A Comparison of Pointwise Screening and Empirical Orthogonal Functions in Specifying Monthly Surface Temperature from 700 mb Data

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ABSTRACT

A comparison is made between two types of specification of monthly wintertime surface temperatures over the United States. The specifications are obtained by multiple regression of station temperature anomaly at each of 37 stations onto 700 mb height anomalies represented by 1) grid-point values selected by a forward stepwise screening procedure, and 2) coefficients of the dominant empirical orthogonal functions (EOF's). Various measures of skill show that specifications derived from the pointwise screening are superior in both developmental (dependent) and independent samples. The differences in the skill levels are interpreted as a disadvantage of the spatial generality inherent in the EOF representations.

1. Background

Because surface weather systems evolve in conjunction with the circulation of the middle and upper troposphere, surface temperatures and the tropospheric fields of geopotential height display quantifiable associations. These associations can be utilized in the preparation of weather forecasts at ranges of several days to a season. The U.S. National Weather Service (NWS), for example, bases its average monthly weather outlooks on forecasts of the 700 mb height anomaly pattern for the coming month (National Weather Service, 1979). Quantitative estimates of surface temperatures can then be obtained using associations with the 700 mb height field (Klein, 1962). An advantage of this approach is that gross features of the 700 mb circulation can be extrapolated to 30-day periods (via persistence, anomaly propagation, teleconnections, etc.) with greater justification than can surface temperature anomalies, which are often subject to considerable local influences. Since the link between the 700 mb and surface anomalies is an essential component of such a forecasting procedure, the accuracy with which surface temperatures can be prescribed from 700 mb height fields should be assessed.

Two types of specification procedures have recently been described in the literature: 1) the application of multiple regression equations which specify monthly surface temperature anomalies from 700 mb height anomalies at individual points selected by forward stepwise screening (Klein, 1982), and 2) multiple regression of the temperature anomalies onto the coefficients or amplitudes of the first few empirical orthogonal functions (EOF's) of 700 mb height anomalies (Walsh *et al.*, 1982). The rationale for the latter approach is that the strong spatial coherence exhibited by the 700 mb anomalies is captured by EOF representations. Because the first EOF's describe a greater portion of the variance of a set of data fields (e.g., 700 mb height) than any other combination of the same number of parameters or functions, EOF's permit the most effective compression of the data.

This note describes the results of a direct comparison of temperature specifications employing 700 mb EOF coefficients and screened grid point heights as independent variables. Results obtained from both dependent (developmental) and independent data samples are presented in Section 3. Section 2 describes the (test) data and the specification equations.

2. Data and specification equations

The data consist of surface station temperatures and grids of 700 mb height for the winter months of December, January and February of the years 1948–81. While the previously referenced studies by Klein (1982) and Walsh *et al.* (1982) were based on surface temperatures at 109 and 61 stations, respectively, comparison of the error statistics in Section 3 is based on only the 37 stations common to both studies. As shown in Fig. 1, all 37 stations are within the contiguous United States. All temperatures are in the

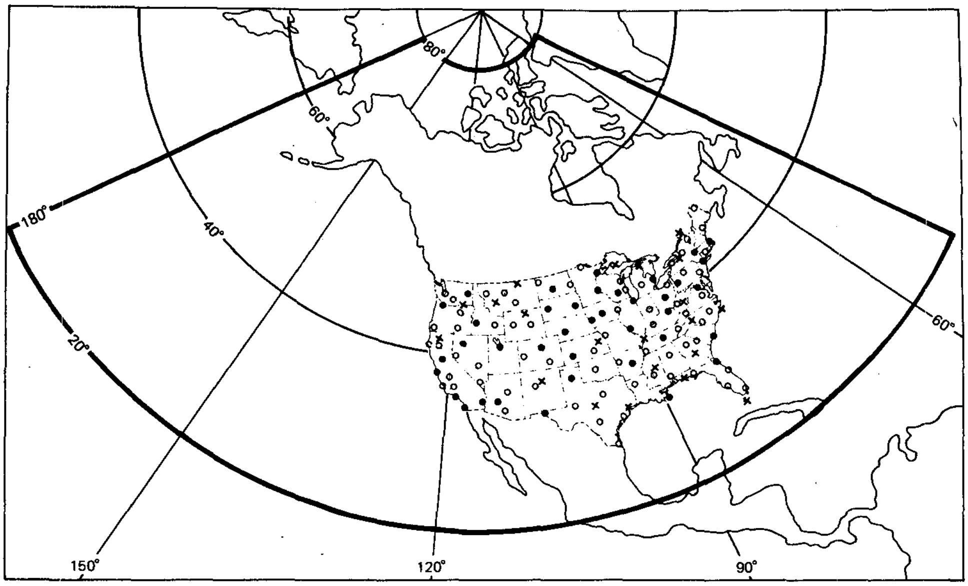

FIG. 1. Boundary (heavy line) of domain covered by 700 mb grid. Surface temperature stations used in studies by Klein (1982) and Walsh *et al.* (1982) are identified by open circles and crosses, respectively. 37 stations common to both studies are identified by solid circles.

form of departures from the monthly station means for the 30-year period, 1948–77.

