## Discussion

**J. E. Levy** (Technical Consultant): Does the history of air collisions indicate the cause as inadequate flight programming or inaccuracy of airborne instruments?

**Mr. Weihe:** The 172 air collisions of which I spoke, took place under conditions of good visibility when no traffic control action was being exercised. Under such conditions it is each pilot's responsibility to maintain visual alertness, and to see and avoid other aircraft on collision courses.

**M. Stateman** (Sylvania Electric), **T. Brady** (Ford Instrument Co.): Where can I get a copy of SC-31 Guide Plan?

**Mr. Weihe:** The SC-31 Guide Plan was published by the Radio Technical Commission for Aeronautics, 1724 F Street, Washington, D. C. The price is one dollar per copy.

**W. P. Byrnes** (Teletype Corporation): At what speed per minute should a telegraph system operate in order to have it fit in with future traffic control systems?

**Mr. Weihe:** We have a group of different jobs to do in air traffic control. We have the initial clearance, programming of the aircraft through the system, and we have the problems of safe separation, and expeditiousness of flow. The teletype or telegraph requirements are different in each category. But I would say that we will unquestionably start with the speeds which we now have and at a later date certain parts of the problem may require speeds up to ten times the present speed. But meanwhile we have to cope with the speed problem by having more circuits; when the techniques develop so that we can use fewer circuits at a higher rate of speed then I think we will evolve towards the higher rate system. I would suggest that you talk to Mr. Gross of CAA TDEC on this subject; he knows far more about it than I do.

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# Data Processing Requirements for the Purposes of Numerical Weather Prediction

JOSEPH SMAGORINSKY†

*Summary*—**The physical background and historical development of numerical weather prediction is summarized. The nature of the mathematical problem and the work-load for a digital computer are then described. The existing system of processing meteorological information (particularly upper air data) for operational weather prediction is examined in the light of the anticipated needs tor operational numerical weather prediction. The critique exposes deficiencies which may be intolerable for operational numerical weather prediction. Some suggestions are offered for revamping the existing system utilizing modern technological advances.**

## NUMERICAL WEATHER PREDICTION

### *Historical and Physical Background*

The central theme of this paper is the class of problems brought to light by the introduction of numerical methods for the purpose of weather prediction. What I will have to say must, out of necessity, be based on anticipated difficulties, since experience in *operational* numerical weather prediction by means of high-speed computers is nonexistent at this time. One can only speculate on the basis of experimental experience in numerical weather prediction and operational experience with conventional methods of prediction.

In preface, it will aid our perspective to give some background regarding numerical weather prediction itself.

The prediction of changes in the large-scale weather elements by means of physical laws has occupied theoretical meteorologists for many years. Lack of observations, an incomplete understanding of the physical laws and inadequate computational means prevented a break through in this problem until 1947. It was then that Rossby's basic work[1] of the late 30's stimulated Charney to develop a rationale for the prediction of large-scale atmospheric motion.[2] Only the availability of adequate synoptic observations and of high-speed computing machinery enabled him to carry his investigations beyond the initial stages.

The primitive hydrodynamic equations of motion for a compressible fluid in a rotating system reflect the fact that the atmosphere is capable of sustaining a wide spectrum of disturbances. However, for the purposes of large-scale short-range weather prediction (1 to 3 days), attention is focused only on those disturbances of planetary dimensions with periods of 3 to 7 days. For this scale of motions, the atmosphere behaves quasi-hydrostatically. Furthermore, because of the earth's rotation, the accelerations are relatively small so that the pressure gradient forces are approximately balanced by the Coriolis force. This "quasi-geostrophic" property of large-scale atmospheric motions together with the quasi-hydrostatic approximation when applied to the equations of motion have the effect of filtering out the meteorological-noise motions, that is gravity and sound waves.[3] The prediction problem is thus greatly simplified from both the observational and computational point of view, with scarcely any loss of applicability. For initial conditions, one needs in general only a knowledge of the three-dimensional mass (or pressure) field; it is not necessary to specify the wind field in addition, however, the geostrophic approximation permits one to utilize the wind field as an aid in determining the initial mass distribution.

All models thus far used for prediction purposes assume that the atmosphere is a thermodynamically

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[1] C. G. Rossby, "Relation between variations in the intensity of the zonal circulation of the atmosphere and the displacement of the semi-permanent centers of action," *Jour. Marine Res.*, vol. 2, pp. 38–55; June, 1939.

[2] J. G. Charney, "The dynamics of long waves in a baroclinic westerly current," *Jour. Met.*, vol. 4, pp. 135–162; October, 1947.

