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International Geophysical Year

The first of a two-part summary of IGY activities covers studies of the sun and upper atmosphere.

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An earlier report outlined some of the activities of the IGY, especially as reflected in our own program, during the first months of the endeavor (*1*). Here an attempt will be made to narrate, on behalf of the IGY scientific community and based upon their reports to the National Academy of Sciences, some of the events as the IGY reaches its formal close on 31 December 1958 (*2*). Just as the earlier report could be only suggestive, this too can but touch upon a few of the happenings, largely within the U.S. program, but perhaps some feeling for the whole effort can be conveyed. Some of the work described here has been reported in the scientific literature, and various papers are in press or preparation. IGY bibliographies are being prepared by several agencies; they now exist in interim and draft form (*3*, *4*).

The magnitude of the effort was appreciable, and some statistics show this clearly. For example, Table 1 presents the number of principal stations in each activity, grouped by latitude zone and indicating the degree of geographical coverage that was attained. The total number of stations is incorrect because there is duplication where projects in two or more fields were housed in a single structure. The correct total, in the sense of the table and based on the CSAGI geographical distribution list of 27 June 1958, turns out to be 2461, but this too fails to present the whole picture: First, from a scientific point of view, the uncorrected table number of some 3500 stations is more truly representative of the total station activity. Second, some stations were added after the compilation of the list. Third, many temporary stations, all surface meteorological stations (about 2500), and perhaps 1000 auroral and satellite volunteer observation stations and sites have been excluded. The best that one can do, therefore, is to say that some 4000 principal scientific stations and several thousand contemporary and volunteer sites or stations were active.

Similar difficulties beset one in establishing how many individuals took part in the IGY or in estimating the costs of the over-all effort. Both of these difficulties stem in part from the variety of ways in which the various national committees funded their programs and from the extensive voluntary contributions made by public and private institutions. It is probable that some 20,000 to 30,000 scientists, engineers, and technicians were engaged in the effort, supplemented by a somewhat comparable number of volunteer observers.

The story that can now be told encompasses three aspects of the IGY: (i) the discoveries and specific results that can readily be interpreted; (ii) the synoptic effort, which yielded vast quantities of data; (iii) the direct impact upon coming geophysical programs. In this article, the sampling is concerned with the upper atmosphere and the sun. Part II will similarly survey the heat and water regimen, the earth sciences, the synoptic data aspects, and post-IGY developments, particularly those for 1959.

Studies of solar activity, aurora and airglow, cosmic rays, geomagnetism, and the ionosphere provided a wealth of data and many concrete, striking findings. The simultaneity of the observations and measurements, which the IGY emphasized, proved invaluable, while the availability of rocket and satellite vehicles remarkably augmented the information secured from ground stations and observatories and balloons and aircraft (see Figs. 1 and 2).

Solar Activity

Studies of the sun during the IGY may be divided into two groups, regular surveys and special researches, even though the former also has important research values.

More than 100 patrols—visual, optical, photographic, photometric, and radio—kept the sun under constant watch at every minute throughout the IGY period. This unprecedented watch on the sun yielded ample returns. It permitted the detection of solar flares, and such information was channeled by solar observatories to the IGY World Warning Agency in the United States, where daily analyses were made of the likelihood of a solar disturbance with ensuing terrestrial effects. Between 28 June 1957 and 30 November 1958 these analyses led to the calling of 38 "alerts"—messages radioed throughout the world calling attention to the probability of the declaration of a Special World Interval. These intervals, of which there were 20 between 28 June 1957 and 30 November 1958, permitted scientists everywhere to intensify their measurements during the great periods when high atmospheric disturbances followed in the wake of major solar flares.

Chosen because it coincided with the current maximum of the sunspot cycle,

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the IGY period witnessed the greatest level of solar activity in history: the Zurich Observatory, international clearing house for sunspot statistics, reported that 1957 had the highest yearly mean in relative sunspot numbers since 1778, while the level of activity during 1958 seems to have been somewhat lower. The maximum of the present cycle fell almost in the middle of the IGY period.

In the patrol program photographs of the sun were taken by many observatories—every minute and even more often—in the light of hydrogen and calcium lines. These photographs, in effect a time-lapse study of the solar disk, provide, together with other related observations, the most detailed record of the sun in history. Taken during the greatest cycle of sunspot activity ever observed, this corpus affords a great body of information for astronomical analysis.

One of the new devices used in the solar program was the K-coronameter, used to measure the brightness of electron-scattered light in the K^- or electron corona of the sun. Much fainter than the emission corona of ordinary atomic transitions, the K-corona requires unusually clear skies. Some fifty such days at the High Altitude Observatory Climax station yielded previously unobserved details of the sun. W. O. Roberts reports that variations of the depths of the layers of the corona, where temperatures of 1.5×10^6 °K, prevail and where appreciable solar radio noise originates, were studied.

At the High Altitude Observatory, a line profile spectrograph has yielded some interesting data. D. E. Billings has completed a pilot analytical study which shows promising preliminary results on analyses of line spectra in H-alpha of about 50 small flares. Billings has produced a detailed graph of the optical depths of the flare gases as a function of wavelength, from the center of the spectrum line into its wings. Observatory scientists believe that if it proves possible to extend this kind of analysis to other flares, the results will be of the highest importance in flare physics. Such work will have a crucial bearing on problems of flare emission at wavelengths beyond the visible and on studies of the effects of flares in the earth's upper atmosphere and on geomagnetic disturbances.

