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FORECASTING IN CANADA - PAST, PRESENT AND FUTURE

A Panel Discussion

Historical Development .... - K. T. McLeod, M.A.
Numerical Forecasting .... - Dr. W. L. Godson
Forecasting by Statistical Methods .... - B. Muller, M.A.
Forecasting by Assembly-Line Procedures .... - B. W. Boville, M.A.
Moderator .... - Dr. D. P. McIntyre

Presented at the regular meeting of the Royal Meteorological Society, Canadian Branch, Thursday, May 27, 1954.

PREFACE

The panel discussion recorded herein is a departure from the normal proceedings of meetings of the Canadian Branch of the Royal Meteorological Society. It was voted a success by all members in attendance and should, therefore, be followed by many more of the same type of meeting which has become increasingly popular as a means of holding audience interest on radio and television in recent years. The difficulties in producing an accurate transcription of the discussion have also been encountered and hurdled for the first time. From the experience gained, improved procedures will result and will ensure that an accurate record is obtained in future.

The recorded panel discussion, which follows the four short papers presented by the panel members, is not an accurate reproduction of the proceedings in detail. For instance, all participants in the discussion, whether panel members, moderator or audience, are not necessarily specifically mentioned, but the subjects or queries raised by them are included and covered by the remarks of other speakers.

M.G.H.

HISTORICAL DEVELOPMENT

K.T. McLeod, M.A.

A new science usually begins with a few chance observations of certain phenomena. Interest is created, and an organzied program of observations results. Eventually, the observations are worked up in a systematic manner, more or less along statistical lines. Then the theorist tries to extract from the observations and from any empirical rules that may have been devised, the laws of nature that govern the phenomena. With the discovery of these laws, the science passes from the descriptive stage to the exact.

Visual weather observations go back at least to the Fifth Century B.C. Instrumental observations in the Sixteenth Century mark the first step towards exactitude.

The dawn of forecasting came with the Royal Decree of the French Emperor, Napoleon the Third, who charged the astromomer, Leverrier, with the task of organizing a system of weather forecasting. Leverrier, uncertain but undaunted, back-casted a destructive Black Sea storm, and from his observations concluded that storms could be followed from plotted and analyzed weather charts, and their future movement extrapolated. Simultaneous observations were essential, but they awaited the invention of telegraphy in 1844 and more recently the radio and teletype.

With rapidly expanding networks of surface observations, the development of the scientific balloon, the aeroplane meteorograph and later the radiosonde and radar tracking techniques, came accelerated theoretical and statistical research and steady growth in the art of forecasting. Worthy of note in passing are Buys Ballot's Law, developed in 1860, Helmholtz' papers on atmospheric motion, Bjerknes' circulation theorem, 1898, and Solberg's addition to the wave theory, of the inertia force due to the earth's rotation.

But the most startling advances in meteorology have come relatively recently. Among the outstanding achievements during the past thirty years are the discovery of the polar front, the wave theory of cyclones, the airmass and frontal methods of weather forecasting developed by Bjerknes and his collaborators in Norway,isentropic analysis as initiated by Rossby and his collaborators in the United States, the expansion and application of Rossby's long-wave theory, discovery of the Jet Stream, fostering of numerical forecasting by Charney and Elaiison, and the Canadian contribution - the 3-front model and FCA charting - offspring of Penner-Crocker-Godson and the CAO staff.

Today, forecasting in Canada may seem to have settled into a routine; methods may appear to be pretty much standardized. Yet, realize it or not, we are being swept along in the tide of progress. The results of analytical studies, of objective investigations, and of statistical and theoretical research persistently lead to local stirrings of forecast offices and forecasters. Rules for forecasting tornadoes appear, precipitation patterns are typed and rules applied, and isotach wind patterns are tested on high-level charts. Meteorology is in a continual state of unrest; forecasters are subjected to and adjust in some degree to the continual flow of reports, journal contributions and circulars on research and investigation.

The recent acceleration of progress within the Canadian Weather Service is illustrated by reference to the Annual Report of 1904. Fifty years ago, synoptic reports were received twice-daily from 34 Canadian stations. The Annual Report advises that the weather was charted twice-daily, Sundays and holidays included; no aviation forecasts were issued; no upper-air observations were taken. 12,970 predictions were made for 10 regions with a percentage of fulfilment of 85.6%.

