International Geophysical Year

The second part of a two-part summary of IGY activities covers heat and water, the earth, and data exchange.

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The first part of this article (*1*) outlined the scope of the IGY effort and attempted to summarize some aspects of the work dealing with the physics of the upper atmosphere, including solar and interplanetary medium relationships. This second part (*2*), also drawn from reports of the IGY scientific community and illustrative of their activities, takes up the story of typical findings in the areas of the heat and water regimen (meteorology, oceanography, and glaciology) and of the earth sciences (seismology, gravity, and longitude and latitude determinations). It also summarizes the status of data flow, for the IGY was above all a synoptic data effort, and then takes a look at post-IGY programs growing out of the IGY.

Heat and Water

Just as studies of particles, radiations, and fields benefited during the IGY from its concerted studies in a half a dozen fields of science, the opportunity for simultaneous investigations in oceanography, glaciology, and meteorology brought with it possibilities of better understanding of the complex of heat and water. While the three chains of pole-to-pole meteorological stations yielded the raw data from which major atmospheric circulation patterns can be devised, some eighty oceanographic vessels provided data of various kinds for delineation of oceanic circulation systems. Carbon dioxide was measured in atmosphere and ocean. Sea-level measurements, humidity determinations, and snow and ice estimates all tie into establishment of the role of water in all three of these states, relating inevitably to the heat budget and currents.

Meteorology. To explore more completely atmospheric circulation patterns, the IGY upper-air sounding program was characterized by two major efforts: (i) the filling in of major geographic gaps in the world networks, particularly in and near Antarctica, and (ii) the extension in altitude of balloon soundings up to about 100,000 feet.

Prior to the IGY emphasis on higher soundings, routine 600-gram balloon flights averaged about 71,000 feet. It should be noted, however, that the U.S. Weather Bureau and the balloon manufacturers have engaged in a continuing program to improve balloon performance, and that during the IGY an improved 600-gram balloon was used at all stations for the 0000Z observations and at one-third of the stations for the 1200Z observations. In pre-IGY tests, 80 percent of the 600-gram balloons had an average burst altitude of 82,020 feet, with a highest altitude of 99,670 feet. A high-performance 800-gram balloon was used at two-thirds of the stations for the 1200Z observations (chosen because this is the observation used for preparation of the IGY world weather maps); 24 of these balloons tested at the beginning of the IGY had an average burst altitude of 107,180 feet. During the IGY the 600-gram balloons have performed well, with average burst altitudes of about 83,000 feet; average altitude attained with the 800-gram balloons was about 90,000 feet. This program has achieved its objectives well enough to allow routine preparation of 10-millibar maps for stratosphere circulation studies.

Much was learned about antarctic weather; this is the first time such data have been collected to any appreciable extent. The coldest part of our planet is not at the South Pole but some 400 miles westward. Near there, Soviet scientists recorded a low of minus 124°F on 17 August 1958. The South Pole station was the coldest of the United States–IGY stations, with a minimum of minus 102.1° and an annual average of minus 56°F. Byrd station recorded a low of minus 82°, a maximum of plus 24°, and an average of minus 18°F; wind averaged 20 knots from the northeast, with maximum of 83°. The many overcast days during the winter contributed to making the weather environment there the worst of that at any of our stations.

The weather of Little America and Ellsworth stations was similar to that at the South Pole station but somewhat warmer, while at the Wilkes station the lowest temperature was minus 27°F. United States Weather Bureau scientists at Little America report a five-degree rise in annual mean temperature there over about fifty years—about one-half that noted at Spitzbergen in the Arctic—confirming a belief in the warming trend of the last few decades.

Beyond the extensive measurements of temperature, pressure, wind speed and direction, humidity, precipitation, and so on, made in programs conducted synoptically around the world, the IGY program embraced special studies. Thus, the United States program included research in solar radiation, ozone, carbon dioxide, and natural and artificial atmospheric radioactivity (see Fig. 1). Special solar radiation studies were conducted at seven Antarctic stations (Fig. 2), at the two ice stations in the Arctic Basin, and on Mauna Loa, Hawaii. Measurements were made of the intensity of total solar and sky radiation on a horizontal surface, intensity of the direct solar beam, natural illuminations, surface albedo, and hemispherical and net radiation.

The large amount of data stemming from this work is being reduced and processed. One of the observations at hand has to do with atmospheric purity: It turns out that the purities at Little America and Mauna Loa are comparable, while at the South Pole the sky is even clearer. Preliminary results from Station Alpha in the Arctic indicate the great importance of long-wave radiation from overcast skies in melting, for melting proceeded much more rapidly under overcast skies than beneath clear skies and in bright sunshine; conversely, refreezing may occur under clear summer skies because of increased outgoing radiation.

At Little America station, both surface concentrations and total ozone were measured. United States Weather Bureau scientists have analyzed some of the

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data (Figs. 3 and 4). They point out that the data are yet tentative, subject to further calibration of the equipment. Total ozone was observed with a Dobson ozone spectrophotometer, while the surface values were obtained with equipment developed by V. Regener (University of New Mexico) which employs the potassium-iodide–sodium-thiosulfate method with electrolytic titration.

During the winter months, the total ozone averages shown in Fig. 3 were based on two to four measurements taken on the full moon; averages for the remaining months are based only on measurements taken on the direct sun.

A marked feature of the annual variation in surface ozone (Fig. 4) is the rapid rise of ozone in March and April, when the sun leaves, and the slow decrease beginning in September after the sun returns. The dependency of surface ozone on wind direction is shown in Fig. 5, for June 1957. The "ozone rose" is drawn in terms of deviation in percentage from the average monthly concentration of 64 micrograms per cubic meter of air.

The usual diurnal variation of surface ozone concentration found at middle-latitude stations shows an ozone maximum during the late morning or early afternoon with a minimum during the late evening or early morning hours. This variation is believed to be due to the change of the vertical "Austausch" during the day. Afternoon convection activity permits the ozone to be carried down from the upper layers, but during the evening the lower air layers become stratified and the downward transport weakens. Eventually the surface ozone is destroyed more rapidly than it can be replaced from above, and the concentration may drop almost to zero. At mountain stations this diurnal variation may be wholly absent or it may be influenced by the diurnal variation of the mountain-valley wind.

The hourly values of ozone concentration for Little America are presently available only for the months of April to November 1957, inclusive. The results of a harmonic analysis of this data are shown in Table 1.

The diurnal variation found at Little America differs markedly from diurnal variations reported at middle-latitude stations. During the winter months the maximum occurs during the early morning, at about 0300 hours (165th meridian time), but during the spring it shifts to 0600 hours. The amplitude of the variation is rather uniform during the winter but increases by a factor of three in September and then decreases again during the spring.

As a result of the IGY, daily weather maps of the entire globe will be prepared; the United States is assigned responsibility for the Northern Hemisphere; South Africa, for the Southern Hemisphere; and the German Weather Service, for the equatorial belt. Daily maps at two levels—sea level and 500 millibars—will be prepared. It is expected that the IGY world weather maps will be available after an interval of one or two years.