H. Smith and his associates at Sacramento Peak Observatory report that a detailed discussion of the physics of the flare of 18 September 1957 is in process. The flare was photographed with the Sacramento Peak universal solar spectroraph covering 3878 to 7200 angstroms,

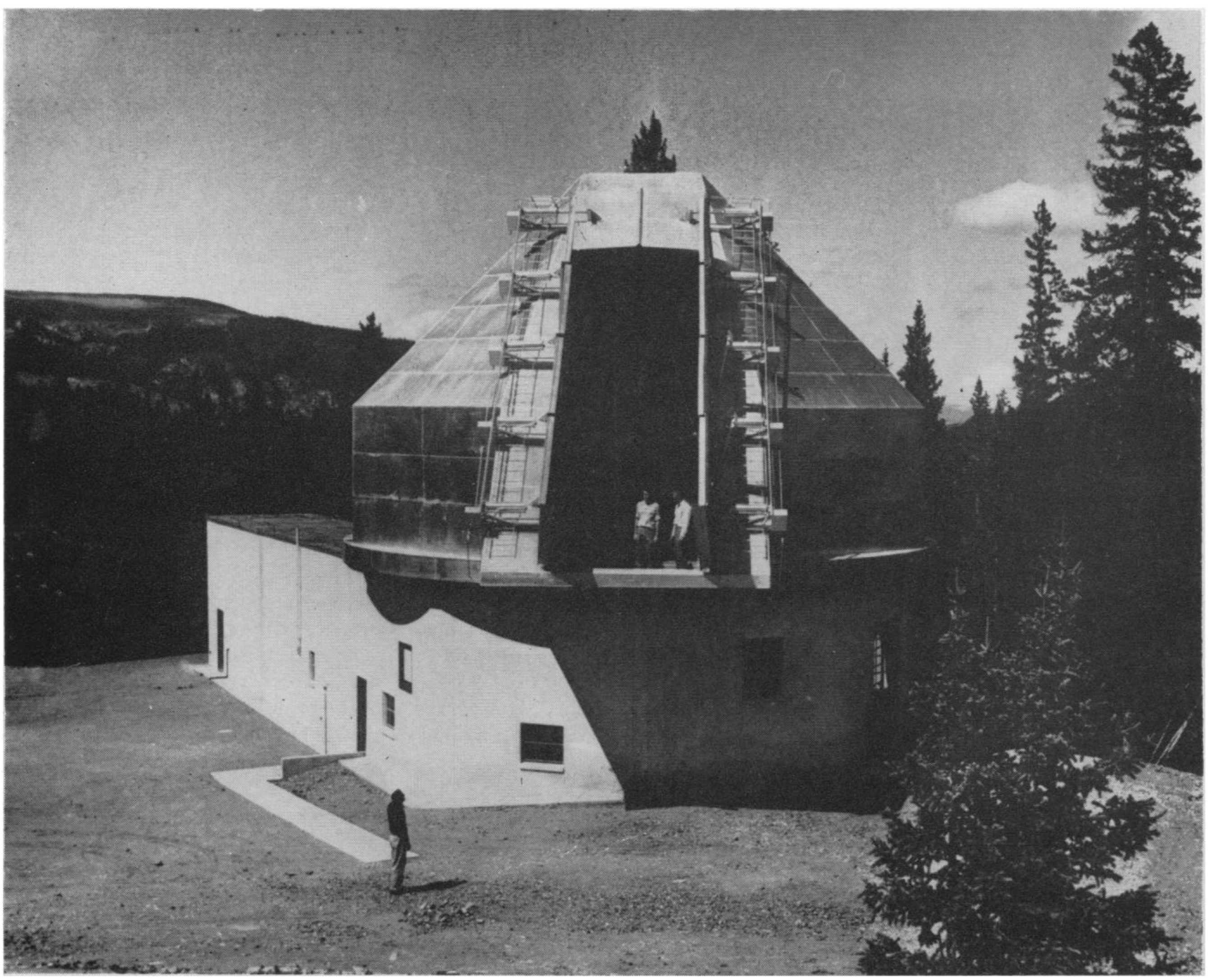

Fig. 1. The large solar laboratory of the High Altitude Observatory at Climax, Colorado. In this rotatable solar dome is located a 26-foot equatorial platform on which are mounted solar telescopes for special solar research. One of the instruments in this dome was built specifically for the IGY and detects the faint streamers of the corona from day to day, without natural eclipse of the sun. [University of Colorado].

Table 1. General list of principal IGY stations (from CSAGI Geographical Distribution List, 27 June 1958).

