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JOINT NUMERICAL WEATHER PREDICTION UNIT

Bulletin No. 1*
(Effective 6 May 1955)

## 1. Introduction

Beginning on 6 May 1955, the JNWP Unit will issue daily short range numerical predictions of isobaric contour and vertical motion patterns over the U.S. and immediate surroundings. These prognostic charts will be distributed to the NWAC and to each of the participating services, to be used either without modification, as advisory aids in the preparation of conventional forecasts, or for whatever special purposes each service considers appropriate. The aim of this and subsequent bulletins is to inform the recipients and users about what goes into a numerical prediction, what information it contains, how it should be interpreted, and what it can be used for.

## 2. The Model

The present system of numerical forecasting is based on a rather general baroclinic model --- one of the so-called "three-level" models developed by Charney and described in detail in (1). The state of this model is completely specified by the heights of three isobaric surfaces, located at 900, 700, and 400 millibars. The most restrictive approximations inherent in the model are:

(1) The flow is assumed to be geostrophic for purposes of computing vorticity and horizontal advection.
(2) The flow is assumed to be nonviscous and adiabatic.
(3) The underlying terrain is assumed to be very nearly flat.
(4) The static stability is assumed to vary only in the horizontal.

## 3. Data Preparation

The initial data required by the present forecasting system are the heights of the 900, 700, and 400 millibar surfaces. At the present time, the 1000, 700, and 400 millibar height data for 1500Z each day are analyzed manually by more or less standard methods but with more than ordinary care. The 1000** 700, and 400 millibar heights are next interpolated at a standard rectangular array of 19 x 29 points, spaced about 300 kilometers apart (or,

*Additional bulletins will be issued whenever significant changes in the scheduling and content of the numerical forecasts have been introduced into the operating routine, or whenever changes in the use and interpretation of the forecasts appear desirable.

**The 900 mb information is obtained internally in the computer by a linear interpolation in ln p between 700 mb and 1000 mb.

to be exact, .8 inches on a mapscale of 1:15 million). This array, or "grid", covers an area somewhat larger than the U.S. The interpolated values of the 1000, 700, and 400 millibar heights at the grid points are then read off, recorded on punch cards, and checked. The resulting deck of cards comprises the initial data for map time, and is usually punched and checked by 1700 EST.

## 4. Computation

Once the intial data for map time are punched on cards, the data and instruction decks are placed in the input component of the machine, and the preparation of the forecast is carried out entirely automatically. The machine first reads the input initial data and instructions, and stores this information in its memory. Its logical and numerical components then receive, interpret and execute the instructions. In about 1.5 hours after receiving the initial data, the computer has integrated the prognostic equations over periods ranging up to 36 hours. It is generally instructed to stop at this point, at about 1900 EST, and the results of its computations are recorded in permanent form --- on punch cards, as numbers printed on a roll of paper at the gridpoints, and as printed isopleth analyses.

## 5. Output Information

It was pointed out earlier that the model on which the existing prediction system is based is completely described by the heights of the 900, 700, and 400 millibar surfaces. Accordingly, these are also the quantities that are predicted. As a by-product, however, the computational procedure also yields the predicted vertical air speed at about 800 and 550 millibar levels. Forecasts of these elements are prepared daily for 24 and 36 hours after map time. The forecasts cover an area slightly greater than the continental U.S. The area outside the U.S., which are the most subject to contamination by boundary errors, will be masked out of the reproduced prognostic charts. The heights of the pressure surfaces are given units of 10 feet, and vertical air speed in millimeters per second.

From these forecasts, one may derive the mean temperatures in the layers separating adjacent levels of the model (using the hydrostatic equation), and the winds at the 900, 700, and 400 millibar surfaces (using the geostrophic wind equations). The pattern of vertical motion provides an essential ingredient of methods for predicting precipitation.

## 6. Suggestions for Use

It should be emphasized that no system of prediction --- numerical methods not excepted --- can predict in greater detail than the detail in which the initial state is observed. Thus, a numerical prediction cannot yield information about the detailed and highly localized fine structure of the flow, but is essentially a prediction of general conditions over areas at least 200 miles square. One should also remind himself that numerical forecasts are not strictly weather predictions, in that they do not refer directly to cloudiness, precipitation, fog formations, etc. --- even though they obviously have some connection with the thermodynamics of moist air. In short, they are of essentially the same type as the prognostic charts currently being issued by the NWAC. The present system of numerical forecasting will establish the general setting or environment in which localized influences act to produce "weather" in the usual sense.

From experience to date, we have the following specific recommendations to make about the interpretation and use of numerical forecasts:

1. At present, the scale of reproduction is accurate to within ten percent. Accordingly, one should use some discretion when measuring gradients to compute the geostrophic wind. Moreover, the gradient wind approximation is not consistent with approximations used elsewhere in the predictions, and is a meaningless refinement.

2. It should be emphasized that moisture is a necessary ingredient for precipitation, and that the moisture distribution changes must be taken into account when applying the prognostic charts of vertical motion.

3. The absolute value of the height of an isobaric surface is influenced considerably by the average height on the lateral boundaries, which is arbitrarily specified. In interpreting the prognostic charts, therefore, one should not rely too much on absolute values of height. The height gradients, however, are less dependent on boundary conditions and are more reliable.

4. Oscillations (wiggles) of small amplitude and scale occasionally appear on the 24 hr and 36 hr prognostic charts. These are caused by truncation errors and should be disregarded or smoothed out.

5. The present model tends to overpredict anticyclogenesis in certain types of situations. This effect is most frequently observed south of the jet stream, when the amplitude of the long wave pattern is large or increasing rapidly.

6. Since the winds in a sharp trough aloft are usually subgeostrophic, the vorticity maximum is sometimes predicted to move too far east. Consequently, being caught up in the SW flow ahead of the trough, the vorticity maximum is frequently predicted to move too far northward.

(1) Charney, J. G.
Numerical prediction of cyclogenesis. (National Academy of Sciences, Proceedings. vol. 40, no. 2, pp. 99-110. Feb. 1954).

