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BAROTROPIC ROSSBY WAVE ENERGY DISPERSION AND LARGE SCALE ANALYSIS

Analyzing the large scale hemispheric flow pattern can be somewhat complex and, at times, even deceiving. In these cases, it is often difficult for the forecaster to determine the quality of the large scale changes exhibited by the model. Additionally, traditional climatological support (i.e. - large scale theory, conditional climatology, etc.) may not indicate how or if the long range model results should be modified.

In such cases, there may be indications that the model is responding to a forcing outside the domain depicted on the AFOS hemispheric charts. In particular, reference here is being made to the patterns associated with Barotropic Rossby Wave Energy Dispersion. The point of the following discussion is to show the patterns associated with Barotropic Rossby Wave Energy Dispersion as determined by theoretical model results, to relate these results to climatological observations and to show real-time examples of its use in hemispheric analysis.

Barotropic Rossby Wave Energy Dispersion is essentially the manner by which a succession of troughs and ridges form "downstream" from a source of vorticity be it diabatically or topographically induced. The downstream troughs and ridges develop with the group velocity (the propagation speed of the energy) along great circle arcs. If the vorticity source is quasi-stationary, the downstream pattern may remain relatively constant for an extended period of time. The idea of downstream development of troughs and ridges has been applied in operational forecasting to mid-latitude systems. A case in point was documented in Western Region TA No. 82-38. On the average, the group velocity is about 30 degrees longitude per day at 45 N.

An example of this is shown in Hoskins, et al (1977), where a barotropic atmosphere was perturbed with a constant circular vorticity source at 30 N. The results of that experiment are shown in Figure 1. At day 2-1/2, downstream anomalies become evident. Through day 5-1/2 to day 8, tile downstream anomalies develop both in the northern and southern latitudes. The heavy dashed lines indicate what have come to be known as Rossby-Haurwitz wave trains. Since 1977, Hoskins and Karoly (1981), Opsteegh and Van Den Dool (1980) and Simmons, et al (1983) have shown similar Rossby wave results in modelling studies.

Climatological observations with relationships to these Rossby wave train characteristics can, in general, be put into two areas of study up to this point - 1) those associated with the El Nino/Southern Oscillation (ENSO) and 2) those associated with 30 to 60 day oscillations.

Figure 2 is from the work of Horel and Wallace (1981). It shows the hypothesized global teleconnection pattern at upper tropospheric levels and represents the anomaly conditions during a Northern Hemisphere winter during which sea surface temperatures are well above normal in the central equatorial Pacific (ENSO). This schematic was derived using the results of a number of other papers. Note in particular the wave train of anomalies downstream from the shaded heat source (i.e. - enhanced cloudiness and rainfall).

On the 30 to 60 day time scale, Weickmann et al (1985) have shown a very similar wave train of anomalies downstream from a central equatorial Pacific heat source (Figure 3). The relationship between the enhanced convection and the wave train was shown to be highly significant (statistically) over much of the mid-latitudes over the Pacific and North America. The opposite pattern of circulation anomalies is evident in Figure 4, with positive height anomalies extending across much of the Pacific and North American mid-latitudes. This pattern is climatologically favored with enhanced convection over the eastern Indian Ocean. Note again the Rossby wave pattern on this figure.

The Climate Analysis Center has acknowledged the potential utility of these relationships with regard to long-range prediction in the following statement excerpted from its 1985 Annual Report:

> Intraseasonal (30-60 day) oscillations are now monitored in near real-time. During late 1984 and early 1985, variations in the longitudinal position of tropical convection, as determined from outgoing longwave radiation (OLR) anomaly patterns, have been related to variations in the circulation pattern over and in the vicinity of North America. It was noted that as anomalously strong convective activity shifts from the Indian Ocean eastward towards Indonesia, 100-700 mb thickness values over the eastern United States are positive and upper tropospheric ridges are found along the East Coast and in the Gulf of Alaska. Then, as anomalously strong convection shifts from Indonesia eastward towards the date line, the inverse pattern tends to occur. Since it takes 20-30 days for anomalously strong convection to shift from the Indian Ocean to the central Pacific, real-time monitoring of tropical convective activity may yield useful information for long-range prediction.