The 700 mb data cover the region 20–80°N, 50–180°W with a resolution of 5 or 10° latitude × 10° longitude. The 700 mb domain is shown in Fig. 1. The grid point screening procedure is based on a set of 133 points in this domain, while the EOF's are constructed from a set of 98 points covering the same domain. As in the case of the surface temperatures, all 700 mb heights were converted to departures from the corresponding monthly means. The EOF's were computed using normalized departures from the monthly means in order to prevent regions of maximum variance from dominating the eigenvectors. As noted in the following section, the error statistics were nearly identical when non-normalized anomalies were used to compute the EOF's.

All the specification equations compared here contain 10 independent variables for each station. In the case of the pointwise specifications, these variables were selected by applying a forward stepwise screening procedure (e.g., Miller, 1962) to the set of 133 concurrent grid point height anomalies. The temperature anomaly, T_{n-1}, observed at the same station during the previous month was also included as a potential predictor. T_{n-1} was used in this experiment because the antecedent temperature is an available and often useful tool in the forecasting procedure of the NWS, for whom the specification equations of Klein (1982) were designed. In the case of the EOF-based specifications, the independent variables were the monthly coefficients of the first 10 EOF's; screening was not used. These 10 patterns ($\mathbf{H}_1$–$\mathbf{H}_{10}$) describe 85.7% of the total height variance over the domain of Fig. 1 during the winter months. As illustrated by the plots of $\mathbf{H}_1$–$\mathbf{H}_4$ in Fig. 2, the EOF's contain broad-scale features compatible with the scales of the anomalies associated with stationary/planetary waves of the winter season. For consistency with the pointwise specifications, the surface temperature anomaly of the previous month was used in place of $\mathbf{H}_{10}$ at those stations where T_{n-1} produced a greater reduction of variance than did $\mathbf{H}_{10}$.

It should be noted that EOF's show some sensitivity to the choice of the domain. In an alternative set of EOF's computed for the larger domain 30–70°N, 20°W–160°E, the Pacific/North American portions of $\mathbf{H}_2$ and $\mathbf{H}_3$ appeared in the third and second patterns, respectively. The second, third and fourth patterns contained strong features in the North Atlantic, and the described variance was distributed more evenly over the first 10 patterns.

3. Comparative results

Fig. 3 contains maps of the fraction of variance described by the two sets of specification equations based on the entire 101-month sample. The patterns of the described variance are similar in each case: the highest values are in the Southeast and the northern Great Plains, while the lowest values are in the interior of the Far West, the southern Plains and Rocky Mountain States, and the Northeast. It is apparent, however, that the equations obtained by the pointwise

