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ERRORS IN OBJECTIVE TEMPERATURE FORECASTS FOR OTTAWA

by
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ABSTRACT

An analysis of the errors appearing in the temperature forecasts provided by the Central Analysis Office for Ottawa has been carried out for the period 1 December 1969 to 30 November 1970. It was found that cloud cover and precipitation occurrence has a marked influence on these errors.

ERREURS DES PRÉVISIONS OBJECTIVES DE TEMPÉRATURE POUR LA RÉGION D'OTTAWA

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RÉSUMÉ

L'analyse des erreurs des prévisions de température émises par le Centre d'analyse d'Ottawa au cours de la période du 1er décembre 1969 au 30 novembre 1970 a montré que la couverture nuageuse et les précipitations ont une influence considérable sur les erreurs de prévision.

ERRORS IN OBJECTIVE TEMPERATURE FORECASTS FOR OTTAWA

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W. I. Pugsley

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1. Introduction

Until quite recently prognostic fields forecast by computer in Canada were restricted to upper level or large scale features of the atmosphere. In the fall of 1969, the Central Analysis Office (CAO) began routine forecasts of surface temperature maxima and minima for periods up to sixty hours in advance. The approach was similar to that of the United States Weather Bureau which began routine objective temperature forecasts for various urban centers in 1968.

Both countries have developed regression equations from statistical analyses of upper air fields and persistence correlated to surface temperature extremes. Although additional factors, such as frontal discontinuities, clouds, and local influences undoubtedly affect the temperature regime, these elements either cannot be forecast with sufficient accuracy or have a minor influence.

In the formulation of the regression equations, various parameters were screened by their correlation with temperature extremes. By this means the relative importance of the parameters was established. Of the parameters considered by Yacowar (1968) for Canadian stations, the 850 mb. temperature was most highly correlated to predicted surface temperatures. Klein and Lewis (1970), in a similar examination of thicknesses and heights in the United States, found that the 1000 to 500 mb thickness had the highest correlation to the predictand.

From the standpoint of the forecaster in the field, subjective temperature forecasts are influenced primarily by low level thermal advection, persistence, cloud amount, and precipitation occurrence. Neither objective method mentioned above considered the last two factors, except indirectly through thickness advection. In this study the objective temperature forecasts issued by the CAO were verified for Ottawa, Ontario, for a twelve month period. An attempt was made to find the effect of varying cloud cover and precipitation on the errors.

2. Method

The CAO produces temperature forecasts at 1600Z and 0400Z for selected stations in Canada. Both issues contain forecast minima for the next two nights (referred to below as MIN1 and MIN2) and maxima for the next two days (referred to below as MAX1 and MAX2). The minimum is forecast for the period midnight to noon local time, and the maximum for the period noon to midnight. The valid time of the upper level predictors for minima is 1200Z and for maxima, 0000Z.

These forecasts were verified against the temperature extremes observed at Ottawa International Airport (OW) for the period prescribed above. The forecasts issued at 1600Z were examined for the period 1 December 1969 to 30 November 1970; those issued at 0400Z, for the period 1 April 1970 to 30 November 1970. The commencement of verification was determined by the first month of regular transmission of the forecasts. Where an abnormal trend existed, the appropriate extreme was chosen within the defined period. For example, when a maximum occurred after midnight, the highest temperature up to midnight was selected for verification.

For comparison, the temperature forecasts issued by the duty forecaster at Canadian Forces Base Uplands (UP) and the climatological values for Ottawa (1890-1964) were considered over the same period. A degree of independence from the objective forecast was sought by selecting the mid-morning subjective forecast (issued at 1000 hours local time) for comparison with the 1600Z CAO forecast, and the late evening subjective forecast (issued at 2130 hours local time) for comparison with the 0400Z CAO forecast. In the mid-morning, a comparison is available for the minimum the following night, as well as for the maximum the next day. In the late evening, only the next day's maximum was compared as there is no short range objective minimum forecast for the coming night.

