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A CASE STUDY DEMONSTRATING THE NECESSITY FOR HAVING SUBJECTIVELY PRODUCED UPPER LEVEL WIND FORECASTS

by

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ABSTRACT

Upper wind forecasts can be in serious error in the vicinity of jet streams due to the inability of the numerical models to resolve the abrupt changes of wind, temperature and pressure gradients. While this study examines one particular case, its aim is to demonstrate the necessity for having subjectively produced upper level wind forecasts.

ÉTUDE DE CAS DÉMONTRANT LA NÉCESSITÉ D'AVOIR DES PRÉVISIONS SUBJECTIVES DE VENT EN ALTITUDE

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RÉSUMÉ

Les prévisions de vent en altitude risquent d'être fortement erronées dans le voisinage de courants-jets car les modèles numériques ne sont pas aptes à analyser les changements brusques du vent et des gradients de température et de pression. La présente étude qui n'examine qu'un cas particulier a pour but de démontrer la nécessité d'avoir des prévisions subjectives de vent en altitude.

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1. Introduction

During the past year the authors have been working with the Canadian Forces Air Navigation School in Winnipeg preparing upper wind forecasts near the 300-mb level for various training missions. During de-briefings the navigation instructors frequently reported significant discrepancies between the forecast and observed winds, particularly near jet streams. (These wind reports are very reliable as they are obtained from an on-board computer which uses Doppler radar information.) The purpose of this report is to determine possible reasons for these discrepancies.

The report focuses on one interesting flight where the average error in the forecast wind was over forty percent. The investigation of this situation leads to the conclusion that the problem arises in the initialization of the numerical model which produces the forecast winds.

Since the objective analyses form the basis for the initialization, the analysis schemes are examined and some weakness are highlighted. Finally suggestions are made for improvements to the current wind forecasts.

2. The Flight

On 16 February 1977 at 2330Z a C130 Hercules aircraft departed from Winnipeg for a five-hour navigation training exercise. The flight was at 29,000 feet along a straight line route to Stony Rapids, Saskatchewan (at the eastern tip of Lake Athabasca) and return.

The most recent 300-mb chart available was from CMC, for 16 February 1200Z (Figure 1). The main features on this analysis are: a weak ridge in a line from Kenora to Trout Lake; a weak trough along the Manitoba-Saskatchewan border; a major ridge along the British Columbia-Alberta border; and a band of strong winds running from northern Alberta to Wyoming. A light northwesterly flow of about 40 knots is present at this time along the flight path.

Figure 2 is the 24-hour NMC 250-mb prog valid at 17 February 0000Z which was available before the flight. This predicts a broadening of the major ridge and the axis of maximum wind is expected to lie from central Alberta to the western Dakotas. The FD winds, valid for the same time, but based on 16 February 1200Z data, are plotted in Figure 3. Based on the above information winds for the flight were forecast to be 330/80 from Winnipeg to The Pas and 310/60 from The Pas to Stony Rapids.

The winds encountered by the aircraft are plotted in Figure 4. When the aircraft reached the top-of-climb (29,000 feet) at 17 February 0010Z, it encountered winds of 320/120. About an hour later, near Flin Flon, winds were still very strong (320/100) but gradually became lighter from this point on and were 310/70 at the northern end of the route. Generally, the winds averaged forty percent higher than forecast.

The 300-mb subjective analysis for 17 February 0000Z (Figure 5) shows that the route lies very close to a jet axis which has a core strength of 130 knots over Lake Manitoba. The 250-mb prog for this time (Figure 2) indicated no evidence for the presence of this jet.

3. The Problem

The model obviously had difficulty handling this situation and a reasonable place to look for the problem is in the initialization of the model. The initial field is obtained from the objective analyses for all mandatory levels. The 24-hour prog of concern is based on NMC's objective analyses for 16 February 0000Z.

Since the flight was at 29,000 feet, consider NMC's 300-mb objective analysis for 16 February 0000Z (Figure 6). The analysis shows a broad ridge over British Columbia and a trough along the Alberta-Saskatchewan border. There is a wide band of strong winds appear to cross three or four contours.

It was felt that there were probably two jets embedded in this broad stream. Therefore the 300-mb chart for 16 February 0000Z was re-analysed. This analysis (Figure 7) shows a southern polar jet arcing through Port Hardy to north of Vernon and through Great Falls with a jet maximum of 130 knots near Vernon. A northern (maritime) jet lies just north of Annette to south of Fort Nelson and just north of Edmonton with a jet maximum of 130 knots south of Fort Nelson. To verify this analysis a cross-section was prepared from Medford Or. to Cambridge Bay, N.W.T. for 16 February 0000Z (Figure 8). Four air masses are identified on this cross section separated by three fronts (polar, maritime and arctic from south to north). There is a jet north of Spokane associated with the polar front with the maximum winds of 150 knots at 260 mb. There is also a jet associated with the maritime front which has a maximum wind of about 130 knots at 350 mb. In comparing the subjective analysis (Figure 7) with NMC's (Figure 5), the subjective analysis is more reasonable in terms of the isotach pattern, the horizontal shears and the crossing of contours by the jet axes.

To summarize the problem: It would appear that the model was only able to identify, in its initialization, one band of strong winds when in fact there were two separate axes of maximum winds. Naturally the prog would carry only the one stream.