Oceanography. Two major objectives of the oceanographic program were the study of the sea-level changes and oceanic water budget and the study of water masses, particularly current systems. In addition, of course, much related work was included during the IGY cruises—for example, bathymetry, marine geological investigations, biological work, and geochemical investigations. For the study of the water budget, more than 350 tide gauge stations were operated by 25 nations. In addition to tide observations, instruments were installed at some stations to record the long-period ocean waves, variations in atmospheric pressure, and continuous records of air temperature. At as many locations as possible, the temperature of water to depths of 900 feet was measured with bathythermographs (Fig. 6), and water samples were taken for chemical analysis. These observations were designed to permit volumetric corrections to be applied to the observed sea-level fluctuations in order to obtain the true mass fluctuations.

About 80 research vessels, of 20 countries, participated in the cruise part of

Fig. 1. A U.S. Weather Bureau observer checks the plastic shield of a Schultze radiometer. To the right is a Suomi ventilated net radiometer. The instruments in the background are a hip-roof shelter for thermometers, an anemometer and wind vane, a tipping bucket rain gage, and a weighing rain gage. [National Academy of Sciences]

Fig. 2. Kipp and Zonen pyrheliometers used by Herfried Hoinkes of Austria, IGY meteorologist, at Little America station, Antarctica. The pyrheliometers face upward to measure incoming, and downward to measure reflected, thermal radiation. In the background is a "sun pillar"—an optical phenomenon created by the sun shining through fine ice crystals in a clear sky. [Photograph by Herfried Hoinkes]

the program. Many expeditions which involved direct cooperative participation by ships of several countries were conducted; for other parts of the program, oceanographers agreed among themselves on the timing and tracks of cruises to yield synoptic and adequate spatial coverage of the ocean masses under investigation.

An earlier article on the IGY (*3*) described the discovery of the current beneath and opposite the Gulf Stream, in an early cruise sponsored by the Woods Hole Oceanographic Institution and the National Institute of Oceanography, England, and mentioned other early IGY results. The Scripps Institution of Oceanography finished three IGY cruises, the first of which was briefly described in the same article (*3*). The other two cruises were planned to study the Equatorial Undercurrent and Countercurrent in the eastern Pacific. J. A. Knauss reports that the Undercurrent, first investigated in 1954, is centered at the equator and is at least 3500 miles long, with a transport of the order of 30×10^6 cubic meters per second. The highest velocities observed were at depths of 100 to 113 meters and were between two and three-and-a-half knots. The Scripps research vessel *Horizon* and the *Hugh M. Smith* of the Pacific Oceanic Fisheries Investigation participated in the second Scripps Institution of Oceanography–IGY cruise, called Dolphin.

In the third Scripps cruise, Doldrums, Knauss found that the Pacific Equatorial Countercurrent was far more extensive then had been suspected earlier on the basis of calculations of the geostrophic current. The direct-current observations employed in the IGY cruise showed that the Countercurrent extends below the thermocline and actually transports more water below the thermocline than above it; the total transport was found to be about 50×10^6 cubic meters per second.

The measured eastward transport in the equatorial Pacific is estimated to be at least three times that estimated earlier by Sverdrup. This calls for a renewed investigation of the water balance and mass transport in the equatorial Pacific.

Much information on water mass and currents will be obtained not only by means of the direct methods (Swallow float, parachute drogues, current wheels, anchored buoys, and so on) but also from the study of temperature distribution, concentrations and distribution of the various chemical solutes, and radioisotopes. Analysis of cores of bottom sediments will provide clues to past circulation patterns. For example, sediment cores collected in the Arctic Basin before the IGY, at ice island T-3, and in the Atlantic provided information leading to a recently developed theory of glacier fluctuations by M. W. Ewing and W. Donn, of the Lamont Geological Observatory.

Significant contributions to knowledge of marine topography resulted from the bathymetry undertaken on IGY cruises and also from observations from the drifting ice stations in the Arctic Basin. R. L. Fisher and H. W. Menard, of the Scripps Institution of Oceanography, have reported on their exploration (during the first Scripps Institution of Oceanography–IGY cruise, Downwind of Nasca Ridge, a submarine mountain range extending southwest from just outside the Peru-Chile Trench off central Peru for a distance of at least 600 and possibly 1000 miles. Nasca Ridge was known previously only from several spot shoal soundings and a few echo-sounding crossings. Seismic refractions, heat-flow measurements, dredging, and coring completed the exploration of the ridge.

The Peru-Chile Trench was extensively explored, and heat-flow measurements were made near the trench, in the basin to the west, and in the Tuomotu Archipelago and East Pacific Rise. All told, 32 successful heat-flow observations were made—more than had been made previously. R. R. Revelle and R. Van Herzen reported that the highest values, 3 to 7×10^{-6} calories per square centimeter, were observed on the East Pacific

Rise. An indication was obtained of a trend toward much lower values near the axis of the Peru-Chile Trench, to the east. The study of these values of heat flow, particularly in relation to the topography, promises to advance the understanding of the structure of the general area.

Extensive areas were discovered where there existed a sludge containing manganese, iron, cobalt, and copper, in concentrations suggesting an ore value of about $500,000 per square mile. Aside from the possible economic importance of these ores, the understanding of how these metals are concentrated, probably by biological processes, will bear on our understanding of the geochemistry of the oceans.

In the Arctic Basin, Lamont scientists on Station A discovered a submarine ridge parallel to the Lomonsov ridge and lying about 85°N, in the vicinity of 166° to 168°W. The ridge is about 5000 to 6000 feet high; the full linear extent (at least 50 miles) is not yet known.

The Woods Hole vessels *Atlantis* and *Crawford* completed exploration of additional sections in the Atlantic Ocean, providing a coverage during the IGY more extensive than ever before. Woods Hole scientists have also engaged in a comprehensive geochemical program, and water samples have been secured for analysis of H^3, C^{14}, Sr^{90}, Sb^{125}, Cs^{137}, Ce^{144}, and Pm^{147}.

The *Vema* (see Figs. 7 and 8) of the Lamont Geological Observatory completed a 10-month IGY cruise. The two-ship seismic profiles were an important feature of the work; these were made in cooperation with *Atlantis* in the Red Sea. Lamont scientists have also taken many large-volume water samples for C^{14} and H^3 analysis. The *Hidalgo* of the Agricultural and Mechanical College of Texas completed a 60-day cruise in the Gulf of Mexico and Caribbean Sea, for study of currents. The *Brown Bear* of the University of Washington completed a second IGY cruise in the Northwest Pacific, where anomalous warm-water masses were studied, deep-water samples were collected in the Aleutian Trench, and studies were made of water exchange between the Bering Sea and the Pacific Ocean.

United States Navy Task Force 43 vessels in the Antarctic were able to make several crossings of the Antarctic Convergence, taking bathythermograms and water samples. About 190 oceanographic stations have been obtained since the pre-IGY exploratory cruise of the *Atka*. In addition, at Little America and near Hut Point, McMurdo Sound, stations were reoccupied over a period of months. Both at Little America and at Hut Point there was observed a rapid summer decrease in salinity, reflecting melting of pack and shelf ice, with warming confined to the upper layers. In autumn, temperatures rapidly reverted to spring values but salinity responded more slowly.