We've passed through the pioneering stage, let us hope, ably guided by such leaders as Petterssen, who broke trail with his kinematical extrapolation methods of forecasting. Unfortunately, Petterssen's method, in its simplified form, ignores acceleration terms, and the more complete formulas are too difficult to apply. Extrapolation of the current trend can furnish a first approximation of the prognostic synoptic chart, but every experienced forecaster automatically searches the current and past synoptic charts for indications of changes in the trend of development. The key to more accurate forecasting lies within the capabilities of the forecaster to discover and interpret these indications. The experienced forecaster has a distinct advantage here, with his accumulated knowledge of the usual course of development of weather patterns in a given area. In certain cases the experience of the recently posted meteorologist can be bolstered by statistical, climatological or objective studies, which, by developing a group of empirical rules, tend to partly compensate for lack of experience, and contribute as well to the scientific development of meteorological knowledge. We are all more or less aware of the growth and present state of forecasting methods in Canada. We remember - although the memory grows fainter - our almost explosive expansion during World War Two, under Doctor Patterson; the post-war period of reorganization under Mr. Thomson and Mr. McTaggart-Cowan, with our detailed manuals, technical circulars and annual conferences.

We have adhered rigidly to the single-service system. We have adopted the plan of advancement, consolidating and advancing again, incorporating as may be practicable the cream of the research in Canada and elsewhere, as we exploit the analytical and deductive style of forecasting. If we pause and ponder the logic of turning aside to explore other branches in the road leading to our goal of more accurate and longer-range forecasts, we may wonder what potential value - what true merit - lies awaiting in the green fields of numerical forecasting and applied statistical procedures, and other tempting and at times elusive schemes - or, should I say, fruitful alternatives - that periodically open out before us.

Whether 'tis wiser to exploit our chosen system or explore one or other of the currently-fashionable altermates, I leave to my colleagues to advise and our audience to determine.

NUMERICAL FORECASTING

W.L. Godson

The application of the laws and techniques of mathematical physics to forecasting has long been recognized to be a proper objective for theoretical meteorology, as well as a logical approach to forecasting problems. This philosophy was championed by V. Bjerknes as early as 1904, and was stated by him, in 1911, in the following words: "Inasmuch as we know the laws of hydrodynamics and thermodynamics, we know the intrinsic laws according to which the subsequent states of the atmosphere develop out of the preceding ones. We are therefore entitled to consider the ultimate problem of meteorological science, that of precalculation of future states, as one of which we already possess the implicit solution, and we have full reason to believe that we shall succeed in making this solution an explicit one according as we succeed in finding the methods of making full practical use of the laws of hydrodynamics and thermodynamics".

The basic tools for the utilization of these laws were fashioned by L.F. Richardson and published by him, in 1922, in a book entitled "Weather Prediction by Numerical Process." As the title implies, the integration forward in time of the equations of atmospheric dynamics and thermodynamics was to be accomplished by numerical means, employing finite increments of space and time, rather than by the analytical formalism of integral calculus.

Despite this brave beginning, numerical forecasting languished sadly during the next 25 years, for two basic reasons. In the first place, the staff and time requirements of Richardson's techniques were prohibitive. In the second place, a trial pressure forecast presented by Richardson was fantastically inaccurate. The fundamental reason for this failure was not appreciated until after Courant, Friedrichs, and Lewy had developed, in 1928, criteria for the stability of numerical integration procedures. The avoidance of such instability in the forecast problem did not, however, appear possible at that time.

By the late 1940's, the stage had been set for a dramatic revival of interest in numerical forecasting, and indirectly, in theoretical meteorology as a whole. The advent of the high-speed electronic computer, which compressed one year with a desk calculator into one hour of automatic operations, brought the forecast problem within the realm of existing resources. On the theoretical side, studies by Charney and others in 1947 and 1948 had revealed that atmospheric models of surprising realism resulted when major simplifications were introduced into the laws of dynamics and thermodynamics. Fortunately, these same simplifications greatly reduced the danger of computational instability, and the resulting numerical techniques have been applied, with reasonable success, to many prognostic examples since 1949. It is, clearly, too early to attempt to gauge the relative or absolute merits of present-day methods of numerical prediction. Suffice it to say, that the Air Research and Development Command of the U.S. Air Force has been so impressed by the rapid development in this field that they are instituting late this year, in cooperation with the U.S.W.B. and U.S. Navy, a fully-operational unit for numerical forecasting. This was reported, a month ago, in a speech to the American Meteorological Society by General Floyd B. Wood, Deputy for Development of the Air Research and Development Command.

