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Washington, D. C.

200-MB FORECASTS

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U.S. Joint Numerical Weather Prediction Unit

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1. Introduction

For the purpose of determining a 200-mb forecasting method, 36 hour 200-mb height forecasts from 13 initial times were computed and verified. Seven forecasts were for summer situations (Table 1), three were for fall situations (Table 2), and three were for winter situations (Table 3). The forecast model employed was the current operational Joint Numerical Weather Prediction (JNWP) Unit "Mesh Model." 500-mb to 200-mb thickness was forecast for 36 hours and added to the 500-mb 36 hour barotropic height forecast to produce the 200-mb 36 hour height forecast. The thickness forecast equation [1, 2] was:

$$\left[\nabla^2 - \frac{2f\bar{\eta}}{\sigma^2}\right]\frac{\partial h}{\partial t} = \frac{2f\bar{\eta}}{\sigma^2}J(\bar{\psi},h) - fJ(\bar{\psi},\tfrac{1}{f}\nabla^2 h) - J(h,\bar{\eta}) \qquad (1);$$

in which; h is 500-mb to 200-mb thickness; t is time; f is the Coriolis parameter; $\bar{\psi}$ is the 500-mb barotropic stream; $\bar{\eta} = \nabla^2\bar{\psi} + f$; and $\sigma^2 = S\Delta_\omega p \Delta_h p$ in which S is static stability, $\Delta_h p$ = 300 mbs (the pressure interval of thickness), and $\Delta_\omega p$ = 400 mbs (the pressure interval over which ω is differenced) [1, 2]. After obtaining the thickness forecast, then employing the 500-mb barotropic forecast the 200-mb forecast was simply computed as:

$$Z_2 = Z_5 + h_{5-2} \qquad (2);$$

in which; Z is height; h is thickness; and the subscripts refer to the pressure or pressure interval (in hundreds of milibars) for which the quantity is evaluated.

A number of variations in equation 1 were employed. For some situations, S was considered as a constant in space and time and several forecasts were made using different values of S. Also employed was a time and space variable static stability expressed as a regression equation:

$$S = a + b\bar{\psi} \qquad (3).$$

To obtain the constants of equation 3, 500-mb to 200-mb static stability and 500-mb height were related linearly using independent data. Then the 500-mb barotropic stream function, the variations of which are comparable to those of the 500-mb height field was substituted for the 500-mb height. In the JNWP Unit operational 850-mb to 500-mb thickness forecasting model (equation 1), .75 is employed as a multiplier for the 500-mb stream function to reduce the 500-mb flow to the mean level modeled as 600-mb. For one situation three different 500-mb to 200-mb thickness forecasts were made employing values of .75, 1.0, and 1.2, respectively, as multipliers for the 500-mb stream function. For one situation the 500-mb to 200-mb thickness was balanced initially and the 36 hour forecast produced from a modified form of equation 1 was inverted to obtain the 500-mb to 200-mb thickness forecast. For the third winter situation (Table 3), after changing $\Delta_h p$ in equation 1, an 850-mb to 200-mb thickness forecast was computed in addition to the 500-mb to 200-mb thickness forecast. A linear regression equation was determined from smoothed seasonal independent data:

$$Z_2 = 1103.28 + .7720\, Z_5 + .6207\, h_{8.5-2} - 40.3702 \sin e\, \varphi \qquad (4);$$

in which; units are in meters; Z is height; h is thickness; and φ is latitude. Using equation 4, the forecast 200-mb height was then computed from the forecast 850-mb to 200-mb thickness, 500-mb forecast height, and the sine of the latitude.

As an independent check on the 200-mb forecast obtained by the method described above, a 200-mb height forecast for each situation was extrapolated by applying a regression equation to the 36 hour 500-mb height and 850-mb height forecasts operationally computed at JNWP Unit. This regression equation was derived from independent yearly data [3] and is stated as:

$$Z_2 = 2023 + 2.1371\, Z_5 - 1.4618\, Z_{8.5} \qquad (5);$$

in which; units are meters; Z is height; and subscripts refer to pressure (in hundreds of milibars) for which the quantity is evaluated. As an additional independent forecast, the initial 200-mb analysis was verified as a 36 hour persistence forecast for a number of the situations. For some situations the 36 hour 500-mb barotropic forecast was verified.

The forecast verifications computed were the mean and root mean square error (RMSE) in height and the root mean square vector error (RMSVE) in the geostrophic wind. The verifying analyses were machine analyzed. 850-mb and 500-mb machine analyses and equation 5 were employed in obtaining the first guess to both the initial and verifying 200-mb analyses. Primarily two regions of the 1977 grid point forecast area were verified (figure 1): a North American region and an European region. Some of the forecasts were also verified for the entire 1977 point grid area.

2. Forecasts

To eliminate the numerous short waves, having a nearly linear growth with time, resulting from computation with equation 1, it was necessary to apply a heavy smoother to the 36 hour forecasts. With approximately the same results, this smoother could be applied to either the 500-mb to 200-mb thickness forecast or to the 200-mb height forecast after the unsmoothed thickness forecast had been added to the 500-mb height forecast. The 9 grid point smoother employed was:

$$Z_0 = \frac{1}{4}\left[Z_1 + Z_3 + Z_5 + Z_7\right] \qquad (6);$$

in which; Z is height and the subscripts refer to values at the numbered points of the grid shown in figure 2. These short waves could have been eliminated also by applying some light smoother to the thickness at each hour time step of the forecast. Figures 3, 4, and 5 are typical 200-mb forecasts obtained by the thickness forecast method (equations 1 and 2), extrapolation (equation 5), and persistence, respectively. These can be compared with their verification, figure 6. Figures 7, 8, 9, and 10 are, respectively, the geostrophic wind computed for each of the maps.

From a study of forecast maps and their verifications, a number of general comments can be made. Systematic and non-systematic errors in the 500-mb barotropic forecasts are reflected in the 200-mb forecasts. As examples, the barotropic 500-mb forecasts tend to move the westerly jet poleward, are relatively inaccurate at low latitudes near the boundaries of the forecast grid area, and do not normally account for baroclinic developments. The thermal jet in the 500-mb to 200-mb thickness forecasts did not maintain a normal vertical phase relation with the westerly jet in the 500-mb barotropic forecast, which resulted in a latitudinal dispersion of the jet at 200-mb when equation 2 was applied. Also, the thickness forecasts were inaccurate near the boundaries because of boundary influences in the thickness forecast model itself, and inaccuries in the 500-mb barotropic forecast (equation 1). From equation 5, we see that a vertical phase relation between the westerly jet at 500-mb and 200-mb is enforced since the gradient at 850-mb is normally much weaker than at 500-mb. For these reasons the jet maxima in the extrapolated 200-mb forecasts (equation 5) were stronger and more concentrated latitudinally than in those forecasts obtained from equation 2.