4. The Objective Analysis Schemes

NMC's objective analysis procedure uses wavelike mathematical functions to compute its analyzed fields. The heights and winds are coupled through a realistic physical relationship and as a result the height and wind fields are analyzed simultaneously. Satellite data and radiosonde observations are incorporated into the mathematical functions using an empirical relationship. The analysis is made to fit the true field as closely as possible by minimizing the mean square differences between the analysis and the observations, or in areas where observatins are lacking, between the analysis and the first guess field (12 hour forecast). In comparison, CMC's objective analysis procedure also uses a first guess field (6 hour forecast) but its analyzed values are obtained differently. The value of an analyzed parameter at any one particular grid point is the predicted value plus the mean weighted differences between the observed and predicted values at a number of surrounding locations.

Despite the significant differences between these two analyzing procedures the final results are usually very similar.

One limitation of both procedures arises in regions where the data network is sparse. There is a quasi-geostrophic dependence in all regions, however there is a strong geostrophic dependence in low density data areas. Also, in these areas, the schemes place greater emphasis on the trial fields.

A further significant limitation of both procedures is the resolution. For the CMC scheme, the minimum resolution is two grid lengths, while NMC's scheme is spectral and has resolution only to one wavelength (the smallest wavelength is 15° longitude). This was the problem with NMC's 300-mb analysis for 16 February 0000Z (Figure 6); the objective analysis scheme was unable to resolve the two jet streams.

5. Model Initialization

The objective analyses form the basis for the initialization of both CMC's and NMC's numerical models. The analyses of each mandatory level are interpolated to sigma surfaces and additional smoothing is carried out to ensure that the initial conditions are compatible with the resolution of the models. This is necessary to avoid the generation of gravity waves. As a result it would not be practical to have an objective analysis with better resolution than that of the numerical models.

6. Recommendations

At the present time the upper air data network over Canada is sparse. The amount of data could be increased to give a more accurate objective analysis which would still be compatible with the models. This could be accomplished by two means: firstly, increasing the number of upper air stations throughout Canada, and secondly, encouraging briefers to obtain and transmit pilot reports (PIREPS).

The importance of having more upper air stations cannot be overstressed. The addition of even one station can result in major amendments to an analysis. This is often observed in the west when the infrequent observations from Shilo are included.

In Canada, PIREP information appears to be very infrequent. Commerical as well as military pilots should be required to report standard weather information at various intervals while in flight, as is currently the case over ocean areas.

Incorporating these ideas would help to improve the numerical products, however, it must be remembered that computerized progs are meant to be used only as guidance in assisting a meteorologist in the preparation of his forecasts.

Meteorologists are currently preparing subjective progs, using the computer guidance, to assist them in arriving at weather forecasts. A similar procedure should be followed in preparing upper level wind forecasts.

The first step in preparing such a wind forecast is to start with a good subjective analysis, identifying the significant features such as jet streams, ridges and troughs. When analyzing jet streams it should be remembered that:

(i) a jet should be located near a 500-mb front (thermal wind relationship);

(ii) there is a maximum shear on the right side of the jet axis determined by the Coriolis parameter;

(iii) there is greater shear on the left side than on the right side of the jet axis;

(iv) the horizontal wind is composed of ageostrophic as well as geostrophic components.

The effects of ageostrophic components can be understood by considering the horizontal wind equation written in the following form:

$$\vec{V}_h = \vec{V}_g + \underbrace{\frac{1}{f}\left(\frac{d\vec{V}_h}{dt}\right)\hat{n}}_{(a)} - \underbrace{\frac{K\,V_h^{\,2}}{f}\,\hat{t}}_{(b)} + \underbrace{\frac{W}{f}\left(\hat{k} \times \frac{\partial \vec{V}_h}{\partial Z}\right)}_{(c)} + \underbrace{W\,\mathrm{COT}\,\emptyset\,\hat{j}}_{(d)} + \underbrace{\frac{\vec{F}_h}{f} \times \hat{k}}_{(e)}$$

where $\vec{V}_h$ - horizontal wind speed

$\vec{V}_g$ - geostrophic wind speed

f - Coriolis parameter

$\hat{n}, \hat{t}$ - unit vectors in natural coordinates

$\hat{k}, \hat{j}$ - unit vectors in cartesian coordinates

K - curvature parameter

$\emptyset$ - latitude

W - vertical velocity

$\vec{F}_h$ - friction.

The effect of the ageostrophic terms (a) through (e) can be best seen by considering each term independently.

a) Acceleration term - This produces an ageostrophic component which is perpendicular to the horizontal wind. Therefore the horizontal wind would be deflected towards lower pressure under conditions of positive acceleration. For a typical jet stream where winds might accelerate along the axis from 60 knots to 140 knots, the resulting deflection to lower heights will be about 240 m.

b) Curvature term - The gradient wind results from adding this term to the geostrophic wind to account for the effects of curved flow. When a strong jet passes through a ridge the horizontal wind can be up to twice as large as the geostrophic wind, while in a deep trough the winds could be significantly lighter than geostrophic.

c) Vertical wind shear term - This term is small near jet streams because the vertical wind shear is zero at the level of maximum wind.

d) Latitude term - This term is small in mid-latitudes because vertical velocities are much smaller than horizontal winds.

e) Friction term - Even though friction has been shown to be nearly as significantly near jet streams as in the boundary layer, the effect of the friction term is still small in comparison to the magnitude of the horizontal winds in the vicinity of jet streams.

If careful consideration was made of the points mentioned in the foregoing discussion, a meteorologist could prepare a significantly better jet stream analysis than the present objective ones.