Though we in the National Weather Service currently do not have the data necessary to use the heat source/mid-latitude response relationships suggested by these studies, we can recognize the patterns which they create, specifically the wave train anomaly pattern. It is also important to realize the relationship between the wave train anomaly pattern and a strong wave number 1 anomaly.

A large amount of energy in wave number 1 essentially indicates an eccentricity of the circumpolar vortex toward a certain half-hemisphere and away from the opposite half-hemisphere. The polar stereographic height anomaly pattern of such an eccentricity is shown in Figure 5, taken from Opsteegh and Van Den Dool (1980). This pattern was a model response to heating in the hatched area. A nearly identical pattern is shown on a mercator projection from observational evidence (taken from Weickmann, et al - 1985) in Figure 6, though the longitudinal locations are different. This figure is also nearly identical to that in Figure 4, except derived in a different manner. The point is that we can often relate these wave train anomaly patterns to shifts in the polar vortex anomaly. The resultant effect on the mid-latitude circulation is a southward intensification of westerlies in quadrant 1 of Figure 5 and a northward push of westerlies in quadrant 3.

Figure 7 demonstrates this in a real-time case. This case was not difficult to analyze since there was good conditional climatology to support the pattern. It shows the eccentricity of the polar vortex anomaly (the Low in Canada) and the wave train of anomalies beginning near the date line and extending across North America. This figure is similar to Figures 5 and 6, with anomalous intensification of westerlies at different latitudes on opposite sides of the hemisphere.

This was a relatively simple case. Suppose, however, the pattern is changing and it is difficult to find "traditional" climatological support for the changes. Suppose also that the changes were being dictated by a forcing similar to that which created either Figure 3 or 4. One would expect the model trend to exhibit a tendency toward a stronger wave number 1 and a wave train type of anomaly pattern.

Such a change occurred between 7 Jan 1986 through 11 Jan 1986 . The spectral wave analysis chart (Figure 8, a locally generated product at SSD) shows this change with a significant increase in energy in wave number 1. However, traditional climatological support for the details of the change appeared to be weak. Note the discussion in the Western Region Prognostic Map Discussion (PMD) from 8 Jan 1986 below:

THRFR. THR IS LITTLE CLIMO SPRT FOR THESE SGGSTD LRG SCL CHNGS
IN SPITE OF THIS FACT.. I FEEL THAT THR ARE SM LRG SCL CHNGS
OCCRG DURG THE NXT 5 DAYS. THE LCLY PRODUCD 120 HR HT CHNG CHRT..
5XH MINUS 5NH.. SHWS A STG WV NMBR 1 SHFT OF ENRGY TWRD THE DTLN.
WHL THIS MAY BE OVERDONE DUE TO THE MDL TENDNCY TO LWR HTS TOO MCH
IN THE C PAC LOW LAT RDG RGN.. THR IS STILL A VRY STG SHFT ON THE
HEMIS SPACE SCL. THIS HEMIS SHFT IS REMINISCNT OF THOSE WHCH MAY
OCCR DUE MODULATNS IN TROPICAL FORCG..SEE MWR 6/85 PGS 942-961. AS
A RSLT.. I FL THE HEMIS CHNGS ARE REALISTIC.

The biggest clue to the forecaster that the large scale changes suggested by the model may be realistic was the similarity of the height change pattern to a Rossby wave energy dispersion type of response to an "outside" forcing. Figure 9 shows the verifying departure from normal pattern valid OOZ 14 Jan 1986, with Rossby wave train type anomalies across the central Pacific and North America. In this case, the application of Barotropic Rossby Wave Energy Propagation and its associations with mid-latitude circulation anomalies provided a higher confidence level in the trend of the model output. Since the model performed quite well, this proved to be a benefit to the forecaster.