3. Verifications and Conclusions

RMSE and RMSVE verifications (see tables 1, 2, and 3) showed the 36 hour 200-mb forecasts derived by the two methods (equations 2 and 5) to be of approximately the same accuracy. Both forecast methods produced forecasts greatly superior to 36 hour 200-mb persistence. Both methods tended to underforecast the maximum geostrophic wind in the westerly jets when verified against machine analyses. This tendency would be even more noticeable were the forecast geostrophic wind verified against observed maximum winds in the jet as a certain amount of lateral dispersion of the jet occurred from smoothing in the machine analysis computation. The 200-mb analysis problem could not be described as completely solved at the time the forecasts were made. Changing the constant for static stability or employing a variable static stability had no significant effect on the 500-mb to 200-mb thickness forecast. The multiplier 1.0 for the stream function in equation 1 gave the best 500-mb to 200-mb thickness forecasts. Multipliers .75 and 1.2 caused systems to move too slowly and too fast, respectively. The 200-mb forecast resulting from balancing the initial 500-mb to 200-mb thickness was slightly worse than that obtained by forecasting the thickness. Forecasting the 850-mb to 200-mb thickness, then employing equation 4 gave a better 200-mb forecast (Table 3) than the other methods for the one situation. This suggests that the use of smoothed seasonal data and perhaps a latitude function in determining a new equation 5 could result in improved extrapolated 200-mb forecasts.

Excluding persistence, all methods of forecast computation produced usable 200-mb height forecasts. But, these forecasts require interpretation and modification in regions of baroclinic development, in the jet maximum, and near the boundaries of the forecast grid area. Comparing the root mean square vectors (RMSV) of the observed geostrophic wind (see tables) at 200-mb with that at 500-mb we have a measure of the flow at one level in terms of the other. If we then compare the forecast RMSE and RMSVE with the RMSV at a level, we see that the 200-mb forecasts show about the same percentage accuracy or error as the 500-mb barotropic forecasts. Computing a 36 hour thickness forecast employing equation 1 requires approximately one hour of computer time. Computing a 200-mb height with equations 2 or 5 requires at most 3 minutes of computer time. If within the current JNWP Unit operational framework which now provides 850-mb and 500-mb forecasts, one were to choose the better of the two 200-mb forecast methods, he would choose the extrapolated forecast method on the basis of economy in computation time.

REFERENCES

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Ellsaesser, H. W.: JNWP Operational Models August 1958 to advent of IBM 7090 (1960), Office Note No. 15, Joint Numerical Weather Prediction Unit, 1960, pp. 33.

Brown, J. A.: Multiple Linear Regression Equations Expressing Heights of Certain Pressure Surfaces, Technical Memorandum No. 15, Joint Numerical Weather Prediction Unit, April 7, 1959, pp. 5.

TABLE 1. Summer Situations, 36 Hour Forecasts, Root Mean Square Vector (RMSV) Geostrophic Wind of the Verification and Root Mean Square Vector Error (RMSVE) of Forecast Geostrophic Wind in Knots; Mean Error and Root Mean Square Error (RMSE) of Forecast Height in Feet.

	200 mb 500mb to 200 mb Thickness Forecast and Equation 2		200 mb Extrapolation Equation 5		200 mb 36 Hour Persistence		500 mb Barotropic	
			INITIAL TIME - 12Z 10 August 1959					
N. AMERICA								
RMSV-RMSVE	(42.7)	19.7	(42.7)	19.8				
MEAN - RMSE	-129	188	-193	228			+7	96
EUROPE								
RMSV-RMSVE	(39.1)	18.2	(39.1)	15.0				
MEAN - RMSE	+67	151	-12	149				
			INITIAL TIME - 12Z 14 August 1959					
N. AMERICA								
RMSV-RMSVE	(39.0)	19.4	(39.0)	19.6				
MEAN - RMSE	-165	165	-265	173			+15	106
EUROPE								
RMSV-RMSVE	(43.2)	28.3	(43.2)	23.3				
MEAN - RMSE	+16	235	-61	223				
			INITIAL TIME - 12Z 18 August 1959					
N. AMERICA								
RMSV-RMSVE	(46.6)	25.3	(46.6)	24.7				
MEAN - RMSE	+8	275	-154	277			+13	91
EUROPE								
RMSV-RMSVE	(42.6)	21.4	(42.6)	21.0				
MEAN - RMSE	+106	180	+36	177				
			INITIAL TIME - 00Z 1 September 1959					
N. AMERICA								
RMSV-RMSVE	(42.8)	18.0	(42.8)	20.3			(23.7)	13.0
MEAN - RMSE	+25	135	-136	182			-15	123
EUROPE								
RMSV-RMSVE	(45.9)	18.0	(45.9)	19.7			(27.0)	13.2
MEAN - RMSE	+3	167	+32	190			-3	122
			INITIAL TIME - 12Z 15 September 1959					
AMERICA								
RMSV-RMSVE	(54.1)	16.4	(54.1)	18.2	(54.1)	30.4	(34.2)	12.2

TABLE 1. Summer Situations (CONTINUED)

	200 mb 500mb to 200mb Thickness Forecast and Equation 2		200 mb Extrapolation Equation 5		200 mb 36 Hour Persistence		500 mb Barotropic	
	INITIAL TIME - 12Z 15 September 1959							
N. AMERICA								
MEAN - RMSE	-52	153	-87	214	-71	326	-19	115
EUROPE								
RMSV-RMSVE	(47.0)	22.5	(47.0)	21.4	(47.0)	33.0	(33.8)	14.9
MEAN - RMSE	+89	212	+43	191	+111	350	+12	148
	INITIAL TIME - 00Z 17 September 1959							
N. AMERICA								
RMSV-RMSVE	(53.9)	22.0	(53.9)	20.1	(53.9)	37.0	(36.0)	13.1
MEAN - RMSE	-5	212	-89	184	-114	372	-31	133
EUROPE								
RMSV-RMSVE	(47.9)	17.4	(47.9)	16.4	(47.9)	30.7	(32.7)	14.0
MEAN - RMSE	-77	156	-57	160	-89	315	-69	133
	INITIAL TIME - 12Z 18 September 1959							
N. AMERICA								
RMSV-RMSVE	(44.9)	19.4	(44.9)	18.1	(44.9)	36.1	(29.4)	16.6
MEAN - RMSE	-25	146	-92	164	-151	331	-29	149
EUROPE								
RMSV-RMSVE	(49.3)	28.5	(49.3)	27.3	(49.3)	39.0	(34.8)	19.6
MEAN - RMSE	+188	272	+182	265	+165	369	+99	198

TABLE 2. Fall Situations, 36 Hour Forecasts, Root Mean Square Vector (RMSV) Geostrophic Wind of the Verification and Root Mean Square Vector Error (RMSVE) of Forecast Geostrophic Wind in Knots; Mean Error and Root Mean Square Error (RMSE) of Forecast Height in Feet.