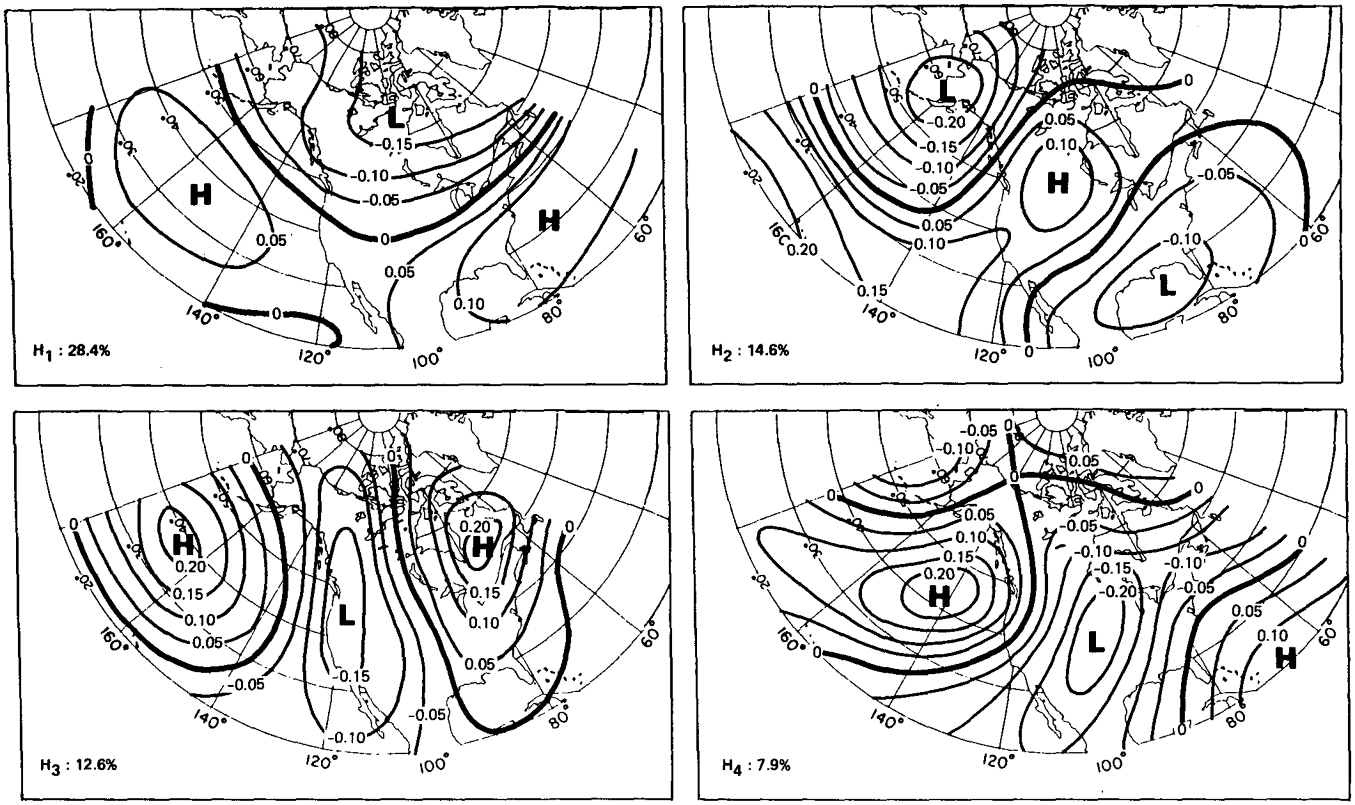

FIG. 2. The first four EOF's of 700 mb winter height based on normalized departures from mean for appropriate month and grid point. Numbers at lower left give the percent of height variance explained by each function (after Walsh *et al.*, 1982).

screening procedure describe about 10–20% more variance than do those based on the EOF coefficients.

Because a sample-derived variance fraction (ρ) is larger than the corresponding fraction (ρ_0) appropriate to the population, the results shown in Fig. 3 contain artificial components. The relationships between these two variance fractions take the form of the Wherry (1931) expression for shrinkage correction:

$$\rho = \rho_0 + \frac{M}{N-1}(1-\rho), \qquad (1)$$

where M is the number of predictors and N the sample size. [Derivations of expressions of this form are given by Davis (1976) and Lorenz (1977).] The EOF-based specifications are characterized by $M = 10$, $N = 101$, and $\rho \approx 0.50$–0.75. The artificial component of the described variance therefore ranges from 0.02 to 0.05. However, (1) cannot be applied directly to the results of the screening procedure because the number of predictors considered *a priori* is quite large, i.e., equal to the number of effectively independent grid points among 133. In order to address this problem of sample dependence in a manner consistent with both specification procedures, the total data set was partitioned into a 90-month developmental (dependent) sample (January 1948–December 1977) and an 11-month test (independent) sample (January 1978–February 1981). Specification equations obtained from the developmental sample were then applied to the independent sample. It can be shown (e.g., Davis, 1976) that ρ_0 is approximately midway between the corresponding fractions for the dependent and independent samples.

Use of the complete 101-month sample in the computation of the EOF's introduces a bias into the experiment. When used in an operational mode, EOF's calculated on a dependent data set would be used in specifications on an independent data set, over which they might be less representative of the spatial patterns. In this regard, the specification skill of the EOF's might be slightly overestimated in the following discussion.

The error statistics obtained from the independent sample for 37 stations are listed in Table 1, which also includes the error statistics for persistence and climatology. The results summarized in Table 1 are consistent with Fig. 3 insofar as the pointwise screening procedure outperforms the EOF-based procedure according to each error statistic. The largest discrepancy between the two sets of equations is in the fraction of described variance, (R^2), where screening improved on the EOF's by 15%. The smallest discrep-