	World days and communications	Meteorology	Geomagnetism	Aurora and airglow	Ionosphere	Solar activity	Cosmic rays	Longitudes and Latitudes	Glaciology	Oceanography	Rockets and satellites	Seismology	Gravimetry	Nuclear radiation	Totals
Arctic ($\Phi > 60°N$ or $\phi > 60°N$)	4	158	46	77	51	2	19	2	31	16	7	23	13	43	492
Subauroral North ($60°N > \Phi > 45°N$ except if $\phi > 60°N$)	18	358	56	42	66	63	38	37	12	46	21	83	37	160	1037
Minauroral North ($45°N > \Phi > 20°N$)	20	270	46	19	54	39	34	23	10	74	21	86	40	90	826
Equatorial North ($20°N > \Phi > 0°$)	10	89	18	4	33	9	8	4	—	50	5	35	9	30	304
Equatorial South ($20°S > \Phi > 0°$)	9	96	20	5	28	6	9	4	6	29	8	39	8	26	293
Minauroral South ($45°S > \Phi > 20°S$)	6	100	12	3	23	7	7	8	5	57	8	43	18	41	338
Subauroral South ($60°S > \Phi > 45°S$ except if $\phi > 60°S$)	1	13	6	8	11	1	7	1	1	17	1	8	6	9	90
Antarctic ($\Phi > 60°S$ or $\phi > 60°S$)	1	34	19	23	18	—	6	—	38	12	5	15	19	1	191
	69	1118	223	181	284	127	128	79	103	301	76	332	150	400	3571

with dispersion of 2 angstroms per millimeter and exposure of 3 seconds. The analysis of the observation showed a marked red shift, indicating a downward motion of material toward the solar disk. Twenty different ions were detected in the flare spectrum, and excellent profiles were obtained for the heavier lines.

Measurements of the sun's surface magnetic field were made at Mount Wilson Observatory, revealing very high fields associated with some sunspots—as much as 8000 times the earth's field at the equator. H. D. Babcock and W. C. Livingston reported that the south magnetic pole of the sun reversed its polarity and that the north pole intensity decreased: these events have a time-lag of some 3 years with respect to minimum sunspot count. Mount Wilson scientists believe that variations of the sun's field probably reflect large-scale patterns of circulation related to the 22-year solar magnetic cycle, and they seem to be related to various solar-terrestrial phenomena.

Aurora

The IGY period was remarkably rich in auroral observations. C. W. Gartlein (Cornell University), responsible for the visual observation program in the United States, reports that in the first six months of the IGY there were 103 nights on which auroras were seen in the United States. In the first six months of 1958 there were over 110 nights on which auroras were seen. In March 1958 auroras were seen on every night except that of the 31st.

Auroral activity was also monitored by all-sky cameras, radar, and absorption equipment (see Fig. 3). The absorption program has turned up some interesting information that possibly bears on emission of soft cosmic rays from the sun during flares. H. Leinbach and G. Reid (Geophysical Institute, University of Alaska) report that absorption records from Thule and two locations in Alaska, following a solar flare, give strong suggestion of solar cosmic ray emission at low energies. The absorption equipment, a relatively simple and reliable noise receiver, promises to play an important role in the study of the relationships of auroral, ionospheric, and solar phenomena.

A new twilight phenomenon, the presence of a line at wavelength approximately 6700 angstroms, has been discovered in spectra taken in Antarctica during the last few months of 1958. First reported by the joint New Zealand-U.S. station at Cape Hallett on 5 August 1958, the radiation has been observed at all the U.S. antarctic stations with the exception of Little America, and by the New Zealand station at Invercargill. This radiation has been attributed to lithium in the high atmosphere, a constituent not previously known to be present there. The twilight display is evidently analagous to the familiar sodium twilight radiation often observed. A plain inference is that these new manifestations could be related to nuclear tests carried out during the same period as the IGY program.

At a recent meeting of the USNC-IGY Technical Panel on Cosmic Rays there was discussion of the suggestion by E. P. Ney and P. J. Kellogg of the University of Minnesota that a large nuclear explosion might result in some permanent perturbation of the earth's external magnetic field. Although it was recognized that the energy contained in the external field is a small fraction of that in the internal field of the earth, Ney and Kellogg pointed out that the total energy contained in the external field is of the order of that in a large nuclear explosion, which suggests the possibility of appreciable effects. No a priori reason was advanced why this could not take place. The temporary effects would disturb the trapping conditions for the Van Allen particles and, allowing their release, could produce an aurora. [In this connection it is interesting to note that A. L. Cullington of New Zealand has recently reported the observation, at Apia on 1 August 1958, of a man-made or artificial aurora (*5*).]

The interdisciplinary value of the simultaneously conducted IGY studies, often already indicated, is perhaps most strikingly suggested in the report of scientists at the University of Minnesota (J. R. Winckler, L. Peterson, R. Hoffman, and R. Arnoldy) on the great auroral storm of 10–11 February 1958, summarized as follows:

Balloon-borne instruments at Minneapolis detected two groups of strong x-ray bursts during the storm. These coincided with two large magnetic bays, with strong absorption of radio noise, and with the passage across the zenith of a very large amount of auroral luminosity. A cosmic ray decrease also accompanied the storm. The University of Minnesota workers believe that these terrestrial disturbances were associated with the earth's entry into a large cloud of solar gases that may have originated in a solar flare occurring about a day earlier.

The aurora observed in North America during this storm was one of the most spectacular in recent years. It was reported as far south as Cuba. At Minneapolis, the aurora was seen by visual observers simultaneously with the sudden commencement of the magnetic disturbance, at 0126 U.T. on 11 February. The all-sky camera record from Hanover, N.H., shows its appearance a few minutes after the magnetic disturbance began. At Minneapolis, from 0130 to 0330 U.T., a very intense diffuse green arc covered the sky from 20 degrees above the northern horizon to the zenith and from the eastern to the western horizon. The outstanding feature, however, was the red color, also very intense, which appeared in diffuse patches at high angles above the northern horizon and, at 0200 U.T., covered the northern sky from 15 to 30 degrees elevation as a diffuse arc.

