70% sunshine (T1+5) during (A) Jun-Aug 1990, (B) Sep-Nov 1990, (C) Dec 1990-Feb 1991, (D) Mar-May 1991, and (E) Jun 1990-May 1991 for all periods combined.

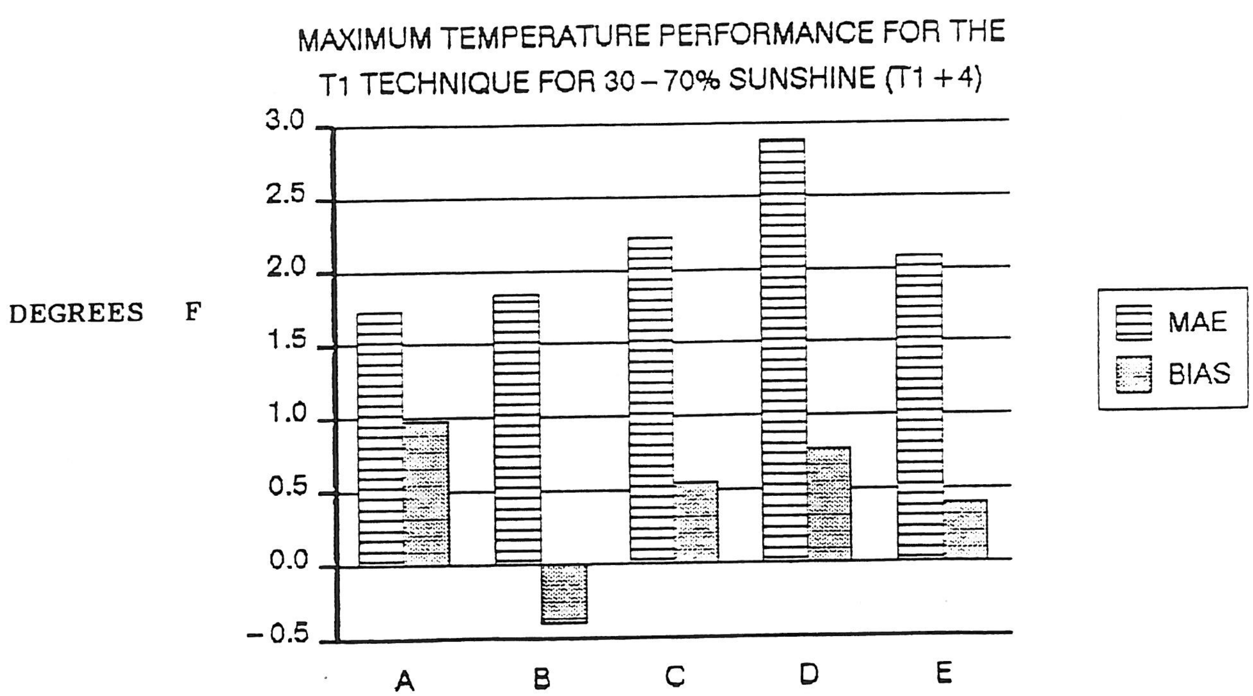

Figure 4b. Same as Figure 4a, except for 30-70% sunshine (T1+4).

