NOAA Technical Memorandum NWS NMC-58

OPERATIONAL-TYPE ANALYSES DERIVED WITHOUT RADIOSONDE DATA FROM NIMBUS 5 AND NOAA 2 TEMPERATURE SOUNDINGS

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Washington, D.C.
March 1976

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ABSTRACT. Test analyses were produced with the NMC global analysis/forecast system using only surface reports and satellite temperature soundings. Data were assimilated over a period of 4 days using a 6-hr analysis/forecast cycle. The final test analysis describes the major features shown on the corresponding NMC analysis but underestimates the amplitudes of disturbances and the intensity of thickness gradients. This appears to be due, at least in part, to systematic biases in the regression-derived satellite temperatures.

1. INTRODUCTION

This study describes a limited experiment in which a series of numerical analyses were produced using only surface reports and upper air temperature data obtained from satellite soundings. The latter data were regression-derived temperatures from radiance measurements made by the VTPR (Vertical Temperature Profile Radiometer) instrument on NOAA 2 (see McMillin et al. 1973), and the ITPR (Infrared Temperature Profile Radiometer), NEMS (Nimbus-E Microwave Spectrometer), and SCR (Selective Chopper Radiometer) instruments that are carried by Nimbus 5 (see Smith et al. 1974). These temperatures were converted to thicknesses between mandatory pressure levels and 1000 mb and were used with surface reference-level data, in a "test" analysis/forecast cycle which produced global analyses at 6-hr intervals. The analysis scheme is the global spectral model (Flattery 1971) which became operational at the National Meteorological Center (NMC) in September 1974. First-guess fields for each analysis were provided by the 8-layer global primitive-equation model described by Stackpole, Vanderman and Shuman, (1974).

The purpose of the experiment was to determine the extent to which major features of the flow could be defined by assimilation of only satellite-derived temperature and surface reports. Test analyses were compared with the corresponding operational analyses produced with the conventional NMC data base which includes VTPR but not Nimbus soundings. The operational VTPR soundings at that time were derived by a different technique which used 6- to 18-hr NMC forecasts as first guess profiles for the temperature retrievals.

Analyses were produced using observations made between 21 GMT 31 March and 03 GMT 5 April 1973. This period was selected primarily because of the availability of processed clear-column or sounding radiances derived from Nimbus 5. The experiment began from a near random first guess (an analysis valid on 23 June 1973). Satellite and surface reports were stratified into 6-hr time blocks, centered at 0, 6, 12 and 18 GMT and inserted into the test analysis/forecast cycle at intervals of 6 hrs from 00 GMT 1 April to 00 GMT 5 April.

Although comparisons between test and operational analyses were made at 12-hr intervals during the course of the experiment, comparisons on 1 and 2 April were contaminated by the fact that NMC analyses on these days were used to derive the regression equations for the Nimbus 5 soundings. For this reason, we will concentrate only on the final test analysis, valid at 00 GMT 5 April. This analysis is compared with the NMC analysis and with radiosonde observations. A numerical forecast produced from the test analysis is compared with the operational 48-hr forecast from the normal NMC analysis.

2. DATA

Temperature profiles were derived for both satellites by simple regression techniques. The dependent sample used for NOAA 2 VTPR soundings consisted of 64 co-located VTPR, radiosonde measurements collected from 29 March through 26 April. Soundings were considered to be co-located if the VTPR observation occurred within a distance of 2 deg latitude and ± 3 hrs of the location and time of a radiosonde report. Layer mean temperatures were determined from NMC analyses of the heights of mandatory pressure levels interpolated to the position and time of the satellite sounding. Mean temperatures, determined in this way, were regressed against the operationally derived clear-column radiances in the seven VTPR channels measuring in the 15 μm region of the spectrum (see McMillin et al. 1973).

The dependent sample for Nimbus 5 measurements was taken from NMC temperature analyses for the first 2 days of April. Analyses were interpolated in space and time to the locations of nadir soundings. Temperatures were regressed against various combinations of clear column radiances, so that soundings could be derived in situations where one or more instruments were not recording data or some of the channels were contaminated with clouds. Because the scanning mechanism operated only intermittently, most of the Nimbus soundings inserted during the first 2 days of the test were soundings which were included in the dependent data sample. Soundings for both satellites were derived only within the Northern Hemisphere.

An average of about 3000 surface reports and 155 satellite soundings were inserted at each analysis time. The coverage provided by satellite soundings during a typical 24-hr period is shown in figure 1. Notice that VTPR observations are available only over the oceans (McMillin et al 1973). Coverage over the oceans is generally quite good. Over the continents, however, convergence towards the NMC analysis must be accomplished through the propagation of forecast features from the oceans and through a limited number of Nimbus reports.

Our experience and experiments by Smagorinsky, Miyakoda, and Strickler (1970) and by Gauntlett and Seaman (1974) indicate that the input of surface data will have little direct impact on conditions aloft. Surface data, in this experiment serve mainly to provide the reference level required to convert from satellite-derived temperature to heights of constant pressure levels.

3. ASSIMILATION PROCEDURE

NMC analyses at the time of the test were produced on a rectangular grid (see Shuman and Hovermale 1968) by a "successive correction" technique (Bergthorssen and Döös 1955, Cressman 1959). The "test" or satellite-only analyses were produced with a different analysis scheme. A partial description of this scheme is given by Flattery (1971). Here, we will only try to summarize some of its major features.

The analysis scheme is spectral and 3 dimensional. Vertical variations are expressed by empirical orthogonal functions. Representations at constant pressure levels are in terms of trigonometric functions (west-east direction) and Hough functions (north-south directions). A total of 7 vertical functions and 24 Hough functions are used with sine and cosine terms through wave number 24 to specify heights and winds at 12 pressure levels.