	200 mb 500mb to 200 mb Thickness Forecast and Equation 2		200 mb Extrapolation Equation 5		200 mb 36 Hour Persistence		500 mb Barotropic	
	INITIAL TIME - 12Z 3 November 1959							
N.AMERICA								
RMSV-RMSVE	(68.6)	31.9	(68.6)	35.3	(68.6)	66.9	(44.3)	22.1
MEAN - RMSE	-164	291	-203	304	-185	723	-117	228
EUROPE								
RMSV-RMSVE	(51.0)	26.6	(51.0)	27.4	(51.0)	55.3	(35.9)	20.7
MEAN - RMSE	+168	267	+207	272	+139	558	+111	218
ENTIRE GRID								
RMSV-RMSVE	(52.7)	26.9	(52.7)	29.5	(52.7)	42.7	(31.9)	16.3
MEAN - RMSE	+5	230	-20	264	-1	381	+2	153
	INITIAL TIME - 00Z 5 November 1959							
N. AMERICA								
RMSV-RMSVE	(68.5)	19.6	(68.5)	19.7	(68.5)	42.3	(45.2)	15.7
MEAN - RMSE	+104	170	+16	161	-98	429	+22	139
EUROPE								
RMSV-RMSVE	(49.7)	26.4	(49.7)	25.8	(49.7)	51.0	(37.3)	20.4
MEAN - RMSE	+174	350	+220	263	+215	603	+104	259
ENTIRE GRID								
RMSV-RMSVE	(52.2)	24.7	(52.2)	25.4	(52.2)	36.9	(32.1)	15.4
MEAN - RMSE	+50	225	+19	237	+43	344	+31	148
	INITIAL TIME - 00Z 16 November 1959							
N.AMERICA								
RMSV-RMSVE	(67.3)	38.0	(67.3)	34.1	(67.3)	58.6	(48.8)	24.8
MEAN - RMSE	+84	420	+20	362	-108	630	+102	278
EUROPE								
RMSV-RMSVE	(44.2)	23.1	(44.2)	27.4	(44.2)	42.3	(35.2)	18.8
MEAN - RMSE	+67	218	+46	255	+171	431	+45	181
ENTIRE GRID								
RMSV-RMSVE	(57.4)	30.2	(57.4)	28.4	(57.4)	39.9	(35.9)	16.6
MEAN-RMSE	+52	255	+39	256	+46	374	+29	152

TABLE 3. Winter Situations, 36 Hour Forecasts, Root Mean Square Vector (RMSV) Geostrophic Wind of the Verification and Root Mean Square Vector Error (RMSVE) of Forecast Geostrophic Wind in Knots; Mean Error and Root Mean Square Error (RMSE) of Forecast Height in Feet.

	200 mb 500mb to 200mb Thickness Forecast and Equation 2		200 mb Extrapolation Equation 5		200 mb 36 Hour Persistence		500 mb Barotropic		200 mb 850mb-200mb Thickness Forecast and Equation 4	
INITIAL TIME - 00Z 6 December 1959										
N. AMERICA										
RMSV-RMSVE	(79.5)	47.1	(79.5)	55.1						
MEAN - RMSE	+204	398	+248	449						
EUROPE										
RMSV-RMSVE	(54.6)	24.8	(54.6)	27.6						
MEAN - RMSE	-113	284	-15	285						
ENTIRE GRID										
RMSV-RMSVE	(59.8)	33.2	(59.8)	35.6						
MEAN-RMSE	+39	247	+25	279						
INITIAL TIME - 12Z 20 December 1959										
N. AMERICA										
RMSV-RMSVE	(67.4)	29.9	(67.4)	41.4						
MEAN - RMSE	+73	262	+157	312						
EUROPE										
RMSV-RMSVE	(52.5)	20.0	(52.5)	30.0						
MEAN - RMSE	+23	180	+234	261						
ENTIRE GRID										
RMSV-RMSVE	(62.7)	28.9	(62.7)	33.1						
MEAN - RMSE	+23	268	+25	307						
INITIAL TIME - 00Z 12 January 1960										
N. AMERICA										
RMSV-RMSVE	(69.4)	35.5	(69.4)	39.7	(69.4)	43.0	(45.6)	32.4	(69.4)	34.9
MEAN - RMSE	-26	315	±0	322	-75	384	-94	298	-5	286
EUROPE										
RMSV-RMSVE	(55.9)	28.3	(55.9)	28.2	(55.9)	47.4	(41.5)	17.9	(55.9)	24.7
MEAN - RMSE	-171	309	+121	301	-101	474	-112	193	-52	256
ENTIRE GRID										
RMSV-RMSVE	(69.4)	33.0	(69.4)	35.1	(69.4)	41.3	(41.8)	20.2	(69.4)	32.5
MEAN - RMSE	+29	285	+58	293	+25	337	+6	197	+28	249