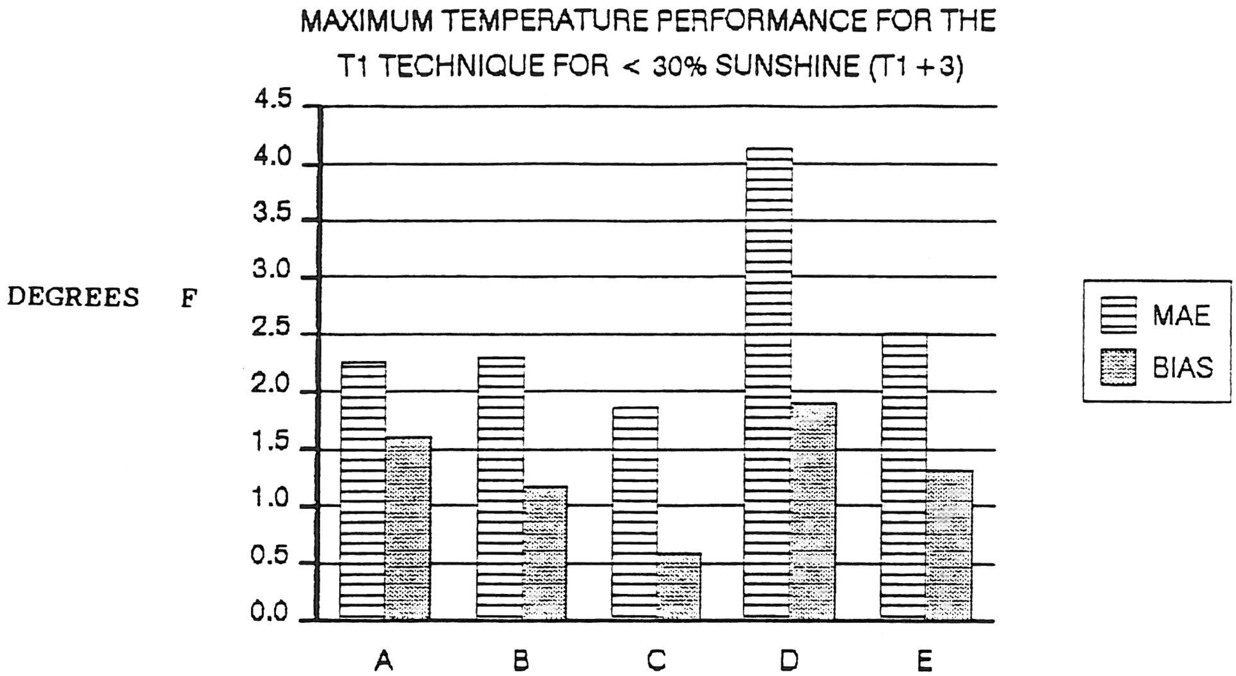

Figure 4c. Same as Figure 4a, except for less than 30% sunshine (T1+3).

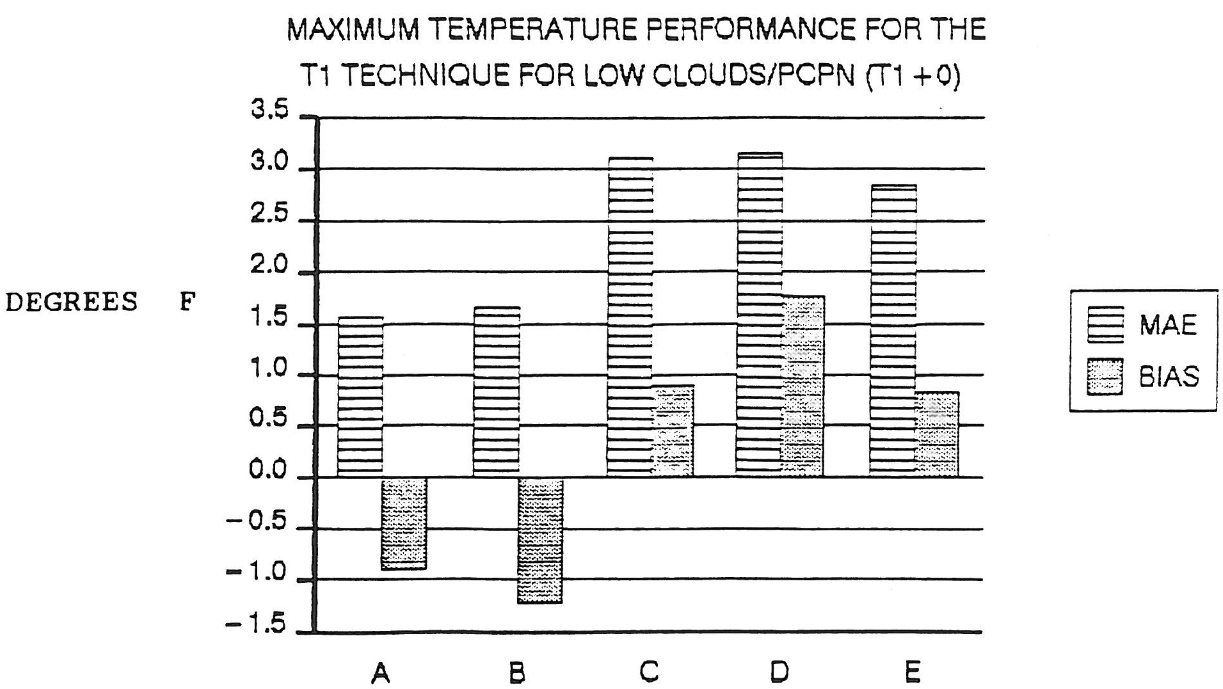

Figure 4d. Same as Figure 4a, except for low clouds and/or precipitation (T1+0).

