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Research and Development at the National Meteorological Center

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RESEARCH AND DEVELOPMENT AT THE NATIONAL METEOROLOGICAL CENTER

ABSTRACT

A description of major areas of research of the Development Division of the National Meteorological Center (NMC) is presented. The numerical modeling program is pointed in two main directions. One is in the area of regional modeling for short-range prediction, which includes efforts in hurricane modeling, planetary boundary layer modeling, and limited-area fine-mesh modeling in general. The other is in the area of global or hemispheric modeling for extended-range predictions which, in the case for NMC, includes both grid-point and spectral modeling. Associated with both of these are the problems of parameterization of sub-grid scale processes and the problems of initial data, which encompass the area of objective analysis, initialization, and more recently, four-dimensional data assimilation.

The plan for operational model implementation on the newly-acquired dual IBM 360/195 computer system is presented. The characteristics of the analysis-forecast systems to be used routinely are discussed.

I. Introduction

The National Meteorological Center (NMC) can be viewed as the analysis-forecast arm of the World Meteorological Center (WMC) in Washington, D.C. The National Environmental Satellite Service and the Environmental Data Service provide the other types of support required in the WMC. The Development Division is the primary research body of the NMC. It is the work of this Division which I intend to first address my remarks. It is, of course, not possible to describe each research project of the Division. I have purposely confined my remarks to two major efforts which I think will be of interest to you. In addition, I will present the current plan of the operational model configuration for the newly-acquired dual IBM 360/195 system.

II. The Research Organization

The Development Division of the NMC as an organizational component dates back to 1954 to the days of the Joint Numerical Weather Prediction Unit. Since those early days, the unit has gone through many different forms. While it is still changing today, it now consists of approximately 50 staff members, of whom 40 are meteorologists and mathematicians.

The Division is substructured into four Branches:

Upper Air Branch. The primary function of this Branch, headed by Frederick Finger, is to conduct investigations of the physical structure and circulation of the upper atmosphere, e.g., investigations of the midwinter sudden warming phenomenon in the stratosphere. In addition to determining instrumental corrections such as due to radiation effects, satellite, rawinsonde, and rocketsonde compatibility studies are being made.

Data Assimilation Branch. This group, under the direction of William Bonner, is responsible for the development, test and evaluation of data assimilation systems appropriate to operational forecasting. It is now committed to the Level II and Level III data archiving role for the Data Systems Test of the Global Atmospheric Research Program. It is also directing its attention to determining the impact of some of the new satellite data systems on operational forecasting. Section III below briefly describes the first such study for the Vertical Temperature Profile Radiometer (VTPR) data from NOAA-2.

Global Modeling Branch. Under the direction of John Stackpole, resources of this Branch are directed towards the research and development in numerical prediction of improved analysis and forecasting techniques requiring the use of global modeling methods. Of particular interest is the 8-layer global model and the spectral analysis system scheduled to be a major part of the operational numerical weather prediction of the IBM 360/195 system.

Regional Modeling Branch. Headed by Joseph Gerrity, this group is presently conducting research in the area of limited-area modeling directed toward the improvement of operational analysis and prediction of small-scale atmospheric phenomena. The limited-area fine-mesh modeling effort directed towards the hurricane problem is described in Section IV.

III. The First VTPR Impact Study

Since December 1972, the NMC has been using the VTPR data operationally. A study was made in March and April of 1973, under a NASA contract, to determine the impact of this particular type of data on the numerical prediction system which was operational at that time. These results must be interpreted as a measure in a short period of time of the effect of this data on the NMC model environment. They are not to be interpreted as a measure of an optimally designed system from the standpoints of the satellite data retrieval method, nor from the numerical analysis-prediction system. It is intended that this study be used as a benchmark for future testing in the Center.

The objective analysis method for geopotential heights, temperatures, winds, surface pressure, tropopause pressure, and moisture is based on the successive correction technique; e.g., Cressman (1959). A first estimate of the analysis was based on the most recent 12-hr forecast verifying at the analysis time. The grid points were corrected by nearby observations through the judicious use of a distance weighting function. The first guess for winds, however, was based on a gradient wind approximation using the analyzed heights. All analyses were made on the 1977-point octagon. For further details of the analysis method, see McDonell (1973).

The forecast model was the 6-layer primitive equation model, originally described by Shuman and Hovermale (1968). At the initial time, there were four layers in the troposphere and two layers in the stratosphere. Moisture is treated as a thermodynamically active variable in the lowest three layers, and a simple convective adjustment scheme is used to simulate small-scale vertical exchange processes. Simple radiative effects, skin friction, and sensible heat exchange are included. Orographic effects are included through use of a modified Phillips' sigma (Phillips 1957) vertical coordinate.

The analyses on the constant pressure surfaces were interpolated to the sigma system and extrapolated to the boundaries of the 53 x 57 grid. The horizontal divergence of the resulting winds, as measured in the sigma system, was replaced with the 12-hr forecast component verifying at the analysis time.

Each temperature sounding which was retrieved from the satellite-measured radiances was taken to be representative of a box roughly 600-km square. Soundings were obtained only over ocean areas. Geopotential heights were obtained hydrostatically using the analyzed 1000-mb heights. The first guesses for the retrievals were obtained from the 12- and 18-hr forecasts made earlier, and the time-smoothed forecast tendencies were used to update the data to the 0000 and 1200 GMT synoptic times. The updating procedure has been described by Desmarais (1972). The retrieval method has been described by McMillan, et al. (1973).

The impact study was conducted from March 9 to March 21 and from March 27 to April 13, 1973. During these periods, an analysis-forecast system identical in design to the NMC operational system was run continuously and in near real-time, using the same data with the important exception that the VTPR data were excluded. This cycle is referred to as the B-mode, while the operational cycle is referred to as the A-mode. In the operational cycle, there is a need to use "fill-in bogus" data to better delineate systems in sparse data regions. Because of the subjective nature of this procedure, it was not possible to exactly duplicate this in the B-mode. Nevertheless, experienced synopticians performed this bogusing function independently in the B-mode system, without prior knowledge of the A-mode results. The average number of such reports was near 40 per cycle and most of these were created for the Pacific Ocean region.

