

MONTHLY OUTLOOKS FOR FIRE-WEATHER ELEMENTS IN THE CONTINENTAL UNITED STATES*

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Abstract

This paper describes a system for preparing monthly outlooks for fire-weather elements in the continental United States. The system is based on multiple regression equations that specify monthly mean anomalies of temperature, dewpoint, precipitation and wind speed from concurrent anomalies of the 700-mb height field plus local persistence. The equations are derived by applying a forward selection (screening) procedure, with cutoff criteria determined by Monte Carlo simulations and physical reasoning.

Averaged over all months, the equations explain 68% (72%) of the temperature variance in the contiguous United States (Alaska) by means of only four variables. The corresponding statistics for dewpoint are 57% (65%) and 3 terms, precipitation 41% (43%) and 3 terms, and wind speed 37% (32%) and 2 terms. Better results in Alaska (than in the lower 48 states) may be due to its higher latitude and greater proximity to water.

The equations were derived from a long period of observed 700-mb heights by assuming a perfect circulation forecast. In practice, however, they are applied to prognostic heights prepared monthly by the NOAA Climate Analysis Center and therefore suffer considerable loss of skill. We are now evaluating this loss by a detailed verification study that will allow the outlooks to be expressed in probability form.

1. Introduction

Recent papers by Klein and Whistler (1989, 1991) described a system for specifying monthly mean anomalies of the following fire-weather elements: daily precipitation frequency (P) and midday values of surface temperature (T), dewpoint (D) and wind speed (S) in the contiguous United States. The system utilizes a forward selection procedure of linear multiple regression called screening (Miller, 1962), with equations derived by the perfect prog method (Klein, 1982).

The specification equations described above are now being applied routinely by the United States Forest Service in

Riverside, California to prognostic monthly mean 700-mb height anomalies prepared twice a month by the Climate Analysis Center (CAC), National Weather Service, as explained by Fujioka and McCutchan (1989) and Fujioka et al. (1991). The resulting monthly outlooks are then used to compute nationwide maps of the fire-weather elements and the Burning Index (Chandler et al., 1983). These maps help the Forest Service to identify areas of potential fire danger and plan its fire-fighting activities. The outlooks can also be extended to a dense network of fire-weather stations by a method of spatial interpolation described by McCutchan and Chow (1991).

This paper expands the system described above from the lower 48 states to the 49th state of the United States; i.e., Alaska. Differences between the two systems are summarized in Table 1. Section 2 describes the data and method used in this paper. Section 3 illustrates some unusually good specification equations. Section 4 discusses seasonal and regional differences in the results. Section 5 compares overall results in Alaska with those for the lower 48 states and presents some skill scores for forecasts based on prognostic 700-mb heights.

2. Data

Figure 1 shows the network of 14(4) stations in Alaska for which 19(20) years of surface data were observed at approximately 1500 LST for T in °F, D in °F and S in knots. The period of record was July 1, 1969 to June 30, 1988 for the first 14 stations and January 1, 1964 to December 31, 1983 for four interior stations added later (FVU, BIG, TKA and GAL). The latter 20-year period is the same one we used previously for the lower 48 states. For each weather element, the daily afternoon observations were combined to obtain the individual mean for each month of each year (X) and the 19-year mean (normal) for each month (\bar{X}). The anomaly was then defined as: $X' = X - \bar{X}$ and used as the predictand (dependent variable) in this study. A similar system was used for P except that 24-hour amounts were examined to identify

Table 1. Characteristics of data used to derive monthly specification equations for midday anomalies of temperature, dewpoint and wind speed, as well as precipitation frequency (P), in the continental United States.

	Lower 48 States	Alaska
Period of record	20 yr: 1964–1983 (30 yr: 1951–1980, for P)	19 yr: 7/69–6/88 (1964–1983 for 4 stations)
700-mb heights	121 grid points every 5° lat. (79 points for P)	118 grid points every 10° lat. (5° lat. over Alaska)
Surface data	116 stations (11 added later) (60 climate divisions for P)	14 stations (4 added later) (17 for P)
Persistence predictors	Previous month's local value for all elements except P	Previous month's local value for all elements