In the analysis procedure, coefficients determined from a first guess field (in our case, a 6-hr forecast for all but the initial time) are modified successively in nine scans which gradually tighten the fit of the analysis to the data. At each scan new coefficients are determined by a least-squares technique which minimizes the difference between the analysis and the observations. Heights and winds are analyzed simultaneously at all levels. The winds which result are essentially nondivergent and no special procedures are required to initialize the forecast model.

Satellite soundings are provided to the analysis scheme as thicknesses between mandatory pressure levels and 1000 mb. Thicknesses are converted to heights at each scan by adding the 1000 mb height, interpolated to the location of the sounding, from the previous scan. Thus, the satellite temperatures are not used directly. The heights, determined from the vertically integrated temperatures, change with each pass through the data.

Six-hour forecasts were made with the NMC global primitive-equation model. Physics of the model are essentially the same as in the operational 6-layer model (Shuman and Hovermale 1968). The vertical coordinate is a modified σ (Phillips 1957) with coordinate surfaces at the surface of the earth and at the tropopause. There are six layers in the troposphere and two in the stratosphere. A ninth layer, above 50 mb, is carried strictly for computational purposes. Model equations are solved on a 2.5 deg latitude/longitude grid.

4. RESULTS

A. Comparisons Between Test and NMC Analyses

Test and NMC analyses of geopotential heights at 1000 and 500 mb, valid at 00 GMT 5 April, are shown in figures 2 and 3. At 1000 mb, test and NMC analyses are essentially the same. Major features of both analyses include the family of cyclones to the northeast of Japan, the Low in the eastern Pacific near 30N, 150W, the two cyclones over North America, and the deep Low in the North Atlantic between Iceland and Scandinavia. The analysis at this level is determined primarily by surface reports. Those differences which do exist between the two maps can be explained by the use of 06 and 18 GMT surface data in the test analysis cycle and by the fact that the two analyses were produced by different analysis schemes.

At 500 mb, the analysis produced from satellite soundings is similar in its major features to the operational NMC analysis. In general the positions of the features are the same on the two analyses but the systems are weaker on the test case. Over the Pacific, both analyses show a long-wave trough near 130 to 135E. There are short-wave troughs near 150E and 170W that are associated with the two surface Lows in the western Pacific (fig. 2). The surface Low to the northeast of Hawaii (fig. 2) is reflected aloft as a closed 500-mb Low on the NMC map and as a trough on the test analysis. Over North America, both test and NMC analyses indicate a vorticity maximum over the Great Lakes with a trough extending southwestward into Arizona and southern California. Height gradients in both analyses imply strong southwesterly winds in the southeastern United States and west-northwesterly flow in the western part of Canada. However, there are major differences between the two analyses in the flow over the western United States and in the vicinity of the 1000-mb Lows in Canada and over the eastern United States. Both analyses show a short-wave trough embedded in the ridge over the eastern Atlantic and northerly flow over Europe. A closed 500-mb Low over the central Mediterranean appears on the test analysis as a 500-mb trough. There are some differences over Asia; however, the flow in this region appears to be relatively undisturbed and the differences cannot be described in terms of specific features of the flow. In summary, except for the area over North America where the coverage provided by satellite soundings was relatively poor (fig. 1), the major qualitative differences between test and NMC analyses of 500-mb heights are in the intensity of major systems and in the strength of the meridional height gradients. In the region from 30 to 40N, Highs and Lows on the NMC map are represented by ridges and troughs in the test analysis. The test analysis shows weaker height gradients in almost all areas where the gradient is strong. This difference is especially pronounced in the North Atlantic, in western Canada, and to the south of the cut-off Lows in the Mediterranean and near Hawaii.

Figure 4 shows the differences (test - NMC) between test and NMC analyses of 500-mb heights. Differences are distributed quite uniformly across the map although in a root-mean-square sense; the differences are actually larger over the oceans than they are over North America or Asia. Notice that positive difference centers tend to be located within troughs or Low centers in figure 3b; negative difference centers are associated with 500-mb ridges. Differences in geostrophic winds implied by the gradient of the height difference contours indicate, in general, lower geostrophic wind speeds in the test than in the NMC analysis.

Similar results are evident at other levels. For example, test and NMC analyses of 300-mb wind speeds are shown in figure 5. Notice that major jet streams appear in both analyses at about the same locations; however, in the test analysis wind speeds are relatively weak and the individual jet maxima are less clearly defined.

Figures 6 through 9 summarize results of harmonic analyses of test and NMC 500-mb height fields from 20 to 70 deg N. The analysis in each case consists of Fourier decomposition of heights along longitude circles at intervals of 5 deg latitude.

Total variance of the heights along each latitude circle is graphed in figure 6. Maximum variance occurs at 50N in both test and NMC analyses. At all latitudes except 20N, the variance is lower in the test than in the NMC analysis.

Zonal mean heights (wave number 0) are graphed in figure 7. Notice that the test heights are lower than the NMC heights from 20N to about 55N; from 55N to about 65N the heights are the same. Prior to the first insertion of satellite data, guess heights in the test analysis were higher at all latitudes than in the corresponding NMC analysis. The mean height difference pattern shown in figure 7 evolved during the course of the experiment and almost certainly reflects biases that were present in the satellite soundings. The net effect of the change in the biases between 50 and 60N is to reduce the meridional gradient of the 500-mb zonally averaged height, giving weaker geostrophic westerly winds at this latitude in the test than in the NMC analysis (fig. 8).