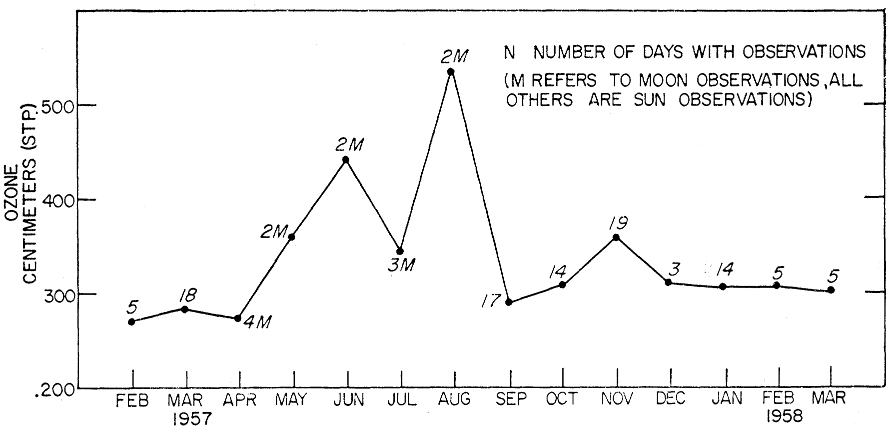

Fig. 3. Mean monthly total ozone values, Little America V (78°S, 162°W). [U.S. Weather Bureau]

Glaciology. Glaciers are among the most sensitive climatic indicators in nature. Past climates and climate fluctuations can be read from the snow and ice strata deposited from year to year, and annual variations in accumulation or shrinkage and in advances or retreats of the ice front provide keys to past and current climatic trends. During the IGY, glaciologists of 28 countries are making observations covering all the known ice areas of the world, including the great ice sheets of Greenland and Antarctica and a large number of valley glaciers in both polar and equatorial regions.

At the IGY Byrd station in the Antarctic a deep drilling program reached a depth of 1013 feet. Because of the relatively small annual accumulation of snow in the Antarctic, ice at 1000 feet below the surface at Byrd station is roughly equal in age to ice at the 2000-foot level in Greenland. However, the Antarctic cores are more difficult to date. In Greenland, the annual layers of snow are generally marked by a thin crust of refrozen summer melt; in the Antarctic, the annual layers are thinner and more closely packed, and there is often little or no summer melt. Careful chemical analysis may be needed to date the deep-lying cores, but it is estimated that the ice removed from the Byrd station 1000-foot drill hole fell as snow about the time of Charlemagne's birth.

At Little America, approximate ice temperatures at various depths were as follows: at 55 feet, −9.9°F; at 85 feet, −8.7°F; and at 130 feet, −8.0°F. This increase in temperature with depth is caused by the conduction of heat from the warm ocean below the 800- to 950-foot-thick ice shelf. The gain of heat at

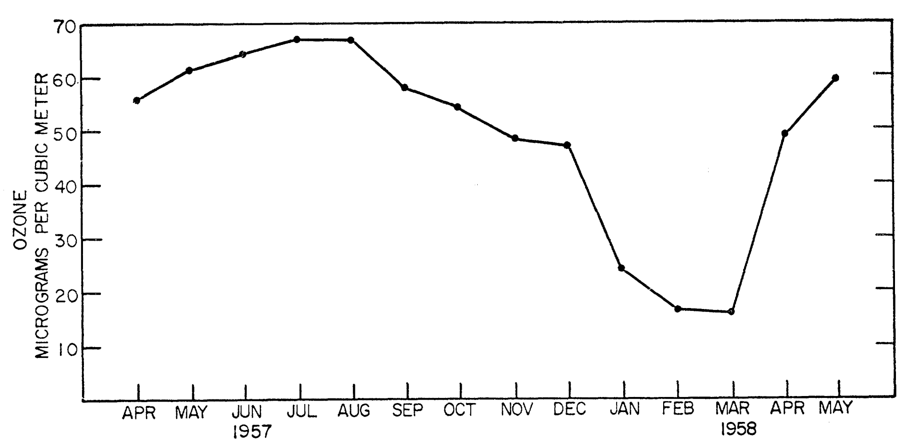

Fig. 4. Mean monthly surface ozone values, Little America V (78°S, 162°W). [U.S. Weather Bureau]

Table 1. Harmonic parameters for diurnal ozone concentration variations for the year 1957. [U.S. Weather Bureau]

Month	Amplitude ($\mu g/m^3$)	Time of maximum of the oscillation (hr after midnight)
April	2.7	2.0
May	0.6	2.1
June	2.2	2.6
July	2.0	2.9
August	1.9	2.7
September	6.1	2.9
October	2.6	4.0
November	1.2	5.5

the top of the shelf, however, is only 1 percent that of the average loss to space by radiation and so does not serve to ameliorate the climate very much. The "barrier" or edge of the shelf near Little America moves seaward about five feet a day. Stakes have been located across two ice valleys for movement-rate studies. Precise measurements made in February 1958 by A. P. Crary across "Crevasse Valley," between Little America and the barrier, showed that the 11,500-foot-long line laid out 375 days earlier had stretched 14 feet; this confirmed earlier observations showing that the valley is widening and that its underlying ice is becoming thinner.

To study the properties of larger areas of the great Antarctic icecap as well as other phenomena, United States–IGY Antarctic scientists completed three major traverses which covered a total of over 4000 miles out of the IGY Little America, Byrd, and Ellsworth stations.

The Ross Ice Shelf traverse from Little America covered a distance of 1440 miles in 113 days. It found that the shelf thickness varies from 800 to 950 feet, near Little America, to 1000 to 1100 feet west of Roosevelt Island and gradually increases to 1400 feet at the Beardmore Camp. The shelf floats but is grounded at Roosevelt Island and probably at other shallow areas. The ocean depth varies from 2000 feet at Little America to 2600 feet near Minna Bluff and then decreases south toward the Beardmore.

The Byrd traverse covered 1180 miles from 19 November 1957 to 20 February 1958 (see Fig. 9). It found that from the boundary of the Ross Ice Shelf to the Sentinel Mountains the underlying topography is alpine, with ice thickness varying between 2000 and 9000 feet. All but a few peaks of the rock floor are at present below sea level; the major portions are far enough below sea level to be under water even if the ice were removed and the land were allowed to rise, as it would without its great burden of ice. The second leg of the Byrd station traverse shows quite a different picture—a smooth bottom, great ice thickness of 7500 to over 11,500 feet, and broad gravity anomalies. The underlying rock along the final leg of the traverse, southwest and then west from the Sentinels, shows still another character. Surfaces there are very rough and mostly above sea level, in several places breaking the ice surface to form nunataks. One hundred miles east of Byrd station, ice 14,000 feet thick was found resting on a rock bed 8200 feet below sea level. This is believed to be the thickest ice layer measured anywhere in the world.

The Ellsworth traverse investigated the Filchner Ice Shelf and the inland ice of Edith Ronne Land. In addition to making glaciological studies, the Ellsworth party investigated mountains and rock outcrops in and near its route of travel. An important goal of this traverse was to occupy a point that could be reached by the Byrd station traverse of 1958–1959, thus providing a link across which data could be correlated. The traverse party traveled 1250 miles in 81 days. The party deviated about 120 miles from the planned route to make geological studies and collect rock specimens at a newly discovered mountain range, at 82°30′S and between longitudes 50° and 54°W, which may be part of the Pensacola Range (Fig. 10). Black stratified bands were noted high on the mountains, and a 5000-foot escarpment was discovered on the southern side. Evidence of mineralization was present in the form of abundant green malachite stains. Some of the bright green stains were visible at 100 yards. Large ice-free areas also were found along the northern foot of the range. One of these dry valleys contained a fresh-water lake about 100 yards in diameter, partly ice-free, caused undoubtedly by melting of snow in contact with the dark ground, which heats rapidly in the brilliant sunshine. The lake contained abundant plant life, and specimens were collected for botanical analysis.