[3] J. G. Charney, "On the scale of atmospheric motions," *Geofysiske Publikasjoner* (Oslo), vol. 17, no. 2, pp. 1–17; 1948.

closed system which slips along its lower boundary. First experiments in numerical weather prediction involved highly simplified models of the atmosphere. One finds that the flow at 20,000 feet or 500 mb closely approximates the mean flow obtained by integrating through the entire depth of the atmosphere. If one wishes to predict the 500 mb flow using information just at this level for initial conditions, it is necessary that the flow at all other levels be implied. To do this, we assume that the wind is parallel at all levels. This tacitly assumes that the lines of constant temperature in an isobaric surface are parallel with the streamlines. Thus, we have a model of the atmosphere which has only one degree of freedom in the vertical—normally referred to as the "equivalent barotropic model."[4] This may seem to be a gross oversimplification of the atmosphere which has no semblance to reality. In fact if we examine the constraint that is imposed on energy transformations we find that such a model is only capable of redistributing kinetic energy by means of dispersive processes—it is not possible in this model for potential energy to be converted to kinetic energy. As it turns out, this is not catastrophic. Large conversions of potential to kinetic energy occur only sporadically in time and in space in the atmosphere. They occur at the beginning stages of storm development, which may lasting for 12 or 24 hours, and in extreme cases for 36 hours. Developments of this type occur somewhere over the United States on the average of once every 3 or 4 days. Between times the flow behaves essentially barotropically.

The very first forecasts not only assumed barotropy but also assumed the disturbances at 500 mb to be small perturbations on a uniform constant west-to-east current and that these disturbances had a fixed character in the north-south direction so that the flow was essentially one-dimensional.[5] So simple was this model that predictions could be made by means of a desk calculator. Surprisingly, the results had sufficient resemblance to reality to indicate that a nonlinear two-dimensional barotropic model would give much better results. Such a model out of necessity required high-speed computing machinery to carry out 24-hour predictions. For this purpose, the ENIAC was made available in early 1950.[6] Under ideal operating conditions, it took 24 hours for a 24-hour prediction to be calculated for an area comparable to twice the size of North America. These tests bore out supposition that atmosphere tends to behave barotropically except for short but important periods during which storms develop.

It was thus apparent that if one expected to predict development, it was necessary that the atmospheric model be capable of making available potential energy which could be converted to kinetic energy. To do this, it is necessary to specify at least two independent pieces of information in each vertical aside from the boundary conditions. This is equivalent to spanning the vertical dimension of the atmosphere with at least two internal mesh points. Predictions with a two-level model were performed last year on the IAS computer.[7] The weather situation chosen for this series of calculations was the famous Thanksgiving Day storm of 1950 in the eastern United States. This storm was one of the most rapid and intense developments ever to have been adequately recorded by a modern observational network. The two-level model definitely improved the predicted motion, but the degrees of freedom of at least a three-level model were necessary to predict the full development which was observed to occur.

The two-layer results indicated that the accuracy of prediction by means of the simpler barotropic model degenerated much more rapidly as the forecast period was extended. One could then conclude that more realistic models would probably yield good results for forecast periods of 36 or possibly even 48 hours.

A three-layer model embodying quasi-linearizing approximations in order to simplify calculation was then devised.[8] For prediction over an area approximately three-fourths of the size of North America, spanned in three dimensions by 1,083 grid points, it was necessary to use an external memory to augment the 1,024-word Williams' memory of the IAS machine. This was done first with punch cards and later by means of magnetic drum. A measure of the success of this model is that it forecast the occurrence of 90-mile-an-hour winds at the 3,000 foot level during the peak of development of the Thanksgiving Day storm.

Although we call our business numerical *weather* prediction, the only weather elements that I have spoken of are the wind and pressure fields. Actually, the predicted large-scale temperature field is also directly deducible. However, the predicted field of motion is only a necessary, though not a sufficient, prerequisite for predicting cloudiness and precipitation.

At least at the present, it appears that the large-scale field of precipitation can be predicted from a knowledge of the three dimension field of motion and the field of moisture.[9] Small-scale precipitation such as from individual thunderclouds is not predictable by the models described. In fact, our knowledge at this time of the

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[4] J. G. Charney, "On a physical basis for numerical prediction of large-scale motions in the atmosphere," *Jour. Met.*, vol. 6, pp. 371–385; December, 1949.

[5] J. G. Charney and A. Eliassen, "A numerical method for predicting the perturbations of the middle latitude westerlies," *Tellus* (Stockholm), vol. 1, pp. 38–54; May, 1949.

[6] J. G. Charney, R. Fjörtoft, and J. von Neumann, "Numerical integration of the barotropic vorticity equation," *Tellus* (Stockholm), vol. 2, pp. 237–254; November, 1950.

[7] J. G. Charney and N. A. Phillips, "Numerical integration of the quasi-geostrophic equations for barotropic and simple baroclinic flows," *Jour. Met.*, vol. 10, pp. 71–99; April, 1953.

[8] Results to be published.

[9] J. C. Thompson and G. O. Collins, "A generalized study of precipitation forecasting, part 1: Computation of precipitation from the fields of moisture and wind," *Monthly Weather Review* (U. S. Weather Bureau, Washington), vol. 81, pp. 91–100; April, 1953.

mechanisms governing the formation, propagation, and dissipation of atmospheric disturbances of the scale of squall lines, tornadoes, and hurricanes, is so deficient that an adequate quantitative theory still remains to be formulated. The same may be said for the other end of the spectrum, namely weather changes over periods of the order of a month.