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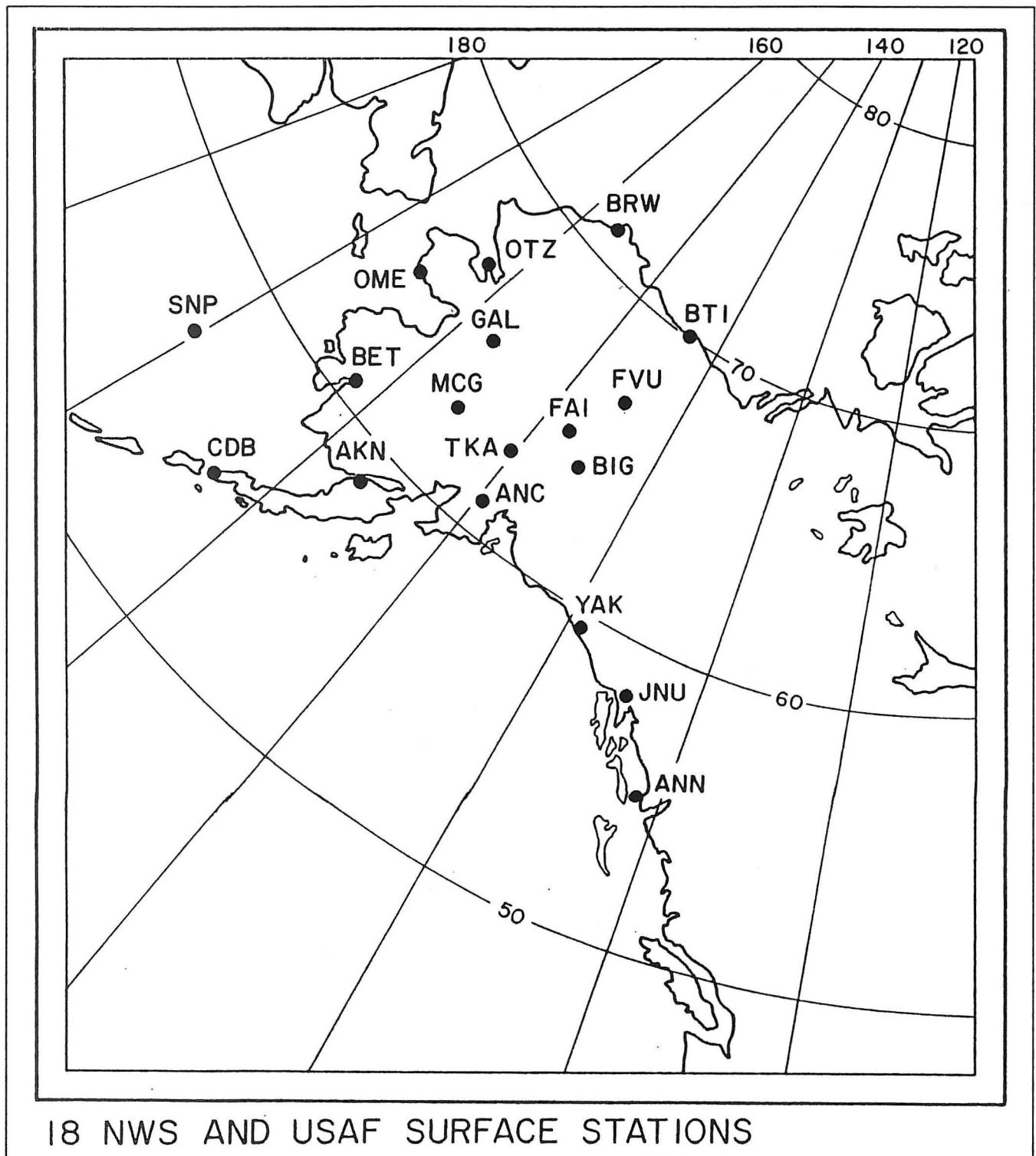


Fig. 1. Network and call letters of the 18 surface stations in Alaska used in this study.

the number of days per month with at least 2.54 mm. (0.10 in.) of precipitation.

The potential predictors were monthly mean 700-mb height anomalies (H) located at the network of 118 grid points illustrated in Figure 2, with all normals computed for the same 19–20 year period used for the predictand. This grid is shifted north and west of the 121-point grid used previously for the lower 48 states, and it has a higher resolution over Alaska

(every 5° latitude) than elsewhere (every 10° latitude). As before, all H predictors were concurrent with the predictand, the data for each month were pooled with data for its two adjacent months, and one additional predictor was offered to the screening program; namely the previous month's local observed anomaly of the weather element being specified. This procedure included P, whose persistence had not been considered previously because it was found to be negligible

