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DEPARTMENT OF TRANSPORT
METEOROLOGICAL BRANCH

Technical Memoranda

CYCLONE DEVELOPMENT ASSOCIATED WITH A LOW-LATITUDE WESTERLY STREAM

by

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ABSTRACT

The development of certain surface cyclones which are embedded in a low-latitude westerly stream, and which occasionally deepen strongly after leaving the east coast of the United States is examined.

Regression equations for estimating the deepening to be expected twenty-four hours after the surface cyclone leaves the coast are provided.

RÉGRESSION DE CYCLONES ASSOCIÉS À UN COURANT AÉRIEN D'OUEST À BASSE ALTITUDE

par

R.V. Tyner

RÉSUMÉ

L'auteur examine l'évolution de certains cyclones de surface dans un courant aérien d'ouest à basse altitude, et qui parfois se creusent fortement après avoir laissé la côte est des Etats-Unis.

Il donne des équations de régression pour évaluer le creusement que l'on peut prévoir dans une période de 24 heures après que le cyclone de surface a laissé la côte.

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(Manuscript received November 21, 1969)

1. INTRODUCTION

In winter and early spring the storms which most frequently affect the eastern United States and the Atlantic Provinces originate near the coast of the Gulf of Mexico. In most cases these storms move off to the northeast in a more or less predictable manner.

However, one of these cyclones may occasionally be carried into the Atlantic by a low-latitude westerly stream. These easterly-moving lows usually show little development as they move along or to the north of the coast of the Gulf of Mexico, but may show a remarkable deepening once they have moved into the Atlantic.

The storm of 1 December 1967 may serve as an extreme example. A surface low, central pressure 1007 mb., moved east of Cape Hatteras about 1800Z, 30 November 1967. At this time the low gained support from a short-wave trough in the low-latitude westerlies and began to deepen very rapidly, reaching a depth of 954 mb. within the succeeding 30 hours. Neither the path nor depth of this storm was predicted with sufficient accuracy either by the numerical prognostics, or by such statistical or partly statistical methods as the Ostby-Veigas (1) or Jarvis (2) techniques.

2. SOME CHARACTERISTICS OF THE 500 MB. FLOW ASSOCIATED WITH EASTERLY-MOVING CYCLONES

During the winter months a surface low usually forms near the northwest coast of the Gulf of Mexico whenever a short-wave trough at 500 mb. with a band of strong westerly winds at the base of the trough crosses the coast of Southern California and progresses across Texas (3). The surface low is carried eastward in the westerly stream and deepens strongly once it has moved east of the Gulf Stream, with the extent of deepening depending largly on the support provided by the 500 mb. trough.

In most cases the axis of the 500 mb. trough, often oriented in a north-south direction when the trough enters Southern California, tilts as the strongest winds move around the base of the trough, with the surface cyclone, formed near the Gulf of Mexico, being carried northeastward in the strong southwesterly flow to the east of the trough. Occasionally, the axis of the trough retains its north-south orientation as it moves across the southern United States and into the Atlantic. The surface low associated with one of these troughs is carried eastward with little deepening until it moves east of the coast, when deepening is often very rapid. Figures 1a, b, c are typical examples of these troughs. Figure 1 a shows two troughs of this type, both of which gave rise to damaging storms in the Atlantic. Isopleths of absolute vorticity are drawn at intervals of 2×10^{-5} c.g.s. units. 12-hour motions of centres are indicated.

Rather frequently, during the colder months of the year, a 500 mb. trough will "dig" east of the Rockies to produce a cut-off and north-south trough in the Gulf of Mexico region. None of the troughs formed in this manner during the period of investigation, which included the winters of 1966-67, 1967-68 and 1968-69, moved eastward as far as the east coast of the United States, and in all cases the surface low moved northward or northeastward in the southwesterly flow east of the trough line. Examples of this kind of trough formation are shown in Figures 2a, b.

Histories of the motion, orientation and intensity, measured in terms of number of troughed contours, of a north-south trough moving across the California coast are shown in Figure 3a; of a north-south trough formed by "digging" through the Mississippi Valley are shown in Figure 3b. In the diagrams, the 500 mb. height of the greatest depth of the trough or cold low is indicated above ths solid rectangles representing in length and direction, the relative intensity and orientation of the 500 mb. trough.

An examination of the Central Analysis Office (CAO) 500 mb. analyses for the months of November and December 1966; January, February, March, April, November and December of 1967 and 1968; January, February, March and April of 1969 yielded 39 examples of north-south troughs which either moved across the coast of the southwestern United States or formed from a trough digging east of the Rockies or through the Mississippi Valley.

North-south troughs which formed as the result of "digging" are listed in Table 1. With the exception of the storm of 21-25 February