Once an accurate analysis is available a twelve- and eighteen-hour prog can be prepared using the numerical guidance along with subjective forecasting techniques. At CFB Winnipeg, where six-to twelve-hour wind forecasts are required, short-range forecasting techniques in conjunction with a subjective analysis have resulted in significant improvements.

7. Conclusions

It has been shown that one reason for poor upper wind forecasts is that the objective analysis schemes and numerical models are unable to resolve the abrupt changes in the wind, pressure and temperature gradients in the vicinity of jet streams.

The primary users of wind progs are briefing technicians and air crews. At the present time these users are given the objective progs as guidance but they are not informed of the weaknesses; and even if they were, they do not have the background necessary to make adjustments based on sound reasoning.

Therefore upper wind forecasts should be prepared by the meteorologist using the numerical progs as guidance but relying on his knowledge of synoptic meteorology to produce the final forecasts.

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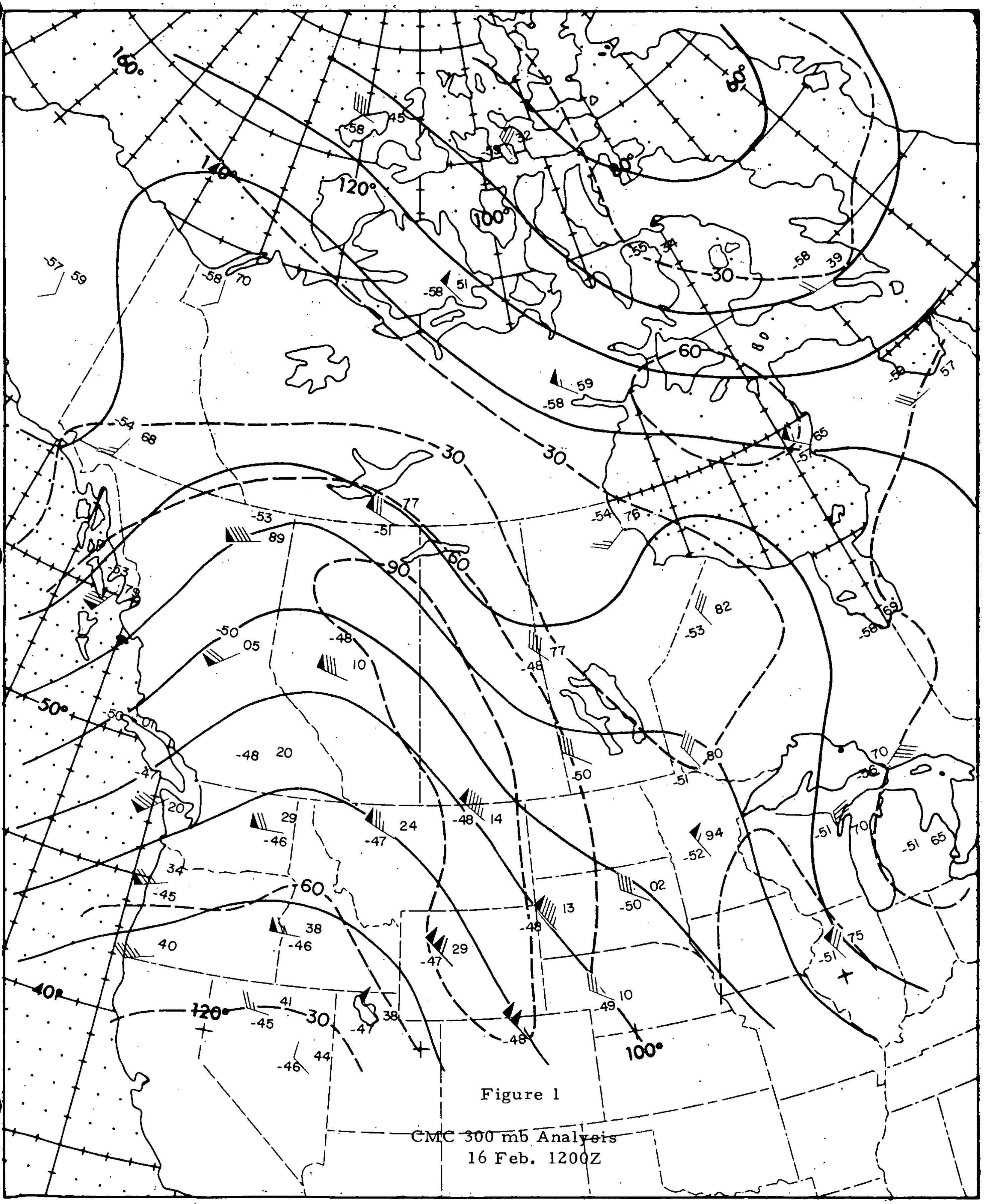