In view of the extremely rapid progress in this field in the last five years, the ultimate success of numerical prediction techniques appears assured. The routine use of such techniques for the preparation of prognostic 24- and 48-hour charts of contour heights and vertical velocities is, to me at least, inevitable. There are a number of reasons for this belief. In the first place, the broad-scale atmospheric features, associated with clearly-definable weather patterns, are characterized and governed by relatively simple properties and laws which are ideally suited to numerical analysis and treatment. These properties and laws include: the quasi-geostrophic character of the wind field; the quasi-conservatism of a mid-tropospheric level of negligible divergence; the limited effects on short-range atmospheric evolution of surface friction and topography, eddy diffusivity, radiation, and evaporation and condensation; and, finally, the basic simplicity of the more-intense thermal patterns, associated with parallelism of fronts. In the second place, the major effects of vertical motions are incorporated in the computation routine. Thirdly, vertical consistency between prognostics at various levels is automatically achieved. Finally, the gradual interaction between developments at various levels, including the effects of modifications to the steering current, is allowed for by the sequence of one- or two-hour time extrapolations using centred finite differences, a procedure which is automatically correct even in the presence of first-order acceleration-type terms.

Finally, a look into the future. Many meteorologists envisage the day when raw data from teletype circuits will be fed directly into an electronic computer, which will check the data and store the information at grid, rather than observation, points by fitting high-order polynomial expressions to the data at various levels. With this accomplished, the machine will proceed to grind out prognostic contour-height and vertical-motion data for various levels and time-intervals, and these data will emerge as teletype transmissions. The prognostic computations would presumably incorporate many features absent in present-day techniques - such as the contributions of non-adiabatic processes and of ageostrophic advection. Developments such as these will require computers capable of greater speed and memory capacity than are now available, as well as advances in numerical procedures, but it would be folly to deny that they are both possible and feasible. In the more-immediate future, however, we shall have to be content with 24- and 48-hour prognostics, at the surface and for several upper levels, which will be only slightly more accurate than those which could be prepared, by experienced forecasters, using conventional techniques. On the other hand, the vertical motion charts, which will be produced simultaneously, will represent a tremendous potential advance in the science of forecasting, by permitting a full appreciation of the single element most responsible for weather, or its absence. Quite literally, these charts will add a new dimension to the tools available to the weather forecaster, and it is in this phase of numerical forecasting that I look for the earliest realization of the benefits that should accrue when the evolution of the atmosphere is traced out, in advance, using the same basic principles and laws which the atmosphere, itself, follows.

FORECASTING BY STATISTICAL METHODS

OR

"Systematic Use of Experience"

B. Muller, M.A.

I was rather confused that I should be picked out of the Malton staff as a representative, I presume, of the practising forecaster to present my ideas about the direction for progress for Meteorology in Canada. On further reflection I have decided there may have been ulterior motives ....even my thick forecaster's skin, which I have developed in recent years, would not allow me to participate in a Royal Meteorological Society panel while still classified on the books of that Society as a Delinquent ....Mr. Treasurer here are my dues for 1954.

I am sorry that the program lists 'Statistical Methods' as my cure-all. When I was asked to speak I accepted more on the idea that I, as one man in the field, would present my thoughts about the way out of the difficulties that beset me from day to day. In its broadest sense I do believe that statistics present the answer to many of our short period forecast problems... and by that I mean that I have developed the conviction, amounting almost to an obsession, that far too much emphasis is placed in practice and in research on obtaining solutions to the forecast problem by physical and mathematical reasoning concerning the current synoptic situation and its immediate history. I believe that we make use of past experience only in an unreliable and haphazard way and that our forecasting procedures and research are not geared to making the past readily available in the prediction of the future.

With this conviction I readily accepted to participate in this panel and found to my joy that indeed exciting new prospects have been opened up in this field. I also found that they appear to have gone by without creating much interest in the current meteorological literature. This new development, it should not surprise us to find, comes from Norway. Since I have not seen it referred to in current reviews of meteorological progress, I take the liberty of assuming that many of us here tonight have not heard of this work and so I will spend the rest of my few minutes describing it.

The method is due to Elias Grytoeyr and appeared in Geofisike Publikasjoner, Vol. 17, No. 9.

Grytoeyr's method is based on the idea that previous attempts to classify synoptic charts have been either too static (pressure system classification) or too general (Synoptic types). The daily synoptic charts present the best possible synthesis of current weather, but Grytoeyr desired a higher synthesis which would show the movement of weather, and accordingly he developed his Clue Diagram Method.