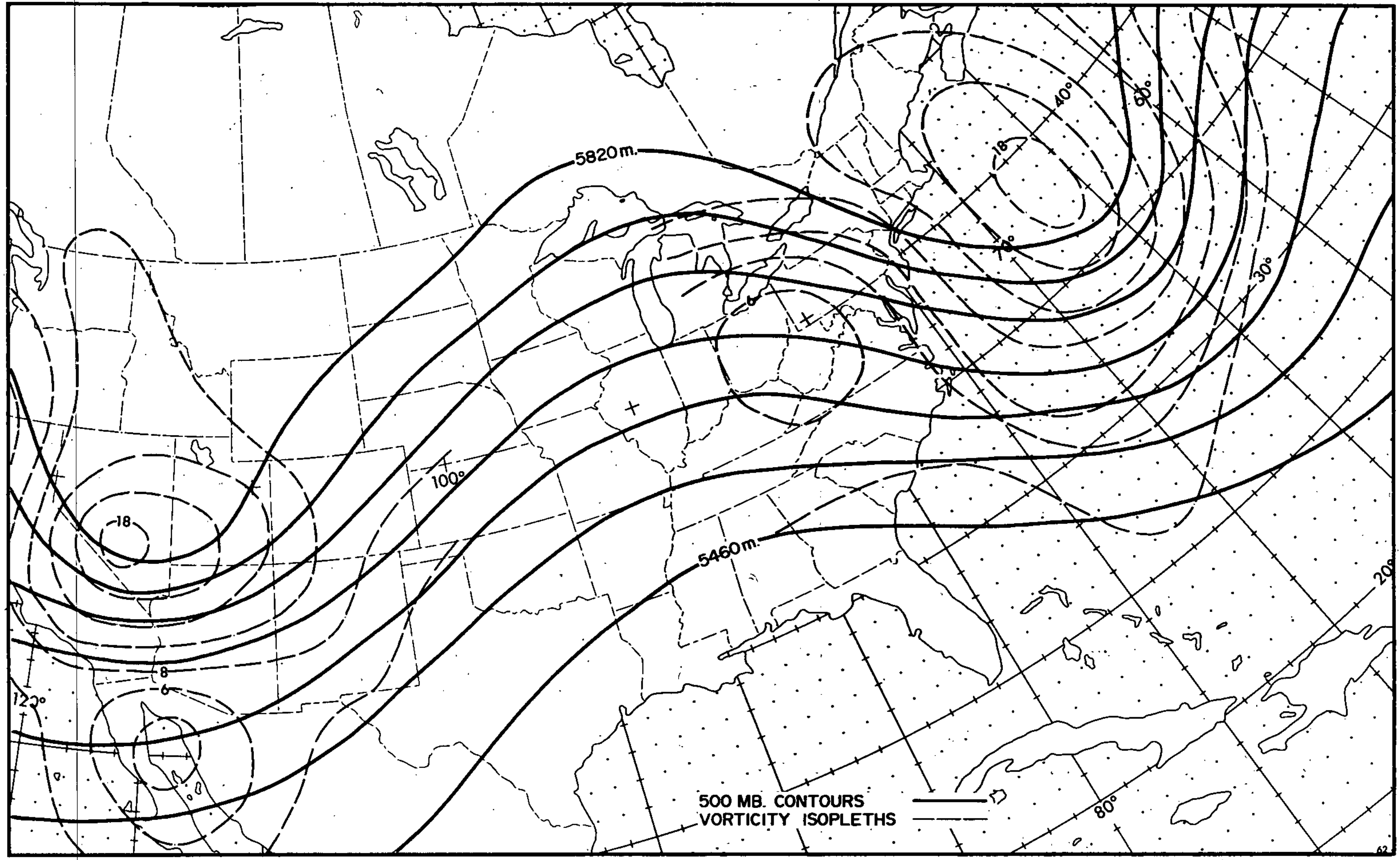

Figure 1a
North-South Troughs in Low Latitude Westerlies

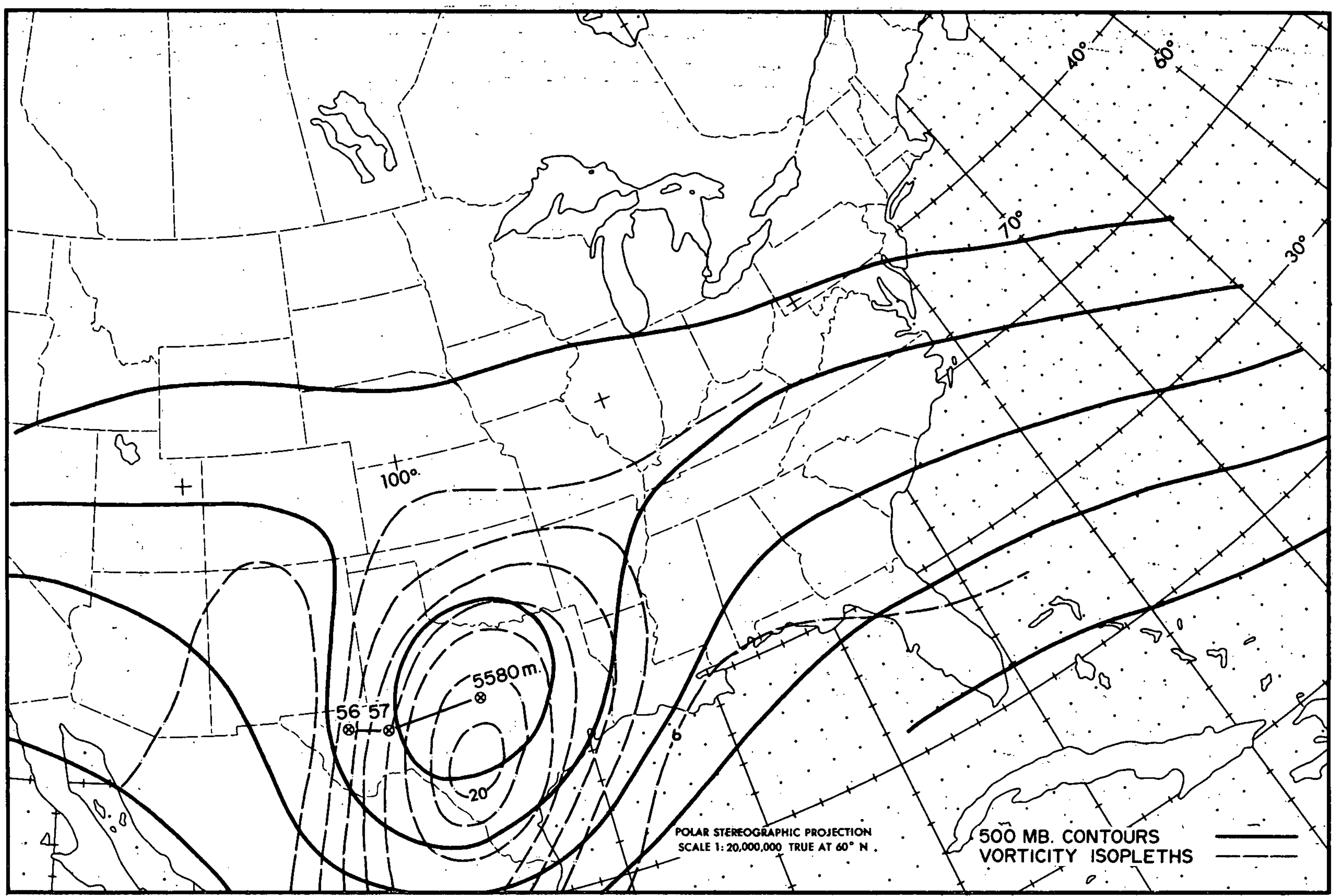

Figure 1b
North-South 500 mb. Trough and Cold Low
Moving Eastward from Southern California

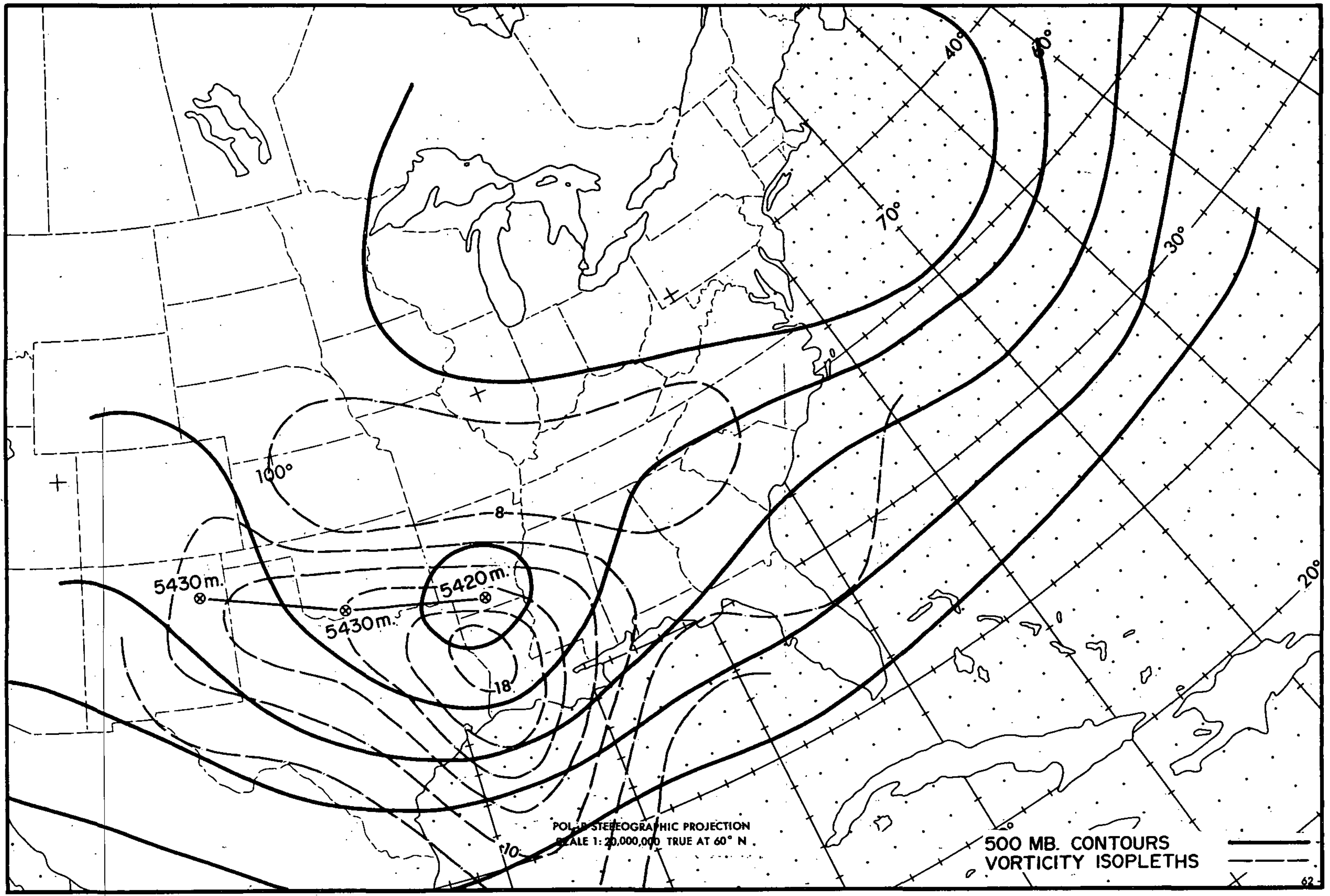

Figure 1c
North-South 500 mb. Trough and Cold Low
Moving Eastward from Central California