### *The Mathematical Problem*

I would like to make some remarks regarding the nature of the mathematical problem involved and the workload that it presents to a high-speed computer.

In the models previously described, the prediction equations for an $n$-level model take the form of $n$-two (space) dimensional Helmholtz equations which must be solved simultaneously. For $n$ equal to or greater than one, one of the equations reduces to Poisson's equation. Thus, for $n$ equals one (the barotropic model) there is only a Poisson's equation to be solved. There are also $n$ first-order linear equations in time which are solved by quadratures in a trivial calculation. The inhomogeneous terms of the Helmholtz equations involve Jacobian operations performed on the heights of a pressure surface and a quantity containing two-dimensional Laplacians of the height. Prediction for say 24 hours requires consecutive predictions for periods of half an hour, using the newly predicted field of motion as initial conditions for the next prediction. In general, the Jacobians must be calculated and Helmholtz equations solved for each short-period prediction. The Helmholtz equations, when transformed to finite difference form, are solved by means of a systematic over-relaxation scheme.

For the single level model, using a rectangular grid of 361 points, the machine performed 1,640,000 multiplications and divisions in order to yield a 24-hour prediction in one-hour steps. Approximately 13 iterations were required to reduce the relaxation residual to approximately one part in a thousand, so that the solution of the difference equation took 6 times as long as the formation of the Jacobians. This produced a 24-hour forecast in 48 minutes on the IAS computer. By rationalizing the code for maximum efficiency, and introducing a number of physical approximations, it was possible to reduce the time to 6 minutes. The two-layer model requires a little more than twice the time it takes for the barotropic prediction.

One can derive the equations for a general 3-dimensional baroclinic atmosphere, which in finite difference form with $n$ internal vertical grid points reduces to the $n$-layered models when certain of the coefficients are fixed as constant. The general model requires the solution of a single three-dimensional Poisson equation in which the vertical second derivative has a variable and, in fact, nonlinear coefficient. It is quite likely that some version of such a model, with the further complexity of an earth's surface of variable height, will be used for subsequent experiments and ultimately for operational numerical weather prediction.

## REQUIREMENTS ON DATA

We tacitly assumed that somehow observational data in the correct form and appropriately processed are available to be used for initial conditions. The truth is that meterological data are not only far from suitable for numerical weather prediction but certainly are less than ideal for existing forecasting techniques.

Present methods for the measurement of meteorological elements, the transmission of the data, the processing at collection points, and finally the central recording have developed largely through patchwork and improvisation. Whenever a new need arose, its solution was sought on an individual basis and if some times this might have required redesign of the entire system, it was not economically feasible to do so. Under present practices, a piece of meteorological data passes through a "nondescript" gamut of processing—especially in the light of the requirements for operational numerical weather prediction.

In analyzing the meteorological data problem in general, one finds that in addition to the unnecessarily large time-lag between the taking of an observation and its ultimate usable form, there are many opportunities for errors to be introduced. In both instances the difficulty can be traced to the human element. I want to make it clear that the defects which I am pointing out cannot be corrected until adequate technological improvements are available—automatic instruments, better communications, high speed computers etc. The present system of weather data collection and processing may be the best that could be found until these communications and computer facilities came within reach.

The present framework governing the flow of data, because of its improvised mode of evolution, is in retrospect illogical, as illustrated by the following:

The analogue information from an instrument is evaluated and transformed into digital meteorological information and thereupon the data are entered into a station record manually; they are then put into automatic digital form by the manual punching of a teletype tape. When a collection of such data is received on another teletype tape, the digital message is converted to a written digital form by means of a teletype printer. *The tape is then discarded.* At perhaps 50 such central locations, some of the digital information on the digital sheet is then transcribed manually onto maps to be used for analysis and prediction. Others, who may wish the data for climatological purposes, will refer either to the original written station record, or to the teletype sheets, or to the plotted maps to again copy manually and perhaps rearrange the data. The paradox is that the data were in the most useful form when they were first placed on the teletype tape! Of course we must assume the tape was punched correctly at its source. Also, there is no guarantee that the message was not garbled in transmission, since there is no routine check. This example illustrates a number of weaknesses of the present system. Time has been wasted, manifold manual operations have been required, and errors have probably been introduced.

### *Collection*

To give a concrete example of the time involved in collecting data, I have taken the following from the time schedule of the Weather Bureau-Air Force-Navy Analysis Center located here in Washington.

Upper air observations are taken simultaneously over the world twice a day at 0300 and 1500 Greenwich Meridian Time. The radiosonde apparatus takes about 20 minutes to get up to 400 mb of pressure or approximately 24,000 feet. While the balloon is still rising above this level, the lower portion of the sounding is evaluated and a teletype tape is punched within an hour. For the 0300 observation time, this means that a tape containing information from ground level to 400 mb (called the first transmission) is ready at 0400. For an area such as shown in Fig. 1, page 27, most such data are received centrally by 0630; however, it may be 2 or 3 hours later before all reports are in. The radiosonde apparatus reaches its normal top, which is 15 to 20 mb or approximately 90,000 feet, 80 or 85 minutes after the balloon is launched. Most of this information (the second transmission) is received by 0915 and again it may be two or three hours before it is all in. Thus for such an area it takes about nine hours for all of the data to be collected. If one wished all of the hemispheric data including Russia and Greenland, it might take another hour or two. This gets very close to the time for the next observation, and when one reflects on the fact that forecasts are highly perishable, we must conclude that the situation is highly incongruous.

