RESEARCH MEMORANDUM

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QUICK KEY Report No. 3
(ARPA Order 11-59)
AF-49 (638)-500

RESEARCH MEMORANDUM

AVAILABILITY OF UPPER ATMOSPHERIC AND OTHER SELECTED DATA FROM THE I.G.Y.

S. M. Greenfield

RM-2309-ARPA

January 7, 1959

Assigned to ______________________

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The RAND Corporation
1700 MAIN ST. • SANTA MONICA • CALIFORNIA

SUMMARY

Basic understanding of the physics of the upper atmosphere has been hampered by a lack of sufficient data on the various complex phenomena of that region. During the I.G.Y. the United States spent several hundred million dollars on our part of the international effort to collect raw geophysical data. Much of this was spent specifically for the acquisition of data on the upper atmosphere.

This memorandum describes the U.S. I.G.Y. data archives pertaining to the geophysics of the upper atmosphere. It then reviews the general state of knowledge and the major lines of investigation of the U.S. I.G.Y. programs in the interrelated fields of the ionosphere, aurora, cosmic rays, solar activity, and geomagnetism. The program for using rockets and satellites as scientific tools in these I.G.Y. studies is also discussed.

Thorough analysis of the I.G.Y. data is necessary in order to gain better understanding of the geophysical problems investigated -- in short, to realize on the investment in the I.G.Y. program. Except for one modest study, American workers are not carrying out extensive analyses of the accumulated I.G.Y. data. However, Russian and other foreign workers are performing extensive world-wide analyses of the data contributed by all nations, including the United States.

CONTENTS

I. INTRODUCTION

In August, 1958, by ARPA Order 11-59, the information center known as Project QUICK KEY was started at The RAND Corporation under Contract AF 49(638)-500 with the Air Force Office of Scientific Research. Project QUICK KEY was to arrange for the collection and further distribution of data on high-altitude atmospheric effects of nuclear detonations as they apply to interests of the Department of Defense. The areas of information to be treated include the results of measurements taken during nuclear tests, the results of applicable basic experimental and theoretical work, pertinent results of I.G.Y. measurements, and the results and conclusions of applicable analytic or systems studies.

This report is concerned with information about the International Geophysical Year Program. It was written for Project QUICK KEY at the suggestion of Dr. P. Tamarkin, Project Leader. Knowledge of geophysical data of the upper atmosphere is clearly of great importance in obtaining an understanding of phenomenology attending very-high-altitude nuclear detonations. It is, of course, useful for other military applications too, quite apart from its paramount importance in providing the basic means for achieving an understanding of the earth's environment. Because the readers for whom QUICK KEY information is intended are not primarily engaged in the geophysics of the upper atmosphere, it was thought useful to provide them with a description of various aspects of the I.G.Y. program dealing with the upper atmosphere. The I.G.Y. data collection and dissemination system is described, and an outline is given of the major physical questions with which the I.G.Y. program is dealing related to the upper atmosphere. Also included is a brief description of the experimental means of obtaining data. Finally, there is a short discussion of the broad area of data analysis, which many experts in this country feel is being neglected.

II. I.G.Y. DATA CENTERS

The I.G.Y. was started in July, 1957, as the result of an international agreement among 67 nations to devote 18 months to a coordinated collection of geophysical data on a world-wide basis. These were to be available to all participating agencies. To this end it was decided to establish three World Data Centers to maintain collections of I.G.Y. data. World Data Center A is in the United States, Data Center B is in the USSR, and Data Center C is distributed among eight nations of Western Europe, Australia, and Japan. This memorandum will consider the make-up of Data Center A as being typical of the three Data Centers.

The U.S.-I.G.Y. Data Center A is divided according to fields into archives located at various institutions in the country. Each institution chosen as a depository is noted for either its previous work in the particular field or for its demonstrated ability to handle large amounts of data.

The eleven archives, their addresses and fields of data collection, are as follows:

Airglow and Ionosphere:

I.G.Y. World Data Center A: Airglow and Ionosphere
Central Radio Propagation Laboratory
National Bureau of Standards
Boulder, Colorado, U.S.A.

Aurora (Instrumental):

I.G.Y. World Data Center A: Aurora (Instrumental)
Geophysical Institute
University of Alaska
College, Alaska, U.S.A.

Aurora (Visual):

I.G.Y. World Data Center A: Aurora (Visual)
Rockefeller Hall
Cornell University
Ithaca, New York, U.S.A.

Cosmic Rays:

I.G.Y. World Data Center A: Cosmic Rays
School of Physics
University of Minnesota
Minneapolis 14, Minnesota, U.S.A.

Geomagnetism, Gravity, and Seismology:

I.G.Y. World Data Center A: Geomagnetism, Gravity and Seismology
Geophysics Division
U.S. Coast and Geodetic Survey
Washington 25, D.C., U.S.A.

Glaciology:

I.G.Y. World Data Center A: Glaciology
American Geographical Society
Broadway at 156th Street
New York 32, New York, U.S.A.

Longitude and Latitude:

I.G.Y. World Data Center A: Longitude and Latitude
U.S. Naval Observatory
Washington 25, D.C., U.S.A.

Meteorology and Nuclear Radiation

I.G.Y. World Data Center A: Meteorology and Nuclear Radiation
National Weather Records Center
Asheville, North Carolina, U.S.A.

Oceanography:

I.G.Y. World Data Center A: Oceanography
Department of Oceanography and Meteorology
Agricultural and Mechanical College of Texas
College Station, Texas, U.S.A.

Rockets and Satellites:

I.G.Y. World Data Center A: Rockets and Satellites
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington 25, D.C., U.S.A.

Solar Activity

I.G.Y. World Data Center A: Solar Activity
High Altitude Observatory
Boulder, Colorado, U.S.A.

ARCHIVE FUNCTIONS

These eleven archives are charged with keeping on hand an up-to-date collection of the data gathered in their respective fields throughout the world. They are also charged with making copies of these data available on a cost basis. In addition to data handling, each archive publishes a catalogue (with the exception of the one concerned with rockets and satellites) of the available data. These catalogues present a month-by-month summary of the data completeness. Several of the archives also issue a series of reports presenting detailed descriptions of various activities in their respective fields. These reports usually consist of articles by workers in the field and cover instrumentation used for a particular experiment, data collected, and some preliminary analytical results. The archives that put out these report series are: (1) Glaciology, (2) Solar Activity, (3) Rockets and Satellites. In addition to these individual report series, the National Academy of Sciences is in the process of publishing a report series, entitled Annals of the International Geophysical Year, which will attempt to cover all the work done under the auspices of the I.G.Y. In practice, however, it will be impossible to cover every phase in detail; hence these reports will mainly contain survey articles about experiments and measurements in the different fields. However, these reports contain a rather complete description of experimental instrumentation and methods of analysis.

OTHER WORK

It must be realized that the I.G.Y. program does not include all the work that has been done by the U.S. in the eleven basic fields in the past 18 months. Some work sponsored by various military agencies is of a classified nature and cannot be released at the present time. Also, other data have been collected by private groups as input information for other studies. In general, these latter data are not available under the auspices of the I.G.Y. For example, information on radar echoes from aurora has been collected in connection with the development of electronic equipment to be used in the far northern latitudes and has not been reported to I.G.Y. archives.

PROBLEMS OF INTEREST

Of the 11 activities mentioned, six deal with subjects of special interest to Project QUICK KEY, since these subjects are concerned with various phenomena in the upper atmosphere. These six activities are:

1. Ionosphere
2. Aurora
3. Cosmic Rays
4. Solar Activity
5. Geomagnetism
6. Rockets and Satellites

This paper presents brief summaries of interesting problems in these six fields. These summaries include short historical backgrounds of the fields, statements of the geophysical problems being investigated, and descriptions of the experimental methods of the investigations. One of the purposes of the I.G.Y. program is, of course, to obtain data that will increase our understanding of geophysical problems. In preparing this paper, the writings of experts in these fields have been used extensively. A list of these references is provided at the end of the paper.

III. THE IONOSPHERE

HISTORY AND THEORY OUTLINE

The existence of an ionosphere--ionized layers in the upper atmosphere--was first postulated in order to explain the long-range propagation of radio beams. As early as 1926 Breit and Tuve independently showed, by means of reflected radio pulses, that this ionized region consisted of several layers, each capable of reflecting a slightly different range of frequencies. Further, these experiments showed that these layers were not a static phenomenon and that their characteristics changed markedly. These changes consisted of daily regular variations, and irregular variations when magnetic or ionospheric storms took place. It was shown in the 1930's, utilizing the techniques that were first employed to show the existence of these layers, that the data gathered were of considerable value in the planning and operating of long-distance communication networks. Due to commercial pressure for better communication facilities, improved ionospheric sounding equipment was developed. By 1955 some 90 ionospheric sounding stations throughout the world were collecting data on a regular basis. As in any new field of this type, increased data only served to point out previously unknown complexities. It was soon observed that the ionosphere, being essentially under solar control, showed not only a variation with terrestrial latitude and longitude, like a diurnal variation, but also a variation with the eleven-year sunspot cycle as well. The extensive world-wide character of the I.G.Y. has provided not only the ability to obtain more complete data on the ionosphere, but it has also shifted the emphasis from obtaining only electron densities over individual stations to studying the ionosphere on a regional and global basis.

Several examples of major investigative objectives that are planned as a result of the increase in the network of stations are discussed in the remainder of this section.

MAJOR LINES OF INVESTIGATION

Diurnal Variation of F2 in Polar Regions[1]

One important question concerns whether during the long arctic and antarctic night the F2 layer is maintained. During some experiments in 1954 and 1956[2] an airborne ionospheric sounder indicated an appreciable electron density remaining long after the source of ionizing radiation from the sun was shut off.

Speculations have been advanced that this persistance is caused by ionizing particles that are directed to the night pole through interaction with the geomagnetic field. Hence fluctuations in the electron density during the polar night might be very much under geomagnetic control.

North-South Polar Ionospheric Relationships[1]

The question here is whether there is a complete equivalence of ionospheric characteristics in the two polar regions. This question can only be answered by a large collection of data taken at various times and under various conditions. The technique of probing the ionosphere with radio waves (vertical soundings) lends itself very well to the I.G.Y. program.