A 2500-foot-high, ice-covered island extending for about 230 miles south and west from Gould Bay was discovered. Seismic soundings near its eastern ex-

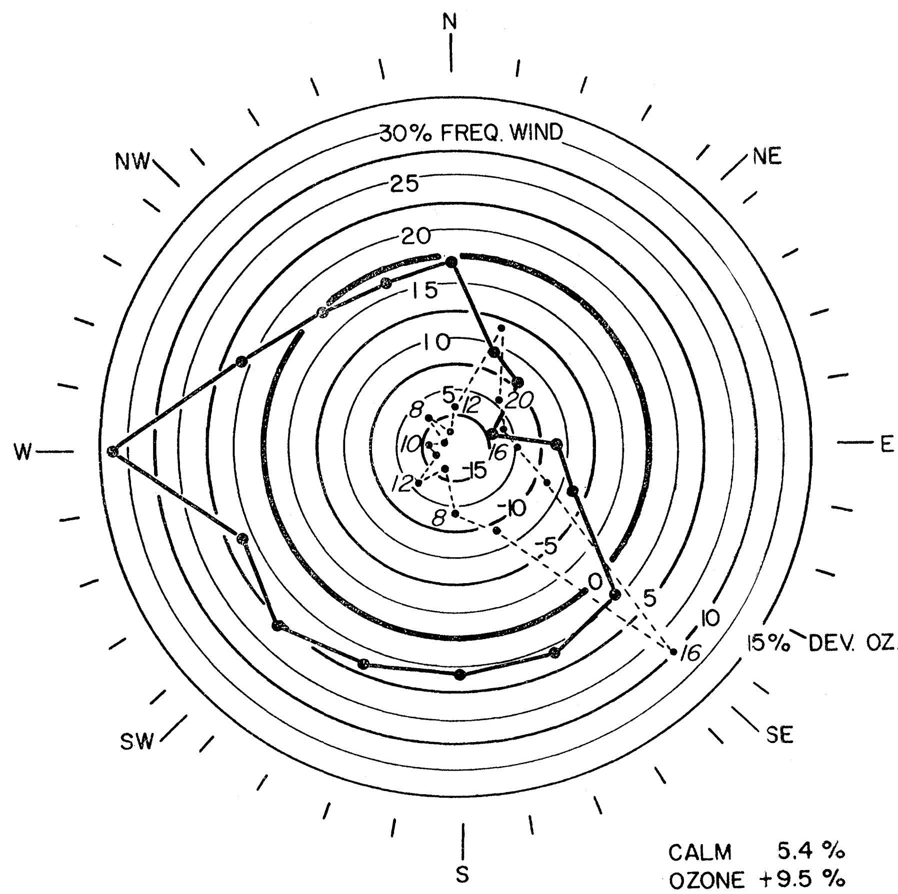

Fig. 5. Surface ozone and wind roses, Little America Station, June 1957. Solid line, surface ozone in percent of deviation from monthly average; broken line, wind direction frequency in percent; numerals, average wind speeds in knots. [U.S. Weather Bureau]

treme showed the land surface beneath the island's ice mantle to be at about sea level. Other islands, whose contours were not fully delineated, were seen still farther westward. Under the Ice Shelf a deep trough was detected extending inland from the vicinity of the Belgrano station, located 35 miles east of Ellsworth station. The bottom of the trough averages 3500 feet below sea level. After heading southward from Belgrano for some distance, the trough swings southwesterly, passing between the island and the newly discovered mountains. It continues beyond the southerly limits of the traverse.

The various determinations of ice thickness in Antarctica indicate that perhaps 40 percent more ice, (or almost 4.5×10^6 cubic miles) is present than was estimated before.

An ice-deformation project, concerned mainly with the measurement and mapping of deformed ice features of the Ross Ice Shelf between Roosevelt Island and the Bay of Whales, also was undertaken, under the direction of J. A. Zumberge of the University of Michigan. Large-scale topographic maps were made of selected areas so that details of change in the shelf-ice surface could be recognized in future years. Zumberge reports that several deformational features were recognized during the studies: (i) ice anticlines produced by horizontal tensional stresses; (ii) the transverse crevasses lying across the anticlinal axes, produced by horizontal tensional stresses; and (iii) the products of shearing action. Thermal studies and meteorological observations were also made during the project.

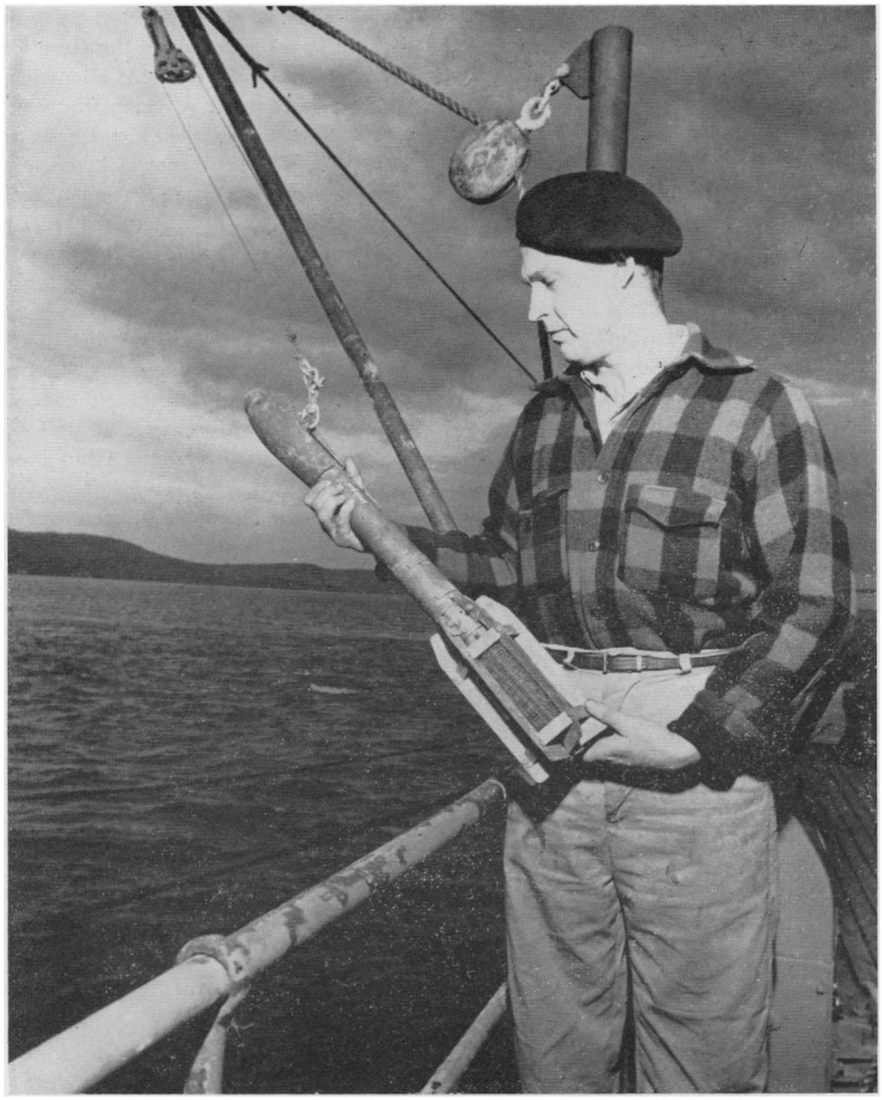

Fig. 6. An oceanographer prepares to lower a bathythermograph over the side of the research vessel *Vema* of the Lamont Geological Observatory. Bathythermographs record the temperature of the water at depths to 900 feet. [National Academy of Sciences]