The influence of clouds and precipitation on objective temperature error was determined by first ascertaining the average hourly cloud amount (including obstruction by ground based phenomena) and the occurrence of precipitation in each twelve hour period. The periods selected (0100Z to 1200Z for minima, 1300Z to 2400Z for maxima) were assumed to have the greatest influence on the respective extremes. The average cloud amounts were categorized as follows: 0.0 to 0.20, 0.21 to 0.40, 0.41 to 0.60, 0.61 to 0.80, 0.81 to 1.00. The average monthly bias (algebraic error) and average monthly absolute error of the CAO temperatures were calculated for each cloud category. The bias error was calculated by subtracting the observed temperature from the forecast value.

3. Results

Several factors should be considered before a detailed examination of the forecast errors presented below.

i) If consecutive temperature extremes (maximum, minimum, maximum, etc.) are thought of as related events, the knowledge of the one immediately preceding the forecast is an advantage in the forecast preparation. When the 1600Z forecast is issued, the previous day's maximum and minimum are known. From this, forecasts of the coming night's minimum and the next day's maximum are issued. By 0400Z the forecast of the next day's maximum is aided by the maximum observed just before issue time. For this reason alone, the 0400Z forecast of the next day's maximum should be more accurate than that of the 1600Z forecast. As well, the forecast minima should be more accurate than the next day's maximum when both are issued at 1600Z. This line of reasoning negates a comparison of the late evening's forecast minimum with the last objective forecast of this temperature issued at 1600Z (or 0400Z).

ii) On the 13 July 1970 the format of the Canadian public forecast was changed. Previously, temperatures were forecast to the nearest five degrees (e.g., 80). Under the new format, temperatures are forecast by a five degree range (e.g., 80 to 85). Superficially the new format appears less precise. It has the advantage, however, of refining the forecast to the nearest 2.5 deg. F. if one takes the middle of the range for verification, as was done in this study. In addition, where uncertainty exists as to the forecast extreme, there should be less temptation to forecast maxima too high or minima too low. One would expect that any positive bias for maxima and any negative bias for minima would be reduced or eliminated in forecasts issued after 13 July 1970.

iii) Abnormal temperature trends present a problem from both a forecast and verification viewpoint. The computer forecast extremes are valid for given periods, and so, do not take account of abnormal trends. Where upper air data, such as 1000 to 500 mb. thickness, is used, the valid time for minima is 1200Z, and for maxima, 0000Z. These times are appropriate for normal temperature trends. In this study the maximum temperature for verification was taken to be the highest hourly temperature between noon and mid-night, and the minimum, the lowest hourly temperature between mid-night and noon. The forecast temperatures were selected in like manner. No account was taken of an extreme observed

in the "wrong" period. This gives an advantage to the more flexible subjective forecast. Up to the end of 1970, there has not been one instance of an abnormal trend forecast by computer for Ottawa (i.e., a minimum forecast higher than a succeeding or preceding maximum).

Monthly values of the root mean square error (RMS) and the average bias of the 1600Z objective, subjective and climatological forecasts are shown in Table 1 (maxima) and Table 2 (minima). Corresponding maximum temperatures from the 0400Z forecasts are shown in Table 3. For reasons stated above, temperature minima forecast subjectively in the late evening are not comparable with objective values.

Deviations from climatological values are useful in a comparison with forecasts. The RMS error for a given month was computed from the sum of the squares of the daily errors, meaned over the number of days in the month. The square root of this mean of the squared errors is the RMS error. The magnitude of the RMS error is an indication of the degree of scatter of observed temperatures about normal values, and consequently, the probable estimation difficulty. Any positive or negative deviation from normal can be compared with the appropriate forecast bias to ascertain the interdependence of the two.

4. RMS and Bias Errors

An examination of Tables 1, 2 and 3 reveals several features foreseen above, as well as a few unexpected ones. The RMS errors of the climatological values are highest in winter and smallest in spring and summer. This result could have been anticipated from the standard deviation of monthly observed temperatures shown in the Hourly Data Summaries for Ottawa. The greatest RMS errors in the UP and CAO forecasts issued at 1600Z occurred in February, the same month as in the climatological forecast. There was no similar relationship between the least RMS errors. In Table 1 the objective forecast had the smallest RMS error for maxima in three months. In Table 2 the objective forecasts were more accurate in six months. More surprisingly, in Table 3, the CAO product was the better in six out of eight months. Tyner (1970) as well found the CAO temperature forecasts more accurate than the subjective forecasts of the Atlantic Weather Central for selected maritime locations in the winter of 1969, 1970.

