Specifying Monthly Mean Surface Temperatures in Canada and Alaska from the 500 mb Height Field

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ABSTRACT

Specification equations for monthly mean air temperature anomalies at 68 surface stations in Canada and Alaska are derived by applying a forward selection screening procedure to simultaneous monthly mean 500 mb height anomalies at 110 grid points in the Northern Hemisphere and the previous month's local temperature anomaly. For the annual average, these equations explain about 72% of the temperature variance (on dependent data) by means of only 4.3 variables, but with marked regional and seasonal differences.

The average properties of the specification equations closely resemble those derived previously from the field of 700 mb heights. The 500 mb equations, however, explain about 2% more of the temperature variance by means of 0.7 fewer terms in the equations. This small but consistent superiority is evident during each month of the year and for equations based on heights only, as well as those including previous local temperature. The superiority is produced by higher correlations of temperature with local heights and suggests that the 500 mb level is more equivalent barotropic than 700 mb.

The specification equations are tested by means of several verification statistics computed for 5 years of independent data at 51 Canadian stations. The results show that equations based on concurrent 500 mb heights and previous local temperature perform slightly better than those based on heights only and much better than climatology or month-to-month persistence.

1. Introduction

Specification of monthly mean air temperature anomalies near the surface of the earth (T) from the midtropospheric circulation pattern is an important aspect of extended weather forecasting (Namias 1953; Gilman 1983; Epstein 1988). In a previous paper (Klein 1983), a system was described for objectively specifying T during the winter season from the field of simultaneous monthly mean 700 mb height anomalies (H_7), plus the previous month's local surface temperature anomaly (L). A set of multiple regression equations was derived for each of 109 surface stations in the contiguous United States by applying a forward selection procedure of screening (Miller 1962; Draper and Smith 1981) to L and concurrent values of H_7 at 133 grid points over North America and adjacent bodies of water. Tests on independent data showed that the temperature specification equations were approximately 70% better than monthly temperature persistence, 20% better than an older set of equations based on 5-day mean data, and 15% better than equations derived from empirical orthogonal functions (Klein and Walsh 1983). Later tests showed that the equations are about as skillful as experienced forecasters in specifying T from prognostic values of H_7 (Klein 1985a).

In view of the above results, the pointwise screening system was extended from the winter months to the remainder of the year (Klein 1985a), from the contiguous 48 states to a network of 68 surface stations covering Alaska and Canada (Klein 1985b), and from North America to 115 stations in Europe and Asia (Klein and Yang 1986). Because these equations can readily give objective forecasts of T by using a prognostic mean 700 mb map as input, they are now being applied on a routine basis by the Climate Analysis Center (CAC) of the United States National Weather Service as an aid in preparing official monthly weather outlooks for the public.

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Encouraged by the above results, the Canadian Climate Centre (CCC) started its own program of monthly weather forecasting in 1986. Its methodology was very similar to that of CAC except that the level it used to depict the midtropospheric circulation pattern was 500 mb instead of 700 mb. We therefore derived another set of temperature specification equations for Canada and Alaska by screening the field of 500 mb monthly mean height anomalies (H_5) for use by CCC.

The main objectives of the present note are to explain the derivation of the 500 mb equations and to compare their properties with those of the 700 mb equations derived previously. Secondary objectives are to report on equations based on heights only, compare them to equations that include L as a potential predictor, and to test the equations on independent data.

Section 2 describes the basic data and procedure and gives a sample specification equation. Section 3 compares the characteristics of the equations at 500 mb and 700 mb, both with and without temperature as a predictor. Section 4 summarizes a test on independent data. Section 5 gives a summary and recommendations for future research.

2. Data and procedure

The basic temperature data for this study consisted of values of T at the 55 stations in Canada and 13 in Alaska plotted in Fig. 1. The period of record covers 30 yr from January 1951 through December 1980. Thus, all values of T are identical to those used in our earlier derivation for Canada and Alaska (Klein 1985b).

The concurrent 500 mb monthly mean height anomalies (H_5) were obtained from the CCC. The network of 110 grid points used as potential predictors is depicted in Fig. 2. Note that the meridional grid spacing is 10° latitude, but the zonal spacing varies so as to provide a denser resolution over the target area (Fig. 1). The grid is identical to that used for the 700 mb derivation except for small differences at 70°N (see Fig. 2 of Klein 1985b).

To reduce random effects in regression equations derived from a small sample, each month's data was combined with its two adjacent months to triple the size of the sample (from 30 to 90). For example, the equations for February were derived from the pooled data for the months of January, February, and March. Serial correlation in the data, however, still limits the effective sample size to approximately 80 (Walsh 1984). All anomalies were computed as departures from the 30-yr mean for each month separately.