There are approximately 160 radiosonde and 300 wind stations in North America, the North Atlantic, and the North Pacific. Of these, approximately half are in the continental United States. On the average, each radiosonde message (1st and 2nd transmissions taken together) contains 64 words and each wind message contains 52 words. A word consists of 5 decimal digits and a space. Thus for one aerological observation time, approximately 16,000 words need be collected. Transmitting linearly on a single teletype circuit at the present rate of 60 words per minute would consume $4\frac{1}{2}$ hours. In practice this is reduced by the use of multiple circuits. Some of the upper air winds are also transmitted at intermediate 6-hourly intervals. Thus roughly 50,000 words of aerological data for North America and the oceans are transmitted each day. It is of interest that this figure represents less than 10 per cent of the total meteorological wordage transmitted for the Northern Hemisphere. The bulk of this consists of observations of conditions at the surface of the earth taken each hour for use in airways forecasting.

### *Processing*

Thus far we only have accounted for the time to collect raw information. These data are located at observation stations which are randomly distributed in the horizontal. The horizontal density of reports varies between large limits, very often falling below the necessary minimum, for instance in Canada and the oceans. However, predictions are still needed in these areas. The raw data contain small random instrumental errors and also physically real small scale variations which cannot be interpreted by the same mechanisms governing the large-scale variations. Such small-scale variations, instrumental or real, must be smoothed out. Furthermore, there may be gross errors in individual soundings which first must be detected and then must either be corrected or discarded. Finally, one would like an interpolated distribution of the quantities. The process which copes with these difficulties is called "analysis." The final form of the analysis is usually a representation of the variable in continuous graphical form mapped on a surface. An example is given in Fig. 2, page 28, where the observed heights of a pressure surface have been smoothed and interpolated. The contours are lines of constant height of a constant pressure surface. A good meteorological analyst takes years to develop a skill in making the necessary judgments to suitably process the data for prediction. The needs for numerical prediction have made the requirements for a good analysis much more critical and there is some question as to whether a good enough subjective analysis of the three-dimensional weather element distribution can be produced in a sufficiently short time in order that the analyzed data may be used for operational numerical prediction. Putting more men on the job is probably not the answer since all of the raw data must be scanned in a fully coherent manner and it is rather difficult to co-ordinate a group of men so closely. The natural question to ask is whether the judgments made by the subjective analyst are logical enough to be programmed. A psychoanalysis of the subjective analyst reveals that in general his decisions are rational rather than mysterious. He requires smoothness or continuity of the variables in time as well as in the three spatial dimensions, with weight depending heavily on the relative horizontal density of observations. His greatest skill lies in the smoothing and interpolation with respect to the horizontal distribution of observations, mainly as a result of years of conditioning in this type of analysis. Smoothing in time involves a crude short period forecast, and smoothing in the vertical in effect requires a re-evaluation of the original soundings with respect to horizontal and temporal smoothness. One finds that the subjective analyst is not always very thorough and consistent. As a matter of fact he sometimes even undoes the vertical consistency inherent in the original sounding since the raw data are essentially continuous in the vertical in contrast to their discreteness in the other dimensions. These deficiencies of the human analyst invariably can be traced to his inability to scan so much data as a function of four dimensions, even if the speed with which he can do this were not a factor. Now that I have made some disparaging remarks about the subjective analyst, and incidentally I am sure that many would argue violently, I would like to point out a skill which is not at all easy to duplicate by objective means —and that is the detection and possible correction of gross errors. The ability to do so is highly useful since every observation counts, and we would like to utilize an observation without its being misleading. For instance, the experienced subjective analyst can often make sense of garbled teletype messages.

For the past few months, we, at the Weather Bureau, have been performing experiments to determine the feasibility of objective analysis.[10] Preliminary results under controlled conditions indicate that in the case of horizontal smoothing and interpolation, the deviation of the objective analyses from the mean of 8 or 9 subjective analysis is no greater than the standard deviation of the subjective analyses. Considering that the subjective analyst has his greatest skill in a horizontal analysis, this is an extremely significant result. These experiments were performed over continental United States, where there was an adequate data density. Oceanic regions would present a greater challenge to objective analysis. Indeed, a preliminary experience indicates that a general objective analysis performed on a four-dimensional distribution of data with widely varying density will require as many logical as arithmetic operations. The problem is thus ideally suited for high-speed digital computers. It is hoped in the next few months actual tests will be performed toward development of a fully objective analysis system.

