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THE APPLICATION OF A GRID
TECHNIQUE FOR FORECASTING
FRONTAL CYCLONES

BY
E.C. JARVIS

U.D.C. 551.509.313
551.509.311

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CANADA - DEPARTMENT OF TRANSPORT - METEOROLOGICAL BRANCH
315 Bloor Street, West,
TORONTO 5, Ontario.

THE APPLICATION OF A GRID TECHNIQUE FOR FORECASTING FRONTAL CYCLONES

by

E. C. Jarvis

ABSTRACT

A simple baroclinic prediction model has been adapted to the Wilson grid for predicting the displacement and central pressure of frontal cyclones for periods up to 24 hours. It was determined that the primary component of displacement, equivalent to the 500-mb vector wind within the area enclosed by the Wilson grid, should be adjusted for the secondary displacement resulting from the influence of sloping terrain, major diabatic processes, and the latitudinal variation of Coriolis force. Charts which permit an objective quantitative evaluation of the secondary displacement, in a convenient form for operational use, are presented for continental North America and adjacent oceanic areas between latitudes 30N and 60N. Procedures for the application of the technique are presented, and assumptions and approximations used in developing the model are discussed qualitatively with a view to establishing a set of principles to refine the objective prediction by subjective adjustment.

APPLICATION D'UNE TECHNIQUE DE CARROYAGE À LA
PRÉVISION DES CYCLONES FRONTAUX

par

E. C. Jarvis

RÉSUMÉ

Un modèle simple de prévision barocline a été adapté à la grille Wilson afin de prévoir le déplacement et la pression centrale des cyclones frontaux pour des périodes de prévision allant jusqu'à 24 heures. Il a été déterminé que la composante primaire du déplacement, qui est équivalente au vent vectoriel moyen de 500 mb dans l'aire comprise par la grille Wilson, doit être ajustée pour le déplacement secondaire résultant de l'influence du terrain en pente, des transformations diabatiques majeures et de la variation latitudinale de la force de Coriolis. Des cartes qui permettent une évaluation quantitative objective du déplacement secondaire sont données sous une forme se prêtant à l'utilisation pratique pour l'Amérique du Nord continentale et les régions océaniques adjacentes entre 30 et 60 degrés de latitude Nord. Les moyens d'appliquer la technique sont exposés, et les hypothèses et les approximations employées dans la mise au point du modèle sont étudiées du point de vue qualitatif afin d'établir un ensemble de principes propres à améliorer la prévision objective par ajustement subjectif.

THE APPLICATION OF A GRID TECHNIQUE FOR
FORECASTING FRONTAL CYCLONES

by

E. C. Jarvis

1. INTRODUCTION

In the past few years considerable success has been achieved in the preparation of prognostic charts by means of the dynamical equations. This success has been noted in the preparation of 1000-mb prognostic charts as well as charts of the 500-mb contour and vorticity fields, and a 24-hour 1000-mb prognostic chart following the method developed by Reed (9, 10) has found operational application. Prognoses of this type are limited to 24 hours as the prediction equation is rarely conserved for longer periods, and since it is most efficiently produced by high-speed electronic computers, it is centrally produced. The chart is, therefore, not always available to meet the immediate requirements of the operational forecaster. Recently Jarvis (6) adapted a prediction equation similar to that of Reed, and credited to Haltiner and Wang (5), to determine a single-point prediction of displacement and central pressure of frontal cyclones by making use of the Wilson grid (11). The technique can be rapidly applied, making use of charts currently available at all forecast offices. From the prediction model employed, it is determined that the primary displacement field, which is the mean 500-mb vector wind in the area enclosed by the Wilson grid, should be adjusted by means of a secondary displacement field which takes into account the effect of terrain-induced vertical velocity, as well as the large-scale vertical velocity associated with synoptic systems; major diabatic processes; and the influence of Coriolis force.

The purpose of this paper is to present monthly-mean charts of the secondary displacement field, in a readily usable form, for continental North America and bordering seas between latitude 30N and 60N. A second objective of this paper is to discuss the approximations and assumptions inherent in the model for the purpose of obtaining the most useful forecast of the movement and central pressure of frontal cyclones that the technique can provide. This is a necessary feature for the successful application of the method, since in some instances components of the secondary displacement field may depart appreciably from monthly-mean values, while in other cases processes which are given minor emphasis in the model may take a prominent role in the movement and intensity of a frontal cyclone. In addition, detailed procedures for applying the technique are listed, and a series of examples is discussed.

2. PREDICTION MODEL

The theoretical background to the prediction equation has been discussed in detail by the authors listed above, and the reader is referred to these papers for the development of the model. This paper begins with the prediction equation adapted to the Wilson grid. Expressed in vector notation, it is:

$$\frac{\partial}{\partial t} (D) = \frac{g}{f} \nabla (\bar{Z}_5 + G + FH + NT_s) \times \vec{k} \cdot \nabla (D) \quad (1)$$

where

$$D = \bar{Z}_0 - Z_0 + CH + G + FH + NT_s \quad (2)$$

$$G = f (\phi, d^2, m^2) \quad \text{a Coriolis parameter}$$

$$F = f (\phi, d^2, m^2, \rho_0, \sigma, k_1) \quad \text{a terrain parameter}$$

$$N = f (\phi, d^2, m^2, \sigma, k_2) \quad \text{a diabatic parameter}$$

$$C = f (\phi, d^2, m^2, \sigma) \quad \text{a stability parameter}$$

\bar{Z}_5 is the mean 500-mb height in the area enclosed by the Wilson grid, with grid length d , and \bar{Z}_0 is the corresponding height on the 1000-mb surface. Z_0 is the 1000-mb height at the center of the grid, and h is the 1000-500-mb thickness at the same location. T_s is the temperature of the underlying surface, H is the terrain height, and ρ_0 is the density at the base of a column of air with stability σ . ϕ is the latitude, m is a map scale factor, and k_1 and k_2 are constants of proportionality.

Equation (1) implies the quantity D is conserved with the geostrophic wind given by the height field $\bar{Z}_5 + G + FH + NT_s$. For convenience the displacement given by this height field is considered to be composed of a primary component of displacement, which is the geostrophic wind given by the \bar{Z}_5 field, and a secondary component of displacement, which is the geostrophic wind given by the $G + FH + NT_s$ field.

It has been shown (6) that if this displacement field is assumed to remain constant during the forecast period, an assumption which is implied by the prediction equation, the forecast change in central pressure is proportional to $(Z_5)_2 - (Z_5)_1$. $(Z_5)_2$ is the forecast 500-mb height at the forecast position of the cyclone, and $(Z_5)_1$ is the initial 500-mb height at the forecast position which is given by the primary displacement field. If the pressure is in millibars and contour heights are measured in meters, then

$$\text{Forecast central pressure} = \text{Initial central pressure} + \frac{(Z_5)_2 - (Z_5)_1}{7.6}$$

As noted by Petterssen (8) and Haltiner and Martin (4), the Coriolis parameter, G , represents the influence of the earth's rotation, and is weighted by the square of the grid length, d . Isopleths of the G field, which are in height units, are parallel to latitude circles with larger values of height to the north. The influence of the G field in the prediction equation is, therefore, to give a westward-directed vector displacement which retards the eastward motion, and increases the westward motion, of frontal cyclones. In using a displacement field based on a grid length less than 600 km, the effect of the G field can usually be neglected, but it becomes increasingly significant as the grid length is increased (8). In applying this technique, the Wilson grid was used because it is roughly equivalent to a grid length of 1000 km, which was found by Estoque (3) to achieve best results for forecasting synoptic features on the 1000-mb surface. In applying the technique, it is, therefore, necessary to consider the geostrophic displacement wind which is given by the G field. However, this presents little difficulty, since once the grid length and map scale have been specified, the G field can be constructed, and it remains constant for all time. Values of G at selected latitudes are given in table 1.

As was the case of the G field, the terrain parameter, F , depends on ϕ , d , and m . In addition, however, F also depends on density ρ_0 , a stability term, σ , and a constant of proportionality, k_1 . σ is a slowly varying quantity which is usually assigned some standard value (3, 5, 9). In this technique, σ was chosen to be typical of moist maritime polar air in winter.

The constant of proportionality, k_1 , was introduced because an attempt was made to account for the influence of terrain-induced vertical velocity which was assumed proportional to the gradient of terrain height. If the horizontal wind is fully translated into upslope motion, $k_1 = 1$. As discussed by Haltiner and Wang (5), where the terrain gradient is large, $k_1 < 1$, since the horizontal wind will then not be fully translated into upslope motion. In this technique, $k_1 = 1$ was used except in the region of the Cordilleras of western North America where a value of $k_1 = 0.5$ was arbitrarily chosen. Values of F at selected latitudes, and for application to the Wilson grid, are shown in table 1 for values $k_1 = 1$ and $k_1 = 0.5$. These values of F were then used to multiply with a smoothed contour chart of North America to construct the FH field which, as was the case of the G field, remains constant for all time.

In addition to ϕ , d , and m , the diabatic parameter, N , also depends on σ and a constant of proportionality, k_2 . It was initially assumed the flux of sensible heat from an underlying

sea surface was the dominant diabatic process affecting synoptic-scale cyclones, and the flux was proportional to the gradient of sea-surface isotherms. k_2 is the constant of proportionality

that relates the heat flux to the sea surface isotherm gradient. Unfortunately, k_2 cannot be evaluated, so N cannot be evaluated explicitly. However, on the basis of tests conducted by Haltiner and Wang (5), it was concluded that N could be assigned a value of -20 feet per degree Fahrenheit for converting sea-surface isotherms into equivalent height units when the Wilson grid was used. This value of N achieved results consistent with observations, so, in addition to the flux of sensible heat to or from the sea being accounted for empirically, it also considers all other diabatic processes occurring over the sea in a coarse statistical sense.

Diabatic processes occurring over land are not accounted for. Frictional dissipation of kinetic energy and the radiative transfer of heat are generally considered very small over forecast periods of a few days or less. Priestley (7) has shown the sensible heat flux over land is negligible compared to the heat flux over the sea, since the sea can be regarded as an infinite heat source, whereas the flux of heat over land is restricted by the slow rate at which heat is conducted to the exposed surface of solid bodies. The most significant diabatic process omitted over land areas would appear to be the latent heat of condensation and sublimation released as a result of cooling by large-scale ascent. It has been shown by Danard (2) that this process can play an important role in cyclone development.

In order to adapt the diabatic processes over the sea in an operationally useful manner, monthly-mean values of sea surface temperature were used. The day-to-day variation in sea surface temperature is negligible except along the gulf stream in the North Atlantic Ocean, where local variations of 4 to 5 degrees Celsius have been observed in a 24-hour period. However, even in this region the change becomes negligible when the temperature at a point is smoothed over the area enclosed by the Wilson grid. Further support to justify using monthly-mean temperatures is determined by an inspection of isotherm charts of the sea surface which show only small variations from month to month.

The stability parameter, C , depends on θ , d , m , and the stability of the air column, σ . When σ is assigned some standard value, and grid length and map scale are specified, C becomes only a function of latitude. As noted in table 1, C varies slowly in middle latitudes where frontal cyclones usually spend their active lifetime. C was, therefore, assumed to have a constant value of 1.0.

TABLE 1

Values of G, F and C at selected latitudes for a polar stereographic map projection and for adaptation to the Wilson grid. G is in meters and F and C are dimensionless parameters.

Latitude	30	35	40	45	50	55	60	65
G	21	29	39	51	65	77	90	103
F ($k_1 = 1.0$)	0.057	0.096	0.103	0.145	0.176	0.220	0.259	0.292
F ($k_1 = 0.5$)	0.028	0.048	0.052	0.072	0.088	0.110	0.130	0.146
C	0.48	0.70	0.86	1.23	1.47	1.84	2.16	2.44

Using the values shown in table 1, isopleths of G were charted for the area of interest to give the G field in height units. The terrain height, H, was multiplied by the appropriate value of F to construct the FH field, in height units. Following Haltiner and Wang (5), monthly-mean sea surface isotherms were re-labelled in height units according to the convention that IF = -20 feet, where zero height corresponded to the 75F isotherm. A height field of NT_s was then drawn for each month over the oceanic areas. The charts of G, FH and NT_s were then added graphically and smoothed over an interval of 2.5 degrees latitude to obtain the secondary height field, $G + FH + NT_s$, for each month. This additional smoothing was applied in order to avoid discontinuities in the field that appeared along the coastlines of North America.

The secondary height field charts were then converted to a form more convenient for operational application. Using the Wilson grid, west and south components of the secondary displacement field were computed at grid points 2.5 degrees latitude apart over the area of interest, and a west component, and south component, of secondary displacement was drawn up for each month. The components of secondary displacement for 24 hours could then be read directly from the appropriate charts. For 12-hour forecasts, half the charted values should be used. These charts are shown in figures 1 to 24.

3. THE FORECAST PROCEDURE

The procedure for obtaining a 24-hour forecast of displacement and central pressure of frontal cyclones follows:

1. Locate the surface position of the cyclone on the 500-mb chart for the same time, and with the Wilson grid (Canadian Weather Service Scale 71)

centered at this location, and oriented north-south and east-west, compute the eastward and northward components of primary displacement according to the following equations:

$$C_E = K(\phi) \left[(Z_2 - Z_1) + (Z_4 - Z_3) + (Z_6 - Z_5) \right]$$

$$C_N = K(\phi) \left[(Z_5 - Z_1) + (Z_8 - Z_7) + (Z_6 - Z_2) \right]$$

Z_1 is the 500-mb height, in tens of meters, at location 1 on the Wilson grid,

Z_2 is the 500-mb height at location 2, and so on. Using the values of $K(\phi)$ that appear on the Wilson grid scale, the components of primary displacement,

C_E and C_N , are in degrees latitude per day, where the degree of latitude at 45N is used as the unit of length.

2. Measure C_E along the appropriate latitude circle from the initial position of the cyclone, and add C_N along the appropriate longitude line from the endpoint of C_E . The location reached by the vector addition of C_E and C_N is the primary forecast position of the cyclone. Record the 500-mb height at this location and label it $(Z_5)_1$.

3. Locate the initial position of the cyclone on the secondary displacement charts for the appropriate month and read off the east-west component of secondary displacement, C_W , and the north-south component, C_S . From the primary forecast position given by step 2 add C_W and C_S vectorially in the same way as C_E and C_N were added. This vector addition gives the forecast position of the cyclone in 24 hours. Record the forecast 500-mb height at this location, which can be read from an available 500-mb prognostic chart, and label it $(Z_5)_2$.

4. Forecast the central pressure according to the relation:

$$\text{Forecast pressure} = \text{Initial pressure} + \frac{(Z_5)_2 - (Z_5)_1}{7.6}$$

In some cases a forecast can be made when the surface wave or cyclone is not present at the initial time. If a qualitative assessment of Petterssen's development equation (8) indicates cyclogenesis is likely, the computation can be performed with the Wilson grid centered on the area of maximum cyclonic 500-mb vorticity advection that will take part in development of the surface cyclone.

The technique can be applied for forecast period of 12 hours by using a value $K(\emptyset)/2$ in place of $K(\emptyset)$ for computing C_E and C_N , and by using one-half the value of C_W and C_S given by the appropriate secondary displacement charts. The technique can be applied in a similar manner for any forecast interval, but the accuracy of the technique diminishes rapidly beyond 24 hours in most cases because the displacement field is no longer conserved.

A sample computation is shown in figure 25.

4.

EXAMPLES

Forecasts of frontal waves and cyclones which could be associated with well-defined areas of cyclonic vorticity at 500 mb were made at 0000Z for the month of January, 1964. Figures 26 to 56 show the 0000Z surface isobars, in thin solid lines at 8 mb intervals, for each day of the month. The usual convention is used to denote surface frontal positions, and the associated 500-mb contour patterns are shown by broken lines at 60 meter intervals. Arrows point to dots which give the 24 hour forecast position of the cyclones, obtained by means of the grid technique, and central pressure forecasts are shown in parentheses near the forecast location.

Figure 57 is a displacement-error diagram of forecasts made during the month. The origin of the graph is the observed location of the cyclone, and forecast displacements relative to observed location at forecast time are entered. A graph comparing forecast change in central pressure with the observed central pressure change is shown in figure 58. The root mean square error in predicted displacement was 3.5 degrees latitude, and the root mean square error in central pressure was 7.8 mb.

5.

DISCUSSION

The stability parameter, C , was assigned the value 1.0 for the application of the technique. This value of C is accurate for typical moist maritime polar air at 42N in winter. The amount by which this parameter varies with latitude is shown in table 1. It is also of interest to know what value

of C is most representative of other air masses associated with frontal cyclones. Using characteristic temperatures of North American air masses at standard pressure levels (1), and using as a standard $C = 1.00$ for maritime polar air in winter, the stability parameter was calculated for other air masses. These values are given in table 2.

TABLE 2

Values of stability parameter, C, for characteristic temperatures of North American air masses, based on a standard value of $C = 1.00$ for mP air in winter.

	Air Mass	C
mT	winter	0.76
	summer	0.72
mP	winter	1.00
	summer	0.84
mA	winter	1.30
	summer	0.94
cold mA	winter	1.72
	summer	1.02

Except for cold mA air in winter, it is indicated by table 2 that choosing a standard value of C with regard to air masses appears to be no more serious an assumption than making C independent of latitude. However, the error incurred by these two assumptions will be compounded in many cases since the warmer air masses with $C < 1$ are usually found at low latitudes where $C < 1$. The converse is the case for cold air masses, which are usually found at high latitudes. When C is less than the assumed value, the forecast displacement will tend to be less than the actual displacement, and when C is greater than the assumed value, the forecast displacement will tend to be too great. In general terms, then, the vector displacement of frontal cyclones at low latitudes and associated with tropical air may be under-estimated by the technique, while the displacement of frontal cyclones at high latitudes and associated with Arctic air is to be over-estimated. For the case of cyclones with tropical air at high latitudes, or arctic air at low latitudes, the trend will be for latitude and stability effects to compensate.

In determining the terrain influence on secondary displacement, highly smoothed contours of terrain height were used, and upon the secondary displacement field additional smoothing was made. Some justification for using a smoothed contour pattern can be made since it is a synoptic-scale system that is being forecast, and a large smoothing interval achieves best results. However, it is not yet known precisely what amount of smoothing achieves optimum results, so it is anticipated the technique would be least satisfactory for application in western North America. Preliminary tests of the technique have, however, yielded some very useful forecasts, so the use of the technique in mountainous areas warrants close investigation.

The terrain effect causes a cyclone to deviate to the left and decelerate when it approaches a mountain range, and to accelerate and deviate to the right when it recedes from a mountain range (11). For cases where the low-level winds are parallel to the terrain contours, the terrain influence which is accounted for by the technique will be over-emphasized. In this case the trend will be for the technique to cause the low to move too far to the left on approaching the mountain range, and to move too far to the right on receding from the mountain range. The trend will be for the converse to occur when the low-level wind has a large component perpendicular to the terrain contours.

It has been noted in section 3 that the released latent heat of condensation and sublimation, which is not considered by the technique over land areas, can have a significant effect on the kinetic energy of frontal cyclones. The added buoyancy that results from released latent heat will contribute to the lowering in central pressure of the cyclone. The omission of this diabatic process over land will result in an underestimate of development, and the trend will be for the error to be greater during cases of heavy precipitation than for cases of light precipitation.

The empirical relation for relating the flux of sensible heat over the sea to the gradient of sea surface isotherms is based largely on cases of cyclogenesis. The diabatic influence used in the technique is, therefore, best suited to cases of moderate or strong development over the sea. Cases where the cyclones are embedded in a strong zonal flow, or which have an absence of cold arctic air behind them, will usually be displaced farther to the west than observed, and the computed central pressure will be lower than observed. This will occur because the diabatic effect causes a cyclone to deviate to the left and decelerate.

However, it is found in the majority of cases that the forecast position using only the primary displacement component, and the forecast position using both primary and secondary displacement components, give the extreme locations between which the cyclones are observed to be located at forecast time, regardless of the diabatic influence. When deepening over the sea is moderate or explosive, the observed location usually lies close to the position forecast by the complete grid technique; but where the diabatic processes are weak, the observed position is shifted in the direction of the location predicted by the primary displacement field.

Forecast errors resulting from the initial contour pattern at 500 mb have been discussed at some length in an earlier paper (6). It is of interest to note, however, that cyclones which are initially in an area where the 500-mb relative vorticity is cyclonic will be forecast to have a lower central pressure than observed. Frontal cyclones usually begin to develop in a region where the 500-mb relative vorticity is close to zero. There are cases, notably the Texas low, where development is noted to originate near the base of a major 500-mb trough.

Experience in applying the technique also indicates the method should be used with caution in cases where there is a major 500-mb trough which lies partially within the Wilson grid downstream from the initial position of the cyclone, and in cases where a major 500-mb ridge lies partially within the grid area upstream from the initial position of the cyclone. Cases where this occurs are usually associated with "blocking" situations, and although accurate forecasts sometimes result, the forecast must always be evaluated in the light of additional information.

To summarize the foregoing discussion, the forecast displacement will be too small, and the forecast central pressure will be too low, when (i) frontal cyclones are associated with warm air masses at low latitudes, (ii) a large low-level wind component perpendicular to terrain contours is associated with cyclones receding from a mountain range, (iii) a large low-level wind component parallel to the terrain contours is associated with cyclones approaching a mountain range, (iv) frontal cyclones over the sea are embedded in a strong zonal flow aloft, or there is an absence of Arctic Air to the rear of the system, and (v) a closed low exists at 500-mb within the grid area upstream from the initial position of the cyclone. On the other hand, the forecast displacement will be too large and the forecast central pressure will be too high when (i) frontal cyclones are associated with cold air masses at high latitudes, (ii) a large low-level wind component parallel to terrain contours is associated with cyclones receding from a mountain range, (iii) a large low-level wind component perpendicular to terrain contours is associated with cyclones approaching the mountain range, and (iv) there is a major 500-mb trough lying within the grid area downstream from the initial position of the cyclone.

In order to test the feasibility of using these general comments in applying a subjective correction to the forecast given by the technique, the departure of the values of C, F, N, and the 500-mb contour pattern, from those assumed by the technique were assessed for a number of cases. This departure is indicated in Table 3, and the observed displacement and central pressure are included for the purpose of comparison. Cases used were those of the January, 1964, series shown in figures 26 to 56 which exceeded the root-mean-square errors of the whole series.