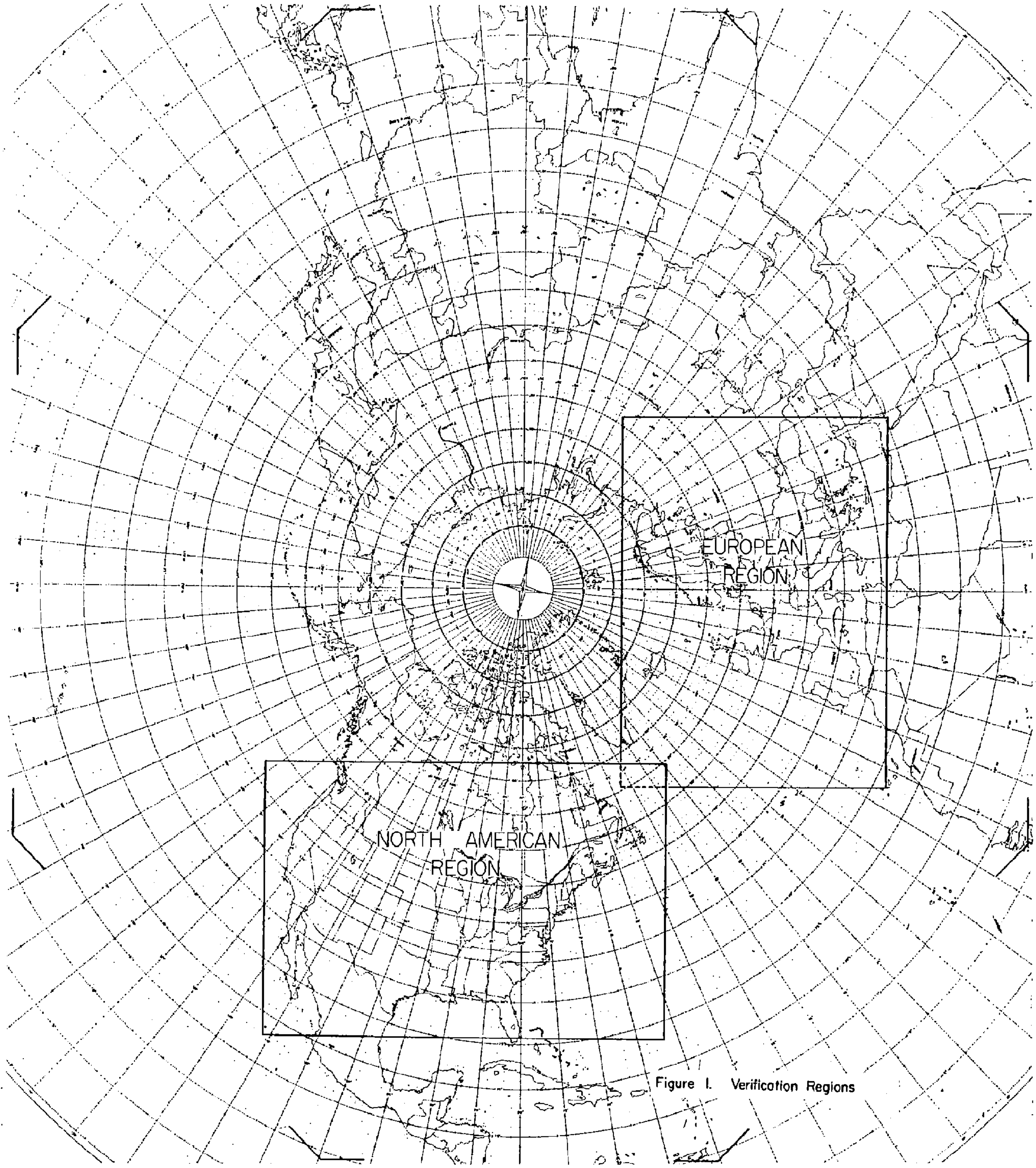

Figure I. Verification Regions

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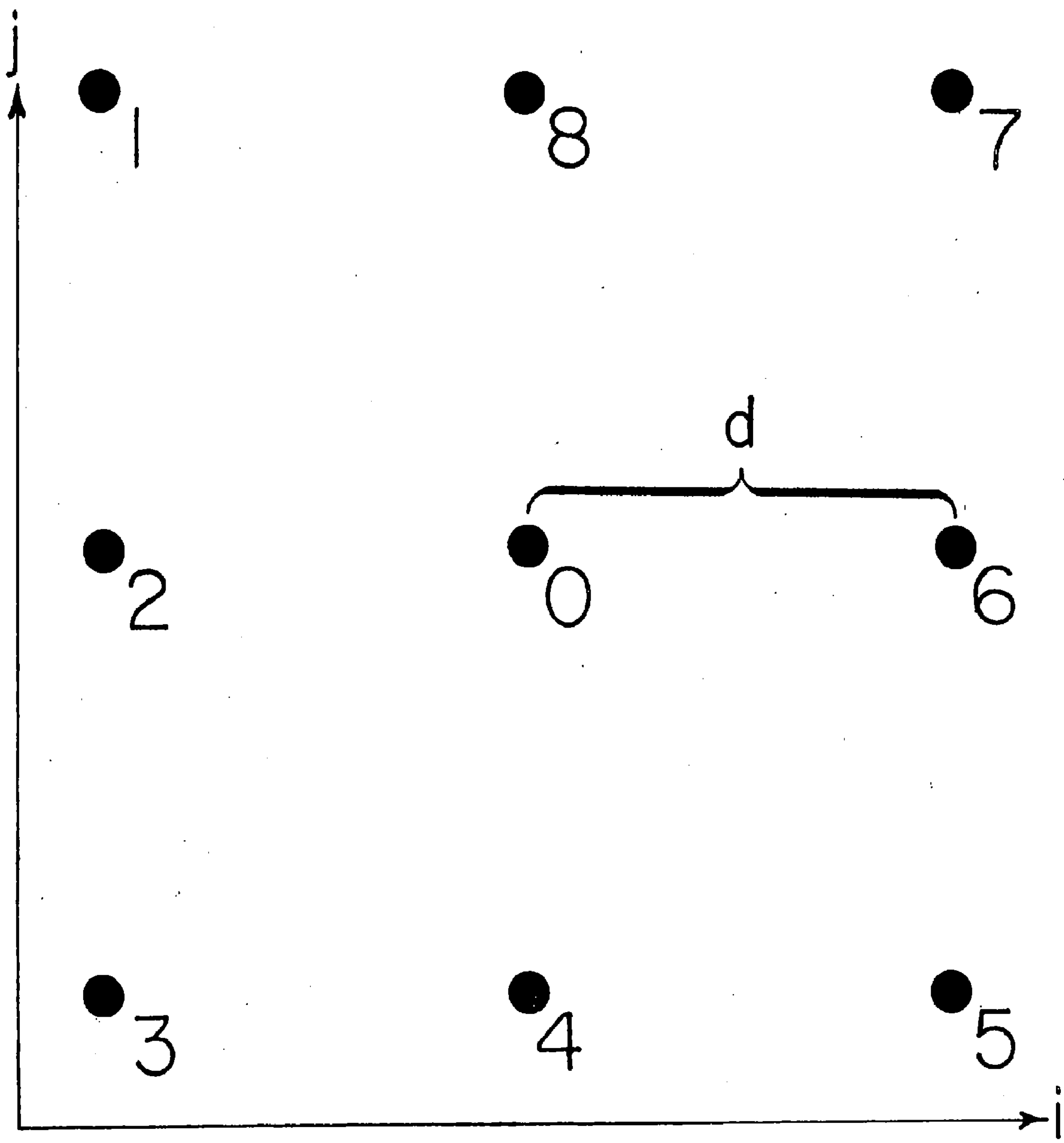

Figure 2. Grid for 9 point smoother
d = one grid length (381 km at 60 deg.)