The southern limit of arc forms reached a geomagnetic latitude of 46°N at 1000 U.T. on 11 February 1958. It is estimated that the aurora extended from a height of about 200 to 800 kilometers, and for a distance of about 9600 kilometers east-west and 400 kilometers north-south. In addition to a very high intensity of both the red and green spectral lines, other unusual features of the aurora were the diffuseness and extent of the luminescence and its persistence for long periods without major changes in form. Spectra taken in Alaska by scientists of the Geophysical Institute showed unusually strong development of infrequently noted emission lines. The outstanding solar event of the period preceding this aurora was a flare, reported by Honolulu Observatory as class 2 and by Sacramento Peak Observatory as 2+; this flare started at 2108 U.T. on 9 February and ended at 2302 the same day, with its maximum phase at 2140. Nevertheless, since considerable solar activity was present for several days prior to the terrestrial storm, the solar-terrestrial relationship is not completely certain. Large radio-noise fluxes were reported by several stations during the flare.

Fig. 2. One of the solar radiometers at the Gunbarrel Hill field site of the Boulder Laboratories, National Bureau of Standards. The reflector is 25 feet in diameter and is mounted so as to follow the sun throughout the day. It is in continuous operation to monitor radio noise from the sun. [National Academy of Sciences]

The terrestrial effects of this storm began at 0126 U.T. on 11 February, according to the rapid-run magnetogram of Fredericksburg (Va.) Observatory. The horizontal component (H) of the earth's magnetic field immediately showed a bay of $+117\gamma$, followed by a disturbed period and a second sharp, positive bay of about 500γ, which appeared at 0159. This sudden increase in the horizontal component was accompanied by sharp drops of about 150γ in the vertical component (Z) and 30γ in the magnetic declination (D). It is assumed that these pulses represent the initial encounter of the solar gas cloud with the earth's dipole field or the sudden appearance of ionospheric current systems, or both.

Large earth currents were observed coincident with the horizontal-component peak at 0159. T. E. Talpey (Murray Hill, N.J.) has stated that the earth's potential at the western end of the North Atlantic Telephone Cable from Newfoundland to Scotland dropped from a maximum of about 2650 volts at 0202 U.T. on 11 February, through zero to a peak in the opposite direction at 0209. The current was driven from west to east through the cable and seemed to be an induction effect associated with the second magnetic peak.

The circuit loop of the earth current, if considered to lie in a vertical east-west plane, requires a return path through the sea *above* the cable. However, derivation of the potential in the water gives only about 15 volts around the circuit, compared with the measured maximum of 2650 volts.

Thus the earth current was apparently part of a system flowing in the earth's surface and associated with changes in the vertical component in an unexplained way. The current system seems to have been centered over the eastern United States.

A balloon launched at Minneapolis at 0445 U.T. on 11 February encountered the first detectable x-ray bursts at 0622, coincident with the major decrease in the first large magnetic bay of the second phase of the storm; these bursts continued until 0730. A second large period of bursts occurred at 0850, coincident with the second magnetic bay of this phase.

It is thought reasonable to assume that both the changes in conductivity of the ionospheric E-layer, which produced the magnetic bays, and the observed x-rays had a common origin in electrons produced by the solar gas stream. Their energies would lie in the range from 40 to 100 kv or higher; most of their energy, however, would be lost in the atmosphere as ionization and as the visible auroral light. About 1/1000 of the energy would be radiated as bremsstrahlung x-rays, the higher-energy components of which are detected at balloon levels (about 100,000 feet).

Large absorption of cosmic radio noise at 18 megacycles per second at Boulder, Colo., was observed exactly coincident with the magnetic bays and the x-ray bursts. The records give evidence of a very widespread increase in ionospheric electron density extending north-south for at least 150 kilometers. The correspondence of data from Fredericksburg, Minneapolis, and Boulder (Fig. 4) shows that the major primary fluctuations were simultaneous over distances of thousands of kilometers.

The large changes in the horizontal component of the magnetic field, the strong cosmic-noise absorption, the auroral x-rays, and the general presence of the aurora itself are all consistent with a very intensified bombardment of the ionosphere by high-energy electrons between 0530–0700 and 0830–0930 U.T. on 11 February over central United States.

It is interesting to note that, on the basis of the auroral electron flux (6×10^6 electrons per square centimeter, per second) inferred from x-ray intensity and energy, the electron density at Boulder coincident with the 10–11 February aurora is computed to be 1.2×10^5 electrons per cubic centimeter. This is in reasonable agreement with the value of 1.4×10^5 electrons per cubic centimeter obtained through cosmic-noise absorption studies on the assumption that absorption during an auroral storm occurs mainly in the upper D-layer, at altitudes of 80 to 90 kilometers.

There is, however, a discrepancy between visual estimates which placed the lower limit of the auroral luminosity at 200 kilometers and any suggestion that soft x-rays in the form of bremsstrahlung produced at this level might be responsible for the D-layer electrons causing noise absorption. This arises because there is insufficient x-radiation produced as bremsstrahlung to account for the lower level ionization if the limit of luminosity marks the lowest level of penetration of the electrons or other primary ionizing agent.

