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Foreword

New knowledge in the geophysical sciences is accumulating rapidly. Since the start of World War II the research effort in geophysics has increased by several orders of magnitude. This trend has been fostered by commercial, industrial, and military interests. The journals and monographic series publishing results in the various subfields of geophysics have also multiplied in number and scope. In recent years there has further been a tendency toward greater specialization.

While many workers in geophysics are busily engaged to advance the frontiers of this science dealing with our planet, the earth, little has been done toward integration of the findings. Textbooks appear only at intervals of several years—and then usually cover just one topic, such as meteorology or oceanography. The handbooks, now in existence, have become very dated by the rapid progress. The cross fertilization possible between closely allied fields has been retarded by the widely scattered literature and by the aggravating tendency of using obscure and limited means of communication. Duplicated progress reports, distributed in a haphazard fashion and in limited number, especially on some government-sponsored projects, hardly deserve to be called *publications*.

For these reasons it seems that the time is ripe for a series of monographic treatises that summarize, from time to time, the advances that have been made in geophysics. Other rapidly expanding fields of science have found this method advantageous. It serves many useful purposes. One is, of course, stock-taking. Another is an attempt at keeping investigators in closely allied fields aware of progress in each other's specialties. Finally, there is the value of critical reviews, which will disclose the gaps and serve as stimuli for further work.

In this first volume of *Advances in Geophysics,* several such review articles appear. Some of them summarize established knowledge, others point out new work which is needed to fill in the lacunae. Two of the papers deal with problems of evaluating geophysical data. The rate at which such data have accumulated is staggering. This concerns all fields of geophysics; they are all plagued by vast archives of raw material. Evaluation and interpretation is imperative and the old-fashioned approaches are manifestly inadequate.

We have further selected papers in fields where major progress has been made in the recent past. Most of these should be of interest to geophysicists at large. They cover the general circulation in the atmosphere; the action of the ocean at the land-sea interface in estuaries; the gravity field of the earth; the airborne magnetic survey methods. Two other papers concern themselves with the very high atmosphere. Both of them point to the fact that other sciences can contribute materially to geophysics. One covers the specific results obtained by astronomical techniques through the survey of meteorites. The other points to the great opportunities still open in solving the many puzzles of suprastratospheric regions. This should be both a challenge and an invitation to the physicists.

Not all specialties of geophysics find coverage in this first collection of *Advances*. Hydrology, Seismology, Volcanology, and Tectonophysics will have to await further volumes in this series. It is not that they have no advances to report but considerations of space set a limit to the present effort. We hope that it will be received kindly by our colleagues whose future collaboration in this endeavor we bespeak.

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Cambridge, Massachusetts
September 1952

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Automatic Processing of Geophysical Data

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1. INTRODUCTION

The need for processing large amounts of observational data in most fields of science has been growing very rapidly in recent years. This growth can be attributed to the fact that those problems involving essentially steady states of but few interdependent parameters have been solved in large part, leaving for study those problems involving rapidly changing conditions of several interdependent parameters. Investigations of these latter problems have produced vast amounts of observational data by the accumulation of observations, and by the introduction of instruments and recorders capable of high frequency response. This is especially true of the geophysical sciences in which the experimental conditions cannot be controlled in order to limit the rate and range of variations or the number of effective parameters. It has become quite evident that conventional methods of manually processing these great masses of data are wholly inadequate, and that rapid and convenient means of automatic processing must be used for both basic research and routine use such as is required for weather forecasting.

Although most recent instrumentation developments have concentrated on obtaining large numbers of more automatic, more accurate and faster observing instruments, considerable attention has also been given to the development of automatic data processing equipment, especially automatic data communication and computing equipment. However, there are a few operations in present data processing systems which have not yet been developed sufficiently to permit the full utilization of the capabilities of the newer types of observing instruments, communication systems or automatic computers. It is the plan of this article to describe in some detail the characteristics of presently available equipments in terms of how they are or can be used in a complete system of data processing so that the weak links in the data processing chain become obvious. In addition, the basic concepts of some present developments of means of strengthening these weak links are to be described. It is hoped that these descriptions will aid geophysicists in planning and executing expanded research and operational programs in the future as well as stimulate the development of automatic data processing equipment which will better serve the needs of the geophysical sciences.