The forward selection regression procedure (screening) was used to choose predictors among 110 H_5 variables and the previous local temperature (L) for each month and each station. Only the first eight predictors selected by the screening program were considered, since additional variables reduce the unexplained variance of T by a very small amount. RV will be used here to denote the reduction of variance; it equals the coefficient of determination R^2, where R is the multiple

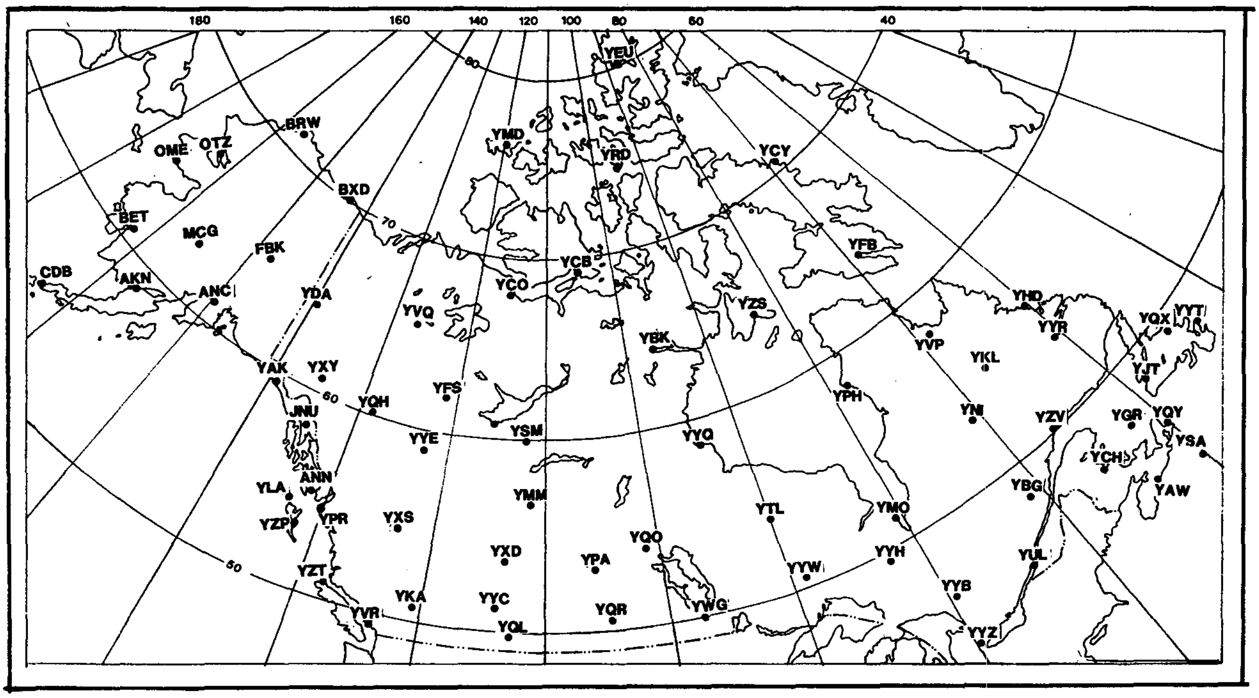


FIG. 1. Location and call letters of 55 surface stations in Canada and 13 in Alaska for which monthly mean surface temperatures were available during the 30-yr period: 1951–1980.

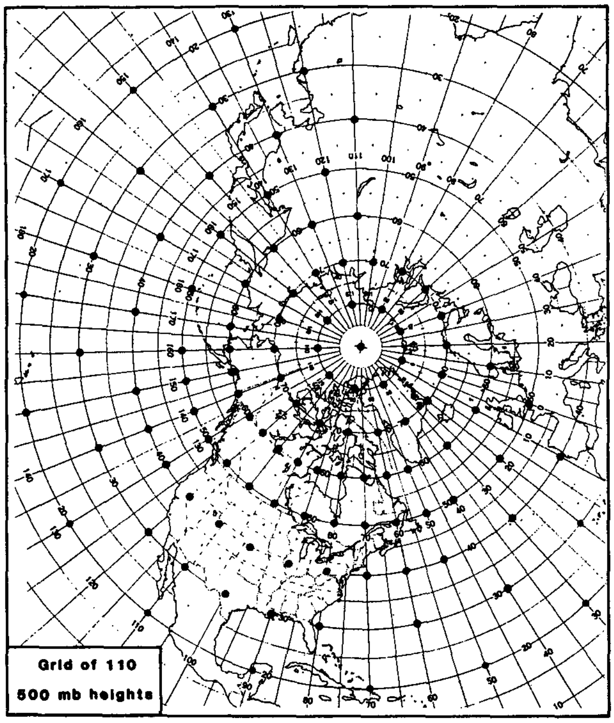


FIG. 2. Network of 110 grid points used to delineate the field of monthly mean 500 mb height.