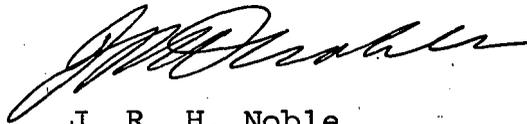
The results shown in Table 3 would suggest an improvement to the forecast could have been achieved for the majority of cases considered if the magnitude of C, F, N, and the 500-mb contour pattern, of each case had been considered in the light of the values assumed by the technique.

6.

SUMMARY

The westward and southward components of secondary displacement for the application of the Wilson grid in forecasting the displacement and central pressure of frontal cyclones were presented for each month of the year. The procedure to follow in applying the technique was outlined and results obtained by the technique were shown for the month of January, 1964, at 0000Z. The results achieved would indicate the technique can be used to give a useful first approximation in 24-hour forecasts of displacement and central pressure of frontal cyclones in many instances. By comparing the actual magnitude of stability parameter, Coriolis parameter, diabatic parameter, and 500-mb contour pattern, with the magnitude assumed by the technique, the forecasts given by the technique can be refined to achieve useful forecasts for cases where the departure from assumed conditions is significant.

APPROVED,



J. R. H. Noble,
Director.

TABLE 3

Assessment of displacement and central pressure errors incurred by the technique which result from the assumptions and approximations made in stability parameter, C, the terrain parameter F, the diabatic parameter, N, and the configuration of the 500-mb contour pattern. Large values signify the forecast displacement is too great and forecast central pressure is too high. Small values signify the forecast displacement is too small and the forecast central pressure is too low. One star denotes a slight departure in the values assumed by the technique, and 2 stars denote a significant departure.

CASE		DISPLACEMENT AND CENTRAL PRESSURE FORECAST BY THE TECHNIQUE								OBSERVED DISPLACEMENT AND CENTRAL PRESSURE			
Date	Initial Location	C		F		N		500-mb contours		Displacement (deg. lat.)		Central pressure (mb)	
		Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small
000Z, 1964													
Jan.	30N82W								**		2		16
Jan.	60N80W	*							**		3		10
Jan.	38N102W		*	*					*		3		12
Jan.	53N98W	*						*		4		2	
Jan.	57N110W	*						*		4		5	
Jan.	44N58W							*		4		7	
Jan.	61N119W	*			*			*			2		10
Jan.	47N79W										5		4
Jan.	31N87W		**				*				7	2	
Jan.	48N110W				*						3		12
Jan.	35N101W		*								0		5
Jan.	48N52W	**							*	3		7	
Jan.	32N92W		*						*		7		7
Jan.	36N90W								*		2		11
Jan.	51N102W							*		4		2	
Jan.	47N79W		*						**	1			11
Jan.	47N72W		*					**		0		20	
Jan.	37N101W		*							1			6
Jan.	46N107W				*				*		2		10
Jan.	30N95W		*						*		5		0
Jan.	37N82W								**		2		10
Jan.	46N48W								**	1			14
Jan.	32N109W		*						**		4		7
Jan.	52N79W	*						*	*		4		10
Jan.	30N87W		*						*		2		11
Jan.	53N117W	**						*	*	5		4	
Jan.	42N120W			*				*		0		10	
Jan.	36N60W						*				2		10
Jan.	37N112W	*			*						1		14
Jan.	53N106W	*							*		0		10
Jan.	53N73W		*						*	1			10
Jan.	40N73W								**	1			18
Jan.	45N117W									5		4	
Jan.	48N86W	*							*		4		8
Jan.	35N101W		**						*		2		18
Jan.	42N65W	*							**		3		11
Jan.	45N51W								*		2		12

7.

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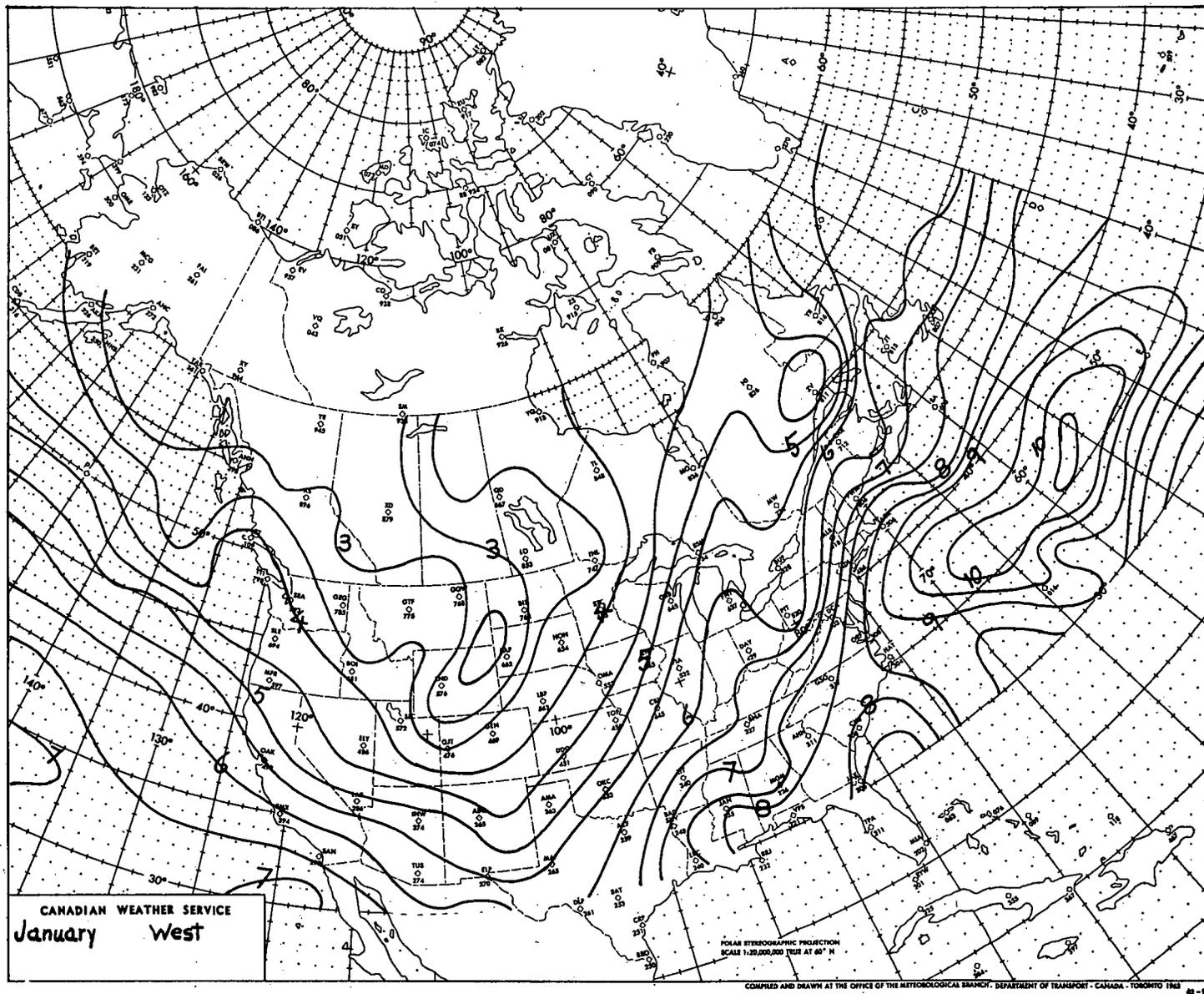


FIG. 1
Westward component of secondary displacement for January.
Units are degrees of latitude.

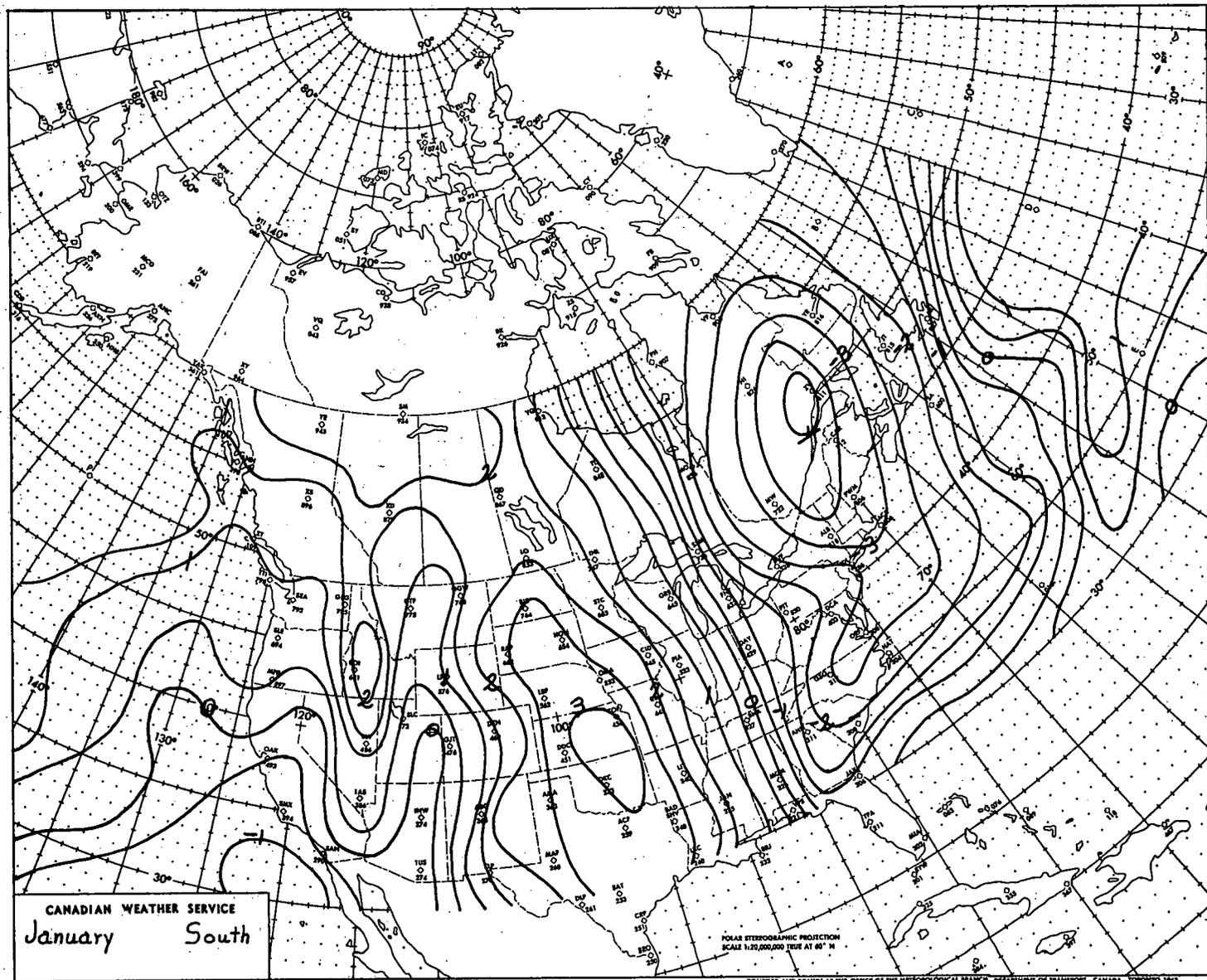
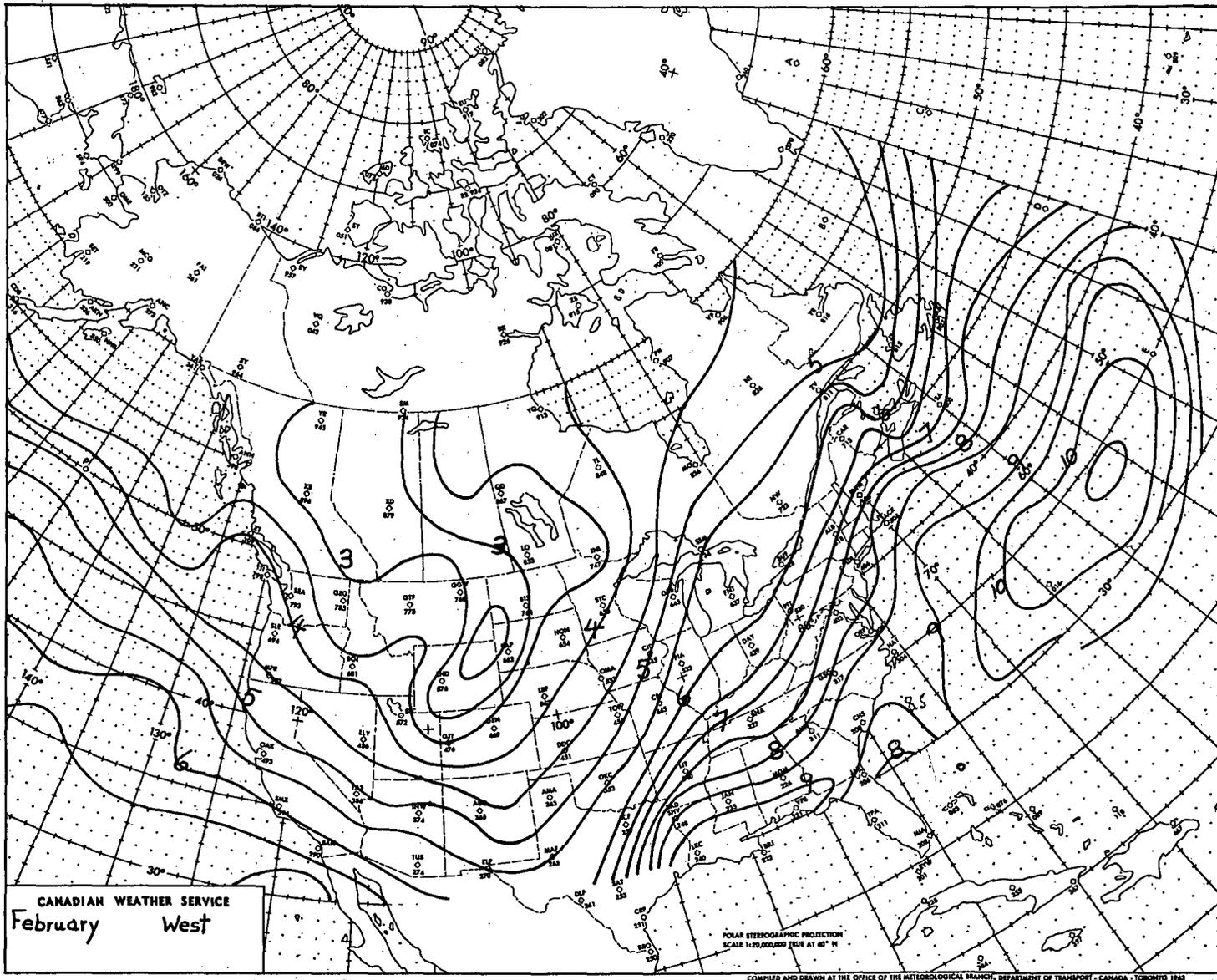


FIG. 2
 Southward component of secondary displacement for January.
 Units are degrees of latitude.



Feb 7, 008
 $L = 28N 76.5W$
 $79 - 52 = 27$
 $C_E = 81 - 53 = 28$
 $84 - 60 = 24$

 $.2 \times 79$
 $C_E = 15.8^\circ$
 $C_N = 60 - 52 = 8$
 $+ 85 - 63 = 122$
 $84 - 79 = 5$

 25
 $C_N = 5^\circ$

Primary position
 $60.7W$
 $133^\circ N 60.7W$
 Sec Comp $C_W = 8.5^\circ$
 $C_S = -1^\circ$

 Sec Position
 $134^\circ N 69.2^\circ W$

$$L_y = L_0 + \frac{252 - 251}{7.6} =$$

FIG. 3
 Westward component of secondary displacement for February.
 Units are degrees of latitude.

Sec
 -40 STDFCS
 $76.5 - 15.8 = 60.7$
 $452 = 58$
 $2(5)1 = 68$ } $\frac{-100}{7.6} = -13mb$

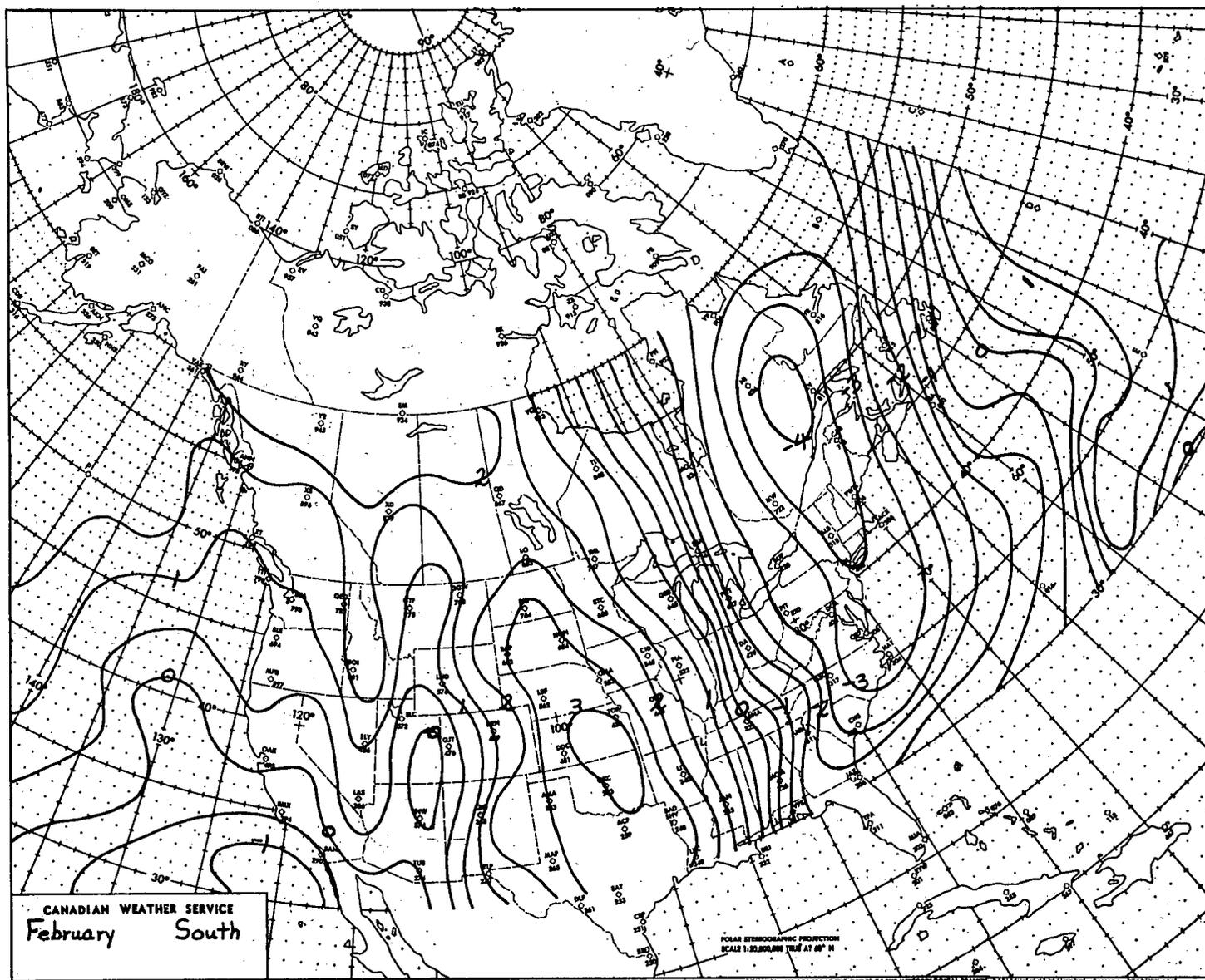


FIG. 4
Southward component of secondary displacement for February.
Units are degrees of latitude.

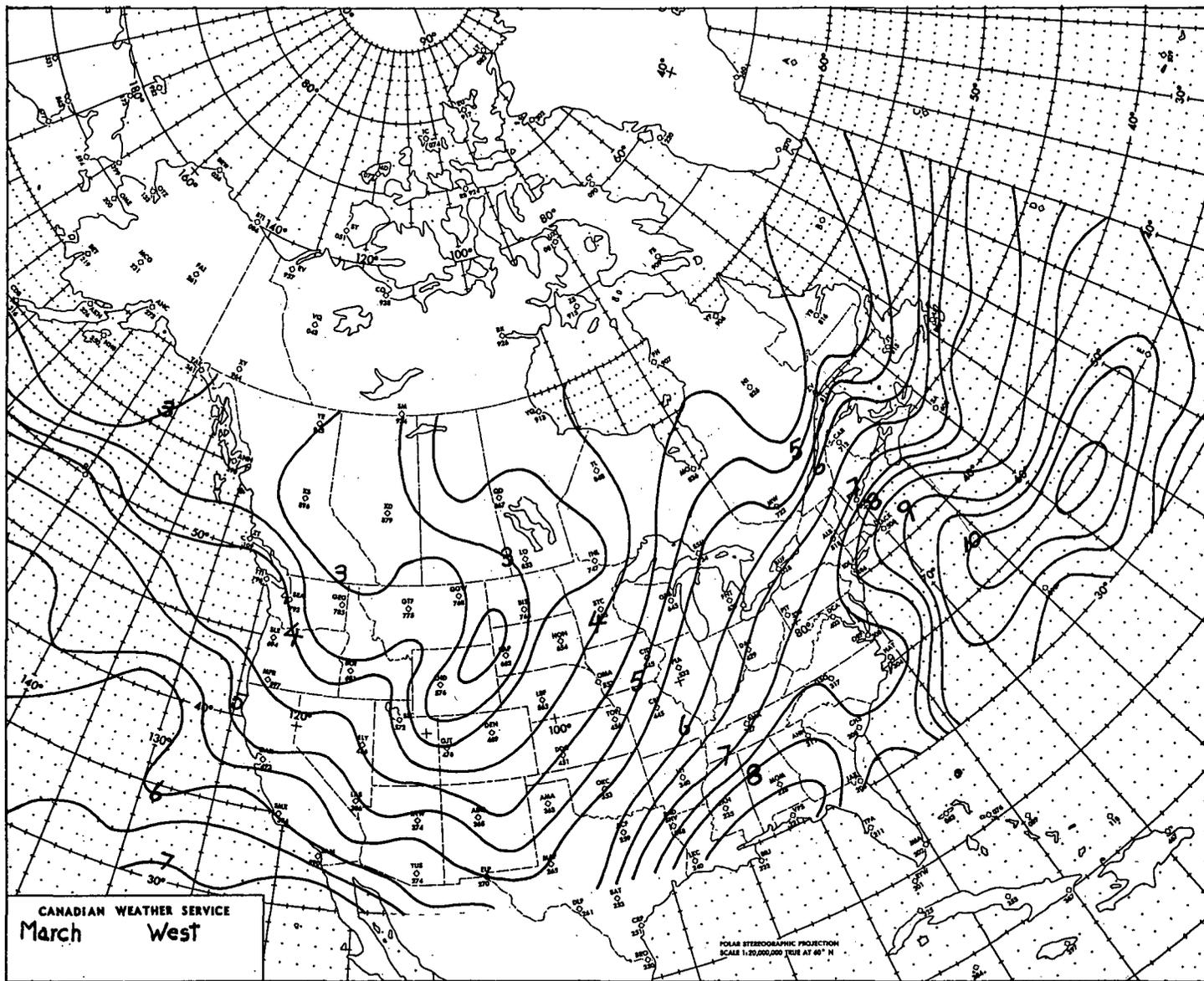


FIG. 5
Westward component of secondary displacement for March.
Units are degrees of latitude.