The average number of VTPR reports in the A-mode analyses was 88 per 12-hr cycle in the data base collected 3 hours and 30 minutes after synoptic observation times. At the 10-hour data cutoff time, this number was 100.

The resulting analyses and forecasts of the A- and B-modes were compared both subjectively and statistically. The root-mean-square, mean, and standard deviation of the differences for the height, temperature, and wind at the ten analysis levels to 100 mb for the entire octagon grid and for five subregions were computed. Since the analyses were essentially the same over the continents, forecasts were verified against the A-mode analyses. Over the oceans, the forecasts were verified mainly against radiosonde reports. The forecast height gradients were also verified together with the precipitation forecasts at 60 observing stations in the United States and southern Canada.

The root-mean-square 500-mb analyzed height differences averaged 15 m in the Atlantic and 25 m in the Pacific. This compares with 40 m for two analyses 12 hours apart in the Pacific region. Figure 1 shows the 500-mb analysis differences for the second period of this study for three subregions. Note that the root-mean-square difference over North America was only 4 m. The April 4 case, where a maximum root-mean-square difference in the Pacific region reached 57 m, was studied in great detail. Note that this large difference diminished rapidly in the analyses which followed.

Figure 2 shows the March 30 500-mb analyses of the A- and B-modes, their differences, and the VTPR data coverage. Figure 3 shows the 500-mb forecast differences out to 48 hours. Figures 4 and 5 show the same results for the April 4 case.

This report is not intended to be a full documentation of the impact study, but only a brief presentation of the study performed by Dr. Bonner and his staff. Therefore, rather than show the many forecast verification statistics, I will only state the general conclusions of the study. In this particular experiment, the VTPR data played a relatively minor role in the A-mode, or operational system. Unfortunatley, from the evidence obtained we cannot state that the data were beneficial. We also cannot say that the evidence was detrimental. During most of the test periods, the analyses were surprisingly similar. With few exceptions, there were apparently sufficient conventional data in the B-mode to guide the monitoring synopticians towards a similar solution for the analysis. It became quite evident that the bogusing function is a powerful tool available to the synoptician. Unfortunately, this effect could not easily be isolated from the VTPR effect. For example, the extreme southward displacement of the jet on April 4 in the A-mode was the result of a combination of VTPR and bogus reports.

The main conclusion of this study is that the VTPR data gave no new information which could be utilized by this analysis-forecast system. At this point, one can only speculate why this was the case. In any event, we must be aware that this particular impact study was made only 10 weeks after the data were first available operationally. This was a test with an operational numerical system designed primarily for the utilization of conventional, synoptic-type data. The results of such experiments, however, can be used to guide us in our efforts to construct systems which are capable of better separating the signal from the noise of these new observing systems.

The detailed report of this study is presently available in the form of a contract report (Staff Members, Data Assimilation Branch, NMC, 1973).

IV. Hurricane Modeling

An effort is underway to test the present state-of-the-science of hurricane modeling for operational purposes. A four-man team, under the direction of John Hovermale, was organized in the summer of 1973 to accomplish this. The short-term objective is to design, construct, and test an analysis-forecast system (first generation system) suitable for operational implementation on the IBM 360/195 computer system. It is to be used primarily for short-range predictions (24 to 36 hours) of hurricane motion, particularly for storms threatening populated coastal areas, and secondarily for predicting the associated amounts of precipitation in them. The results of studies by Miller, et al., (1972), Mathur (1974), and Ceselski (1974) have demonstrated that models with fairly coarse spatial resolution can produce skillful track forecasts.

The long-term objective of this group is to embark into promising avenues of research to raise the level of forecast skill. This could involve a search for improved grid nesting techniques, cumulus convection parameterization techniques, and improved methods of obtaining the initial atmospheric state.

A coordinated effort has been planned with scientists from other NOAA groups (National Hurricane Research Laboratory, National Hurricane Center, and the Geophysical Fluid Dynamics Laboratory) to develop a second generation hurricane prediction model for operational forecasting. It is intended that this analysis-forecast system also be used to serve the needs of the Environmental Research Laboratories. It is generally believed that the ultimate requirements for accurate forecasting can only come with such three-dimensional numerical systems with a high resolution grid which resolves the details of the storm core and incorporates a sufficiently large domain to capture the interactions of nearby meteorological systems.

In the construction of the first generation model, operationally tested methods will be used whenever possible. For example, a finite-difference system will be used which is known to be reliable for short-range forecasting purposes. The numerical grid will be of uniform spatial resolution, rather than one which increases in resolution towards the core of the storm. However, it was recognized from the beginning that testing of untried methods for objective analysis would have to be undertaken.

Dr. Hovermale and his staff have now constructed a 10-layer primitive equation model using the Phillips sigma vertical coordinate. This model will contain a 60-km 51 x 51 grid which will move with the center of the storm. The lateral boundary conditions will be obtained from the most recent operational coarse mesh model predictions. The computer program is written so that horizontal and vertical grid resolution can be easily varied to adapt to a running time of about 1 hour on the IBM 360/195. It is furthermore modularized to allow for ease in testing the effects of various formulations of the physical processes. The original version has Kuo's (1965) method of parameterizing cumulus convection incorporated. Also, the semimomentum differencing system is used (Shuman and Stackpole, 1968).

A two-dimensional, axially symmetric version of the three-dimensional model has also been constructed. It is used to perform experiments inexpensively prior to testing in the three-dimensional version. It will also be used in representing the vortex initially in a four-dimensional data assimilation technique.

In the four-dimensional data assimilation process, estimates of the analyses at synoptic times will be obtained for a short time period (say up to 24 hours) prior to the initial time, t_o. These will be first spatially interpolated from coarse mesh analyses and reanalyzed on the fine mesh grids using isentropic analysis techniques. The two-dimensional version of the model will be used to prescribe the initial guess in the vicinity of the vortex. The three-dimensional model will then be integrated from t_o-24 to t_o, treating the analyzed fields as grid point "data." The forecast state will be nudged towards these analyzed states through a fictitious term in each prediction equation of the form $K\nabla^2(\alpha - \alpha_A)$. Here α represents the predicted value of a parameter, and α_A represents the "data", and K is a coefficient to be determined. K could be a function of time, maximizing near the valid time of the "data." In the predictions beyond t_o, these fictitious terms must be rapidly vanishing in a way that the shock is minimized.