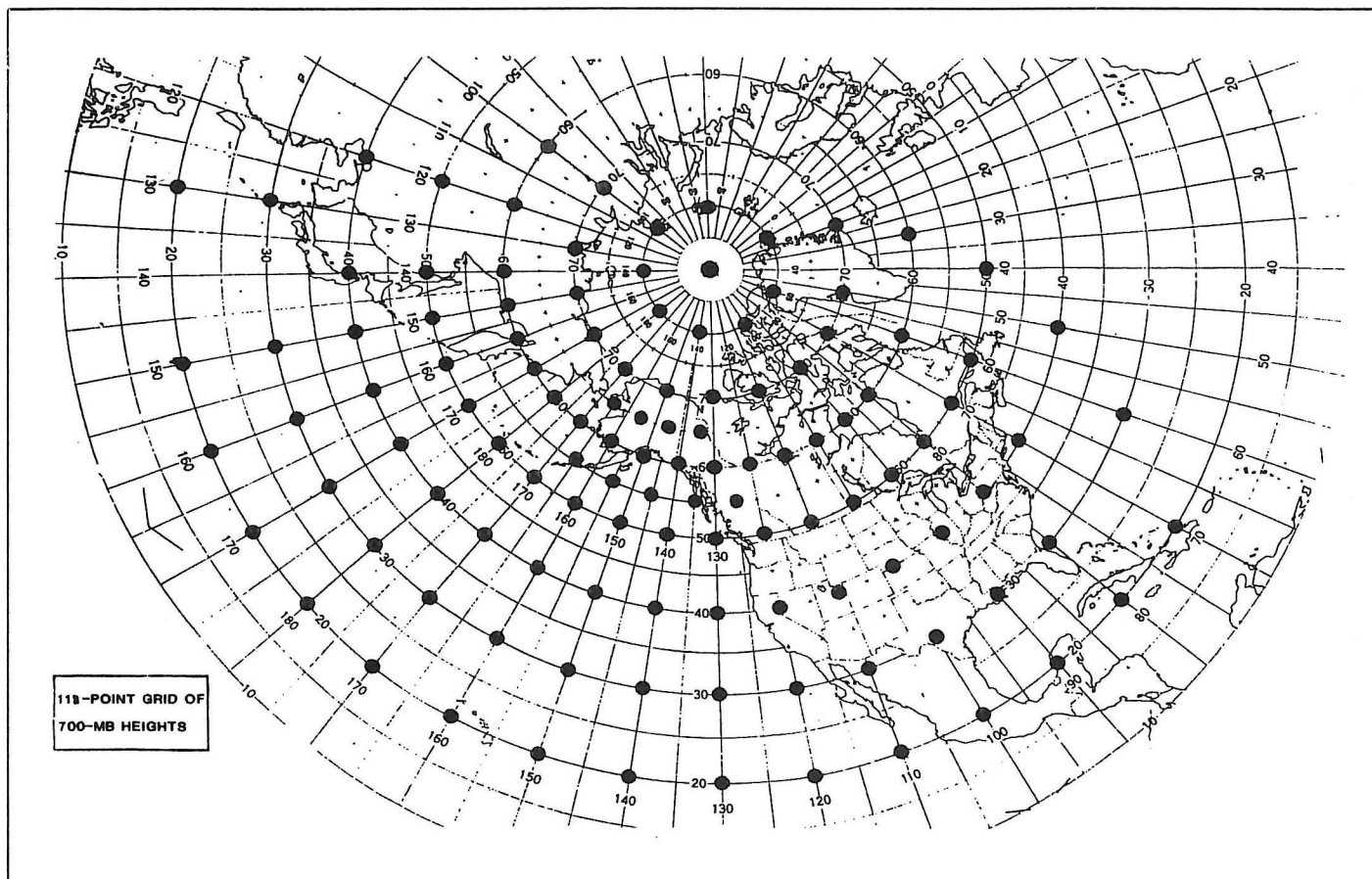


Fig. 2. Network of 118-grid points used to delineate the field of 700-mb heights.

in the lower 48 states by Klein and Bloom (1989). However, a recent study for California and Arizona river basins showed that P tended to persist during the winter and early spring months (Klein and Bloom, 1992) and therefore might be worth including as a potential predictor. In addition, P was now taken at single stations, instead of 60 climate divisions (Englehart and Douglas, 1985) as used in the lower 48, because no climate division data were available in Alaska. Additional details about the data in Alaska and the contiguous United States are given in Table 1.

3. Specification Equations

The statistics involved in selecting a specification equation for temperature in January are illustrated for Annette in

southeast Alaska in Table 2. The first predictor selected is the 700-mb height anomaly at 50°N , 110°W , about 1500 km southeast of Annette, which by itself explains almost 74% of the temperature variance (RV). The positive sign of its regression coefficient reflects the tendency for the troposphere to be equivalent barotropic (Charney 1949). The second H selected, at 60°N , 170°W , about 2500 km northwest of Annette, adds almost 12% to the cumulative RV. Its location and negative regression coefficient indicate the importance of the upstream ridge in controlling the deployment of cold air southeastward (Namias, 1953). The third predictor selected, T for the previous month, adds over 3% to the RV and illustrates the importance of month-to-month temperature persistence, especially in coastal regions (Van den Dool et al., 1986). The selection procedure was terminated at this

Table 2. Summary of the stepwise regression statistics obtained by screening monthly mean anomalies of midday temperature at Annette, Alaska (55°N , 132°W) during December, January and February as a function of the concurrent field of 700-mb height anomalies, plus the previous month's temperature anomaly. The critical F-values were determined by a Monte Carlo procedure. The final equation selected for use in specification is starred.

Step	Grid point for height	Reg. coeff. on entry	Added RV(%)	Total RV(%)	Classical F-value	Prob. level(%)	Critical F-value
1	50°N , 110°W	+0.098	73.8	73.8	154.6	100.0	9.9
2	60°N , 170°W	-0.026	11.7	85.5	43.4	100.0	6.9
3*	Prev. Temp.	+0.188	3.4	88.9	16.3	99.9	5.6
4	60°N , 100°E	+0.011	1.2	90.1	6.5	98.6	5.1
5	20°N , 100°W	-0.044	0.7	90.8	3.9	94.7	4.7

Table 3. Summary of the stepwise regression statistics obtained by screening monthly mean anomalies of daily precipitation frequency in Yakutat, Alaska (60°N, 140° W) during December, January and February as a function of the concurrent field of 700-mb height anomalies. The critical F-values were determined by a Monte Carlo procedure. The final equation selected for use in specification is starred.