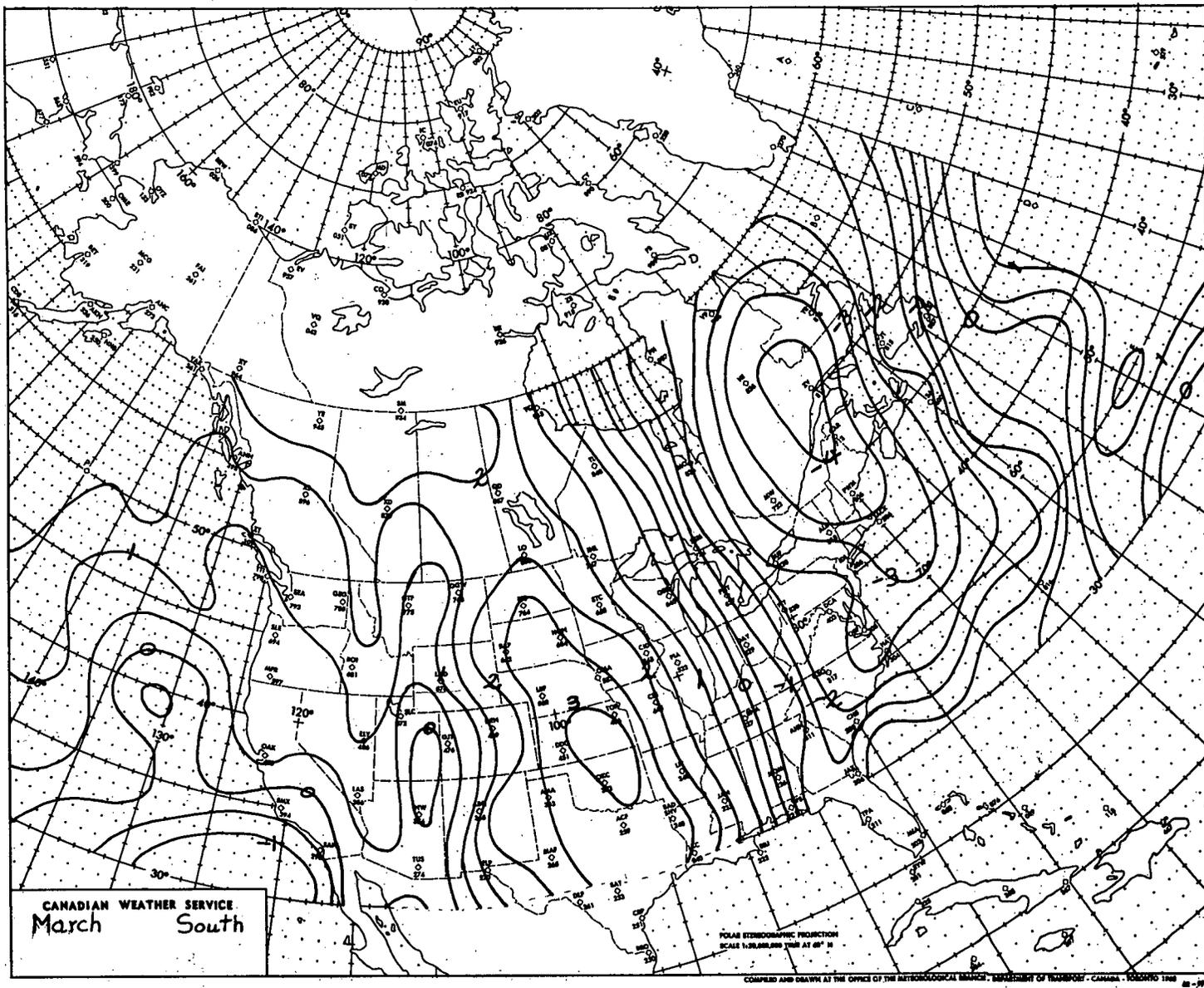


FIG. 6
 Southward component of secondary displacement for March.
 Units are degrees of latitude.

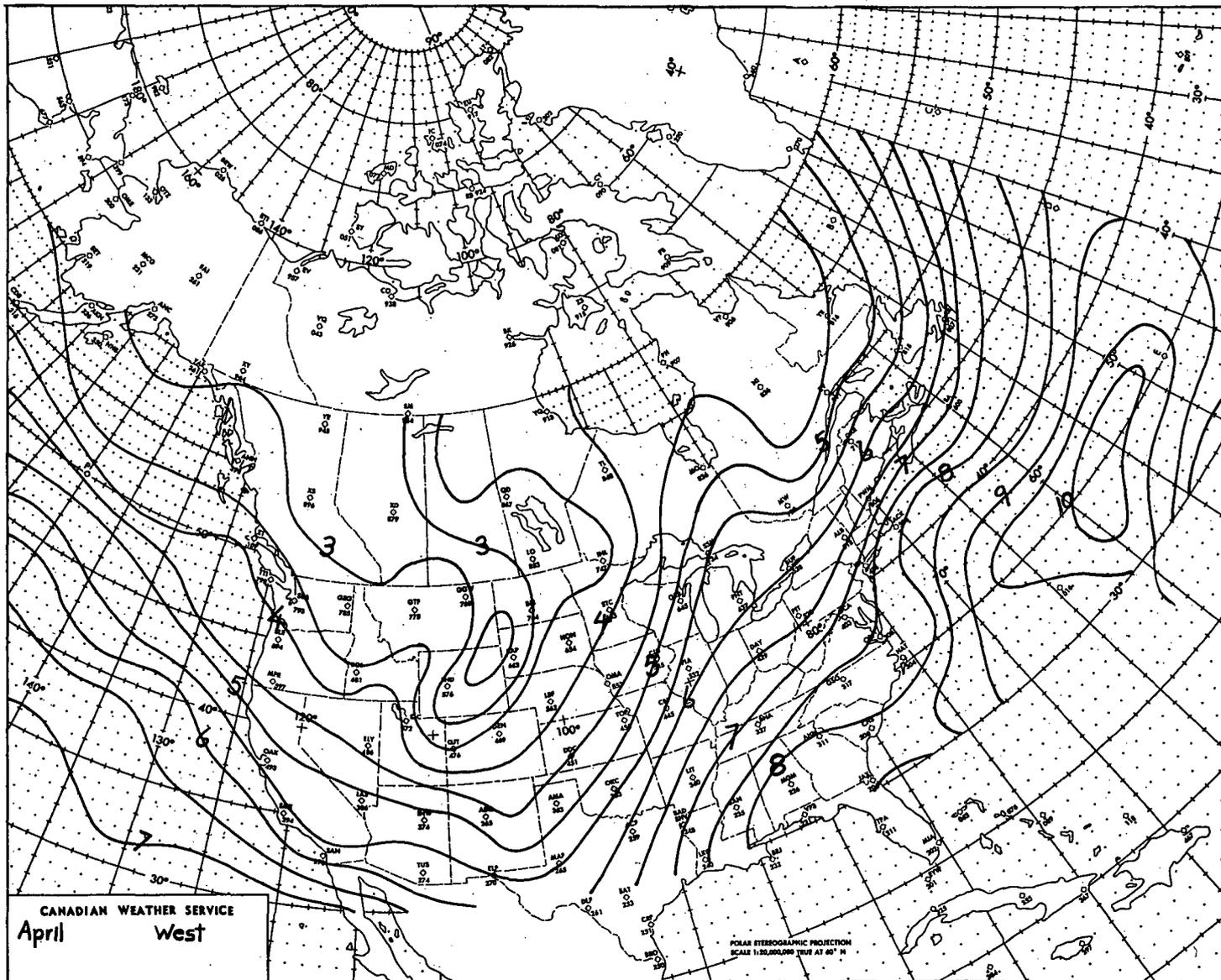


FIG. 7
 Westward component of secondary displacement for April.
 Units are degrees of latitude.

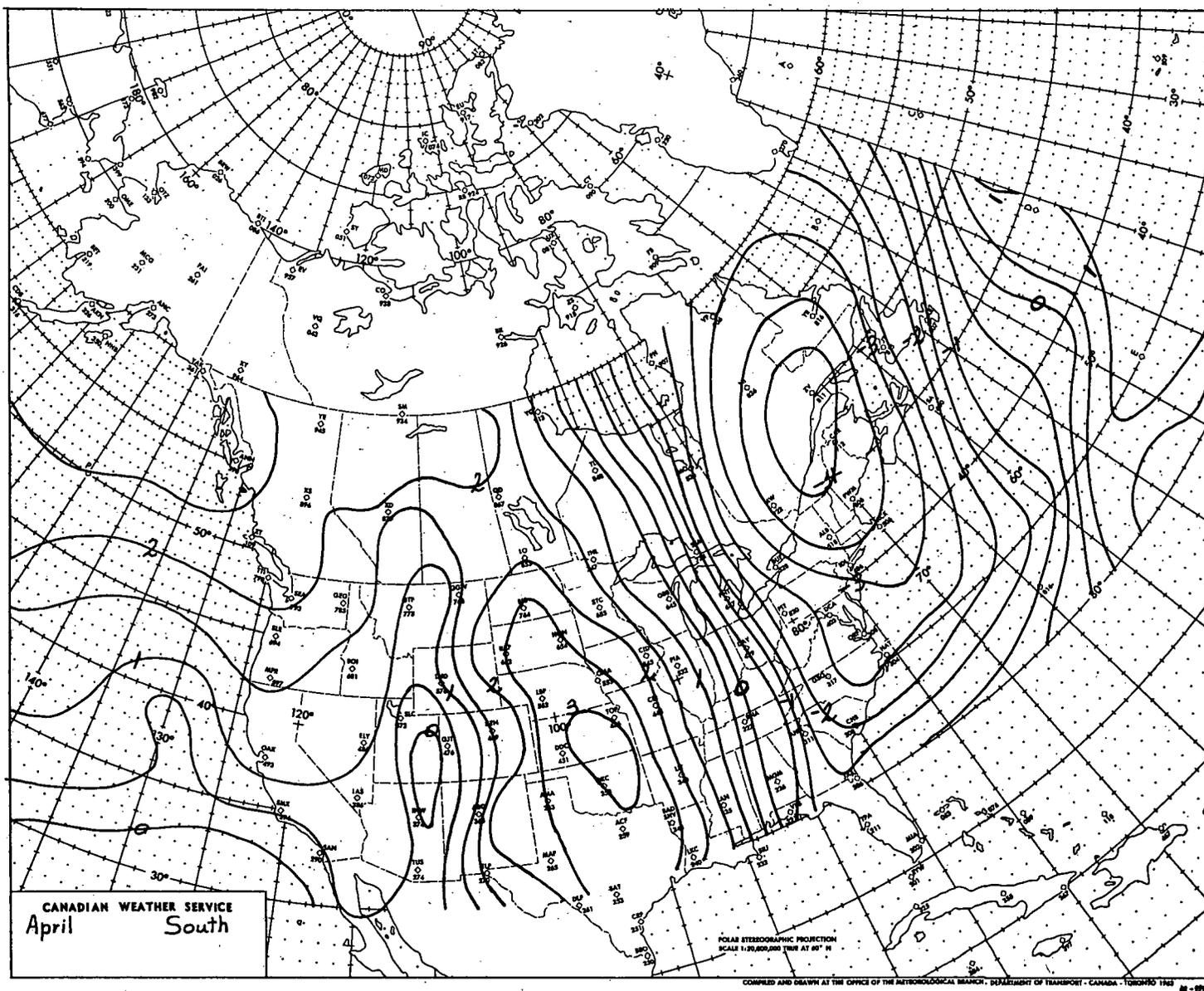


FIG. 8
 Southward component of secondary displacement for April.
 Units are degrees of latitude.

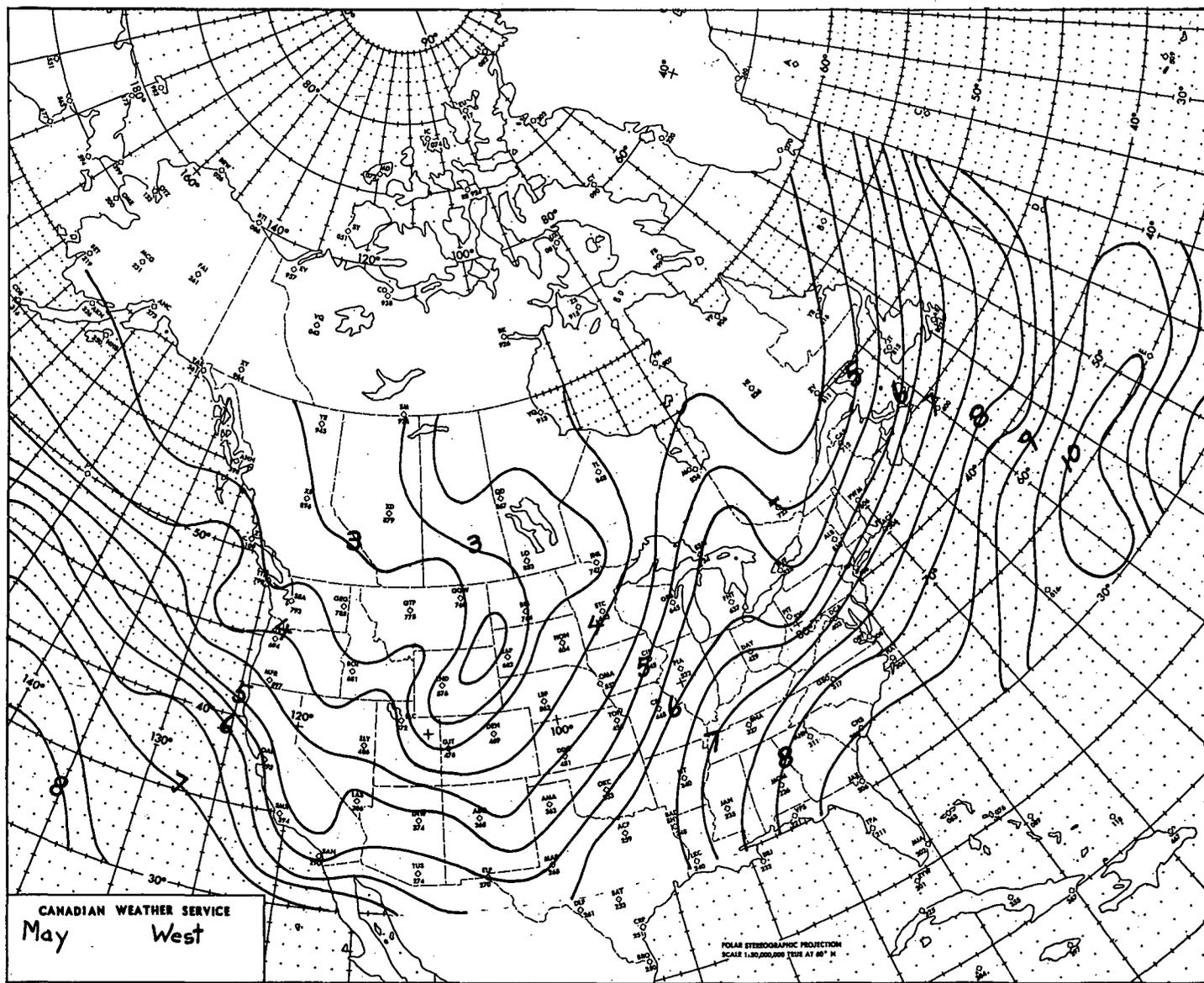


FIG. 9
Westward component of secondary displacement for May.
Units are degrees of latitude.

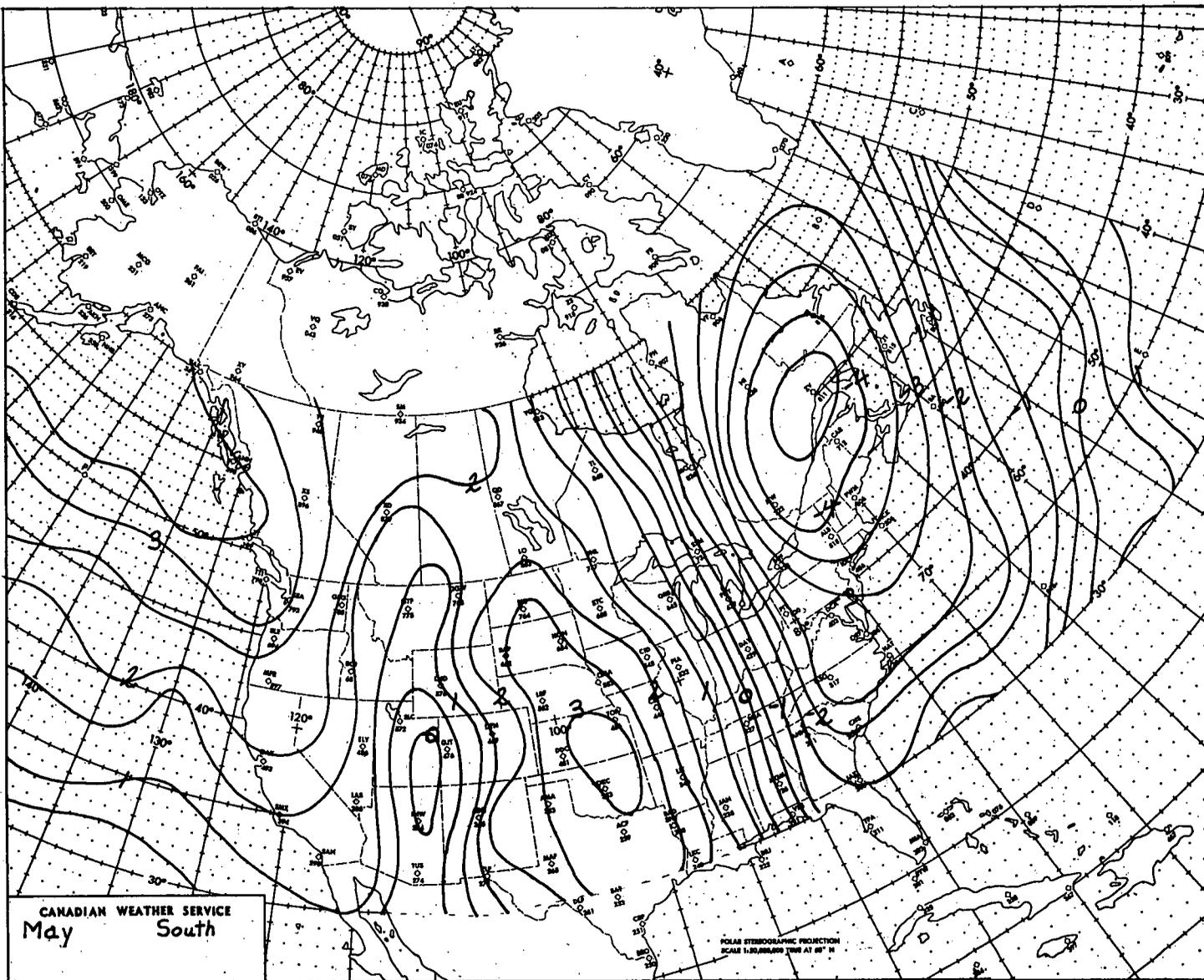


FIG. 10
 Southward component of secondary displacement for May.
 Units are degrees of latitude.

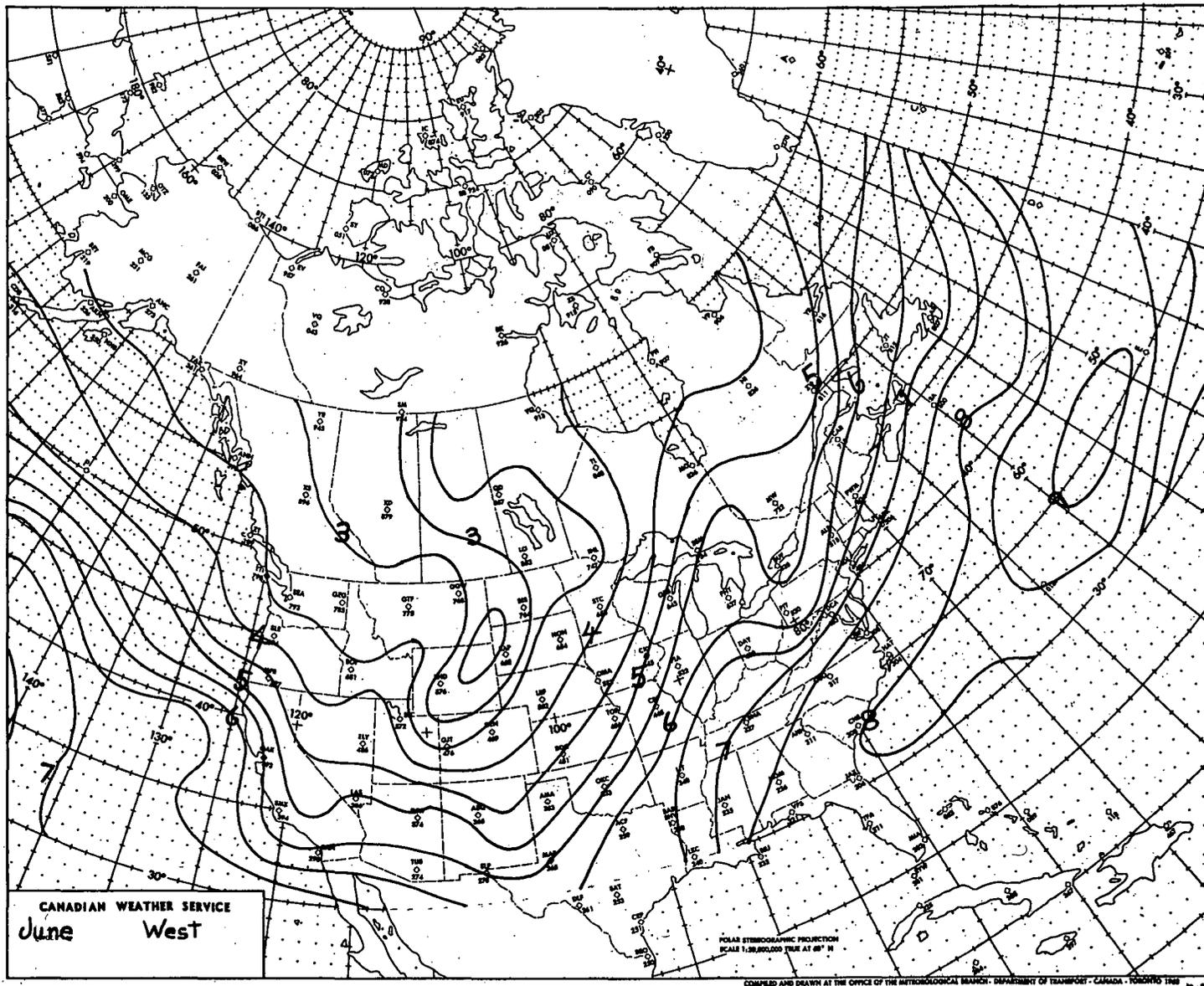


FIG. 11
Westward component of secondary displacement for June.
Units are degrees of latitude.

