NOTE

Report on a conference on the application of numerical methods in forecasting atmospheric flow patterns.

During the week of 12 to 14 May, 1952 a conference was held at the Institute of Meteorology, University of Stockholm, on the various aspects of numerical methods for forecasting atmospheric flow patterns. The following papers were presented. (Some of the papers will be published in forthcoming issues of Tellus).

May 12

Dr. A. Eliassen[1] (Norwegian Meteorological Institute): *A comparison of different dynamic models designed for computational purposes.* The barotropic model developed by Charney and collaborators at Princeton (*Tellus*, 2, 237—254) as well as various simplified models developed more recently in an attempt to incorporate the baroclinic character of the atmosphere (i. e. Fjørtoft, *Tellus*, 2, 237—254; Phillips, *J. Meteor.*, 8, 381—394; Eady, Eliassen and Bolin) were discussed and compared with specific attention to basic assumptions made and the ease of intrepreting the models in terms of the atmosphere.

Fil. lic. B. Bolin (University of Stockholm): *A series of tests of the barotropic model.* The several independent series of tests of this model were discussed and results presented. (*Tellus*, 3, 248—257, *Tellus*, 4, 21—30, *Tellus*, 2, 237—254).

Civiling. G. Neovius (Swedish Computer Project): *Demonstration of the Swedish relay-computor (Bark).* Bark is a Swedish realy computer similar to Harvard University Mark I and has been in use since spring 1950. An explanation of its operation was followed by a demonstration.

May 13

Dr. J. Bellamy (Cook Electric Company, U.S.A.): *Comments on the communication problem.* The speed of the modern computing machine points out the urgent necessity for speeding up the transmission of weather data from the observer or instrument to the forecaster. Since most of the time involved is spent in coding or decoding for purposes of transmission, accessibility and utility, it was suggested that a method of representation be developed which would serve all purposes and eliminate the necessity for more than one code. A unitary decimal digitary system which can be read automatically or visually was suggested as a possible solution.

Prof. R. Fjørtoft (University of Copenhagen): *Preliminary tests of a simplified graphical method for integrating the barotropic vorticity equation.* By advecting the vorticity field with a spacially-averaged wind field a 24-hour forecast may be obtained in one time step. Since this whole method is done graphically a forecast may be completed in approximately three hours by one person. Results look encouraging although no statistics are available yet.

Fil. kand. G. Kjellberg (Swedish Computer Project): *The Swedish Electronic Computer (BESK).* This computer is of the Princeton type and is expected to be completed during 1953. It has an internal memory capacity of 256 40-binary digit numbers. The capacity will be increased by magnetic drum storage. The speed and capacity of this machine will permit its use for meteorological purposes.

Prof. E. T. Eady[2] (Imperial College of Science, London): *Methods of representation and techniques of integration of Poissons and Helmholtz's equations.* Dr. Eady indicated some of the main points to be considered when planning the *continued* integration by

[1] Deputy director of the Institute of Meteorology; on leave from Norwegian Meteorological Institute.

[2] Temporarily attached to the Institute of Meteorology, University of Stockholm.

mechanical methods of the Poisson and Helmholtz equations appearing in problems of largescale atmospheric flow. For a *single* integration, three main methods have been used, namely Green's function, harmonic (or spherical harmonic) analysis and mechanical "relaxation"; the last is probably both the quickest and the simplest to programme for large networks, being particularly suitable when spherical coordinates must be used. However, the use of finite difference approximations to differential coefficients leads to errors which may mount up and become serious when the integration is repeated many times.

May 14

Dr. A. Eliassen and Lt. W. Hubert[2] (Office of Navel Research); *A three dimensional study of the vertical motion and the vorticity balance in a blocking case.* The barotropic model was applied to a blocking situation over Eastern Atlantic and Western Europe. The computed 500 mb tendencies showed certain significant discrepancies. Tendency computations were also performed on the maps of height averaged with respect to pressure, but there were still considerable errors. The incorporation of the mean thermal vorticity advection improved the tendencies somewhat.

Interpreting the errors as a combined effect of horizontal divergence and vertical vorticity transport, the vertical motion necessary to explain the local vorticity changes was computed at 850, 700, 500 and 300 mb. The result is in excellent qualitative agreement with the vertical motion inferred from observed weather phenomena.

Fil. lic. B. Bolin: *A study of the three dimensional field of vertical motion in a selected case and some remarks on baroclinic models of the atmosphere.* The vertical velocity was computed by the same method as reported by Eliassen and Hubert. The importance of the term expressing a transformation of vorticity around the horizontal axis into vorticity around a vertical axis was demonstrated in a synoptic example with a pronounced frontal zone. Some of the basic parameters for incorporating the baroclinic structure of the atmosphere in numerical forecasting procedures were discussed.