JOINT NUMERICAL WEATHER PREDICTION UNIT

Bulletin No. 2
(Effective 8 July 1955)

The following amendments to Bulletin No. 1 will go into effect

3. Data Preparation

900 mb information is now obtained internally in the computer by an interpolation scheme assuming the temperature to be a linear function of ln p. Hence three pieces of information are necessary ——— the heights of the 400 mb, 700 mb, and 1000 mb surfaces. It should be noted that thus one no longer assumes a standard lapse rate, since the actual mean lapse rate in each vertical column is used.

5. Output Information

Assuming the same temperature variation as in 3. above, forecast 1000 mb charts and initial and forecast 500 mb charts are being computed. The 900 mb chart will no longer be distributed.

6. Suggestions for use

Care must be exercised in interpreting the forecast 1000 mb chart since it is assumed to be devoid of boundary surface effects. The influence of skin friction, summer time heating in southwestern U. S. and terrain are not included in the prediction model.

Joint Numerical Weather Prediction Unit

Bulletin No. 3A

Effective 29 September 1955

## 1. Introduction

Beginning this date, experimental barotropic forecasts for a large section of the Northern Hemisphere will be given limited distribution.

## 2. The Model

The barotropic model is well-known, and is described, for example, in (1). The model used for these particular forecasts assumes geostrophic winds and no mountains. Unusual features of the computation are

(a) The grid mesh length used is double the mesh length used for the baroclinic model described in Bulletin No. 1. There are approximately 550 to 600 kilometers between grid points, varying somewhat with latitude.

(b) The Laplacian of the height field is smoothed each time step by a smoothing function which almost completely suppresses features having a wave length of two grid intervals, leaving practically unaltered features having wave lengths of more than five grid intervals.

(c) A time step of two hours is used.

## 3. Data

The data used for the initial time consist of the heights of the 500 mb surface read from the 0300Z 500 mb analysis issued by NWAC.

## 4. Output Information

The 500 mb prognostic charts are printed at 24 hour intervals. The forecast is usually stopped after the 72-hr print. As a rule, only the 48 and 72-hr prognostic charts will be issued.

## 5. Suggestions for Use

These prognostic charts will be considered as experimental only. Preliminary distribution of these is given in order to ascertain whether or not these charts might prove useful. Your comments are requested on the following:

(a) What is your general impression regarding the usefulness of
(1) the 48-hr prognostic charts, and
(2) the 72-hr prognostic charts?

(b) Do some areas on the charts prove more or less useful than others?

(c) Do you observe any systematic errors?

The following specific recommendations can be made:

(a) Absolute values of height are influenced by arbitrarily specified boundary conditions, and cannot be relied upon. The height gradients, however, are more reliable

(b) The smoothing process, mentioned above, eliminates small-scale patterns, which therefore do not appear in the prognostic charts.

(c) It should be remembered that the barotropic model is not capable of predicting the sudden increases in energy observed in cases of strong cyclogenesis

(d) A systematic error has been observed such that the position of troughs and ridges in the westerlies are not far enough east, particularly by 72 hours. Investigations designed to remedy this type of error are under way.

(1) J.G. Charney and N.A. Phillips:
Numerical integration of the quasi-geostrophic equations for barotropic and simple baroclinic flows. (Journal of Meteorology. vol. 10, no. 2, pp. 71-99).

JOINT NUMERICAL WEATHER PREDICTION UNIT

Bulletin No. 4
(Effective 10 October 1955)

The following amendments to Bulletin No. 3 are now in effect:

## 2. The Model

(d) The height of the 500 mb surface is rescaled internally (in the program) according to

$$\hat{\hat{D}} = 1.2\,\hat{D},$$

where $\hat{\hat{D}}$ is the new scaled value of the 500 mb height and $\hat{D}$ is the old scaled value of the 500 mb height. This rescaling has the effect of increasing the winds by one fifth. This rescaling is effective only internally, and does not appear in any of the printed charts.

## 5. Suggestions for Use

Delete section (d).

JOINT NUMERICAL WEATHER PREDICTION UNIT

# Bulletin No. 6
(Effective 28 December 1955)

Beginning with the baroclinic forecasts* made from the 1500Z, 28 Dec. 1955 data, a minor modification of physical assumptions will be introduced in JNWP Unit's operating procedures.

The Princeton 3-layer model, which is the current basis for numerical forecasts, treats atmospheric disturbances as perturbations on a mean atmosphere. In past operational forecasts, the mean atmosphere was taken to be the U.S. Standard Atmosphere. In studying the effects of stability upon divergence fields, it was found that relatively small changes in the stability of the mean atmosphere had considerable effects upon the quality of the forecasts—in particular on spurious anticyclogenesis in the low levels. In checking the validity of the U.S. Standard Atmosphere, it was found that it was less stable than winter mean soundings in the JNWP forecast area. Accordingly, monthly mean soundings are being computed from selected North American stations, and these will be used in future baroclinic forecasts.

For purposes of comparison, the table below contains temperatures and pressures from the U.S. Standard Atmosphere and from the JNWP mean sounding for January.

| pressure (mb) | temperature (°K) U.S.S.A. | JNWP (Jan) |
|---|---|---|
| 400 | 241.3 | 239.7 |
| 550 | 256.4 | 254.9 |
| 700 | 268.4 | 264.9 |
| 800 | 275.3 | 269.1 |
| 900 | 281.6 | 271.3 |

From experiments run to date, a significant improvement in verification scores may be expected with the new mean soundings, but the general level of quality is not expected to change. The errors of spurious anticyclogenesis which sometimes characterizes the forecasts are expected to be reduced, but not eliminated.

*See Bulletin No. 1 in this series.

Joint Numerical Weather Prediction Unit

Bulletin No. 8

(Effective 20 April 1956)

References:

Bulletin No. 3 & 4, this series.
Bolin, B., 1955: Numerical forecasting with the barotropic model. Tellus, Vol. 7, No. 1, pp. 41-45.
Shuman, F. G., 1955: A method for solving the balance equation. JNWP Unit Technical Memorandum No. 6, May 23, 1955.