Dr. Hovermale is also considering the use of the fictitious terms mentioned above in the blending of the lateral boundaries of the fine-mesh grid with the coarse-mesh forecasts. He has been successful in incorporating this idea into a primitive equation barotropic system.

We plan to test the three-dimensional hurricane system presently under development on midlatitude disturbances as well. A modified version of this system will be tested for possible future implementation for operational short-range forecast guidance.

V. NMC's Operational Modeling Plans

The dual IBM 360/195 NOAA computer system was installed in Suitland in early 1974. It is to replace two of the three CDC 6600 computers. A large portion of the NMC staff, particularly in the Automation Division, are committed to the job of converting the entire operational system to the new computer configuration.

The operational analysis-forecast system to be eventually implemented on the 360/195 system is given in Table 1. The times shown are the times (hours + minutes) after the synoptic data times 0000 and 1200 GMT. The HUF analysis system is a global-type objective analysis technique developed by Thomas Flattery. It is a three-dimensional technique in which data are fit to a set of spectral (Hough) functions in the horizontal dimensions and to a set of empirical orthogonal functions in the vertical dimension. The fit is accomplished through a process of minimizing the mean-square differences between the analysis and the observations. Twenty-four Hough functions with

24 zonal wave components each are used together with 7 vertical functions. Further details of the analysis technique can be found in Flattery (1967 and 1970) and Technical Procedures Bulletin No. 105 (1974).

SC refers to the present successive correction analysis technique used operationally (McDonell 1973). The 6L PE is the operational 6-layer primitive equation model. It differs from the CDC 6600 version mainly in that the horizontal grid is expanded from a 53 x 57 to a 65 x 65 grid array. This change puts the lateral wall further south, yielding a larger valid forecast domain. The main reasons for running the 6L PE at 2+00 are (1) to produce forecast guidance to 48 hours for meeting tighter deadlines brought about by continual daylight savings time, (2) to maintain a forecast product for Model Output Statistics (until the statistics can be accumulated on the new models), and (3) to establish with the LFM a vehicle through which we can develop and test a two-way interacting nested grid system.

The 8L GLOBAL is a new global forecast model presently under development (Stackpole, et al., 1974). 8L HEM is the hemispheric version of the model. Initially, the model resolves the atmosphere with six equipartitioned layers in the troposphere and two layers in the stratosphere. Material surfaces exist at the top and bottom of the atmosphere and at the tropopause. A computational cap is present which is similar to that in the 6L PE. This vertical configuration is subject to change pending the outcome of testing. The model contains a latitude-longitude grid. The stringent linear stability criterion brought about by the converging meridians at the poles is relaxed through use of an averaging technique for the tendencies along the latitude circles on each side of the grid points. Moisture equations are integrated in the lowest five layers of the model. In the initial version, the physics of the model will be similar to those of the 6L PE. An intensive testing period is planned prior to implementation of the 8L HEM at the 3+20 time. In the interim, the prediction model will be the present 65 x 65 version of the 6L PE.

The global system to be run at 10+00 will allow for the collection of data arriving after the main forecast cycle at 3+20. Twelve-hour forecasts from this model will be used for the first estimates of the analyses at the 1+30, 2+00, and 3+20 times. The global forecast system can also be used to provide the first estimates of the vertical temperature profiles for retrieving the temperatures from the satellite measured radiances. It is also intended to be used to fill the upper air forecast requirements of the Air Transport Association.

The details of the numerical systems presented in Table 1 are still to be taken as tentative estimates since some of the new systems are yet to be fully tested.

Time	Analysis	Prediction Model	Horizontal Resolution	Area Domain	Forecast Period
1+30	HUF	Barotropic	381 km	1977-pt Octagon	48 hrs
2+00	HUF	6L PE	381 km	Northern Hemisphere (65 x 65 pt grid)	48 hrs
	SC	LFM	381/2 km	North America (53 x 45 pt grid)	36 hrs
3+20	HUF	8L HEM	2 degree	Northern Hemisphere	48/96 hrs
10+00	HUF	8L GLOBAL	2½ degree	Global	24 hrs

Table 1. NMC's operational model system planned for the IBM 360/195 NOAA computer system

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LIST OF FIGURES

Figure 1. The root-mean-square differences (meters) between the A- and B-mode analyses for 500-mb geopotential heights as a function of time during the second period of the investigation. Below is given the total number of VTPR reports received each 12 hours in the Pacific region (upper row) and in the Atlantic region (lower row).

Figure 2. 0000 GMT March 30, 1973.

A. 500-mb height analysis for A-mode.
B. 500-mb height analysis for B-mode.
C. 500-mb height difference A-mode minus B-mode (meters).
D. Locations of VTPR reports in the A-mode.