This case also suggests that the global models (such as the MRF) may handle tropical forcings fairly well at times, whether it be the actual forcing or the initial local tropical height anomalies that attend the anomalous convection that the model responds to.

The next step toward improving our capabilities in forecasting on the time scale of 5 to 10 days may be to get real time information on the forcings which occur outside the domain of the traditional hemispheric charts.

References

[1] Hoskins, B.J. , A.J. Simmons and D.G. Andrews, 1977: Energy dispersion in a barotropic atmosphere. Q. Journ. Royal Met. Soc., 103, 553-567.

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[3] Hoskins, B.J. and D.J. Karoly, 1981: The steady linear response of a spherical atmosphere to thermal and orographic forcing. J. Atmos. Sci., 38, 1179-1196.

[4] Horel, J.D. and J.M. Wallace, 1981: Planetary-scale atmospheric phenomena associated with the southern oscillation. Mon. Wea. Rev., 109, 813-829.

[5] Western Region Technical Attachment 82-38: Examples of use of Hovmoller diagram.

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[7] Weickmann, K.M., G.R. Lussky and J.E. Kutzbach, 1985: Intraseasonal (30-60 day) fluctuations of outgoing longwave radiation and 250 mb streamfunction during northern winter. Mon. Wea. Rev., 113, 941-961.

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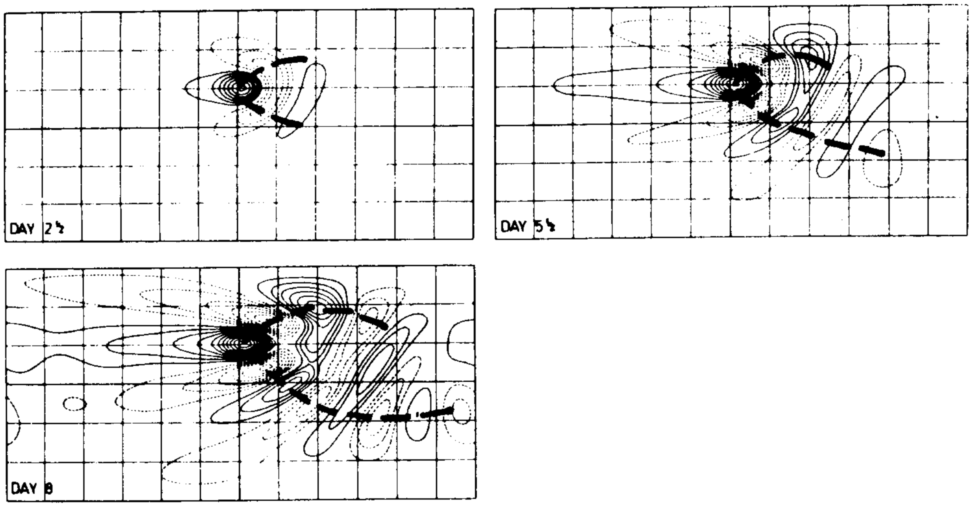

Figure 1. The vorticity perturbation generated with a circular forcing centered on 30 N. Heavy dashed lines indicate wave trains (after Hoskins, et al, 1977).

