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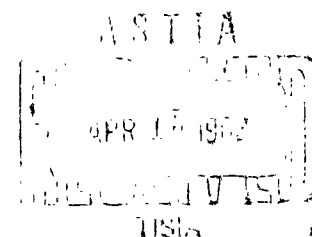
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FORECASTING
the MOVEMENT and INTENSIFICATION
of CYCLONES and ANTICYCLONES
over EUROPE and ASIA

MARCH 1963
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THE TRAVELERS RESEARCH CENTER INC.

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FORECASTING THE MOVEMENT AND INTENSIFICATION
OF CYCLONES AND ANTICYCLONES
OVER EUROPE AND ASIA

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March 1963
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Multiple linear-regression prediction equations have been derived for the winter-time 12-, 24-, and 36-hr displacements and changes in central pressure of cyclones and anticyclones over Europe and cyclones over Asia. An important feature of the statistical prediction technique used in developing the equations is that the coordinates of measurement accompany the cyclone or anticyclone. The equations were tested on sizable independent data samples and found to be stable; limited comparative-accuracy tests indicate that their results are competitive with those obtained by experienced subjective forecasters.

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1.0 INTRODUCTION

Predicting the behavior of significant features in the distribution of surface pressure, such as cyclones, anticyclones, fronts, ridges (high pressure), and troughs (low pressure), is an important step in the preparation of a weather forecast. Gross significant features like these have drawn attention because their initial configuration and their subsequent movement and intensification (or dissipation) permit a reasonably accurate sequential specification of the weather at stations along their paths. These relationships have long been regarded as primarily qualitative. Their quantitative study, which is urgently needed, can lead to new characteristics that should be predicted or to new significant features that are rich in weather-predictive information.

Formulating the problem of predicting the distribution of surface pressure in terms of the behavior of significant features permits two important departures from the customary statistical formulation, in which predictors for a given gridpoint pressure or array of gridpoint pressures are defined as observations in a fixed-coordinate system [6]. First, it permits the minimization of the errors (in a least-squares sense) of more meaningful parameters than simply the pressure at a gridpoint. Second, it permits the introduction of a type of nonlinearity in the predictor-predictand relationships. Consider, for example, the extension of this approach to the derivation of equations for forecasting the behavior of a large number of significant features. The forecasts can be combined by methods analogous to those used in objective weather analysis to yield a prediction of the surface pressure at an array of gridpoints. The predicted pressure at any gridpoint is a function of the synoptic situation; that is, predictors affecting the pressure at the gridpoint stem from the location and type of significant features present at the initial time of the forecast period.

In the work described here, the cyclone (defined as having at least one closed isobar) was chosen as the primary feature for study. Partly because of its association with cloudiness and precipitation, the cyclone has been under investigation by meteorologists since the advent of synoptic maps. The anticyclone (likewise defined as having at least one closed isobar) was also studied. Earlier work on the problem of predicting the movement and intensification of cyclones over the eastern United States by statistical methods

[12] proved promising enough to warrant the extension of such an approach to other geographical areas. Accordingly, Europe and eastern Asia were selected as regions for technique development.

2.0 DESIGN OF THE STUDIES

2.1 Areas Studied

Regression equations for predicting the wintertime (November–March) behavior of cyclones were derived separately for Europe and eastern Asia and for each of the zones defined in Fig. 2-1. Anticyclones were examined also, and equations were derived for Europe; the "winter season" was extended to include October and April so that there would be enough cases to test.

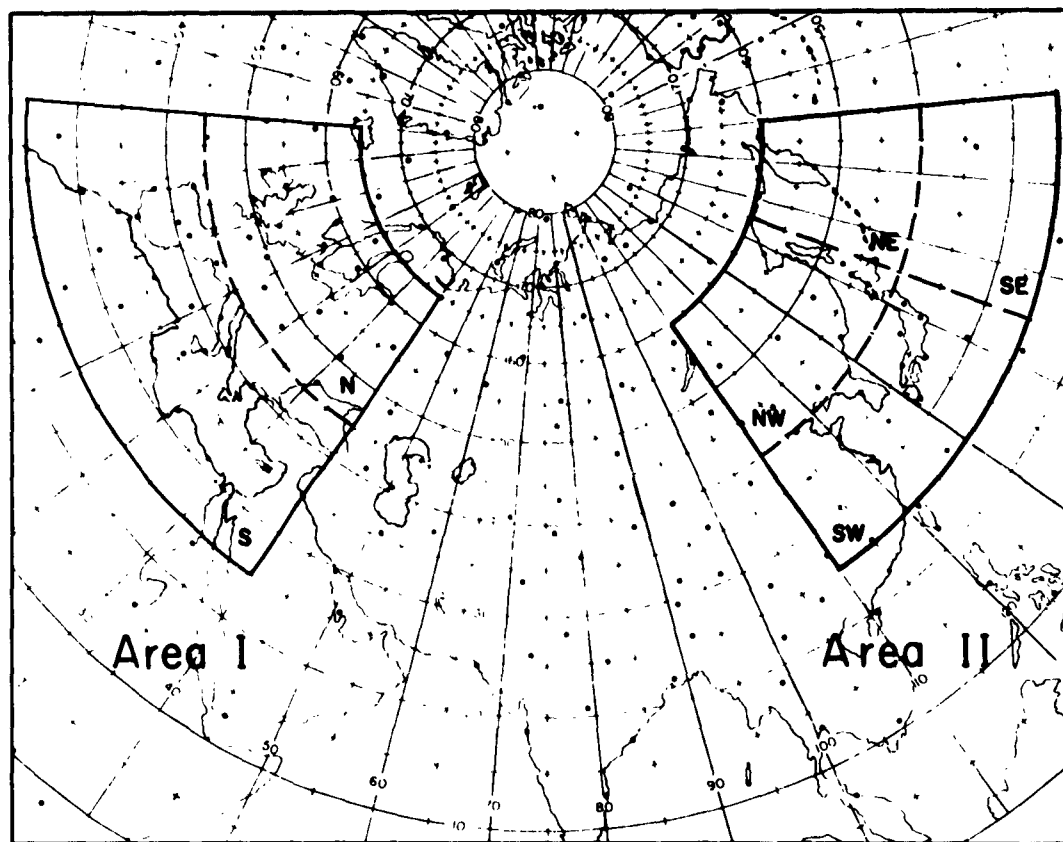


Fig. 2-1. Areas for which cyclones and anticyclones were predicted. Area I (Europe) is divided into two zones (northern and southern) by latitude 45°N . Area II (Asia) is divided into four zones (northwestern, northeastern, southwestern, and southeastern) by latitude 40°N and longitude 145°E .

TABLE 2-1
SELECTED WINTER CYCLONES AND ANTICYCLONES OVER EUROPE AND ASIA,
1955-1960

Area*	Zone	No. of cyclones			No. of anticyclones		
		1955-1959†	1959-1960‡	1955-1960	1955-1959†	1959-1960‡	1955-1960
I Europe§	N	402	121	523	-	-	-
	S	318	82	400	-	-	-
	Both	720	203	923	658	106	764
II Asia§	NW	266	72	338	-	-	-
	NE	433	118	551	-	-	-
	SW	196	39	235	-	-	-
	SE	196	37	233	-	-	-
	All	1091	266	1357	-	-	-

*See Fig. 2-1.

†Dependent sample.

‡Independent sample.

§Dividing line between zones is 45°N.

§Dividing lines between zones are 40°N and 145°E.

2.2 Selection of Cases

Table 2-1 shows the number of cyclones and anticyclones selected for each of the zones of Fig. 2-1. The cyclones were selected by examining all the 0000- and 1200-GCT surface charts** for the winters (November-March) of 1955-1956 through 1959-1960. A cyclone was accepted if it retained its identity for at least 36 hours. European anticyclones were selected in the same way except that the "winter season" was extended to include October and April to provide a large enough sample.

The samples of cyclones and anticyclones selected for the winters of 1955-1956 through 1958-1959 were designated as the dependent samples and were used in deriving the equations. The samples for the winter of 1959-1960 were designated as the independent samples and were used to test the equations.

**Microfilm copies of surface maps, analyzed by the National Weather Analysis Center, were used. From these it was possible to construct maps showing individual cyclone and anticyclone tracks at 12-hr intervals, which served as the basis for selection.

TABLE 2-2
PREDICTANDS

Class	Symbol	Unit of measurement
Northward displacement	$\hat{N}$	deg. lat.
Eastward displacement	$\hat{E}$	deg. lat.
Change in central pressure	$\hat{D}$	mb

2.3 Predictands

Latitudinal displacement, longitudinal displacement, and change in central pressure, for 12, 24, and 36 hr, were chosen as predictands (Table 2-2) for both the cyclone and anticyclone equations. The same National Weather Analysis Center maps used to select the cases (see Sec. 2.2) were used as the source of predictand data.

2.4 Predictors Considered

System 433L hemispheric-data tapes [8] were used as the basic source of predictor data. Special preprocessing programs (see App. A) automatically derived gridpoint arrays of the various pressure, height, and thickness data for each cyclone and anticyclone in the developmental sample, yielding altogether six grid arrays of 221 points each, or about 1300 potential predictors.

To comply with the maximum of 200 possible predictors acceptable by the screening-regression program (see Sec. 2.6), a preliminary reduction in the number of predictors was made subjectively by increasing the spacing between gridpoints. Due to the spatial redundancy of the meteorological information under consideration, this hypothetically lost very little of the predictive information contained in the original set of data.

Table 2-3 lists the possible predictors that remained. There are two categories: one includes both surface and upper-air predictors in combination, and the other includes surface predictors only. No attempt was made to incorporate so-called derived predictors (vorticity, vorticity advection, etc.) because a previous feasibility test involving such predictors [12] did not demonstrate significant improvement over simply using point-value

TABLE 2-3
POSSIBLE PREDICTORS

Class	Symbol	Unit of measurement	No. of predictors	
			Including upper-air data	Excluding upper-air data
Sea-level pressure	P	mb	35	84
12-hr sea-level pressure change	ΔP	mb	34	84
500-mb height	Z	10 ft	41	-
12-hr 500-mb height change	ΔZ	10 ft	40	-
1000-500-mb thickness	H	10 ft	24	-
12-hr 1000-500-mb thickness change	ΔH	10 ft	24	-
Present latitude of cyclone	ϕ	deg. lat.	1	1
Present longitude of cyclone	λ	deg. long.*	1	1
Total			200	170

*Positive for W long., negative for E long.

predictors, although only a thorough investigation could support any contention that derived predictors contain no independent predictive information.

2.5 The Moving-coordinate Grid

The grid for extracting predictor information accompanies the feature as it moves, so variables are measured at constant positions relative to its center. The grid is shown in Fig. 2-2. The gridpoint defined by the (k, l) -location (10, 5) is placed at the center of the feature, and the grid is oriented so that the line $k = 10$ coincides with the meridian passing through the center of the feature. In practice, grid placement and data tabulation are done by computer programs, and "analyzed maps" are on magnetic tape. On a polar stereographic projection with standard parallel at 60°N, the 17×13 array forms a set of evenly spaced points. On a map scale of 1:15,000,000, the grid interval is 1 in. This is the same interval as in the JNWP grid [2, Fig. 1]. At 60°N, where the scale is true, one grid interval equals 381 km. The 221 points defined by this grid system were the ones

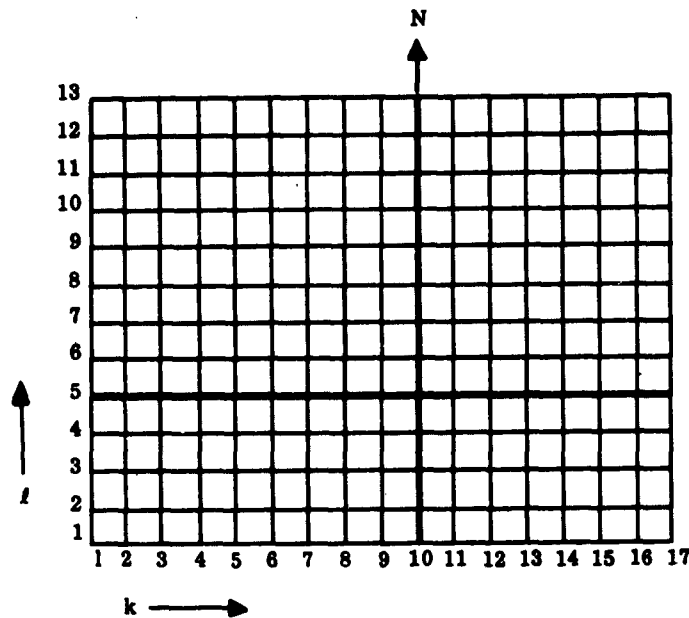


Fig. 2-2. Moving-coordinate grid overlay. Gridpoint (10, 5) in the (k, l) -array is always positioned at the center of the cyclone or anticyclone, and the grid is always oriented so that the line $k = 10$ coincides with the meridian passing through the center of the feature. One grid interval equals one JNWP grid interval (381 km at 60°N).

used for predictor tabulation by superimposing the grid on analyzed maps of sea-level pressure and 500-mb height.

An important preliminary step in the preparation of the data for the prediction experiments was a systematic machine-man search for and correction of gross errors. Suspicious gridpoint values of parameters were identified by a series of tests performed by the IBM 7090, and listings of these values were compared with microfilm copies of manuscript maps; where necessary, corrections were made to the data filed on magnetic tapes. The details of the computer programs, data-handling procedures, and error-checking procedures are given in Appendix A.

2.6 Screening-regression Technique

The screening procedure suggested by Bryan [1] and developed for the IBM 704 electronic computer by Miller [5, 7] was used to screen the possible predictors identified

in Table 2-3. One who designs a statistical prediction experiment likes invariably to consider all predictors deemed important on the basis of previous theoretical, synoptic, and empirical work (in this case, all those listed in Table 2-3), but, as Lorenz [4] points out, a prediction equation should contain few predictors in comparison with the size of the developmental sample; if there are too many, a relationship that fits the sample used to establish it is likely to fail when applied to a new sample. The object of the screening procedure is to select from a set of possible predictors the subset that contributes most significantly and independently to reducing the variance of the predictand.

From an array of possible predictors, the screening procedure selects first the one that has the highest linear correlation with the predictand in question. This predictor is then held constant, and partial-correlation coefficients between the predictand and each of the remaining predictors are examined; the predictor now associated with the highest coefficient is the second one selected. Additional predictors are chosen similarly until a selected predictor fails to explain a significant additional percentage of the remaining variance of the predictand.

The criterion of significance as applied to the screening procedure is not clear cut since the usual F-test methods (e.g., [10]) are not applicable [7]. If a predictor is chosen at random from a group of predictors, an F-test is usually taken at the 95% level; this allows for a 1-in-20 chance of considering the predictor significant when in fact it is not. Because the screening procedure does not select predictors randomly, a more severe test is needed to specify a 1-in-20 chance. For his screening procedure, Miller suggested [7] that the critical F-value be a function of the number of possible predictors. The F-test was used in this form in these experiments.

3.0 RESULTS

Preparatory to deriving prediction equations for cyclones or anticyclones, the climatological characteristics of these features and the atmospheric variables believed to be related to them were computed as an aid for suggesting possible predictors to be used in the screening-regression program. Also of interest was a determination of the difference in characteristics for different regions of the same area to assess the desirability of stratifying the data sample. Accordingly, the means and standard deviations of all predictands and possible predictors were computed both for entire areas (unstratified) and for regions within areas (stratified). Some of these characteristics are discussed in the sections that follow, in addition to the results obtained by the regression analysis.

The prediction equations are given in Appendix B.

3.1 European Cyclones

Europe (area I of Fig. 2-1) was divided by latitude 45°N into two zones on the basis of charts of principal tracks of cyclones and their frequencies described by Klein [3], which indicate separate maxima of cyclone activity and different behavior over northern Europe and in the Mediterranean area. The main purpose of the stratification was to attempt to account for differences in predictor-predictand relationships that may be present between one geographical zone and another. The need for stratification is not always clear cut. For example, it is possible that one or more of the predictors themselves may be able to express such differences, making stratification unnecessary.

3.1.1 Synoptic Climatology

Table 3-1 contains the means and standard deviations of the northward and eastward displacements and changes in central pressure of 720 cyclones for 12, 24 and 36 hr. This information is also shown graphically in Fig. 3-1. The mean tracks were constructed by simply connecting the mean displacements for the three time periods of interest. Note that the mean track for both northern- and southern-zone cyclones is toward the east-northeast but that the speed of the northern cyclones (about 15 knots) is slightly greater than that of the southern cyclones (about 12 knots). Both samples exhibit filling characteristics in contrast to the deepening tendencies of cyclones in, say, the eastern United States.

TABLE 3-1
CHARACTERISTICS OF WINTER CYCLONES OVER EUROPE,
1955-1959 (DEPENDENT SAMPLE)

Zone	Forecast interval, hr	Observed northward displacement, deg. lat.		Observed eastward displacement, deg. lat.		Observed change in central pressure, mb	
		Mean	Std. dev.	Mean	Std. dev.	Mean*	Std. dev.
N	12	0.37	2.39	-3.22	2.49	-0.09	5.82
	24	1.08	4.00	-6.02	4.13	1.51	8.70
	36	1.98	5.27	-8.71	5.68	3.74	10.08
S	12	0.40	2.09	-2.38	2.13	-0.24	3.99
	24	0.85	3.15	-4.77	3.48	0.66	5.46
	36	1.32	4.04	-6.94	4.76	2.14	6.62
Both	12	0.38	2.26	-2.85	2.38	-0.16	5.10
	24	0.98	3.65	-5.47	3.91	1.14	7.46
	36	1.69	4.78	-7.93	5.36	3.03	9.21

*Negative values represent deepening.

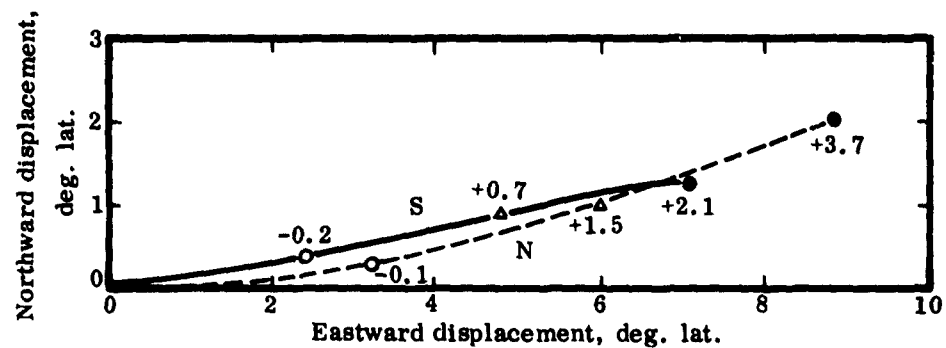


Fig. 3-1. Mean tracks of winter cyclones in Europe by zone, 1955-1959 (dependent sample). ○ 12-hr displacement; △ 24-hr displacement; ● 36-hr displacement. Value adjacent to symbol refers to mean change in central pressure (millibars).

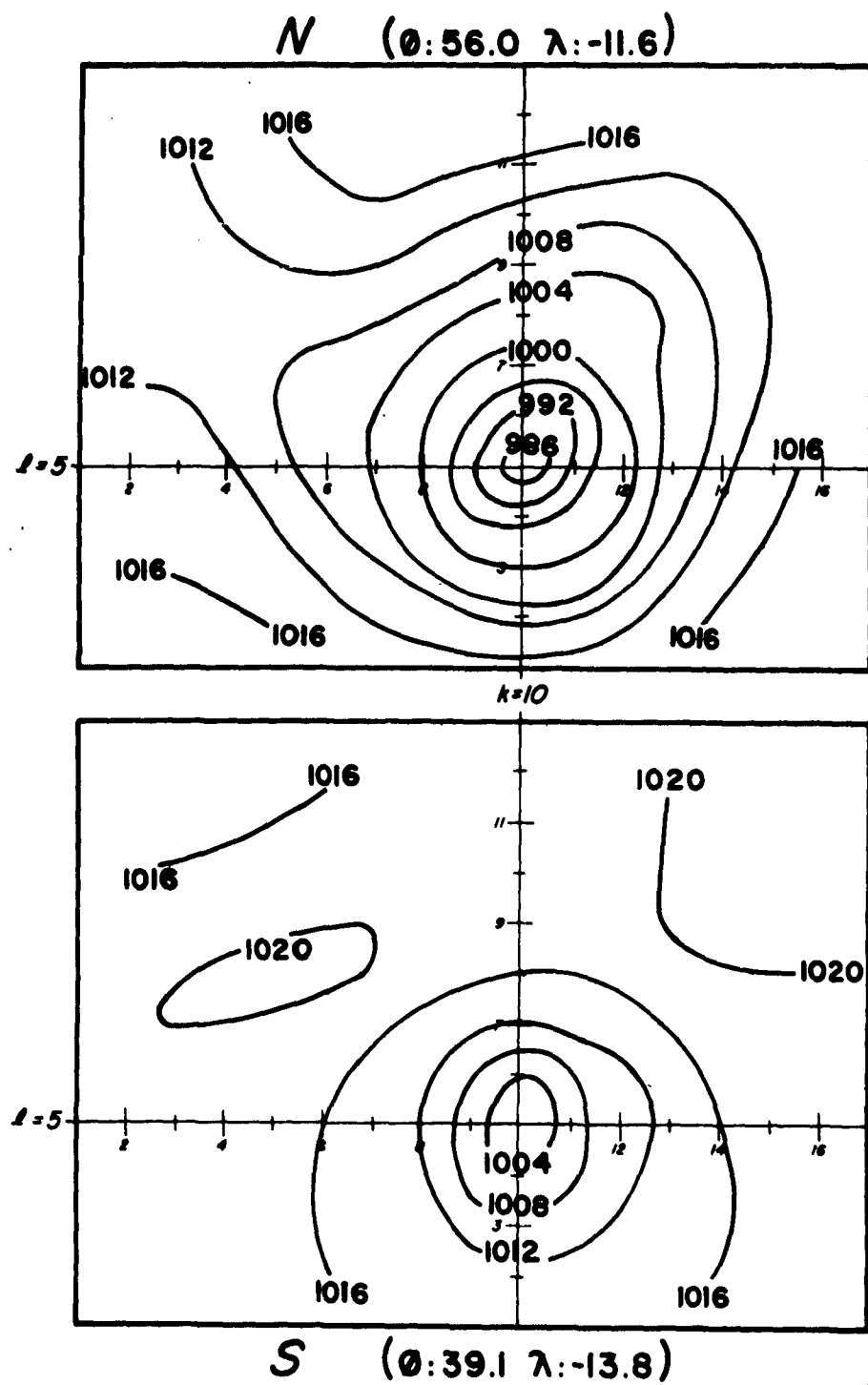


Fig. 3-2. Mean maps of sea-level pressure for winter cyclones in Europe, 1955-1959 (dependent sample). Isobars are labeled in millibars.

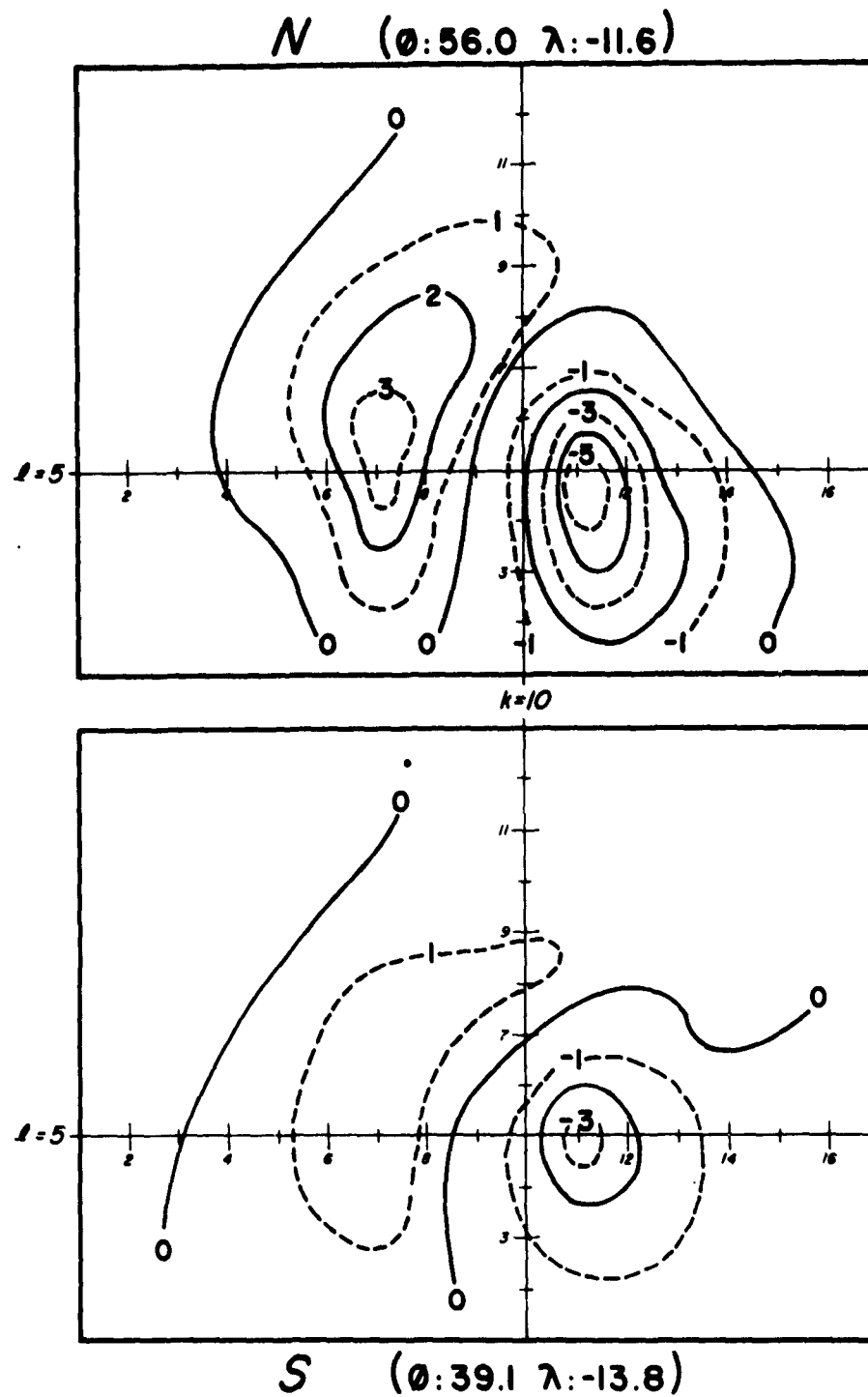


Fig. 3-3. Mean maps of 12-hr pressure change for winter cyclones in Europe, 1955-1959 (dependent sample). Isallobars are labeled in millibars.

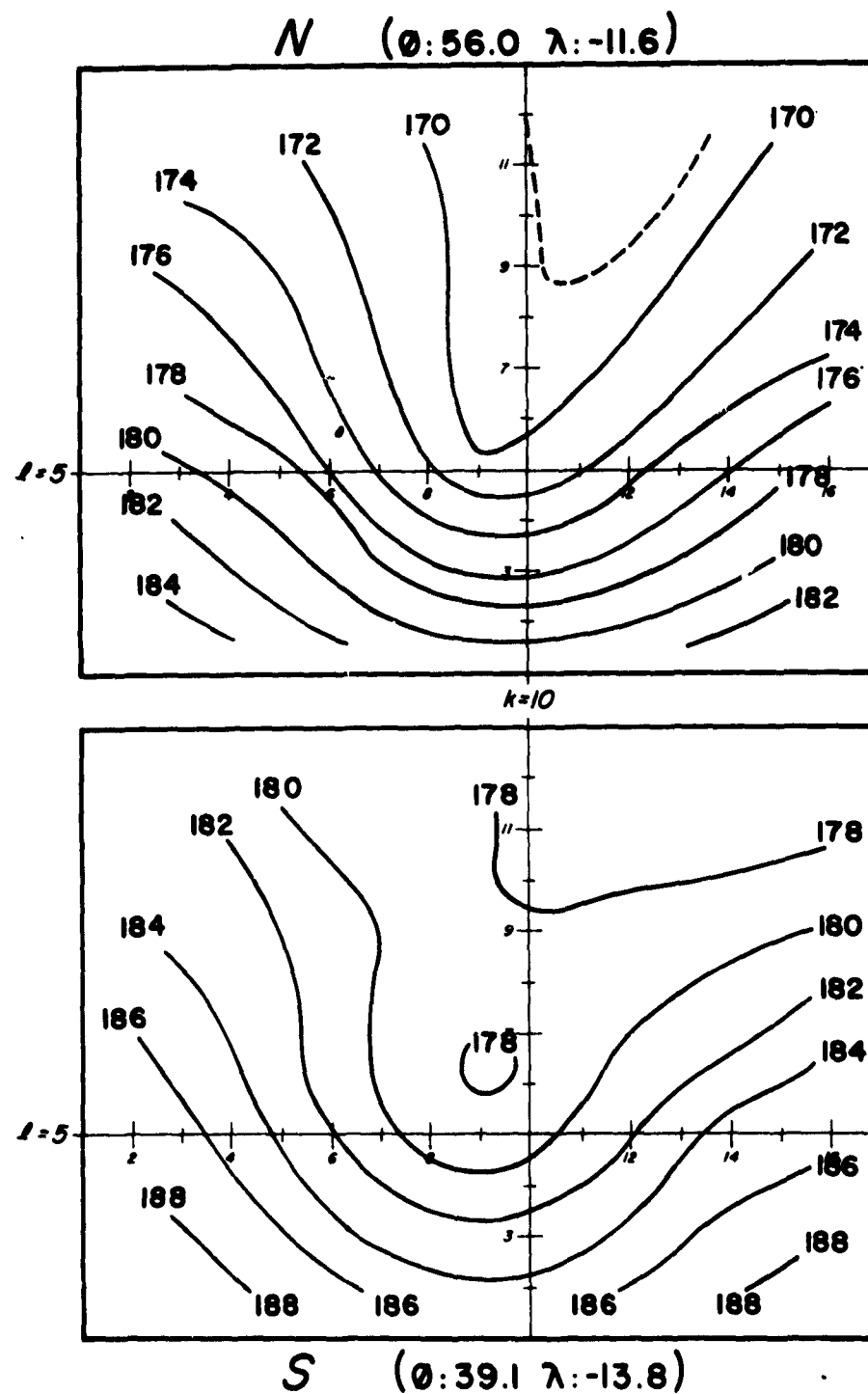


Fig. 3-4. Mean maps of 500-mb height for winter cyclones in Europe, 1955-1959 (dependent sample). Isohypsers are labeled in tens of feet.