### *Visual Form*

The most common visual representation of meteorological data is a geographical map upon which simultaneous observations of weather elements are plotted in coded form at the station locations. These are usually analyzed so as to give a field representation—for instance, Fig. 1. Both the plotting and, as has been pointed out, the analysis are time consuming and expensive, especially since this is duplicated at many forecast centers. For numerical prediction this need not be done if the raw data can be fed directly into a computer for objective analysis. Since the results of the objective analysis are interpolated-smoothed values of the quantities in a three-dimensional mesh, one can program a further interpolation to give the location of a contour of given value and then have a printer transcribe this information into a visual form. An example of the appearance of such a map is shown in Fig. 3, page 29. A similar representation can be given to results of numerical prediction. It thus appears that for large-scale meteorological work, one could completely dispense with the manual plotting and analysis functions for both the purposes of preparing initial data or presenting a visual picture of a prediction. It must be pointed out that for subjective small-scale prediction, the manual plotting and analysis routines or an appropriate substitute would still be necessary, but since this involves small local areas, the time consumed is not very large and duplication is nonexistent.

### *Dissemination*

Up until 1946 almost all large-scale predictions formulated at an analysis center were distributed to district centers in coded forms via teletype. However, in the last 8 years facsimile has been utilized to transmit prognostic charts. The major deficiency of the present system is the time element. It takes 20 minutes for each chart to be transmitted. Often charts are detained for over an hour before there is an opening in the circuits. Possible solutions are additional circuits or higher speed facsimile.

There is an alternative which would require again a discrete communications system such as teletype. One could arrange for the results of an objective analysis or a prognosis in the form of isolines and value at mesh-points to be printed at the district centers. Signals could be sent directly from the computer or delayed by storage on a magnetic tape and then transmitted.

Some experimentation is already being carried out to speed the transmission of raw data for short-term airways forecasting. Under consideration is the selective broadcasting of blocks of data from a centrally located magnetic drum to given forecasting stations.

### *A Possible System*

In the preceding analysis I have tried to outline present data handling practices and their deficiencies. In some instances, means for streamlining the process were self-evident. In other phases much experimentation must still be done. For instance it is essentially that an observational system, relatively inexpensively, give us adequate aerological data density in inaccessible regions, such as the oceans. It would be desirable that the analogue data from instruments be transmitted directly, in an attempt to eliminate all processing at observation stations. Higher speed communications systems must be utilized for the collection and dissemination of raw and processed information.

With a little imagination, one can lay out a possible system. We take license to incorporate devices which are yet to be developed. Referring to Fig. 4, page 30, we begin with automatic instruments which can remain unserviced for long intervals. Automatic surface devices have already been worked on, especially during the war when it was necessary to gain information behind enemy lines. Aerological soundings are a bit more difficult. One could consider floating vessels for which power is generated by wind, solar radiation or ocean shear currents. These vessels could also serve as microwave relay stations. Conceivably the radiosonde apparatus could be brought to a sufficiently high level by rocket and then dropped by balloon; or why not indirect sounding devices which do not depend on an instrument to pass through the atmosphere?

The analogue data from such instruments could then be relayed by the microwave network to collection points where the information is temporarily stored on a high-speed memory device such as magnetic tape.

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[10] Results to be published.