The Pleistocene glacial chronology of the McMurdo Sound region was studied during the 1957–1958 antarctic summer season by a two-man field party, led by Troy L. Péwé, of the University of Alaska. Péwé found, by examination of the glacial deposits in the region, that both the alpine and outlet glaciers have fluctuated widely in the geologic past. The two groups of glaciers are now independent, but in the past they merged to fill McMurdo Sound with ice. At several times in the latter part of the Pleistocene epoch many large lakes formed when valleys were blocked by glaciers or glacier moraines. These valleys are now dry, but shore lines, deltas, lake clays, and evaporite deposits (mirabilite) remain to attest to the former existence and extent of these lakes. A comparison of the present positions of the fronts of many glaciers of the McMurdo Sound region with the positions of the same fronts shown in photographs taken 46 years ago reveals that very little or no change has taken place in this almost half-century interval. Adjacent to many alpine glaciers are small ice-cored lateral moraines about 100 feet high. These moraines are extremely fresh and may represent minute glacial advances of the last few centuries.

The glaciology program also includes an effort to determine the present pattern and magnitude of shrinkage or growth of glaciers in the United States. Two teams of scientists are studying the Blue Glacier situated in Olympic National Park (Fig. 11). An important finding to date is the unexpectedly high precipitation in the area. E. LaChapelle of the University of Washington reports that, judging by records obtained during the first six months of the operation, it may well be that Mount Olympus is the wettest area in the continental United States. In January 1958, for example, snow accumulated on Blue Glacier to a depth of 120 inches, with a water equivalent of 30.44 inches, and by the end of February, 417 inches of new snow had fallen. R. A. Sharpe of the California Institute of Technology reports that seismic soundings indicated a maximum thickness of the glacier of 920 feet. Maximum surface movement was found to be about 5.9 inches per day.

Additional glaciological studies were carried out in other parts of the western United States, principally at South Cascade Glacier in the Cascade Mountains, at Grinnell Glacier in Glacier National Park, at Nisqually Glacier in Mount Rainier National Park, and in other national parks, including Yosemite National Park. The McCall Glacier in the Brooks Range, the Lemon Glacier near Juneau, and parts of the Alaska Range were also studied by United States–IGY glaciological teams.

Earth Sciences

Seismology. During the IGY, the United States undertook three major programs in seismology: study of the earth's crust, largely by means of explosion seismology on land and sea; study of the earth's interior by means of earthquake seismology, with special attention to new long-period seismometers; and measurements of the ice thickness in Antarctica by seismic traverse parties.

As part of the study of the earth's crust, M. A. Tuve and H. E. Tatel of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington undertook an expedition to the Andes in Chile and Peru. Large explosions (40 to 60 tons) used in copper mines were observed near Chuquicamata, Chile, and Toquepala, Peru. The indications are that the depth to the mantle in Peru in a region where the elevation averages 9000 feet is about 34 kilometers, whereas in Chile, in a region where the average elevation is 5000 feet, the depth to mantle is more nearly 55 kilometers. These findings are not in agreement with the simple theory of isostasy; however it has been suggested that the lofty mountains of Peru may be supported by a network of fine roots penetrating to great depth into the mantle. The work in the Andes served to strengthen the belief of the Carnegie group that the old concept of a broadly featureless and uniform upper region of the mantle is an oversimplification.

Crustal studies have also been carried out by the Wisconsin group under G. P. Woollard. In 1957, this group made seismic profiles in the Mexican plateau. Under average elevations of 5000 feet, the depth to the Mohorovicic discontinuity was calculated to be about 40 kilometers. Detailed work near the shot point revealed two layers overlying the "normal" (6.1 kilometers-per-second) crustal layer: 1 kilometer of 3.3-kilometers-per-second and 5 kilometers of 5.1-kilometers-per-second crustal layer. In the summer of 1958, this group made seismic profiles along a gravity high (+ 10 mgal) on the Keweenaw Peninsula in Michigan, along a gravity low (– 40 mgal) in northern Wisconsin, and in a region of zero anomaly in Arkansas. Woollard reports that the respective depths to the Mohorovicic discontinuity were found to be 35, 37, and 43 kilometers. As in the Mexican plateau, a layer with thickness of 1 to 2 kilometers and velocity of less than 5 kilometers per second was found in each of these three areas. The need for careful attention to such layers has been emphasized by Woollard, Press, and others.

Fig. 7. A deep-sea camera is lowered over the side of the research vessel *Vema* of the Lamont Geological Observatory. This camera takes from 100 to 200 photographs of the ocean bottom at a single lowering, on 35-millimeter film with FT-118 strobe light for illumination. A transducer sends up a sound signal when the camera comes in contact with the ocean floor. [National Academy of Sciences]

As part of the oceanographic work of the Scripps Institution of Oceanography during the Expedition Downwind (21 October 1957–28 February 1958), seismic refraction and reflection studies were made by R. W. Raitt and G. G. Shor. Among the findings of this group were the thinnest (4 kilometers) and thickest (15 kilometers) crustal sections ever measured in the Pacific. Careful work revealed the presence of a layer of intermediate velocity (4 to 6 kilometers per second) between the sediments and the "normal" crustal layer.

Heat flow ranged over a factor of 50, demonstrating interesting correlations with seismic determination of crustal thickness. For example, on the East Pacific Rise, where heat flow is greater than in most areas, the crust is thicker and the seismic velocity of the layer presumed to be the mantle is nearly 7.6 kilometers per second. These correlations are being studied at the present time. The vital role played by many phases of the oceanographic program of this expedition is worth noting. Temperature, salinity, depth of water, and heat-flow measurements are all essential to the reduction and understanding of seismic data.

Another part of the IGY program has been the installation of a world-wide network of a special long-period seismometer of a type recently developed at the Lamont Geological Observatory and the California Institute of Technology. These instruments have revealed the existence of important energy components in seismic waves with periods greater than 50 seconds. These long waves include surface waves with periods of 600 seconds and low-velocity waves with periods of 200 seconds, which are as yet unexplained.

Two extensometers, or strain seismometers, have been installed in South America (Chile and Peru) by Hugo Benioff of the California Institute of Technology. These instruments, capable of measuring a strain equivalent to a change in distance of 1/10 inch in 2000 miles, also serve as long-period seismometers and, as such, have measured long-period waves from earthquakes and the longer period (12-hour) strains due to earth tides. The site chosen for the extensometers in Peru has proved to be an unusually quiet site for a seismometer.

Seismograph stations at four United States stations in Antarctica have provided the first seismic records from this area. Records from these stations, which fill a gap in the previous seismic network, will make it possible to confirm and modify existing travel-time curves for the Pacific region.