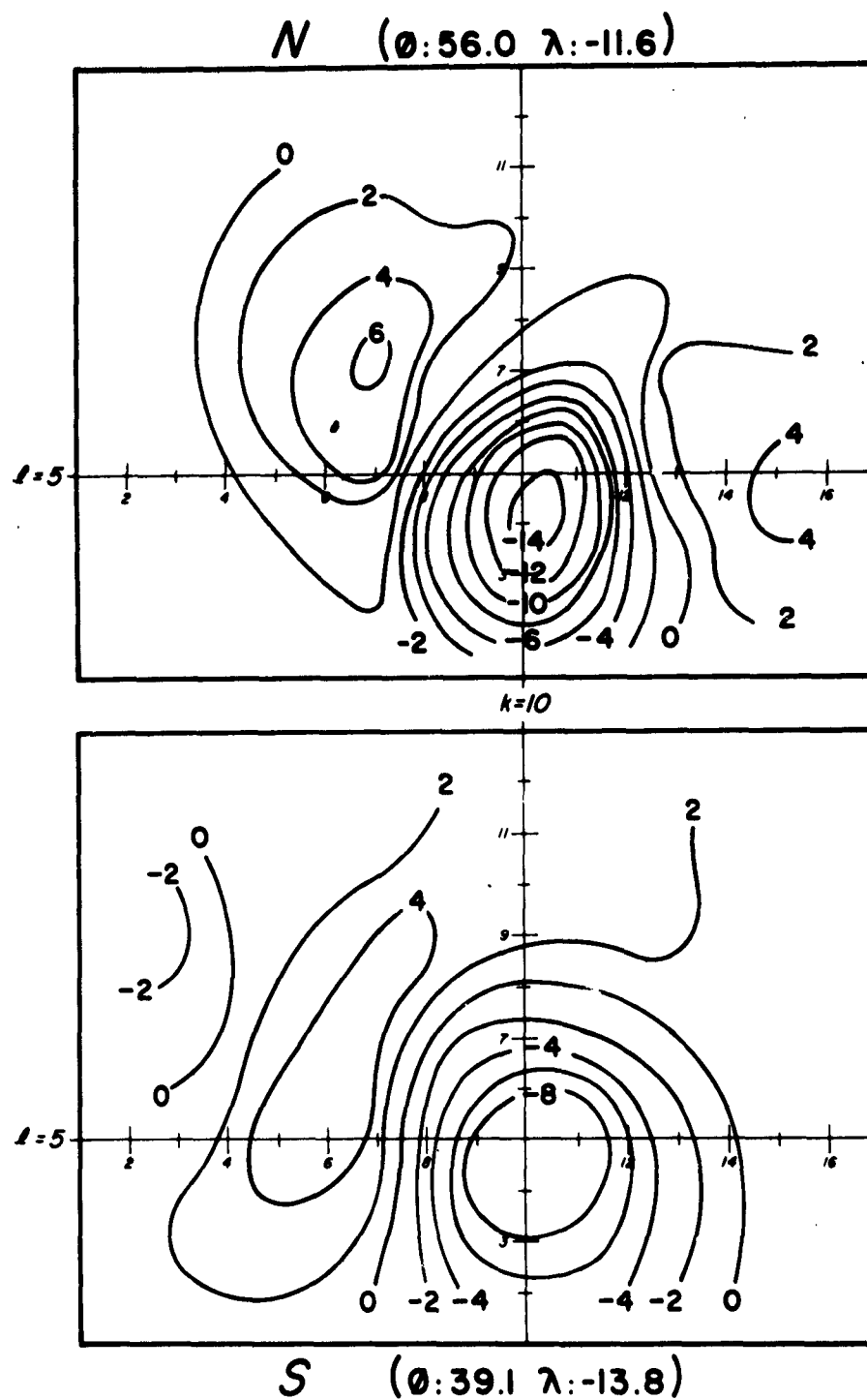


Fig. 3-5. Mean maps of 12-hr 500-mb height change for winter cyclones in Europe, 1955-1959 (dependent sample). Isallohypsies are labeled in tens of feet.

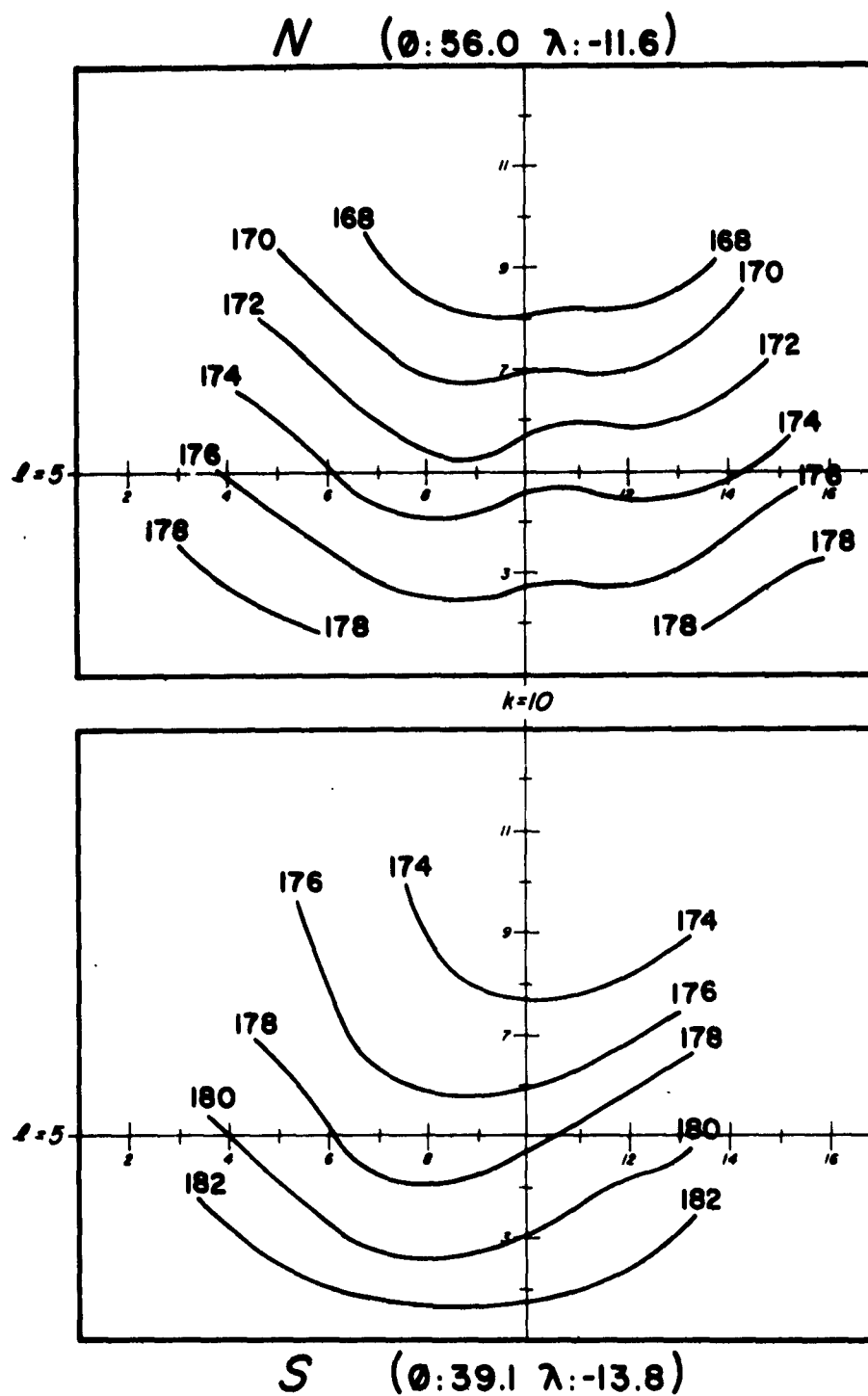


Fig. 3-6. Mean maps of 1000-500-mb thickness for winter cyclones in Europe, 1955-1959 (dependent sample). Isopachs are labeled in tens of feet.

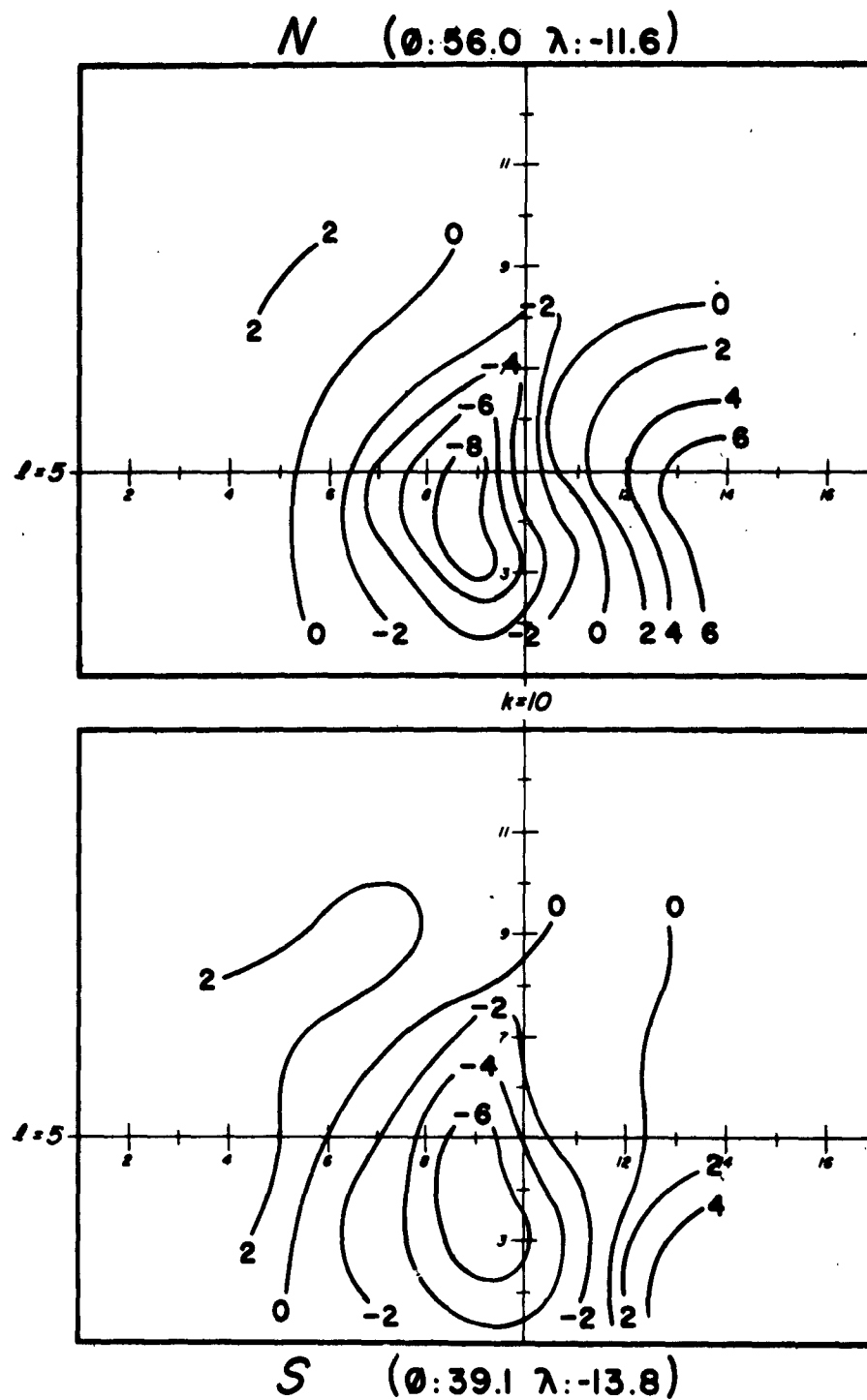


Fig. 3-7. Mean maps of 12-hr 1000-500-mb thickness change for winter cyclones in Europe, 1955-1959 (dependent sample). Isallopachs are labeled in tens of feet.

Although the cyclone tracks in the two zones seem similar, there is a sizable difference in variability about the means, as indicated by the standard deviations in Table 3-1. For every time period, the standard deviations for the northern zone are greater than for the southern. Other interesting characteristics are shown in Figs. 3-2 through 3-7, in which the means of all the possible predictors have been plotted and analyzed. The resulting charts depict the mean distributions of pressure, height, and thickness and their 12-hr changes relative to the cyclone center. Comparison of Figs. 3-2(a) and (b) shows that the mean northern-zone cyclone (984 mb) is about 17 mb deeper than the mean southern-zone cyclone (1001 mb) and is much larger in extent. This is characteristic of most of the other features; i.e., the northern zone shows pressure- and height-change centers of greater magnitude, and higher-amplitude 500-mb troughs.

3.1.2 Results of Using Both Surface and Upper-air Predictors

Regression equations were derived for the two zones separately and for the entire area. The possible predictors that were screened are listed in Table 2-3. The predictands are northward displacement, eastward displacement, and change in central pressure, for 12, 24, and 36 hr.

The results of the screening regression on dependent data are presented in Tables 3-2 and 3-3. Table 3-2 lists the predictors in the order of their selection by the screening procedure and the percentage of the total variance of the predictand explained by each for northern-zone cyclones, southern-zone cyclones, and the complete unstratified sample. Table 3-3 summarizes the initial and residual standard deviations, along with the percent reductions. The numbers in parentheses accompanying the predictors in Table 3-2 refer to the (k, l)-predictor locations in the grid system shown in Fig. 2-2.

From Table 3-2(a), it can be seen that the six displacement predictands for the northern zone (two for each time period) counted heavily on upper-air information. For the northward displacement, Z(15, 5) was the first predictor selected for all three time periods. Z(15, 5) is the 500-mb height about six grid intervals east of the cyclone. It is correlated with the northward component in such a way as to favor large northward displacements when the heights there are high. This seems consistent with synoptic reasoning; i.e., a large-amplitude ridge east of a cyclone is conducive to a sizable northward displace-

TABLE 3-2
PREDICTORS SELECTED BY SCREENING REGRESSION
FOR WINTER CYCLONES OVER EUROPE*

(a) Northern zone

Forecast interval, hr	Order of selection	$\bar{N}$		$\bar{E}$		$\bar{D}$	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	Z(15,5)	23.3	Z(9,1)	26.8	$\Delta P(9,5)$	26.6
	2nd	Z(9,7)	15.0	Z(13,9)	10.2	P(10,5)	9.1
	3rd	P(5,1)	5.8	$\Delta P(9,5)$	5.1	P(11,5)	2.9
	4th	Z(13,5)	4.4	Z(13,1)	2.1	P(13,1)	3.1
	5th	-	-	Z(11,7)	2.0	$\Delta P(7,1)$	2.3
	6th	-	-	Z(9,5)	2.5	$\Delta Z(9,5)$	1.9
	7th	-	-	-	-	λ	2.1
	8th	-	-	-	-	Z(9,7)	2.5
Total		48.5		48.7		50.5	
24	1st	Z(15,5)	25.3	Z(9,1)	26.7	$\Delta Z(9,5)$	20.0
	2nd	Z(9,7)	15.6	Z(13,9)	17.1	P(10,5)	13.2
	3rd	Z(5,1)	5.3	Z(13,1)	4.1	$\Delta H(9,5)$	6.4
	4th	Z(11,1)	4.9	$\Delta Z(9,5)$	2.7	λ	2.7
	5th	ϕ	2.8	Z(13,7)	1.6	Z(9,7)	3.6
	6th	P(15,7)	1.5	P(10,5)	1.2	-	-
	7th	H(9,1)	1.3	Z(5,11)	1.7	-	-
Total		56.7		55.1		45.9	
36	1st	Z(15,5)	20.4	Z(9,1)	24.4	Z(9,3)	19.3
	2nd	Z(9,7)	17.1	Z(13,9)	17.9	$\Delta P(9,5)$	11.6
	3rd	Z(13,5)	3.8	Z(13,1)	3.8	P(10,5)	9.6
	4th	Z(5,1)	2.9	$\Delta Z(9,5)$	2.4	H(9,7)	2.3
	5th	-	2.8	Z(15,7)	1.7	Z(13,1)	2.8
	6th	P(13,1)	2.4	-	-	P(11,5)	2.7
Total		49.4		50.2		48.3	

*Including upper-air data.

(b) Southern zone

Forecast interval, hr	Order of selection	A		E		D	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	P(7,7)	10.9	Z(11,9)	9.6	$\Delta P(9,3)$	11.4
	2nd	Z(13,3)	4.2	P(5,7)	7.8	P(10,5)	10.3
	3rd	Z(9,7)	9.6	Z(7,1)	3.7	P(11,7)	4.7
Total		24.7		21.1		26.4	
24	1st	P(7,5)	11.7	Z(11,9)	14.0	P(10,5)	16.8
	2nd	Z(13,3)	6.2	P(3,7)	9.4	$\Delta P(9,3)$	13.6
	3rd	Z(9,9)	12.2	Z(9,5)	4.1	P(11,7)	7.0
	4th	$\Delta Z(7,9)$	3.0	-	-	λ	1.7
	5th	-	-	-	-	H(9,9)	5.2
Total		33.1		27.5		44.3	
36	1st	Z(9,9)	14.6	Z(13,9)	16.5	P(10,5)	23.4
	2nd	Z(13,3)	14.8	P(5,7)	10.7	Z(11,9)	10.6
	3rd	P(5,3)	4.5	-	-	λ	6.9
	4th	-	-	-	-	$\Delta P(9,3)$	3.3
	5th	-	-	-	-	$\Delta P(3,3)$	2.4
Total		33.9		27.2		46.6	

(c) Both zones

Forecast interval, hr	Order of selection	N		E		D	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	P(7,1)	9.5	P(15,9)	11.9	$\Delta P(9,5)$	20.2
	2nd	P(13,3)	6.6	P(11,1)	6.8	P(10,5)	5.7
	3rd	P(9,7)	8.4	P(5,7)	5.5	Z(9,7)	4.5
	4th	Z(15,5)	9.0	$\Delta P(7,5)$	3.4	λ	5.4
	5th	H(7,7)	4.4	Z(9,1)	2.1	P(11,5)	1.8
	6th	P(11,3)	1.8	Z(11,7)	5.2	P(13,3)	2.0
	7th	-	-	P(10,5)	2.6	$\Delta Z(9,3)$	1.4
	8th	-	-	P(11,5)	1.9	-	-
	9th	-	-	H(13,3)	1.5	-	-
	10th	-	-	Z(5,3)	1.3	-	-
	11th	-	-	P(9,5)	1.2	-	-
Total		39.7		43.4		41.0	
24	1st	P(7,1)	10.9	P(15,9)	16.8	$\Delta P(9,5)$	15.6
	2nd	P(13,3)	7.5	P(11,1)	7.7	P(10,5)	12.5
	3rd	P(9,9)	5.0	P(5,7)	5.5	Z(9,7)	6.0
	4th	Z(15,5)	7.6	Z(9,1)	2.3	λ	5.6
	5th	Z(9,7)	8.2	Z(13,9)	6.2	$\Delta P(11,3)$	2.1
	6th	Z(11,3)	3.3	$\Delta Z(7,5)$	1.8	P(11,5)	1.5
	7th	$\Delta Z(9,9)$	1.7	Z(11,9)	0.8	P(13,1)	1.3
	8th	H(7,3)	1.6	H(13,3)	1.0	$\Delta Z(9,5)$	1.1
	9th	P(11,7)	0.9	Z(13,7)	1.7	$\Delta P(11,9)$	0.7
	10th	P(15,7)	1.2	P(10,5)	2.1	-	-
Total		47.9		45.9		46.4	
36	1st	P(7,1)	9.3	P(15,9)	18.9	P(10,5)	16.1
	2nd	P(9,9)	7.3	P(11,1)	7.2	$\Delta P(9,5)$	14.5
	3rd	Z(15,5)	7.7	P(5,7)	4.9	Z(13,9)	6.1
	4th	Z(9,7)	10.6	Z(9,1)	1.9	λ	2.7
	5th	P(13,1)	3.5	Z(13,9)	5.8	Z(9,7)	3.1
	6th	$\Delta Z(9,9)$	1.5	$\Delta P(9,5)$	1.5	$\Delta Z(11,3)$	1.3
	7th	$\Delta Z(13,3)$	1.4	Z(13,3)	1.0	H(11,3)	1.5
	8th	-	-	P(9,3)	0.7	$\Delta Z(11,7)$	1.0
	9th	-	-	P(13,5)	1.1	-	-
Total		41.3		43.0		46.3	

TABLE 3-3
RESULTS OF SCREENING REGRESSION* ON WINTER CYCLONES OVER EUROPE,
1955-1959 (DEPENDENT DATA)

Zone	Forecast interval, hr	No. of predictors			Std. dev.			Residual std. dev.			% reduction		
		$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$
N	12	4	6	8	2.39	2.49	5.82	1.73	1.80	4.10	49	49	50
	24	7	7	5	4.00	4.13	8.70	2.72	2.78	6.40	54	55	46
	36	6	5	6	5.27	5.68	10.08	3.76	4.00	7.75	49	50	48
S	12	3	3	3	2.09	2.13	3.99	1.81	1.89	3.42	25	21	26
	24	4	3	5	3.15	3.48	5.46	2.59	2.97	4.08	33	27	44
	36	3	2	5	4.04	4.76	6.62	3.29	4.05	4.83	34	27	47
Both	12	6	11	7	2.26	2.38	5.10	1.76	1.79	3.91	40	43	41
	24	10	9	7	3.65	3.91	7.46	2.65	2.88	5.46	48	46	46
	36	7	9	8	4.78	5.36	9.21	3.66	4.06	6.72	41	43	46

*Including upper-air predictors.

ment. $Z(9, 1)$, the 500-mb height about four grid intervals south-southwest of the cyclone, was selected first for all three time periods for the eastward component. Its correlation with the eastward component is such that low heights in this region are associated with small eastward displacements. Low heights in that location imply high-amplitude systems at 500 mb or lack of a strong zonal flow. The central pressure's lead predictors of $P(9, 5)$ for 12 hr and $Z(9, 5)$ for 24 hr correlate 12-hr pressure and height falls to the immediate west of the cyclone with deepening.

In the southern zone [Table 3-2(b)], there is a greater reliance placed on surface predictors. This is carried over even to the unstratified equations [Table 3-2(c)], where the first (and even the second) predictor selected is a surface variable in all nine instances. For the northward component, $P(7, 1)$, the sea-level pressure five grid intervals southwest of the cyclone, correlates high pressure there with large northward displacements. $P(15, 9)$, the lead predictor for eastward displacement, is located about six grid intervals northeast of the cyclone, and the relationship is such that high pressure there retards eastward cyclone displacement. For central pressure, $P(9, 5)$ is the same predictor as in the northern zone. $P(10, 5)$ is the initial central pressure itself and is correlated in such a way that little additional deepening takes place when the cyclone is initially deep.

Of particular interest is the comparison between the stratified and unstratified regression analyses. Such a comparison is shown in Table 3-4. The vector column refers to the rms vector error, which is the square root of the sum of the squares of the two component rms errors. Note that the vector errors for the unstratified equations are smaller for all three time periods for both the northern zone and the southern zone. For central pressure, the unstratified equations yield smaller rms errors except for the 36-hr southern-zone predictions.

The failure of the stratified equations to improve the results would seem to indicate that, at least for this problem, there is no benefit in processing the cases separately according to the latitude of the cyclone. One factor to consider is that 720 cases were used to develop the unstratified equations, whereas only about half that number were used to develop the stratified equations for each zone. The smaller number of cases could result in less stable coefficients. If this is true, then much care needs to be taken in

TABLE 3-4
RMS ERRORS IN TESTS* ON WINTER CYCLONES OVER EUROPE,
1959-1960 (INDEPENDENT SAMPLE)

Zone	Percent interval, %	Northward displacement, deg. lat.				Eastward displacement, deg. lon.				Vector, deg. lat.				Change in central pressure, mb			
		Climatol.		Regression		Climatol.		Regression		Climatol.		Regression		Climatol.		Regression	
				Strat.	Unstrat.			Strat.	Unstrat.			Strat.	Unstrat.			Strat.	Unstrat.
N	12	2.24	1.69	1.79	1.70	2.31	1.87	1.87	1.70	3.43	2.32	2.37	6.19	4.39	4.32	4.32	4.32
	24	4.25	2.97	2.79	2.79	3.82	2.97	2.97	2.79	5.79	4.20	3.95	5.49	6.60	6.16	6.16	6.16
	36	5.62	4.05	3.65	3.65	5.43	4.35	4.35	3.65	7.81	5.92	5.24	11.27	8.15	7.47	7.47	7.47
S	12	2.22	2.05	1.99	1.76	1.95	1.91	1.91	1.76	3.05	2.79	2.66	4.37	3.94	3.42	3.42	3.42
	24	3.80	3.19	3.08	2.95	3.00	2.90	2.90	2.95	4.84	4.31	4.26	6.46	4.77	4.48	4.48	4.48
	36	5.13	4.38	4.24	3.77	3.65	3.77	3.77	3.77	6.30	5.78	5.25	8.20	5.77	5.97	5.97	5.97

*Including upper-air predictors.

TABLE 3-5
CUMULATIVE FREQUENCY OF ERROR IN 24-hr
PREDICTIONS OF CYCLONES OVER EUROPE,
1959-1960*

(a) Total displacement

Error ϵ , deg. lat.	Percentage of cases			
	Regression† (203 cases)	Dunstable (784 cases)	Offenbach (1195 cases)	Moscow (1126 cases)
$0 \leq \epsilon \leq 1$	8	6	6	8
$0 \leq \epsilon \leq 2$	23	19	18	23
$0 \leq \epsilon \leq 3$	43	37	35	43
$0 \leq \epsilon \leq 4$	61	53	51	61
$0 \leq \epsilon \leq 5$	75	64	61	72
$0 \leq \epsilon \leq 6$	87	74	72	81
$0 \leq \epsilon \leq 7$	90	85	84	90

(b) Change in central pressure

Error ϵ , mb	Percentage of cases			
	Regression† (203 cases)	Dunstable (784 cases)	Offenbach (1195 cases)	Moscow (1126 cases)
$0 \leq \epsilon \leq 1.5$	25	22	23	28
$0 \leq \epsilon \leq 4.5$	61	54	58	64
$0 \leq \epsilon \leq 7.5$	79	73	77	83
$0 \leq \epsilon \leq 10.5$	92	84	87	92
$0 \leq \epsilon \leq 13.5$	98	91	92	96
$0 \leq \epsilon \leq 16.5$	99	96	96	98
$0 \leq \epsilon \leq 19.5$	99	98	98	99

*Regression predictions are for Nov. 1959 through Mar. 1960. Dunstable, Offenbach, and Moscow predictions are for Jun. 1959 through Mar. 1960.

†Unstratified.

determining criteria for stratification, particularly if the investigator has a limited amount of data at his disposal.

Table 3-4 also contains a comparison of the regression predictions with climatology. The climatology used was based on the computed means (Table 3-1) of the predictands for the dependent sample. These were used as predictions for the 203 cases of the independent sample. The rms errors for climatology are substantially larger than for regression for all time periods.

To determine the usefulness of a prediction technique, it is desirable to test its skill against some other technique—preferably the current operational system for which the new technique is hoped to serve as an aid. One such comparison would be with prognoses issued by a forecast center. This type of test is being performed by a USAF Air Weather Service (AWS) unit in Europe, but results are not currently available. Some indication of the performance of the regression techniques can be obtained, though, from a comparison of some verifications of prognostic charts prepared by Scherhag [9]. In his report, Scherhag presents error distributions of 24-hr cyclone-position and central-pressure forecasts for three forecast centers: Dunstable, Offenbach, and Moscow. These results are shown in Table 3-5, with the 203 independent regression predictions (unstratified) for comparison. Although the data samples are not exactly the same, Table 3-5 indicates that the regression technique at least maintained the same level of skill as the prognoses of the Dunstable, Offenbach, and Moscow forecast centers.

3.1.3 Results of Using Surface Predictors Only

There are limitations to the application of this prediction technique. For example, since 500-mb-height data are received only every 12 hr and the method requires input of such information, it is not possible to apply the regression equations, operationally, at 0600 and 1800 GCT. Also, in many instances, there is a time lag of at least an hour between the receipts of surface and upper-air information for the applicable times of 0000 and 1200 GCT. One possible way to overcome these problems is to use a prognosis of the 500-mb data. Another approach is to derive regression equations that use only surface data as predictors. A regression analysis that excludes upper-air data, if successful, would provide a useful

TABLE 3-6
PREDICTORS SELECTED BY SCREENING REGRESSION
FOR WINTER CYCLONES OVER EUROPE*

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		$\hat{O}$	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	P(7,1)	9.9	P(15,9)	12.1	$\Delta P(9,5)$	20.2
	2nd	P(14,4)	6.6	P(11,1)	6.6	P(10,5)	5.6
	3rd	P(9,7)	6.2	P(5,7)	5.5	P(11,7)	4.3
	4th	P(11,3)	5.4	$\Delta P(8,6)$	4.4	ϕ	1.9
	5th	$\Delta P(8,2)$	3.4	P(13,5)	1.0	λ	2.3
	6th	ϕ	2.5	P(10,5)	5.8	P(10,4)	1.8
	7th	P(10,6)	3.3	$\Delta P(11,5)$	2.9	$\Delta P(11,5)$	1.7
	8th	P(5,13)	1.6	P(12,6)	1.8	P(5,9)	1.3
	9th	P(17,7)	1.5	P(5,1)	1.3	-	-
Total		40.4		39.4		39.1	
24	1st	P(7,1)	11.3	P(15,9)	17.0	$\Delta P(9,5)$	15.6
	2nd	P(15,5)	7.3	P(11,1)	7.3	P(10,5)	12.4
	3rd	P(11,9)	6.7	P(5,7)	5.5	P(12,8)	5.1
	4th	ϕ	3.7	$\Delta P(8,6)$	2.7	ϕ	1.8
	5th	P(7,13)	2.4	P(10,5)	1.3	P(11,5)	1.8
	6th	$\Delta P(9,1)$	2.1	P(11,5)	3.9	λ	1.7
	7th	P(13,1)	2.3	$\Delta P(12,4)$	1.0	$\Delta P(11,5)$	1.9
	8th	P(11,7)	2.3	P(13,5)	1.3	-	-
	9th	P(15,7)	1.5	P(5,1)	1.6	-	-
	10th	P(11,3)	1.6	-	-	-	-
	11th	P(7,9)	1.2	-	-	-	-
	12th	$\Delta P(15,7)$	1.2	-	-	-	-
Total		43.6		41.8		40.5	
36	1st	P(7,1)	9.6	P(15,9)	19.2	P(10,5)	16.0
	2nd	P(9,9)	7.9	P(11,1)	6.9	$\Delta P(9,5)$	14.5
	3rd	P(13,3)	5.6	P(5,7)	5.0	P(15,9)	5.4
	4th	P(7,13)	2.5	P(10,5)	1.2	ϕ	2.2
	5th	ϕ	2.1	P(11,5)	3.5	P(12,6)	1.7
	6th	P(11,7)	4.9	-	-	P(15,1)	1.4
	7th	P(17,7)	3.3	-	-	λ	1.5
	8th	$\Delta P(13,7)$	1.6	-	-	P(5,13)	1.2
	9th	$\Delta P(9,9)$	1.4	-	-	$\Delta P(11,3)$	1.3
Total		38.9		35.8		45.2	

*Excluding upper-air data.

TABLE 3-7
RESULTS OF SCREENING REGRESSION* ON WINTER CYCLONES OVER EUROPE,
1975-1979 (DEPENDENT SAMPLE)

Forecast interval, hr	No. of predictors			Std. dev.			Residual std. dev.			% reduction		
	$\bar{n}$	$\bar{e}$	$\bar{\delta}$	$\bar{n}$	$\bar{e}$	$\bar{\delta}$	$\bar{n}$	$\bar{e}$	$\bar{\delta}$	$\bar{n}$	$\bar{e}$	$\bar{\delta}$
12	9	9	8	2.26	2.38	5.10	1.75	1.85	3.98	40	39	39
24	12	9	7	3.65	3.91	7.46	2.74	2.98	5.76	44	42	40
36	9	5	9	4.78	5.36	9.21	3.74	4.30	6.82	39	36	45

*Excluding upper-air data.

TABLE 3-8
RMS ERRORS IN TESTS ON WINTER CYCLONES OVER EUROPE,
1975-1980 (INDEPENDENT SAMPLE)

Forecast interval, hr	Northward displacement, deg. lat.		Eastward displacement, deg. lat.		Vector, deg. lat.		Change in central pressure, mb	
	Including upper-air data	Excluding upper-air data	Including upper-air data	Excluding upper-air data	Including upper-air data	Excluding upper-air data	Including upper-air data	Excluding upper-air data
12	1.87	1.79	1.72	1.88	2.54	2.60	4.11	4.17
24	2.91	3.13	2.86	3.01	4.07	4.34	5.57	5.87
36	4.01	4.33	3.82	3.95	5.54	5.86	6.90	7.24

product applicable to any observation time for which surface data are available. Accordingly, one screening-regression run was made on the full sample of 720 cases (unstratified) in which 500-mb height, 1000-500-mb thickness, and the time changes of these variables (see Table 2-3) were eliminated as possible predictors. Table 3-6 lists the selected predictors, in the order of their selection.

The comparative results of the two tests, excluding and including upper-air data, are shown in Tables 3-7 (dependent sample) and 3-8 (independent sample). Although generally better results were obtained when upper-air data were included, the differences do not appear to be excessive, and the use of regression equations that exclude upper-air data appears to be of value in situations where upper-air data are unavailable.

3.2 Asian Cyclones

Asia (area II of Fig. 2-1) was divided by latitude 40°N and longitude 145°E into four fairly even zones providing a separation of the relatively young, western cyclones from the older, eastern cyclones.