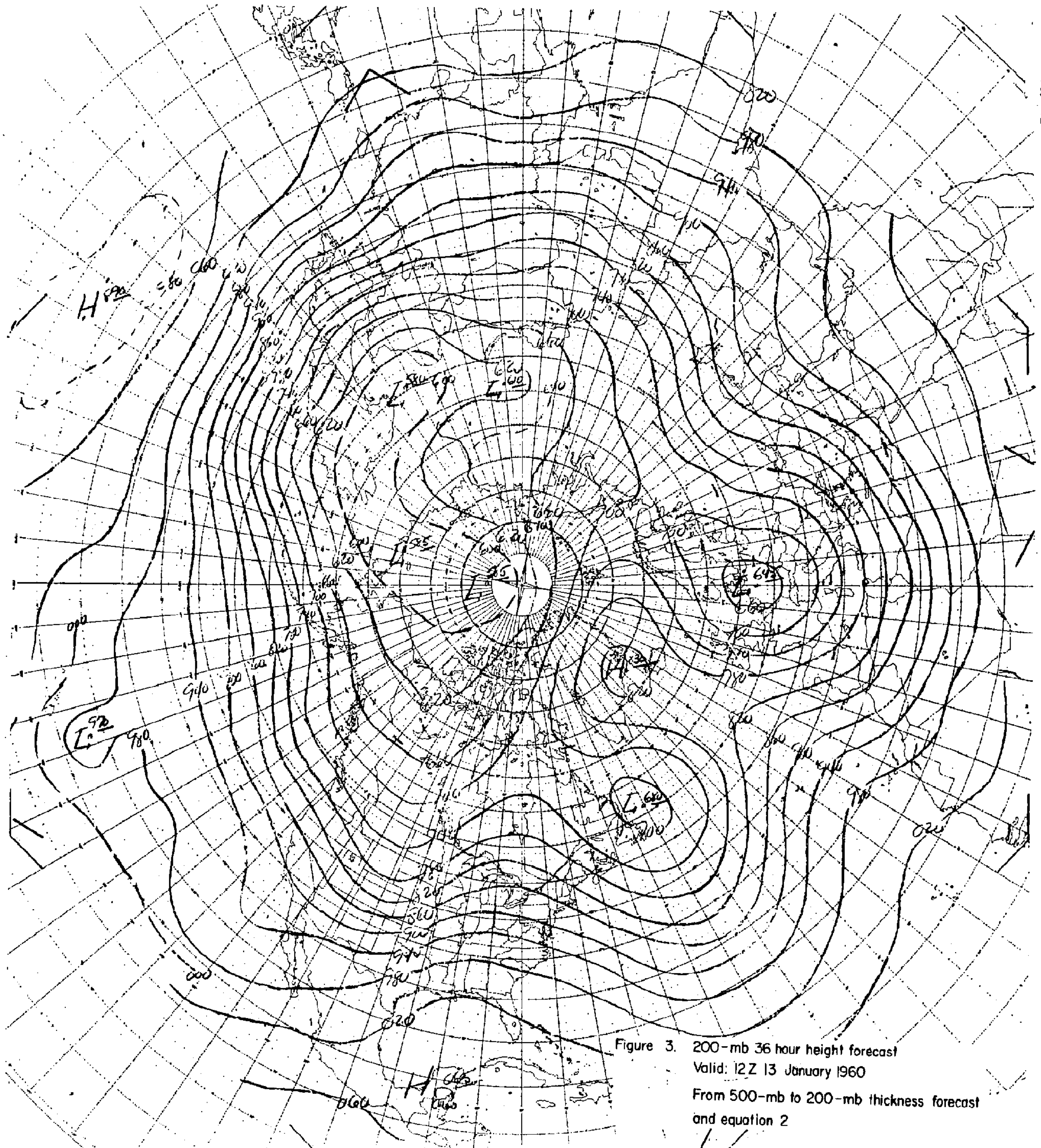

Figure 3. 200-mb 36 hour height forecast
Valid: 12Z 13 January 1960
From 500-mb to 200-mb thickness forecast and equation 2

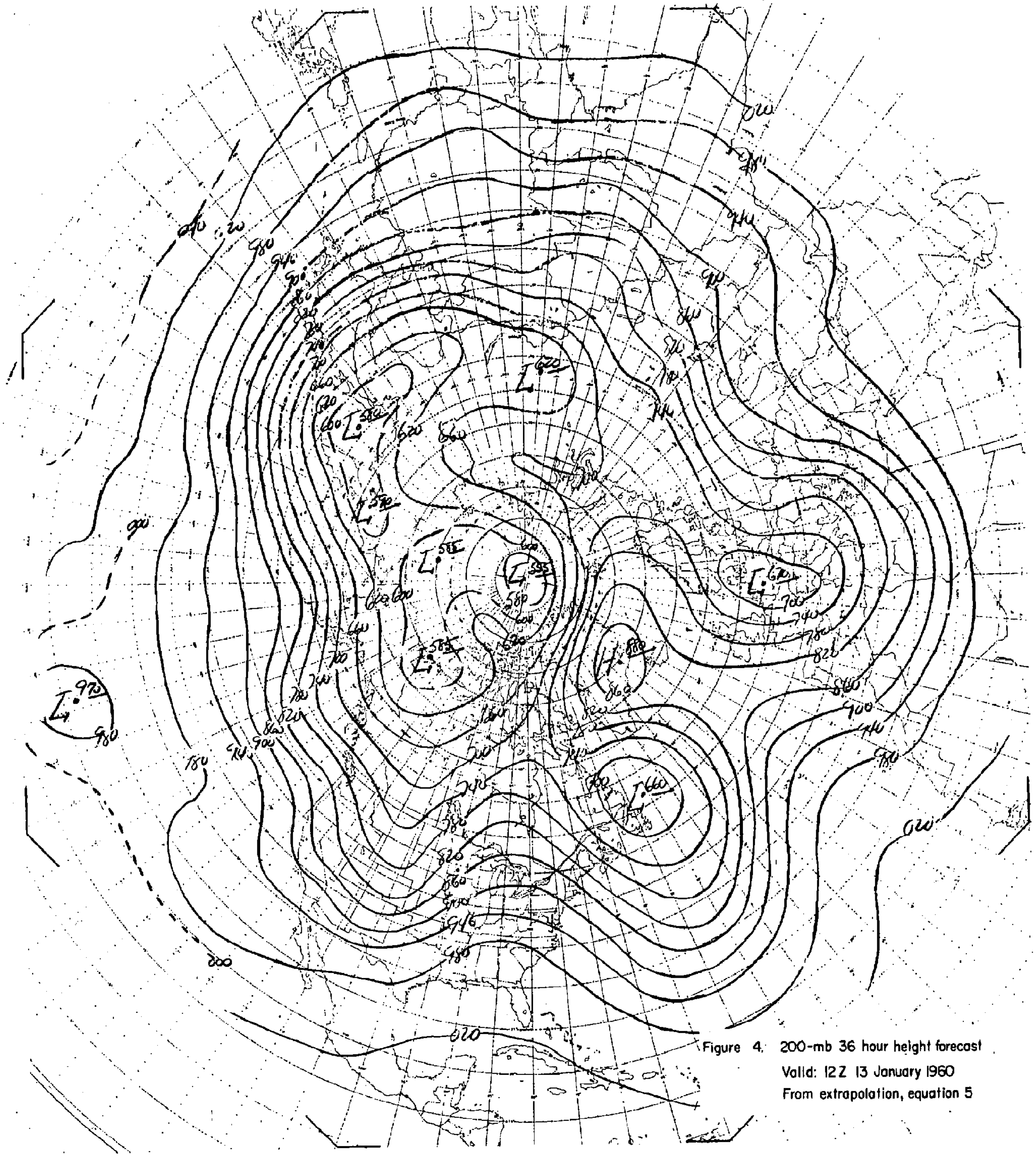

Figure 4. 200-mb 36 hour height forecast
Valid: 12Z 13 January 1960
From extrapolation, equation 5