correlation coefficient. Specification equations were selected subjectively according to four criteria (considered simultaneously): synoptic and physical reasonableness, statistical significance, number of terms in the equation, and percent of variance explained by the added variable (added RV). Even after allowing for persistence in the data, the probability level used for statistical significance was higher than the corresponding classical probability level because of the a posteriori nature of screening (i.e., selection of the best variable after the fact). The true 95% significance level for equation selection was therefore approximated by the classical F-test at the 98%–99% level. This is consistent with the results of Walsh (1984) who applied a Monte Carlo technique to data of T and H_7 in the United States, and with the selection procedure used by Klein (1985a).

Table 1 shows the statistics obtained by screening T at Regina, Saskatchewan during 90 winter months (December, January, and February). The first predictor selected, H_5 at 50°N, 110°W, is located about 5° longitude west of Regina. It explains almost 43% of the temperature variance by means of an equivalent barotropic effect (cold lows and warm highs at 500 mb). The second predictor, H_5 about 3000 km to the northwest, increases the RV by almost 26%. Its location and negative regression coefficient show the importance of the upstream ridge (trough) in controlling the deployment of cold (warm) air into Regina. The third predictor, L, adds over 4% to the RV through the persistence of local surface temperature. The screening procedure was stopped at this point because no other variable had a probability level over 99%, increased the RV by more than 2% or made good synoptic sense.

3. Comparison of equations at 500 mb and 700 mb

The procedure described above was followed for all 68 stations during all 12 months of the year, with results summarized in Fig. 3. As expected, at both 500 and 700 mb, the mean annual RV increases approximately logarithmically as the number of terms in the regression equation increases. The 500 mb equations, however, consistently outperform the 700 mb equations by a few percent. This result was unchanged when similar graphs were plotted for each season separately (not shown). It is consistent with earlier results of Klein and Marshall (1973) who obtained about 4% higher RV at 500 mb than 700 mb in specifying daily maximum and minimum temperatures at 51 surface stations in the contiguous United States from daily heights at 123 grid points over North America.

Figure 4 gives mean annual values of RV for specification equations based on: 1) H_5 only, 2) H_7 only, 3) H_5 plus previous L, and 4) H_7 plus previous L. The superiority of the 500 mb level is again evident—for equations based on heights only (1 and 2) as well as those including previous local temperature (3 and 4). This superiority is even more marked for the first variable alone (left), selected purely objectively. Another advantage of the 500 mb specification equations is that they contain fewer terms (mean of 4.3) than the 700

TABLE 1. Summary of the forward selection regression statistics obtained for Regina, Saskatchewan (50.4°N, 104.7°W) during winter months. The star shows the final equation selected for specifying monthly mean temperature anomaly from anomalies of 500 mb height field and previous month's temperature.

Step no.	Predictor selected	Regression coefficient upon entry	Probability (F-test)	Added RV (%)	Cumulative RV (%)	Standard error (°C)
0	0	0	0	0	0	3.84
1	50N, 110W	+.050	100.0	42.78	42.78	2.91
2	70N, 160W	−.029	100.0	25.87	68.65	2.15
3*	prev. temp.	+.219	99.96	4.34	72.99	2.00
4	20N, 70W	+.026	96.26	1.35	74.34	1.95
5	20N, 150E	−.021	90.73	0.85	75.19	1.91

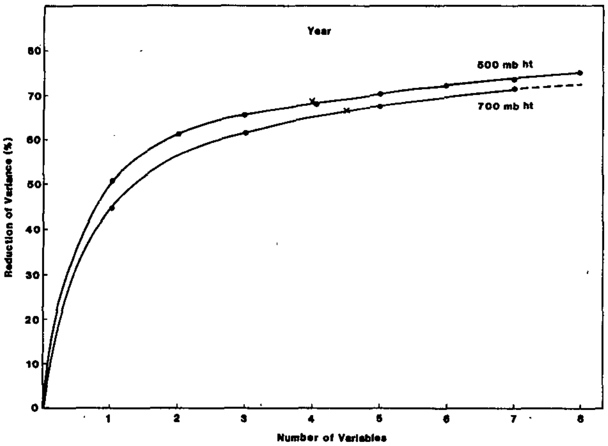


FIG. 3. Reduction of variance of monthly mean temperature anomaly specified from heights only (at 500 or 700 mb) by regression equations containing from 1 to 8 variables. The dots represent a fixed number of terms in each equation, the crosses a variable number in the final specification equations (selected subjectively). All results are based on 68 stations in Canada and Alaska, 12 months of the year and dependent sample of 30 years.