This method consists of plotting on a time-space diagram the movement of all airmasses which might be assumed to affect his forecast area centred in Oslo. The horizontal axis is chosen as the time axis and four vertical lines are erected per day to represent synoptic hours. At each synoptic hour is entered the distance along the normal from Oslo to every significant front within a given radius of Oslo. The cold side of a front is reckoned positive and the warm side nagative. Thus warm fronts make their appearance on the top left and their 'distance lines' slant downward to the right. Cold fronts appear on the bottom and move upward to the right. Occlusions are represented as dashed lines and their distance lines are usually positive at first.

In addition the 'past weather' for each synoptic hour and the amounts of precipitation observed are noted and, on their appropriate line, maximum and minimum temperatures. Notes may be added concerning unusual phenomena and references to a press clipping file concerning the effects of weather. Airmasses are represented by broad shaded lines. The breadth of the line indicates the degree to which it represents typical airmass characteristics. Usually tropical air comes in with a frontal distance line, or if there is no good front between it and Oslo it may simply appear as a broad band at a distance corresponding to the nearest point where true tropical air may be said to be found. Arctic air is only represented when actually over Oslo and so appears as a broad band which rests on the time axis.

Underneath the airmass portion of the clue diagram, and located at convenient intervals, are path charts. These show the movement of pressure systems. An arrow indicates the movement of a cyclone, a small circle connected to the arrow indicates either cyclogenesis or cyclolysis. An 'H' stands for high pressure, and its movement is also indicated by an arrow. The time interval for each path chart is shown by brackets on the time axis.

There are a number of further details but time does not permit their description.

Using this method, charts for twenty years from Oslo's weather archives have been entered on clue diagrams; the result I hold here in this sheaf of papers in my hand - the complete index to some fifty thousand weather charts. It should be noted that the originals are twice the size and details stand out much more clearly.

These clue diagrams have been used to discover analogues. Using only corresponding months some one hundred meteorological tangencies have been discovered lasting from 2 - 12 days. Using adjacent months Grytoeyr estimates the number of tangencies would have been doubled, making 200, or 10 per year.

A very interesting feature shows up when the frequency of analogues is plotted with respect to time of their separation....a very pronounced maximum is found at about ten to twelve years. This is taken to correspond to the sunspot cycle.

Once discovered, analogues are used in the preparation of prognostic charts and also for preparing the forecast. Of course the analogues are not intended to be used slavishly, but rather the prognosis is to be prepared by detailed physical and logical argument from the differences from and similarities to the current situation. Even using slavish methods, however, a series of tests showed that for three twenty day periods the analogue forecast had a slight edge on the conventional method.

The method of using the clue diagrams is not in the least time consuming. Less than a quarter of an hour suffices to select four or five likely cases. The current situation is plotted on a transparent clue diagram form and then passed over the historical diagram until a likely situation emerges. It is found that the path charts for the most part give the best preliminary selection. Detailed examination of the charts is found to be a little more time consuming. Of course the actual preparation of the prognostic chart and the forecast takes somewhat longer than conventional methods because there is more physical-logical brain work associated with using two or more series of charts as a basis for the forecast than when using the single current series. However this is more than made up for by the increased objectivity. Pencil chewing and agonizing indecision are replaced by logical thought processes.

What of the future of this method? Will enough analogues be found to make it useful? I think yes. On the twenty year period used so far, one hundred forecasting days can be expected to provide thirty days when reasonably good analogues are available....these will include about three tangencies lasting an average of five days each. I mentioned before that there is a very pronounced maximum frequency of analogues at about 12 years, so that an additional fifteen years might be expected to more than double the frequency of analogues to current situations. I believe that sufficient historical material is available to make this method immediately applicable and that for a considerable fraction of the time useful help could be obtained from it.

Apart from the selection of analogues, the clue diagram method enables one to conduct much needed synoptic studies. These have quite an advantage over ordinary statistical studies in that they can be related to synoptic situations and to the movement of weather systems. For instance, a statistical study on the duration and intensity of warm front precipitation at Toronto could readily be undertaken by rapidly selecting all warm front situations month by month over a long period of time.

Since the report of Grytoeyr's work appeared in 1951, I felt that this Meeting should know whether his work is still proving useful. In response to my request for information on this point I received a cable especially for this Meeting. In it Grytoeyr states "Further developments planned ---delayed due staff shortage stop hopeful about possibilities".