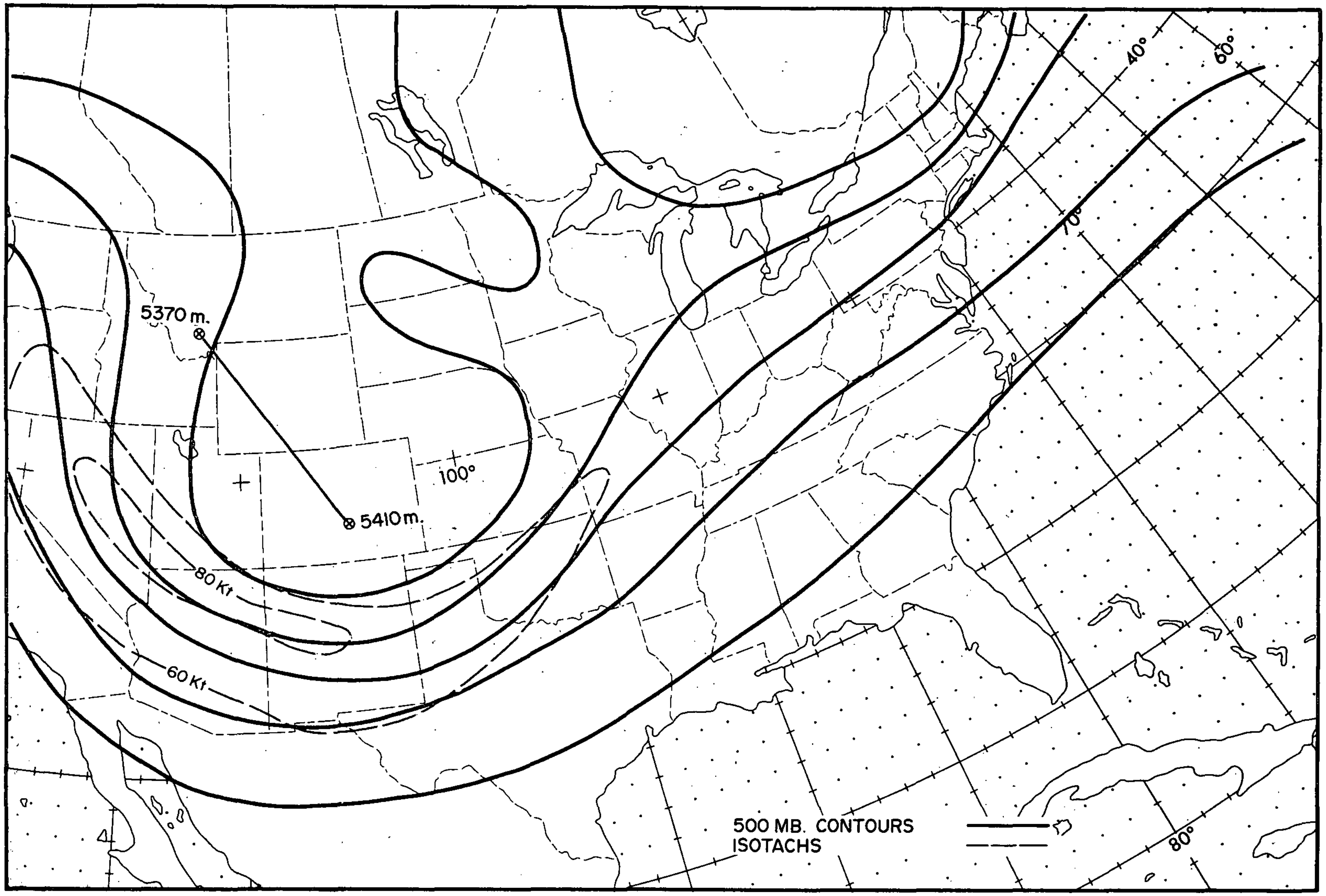

Figure 2a
North-South Trough Formed by "Digging"
East of Rockies

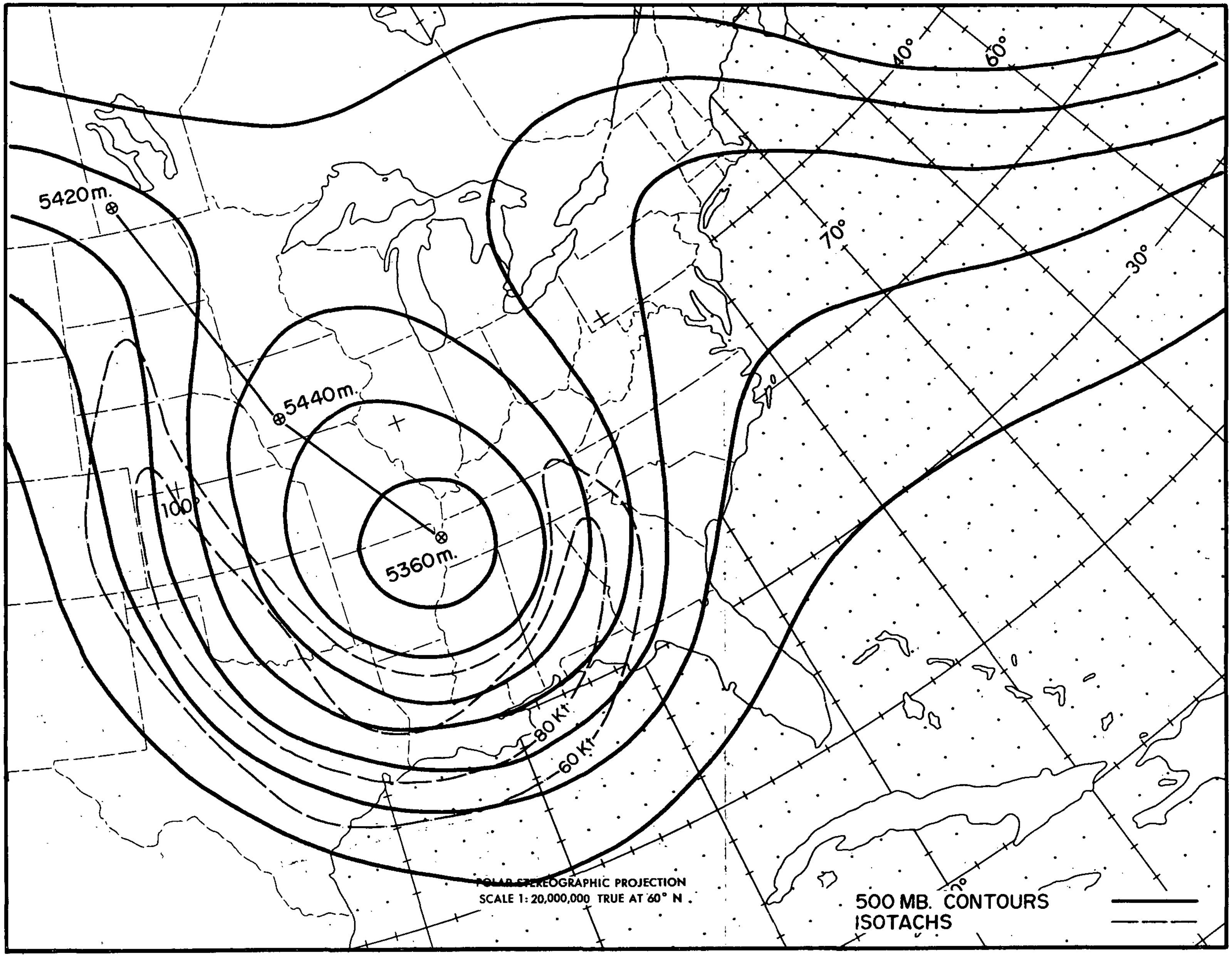

Figure 2b
Cut-Off Low and North-South Trough
Formed by "Digging" East of Rockies

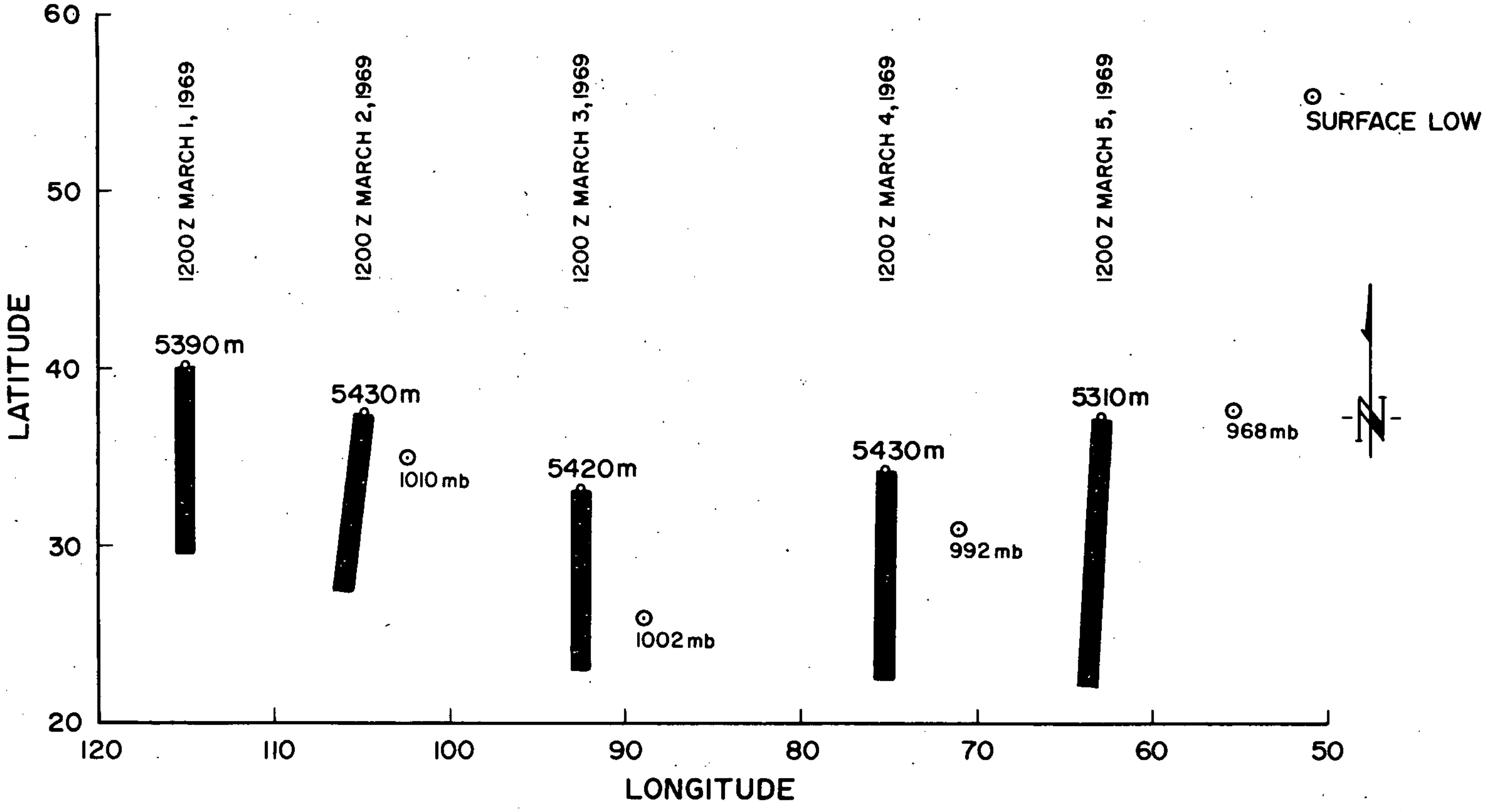
60
50
40
30
20
LATITUDE
120
110
100
90
80
70
60
50
LONGITUDE
1200 Z MARCH 1, 1969
1200 Z MARCH 2, 1969
1200 Z MARCH 3, 1969
1200 Z MARCH 4, 1969
1200 Z MARCH 5, 1969
SURFACE LOW
5390 m
5430m
1010 mb
5420m
1002 mb
5430m
992 mb
5310m
968 mb