In a follow up to Tyner's study, Fitzgerald (1970) examined temperature errors in the Maritimes during the summer of 1970. He found that the Atlantic Weather Central had superior forecasts for Nova Scotia and Newfoundland in terms of standard deviation, although the CAO product was better in Prince Edward Island and New Brunswick. Where

the CAO forecasts were inferior, the tendency was to overestimate maxima and underestimate minima in provinces where maritime influences are greatest. Interestingly, the CAO's success in New Brunswick and Prince Edward Island was tempered by a negative bias in both maxima and minima, whereas the Weather Central was positively biased in both forecasts.

The bias of the Uplands subjective forecast was generally positive for maxima, and negative for minima as anticipated above. On the average the CAO overestimated the maximum temperatures every month, while a small negative bias was evident in the CAO minima. In this case, the local influence of the Ottawa river valley in trapping cold air and yielding lower maxima was the probable cause, as discussed by Powe (1968) and McHattie (1957). There does not seem to have been any noticeable improvement in the bias of the subjective forecast after July under the new forecast format.

5. Influence of Cloud Cover on Temperature Errors

Attention will be turned at this stage to a closer examination of the objective temperature errors and their relationship to cloud cover and precipitation occurrence. If a forecast of temperature is made without regard to cloud cover, one might expect the following errors. With clear skies observed minima should be lower due to optimum long wave radiation emission, and observed maxima higher due to optimum incoming short wave radiation. With overcast skies the sign of the error is reversed; minima should be higher due to back radiation from cloud and maxima lower due to a decrease in insolation. The question remains, how large are these errors? The data that follows should give part of the answer.

In Figure 1, the average error of the objective temperature forecast over the twelve month period (December 1969 to November 1970) is plotted against the corresponding cloud cover interval. Only the short range forecasts of the first night's minimum (MIN1) and the next day's maximum (MAX1) are shown. The minimum error curve follows the expected range, varying from a positive bias under clear skies to an almost equal negative bias under overcast skies. Zero bias occurs at about 0.2 cloud cover. While the bias for the maximum error is positive for overcast conditions and decreases with less cloud down to 0.3 cloud cover, it increases to a larger positive value under clear conditions. It is in the maximum forecast, particularly, where the influence of the Ottawa valley should be greatest in producing a positive bias. From Figure 1 it appears that the valley effect, on an annual basis, overwhelms the opposite influence of clear skies. The probable reason for this is the frequent combination of light winds with clear skies and the subsequent formation of a strong inversion in the morning.

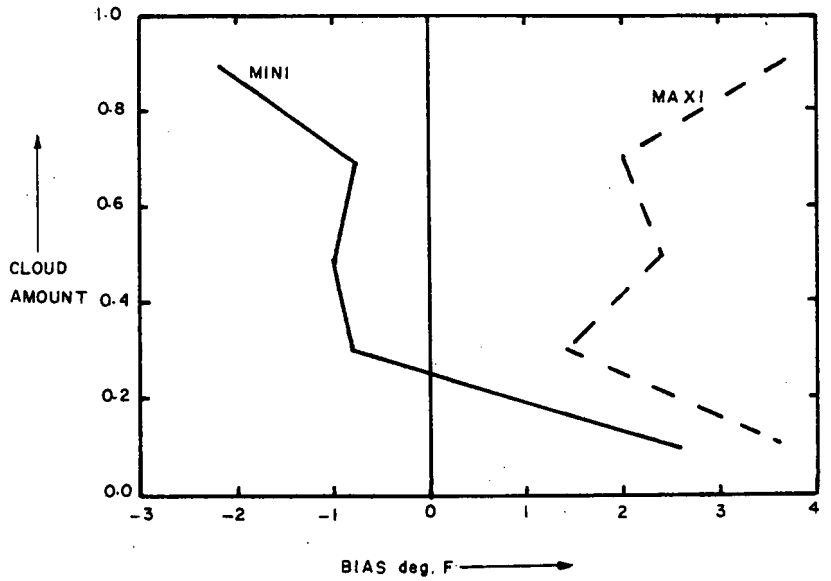

Figure 1.
Average Bias Error of MAXI (1600Z) and MINI (1600Z)
as a Function of Cloud Amount

The seasonal variation of the bias of the CAO forecasts with regard to cloud amount was examined. As the bias errors for clear and overcast conditions were greater month by month, than for scattered to broken skies, these two cloud amount intervals were selected. In Figure 2 the bias of the 1600Z MAX1 forecast is plotted for each month. In Figure 3 the corresponding monthly bias of the 1600Z MIN1 is shown.