Step	Grid point for height	Reg. coeff. on entry	Added RV(%)	Total RV(%)	Classical F-value	Prob. level(%)	Critical F-value
1	60°N, 160°W	-0.079	69.9	69.9	127.6	100.0	9.9
2	50°N, 130°W	+0.039	9.8	79.7	26.2	100.0	6.9
3*	70°N, 150°W	-0.027	3.1	82.8	9.7	99.7	5.6
4	20°N, 100°W	-0.084	1.5	84.4	5.1	97.2	5.1
5	40°N, 100°W	+0.030	1.7	86.0	6.2	98.4	4.7

point because the next two variables selected either did not make good synoptic sense or did not have an F-statistic significant at the true 5% level (determined by a Monte Carlo simulation). It is noteworthy that the final RV of 89% is higher than that obtained for any other month, element or station anywhere in the continental United States! However, the physical interpretation of this equation is similar to that used previously for specification equations for monthly mean temperature in Alaska (Klein, 1985a).

Sample statistics for precipitation frequency are illustrated for January at Yakutat (on the southeast coast of Alaska) in Table 3. The first H selected has an RV of 70%, a negative regression coefficient and a location to the west of the station. The second height adds 10% to the cumulative RV, has a positive regression coefficient and is located southeast of Yakutat. The third H adds 3% to the RV, has a negative regression coefficient and is northwest of the station. These results indicate that high (low) values of P are favored by anomalous flow of moist (dry) air from the southwest (northeast). The selection process was stopped at this point, with 83% of the variance explained by only three terms, because no other predictor could add even 2% to the RV. This is the highest RV for P obtained for any month or station in Alaska or the lower 48 states. Moreover, the equation resembles one for monthly precipitation amount in northern California discussed by Klein and Bloom (1989).

The highest RV obtained for dewpoint anywhere in the continental United States during any month of the year is 87% in December for Nome, located on the east coast of the Bering Sea. The relevant statistics, listed in Table 4, show that the final equation selected contains four heights. The first and third are located east of Nome with positive regression coefficients; the second and fourth to its west with negative coefficients. This indicates that high (low) values of D are favored by anomalous southerly (northerly) flow of moist (dry) air between a trough (ridge) to the west and a ridge

(trough) to the east of Nome. Note that each term of this equation is statistically significant, makes good synoptic sense and adds at least 5% to the total RV.

4. Seasonal And Regional Differences

The annual cycle of RV for each weather element is plotted in Fig. 3, where each month's value is the average of the first 14 stations of Fig. 1. Values generally tend to be highest in winter months and lowest in spring and summer. During each month, the mean RV is greatest for T, second largest for D, third highest for P and lowest for S. The difference between T and D is very small in winter, when both elements are well specified by the large scale 700-mb circulation. The difference is largest in May, when D is poorly specified because of its sensitivity to boundary and small scale phenomena. We found similar results for the lower 48 states, but the minimum for D occurred in July rather than May.

In order to study the geographical distribution of the RV at the 18 stations of Fig. 1, maps were prepared separately for each element and month, as well as for the annual mean. The latter is illustrated for D in Figure 4. A distinct minimum (<50%) appears over north-central Alaska, with maxima (>70%) along west and south coasts. This pattern is remarkably constant during the course of the year, but with highest values in December and lowest in May. The annual mean for S (Fig. 5) is also characterized by a well-defined minimum (<25%) in north-central Alaska, flanked by maxima (>40%) over northwest and southeast parts of Alaska.

Seasonal differences in the pattern of RV for any element were greatest for T. This is illustrated by comparing Figure 6 for January with Figure 7 for July. The January map contains a low center in the northern interior basin, probably because of radiational cooling over snow cover. Values increase rapidly towards all coasts, with a maximum of 90% in southeast Alaska. In July, the RV pattern tends to reverse,

Table 4. Summary of the stepwise regression statistics obtained by screening monthly mean anomalies of midday dewpoint at Nome, Alaska (64°N, 165° W) during November, December and January as a function of the concurrent field of 700-mb height anomalies, plus the previous month's dewpoint anomaly. The critical F-values were determined by a Monte Carlo procedure. The final equation selected for use in specification is starred.

Step	Grid point for height	Reg. coeff. on entry	Added RV(%)	Total RV(%)	Classical F-value	Prob. level(%)	Critical F-value
1	60°N, 130°W	+0.155	57.4	57.4	74.2	100.0	9.9
2	60°N, 160°E	-0.073	17.5	74.9	37.5	100.0	6.9
3	65°N, 145°W	+0.074	7.3	82.1	21.5	100.0	5.6
4*	40°N, 170°E	-0.053	5.1	87.2	20.5	100.0	5.1
5	30°N, 150°W	+0.061	2.5	89.7	12.2	99.9	4.7