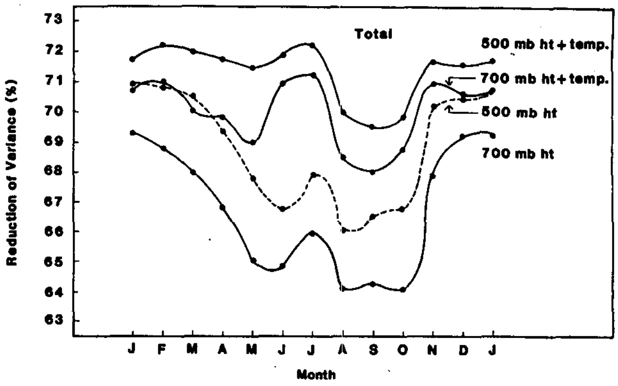


FIG. 5. Annual cycle of the reduction of variance for the four types of temperature specification equations described in legend to Fig. 4, averaged by month at 68 stations on the dependent sample.

mb equations (mean of 5.0). This should increase their statistical stability relative to the 700 mb equations and decrease overfitting or artificial skill (Davis 1976). They should also be easier for forecasters to understand and apply.

Month-to-month variations in the above characteristics are illustrated in Figs. 5 and 6 for all four sets of equations. Here the 500 mb results are better than those at 700 mb (obtained from Klein 1985b) during each month of the year, not only with higher RV (Fig. 5) but also with smaller number of variables (Fig. 6). Although differences are small, the RV tends to be higher in winter and summer and lowest in early fall, while the equations contain more variables during the warm than the cold season.

Regional differences in the specification equations based on *H* and *L* are depicted in Fig. 7 in terms of the mean annual RV for 500 mb (a) and 700 mb (b). The patterns for the two levels are remarkably similar,

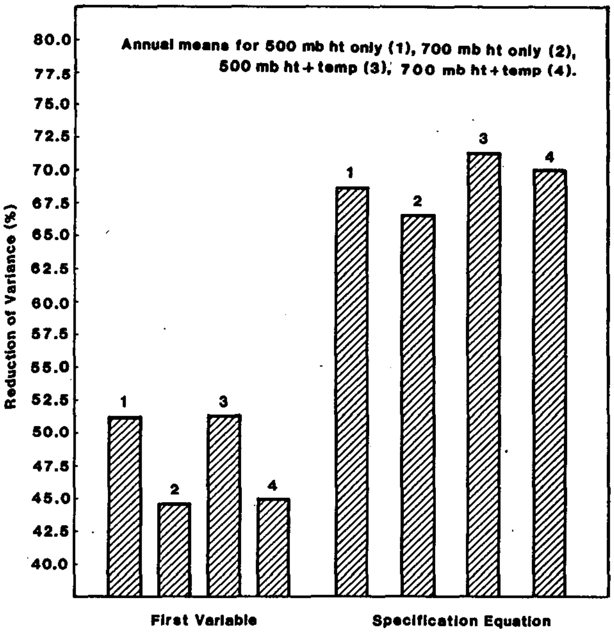


FIG. 4. Reduction of variance in regression equations for specifying monthly mean temperature anomaly from anomalies of: 1) 500 mb height field, 2) 700 mb height field, 3) 500 mb heights and previous month's temperature, 4) 700 mb heights and previous temperature. The reduction of variance given by the first selected variable alone is shown on the left and by the full specification equation on the right. All results are based on 68 stations, 12 months and dependent sample of 30 yr.