Several features of these graphs are noteworthy. In Figure 2 the positive bias of MAX1 forecasts reached a maximum under clear skies in February and, under overcast skies, in June. In both months the alternate cloud amount bias was small or slightly negative. The overestimation of maximum temperatures under clear skies in mid-winter suggests that the valley effect is a maximum when cloud cover and insolation are least. The midsummer peak of the overcast sky maximum temperature bias may be explained by the greater proportionate decrease of insolation by cloud in summer. A secondary maximum for both cloud categories occurred in September and October. No explanation is offered.

In Figure 3 the MIN1 positive bias with clear skies and negative bias with an overcast increased steadily in magnitude from near zero in April to a maximum in November, then dropped to small values again in February. The form of the clear sky curves suggests a relation between minimum temperature and soil moisture that normally drops through the late summer and early fall and thereby leads to colder night temperatures. The overcast sky minimum temperature curve may be influenced in an opposite sense by the same factor. Upstream minima, produced under clear skies in dry land areas away from large bodies of water, may have been used to calculate minima at Ottawa. In eastern Ontario air is modified to a greater degree by water trajectories or through advection of moisture at low levels. In either case this factor would lessen in December because of freeze-up and the build-up of a substantial snow cover.

The mean biases of the 1600Z and 0400Z temperature forecasts are presented in Table 4 and Table 5, respectively. With the exception of the large positive bias of the 1600Z forecast maxima, all biases follow the expected trend in relation to cloud amount. It is noted that 0400Z forecasts cover only the months April to November and lack the large positive bias under clear skies.

The mean monthly absolute errors for each cloud category, averaged over the given periods for the 1600Z and 0400Z objective forecasts, are shown in Table 6 and Table 7 respectively. The absolute error is least in the first temperature forecast at each issue time for a cloud cover less than 0.7, with an error of the same magnitude for MIN1 (0400Z) with 0.5 to 0.7 cloud amount. The absolute error increases with the extent of the forecast period. Of note is the high

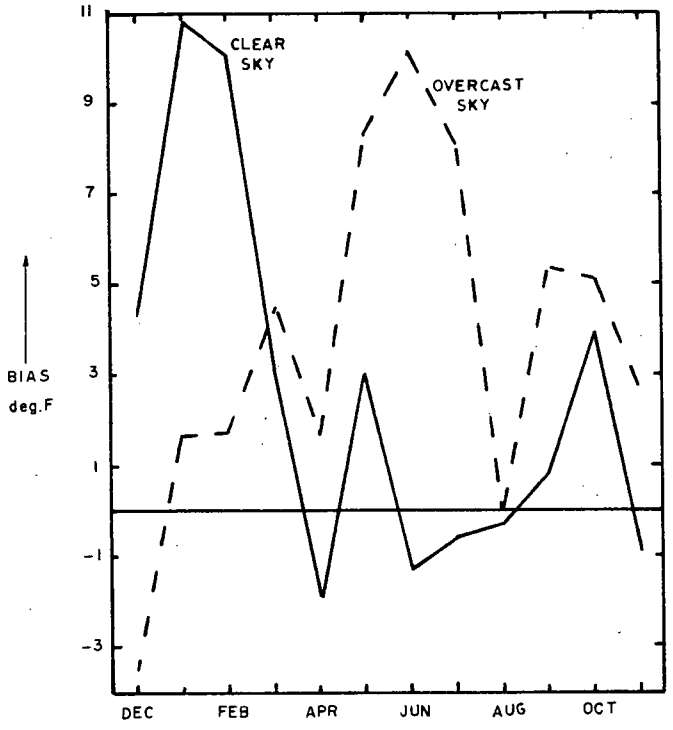

Figure 2.
Monthly Variation of MAXI (1600Z) Bias Error Under Clear
(0.0 to 0.2 cloud amount)
and Overcast (0.8 to 1.0 cloud amount) Sky Conditions