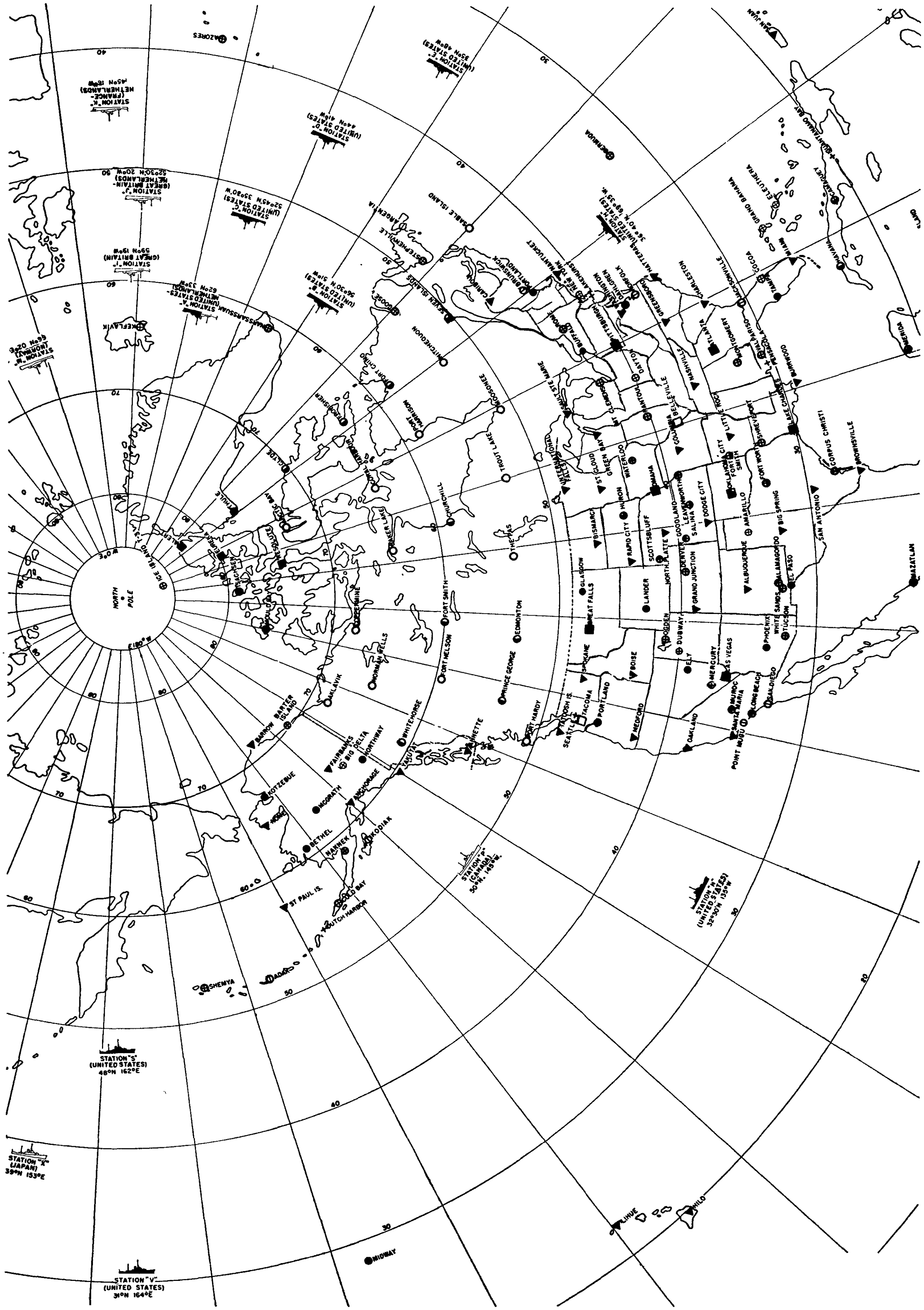

Fig. 1—Geographical locations of radiosonde stations in North America, and most of the North Atlantic and Pacific. The observation stations also measure winds of the upper atmosphere; however, stations which only observe winds are not shown. (Turn to read)