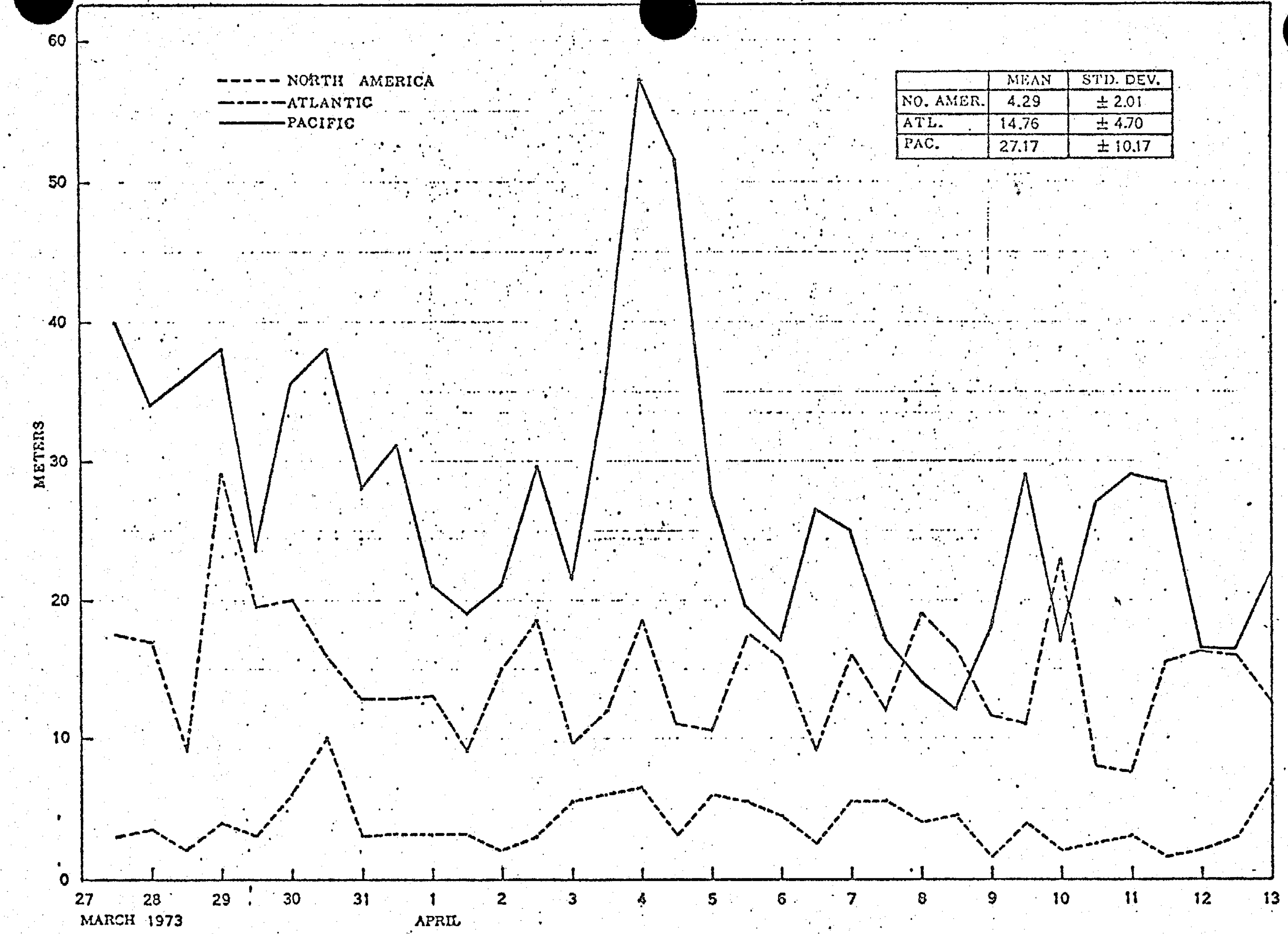
Figure 3. 0000 GMT March 30, 1973. 500-mb height forecast difference A-mode minus B-mode (meters).

A. 12-hr.
B. 24-hr.
C. 36-hr.
D. 48-hr.

Figure 4. Same as Figure 2, but for 0000 GMT April 4, 1973.

Figure 5. Same as Figure 3, but for 0000 GMT April 4, 1973.

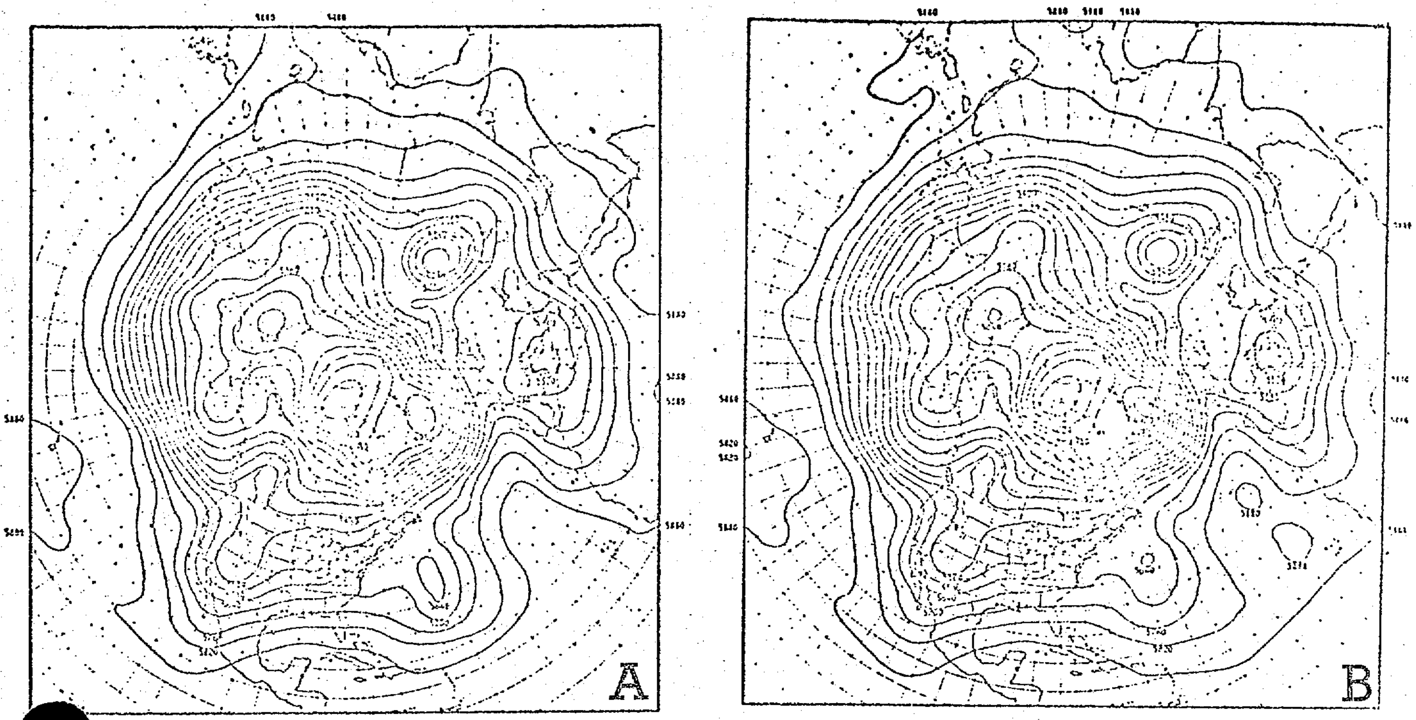
RMS DIFFERENCES, A-MODE vs. B-MODE, FOR 500MB GEOPOTENTIAL HEIGHTS