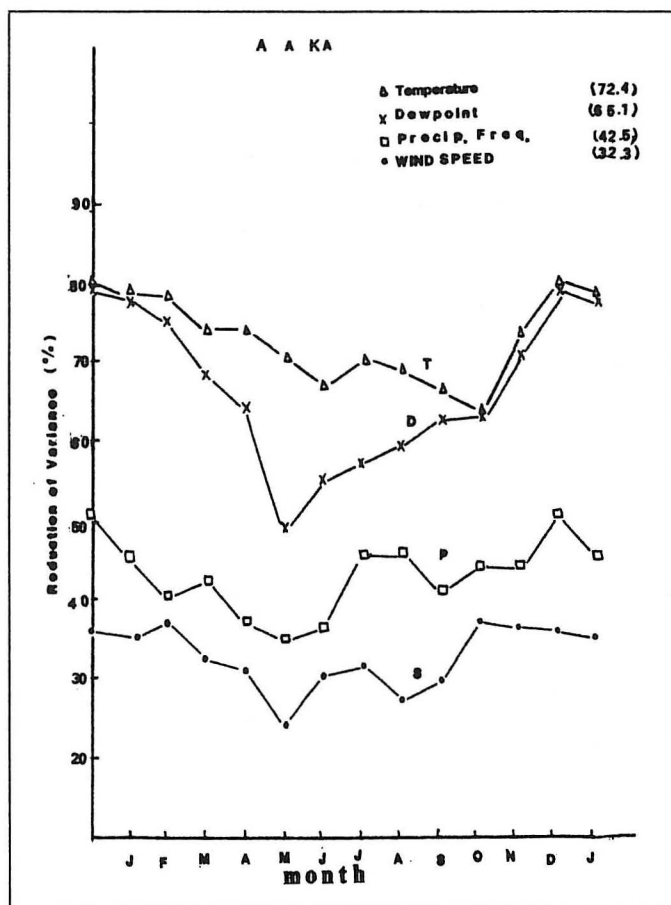


Fig. 3. Percent of variance explained by monthly specification equations for temperature, dewpoint, precipitation frequency and wind speed, averaged over the first 14 stations in Alaska. Numbers in upper right give annual averages for each element.

with higher values inland under steep lapse rates and lower values along the coasts, where fog and low stratus clouds may decouple the surface from 700 mb. Similar behavior was noted for monthly mean temperature in California by Klein (1985b).

5. Conclusion

Table 5 summarizes mean annual values of both RV and number of variables (steps) in the specification equations for each element. The first line presents values averaged over the first 14 stations in Alaska (A), the second line gives

averages for the first 116 stations in the lower 48 states (L) obtained previously, and the bottom line shows the difference: A-L. The relative rank of the elements is the same for both regions; namely, T, D, P and S. However, both T and D exhibit higher RV in Alaska for the same number of steps, while P has slightly higher RV for less steps. Only S gives poorer results in Alaska. The superior performance of T, D and P in Alaska (compared to the lower 48 states) may be due to its higher latitude and greater proximity to water, while its poorer results for S may be due to more mountainous terrain. On an overall basis, the specification equations in Alaska (lower 48) explained approximately 72% (68%) of the temperature variance, 65% (57%) of the dewpoint variance, 43% (41%) of the precipitation variance, and 32% (37%) of the wind speed variance by means of 2-4 variables.

Of course, the numbers above will be reduced considerably when the equations are applied to imperfect values of monthly mean 700-mb heights forecast routinely by CAC. We are now evaluating this loss of skill by a detailed verification study for the lower 48 states, based upon the CAC prognostic values of H for the 18-year period: 1973-1990 (Klein and Charney, 1991). For all stations and months, application of the equations to these "imperfect" specifications gave 2-class skill scores of 17 for T, 16 for D, and 13 for W. When 5 classes were considered, skill scores dropped by about 45% to values of 9, 9, and 7 for T, D, and W, respectively. In addition, for all elements and stratifications, the scores were higher when data from the last seven years (1984-1990) only were used for the evaluation. This is most likely a reflection of the increased skill of the CAC prognoses during recent years. Although a comparable test has not yet been performed for P, similar results were obtained for specification of monthly precipitation amounts in the lower 48 states in an operational test described by Klein and Bloom (1989). Thus the specification equations used in a forecast mode show a small but consistent improvement over climatology or a random guess for all weather elements tested thus far in the contiguous United States. We expect that similar results will be obtained in Alaska.

Acknowledgments

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Table 5. Mean annual reduction of variance (RV in %) and number of variables (Step) in specification equations for monthly mean anomalies of surface temperature, dewpoint, precipitation frequency and wind speed in the continental United States. RVs and steps were averaged over 12 months of the year, for 14 stations in Alaska and 116 stations in the lower 48 states.

Area	Temp.		Dewpoint		Precip. freq.		Wind Speed	
	RV	Step	RV	Step	RV	Step	RV	Step
Alaska	72.4	3.5	65.1	3.1	42.5	2.6	32.3	2.1
Lower 48	67.7	3.5	56.5	3.1	41.4	2.8	37.2	2.4
A-L	4.7	0	8.6	0	1.1	-0.2	-4.9	-0.3