Figure 9 shows the amplitudes of each wave number from 1 through 21 in test and NMC analyses at 50N and 30N. The variance explained by each harmonic, except the last, is simply the square of its amplitude (Panofsky and Brier 1958). At 50N, most of the variance is in the Rossby waves (wave numbers 1 through 5, see Miyakoda et al. 1972). Most of the "underestimate" of the total variance in the test analysis (fig. 6) is due to the relatively low variance in wave numbers 1 and 2. At 30N, maximum variance in the NMC analysis is associated with wave number 6, which reflects roughly the separation between the cut-off lows or cold troughs appearing at this latitude between about 150W and 15E (fig. 3). The test analysis shows maximum amplitude at wave number 4. There is a relative maximum at wave number 6; however, its amplitude is "underestimated" by about a factor of 2. It appears from comparison of the very different wave spectra at both latitudes that the "underestimate" of the "true" variance in the test analysis is not restricted to certain wave numbers. It may occur throughout almost the entire spectrum; however, the "underestimate" appears to be greatest in those wave numbers which explain most of the variance. From examination of the height differences in figure 4 and the spectral amplitudes in figure 9, it appears that the satellite soundings produce a conservative analysis which underestimates the heights in ridges and overestimates the heights in the troughs. The "errors" in the satellite data appear to be bound to the scale of the weather disturbances.

B. Comparisons Between Test Analyses and Radiosonde Observations

Although the maps presented in the previous section give a qualitative view of the accuracy of the test analysis, it may be of interest to show some quantitative comparisons between the test analysis and radiosonde observations. Table 1 gives comparisons between the test analysis for 00 GMT 5 April and radiosonde observations of 500-mb heights and temperatures and 300-mb wind speeds at 53 radiosonde stations scattered over North America.

Table 1.--Mean difference (analysis - observation), standard deviation of difference (σ) and root-mean-square (rms) difference between test analysis and radiosonde observations.

	500-mb height (m)	500-mb temperature (deg C)	300-mb wind speed (m/s)
Mean	-15.6	-1.3	- 5.7
σ	54.1	3.3	12.6
rms	56.3	3.5	13.9

Notice that the analyzed 500-mb temperatures are too cold, 500-mb heights are too low and 300-mb wind speeds are too weak. Root-mean-square differences shown are about equivalent to typical errors in spring of NMC 48-hr forecasts over North America. Differences in table 1, however, cannot be related directly to satellite observational errors. They depend very strongly upon the errors introduced by 4-dimensional interpolation, through the analysis and forecast models, of the very limited number of Nimbus 5 observations available in this region (fig. 10).

C. Comparisons Between Forecasts Made From Test and NMC Analyses

Thus far we have proved only that the two analyses are different. We believe it is self evident that the NMC analysis is superior - based as it was on a wide variety of upper air reports including radiosonde observations, aircraft reports, operational VTPR soundings, and "bogus" reports created from subjective interpretation of satellite photos. This belief can be tested, in part, through a forecast, since one measure of an analysis is the quality of a forecast which begins from that analysis. For this reason, we made a 48-hr forecast from the test analysis at 00 GMT 5 April, and compared it with the operational 48-hr forecast from the corresponding NMC analysis. Both forecasts were made with the 6-layer primitive-equation model (Shuman and Hovermale 1968) and verified against the NMC final analysis for 00 GMT 7 April.

The forecasts and verifying analysis at 500 mb are shown in figure 11. It is obvious that the NMC product initialized with conventional data is superior. As in the initial analyses, the superiority is principally established in the intensity of disturbances. Notice especially the trough-ridge-trough pattern across the northern Atlantic and the short wave feature at the tip of the Aleutian chain. These features are reasonably well positioned in the test forecast, but the intensities are grossly underestimated. The test forecast is seriously in error over the southern United States as a result of the failure of the test analysis to capture the magnitude of the cut-off Low in the Southwest (fig. 3).

Statistical verification scores comparing the test and operational forecasts were made in 5 regions: North America, the Atlantic, Europe, Asia, and the Pacific. The grid point root-mean-square difference (weighted to account for the map scale factor on the polar stereographic grid) and the correlation between forecasts and verifying height fields are summarized in table 2 for 850-, 500-, and 300-mb levels. By either measure, the NMC forecasts at all levels and in all regions are much superior to those produced from the satellite-derived analysis. Errors in the test forecasts, relative to the NMC forecasts, are lowest in general over the Pacific and in Europe. Largest errors occur in the Atlantic where the forecasts are strongly affected by the relatively poor definition of the initial state in the "data sparse" region over the eastern United States.

5. SUMMARY AND CONCLUSION

From satellite observations and surface reports we were able to produce, from a near random first guess, a "reasonable" definition of the major features of the flow. Troughs, ridges, and large-scale baroclinic zones were placed in approximately the "correct" positions; however, the amplitudes of disturbances and the intensity of the height or thickness gradients were seriously underestimated in the satellite-derived analysis.

The errors in amplitude and in the height gradients appear to derive from systematic biases in the satellite soundings. The biases are "tuned" to the synoptic situation in that the derived temperatures are too cold in the ridges and too warm in the troughs. The net result is a conservative analysis which underestimates the intensity of disturbances and the strength of the winds. We are not certain as yet of the extent to which these biases are characteristic of the particular data sample used in the test. They may simply arise from the regression method with which the soundings were derived, or they may reflect general characteristics of existing retrieval methods which produce average temperatures over fairly large horizontal areas.

ACKNOWLEDGMENTS

We would like to thank Mr. Paul Lemar who helped run the test analysis cycle and Mr. Hugh O'Neil who provided and ran programs used in the analysis of results. This test was conducted under NASA Contract S-70252-AG.