2. Description of Present Techniques

2.1. General Remarks

In order to maintain and clarify over-all system relationships, the following descriptions of presently available techniques are organized with respect to the way they are used in the processing of one particular type of geophysical data, namely the observations made with radiosondes of upper air pressure, temperature and moisture conditions. The relationships among the various processes and records are indicated in Fig. 1.

Although most of the following descriptions refer specifically to radiosonde observations, essentially the same type of detailed conditions and operations occur with most other types of geophysical measurements. Thus these descriptions and subsequent conclusions apply quite generally to the processing of almost any kind of geophysical data.

2.2. Measured Conditions

The geophysical conditions which are measured in this particular example are the pressure, temperature and moisture content of the air along essentially vertical lines above the various radiosonde observation stations at the time of the observations.

2.3. Observation

In the radiosondes used in the United States, rising balloon-borne pressure, temperature, and moisture sensing elements cause changes of

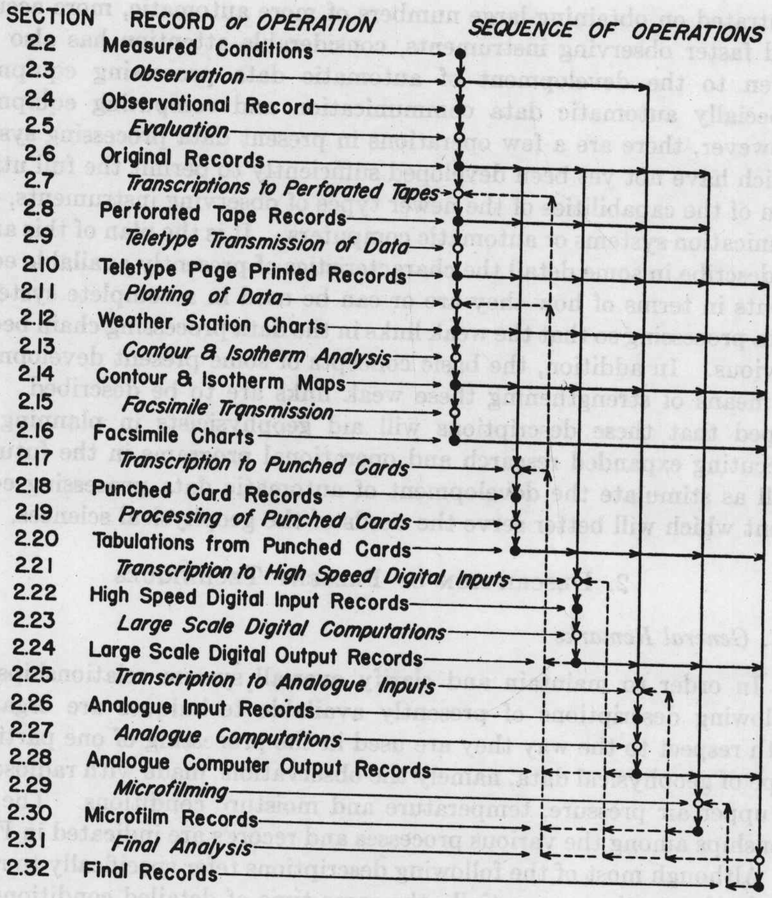

FIG. 1. Operational diagram.

the audio frequency of modulation of radio signals. The radio signals are received at a ground station and demodulated into electrical signals of varying audio frequencies which are automatically measured and recorded. The pressure sensing element is used to switch the frequency determining temperature and moisture sensing elements, along with fixed calibration elements, into the active circuit in a predetermined sequence at definite (calibrated) values of pressure.

2.4. Observational Record

The record of the received audio frequencies consists of the position of a broken ink line with respect to frequency and time scales preprinted on a paper strip chart.

2.5. Evaluation

The values of the temperature and humidity at various values of pressure are determined by manual reading of the frequency record and reference to calibration charts of switching points vs. pressure and of frequency vs. temperature and humidity. Errors due to oscillator drift and changing registry of the inking pen with respect to the preprinted grid are reduced by comparison to the reference frequency signals which have been periodically received. The results of these evaluations are written on the original records, see Section 2.6.1.

Since the indication of pressure values is in terms of the switching between various input sensing elements, and since there is no identification of the various types of signals other than continuity and expected values, considerable human selection and judgment is exercised in this evaluation.

In order to eliminate excessive evaluation times, only those points in the record (significant levels) are evaluated at which marked changes of the slope of the frequency vs. time curves for either temperature or moisture are evident.