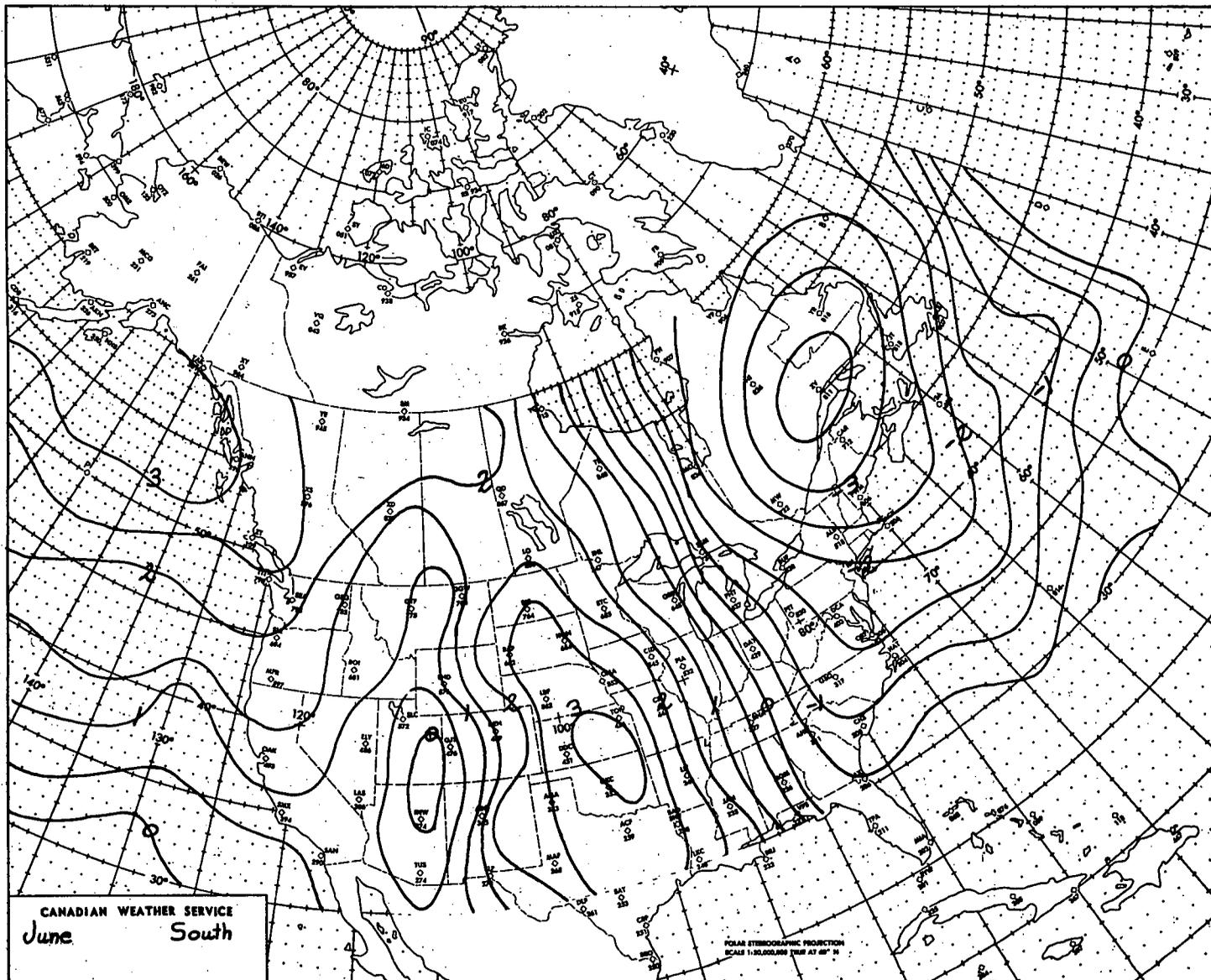


FIG. 12
 Southward component of secondary displacement for June.
 Units are degrees of latitude.

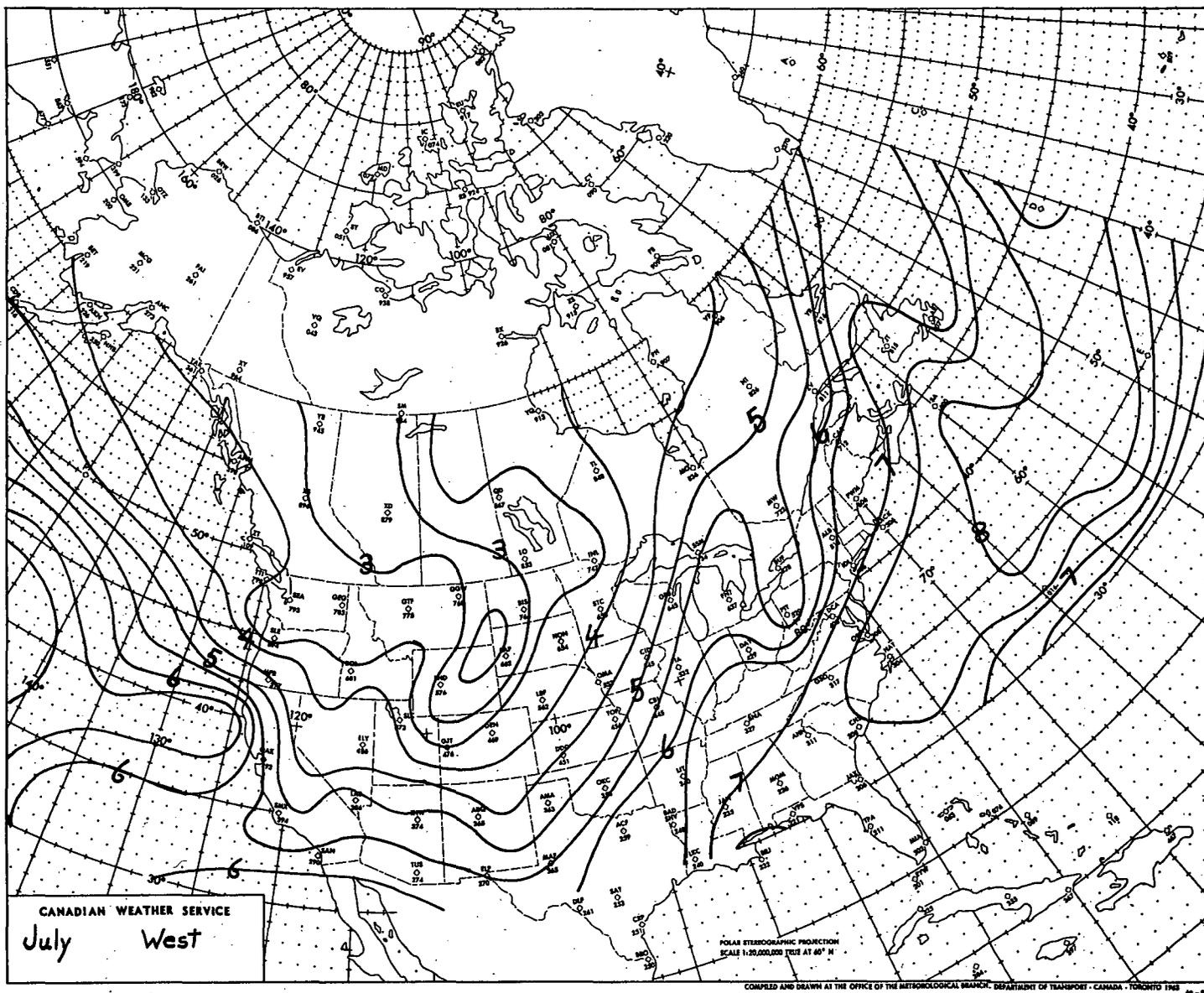


FIG. 13
 Westward component of secondary displacement for July.
 Units are degrees of latitude.

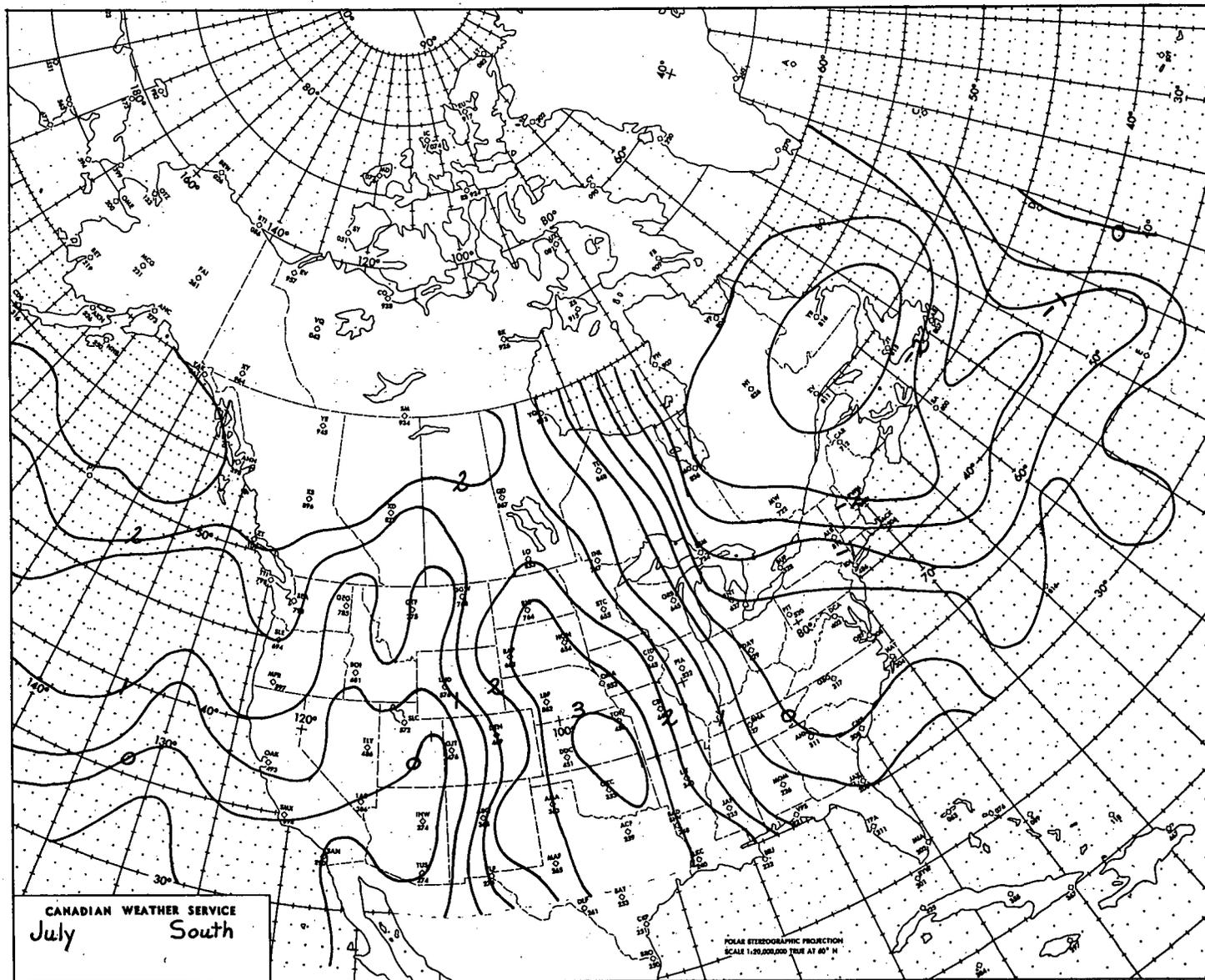


FIG. 14
 Southward component of secondary displacement for July.
 Units are degrees latitude.

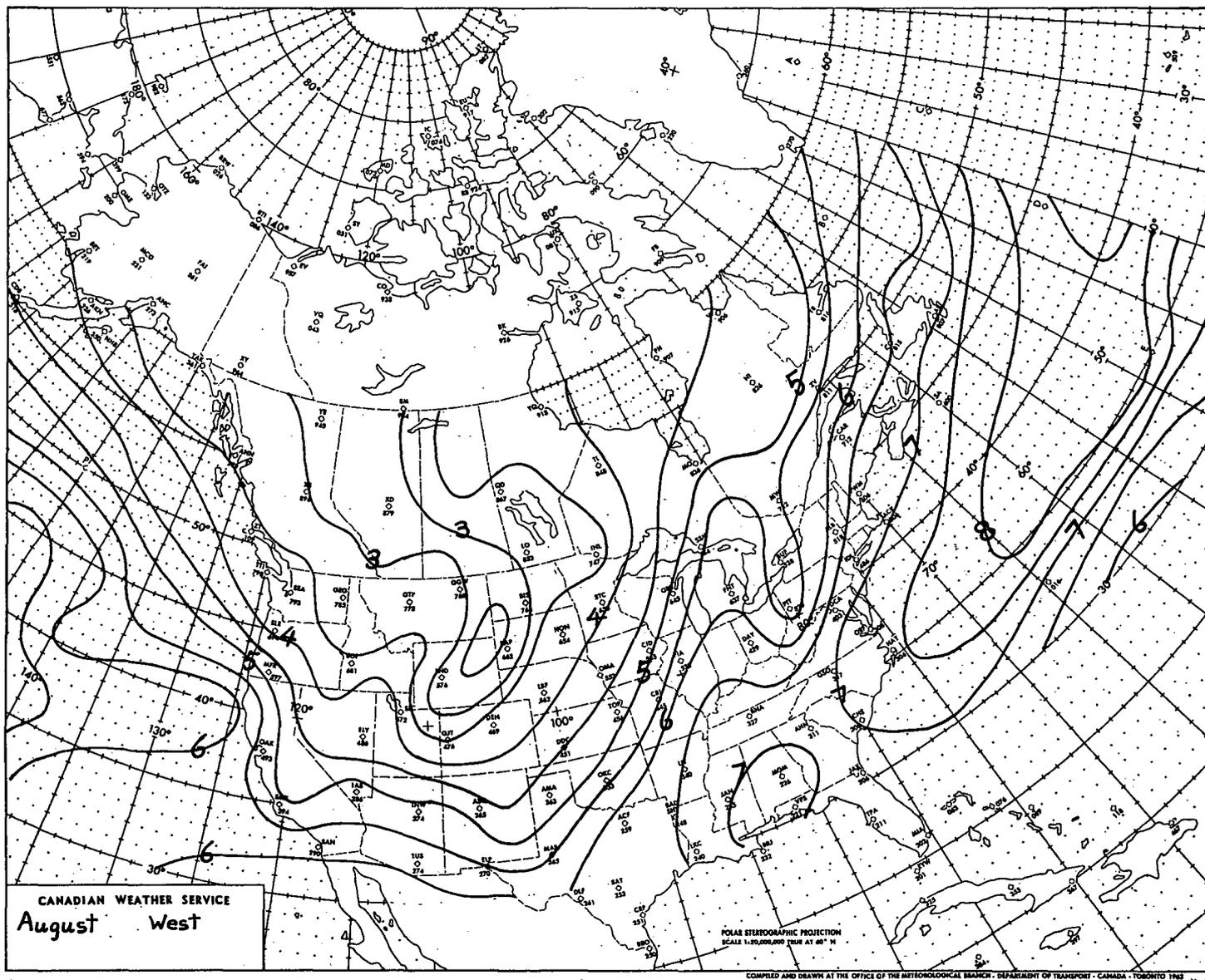


FIG. 15
 Westward component of secondary displacement for August.
 Units are degrees of latitude.

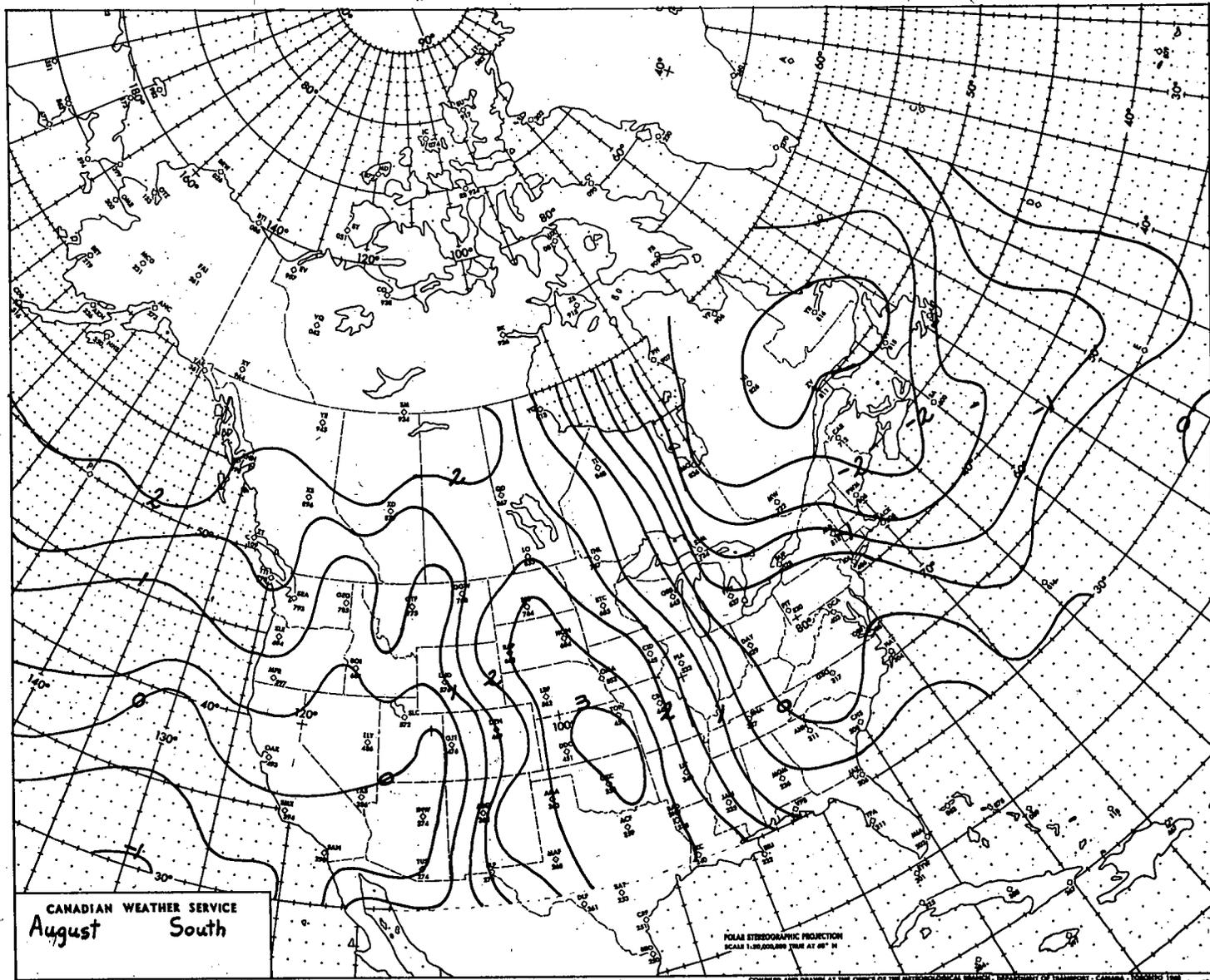


FIG. 16
Southward component of secondary displacement for August.
Units are degrees latitude.