3.2.1 Synoptic Climatology

Table 3-9 contains the means and standard deviations of the northward and eastward displacements and changes in central pressure of 1091 Asian cyclones, for 12, 24, and 36 hr. Figure 3-8 depicts the mean cyclone tracks in each of the four zones. The southern cyclones tend to move much faster than the northern cyclones (approximately 27 knots in the south, 17 knots in the north). The maximum deepening was also noted in the southern zones, with lesser deepening over the northern zones. In fact, after 24 hr in the northeastern zone, there was a slight tendency for filling. This is not surprising inasmuch as cyclones in the northeastern zone are usually in or nearing their occluded phase.

The associated mean maps of pressure, height and thickness are shown as Figs. 3-9 through 3-14. Comparison of the sea-level pressure maps (Fig. 3-9) reveals a cyclone's stage of development; i.e., the farther east the cyclone, the lower its central pressure. The younger cyclones, which comprise much of the data samples of the northwestern and southwestern zones, have mean central pressures of 1004 and 1006 mb, respectively.

TABLE 3-9
CHARACTERISTICS OF WINTER CYCLONES OVER ASIA,
1955-1999 (DEPENDENT SAMPLE)

Zone	Forecast interval, hr	Observed northward displacement, deg. lat.		Observed eastward displacement, deg. lat.		Observed change in central pressure, mb	
		Mean	Std. dev.	Mean	Std. dev.	Mean*	Std. dev.
NW	12	0.14	2.34	- 3.87	2.34	- 2.79	5.05
	24	0.70	3.53	- 7.50	3.60	- 5.84	8.34
	36	1.53	4.54	-10.87	4.95	- 8.56	11.20
NE	12	1.86	2.44	- 2.95	2.64	- 2.75	7.31
	24	3.45	4.12	- 5.66	4.67	- 3.55	10.80
	36	4.72	5.56	- 8.31	6.70	- 2.85	13.74
SW	12	1.90	2.09	- 4.92	2.42	- 5.43	5.49
	24	4.05	3.52	- 9.78	4.14	-10.99	9.26
	36	6.58	4.75	-14.16	5.94	-14.87	11.57
SE	12	2.43	2.38	- 5.40	3.06	- 4.82	6.39
	24	4.79	3.89	-10.36	5.12	- 8.91	9.77
	36	7.45	5.31	-14.58	7.07	-12.05	12.59
All	12	1.55	2.49	- 3.97	2.79	- 3.61	6.44
	24	3.13	4.10	- 7.69	4.83	- 6.41	10.20
	36	4.77	5.56	-11.11	6.79	- 8.05	13.42

*Negative values represent deepening.

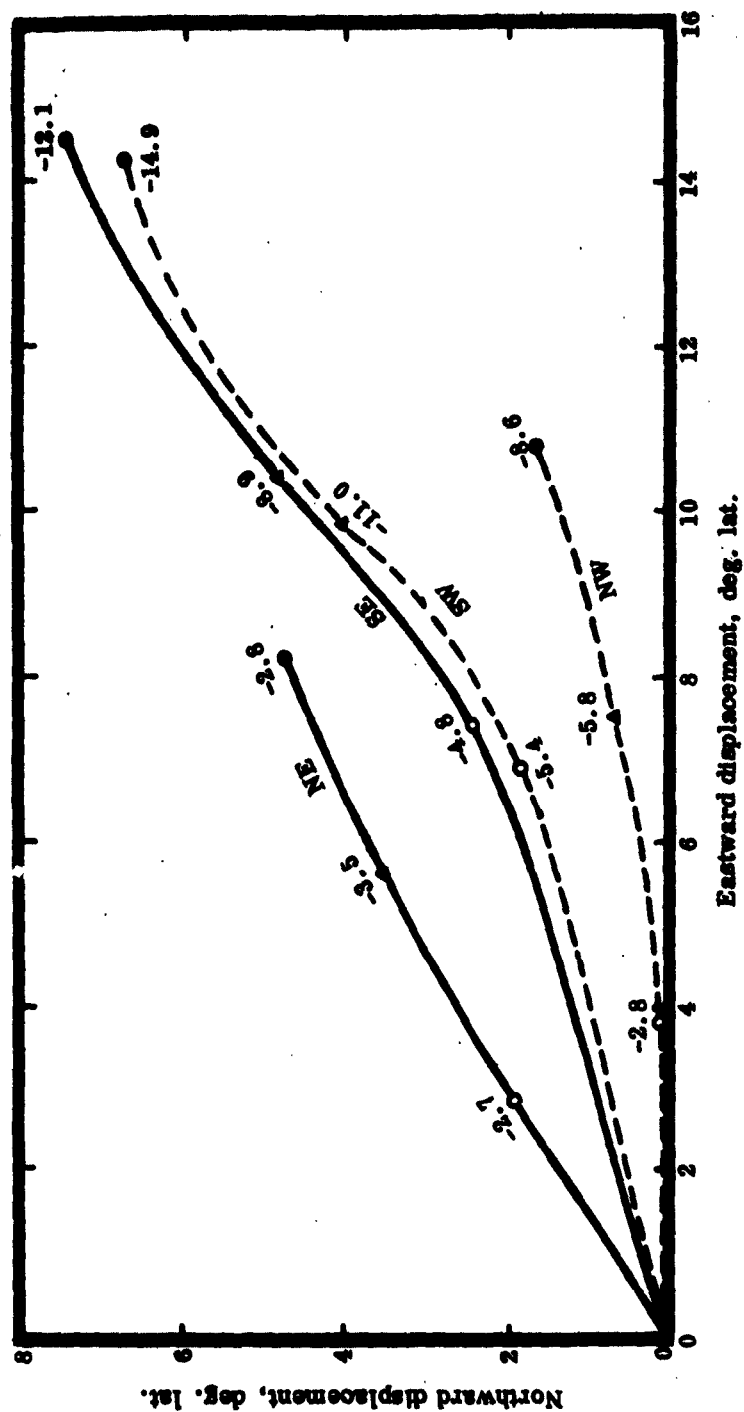


Fig. 3-8. Mean tracks of winter cyclones in Asia by zone, 1955-1959 (dependent sample). O 12-hr displacement; Δ 24-hr displacement; $\bullet$ 36-hr displacement. Value adjacent to symbol refers to mean change in central pressure (millibars).

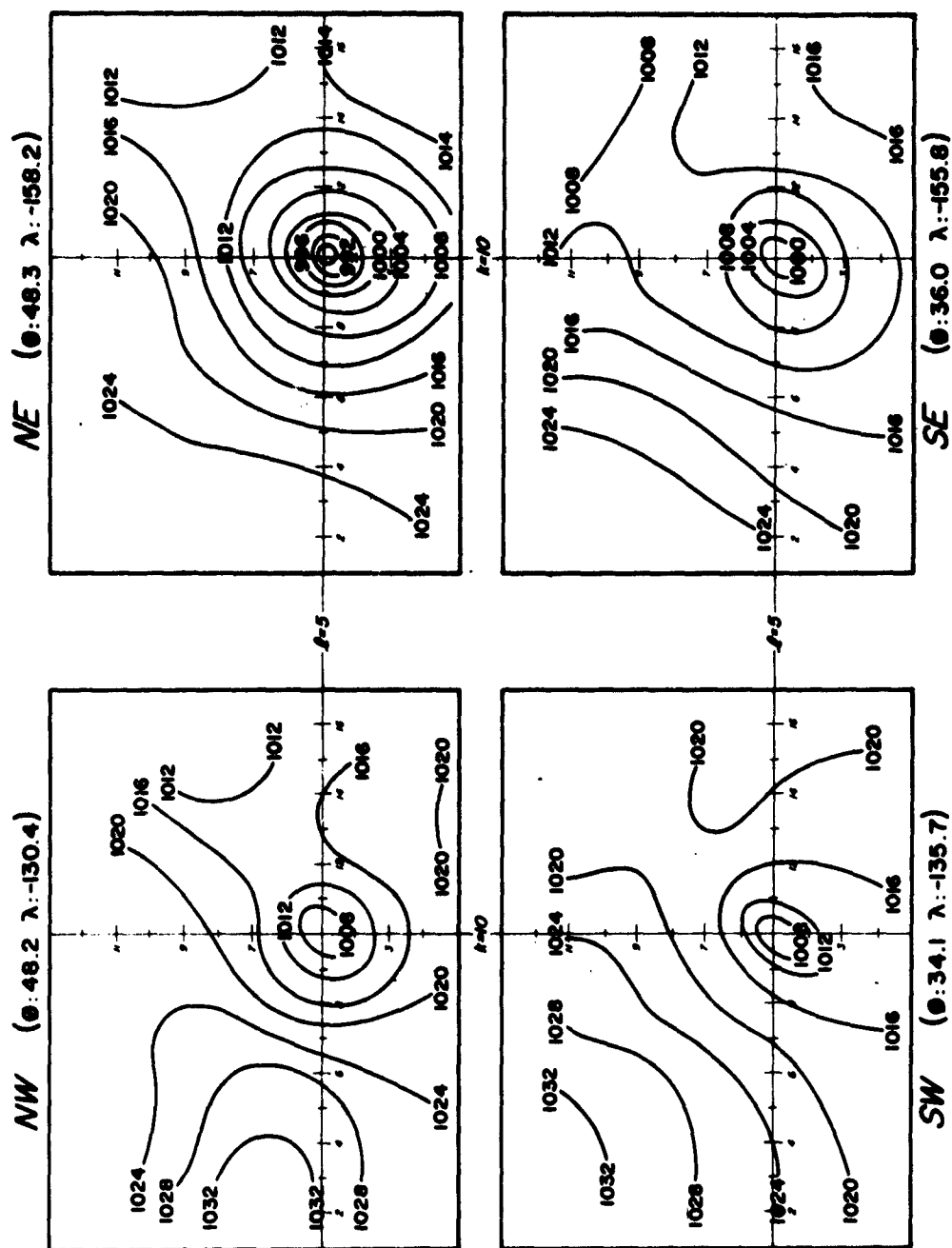


Fig. 3-9. Mean maps of sea-level pressure for winter cyclones in Asia, 1955-1959 (dependent sample). Isobars are labeled in millibars.

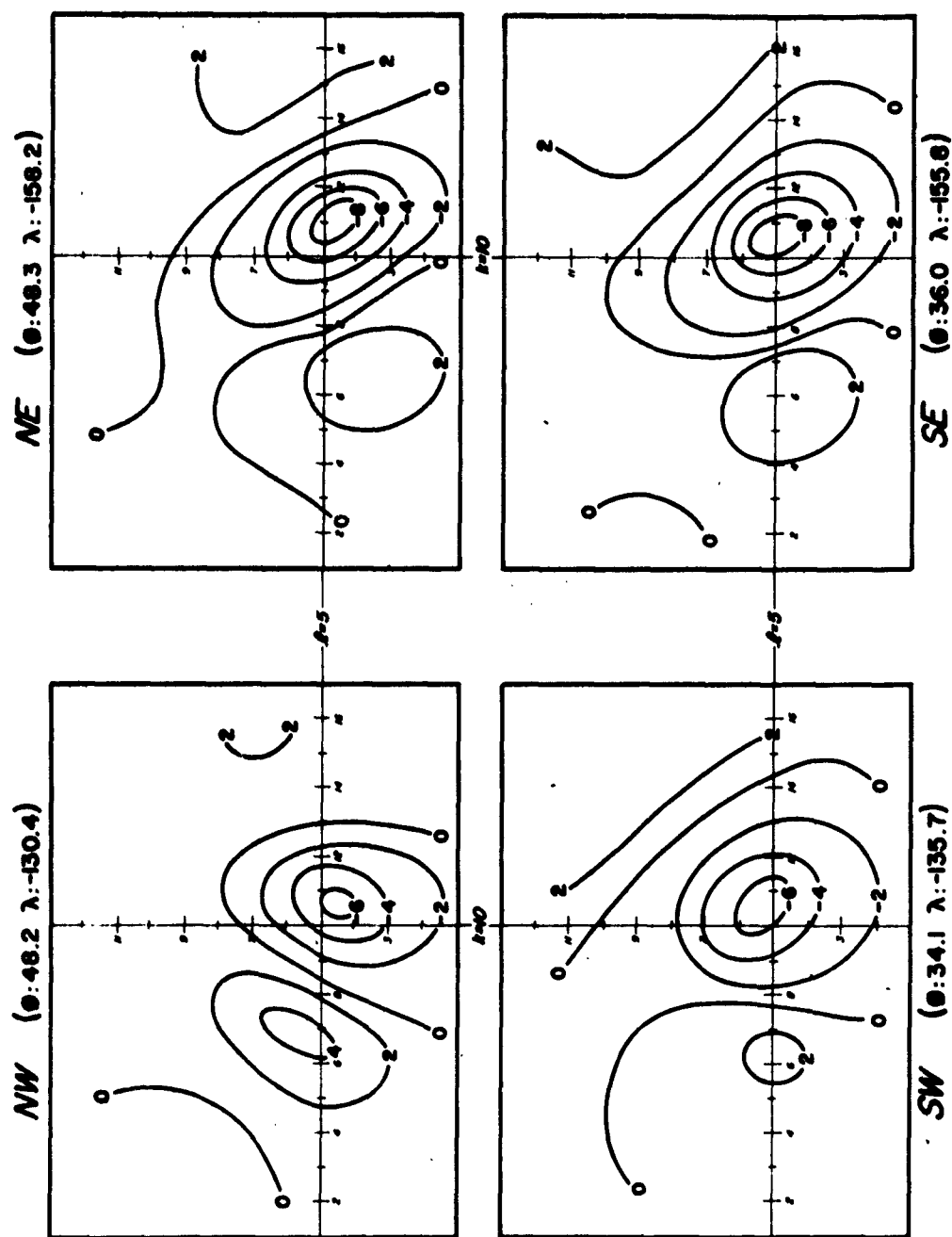


Fig. 3-10. Mean maps of 12-hr sea-level pressure change for winter cyclones in Asia, 1955-1959 (dependent sample). Isallobars are labeled in millibars.

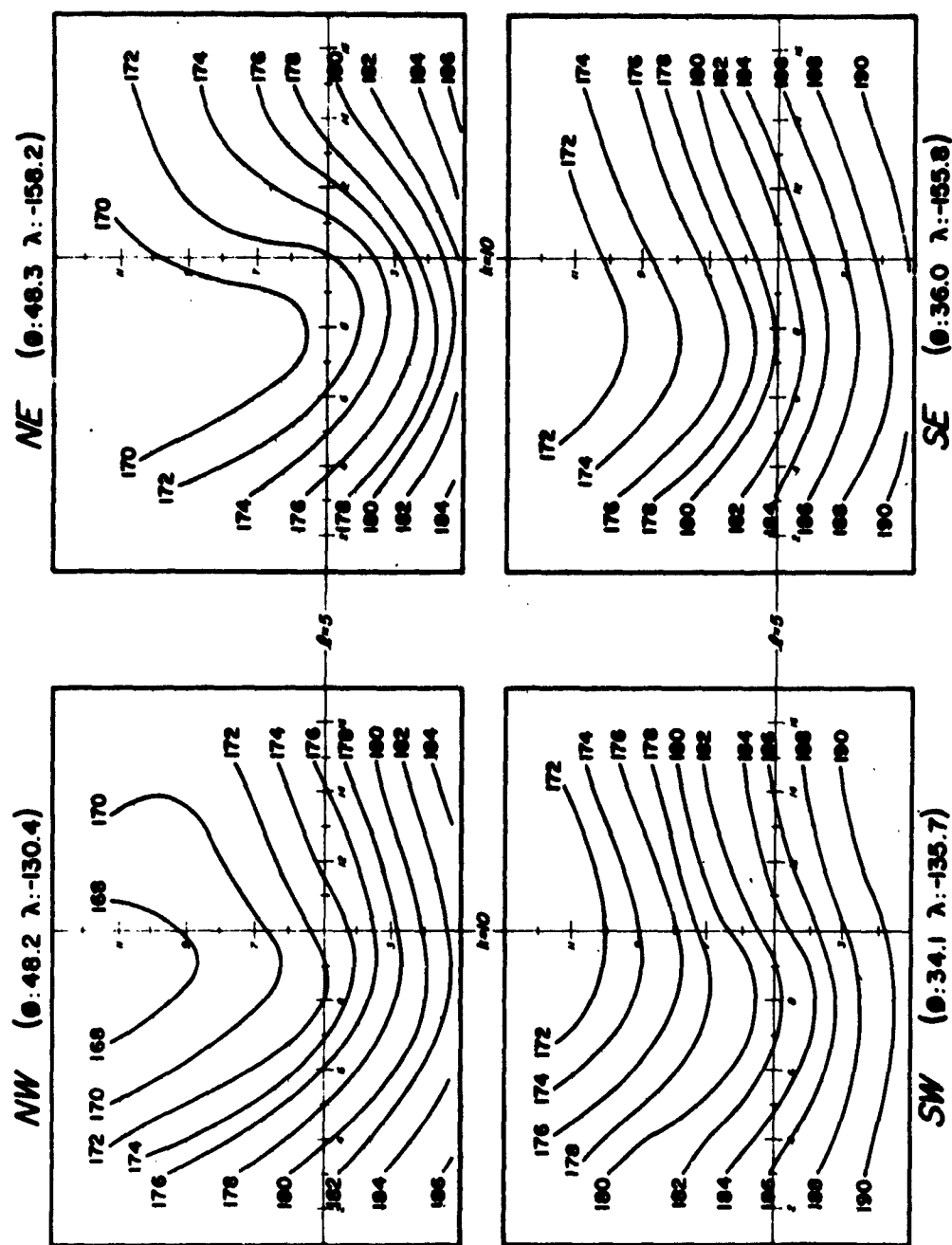


Fig. 3-11. Mean maps of 500-mb height for winter cyclones in Asia, 1955-1959 (dependent sample). Isohypsies are labeled in tens of feet.

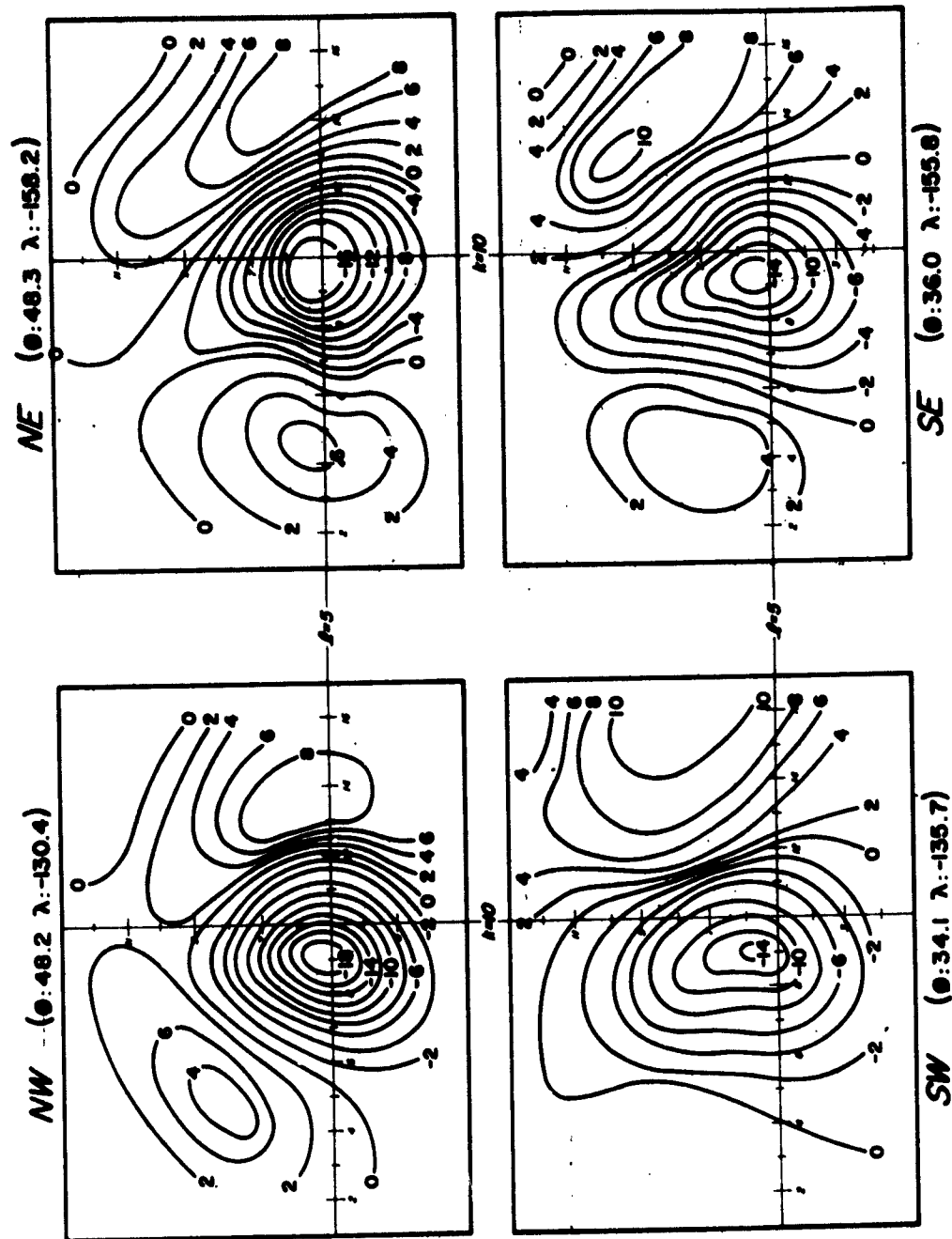


Fig. 3-12. Mean maps of 12-hr 500-mb height change for winter cyclones in Asia, 1955-1959 (dependent sample). Isallobypses are labeled in tens of feet.

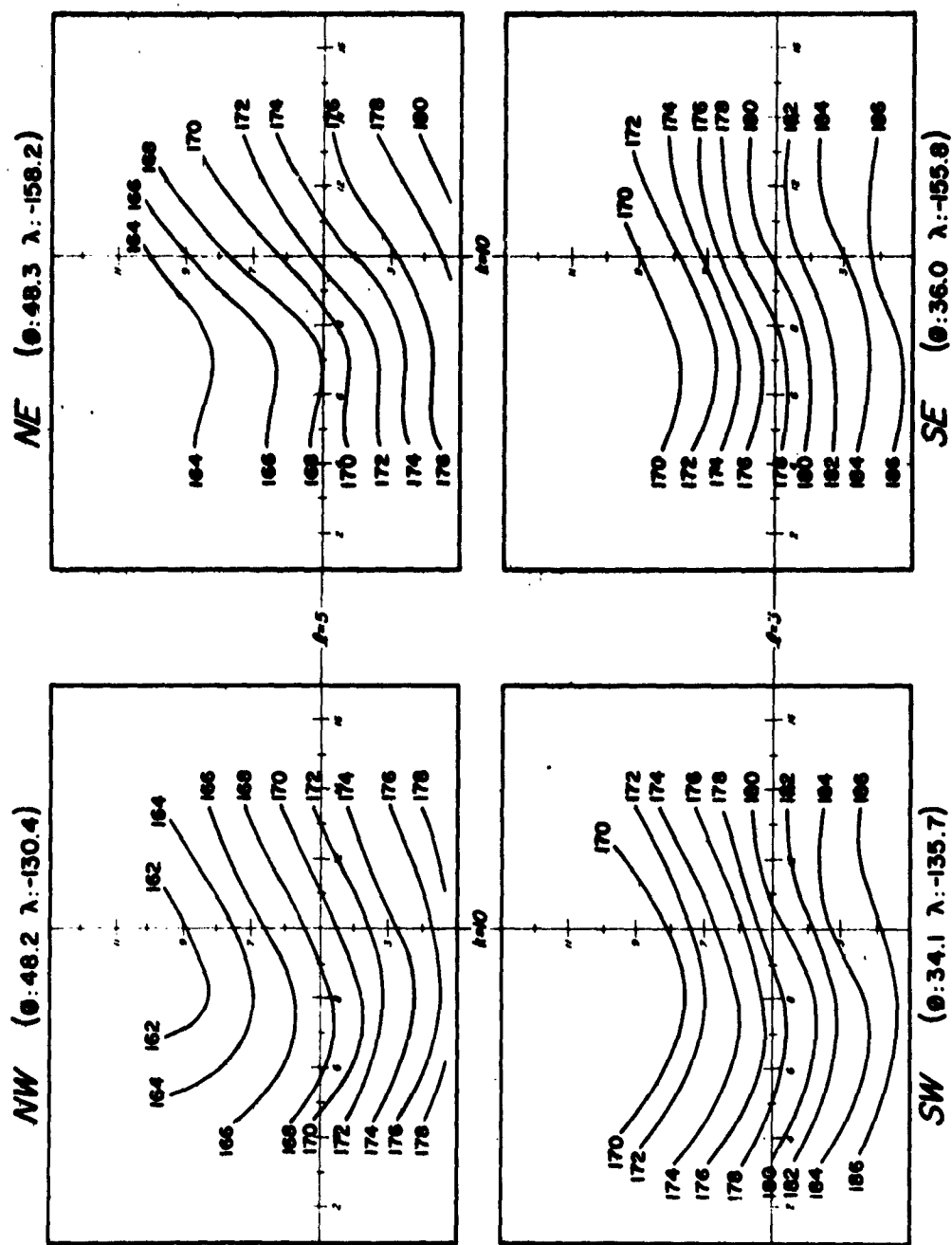


Fig. 3-13. Mean maps of 1000-500-mb thickness for winter cyclones in Asia, 1955-1959 (dependent sample). Isopachs are labeled in tens of feet.

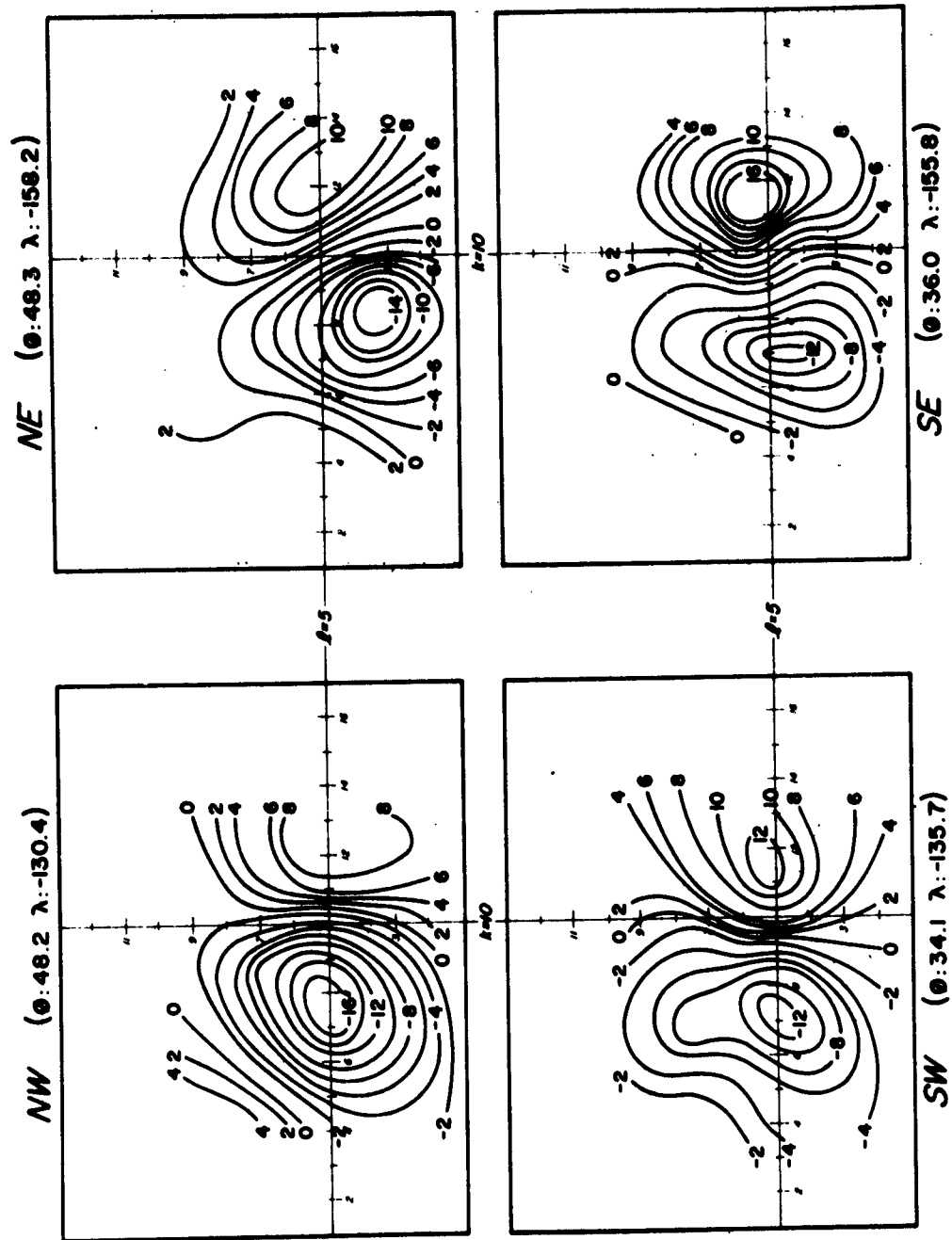


Fig. 3-14. Mean maps of 12-hr 1000-500-mb thickness change for winter cyclones in Asia, 1955-1959 (dependent sample). Isallopachs are labeled in tens of feet.

The more mature cyclones, which dominate the northeastern and southeastern zones, have central pressures of 987 and 996 mb, respectively. The four 12-hr pressure-change charts (Fig. 3-10) have similar isallobaric characteristics—a katallobaric center about one grid interval east and an anallobaric center about four grid intervals west. At 500 mb (Fig. 3-11), the height contours have larger amplitude in the two northern zones than in the southern. The same can be said for the 1000–500-mb thickness field (Fig. 3-13). The absolute values of the thickness contours are about 1000 ft lower in the northern zones than the southern, which is simply a reflection of the temperature variation with latitude in the troposphere. There is similarity among the 500-mb height-change charts (Fig. 3-12). The center of maximum falls is near or slightly west of the cyclone center. The rather small magnitudes of both maxima and minima can be accounted for only by the apparent variability in location of the rise and fall centers among individual cases, tending to damp them in the mean. The 12-hr thickness change for the 1000–500-mb layer (Fig. 3-14) is proportional to the changes in mean temperature for the layer. Furthermore, it is likely that this temperature change provides a rough estimate of thermal advection for the layer. In the mean-thickness-change maps, negative values refer to cold advection and positive values to warm. Of particular interest is the contrast between the cyclones in the southwestern and northeastern zones of Fig. 3-14. The former, due to its geographical location, may be thought of as a young cyclone, and the latter a mature one. Note how the axis between the centers of cold and warm advection shifts from an east-west orientation in the southwestern zone to a northeast-southwest orientation in the northeastern zone. This is consistent with life-cycle cyclone models, in which the mature cyclone has polar air penetrating equatorward to its rear and warm air being transported poleward in advance of it.

3.2.2 Results of Using Both Surface and Upper-air Predictors

Regression equations were derived for the four zones separately and, as in the experiment with European cyclones, the unstratified sample of the entire area was also screened. The predictands and possible predictors are the same as were used for Europe (Tables 2-2 and 2-3).