Table 2.-- Verification scores for 48-hr forecasts from test and NMC analyses. Statistics shown are the root-mean-square height errors (RMS) and correlation coefficient (C.C.) between forecast and verifying height field at 850 , 500 , and 300 mb. Verification regions are defined in figure 10.

PRESSURE LEVEL	STAT-ISTIC	N. AMER.		ATLANTIC		EUROPE		ASIA		PACIFIC	
		TEST	NMC	TEST	NMC	TEST	NMC	TEST	NMC	TEST	NMC
850	RMS	65.9	37.7	94.0	44.5	71.7	37.9	58.6	40.8	54.0	47.4
	C.C.	.72	.90	.58	.93	.69	.92	.69	.82	.90	.93
500	RMS	90.9	51.1	138.0	62.9	97.4	60.8	110.5	38.0	92.3	52.2
	C.C.	.90	.97	.73	.94	.86	.94	.93	.98	.95	.98
300	RMS	141.0	66.9	200.4	101.3	127.5	83.0	142.9	54.9	117.6	71.9
	C.C.	.91	.98	.75	.93	.88	.95	.96	.99	.97	.99

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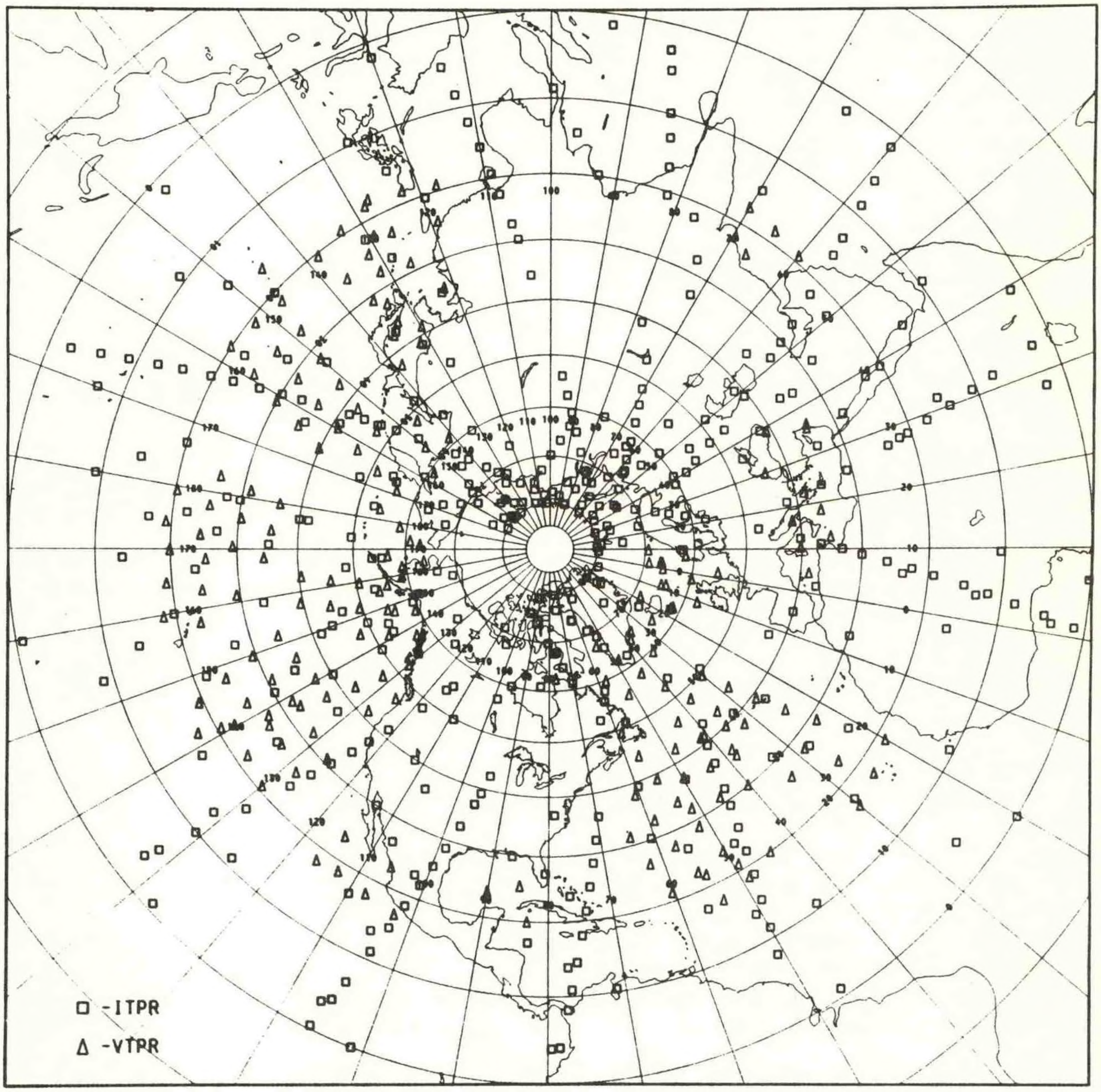
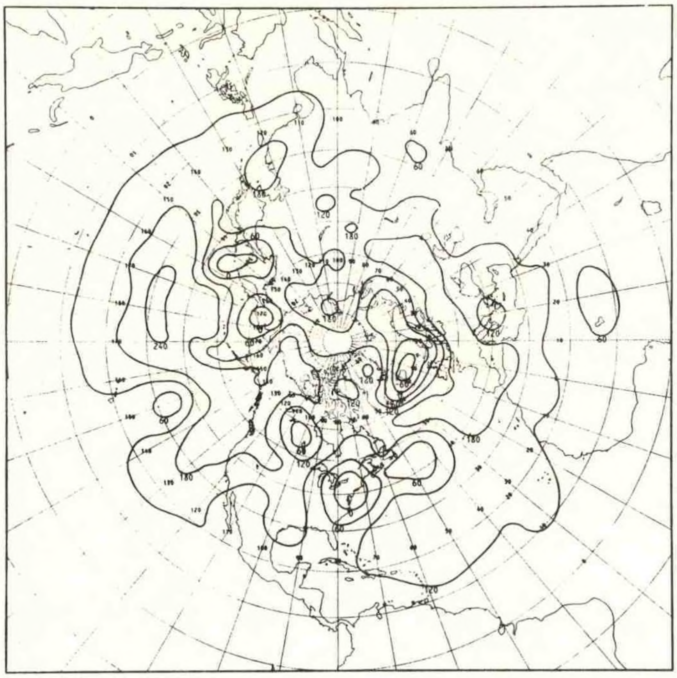
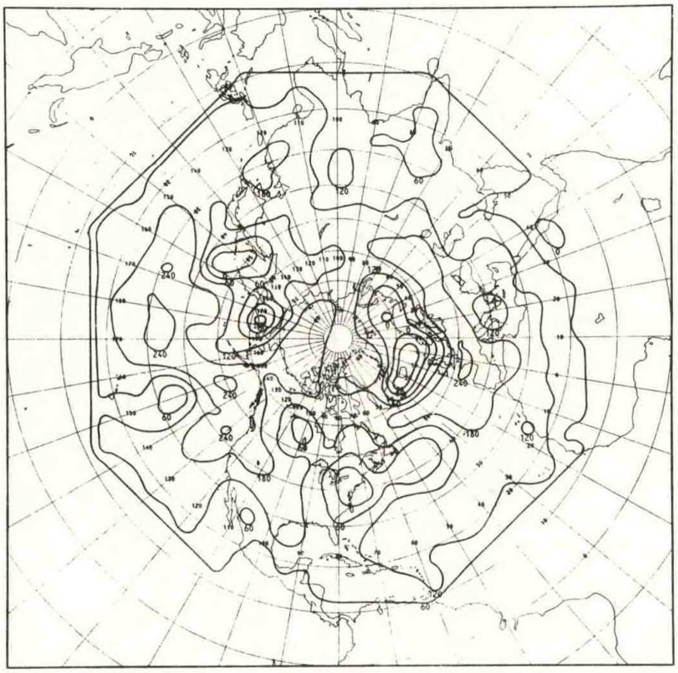