North-South Auroral Relationships[1]

A third question that is being asked is whether short-lived auroral phenomena or their ionospheric or geomagnetic equivalents occur simultaneously in both hemispheres. Simultaneity of appearance in both hemispheres might indicate that the assumed stream of solar particles was not polarized and was of approximately uniform density. Lack of simultaneity might indicate that these phenomena in the auroral zones were much more influenced by local conditions in the upper atmosphere. These local differences may take the form of variations in electron densities, or possibly local magnetic field anomalies produced by current flows generated by ionospheric winds.

Network Studies[1]

A deliberate attempt has been made to install any new station for the I.G.Y. vertical sounding net in such a way as to assure completeness of pole-to-pole coverage along selected meridians. Such a network will allow the delineation of latitudinal profiles, and will further aid in distinguishing the variation of electron density between the effects due to solar control and those due to geomagnetic control.

In addition to the general objectives just mentioned some more specific objectives are as follows:

Absorption[3]

Utilizing an instrument known as a riometer, which essentially measures the "cosmic-radio noise" background, an attempt is being made to measure the relative ionospheric absorption at selected wavelengths. This is possible because of the fact that the normal level of cosmic noise is quite stable. Other determinations of absorption based on observations of vertical incidence echo amplitudes[4] are being made at the Pennsylvania State University and other institutions.

Winds and Drifts in the Upper Atmosphere[3]

Radio star scintillations seem to indicate that patches or clouds of electrons (1-6 miles in diameter) are swept through the upper atmosphere at velocities of 200-800 mph. These drifts apparently take place at altitudes of the order of 300 miles. During magnetic and auroral disturbances, there appears to be an increase in the velocity of drift. Drift measurements are accomplished by using a network of three observing radio stations spaced no more than 2-3 miles apart. Using lag correlation techniques, it is possible to identify the components of drift velocities from the star scintillation records. In addition to the radio scintillation technique, correlation of fading of three close-spaced receivers of vertical incidence echoes and observations of ionized meteor trail motions also can yield estimates of drift velocities.

Anomalous Propagation[3]

Over 1000 amateur radio operators in Japan and Central and South America and many amateur operators in this country are cooperating with the I.G.Y. by reporting detections of all unusual signals or periods of communication. Eventually there will be a central collection agency for these reports. It is hoped that an analysis of these reports will yield information on times when signals are reflected from auroral curtains, clouds of sporadic-E ionization, ionized meteor trails, etc.

True Height Computations[3]

Utilizing specially-developed electronic computers, Pennsylvania State College plans to do the large amount of tedious work necessary to determine the true height of the reflecting ionized layers, as does the Central Radio Propagation Laboratory of the National Bureau of Standards.

Whistlers and Very Low Frequency Emissions[5]

As early as World War I naturally-occurring radio noise with distinct, recognizable audio characteristics was observed. One form of this noise is called "whistlers," to describe its audio signature. A second form of this noise is categorized as "VLF emissions." These signals occur in a frequency range extending from somewhat under 1000 cps to somewhat in excess of 30,000 cps, and can be picked up with the aid of an ordinary audio amplifier connected to a long wire or loop antenna. In 1931 Eckersley(6) found a correlation between whistlers and the energy emitted by lightning discharges, and in 1935(7) derived a dispersion equation which explained the whistler's descending pitch. He assumed propagation to be entirely along the earth's magnetic field lines. Storey, in 1953,(8) showed that some of the electromagnetic energy from lightning discharges penetrates upward into the ionosphere and follows the magnetic lines of force to a conjugate point on the opposite side of the geomagnetic equator. He further concluded that a minimum free electron density of 600 electron/cc in the propagating medium was necessary to account for his results. Recently a second type of whistler was found. This is the so-called "nose whistler," characterized by a time frequency variation with both a rising and a falling component. It was found that this new form could be explained theoretically if the requirement (used in explaining the first type) that the whistler frequency be small compared to the electron gyromagnetic frequency was removed. When this restriction was removed it was found that it was possible to show a dependence of the "nose whistler" frequency on the gyromagnetic frequency (group velocity reaches a maximum when frequency is one-fourth of gyromagnetic frequency). Further, it was shown that the group velocity decreased under these conditions with either increased or decreased frequency; hence the simultaneous appearance of both rising and falling components. Due to this newly discovered dependence on gyromagnetic frequency, it is apparent that the shape of the "nose whistler" curve can yield valuable information on the earth's magnetic field.

Setting up stations to record whistler and VLF emissions* offers a possibility of calculating the free electron density distribution in the exosphere, obtaining information on the earth's magnetic field at several earth radii, and even measuring the velocity and density of plasma streams from the sun. The instrumentation used for collecting these data consists of an automatic whistler recorder and a direction finder and waveform recorder.

Oblique Incidence Forward- and Back-Scatter(4)

For back-scatter experiments a network of stations are used which have pulse equipment on three fixed frequencies (12, 18, and 27 mc). Pulse duration is 2 millisec with shorter pulses available for 27 mc. Pulses are transmitted with a peak power of 2 kw.

Forward-scatter is studied by CRPL from F and E regions in the vicinity of the geomagnetic equator. (CW operation with a 3-kw level at 50 mc is used.) Forward- and back-scatter experiments essentially provide a panoramic map of critical frequency over a wide area.

Sporadic-E Reflection Coefficients at Oblique Incidence(4)

These experiments provide a map of the appearance and the variations of the highly transitory and non-continuous ionized layer known as sporadic-E. The equipment used consists of CW transmitters operating at a frequency of 50 mc, with a power of approximately 2 kw operating in two circuits. Highly directional antennas are utilized.

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*VLF emissions are apparently generated in the high atmosphere but the mechanism is still uncertain.

Vertical Incidence Sounding Equipment

In addition to the instrumentation used for the specific experiments mentioned above, vertical incidence ionosondes are accomplished with the following equipment: C-3 and C-4 NBS-designed ionosondes; frequency sweep of 1 to 25 Mc; peak pulse power of 10 kw. Measurements are taken routinely every 15 minutes, with the additional ability to take them every 15 seconds.

Form of the Data

Several types of data and records are kept and are made available. The data appear in several forms and are coded as follows:

- T daily-hourly tabulations, one sheet per month per characteristic
- D daily sheets, one sheet per day per station, listing all measurements
- F f-plots--frequency measurements vs time from significantly different ionograms
- I ionograms--virtual height vs frequency
- H h'-plots--virtual heights
- E E-plots--E-region critical frequency
- z true heights
- FES fEs-plots -- sporadic E critical frequency
- HES h'Es-plots -- sporadic E virtual height

It should be noted that in addition to the regular data collected by each station, additional efforts are put forth on designated "World Days" and when "storm days" are indicated.

SUMMARY OF THE IONOSPHERE PROGRAM

Figure 1 is a world map showing the location of all the U.S. ionospheric stations participating in the I.G.Y. The measurements or experiments being conducted at each station are indicated.

Fig.1—Location and mission of U.S.IGY stations

One method of summarizing the availability of ionospheric data is to draw bar graphs indicating the percentage of reporting stations that have provided a given number of complete months of data. These bar graphs are based on information supplied in archive catalogues.* For example, in the case of vertical soundings, Fig. 2 shows the completeness of data for the daily-hourly tabulations (Code T in the preceding section). It should be noted that this compilation represents only the first 11 months of operation of the I.G.Y. In the case of the vertical sounding data, all other formal ionograms, f-plots, etc., show about the same completeness as the daily-hourly tabulations.

*This information is supplied in I.G.Y. twelve-month catalogues of data, available from World Data Center A, at the archive for the specified field as listed in Sec. II.

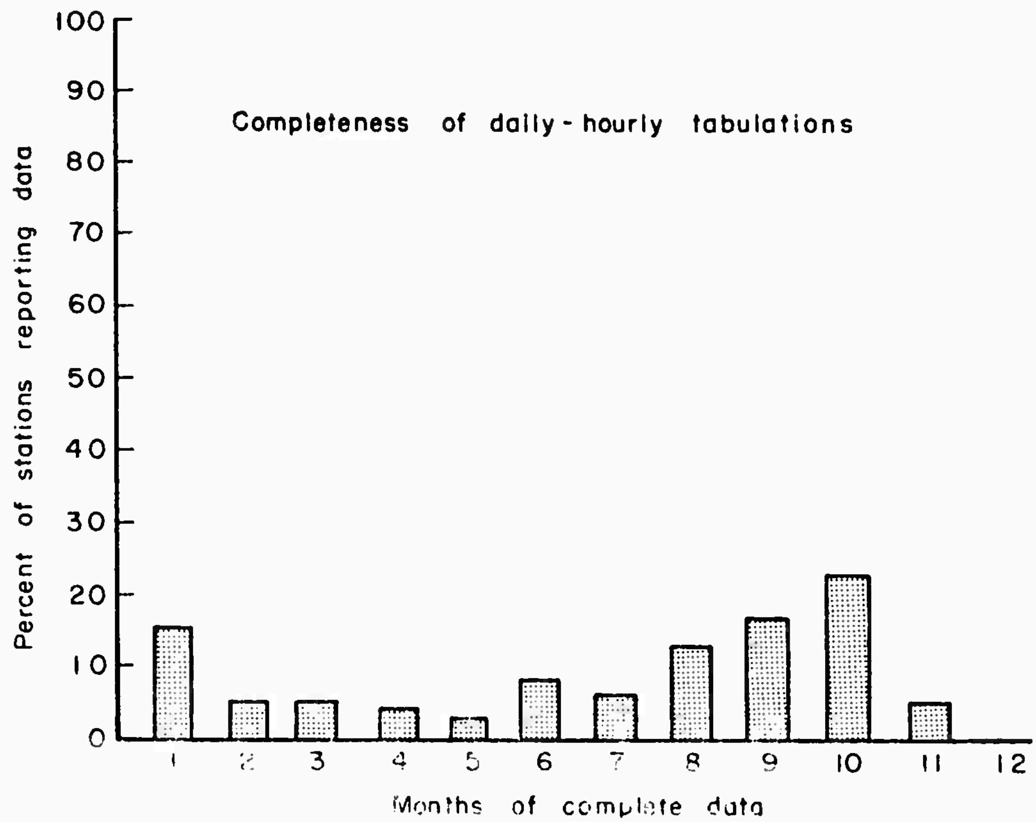

Fig. 2 — Ionospheric data

As of July 1958

IV. AURORA[9]

HISTORY AND THEORY OUTLINE

Although locally observed for many centuries, the full scale of the aurora phenomenon was not appreciated until late in the last century. At this time it was shown that there existed a zone of maximum appearance of the aurora and that this zone was centered around the magnetic dipole of the earth. It was then also clear that the aurora was the visible manifestation of charged particles entering our atmosphere.* Previous data have produced only curves showing the frequency of visibility of the aurora as a function of time. Existing data is insufficient to indicate the frequency of overhead occurrence. Two main questions that the I.G.Y. auroral program seeks to