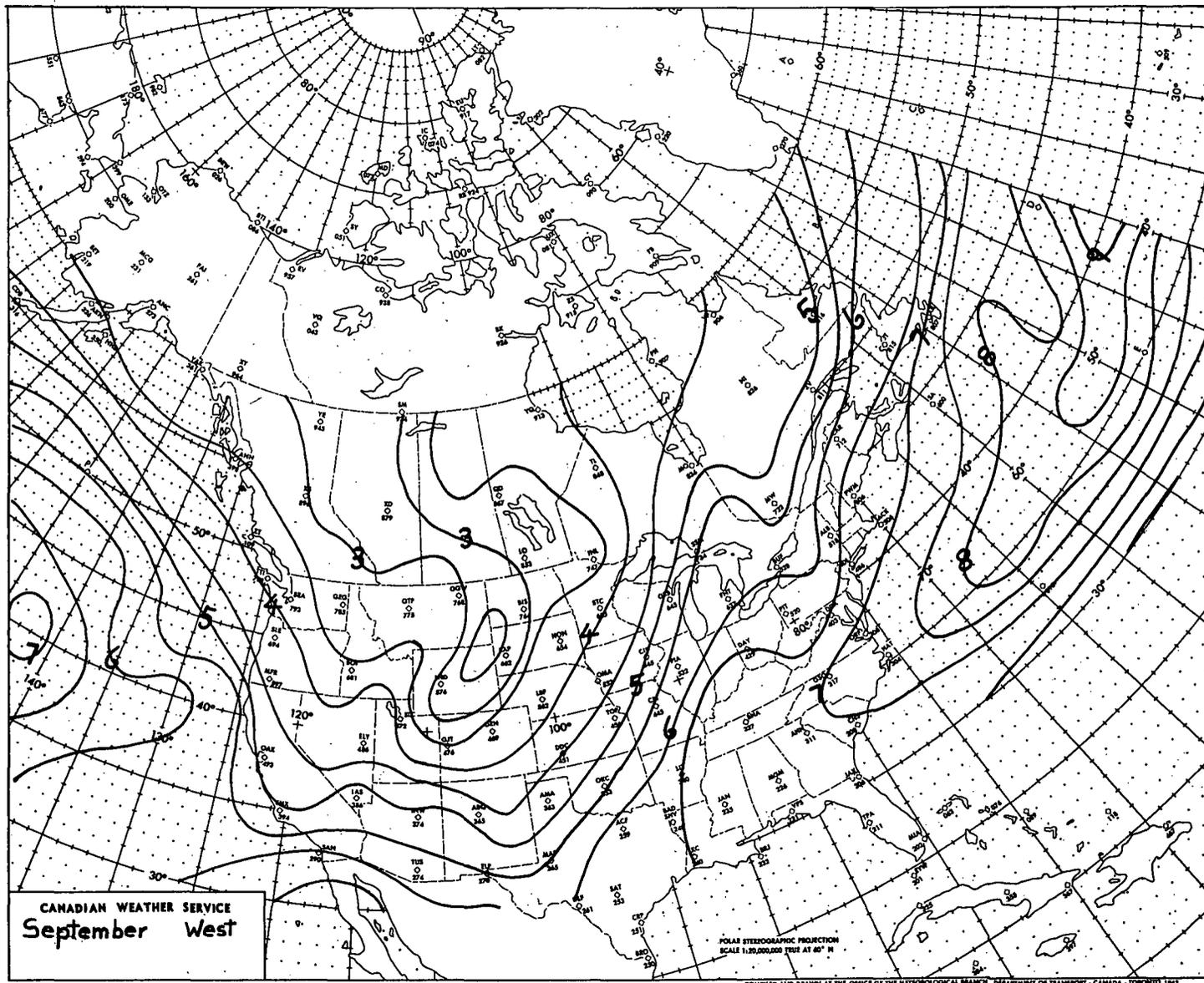


FIG. 17
 Westward component of secondary displacement for September.
 Units are degrees of latitude.

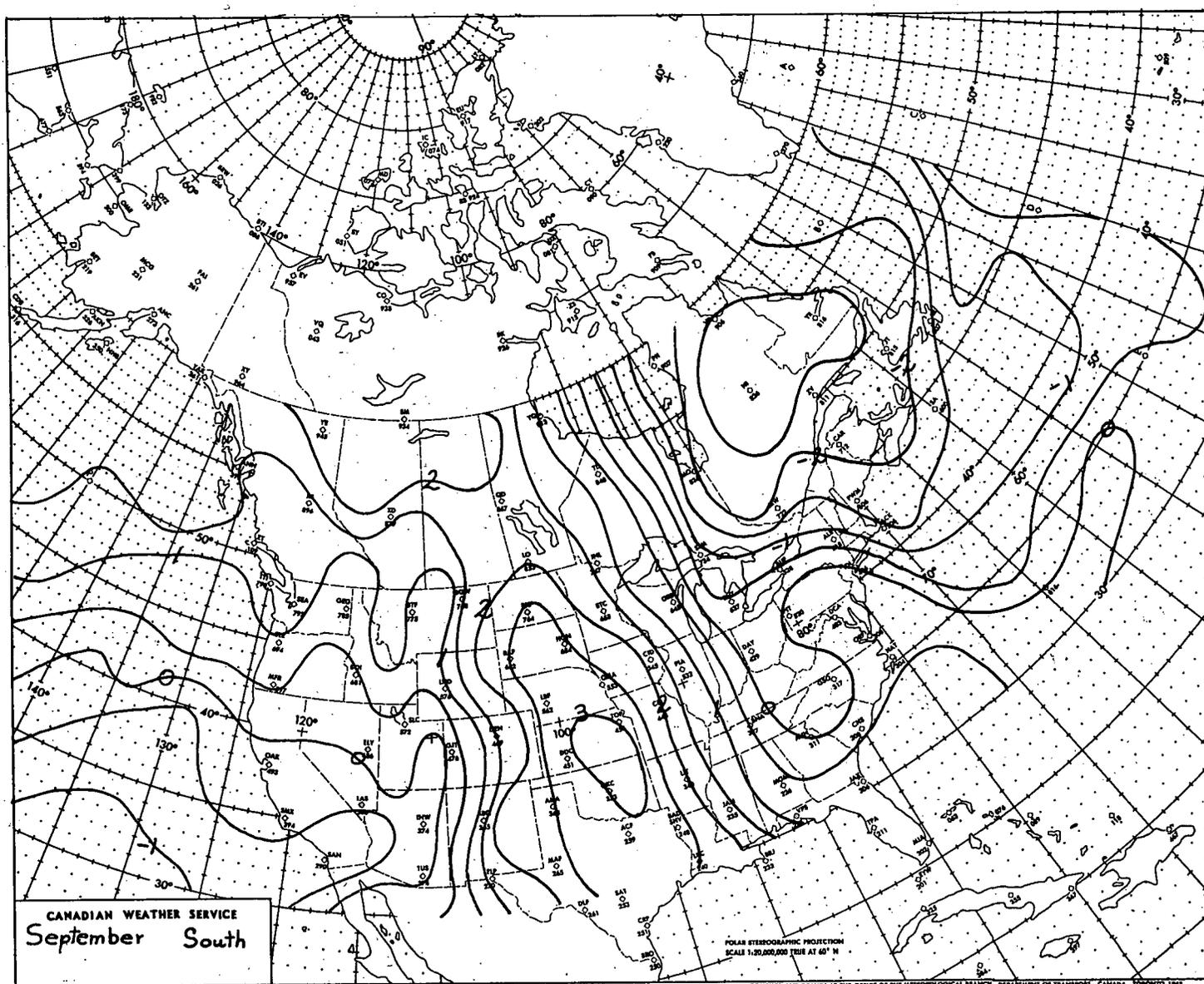


FIG. 18
Southward component of secondary displacement for September.
Units are degrees of latitude.

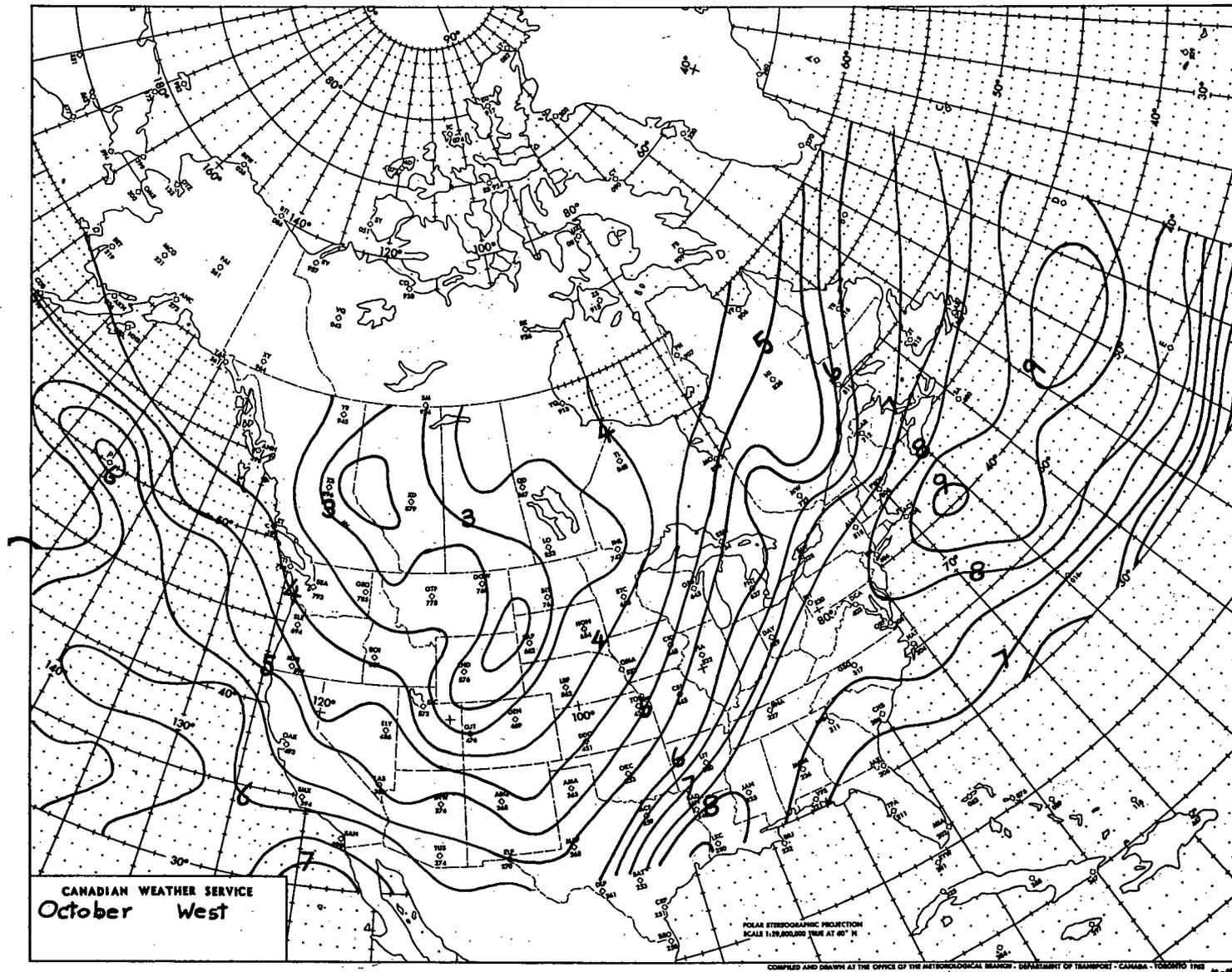


FIG. 19
Westward component of secondary displacement for October.
Units are degrees of latitude.

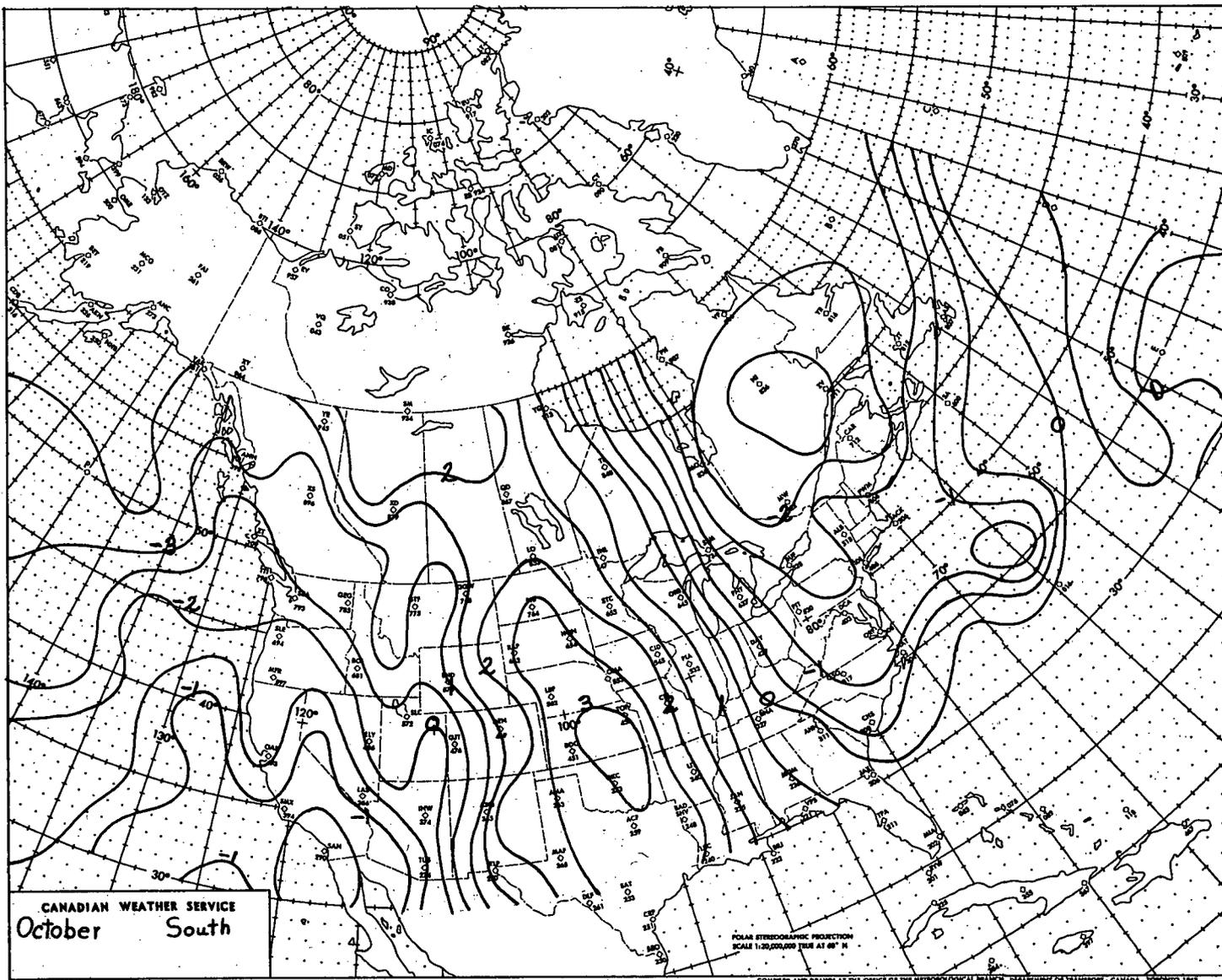


FIG. 20
Southward component of secondary displacement for October.
Units are degrees of latitude.

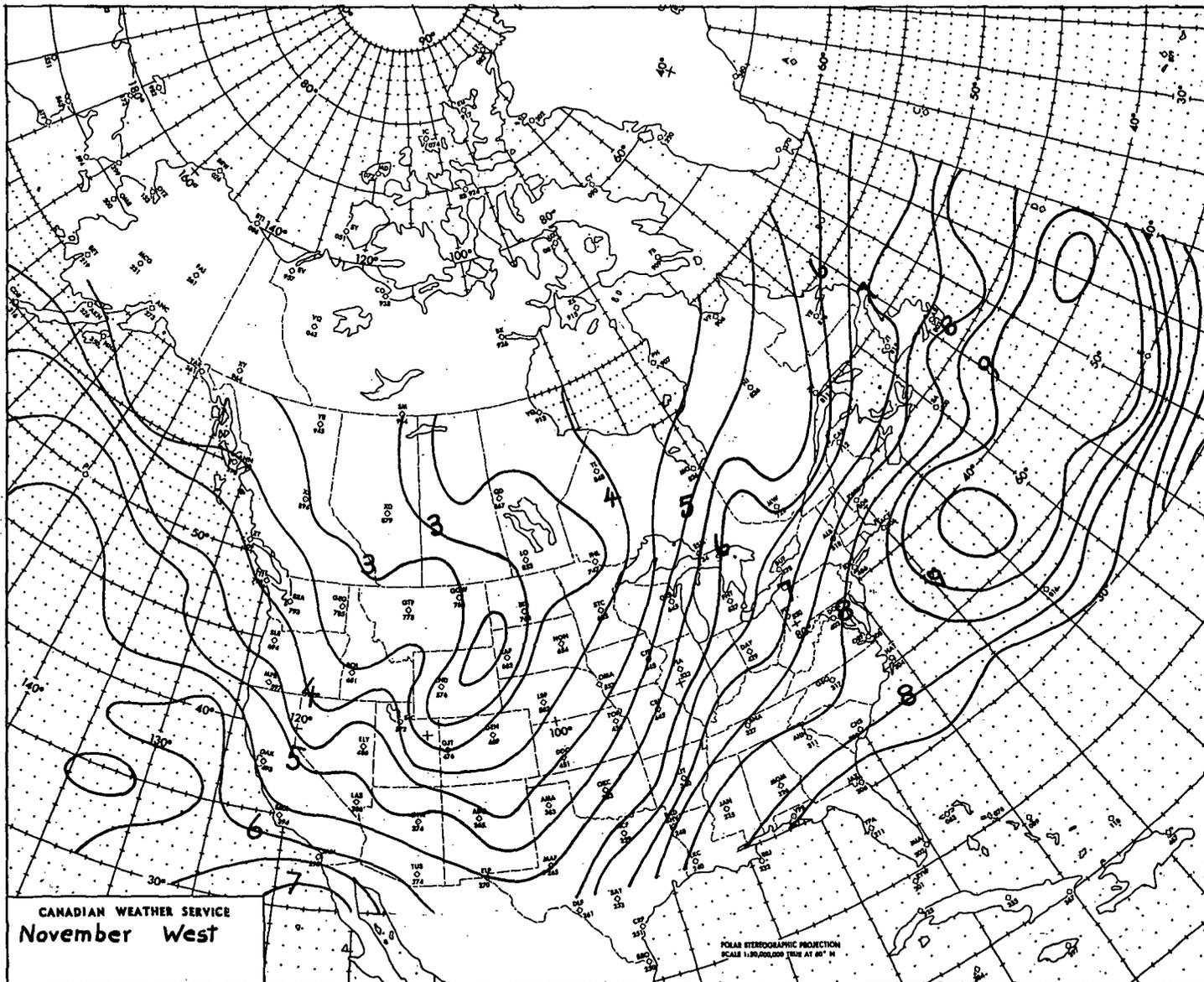


FIG. 21
 Westward component of secondary displacement for November.
 Units are degrees of latitude.

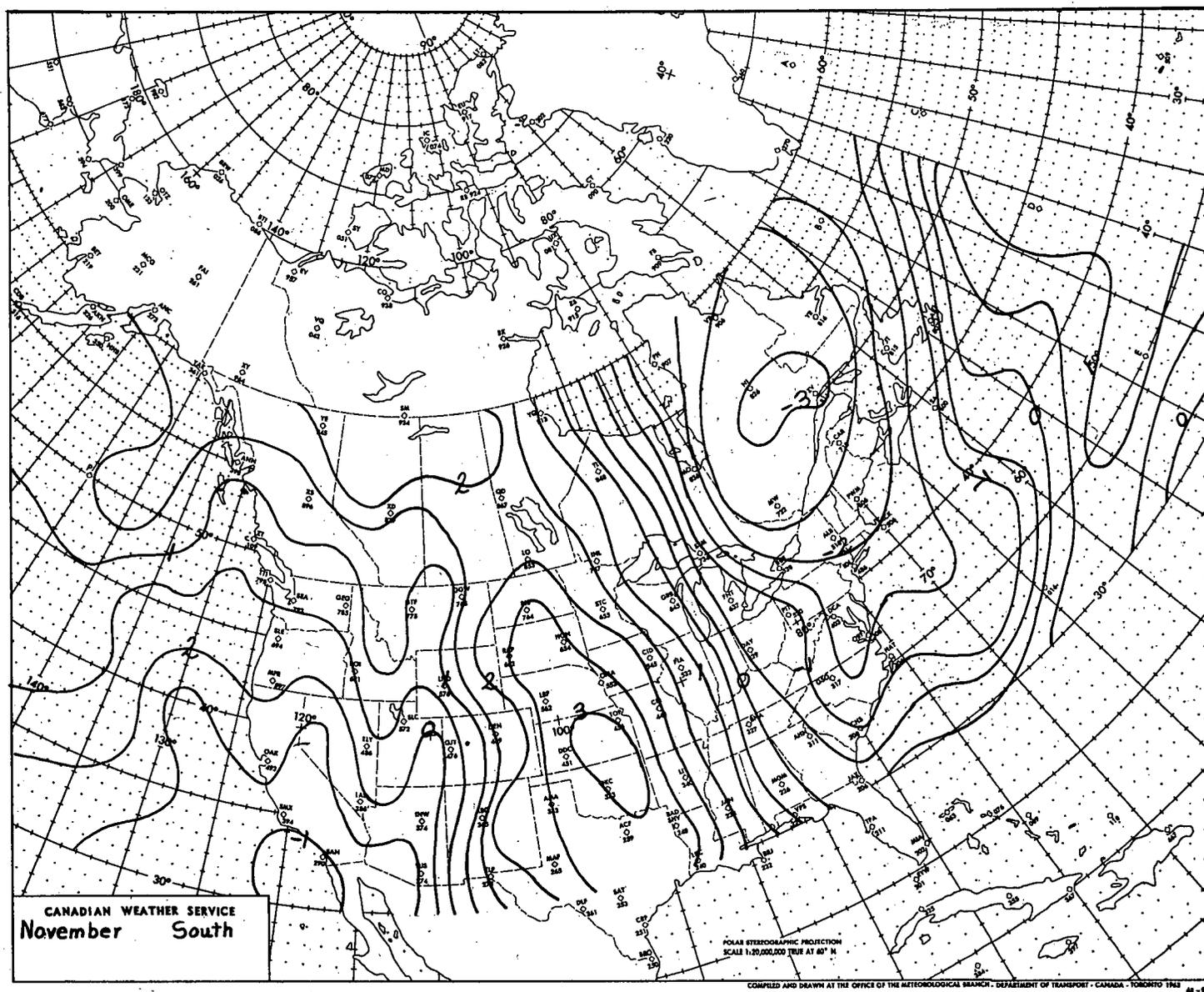


FIG. 22
 Southward component of secondary displacement for November.
 Units are degrees of latitude.