Therefore, either the estimated height of 200 kilometers was too high and the lower border of the aurora was actually at the usual height of 75 to 100 kilometers, or electrons or other particles carried considerable energy downward, below the visual auroral border.

The storm was accompanied by a world-wide Forbush-type decrease in the intensity of galactic cosmic rays as demonstrated by recordings of two groups of ground-level neutron monitors: one in Europe and Africa, close to the longitude of Greenwich, except for a station at Hobart, Tasmania (longitude 145°E), and the other in the Western Hemisphere extending from Northern Canada to the Antarctic approximately along 90°W. All stations showed an initial drop at 0200 U.T. on 11 February of roughly the same amount, 4 to 6 percent. An interesting feature of this Forbush-type decrease, apparently reported for the first time, was a "precursor" drop in intensity that occurred closely coincident with the sudden commencement of the magnetic storm, at 0127 U.T.

High altitude soundings with a standard ion chamber and counter were taken before, during, and after the decrease. The total influx of cosmic-ray energy, obtained by integrating the ion chamber rates throughout the atmosphere, dropped 14.9 percent during the storm; by 16 February it had recovered to within 8.4 percent of the 8 February value.

All the phenomena described are consistent with the passage of the earth into a remarkably intense solar cloud, which may have originated in the solar flare beginning at 2108 U.T. on 9 February and ending at 2302 on 9 February.

If the cloud originated with the 2-hour

Fig. 3. Photograph taken just prior to removal of the protective plastic dome from the all-sky camera installation at Fritz Peak, Colorado, field station for the National Bureau of Standards, Boulder Laboratories. The camera, using an image from a hemispherical mirror, shown in the center, gives horizon-to-horizon sky coverage for the IGY aurora program. [National Academy of Sciences]

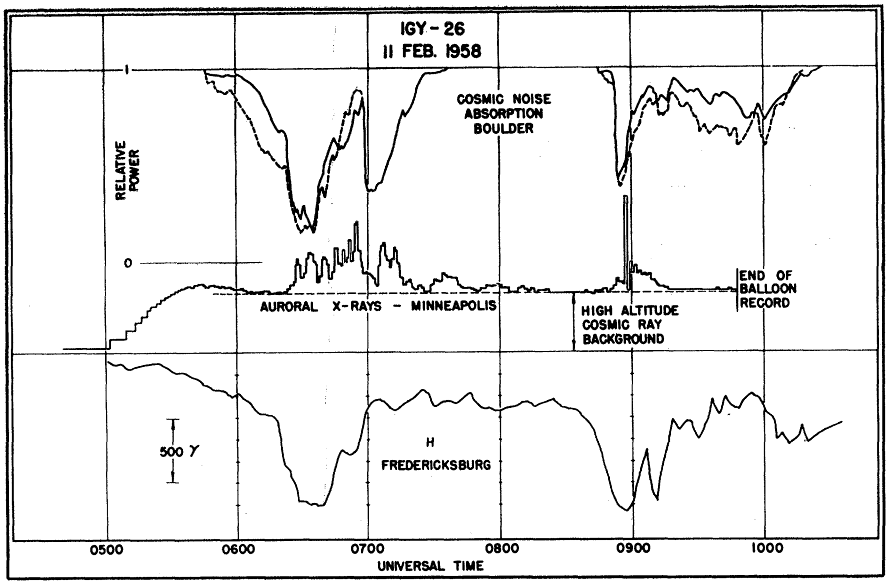

Fig. 4. Comparison of the horizontal field at Fredericksburg, auroral x-rays measured at Minneapolis, and cosmic noise absorption measured at Boulder. Two cases of intense ionospheric ionization apparently occurred, reaching maxima at approximately 0630 and 0900. The ionization was very widespread, as shown by this correlation and by all-sky camera photographs.

interval of the flare and required 24 hours to pass the earth, considerable velocity dispersion must have been present in the solar gas so that the slower solar particles could predominate later in the storm. The leading edge of the cloud must have been exceedingly well defined, and the cloud must also have contained considerable internal structure, as revealed by "spikes" in the first phase and by the two large bays accompanying the x-ray bursts later in the storm. These structural features persisted during the sun-earth passage despite the large velocity dispersion.

Although the modulation of galactic cosmic rays in this storm, while appreciable, was in no way exceptional when compared with other Forbush-type decreases, the storm was nevertheless unique with respect to the great intensity of the associated ionospheric phenomena; this may reasonably be attributed to an exceptionally high density of the solar gas enveloping the earth. The aurora of 10–11 February was one of the most intensely studied solar-terrestrial phenomena of the IGY.

Cosmic Rays

The scheduling of the IGY for a period of maximum solar activity was of particular value to cosmic ray research. Appreciable advances were made in our understanding of cosmic rays and their causes, effects, and interrelationships with other phenomena (see Fig. 5). A very interesting aspect was the relevance of cosmic rays to explorations of the geomagnetic field.