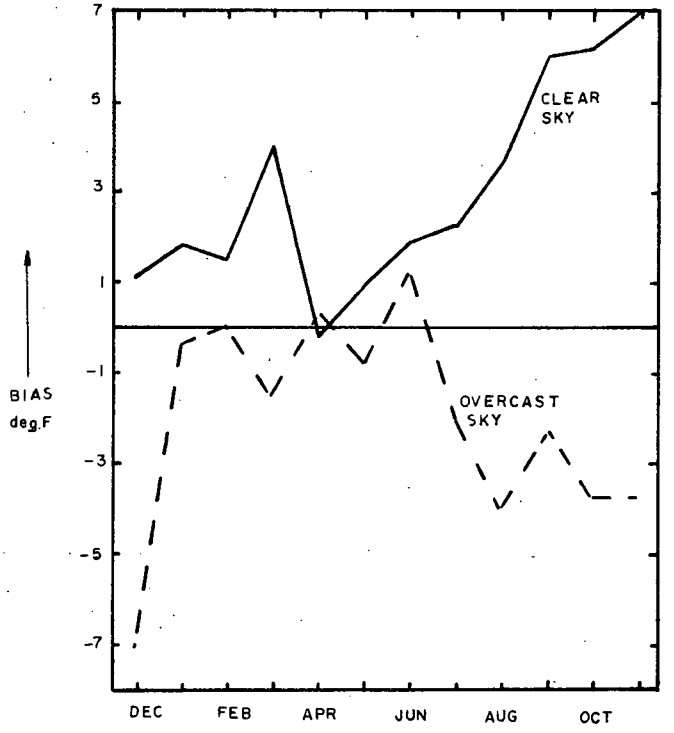

Figure 3.
Monthly Variation of MINI (1600Z) Bias Error Under Clear
(0.0 to 0.2 cloud amount)
and Overcast (0.8 to 1.0 cloud amount) Sky Conditions

error of the second forecast maximum, particularly under overcast conditions. MAX2 (0400Z) is less than MAX2 (1600Z) for each cloud category because of the knowledge of an additional maximum before issue time. It is curious that the error for MIN2 (0400Z) is less than that for MAX2 (0400Z) in that the error was not propagated and enlarged with time. This suggests again that a local influence, such as the valley effect, affects the maximum to a greater degree than the minimum.

6. Influence Of Precipitation Occurrence On Temperature Errors

It was the hope of the author that a subjective adjustment could be applied to the objective temperature forecast on the basis of parameters foreseen by the forecaster in the field but not available in numerical form. Such a parameter is the occurrence of precipitation, regardless of cloud cover, within twelve hour periods for up to sixty hours in advance. Intuitively one would expect prolonged precipitation to lower the diurnal range of temperature (i.e., maximum lower and minimum higher), and an absence of precipitation to increase the range.

A survey of precipitation occurrence within the "maximum temperature period" (1200Z to 2400Z) and the "minimum temperature period" (0000Z to 1200Z) was completed together with the appropriate 1600Z and 0400Z temperature errors. The average bias and absolute error for precipitation, no precipitation, and for all cases are shown for the 1600Z and 0400Z forecasts in Table 8 and Table 9 respectively.

Precipitation had the expected effect of raising minima and lowering maxima from the values forecast. A negative bias for the minima forecasts averaged between -1.0 and -1.9 deg. F. in both the short and long range. A larger positive bias existed for maxima with about 3.5 deg. F. in the short range and 5.0 deg. F. in the long range. Absolute errors lay between 4.8 and 7.0 deg. F., increasing with the length of the forecast period. A small positive bias was most evident in all forecasts of periods without precipitation with values less than 1.1 deg. F. for minima, and between 1.0 and 3.0 deg. F. for maxima. Absolute errors were smaller than during periods with precipitation. For all cases the sign of the errors resembled those with precipitation although the magnitude was less.

7. Conclusions and Suggested Improvements

The RMS errors and biases of objectively forecast temperatures compared favourably with the subjective product of the Uplands weather office, particularly during the non winter months. Forecast maxima tended toward an average positive bias of 1.9 to 2.9 deg. F.