The values of the temperature and moisture are then plotted with pencil on thermodynamic diagrams, see Section 2.6.2, and successive points are connected with straight lines. These graphs are used to check the consistency of the evaluations and to determine graphically mean temperatures between various pressure surfaces for manual numerical hydrostatic calculations of the height of prescribed standard (mandatory) pressure surfaces. The results of these calculations are then manually entered on both types of original records (2.6.1 and 2.6.2). In addition, the interpolated values of temperature and moisture at the mandatory pressure surfaces are read from the graphs of 2.6.2 and entered in the record of 2.6.1.

2.6. Original Records

The original records of the evaluations of the radiosonde observations are made in the following forms:

2.6.1. Raob Computation Data Record. This record consists of tabulations in Arabic decimal numerals, of the values of the temperature, moisture and height of all mandatory and significant levels. These forms also include the values of the frequencies read at the significant levels, as well as a simplified or modified written record of the message which is to be transmitted over communication systems as described in the following sections.

2.6.2. Graphical Thermodynamic Evaluation Diagram. This record consists of graphs of the temperature, moisture and geodynamic height as functions of pressure in which the points plotted for each significant level are connected with straight lines.

2.7. Transcription to Perforated Tapes

The original tabulations (see 2.6.1), are manually rearranged and recorded on the Raob computation data record in the form in which it is to be transmitted over communication links. This arrangement consists of selecting the "more significant" of the significant levels, and arranging the values into a predetermined sequence of groups of five digits each. The first two groups of five digits are used to identify the station and time at which the observation was made. Usually the values for about twenty significant and mandatory pressure levels are included in this message.

Sometimes this data is transmitted manually with Morse code either over land lines or radio links. Usually, however, the written encoded form of the recording is transcribed into perforated tape records by manually typing with a teletype perforator.

2.8. Perforated Tape Records

This type of record of the observations consists of holes punched in a paper tape with a hole in a given position representing a unit of a binary digit and the absence of a hole in that position representing a zero of the corresponding binary digit (see Fig. 2a3 and Section 4.2). Five binary digit positions (hence $2^5 = 32$ possible combinations of holes) are usually used across the tape to represent decimal digits, alphabet letters or machine instructions such as space, line shift, upper or lower case, etc. By using upper and lower case shifts, $2 \times 2^5 - 2 = 62$ different characters or additional instructions can be represented. The normal size of the tape is 0.7 inch wide with 0.1 inch along its length allotted for each character or machine instruction.

2.9. Teletype Transmission of Data

The perforated tape record is manually introduced to a teletype transmitter which then automatically transforms the entire record into a time sequence of "on" or "off" electrical conditions corresponding respectively to values of the binary digits zero or one. The usual rate of sending this information on land lines is six characters per second with an occasional speed-up to ten characters per second.

Usually the transmissions from the various observing stations are collected at distribution centers where duplicate perforated tape records of the observations are automatically made with teletype reperforators.

These tapes are then manually arranged into desired sequences and automatically retransmitted to various weather analysis and forecasting offices. At each of these receiving points teletype page printers automatically produce the following type of record.

2.10. Teletype Page Printed Records

This record consists of Arabic decimal numerals (or alphabetical characters) printed on a strip of paper 8½ inches wide in the same coded form as originally set up in the process described in Section 2.7. The records from the various observing stations are recorded in sequence, with the station identification being given in the first five digit group of the report from a given station.

The same type of record is also obtained by manual typing by a radio or telegraph operator when Morse code transmission is used.

2.11. Plotting of Data

The values reported and recorded in Section 2.10 are manually selected and transcribed with either pen or pencil into the following forms:

2.12. Weather Station Charts

2.12.1. Constant Pressure Maps. The values of the geodynamic height, temperature and dew point observed at each observation station at any particular mandatory level are written in Arabic decimal numerals at predetermined positions with respect to the positions of the observation stations on a map. One such map is normally plotted for each conventional level, subject to the plotting manpower, time, and desires of the individual forecaster. Normally, wind observations for the same time and height are also plotted on these maps.

2.12.2. Thermodynamic Diagrams. The values of the temperature and dew point at each transmitted pressure level are plotted with pencil on a graphical reference grid of, essentially, temperature vs. pressure. These diagrams are similar to those of Section 2.6.2 with the exception that the ones considered here usually are overprinted with many related thermodynamic reference grids to facilitate thermodynamic evaluation of the soundings. One such plot on a separate sheet of paper is normally made for each of the observations the forecaster desires, with each sounding identified with respect to time and the observation station with Arabic decimal numerals.