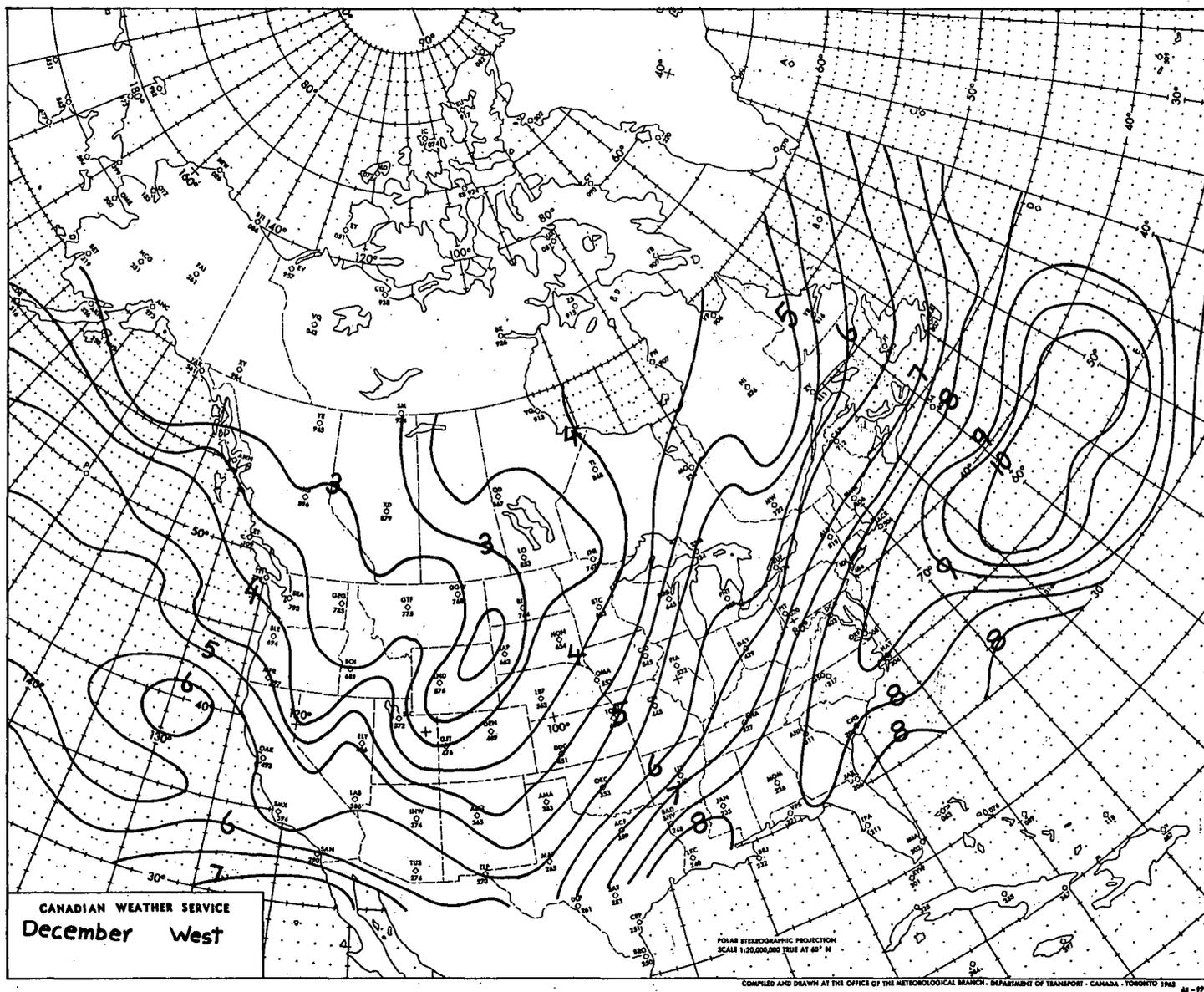


FIG. 23
Westward component of secondary displacement for December.
Units are degrees of latitude.

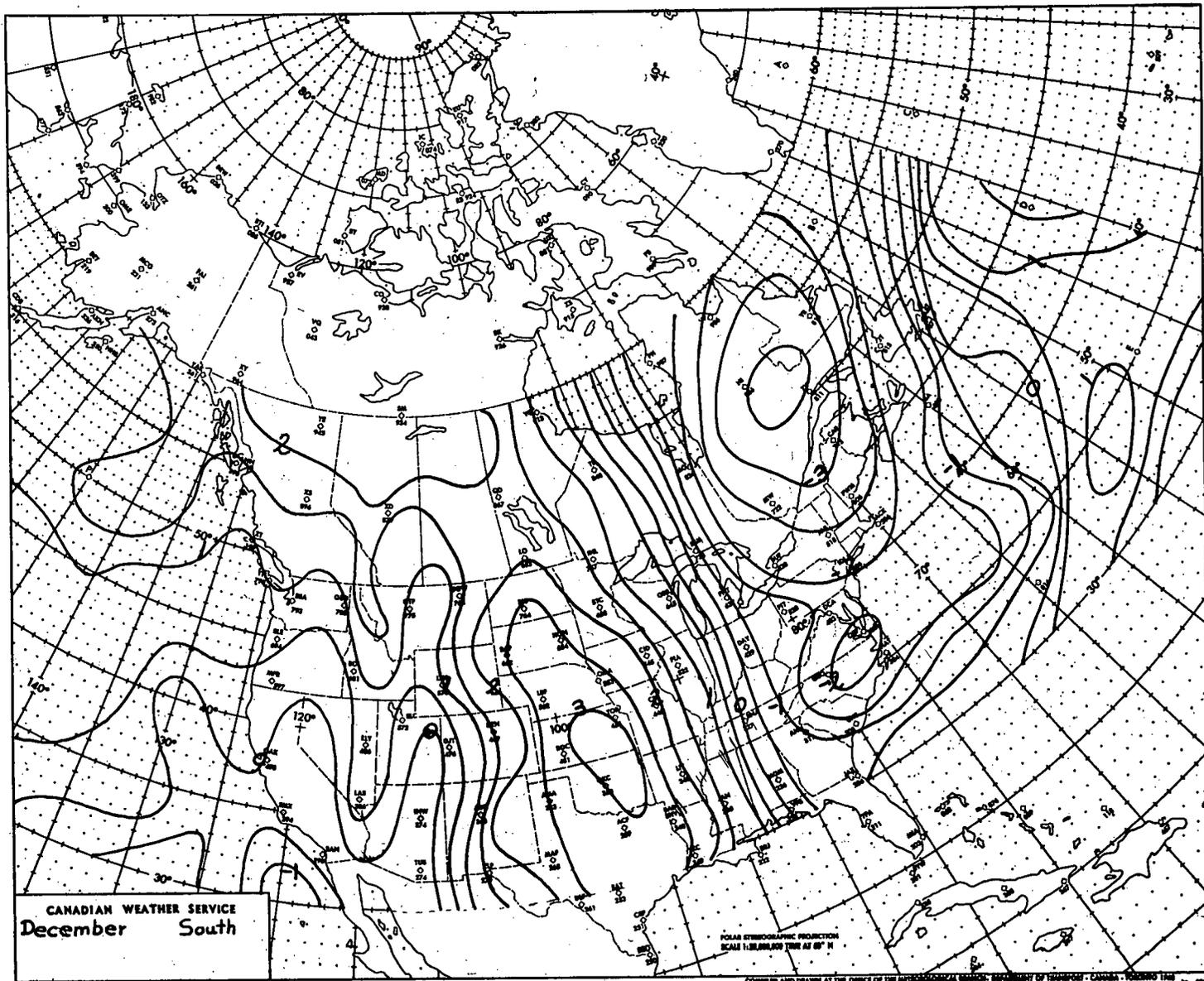


FIG. 24
Southward component of secondary displacement for December.
Units of degrees of latitude.

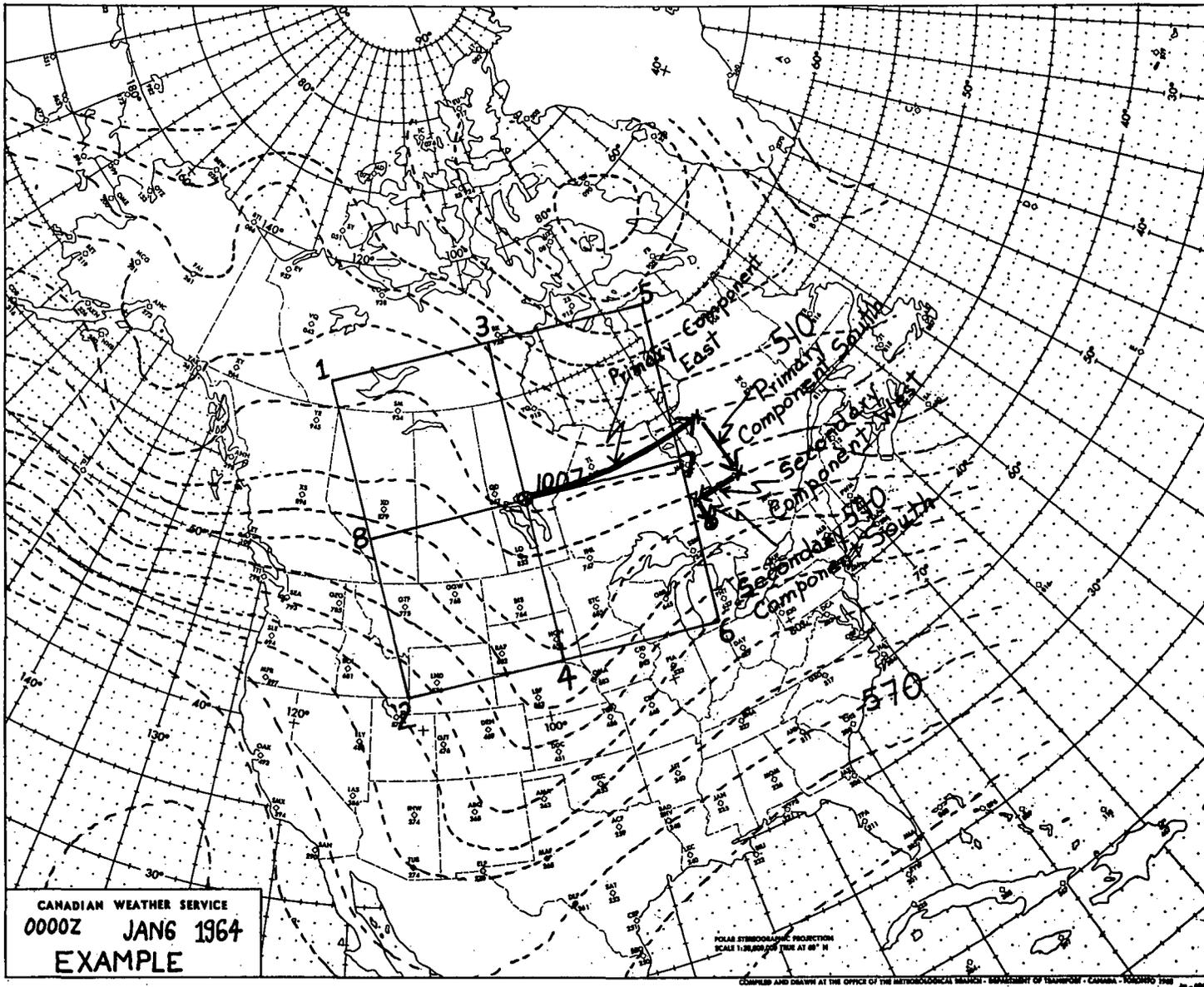


FIG. 25
An example of the grid computation

FIGS. 26 - 56

Surface and 500-mb charts at 0000Z for the month of January, 1964.

Surface pressures are indicated in thin full lines at 8-mb intervals, and heavier broken lines indicate 500-mb contours at 60 meter intervals.

Surface frontal surfaces are shown in the usual convention.

Arrows point to dots which give the 24-hour forecast positions of cyclones, obtained using the grid technique, and central pressure forecasts are given in parentheses.