Beginning this date, the barotropic forecasts (Bulletins No. 3 & 4) made from 0300 GMT data will include non-geostrophic effects. The wind field needed in the predictive vorticity equation, is computed from a stream-function; which in turn is derived by integration of the balance equation (Bolin, 1955; Shuman, 1955).

The balance equation is the divergence of the horizontal equations of motion, and includes cyclostrophic, difluence, and other acceleration effects on the wind field. The geostrophic approximation is included in the balance equation as a special case.

The primary benefit to be expected from the use of the more general wind field is the virtual elimination of spurious "barotropic anticyclogenesis", although other benefits may be expected, such as more correct translation of pressure systems.

The internal re-scaling constant has been increased to 1.3 (Bulletin No. 4). This change was empirically found to be necessary to correct for that part of the truncation error which errors in the geostrophic approximation had been compensating.

# JOINT NUMERICAL WEATHER PREDICTION UNIT

Bulletin No. 11

(effective 21 September 56)

Reference: JNWP Unit Bulletin Nos. 7 and 10.

As of 21 September 56, the routine procedure for computing the 2-level "thermotropic" forecasts was modified in the following respect: The coefficient $\mu^2$, which represents the thermodynamical effect on thickness changes[1], was increased by 60%. In essence, this modification takes account of the observed decrease and reversal of temperature gradient as one proceeds upward through the tropopause. The original value of $\mu^2$ was based on a linear relation between wind and pressure.

On theoretical grounds alone, this modification should result in more rapid eastward displacement of surface cyclones and more rapid surface cyclogenesis. Prior to this change, a long series of 1000 mb "thermotropic" forecasts showed a tendency to underpredict the movement and intensification of surface lows, frequently resulting in anomalous vertical tilting of the troughlines. In a smaller number of cases, this tendency was corrected partially by the modification described above.

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[1] See Thompson and Gates, Journal of Meteorology, April 1956, p. 131.

# Joint Numerical Weather Prediction Unit
## Bulletin No. 13
(effective 1 October 1956)

1. Beginning 1 October 1956, the data used for preparation of the barotropic forecast from 15Z on the 19x29 grid are processed automatically.

2. The steps in data preparation are:
   a) The use of teletype reperforators to cut tape from the signals on the meteorological circuits.
   b) Automatic conversion from teletype tape to IBM punched cards by means of 046 tape to card converters.
   c) Editing of the raw data by the 701 computer. This includes hydrostatic checks of all soundings and checking of duplicating reports against each other.
   d) Use of the 12hr barotropic forecast from 03Z to furnish supplemental data over the oceans for the objective analysis.

3. The data processing is then followed by the objective analysis and the barotropic forecast.

# Joint Numerical Weather Prediction Unit

## Bulletin No. 15
(effective 6 December 1956)

References: JNWP Unit Bulletins 7, 10, 11, 14

1. Effective 6 December 1956 the issuance of the thermotropic forecasts based on initially balanced conditions (as described in Bulletin No. 14) is temporarily discontinued. Instead the quasi-geostrophic thermotropic forecasts will be resumed.

2. This temporary change is made in order to enable the JNWP Unit to take steps to reduce the large-scale systematic boundary errors found in the thermotropic forecasts from balanced initial conditions. These boundary errors have been aggravated by the advance of the season, reaching unacceptable dimensions of a size previously unrevealed by the extensive tests conducted on this model.

# JOINT NUMERICAL WEATHER PREDICTION UNIT

## BULLETIN No. 16
(effective 13 December 1956)

Reference: Bulletin No. 12

1. As of 14 December 1956 a modification was introduced into the boundary conditions of the barotropic forecasts computed on the 30x34 grid. The Jacobians at each point in the rows and columns adjacent to the boundary rows and columns have been set at constant zero values throughout the forecast period. The effect of this change is to reduce the erroneous anticyclogenesis near inflow boundaries.

# JOINT NUMERICAL WEATHER PREDICTION UNIT

## Bulletin No. 19

(Effective 25 March 1957)

1. Beginning 25 March, 1957, the 500mb data used for preparation of all forecasts from 15Z are processed automatically. The automatic processing is done by a method outlined in JNWP Bulletin No. 13.

2. A new objective analysis program is now being used for preparation of the 500mb maps over the entire grid.

# JOINT NUMERICAL WEATHER PREDICTION UNIT

## Bulletin No. 20
(Effective 2 April, 1957)

References: Bulletins 12 and 16

1. Beginning 2 April, 1957, the barotropic forecast made from 15Z is now made over the entire 30 x 34 grid, using the barotropic model described in bulletins Nos. 12 and 16.

2. This forecast is required by NAWAC by 1730 E.S.T. Due to this requirement it is occasionally necessary to conclude the analysis before all the important but late data from Canada and the Atlantic have been received. The normal close-out time for receipt of data is now 1415 E.S.T. (1915Z).

# JOINT NUMERICAL WEATHER PREDICTION UNIT

Bulletin No. 21
(Effective 3 June, 1957)

1. The projected JNWP IBM EDPM 704 will be operating about the middle of July. The transition from the 701 will begin with the prediction made from 12Z 3 June data.

2. During the transition period, numerical predictions will be made on the 704 presently installed at the National Bureau of Standards. There will be available daily a 48-hour 500mb forecast made from 00Z initial data, and a 72-hour 500mb forecast made from 12Z initial data. All machine processing and analysis of data will be suspended. Predictions will be made at 500mb only, with a barotropic model, similiar to our present one, described in Bulletin No. 12, as amended by Bulletin No. 16. The important difference from our present barotropic is that the barotropic to be run on the NBS machine will be a semi-geostrophic model. In place of the balance equation described in Bulletins No. 8 and 12, the equation (1a) of Bulletin No. 18 will be used.

$$\nabla^2 \psi = \frac{\bar{f}}{f} \nabla^2 \phi + \nabla \phi \cdot \frac{\bar{f}}{f}$$

The resulting true stream function, $\psi$ describes a non-divergent wind field very nearly equal to the geostrophic. The use of such a non-divergent wind eliminates some of the spurious anticyclogenesis of the conventional barotropic model in which the geostrophic approximation is made in a more direct manner.

