MEETING REPORTS

Handling, Reducing, and Interpreting Geophysical Data

In recent years the spectacular increase in geophysical investigation, particularly in space physics, seismology, meteorology, and oceanography, has led to the development of a wide variety of new observational techniques. The consequent high rate of collection of data is creating a major problem in reduction and analysis. The magnitude of this problem is illustrated by the Observatory Satellites shortly to be launched by NASA. On the average, the Observatories will transmit 8000 bits per second, generated by about 40 different sensors. Over the planned lifetime of a year, something like 2×10^{11} bits will be generated. If nothing more, this amount of so-called valuable information presents a storage problem. A foot-high stack of paper printout contains about 10^7 bits. Thus, an Observatory will generate in excess of 20,000 cubic feet of the paper printout which is so dear to the experimentalist.

Electronic computers are now widely employed in the business. After initial euphoria, it is widely recognized that while computers are adding a new dimension to data processing they also are presenting the investigator with a multitude of unsolved problems. Because of the widespread interest in the use of computers in data handling, reduction, and interpretation, the International Business Machines Corporation organized a conference bringing together workers in various fields for a 3-day meeting, 30 October to 1 November, at the IBM Thomas J. Watson Research Center.

J. McPherson opened the conference with a brief history of the interaction of computers and geophysics. The historical presentation included a recording of a talk by John von Neumann given in 1954 at Columbia on the use of the NORC computer in geophysics. Von Neumann recognized that geophysics presented a unique field for computer application because of the vast amounts of data to be processed and the spatial and temporal largeness of the problems. Geophysical problems are characteristically multidimensional and it is because of this that geophysics makes severe demands, even on the modern high-speed computer. Von Neumann regarded the computer as particularly suited to dealing with the numerical prediction of weather conditions, prediction of tidal motion, and the treatment of those motions within the earth's core that lead to the external magnetic field. Since 1954, remarkable progress has been made in numerical calculation of weather conditions, and about one-fourth of the present conference was devoted to a discussion of current problems in this field. The tidal problem has been treated by Pekeris in Israel and agreement has been obtained between calculated and observed ocean tides. The only area of which von Neumann spoke in which little progress has been made is that of treating the magnetohydrodynamic motions in the core. The preliminary numerical tests made by a number of groups have so far provided little insight into the complexity of the coupled magnetic and velocity fields of the earth's core.

Papers dealing with data acquisition emphasized the problems involved in obtaining reliable data under conditions where instrument repair is either difficult or impossible. Remote seismic stations, oceanographic vessels, and space vehicles suffer from these difficulties. In both meteorology and space physics the nature of data that should be provided to the user constitutes a problem. V. Lally, in considering data acquisition in meteorological research, brought up the problem of transmission of raw or processed information. This question underlay much of the later discussion which revolved around the demand of the scientist for so much raw data as to put heavy burdens on communication systems, both ground-to-ground and ground-to-satellite. Some progress has been made in the development of digitized acquisition systems. R. Phinney described a fully digitized seismic observatory now in operation at the Seismological Laboratory of the California Institute of Technology. The continuous digital recording of large volumes of data raises a multitude of problems regarding the editing, identification, and storing of the data in an accessible format.

C. Leith in his analysis of the display of calculations of atmospheric general circulation pointed out that computers also generate information at a remarkable rate. Calculations of numerical models of the atmosphere produce 50,000 bits per second. The question of representation of such large amounts of data is one which Leith has attempted to solve through the use of computer-produced two-dimensional spatial displays and the construction of motion pictures to illustrate the temporal aspects of the problem. The motion pictures show in a remarkable way the development and dissipation of low-pressure systems in the numerical models of the atmosphere.

A major difficulty in the application of computers to data-reduction problems is the excessive time spent in programming; the programs produced are often inflexible and inefficient. The principal causes of trouble lie in the great variety of formats in which data is recorded, the inevitable occurrence of errors in the data, and the variety of operations that must be performed. Sir Edward Bullard described a general program applicable to wide classes of data and problems. While such programs are of undoubted aid to a particular group, the general application can be questioned. The ingenuity of recorders of data will result in schemes that require special programs to read it. Sir Edward emphasized that eccentric methods of recording frequently bring no benefit to anyone and that insufficient thought is often given to the matter of data processing when an experiment is designed.