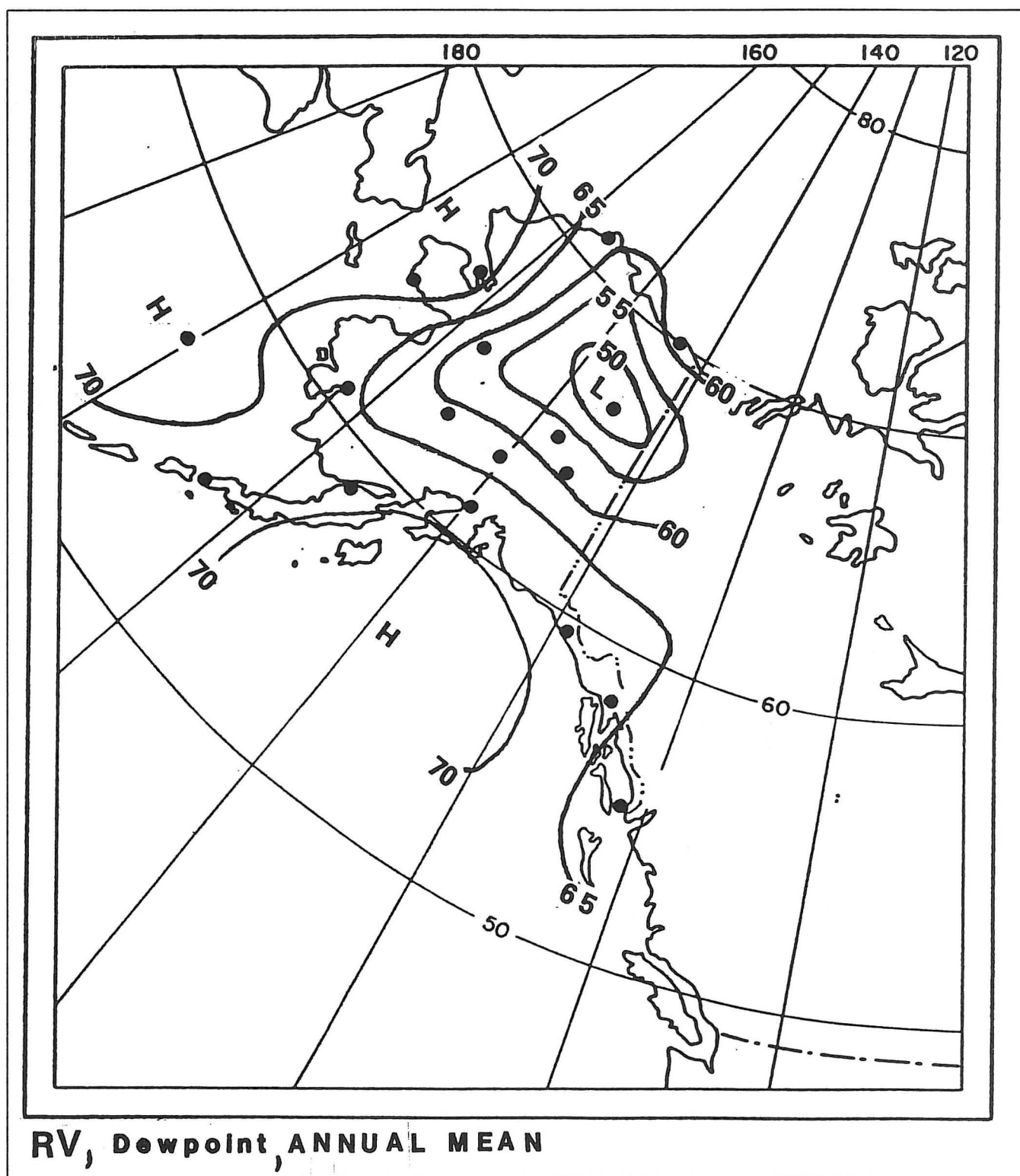


Fig. 4. Spatial distribution of percent explained variance for afternoon dewpoint at 18 stations in Alaska, averaged over all 12 months of the year.