JOINT NUMERICAL WEATHER PREDICTION UNIT

Bulletin No. 22

(Effective 3 October 1957)

References: JNWP Unit Bulletin Nos. 8 and 12.

1. As of 3 October 1957, the JNWP Unit will begin issuing barotropic 500mb height forecasts on a routine basis for an area covering all of the northern hemisphere except the equatorial region south of about 13° Lat. N. This change represents a considerable and significant departure from earlier procedure, in that:

   (a) Numerical forecasts will be available for areas of interest not previously covered, and
   (b) The forecasts will be less subject to errors originating in arbitrarily specified conditions on the boundaries of the forecast area.

   The basic theory, the computing procedure, data processing, and form of the final product of this new procedure are outlined below. The forecasts described in JNWP Unit Bulletin No. 21 will be discontinued as of 3 October 1957.

2. Basic theory
   The new barotropic forecasts are based on the vorticity equation for nondivergent barotropic flow. The main features of the model are identical to those described in section 2 of JNWP Unit Bulletin No. 12.

3. Computing Procedure
   The numerical methods by which the barotropic vorticity equation is integrated are essentially the same as those outlined in Section 3 of JNWP Unit Bulletin No. 12.

   The method by which the initial wind field is computed from the initial height field has been modified slightly, in order to eliminate systematic errors in numerical solutions of the "balance equation". The role of the latter equation is referred to in JNWP Unit Bulletin No. 8, and is described more fully in JNWP Unit Tech. Memo. No. 6, by F. G. Shuman.

4. Data processing
   The input data are the 500mb height values for either 00Z or 12Z, interpolated at 1977 points spread evenly over the N. Hemisphere. The grid points form an octagonal array, as shown on Attachment 1, and are spaced 381 kilometers apart (at Lat. 60°N.) on a polar stereographic projection. The southernmost point of the boundary is at Lat. 9.7°N, and its northernmost point at Lat. 17.2°N. The

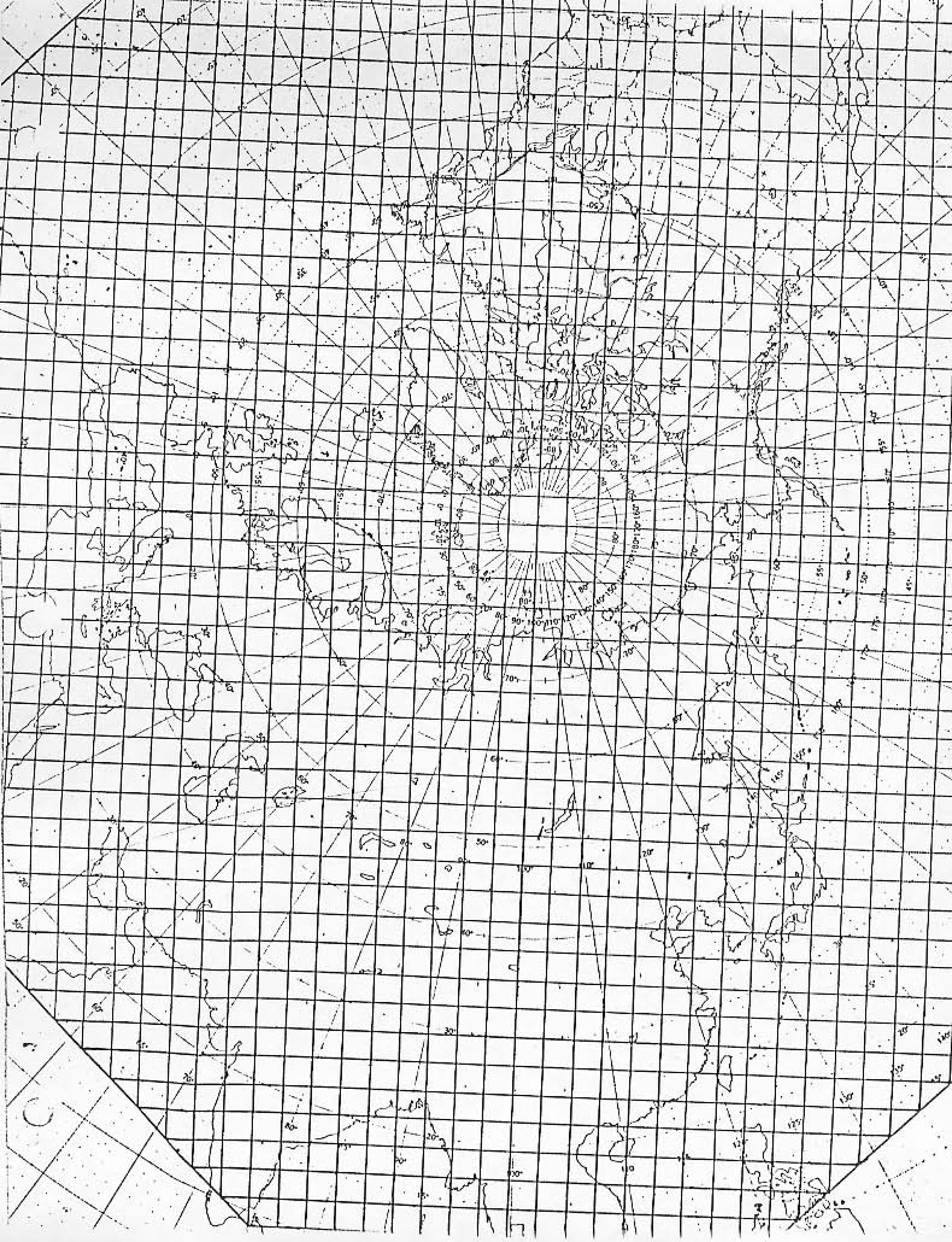
initial 500mb height pattern is plotted and analyzed manually, and the interpolated initial height values at the gridpoints are estimated by eye.