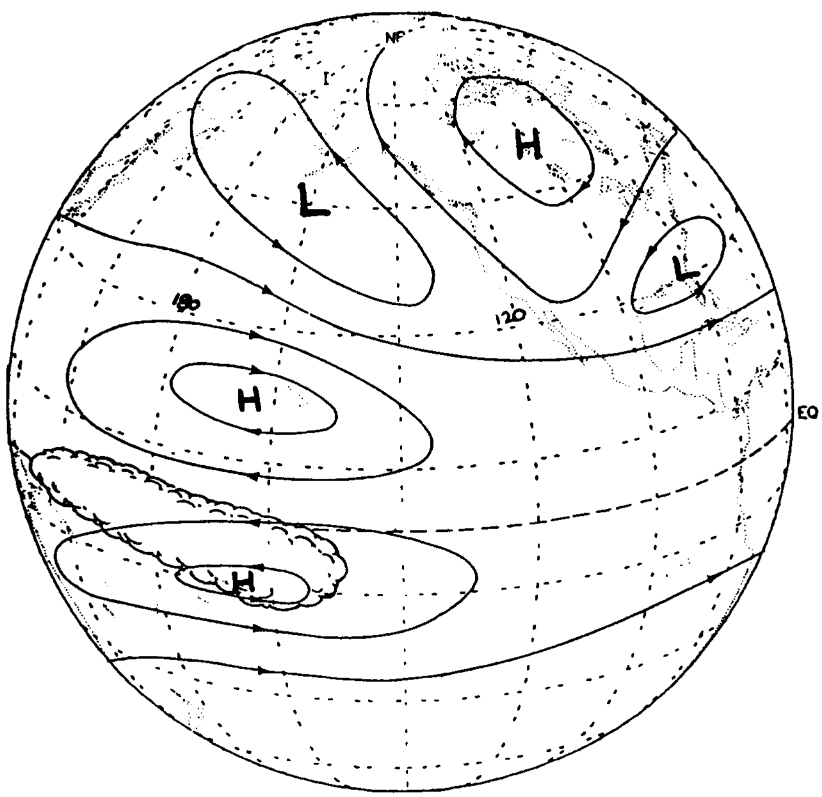

Figure 2. Schematic of upper tropospheric height anomalies following the peak of a typical ENSO episode. Cloud outline indicates region of enhanced precipitation (after Horel and Wallace, 1981).

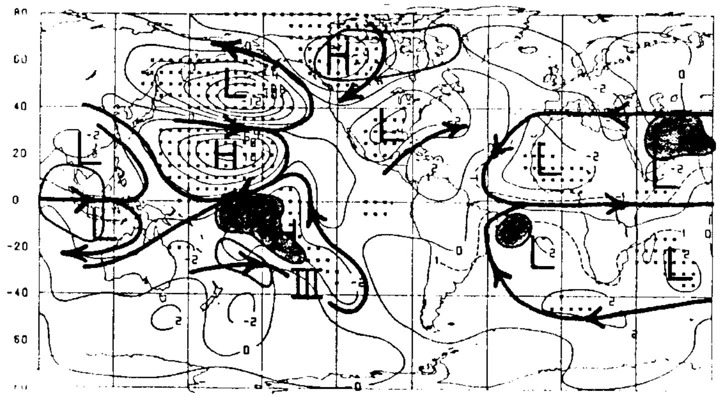

Figure 3.

Streamfunction composite and schematic circulation features for anomalous cloudiness in the central equatorial Pacific (shaded). Dots represent points passing a two-sided t-test at the 95% level (after Weickmann, et al, 1985).

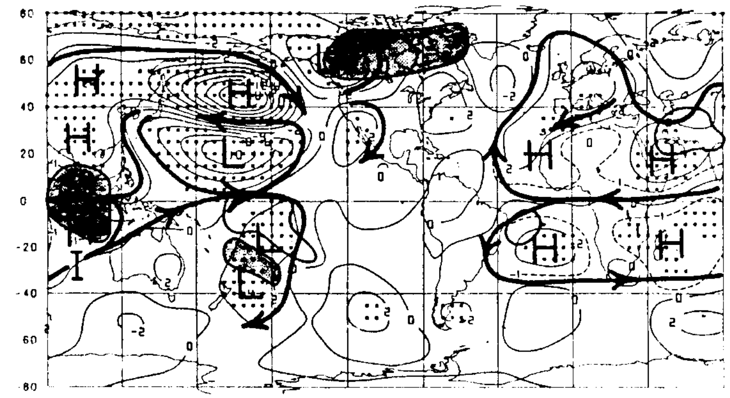

Figure 4.

As in Figure 3, except for anomalous cloudiness over the eastern equatorial Indian Ocean.