	MEAN	STD. DEV.
NO. AMER.	4.29	± 2.01
ATL.	14.76	± 4.70
PAC.	27.17	± 10.17

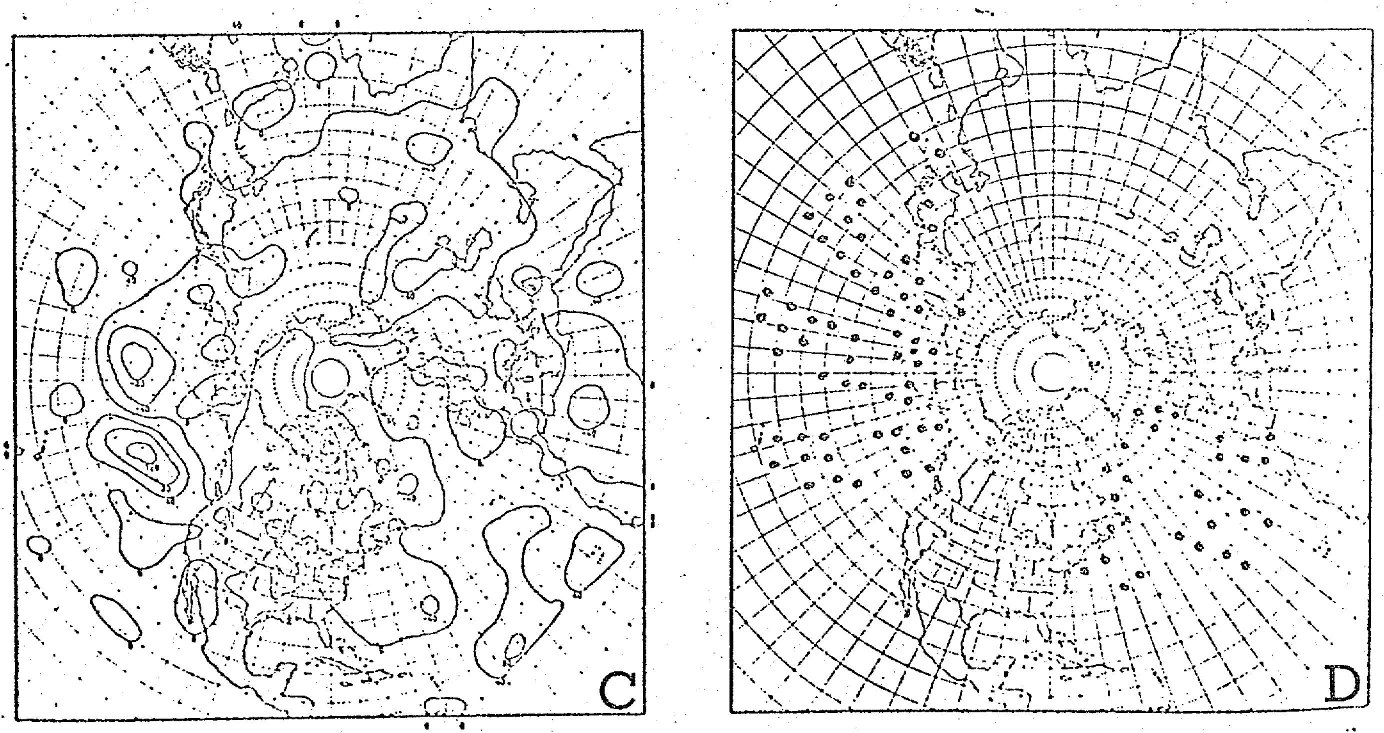
NO. OF VTPR RPTS.	32	31	M	67	39	60	50	64	43	48	49	37	46	54	32	39	M	47	42	57	58	60	45	59	41	64	37	53	42	62	43	59	38	71
	38	28	M	58	28	32	40	51	30	40	36	32	31	39	39	35	M	48	40	36	46	41	42	41	37	34	45	44	36	44	34	35	44	56