The results of the screening regression are listed in Tables 3-10 and 3-11. Table 3-10 lists the selected predictors, in order of their selection by the screening

TABLE 3-10
PREDICTORS SELECTED BY SCREENING REGRESSION
FOR WINTER CYCLONES OVER ASIA*

(a) Northwestern zone

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		$\hat{D}$	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	Z(13,9)	31.2	Z(13,9)	10.3	$\Delta P(9,3)$	9.7
	2nd	Z(9,7)	5.6	H(7,1)	7.7	Φ	6.6
	3rd	-	-	Z(11,7)	5.9	Z(7,7)	6.1
	4th	-	-	-	-	$\Delta P(9,9)$	3.5
	5th	-	-	-	-	P(3,3)	2.8
	6th	-	-	-	-	P(13,9)	2.4
	7th	-	-	-	-	$\Delta P(13,5)$	2.8
	8th	-	-	-	-	$\Delta H(9,7)$	2.0
	9th	-	-	-	-	$\Delta P(7,3)$	1.4
	10th	-	-	-	-	P(10,5)	1.7
	11th	-	-	-	-	P(11,5)	3.7
Total		36.8		23.9		42.7	
24	1st	Z(13,3)	42.2	Z(13,9)	18.6	P(13,9)	15.1
	2nd	Z(7,9)	7.3	H(7,1)	10.4	P(3,7)	9.7
	3rd	H(13,7)	3.3	H(11,7)	7.4	$\Delta P(9,3)$	5.7
	4th	P(11,1)	2.6	$\Delta Z(5,9)$	4.3	H(11,1)	4.8
	5th	P(9,7)	2.6	$\Delta P(11,7)$	2.7	H(9,5)	5.7
	6th	P(3,9)	3.4	$\Delta Z(7,5)$	2.9	P(10,5)	3.3
	7th	-	-	-	-	P(11,5)	6.4
	8th	-	-	-	-	Z(5,9)	2.7
Total		61.4		46.3		53.4	
36	1st	Z(13,3)	46.1	Z(13,9)	23.5	P(13,9)	16.0
	2nd	Z(7,9)	9.3	Z(7,3)	7.8	P(3,7)	11.7
	3rd	H(13,7)	4.3	Z(11,7)	6.9	P(10,5)	6.1
	4th	$\Delta H(11,3)$	3.0	-	-	P(9,3)	7.7
	5th	$\Delta P(9,9)$	2.5	-	-	$\Delta P(11,7)$	4.3
	6th	$\Delta H(5,3)$	2.0	-	-	λ	3.7
	7th	-	-	-	-	$\Delta P(11,3)$	3.3
	8th	-	-	-	-	Z(9,7)	2.1
	9th	-	-	-	-	Z(5,1)	4.5
Total		67.2		38.2		59.4	

*Including upper-air data.

(b) Northeastern zone

Forecast interval, hr	Order of selection	A		B		C	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	Z(13,5)	26.8	Z(9,1)	25.1	$\Delta P(11,3)$	15.9
	2nd	Z(9,7)	17.3	Z(11,7)	14.6	P(10,5)	11.6
	3rd	$\Delta H(5,3)$	1.5	-	-	P(11,7)	7.4
	4th	P(9,7)	1.5	-	-	$\Delta P(11,5)$	4.6
	5th	P(11,3)	1.7	-	-	P(3,3)	2.4
	6th	H(7,9)	1.8	-	-	-	-
Total		50.6		39.7		41.9	
24	1st	Z(13,5)	30.5	Z(9,1)	29.4	$\Delta P(9,3)$	28.1
	2nd	Z(9,7)	21.3	Z(13,7)	14.5	H(11,1)	5.9
	3rd	H(11,7)	1.8	H(13,5)	2.3	Z(11,9)	5.6
	4th	P(13,3)	2.1	P(3,3)	1.7	P(10,5)	7.8
	5th	Z(9,11)	1.5	P(9,5)	2.2	P(11,3)	5.7
	6th	H(5,5)	1.4	-	-	$\Delta H(5,7)$	1.3
	7th	ϕ	2.1	-	-	$\Delta P(11,5)$	1.2
Total		60.7		50.1		57.9	
36	1st	Z(13,5)	26.7	Z(9,1)	27.5	$\Delta P(9,3)$	32.8
	2nd	Z(9,7)	22.1	Z(13,9)	12.4	P(10,5)	10.9
	3rd	Z(13,7)	2.7	P(13,7)	2.5	$\Delta P(11,3)$	5.6
	4th	P(11,9)	2.3	Z(13,3)	1.7	P(13,5)	5.1
	5th	H(5,5)	4.6	H(9,1)	1.8	H(11,1)	3.1
	6th	$\Delta Z(9,9)$	1.4	-	-	Z(11,9)	3.5
	7th	P(13,5)	1.1	-	-	Z(13,11)	1.2
	8th	$\Delta H(9,5)$	1.1	-	-	Z(9,9)	1.3
	9th	H(7,9)	1.1	-	-	-	-
	10th	Z(5,1)	1.0	-	-	-	-
	11th	ϕ	1.3	-	-	-	-
Total		65.4		45.7		63.5	

(c) Southwestern zone

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		$\hat{D}$	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	$\Delta P(11,7)$	19.8	$Z(11,3)$	12.5	$\Delta Z(9,5)$	18.6
	2nd	$H(13,7)$	7.8	$H(5,7)$	8.0	$Z(11,11)$	8.1
	3rd	$Z(9,7)$	9.3	$\Delta P(13,5)$	5.6	$\Delta P(11,7)$	7.1
	4th	-	-	$Z(11,7)$	2.9	-	-
	5th	-	-	$Z(13,1)$	6.8	-	-
Total		36.9		35.8		35.8	
24	1st	$\Delta P(11,7)$	18.9	$Z(15,11)$	13.8	$\Delta Z(9,5)$	15.9
	2nd	$P(11,7)$	10.0	$P(9,11)$	10.3	$Z(11,11)$	9.7
	3rd	$Z(15,7)$	8.5	$Z(3,1)$	5.6	$P(15,7)$	7.5
	4th	$H(7,7)$	8.8	$\Delta Z(11,7)$	2.9	$\Delta Z(5,7)$	4.9
	5th	-	-	$Z(11,9)$	3.1	$\Delta P(11,7)$	4.4
	6th	-	-	$Z(15,1)$	4.3	$P(15,5)$	3.4
	7th	-	-	-	-	$P(13,7)$	4.1
Total		46.2		40.0		49.9	
36	1st	$P(11,7)$	18.2	$Z(15,1)$	15.7	$Z(11,11)$	15.7
	2nd	$P(15,7)$	9.0	$Z(13,11)$	12.0	$P(15,7)$	7.4
	3rd	$\Delta P(9,5)$	4.7	$Z(3,3)$	5.0	$\Delta Z(5,7)$	5.7
	4th	$Z(15,7)$	5.2	-	-	$\Delta Z(7,7)$	7.0
	5th	$P(3,7)$	6.8	-	-	-	-
	6th	$\Delta Z(9,7)$	4.2	-	-	-	-
Total		48.1		32.7		35.8	

(d) Southeastern zone

Forecast interval, hr	Order of selection	$\hat{N}$		$\hat{E}$		$\hat{D}$	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	$P(15,7)$	19.1	$P(15,11)$	16.5	$\Delta P(9,3)$	16.0
	2nd	$P(11,7)$	10.3	$Z(3,1)$	7.2	-	-
	3rd	$P(13,3)$	6.0	$Z(11,9)$	6.2	-	-
Total		35.6		29.9		16.0	

(d) Southeastern zone

Forecast interval, hr	Order of selection	A		E		G	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
24	1st	P(15,7)	16.9	P(13,11)	24.1	ΔP(9,3)	23.5
	2nd	P(13,7)	12.3	Z(7,1)	10.2	P(10,5)	5.6
	3rd	ΔP(9,7)	4.8	Z(11,9)	8.9	ΔP(11,1)	8.6
	4th	ΔP(13,7)	4.2	-	-	-	-
	5th	ΔZ(11,11)	3.9	-	-	-	-
	6th	P(3,7)	2.8	-	-	-	-
	7th	Z(15,9)	2.8	-	-	-	-
	8th	P(13,3)	3.8	-	-	-	-
Total		51.5		43.2		37.7	
36	1st	Z(15,7)	13.2	P(13,11)	23.9	ΔP(9,3)	17.4
	2nd	Z(11,9)	18.1	Z(7,1)	14.2	P(10,5)	11.3
	3rd	P(11,7)	3.7	Z(11,9)	6.7	ΔP(11,1)	7.7
	4th	P(13,3)	7.2	P(13,3)	3.6	Z(13,9)	4.3
	5th	-	-	P(9,7)	4.1	-	-
Total		42.2		42.5		40.7	

(e) All zones

Forecast interval, hr	Order of selection	A		E		G	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	Z(13,5)	23.5	Z(7,1)	22.2	ΔP(9,3)	14.8
	2nd	Z(7,7)	12.4	Z(11,9)	11.7	ΔP(11,3)	4.7
	3rd	Z(13,3)	3.6	P(13,3)	1.3	P(10,5)	3.0
	4th	P(11,7)	2.3	Z(11,1)	1.5	P(11,3)	3.3
	5th	P(13,3)	2.8	P(9,3)	1.3	ΔP(9,3)	3.2
	6th	ΔP(13,1)	0.9	ΔP(11,3)	1.9	ΔP(3,3)	2.0
	7th	ΔP(9,7)	0.7	P(3,3)	1.4	λ	1.6
	8th	P(13,9)	0.7	ΔZ(7,7)	0.7	ΔZ(9,7)	1.6
	9th	Z(9,7)	0.6	P(11,7)	0.5	Z(11,11)	1.2
	10th	P(11,3)	0.4	Z(13,11)	0.8	ΔP(13,3)	1.0
	11th	P(10,3)	0.7	-	-	ΔH(3,3)	0.9
	12th	Z(3,3)	0.5	-	-	ΔZ(13,7)	0.8
	13th	φ	0.6	-	-	-	-
Total		49.7		43.3		40.1	

(e) All zones

Forecast interval, hr	Order of selection	A		E		B	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
24	1st	Z(15,5)	29.5	Z(7,1)	29.6	$\Delta P(9,3)$	24.7
	2nd	Z(7,7)	14.8	Z(15,9)	12.7	M(11,1)	6.0
	3rd	Z(11,3)	3.4	P(15,7)	1.4	M(9,7)	6.8
	4th	P(11,7)	1.9	Z(9,3)	1.7	P(10,5)	2.6
	5th	P(15,5)	4.0	Z(11,9)	0.7	P(11,5)	3.3
	6th	Z(5,3)	1.4	Z(15,11)	1.0	$\Delta P(9,7)$	2.0
	7th	$\Delta Z(9,7)$	1.0	$\Delta Z(7,5)$	0.8	λ	1.6
	8th	Z(15,7)	1.0	Z(15,1)	0.6	$\Delta P(11,3)$	1.6
	9th	Z(9,11)	1.0	P(9,7)	0.7	Z(15,11)	1.2
	10th	-	-	P(5,5)	0.8	$\Delta M(5,7)$	1.1
	11th	-	-	$\Delta P(11,5)$	0.5	$\Delta P(5,3)$	0.9
	12th	-	-	P(9,5)	0.6	Z(11,3)	0.7
	13th	-	-	P(15,5)	0.7	M(11,7)	0.9
	14th	-	-	-	-	Z(11,7)	1.1
	15th	-	-	-	-	$\Delta P(11,5)$	0.8
Total			58.0		51.8		55.3
36	1st	Z(15,5)	32.6	Z(7,1)	29.6	$\Delta P(9,3)$	27.1
	2nd	Z(7,9)	14.3	Z(15,9)	11.8	P(10,5)	9.7
	3rd	P(11,9)	2.7	M(7,5)	1.5	M(11,1)	3.2
	4th	M(5,5)	2.1	P(15,7)	1.0	Z(9,7)	6.9
	5th	P(15,5)	1.9	Z(15,1)	0.9	Z(15,11)	2.7
	6th	$\Delta Z(9,7)$	1.7	P(9,5)	1.5	P(11,3)	1.9
	7th	P(11,7)	1.0	Z(11,7)	0.9	λ	1.6
	8th	Z(15,9)	0.9	Z(15,11)	1.0	P(5,5)	1.2
	9th	ϕ	0.6	Z(3,7)	0.8	ϕ	0.8
	10th	Z(5,3)	0.7	-	-	$\Delta M(5,7)$	0.6
	11th	Z(15,11)	0.6	-	-	-	-
Total			59.1		49.0		57.7

TABLE 3-11
RESULTS OF SCREENING REGRESSION* ON WINTER CYCLONES OVER ASIA,
1955-1959 (DEPENDENT DATA)

Zone	Forecast interval, hr	No. of predictors			Std. dev.			Residual std. dev.			% reduction		
		$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$
NW	12	2	3	11	2.34	2.34	5.03	1.86	2.04	3.80	37	24	43
	24	6	6	8	3.53	3.60	8.34	2.20	2.64	5.70	61	46	53
	36	6	3	9	4.54	4.95	11.20	2.60	3.89	7.14	67	38	59
NE	12	6	2	5	2.44	2.64	7.31	1.72	2.05	5.57	51	40	42
	24	7	5	8	4.12	4.67	10.80	2.58	3.30	7.01	61	50	58
	36	11	5	8	5.56	6.70	13.74	3.27	4.94	8.29	65	46	64
SW	12	3	5	3	2.09	2.42	5.49	1.66	1.94	4.47	37	36	34
	24	4	6	7	3.52	4.14	9.26	2.58	3.20	6.55	46	40	50
	36	6	3	4	4.75	5.94	11.57	3.43	4.87	9.27	48	33	36
SE	12	3	3	1	2.38	3.06	6.39	1.91	2.56	5.86	36	30	16
	24	8	3	3	3.89	5.12	9.77	2.71	3.85	7.71	52	43	38
	36	4	5	4	5.31	7.07	12.59	4.04	4.87	9.70	42	53	41
All	12	13	10	12	2.49	2.79	6.44	1.76	2.10	4.98	50	43	40
	24	9	13	15	4.10	4.83	10.20	2.66	3.55	6.82	58	52	55
	36	11	9	10	5.56	6.79	13.42	3.55	4.84	8.73	59	49	58

*Including upper-air predictors.

TABLE 3-12
RMS ERRORS IN TESTS ON WINTER CYCLONES OVER ASIA,
1979-1980 (INDEPENDENT SAMPLE)

Zone	Forecast interval, hr	Northward displacement, deg. lat.				Eastward displacement, deg. lat.				Vector, deg. lat.				Change in central pressure, mb			
		Climatol.		Regression		Climatol.		Regression		Climatol.		Regression		Climatol.		Regression	
		Strat.	Unstrat.	Strat.	Unstrat.	Strat.	Unstrat.	Strat.	Unstrat.	Strat.	Unstrat.	Strat.	Unstrat.	Strat.	Unstrat.	Strat.	Unstrat.
NW	12	2.19	1.57	1.87	2.17	2.14	1.95	3.08	2.65	2.43	3.96	4.26	4.26	4.26	4.26	4.26	4.26
	24	3.50	2.18	2.02	3.88	3.36	3.39	5.25	4.19	4.12	8.15	7.09	5.82	7.09	5.82	7.09	5.82
	36	4.79	3.29	3.23	5.44	5.14	5.06	7.25	6.10	6.00	11.22	9.98	8.92	9.98	8.92	9.98	8.92
NE	12	2.42	1.69	1.66	2.75	1.70	1.81	3.66	2.40	2.46	7.77	5.09	5.36	7.77	5.09	5.36	5.36
	24	4.02	2.58	2.29	5.11	3.32	3.06	6.50	4.09	3.82	12.30	6.85	6.59	12.30	6.85	6.59	6.59
	36	5.30	3.15	3.15	7.27	4.64	4.39	9.00	5.61	5.40	16.15	7.48	7.68	16.15	7.48	7.68	7.68
SW	12	2.89	1.92	1.71	3.05	3.09	2.94	4.20	3.68	3.40	5.29	4.61	4.31	5.29	4.61	4.31	4.31
	24	3.16	2.51	2.18	5.05	4.61	4.31	5.94	5.25	5.01	9.36	7.71	8.00	9.36	7.71	8.00	8.00
	36	4.19	3.25	3.50	6.50	5.38	6.32	7.75	6.61	7.22	13.95	11.65	11.70	13.95	11.65	11.70	11.70
SE	12	2.76	2.35	2.26	2.67	2.50	2.38	3.64	3.43	3.28	6.89	6.36	6.49	6.89	6.36	6.49	6.49
	24	4.36	3.47	3.85	4.60	3.87	3.62	6.49	5.20	5.28	10.72	11.75	10.29	10.72	11.75	10.29	10.29
	36	6.22	5.69	5.42	7.44	5.81	5.76	9.70	8.15	7.91	12.95	13.90	13.30	12.95	13.90	13.30	13.30

including upper-air predictors.

TABLE 3-13
PRELIMINARY RESULTS
OF CATEGORY III TESTS BY AMS
ON APPROXIMATELY 100 WINTER CYCLONES OVER ASIA,
1962-1963

Forecast interval, hr	Av. abs. error in northward displacement, deg. lat.		Av. abs. error in eastward displacement, deg. long.		Res vector error in total displacement, naut. mi.		Av. abs. error in change in central pressure, mb	
	Regression	MX Central	Regression	MX Central	Regression	MX Central	Regression	MX Central
12	1.1	1.5	2.1	2.7	118	183	3.8	3.6
24	2.2	2.4	3.4	4.8	203	262	6.5	6.6
36	3.2	2.9	5.1	5.6	299	301	8.3	7.3

procedure, and the percentage of the total variance explained by each. Table 3-11 summarizes the initial and residual standard deviations, along with the percent reductions.

One interesting feature of Table 3-10 is that, for a particular predictand, there is a tendency for the screening-regression program to select the same or similar predictors, whether it be for a lag of 12, 24, or 36 hr. For example, for the northward component of displacement ($\hat{N}$) in Table 3-10(e), the first predictor selected is $Z(15, 5)$ for all three time periods. The same holds true for the eastward component ($\hat{E}$), for which $Z(7, 1)$ was selected first, and central pressure ($\hat{P}$), for which $\Delta P(9, 3)$ was selected first. In addition, several of the second predictors selected are either the same or similar. These predictors are like those selected for the northern zone of Europe (see Sec. 3.1.2).

Table 3-12 contains the rms errors found in the independent sample. Note that, as in the case of European cyclones, the unstratified equations compete well with the stratified equations.

Category III testing on cyclones in Eurasia is being done by an Air Weather Service (USAF) Weather Central in Japan. Preliminary results on approximately 100 cases for the 1962-1963 winter season are available and are shown in Table 3-13. The regression equations for total displacement had smaller rms errors than the Weather Central's operational forecasts for all three time periods, although the 36-hr rms errors were nearly equal. For central pressure, the regression method is competitive with the Central's prediction through 24 hr.

3.2.3 Results of Using Surface Predictors Only

A screening-regression run was made using surface data only, in the same manner as for the European cyclones. The predictors, in order of their selection, are listed in Table 3-14. Table 3-15 (dependent sample) shows the percent reduction of variance and residual standard deviation. Table 3-16 (independent sample) compares the rms errors involved in including and excluding upper-air data. As in the European test, better results were obtained when upper-air predictors were included, but the surface-data regression equations appear to be useful should upper-air data be unavailable.

TABLE 3-14
PREDICTORS SELECTED BY SCREENING REGRESSION
FOR WINTER CYCLONES OVER ASIA*

Forecast Interval, hr	Order of selection	N		E		D	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	P(15,5)	16.2	P(15,11)	16.5	ΔP(9,3)	14.8
	2nd	P(9,7)	12.5	Φ	6.9	ΔP(12,4)	5.9
	3rd	Φ	4.0	P(9,1)	4.4	P(10,5)	4.1
	4th	P(17,9)	2.0	ΔP(11,3)	3.5	P(10,6)	6.6
	5th	λ	1.7	ΔP(8,6)	2.6	ΔP(6,2)	2.8
	6th	P(12,4)	1.6	P(12,6)	1.8	λ	1.3
	7th	P(1,3)	1.5	P(9,5)	2.7	P(11,5)	1.2
	8th	P(10,6)	1.5	P(6,2)	1.6	ΔP(10,5)	1.5
	9th	P(9,5)	1.0	ΔP(11,5)	1.7	ΔP(3,9)	0.8
	10th	ΔP(10,2)	0.9	-	-	-	-
	11th	P(7,1)	0.9	-	-	-	-
Total			43.8		41.7		39.0
24	1st	P(15,5)	19.6	P(15,11)	19.0	ΔP(9,3)	24.7
	2nd	P(10,8)	15.6	Φ	9.5	Φ	4.3
	3rd	P(17,9)	4.3	P(11,1)	8.2	P(3,3)	3.0
	4th	ΔP(9,7)	3.1	P(15,7)	3.2	P(15,11)	2.6
	5th	Φ	2.1	ΔP(12,2)	2.2	P(10,5)	1.8
	6th	P(1,7)	1.8	P(17,11)	1.4	P(10,6)	4.3
	7th	λ	1.7	P(9,5)	1.1	ΔP(12,4)	3.1
	8th	ΔP(15,5)	0.9	ΔP(12,6)	1.3	λ	1.8
	9th	-	-	P(5,3)	1.1	ΔP(6,2)	1.1
	10th	-	-	ΔP(7,5)	1.2	ΔP(3,9)	0.9
	11th	-	-	-	-	P(12,6)	0.8
	12th	-	-	-	-	ΔP(9,5)	0.9
Total			49.1		42.8		51.3
36	1st	P(17,6)	20.7	P(15,11)	18.5	ΔP(9,3)	27.1
	2nd	P(10,8)	11.2	Φ	10.5	P(10,5)	9.6
	3rd	P(15,5)	6.1	P(11,1)	9.9	P(15,11)	3.7
	4th	Φ	4.2	P(15,7)	2.6	ΔP(12,2)	3.6
	5th	P(1,7)	2.5	ΔP(12,2)	1.2	P(12,6)	2.4
	6th	λ	1.7	P(9,5)	1.0	ΔP(10,6)	2.0
	7th	P(17,9)	1.7	P(5,5)	0.9	ΔP(5,3)	1.8
	8th	ΔP(14,4)	1.0	ΔP(12,6)	1.0	λ	1.6
	9th	-	-	-	-	P(5,9)	0.8
	10th	-	-	-	-	ΔP(5,9)	0.8
Total			49.1		45.6		55.4

*Excluding upper-air data.

TABLE 3-15
RESULTS OF SCREENING REGRESSION* ON WINTER CYCLONES OVER ASIA,
1975-1979 (DEPENDENT SAMPLE)

Forecast interval, hr	No. of predictors			Std. dev.			Residual std. dev.			% reduction		
	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$	$\hat{N}$	$\hat{E}$	$\hat{D}$
12	11	9	9	2.49	2.79	6.44	1.87	2.13	5.03	44	42	39
24	8	10	12	4.10	4.83	10.20	2.93	3.47	7.12	49	48	51
36	8	8	10	5.56	6.79	13.42	3.97	5.01	8.96	49	46	55

*Excluding upper-air data.

TABLE 3-16
RMS ERRORS IN TESTS ON WINTER CYCLONES OVER ASIA,
1959-1960 (INDEPENDENT SAMPLE)

Forecast interval, hr	Northeast displacement, deg. lat.		Eastward displacement, deg. lat.		Vector, deg. lat.		Change in central pressure, mb	
	Including upper-air data	Excluding upper-air data	Including upper-air data	Excluding upper-air data	Including upper-air data	Excluding upper-air data	Including upper-air data	Excluding upper-air data
12	1.71	1.87	2.13	2.19	2.73	2.88	5.22	5.19
24	2.45	2.96	3.54	3.75	4.31	4.78	7.19	7.93
36	3.32	3.92	5.07	5.51	6.17	6.76	9.38	10.18

3.3 European Anticyclones

The test on European anticyclones reported herein represents an initial feasibility test on anticyclones. Although the anticyclone has received recent attention [11] as a significant feature in a moving-coordinate statistical-prediction model, the form of the predictand to use is not so obvious as it is in the cyclone problem. An anticyclone obviously cannot be adequately described simply by its central pressure and location. The specification of a predictand that describes the shape of an anticyclone or the orientation of its major axis could be rewarding. For this particular study, the first attempt, however, was a straightforward application of the technique to predict only displacement and change in central pressure.

The geographical area for which cases were selected is area I of Fig. 2-1, the same as for European cyclones. In this case, however, no attempt was made at stratification, nor was there an experiment to use surface predictors only, although, based on results of surface-data regression for cyclones in Europe and Asia, such an approach seems entirely within reason.

3.3.1 Synoptic Climatology

Table 3-17 contains the means and standard deviations of the northward and eastward displacements and changes in central pressure for 658 European anticyclones for

TABLE 3-17
CHARACTERISTICS OF WINTER ANTICYCLONES OVER EUROPE,
1955-1959 (DEPENDENT SAMPLE)

Forecast interval, hr	Northward displacement, deg. lat.		Eastward displacement, deg. lat.		Change in central pressure, mb	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
12	-0.44	2.05	-1.90	2.50	0.40	2.57
24	-0.91	3.29	-3.87	4.47	0.59	4.06
36	-1.35	4.26	-5.83	6.37	0.57	5.39

($\phi: 49.2$ $\lambda: -7.2$)

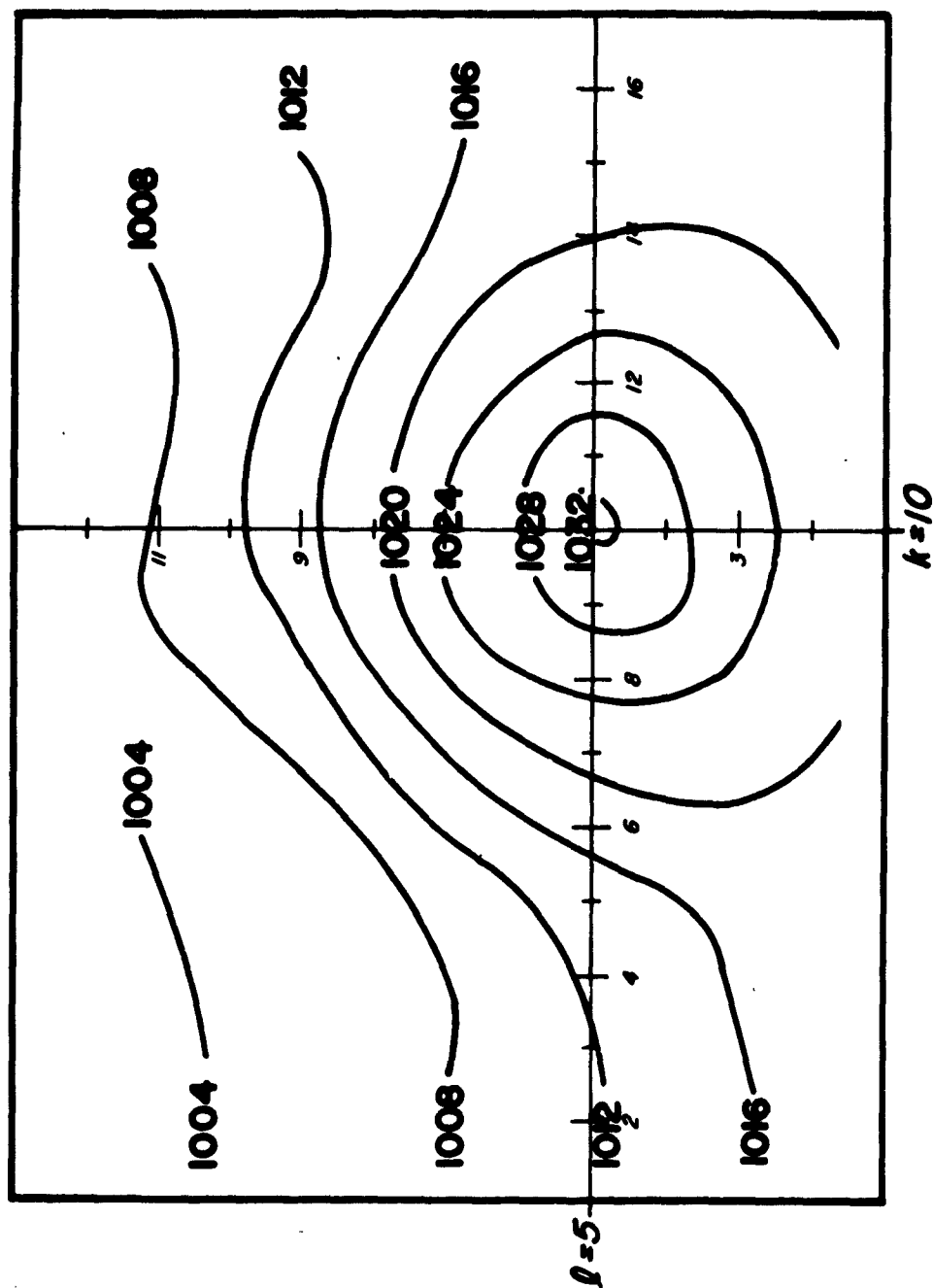


Fig. 3-15. Mean maps of sea-level pressure for winter anticyclones in Europe, 1955-1959 (dependent sample). Isobars are labeled in millibars.

($\phi:49.2$ $\lambda:-7.2$)

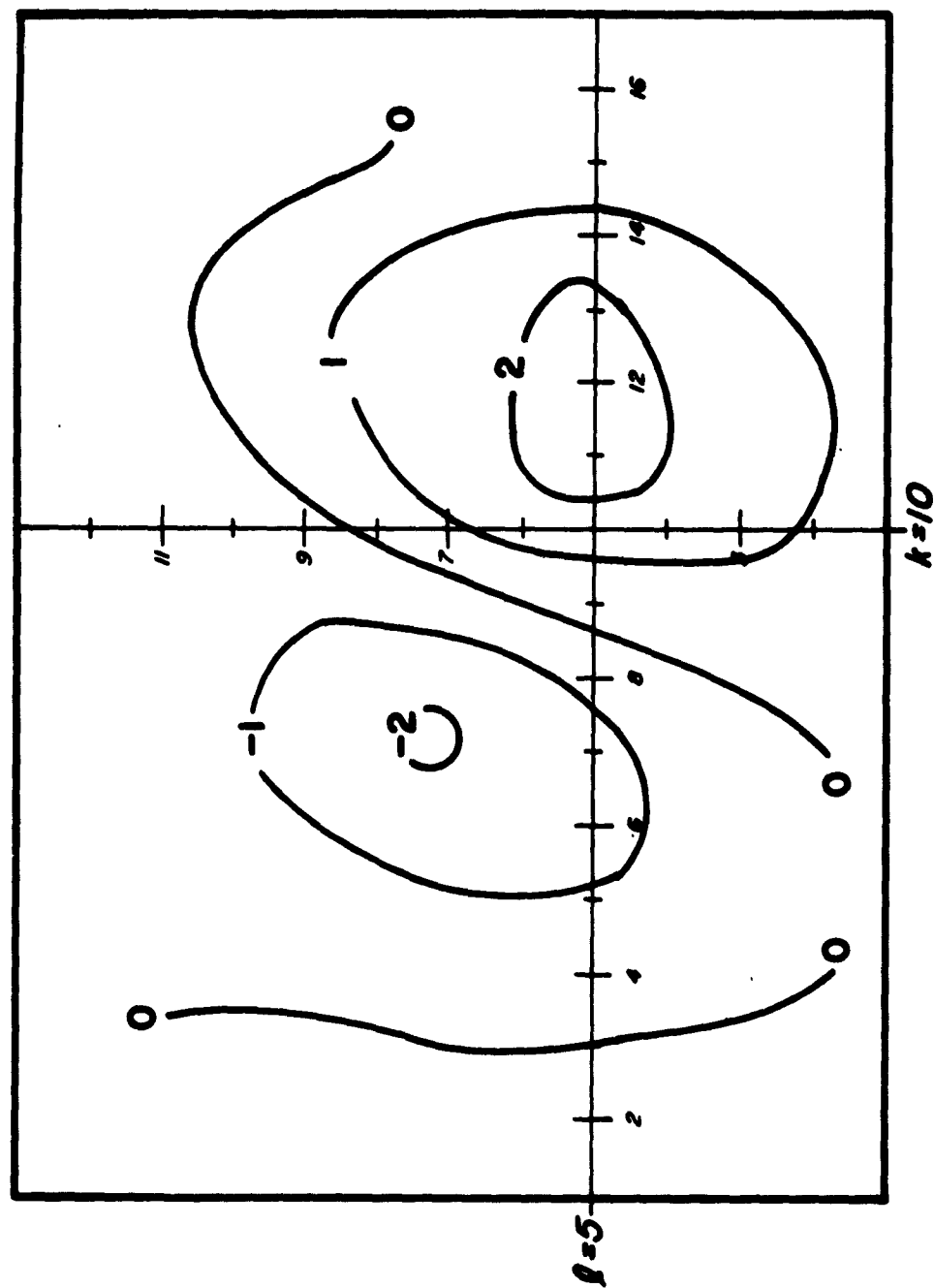


Fig. 3-16. Mean maps of 12-hr pressure change for winter anticyclones in Europe, 1955-1959 (dependent sample). Isalobars are labeled in millibars.