*Some theoretical work has been done on aurora displays. It is known, for example, from laboratory work on traveling wave tubes[10] that electron beams of tight cross section, traveling along magnetic lines, tend to spread as they move down the tube. This spreading or flying apart is normally in a curved or spiral formation. Further, it has been found that the higher the intensity of the beam, the shorter the distance it will travel down the tube before spreading occurs. Applying this to the aurora, one would suspect that a wide, uniform beam of protons occurring in an area outside the atmosphere, constrained by a magnetic field and moving toward the north pole, would exhibit a gradual drift to the East in the southern edge of the beam cross section, and a drift to the West along the northern edge (the reverse would be true if the southern pole were considered). This drift would be caused by the gradual expansion of the beam (i.e., northward-moving protons would be constrained to move west and southward-moving protons would be constrained to move toward the east). An examination of aurora photographs shows that when the aurora exhibits this slanting, the slanting is in the direction (depending on the hemisphere) that one would suspect if proton beams were involved. If the beam is not uniform, the cross-section segment containing the more intense portion gradually curves into an S shape, and if the intensity is high enough or the travel time long enough, finally evolves into spiral shapes. If the travel time is sufficiently long or the intensity sufficiently high, the final result is the break-up of the sheet into small narrow rays. Calculations of the curvature of the beam, assuming proton sheets, are confirmed by auroral observations, leading one to suspect that the visible manifestation proceeding from arc formation to well after ray formation is the expected effect due to protons. It has been suggested[9] that this theory may help one to detect auroral cases where electrons play the major role. It may also help through observation of spreading velocities and formation sizes, to determine the distance to the focusing region.

answer are: (1) With better frequency-of-appearance data (more and better observations), would there be a tendency to expand (both north and south) the presently defined auroral zones? (2) Is the observed frequency of occurrence applicable to a given display or does this frequency merely represent a long-time statistical effect?

MAJOR LINES OF INVESTIGATION

Types of Auroral Data

Visual observations are taken by trained observers and are recorded on a standard form which is readily converted into punch card data. Data cards contain areas representing the sky, which is divided into four quadrants. Each area contains horizontal elevation lines of 30°, 60°, and 90°. The observer then draws a symbolic picture of the observed aurora in the appropriate quadrant, indicating such items as color; specific details, such as recognized formations; and directions of motion of the formations. Elevation angles are measured where possible.

In addition to the visual observation program, there is a program for either direct or indirect instrumental observations of aurora and auroral phenomena. This program and its objectives are as follows:(11)

- o Photographic observations from independent stations
- o Photographic observations from two or more associated stations, to determine the auroral location
- o Photometric studies using photography
- o Photometric studies employing photoelectric or other special types of photometers
- o Spectrographic studies
- o Auroral location by means of radar echoes

- Auroral ionization by absorption of cosmic radio noise
- Auroral ionization by vertical incidence sounding techniques
- Auroral detection by abnormal reception of short-wave radio signals, indicating reflection or scattering by auroral ionization
- Rocket studies of:
  - a. Auroral ionization and ionizing agents
  - b. The ultraviolet part of the auroral spectrum
  - c. The geomagnetic field in and near the luminous auroral region
- Geomagnetic and earth current studies
- Atmospheric electricity observations during auroras
- Sound associated with auroras
- Colorimetric studies of bright auroras

It is apparent that observations and studies of these types of auroral phenomena will aid in establishing information on atmospheric composition at auroral altitudes, and better estimates of attachment, detachment, and recombination rates for charged particles.

SUMMARY OF THE AURORA PROGRAM

Figure 3 is a world map showing the location of the U.S. stations carrying out the I.G.Y. auroral program. The types of measurements that are being made are indicated at each station.

Due to the nature of the auroral phenomena, and the types of observations that are made, it is meaningless at this time to discuss the completeness of the data. A personal communication from Dr. C. W. Gartlein, Cornell University, indicates that the punch card data are presently up to date to within one or two months. Also, lists of the southern extent of overhead aurora are available. As in the other archives of Data Center A, however, the raw data are available.

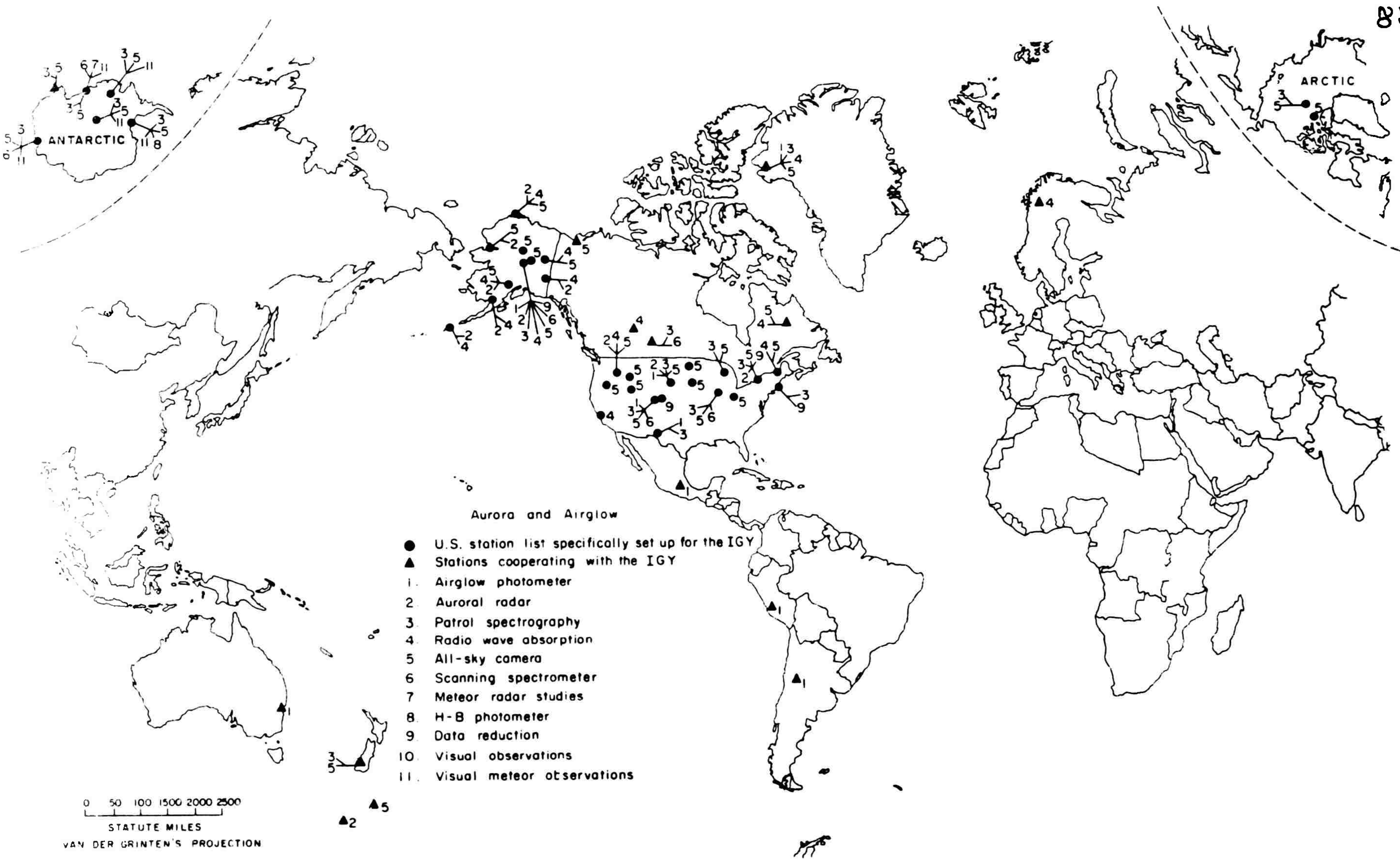

Fig. 3—Location and mission of U.S. IGY stations

V. COSMIC RAYS

HISTORY AND THEORY OUTLINE

Advances in cosmic ray studies in the last few years have brought the field to the point where it is felt that at least a working knowledge of this radiation is available.

Although many questions remain about the spectral details of the primary cosmic ray particles and their history in the earth's atmosphere and magnetic environment, the knowledge we do have permits the field to expand into studies of the dynamics of cosmic ray particles in interplanetary and galactic environments. Still unanswered are primary questions as to the mechanisms that give birth to this kind of particle and as to how they are accelerated to the extremely high energies they are observed to have.

The I.G.Y. cosmic ray program may be divided roughly into two main segments. One is a monitoring program conducted on the surface of the earth, and the other involves measurements at high altitudes. The following circumstances determine the nature of the monitoring program: due to the shielding action of the atmosphere only a small flux of particles under normal conditions are available at the earth's surface. Further, because of our position relative to the sun, particles from the sun serve as a dilution factor, which makes it more difficult to make quantitative statements about particles from other sources. In addition, fluctuations in atmospheric properties and in electric and magnetic fields can also cause changes in cosmic ray intensity received at the earth. To some extent these effects can be separated. For instance, cosmic rays are measured during solar and geomagnetic quiet periods. Attempts are made to correlate the observed fluctuation with those of barometric pressure, atmospheric temperature, mass distribution, and the height of constant-pressure surfaces. The overall aim is to factor out environmental effects and to arrive at conclusions as to changes in primary cosmic ray source strength and distribution, and in the time and space variations of the charge and momentum spectrum of the primary cosmic rays. Of particular importance are questions about the anisotropic nature of high-energy cosmic radiation, and consequent speculation as to the possibility of extra-galactic sources.

Measurements made at various altitudes have indicated that less than 10 to 20 per cent of the primary cosmic rays would be altered by interaction with the air by the time they had reached a minimum altitude of 100,000 ft. It is evident then that measurements made at this altitude would indeed be measuring primary radiation with very little contamination from secondaries. By 1947 plastic balloons capable of reaching these altitudes with a 50-lb payload became available. Early experiments using these new tools indicated that primary cosmic rays consisted of the nuclei of many elements in the periodic table as well as protons. Also, it was shown that only a very small fraction of incoming high-energy primary cosmic rays were electrons. Primary cosmic rays may be thought of as representing, to some degree, matter from another portion of our universe that has been accelerated to extremely high energies.