Figure 1

CMC 300 mb Analysis
16 Feb. 1200Z

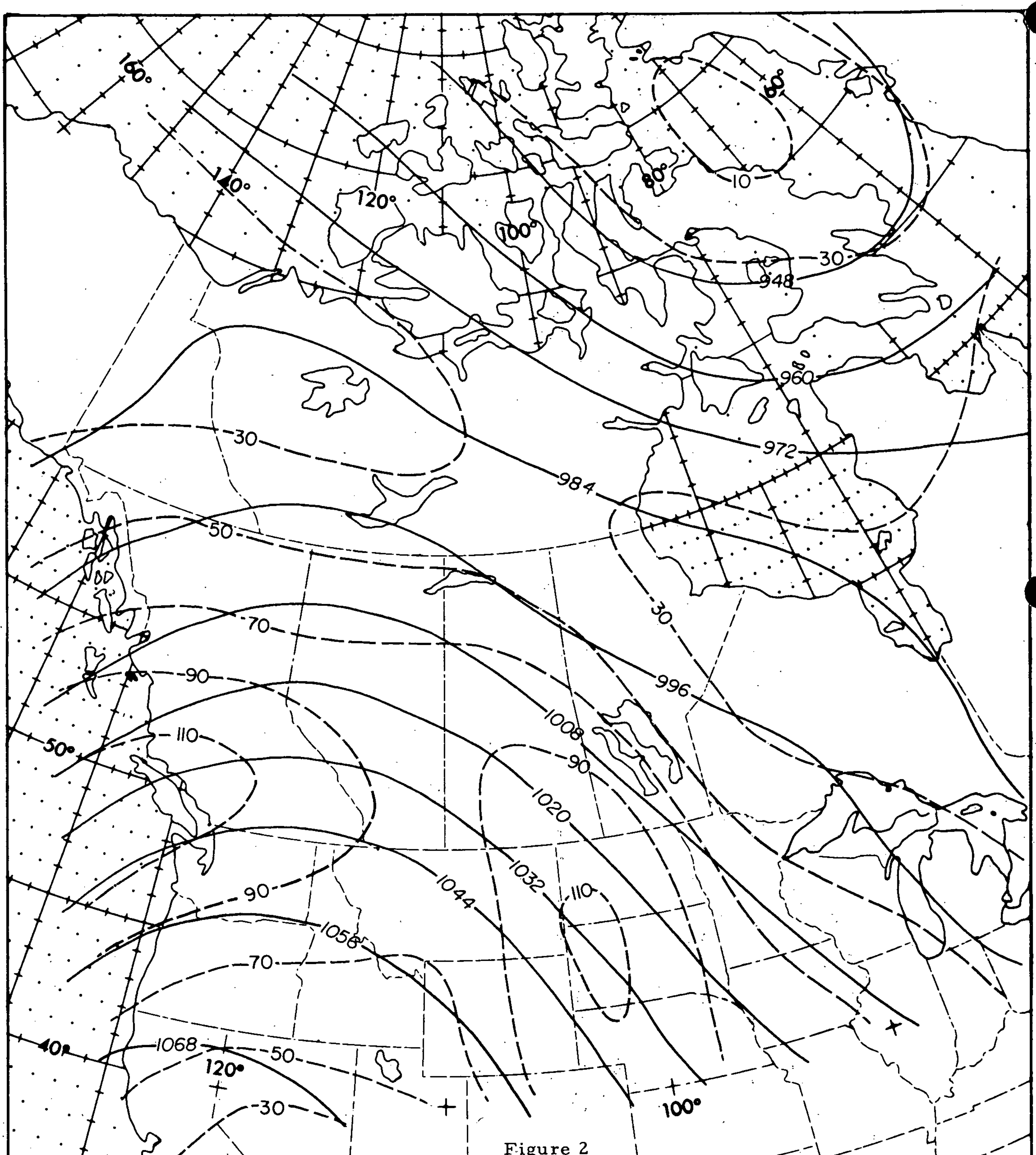

Figure 2

~~NMC 24 Hour 250 mb Prog~~
valid 17 Feb. 0000Z