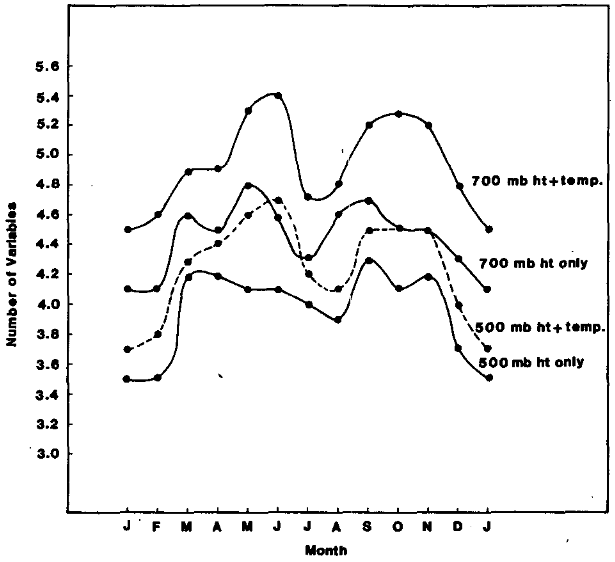
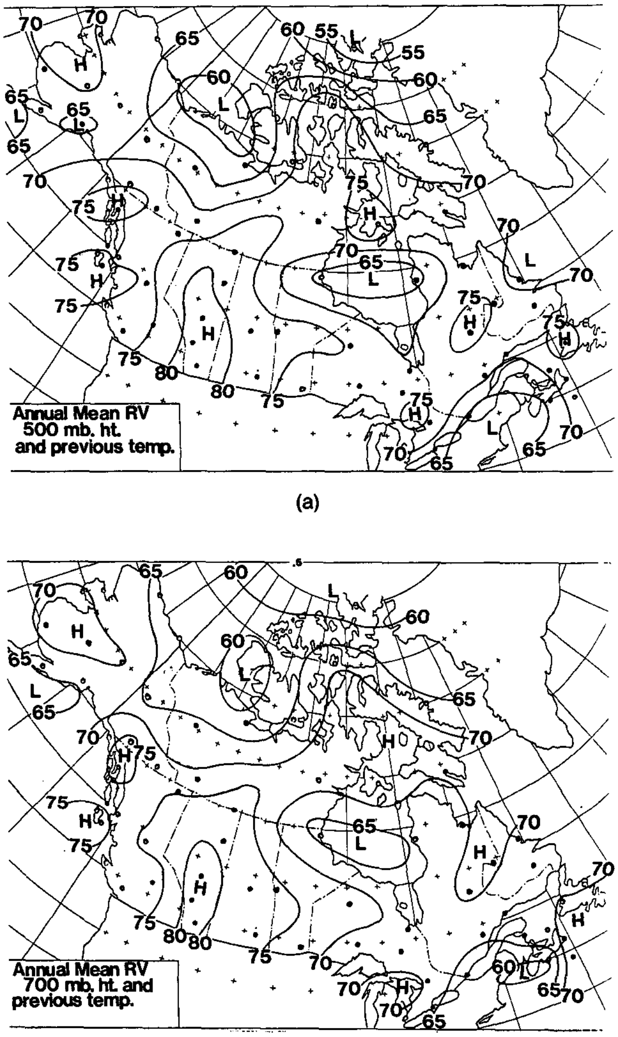


FIG. 6. Number of predictors in the four types of temperature specification equations described in legend to Fig. 4, averaged by month at 68 stations on dependent sample.



(a)

(b)

FIG. 7. Percent of variance of monthly mean temperature anomaly explained by specification equations based on heights and previous temperature, averaged over 12 months of the year, for (a) 500 mb and (b) 700 mb. High and low centers are marked *H* and *L*, respectively.

with maxima over the prairies, the Pacific Coast and parts of eastern Canada and minima over the Arctic and Hudson Bay, but with slightly higher values at 500 mb. Thus, differences between 500 mb and 700 mb are consistent from place to place, as well as from month to month. Some explanation for the geographical distribution was given by Klein (1985b).

To gain further insight into these differences, the highest simple correlation between *T* and *H* was computed separately for the maximum positive (MPC) and negative (MNC) coefficients during January, April, July and October (the midmonth of each season). Figure 8 (upper) shows that the MPC is greater at 500 mb than 700 mb during each season of the year. Because the MPC is usually located close to the station, this suggests

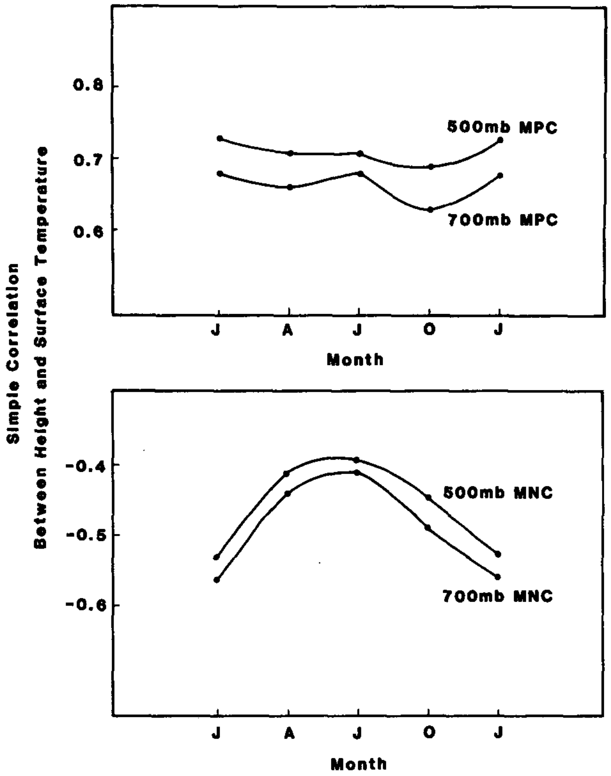


FIG. 8. Maximum positive correlation (MPC) and maximum negative correlation (MNC) between monthly mean anomalies of temperature at 68 stations and height at 110 (107) grid points at 500 (700) mb. All coefficients were computed separately by station, level and month (January, April, July or October).