One important role that high-altitude measurements have played in the field of cosmic rays has been the work done toward obtaining the energy spectrum and composition of the primary radiation. This has been accomplished primarily by making high-altitude observations at various latitudes and by letting the earth's magnetic field act as a mass spectrometer. To date it has been found that hydrogen is about five times as abundant as helium.

Further, the relative amounts of lithium, beryllium, and boron appear far out of proportion to the astronomical abundances of these elements. Current theories indicate that the relatively high abundance of these elements might be explained by the long travel time of primary particles through space. No element heavier than iron has been found among primary cosmic rays. In summation, the distribution of elements in cosmic rays has been found to be essentially similar to that inferred by astrophysicists for average cosmic abundances. If we accept the explanation for the high abundance of lithium, beryllium, and boron, then the one distinguishing feature between the observed cosmic ray distribution and the inferred astrophysical distribution is the relatively high ratio of iron to hydrogen in cosmic rays.

MAJOR LINES OF INVESTIGATION

Problems Treated by the Monitor Program[12]

Monitor experiments might be called static types of cosmic ray studies, in that they are designed to operate for long periods of time without interruption. Their primary purpose is to record all fluctuations of cosmic ray intensity. The data one collects from such experiments is, first, of high statistical value, and second, of extreme value for observing the unpredictable.

Time and space variations of cosmic ray intensities have been observed as follows:

- Non-periodic fluctuations in intensity, including geomagnetic storm decreases, meteorological effects, and effects of solar flares
- Periodic time fluctuations, including solar diurnal, annual, 27-day cycle, seasonal, sidereal diurnal effects, etc.

- Variations due to latitude, longitude, zenith angle, altitude, and east-west asymmetry (a time variation is also observed when examining spatial fluctuations)

The basic types of instruments used for monitoring studies are as follows:

- Counter telescopes for detecting charged particles (Geiger counters, proportional counters, scintillation devices, etc.)
- Ionization chambers
- Neutron detectors
- Wilson cloud chambers
- Nuclear emulsions

In summary, then, the monitoring program for the I.G.Y. represents an extension of the pre-I.G.Y. program. The experiments to be carried out are mainly improved versions of experiments that have been successfully operated for many years. One important improvement of the I.G.Y. over the pre-I.G.Y. experiments is the standardization of the world-wide observation equipment. This standardization should result in data with a minimum of station-to-station ambiguity. The two types of equipment used throughout the monitoring network are:

- Triple coincidence counter telescopes with cubical geometry and minimum prescribed counting rate and sensitivity
- A neutron monitor pile for the detection of the low-energy nucleonic component

Problems Treated by the High-Altitude Program[13]

Due to the relatively small number of primary cosmic rays impinging on the top of our atmosphere (approximately $1/cm^2/sec$ at high latitudes), a study of the energy spectrum must naturally use the more abundant elements.

One such element is helium. Examining the alpha particle differential energy spectrum (number of particles per unit area, per unit time, per unit energy interval), it is found that a maximum number of particles exists at about 300 million electron volts per nucleon. Further, it was found that this maximum was rather broad and did not represent a sharp cut-off of lower energies. It is not known whether this maximum is caused by the effects of the accelerating mechanism or, possibly, by the effects of transmission through the interplanetary medium. It is probable, however, that the lower energy cosmic rays would be the most affected by solar activity. Studies of the alpha particle spectrum will aid in understanding the geomagnetic energy cut-off as a function of latitude and the solar activity effects. Both of these interesting problems are being studied as a part of the I.G.Y. program. The solar effect on cosmic rays is of particular interest. When solar activity increases (an increase in number of sun spots) there is an apparent increase in the intensity of cosmic rays at least in the higher energy region. Simultaneously, there is an apparent decrease of intensity in the lower energy region.* This increase and decrease may both be due to transient magnetic fields contained in plasmas ejected by the sun, or conceivably, they could be the result of ring currents around the earth, caused by the solar activity, at several earth radii. In addition to these indirect effects, sporadic increases have been observed in cosmic ray intensities due to particles coming directly from the sun during large solar flares.

As part of the I.G.Y. high-altitude cosmic ray program, the University of Minnesota has flown, and is flying, a set of 50 to 75 balloons at altitudes

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*During very intense solar flares a general increase in cosmic ray intensities has been observed, with the lower energies showing a greater increase than the higher energies.

of 100,000 feet. These are designed to stay aloft for 24 hours and to measure short- and long-term primary intensity changes. In addition, an attempt is made to obtain as much information as possible on what components of the primary beam are changing as a function of time. The equipment used is an omnidirectional Geiger counter, a spherical integrating ionization chamber, and an emulsion package. In addition to this program there are other high-altitude experiments, some involving balloons and others rockets and satellites (see Sec. VIII).

SUMMARY OF COSMIC RAY DATA

Figure 4 is a world map showing the location of all U.S.-sponsored I.G.Y. cosmic ray experiments, both monitor and high-altitude (with the exception of rockets and satellites). Figure 5, an example of data availability, is a bar graph similar to Fig. 2. In this case, the experiment indicated is the neutron monitor measurements.