More attention should be paid to cloud amount in the use or numerical development of the CAO product. A predictable and consistent bias of temperature error with cloud amount was shown in this study for Ottawa in 1970. Several publications have outlined the use of upper level isanabat and moisture prognostic charts in the prediction of cloud and precipitation. Jarvis, Kagawa and MacNeil (1968) suggest that, on the average, an upward vertical velocity of 0.25 x 10^{-3}mb. sec^{-1} or more produces broken middle cloud, and 0.90 x 10^{-3}mb. sec^{-1} or more produces precipitation. A further study of cloud probability from vertical velocity was presented by Hierlihy (1969). Since the date of that publication, a relative humidity-vertical velocity forecast map valid for up to thirty six hours has been transmitted to Canadian weather offices. The probability of cloud amount and precipitation may be obtained from this chart following the work of Moore and Pruett (1968). They point out that when the vertically meaned relative humidity is greater than 70%, the frequency of precipitation is greater than 99%. A second approach to the forecast of temperature, as well as cloud and precipitation, is through the use of numerically predicted air parcel trajectories. Barnum and Diercks (1969) have presented this technique as used for various stations in the United States by the Air Weather Service. This method, ideally suited to prognosis by computer model, appears most promising.

The influence of topography remains the basic problem in the advection of surface weather conditions. It has been shown that the Ottawa valley is responsible for an appreciable positive bias in the forecast of maximum temperatures. Further investigation into local factors at other sites, together with the development of more accurate guidance material, should produce an objective forecast with minimal error.

APPROVED

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TABLE 1

MAXIMUM TEMPERATURE ERRORS FOR FORECASTS ISSUED 1600Z-deg. F.
(bias without parentheses, RMS errors within parentheses).

MONTH	CAO	UP	CLIM.
12/69	3.8(6.8)	1.8(5.3)	7.2(11.2)
1/70	6.9(9.9)	0.6(5.0)	8.5(13.7)
2/70	4.2(11.1)	-2.1(8.0)	2.8(14.4)
3/70	3.8(5.7)	1.8(4.9)	1.7(6.4)
4/70	0.9(6.9)	-0.1(6.6)	-0.1(9.1)
5/70	4.4(8.0)	1.0(6.9)	2.7(8.6)
6/70	2.3(6.6)	0.9(6.4)	0.6(7.6)
7/70	2.5(5.3)	1.3(5.8)	1.1(6.6)
8/70	0.1(4.6)	1.3(5.1)	0.2(7.1)
9/70	3.5(5.9)	3.1(5.8)	2.8(7.6)
10/70	4.5(7.4)	1.1(5.9)	-1.9(8.7)
11/70	1.3(4.4)	-1.1(5.6)	-1.7(6.6)
MEANS	2.9(6.8)	0.9(6.0)	1.6(8.8)

TABLE 2

MINIMUM TEMPERATURE ERRORS FOR FORECASTS ISSUED 1600Z-deg. F.
(bias without parentheses, RMS errors within parentheses).

MONTH	CAO	UP	CLIM.
12/69	-1.5(7.4)	0.7(5.7)	-3.6(10.8)
1/70	0.0(5.4)	-1.1(6.1)	4.1(11.3)
2/70	-0.8(9.5)	-2.8(6.6)	-1.8(16.4)
3/70	0.7(4.4)	-0.5(5.6)	-1.1(7.8)
4/70	-0.9(4.0)	-0.4(4.1)	-0.8(5.6)
5/70	-0.2(5.4)	-0.7(5.1)	-0.8(8.6)
6/70	1.1(3.5)	-0.4(4.3)	0.0(7.7)
7/70	-0.7(3.4)	-0.4(3.6)	-2.4(6.7)
8/70	0.3(4.3)	-0.1(4.0)	-2.8(6.7)
9/70	0.1(5.0)	0.0(3.6)	-3.7(8.2)
10/70	-0.5(5.1)	-0.1(5.1)	-4.2(10.0)
11/70	-1.1(5.7)	-1.1(5.4)	-5.1(10.2)
MEANS	-0.3(5.3)	-0.6(4.9)	-1.9(9.2)

TABLE 3

MAXIMUM TEMPERATURE ERRORS FOR FORECASTS ISSUED 0400Z-deg. F.
(bias without parentheses, RMS errors within parentheses).