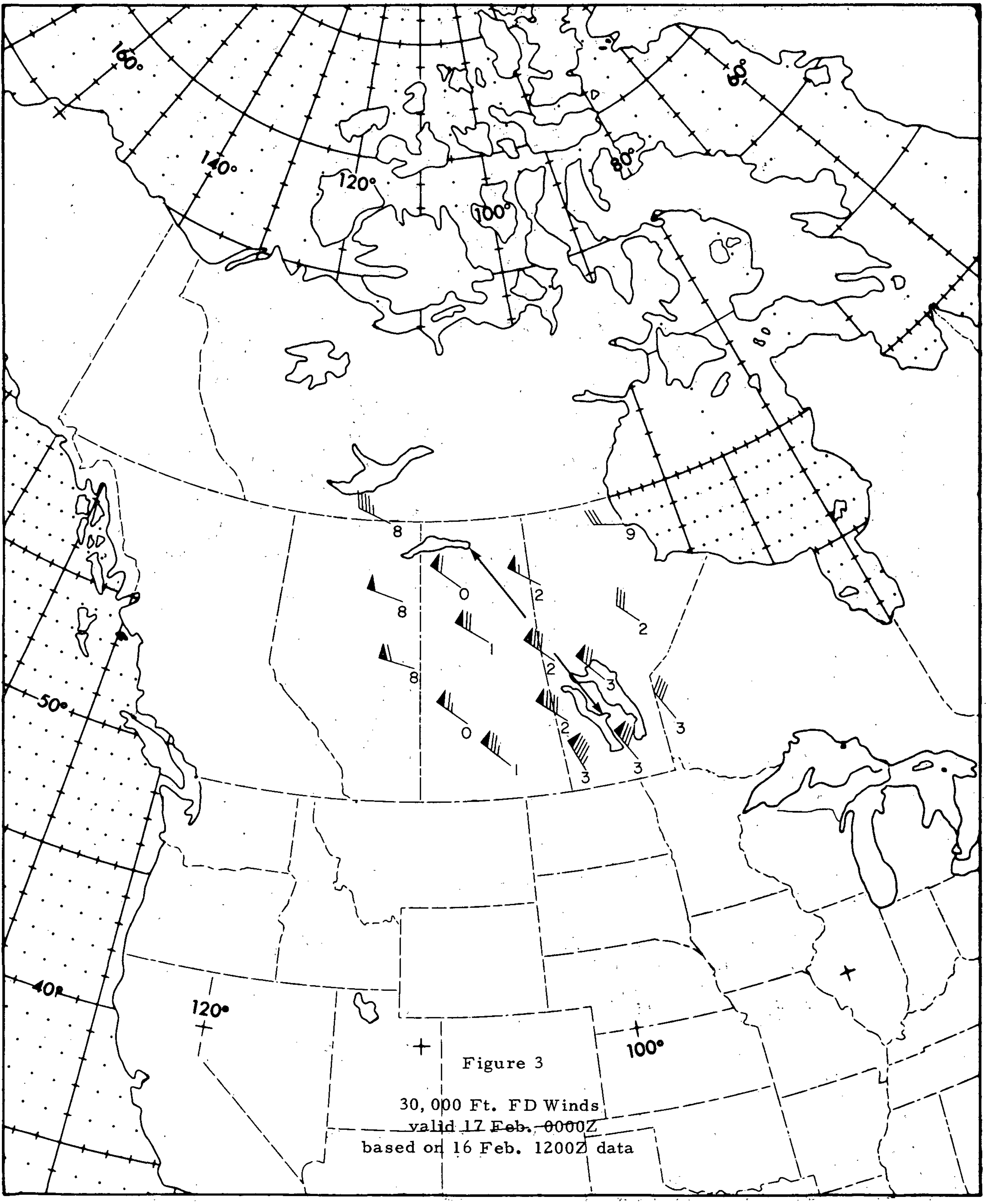

Figure 3

30,000 Ft. FD Winds
valid 17 Feb. 0000Z
based on 16 Feb. 1200Z data

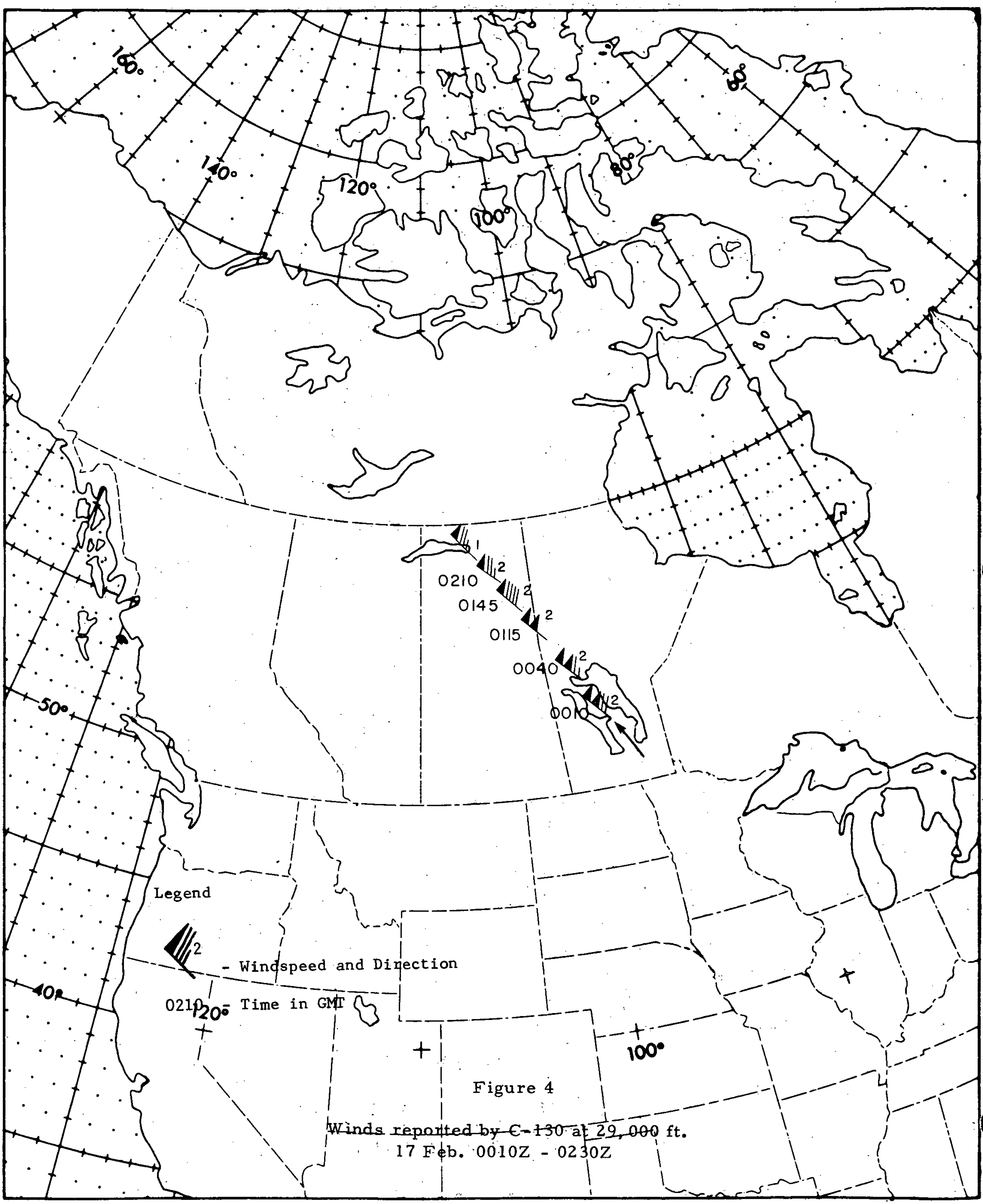

Figure 4