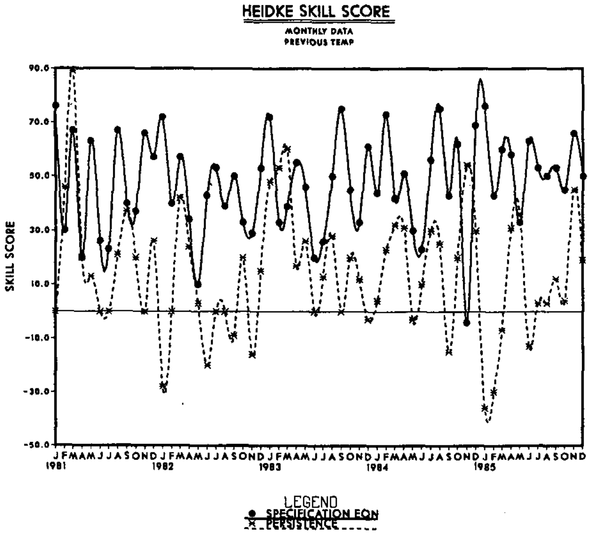
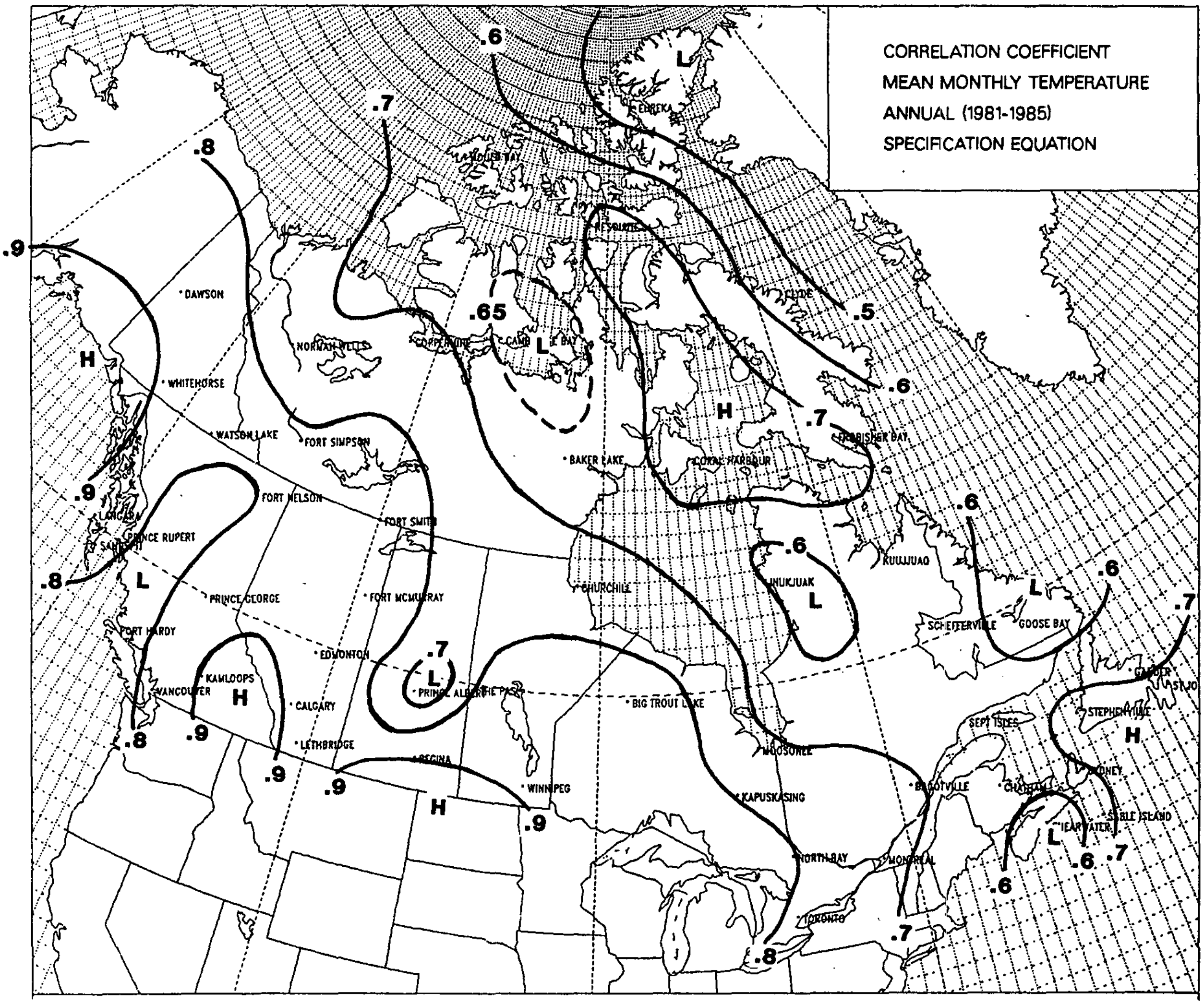