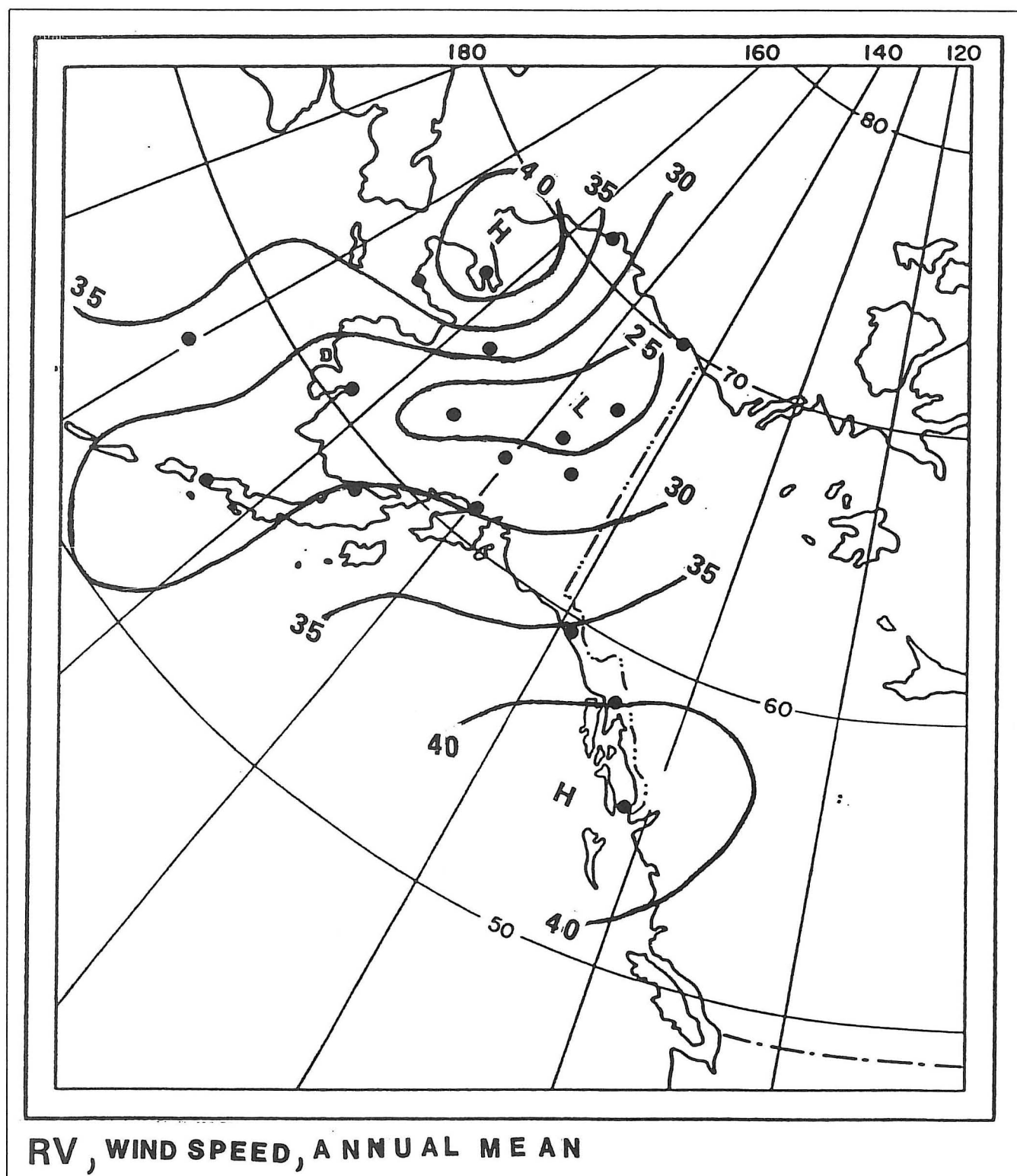


Fig. 5. Same as Figure 4 but for wind speed.