The Wilkes station, whose seismograph was installed under the guidance of Frank Press of the California Institute of Technology, has a very special locality. This station is so situated that it is diametrically across Antarctica from the tip of South America. The direct path from an earthquake in this area to Wilkes must therefore follow a transantarctic path. When such an earthquake of proper size has been recorded at Wilkes and when the records have been analyzed, it will be possible from the study of group velocities to determine whether the structure of Antarctica is essentially continental or oceanic—that is, whether Antarctica is a continent or an island group.

This same problem has been attacked by seismic traverse parties, whose work has revealed the antarctic ice sheet to be much thicker than had originally been supposed. Measurements made by seismic traverse parties in the antarctic summer of 1957–1958 and in the pre-IGY period demonstrated that the rock underlying the ice sheet is considerably below sea level in many regions. The traverse party from Little America led by A. P. Crary provided new evidence that East and West Antarctica may be separated by a deep ice-filled trough, through the recent discovery of the greatest recorded depth to bottom beneath the Ross Ice Shelf—4400 feet below sea level.

The existence of such a trough (from the Ross Sea to the Weddell Sea) was postulated by Griffith Taylor, geologist with the 1901–1904 Scott Expedition.

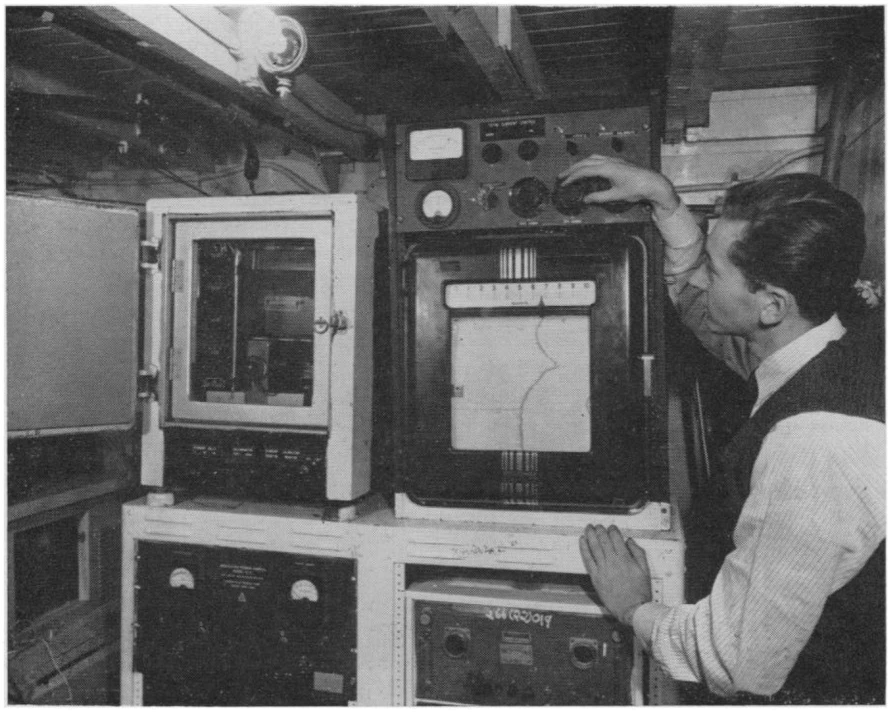

Fig. 8. The recording apparatus of a marine magnetometer—an instrument which makes continuous measurements of the earth's magnetic field—aboard the *Vema,* research vessel of the Lamont Geological Observatory. [National Academy of Sciences]

Fig. 9. Seismic explosion on the Byrd station oversnow traverse, made to determine the thickness of the ice. Shock waves from the explosion travel downward to the bedrock and echo to the surface, where they are picked up by receiving equipment. The time required for the waves to reach the bedrock and return indicates the thickness of the ice. The "sno-cat" contains the amplifiers and the recorder. [National Academy of Sciences]

His conclusion was based largely on the division of Antarctica into two distinct segments (East and West) on the basis of geologic and geographic character.

East Antarctica is a vast elevated shield of Pre-Cambrian metamorphic and igneous rocks, overlain by a thick series of flat-lying sedimentary rocks, intruded in places by igneous materials. West Antarctica is characterized primarily by folded ranges and plateaus of metamorphic rock and igneous intrusions similar to those of the Andes. These are also overlain by younger sediments. The existence of this trough is also suggested by the deep penetration into Antarctica of the Ross and Weddell seas.

Further work is in progress during the present antarctic summer to determine whether the trough extends all the way to the deep basin discovered earlier in Marie Byrd Land and from there to the Ross Sea. An IGY Byrd station traverse, led by Charles Bentley, is now en route to the Horlick Mountains, which extend southeastward from the southeast corner of the Ross Ice Shelf; this group is making geophysical studies that are expected to help solve the problem of the trough's existence and exact location. An IGY airborne traverse led by Edward Thiel has launched a series of seismic and gravity measurements in Marie Byrd Land to seek further evidence as to whether the ice-filled basin found there by members of the 1957–1958 Byrd station traverse may be part of the hypothetical trough connecting the Ross and Weddell seas.

Gravity. The IGY program in gravimetry was designed to provide standards for calibration of gravimeters and for international datum control. Four meridional lines were established by the group led by G. P. Woollard of the University of Wisconsin: Alaska to Chile, Greenland to Argentina, Norway to South Africa, and Japan to Antarctica. These measurements were made by means of Gulf compound quartz pendulums. For comparison of possible systematic difference, some of these stations were also measured with the Cambridge compound Invar pendulum.

Gravimeter measurements were made in conjunction with seismic observations (but more frequently than the latter) by the Ellsworth, Byrd, and Little America traverse parties. In addition, the British Trans-Antarctic Expedition, led by Sir Vivian Fuchs, made gravity observations at approximately ten-mile intervals along its entire route (using a gravimeter loaned by Woollard).

The first successful measurements of gravity on the surface of the open sea were made on 22 November 1957, by J. Lamar Worzel of Lamont Geological Observatory, using the recently developed Graf sea gravimeter. This instrument overcomes the principal difficulties previously encountered in making gravity measurements at sea: (i) nonavailability of the submarines that were required for this work and (ii) poor determination of position by a submerged submarine.

The new sea gravimeter was found to have additional advantages over the standard submarine pendulums. Surface gravity measurements made by Worzel from a stabilized platform aboard the *U.S.S. Compass Island* were taken in nine hours, as compared with two days required for earlier submarine measurements of comparable areas. The data were reduced in just one-half day, as compared with two weeks needed to adjust and compute data from the submarine measurements. Two sea gravimeters are now in operation at Lamont. In a relatively short time it will be possible to cover the oceans with an impressive network of gravity profiles.

L. B. Slichter of the University of California (Los Angeles) has directed the United States program for measuring earth tides by special gravimeters sensitive to changes in gravity of one part (or less) per billion. Recordings have been made by two such instruments at 13 sites: Glendora (California), Honolulu, Wake Island, Baguio City (Philippines), Saigon, New Delhi, Bermuda, the Azores, Bukavu and Bunia (Belgian Congo), Trieste, and Winsford and Bidston (England). Each observation requires about 40 days (including ten days for the instrument to settle down after transit). These measurements are made to compare calculated and theoretical tides of semidiurnal and diurnal periods as a function of position on the earth and distance from the ocean. In addition, these data will be searched for the presence of disturbances with a period corresponding to that of free vibrations in the earth—about 55 minutes.