Figure 1



HEIGHT A MODE VALID 00 HOURS AFTER 00Z 30 MAR 73

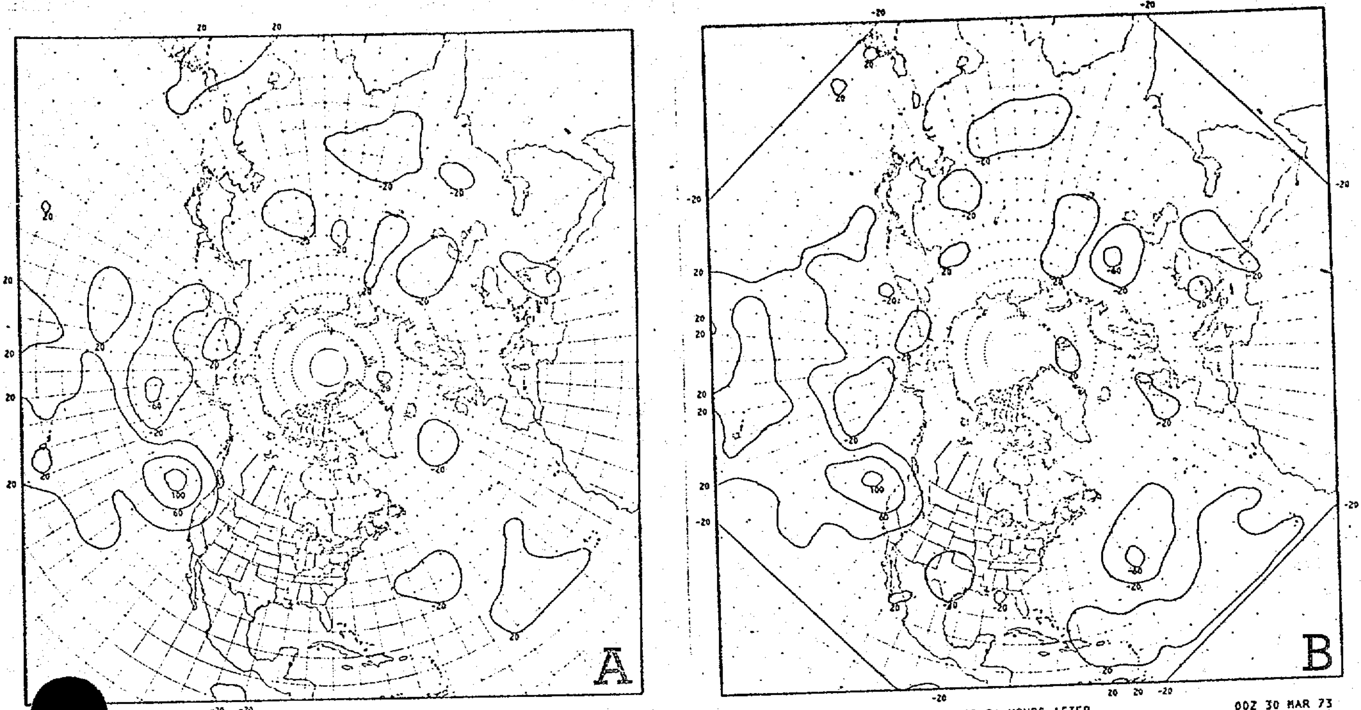
500 MB HTS B-MODE VALID 00 HRS AFTER 00Z 30 MAR 73



500MB HT DIFF A-B MODE VALID 00 HRS AFTER 00Z 30 MAR 73

VTPR REPORTS 00Z 30 MAR. 1973

Figure 2



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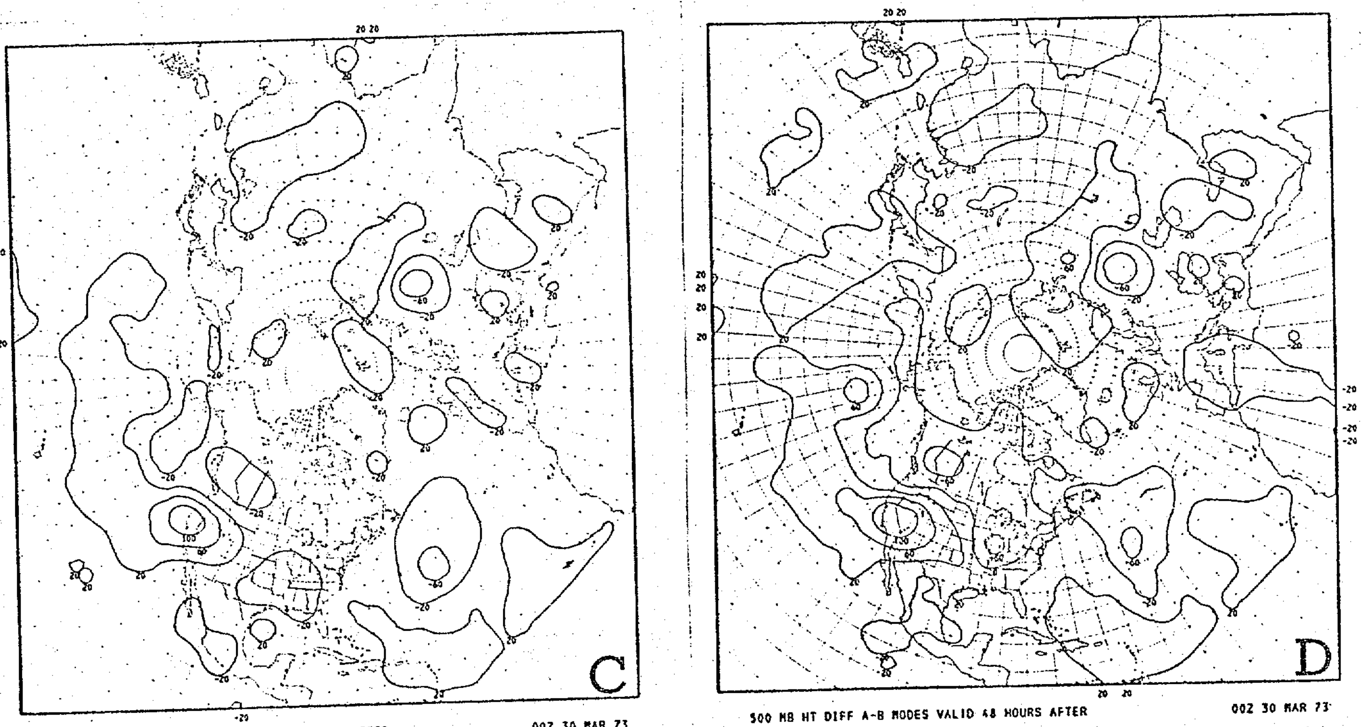