Figure 3a

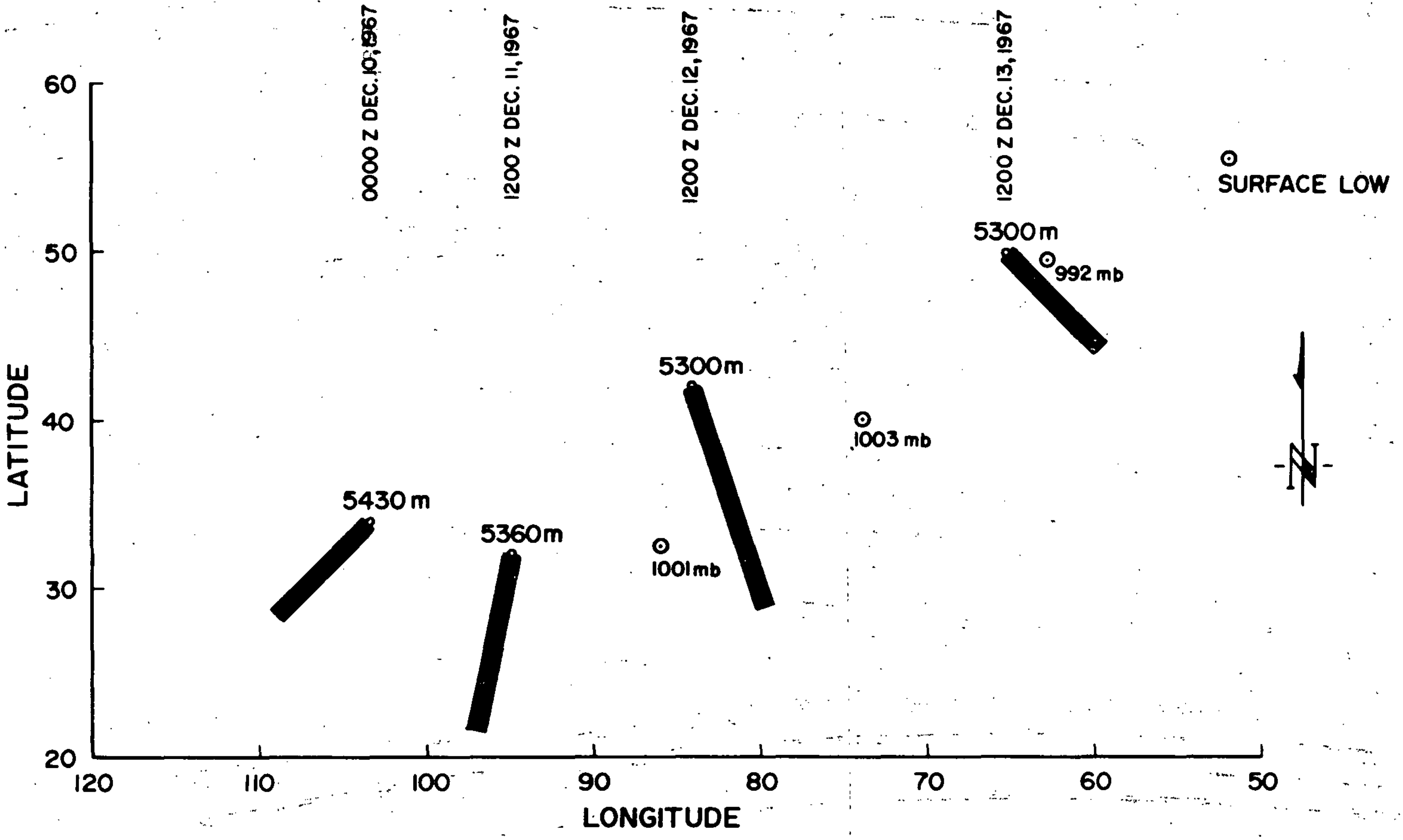
0000 Z DEC. 10, 1967
1200 Z DEC. 11, 1967
1200 Z DEC. 12, 1967
1200 Z DEC. 13, 1967
SURFACE LOW
5300m
992 mb
5300m
1003 mb
5430 m
5360m
1001mb
N
LATITUDE
60
50
40
30
20
120
110
100
90
80
70
60
50
LONGITUDE

Figure 3b

1968, the surface lows associated with each of these troughs moved off to the northeast in the southwesterly flow to the east of the trough. In Table 2 are listed those north-south troughs which moved across the coast of California, but which supported surface lows which moved northeastward along the east side of the trough. Table 3 lists those north-south troughs which moved across the California coast and supported surface lows moving in a predominantly easterly direction into the Atlantic.

TABLE 1.

Surface Lows Associated with a Digging 500 mb. Trough

1. 1200Z, 26 November 1966 - 0000Z, 29 November 1966.
2. 0000Z, 21 December 1966 - 1200Z, 22 December 1966.
3. 0000Z, 26 December 1966 - 0000Z, 30 December 1966.
4. 1200Z, 29 April 1967 - 0000Z, 03 May 1967.
5. 0000Z, 14 October 1967 - 1200Z, 19 October 1967.
6. 1200Z, 28 October 1967 - 1200Z, 02 November 1967.
7. 0000Z, 18 January 1968 - 1200Z, 25 January 1968.
8. 1200Z, 21 February 1968 - 1200Z, 25 February 1968.
9. 1200Z, 09 March 1968 - 0000Z, 12 March 1968.
10. 1200Z, 21 March 1968 - 1200Z, 23 March 1968.
11. 0000Z, 15 December 1968 - 1200Z, 16 December 1968.
12. 1200Z, 23 March 1969 - 0000Z, 27 March 1969.
13. 0000Z, 19 April 1969 - 1200Z, 21 April 1969.

TABLE 2.

Surface Lows Move Northeastward Ahead of North-South 500 mb. Trough

1. 0000Z, 09 November 1966 - 1200Z, 12 November 1966.
2. 1200Z, 15 December 1966 - 1200Z, 19 December 1966.
3. 0000Z, 25 January 1967 - 0000Z, 28 January 1967.
4. 0000Z, 01 February 1967 - 0000Z, 03 February 1967.
5. 0000Z, 04 March 1967 - 0000Z, 07 March 1967.
6. 0000Z, 12 April 1967 - 1200Z, 15 April 1967.
7. 0000Z, 14 November 1968 - 1200Z, 16 November 1968.
8. 1200Z, 11 December 1968 - 0000Z, 14 December 1968.
9. 1200Z, 26 December 1968 - 0000Z, 28 December 1968.
10. 0000Z, 22 March 1969 - 1200Z, 25 March 1969.
11. 1200Z, 10 April 1969 - 1200Z, 13 April 1969.
12. 1200Z, 14 April 1969 - 0000Z, 19 April 1969.

TABLE 3.

Surface Lows Move Eastward into Atlantic Ahead of North-South 500 mb. Trough

1. 0000Z, 16 April 1967 - 1200Z, 19 April 1967.
2. 1200Z, 22 April 1967 - 0000Z, 26 April 1967.
3. 1200Z, 24 April 1967 - 1200Z, 28 April 1967.
4. 0000Z, 28 November 1967 - 0000Z, 04 December 1967.
5. 0000Z, 01 December 1967 - 0000Z, 05 December 1967.
6. 0000Z, 08 January 1968 - 1200Z, 12 January 1968.
7. 1200Z, 01 November 1968 - 0000Z, 06 November 1968.
8. 0000Z, 07 February 1969 - 0000Z, 11 February 1969.
9. 1200Z, 22 February 1969 - 1200Z, 25 February 1969.
10. 1200Z, 01 March 1969 - 1200Z, 04 March 1969.
11. 0000Z, 04 March 1969 - 1200Z, 08 March 1969.
12. 0000Z, 06 March 1969 - 1200Z, 10 March 1969.
13. 0000Z, 11 March 1969 - 0000Z, 14 March 1969.
14. 1200Z, 13 March 1969 - 1200Z, 20 March 1969.