The beam of cosmic rays coming largely from the galaxy changed drastically between the last minimum of solar activity (1954) and the present maximum (1957–58). S. E. Forbush, studying μ-meson intensities, found that the results show an 11-year cycle of intensity variations which is roughly opposite in phase to that of sunspot numbers but lagging in phase by about 1 year. J. A. Simpson and his colleagues (University of Chicago) found a decrease of 25 percent in neutron intensity at Climax, Colorado, between 1954–55 and the early part of 1958, with a more than twofold decrease in this period for particles with energies of 1 Bev or greater. H. V. Neher (California Institute of Technology) found that ionization at Thule, measured aboard balloons at 93,500 feet, was only half that of 1954 and that the number of primary particles was diminished by a factor of 4. J. R. Winckler and L. Peterson (University of Minnesota) studied vertical particle flux using balloons at northern geomagnetic latitudes between 51.2 and 64.2 degrees: above 33,000 feet the flux decreased near sunspot maximum; the decrease becomes greater with increasing height and at both high latitudes and altitudes was down by nearly a factor of two. These experiments showed that, of the additional particles admitted at some 100,000 feet in 1955 between north geomagnetic latitudes 51.2 and 58.6 degrees, at most only one-sixth remained near sunspot maximum and that the relative latitude effect in this range was reduced from 40 to 10 percent or less.

During the past several years, it has become clear through the work of U.S. investigators that the intensity of the cosmic radiation reaching the earth undergoes large changes with time, and that these changes are associated with electromagnetic phenomena on the sun. Phenomena that produce large changes in the cosmic ray intensity at the earth have become the central problem of interest. Not only does their study add to an understanding of cosmic ray and solar effects, but analysis of these data is leading to knowledge of magnetic fields in interplanetary space and to explanation of many magnetic storm effects at the earth's surface.

In 1957, large decreases in cosmic-ray intensity during magnetic storms were unusually numerous. Several U.S. investigators have recorded large variations in daily mean neutron intensity for various intervals during the IGY. The sudden decrease in daily mean neutron intensity from 29 to 30 August 1957 was between 8 and 10 percent at IGY stations operated by the universities of California and Chicago and the Bartol Research Foundation (Pennsylvania). This is about 2.5 times the change in ionization at Huancayo.

M. A. Pomerantz (Bartol Research Foundation) reports that values of daily means of neutron intensity at Thule (20 August 1957 to 31 March 1958) correlate well with values obtained by D. C. Rose at Ottawa and Resolute, Canada. Using balloons on several days between 21 August and 18 September, Pomerantz also measured the vertical quadruple-coincidence rate under 7.5 centimeters of lead at altitudes above the 28-gram-per-square-centimeter pressure level (80,000 ft). These results show a decrease of about 20 percent near 1 September 1957 as compared with 20 August 1957.

Two experiments conducted in 1958 with balloon-borne pulsed ionization chambers revealed that the fluxes of both heavy nuclei and high energy protons did not change at the same time when a decrease of 23 percent in the total intensity was recorded as indicated above. Taking the results of other investigators into account, as well, Pomerantz concludes that the current general reduction in the primary cosmic ray intensity is a consequence of a change in the cutoff rigidity only. He points out that a sharp cutoff of protons unaccompanied by a corresponding cutoff of heavy nuclei could be reconciled by ascribing the observed decrease in primary intensity to the action of a cutoff mechanism at the sun upon low energy cosmic rays of solar origin.

Twelve-hour neutron-intensity means at Chicago from 22 July to September 1957 reported by Peter Meyer (University of Chicago) showed a range of nearly 20 percent. Meyer has also conducted balloon flights in Canada on days when the neutron intensity at Chicago differed, from one to another of these days, by 12 percent. His purpose was to determine whether the change in proton and alpha-particle flux is different at these two locations. On the basis of these balloon flights conducted during 1957 and 1958, Meyer reported at a recent meeting of the American Physical Society in Chicago that in general the modulation mechanisms responsible for intensity variations in cosmic rays affect both alpha-particles and protons in the same manner so that the ratio of fluxes remains constant. However, the independent behavior of the alpha-particle flux, when compared with the proton flux, as observed on certain individual flights, if real, may occur only at certain times, and perhaps only following Forbush decreases.

Because cosmic rays are deflected by magnetic fields, they may be thought of as probes to reveal the distribution and configuration of the magnetic field in the regions surrounding the earth. Investigations to locate the magnetic equator for cosmic rays are being carried out through multiple crossings of the equatorial region by ships and aircraft. These studies by J. A. Simpson (University of Chicago) and M. A. Pomerantz (Bartol Research Foundation) were mentioned in the earlier report (*1*).

K. A. Anderson (State University of Iowa) has reported unusual balloon observations taken at an atmospheric depth of 10 grams per square centimeter at Churchill on 22 August 1958, in which ionizing radiation appeared beginning at 1525 UT in time association with a great solar noise storm. The response of three balloon-borne detectors was not consistent with x-rays, high-energy gamma rays, or with electrons as a principal cause, but did correspond to protons with a kinetic energy of 170 Mev. From one previous balloon flight made from Churchill in 1957 there was strong evidence for the appearance of protons in the 100-Mev energy region during a period of high solar activity, but no further confirmation was obtained until the occurrence of the more recent event. The time scale and certain of the details of the event bore a strong resemblance to an x-ray shower observed on 29–30 August 1957, which suggests that the protons in the present event and the electrons, presumed to have given rise to the x-rays in the earlier event, are affected by a common mechanism. It was definitely established that the radiation present during the 1958 event was not associated with visible auroras, for sky conditions were excellent for observations. There was little if any magnetic disturbance present at the time.