Dr. C. W. Newton[2] (University of Chicago): *Comments on the analysis and data problems associated with numerical forecasting.* Since present numerical prognosis methods involve multiple differentiation of the isobaric contour field, the analysis used must be more accurate than those in ordinary forecasting practices. Smoothness and space- and time-continuity of the vorticity field are essential. Subjective analysis methods must be used at present since objective analysis of any but the larger-scale features of the circulation is very inaccurate due to the inhomogeneity and inaccuracy of radiosonde observations. For improvements in either subjective or objective analysis, an increase in the density of the radio wind-finding network is the most urgent need.

Dr. S. Reisch (Royal Institute of Technology, Stockholm): *A proposed analog type of computer for use in numercal forecasting.* The principles for a machine for solving partial differential equations by relaxation methods were explained. By using a "spider" with a series of adjustable heads the information required from the storage fields (magnetic drum or magnetic tape) during the process of relaxation are available simultaneously, whereby all transfer problems are simplified considerably. The computational units also become simpler than those at present in use in electronic computers.

May 15

Prof. J. Van Mieghem[2] (University of Brussels): *Energy conversions in the atmosphere on the scale of the general circulation.* The equations of the mechanical energy of the zonally averaged motion, of the kinetic energy of the large scale eddies and of the internal energy are deduced from the equations of motion and from the first law of thermodynamics. The fluxes and the rates of production of these energy forms are given. The two most important energy conversions on the scale of the general circulation are: 1) For the maintenance of the large scale disturbances, the conversion of potential energy into the kinetic energy of the large scale eddies as a result of the positive correlation between the fluctuations of temperature and vertical velcity; 2) For the maintenance of the mean zonal motion, the conversion of kinetic energy of the largescale eddies into kinetic energy of the mean motion as a result of the signs of the lateral Jeffreys stress and of the meridional mean zonal wind shear.

Met. K. Hinkelmann (Weather Bureau, Bad Kissingen): *A report on preliminary tests of a three-dimensional model in Bad Kissingen, Germany.*

From the quasi-static and geostrophic approximations, a linear, second-order differential equation in the height tendency is derived, using pressure as vertical coordinate. The boundary conditions at the top and the bottom are used in an integrated form to avoid non-centered differences when a finite grid is used. The com-

[2] See note p. 141.

putation of the coefficients of the equation from the synoptic data is discussed.

The equation is solved by relaxation for a standard atmosphere with the inhomogeneous term equal to unity in one gridpoint, and zero in all other points. Three Green's functions for the tendency field computed in this way, and with the disturbance located at 900, 500 and 200 mb respectively, are demonstrated.

Met. S. Smebye[2] (Norwegian Meteorological Institute): *A numerical test of a simplified atmospheric model.* It is possible to take the thermal structure of the atmosphere into account in a crude manner by expressing the vertical temperature distribution as a function of the deviation of the 1,000—500 mb thickness from some standard value. The function is chosen so that a warm troposphere gives a cold stratosphere and vice versa. The height of an isobaric surface and the thickness are the variables to be evaluated. Surface tendencies may then be computed. In the first case computed the calculated tendencies are an improvement over those calculated with the barotropic model.

Fil. lic. O. Lönnquist (Swedish Meteorological and Hydrological Institute): *Present methods in common use for forecasting upper flow patterns.* Particular emphasis was placed on methods in use for preparing the prognostic 500-mb chart. It was stressed that the results of present methods must be used as a standard in judging the value of numerical forecasting techniques. The average of the correlation coefficients between forecast and observed 24-hour changes of the 500 mb surface for two years at Swedish Weather Bureau was 0.72. The correlation coefficients were highest when pure extrapolation methods were successful.

Mr. Ph. Clapp[2] (U. S. Weather Bureau): *Application of the barotropic model to medium and long range forecasting.* The simple barotropic vorticity equation has been used to compute height tendencies on a few 5-day mean 500 mb charts. The results are approximately as good as similar computations made on synoptic charts despite the fact the time intervals between observed charts are 5 times as great. The method may be applied to forecasts of mean monthly circulation patterns provided some account is taken of the effects of transformation of potential into kinetic energy, surface friction, and non-adiabatic heating. A first approximation to these factors can be obtained by setting them equal to their climatological or normal values.

[2] See note p. 141.