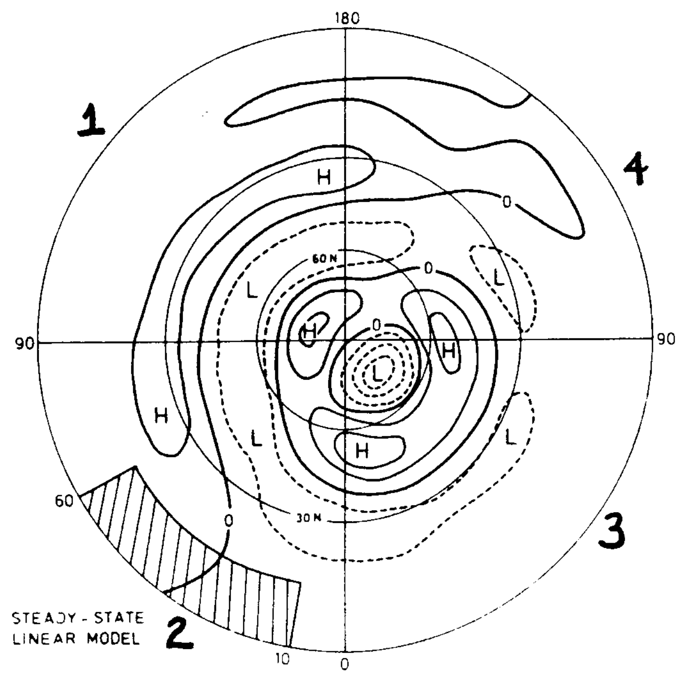

Figure 5.

Geopotential height anomaly response at 400 mb to a steady state heat source (hatched area). After Opsteegh and Van den Dool (1980).

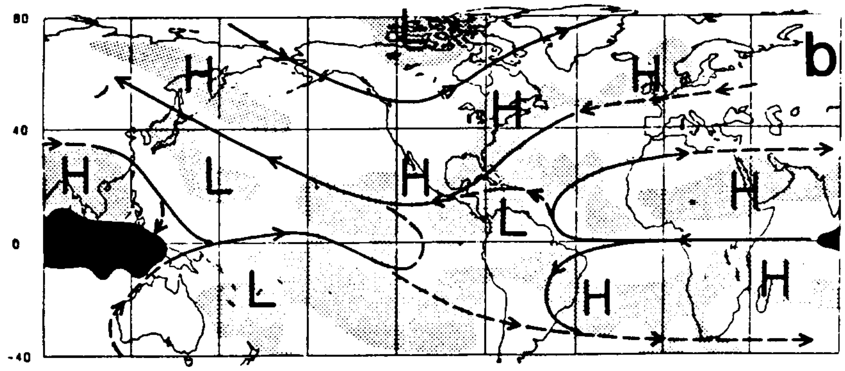

Figure 6. Schematic representation of cross-spectral coherence and phase information between outgoing longwave radiation and 250 mb streamfunction for cloudiness centered at EQ,100 E (after Weickmann, et al, 1985). Dark shading represents the anomalous cloudiness. Light shading represents the locations where the cross-spectral coherence is significant at 95%.