Since the numbers of occurrences of north-south 500 mb. troughs in Tables 2 and 3 are approximately equal, the question arises as to why some of these 500 mb. troughs which maintain a north-south orientation carry the surface low out to the east or east-northeast while others tilt, most frequently towards the northeast, with the surface low moving off to the northeast in the southwesterly flow ahead of the trough. Examination of the examples of Tables 2 and 3 brought to light the fact that the 500 mb. troughs which carried surface lows eastward into the Atlantic (set out in Table 3), were those in which blocking occurred. At the surface, blocking was usually indicated by the presence of a strong cold ridge oriented either east-west across the northern United States or southern Canada, or by a cold ridge of high pressure oriented in a northeast-southwest direction and extending across the Atlantic Provinces into New England. The mean surface isobaric map for the examples set out in Table 3, based on the time at which the surface low moved east of the coast of the United States, indicates the type of surface blocking described above (Figure 4). A brief glance at Table 3 will show that many of the north-south 500 mb. troughs which carry the surface low eastward occur with a persistent blocking situation, for example, the 500 mb. troughs occurring from 28 November to 5December 1967, those of April 1967 and the remarkable group of February and March 1969. The blocking during the periods 28 November to 5 December 1967, and April 1967 was characterized by the presence of deep cold airmasses over eastern North America, while that of March 1969 was most

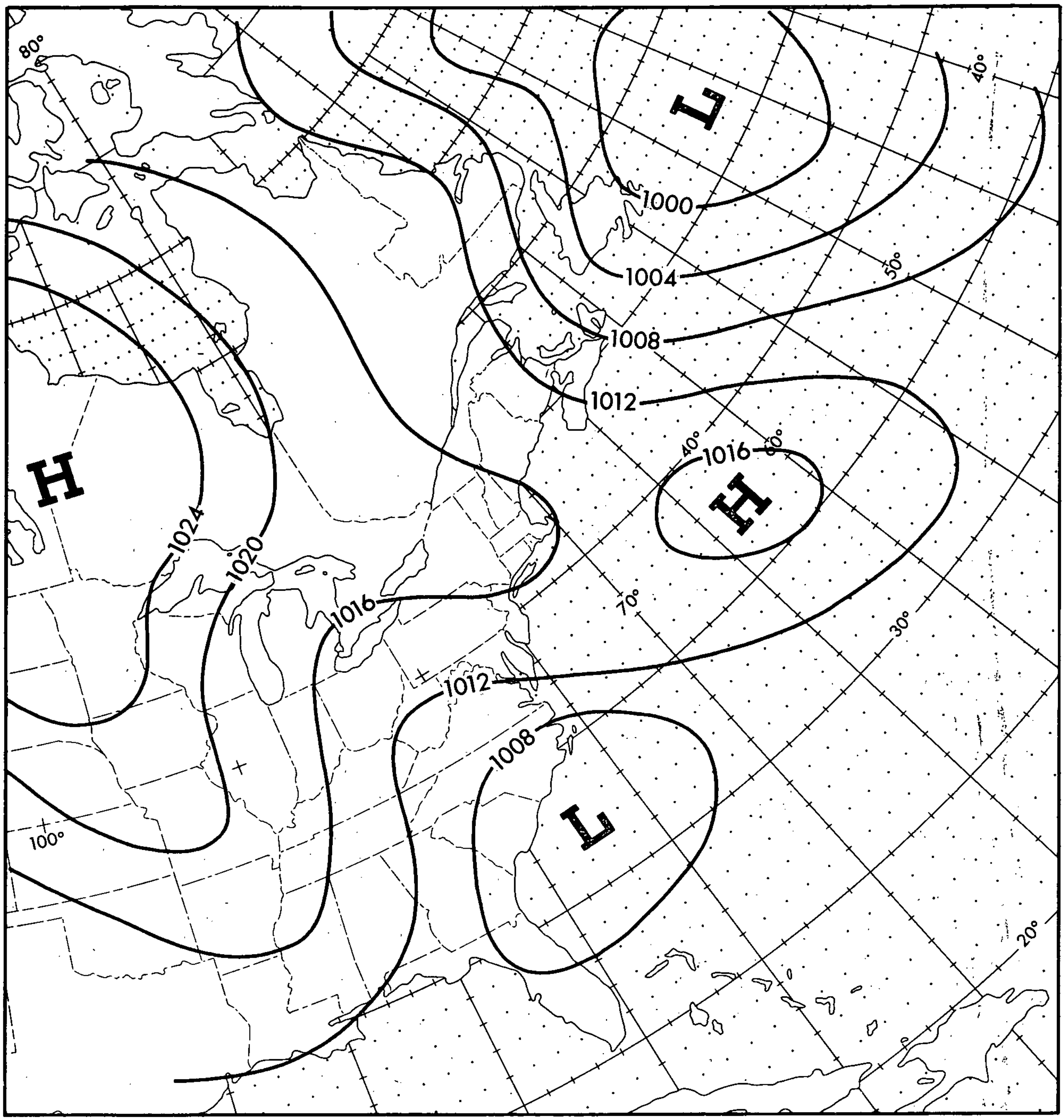

Figure 4
Mean Surface Map of Examples
in Table 3

remarkable for the very strong sub-tropical westerly stream across the southern United States and the western Atlantic (4).

The examples set out in Table 2 of 500 mb. troughs, originally oriented north-south, but which supported surface lows that moved northeastward in the southwesterly flow on the east side of the trough, were associated with a characteristic surface pressure pattern of a north-south trough through central North America with high pressure over both western and eastern parts of the continent. A mean surface chart constructed from the examples of Table 2, at a time 24 hours prior to the time at which the surface low moved off the continent indicates this type of pressure distribution (Figure 5).

The 24-hour deepening of the lows appearing in Table 3, measured from the time at which the surface low crossed the east coast of the United States (t_o) along with the speed of the 500 mb. trough supporting the surface low, measured at time t_o, appears in Table 4A.

TABLE 4A

Surface Low Leaves East Coast U.S.: Time/Date (t_o)	Pressure at t_o	Pressure at t_o + 24 hrs.	24-hour Deepening	Speed of Supporting 500 mb trough at t_o
1. 0000Z, 18 April 1967	1003 mb.	986 mb.	17 mb.	30 kts.
2. 1200Z, 24 April 1967	1003 mb.	990 mb.	13 mb.	30 kts.
3. 0600Z, 27 April 1967	1006 mb.	982 mb.	24 mb.	32 kts.
4. 1800Z, 30 Nov 1967	1007 mb.	974 mb.	33 mb.	35 kts.
5. 1800Z, 03 Dec 1967	999 mb.	984 mb.	15 mb.	30 kts.
6. 0000Z, 11 Jan 1968	1013 mb.	1004 mb.	9 mb.	20 kts.
7. 0000Z, 05 Nov 1968	1007 mb.	996 mb.	11 mb.	25 kts.
8. 0600Z, 09 Feb 1969	998 mb.	966 mb.	32 mb.	35 kts.
9. 1200Z, 23 Feb. 1969	1012 mb.	1001 mb.	11 mb.	25 kts.
10. 0000Z, 04 Mar 1969	1000 mb.	984 mb.	16 mb.	35 kts.
11. 0000Z, 07 Mar 1969	995 mb.	952 mb.	43 mb.	50 kts.
12. 1200Z, 09 Mar 1969	997 mb.	964 mb.	33 mb.	42 kts.
13. 0600Z, 13 Mar 1969	1013 mb.	992 mb.	21 mb.	35 kts.
14. 0000Z, 19 Mar 1969	1004 mb.	984 mb.	20 mb.	30 kts.

Values at t_o of the maximum west component of the 500 mb. winds at the base of the 500 mb. trough and of the maximum positive vorticity advection at 500 mb. ahead of the 500 mb. trough supporting the surface low were obtained for each of the lows listed in Table 3.