Latitude and longitude. In cooperation with astronomers at the various observatories, special moon-position cameras developed by William Markowitz are in operation under the auspices of the U.S. Naval Observatory at some 20 astronomical observatories around the world. The Markowitz camera takes simultaneous exposures of the moon and surrounding stars, holding the moon's image fixed relative to the stars. Several observations taken on a single night fix the position of that station with reference to the center of the earth and without dependence upon a plumb line. The Markowitz camera is also useful in making determinations of uniform time, the moon performing a function comparable to the minute hand on a clock and the stars acting like the hour hand (*4*).

Synoptic Program

The primary objective of the IGY was the acquisition of data taken simultaneously at various points on the earth in order to give a planetary view of phenomena and events in most of the major fields of geophysics. Both space and time variations were important, and this accounts for the broad geographical coverage and for the 18-month period (1 July 1957–31 December 1958).

World Data Centers. This basic goal of the IGY was reached, for the observational program of the IGY was prosecuted even more effectively than anyone had hoped during the planning period. The evidence for this generalization lies within the three world data centers, established to maintain collections of IGY data. One of these is in the United States, a second is in the U.S.S.R., and a third has subcenters located according to scientific discipline in Australia, Japan, or any one of several nations of western Europe.

World Data Center A comprises subcenters in 11 institutions in the United States. World Data Center B (maintained by the U.S.S.R.) is divided into four subcenters; three of these are in Moscow, while the fourth subcenter, for flare and plage indices, is in the Crimea. World Data Center C has subcenters in eight nations of western Europe and in Australia and Japan, as follows: meteorology (Switzerland), geomagnetism (Denmark, Japan) aurora (Sweden, Great Britain), airglow (France, Japan), ionosphere (Great Britain, Japan), solar activity (Switzerland, Italy, Great Britain, France, the German Federal Republic, Australia), cosmic rays (Sweden, Japan), glaciology (Great Britain), rockets and satellites (Great Britain), seismology (France), gravimetry (Belgium), and nuclear radiation (Sweden, Japan).

The status of data interchange within the IGY may be summarized by examining the data in the 11 subcenters of World Data Center A in the United States. By and large the record is an impressive one, indicating wholehearted cooperation in this as well as in the observational phase of the program.

Airglow and ionospheric physics (National Bureau of Standards). After completion of the absolute calibration of IGY airglow photometers in the spring of 1958, data from the first year's observations from many stations reached the data centers. The flow of ionospheric data is immense. Data have been received from each of the other world data centers, and directly from 149 stations in 43 nations. Over 100 miles of ionogram film have been processed. The dispatch to other data centers of data received by center A is fully current. Interim catalogs on airglow and ionosphere were issued by the center in April and July 1958.

Aurora—instrumental observations (University of Alaska). Data from instrumental auroral studies are flowing more slowly than anticipated. More time had been required for processing and reducing all-sky camera films and for transmitting them to the data center than was estimated in the schedule of the Special Committee for the International Geophysical Year (CSAGI). However, data have been received from 33 of the all-sky cameras operated as part of the United States program. Films have also been sent to World Data Center A from Canada, Chile, and the U.S.S.R. Center A is copying and shipping all-sky camera film on a routine basis to centers B and C, and to center A for aurora (visual observations) in support of the mapping program conducted at that center.

Aurora—visual observations (Cornell University). The number of stations from which data are expected, by area, is approximately as follows: United States, 500; Canada, 400; World Data Center B, 400; World Data Center C, 350. Some data have been received from about 1100 of these. The center has IBM cards for visual observations up to October 1958 and hourly (in some instances quarter-hourly) auroral maps, provided through the U.S. Reporter, up to September 1958. The center has also received IBM cards for 1957 from the following U.S. Antarctic stations: Little America, Ellsworth, and South Pole. Data and catalogs of data have been sent to the other world data centers. Data have been received from data center C and directly from Argentina, Canada, Cuba, Hungary, Mexico, New Zealand, and Rumania.

Cosmic rays (University of Minnesota). Data are flowing regularly to data center A from centers B and C. Most stations send data directly to all world data centers. Data have been received at center A from 70 of 111 stations, representing 21 of the 38 nations participating in the IGY cosmic ray program. By October 1958, 12 months of data were due in; of these approximately 43 percent had been received.

Geomagnetism, gravity, and seismology (U.S. Coast and Geodetic Survey). World Data Centers B and C act as collecting institutions and have forwarded some data to center A in that capacity. Data received in World Data Center A are forwarded regularly to the other data centers as required. Geomagnetic data have been received from 115 of 262 sta-

Fig. 10. The Ellsworth station traverse party near peaks of the Dufek Massif in Edith Ronne Land—probably a part of the Pensacola Range. This was the first surface exploration of these mountains, which were discovered from the air in 1956. The "sno-cat" in the foreground has an electronic crevasse detector mounted in front of the hood. [National Academy of Sciences]

Fig. 11. View of the Blue Glacier IGY Glaciological Station and of the Olympic Mountains, Olympic National Park, Washington. Living quarters and laboratory building are in the center of the picture; meteorological instruments, at right. [University of Washington]

tions in 30 of the 49 nations participating in the IGY geomagnetic program.

So far the flow of gravimetric data has been small. Data have been received in World Data Center A from 26 of 230 stations in five of the 18 nations conducting earth tide studies: Argentina, Hungary, Iran, Italy, and Japan. Data have been received from 207 of the 398 stations conducting seismic observations. Bulletins containing seismic data have been sent directly to center A from stations or national collection agencies of 28 of the 52 nations which are participating in the IGY seismological program.

Glaciology (American Geographical Society). Glaciological data from the traverses conducted during the antarctic summer of 1957–1958 have been collected and processed at Ohio State University. The seismology and gravity data from these traverses have been processed at the University of Wisconsin. All of these traverse data are now ready for transmission to the respective data centers. This center has issued the first volume of the "WDC-A Glaciological Report Series." This volume includes preliminary reports received by the center prior to 23 June 1958.

Longitude and latitude (U.S. Naval Observatory). Data from the two programs in longitude and latitude are reaching the appropriate primary data centers; astrolabe data are sent to Paris, moon-position data to Washington. These data will be reduced and published by the primary data centers. The flow of moon-position data commenced late because of delays in starting the observation program. Data for the moon-position program are originally in the form of photographic plates from the 20 moon-position cameras. These plates are sent to one of four measuring centers: Washington, the Cape of Good Hope, Paris, and Herstmonceux. Measurements are sent to the U.S. Naval Observatory for computation and publication.

Meteorology and nuclear radiation (U.S. Weather Bureau). All stations in this discipline send their data either direct to World Data Center C (World Meteorological Organization, Geneva) or to center C via centers A or B. In accordance with CSAGI agreements, center C will reproduce all IGY meteorological data on microcards, which will be available to other interested persons or agencies. The flow of basic data from stations within the United States' area of responsibility is quite prompt. Data have been processed and machine listings have been made and shipped to World Data Center C as follows: synoptic land, through May 1958; synoptic sea through May 1958; radiosondes, through April 1958; and upper winds, through May 1958.

The flow of meteorological data from the various United States stations to World Data Center A, and thence to the World Meteorological Organization, World Data Center C, depends on the communication facilities available and the time required for checking the data and transcribing them to WMO-IGY data forms. Data from stations in Antarctica, for example, come in only once yearly. Several months then are required for checking them and entering them on the WMO-IGY forms. At the same time that data are submitted to the World Meteorological Organization, selected data are also processed at the U.S. Weather Bureau's National Weather Records Center at Asheville, North Carolina, and put on punched cards. The flow of data to center A from the stations in North America alone amounts, on the average, to 25,000 punched cards per day; for the entire world network of stations, at least 100,000 cards per day would be required. The punched cards are most useful in analyzing the data and retrieving specialized information; for general use of scientists throughout the world, World Data Center C is making the data available on microcards.