In conclusion may I restate my belief that no decisive improvement in short range forecasting is likely until we make systematic use of past experience. Furthermore I believe that Elias Grytoeyr has made a most hopeful advance in this direction and can only hope that funds, staff and time will be made available to investigate the application of this idea to Canadian Meteorology.

FORECASTING BY ASSEMBLY-LINE PROCEDURES

B. W. Boville, M.A.

Introduction

In the first instance it is necessary to consider the factors involved in assembly-line procedures.

In order that such a procedure may be justified the requirement for a product which involves a complex manufacturing process must exist. There can be no doubt on this point insofar as weather charts and forecasts are concerned.

The basic materials must be standardized and organized. In weather reports and the primary fields of the synoptic charts this has to a large extent been accomplished. There remains much to be done with regard to fields concerning higher order derivatives of the atmospheric equations, e.g. thermal gradients (fronts), isotachs, temperature and pressure change, vorticity.

An exact processing system must be set up. The basic materials must be used efficiently and in such a manner as to yield a reliable standard product. Exclusive use of rule of thumb techniques and methods which vary from shift to shift and person to person cannot achieve such an end. The method should be as objective as possible; subjective consideration should follow and complement the objective not replace it.

There must be an organzied and standard system for each step, from basic reports to analyzed charts to prognostic charts to weather forecasts. Further the product of each step must be so formulated that it is self-explanatory and so that the next step may be carried out by a separate section of the assembly line.

The necessary equipment and trained personnel must be available to carry out the procedures.

The fax circuits are now supplying the final link in the communications chain and the trained personnel are slowly becoming available to man the key positions in the assembly line.

Past History

Assembly line procedures were adopted to meet National Defence requirements in the last war. The system of relays from observing station to main forecast office to dependent RCAF offices to consumer (air crew) was instituted. The ideas that an analyst must plot his own chart and that the initial forecaster must brief air crew were abandoned.

Present

The overall assembly line structure is now undergoing a stage of change and consolidation with the operation of the CAO. At present the structure between basic data and consumer is:

The CAO - provides analyzed charts (pressure contour fields, temperatures, fronts, jet stream)

Main forecast offices - prognostic charts and weather forecasts.

Dependent Forecast Offices - specialized interpretation of the charts and forecasts.

Future

The CAO will relieve the main forecast offices of a considerable load in the field of prognostic charts. However the preparation of special progs such as variable time and composite progs will continue to give the Main Forecast Offices considerable responsibility in this field.

Basic Requirements to Make it Work

Efficient communications - The receiving of basic data is now being achieved effectively by teletype. The dissemination of Charts can now be accomplished by Fax.

Standard Systems for basic synoptic analysis.

It is clear that if analyses are to be adaptable to assembly line procedures they must be accomplished in a reasonably objective fashion and subject to ready interpretation. The pressure and contour fields, up to the 500 MB level, which vary in a reasonably linear manner between observed values can be mapped objectively. Elements, such as fronts and jet streams do not fit into this category and in order to achieve objectivity must be analyzed according to fairly rigid definitions and models. With regard to jet streams at 300 MB the field is now defined by isotachs which have a precise interpretation and is analyzed with respect to a reasonably rigid model so that objectivity has been achieved.

It is felt that the reason for the wide variations in frontal analyses can be attributed to the lack of rigid definitions and the lack of consistent models defining the roles fronts play in synoptic developments. CAO has attempted to supplement the Research and Training work in this field to achieve the desired uniformity.

Standard System for Prognosis (Prebaratic charts)

It is also clear that if prognosis is to be susceptible to assembly line procedures it must be carried out according to fairly rigid atmospheric models. In so far as possible the prognosis should be carried out utilizing objective techniques. Subjective corrections can then be applied according to prescribed models.

Adoption of the Standard Prebaratics to Specific Forecast Problems

Here again the forecast offices should be concerned with adopting reasonably objective and consistent procedures to adapt the prebaratics to specific forecast problems.

How it Works at CAO

1. Preparation of surface and Upper Air analyses by separate personnel with co-ordination.

2. Preparation of a 500 mb prog using semi-objective techniques.

3. Preparation of a surface prog using the 500 mb prog and 300 mb analysis according to a prescribed model.

PANEL DISCUSSION, DR. D.P. McINTYRE, MODERATOR

Dr. Godson: Mr. Muller, do you accept the cause and effect concept?