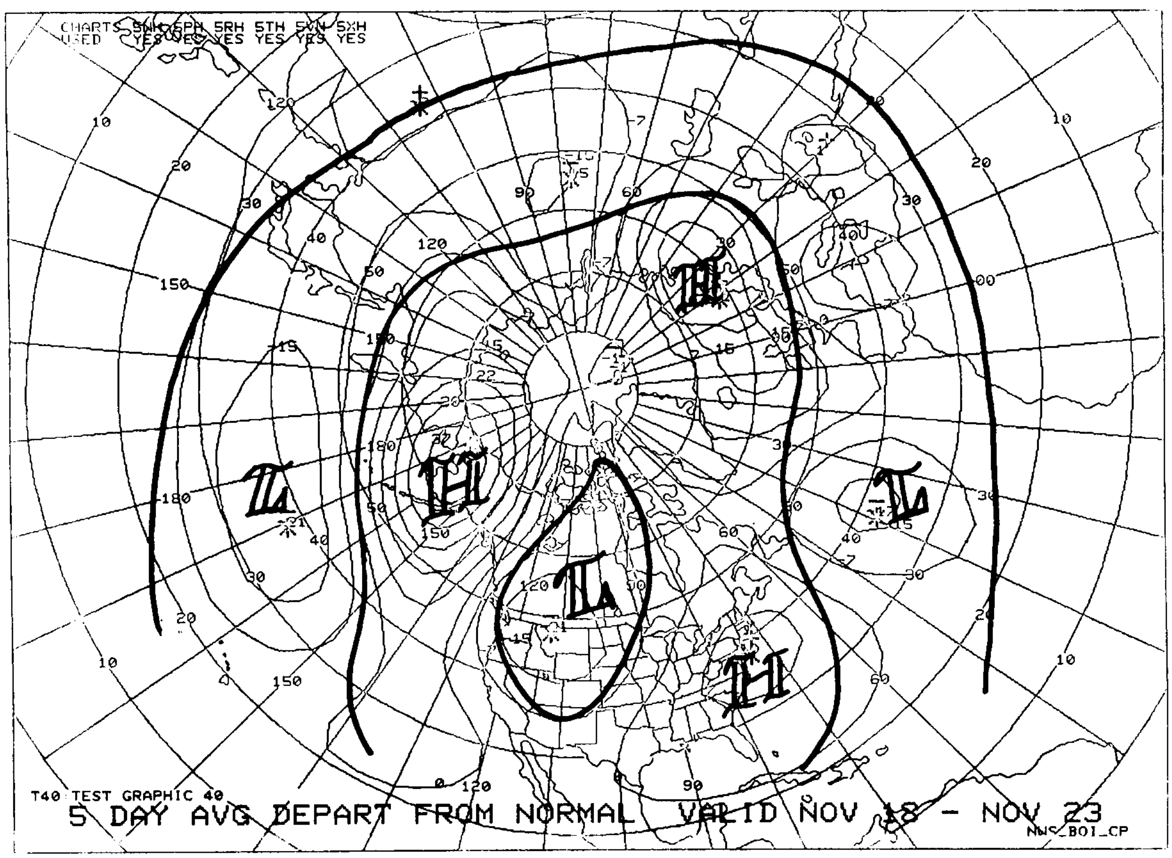

Figure 7. Five day mean prog departure from normal for MRF model run 00Z 18 Nov 1985. Heavy lines contain a smoothed analysis.

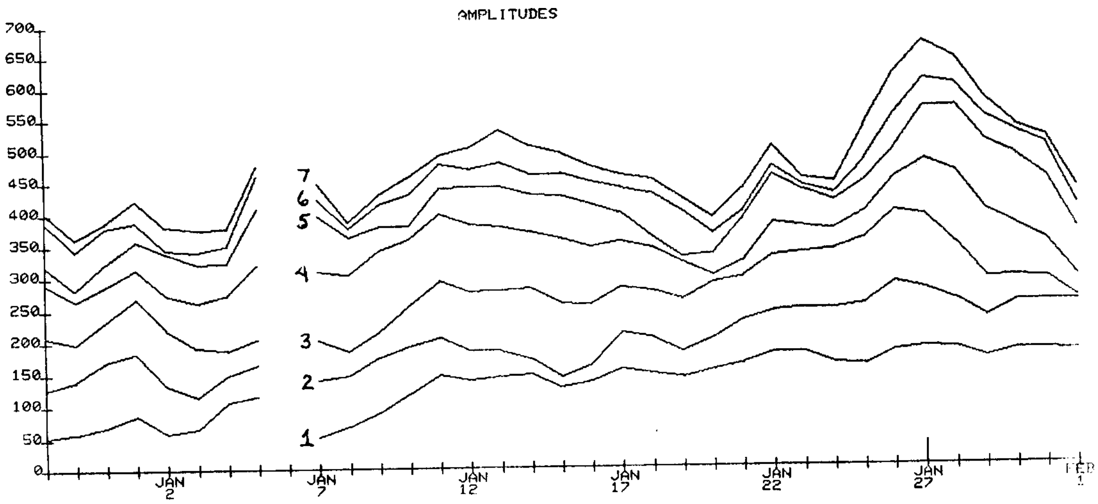

Figure 8. Cumulative spectral wave energy analysis.