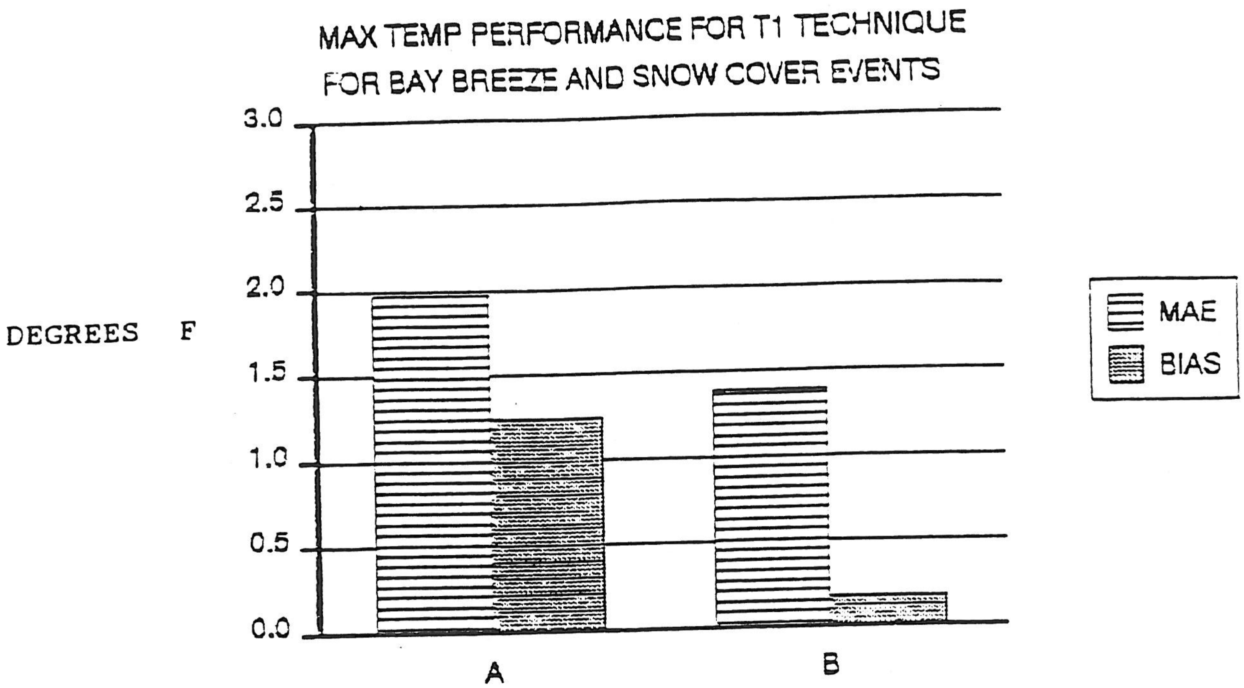

Figure 5. Mean absolute error (MAE; °F) and mean algebraic error (BIAS) for the T1 technique for (A) all bay breeze cases and (B) all snow cover cases independent of sunshine.

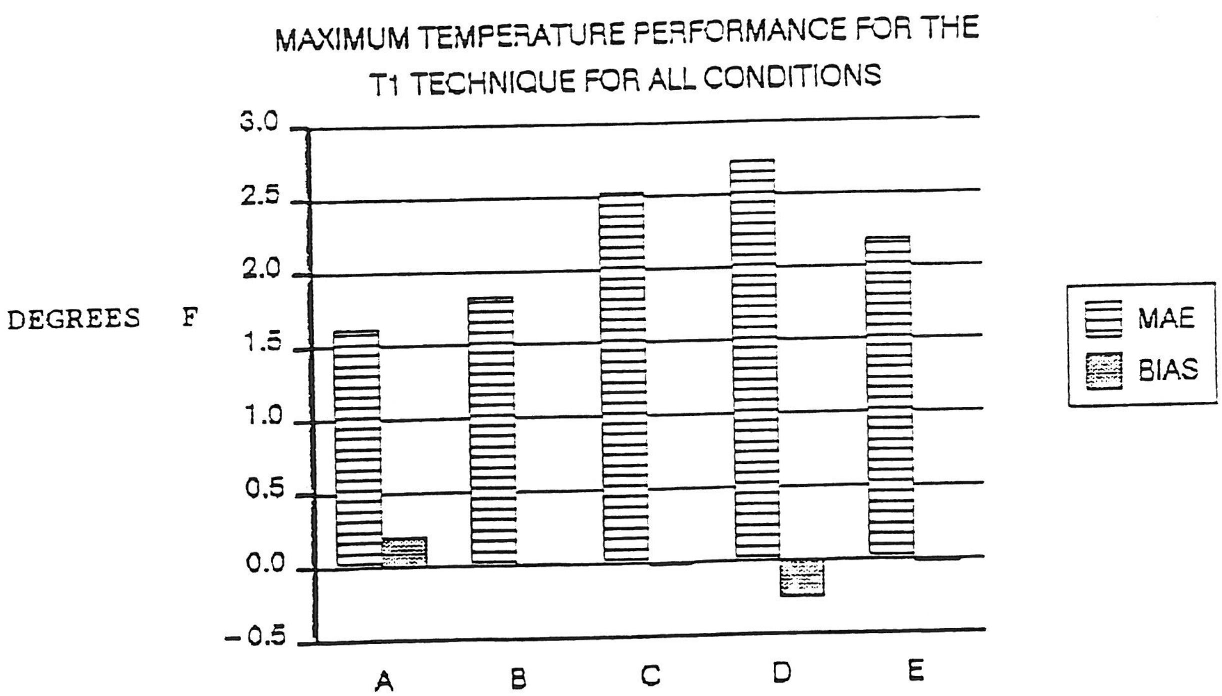

Figure 6. Same as Figure 5, except for all conditions during (A) Jun-Aug 1990, (B) Sep-Nov 1990, (C) Dec 1990-Feb 1991, (D) Mar-May 1991, and (E) Jun 1990-May 1991 for all periods combined.