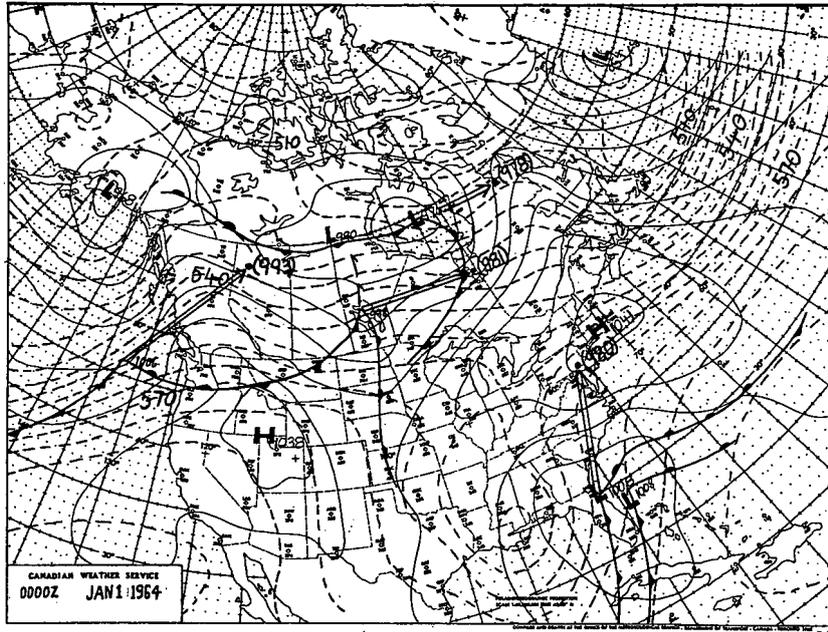


FIG. 26

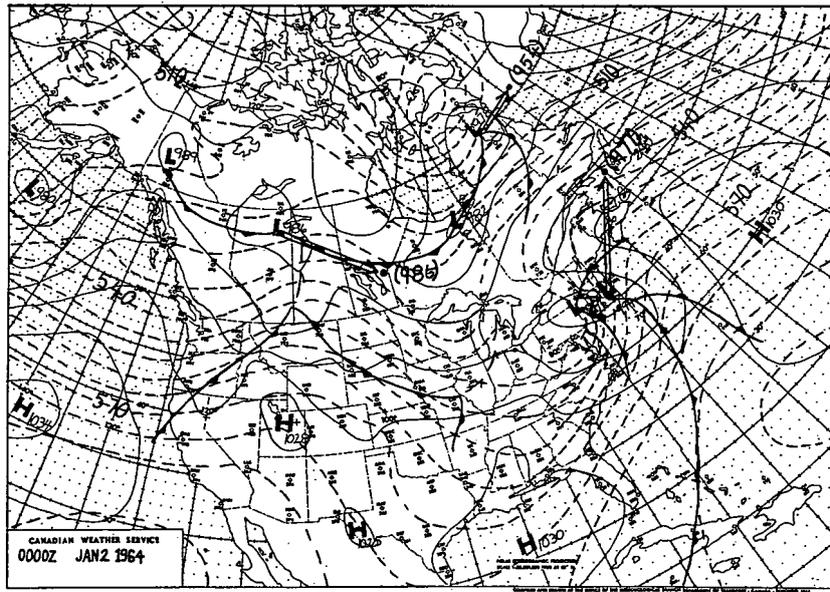


FIG. 27

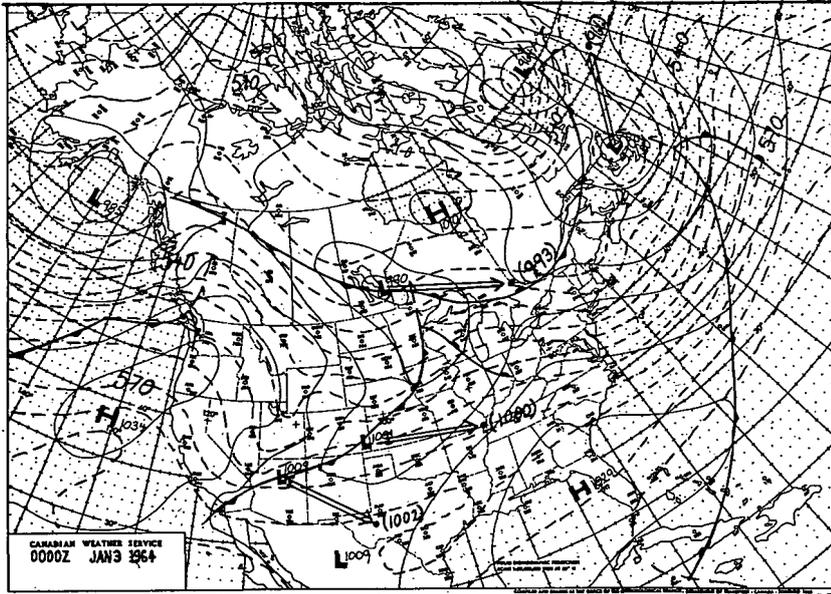


FIG. 28

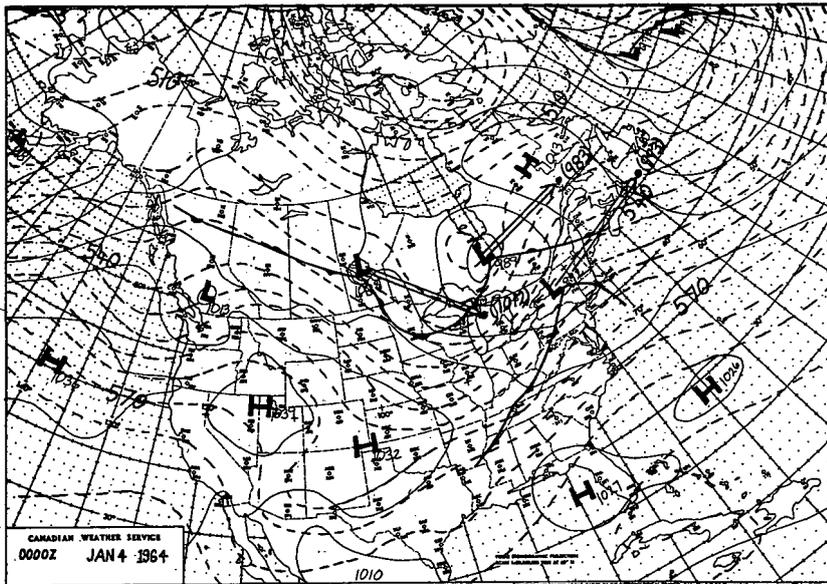


FIG. 29

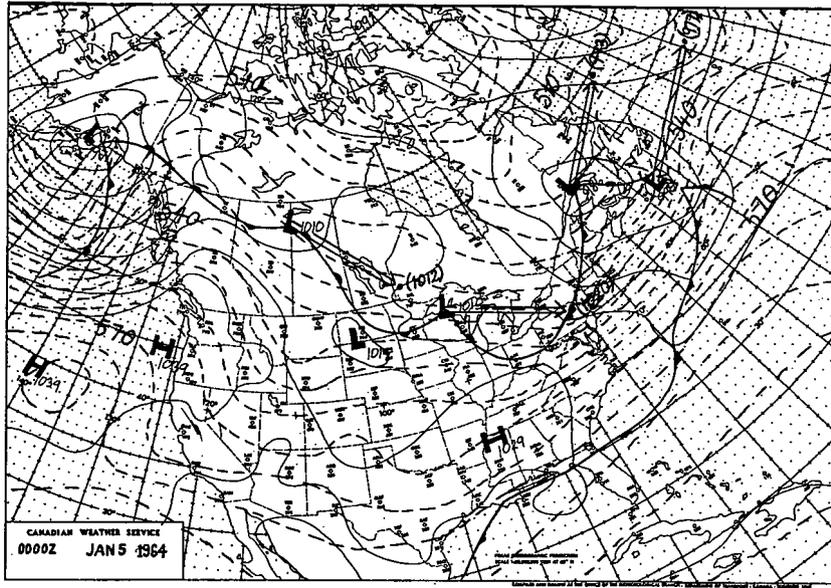


FIG. 30

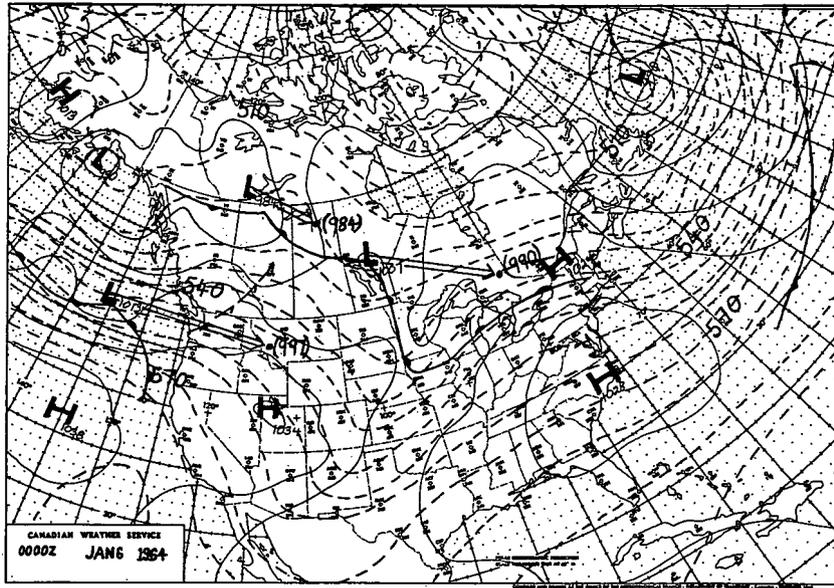


FIG. 31

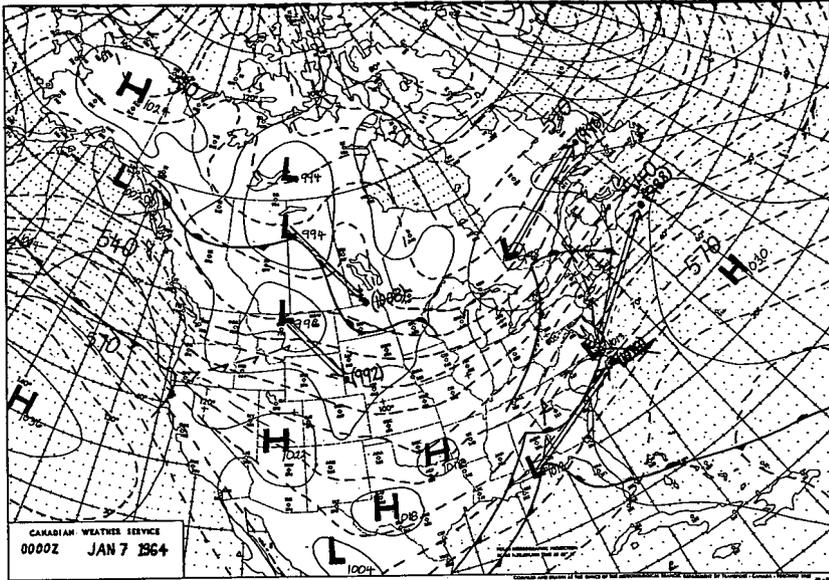


FIG. 32

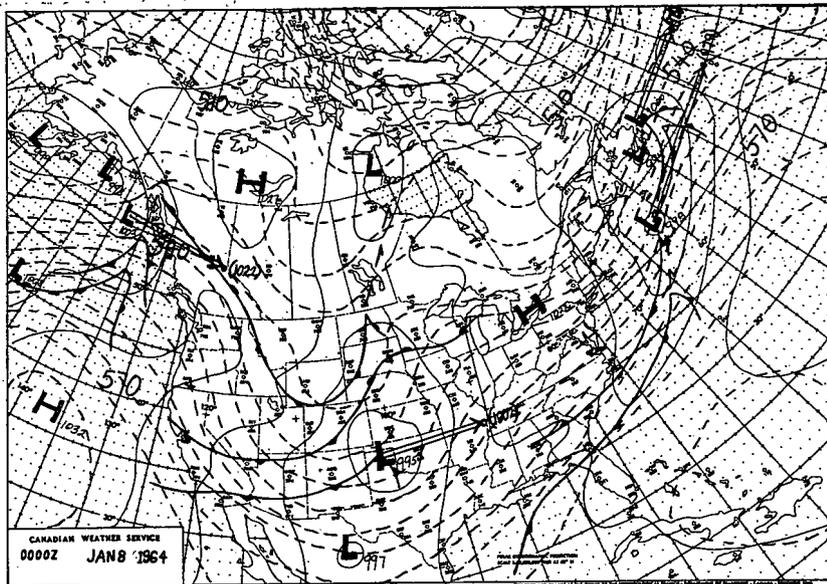


FIG. 33

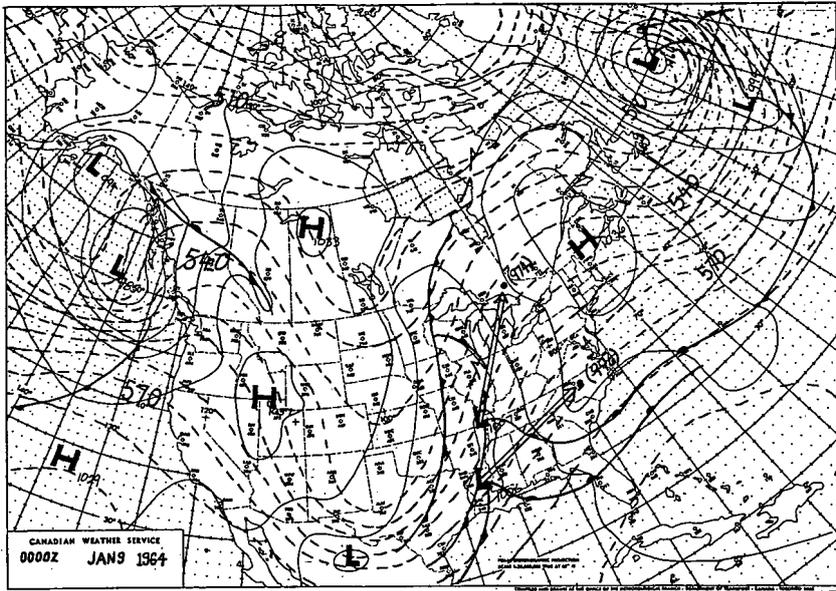


FIG. 34

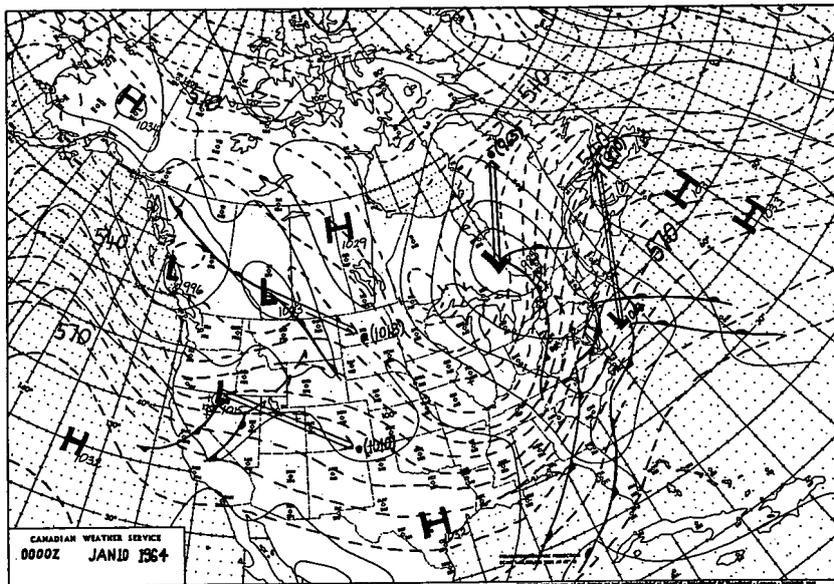


FIG. 35

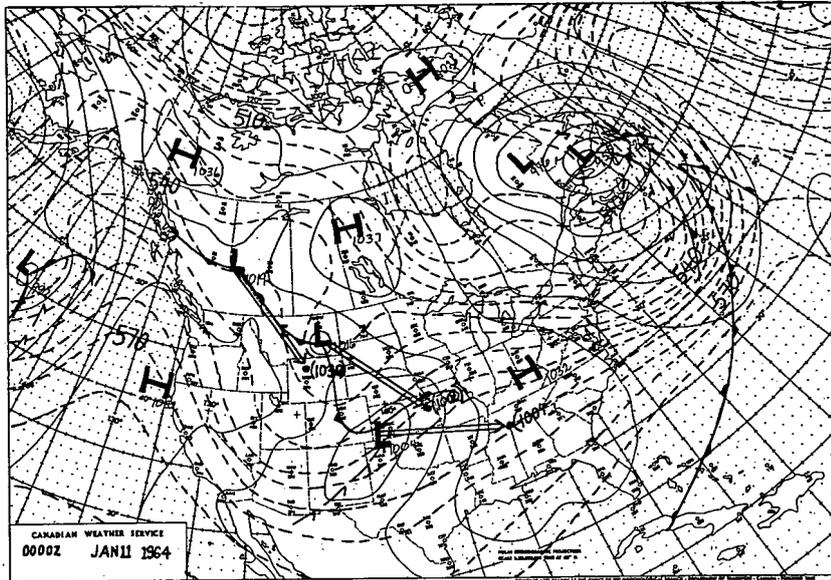


FIG. 36

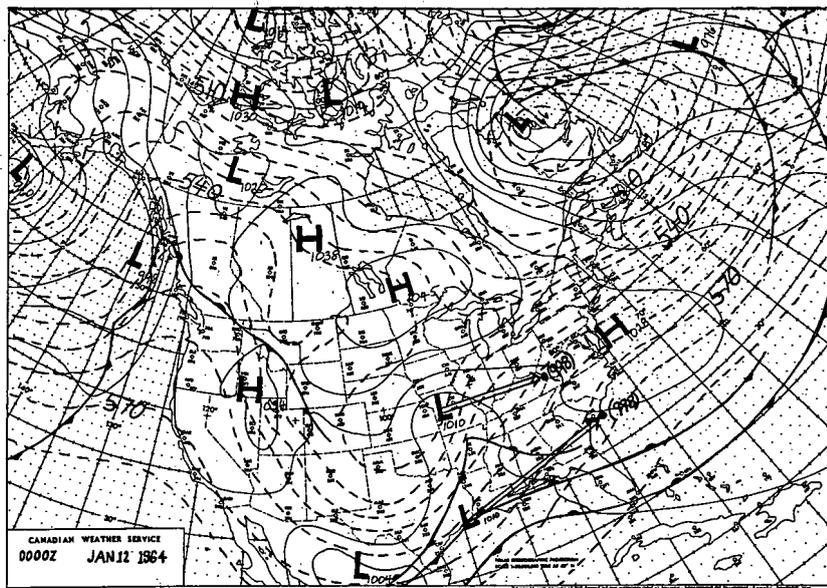


FIG. 37

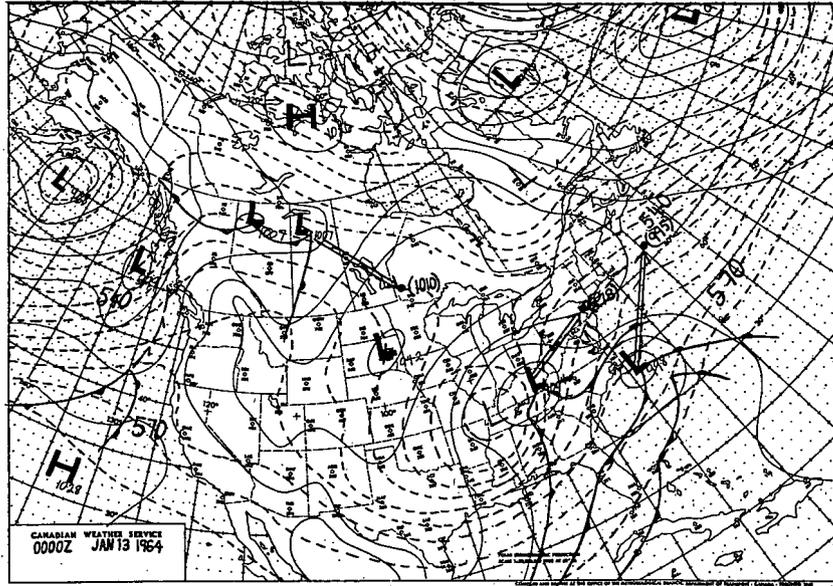


FIG. 38

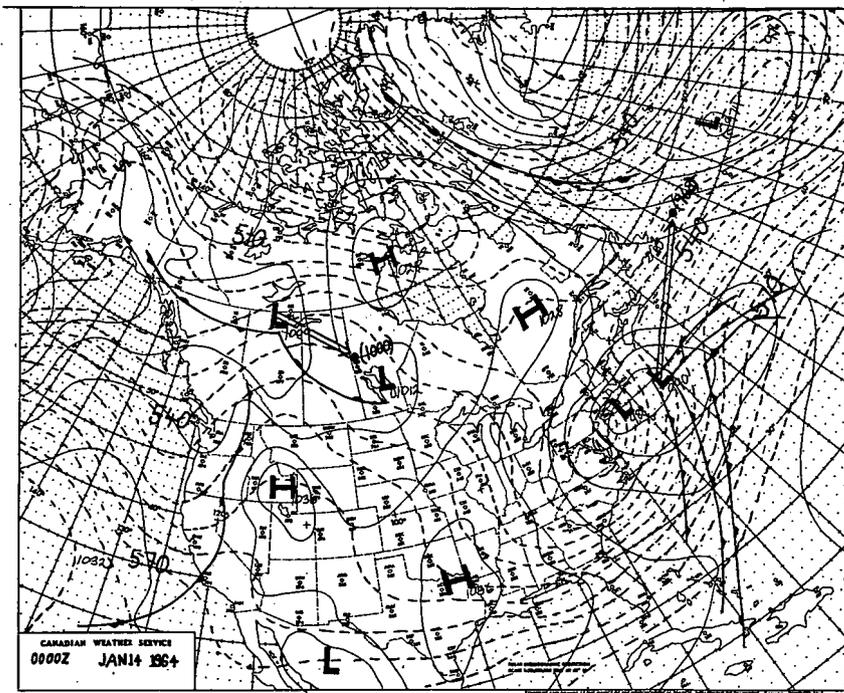


FIG. 39

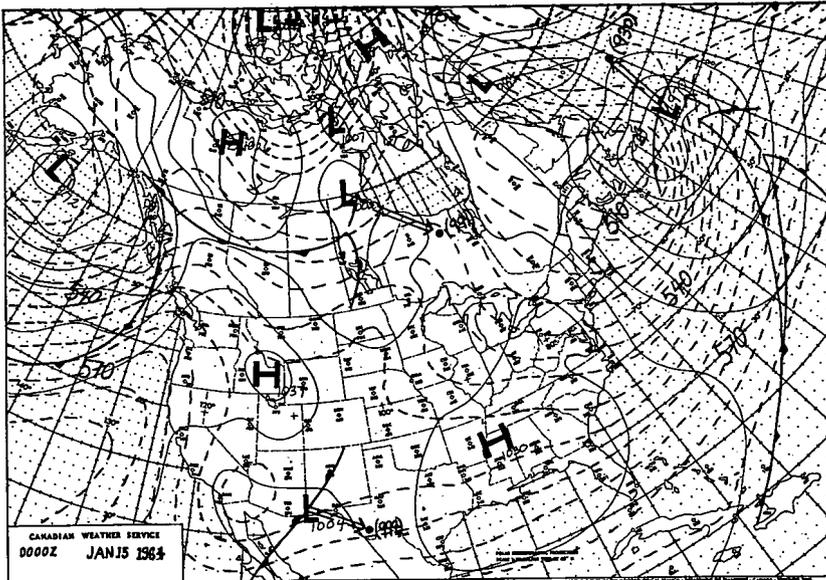


FIG. 40

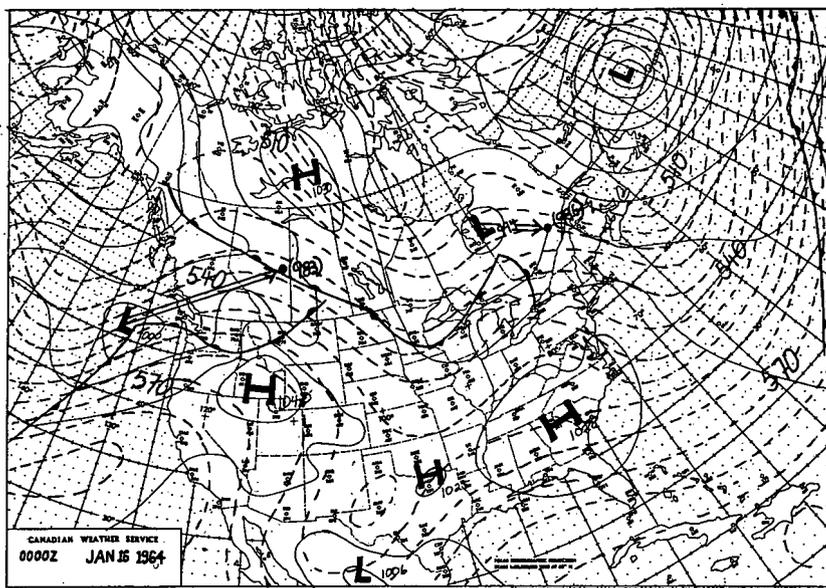


FIG. 41

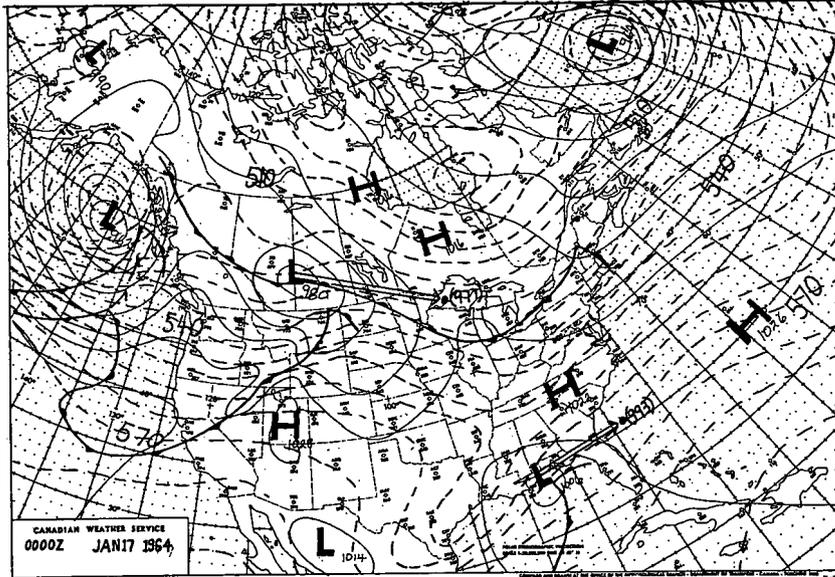


FIG. 42

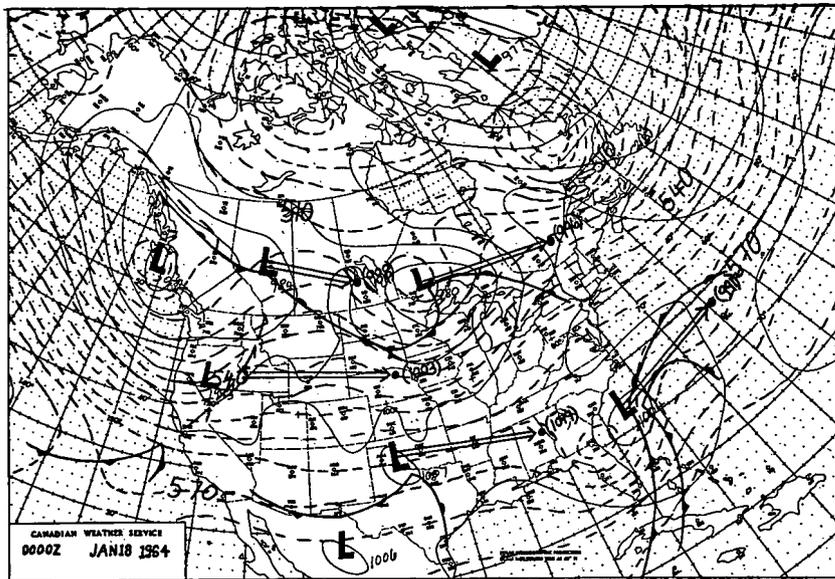


FIG. 43

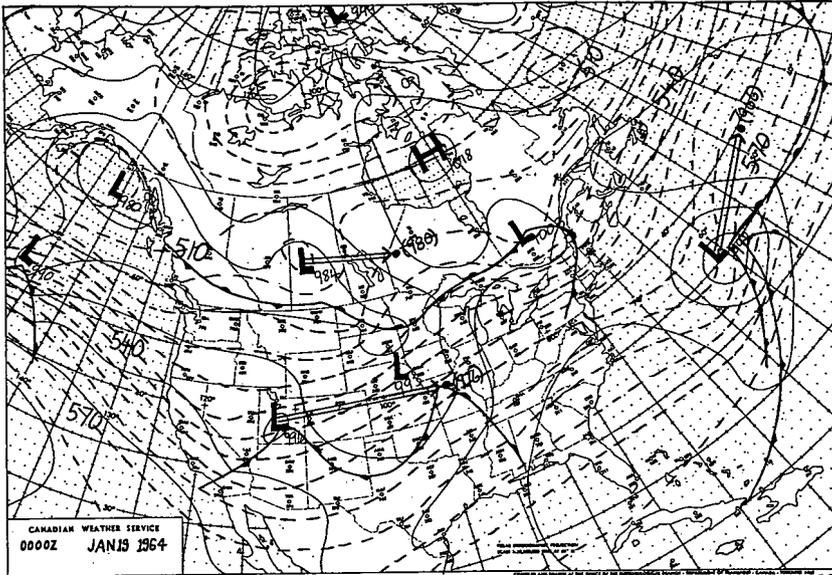


FIG. 44

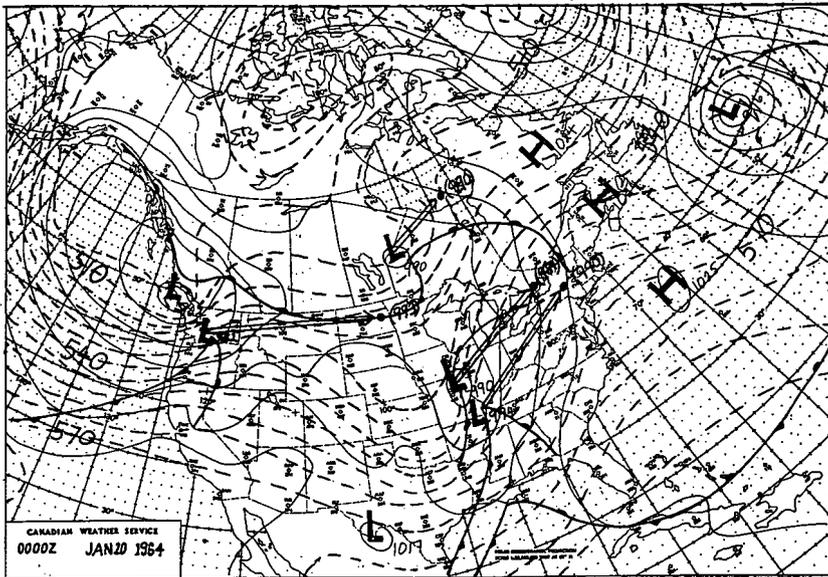


FIG. 45

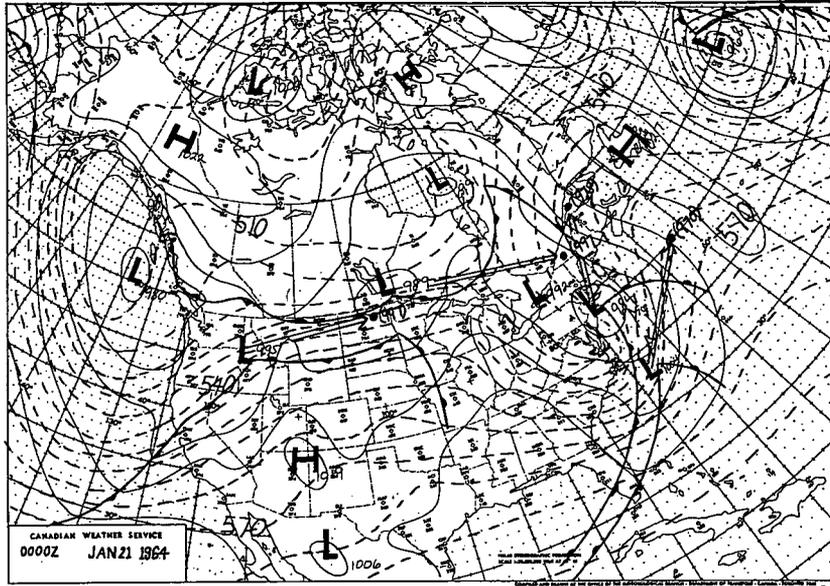


FIG. 46