FIG. 9. Heidke skill scores obtained on independent data by applying specification equations at 51 stations in Canada to observed anomalies of concurrent 500 mb heights and previous local temperature during each month of 5-yr period from January 1981 through December 1985. The dashed line shows the skill that would be obtained by assuming simple persistence of last month's temperature class.

TABLE 2. Comparative accuracy of monthly mean surface temperature anomalies in Canada specified from observed 500 mb height fields, with and without previous local temperature as potential predictor, in terms of five different verification statistics. Scores obtained by simple persistence of last month's temperature are also listed. All results are averaged over 60 months and 51 stations on independent data from January 1981 through December 1985.

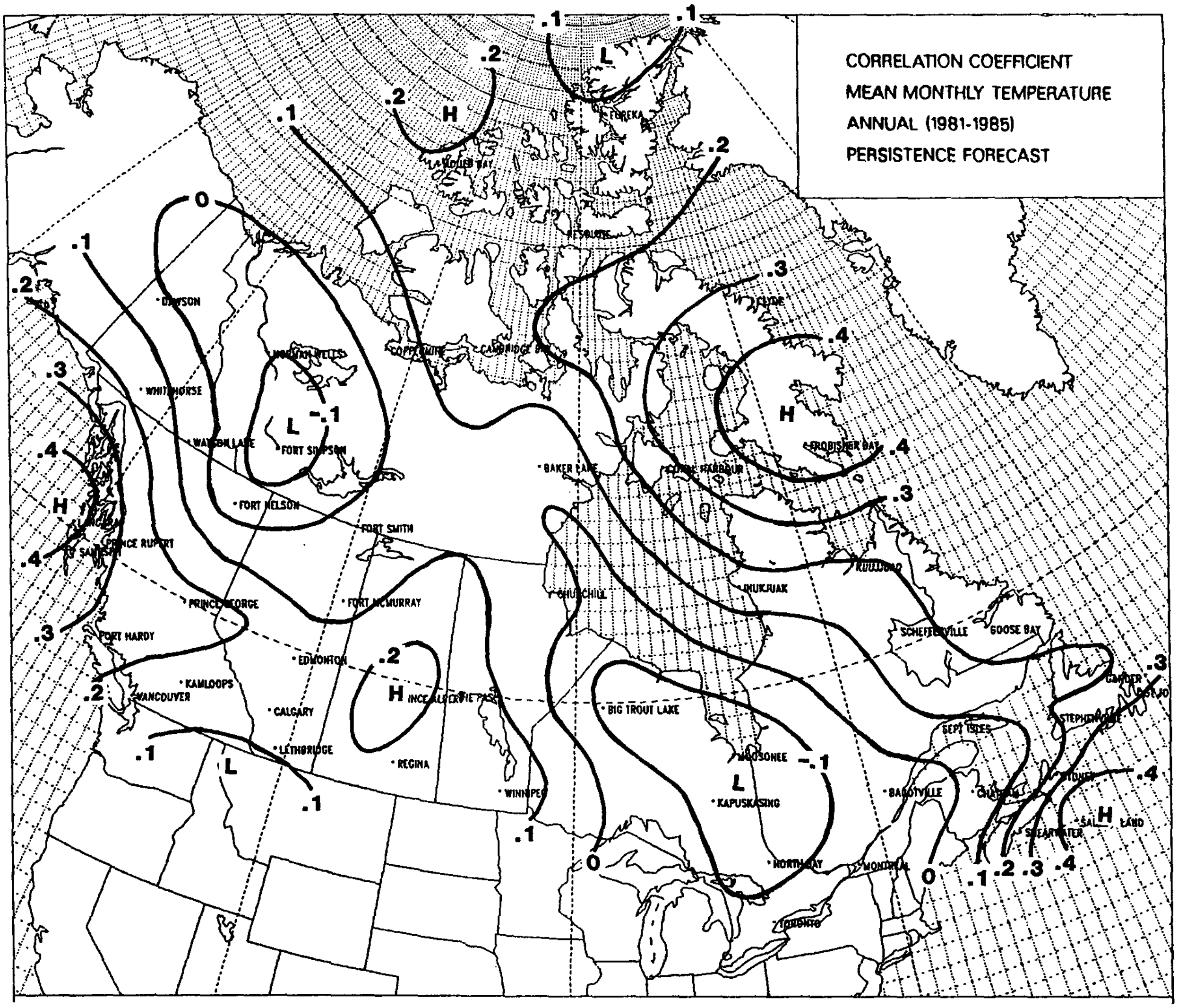
Statistic	Heights only	Height and temperature	Persistence
Percent correct (2 classes)	80.8	82.3	60.0
Root-mean-square error (°C)	1.6	1.5	3.3
Correlation coefficient squared between specified and observed temperatures	0.50	0.57	0.02
Reduction of error (%)	48.0	52.4	−78.4
Heidke skill score (3 classes)	43.7	47.5	13.0