Mr. Muller: Yes. I accept it and believe a great contribution to its solution is to be found by using the past in conjunction with all the available logical, physical and numerical methods that we have for analyzing and prognosticating. That is, I believe a very powerful tool of analysis and prediction exists when we apply our complete theoretical understanding to the present situation in comparison to the past situation. As a matter of fact, we have doubled our clues about the situation. If we can discover a situation, and I think everyone recognizes that from analogues one can discover a situation that more or less corresponds to the present, our powers of prediction are increased very greatly by the single process of comparing the way the two situations behave. We can compare by differences, e.g., there is more moisture available in the present situation than in the analogue, or there is less moisture available, thermal gradients are greater, etc., or else we can actually put the past situation through the electronic computor and obtain a solution which can be checked for accuracy. There are endless ways in which analogues can be used, with the big problem the discovery of an analogue that corresponds to the present.

Dr. Godson: The "statistical approach" to forecasting accepts the cause and effect mechanism postulated by the laws of physics, but attempts to deduce the effects by a comparison of the current situation with similar situations in the past, for which the evolution is known. In the absence of an infinite number of past charts, it follows that considerable subjectivity must be introduced into the application of statistical methods, and that the number of key variables to characterize a given situation must be small enough to permit an analogue to be found. Thus the "statistical approach makes use of even less of the available information than the "synoptic approach". A very telling critique of the "statistical approach" has been written by Major P.D. Thompson, who said, in part: "If we have positive knowledge of the general principles that govern the behaviour of the atmosphere, it is logical and consistent with normal judgment to exploit that knowledge by regarding the atmosphere as completely controlled by that strong element of determinism. It can still be argued that purely statistical methods might lead to results approaching positive information. However, if one has any faith at all in the general validity of the laws of mechanics, he is tempted to suspect that the most concise result of an exhaustive statistical study would simply show that the hydrodynamical laws are almost certainly valid." - end of quotation.

If this point of view is accepted, it is logical to ask whether statistical methods should play any part in the forecast routine. I believe that the principles which cuase us to reject the statistical approach to prognostication will, at the same time, suggest the importance of statistical techniques for the actual preparation of many elements of a weather forecast. The criterion is simply this: if the element can be forecast by a quantitative physical approach, do so; if not, try a statistical, or objective, procedure incorporating those physical concepts that appear important. Middle-and high-cloud and precipitation forecasting should, in time, be possible by the simple application of vertical motions to air trajectories, with known initial moisture content. These are examples of the quantitative physical approach, and, incidentally, of the new techniques which will become possible when prognostic vertical motions are transmitted. Maximum-and minimum-temperatures, on the other hand, are affected by so many complex and interrelated physical processes that purely physical forecasts are impossible. Whether statistical or objective methods are related directly to physical equations, or are devised in an empirical manner based on those variables which are known to be physically significant, is, for the present at least, unimportant. What is important is that considerable scope exists here for climatologists and physical and synoptic meteorologists to pool their talents to devise the best means for the translation of numerically-forecast charts into accurate weather forecasts.

Mr. McLeod: Mr. Muller, my first impression of the analogue method you discussed is that the upper air situation is not considered.

Mr. Muller: I think we will agree that if the surface developments behave the same as the analogue over a period of time, the logical assumption is that the upper atmosphere is taken care of. However, we can go farther since once we find an analogous situation we can compare the corresponding upper air patterns as well, whenever the ~~proper~~ upper air charts are available. We may find ourselves in some difficulty in our future approach from the analysis centre, if we assume that all developments are going to take place from the 500 mb level coupled with the 300 mb level and then developed down into the lower levels of the troposphere. This seems to me to be quite a problem, especially when we note that the prognostic charts turned out by the U.S. Weather Bureau, the largest weather organization in the world, are from time to time incorrect. When I see that I wonder whether all developments take place in the upper air or whether we have by any means approached a clue to the situation. That is why I look hopefully to some additional aid to assist in predicting deviations of the one historical series which is available, that is, the current series.

Mr. Clodman: As far as I can make out, the forecasting method described by Mr. Muller amounted to an elaborate singularities and analogue technique. I have hopes that our current meteorological methods are not in such a bad state that a technique based on watching changes at one point at the earth's surface should be superior to them. Why should Grytoeyr's method prove superior to other analogue techniques that have been attempted?