2.12.3. Consolidated Thermodynamic Charts. For the special purposes of operation 2.15, several small scale simplified thermodynamic diagrams are plotted on one sheet of paper. Normally sheets 12 inches by 19 inches, each containing 16 soundings, are used.

2.13. Contour and Isotherm Analysis

The primary use of radiosonde observations in present weather forecasting practice is an interpretation or analysis of the observed (actually calculated) heights of various mandatory pressure surfaces as plotted in constant pressure maps (Section 2.12.1). This analysis consists of manually drawing contour lines of the geodynamic height of the mandatory pressure surfaces at the time of the observations. Normally, this analysis includes considerations of the relationship between winds and horizontal pressure gradients in which the direction and horizontal space of the contour lines are indicated by the direction of the wind.

In similar fashion, isotherms of temperature and of dew point (hence lines of constant vapor pressure or constant mixing ratio) on the mandatory pressure surfaces are normally drawn by interpolation between the observed temperature values as plotted in 2.12.1. In addition, isotherms of the mean temperature (hence the vertical thickness) between two mandatory pressure surfaces are sometimes drawn. Although this can be accomplished by numerical calculation and plotting of the difference in height between the two pressure surfaces, it is usually accomplished by means of a graphical subtraction technique (called the intersection method) using superimposed contour charts for the two pressure surfaces involved.

2.14. Contour and Isotherm Maps

The results of the above analyses are recorded on maps with pencil or ink lines representing the contours and isotherms of temperature and dew point on the various mandatory constant pressure surfaces and the mean isotherms between such pressure surfaces. Two general forms of such maps are drawn, as follows:

2.14.1. Direct Analysis. In this case, the various isolines are usually drawn directly on the same maps on which the observations were plotted in 2.12.1. Distinctions between the various isolines are obtained by using various colored lines, and values corresponding to the lines are entered as Arabic decimal numerals.

2.14.2. Analysis for Facsimile Transmission. Copies of the maps of 2.14.1 are sometimes made in which the distinction between the various isolines is obtained by the types (solid, dashed, dotted, etc.) of lines used and on which a selected few of the original observations of 2.11 are copied. These maps are used as inputs into the type of data transmission described below.

2.15. Facsimile Transmission

In this type of communication the charts in 2.12.3 and 2.14.2 are automatically scanned point by point with a photoelectric cell which produces an electrical signal dependent upon the light reflection from the surface of the chart at the point being observed. These electrical signals are amplified and used to modulate carrier currents for land line or radio transmission, and, after demodulation of the received signal, to control the intensity of current passing through an electro-sensitive paper.

The electrode through which this current passes scans the area of the electro-sensitive paper in synchronism with the scanning of the original chart. Thus, the markings on the original chart are reproduced on the electro-sensitive paper. Normally a chart 12 inches by 19 inches with a resolution to approximately 0.010 inch (or essentially an on-off signal at about 2,280,000 points) is transmitted by this means in about twenty minutes.

2.16. Facsimile Charts

Facsimile charts or records in their usual present form consist of a silver gray sheet of metallized paper upon which black lines have been formed by the passage of current through the paper. The radiosonde data is represented by black lines in the coding as described in Sections 2.12.3 and 2.14.2.

2.17. Transcription to Punched Cards

In order to perform automatic evaluations of radiosonde observations, primarily for research and climatological purposes, many of the records are transcribed into punched cards. This operation involves the manual reading, selection, and encoding of the data as recorded in 2.6.1 or as interpreted at points other than observing stations in 2.14.1, and the manual operation of a key operated card punch called a key punch. This punch can be operated at speeds up to the order of six characters or decimal digits per second and sometimes can be operated in parallel with an electrical typewriter which produces a typewritten copy of the data that has been punched on the card.

2.18. Punched Card Records

Punched cards in common use are $7\frac{3}{8}$-inches long, $3\frac{1}{4}$-inches wide and 0.0065 inch thick and contain holes which are punched in predetermined positions to represent decimal digits or alphabetical characters. The International Business Machines cards contain 80 columns of 12 rows of punch positions with decimal digits represented by punching of the 10 lower positions; alphabetical characters are represented by combinations