5. Content and Form of Output

The output is a series of 500mb height forecasts, verifying 0, 12, 24, 36, 48, and 72 hours after initial time. These forecasts are computed for initial data at both 00Z and 12Z. The area covered by the forecasts is the octagonal region shown on Attachment 1. The printed output is in the form of 500mb heights at every other gridpoint on every other line, together with the usual "contour printout". The contours are then traced manually onto a transparent overlay, on which the geography has already been drawn. The resulting map is reproduced for distribution.

Distribution

Reproduction of these forecasts will be available for messenger or mail distribution. In addition, selected forecasts will be transmitted via facsimile and teletype. Teletype transmissions will be in two different code forms: one, the standard teletype prog code used by NAWAC, and the other, a new prog code specially prepared by Air Weather Service.



JOINT NUMERICAL WEATHER PREDICTION UNIT
October 2, 1957

NOTICE:

All recipients of JNWP prognostic charts are requested to review their requirements with respect to the new charts described in Bulletin No. 22 and inaugurated on October 3, 1957. You are requested to place your requirements with the JNWP Unit by October 21, 1957.

If no reply is received by that date from any organization now receiving charts, we will assume that no requirement exists and will discontinue distribution to that organization.

George P. Cressman

George P. Cressman
Director
Joint Numerical Weather Prediction Unit

# Joint Numerical Weather Prediction Unit

## Bulletin No. 24

(effective 10 April, 1958)

Reference: JNWP Unit Bulletins 22 and 23

As of 10 April 1958, the forecasting procedure described in JNWP Unit Bulletins 22 and 23 will be modified to correct for certain persistent features of the large scale error pattern. Earlier studies of the large scale error pattern revealed a persistent and large positive error center over the east coast of Asia, a somewhat smaller positive error center off the east coast of Asia, a somewhat smaller positive error center off the east coast of the U.S., a large negative error center over Northern Europe, and a smaller negative error center over Western Canada. More recent studies by Cmdr. Wolff have shown that a large part of this quasi-stationary pattern is due to the facts that:

1) The very large scale components of the flow are quasi-stationary in actuality, whereas

2) The very large scale components of a purely barotropic flow travel rapidly westward, the very large scale troughs almost exactly replacing the large scale ridges in 48 hours. Since the large scale trough off the east Asian coast in winter is actually quasi-stationary, the barotropic forecasts contain a systematic positive error in that region. Similar reasoning appears to account for other persistent features of the error pattern.

These stationary, very large scale components of the flow have a much larger amplitude in winter than in the other seasons. Their existence is clearly due to factors not accounted for in the simple barotropic model. Although they are not understood completely, they must ultimately be due to terrain features not included in the forecast model, heating and cooling from contact with the underlying surface, and the existence of preferred locations for baroclinic processes. Since these components of the flow are remarkably persistent and stationary from day to day, it is possible to remove from the forecasts those errors associated with their retrogression in a purely barotropic forecast. This is done as follows:

1) Compute the phase and amplitude of the three longest wave components around each latitude circle. The sum of these three components will be designated the "ultra-large scale component". The ultra-large scale component at the beginning of the forecast period is regarded as the "stationary"component.

2) At regular intervals through the forecast period, compute the ultra-large scale component found at that time. Subtract it from the current wind field, and add the stationary component. This procedure tends to hold the very large components stationary, but permits interaction between components of large and small scale.

The procedure outlined above has been tested in a number of winter cases, and has been found to reduce the root-mean-square height error of 48 hour forecasts by about 47% on the average. The reduction of RMS error ranged from 39% to 55% in the cases cited. A more detailed description of the results will be included in a forthcoming Tech. Memo.

Methods of correcting persistent errors by improved design of the physical models are under study at the present time.

# JOINT NUMERICAL WEATHER PREDICTION UNIT

## BULLETIN NO. 25
(effective 26 June, 1958)

Reference: JNWP Unit Bulletins 22, 23, and 24

Effective with 12Z data of 26 June 1958 a new barotropic forecasting program will be introduced in order to obtain greater accuracy in forecasting long and very long atmospheric waves. A modification of the free-upper-surface model of Rossby, similar to Bolin's tropopause model [1] is used for the forecast equation. This will be described in detail in a forthcoming JNWP Unit publication.

This model contains a divergence field which has the effect of almost completely stabilizing the very long waves, while permitting some movement of the long waves, and giving practically no interference with short waves. This can be contrasted with the procedure previously used, as described in JNWP Bulletin No. 23.

An extensive series of tests indicates a reduction of r.m.s. height errors over the previously used barotropic model of about 10%.

[1] B. Bolin, "An Improved Barotropic Model and some Aspects of Using the Balance Equation for Three-dimensional Flow", Tellus, vol. 8, no. 1, Feb. 1956, pp. 61-75.

Joint Numerical Weather Prediction Unit

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# Bulletin No. 26

(effective 4 August 1958)

Reference: JNWP Unit Bulletin No. 25

As of 4 August 1958, a two-level baroclinic model, made from 12Z data will be put into routine operation once a day.

In brief, the model may be described as follows:

a) <u>Input:</u> 850 and 500 mb heights.
<u>Output:</u> forecast heights for 850 and 500 mb as well as vertical velocity for 600 mb up to 36 hours in advance.

b) Wind and vorticity at 500 mb are obtained by solving the balance equation, whereas the differential wind 850-500 mb is approximated by the geostrophic thermal wind.

c) The two predictive equations, derived from the vorticity equations for 500 and 850 mb, combined with the adiabatic equation, have the 500 mb stream function and the 850-500 mb thickness as dependent variables. Vertical velocity is computed by means of the adiabatic equation.

d) The prognostic equation for the 500 mb stream function is modified in order to deal with the very long waves, as described in JNWP Bulletin No. 25.

e) The effect of mountains is for the time being not included. In the vorticity equation, the twisting -, vertical advection -, and friction terms have been omitted.