Figure 1.-- Locations of Nimbus 5 and VTPR soundings on 3 April 1973. Nimbus 5 indicated by squares; VTPR by triangles.

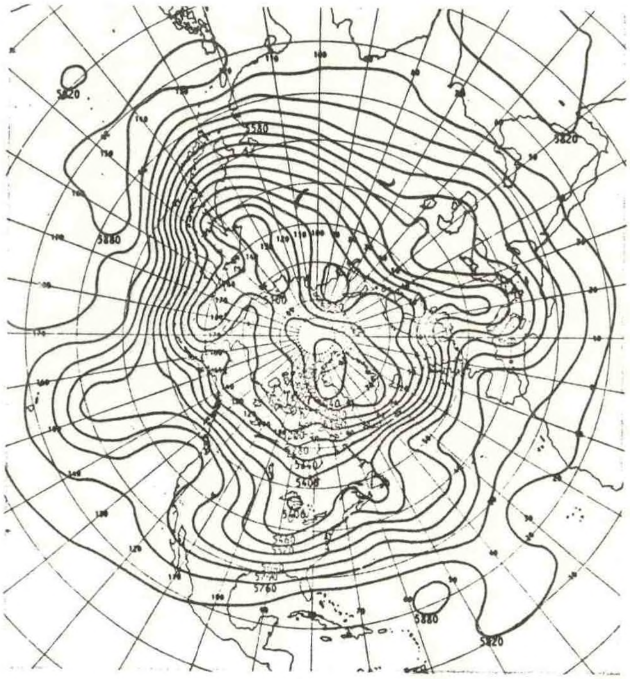


a. Test



b. NMC

Figure 2.--Test and NMC analyses of 1000-mb heights at 00 GMT 5 April. Contour interval is 60 m.



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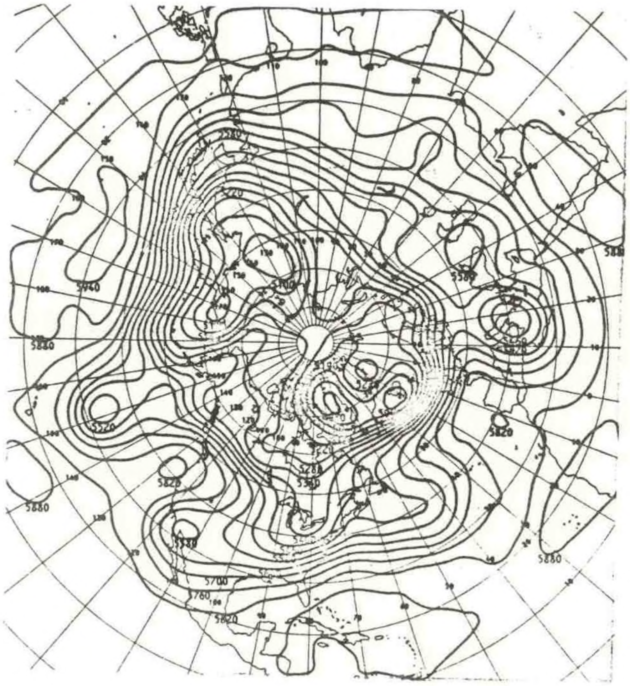


b. NMC

Figure 3.--Test and NMC analyses of 500-mb heights at 00 GMT 5 April. Contour interval is 60 m.