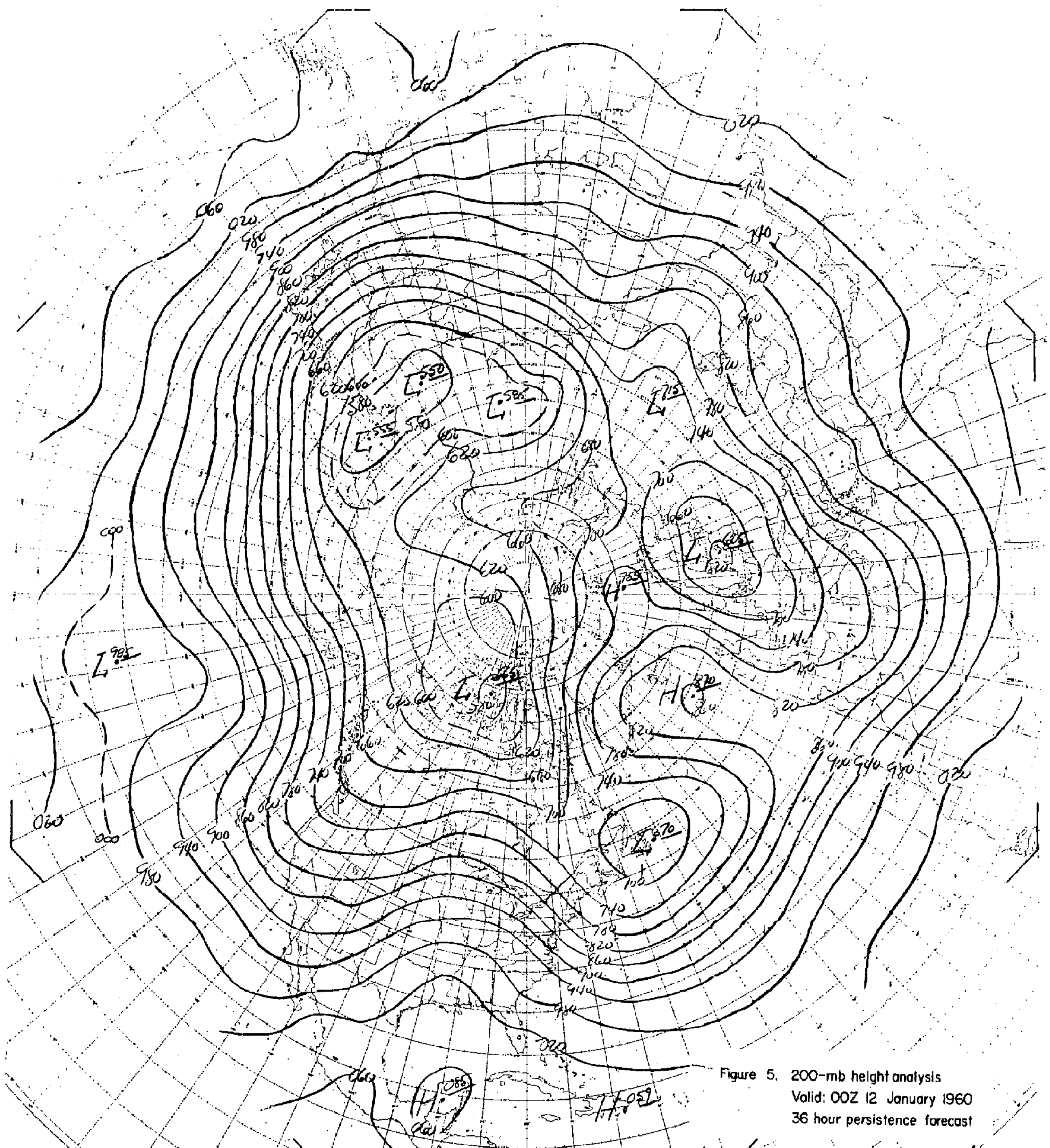

Figure 5. 200-mb height analysis
Valid: 00Z 12 January 1960
36 hour persistence forecast