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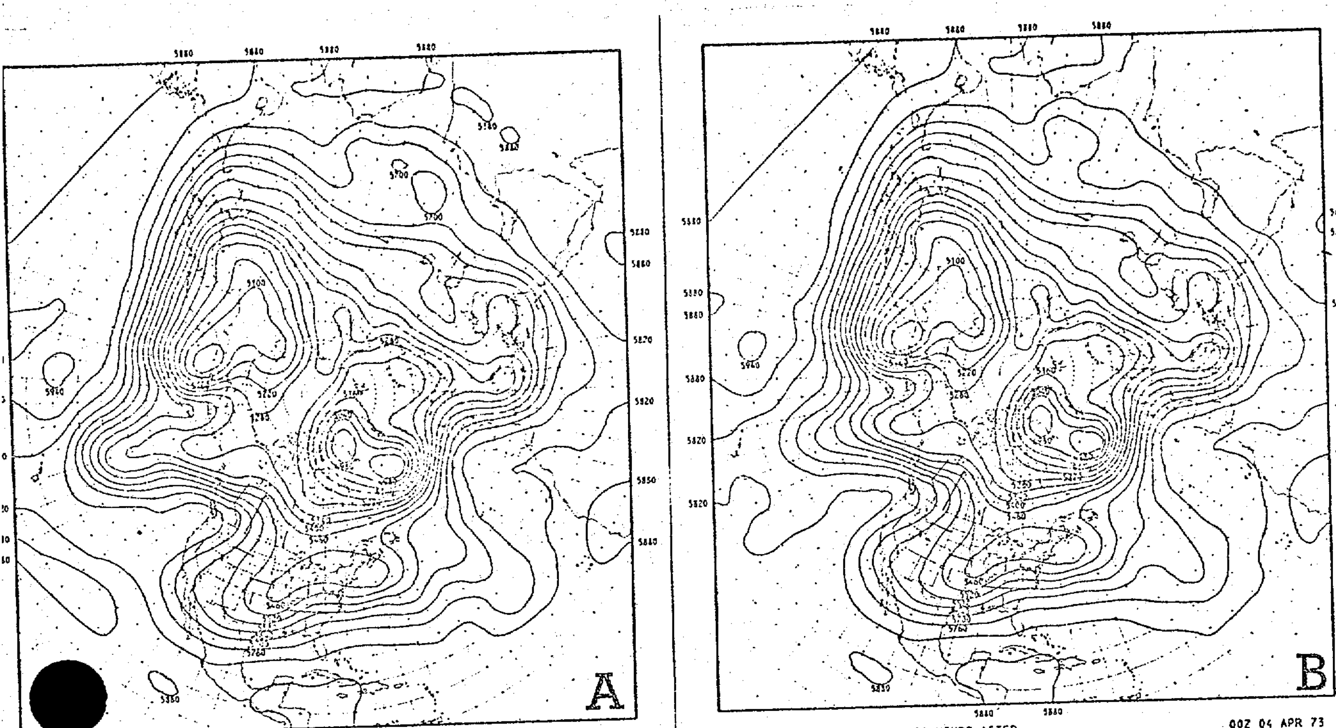
Figure 3



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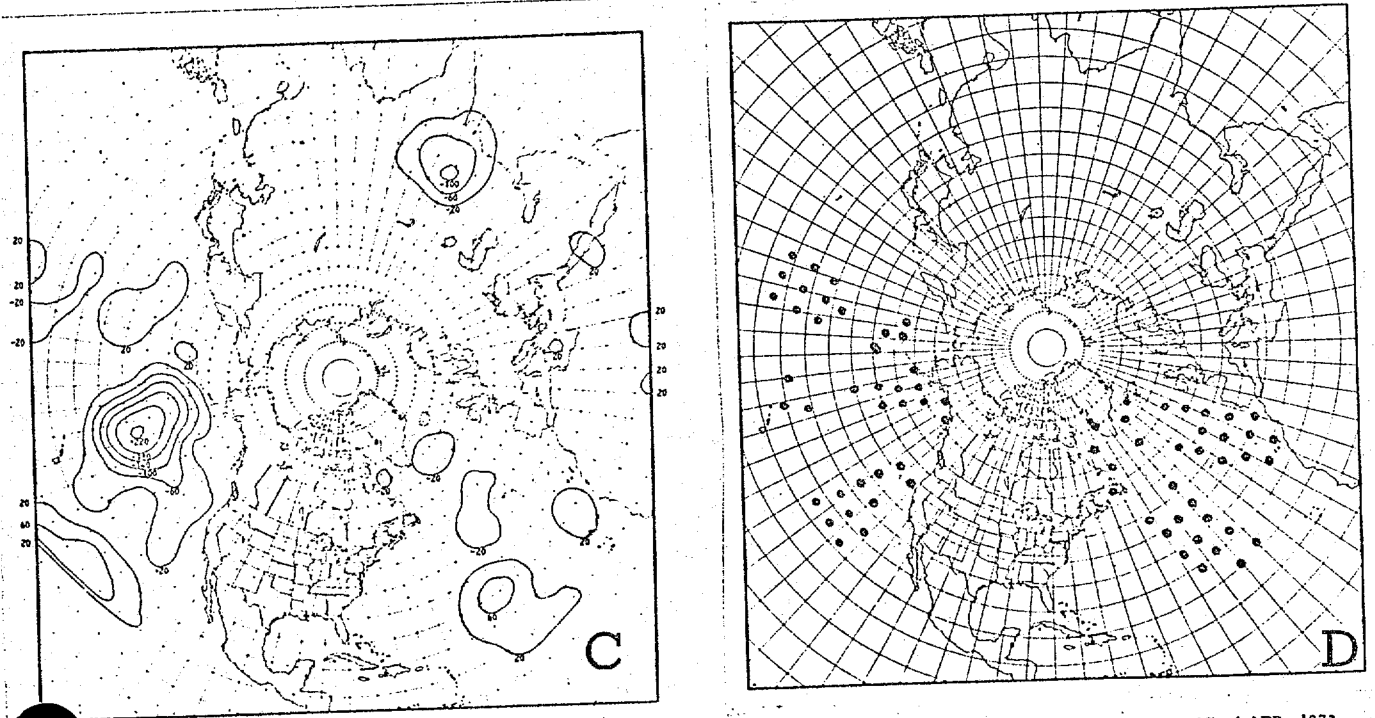