The problems of information processing for small satellites were reviewed by N. Ness. In the system developed at the Goddard Space Flight Center each scientist is regarded as a unique experimenter on the spacecraft. The scientist is provided with complete raw data coverage plus spacecraft performance data. This latter information includes orientation of the spacecraft, and geomagnetic, geodetic, and solar ecliptic coordinates of the spacecraft. Ness emphasized the idealized requirement that each experimenter should understand the entire system including the sensing elements, the local processing of data, the transmission of the data, and the subsequent editing.

R. Nathan described the digital processing of lunar photographs. The corrections to remove noise and geometric and photometric distortion from telemetered video data were carried out on a digital computer. Nathan illustrated the process with a number of artificial examples all of which left the audience with a much clearer understanding of how unclear the early pictures of the moon will be.

John Tukey chaired a lively, if often confusing, session on newer analytical techniques that might be employed in the reduction of geophysical data. The methods of power-spectra and cross-spectra analysis of geophysical time series are now widely used. Such methods are particularly appropriate when the process generating the time series is linear. When nonlinearities become important, for example in the near-shore development of ocean waves, then more complicated analyses are required to bring out the internal structure of the time series. G. MacDonald discussed methods by which the bi-spectra and higher order moments of time series can be estimated. This discussion was illustrated by the bi-spectra for ocean wave heights recorded in shallow water off the California coast.

The probing of the three-dimensional fields in geophysics often requires arrays of stations. Detailed studies of methods of analysis of data generated by station arrays have been carried out both in meteorology and oceanography. In oceanography the analysis of waves requires two-dimensional arrays, while in meteorology the two-dimensional distribution of weather stations is supplemented by observations taken in height at each station. G. Miller presented a discussion of the study of long ocean waves by means of an array of three bottom pressure recorders. An analysis of wave height by cross-spectral methods provides information as to the direction of waves as a function of frequency. Combined with elementary theory this permits an estimate of the distance over which the waves have traveled. Analysis of data from the triangular array of pressure recorders off the southern California coast leads to the identification and location of the wave-generating storms located off the Antarctic coast.

Von Neumann's comments of 1954 quoted above refer primarily to the use of computers in the numerical solution of three- and four-dimensional partial differential equations describing geophysical processes. Since that time remarkable progress has been made in the development of numerical methods that are capable of dealing with linear problems and some progress has been made in treating linear equations with nonconstant coefficients. A superb review of finite difference methods applicable to problems in fluid dynamics was presented by R. Richtmyer. Richtmyer dealt primarily with linear equations; however, the specter of nonlinearity was ominously present. It is clear that conditions for numerical stability of nonlinear equations can often be obtained; it is not clear that the resulting finite difference scheme represents even an approximate solution to the posed problem. The reason is intimately coupled to the fact that finite difference schemes make use of regular grids in time and in space. The nonlinear terms in the equations result in the transfer of energy from lower harmonics to higher harmonics. At a certain point in the calculation the harmonics have no place to go in the specified mesh and are folded back into the existing mesh. As a result, energy at high frequency (or high wave number) appears under the guise of low frequencies. This is the problem familiar to time-series workers as "aliasing." The mislabeling of the energy can lead to "instability," as was first noted by Norman Phillips. Smoothing techniques which lower energy present in the higher harmonics do not always provide a solution, though they can insure ordinary "numerical stability." The characteristic of many nonlinearities is the interaction over large frequency intervals. The arbitrary destruction of higher harmonics removes possible interaction and can result in major distortions of the field.

The six working sessions were supplemented by a banquet at the IBM Thomas J. Watson Research Center at which Lloyd Berkner, chairman of the organizing committee, presented an eloquent description of the progress in geophysics and space physics during the past decade. It is clear that geophysics and computer technology have proceeded at a very rapid rate and that without the development of the computer technology much of the present-day geophysics would be impossible. It is also becoming apparent that the requirements of geophysics are of such a magnitude that they are bound to influence further developments in computers. It is an open question whether the computers will develop faster than geophysics or geophysics will outstrip the services of the projected computers.

GORDON J. F. MACDONALD
Institute of Geophysics and Planetary Physics, University of California, Los Angeles 24

Forthcoming Events

January

14–16. **Radiation Research**, intern. conf., Natick, Mass. (Army Quartermaster Research and Engineering Center, Natick)

14–18. Association of **Surgeons** of West Africa, Ibadan, Nigeria. (V. A. Ngu, University College Hospital, Ibadan)

14–19. Atomic and Molecular **Quantum Theory**, symp., Sanibel Island, Fla. (D. W. Smith, Chemistry Dept., Univ. of Florida, Gainesville)