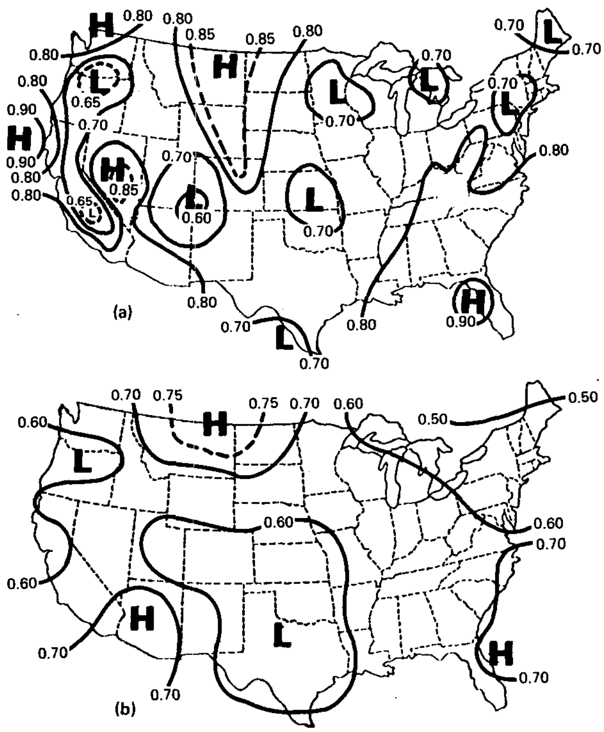

FIG. 3. Fractions of surface temperature variance of 101-month sample described by (a) specification equations derived by pointwise screening, and (b) EOF-based equations.

ancy is in the root-mean-square error, where screening was only 10% better than the EOF's. Both sets of equations clearly outperform persistence and climatology (last two lines).

The error statistics of the EOF-based equations were virtually identical when the experiment was repeated using 1) EOF's computed from non-normalized rather than normalized height anomalies, and 2) a larger set of 61 stations (rather than 37) for temperature and a larger domain for height. Likewise, the verification of the pointwise screening was little changed by using 98, 115 or 133 grid points, 37 or 109 stations, and between 5 and 10 variables in the multiple regression equations. The differences between the two procedures were also very similar when the previous station temperature T_{n-1} was omitted as a predictor and the regression equations were based on 10 heights only.

TABLE 1. Comparative verification of monthly temperature specifications tested on independent data sample of winter months, January 1978 through February 1981. Error statistics of climatology and persistence are also listed. All results are averaged over 11 months and 37 stations.

	Sign (percent correct)	Mean absolute error (°C)	Root-mean-square error (°C)	Square of correlation coefficient (R^2)
Pointwise screening	86.0	1.46	1.88	0.673
EOF equations	77.0	1.71	2.09	0.504
Persistence	70.1	2.28	2.87	0.297
Climatology	—	2.51	3.17	—

4. Conclusion

The results show that the pointwise screening procedure is clearly superior to the EOF-based procedure in the case of wintertime temperature specifications for the United States. While all specification equations used here contained 10 terms, the differences in the error statistics of Table 1 are sufficiently large that the conclusions are not changed by the retention (deletion) of several additional (fewer) terms.

The nature of the EOF representations suggests two possible explanations for the relative levels of skill of the two procedures. First, approximately 15% of the 700 mb height variance is not captured by the first 10 EOF's. Since a similar percentage of the variance will be missing at each grid point, approximately 15% of the variance that is exploited by the pointwise screening-derived equations will be unavailable to the EOF-based specifications. Second, and perhaps more importantly, the EOF's are constrained to maximize the described height variance over the entire domain, whereas pointwise regression selects only a few heights designed to maximize the temperature variance explained at specific cities. Because each surface temperature correlates poorly with heights in at least part of the domain, the pattern of spatial variability represented by each EOF contains some information irrelevant to the station temperature variability. For example, heights in large areas near Hudson and Baffin Bays are never selected in the pointwise screening equations. A reduction in the strength of the association with the station temperature is therefore inevitable.

Such shortcomings of the EOF-based specifications may ultimately be overcome by the use of procedures such as canonical correlation analysis, which would extract maximally correlated patterns of height and temperature. At any rate, the results presented here show that the pointwise screening procedure is consistently superior to the use of EOF-derived equations in the specification of surface temperatures from midtropospheric geopotential height fields during winter months.

Finally, the conclusions obtained here cannot necessarily be extrapolated to specifications based on *forecast* fields of 700 mb height. Since forecasts of 700 mb patterns and anomaly areas may be more successful than forecasts for individual points, EOF coefficients may be more predictable than grid-point anomalies. It is therefore conceivable that specifications based on EOF coefficients will show less degradation than those based on pointwise screening when the specifications are used in an operational forecasting mode. Similarly, the conclusions of this study cannot be directly extrapolated to other seasons and predictands. The spatial scatter of precipitation anomalies, for example, may have different impacts on the two specification procedures. Studies pertaining to specifications for other seasons and predictands are now underway or planned.

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