Mr. Muller: By "singularities technique" I presume you mean the records of barometric pressure. It is presumed that you discover a point of symmetry, or the past corresponding to the present. The point is that the method I discussed is really nothing more than a past weather index, the most useful portion of which is the past chart. It is a very simple idea, but sometimes simple ideas are worth looking at. It has been used with success at Oslo, with Oslo as the center of the past chart. The scale could be made larger or smaller and the chart could, perhaps, be made to cover a larger area. The point is that it simplifies the movement of past weather over 4 or 5 days and so allows one to go rapidly over the past and pick out situations which bear some resemblance to the present. At the present time we have no method for doing that. Our historical maps are not readily available to the forecaster nor are they adaptable to quick scanning to discover analogues.

Dr. Godson: It goes without saying that assembly-line procedures are designed to utilize to the full the so-called "synoptic approach" to meteorological problems. The "synoptic approach" involves primarily a classification of atmospheric patterns and states, utilizing such gestalt concepts as "high", "low", "front", "frontolysis", "blocking action", "discontinuous retrogression", and the like. The "synoptic approach" then proceeds to outline the life-histories of its fictive entities, to develop prognostic relationships between them, and to associate characteristic patterns of weather, and of weather evolution, with them. These relationships are established chiefly by experience, although they generally have sound theoretical backing. Thus the "synoptic approach" utilizes physical principles only in a qualitative manner, as a guide in the interpretation and analysis of statistical data of the past and present. Hence, the "synoptic approach" does not begin to utilize all the available information, nor to deduce the atmospheric evolution from a quantitative consideration of all significant physical factors and processes. Only numerical techniques can hope to do this.

The following question then arises: when numerical predication techniques have demonstrated their superiority for prognostication, what role will be played by the "synoptic approach", and by assembly-line procedures in general, in the forecast routine? It is probably safe to say that the "synoptic approach", as we use it today, will be shorn of much of its significance. It will remain, however, as a useful guide in relating prognostic contour-height and vertical-motion patterns to expected weather. Assembly-line procedures, on the other hand, have a more assured future. Initially at least, atmospheric data will have to be charted, checked, and abstracted by an analysis unit, and the prognostic data from the computor charted, analysed, and transmitted. Fronts and isotachs may well be added to the prognostics, by the analysis unit, at this stage. The field offices will then translate the prognostic contour height and vertical-motion charts into qualitative and quantitative forecast terms, and will be able to concentrate their activities on the full utilization of these prognostics. This should involve considerably more elaborate procedures than are presently employed, and this phase will probably remain as an extremely fertile field for applied research for some time to come.

Mr. Boville: I believe that success or failure on the part of the field offices in producing a forecast from the analyzed and prognostic charts prepared at the Central Analysis office will depend on something along Mr. Muller's line, and on how well the field office can go from an accurately analyzed chart and a presumably accurate prognostic chart to an actual weather forecast, which is a long, long step, wherein, I believe, a large part of the failure, if any, will occur. Present techniques by field offices acknowledge validity extended only a very short time. We can go twelve hours or so with some of these techniques, but beyond that we are lost. I think Mr. Muller's idea would fit in well, with interpretations. I believe we must go a lot further in the interpretation of the prognostic chart in terms of weather. At the CAO for instance, we have found from experimenting over a substantial period that using the 500 mb prog in conjunction with jet stream analysis we can forecast the weather 24 to 36 hours ahead in terms of general fog, precipitation and temperatures, with reasonable accuracy. Physical models have been prepared relating the 500 mb level and the jet stream to vertical motions, and consequently vertical motion is related to the air mass under consideration with no reference to cloud and weather. I feel that some of these broader techniques will get beyond the 12 and 18 hour periods with reasonable accuracy, but, admittedly, we will have to do a considerable amount of work along those lines. Short range forecasts presently are based mainly on extrapolation, from which very good accuracy can be obtained for a limited time period. However, I believe with the development we have had in the last ten years in atmospheric models, how the atmosphere operates, and in utilizing concepts such as the jet stream and the level of non-divergence, if we do not incorporate them into our forecasting techniques then we are blind to the modern developments in meteorology.

Mr. Clodman: Mr. Boville, you have placed considerable emphasis on a rigid model which will give the same results from office to office and forecaster to forecaster. How far can this matter of rigidity be carried before the gain in efficiency is offset by the loss of accuracy resulting from occasional significant departures from reality by the model which the forecaster may be aware of?