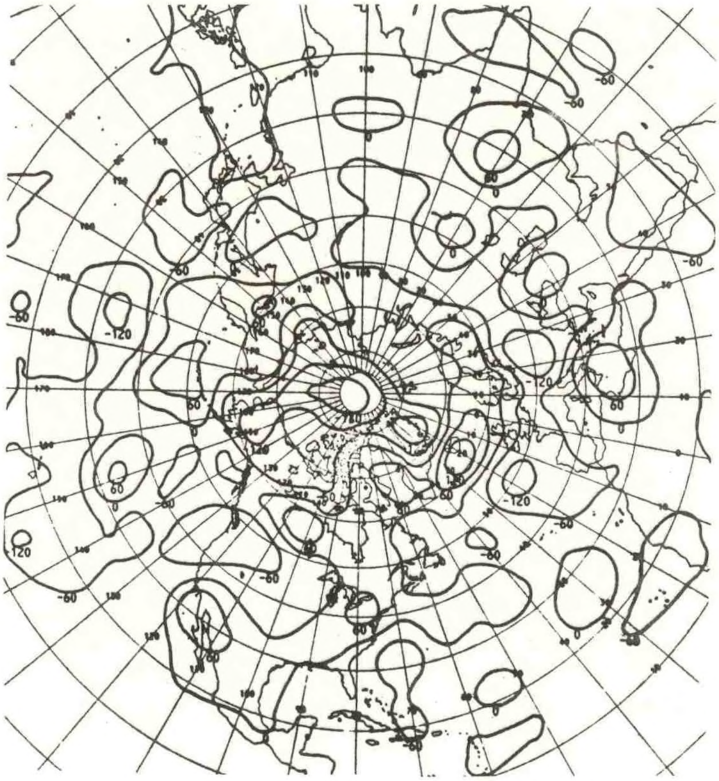
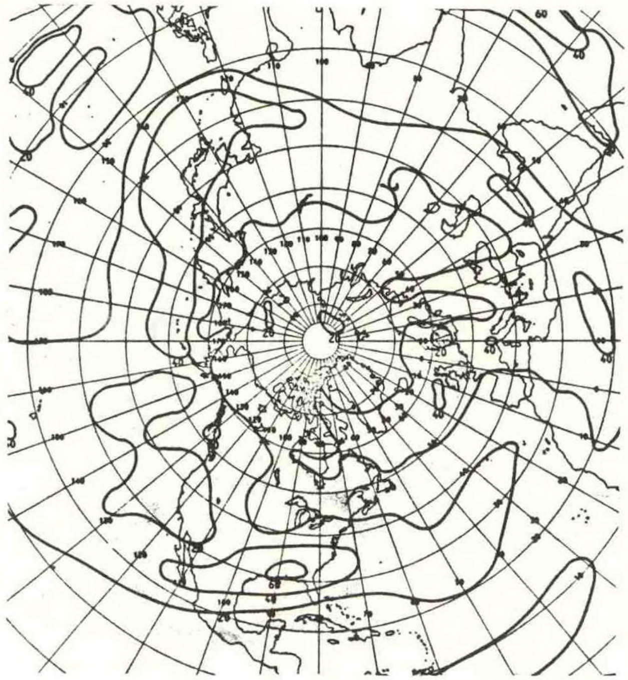
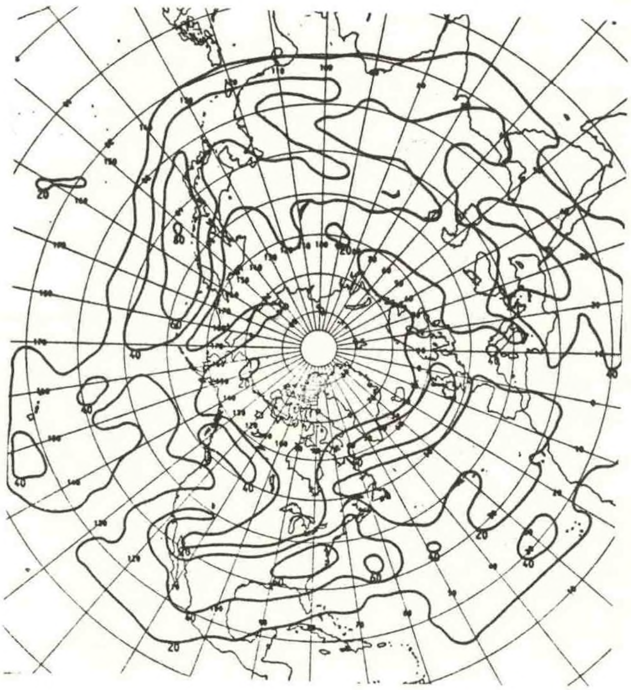


Figure 4.-- Difference (test - NMC) between test and NMC analyses of 500-mb heights. Large negative differences over the pole are due mainly to problems with the analyses scheme and not to the data.