Geomagnetism

Some 200 magnetic observatories recorded magnetic-field vector components on a regular basis during the IGY. These data, calling for appreciable analysis, have as their principal value their utility in interdisciplinary studies, particularly in correlations of events involving solar, ionospheric, auroral, and cosmic ray effects. Studies of cosmic rays themselves proved most revealing in throwing light on the earth's magnetic field in space. Emphasis in the United States geomagnetic effort was also placed on rapid variations, close network studies, and the electrojet phenomenon.

To determine whether magnetic field variations other than the daily variation also show electrojet effects, four stations equipped with Askania variographs were established for the IGY on the west coast of Peru by S. E. Forbush (Carnegie Institution of Washington), in cooperation with the Instituto de Geofisico de Huancayo. The maximum daily variation of the horizontal component was found to occur within 1 degree of latitude of Huancayo (12°S). This is in accord with results from the 1949 survey. It is also confirmed by the fact that the daily variation of the vertical component of the earth's magnetic field, obtained dur-

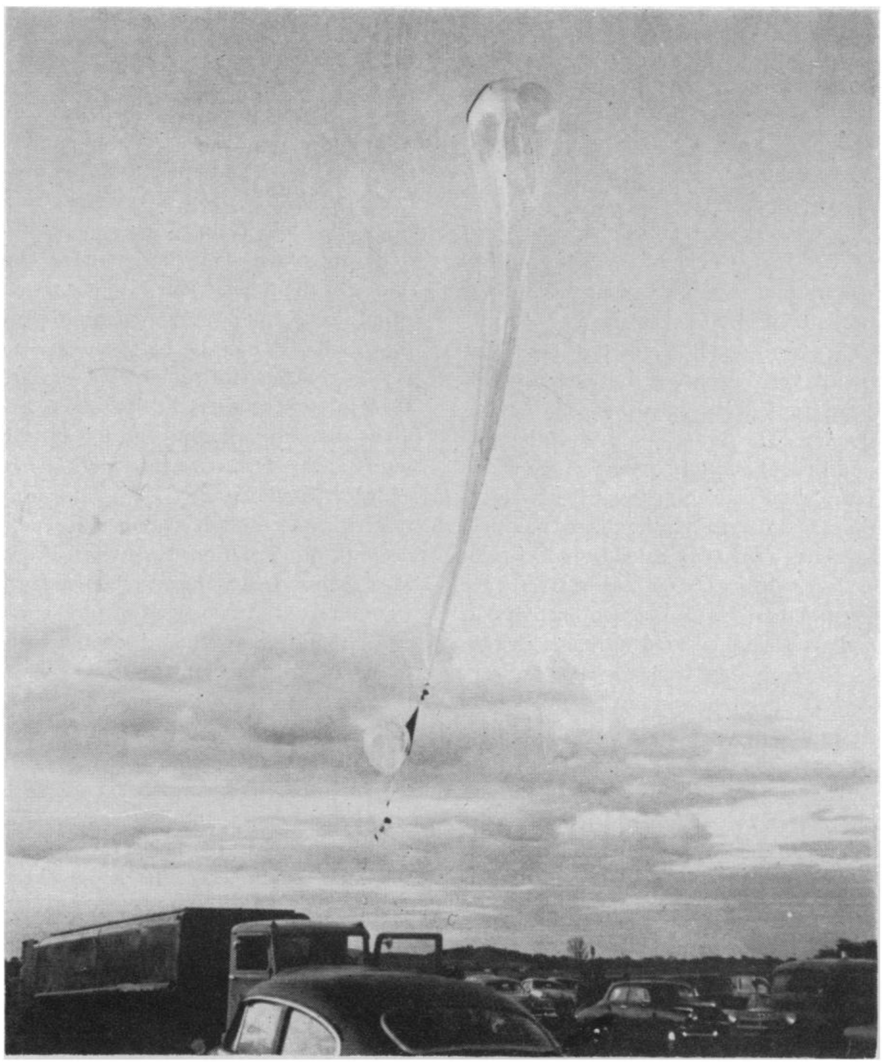

Fig. 5. Sky-hook balloon for the measurement of the variation in intensity in cosmic radiation over a period of time. [General Mills, Inc.]

ing the 1957 survey, changes sign at a latitude within 1 degree of Huancayo. A maximum daily variation in the vertical component occurred at about 16°S, and another maximum, with opposite sign, occurred near 8° or 9°S.

The north-south distance of 500 miles between these extremes provides a rough estimate of the width of the electrojet band. The difference with latitude of the daily variation of the vertical component indicates the importance of the return currents, which must flow westward, to the north and south of the eastward-flowing electrojet.

To estimate reliably the height and width of the electrojet, the electric current system of the electrojet field must first be derived. Before this derivation can be accomplished, the normal, quiet-day solar variation, estimated from data obtained at locations free from the influence of the electrojet, must be subtracted. Such height and width estimates have not yet been completed.

A preliminary examination of records indicates that many of the vertical-component fluctuations related to solar disturbances are greatest at the same latitudes where the largest quiet-day solar tidal variation in this component was observed. The sign of the fluctuations is opposite at these two latitudes, indicating electrojet effects.