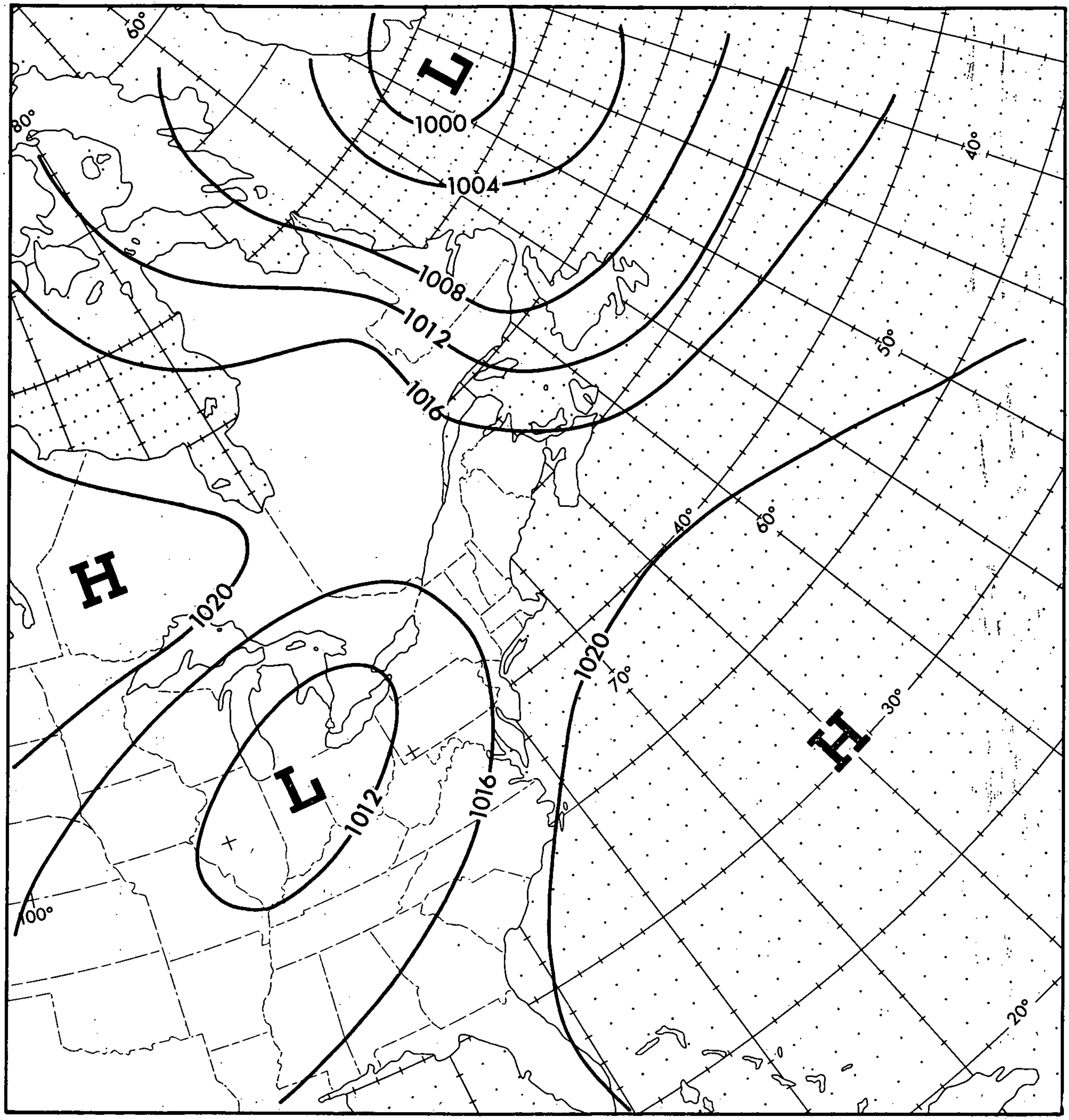

Figure 5
Mean Surface Map of Examples
in Table 2

These data are set out in Table 4B. Values of positive absolute vorticity advection were obtained from the CAO vorticity analyses using the Ferguson advection scale (5).

TABLE 4B.

	Pressure of Surface Low Deepening			Maximum West Component of Winds at Base of 500 mb. Trough at t_o	Maximum Positive Vorticity Advection at 500 mb. at t_o
	at t_o hrs	at t_o + 24 hrs	(t_o - (t_o + 24))		
1.	1003 mb.	986 mb.	17 mb.	75 kts.	130×10^{-5} c.g.s. unit
2.	1003 mb.	990 mb.	13 mb.	90 kts.	120×10^{-5}
3.	1006 mb.	982 mb.	24 mb.	85 kts.	90×10^{-5}
4.	1007 mb.	974 mb.	33 mb.	110 kts.	160×10^{-5}
5.	999 mb.	984 mb.	15 mb.	90 kts.	120×10^{-5}
6.	1013 mb.	1004 mb.	9 mb.	65 kts.	85×10^{-5}
7.	1007 mb.	996 mb.	11 mb.	70 kts.	65×10^{-5}
8.	998 mb.	966 mb.	32 mb.	90 kts.	125×10^{-5}
9.	1012 mb.	1001 mb.	11 mb.	75 kts.	85×10^{-5}
10.	1000 mb.	984 mb.	16 mb.	95 kts.	170×10^{-5}
11.	995 mb.	952 mb.	43 mb.	115 kts.	260×10^{-5}
12.	997 mb.	964 mb.	33 mb.	90 kts.	200×10^{-5}
13.	1013 mb.	992 mb.	21 mb.	100 kts.	80×10^{-5}
14.	1004 mb.	984 mb.	20 mb.	85 kts.	160×10^{-5}

The relation between the 24-hour deepening of the surface low (from t_o hrs. to t_o + 24 hrs.) and the 500 mb. maximum positive vorticity advection ahead of the supporting 500 mb. trough does not appear to be as good as might have been expected. (Figure 6a). A number of reasons for the rather unsatisfactory correspondence between observed deepening and maximum positive vorticity advection might be cited, among them the somewhat imprecise delineation of the 500 mb. vorticity fields appearing on the CAO charts, the difficulty in obtaining a precise measure of the advection with the Ferguson scale, and the implied assumption of a constant level of maximum vorticity advection with the developing cyclone.

The relation between the magnitude of the westerly component of the maximum 500 mb. wind at the base of the supporting 500 mb. trough at t_o and the subsequent 24-hour deepening of the surface low appears to be somewhat better (Figure 6b).

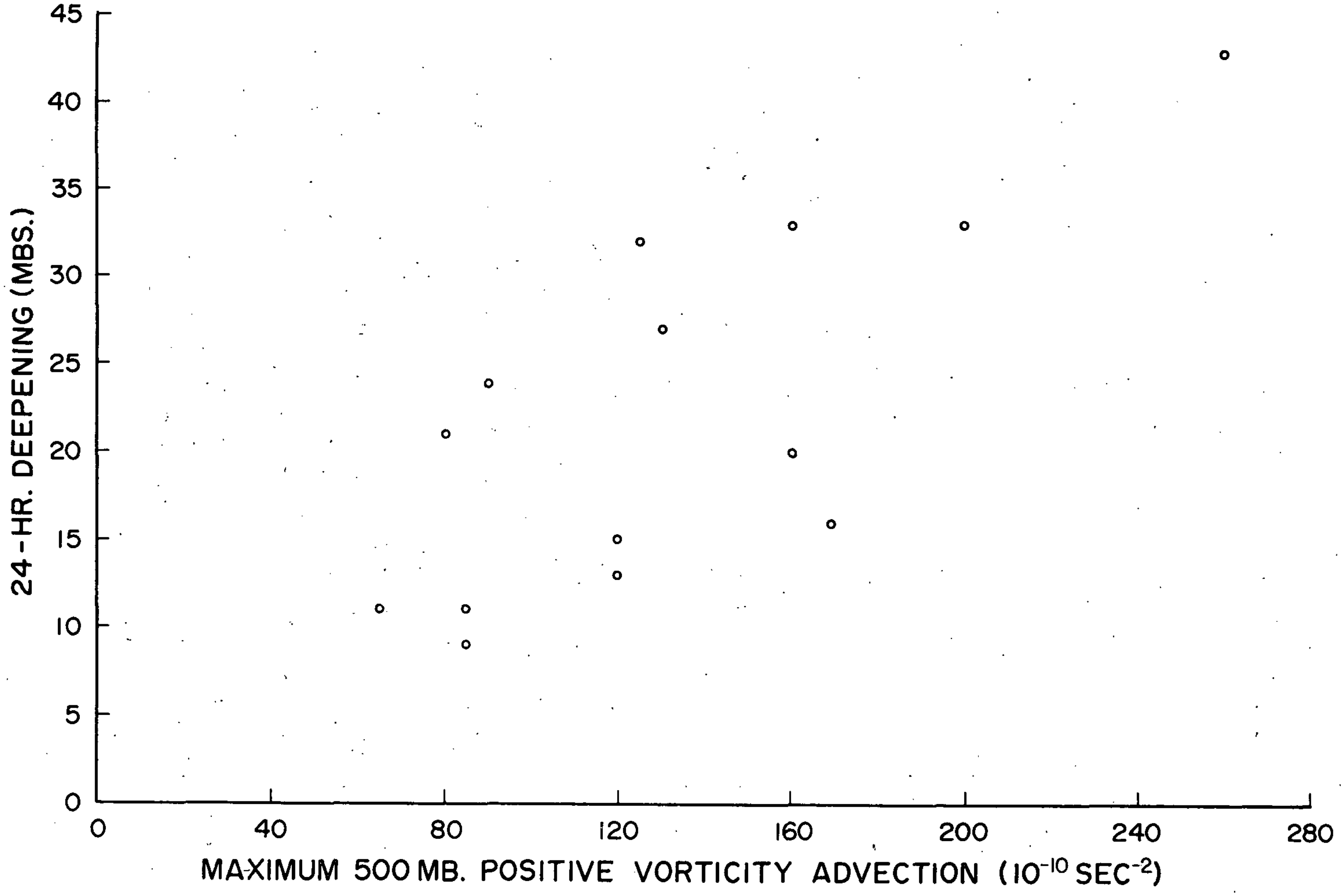
24-HR. DEEPENING (MBS.)
45
40
35
30
25
20
15
10
5
0
0
40
80
120
160
200
240
280
MAXIMUM 500 MB. POSITIVE VORTICITY ADVECTION (10^{-10} SEC^{-2})