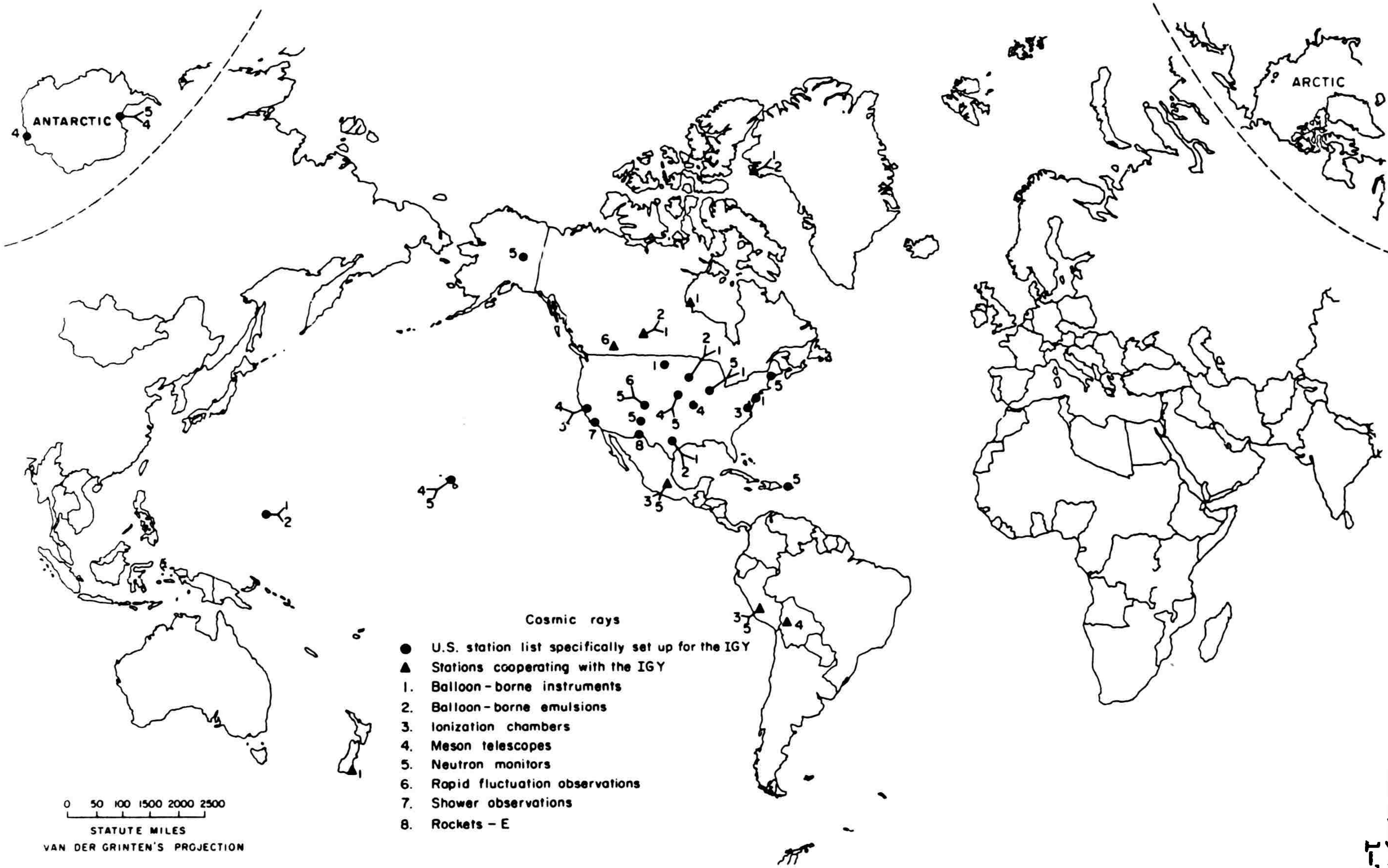

Fig.4—Location and mission of U.S.IGY stations

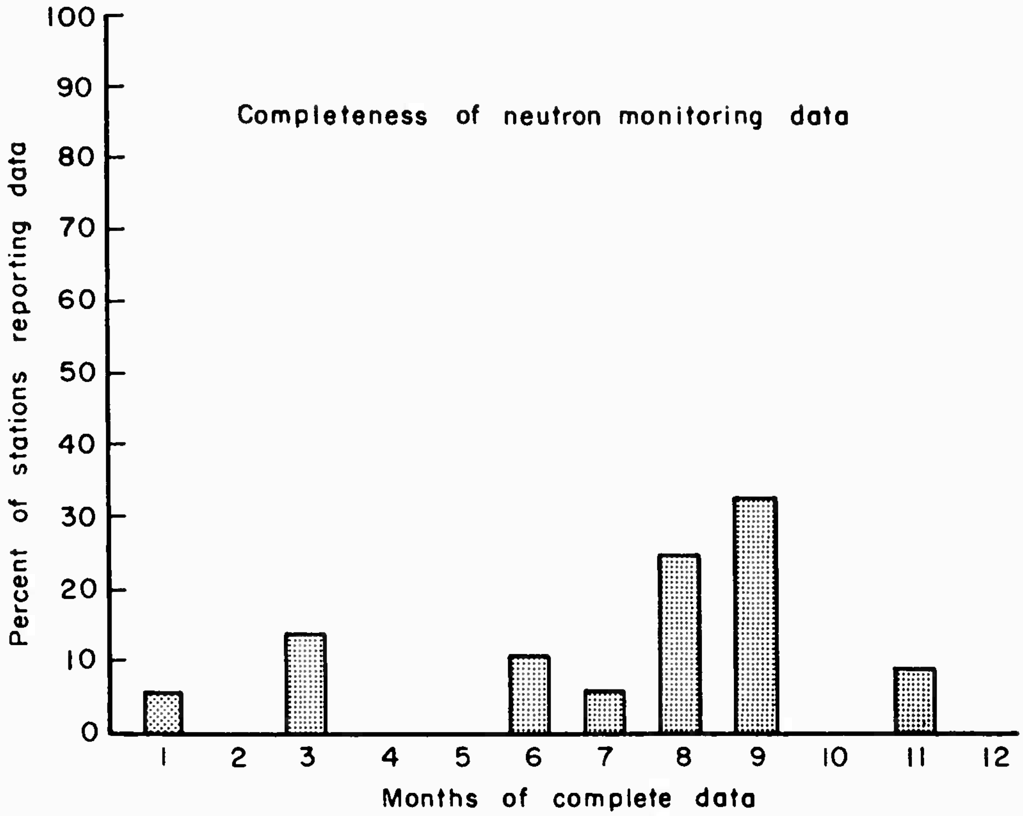

Fig. 5 —— Cosmic ray data
As of July 1958

VI. SOLAR ACTIVITY[14]

HISTORY AND THEORY OUTLINE

The I.G.Y. solar activity program is an extreme extension of the normal solar observation program that has existed throughout the world for many years. Its prime objective is to observe, record, and analyze all solar activity as a function of time and as a function of position on the sun. Its secondary objective is to provide warning of sudden increased solar activity (large flares and prominences, etc.), so that increased observational activity might be started in the scientific field in which there is any suspicion of solar effect on observable phenomena (ionosphere, cosmic rays, geomagnetism, meteorology, aurora, etc.). The object of such activity is to secure coordinated data from which correlation studies might be accomplished, and from which, conceivably, a fuller understanding of the effect of the sun on our planet's environment might emerge. The suspected solar effect on observable atmospheric phenomena has been discussed in related sections of this report. For this reason this section on solar activity will be devoted to a description of what observations are made.

MAJOR LINES OF INVESTIGATION

Solar Flare Patrol

Approximately 30 observing stations are so distributed in longitude around the world as to insure 24-hour observations of the sun. The prototype of the observing instrument used is the Lyot Heliograph of the Meudon Observatory. The heliograph is basically an equatorially mounted 3- to 6-inch telescope guided on the sun. It is equipped with a birefringent filter that transmits a band 0.5 to 0.75 A wide, centered on the hydrogen

H-α line. Recordings are made with a 35-mm movie camera. The solar image formed is 16 mm in diameter and all flares of importance 1 or greater are easily detected.* Photographic observations are made at intervals of 3 minutes during the assigned observation period of a given station.

Solar Tower

The solar tower may be thought of as a rigidly mounted vertical telescope. It may have either reflecting or refracting optics. The sun's image is fed into these optics by a pair of flat mirrors that are driven so as to follow the sun. The resulting image is stationary and non-rotating and may be placed directly onto the slit of the spectrograph or other instrument at the base of the tower. Due to the light-scattering characteristic of the unavoidable plane mirrors, this instrument is not very useful for delicate observations of the solar limb. This difficulty, however, does not affect observations of solar disk phenomena.

The Lyot Coronagraph

For observations at the solar limb, no better instrument has been found than the coronagraph. This is an instrument that essentially produces an artificial eclipse of the sun, and then employs all the known methods of reducing the diffracted light from the edge of the solar disk. However, even the best coronagraph is not sufficiently scatter-free as to show the solar corona. Fortunately, the coronal light consists of emission lines and strongly polarized white light (polarized along the direction of the solar radius). Using a spectrograph in conjunction with a coronagraph,

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*Importance criteria are those established by the International Astronomical Union.

the continuous-scatter spectrum can be reduced sufficiently to allow observations to be made of the brighter coronal emission lines. With somewhat more difficulty, the emission-corona can be photographed through a birefringent filter in the light of the H-α line. Polarized white light is detected by means of an attached sensitive photoelectric polarimeter.

Solar Radio-noise Observations

Unlike optical observations, radio observations of the sun are conducted in a rather gross way. That is to say, most observations taken to date are of integrated radio emission from the entire solar disk (by means of a network of solar "radiometer" stations with receivers operating at 200 Mc). Even this type of observation has yielded interesting results due to the fact that temporary solar activity at this frequency may be a thousand times the steady-state radiation from the entire disk. Presently the sun is under 24-hour-a-day observation at this frequency, although the significance of radio-noise outbursts at this frequency is not really understood.

Development work on solar radio equipment has been pushed in two directions: the recording of the emission spectrum over a broad band of frequencies, and the use of increased resolving power to localize the source regions on the solar disk.

Considerable success has been achieved in the development of radio spectro-meters. The initial instrument developed by Wild in Australia[15] has the capability of sweeping from 60-130 Mc. Another instrument, built for the Harvard Observatory, has the capability of sweeping from 100-600 Mc in 0.3 seconds. Puzzling new observations made recently with these instruments indicate solar radio disturbances that rise with velocities of the order of 500 km/sec through the corona and sometimes fall back with the same velocities. Other observations have indicated disturbances that appear to shoot out with velocities of 10,000 km/sec or more.

Much success is also being achieved in localizing solar radio disturbances. This is being accomplished by means of radio interferometers. The difficulty here is the size of the antennas required. Since a useful resolution is .001 radian (1/10 solar diameter), and since angular resolution is just the angle subtended by one wavelength at a distance equal to the total aperture, an antenna is needed that is 1000 wavelengths across. For a wavelength of one meter, then, an antenna one kilometer wide is required. Since resolution in two dimensions is really desired, it is easy to see why few observatories have the ability to do high-resolution solar radio work.

In addition to the instrumentation described above, measurements are made with photometric devices to determine variations in solar light intensities. Also, specific instruments, such as the Babcock solar magnetograph, for measuring the sun's magnetic field, and rapid data reducing systems, such as direct intensity recording microphotometers, are used.

SUMMARY

Figure 6 is a world map showing the location of all the U.S.-sponsored I.G.Y. solar activity stations with an indication of the experiments done at each station. Figures 7 and 8, bar graphs similar to Figs. 2 and 5, show the completeness of data on "sudden solar disturbances" and "solar radio emission," as of July, 1958.