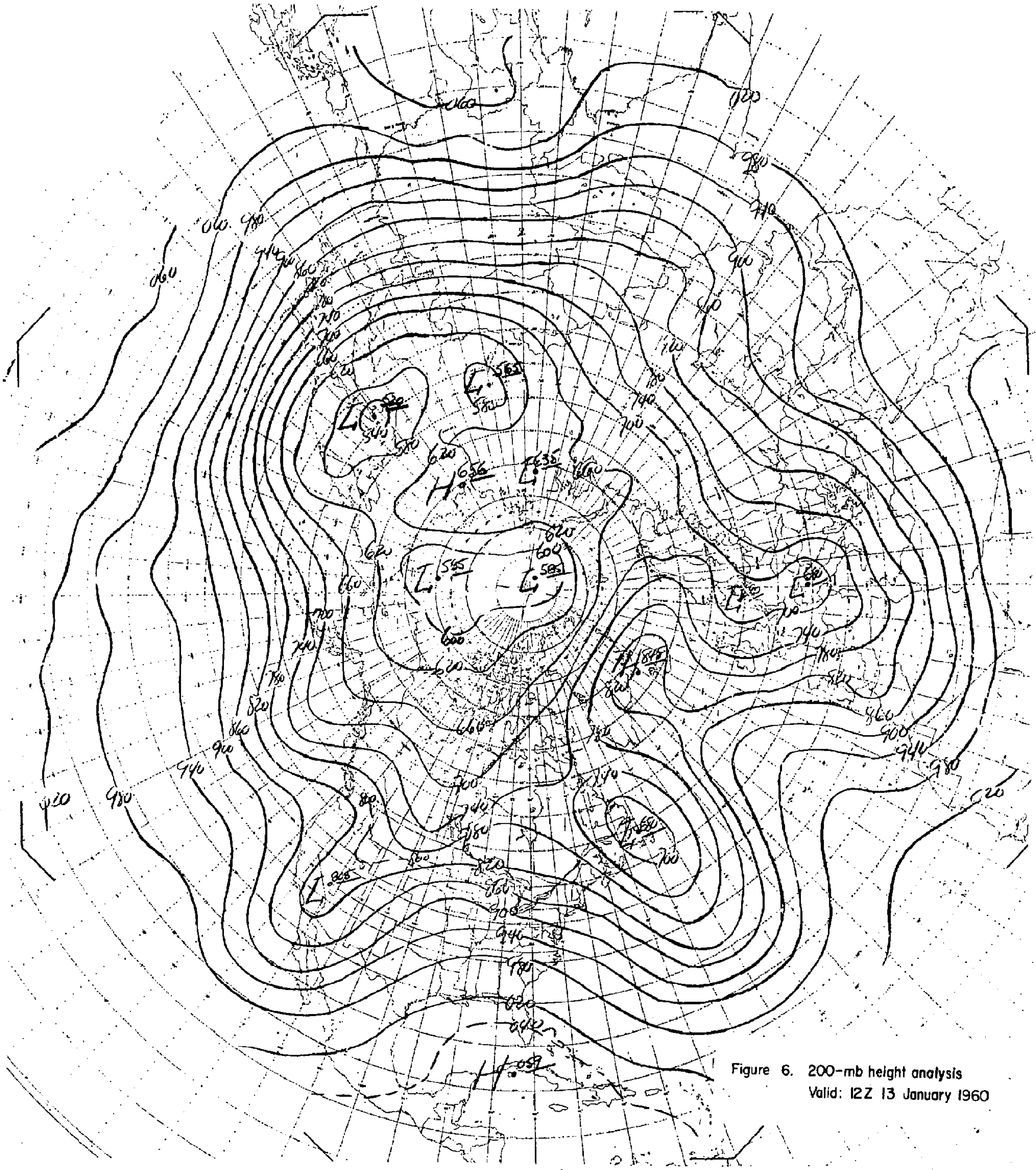

Figure 6. 200-mb height analysis
Valid: 12Z 13 January 1960

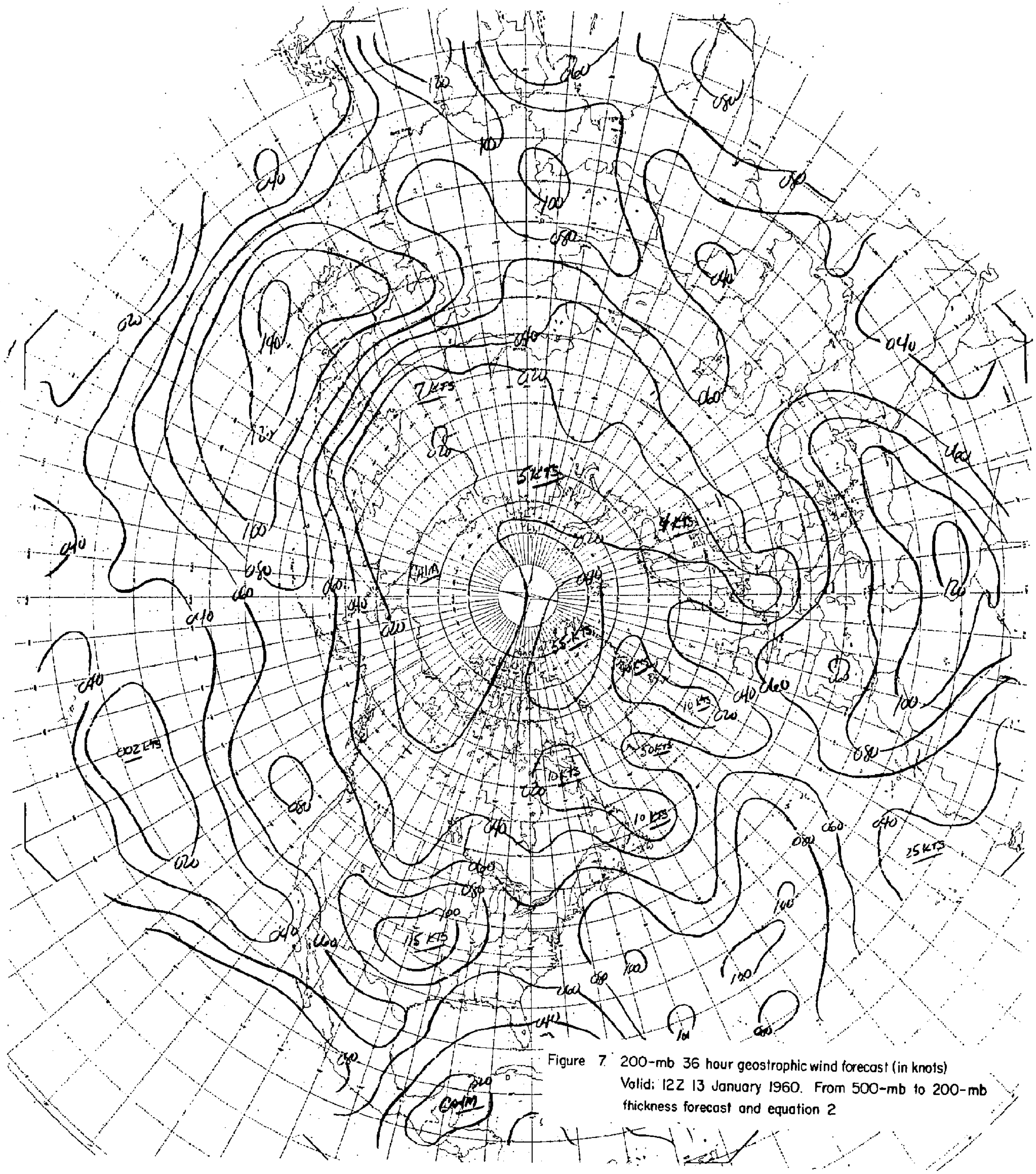

Figure 7. 200-mb 36 hour geostrophic wind forecast (in knots) Valid: 12Z 13 January 1960. From 500-mb to 200-mb thickness forecast and equation 2

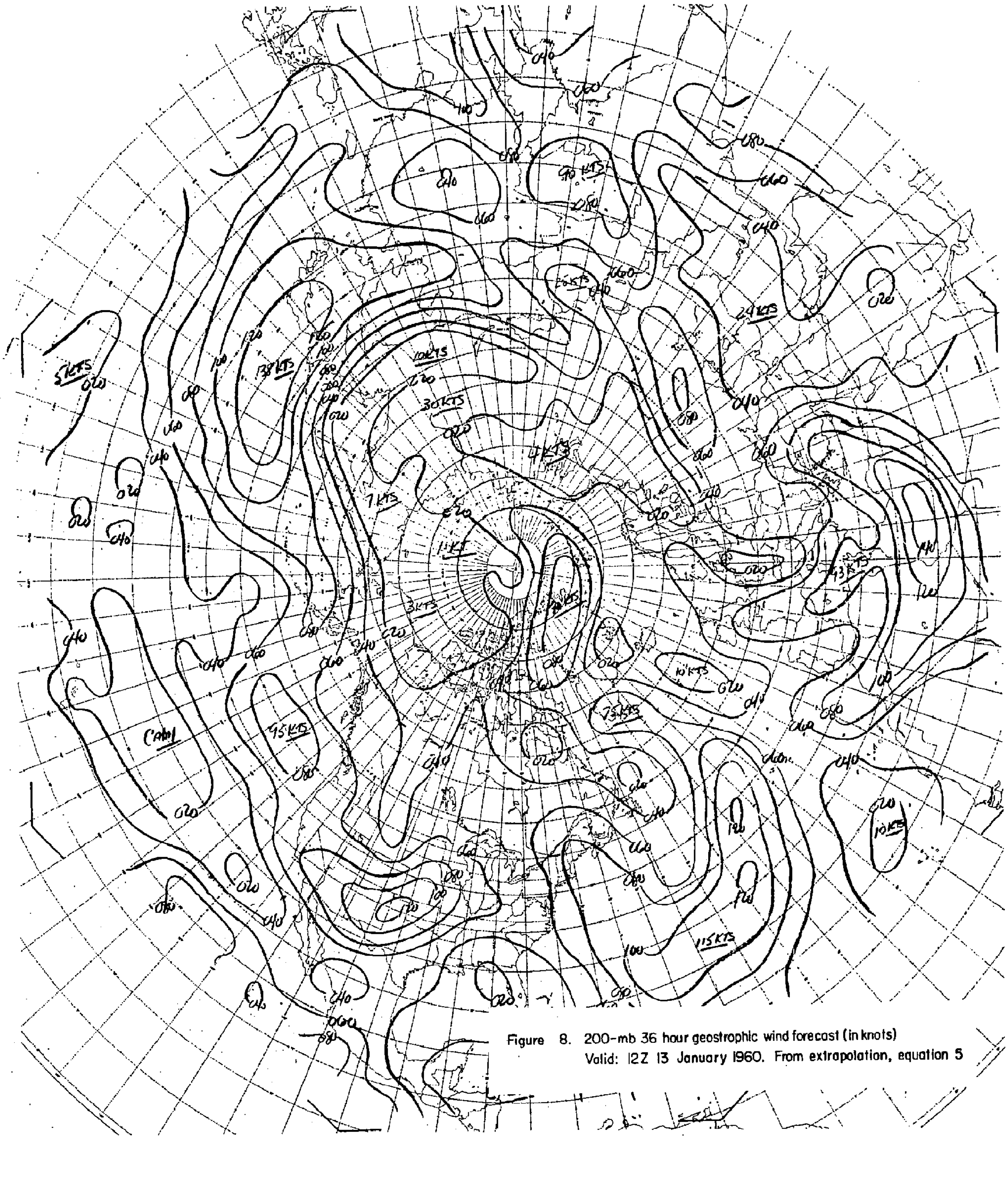

Figure 8. 200-mb 36 hour geostrophic wind forecast (in knots)
Valid: 12Z 13 January 1960. From extrapolation, equation 5