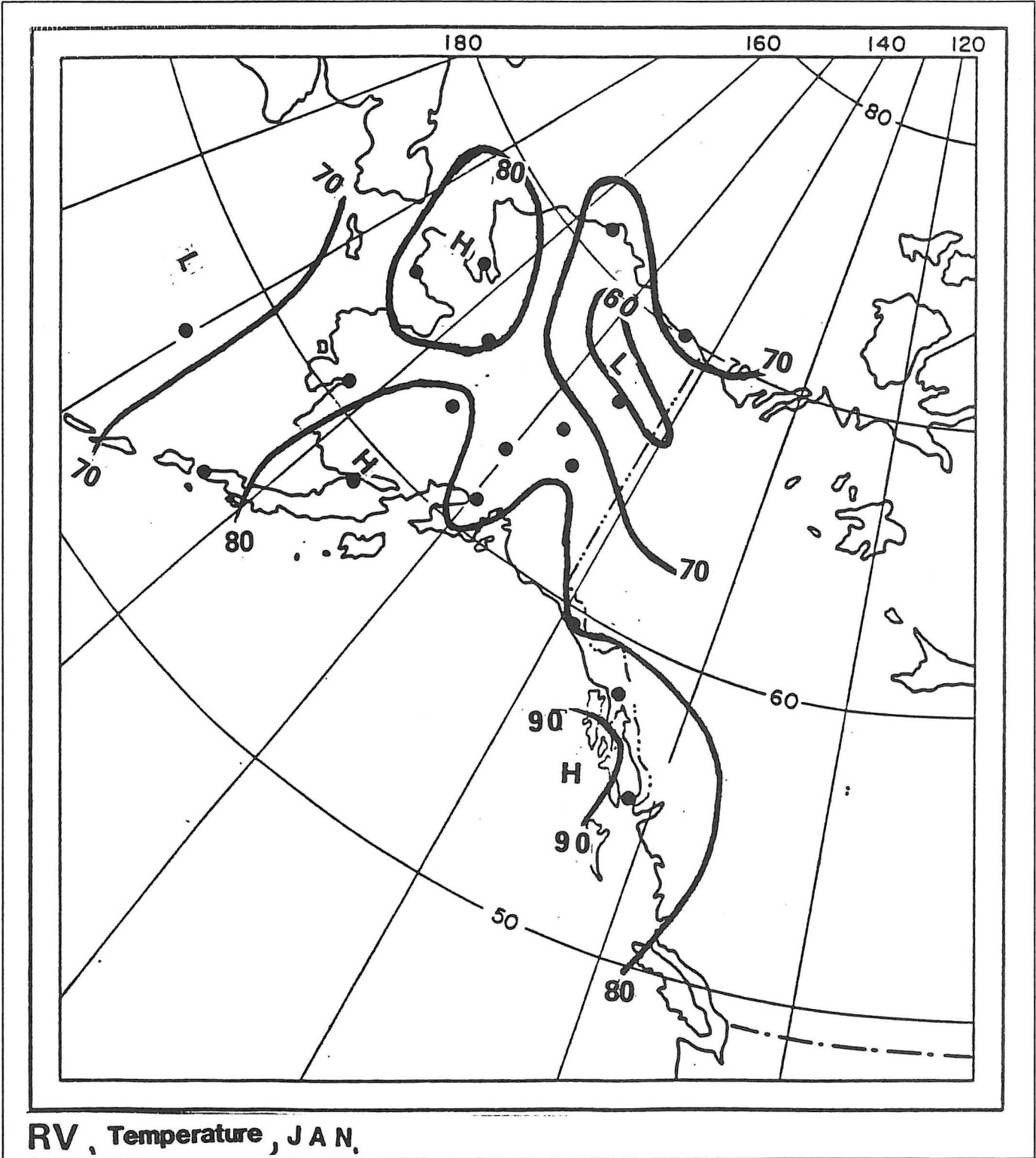
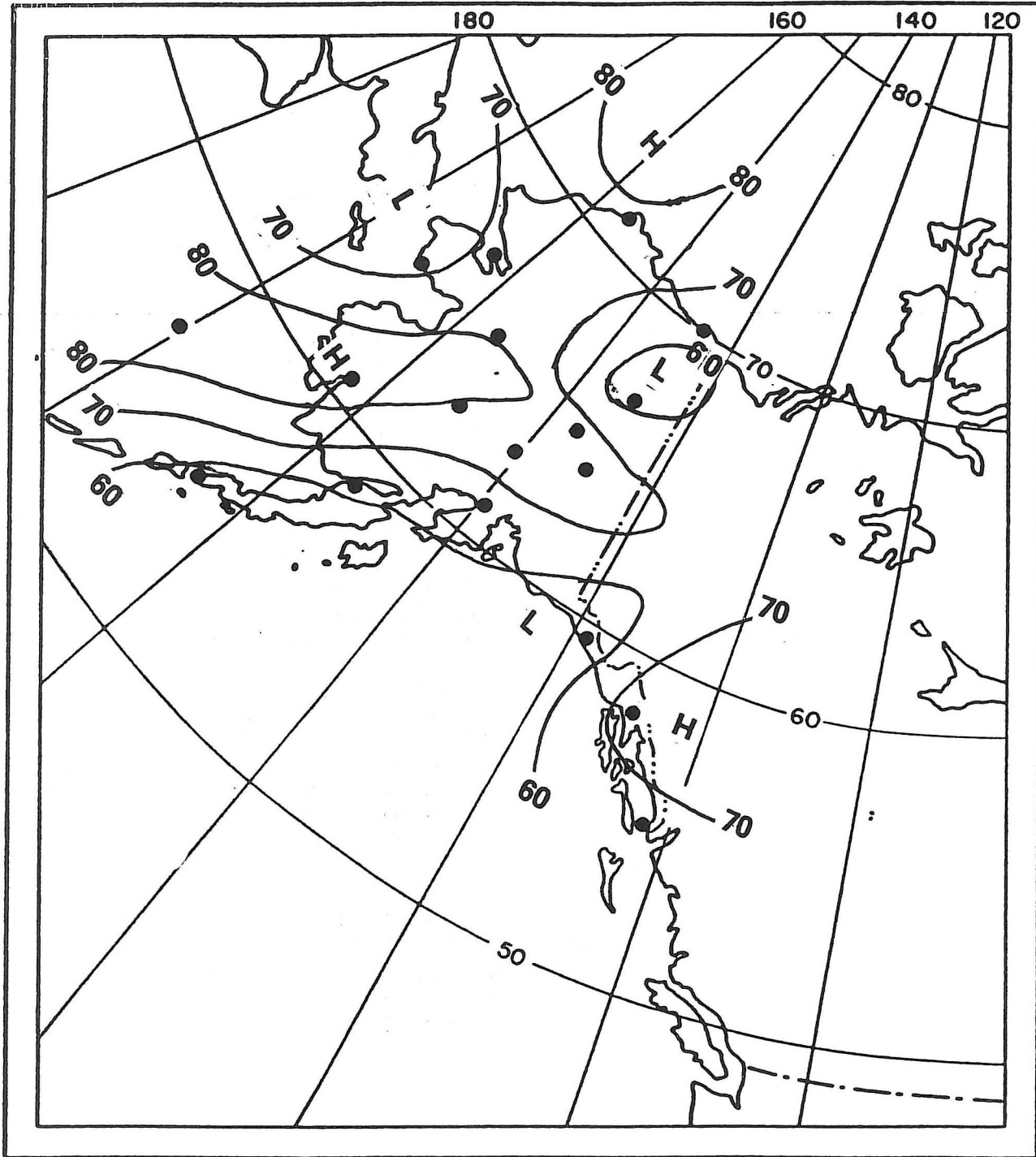


Fig. 6. Spatial distribution of percent explained variance during winter months for mean afternoon temperature at 18 stations in Alaska.



RV , Temperature , JUL,

Fig. 7 Same as Figure 6 except for summer.

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