Continued study of the performance of this two-level model may lead to additional features being included at a later date. Also, forecasts for 700 and 300 mb forecasts, obtained by interpolation and extrapolation respectively, may eventually be added to the output.

Joint Numerical Weather Prediction Unit

Bulletin No. 28

Subject: JNWP Unit 500-mb and 850-mb Initial Contour Analyses during the 1959 Hurricane Season

During the 1959 hurricane season, JNWP Unit 500-mb initial contour analyses from which hurricane forecasts are to be made, will deviate from conventional contour analyses in the region of the hurricane or typhoon. The hurricane vortex will be eliminated and flow determined from the large scale circulation will be imposed on the hurricane region. This is accomplished by analyzing for a wind, determined from the hurricane's past movement, inserted as 500-mb data at the hurricane position and blocking out other data within about seven latitude degrees of the position. Subsequent to completion of this 500-mb analysis, a vortex will be reinserted by hand in the initial and forecast charts drawn at JNWP Unit.

The particle at the hurricane position initially will be tracked in the 500-mb forecast stream fields as the hurricane forecast. This technique of analysis and forecasting was tested on a number of Atlantic hurricanes of the 1958 season. The resulting forecasts were excellent.

Consistent with the 500-mb analyses, synoptic 850-mb height analyses will be altered in the region of the hurricane to reflect an 850-mb to 500-mb thickness of approximately 14,000 feet at the hurricane position. This will be accomplished by inserting as 850-mb data at the hurricane position, a calculated 850-mb height value consistent with the 500-mb height and a 14,000 feet thickness for the layer.

JOINT NUMERICAL WEATHER PREDICTION UNIT

BULLETIN NO. 29
(effective 10 November 1959)

Effective with the 12Z charts of the above date, a slight modification has been introduced into the objective analysis routine. This consists of a change in the weighting function and scan radius of the last scan. The effect is to improve the horizontal resolution of the smaller scale systems, particularly near cyclonic centers.

The entire objective analysis system will be described in detail in a forthcoming issue of the Monthly Weather Review.

JOINT NUMERICAL WEATHER PREDICTION UNIT

BULLETIN NO. 30

10 November, 1959

Due to the lack of precise definition of terms, there have been some misunderstandings concerning the units in which vertical velocity charts have been printed. The vertical velocities are in units of -dp/dt in the c.g.s. system, where p is pressure and t is time. To obtain vertical velocities at 600 mb in centimeters per second, multiply by 1.27.

# JOINT NUMERICAL WEATHER PREDICTION UNIT

## BULLETIN NO. 31

January 18, 1960

Beginning with the forecast made from the 1200Z data of January 18, 1960, JNWP will prepare once per day:

(a) Cloud and precipitation forecasts for 24 and 36 hours in advance.

(b) A quantitative precipitation forecast for the period 12 to 36 hours in advance.

(c) 24 and 36 hour forecasts showing areas of rain and snow.

The theory of the cloud and precipitation forecast is discussed by E. M. Carlstead in the Monthly Weather Review for October 1959. The quantitative precipitation forecast follows the lines of S. J. Smebye's development in "Computation of Precipitation from Large Scale Vertical Motion", Journal of Meteorology, December 1958. The snow and rain forecast makes use of the results of H. H. Lamb, "Two-Way Relationships between the Snow or Ice Limit and the 1000-500 mb Thickness of the Overlying Atmosphere", Q.J. Royal Meteorological Society, April 1955, and those of A. J. Wagner, "Mean Temperature from 1000 to 500 mb as a Predictor of Precipitation Type", Sci. Rep. #2, M.I.T., May 1957, Contract No. AF 19(604)-1305.

These computer products are still experimental, but may be useful for guidance material. After you have used them for awhile, we would appreciate your suggestions on how to improve them.

# JOINT NUMERICAL WEATHER PREDICTION UNIT

## BULLETIN NO. 32

September 12, 1960

Beginning with the forecast made from the 1200Z data of September 12, 1960, the barotropic forecasts contain an improved mountain effect and a surface friction effect.

The new representation of rising and sinking of the air over the mountains uses a constructed surface wind for the level of the terrain instead of a constructed sea-level wind as in the previous version. In obtaining the 500 mb. divergence, the vertical velocity from the terrain effect is assumed to decrease linearly from the level of the terrain to zero at 200 mb. In the previous version it decreased linearly from sea level to zero mb.

For computation of friction effects a skin drag coefficient which varies according to the roughness of the terrain is used. The surface wind, as in the mountain calculation, is obtained by interpolating in a linear wind profile which passes through 100% of the 500 mb., wind speed at 500 mb. and 20% of the 500 mb. wind speed at 1000 mb. The wind direction is assumed constant with varying height. The boundary-layer vertical velocity obtained from the friction effect is assumed to decrease linearly to zero at 200 mb.

A series of tests has shown that the inclusion of mountain and friction effects in the form described above leads to improvements in the forecasts over the larger mountainous areas. Maximum height differences introduced in a 48-hour forecast by these effects under extreme conditions are about 500 ft.

A paper containing details has been submitted for publication.

# JOINT NUMERICAL WEATHER PREDICTION UNIT

## BULLETIN NO. 33

December 15, 1960

Effective this date the objective analysis program is augmented to include the analysis of heights, temperatures, and winds for 850, 700, 500, and 300 mbs. The method of analysis at each surface is essentially that described by Cressman.* The modifications described here are due to H. A. Bedient and J. A. Brown, Jr.

In analyzing heights and temperatures a build-up from the lowest levels is employed. The 850 mb heights and temperatures are analyzed, with the reported height data at 850 mbs augmented by extrapolated surface data over the oceans. Following this, the analysis is built up according to Table 1.

The wind analyses are analyses of the components of the observed winds, in the JNWP grid. At the present, these are combined after the analysis to give the isotachs of the observed wind.

It is expected that some details of the analysis program will be changed from time to time. Bulletins will be issued only for major changes.