Figure 6a

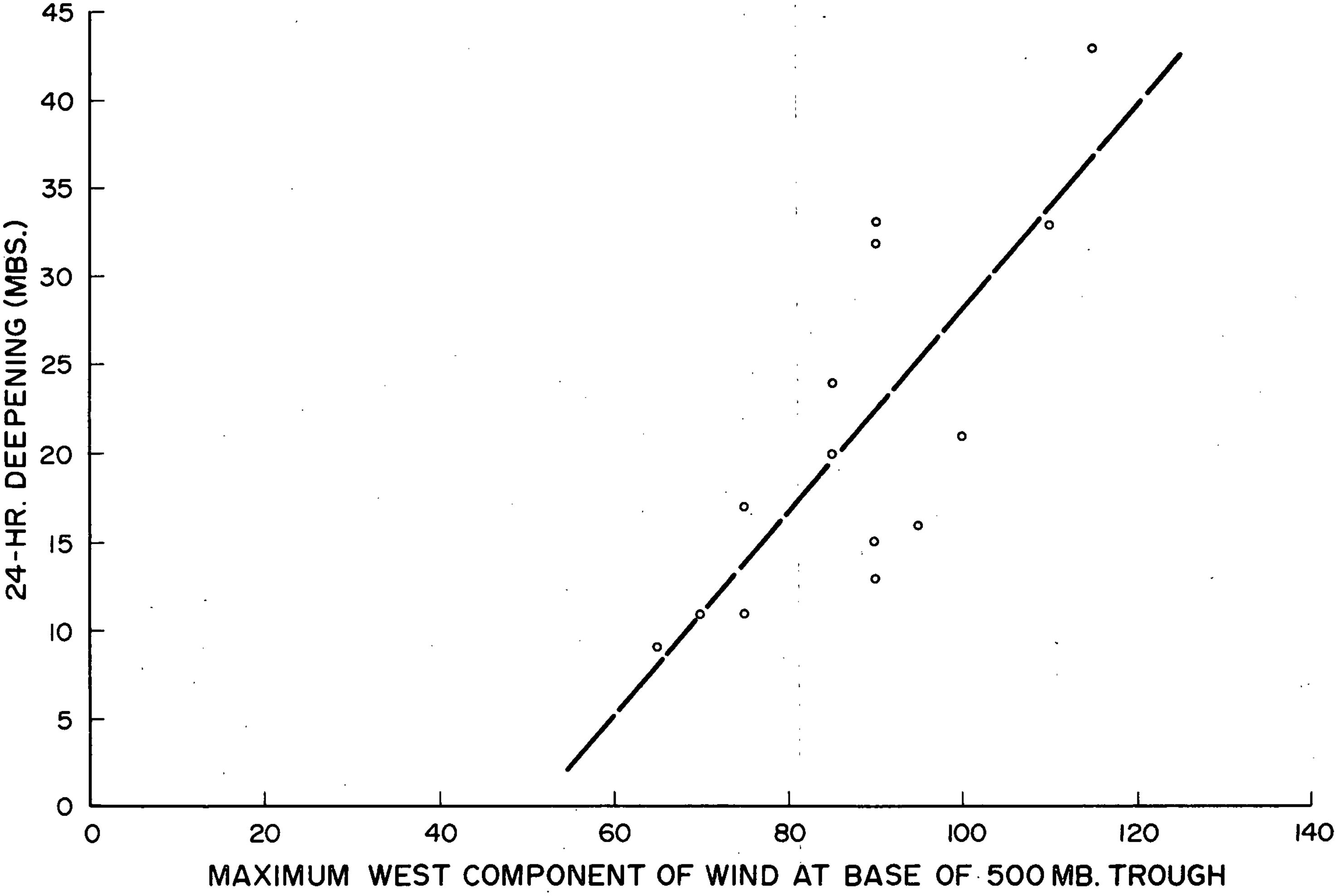
24-HR. DEEPENING (MBS.)
0
5
10
15
20
25
30
35
40
45
0
20
40
60
80
100
120
140
MAXIMUM WEST COMPONENT OF WIND AT BASE OF 500 MB. TROUGH

Figure 6b

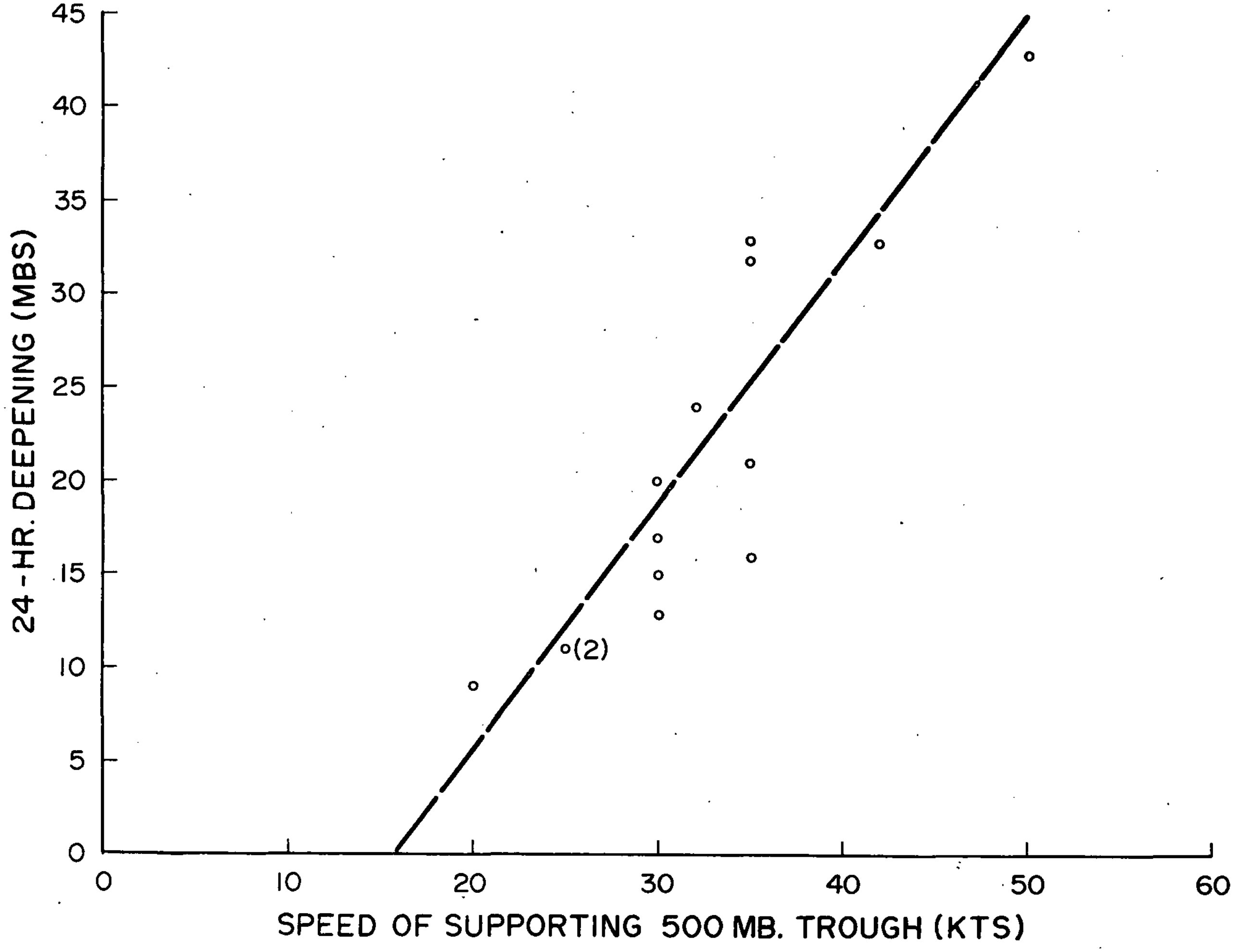
45
40
35
30
25
20
15
10
5
0
24-HR. DEEPENING (MBS)
(2)
0
10
20
30
40
50
60
SPEED OF SUPPORTING 500 MB. TROUGH (KTS)

Figure 6c

The relation between the 24-hour deepening of the surface low, measured from t_o, and the speed of the 500 mb. trough supporting the low, seems to be simplest and fits a straight line moderately well. (Figure 6c). Assuming an equation of the form

$$y = \alpha + \beta x$$

values of α and β were approximated by the least squares estimates obtained by solving the normal equations:

$$\sum_{i=1}^{n} y_i = \alpha' n + \beta' \sum_{i=1}^{n} x_i$$

$$\sum_{i=1}^{n} x_i y_i = \alpha' \sum_{i=1}^{n} x_i + \beta' \sum_{i=1}^{n} x_i^2$$

where:

x_i = speed of the supporting 500 mb. trough at t_o

y_i = deepening in mbs. of the surface lows between t_o and t_o+24 hrs.

n = number of examples (14)

α', β' = the least squares estimates for α, β

For these data the straight line of Figure 6c has the equation

$$y = 1.25x - 19.25$$

The relation between the 24-hour deepening of the surface low, measured from t_o, and the west component of the strongest wind at the base of the 500 mb. trough also appears to be linear with the equation

$$y = .57x - 29.$$

3. SUCCESS OF THE OBJECTIVE OR STATISTICALLY-BASED FORECASTS

The success of the statistically based Ostby-Veigas forecast technique (1) and the forecast technique suggested by Jarvis (2) in predicting the intensification of these lows for the period between t_o and t_o + 24 hrs. was also examined. The results are summarized in Table 5.