(0:49.2 λ :-7.2)

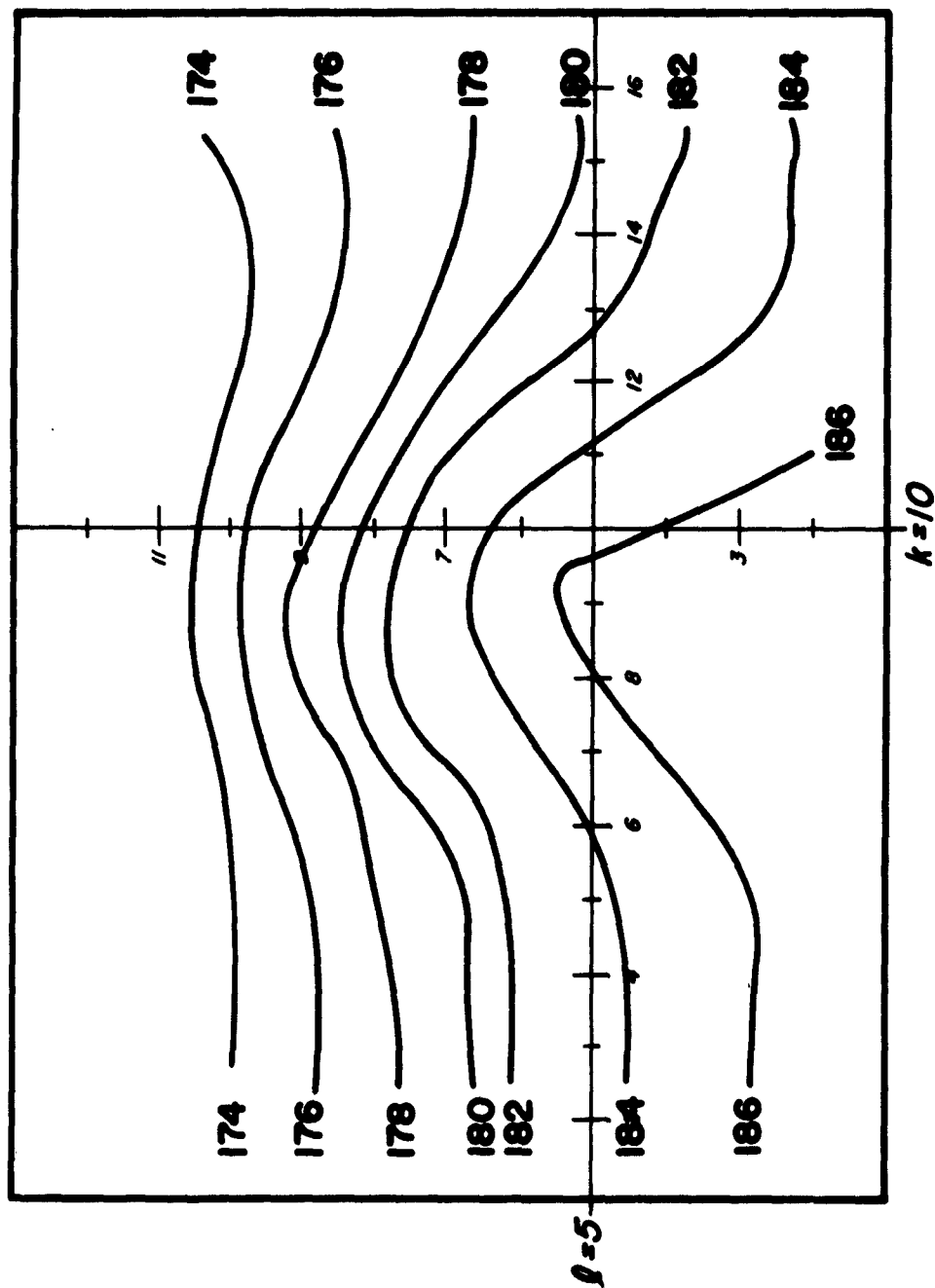


Fig. 3-17. Mean maps of 500-mb height for winter anticyclones in Europe, 1955-1959 (dependent sample). Isohypses are labeled in tens of feet.

($\phi:49.2$ $\lambda:-7.2$)

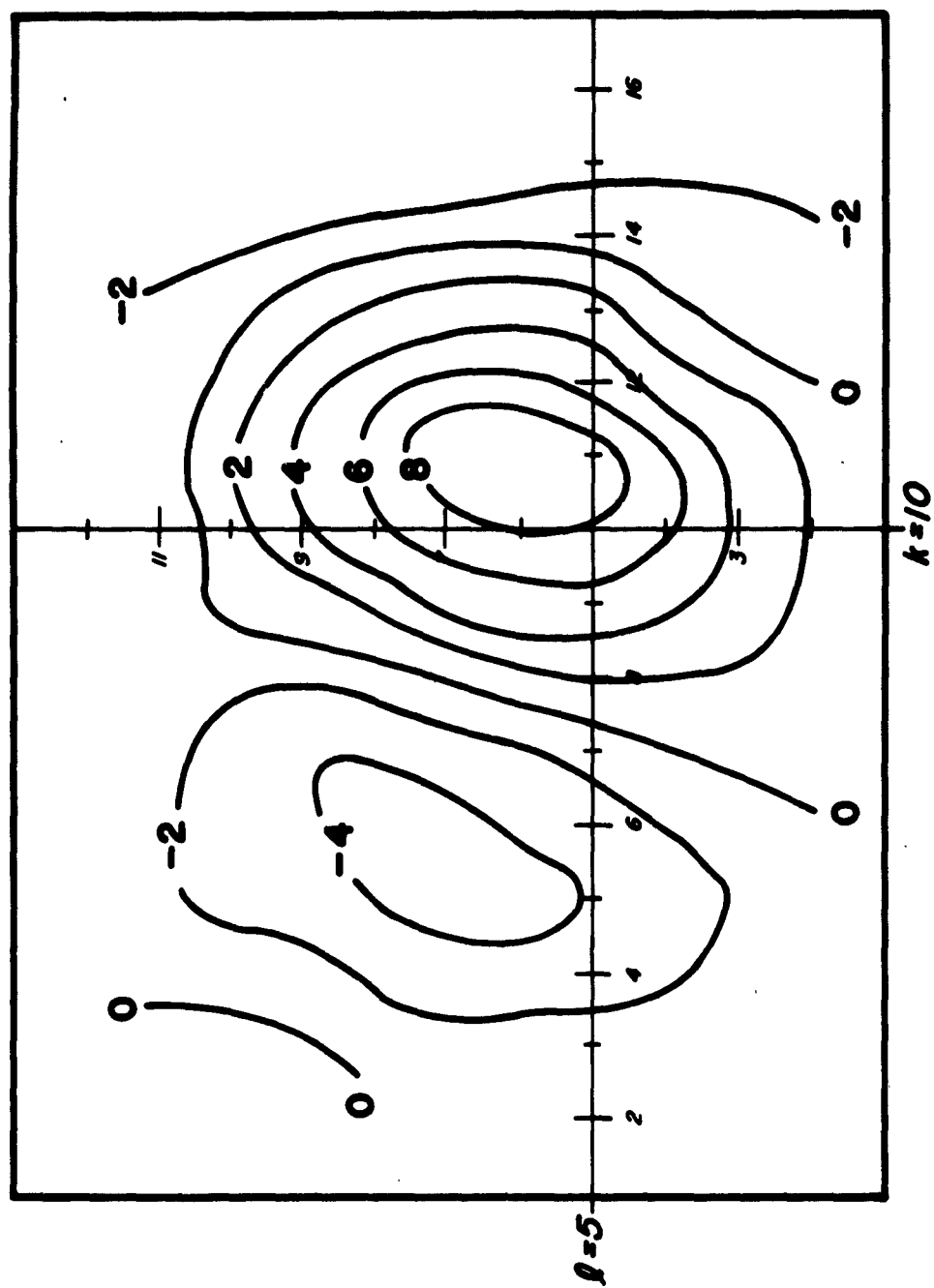


Fig. 3-18. Mean maps of 12-hr 500-mb height change for winter anticyclones in Europe, 1955-1959 (dependent sample). Isallohypes are labeled in tens of feet.

(0:49.2 λ : -7.2)

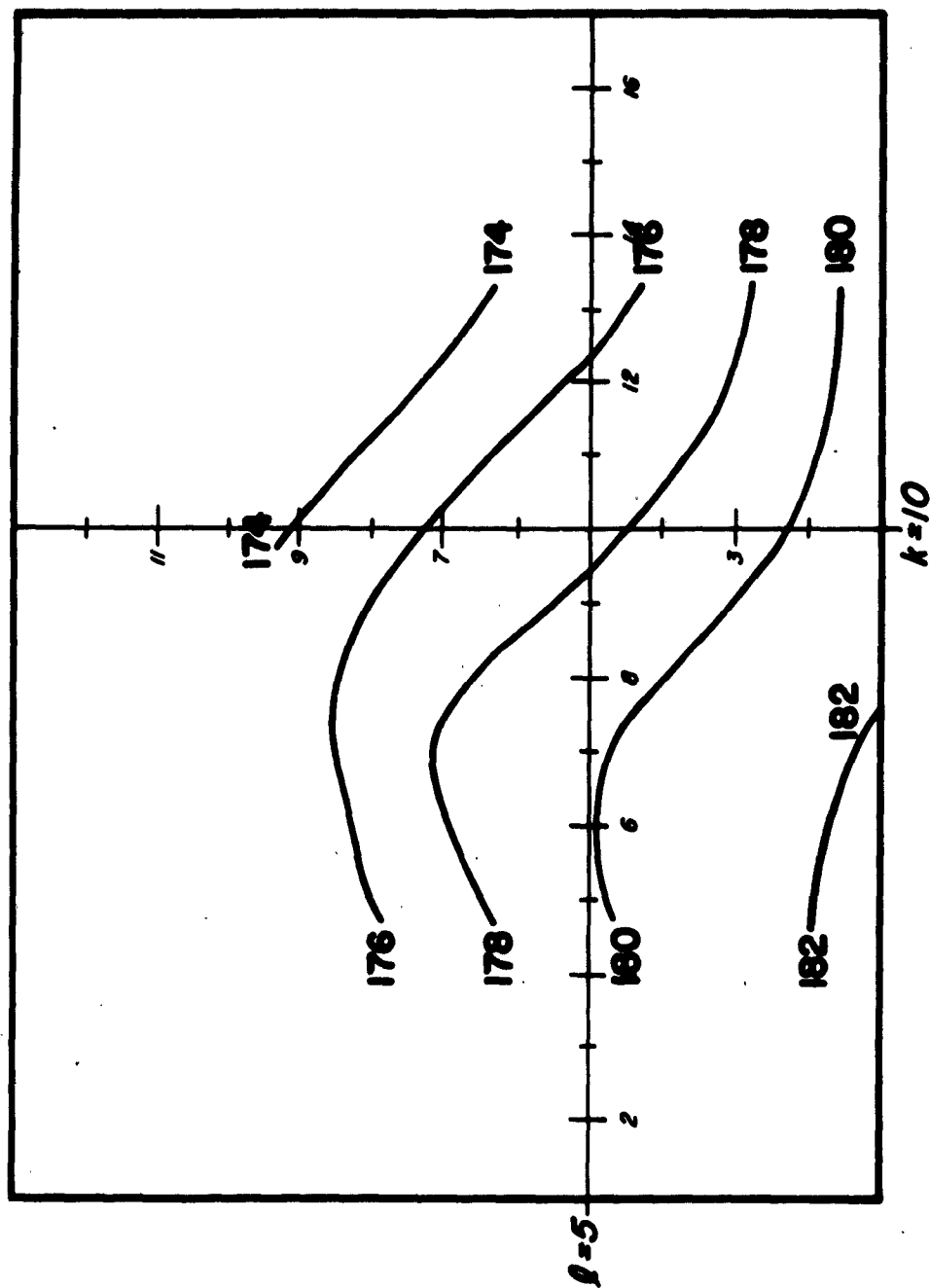


Fig. 3-19. Mean maps of 1000-500-mb thickness for winter anticyclones in Europe, 1955-1959 (dependent sample). Isopachs are labeled in tens of feet.

(0:49.2 λ : -7.2)

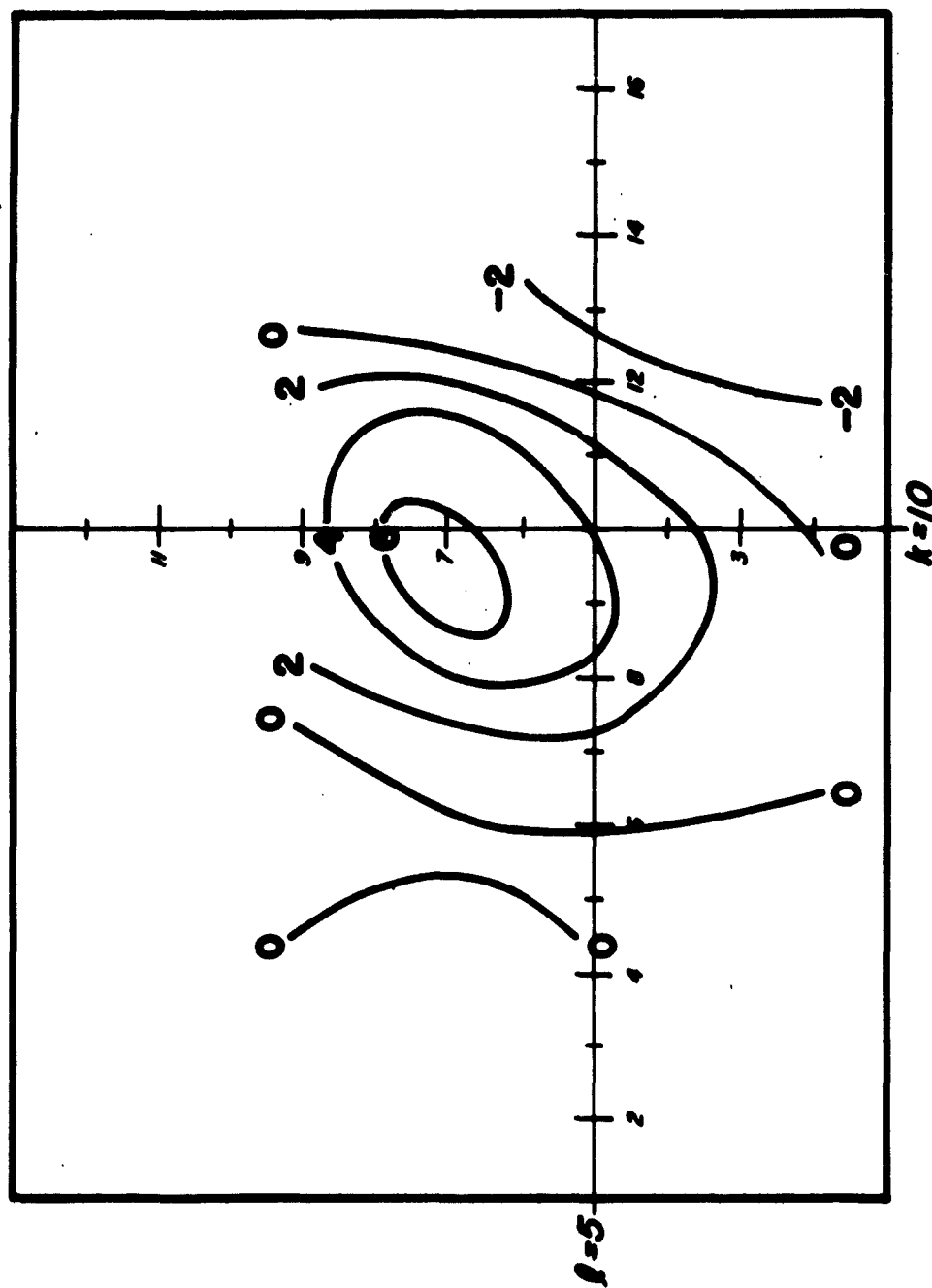


Fig. 3-20. Mean maps of 12-hr 1000-500-mb thickness change for winter anticyclones in Europe, 1955-1959 (dependent sample). Isolopachs are labeled in tens of feet.

12, 24, and 36 hr. It can be seen that the mean track is roughly east-southeastward at about 10 knots, with little change in central pressure.

The mean maps of pressure, height, and thickness are shown in Figs. 3-15 through 3-20. As expected, the features are about reversed from those on the cyclone maps. The mean central pressure of the anticyclones (Fig. 3-15) is 1032 mb. The 12-hr pressure change map (Fig. 3-16) shows a northwest-southeast orientation of isallobaric centers, with very small magnitudes. At 500 mb (Fig. 3-17), there is a north-south ridge about 380 km west of the anticyclone. The anticyclone is located in the northwestward flow ahead of the ridge. Height and thickness rises tend to dominate the 12-hr change maps (Figs. 3-18 and 3-20).

3.3.2 Results of Using Both Surface and Upper-air Predictors

The regression equations for European anticyclones were derived from the entire data sample (unstratified and containing both surface and upper-air predictors). The predictors are listed in Table 2-3. The results of the regression analysis are shown in Tables 3-18 and 3-19.

In Table 3-18, the first predictor selected by the screening procedure for the northward component is the same for all three time periods, $Z(13, 5)$. Its relationship with the predictand is to favor greater southward displacements the lower the height is. Here again, there is evidence of a kind of "steering" predictor. For eastward displacement, the central pressure was picked up first for the 24- and 36-hr forecast intervals, and the pressure one grid interval west was selected first for the 12-hr interval. The relationship is that weaker anticyclones tend to move eastward more rapidly than strong ones. For central pressure, there was a different "leading predictor" for each of the three time periods.

On independent data (Table 3-20), the only comparison currently available is with the climatology. The regression equations show improvement over climatology for all nine predictands.

TABLE 3-18
PREDICTORS SELECTED BY SCREENING REGRESSION
FOR WINTER ANTICYCLONES OVER EUROPE*

Forecast interval, hr	Order of selection	A		E		G	
		Predictor	% red.	Predictor	% red.	Predictor	% red.
12	1st	Z(13,5)	19.1	P(9,5)	18.1	ΔP(9,5)	17.8
	2nd	ΔP(9,7)	6.5	ΔP(7,7)	6.0	ΔP(11,7)	6.7
	3rd	ΔP(11,7)	2.9	ΔP(13,7)	3.2	P(10,5)	3.5
	4th	Z(9,5)	2.2	Z(13,1)	3.2	Φ	4.2
	5th	Z(11,9)	2.3	H(7,7)	3.4	P(11,5)	6.1
	6th	ΔP(9,5)	1.6	-	-	ΔH(9,5)	3.3
	7th	ΔZ(9,9)	1.3	-	-	ΔZ(13,7)	1.9
	8th	ΔP(5,5)	0.7	-	-	ΔP(9,7)	1.2
	9th	H(11,7)	0.6	-	-	H(13,5)	1.5
	10th	λ	0.9	-	-	-	-
	11th	P(9,11)	0.9	-	-	-	-
	12th	P(11,5)	0.9	-	-	-	-
	13th	P(11,7)	2.1	-	-	-	-
Total		42.0		35.9		46.2	
24	1st	Z(13,5)	22.6	P(10,5)	21.8	ΔP(11,7)	19.8
	2nd	ΔP(9,7)	9.2	ΔP(7,5)	8.0	Z(9,5)	11.0
	3rd	ΔP(11,9)	1.9	ΔP(11,5)	3.7	ΔP(9,7)	6.5
	4th	P(13,9)	1.7	P(5,5)	3.0	P(10,5)	3.7
	5th	P(11,1)	1.4	ΔP(13,9)	1.7	P(11,5)	3.9
	6th	Z(5,11)	1.6	Z(11,9)	2.1	Φ	3.5
	7th	ΔP(11,5)	1.4	Z(13,1)	2.9	ΔP(9,5)	2.7
	8th	-	-	Z(7,5)	2.1	-	-
	9th	-	-	ΔP(7,7)	1.4	-	-
Total		39.8		46.7		31.1	
36	1st	Z(13,5)	22.7	P(10,5)	23.7	Z(9,7)	22.2
	2nd	ΔP(9,7)	8.2	ΔP(7,5)	7.4	ΔP(9,7)	11.3
	3rd	P(11,1)	1.8	λ	4.1	P(10,5)	6.9
	4th	Z(5,11)	2.5	ΔP(11,7)	2.6	Φ	4.4
	5th	P(11,9)	1.4	Z(13,1)	2.5	ΔP(13,7)	3.7
	6th	ΔP(5,5)	1.8	Z(13,11)	4.0	-	-
	7th	P(9,11)	1.7	P(3,7)	1.5	-	-
	8th	ΔZ(9,1)	1.1	Z(9,7)	1.7	-	-
	9th	ΔZ(9,9)	0.9	Z(9,1)	1.3	-	-
	10th	H(7,7)	1.4	ΔZ(7,7)	1.2	-	-
Total		43.5		30.0		48.5	

*Including upper-air data.

TABLE 3-19
RESULTS OF SCREENING REGRESSION* ON WINTER ANTICYCLONES OVER EUROPE,
1955-1959 (DEPENDENT SAMPLE)

Forecast interval, hr	No. of predictors			Std. dev.			Residual std. dev.			% reduction		
	N	E	D	N	E	D	N	E	D	N	E	D
12	13	5	9	2.05	2.50	2.57	1.56	2.01	1.89	42	36	46
24	10	9	7	3.29	4.47	4.06	2.47	3.27	2.84	44	47	51
36	10	10	5	4.26	6.37	5.39	3.20	4.50	3.87	44	50	49

*including upper-air data.

TABLE 3-20
RMS ERRORS IN TESTS* ON WINTER ANTICYCLONES OVER EUROPE,
1959-1960 (INDEPENDENT SAMPLE)

Forecast interval, hr	Northward displacement, deg. lat.		Eastward displacement, deg. lat.		Vector, deg. lat.		Change in central pressure, mb	
	Climatol.	Regress.	Climatol.	Regress.	Climatol.	Regress.	Climatol.	Regress.
12	2.29	1.79	2.36	1.97	3.29	2.66	2.71	1.97
24	3.57	2.78	4.07	3.65	5.42	4.59	4.10	2.96
36	4.72	3.63	5.52	4.68	7.26	5.92	5.45	4.25

*including upper-air data.

4.0 FORECAST EXAMPLES

Examples of forecasts prepared for five cases selected from the independent data sample are given here to acquaint the reader with the performance of the various equations when applied to some rather interesting cases. Representative values of the overall accuracy of the equations may be found in the verification statistics (Sec. 3.0) based on the independent-data test of the entire independent sample.

4.1 Two European Cyclones

Figure 4-1(a) shows a portion of the surface chart at initial time 00 GCT 30 Jan. 1960. The cyclone of interest is centered in extreme-western U.S.S.R., just east of the Baltic Sea. The central pressure at forecast time is 1004 mb. The 500-mb chart at the initial time was marked by moderate to strong zonal flow over central and eastern Europe.

The observed positions 12, 24, and 36 hr subsequent to forecast time (reading generally from left to right) are shown as circles in Fig. 4-1(b). Three sets of 12-, 24-, and 36-hr forecasts are also shown: triangles denote the forecasts obtained by the application of the equations derived from the unstratified developmental sample; squares denote the forecasts based on the stratified (northern-zone in this instance) sample; and "x's" denote the forecasts based on equations containing only surface predictors. Observed and forecast central pressures are plotted adjacent to the corresponding observed or forecast position symbols.

The cyclone under consideration here moved due eastward for the first 12 hr and then moved east-southeastward for the next 24 hr of the forecast period. The cyclone slowly deepened; the central pressure had decreased to 998 mb by the end of the forecast interval.

The eastward, then east-southeastward motion of the cyclone was forecast rather well by the unstratified and surface-predictor equations, and the errors in central pressure were rather small for all three sets of forecasts. Table 4-1 is a summary of the verification of the 18 forecasts for this case.

Figure 4-2 illustrates the forecast of an intense mature cyclone. At initial time (00 GCT 18 Dec. 1959), a 966-mb low was centered near the Shetland Islands, due west of Bergen, Norway. This cyclone moved nearly due eastward for the first 24 hr of the

forecast period and then moved north-northeastward at about 25 knots for the next 12 hr. This cyclone filled 28 mb in 36 hr.

Both the stratified-sample and surface-predictor equations yielded more accurate position predictions for 12 and 24 hr than the unstratified-sample equations; however, the unstratified-sample equations gave the better indication of northward change in course of the cyclone center toward the end of the forecast period. All three sets of equations underforecast the 24- and 36-hr observed filling, but appreciable filling was predicted by all three types of equations.

4.2 Two Asian Cyclones

Figure 4-3(a) illustrates the surface chart at initial time (12 GCT 5 Jan. 1960) for one of two Asian cyclone-forecast examples. Figure 4-3(b) illustrates the observed and forecast tracks of the cyclone.

At initial time, the cyclone was centered just north of Hokkaido, and its central pressure was 984 mb. During the subsequent 36 hr, the center moved northeastward to the vicinity of the southern tip of Kamchatka and deepened an additional 20 mb. At 500 mb at initial time, there was a major trough in the westerlies about 10° of longitude west of the surface cyclone. Strong southwesterly winds prevailed in the mid and upper troposphere over the center. The verifications of the forecasts are given in Table 4-3.

Figure 4-4(a) shows the surface chart for 00 GCT 24 Dec. 1959. Forecasts of the 36-hr displacement and change in central pressure were computed for the 1002-mb low centered about 100 naut mi east of Hokkaido. As in the previous example, the 500-mb level was marked by a major trough from 10 to 15° of longitude west of the surface low, with strong southwesterly winds over Japan. In this case, the 500-mb southwesterlies divided into two distinct maxima, with the associated diffluent zone located over the surface cyclone. During the ensuing 36 hr, the surface low moved northeastward with an average speed of about 30 knots and deepened 45 mb!

Figure 4-4(b) shows a plot of the forecast and observed tracks of this rapidly intensifying cyclone. Table 4-4 is a tabulation of the various forecast errors. Each of the sets of forecasts gave good indications of significant deepening, and the maximum displacement error for all forecasts was 216 naut mi.

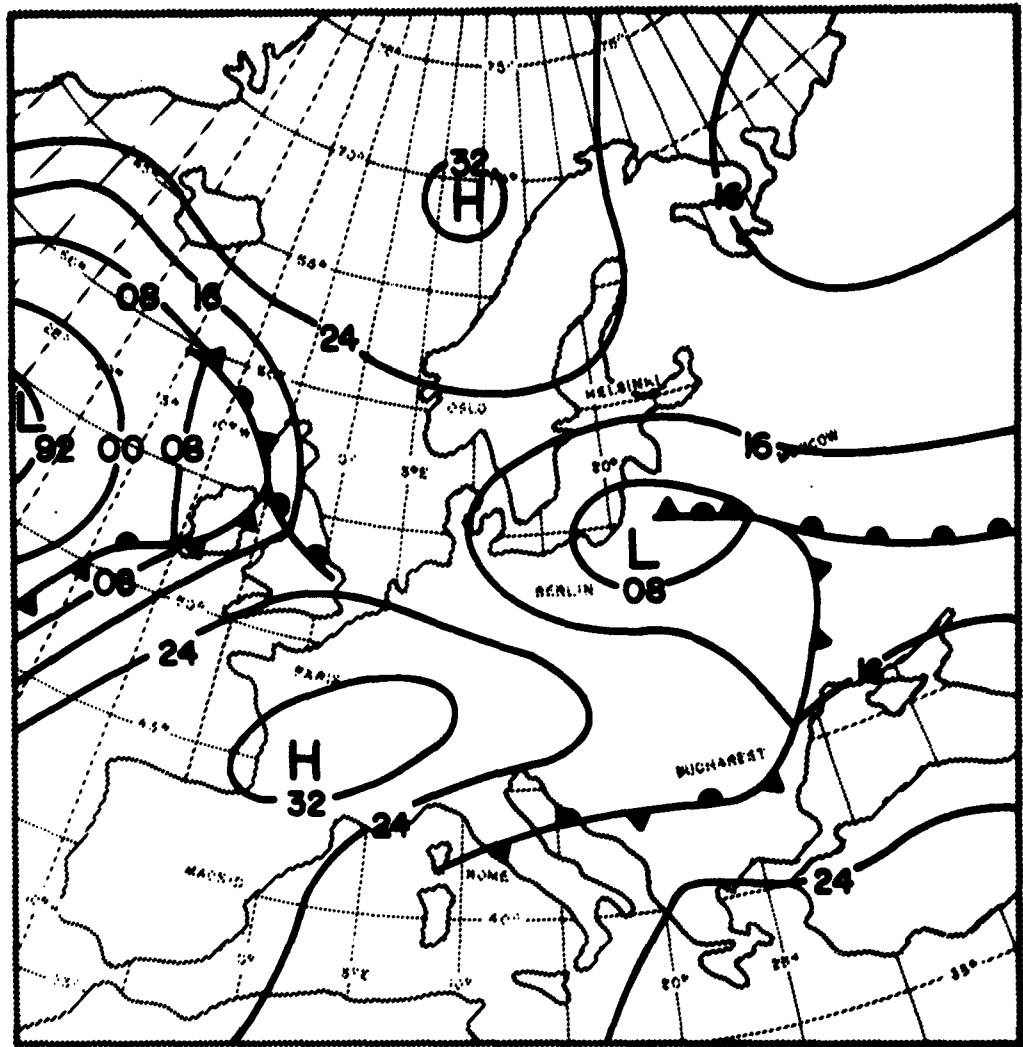


Fig. 4-1(a). First European cyclone-forecast example. Initial conditions at 00 GCT 30 Jan. 1960. Cyclone is located at 55.0°N , 22.5°E ; central pressure is 1001 mb.

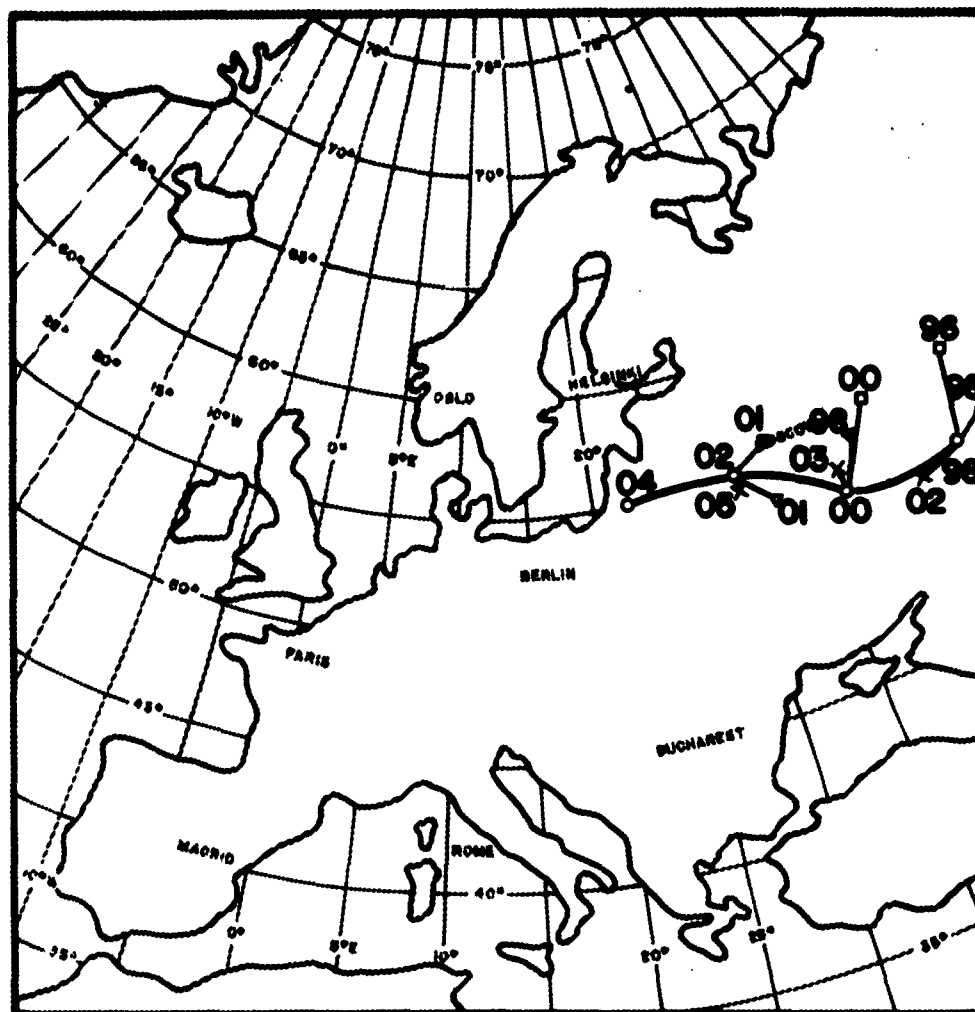


Fig. 4-1(b). Forecast verification. ○ Observed; △ unstratified prediction; □ stratified prediction; × surface predictors only.