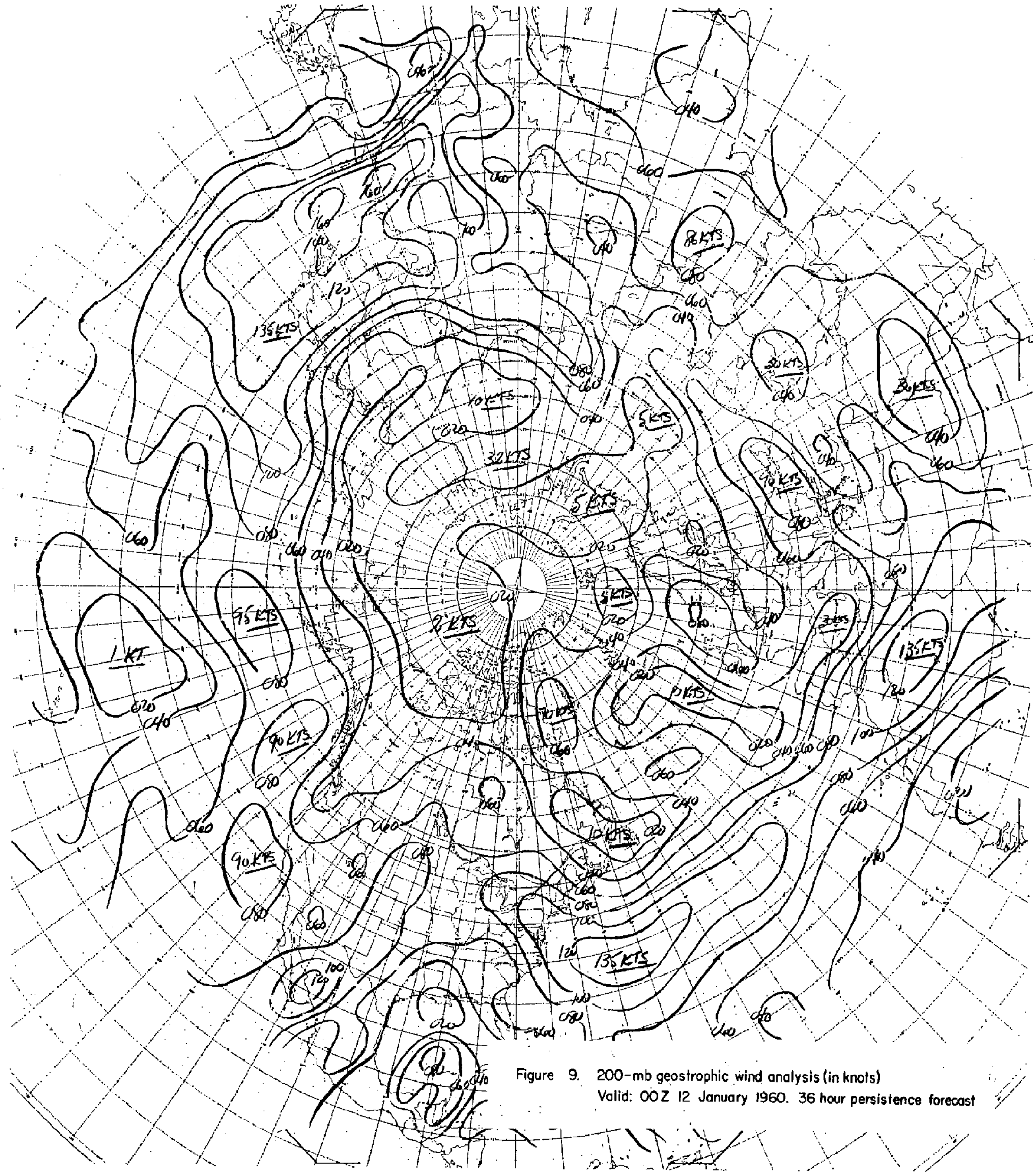

Figure 9. 200-mb geostrophic wind analysis (in knots)
Valid: 00Z 12 January 1960. 36 hour persistence forecast

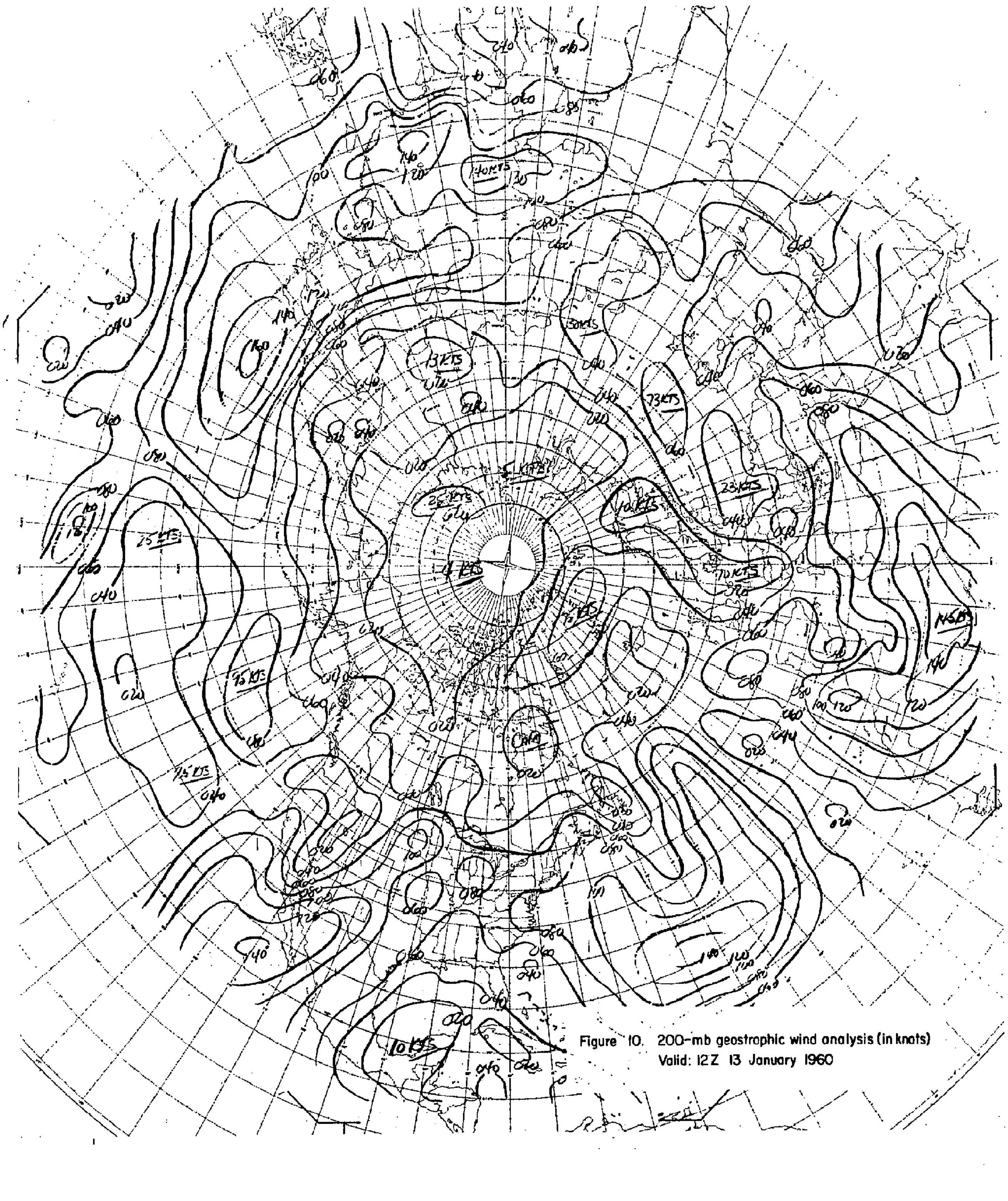

Figure 10. 200-mb geostrophic wind analysis (in knots)
Valid: 12Z 13 January 1960