Winds reported by C-130 at 29,000 ft.
17 Feb. 0010Z - 0230Z

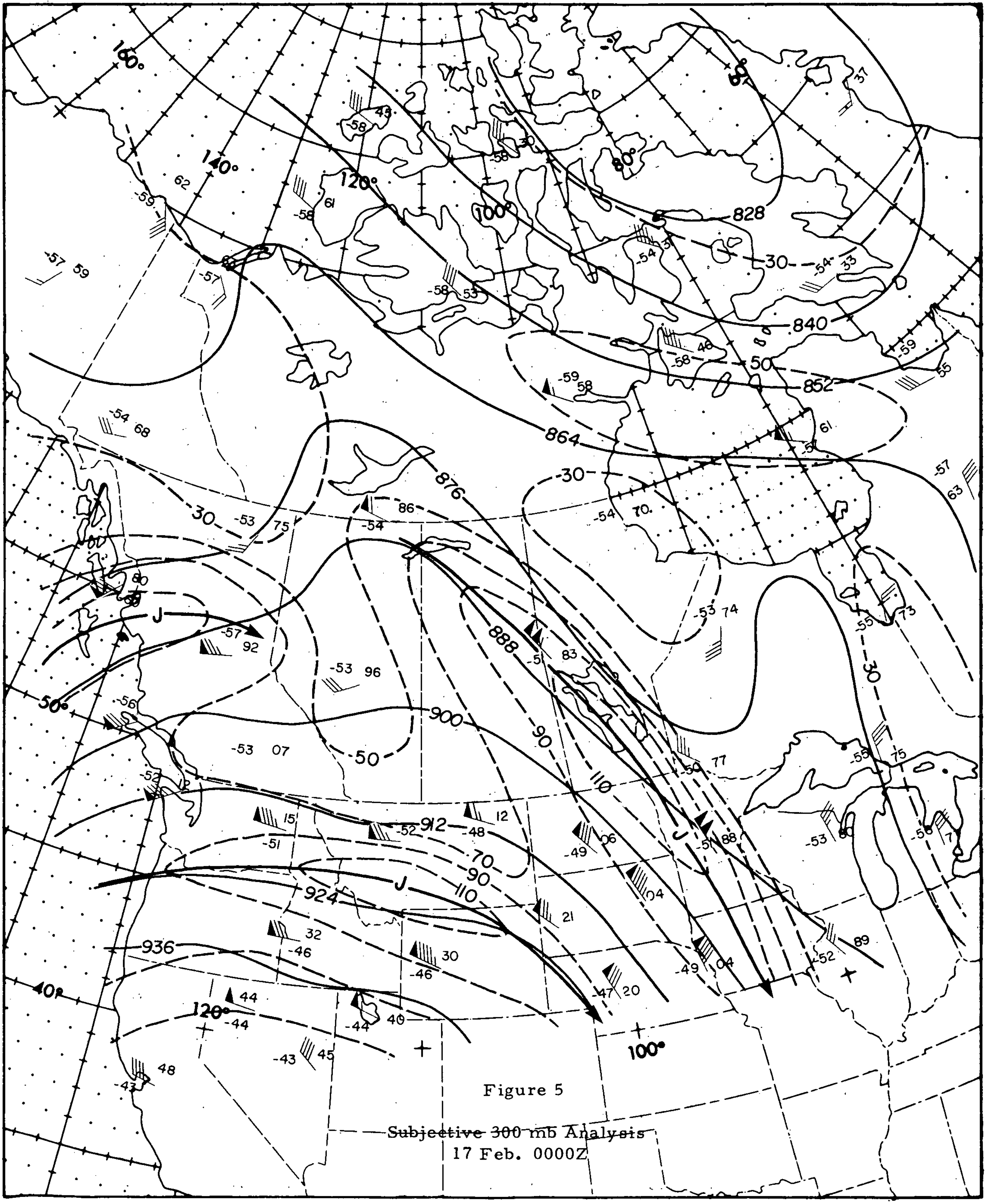

Figure 5

~~Subjective 300 mb Analysis~~
17 Feb. 0000Z