TABLE 4-1
VERIFICATION SUMMARY OF CYCLONE SHOWN IN FIG. 4-1

Forecast length, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Strat. eqs.	Unstrat. eqs.	Surface data only	Strat. eqs.	Unstrat. eqs.	Surface data only
12	102	120	36	-1	-1	+3
24	228	132	60	0	-2	+3
36	222	78	126	-2	0	+4

*Central-pressure error equals predicted central pressure minus observed central pressure.

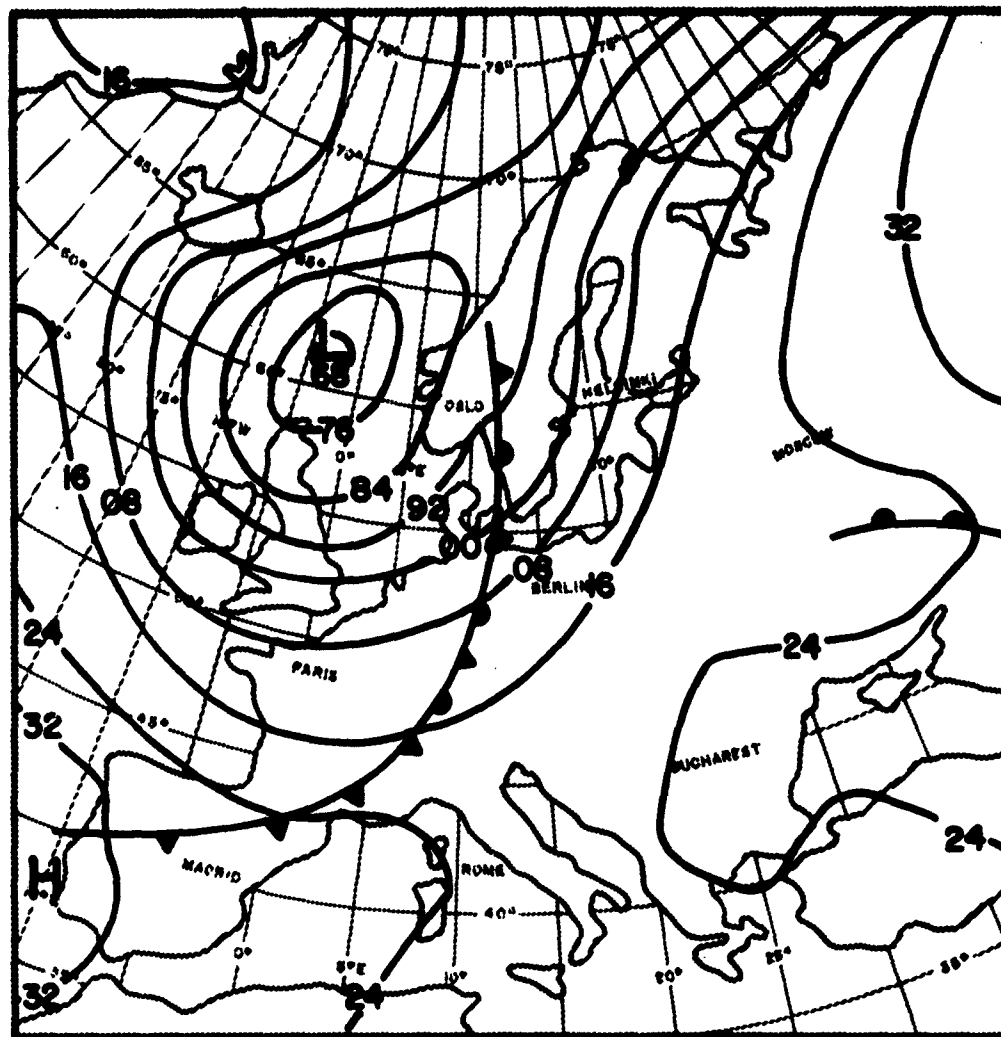


Fig. 4-2(a). Second European cyclone-forecast example. Initial conditions at 00 GCT 18 Dec. 1959. Cyclone is located at 61.5°N , 2.5°W ; central pressure is 966 mb.

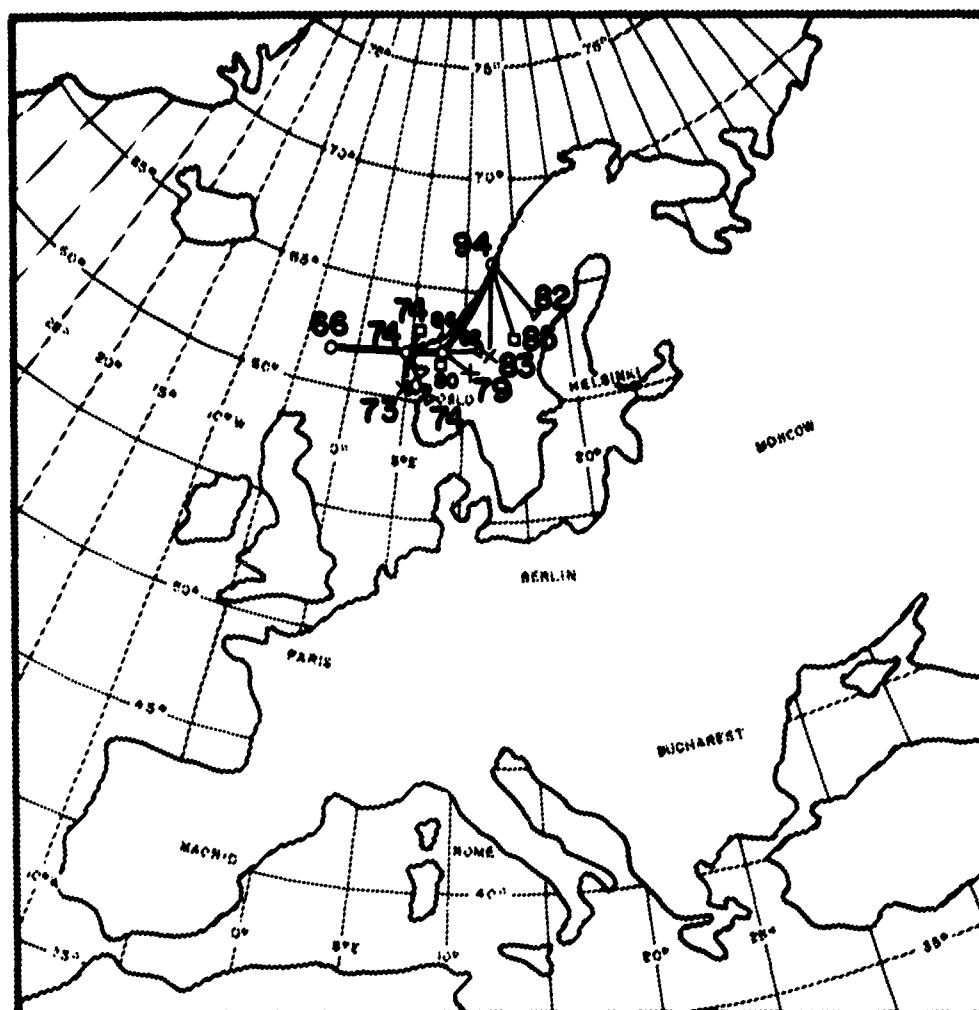


Fig. 4-2(b). Forecast verification. O Observed; Δ unstratified prediction; ◻ stratified prediction; x surface predictors only.

TABLE 4-2
VERIFICATION SUMMARY OF CYCLONE SHOWN IN FIG. 4-2

Forecast length, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Strat. eqs.	Unstrat. eqs.	Surface data only	Strat. eqs.	Unstrat. eqs.	Surface data only
12	54	120	108	0	0	-1
24	18	108	90	-6	-4	-7
36	216	180	234	-9	-12	-11

*Central-pressure error equals predicted central pressure minus observed central pressure.

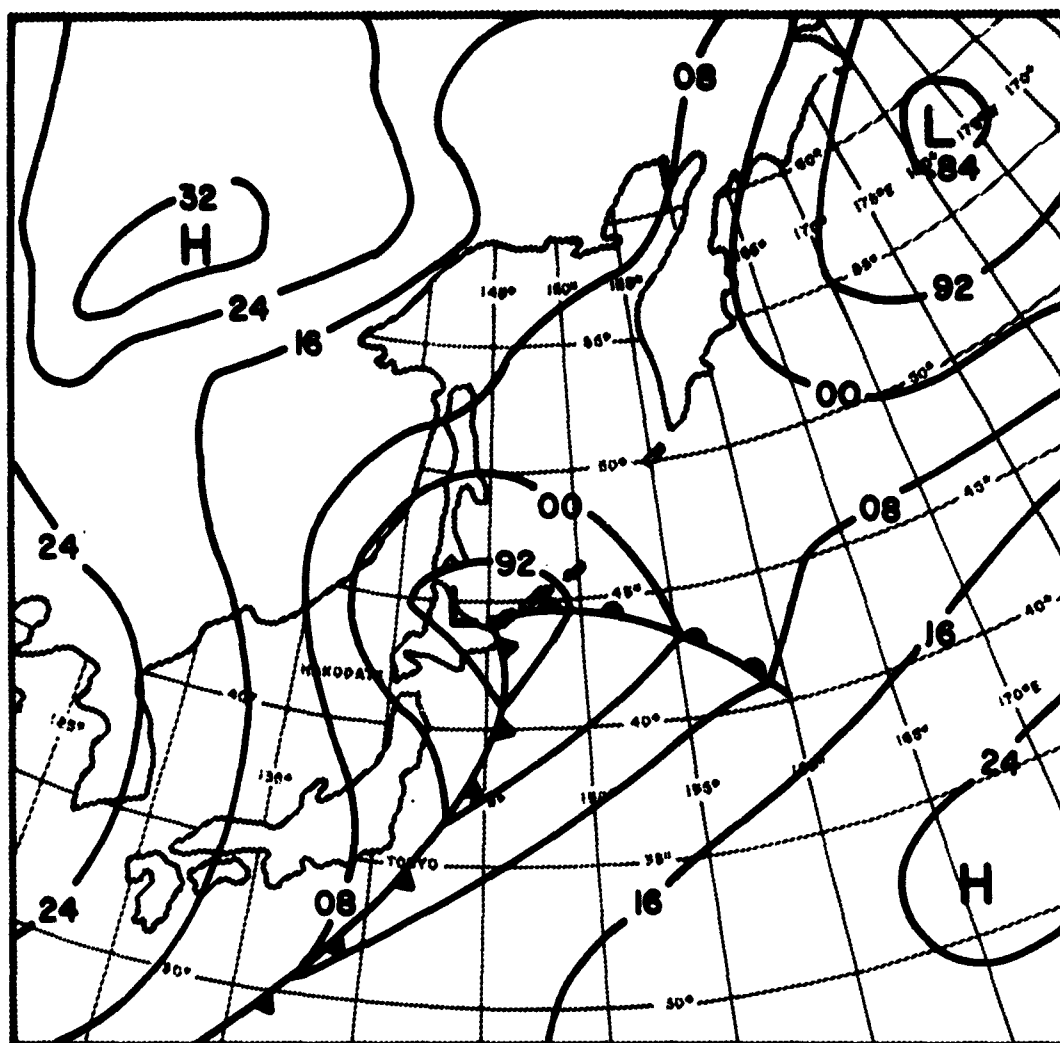


Fig. 4-3(a). First Asian cyclone-forecast example. Initial conditions at 12 GCT 5 Jan. 1960. Cyclone is located at 45.0°N , 145.0°E ; central pressure is 984 mb.

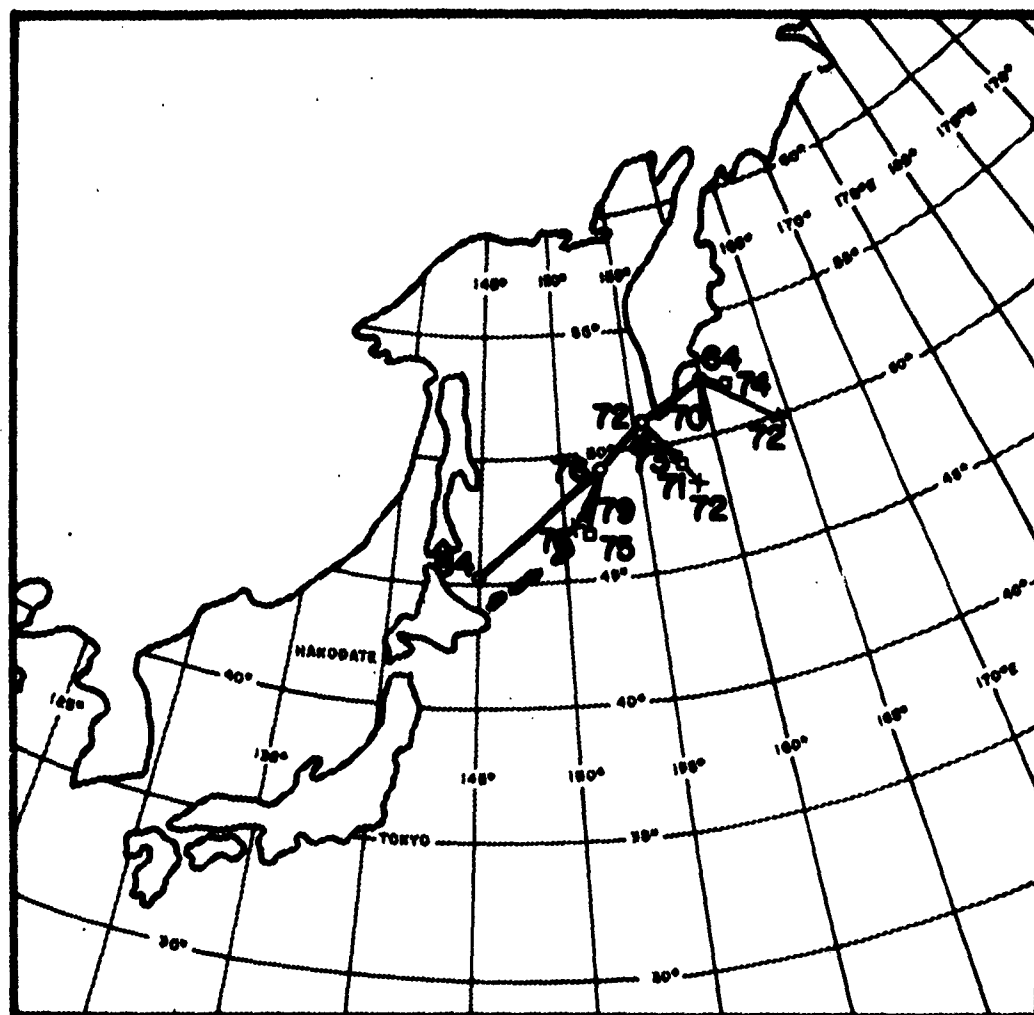


Fig. 4-3(b). Forecast verification. ○Observed; ▲unstratified prediction; ◐stratified prediction; ✕surface predictors only.

TABLE 4-3
VERIFICATION SUMMARY OF CYCLONE SHOWN IN FIG. 4-3

Forecast length, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Strat. eqs.	Unstrat. eqs.	Surface data only	Strat. eqs.	Unstrat. eqs.	Surface data only
12	150	114	144	-1	+3	0
24	168	144	228	-1	+1	0
36	66	78	240	+10	+6	+8

*Central-pressure error equals predicted central pressure minus observed central pressure.

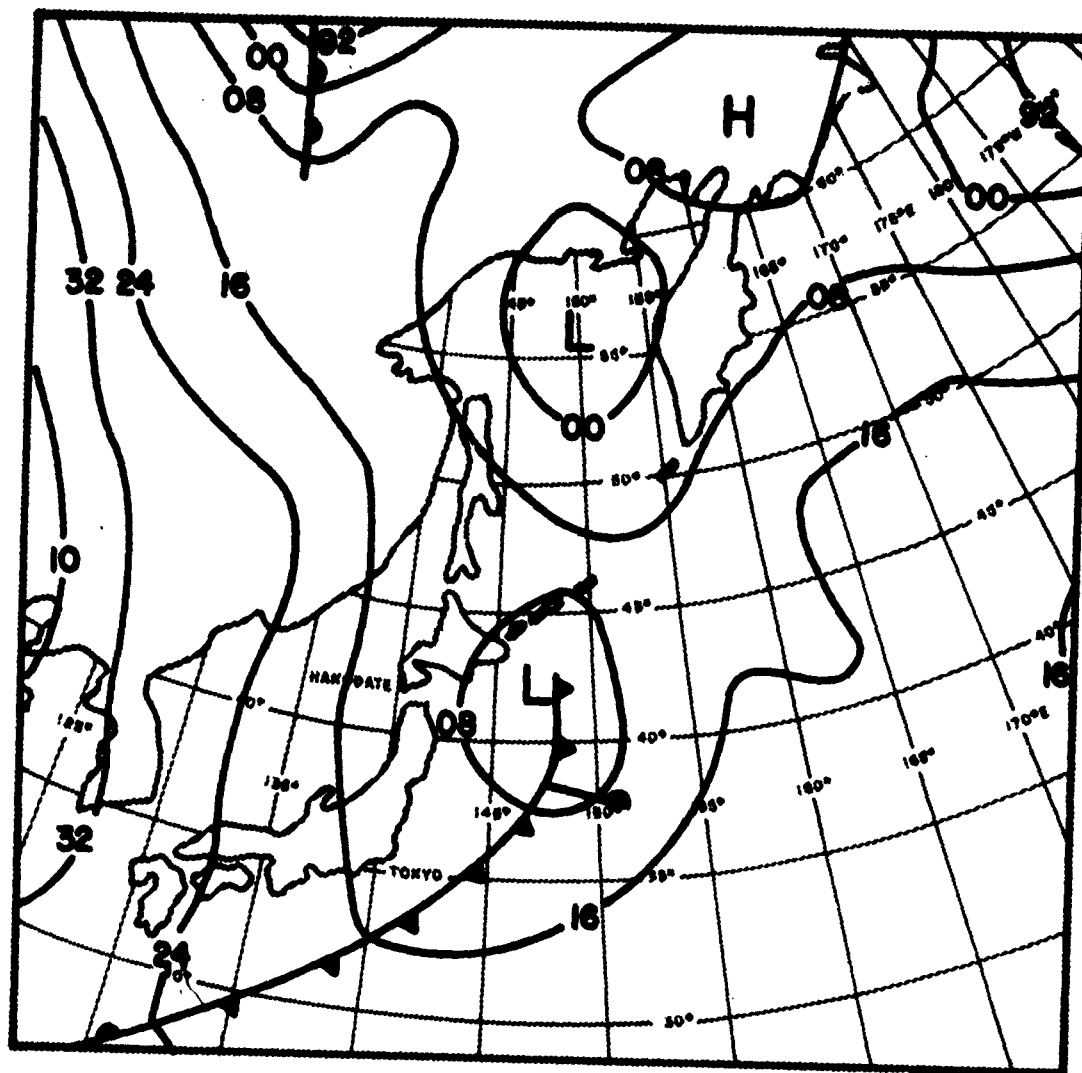


Fig. 4-4(a). Second Asian cyclone-forecast example. Initial conditions at 00 GCT 24 Dec. 1959. Cyclone is located at 42.5°N , 148.0°E ; central pressure is 1002 mb.

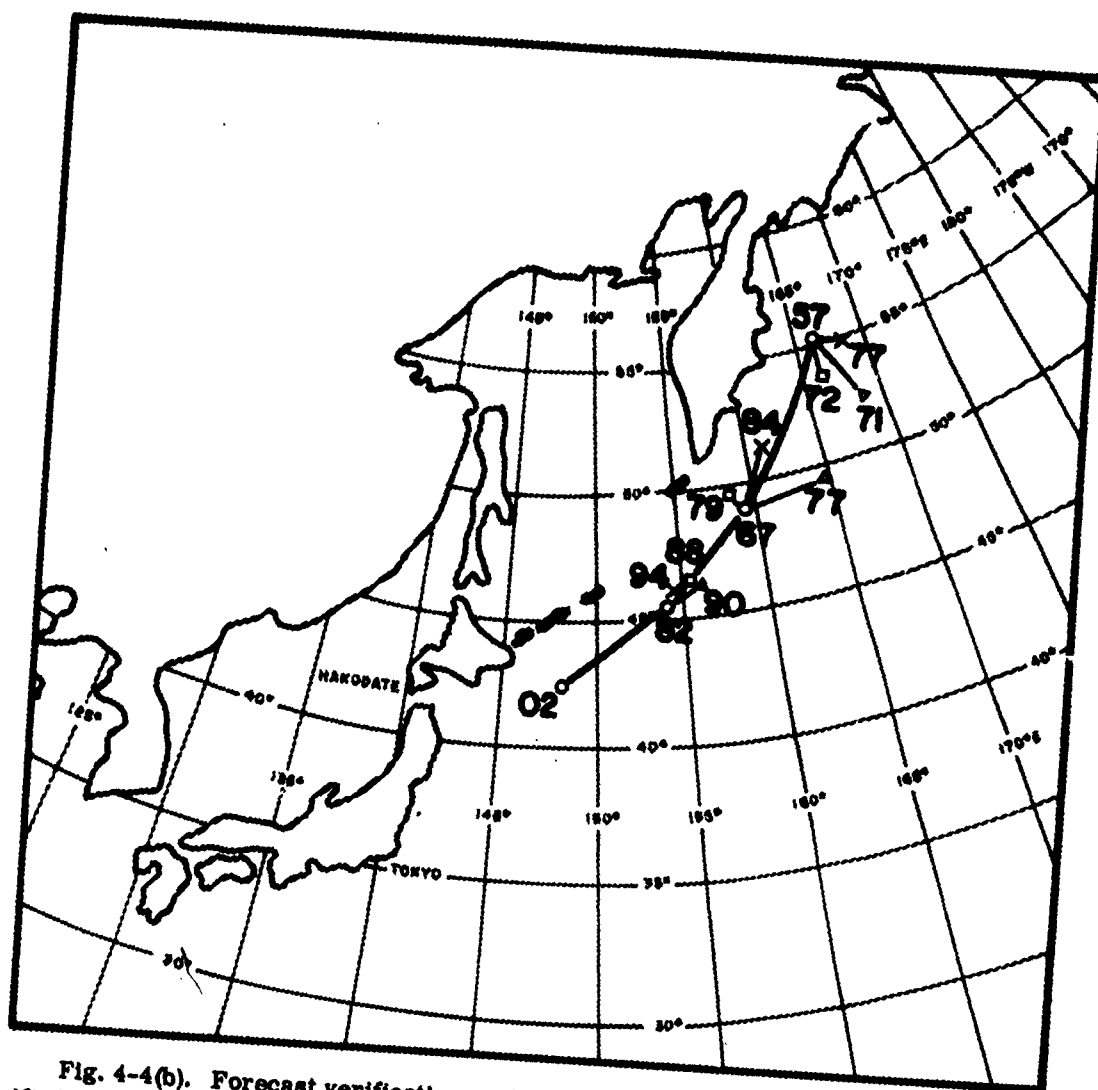


Fig. 4-4(b). Forecast verification. O Observed; Δ unstratified prediction; □ stratified prediction; × surface predictors only.

TABLE 4-4
VERIFICATION SUMMARY OF CYCLONE SHOWN IN FIG. 4-4

Forecast length, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Strat. eqs.	Unstrat. eqs.	Surface data only	Strat. eqs.	Unstrat. eqs.	Surface data only
12	78	96	42	+6	+8	+12
24	36	216	162	+12	+10	+17
36	96	192	78	+15	+14	+20

*Central-pressure error equals predicted central pressure minus observed central pressure.

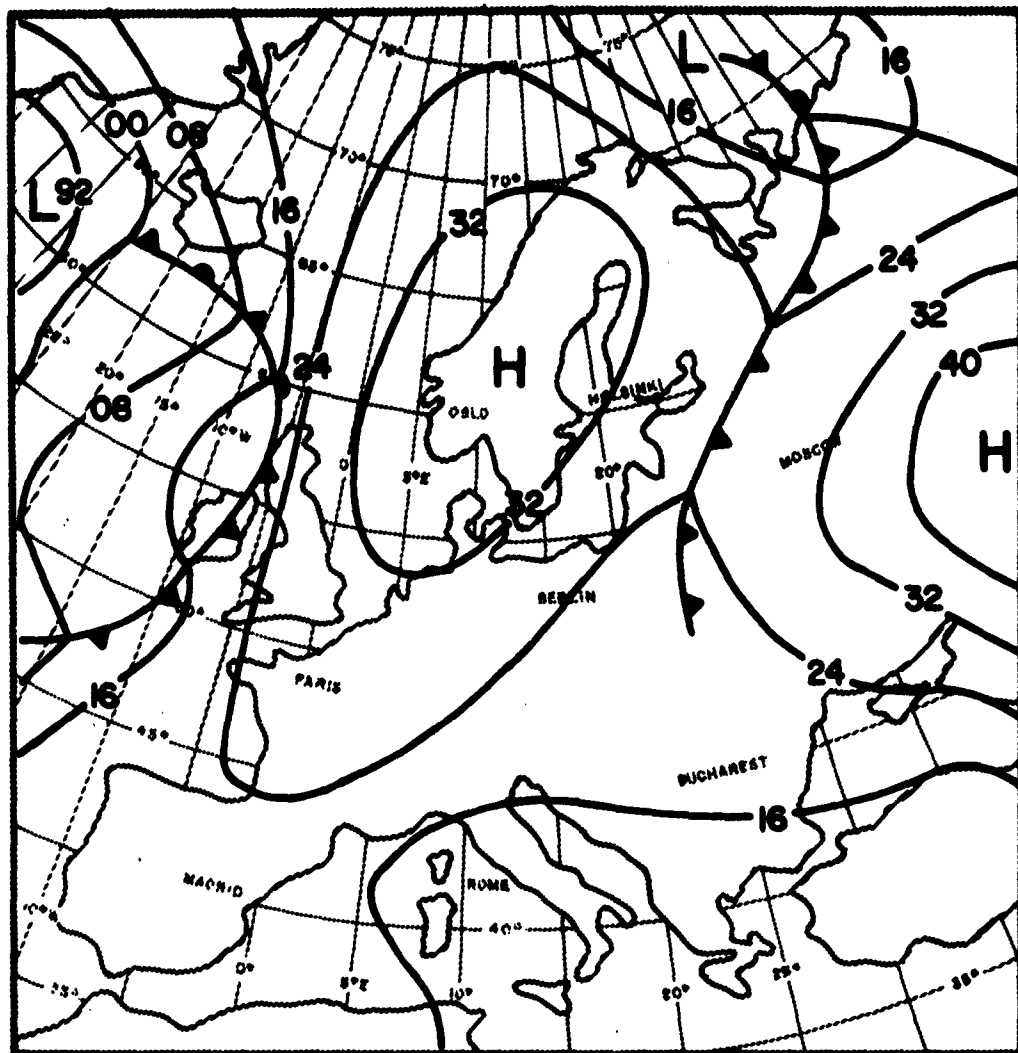


Fig. 4-5(a). European anticyclone forecast example. Initial conditions at 00 GCT 19 Mar. 1960. Anticyclone is located at 63.1°N , 12.5°E ; central pressure is 1038 mb.

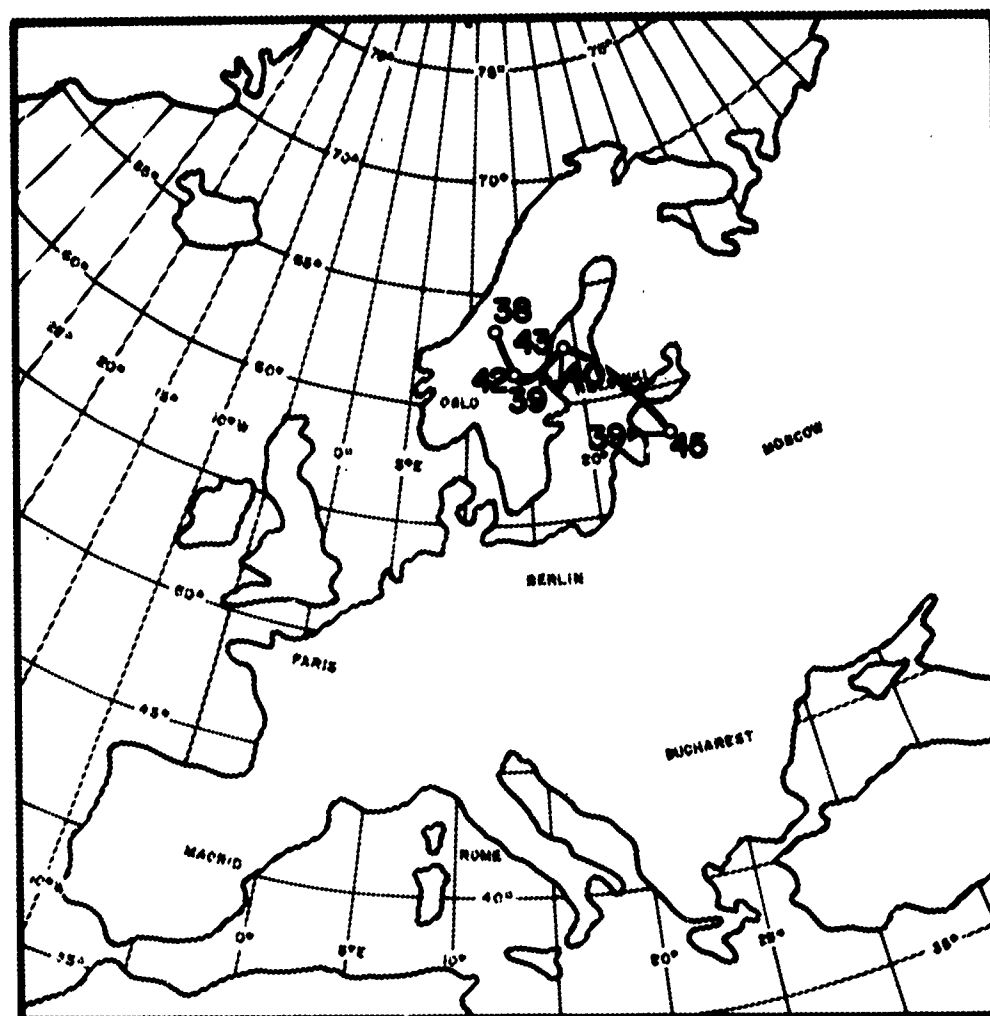


Fig. 4-5(b). Forecast verification. ○ Observed; △ unstratified prediction; □ stratified prediction; × surface predictors only.

TABLE 4-5
VERIFICATION SUMMARY OF ANTICYCLONE SHOWN IN FIG. 4-5

Forecast length, hr	Position-vector error, naut mi			Central-pressure error,* mb		
	Strat. eqs.	Unstrat. eqs.	Surface data only	Strat. eqs.	Unstrat. eqs.	Surface data only
12	-	66	-	-	-3	-
24	-	102	-	-	-3	-
36	-	78	-	-	-6	-

*Central-pressure error, equals predicted central pressure minus observed central pressure.