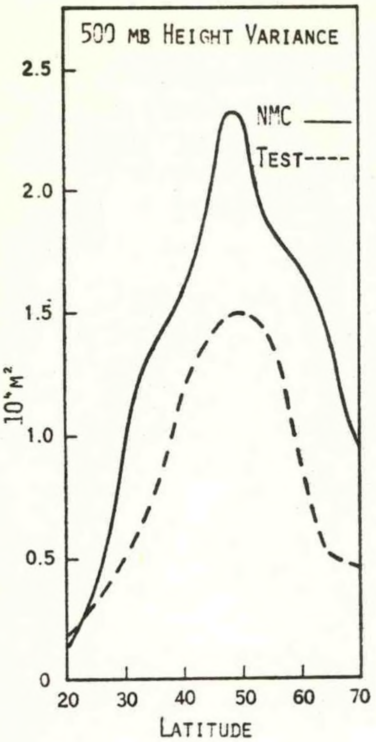


a. Test



b. NMC

Figure 5.--Test and NMC analyses of 300-mb wind speeds. Isotachs are drawn at intervals of 20 m/s.



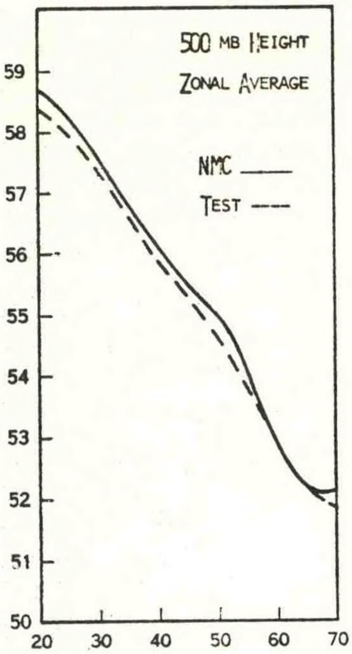


Figure 7.--Zonal mean heights (wave number 0) between 20N and 70N. Test and NMC analyses, 00 GMT 5 April.

Figure 6.--Longitudinal variance of 500-mb heights between 20N and 70N determined from test and NMC analyses, 00 GMT 5 April.

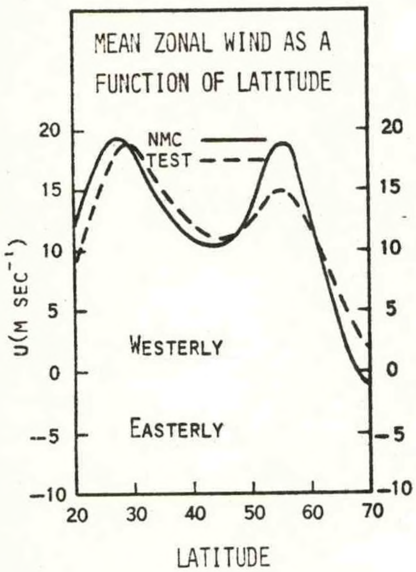


Figure 8.--Mean zonal wind as a function of latitude, determined from height profiles in figure 7.

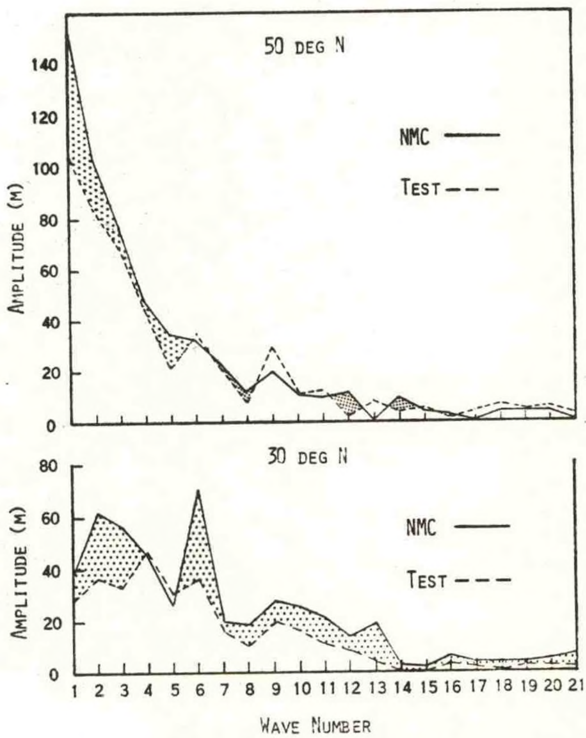
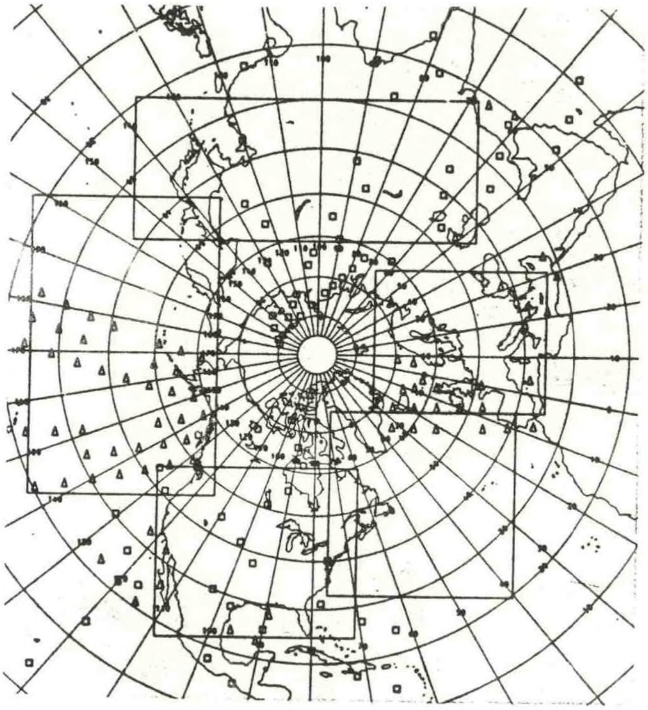
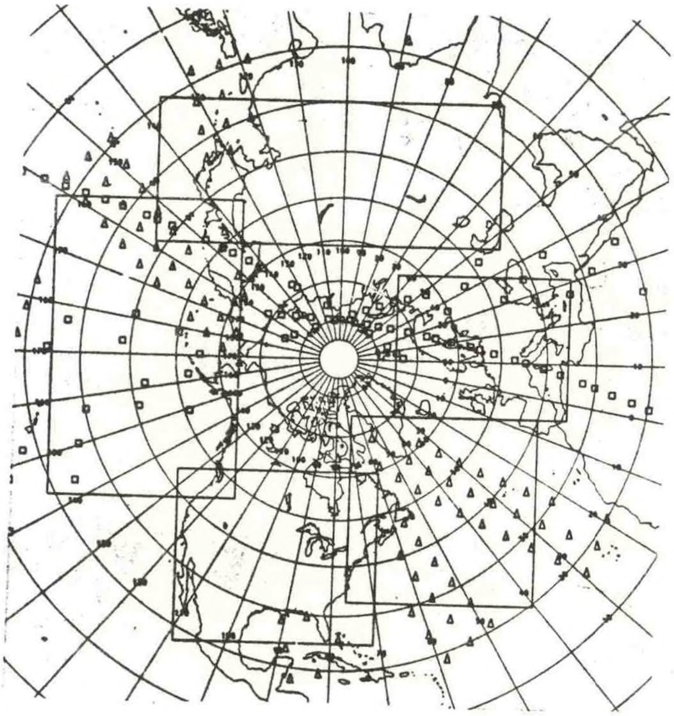