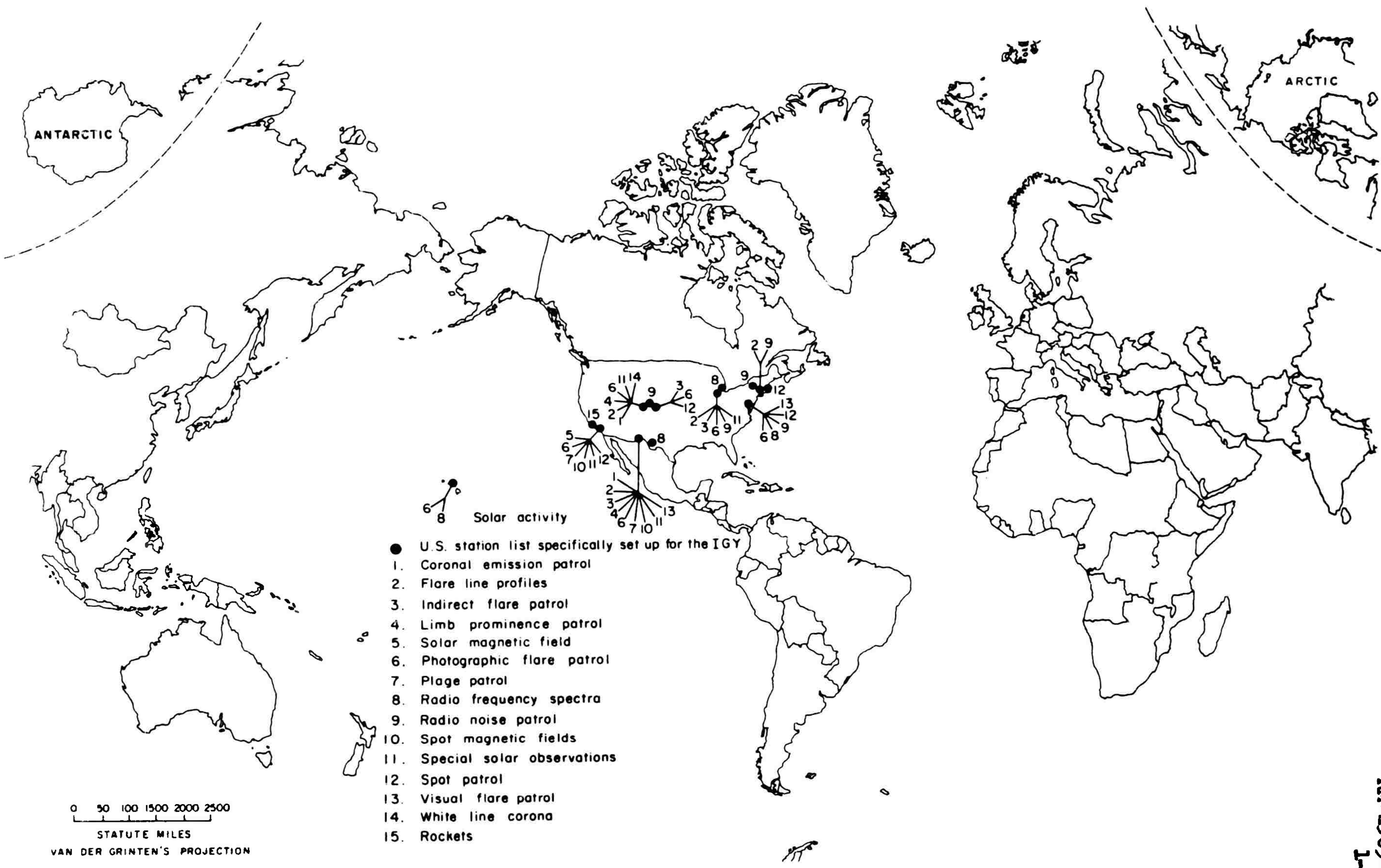

Fig. 6—Location and mission of U.S. IGY stations

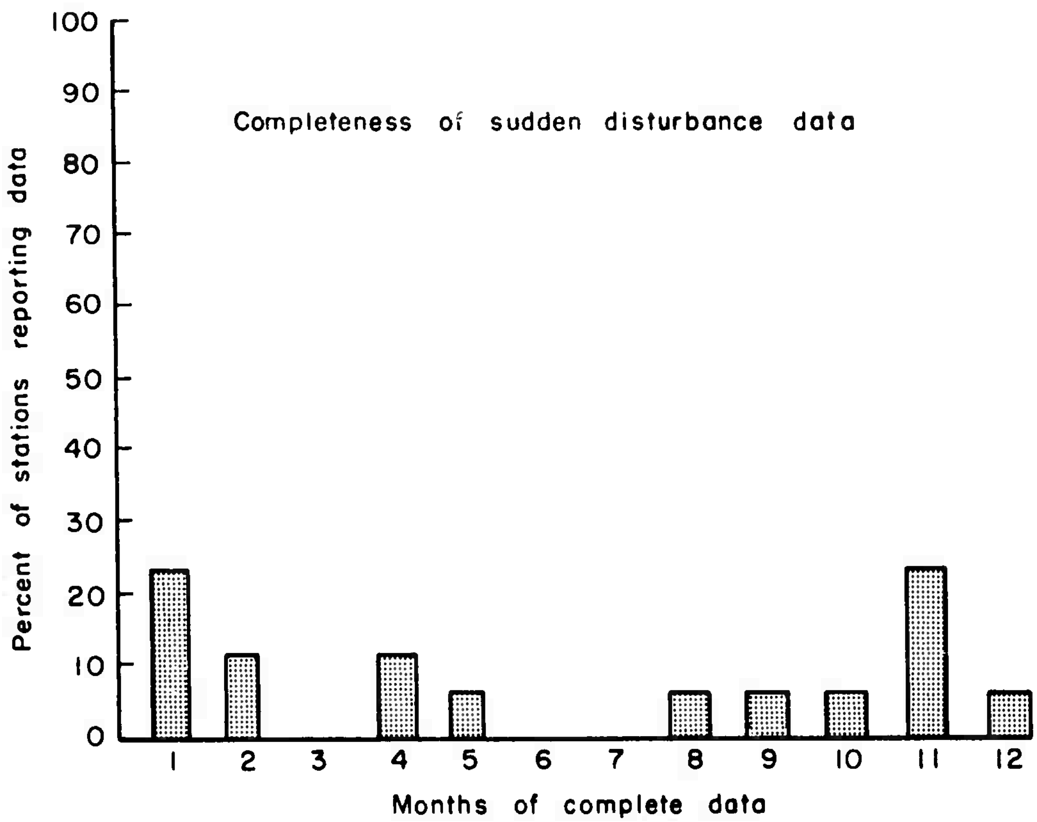

Fig. 7 — Solar activity data
As of July 1958

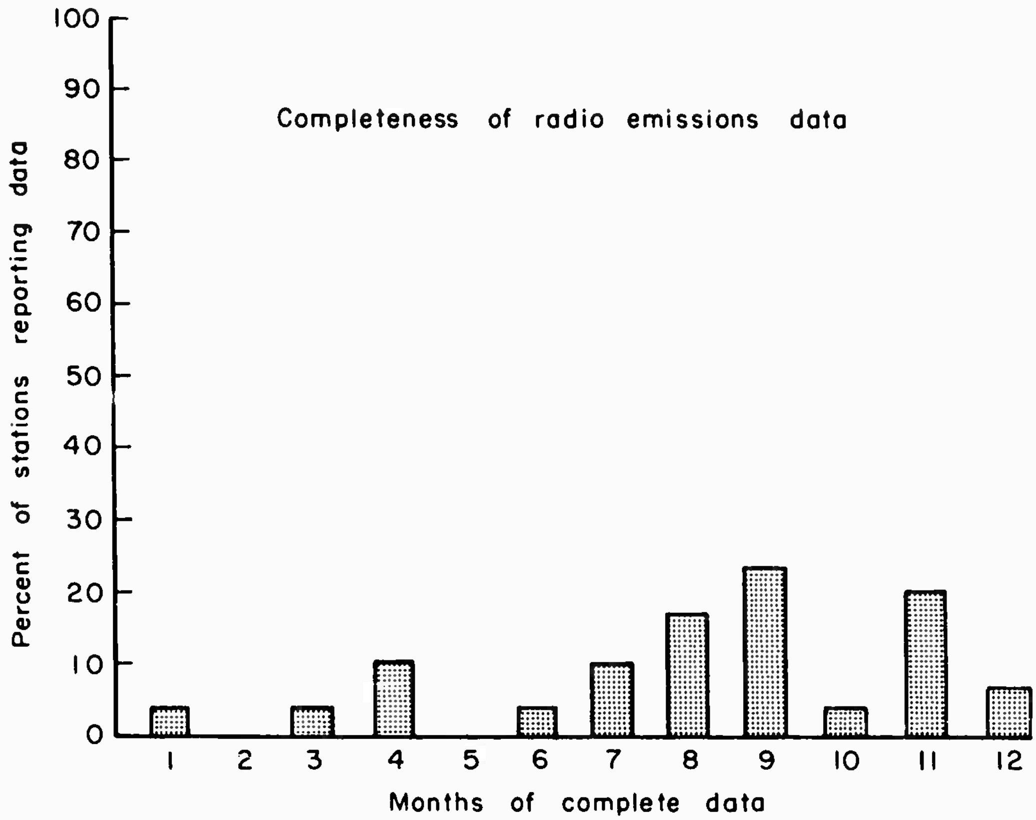

Fig. 8 —— Solar activity data
As of July 1958

VII. GEOMAGNETISM[16]

HISTORY AND THEORY OUTLINE

Geomagnetic fluctuation may be thought of as a very complex phenomenon composed of two segments. The first, and by far the largest segment, is a relatively stable field generated within the earth and exhibiting a slow secular change, the reason for which is still unknown. The second segment, accounting for perhaps 5 per cent of the observed field, is made up of highly variable components which are directly or indirectly associated with electrical current streams in the very high atmosphere. It is this second segment which accounts for most of the present-day activity in the field of geomagnetism.

It is felt that the variation of the intensity of ultraviolet radiation from the sun must play an indirect part in the production of short-term magnetic variations. This is due to the part that ultraviolet plays in producing our ionosphere and the fact that the ionosphere, being conductive, must carry fairly large currents, with resulting magnetic fields that interact with the normal field.

Streams of protons and electrons from the sun (as mentioned previously) are deflected as they enter the earth's magnetic field. The protons move toward the east and the electrons toward the west. It is felt that this produces a current stream or belt above the ionosphere completely surrounding the earth at approximately the equator and at a distance of several earth radii from our planet. Although it is supposed that this belt does not exhibit any longitudinal variations, there is a strong conviction that it does undergo several kinds of time variation. If a current caused by entering particles exists, its behavior can be used to explain the depression of the magnetic field strength H during magnetic storms and the subsequent post-disturbance effects. It can also be used to explain the time structure found in low-latitude records. However, if a current exists in the ionosphere, it too could produce these same effects. This is the type of quandary that workers in geomagnetism find themselves in today. It is hoped that the satellite and rocket data will ultimately help to settle some of these questions of ring currents and current sheets. It is also hoped that, with the extended observation facilities that have been available during the I.G.Y., phenomena supposedly due to the equatorial ring current will be mapped and charted in greater detail than ever before.

Particles streaming along magnetic field lines reach the atmosphere in the vicinity of the poles, producing auroral effects and magnetic changes. In their most severe forms, these magnetic effects are characterized as magnetic storms. These effects are subject to rapid changes in the initiating mechanisms. Due to a lack of observational data at these high latitudes, information and knowledge about these effects are scant. It is hoped, however, that the data collected during the I.G.Y. will have rectified this lack. In addition to the information just presented on geomagnetism, several areas of paramount current interest are listed below.

MAJOR LINES OF INVESTIGATION

Diurnal Variations

A diurnal effect has been observed which is attributed to atmospheric tides involving both heating and ionization in the upper atmosphere. It is felt that this variation is caused by horizontal motions of a conducting gas (dynamo action) across the vertical component of the main field. Harmonic analyses indicate that 75 per cent of the effect is due to causes outside of the solid earth and that 25 per cent are due to induced currents in the earth's crust.

A similar problem exists with the horizontal component of the magnetic field; certain equatorial stations show a much greater amplitude of this variation than do stations at other latitudes. The variation has been likened to that which might exist if the current system overhead exhibited a constraining or "pinch" effect that was most evident at the crossing of its equatorial portions and the noon meridian. A similar enhancement is noted during irregular activity such as magnetic storms. The I.G.Y. program in geomagnetism is making a strenuous effort to trace out this so-called equatorial "electrojet" and to obtain enough data to make a concerted attack on this problem.

General Activity

General activity (or "unrest") has been observed and recorded for many years. Out of these data has appeared a recurrent 27-day cycle which can be traced to solar origin. Also included in general activity are magnetic fluctuations of frequencies approaching radio frequencies. These cannot be picked up by standard instruments, and although not very well understood, they are generally thought to be in part due to lightning discharges. Induction-type detectors that are capable of picking fluctuations in the audio and sub-audio frequency range are presently being used in an effort to gather data on this little-known phenomenon.

Magnetic Storms

Magnetic storms are world-wide phenomena that are generally felt but with intensities increasing towards the two auroral zones. Surface magnetic field changes during magnetic storms may be divided into three parts.