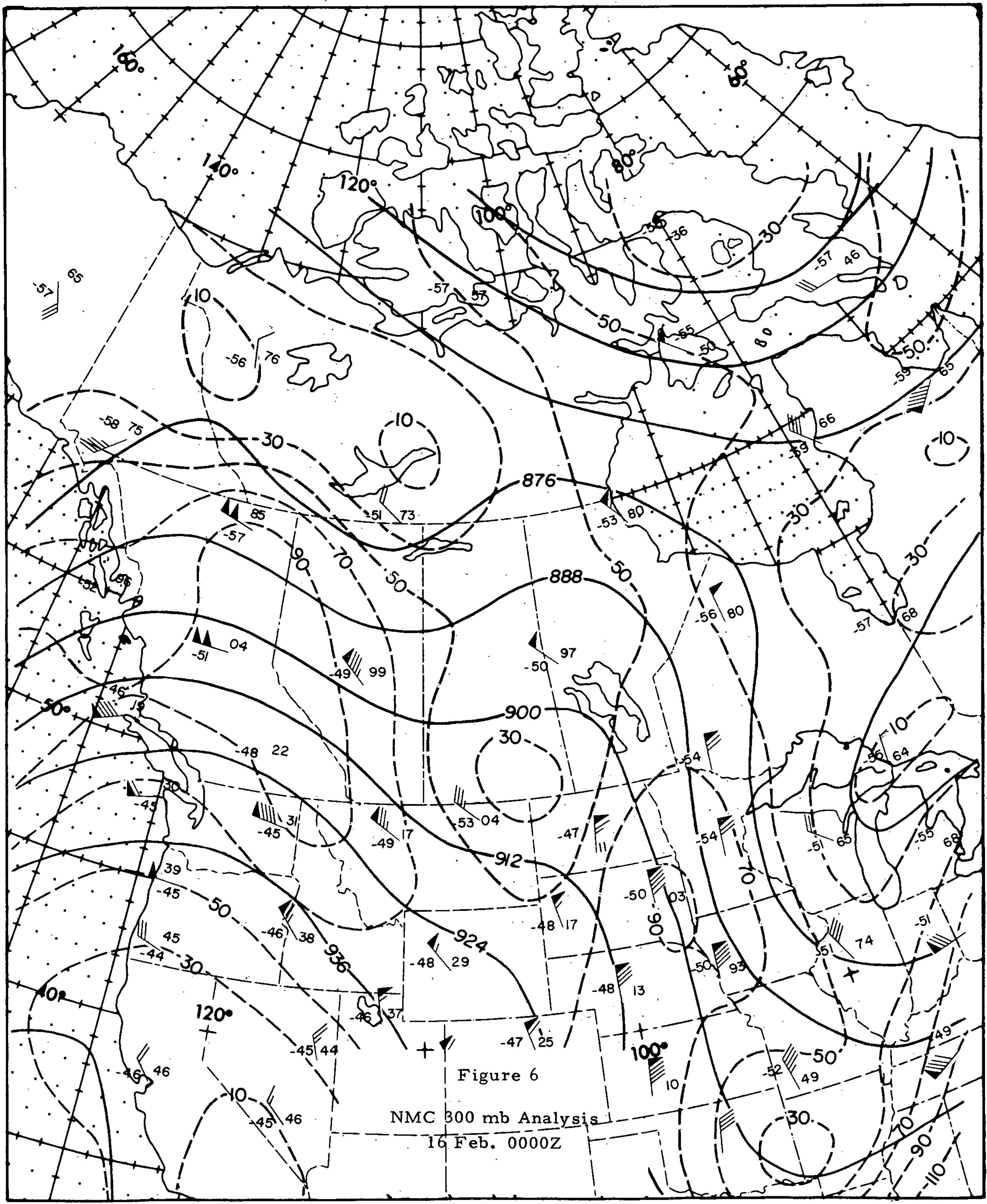

Figure 6

NMC 300 mb Analysis
16 Feb. 0000Z

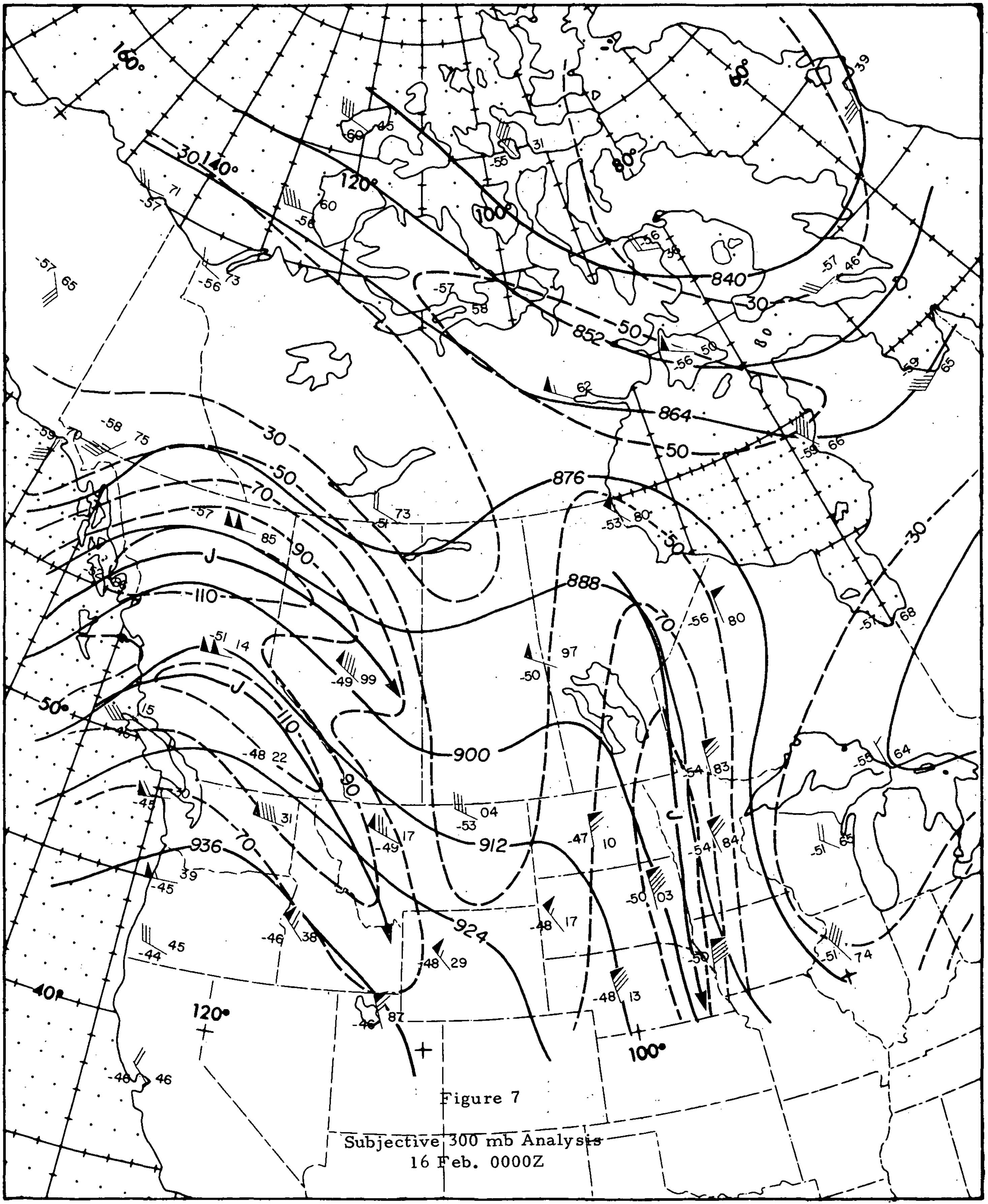

Figure 7

Subjective 300 mb Analysis