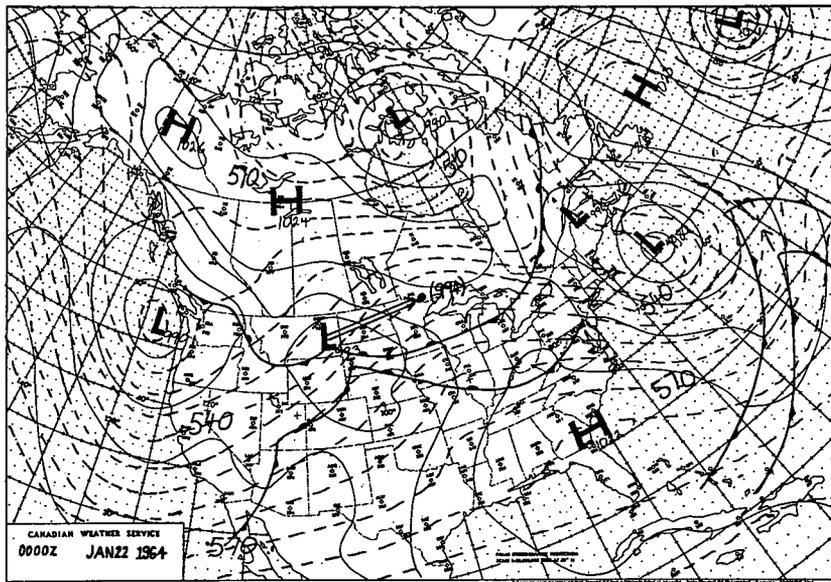


FIG. 47

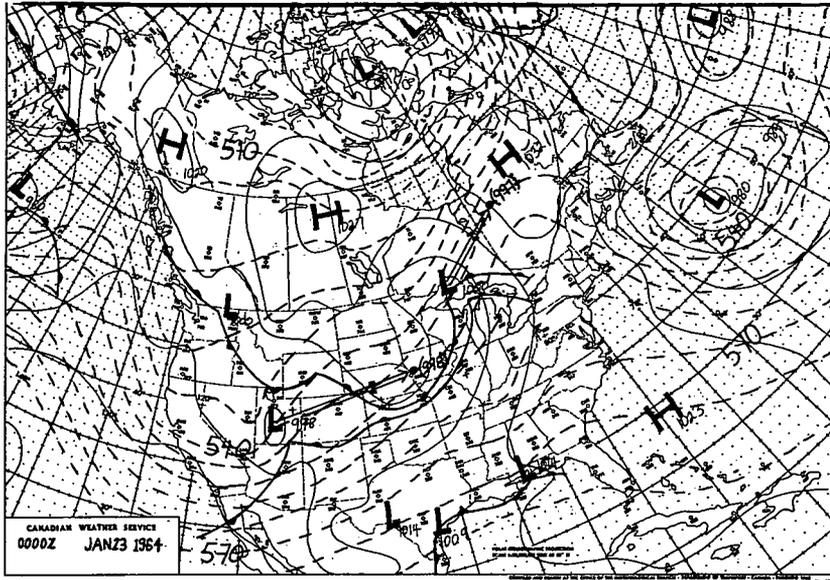


FIG. 48

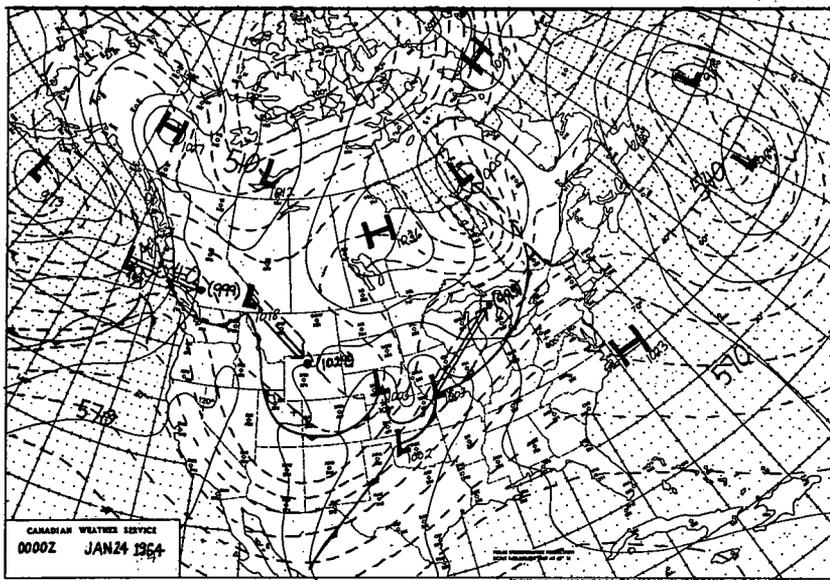


FIG. 49

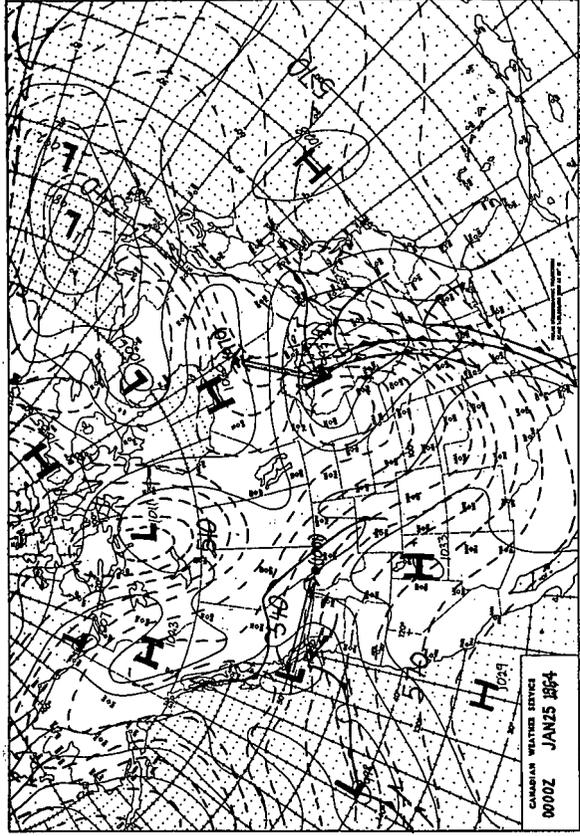


FIG. 50

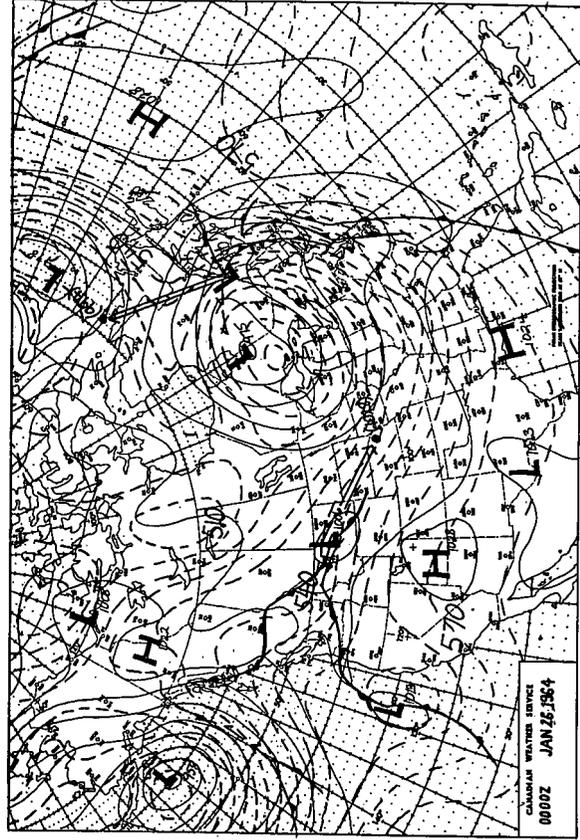


FIG. 51

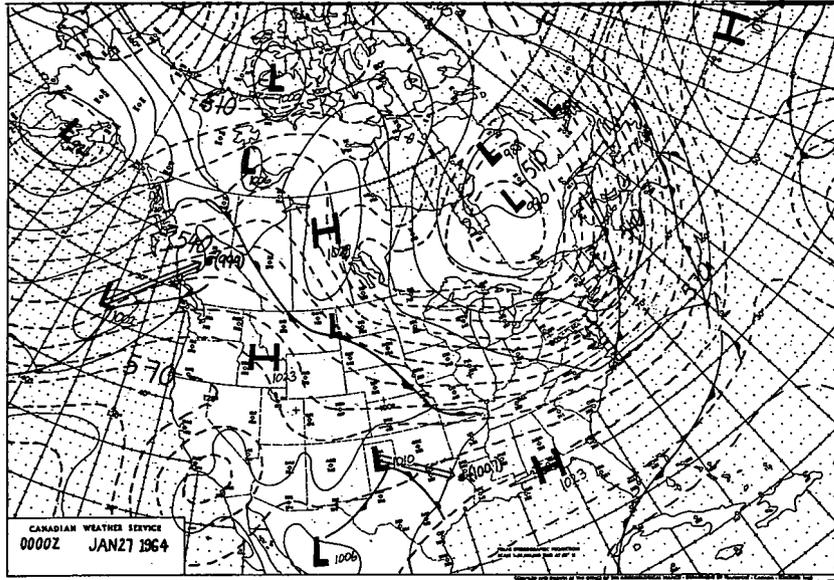


FIG. 52

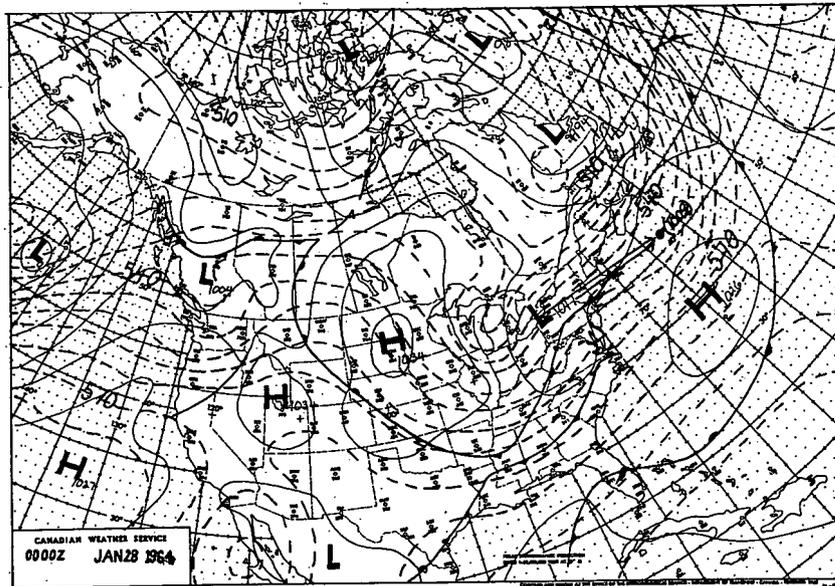


FIG. 53

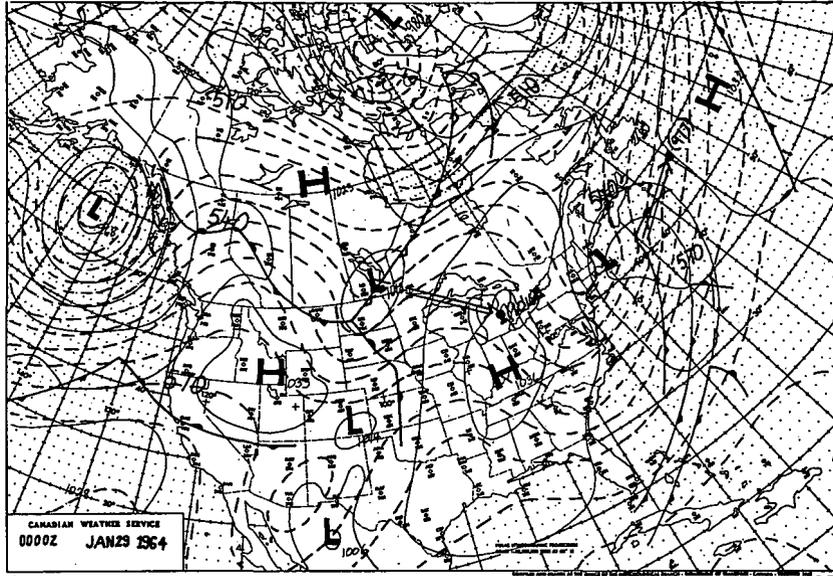


FIG. 54

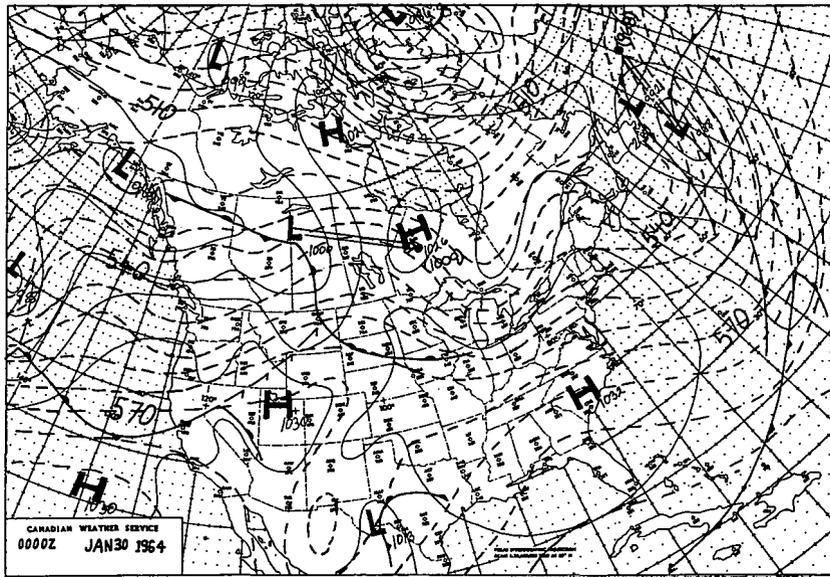


FIG. 55

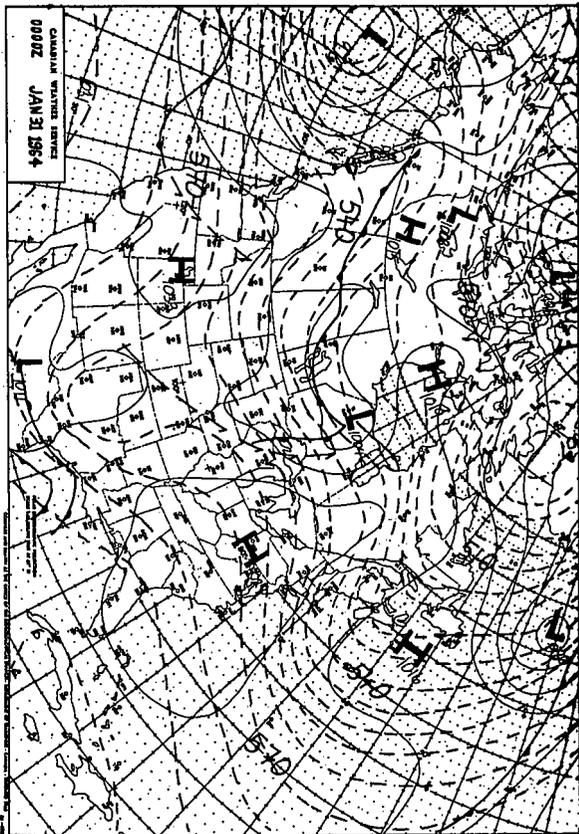


FIG. 56

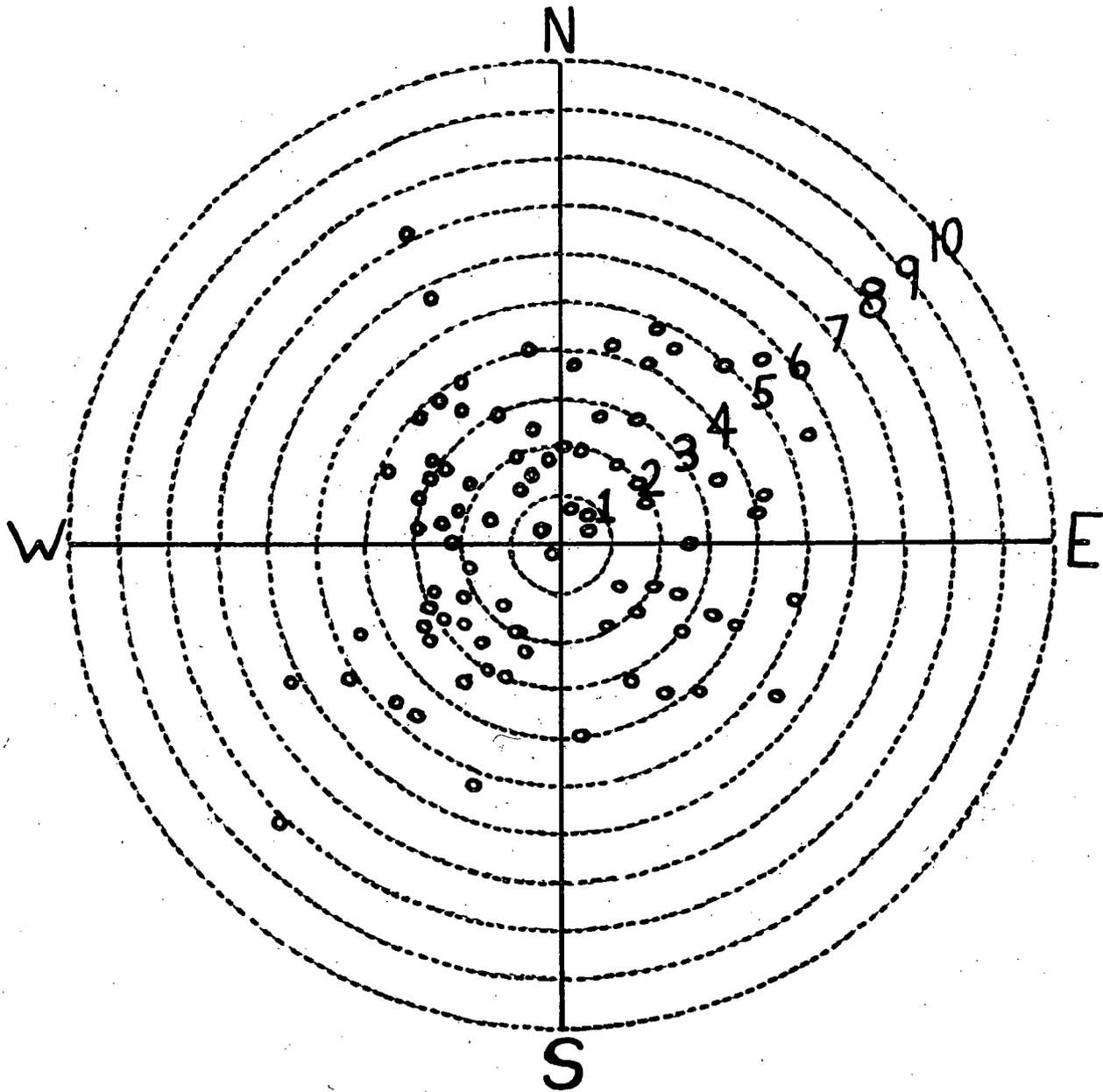


FIG. 57
 24-hour forecast displacement error diagram.
 The origin is the observed location of the cyclone at forecast time,
 and forecast displacements obtained for January, 1964,
 relative to the observed location at forecast time, are shown by dots.
 The radial lines are in units degrees of latitude.

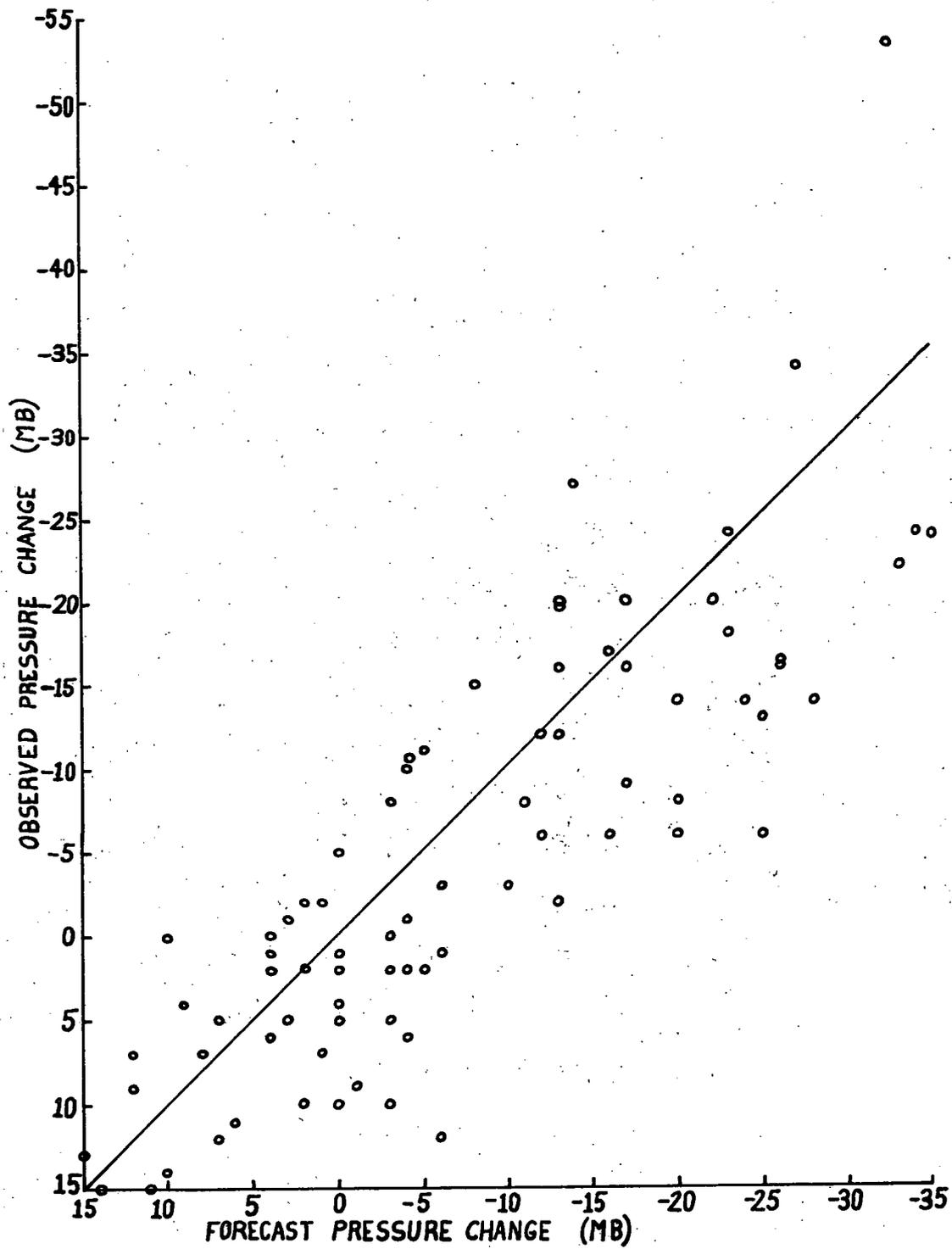


FIG. 58

A graph comparing 24-hour forecast in central pressure with the observed 24-hour central pressure change for frontal cyclones in January, 1964 to which the grid technique was applied.