- o Storm-time variations: a change proceeding according to time measured from the commencement of the storm
- o Disturbance--daily variation: a distinctive pattern of enhanced diurnal variations
- o High-latitude irregular effects

Very often a magnetic storm will occur abruptly (sudden commencement). As near as can be ascertained, these sudden commencements occur simultaneously all over the world. Presently available data indicate that there are important relationships existing between solar disturbances (sunspots) and magnetic storms; yet these relationships are not always consistent. In general, magnetic storms constitute a disordered influx of excited particles flowing towards the earth along magnetic lines of force. Yet, it is not clear where these particles came from. Do they represent leakage from the ring current? Do they emanate directly from the sun? What is clear, however, is that in spite of the data which have been gathered on magnetic storms, one cannot yet describe their features in terms of a general or average storm. In this case the geomagnetician is certainly facing the same types of problems faced by the meteorologists of several years ago when trying to understand the intricacies of atmospheric storms. The only solution to such problems is the obvious one--more data. It is hoped that the data gathered by the I.G.Y. will shed some new light on this very complex set of problems.

Micropulsations

In any observatory record capable of showing the fine structure of the magnetic field fluctuation can often be found long trains of quasi-sinusoidal waves. The origin of these waves has long been a major question in the field of geomagnetism. During the I.G.Y., rapid-run magnetographs were used to measure these waves. From the measurements made by these instruments it is hoped that a sufficiency of data will be forthcoming to enable one to make a reasonable attack on this problem.

Differential Magnetograph Observations

Although it is very important to increase the extent of the observational network in the field of geomagnetism, it is equally important, due to the highly transient nature of phenomena to be observed, to achieve a coordinated simultaneity of observations. To this end an instrument has been developed called the differential magnetograph. This instrument consists of a central recording instrument and two satellite instruments, one about seven miles south and one about seven miles west of the central recorder. These stations are connected by cable and a continuous record of magnetic field difference is made. This results in a continuous record of magnetic field gradient in two directions. Data from these instruments should yield better clues to the form and location of ionospheric currents.

In addition to the information gathered directly, it is apparent that there is a large interrelationship between all the various scientific fields already discussed in this report. For this reason it can be expected that much supplementary geomagnetic data will be forthcoming, indirectly, from auroral observations, solar observations, ionospheric observations, cosmic ray studies, etc. However, these data will not come easily. What is called for here is a very careful interdisciplinary analysis system such as does not yet exist within the United States. In this connection the work done by Simpson and co-workers[17-19] can be cited as illustrations of what can be accomplished through interdisciplinary coordination and cooperation, and of what could and should be the end result of the I.G.Y.

SUMMARY

Figure 9 is a world map showing the location of all the U.S.-sponsored I.G.Y. geomagnetic stations and the experiments accomplished by each station. Figure 10, a bar graph, shows the completeness of data on the K and C indices* as of July 1958.

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*The C index is a subjective estimate of the degree of quietness of the magnetic field. It is based on a scale of 3 where C = 0 indicates quiet, and C = 2 indicates very disturbed. The K index is a measure of the difference vector between the observed three-dimensional field vector at a given time and an assumed undisturbed field vector. The undisturbed vector is established by smoothing observations over a three-hour period containing variations for which the K index is desired.

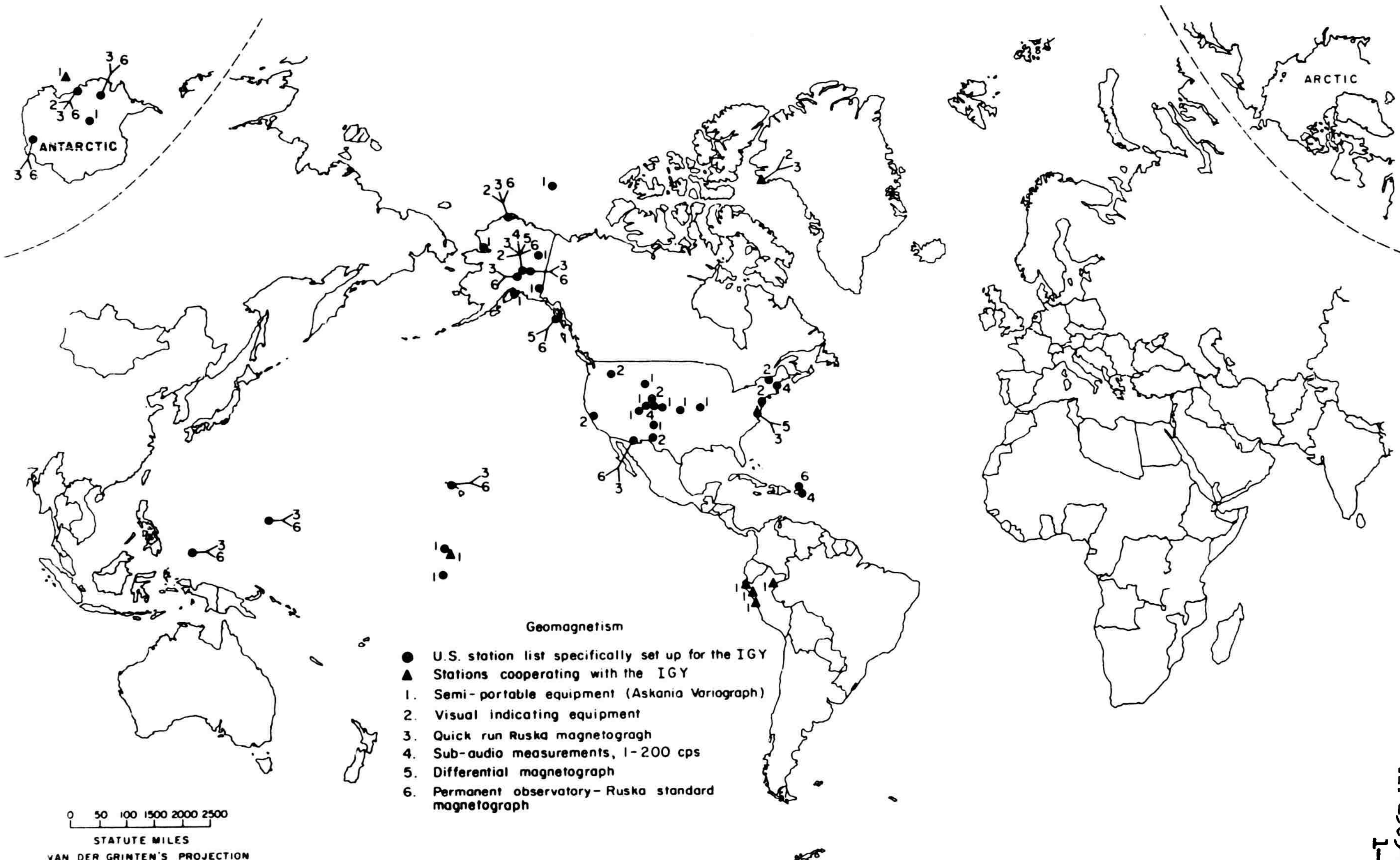

Fig. 9—Location and mission of U.S. IGY stations

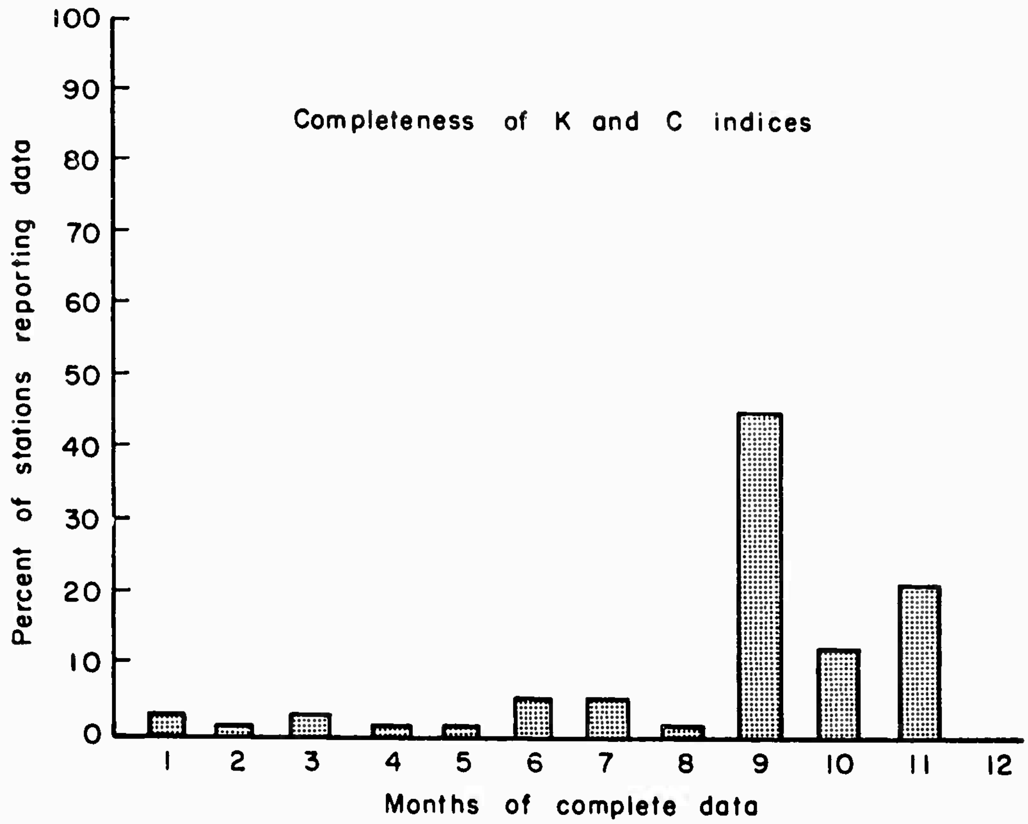

Fig. 10 — Geomagnetic data
As of July 1958

VIII. ROCKETS AND SATELLITES

It would be useless to try to describe every experiment that was planned and/or carried out for the I.G.Y. rocket and satellite program. It is sufficient to say that the program was planned to utilize the potential of these tools to the fullest as a means of extending experiments already described in this report into and beyond our atmosphere.[20]

ROCKETS

Over 200 rockets were fired during the I.G.Y. from five different launching stations. These launching areas are: (1) New Mexico, (2) Fort Churchill in Canada, (3) in Arctic waters, (4) in the Pacific Ocean, and (5) in the Anarctic region. The U.S. rocket program was designed to complement various studies in other fields. Thus, there were experiments in atmospheric composition, solar activity, aurora and airglow, geomagnetism, cosmic rays, and several experiments in ionospheric physics. As mentioned earlier in this report, the Data Center Archive for rockets is issuing a report series which will ultimately contain the findings of all the rocket experiments. The one report issued to date and its contents are:

I.G.Y. World Data Center A
Rockets and Satellites
National Academy of Sciences
I.G.Y. Rocket Report Series

Number 1 (July 30, 1958):

"Experimental Results of the U.S. Rocket Program for the International Geophysical Year to 1 July 1958," 236 pp.; thirty papers on: (1) The summary results of the U.S.-I.G.Y. rocket program to 1 July 1958; (2)

atmospheric structure; (3) ion composition of the Arctic ionosphere; (4) ionospheric measurements; (5) auroral particles and soft radiation; (6) solar radiation, cosmic rays and the earth's magnetic field; (7) US Air Force and Ballistic Research Laboratory (US Army) rocket programs for the I.G.Y.