*Cressman, G. P., "An Operational Objective Analysis System," Monthly Weather Review, vol. 87, no. 10, pp. 367-374, Oct., 1959.

TABLE I

| SEQUENCE | FIELDS | FIRST GUESS |
|---|---|---|
| 1 | 850 mb hts. and temps. | 12-hr forecast for hts. 850 temps. inferred from 12-hr forecast 850-500 thickness. |
| 2 | 850 mb winds | 850 mb geostrophic winds |
| 3 | 700 mb hts. and temps. | A new thickness is formed by subtraction of analyzed 850 hts from 12-hr forecast 500 hts. This is used to obtain a first guess for 700 mb temp. Using the first-guess 700 temps. and the analyzed 850 temps. and heights, a first guess 700 mb chart is computed. |
| 4 | 700 mb winds | 700 mb geostrophic winds |
| 5 | 500 mb hts. and temps. | Using the analyzed 700 mb temps. and a standard lapse rate, a 500 mb temp. guess is obtained. Using this and the 700 mb hts. and temps. a 500 mb ht guess is computed. |
| 6 | 500 mb winds | 500 mb geostrophic winds. |
| 7 | 300 mb hts. and temps. | First-guess temps. obtained from extrapolation of 700 and 500 mb temps. Using these and the 500 mb heights a 300 mb ht. guess is computed. |
| 8 | 300 mb winds | 300 mb geostrophic winds. |

NATIONAL METEOROLOGICAL CENTER

*NUMERICAL WEATHER PREDICTION BULLETIN NO. 34

December 15, 1961

Some time during the latter part of January, 1962 it is planned to implement a 3-level baroclinic model for the main operational forecast calculations. No change in the present operational program is contemplated for the preliminary forecasts. No significant change in operating schedule or output format is expected.

The 3-level model is a nongeostrophic vorticity equation model, carrying both the rotational and irrotational components of the wind. Surface friction and mountain effects are included. Initial data and output information are at 850, 500, and 200 mbs. Vertical motions at 650 and 350 mbs are produced, in units of $-10^{-3}$ mbs/sec. The 650 mb vertical motions will be issued in place of the present 600 mb ones (Bulletin No. 30). Positive signs will represent upward motion and vice versa.

The performance characteristics of the model have been determined by a series of tests which have been evaluated both by jury and by objective numerical measures. These tests indicate a statistically small but definite superiority of the 3-level model at 850 and 500 mbs. over the present operational model over the United States and the Pacific. Over the Atlantic some improvement is obtained, but not much. At high latitudes, where the barotropic forecast is usually very good, no improvement can be obtained by the 3-level model. Improvements are especially noted at 500 mbs during strong cyclogenesis over the east coasts of Asia and North America. The 200 mb forecasts are highly improved in all areas over those obtained by upward extrapolation from the present operational model (and over persistence also). The forecasts at 850 and 500 mbs resemble closely the present operational ones most of the time. However, in strongly baroclinic zones the 3-level model forecasts development. This is of the sense that if the temperature wave lags behind the pressure wave, amplification of the pressure wave takes place. If the temperature wave is ahead of the pressure wave, dampening of the pressure wave occurs. Consequently, cyclonic systems followed by strong cold pushes will generally develop to greater intensity. However, the model contains the essential mechanism of the occlusion process, and will not permit cyclonic growth to proceed indefinitely.

* This bulletin is a continuation of the JNWP Bulletin series.

The errors of the 3-level model as observed in the tests are generally highly correlated with the errors of barotropic forecasts. However, they are often significantly reduced in areas of strong temperature advections. In the situation so characteristic of Mississippi valley cyclonic developments, where only a moderately strong baroclinic zone is found, but high moisture content, small static stability, and copious precipitation accompany sudden cyclonic development, the 3-level model gives forecasts no better than those obtained by the barotropic model.

All analysis problems arising in connection with baroclinic forecasts have not been solved. Over sparse data areas erroneous vertical tilt of systems sometimes develops. This problem is also aggravated by errors from other sources, not all known.

The model uses the wind approximation

$$\mathbb{V} = k \times \nabla\psi + \nabla\chi,$$

where $\psi$ is the stream function obtained from the balance equation and $\chi$ is the velocity potential. A diagnostic equation for vertical velocity is solved;

$$\nabla^2\omega + \frac{(f+\zeta)f}{s}\frac{\partial^2\omega}{\partial p^2} + \frac{f}{s}\frac{\partial(f+\zeta)}{\partial p}\frac{\partial\omega}{\partial p}$$

$$= \frac{1}{s}\left\{ f\frac{\partial}{\partial p}\left[\mathbb{V}\cdot\nabla(f+\zeta)\right] - \nabla^2\left(\mathbb{V}\cdot\nabla\frac{\partial\varphi}{\partial p}\right)\right\}$$

where p is pressure, $\omega$ is the vertical velocity measure, dp/dt, $\zeta$ is the relative vorticity, f is the Coriolis parameter, s is the static stability (assumed to be horizontally constant), and $\varphi$ is the geopotential. For solution of the diagnostic equation only, the second term of the wind approximation is neglected.

For the lower boundary condition, an extrapolation (or interpolation) is made to the level of the ground from the stream functions at 850 and 500 mbs. The stream function obtained in this manner is used for calculations of mountain and surface friction effects to obtain a value of $\omega$ at the lower boundary. Then from the equation of continuity the velocity potential is obtained, i.e.,

$$\nabla^2 \chi + \frac{\partial \omega}{\partial p} = 0.$$

Following this the prognosis is obtained from the vorticity equation,

$$\frac{\partial \zeta}{\partial t} + V \cdot \nabla(\zeta + f) + \eta \nabla^2 \chi + k \cdot \nabla \omega \times \frac{\partial V}{\partial p} = 0.$$

A time extrapolation is made to obtain new values of the stream function and the balance equation is employed to obtain new values of the geopotential. Following this the process is repeated, beginning with another solution of the diagnostic equation.