16 Feb. 0000Z

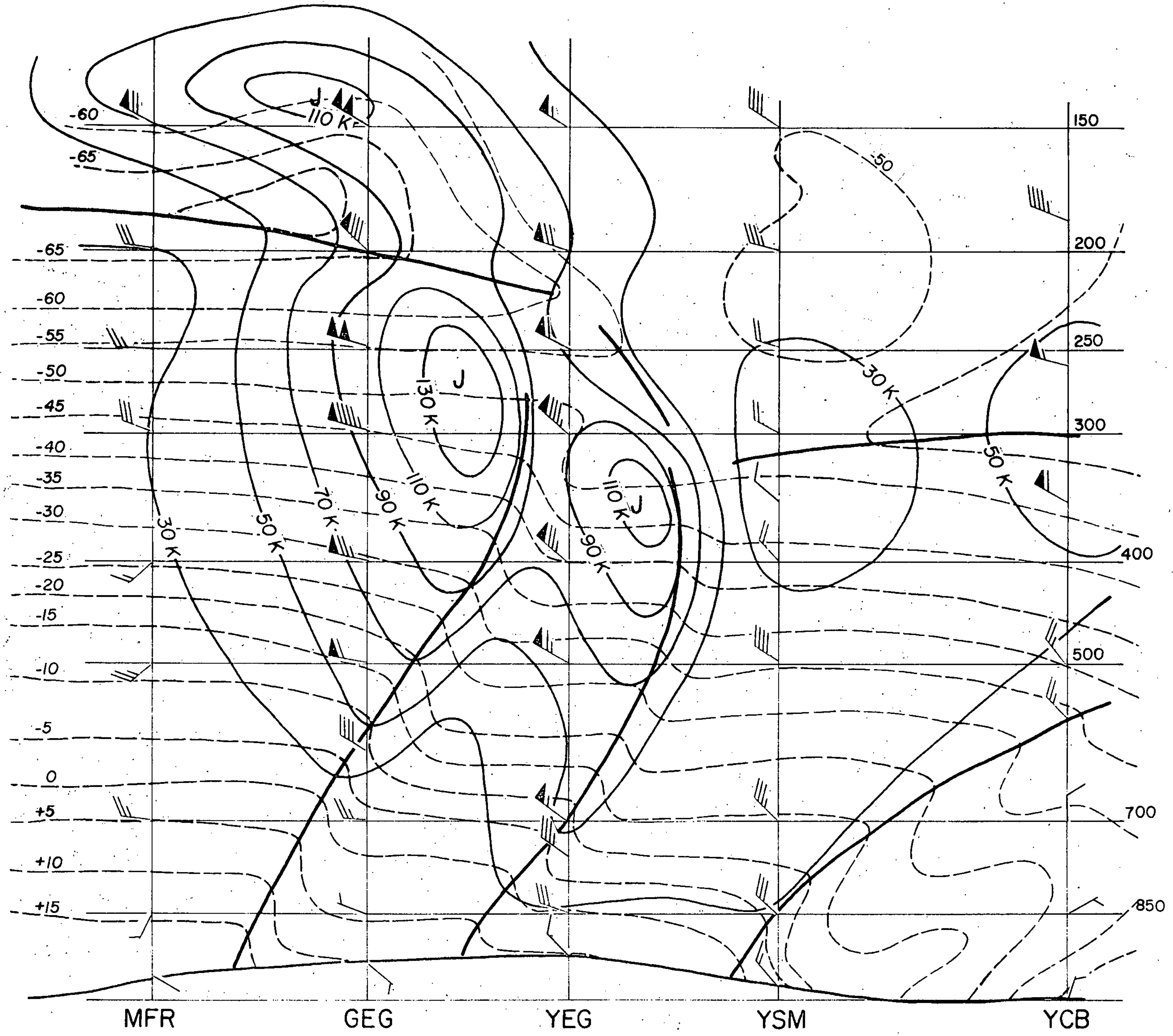

Figure 8 Vertical Cross Section - 16 Feb. 0000Z

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