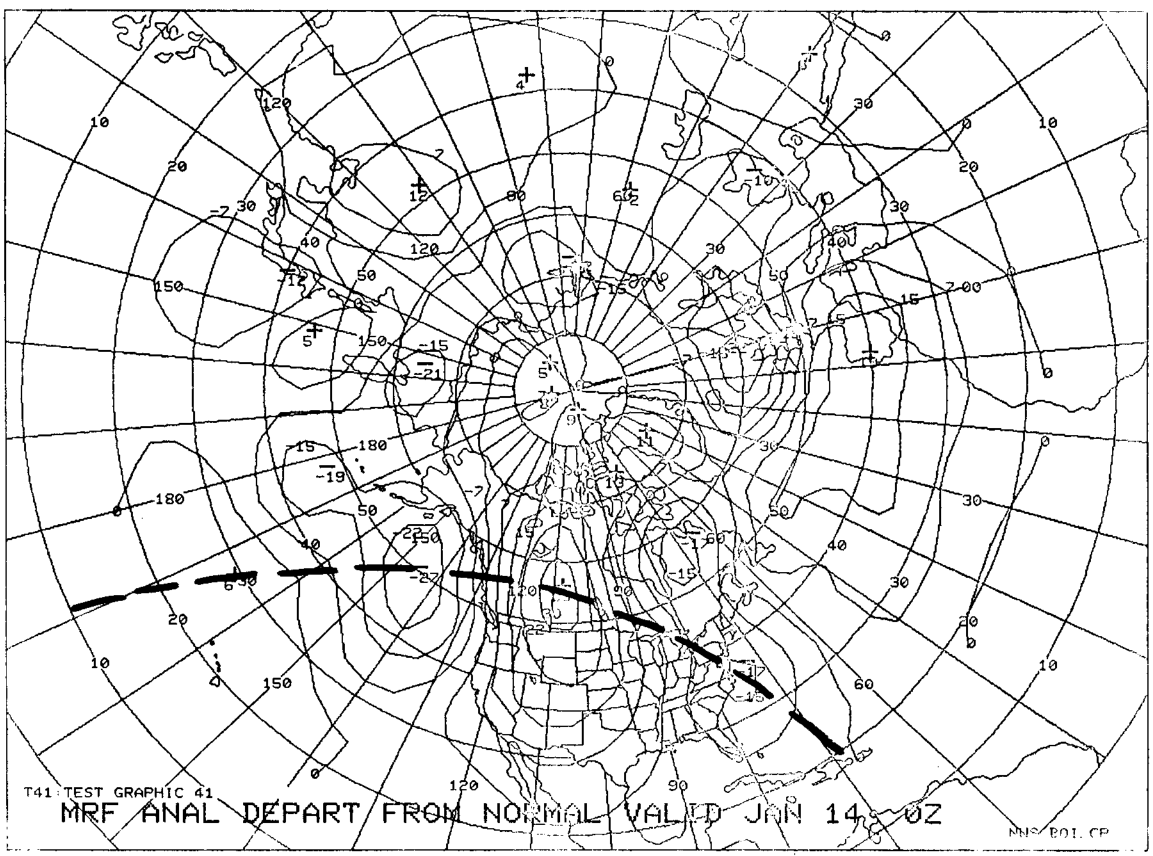

Figure 9. Departure from normal shart valid 00Z 14 Jan 1986. Heavy dashed line indicates the wave train of anomalies.