UNITED STATES DEPARTMENT OF COMMERCE

WEATHER BUREAU

NATIONAL METEOROLOGICAL CENTER

BULLETIN NO. 35

September 1963

At 1200 GMT September 15, 1963 a new truncation error* control was introduced into the NMC 3-level baroclinic (5+30) model. The same error control had been introduced into the RADAT (1+30) barotropic model at 0000 GMT August 24, 1963. It will also be incorporated into the preliminary (4+30) barotropic forecast as soon as possible.

The introduction of truncation error control into the operational models is based on experimental forecasts in which the order of magnitude of truncation error has been reduced in jacobians or advective terms in the forecast equations. It was found that the principal benefit to be derived was in the forecast displacement of systems, particularly those of small scale.

<u>The Method</u> --

Curve A in the figure shows the response,

$$\frac{f(x+\Delta x) - f(x-\Delta x)}{2\Delta x} \Big/ \frac{\partial f}{\partial x}(x)$$

of a centered difference estimate across two grid increments of the first derivative.

The function $f(x)$ is taken here to have the form

$$f(x) = \binom{\sin}{\cos} kx$$

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* Truncation errors are inherent in replacing exact differentials by finite-difference approximations.

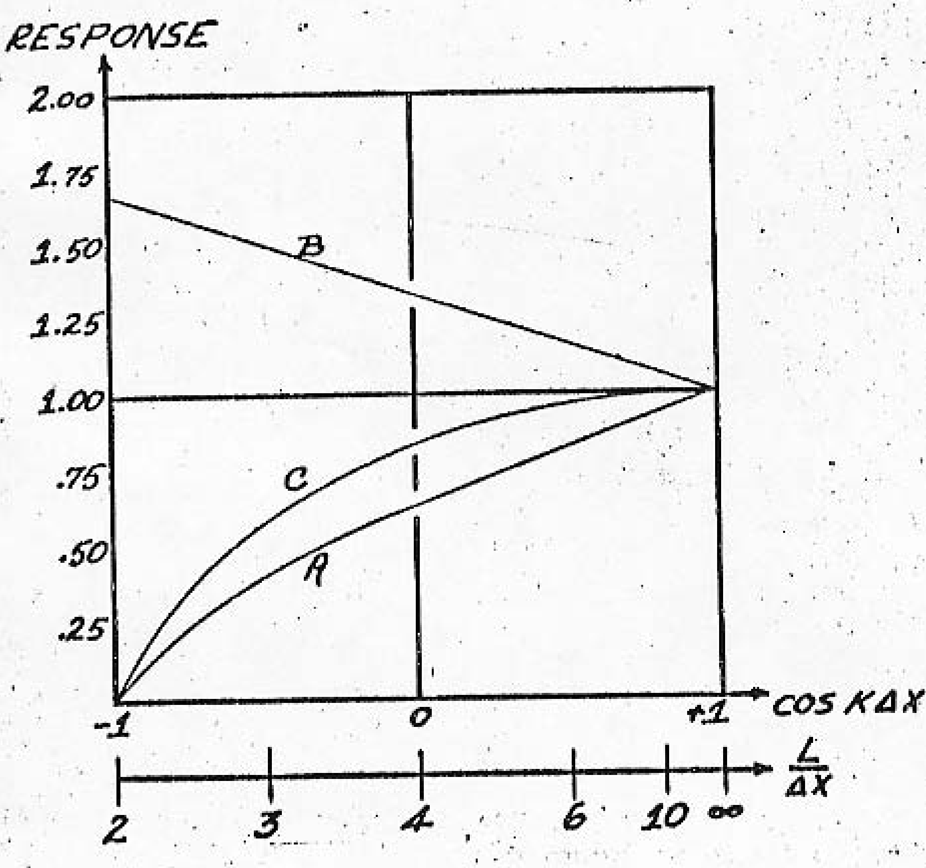
Curve B shows the response,

$$\frac{-1/6\ f\,(x - \Delta x) + 4/3\ f\,(x) - 1/6\ f\,(x + \Delta x)}{f\,(x)}$$

of an elemental "unsmoothing" operator.

Curve C shows the combined response of the other two operators, and represents the response of a centered difference estimate of the first derivative in which truncation error has been reduced, particularly in the longer wave lengths.

These are the essentials of the truncation error control system being introduced in NMC. The ordinary first difference is treated with the "unsmoothing" operator to correct the "smoothing" effect of the difference operator.



UNITED STATES DEPARTMENT OF COMMERCE

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BULLETIN NO. 36

December 1964

Beginning with the forecast from 1200 GMT Dec. 1, the RADAT (1+30) barotropic forecasts will be made with a new "mesh-model" program. The model used is identical with the 850-500 mesh model used at NMC until 1962 except for the computation of the divergence term due to mountain and surface friction effects. [1] In the old version the wind at the earth's surface was assumed to have the same direction as at 500 mb and the speed was reduced by a factor depending only on the height of the surface. This source of error was discussed in [2]. In the new version, the wind at the surface is obtained by extrapolating the 500 mb stream winds downward using the thermal wind shear obtained from hourly 850-500 mb thickness forecasts. In this respect the new model is similar to the current operational 3 level baroclinic model. (See NMC Tech Memo #22 1963.)

Since the slight divergence at 500 mb is due only to mountain and surface friction effects, this new mesh model, like the old one, is essentially barotropic in nature. Differences between this model and the 500 mb (only) barotropic previously used for the RADAT forecast should be minor except in cases where unusually strong 850-500 mb shears occur or are forecast over mountainous regions. The new "mesh" includes the truncation error control described in NMC Bulletin No. 35, Sept. '63. This control was also used in the previous RADAT barotropic model.

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[1] Cressman, G. P., "Improved Terrain Effects in Barotropic Forecasts", Monthly Weather Review, Vol. 88, Nos. 9-12, Sept-Dec. 1960.

[2] Fawcett, E. B., "A Study of Errors in Barotropic Forecasts of Cut-off Lows in the Southwestern United States During Fall and Winter of 1961-1962", Technical Note No. 8, Office of Forecast Development, U.S.W.B. May 1962.