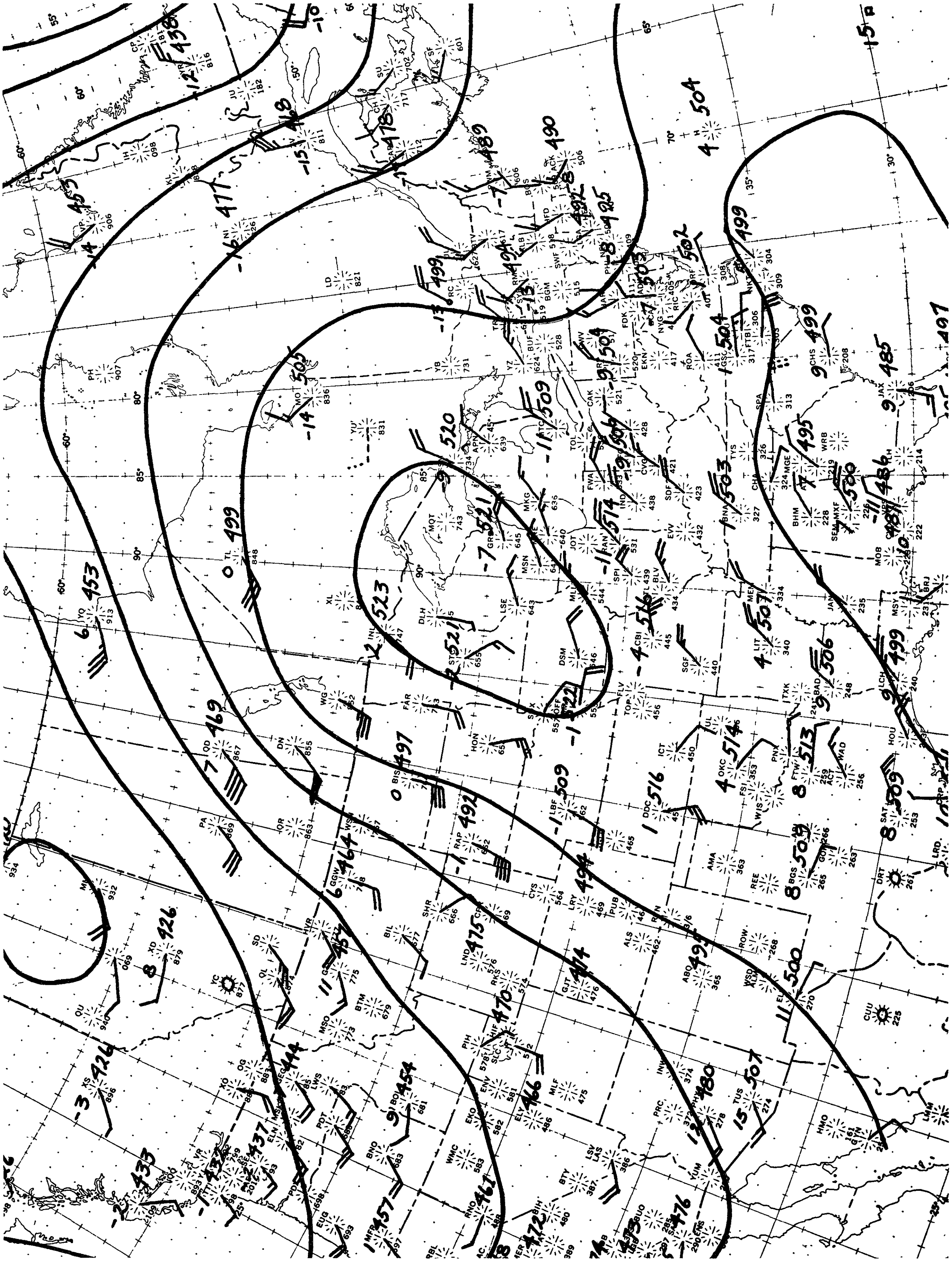

Fig. 2—Typical plot and conventional analysis of meteorological data. The plotted data refer to wind, temperature, and height of the 850 mb surface for 1500 Greenwich Meridian Time, November 5, 1953; the "analysis" consists of smoothed height contours of the 850 mb surface. (Turn to read)

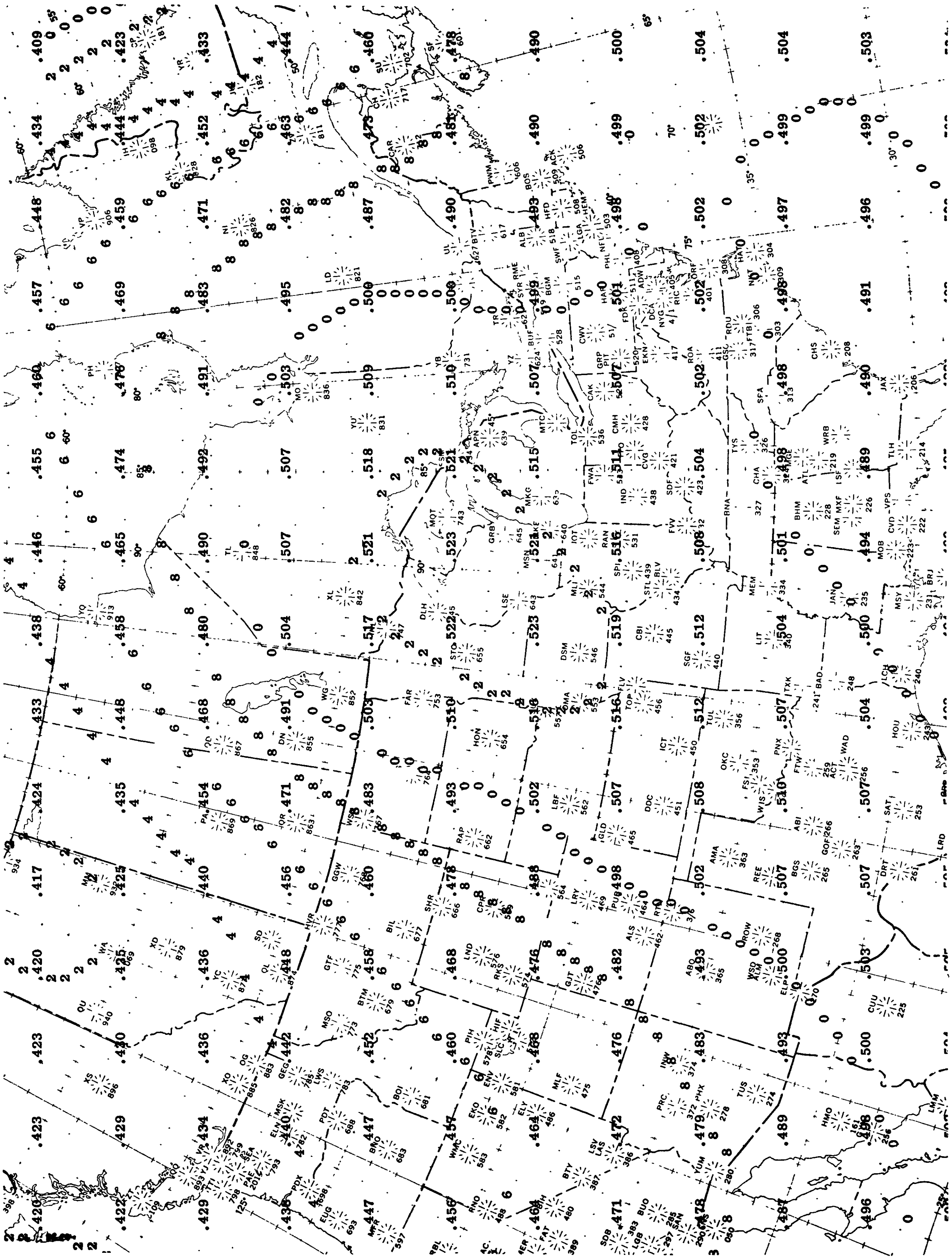

FIG. 3—Appearance of a computer controlled printing of an objective analysis of the data in FIG. 2. Shown are smoothed heights interpolated at grid points of a typical numerical prediction mesh, and contour lines. (Turn to read)