Dr. F. A. Berson (Swedish Meteorological and Hydrological Institute): *Barotropic tendency computations on motions of different time scales.* The response of 5-day mean 500 mb flow to barotropic redistribution of vorticity is tested in a summer blocking situation. The average linear coefficient of correlation between observed contour height changes in three days and those obtained from the barotropic tendencies is as low as 0.49 but increases to 0.71 by using a constant correction equal to the over all "error" for the entire period. A large part of the "errors" could be ascribed to two main effects:

1) standing perturbation possibly set up topographically by the Rocky Mountains;
2) horizontal transfer of vorticity by eddies of comparatively small size. The coefficient of eddy diffusivity is evaluated for a period of 14 days and turns out to be negative.

May 16

Met U. Czapski[2] (University of Hamburg): *A comparative study of barotropically computed 500 mb tendencies for different grid positions and grid sizes.* Considerable differences between vorticity fields were obtained if different grid points and grid sizes were used in barotropic computations and similarly for tendency fields. An improvement of the forecast was obtained if all points were included in the computations instead of every other as was done in the tests reported by Bolin. It is important that computations are done for every grid point in the grid used. The most feasible grid size needs careful consideration.

Dr. L. Vuorela[2] (University of Helsinki): *A synoptic study of deformation fields.* The horizontal deformation has been computed for a situation where the barotropic tendency computation failed as well as for several other situations. The maximum values obtained meant a horizontal dilatation of the order of three times in six hours.

Fil. lic. G. Arnason (University of Stockholm): *Presentation of a baroclinic three dimensional atmospheric model.* The model used consists of a troposphere with constant lapse rate and an isothermal stratosphere. Four basic parameters are used to describe the temperature, pressure, and wind fields; 1) Surface temperature, 2) surface pressure, 3) tropospheric lapse rate and 4) height of tropopause. The mathematical problem of solving the dynamic equations using this model is reduced to solving two partial differential equations in two dimensions. The surface tendencies and average vertical velocities are obtained.

A large number of atmospheric models have been suggested for numerical forecasting. It seems that the general approach will turn out to be fruitful, but we can not judge about the detailed path to be followed until a series of complete forecasts have been made using these various models. A few of the unanswered questions which received particular attention at the conference are as follows. In the first place is a point representation of the variables most feasible or is a representation by functions better? This question is intimately connected with the best way of solving the various differential equations. It also brings up for discussion the question of how to take care of inaccuracies that are introduced by the finite difference method. The magnitude of the deformation field indicates that features which at one instant are caught by the grid are sometimes lost on a later occasion. Furthermore, how many layers or parameters are needed in the baroclinic models in order to account for the major effects of the baroclinicity of the atmosphere? Many of these questions must wait for solution until the high speed computers are available to perform the complete forecasts.

Until these computers are available for routine computations of this kind it is believed that the simple graphical method presented by Fjørtoft will turn out to be very useful. The method is very well suited for being immediately incorporated into the daily routine of forecast centers and tried out in combination with the present methods in use.

In this connection it should be stressed, however, that these methods merely give the three dimensional field of motion as a function of time. In order to prepare an ordinary forecast this field has to be interpreted in terms of weather. This problem represents a major part of the problem of weather forecasting. Here the large number of statistical investigations carried out at forecast centers and elsewhere all over the world should be utilized. However, the vertical velocity field, that is obtained explicitly as a part of the computations using any of the baroclinic models proposed, will simplify this process of translating the flow pattern into weather phenomena.

It was repeatedly stressed that an accurate and careful analysis of the atmospheric flow patterns is of primary importance. At present it is not possible to accomplish this except over limited areas. For example the number of upper air observations over the Atlantic Ocean is hardly sufficient for the needs asked for here.

Even if the problem of numerical forecasting of the upper flow patterns is solved successfully, the process of preparing input data for the machine must be made more efficient. Here the communication problem as well as the problem of objective analysis perhaps represent the two most important problems. With regard to the objective analysis the discussion brought out the need for a method of obtaining a more accurate analysis in the vicinity of a single station by consulting the time record at the station and making use of some dynamic principles.

Some of the results reported here are very tentative and should perhaps in many cases be interpreted as indications of where future research should be concentrated. It is quite obvious that the most important problem at present is to get high speed computors available for all different tests that could answer several of the questions formulated above. However it seems as important that a closer collaboration be established between the mathematicians familiar with the machines and the meteorologists so that the former understand the basic problems of meteorology and the latter can think in terms of the machines. It may be of some interest to mention that an attempt to initiate such a closer collaboration will be started this fall at the Institute of Meteorology, University of Stockholm in cooperation with the Computer Project in Stockholm. A series of lectures will be given dealing with the basic theory of the computers, programming and coding problems.

Bert Bolin, Harriet Newton.