The pattern for the flow of data on nuclear radiation was established several months after the beginning of IGY. Center A has received data in nuclear radiation from 47 of 420 stations in 11 nations participating in this program.

Oceanography (Agricultural and Mechanical College of Texas). Sea-level and long-wave data from 14 countries have been sent to World Data Center A. Most of the data received so far relate to the less extensive cruises or to cruises conducted prior to the IGY, although data have recently been received from nine major United States and two major U.S.S.R. cruises. Data have been sent to and received from World Data Center B and have also been sent to a permanent service for oceanography, the Liverpool Tidal Institute. Interim catalogs of data were prepared by the center in April and July 1958.

Rockets and satellites (National Academy of Sciences). The section of the "CSAGI Guide" outlining the operation of the data centers for rockets and satellites was issued in April 1958 and revised at the Fifth CSAGI Assembly in Moscow in August 1958. At present, data have been received by World Data Center A from Argentina, Canada, Denmark, France, Germany, Japan, South Africa, the United Kingdom, the United States, and the U.S.S.R.

Because of the nature of rocket and satellite data, the agreed-upon timetable allows 12 months after completion of an experiment before published results are expected. In order to keep the scientific public informed during this period, World Data Center A for rockets and satellites initiated two series of reports containing interim and preliminary observations and results. To date, reports Nos. 1 to 6 of the "WDC-A Satellite Report Series" and No. 1 of the "Rocket Report Series" have been issued.

Solar Activity (High Altitude Observatory, University of Colorado). Data flow very promptly in this discipline. Center A has received data from 24 of the 36 nations participating in the solar-activity program. In addition to the telegraphic data, written and tabulated reports are received regularly and promptly. Monthly lists of solar flares are dispatched by the seventh of the following month.

As part of the intermediate publication of data, this center has published "Reports of Surges and Active Prominence Regions" for the months of July 1957 to March 1958 [reports No. 1–3 of the "WDC-A Solar Activity Report Series"] and "Observations of the Solar Electron Corona" for September 1956 to January 1958 [report No. 4 of the series]. The center published a 12-month catalog of data on 15 July 1958.

The problem of data reduction is clearly a formidable one. Fortunately, information processes, techniques, and devices were available to the IGY, and much of the data, particularly in the fields characterized by large volumes, was reduced as it flowed to the subcenters of World Data Center A. The analyses of reduced data have already begun, but this task of analysis and interpretation will occupy theoretical-minded geophysicists and physicists for many years. Even several decades hence, the body of IGY data will provide a valuable reservoir for research, particularly in the light of the discoveries that will be made in coming years.

Meanwhile, the formal end of the IGY program, on 31 December 1958, does not mean the termination of international cooperation in geophysics. During the Fifth General Assembly of the IGY, in Moscow, it was agreed that during the year 1959 cooperation along the lines of the IGY would be continued. This program has been given the designation International Geophysical Cooperation—1959 (IGC-59). Such studies as appear practicable to the participating IGY committees will be conducted as part of an internationally coordinated effort, with interchange of data, as in the IGY, under the aegis of the International Council of Scientific Unions. The council has authorized the establishment of a Special Committee for Inter-Union Cooperation in Geophysics (SCG), which will assume responsibilities for IGC-59 similar to those that CSAGI assumed for the IGY. Moreover, those fields that particularly call for extensive and intensive studies are receiving attention. Thus, the council has established special committees dealing with oceanography, the Antarctic, and space science. Counterpart committees have been established in these areas by the National Academy of Sciences, and significant steps have been taken for planning long-range programs in the above three fields, including activities for 1959. In addition, the council has authorized the continuation of the solar patrol and related world communications services which proved so useful during the IGY both in studying solar activity and in alerting scientists everywhere to solar events that were apt to result in terrestrial effects. Finally, the council has endorsed the proposal for a world magnetic survey during a quiet solar period, some four to five years from now.

References and Notes

1. H. Odishaw, "International Geophysical Year (Part I)," *Science* 128, 1599 (1958).
2. The preparation of this summary of IGY is based entirely upon reports and descriptions of projects supplied by the scientists and institutions engaged in the IGY research program. Many of them are mentioned in the text, although in this short summary it has not been possible to refer to all of the scientists who are producing contributions through their IGY programs or to describe all of the IGY accomplishments. The United States IGY program itself has been made possible only through the great contributions of time and effort of so many individual scientists and the participation and cooperation of public and private institutions. Particular acknowledgement should be made to members of the National Academy of Sciences' IGY staff who have assisted in the collection and preparation of the material contained in this article: Pembroke J. Hart and Stanley Ruttenberg.
3. H. Odishaw, "International Geophysical Year: A report on the United States program," *Science* 127, 115 (1958).
4. Data are being accumulated, and the results will appear in the bulletin of the U.S. Naval Observatory.

Engineering Information—All Is Not Lost

Literature is being effectively used despite current lack of efficient mechanical retrieval systems.

Ralph H. Phelps

More or less continually one is confronted with statements to the effect that the recent growth of the scientific and technical literature has been so great that its use is impracticable, if not impossible. In a general sense this idea goes back to the Old Testament of the Bible, which says, "Of making many books there is no end" (*1*). In the 1890's when the Royal Society of London was contemplating the publication of "The International Catalogue of Scientific Literature" (*2*), as well as at various other times, the increasing amount of the literature and the difficulty of its use have been deplored.

Another matter about which much has been said and written since the advent of the sputniks is the extent and excellence of Soviet abstracting services, often with the implication, if not the statement, that abstracting and indexing services in the United States are inferior. I would not minimize the importance of the Soviet abstracting services; they are impressive, if for no other reason than because they have grown so rapidly since they were started in 1952. Also, because the work is centralized and many literature scientists work in one place, it is physically an impressive operation. In this country, abstracting and indexing services are generally not governmental operations and are scattered throughout the country.

If the Soviets have profited more than we have from the technical literature, I believe it is because they may have worked harder at using it. The Soviet centralized information services are not essentially better than the services available in this country. Some of the larger sections of the Soviet abstracting services have no subject indexes and are therefore very difficult to use. Incidentally, in 1957 the Soviets purchased 54 copies of the 1956 bound volume of the *Engineering Index,* which is published in the United States.

Mechanization

Mechanization is currently being studied as a means of reducing the time and cost of the handling and retrieval of literature. For small collections of literature in restricted subject fields, mechanization has sometimes proved satisfactory. For large collections in broad fields covering diverse subject material, including concepts as well as materials, mechanization is apparently many years away. Its current status and some of its many problems and difficulties have been pointed out by Warheit (*3*), Taube (*4*), Shaw (*5*), and Rabinow (*6*). The overall problems of getting the information ready for the machine and getting it from the machine are perhaps greater than those of developing the machine. Machines work best on repetitive and routine operations. Such operations are not common in literature handling and retrieval.

Like many others, I wish that the literature could be searched more quickly and at less cost. I wish that efficient mechanized systems for large collections were now available, but they are not—not even at the very high prices charged for the large computers which are now

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