4.3 A European Anticyclone

Only one set of equations (unstratified developmental sample) was derived for the displacement and change in central pressure of European anticyclones. Twelve-, 24-, and 36-hr forecasts are illustrated in Fig. 4-5(b) for the 1038-mb high centered over Scandinavia at 00 GGT 19 Mar. 1960 and illustrated in Fig. 4-5(a). This high-pressure cell drifted slowly on a rather erratic path for the first 24 hr of the forecast period and then, during the last 12 hr of the period, moved somewhat more rapidly southeastward and was centered over western U.S.S.R., just east of the Gulf of Riga, at 12 GCT 20 Mar. 1960.

The forecast track gave a good indication of the acceleration of the center but underforecast the increase in central pressure. The vector errors of the 12-, 24-, and 36-hr position forecasts were 66, 102, and 78 naut. mi. respectively, and the corresponding errors in the central-pressure forecasts were -3, -3, and -6 mb.

5.0 SUMMARY AND CONCLUSIONS

Equations for the prediction of 12-, 24-, and 36-hr displacements and changes in central pressure have been derived for Asian cyclones and European cyclones and anti-cyclones.

The equations remained stable when applied to an independent data sample.

Preliminary comparisons with subjective forecasts prepared by European and Asian weather centers indicate that the equations yield results at least as good as those obtained subjectively.

Equations applicable to the entire area considered in Europe and to the entire area considered in Asia produced results at least as good as equations derived for subdivisions of the areas.

Equations were derived from surface data only for application when upper-air data are not available. Only a small decrease in accuracy was noted when these equations were compared with those derived from both surface and upper-air data.

The cyclone-prediction equations have general applicability to cyclones in their respective regions. A history of the cyclone track is not required, nor are the equations restricted to any particular synoptic pattern.

Application of the equations is completely objective, and they can be adapted for use by a weather detachment* or a completely automated weather central.

A useful by-product of the data processing required for the research is a five-year sample of error-checked hemispheric gridpoint values of surface pressure and 500-mb heights filed in a form suitable for direct electronic data-processing machine (EDPM) analysis.

*See App. C for worksheets illustrating application at the detachment level.

6.0 FUTURE INVESTIGATIONS AND EXTENSIONS

Diagnostic studies should be undertaken to establish quantitative relationships between circulation and weather. These should confirm or refute qualitative relationships suggested in the literature and isolate those pressure-pattern characteristics rich in weather-predictive information.

The approach should be extended to the investigation of the predictability of important characteristics isolated in the diagnostic studies and should be followed by the development of methods for combining the ensemble of significant-feature predictions to yield predictions of the entire surface-pressure field. It is worth noting that a major portion of the data required for extending the research to predict the surface-pressure field is now error-checked and available on magnetic tape.

Investigations should be conducted to improve the equations presented in this report by defining new possible predictors with a higher content of predictive information and developing methods for reducing the errors in estimating predictor values.

7.0 ACKNOWLEDGMENTS

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APPENDIX A. DATA PREPROCESSING

One of the major problems encountered when undertaking a statistical problem of the nature described in this report concerns the data to be used in the investigation. When the scope of the problem reaches the point at which some 11,000,000 gridpoint values are extracted manually from analyzed maps, tabulated, and placed on punched cards, there are going to be errors despite the most careful and systematic error-checking procedures. The best that can be hoped for is a minimization of "gross" errors. Although the data received for this project had already undergone considerable checks for errors, it was felt necessary to devise additional automatic error-checking procedures and subject the data to them. Although only a small percentage of additional errors were detected, enough were found to make the procedures extremely worth while.

There were two basic data types used in the development of multiple linear-regression prediction equations for cyclone and anticyclone displacement and intensification over Europe and Asia. Basically, these are historical series of weather maps (predictor data) and summaries of cyclone and anticyclone tracks (predictand data).

A.1 Predictor Data

The basic predictor data are from the gridpoint data collection made for Project 433L at the National Weather Records Center (NWRC) at Asheville, N.C. Pressure-height and temperature at several levels (including surface, 700 mb, and 500 mb) over the Northern Hemisphere were read from weather charts analyzed by the National Weather Analysis Center (NWAC) on a modified JNWP grid of 1020 points. Each map was actually read twice to eliminate errors. These gridpoint values were tabulated, placed on punched cards, and finally on IBM-705 magnetic tapes. The final set of data covered a continuous period of twice-daily (00- and 12-GCT) analyses from April 1955 to March 1960, a complete five-year sample. For the three fields of interest in significant-feature studies, sea-level pressure, 700-mb height, and 500-mb height, this involved more than 11,000,000 numbers. For a detailed description of the 433L gridpoint data-extraction procedures and card-tape formats, the reader is referred to the Reference Manual for Climatic Data Computer Tapes [8].

A.2 Predictand Data

Cyclone and anticyclone tracks were tabulated from microfilmed NWAC surface analyses. The location (latitude and longitude) and central pressure of every winter (November–March) cyclone over Europe (area I of Fig. 2-1) was plotted at 12-hr intervals for the five winters corresponding to the gridpoint data. This included cyclones that were either previously or subsequently outside area I. Similar procedures were used for Asian cyclones and European anticyclones. From these plotted tracks, only cyclones or anticyclones that were identifiable for 36 hr were tabulated and put on punched cards. For those that qualified, the following information was tabulated for each synoptic time (00 or 12 GCT).

- (a) Date and time.
- (b) Latitude, longitude, and central pressure (initial time t_0).
- (c) Latitude, longitude, and central pressure ($t_0 + 12$ hr).
- (d) Latitude, longitude, and central pressure ($t_0 + 24$ hr).
- (e) Latitude, longitude, and central pressure ($t_0 + 36$ hr).

The number of cases shown in Table 2-1 is equivalent to the number of cards that were punched.

With the IBM-705 magnetic tapes and the punched cards of cyclone and anticyclone tracks available for processing, a variety of computer programs (Table A-1) was written at the United Aircraft Corporation Research Laboratory.* These programs and their sequential use are shown in the flow diagram, Fig. A-1. In detail, the programs were used as follows.

The first step was to process each of the Asheville IBM-705 grid tapes separately by the gridpoint data-conversion and -editing program. Since each tape contained only two months of grid data, there were 30 tapes in all to cover the full 60-month (five-year) period. This program selects the variables to be processed: sea-level pressure, 700-mb height,

*Cosponsored by the United States Air Force, under the 433L Contract, and the Federal Aviation Agency, under Contract FAA/BRD-363.

TABLE A-1
COMPUTER PROGRAMS
WRITTEN BY
UNITED AIRCRAFT CORPORATION RESEARCH LABORATORY

Program	Function
Gridpoint data conversion and editing	Selects gridpoint data of interest. Checks for gross errors. Converts 705 tape to 7090 tape.
Grid correction	Inserts corrections. Outputs merged tape.
Gridpoint interpolation	Converts from 433L grid to JNWP grid. Outputs merged tape.
Predictand preprocessor	Converts locations and central pressure to predictand format. Outputs on tape.
Significant-feature preprocessor	Generates a tape for screening regression by (a) selecting maps, (b) reading maps (transforming and interpolating grids), (c) deriving predictors.

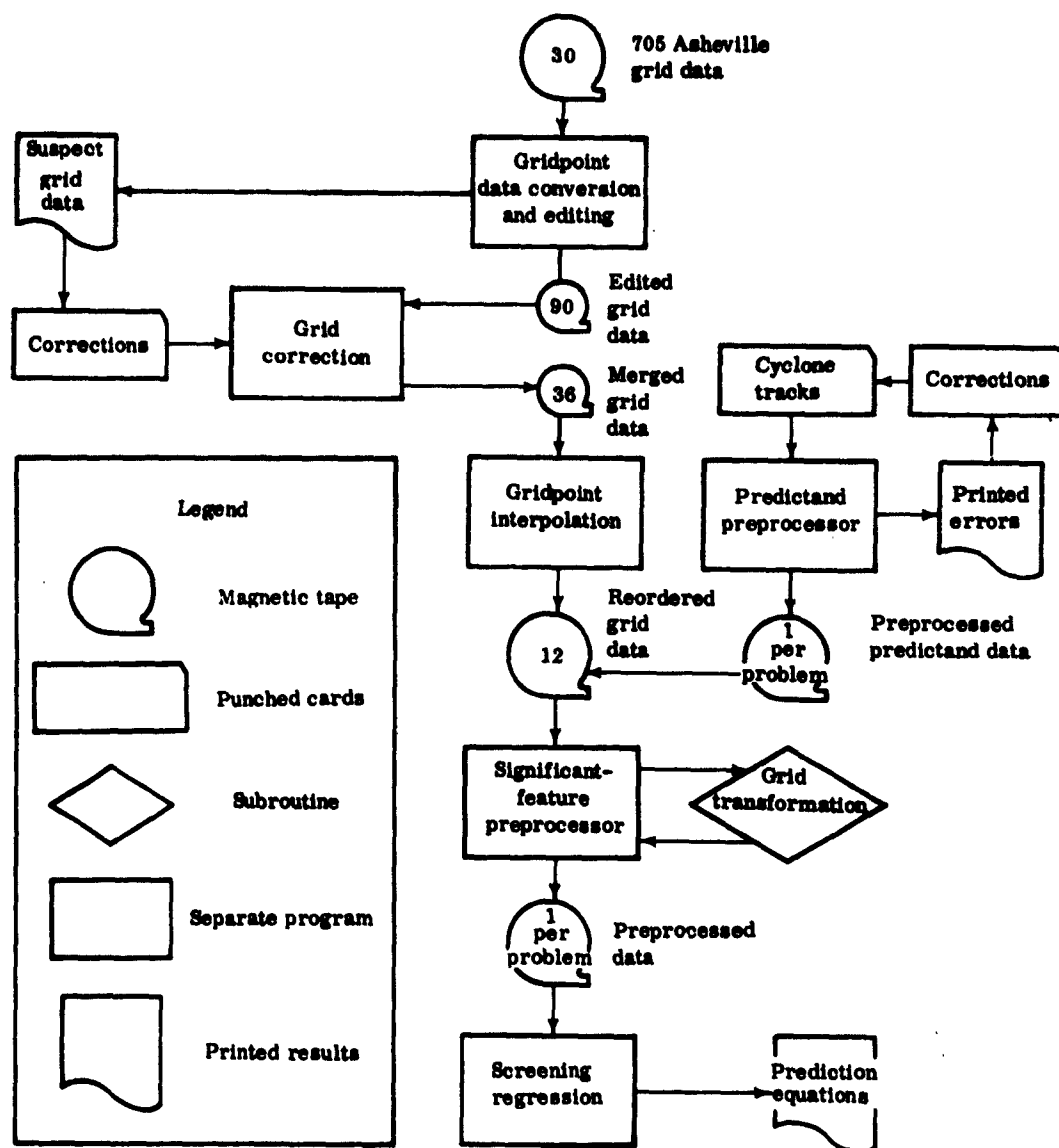


Fig. A-1. Computer programs used to preprocess data for use in screening regression. Numbers appearing within tape symbols refer to the number of magnetic tapes involved.

and 500-mb height. Other variables on the tape, such as heights at other levels (e.g., 300 mb) and temperatures at all levels, were not processed. Having made this selection, the program then examined every "map" for gross errors. Differences in values between adjacent gridpoints were computed, and a preselected percentage of the largest ones were printed out, along with appropriate identification. Also, gridpoints that had missing data were noted as well as values outside certain specified limits, and printed out. This program also converted the selected data and output it onto magnetic tape in a format acceptable to the kind of computer to be used for subsequent stages of processing (the IBM-7090). The output of this program was a set of three 7090 tapes for every one that was used as input, each of which contained only information from one level (surface, 700-mb, or 500-mb) for a two-month period. Thus, the processing of the thirty IBM-705 tapes resulted in ninety IBM-7090 tapes.

The next step was very important and was a strictly manual operation. It consisted of examining the printout of missing and otherwise suspicious gridpoint data. Much of the data, although printed out, were acceptable due to unusually strong gradients or intense systems. For example, all sea-level pressures in excess of 1060 mb were printed out. Many of these were valid because of the Siberian high, for instance. However, there were some pressures between 1090 and 1099 mb that were actually supposed to have been between 990 and 999 mb, as shown by examination of microfilm maps. The practice then was to go from the printout to NWAC microfilmed analyses to verify the validity of suspicious data. In this way, gross errors were noted, and corrected values were tabulated. Corrections to missing data were also supplied from examination of microfilmed maps. It should be emphasized that the grid data received from NWRC were by and large in very good condition, with the error percentage being extremely small. However, the nature of the study required even additional scrutiny of the data to eliminate so-called gross errors.

The gridpoint corrections, having been tabulated, were placed on punched cards to be used as input to the grid-correction program. All corrections cards for one level for five years of one month were processed together (e.g., 500-mb heights for five Januaries). The program inserted the corrections in the proper places and wrote a new tape consisting of the one level for five years of one month. Thus the program not only inserted the necessary

corrections but also reduced the number of required tapes from 90 to 36.

The grid format used for the initial data extraction at NWRC was a modified JNWP grid, in which data were read for every other JNWP gridpoint. It was found desirable to have data at every JNWP gridpoint to facilitate subsequent computations. The grid-interpolation program accomplished this by computing values at the in-between gridpoints by a least-squares fitting of a quadratic surface, using surrounding data at known gridpoints. Thus, the program output complete maps on the 1977-point JNWP grid. Another feature of the program is that it used three tapes as input (e.g., five Januaries of sea-level pressure, 700-mb height, and 500-mb height). It read in the first record (map) from each tape, which were all for the same time (e.g., 00 GCT 1 Jan. 1956), and output them as the first three records of the new tape. Hence, the final tape for a month was in chronological order (i.e., three levels for 00 GCT 1 Jan. 1956, three levels for 12 GCT 1 Jan. 1956, three levels for 00 GCT 2 Jan. 1956, etc., through 31 Jan. 1960). The result was that data on the 36 tapes using a modified JNWP grid were now contained on 12 tapes with a full JNWP grid, each tape representing a complete five-year month. These tapes were then ready to serve as the basic set of "maps" for predictor information.

The predictand data were handled independently of these programs. The predictand-preprocessor program accepted the punched card input of significant-feature tracks and computed the two components of displacement and the change in central pressure, which were the predictand forms desired. This information was then placed on magnetic tape. An important by-product of this program is a printout of displacements and changes in central pressure that deviate a great deal from climatology. Thus, an error-checking procedure was provided, and new punched cards were prepared when errors were noted.

The predictand tape and the predictor tapes were then used as input to the significant-features preprocessor program. This program generated a tape for screening regression by selecting cyclones (or anticyclones), "reading" maps, and deriving predictors. It did so in the following manner. The first cyclone case was determined from the cyclone-tabulation input. Using the time and date of this case, the gridpoint-data tapes were searched to find the three data records corresponding to this time (one record for each map of sea-level pressure, 700-mb height, and 500-mb height) and also for the same three maps 12 hr

previous to that time. These six records were read into the machine. The next step was analogous to superimposing a moving-coordinate grid (centered with respect to the cyclone) over the fixed-grid system and interpolating data values for gridpoints in the moving-coordinate system. The subroutine that computed these locations is the grid-transformation routine. Whereas the JNWP or "fixed" grid has 1977 gridpoints, the moving grid has only 221 points. With the use of data at the four surrounding gridpoints of the fixed grid, values were computed by interpolation at each of the 221 gridpoints of the moving-grid system for all six maps stored in the machine. The procedure of reading maps into the machine, computing locations of gridpoints, and interpolating data, was accomplished for all cyclones to be considered. Selection and derivation of possible predictors from this newly generated set of data was then performed. Possible predictors consisted of point values of sea-level pressure, 500-mb height, 1000-500-mb thickness, and 12-hour changes of these quantities. The changes in latitude and longitude (both in degrees of latitude) and central pressure of the cyclone were used as predictands for 12, 24, and 36 hr.

The results of this series of programs were magnetic tapes that could be used directly as input to the screening-regression program to derive prediction equations for cyclones in Europe and Asia and anticyclones in Europe. In addition, useful by-products included a relatively error-free five-year set of gridpoint data, which can be used for work on significant features in other seasons, such as cyclones in summer, or for other meteorological problems.

APPENDIX B. PREDICTION EQUATIONS

The prediction equations derived from the regression analysis have the form

$$\hat{Y} = A_0 + A_1 X_1 + A_2 X_2 + \dots + A_n X_n, \quad (B-1)$$

where $\hat{Y}$ is the predictand, the A's are constant coefficients derived from the developmental sample, and the X's are the predictors selected by the screening procedure.

Each set of prediction equations consists of nine equations: the three predictands of northward displacement, eastward displacement, and change in central pressure for the forecast intervals of 12, 24, and 36 hr.

The pair of numbers that is associated with a given predictor in the equations refers to the grid location in the (k, l)-grid system of Fig. 2-2. For convenience, the symbols and units of the predictands and predictors are repeated in Table B-1.

For operational application, the equations in worksheet form represent a more convenient means for solution. An example of such worksheets is shown in Appendix C.

B.1 European Cyclones

B.1.1 Equations Using Both Surface and Upper-air Predictors

B.1.1.1 Northern Zone

$$\begin{aligned}\hat{N}_{12} &= 52.9918 + 0.0129 Z(15, 5) - 0.0370 Z(9, 7) - 0.0591 P(5, 1) + 0.0272 Z(13, 5) \\ \hat{E}_{12} &= 39.5583 - 0.0233 Z(9, 1) + 0.0081 Z(13, 9) - 0.0838 \Delta P(9, 5) - 0.0178 Z(13, 1) \\ &\quad + 0.0268 Z(11, 7) - 0.0159 Z(9, 5) \\ \hat{D}_{12} &= 196.012 + 0.4022 \Delta P(9, 5) - 0.4952 P(10, 5) + 0.3473 P(11, 5) - 0.1160 P(13, 1) \\ &\quad - 0.2024 \Delta P(7, 1) + 0.0616 \Delta Z(9, 5) - 0.0800 \lambda + 0.0377 Z(9, 7) \\ \hat{N}_{24} &= 49.9238 + 0.0321 Z(15, 5) - 0.0608 Z(9, 7) - 0.0314 Z(5, 1) + 0.0422 Z(11, 1) \\ &\quad - 0.2643 \phi + 0.0475 P(15, 7) - 0.0306 H(9, 1) \\ \hat{E}_{24} &= 71.2974 - 0.0397 Z(9, 1) + 0.0257 Z(13, 9) - 0.0340 Z(13, 1) - 0.0330 \Delta Z(9, 5) \\ &\quad + 0.0266 Z(13, 7) - 0.0515 P(10, 5) + 0.0104 Z(5, 11) \\ \hat{D}_{24} &= 296.830 + 0.2471 \Delta Z(9, 5) - 0.4131 P(10, 5) - 0.1385 \Delta H(9, 5) - 0.1349 \lambda \\ &\quad + 0.0652 Z(9, 7) \\ \hat{N}_{36} &= - 9.7252 + 0.0530 Z(15, 5) - 0.0753 Z(9, 7) + 0.0270 \Delta Z(13, 3) - 0.0364 Z(5, 1) \\ &\quad - 0.3310 \phi + 0.1294 P(13, 1)\end{aligned}$$

TABLE B-1
SYMBOLS AND UNITS USED IN PREDICTION EQUATIONS

(a) Predictands

Symbol	Description	Unit of measurement
$\hat{N}$	Predicted northward displacement	Deg. lat.
$\hat{E}$	Predicted eastward displacement	Deg. lat.*
$\hat{D}$	Predicted change in central pressure	mb

(b) Predictors

Symbol	Description	Unit of measurement
P	Sea-level pressure	mb
ΔP	12-hr pressure change	mb
Z	500-mb height	10 ft
ΔZ	12-hr height change	10 ft
H	1000-500-mb thickness	10 ft
ΔH	12-hr thickness change	10 ft
ϕ	Latitude of significant feature	Deg. lat.
λ	Longitude of significant feature	Deg. long.†

*Negative values indicate eastward displacement.

†Positive for W longitude, negative for E longitude.

$$\begin{aligned}\hat{E}_{36} = & 55.9758 - 0.0591 Z(9, 1) + 0.0436 Z(13, 9) - 0.0396 Z(13, 1) - 0.0491 \Delta Z(9, 5) \\ & + 0.0232 Z(15, 7)\end{aligned}$$

$$\begin{aligned}\hat{D}_{36} = & 252.359 - 0.0289 Z(9, 3) + 0.8375 \Delta P(9, 5) - 0.7384 P(10, 5) + 0.0893 H(9, 7) \\ & - 0.0748 Z(13, 1) + 0.5178 P(11, 5)\end{aligned}$$

B.1.1.2 Southern Zone

$$\hat{N}_{12} = 32.4831 - 0.0637 P(7, 7) + 0.0374 Z(13, 3) - 0.0207 Z(9, 7)$$

$$\hat{E}_{12} = -74.4198 + 0.0189 Z(11, 9) + 0.0755 P(5, 7) - 0.0187 Z(7, 1)$$

$$\hat{D}_{12} = 139.129 + 0.3750 \Delta P(9, 3) - 0.3095 P(10, 5) + 0.1683 P(11, 7)$$

$$\hat{N}_{24} = 75.8769 - 0.1229 P(7, 5) + 0.0537 Z(13, 3) - 0.0280 Z(9, 9) - 0.0350 \Delta Z(7, 9)$$

$$\hat{E}_{24} = -157.067 + 0.0383 Z(11, 9) + 0.1263 P(3, 7) - 0.0250 Z(9, 5)$$

$$\begin{aligned}\hat{D}_{24} = & 286.717 - 0.6027 P(10, 5) + 0.4455 \Delta P(9, 3) + 0.2411 P(11, 7) - 0.1061 \lambda \\ & + 0.0414 H(9, 9)\end{aligned}$$

$$\hat{N}_{36} = 132.281 - 0.0439 Z(9, 9) + 0.0656 Z(13, 3) - 0.1713 P(5, 3)$$

$$\hat{E}_{36} = -323.286 + 0.0490 Z(13, 9) + 0.2245 P(5, 7)$$

$$\begin{aligned}\hat{D}_{36} = & 568.932 - 0.6602 P(10, 5) + 0.0521 Z(11, 9) - 0.1046 \lambda + 0.4314 \Delta P(9, 3) \\ & - 0.4810 \Delta P(3, 3)\end{aligned}$$

B.1.1.3 Both Zones

$$\begin{aligned}\hat{N}_{12} = & 80.4874 - 0.1099 P(7, 1) + 0.0444 P(13, 3) - 0.1008 P(9, 7) + 0.0198 Z(15, 5) \\ & - 0.0161 H(7, 7) + 0.0796 P(11, 3)\end{aligned}$$

$$\begin{aligned}\hat{E}_{12} = & 53.3866 + 0.0251 P(15, 9) - 0.0638 P(11, 1) + 0.0159 P(5, 7) - 0.0673 \Delta P(7, 5) \\ & - 0.0142 Z(9, 1) + 0.0237 Z(11, 7) - 0.1127 P(10, 5) + 0.1784 P(11, 5) - 0.0165 H(13, 3) \\ & + 0.0088 Z(5, 9) - 0.1007 P(9, 5)\end{aligned}$$

$$\begin{aligned}\hat{D}_{12} = & 208.903 + 0.3983 \Delta P(9, 5) - 0.5119 P(10, 5) + 0.0370 Z(9, 7) - 0.0894 \lambda \\ & + 0.3955 P(11, 5) - 0.1593 P(13, 3) + 0.0371 \Delta Z(9, 3)\end{aligned}$$

$$\begin{aligned}\hat{N}_{24} = & 105.753 - 0.1131 P(7, 1) + 0.0294 P(15, 3) - 0.0067 P(9, 9) + 0.0263 Z(15, 5) \\ & - 0.0359 Z(9, 7) + 0.0412 Z(11, 3) - 0.0355 \Delta Z(9, 9) - 0.0227 H(7, 3) - 0.0898 P(11, 7) \\ & + 0.0576 P(15, 7)\end{aligned}$$

$$\begin{aligned}\hat{E}_{24} = & 67.6409 + 0.0313 P(15, 9) - 0.0763 P(11, 1) + 0.0492 P(5, 7) - 0.0253 Z(9, 1) \\ & - 0.0062 Z(13, 9) - 0.0279 \Delta Z(7, 5) + 0.0240 Z(11, 9) - 0.0354 H(13, 3) + 0.0366 Z(13, 7) \\ & - 0.0630 P(10, 5)\end{aligned}$$

$$\begin{aligned}
\hat{D}_{24} &= 391.755 + 0.3859 \Delta P(9, 5) - 0.7520 P(10, 5) + 0.0551 Z(9, 7) - 0.1249 \lambda \\
&\quad + 0.1883 \Delta P(11, 3) + 0.4173 P(11, 5) - 0.1554 P(13, 1) + 0.0615 \Delta Z(9, 5) \\
&\quad + 0.1603 \Delta P(11, 9) \\
\hat{N}_{36} &= 53.0587 - 0.1541 P(7, 1) - 0.0500 P(9, 9) + 0.0582 Z(15, 5) - 0.0479 Z(9, 7) \\
&\quad + 0.1319 P(13, 1) - 0.0453 \Delta Z(9, 9) + 0.0420 \Delta Z(13, 3) \\
\hat{E}_{36} &= - 3.9246 + 0.0414 P(15, 9) - 0.0593 P(11, 1) + 0.0800 P(5, 7) - 0.0275 Z(9, 1) \\
&\quad + 0.0477 Z(13, 9) - 0.1078 \Delta P(9, 5) - 0.0312 Z(13, 1) - 0.1411 P(9, 3) + 0.0993 P(13, 5) \\
\hat{D}_{36} &= 496.676 - 0.6125 P(10, 5) + 0.5398 \Delta P(9, 5) + 0.0227 Z(13, 9) - 0.1535 \lambda \\
&\quad + 0.0878 Z(9, 7) + 0.0782 \Delta Z(11, 3) - 0.0442 H(11, 3) + 0.0759 \Delta Z(11, 7)
\end{aligned}$$

B.1.2 Equations Using Surface Predictors Only (Both Zones)

$$\begin{aligned}
\hat{N}_{12} &= 37.880 - 0.1313 P(7, 1) + 0.0349 P(14, 4) - 0.0452 P(9, 7) + 0.1745 P(11, 3) \\
&\quad + 0.0938 \Delta P(8, 2) - 0.0710 \phi - 0.1213 P(10, 6) + 0.0206 P(5, 13) + 0.0335 P(17, 7) \\
\hat{E}_{12} &= - 65.852 + 0.0332 P(15, 9) - 0.0872 P(11, 1) + 0.0512 P(5, 7) - 0.1282 \Delta P(8, 6) \\
&\quad + 0.0371 P(13, 5) - 0.1250 P(10, 5) + 0.1240 \Delta P(11, 5) + 0.1123 P(12, 6) \\
&\quad + 0.0396 P(5, 1) \\
\hat{D}_{12} &= 150.26 + 0.3929 \Delta P(9, 5) - 0.5351 P(10, 5) + 0.1693 P(11, 7) - 0.1612 \phi \\
&\quad - 0.0628 \lambda + 0.2688 P(10, 4) + 0.1867 \Delta P(11, 5) - 0.0498 P(3, 9) \\
\hat{N}_{24} &= 68.515 - 0.2075 P(7, 1) + 0.0392 P(15, 5) - 0.0069 P(11, 9) - 0.1361 \phi \\
&\quad + 0.0561 P(7, 13) + 0.1251 \Delta P(9, 1) + 0.0989 P(13, 1) - 0.2152 P(11, 7) + 0.0914 P(15, 7) \\
&\quad + 0.1276 P(11, 3) - 0.0446 P(7, 9) + 0.1138 \Delta P(13, 7) \\
\hat{E}_{24} &= - 96.546 + 0.0988 P(15, 9) - 0.2067 P(11, 1) + 0.0345 P(5, 7) - 0.1538 \Delta P(8, 6) \\
&\quad - 0.1887 P(10, 5) + 0.1076 P(11, 5) + 0.1566 \Delta P(12, 4) + 0.1217 P(13, 5) \\
&\quad + 0.0710 P(5, 1) \\
\hat{D}_{24} &= 224.82 + 0.5714 \Delta P(9, 5) - 0.6890 P(10, 5) + 0.0846 P(12, 8) - 0.1958 \phi \\
&\quad + 0.3841 P(11, 5) - 0.0702 \lambda + 0.2378 \Delta P(11, 3) \\
\hat{N}_{36} &= 93.061 - 0.2107 P(7, 1) - 0.0677 P(9, 9) + 0.2018 P(13, 3) + 0.0625 P(7, 13) \\
&\quad - 0.1684 \phi - 0.1962 P(11, 7) + 0.1266 P(17, 7) + 0.1936 \Delta P(13, 7) - 0.1426 \Delta P(9, 9) \\
\hat{E}_{36} &= - 63.968 + 0.1749 P(15, 9) - 0.2642 P(11, 1) + 0.1113 P(5, 7) - 0.3348 P(10, 5) \\
&\quad + 0.3656 P(11, 5)
\end{aligned}$$

$$\begin{aligned}\hat{D}_{36} = & 621.36 - 0.6580 P(10, 5) + 0.6124 \Delta P(9, 5) + 0.0090 P(13, 9) - 0.2006 \phi \\ & + 0.3248 P(12, 6) - 0.2081 P(15, 1) - 0.0904 \lambda - 0.0793 P(5, 13) + 0.2486 \Delta P(11, 3)\end{aligned}$$

B.2 Asian Cyclones

B.2.1 Equations Using Both Surface and Upper-air Predictors

B.2.1.1 Northwestern Zone

$$\begin{aligned}\hat{N}_{12} &= - 31.4556 + 0.0365 Z(13, 5) - 0.0192 Z(9, 7) \\ \hat{E}_{12} &= - 1.6969 + 0.0052 Z(13, 9) - 0.0265 H(7, 1) + 0.0212 Z(11, 7) \\ \hat{D}_{12} &= - 52.9586 + 0.3259 \Delta P(9, 3) + 0.3065 \phi + 0.0299 Z(7, 7) + 0.2310 \Delta P(9, 9) - \\ &\quad - 0.0688 P(3, 3) + 0.0748 P(15, 9) + 0.1712 \Delta P(13, 5) + 0.0364 \Delta H(9, 7) - 0.1964 \Delta P(7, 3) \\ &\quad - 0.3837 P(10, 5) + 0.3616 P(11, 5) \\ \hat{N}_{24} &= - 169.304 + 0.0379 Z(15, 3) - 0.0224 Z(7, 9) + 0.0292 H(13, 7) + 0.1503 P(11, 1) \\ &\quad - 0.1169 P(9, 7) + 0.0547 P(3, 9) \\ \hat{E}_{24} &= - 10.7959 + 0.0142 Z(13, 9) - 0.0574 H(7, 1) + 0.0489 H(11, 7) + 0.0393 \Delta Z(5, 9) \\ &\quad + 0.1450 \Delta P(11, 7) - 0.0368 \Delta Z(7, 5) \\ \hat{D}_{24} &= 90.2693 + 0.1809 P(15, 9) - 0.1508 P(3, 7) + 0.5431 \Delta P(9, 3) - 0.1095 H(11, 1) \\ &\quad + 0.0593 H(9, 5) - 0.8853 P(10, 5) + 0.7945 P(11, 5) + 0.0344 Z(5, 9) \\ \hat{N}_{36} &= - 97.9147 + 0.0522 Z(15, 3) - 0.0351 Z(7, 9) + 0.0382 H(13, 7) + 0.0456 \Delta H(11, 3) \\ &\quad - 0.1611 \Delta P(9, 9) - 0.0459 \Delta Z(5, 3) \\ \hat{E}_{36} &= - 39.4679 + 0.0305 Z(15, 9) - 0.0505 Z(7, 3) + 0.0391 Z(11, 7) \\ \hat{D}_{36} &= 442.266 + 0.2597 P(15, 9) - 0.2037 P(3, 7) - 0.9115 P(10, 5) + 0.5120 P(9, 3) \\ &\quad + 0.4123 \Delta P(11, 7) + 0.3436 \lambda + 0.3879 \Delta P(11, 3) + 0.0805 Z(9, 7) - 0.1064 Z(5, 1)\end{aligned}$$