Mr. Boville: That is a difficult question to answer. However, at the present time our models are sufficiently accurate, using our present techniques, to obtain a 24 hour, and if the situation is very good, a 36 hour forecast, but our methods break down beyond that period. We cannot get anywhere in analysis or forecasting without a model. The Polar Front theory revolutionized analysis and forecasting because it was a model. If we must make an analysis, we must make it according to a model. All our forecasting must be based on the model and we must have the model which is the best approximation to the atmospheric equations as we know them now.

Mr. McTaggart-Cowan: Mr. Chairman, I would like to make a few comments on the presentations by the Panel, and to perhaps indicate that each facet of the problem that has been expounded has its own place in the scheme of things, and the main point is to properly assess the relative importance, both today and in the future, of each of the approaches that have been so ably outlined by the Panel speakers.

If I may refer first to the points made by Dr. Godson, I believe it is now recognized that the results to date of numerical forecasting represent a very limited amount of success. The difficulties associated with the use of very limited models, and the great part played by the boundary effects if the machine calculation is extended very far into the future, have certainly limited the results to where I do not believe any Service is ready to adopt numerical forecasting as an operational procedure here and now.

I believe Dr. Godson put his finger on one very real point, where he talked of the importance of vertical motion. There is certainly need to integrate this into numerical techniques.

I would also like to point out that the term "numerical forecasting" is really a misnomer. All they are attempting to do so far is to produce prognostic weather maps. The problem of forecasting the weather from these maps, even when they can be produced by electronic computers, will still remain the job of the human forecaster: so that I believe the various titles of "numerical forecasting" or "weather prediction by numerical processes", frequently serve to confuse the audience or the reader, and fail to correctly connote that it is only the second step in a whole chain of events that is being attacked, i.e. that of constructing prognostic charts.

Referring to Mr. Muller's presentation, I would suggest that the statistical methods for forecast improvement have a real place in terminal or single station forecasting, but, unless there are very radical improvements in these statistical methods, their application to area forecasting is pretty limited. Nevertheless, there is certainly a need, as was stressed by Dr. Thom in his address in Toronto some years ago, for the statistician and the meteorologist to get together to learn one another's language and problems, and I would believe that some real help for the practising meteorologist would result.

You will note that I use the phrase "some real help", because I do not believe that, with the number and variability of the parameters involved, any statistical presentation will be found that at once is sufficiently simple for routine application, and yet sufficiently broad in scope to give reasonable weight to all parameters, will be forthcoming. Individual parameters for chosen locations should, however, be amenable to statistical attack.

Referring to Mr. Boville's presentation, I share his views that assembly line procedures will be the accepted backbone of forecast services for many years to come.

This assembly line can certainly be re-designed to take advantage of any numerical work, or statistical approach, at any stage; but I believe that it will for some time remain a product of well-trained brain power working as a team. This will entail the standardization and organization of materials in a progressive manner, and of finding techniques of handling the higher order derivitives of the basic equations involved.

As these improvements are made I believe that it will become more and more obvious that District Forecast Offices and Main Meteorological Offices will have to vacate the field of analysis of pressure or contour maps per se. These maps, after all, are but the foundation upon which weather service is provided. The efficiency of a forecast service is measured by the benefit derived by the forecasts and advice ultimately issued by the practising forecaster in the field. Surely, it is logical that the analysis of the pressure or contour maps by a specially qualified centralized agency, with staff and facilities for improved analysis, should, and can, be relied on to provide this basic foundation. When this is accomplished time will be available at the District Forecast Offices to analyze reasonably objectively all the other observable meteorological parameters. After all, when an upper air chart or a surface chart is analyzed, we have really only analyzed the parameters of pressure, wind speed and direction, and, to some extent, temperature. There are many other observable meteorological parameters of vital importance to many users of our service that are not yet objectively analyzed through lack of time, not through lack of desire, at the district offices. Centralized pressure or contour map analysis on assembly line procedures will free those offices to concentrate on these other parameters.

As presented so ably by Mr. McLeod, each major advance in meteorology has entailed some break with tradition; none come easily because we are essentially conservative in our outlook, as are most people with scientific training, but I believe that the adequate integration of the various techniques and approaches outlined by the Panel hold both a challenge and an encouraging future for the improvement of forecasting services.

Dr. McIntyre: Before adjourning this meeting, I wish to thank the panel members and the audience for their contributions in making our first panel discussion a success. I feel certain that the proceedings contain sufficient thought provoking comments to produce among the members at large discussions as interesting and fruitful as the one we have enjoyed tonight.