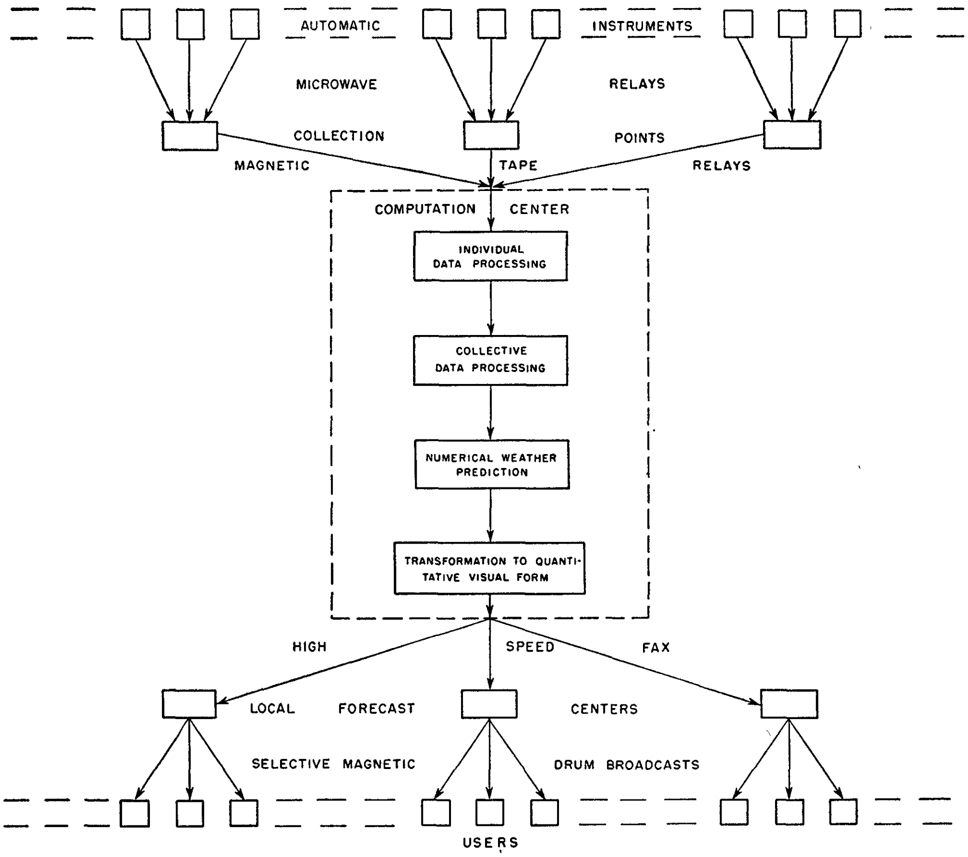

Fig. 4—A flow diagram of meteorological information in a possible system for data processing. The role of small-scale forecasting, extended-range forecasting, and climatological uses is not included.

From these points the information is funneled to a computation center. Here data are converted to digital form, checked for internal consistency, and processed as necessary on an individual basis. These data are then distributed to small-scale and long-range forecasting centers; for numerical prediction they are collectively processed by an objective analysis. A numerical prediction is then computed. The digital prediction is then transformed to visual form and transmitted by high-speed facsimile to local forecast centers.

## CONCLUSION

It is quite apparent from the foregoing that our present system of procurement and processing of data is wholely inadequate. A critique of existing methods points out gross deficiencies and the fact that, in general, we are well behind the times. We have not taken advantage of the fruits of technological progress. All of this has been apparent to meteorologists for some time. In fact, there is presently under consideration a plan to study the data problem from the taking of an observation to its ultimate use. It is the possibility of the introduction of high-speed computing machinery into operational meteorology that has led us to the realization that the moment for reflection and change is urgently at hand.

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## Discussion

**William P. Byrnes** (Teletype Corporation): Would an increase in speed by a factor of ten satisfy your requirements for higher speed?

**Mr. Smagorinsky:** I assume that you mean communication speed. I would say a factor of ten would be highly desirable. It must be remembered that this probably would be reduced bv a factor of two almost immediately, if we impose the requirement that we must be able either to duplicate messages in order to be absolutely certain that we were receiving them as they were sent, or to incorporate some self-checking features in transmission. It is hard to say at this time whether ten would be fully adequate; but it certainly is in the right direction, a very large step in the right direction.

**Mr. Byrnes:** What type of transmitting facilities do you propose for higher speeds? Telephone channels? Microwave relays?

**Mr. Smagorinsky:** Frankly, I do not know; but I think this is a decision for communications engineers, to be made on the basis of requirements. Our requirements probably would not be much different from those of others. We would like the most reliable, fastest, and cheapest medium possible. This last item is very important as far as weather is concerned because, even at present, communications represent a very large amount of money in the running of the weather services.