that the 500 mb level is more equivalent barotropic in behavior than 700 mb—perhaps because 500 mb is closer to the level of nondivergence (Charney 1949). As a result, lows (highs) at 500 mb are usually cold (warm) at the ground. The opposite holds for systems at sea level, where lows tend to be warm and highs



(a)

FIG. 10. Geographical distribution of mean annual correlation coefficient at 51 stations in Canada on independent data from January 1981 through December 1985 for (a) specification from observed anomalies of 500 mb heights and previous local temperature, and (b) persistence of last month's temperature anomaly.



(b)

FIG. 10. (*Continued*)

cold. Because the intermediate level of 700 mb is affected by both types of behavior, the MPC at 700 mb is less than that at 500 mb. The MNC, however, is consistently larger in magnitude at 700 mb than 500 mb (Fig. 8, lower). Because the MNC is usually located about a half wavelength upstream from the reference station (Martin and Hawkins 1950; Klein and Kline 1984; Klein 1985b; Klein and Yang 1986), advection of air masses may be better indicated at 700 mb than at 500 mb.

4. Test on independent data

To test the stability of the regression equations on independent data, they were applied to observed values of H_5 and L to specify T during each month of the 5 yr from 1981 through 1985. The results for 51 surface stations in Canada (four of the original 55 were omitted due to incomplete data) are summarized in Table 2 in terms of four verification statistics used by Klein (1983). In addition, test values are given for the Heidke skill score based on three equally frequent classes, with chance computed from climatological expectancy. As expected, in all cases the equations based on heights and previous temperature did slightly better than those based on heights only and much better than simple persistence of L. The superiority of the specification equations based on H_5 and L over those using H_5 only is also illustrated by comparing the third line of Table 2 (R^2) with Fig. 4. The average RV drops by about 15% between the dependent and independent samples for the first set of equations but by about 20% for the second set. Thus the equations incorporating previous temperature are not only more skillful but also more stable than those based on heights only.

Heidke skill scores for the 500 mb equations based on H_5 and L are presented as a time series in Fig. 9, together with scores obtained by persistence. The specifications exhibit positive skill in 59 out of 60 months, and they score higher than persistence in 55 months. Figure 10a gives the regional variation of the correlation between specified and observed temperature anomalies, averaged over the 5-yr period. The pattern is reasonably similar to that of the RV on dependent data, shown in Fig. 7a. As expected, the skill of persistence (Fig. 10b) is less than that of specification (at all stations), greatest over coastal areas, and least in the interior (van den Dool et al. 1986).

5. Conclusion

This note has described a set of multiple regression equations for specifying monthly mean surface temperature anomalies in Canada and Alaska during each month of the year from the field of concurrent 500 mb heights plus the previous month's local temperature anomaly. On average, these specification equations explain over 70% of the temperature variance by means of only 4.3 variables, but with marked regional, seasonal and month-to-month differences.

When compared to corresponding specification equations derived from 700 mb heights, the 500 mb equations exhibit similar geographical patterns but explain about 2% more of the temperature variance by means of 0.7 fewer terms in the equations. This small but consistent superiority is evident during each month of the year and for equations based on heights only, as well as those that include previous local temperature. This superiority is produced by higher correlations of temperature with local heights at 500 mb than at 700 mb. This suggests that the 500 mb level behaves in a more equivalent barotropic fashion than 700 mb. Advection of air masses is better indicated at 700 mb, however, where negative correlations between temperature and upstream heights have greater absolute value at 700 mb than at 500 mb.

Tests on Canadian temperatures with 5 years of independent data show that equations based on concurrent 500 mb heights and previous local temperature perform slightly better than those based on heights only and much better than simple temperature persistence. The objective specifications exhibit positive skill in all but one of 60 months tested, and they score higher than persistence in all but 5 months.

Future work should extend this research to temperatures in the contiguous United States, Europe and Asia. In addition, the stability of the 700 mb equations should be tested in a similar fashion as performed here for 500 mb to see whether the 500 mb equations outperform the 700 mb equations on independent data and in other portions of the Northern Hemisphere.

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