MONTH	CAO	UP	CLIM.
4/70	0.2(6.6)	-0.2(5.7)	-0.1(9.1)
5/70	3.1(6.5)	0.7(6.8)	2.7(8.6)
6/70	1.7(5.9)	1.3(6.3)	0.6(7.6)
7/70	3.2(5.1)	1.0(5.1)	1.1(6.6)
8/70	0.4(4.2)	1.3(4.3)	0.2(7.1)
9/70	2.7(4.7)	2.5(5.2)	2.8(7.6)
10/70	2.6(5.4)	0.0(4.4)	-1.9(8.7)
11/70	1.0(4.5)	-0.5(4.4)	-1.7(6.6)
MEANS	1.9(5.4)	0.8(5.3)	1.6(8.8)

TABLE 4

AVERAGE BIAS OF FORECASTS ISSUED 1600Z ACCORDING TO CLOUD AMOUNT
(period 1 Dec 69 to 30 Nov 70) - deg. F.

CLOUD AMOUNT	0-.2	.2-.4	.4-.6	.6-.8	.8-1.0
MIN1	2.6	-0.8	-1.0	-0.8	-2.2
MAX1	3.6	1.4	2.4	2.0	3.7
MIN2	4.8	-0.7	0.0	-1.8	-1.6
MAX2	3.1	1.1	3.3	3.1	5.3

TABLE 5

AVERAGE BIAS OF FORECASTS ISSUED 0400Z ACCORDING TO CLOUD AMOUNT
(period 1 Apr 70 to 30 Nov 70) - deg. F.

CLOUD AMOUNT	0-.2	.2-.4	.4-.6	.6-.8	.8-1.0
MAX1	0.4	0.5	1.3	1.3	2.9
MIN1	3.2	-0.9	-0.8	-1.5	-2.8
MAX2	-0.1	0.3	1.9	2.4	6.2
MIN2	3.8	-0.2	0.0	-2.5	-2.4

TABLE 6

AVERAGE ABSOLUTE ERROR OF FORECASTS ISSUED 1600Z ACCORDING TO CLOUD AMOUNT(period 1 Dec 69 to 30 Nov 70) - deg.F.

CLOUD AMOUNT	0-.2	.2-.4	.4-.6	.6-.8	.8-1.0
MIN1	3.7	3.2	3.1	4.5	5.0
MAX1	5.7	4.4	4.6	4.0	6.4
MIN2	5,6	4.1	4.2	4.6	5.5
MAX2	6.3	5.9	5.3	5.0	7.6

TABLE 7

AVERAGE ABSOLUTE ERROR OF FORECASTS ISSUED 0400Z ACCORDING TO CLOUD AMOUNT (period 1 Apr 70 to 30 Nov) - deg.F.

CLOUD AMOUNT	0-.2	.2-.4	.4-.6	.6-.8	.8-1.0
MAX1	3.6	2.7	3.8	4.2	5.4
MIN1	4.4	4.0	3.5	3.0	5.0
MAX2	4.9	4.4	4.3	4.9	7.6
MIN2	5.1	4.5	4.7	3.7	5.0

TABLE 8

AVERAGE ERROR OF FORECASTS ISSUED 1600Z ACCORDING TO PRECIPITATION OCCURRENCE(bias without parentheses, absolute error within parentheses; period 1 Dec 69 to 30 Nov 70) - deg.F.

CATEGORY	PCPN.	NO PCPN.	ALL CASES
MIN1	-1.2(4.8)	0.3(3.5)	-0.3(4.2)
MAX1	3.4(5.9)	2.5(5.0)	2.9(5.3)
MIN2	-1.0(5.5)	1.1(4.8)	0.3(5.2)
MAX2	4.8(7.0)	3.0(6.0)	3.5(6.4)

TABLE 9

AVERAGE ERROR TO FORECASTS ISSUED 0400Z ACCORDING TO PRECIPITATION OCCURRENCE (bias without parentheses, absolute error within parentheses; period 1 Apr 70 to 30 Nov 70) - deg. F.

CATEGORY	PCPN	NO PCPN	ALL CASES
MAX1	3.6(5.8)	1.0(3.6)	1.9(4.1)
MIN1	-1.9(4.3)	0.2(4.2)	-0.5(4.2)
MAX2	5.3(6.8)	1.6(5.1)	2.7(5.5)
MIN2	-1.9(4.5)	0.5(4.9)	-0.3(4.8)

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2. Ottawa, Ontario

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