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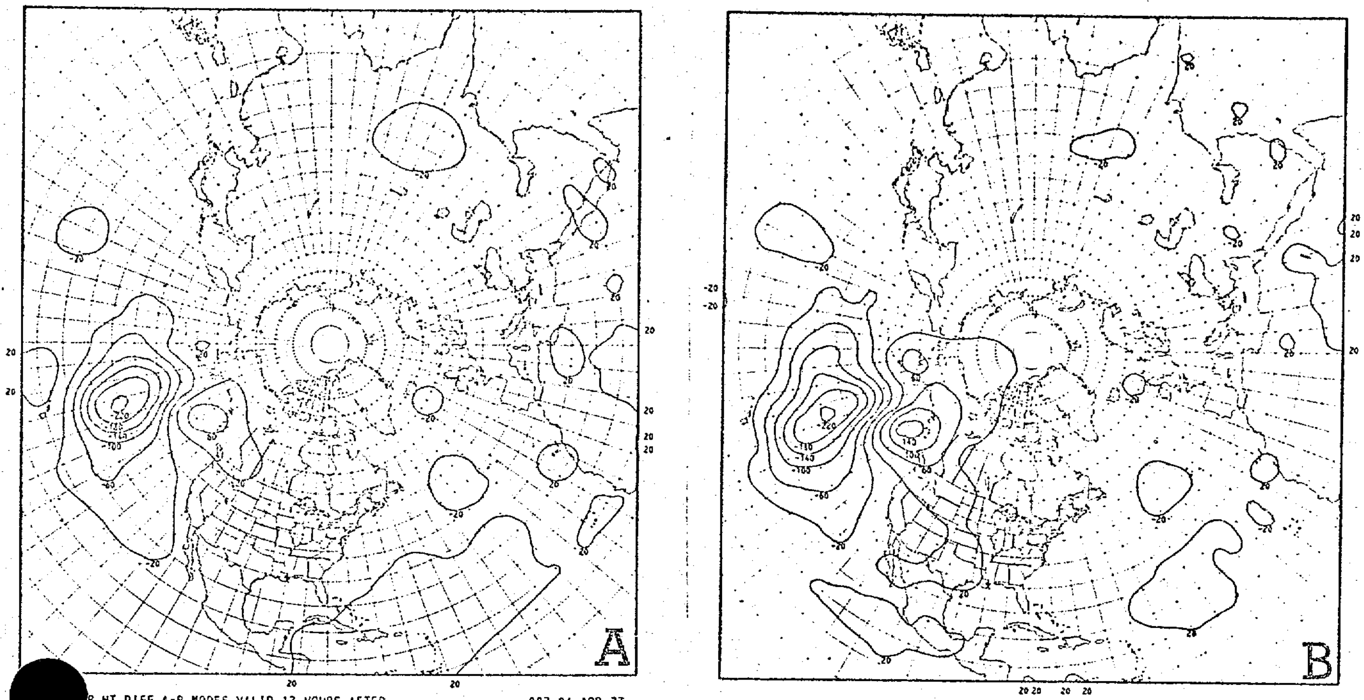
VTPR REPORTS **00Z, 4 APR. 1973**

Figure 4



B HT DIFF A-B MODES VALID 12 HOURS AFTER 00Z 04 APR 73

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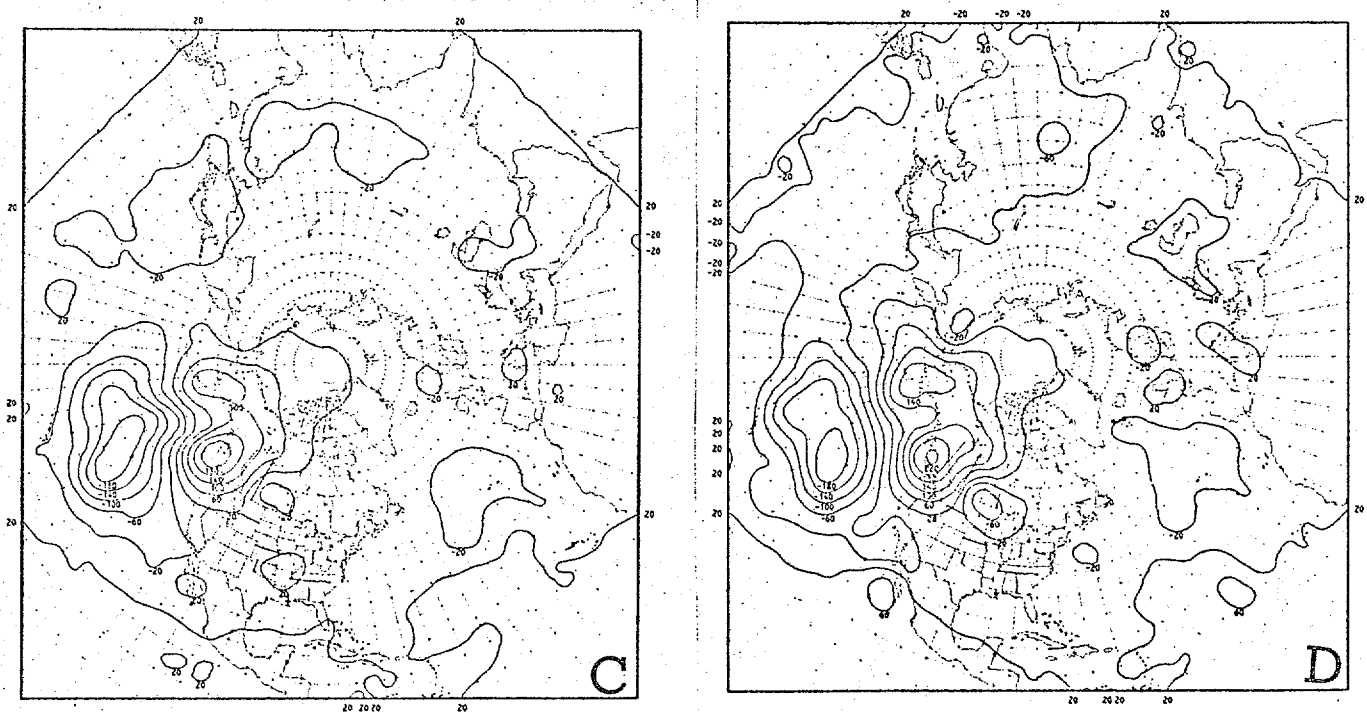

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500 MB HT DIFF A-B MODES VALID 48 HOURS AFTER COMMENT. 00Z 04 AP

Figure 5