B.2.1.2 Northeastern Zone

$$\begin{aligned}\hat{N}_{12} &= 11.6227 + 0.0363 Z(13, 5) - 0.0166 Z(9, 7) - 0.0151 \Delta H(5, 3) - 0.0858 P(9, 7) \\ &\quad + 0.0619 P(11, 3) - 0.0134 H(7, 9) \\ \hat{E}_{12} &= 13.8955 - 0.0315 Z(9, 1) + 0.0235 Z(11, 7) \\ \hat{D}_{12} &= 218.247 + 0.1788 \Delta P(11, 3) - 0.4341 P(10, 5) + 0.3792 P(11, 7) + 0.3394 \Delta P(11, 5) \\ &\quad - 0.1664 P(3, 3) \\ \hat{N}_{24} &= - 96.2233 + 0.0417 Z(13, 5) - 0.0498 Z(9, 7) + 0.0423 H(11, 7) + 0.1084 P(13, 3) \\ &\quad - 0.0174 Z(9, 11) - 0.0209 H(5, 5) - 0.1495 \phi\end{aligned}$$

$$\begin{aligned}
\hat{E}_{24} &= 0.5579 - 0.0353 Z(9, 1) + 0.0651 Z(13, 7) - 0.0506 H(13, 5) + 0.1209 P(3, 3) \\
&\quad - 0.0912 P(9, 5) \\
\hat{D}_{24} &= 43.1036 + 0.4399 \Delta P(9, 3) - 0.0530 H(11, 1) + 0.0409 Z(11, 9) - 0.7568 P(10, 5) \\
&\quad + 0.4279 P(11, 3) - 0.0885 \Delta H(5, 7) + 0.3330 \Delta P(11, 5) + 0.2967 P(11, 7) \\
\hat{N}_{36} &= 127.871 + 0.0399 Z(13, 5) - 0.0061 Z(9, 7) + 0.0307 Z(15, 7) - 0.1991 P(11, 9) \\
&\quad - 0.0179 H(5, 5) - 0.0559 \Delta Z(9, 9) + 0.1168 P(13, 5) - 0.0388 \Delta H(9, 5) - 0.0297 H(7, 9) \\
&\quad - 0.0353 Z(3, 1) - 0.1999 \phi \\
\hat{E}_{36} &= -74.3317 - 0.1068 Z(9, 1) + 0.0267 Z(13, 9) + 0.1603 P(15, 7) - 0.0312 Z(15, 3) \\
&\quad + 0.0612 H(9, 1) \\
\hat{D}_{36} &= 256.719 + 0.4854 \Delta P(9, 3) - 0.7068 P(10, 5) + 0.3633 \Delta P(11, 3) + 0.4300 P(13, 5) \\
&\quad - 0.1017 H(11, 1) - 0.0104 Z(11, 9) + 0.0453 Z(15, 11) + 0.0756 Z(9, 9)
\end{aligned}$$

B.2.1.3 Southwestern Zone

$$\begin{aligned}
\hat{N}_{12} &= -17.3263 - 0.2242 \Delta P(11, 7) + 0.0315 H(13, 7) - 0.0208 Z(9, 7) \\
\hat{E}_{12} &= 53.4754 + 0.0118 Z(11, 11) - 0.0218 H(5, 7) + 0.2077 \Delta P(13, 5) + 0.0347 Z(11, 7) \\
&\quad - 0.0535 Z(13, 1) \\
\hat{D}_{12} &= -67.4397 + 0.1038 \Delta Z(9, 5) + 0.0380 Z(11, 11) + 0.3936 \Delta P(11, 7) \\
\hat{N}_{24} &= 158.162 - 0.3092 \Delta P(11, 7) - 0.1891 P(11, 7) + 0.0467 Z(15, 7) - 0.0279 H(7, 7) \\
\hat{E}_{24} &= 126.452 + 0.0173 Z(15, 11) + 0.0603 P(9, 11) - 0.0730 Z(3, 1) + 0.0735 \Delta Z(11, 7) \\
&\quad + 0.0307 Z(11, 9) - 0.0738 Z(15, 1) \\
\hat{D}_{24} &= 321.998 + 0.1839 \Delta Z(9, 5) + 0.0531 Z(11, 11) - 0.4428 P(15, 7) - 0.1467 \Delta Z(5, 7) \\
&\quad + 0.9770 \Delta P(11, 7) - 0.4673 P(10, 5) + 0.4943 P(13, 7) \\
\hat{N}_{36} &= 17.4652 - 0.3254 P(11, 7) + 0.0621 P(15, 7) - 0.3407 \Delta P(9, 5) + 0.0468 Z(15, 7) \\
&\quad + 0.1645 P(3, 7) - 0.0867 \Delta Z(9, 7) \\
\hat{E}_{36} &= 265.246 - 0.1202 Z(15, 1) + 0.0573 Z(13, 11) - 0.0779 Z(3, 3) \\
\hat{D}_{36} &= 359.260 + 0.0954 Z(11, 11) - 0.5253 P(15, 7) - 0.3533 \Delta Z(5, 7) + 0.2859 \Delta Z(7, 7)
\end{aligned}$$

B.2.1.4 Southeastern Zone

$$\begin{aligned}
\hat{N}_{12} &= -105.598 + 0.1344 P(15, 7) - 0.1610 P(11, 7) + 0.1325 P(13, 3) \\
\hat{E}_{12} &= 35.9840 + 0.0221 P(13, 11) - 0.0573 Z(5, 1) + 0.0261 Z(11, 9) \\
\hat{D}_{12} &= -3.5849 + 0.5958 \Delta P(9, 3)
\end{aligned}$$

$$\begin{aligned}\hat{N}_{24} = & -302.042 + 0.3830 P(15, 7) - 0.4204 P(13, 7) - 0.2458 \Delta P(9, 7) + 0.2044 \Delta P(13, 7) \\ & - 0.0409 \Delta Z(11, 11) + 0.1164 P(3, 7) + 0.0226 Z(15, 9) + 0.1816 P(15, 3)\end{aligned}$$

$$\hat{E}_{24} = 44.9139 + 0.0480 P(13, 11) - 0.1035 Z(7, 1) + 0.0534 Z(11, 9)$$

$$\hat{D}_{24} = 357.931 + 0.8334 \Delta P(9, 3) - 0.3643 P(10, 5) + 1.1836 \Delta P(11, 1)$$

$$\hat{N}_{36} = -94.7719 + 0.0609 Z(15, 7) - 0.0309 Z(11, 9) - 0.2741 P(11, 7) + 0.3170 P(15, 3)$$

$$\begin{aligned}\hat{E}_{36} = & 65.7869 + 0.0394 P(13, 11) - 0.1757 Z(7, 1) + 0.0771 Z(11, 9) + 0.3502 P(13, 5) \\ & - 0.2724 P(9, 7)\end{aligned}$$

$$\hat{D}_{36} = 551.109 + 0.7557 \Delta P(9, 3) - 0.6709 P(10, 5) + 1.4226 \Delta P(11, 1) + 0.0623 Z(13, 9)$$

B.2.1.5 All Zones

$$\begin{aligned}\hat{N}_{12} = & -22.7440 + 0.0031 Z(15, 5) - 0.0051 Z(7, 7) + 0.0275 Z(13, 5) - 0.1019 P(11, 7) \\ & + 0.0362 P(13, 5) + 0.0375 \Delta P(13, 1) - 0.0528 \Delta P(9, 7) + 0.0257 P(15, 9) - 0.0136 Z(9, 7) \\ & + 0.1010 P(11, 3) - 0.0413 P(10, 5) - 0.0092 Z(5, 3) - 0.0541 \phi\end{aligned}$$

$$\begin{aligned}\hat{E}_{12} = & -48.4427 - 0.0118 Z(7, 1) + 0.0139 Z(11, 9) + 0.0874 P(13, 5) - 0.0147 Z(11, 1) \\ & - 0.1408 P(9, 5) + 0.0970 \Delta P(11, 5) + 0.0536 P(5, 3) - 0.0160 \Delta Z(7, 7) + 0.0578 P(11, 7) \\ & + 0.0059 Z(15, 11)\end{aligned}$$

$$\begin{aligned}\hat{D}_{12} = & 125.717 + 0.1680 \Delta P(9, 3) + 0.2612 \Delta P(11, 3) - 0.5793 P(10, 5) + 0.4346 P(11, 5) \\ & + 0.1997 \Delta P(9, 5) - 0.2778 \Delta P(5, 3) + 0.0955 \lambda + 0.0599 \Delta Z(9, 7) + 0.0169 Z(11, 11) \\ & + 0.1281 \Delta P(13, 5) - 0.0423 \Delta H(5, 5) - 0.0371 \Delta Z(13, 7)\end{aligned}$$

$$\begin{aligned}\hat{N}_{24} = & 13.1651 + 0.0215 Z(15, 5) - 0.0170 Z(7, 7) + 0.0218 Z(11, 3) - 0.1677 P(11, 7) \\ & + 0.1289 P(13, 5) - 0.0186 Z(5, 3) - 0.0312 \Delta Z(9, 7) + 0.0186 Z(15, 7) - 0.0116 Z(9, 11)\end{aligned}$$

$$\begin{aligned}\hat{E}_{24} = & -59.9832 - 0.0191 Z(7, 1) - 0.0049 Z(13, 9) + 0.0958 P(13, 7) - 0.0183 Z(9, 3) \\ & + 0.0324 Z(11, 9) + 0.0143 Z(15, 11) - 0.0228 \Delta Z(7, 5) - 0.0193 Z(13, 1) - 0.0660 P(9, 7) \\ & + 0.0882 P(5, 5) + 0.1150 \Delta P(11, 5) - 0.1289 P(9, 5) + 0.0935 P(13, 5)\end{aligned}$$

$$\begin{aligned}\hat{D}_{24} = & 651.448 + 0.5199 \Delta P(9, 3) - 0.1270 H(11, 1) + 0.0637 H(9, 7) - 0.8334 P(10, 5) \\ & + 0.1907 P(11, 5) + 0.2060 \Delta P(9, 7) + 0.1144 \lambda + 0.1316 \Delta P(11, 3) + 0.0341 Z(15, 11) \\ & - 0.0542 \Delta H(5, 7) - 0.3040 \Delta P(5, 3) + 0.0828 Z(11, 3) - 0.1502 H(11, 7) + 0.0998 Z(11, 7) \\ & + 0.2869 \Delta P(11, 5)\end{aligned}$$

$$\begin{aligned}\hat{N}_{36} = & 49.6274 + 0.0471 Z(15, 5) - 0.0205 Z(7, 9) - 0.1116 P(11, 9) - 0.0124 H(5, 5) \\ & + 0.1872 P(13, 5) - 0.0477 \Delta Z(9, 7) - 0.1220 P(11, 7) + 0.0264 Z(15, 9) - 0.1506 \phi \\ & - 0.0207 Z(5, 3) - 0.0167 Z(15, 11)\end{aligned}$$

$$\begin{aligned}
\hat{E}_{36} &= 85.2273 - 0.0239 Z(7, 1) - 0.0028 Z(13, 9) - 0.0472 H(7, 5) + 0.1146 P(15, 7) \\
&\quad - 0.0481 Z(13, 1) - 0.1560 P(9, 5) + 0.0440 Z(11, 7) + 0.0310 Z(13, 11) + 0.0194 Z(3, 7) \\
\hat{D}_{36} &= 470.246 + 0.7513 \Delta P(9, 3) - 0.7542 P(10, 5) - 0.0975 H(11, 1) + 0.0832 Z(9, 7) \\
&\quad + 0.0587 Z(15, 11) + 0.4251 P(11, 3) + 0.2082 \lambda - 0.2011 P(5, 5) + 0.3159 \phi \\
&\quad - 0.0618 \Delta H(5, 7)
\end{aligned}$$

B.2.2 Equations Using Surface Predictors Only (All Zones)

$$\begin{aligned}
\hat{N}_{12} &= - 97.697 + 0.0686 P(15, 5) - 0.0416 P(9, 7) - 0.0848 \phi + 0.0283 P(17, 9) - 0.0276 \lambda \\
&\quad + 0.1276 P(12, 4) + 0.0633 P(1, 3) - 0.2061 P(10, 6) + 0.1119 P(9, 5) + 0.0667 \Delta P(10, 2) \\
&\quad - 0.0551 P(7, 1) \\
\hat{E}_{12} &= - 16.153 + 0.0513 P(13, 11) + 0.0818 \phi - 0.1183 P(9, 1) + 0.0738 \Delta P(11, 3) \\
&\quad - 0.0579 \Delta P(8, 6) + 0.1327 P(12, 6) - 0.1443 P(9, 5) + 0.0870 P(6, 2) + 0.0904 \Delta P(11, 1) \\
\hat{D}_{12} &= 78.857 + 0.3324 \Delta P(9, 3) + 0.2617 \Delta P(12, 4) - 0.7230 P(10, 5) + 0.2674 P(10, 6) \\
&\quad - 0.3066 \Delta P(6, 2) + 0.0661 \lambda + 0.3808 P(11, 5) + 0.1942 \Delta P(10, 5) + 0.1230 \Delta P(3, 9) \\
\hat{N}_{24} &= - 171.36 + 0.1917 P(15, 5) - 0.1505 P(10, 8) + 0.0623 P(17, 9) - 0.1088 \Delta P(9, 7) \\
&\quad - 0.1145 \phi + 0.0657 P(1, 7) - 0.0477 \lambda + 0.0913 \Delta P(13, 3) \\
\hat{E}_{24} &= - 34.132 + 0.0769 P(13, 11) + 0.1788 \phi - 0.1993 P(11, 1) + 0.1447 P(13, 7) \\
&\quad + 0.1444 \Delta P(12, 2) + 0.0430 P(17, 11) - 0.1527 P(9, 5) + 0.1373 \Delta P(12, 6) + 0.1053 P(1, 3) \\
&\quad - 0.1184 \Delta P(7, 5) \\
\hat{D}_{24} &= 275.08 + 0.5172 \Delta P(9, 3) + 0.1573 \phi - 0.1775 P(3, 3) + 0.0834 P(15, 11) - 0.8181 F \\
&\quad + 0.3756 P(10, 6) + 0.4929 \Delta P(12, 4) + 0.1132 \lambda - 0.3627 \Delta P(6, 2) + 0.1972 \Delta P(3, 9) \\
&\quad + 0.2643 P(12, 6) + 0.2361 \Delta P(9, 5) \\
\hat{N}_{36} &= - 237.67 + 0.0367 P(17, 7) - 0.2026 P(10, 8) + 0.2274 P(15, 5) - 0.2013 \phi + 0.1003 F \\
&\quad - 0.0651 \lambda + 0.0754 P(17, 9) + 0.1184 \Delta P(14, 4) \\
\hat{E}_{36} &= 78.152 + 0.1242 P(15, 11) + 0.2854 \phi - 0.2789 P(11, 1) + 0.1929 P(13, 7) \\
&\quad + 0.1747 \Delta P(12, 2) - 0.2679 P(9, 3) + 0.1292 P(5, 3) + 0.1463 \Delta P(12, 6) \\
\hat{D}_{36} &= 434.10 + 0.6815 \Delta P(9, 3) - 0.9251 P(10, 5) + 0.1705 P(15, 11) + 0.5924 \Delta P(12, 2) \\
&\quad + 0.4921 P(12, 6) + 0.3894 \Delta P(10, 6) - 0.4649 \Delta P(5, 3) + 0.1711 \lambda - 0.1558 P(5, 9) \\
&\quad + 0.2665 \Delta P(5, 9)
\end{aligned}$$

B.3 European Anticyclones

B.3.1 Equations Using Both Surface and Upper-air Predictors (Both Zones)

$$\begin{aligned}\hat{N}_{12} &= 12.7498 + 0.0213 Z(13, 5) + 0.0740 \Delta P(9, 7) + 0.0746 \Delta P(11, 7) - 0.0129 Z(9, 3) \\ &\quad + 0.0091 Z(11, 9) - 0.1334 \Delta P(9, 3) + 0.0158 \Delta Z(9, 9) - 0.0405 \Delta P(5, 5) - 0.0105 H(11, 7) \\ &\quad + 0.0121 \lambda - 0.0197 P(9, 11) - 0.1114 P(11, 3) + 0.1059 P(11, 7) \\ \hat{E}_{12} &= - 85.2348 + 0.0837 P(9, 5) + 0.1579 \Delta P(7, 7) - 0.0979 \Delta P(13, 7) - 0.0216 Z(13, 1) \\ &\quad + 0.0211 H(7, 7) \\ \hat{D}_{12} &= 122.741 + 0.2811 \Delta P(9, 5) + 0.1235 \Delta P(11, 7) - 0.4506 P(10, 5) + 0.0695 \phi \\ &\quad + 0.3461 P(11, 5) + 0.0449 \Delta H(9, 5) + 0.0158 \Delta Z(15, 7) + 0.1208 \Delta P(9, 7) - 0.0097 H(13, 3) \\ \hat{N}_{24} &= 13.2920 + 0.0251 Z(13, 5) + 0.2113 \Delta P(9, 7) + 0.1004 \Delta P(11, 9) + 0.0434 P(15, 9) \\ &\quad - 0.0894 P(11, 1) - 0.0071 Z(5, 11) - 0.1539 \Delta P(11, 3) \\ \hat{E}_{24} &= - 70.3194 + 0.1549 P(10, 5) + 0.2875 \Delta P(7, 5) - 0.1661 \Delta P(11, 5) - 0.1028 P(5, 5) \\ &\quad - 0.1060 \Delta P(13, 9) + 0.0112 Z(11, 9) - 0.0332 Z(13, 1) + 0.0289 Z(7, 5) + 0.1619 \Delta P(7, 7) \\ \hat{D}_{24} &= 201.067 + 0.2287 \Delta P(11, 7) - 0.0154 Z(9, 5) + 0.2262 \Delta P(9, 7) - 0.6209 P(10, 5) \\ &\quad + 0.4493 P(11, 5) + 0.1280 \phi + 0.3399 \Delta P(9, 5) \\ \hat{N}_{36} &= 75.5539 + 0.0449 Z(13, 5) + 0.2304 \Delta P(9, 7) - 0.1739 P(11, 1) - 0.0035 Z(5, 11) \\ &\quad + 0.1337 P(11, 9) - 0.1170 \Delta P(5, 5) - 0.0760 P(9, 11) - 0.0429 \Delta Z(9, 1) \\ &\quad + 0.0351 \Delta Z(9, 9) - 0.0191 H(7, 7) \\ \hat{E}_{36} &= - 133.905 + 0.1773 P(10, 5) + 0.3652 \Delta P(7, 5) + 0.0561 \lambda - 0.1780 \Delta P(11, 7) \\ &\quad - 0.0338 Z(13, 1) + 0.0227 Z(13, 11) - 0.0500 P(3, 7) + 0.0461 Z(9, 7) - 0.0344 Z(9, 1) \\ &\quad + 0.0542 \Delta Z(7, 7) \\ \hat{D}_{36} &= 359.208 - 0.0210 Z(9, 7) + 0.6058 \Delta P(9, 7) - 0.3184 P(10, 5) + 0.1777 \phi \\ &\quad + 0.2401 \Delta P(13, 7)\end{aligned}$$

B.3.2 Equations Using Surface Predictors Only (Both Zones)

Not computed.

APPENDIX C. PROCEDURE FOR OPERATIONAL PREDICTION

C.1 Construction of Worksheets

The following example demonstrates the procedure for making an operational forecast of the displacement and change in central pressure of European cyclones for 12, 24, and 36 hr. The case to be illustrated is hypothetical, but should give a general idea of how worksheets for other equations can be derived.

For this example, the unstratified European set of equations was chosen (see Sec. B.1.1.3). In addition to arranging the predictors on the worksheets in a form convenient for tabulation and computation, the following types of modifications are desirable in preparing worksheets.

(a) Transform the predictands so that the final result of the computation yields the forecast latitude, longitude, and central pressure. This can be done easily by adding the initial latitude and central pressure to the $\hat{N}$ - and $\hat{D}$ -equations of Appendix B, which in effect is making these initial conditions predictors multiplied by a coefficient of 1. If an initial condition is already a predictor, its coefficient is modified by adding 1.000 to it. Thus for $\hat{D}_{12}$ (12-hr prediction of central pressure), $P(10, 5)$, which has a coefficient of -0.5119 in Sec. B.1.1.3, becomes +0.4881. The longitude is a little more involved. There, it is necessary to convert the result from degrees of latitude to degrees of longitude before adding on the initial longitude. Thus the final longitude can be expressed by

$$\text{Forecast longitude} = \lambda + \hat{E} \sec \frac{\phi + \phi_F}{2}, \quad (\text{C-1})$$

where λ is the initial longitude in degrees of longitude (negative if east longitude), $\hat{E}$ is the predicted eastward displacement in degrees of latitude, ϕ is the initial latitude in degrees of latitude, and ϕ_F is the forecast latitude in degrees of latitude.

(b) Transform 500-mb height and 1000-500-mb thickness predictors by eliminating the ten-thousands digit from them. This leaves a three-digit number (thousands, hundreds, and tens of feet), which facilitates computations. This transformation will cause the constant additive term of an equation involving height or thickness to change. Note that no such transformations are necessary for height or thickness changes.

(c) When a 1000–500-mb thickness chart is unavailable, the predictor can be computed accurately enough by converting the sea-level pressure to 1000-mb height by use of the hypsometric formula. If a mean temperature of 0°C between the surface and 1000 mb is assumed (which is reasonable for winter situations), the following equation can be used:

$$H = Z - 2.62(P - 1000), \quad (C-2)$$

where H is the 1000–500-mb thickness in tens of feet, Z is the 500-mb height in tens of feet, and P is the sea-level pressure in millibars.

Construction of a grid overlay similar to that in Fig. 2-2 may be facilitated by recalling that the grid has the same spacing between points as the JNWP grid, i.e., 1 in. on a polar-stereographic projection, with standard parallel at 60°N for a map scale of 1:15,000,000.

C.2 Use of Worksheets

C.2.1 Data-tabulation Worksheet

Using the grid overlay to locate the appropriate points, enter the sea-level pressures and 500-mb heights from the current charts (in the correct units and format) under t_0 . [To position the grid overlay, place the point $(k, l) = (10, 5)$ over the t_0 -position of the cyclone, and orient so that the line $k = 10$ coincides with the meridian passing through the t_0 -position.]

Determine the t_{-12} entries for the required points from the 12-hr-old charts. [Maintain the gridpoint $(k, l) = (10, 5)$ over the t_0 -position of the cyclone; the values recorded for t_{-12} are to be used to obtain time changes of heights and pressures at the several points.]

Determine the necessary Δ 's.

Determine the 1000–500-mb thicknesses at the required points either by using the formulae given at the bottom of the page or by reading the values directly from the analyzed 1000–500-mb thickness chart (using the grid as an overlay) or from a nomogram.

C.2.2 Prediction Worksheets

Enter on each of the three prediction worksheets the appropriate parameters from the data-tabulation worksheet.

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Thickness (1000-500 mb) Predictors

$$\begin{aligned} H(7,3) &= Z(7,3) - 2.62 [P(7,3) - 1000] = \underline{798} \\ H(11,3) &= Z(11,3) - 2.62 [P(11,3) - 1000] = \underline{809} \\ H(13,3) &= Z(13,3) - 2.62 [P(13,3) - 1000] = \underline{820} \\ H(7,7) &= Z(7,7) - 2.62 [P(7,7) - 1000] = \underline{752} \end{aligned}$$

Fig. C-1. Data-tabulation worksheet.

EUROPEAN CYCLONE PREDICTION (12 HOUR)

$t_0 = \text{ } Z \text{ } 196 \text{ }$

LATITUDE

Lat(°) 39.1 X 1.0000 =
P(7,1) 1016 X -0.1099 =
P(11,3) 1011 X 0.0796 =
P(13,3) 1014 X 0.0644 =
P(9,7) 1014 X -0.1008 =
Z(15,5) 846 X 0.0198 =
H(7,7) 752 X -0.0161 =
SUM OF PRODUCTS
CONSTANT ADDITIVE 84.1874
FORECAST LATITUDE 39.6

CENTRAL PRESSURE

P(13,3) 1014 X -0.1593 =
P(10,5) 1001 X 0.4881 =
P(11,5) 1007 X 0.3955 =
ΔP(9,5) 0 X 0.3983 =
Z(9,7) 781 X 0.0370 =
ΔZ(9,3) -7 X 0.0371 =
Long (λ) -13.8 X -0.0894 =
SUM OF PRODUCTS
CONSTANT ADDITIVE 245.903
FCST CENTRAL PRESSURE 1001

LONGITUDE

P(11,1) 1014 X -0.0638 =
P(9,5) 1007 X -0.1007 =
P(10,5) 1001 X -0.1127 =
P(11,5) 1007 X 0.1784 =
P(5,7) 1019 X 0.0159 =
P(15,9) 1021 X 0.0251 =
ΔP(7,5) 2 X -0.0673 =
Z(9,1) 868 X -0.0142 =
Z(11,7) 791 X 0.0237 =
Z(5,9) 820 X 0.0088 =
H(13,3) 820 X -0.0165 =

SUM OF PRODUCTS

CONSTANT ADDITIVE 55.1866

- (1) Total -2.274
- (2) 1/2 (initial + fcst lat.) 39.4
- (3) sec (2) 1.293 X (1) = -2.9
- (4) Initial Longitude (λ) -13.8
- (5) FORECAST LONGITUDE [(3) + (4)] -16.7

	FORECAST	CONVENTIONAL OR SUBJECTIVE	VERIFICATION
Latitude	<u>39.6</u>		
Longitude	<u>-16.7</u>		
Cent. Pressure	<u>1001</u>		

Fig. C-2. Twelve-hour prediction worksheet.

EUROPEAN CYCLONE PREDICTION (24 HOUR)

t_0 = _____ 2 _____ 196__

LATITUDE

Lat(ϕ) 39.1 X 1.0000 = _____
P(7,1) 1016 X -0.1131 = _____
P(15,3) 1017 X 0.0294 = _____
P(11,7) 1013 X -0.0898 = _____
P(15,7) 1012 X 0.0576 = _____
P(9,9) 1019 X -0.0067 = _____
Z(11,3) 837 X 0.0412 = _____
Z(15,5) 846 X 0.0263 = _____
Z(9,7) 781 X -0.0359 = _____
 ΔZ (9,9) 3 X -0.0355 = _____
H(7,3) 792 X -0.0227 = _____

SUM OF PRODUCTS

CONSTANT ADDITIVE 114.653

FORECAST LATITUDE 40.1

CENTRAL PRESSURE

P(13,1) 1015 X -0.1554 = _____
P(10,5) 1001 X 0.2480 = _____
P(11,5) 1007 X 0.4173 = _____
 ΔP (11,3) -1 X 0.1883 = _____
 ΔP (9,5) 0 X 0.3859 = _____
 ΔP (11,9) 0 X 0.1603 = _____
Z(9,7) 781 X 0.0551 = _____
 ΔZ (9,5) -8 X 0.0615 = _____
Long (λ) -13.8 X -0.1249 = _____

SUM OF PRODUCTS

CONSTANT ADDITIVE 446.855

POST CENTRAL PRESSURE 1002

LONGITUDE

P(11,1) 1014 X -0.0763 = _____
P(10,5) 1001 X -0.0630 = _____
P(5,7) 1019 X 0.0492 = _____
P(15,9) 1021 X 0.0313 = _____
Z(9,1) 842 X -0.0253 = _____
Z(13,7) 809 X 0.0366 = _____
Z(11,9) 782 X 0.0240 = _____
Z(13,9) 782 X -0.0062 = _____
 ΔZ (7,5) 3 X -0.0279 = _____

H(13,3) 830 X -0.0354 = _____

SUM OF PRODUCTS

CONSTANT ADDITIVE 61.3409

(1) Total -4.555

(2) 1/2 (initial + post lat.) 39.6

(3) sec (2) 1.297 X (1) = -5.9

(4) Initial Longitude (λ) -13.8

(5) FORECAST LONGITUDE [(3)+(4)] -19.7

	FORECAST	CONVENTIONAL OR SUBJECTIVE	VERIFICATION
Latitude	40.1		
Longitude	-19.7		
Cent. Pressure	1002		

Fig. C-3. Twenty-four-hour prediction worksheet.

EUROPEAN CYCLONE PREDICTION (36 HOUR)

$t_0 = \text{_____} Z \text{_____} 196 \text{_____}$

LATITUDE

Lat(0) 39.1 X 1.0000 = _____

P(7,1) 1016 X -0.1541 = _____

P(13,1) 1015 X 0.1319 = _____

P(9,9) 1019 X -0.0500 = _____

Z(15,5) 846 X 0.0582 = _____

Z(9,7) 781 X -0.0479 = _____

$\Delta Z(13,3)$ -3 X 0.0420 = _____

$\Delta Z(9,9)$ 3 X -0.0453 = _____

SUM OF PRODUCTS _____

CONSTANT ADDITIVE 63.3587

FORECAST LATITUDE 40.4

CENTRAL PRESSURE

P(10,5) 1001 X 0.3875 = _____

$\Delta P(9,5)$ 0 X 0.5398 = _____

Z(9,7) 781 X 0.0878 = _____

Z(13,9) 788 X 0.0227 = _____

$\Delta Z(11,3)$ -8 X 0.0782 = _____

$\Delta Z(11,7)$ -3 X 0.0759 = _____

H(11,3) 809 X -0.0442 = _____

Long (λ) -13.8 X -0.1535 = _____

SUM OF PRODUCTS _____

CONSTANT ADDITIVE 562.976

FCST CENTRAL PRESSURE 1003

LONGITUDE

P(11,1) 1014 X -0.0593 = _____

P(9,3) 1011 X -0.1411 = _____

P(13,5) 1013 X 0.0993 = _____

P(5,7) 1019 X 0.0800 = _____

P(15,9) 1021 X 0.0414 = _____

$\Delta P(9,5)$ 0 X -0.1078 = _____

Z(9,1) 868 X -0.0275 = _____

Z(13,1) 885 X -0.0312 = _____

Z(13,9) 788 X 0.0477 = _____

SUM OF PRODUCTS _____

CONSTANT ADDITIVE -14.9246

- (1) Total -7.221
- (2) $1/2$ (initial + fcst lat.) 39.8
- (3) sec (2) 1.301 X (1) = -9.4
- (4) Initial Longitude (λ) -13.8
- (5) FORECAST LONGITUDE [(3)+(4)] -23.2

	FORECAST	CONVENTIONAL OR SUBJECTIVE	VERIFICATION
Latitude	<u>40.4</u>		
Longitude	<u>-23.2</u>		
Cent. Pressure	<u>1003</u>		

Fig. C-4. Thirty-six-hour prediction worksheet.

To determine the forecast latitudes:

- (a) Compute the products of the individual parameters and their respective coefficients.
- (b) Sum these products. (This can be done simultaneously with computing the products by using the "Accumulate Multiply" key on most desk calculators.)
- (c) Add the "constant additive" to this sum; the total thus derived is, in each case, the forecast latitude.

To determine the forecast longitudes:

- (a) Compute the products of the individual parameters and their respective coefficients.
- (b) Sum these products.
- (c) Add the "constant additive" to this sum; enter the total thus derived on line 1 on the right-hand side of the page. [This is the forecast westward (+) or eastward movement (-) in degrees of latitude.]
- (d) To convert the forecast movement to degrees of longitude, take one-half of the sum of the initial latitude (ϕ) and the forecast latitude (determined above). This gives a mean latitude.
- (e) Using a secant table, determine the secant ("sec") of this mean latitude. Enter the value on line 3 on the right-hand side of the page in the blank following the words "sec (2)."
- (f) Multiply this secant value by the value entered on line 1, i.e., by the total cited in (c), above. Enter this product at the far right of line 3.
- (g) Enter on line 4 the initial longitude of the cyclone at time t_0 . Note that east longitude is entered with a minus sign, west longitude with a plus.
- (h) Algebraically add together the values on lines 3 and 4, and enter this total on line 5; this is the forecast longitude. (Thus, the value on line 3 is a forecast longitude change; when added to the original longitude, the forecast longitude is obtained).

To forecast the central pressure of the cyclone, use the same procedure, but with values of pressure.

Unusual displacements or changes in pressure should be recomputed.

Enter the forecast latitude, longitude, and central pressure, the conventional or subjective forecasts, and the verification in the box at the bottom of the page.