SATELLITES

As is well known, the United States placed four successful satellites in orbit during the I.G.Y. These were:

(1)	1958 Alpha (Explorer I)	January 11, 1958
(2)	1958 Beta Two (Vanguard I)	March 17, 1958
(3)	1958 Gamma (Explorer III)	March 26, 1958
(4)	1958 Epsilon (Explorer IV)	July 26, 1958

As in the case of the rockets, the experiments designed for the satellites were extensions of the I.G.Y. program already partially described in this report. As may be imagined, priority was given to experiments that were better suited to satellites than to rockets, that is, problems were investigated, the answers to which required experimental measurements from outside the earth's atmosphere for extended periods of time. As in the case of rockets, a report series is being issued by the Data Center Archive on satellites* which will ultimately contain all the pertinent results of the satellite program. Reports issued to date and their contents are:

*Both the rocket and the satellite report series are available through the following source: Printing and Publishing Office, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington 25, D. C.

I.G.Y. World Data Center A
Rockets and Satellites
National Academy of Sciences
I.G.Y. Satellite Report Series

Number 1 (March 1, 1958):

"Processed Observational Data for USSR Satellites 1957 Alpha and 1957 Beta," 120 pp., a four-page introduction on sources and processing of data; 116 pages of catalogue of observations and a station coordinate list.

Number 2 (April 30, 1958):

"Status Reports on Optical Observations of Satellites 1958 Alpha and 1958 Beta," 41 pp., twelve papers on: (1) preliminary results from optical tracking of the U.S. earth satellites; (2) optical satellite observations; (3) scientific results; (4) the use and distribution of satellite predictions; and Harvard announcement cards.

Number 3 (May 1, 1958):

"Some Preliminary Reports of Experiments in Satellites 1958 Alpha and 1958 Gamma," 100 pp.; five articles: (1) "Status Reports on Optical Observations of Satellites 1958 Alpha and 1958 Beta;" (2) "Determination of the Orbit of 1958 Alpha at the Vanguard Computing Center;" (3) "Satellite Micrometeorite Measurements;" (4) "Satellite Temperature Measurements for 1958 Alpha;" (5) "The Observation of High Intensity Radiation by Satellites 1958 Alpha and Gamma."

Number 4 (July 15, 1958):

"Observational Information on Artificial Earth Satellites," 38 pp.; nine papers on: (1) the USSR satellites; (2) the U.S. satellites; (3) satellite characteristics and scientific results.

Number 5 (July 30, 1958):

"Radio Observations of Soviet Satellites 1957 Alpha and 1957 Beta," 50 pp.; three parts: (1) "Determination of Passage Parameters from Simple Interferometer Records;" (2) "Preliminary Results of the Analysis of Ionospheric Fading and Interferometer Effects;" (3) "Spin Fading."

Number 6 (August 15, 1958):

"Reports and Analyses of Satellite Observations," 60 pp.; four papers: (1) "Moonwatch Catalogue (Tables);" (2) "Preliminary Note on the Mass Area Ratios of Satellites 1958 Delta 1 and 1958 Delta 2;" (3) "The Descent of Satellite 1957 Beta;" (4) "Positions of Satellite 1957 Beta 1 During the First 100 Revolutions (Tables)."

IX. CONCLUSIONS

This report has been an attempt to summarize the pertinent features of the part of the I.G.Y. program concerned with the upper atmosphere and related fields. As such, it has drawn quite extensively from the writings of experts in their respective fields (in each case, the references indicate the writer whose work was summarized) and from information supplied by archives. It has tried to give the reader a feeling not only for what experiments were carried out and what instruments were used, but also for the most interesting problems in the various fields. It has also attempted to give the reader an estimate of the availability of data, not by presenting long catalogs of data files, but rather by showing examples of the completeness of data in at least one specific area of each field discussed, and by giving adequate references to the data files. This, then, has been a task of reporting and summarizing.

From what has been presented, it is obvious that the scale of effort, underwritten by the United States, to obtain upper-atmospheric data--and, indeed, geophysical data of all types--has been large. Specifically, in excess of several hundred million dollars has probably been spent on the U.S. I.G.Y. program (when the Vanguard and Antarctic programs, with their logistic support, are included). The data that have been collected are, of course, of paramount use to people working on a wide variety of research problems. There is, however, another broad use that can be made of the extensive data collected, namely, to obtain world-wide environmental descriptions of upper-atmospheric and associated phenomena.

Such environmental descriptions will be of value to researches being conducted or supported by universities, NASA, the U.S. I.G.Y. Committee of the National Academy, NSF, many industrial and research institutions, and the Department of Defense. In addition, these descriptions will be of great help in many military problems (for example: space and AICBM technology). Unfortunately, the I.G.Y. data-gathering program has not been matched in the United States by comparable attention to a comprehensive analysis of the data. It is estimated that the only comprehensive analysis is one being funded by NSF, to the extent of 1.5 million dollars/year, and only a part of this program involves world-wide analyses. It is of interest to note that the Russians, Japanese, and Europeans are carrying on extensive work of just this nature, using data supplied by all nations, including the United States.

A few publications can be cited as examples of what can be done with I.G.Y. data in world-wide environmental studies. Parts of the Handbook of Geophysics for Air Force Designers(21) contain, in tables and graphs, the kind of information we have in mind, although in much more restricted scope. Some Carnegie Institution volumes(22, 23) on geomagnetism give a good picture of thorough, extensive, world-wide environmental studies, in one subject, for certain years prior to the I.G.Y. Similar studies using I.G.Y. data might well be carried out for the other fields mentioned in this report.*

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*This use of I.G.Y. data has been jointly suggested by P. Tamarkin, E. H. Vestine, and the author.

REFERENCES

1. Shapley, A. H., and R. J. Slutz, "Probing the Ionosphere," in Geophysics and the IGY, Hugh Odishaw and Stanley Ruttenberg (eds.), Geophysical Monograph Series, No. 2, American Geophysical Union of the National Academy of Sciences, National Research Council Publication No. 590, Washington, D. C., 1958, pp. 45-48. Hereinafter cited as Geophysics and the IGY.

2. Gussman, G. J., "Airborne Ionospheric Measurements in the North Pole Area," Journal of Geophysical Research, Vol. 61, No. 1, March, 1956, pp. 136-138.

3. Wells, H. W., "Upper Atmospheric Winds, Absorption, and Other Special Projects in the U. S. Program in Ionospheric Physics," Geophysics and the IGY, pp. 49-54.

4. United States National Committee for the International Geophysical Year, United States Program for the International Geophysical Year 1957-1958, National Academy of Sciences, National Research Council, Washington, D. C., July, 1958.

5. Helliwell, R. A., "Whistlers and Very Low Frequency Emissions," Geophysics and the IGY, pp. 35-44.

6. Eckersley, T. L., "Developments in the Study of Radio Wave Propagation," Marconi Review, No. 31, July-August, 1931, pp. 1-8.

7. Eckersley, T. L., "Musical Atmospherics," Nature, Vol. 135, January 5, 1935, pp. 104-105.

8. Storey, L.R.O., "An Investigation of Whistling Atmospherics," Royal Society of London Philosophical Transactions, Series A, Vol. 246, 1953, pp. 113-141.

9. Gartlein, C. W., "Visual Observation of the Aurora," Geophysics and the IGY, pp. 92-96.

10. Kyhl, R. L., and H. F. Webster, Instability of Hollow Beams, General Electric Company, Research Information Section, Report 56-RL-1556.

11. Chapman, S., et al., "Visual Auroral Observations," Annals of the International Geophysical Year, Vol. 4, Appendix IV, Pergamon Press, New York, 1957.

12. Chasson, R. L., "Significance of Cosmic-Ray Monitor Observations," Geophysics and the IGY, pp. 71-80.

13. Ney, E. P., and J. R. Winckler, "High Altitude Cosmic-Ray Measurements During the International Geophysical Year," Geophysics and the IGY, pp. 81-91.

14. Evans, J. W., "Instrumentation for Global Observation of the Sun During the IGY," Geophysics and the IGY, pp. 21-30.

15. Wild, J. P., "Techniques for Observation of Radio-Frequency Radiation from the Sun," in The Sun, G. P. Kuiper (ed.), University of Chicago Press, 1953, pp. 676-692.

16. Roberts, E. B., and D. G. Knapp, "Background and Technical Objectives in Geomagnetism," Geophysics and the IGY, pp. 55-64.

17. Simpson, J. A., "New Experiments Concerning the Geomagnetic Field Extending into Interplanetary Space," Geophysics and the IGY, pp. 65-70.

18. Katz, L., P. Meyer, and J. A. Simpson, "Further Experiments in the Geomagnetic Field Effective for Cosmic Rays," Nuovo Cimento Supplemento, Series 10, Vol. 8, No. 2, 1958, pp. 277-282.

19. Simpson, J. A., "Cosmic-Ray Experiments Devised from Recent U.S. Antarctic Expeditions," Geophysical Monograph No. 1, American Geophysical Union of the National Academy of Sciences, Publication No. 462, 1956, pp. 107-123.

20. Kellogg, W. W., IGY Rockets and Satellites: A Report on the Moscow Meetings August 1958, The RAND Corporation, Paper P-1501, September 15, 1958.

21. Handbook of Geophysics, Geophysics Research Directorate, Air Force Cambridge Research Center, Air Research and Development Command, U.S. Air Force, 1957.

22. Vestine, E. H., et al., Description of the Earth's Main Magnetic Field and its Secular Change, 1905-1945, Carnegie Institution of Washington, Publication No. 578, Washington, D.C., 1947.

23. Vestine, E. H., et al., The Geomagnetic Field, Its Description and Analysis, Carnegie Institution of Washington, Publication No. 580, Washington, D. C., 1947.

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