Figure 9.--Amplitude (m) at 30N and 50N of wave numbers 1 through 21 in test and NMC analyses of 500-mb heights, 00 GMT 5 April.

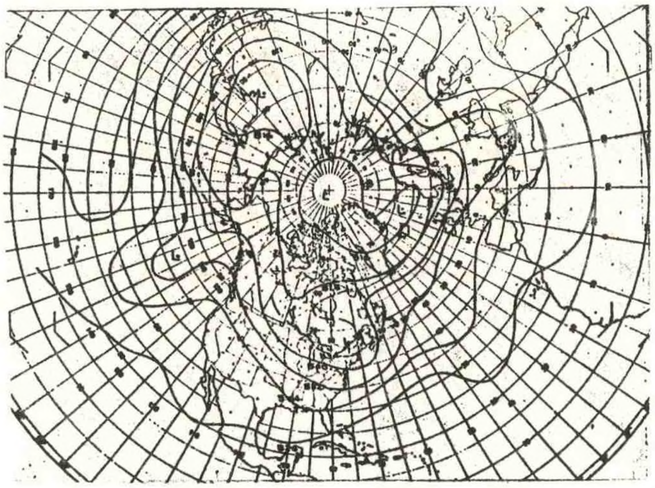


a. 18 GMT 4 April

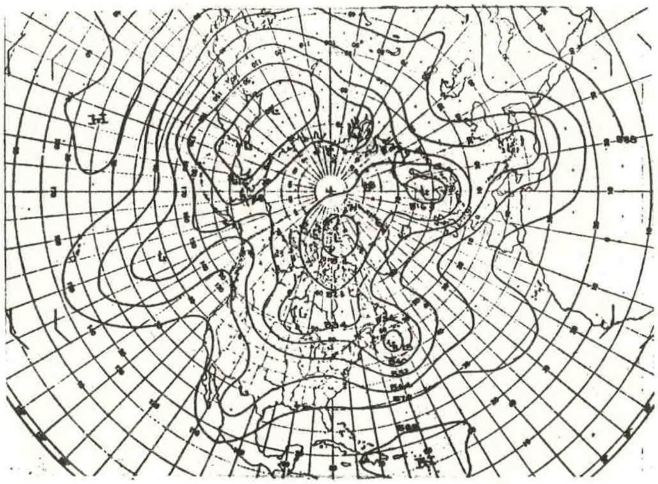


b. 00 GMT 5 April

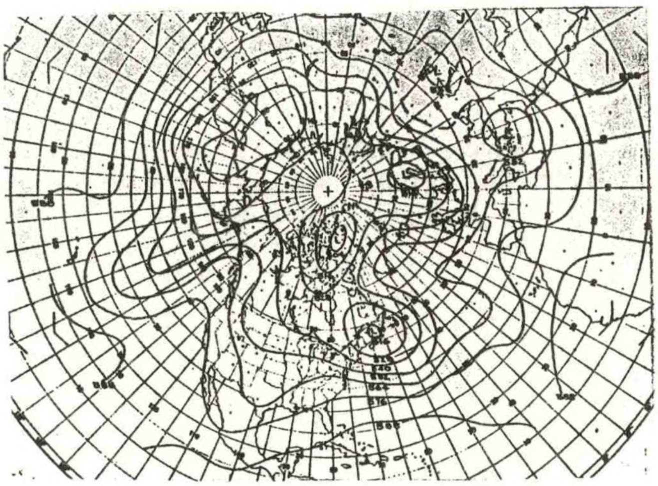
Figure 10.--Locations of Nimbus 5 and VTPR soundings used in the test analyses at 18 GMT 4 April, and 00 GMT 5 April. Coverage over North America is provided only by Nimbus soundings which entered the test analysis/forecast cycle at asynoptic times. Rectangular regions are areas used in forecast verifications.



a. Test forecast



b. NMC forecast



c. Verifying analysis

Figure 11.--Forty-eight hour test and NMC forecasts of 500-mb height and verifying analyses valid 00 GMT 7 April. Contour interval is 120 m.

(Continued from inside front cover)

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