TABLE 5.

Low	Observed Deepening from t_o hrs to $(t_o + 24)$hrs.	Forecast Deepening Ostby-Veigas Technique	Jarvis Technique
18 April 1967	17 mb.	25 mb.	13 mb.
24 April 1967	13 mb.	18 mb.	41 mb.
27 April 1967	24 mb.	15 mb.	5 mb.
30 Nov 1967	33 mb.	14 mb.	15 mb.
3 Dec 1967	15 mb.	12 mb.	28 mb.
11 Jan 1968	9 mb.	19 mb.	12 mb.
5 Nov 1968	11 mb.	9 mb.	0 mb.
9 Feb 1969	32 mb.	21 mb.	34 mb.
23 Feb 1969	11 mb.	5 mb.	1 mb.
4 March 1969	16 mb.	17 mb.	20 mb.
7 March 1969	43 mb.	22 mb.	32 mb.
9 March 1969	33 mb.	9 mb.	22 mb.
13 March 1969	21 mb.	17 mb.	5 mb.
19 March 1969	20 mb.	12 mb.	16 mb.

In applying the Jarvis technique to forecast the deepening of these lows, "perfect" 24-hour prognostic charts, i.e., actual CAO 500 mb. analyses at $t_o + 24$ hrs. were used.

The success of these forecast techniques in predicting the 24-hour deepening of these lows was not great (Figure 7). Mean absolute forecast error of the forecasts based on the Ostby-Veigas technique being 9.4 mb., and of those based on the Jarvis technique, 11.0 mb. Range of forecast-error for the Ostby-Veigas forecasts was from + 10 mb. to -24 mb., and for the Jarvis technique forecasts from + 28 mb. to -19 mb.

Since the surface prognostic charts issued by the CAO are apparently strongly influenced by the numerical prediction models, it was considered reasonable to assume that the success of the CAO prognostic charts in predicting the deepening of the surface lows associated with these 500 mb. troughs in the low-latitude westerlies would also be an indication of the success of the numerical prognostics in these situations. The basic prognostic charts, in particular the P. E. prognostics, were not available for this study.

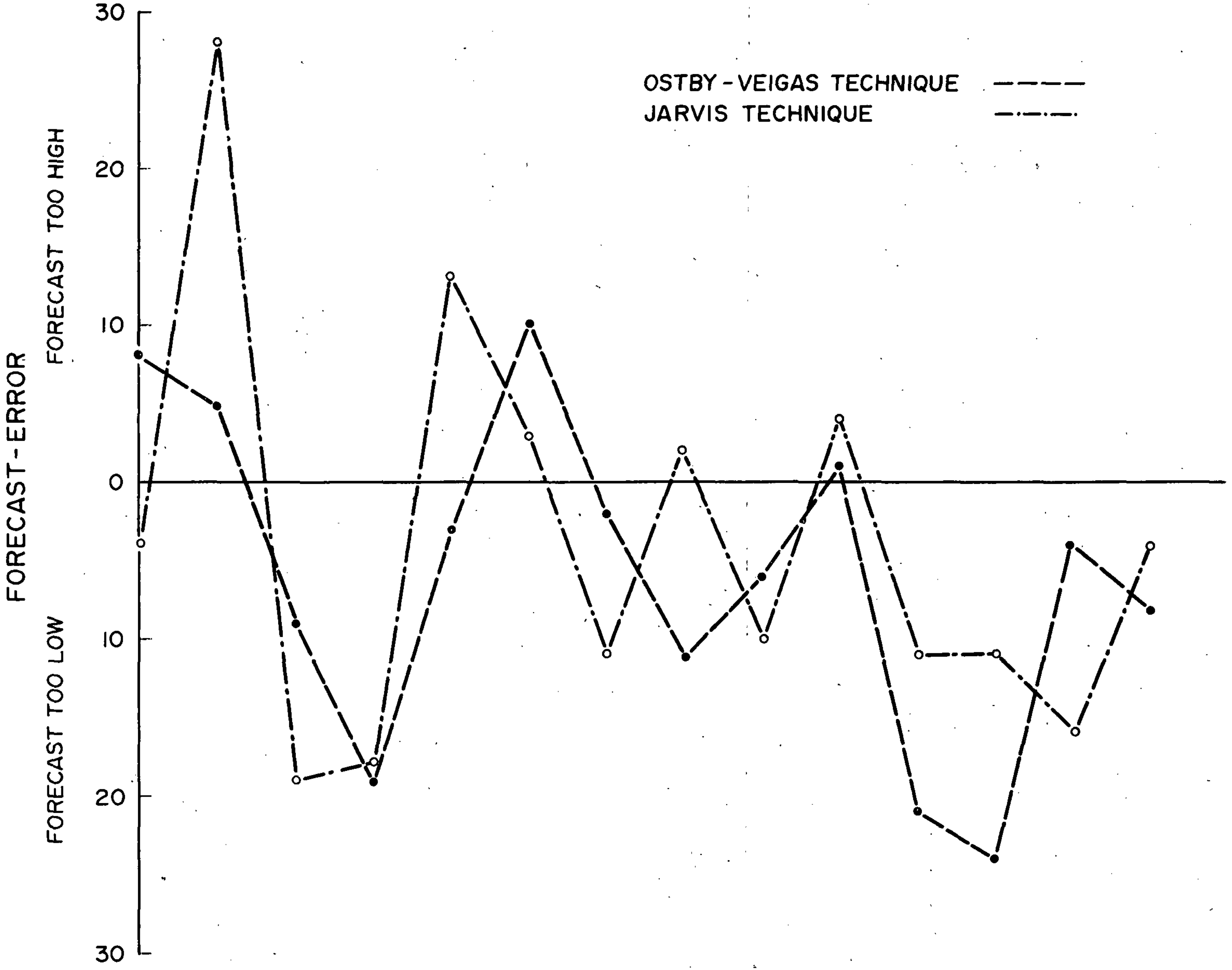
OSTBY-VEIGAS TECHNIQUE
JARVIS TECHNIQUE
FORECAST-ERROR
FORECAST TOO HIGH
FORECAST TOO LOW
30
20
10
0
10
20
30

Figure 7

The CAO prognostic charts for several of these situations were examined to determine the degree of success achieved in predicting the depth of the surface low. Results are set out in Table 6, and indicate the failure of the prognostics to approximate the observed pressure of the lows.

TABLE 6.

Valid Time of Prognostic Chart	Period of Validity of Prognostic Chart	Central Pressure of Low Forecast	Central Pressure of Low Observed	Forecast Errors Central Pressure
1200Z, 1 Dec 1967	36 hr.	998 mb.	984 mb.	14 mb.
0000Z, 2 Dec 1967	48 hr.	994 mb.	956 mb.	38 mb.
1200Z, 9 Feb 1969	42 hr.	992 mb.	983 mb.	9 mb.
0000Z, 8 Mar 1969	42 hr.	988 mb.	958 mb.	30 mb.
0000Z, 10 Mar 1969	42 hr.	992 mb.	976 mb.	16 mb.
1200Z, 12 Mar 1969	36 hr.	986 mb.	954 mb.	32 mb.

The Atlantic Weather Central prognostics, which are strongly influenced by the CAO and numerical prognostics, were no more successful than the CAO in predicting correctly the intensification of the lows occurring in February and March of 1969 (the only months for which copies of the Atlantic Weather Central prognostics were available). (Table 7).

TABLE 7.

Time/Date	Period of Validity of Prognostic Chart	Central Pressure of Low Forecast	Central Pressure of Low Observed	Forecast Errors Central Pressure
1200Z, 9 Feb 1969	30 hr.	996 mb.	983 mb.	13 mb.
0000Z, 10 Feb 1969	30 hr.	990 mb.	970 mb.	20 mb.
0000Z, 8 Mar 1969	30 hr.	984 mb.	958 mb.	26 mb.
0000Z, 10 Mar 1969	30 hr.	999 mb.	976 mb.	23 mb.
1200Z, 10 Mar 1969	30 hr.	984 mb.	954 mb.	30 mb.

4. CONCLUSION

At present, neither the numerically based surface prognostic charts nor the statistically based Ostby-Veigas and Jarvis techniques provide a satisfactory forecast of the offshore deepening of storms developing in low-latitude westerly stream in a blocking situation.

Until a more satisfactory forecast is achieved by numerical methods, it would seem that the least unsatisfactory method of approximating the deepening is by means of a relationship between the speed of the supporting 500 mb. trough, or the westerly component of the strongest winds at the base of the supporting 500 mb. trough and the expected deepening of the surface low.

APPROVED,

C. C. Boughner,
Acting Director,
Meteorological Branch.

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Regression equations for estimating the deepening to be expected twenty-four hours after the surface cyclone leaves the coast are provided.

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