A network of stations was established by E. Maple (Geophysics Research Directorate) to study geomagnetic fluctuations in the frequency range of 1 to 50 cycles per second. Maple has found that oscillations or micropulsations may appear, as well as signals of varying frequency. The latter often resemble the whistlers of audio frequency range. However, these subaudio "whistlers" sometimes first decrease in frequency and then increase, a behavior at odds with current whistler theory. Some correlations have been observed with magnetic activity, as well as occasional predisturbance signals.

The early data from the large network of IGY magnetic stations is under study and analysis by scientists at many institutions. The U.S. Coast and Geodetic Survey reports that operation of the stations, even in difficult and remote areas, has been satisfactory, and data are being received and reduced at the survey.

Ionospheric Physics

Because solar radiation largely determines the nature of the ionosphere, the character of the ionosphere close to the geographic poles during periods of prolonged solar absence was a subject of considerable interest. The South Pole Station provided a unique facility for this study by the National Bureau of Standards because there Antarctica offered a stable platform in contrast to the uncertainties of the shifting ice pack in the Arctic basin. In these regions the ionosphere is subjected to extended exposure to solar ionizing radiations during the long polar summer day, while it is screened for several months during the polar night. Scientists of NBS, Boulder Laboratories, reported that, from analysis of South Pole records at hand, the ionization reached a summer saturation, during the present solar activity, of about 4.5×10^5 electrons per cubic centimeter, which would support transpolar communications up to 22 megacycles per second. Throughout the winter polar night, it was found that the F-layer persists but that this usually rather uniform layer appeared to break up into cloud formations. A density of 2×10^5 electrons per cubic centimeter appears typical, sufficient to support transpolar communications up to 14 megacycles in the absence of ionospheric storms.

There is evidence from the data from both polar regions that the nonsolar variations in the F-layer depend upon the magnetic dip field rather than the geomagnetic field. Analyses of data from the world-wide chain of ionospheric stations are under way to determine the source of these polar ions: Do electronic clouds drift from sunlit regions toward the South Pole or do they manage to persist somehow throughout the winter? It is interesting that the ionization exhibits diurnal variation even though the sun is always at a constant height above or below the horizon.

Backscatter studies, conducted over a network of 13 stations supervised by A. M. Peterson (Stanford University), were directed at two types of problems: those requiring reflections continuously from large regions and those where reflection geometry requires the backscatter oblique-incidence technique. This work permitted the study of large-scale F-layer traveling disturbances and studies of ionospheric tilts. Peterson reports that the former were tracked over several thousand kilometers, and it has been found that the disturbances often extend several thousand kilometers in directions perpendicular to their paths, appearing as huge wave motions in the ionosphere.

Analysis of backscatter data shows that tilts in the F-region permit radio wave propagation over great distances without ground reflections. Tilts or horizontal gradients permit the propagation of radio waves over long distances by successive reflections from the curved F-layer until a particular tilt directs the energy to earth. Propagation over distances in excess of 6000 miles has been observed frequently.

During the IGY an extensive whistler program has been conducted by R. A. Helliwell (Stanford University) and M. G. Morgan (Dartmouth College) who are supervising two chains of stations running north and south along the coasts of North America, including cooperating stations in the Southern Hemisphere. Some of these stations were in operation prior to the beginning of the IGY, and it was at one of them (Hanover, N.H.) that correlation of whistlers and lightning flashes by direct visual and aural observations was definitely made just prior to the IGY. This has recently been reported in the literature with the conclusion that lightning flashes can generate whistlers although many of them do not.

The IGY whistler data show a marked dependence of the frequency of occurrence from place to place. Morgan finds that activity increases northward from none at all at Huancayo up to Hanover where a variety of very-low-frequency phenomena are recorded, and then diminishes nearly to the vanishing point at Frobisher Bay, North West Territories, and Thule, Greenland; high activity is noted from the Ellsworth Station in Antarctica. It is interesting that the Hanover Station has far more activity than does Seattle, Wash., although the two are at comparable geomagnetic latitudes.

Helliwell observes that high activity is also found at Unalaska, Alaska, and that in Alaska short whistlers are predominant whereas on the east coast of the United States short whistlers are a relative rarity. On one occasion the same whistler group was recorded at both Stanford and Seattle. However, the first component of the whistler observed at Stanford was extremely well defined and extended upward to 35 kilocycles per second, whereas no trace of the first component could be found at Seattle. Later traces in the group, on the other hand, were identical with those at Stanford. Nose whistlers (in which the frequencies both rise and fall simultaneously) have been observed for the first time at Stanford, and two have been found with nose frequencies of 10 and 16 kilocycles per second, which are low compared with the expected value of 45 kilocycles per second. A whistler has been recorded simultaneously at Stanford, Seattle, and

Anchorage, even though the distance between Anchorage and Stanford is about 3200 kilometers. The spectrograms show considerable similarity, but the dispersions of the separate components are not exactly the same at the three locations.

E. K. Smith (Central Radio Propagation Laboratory, National Bureau of Standards) has reported a peculiar signal enhancement noted during the last year on a very high frequency (49.84 megacycles per second) circuit operating between the Philippines and Okinawa which was set up to measure sporadic-E. The anomaly observed was a sudden enhancement of signal strength commencing about 2 hours after sunset and continuing until about midnight, being particularly strong during the autumnal equinox. This appears definitely to arise from F-region scatter. Studies by means of a pulse experiment carried out on the circuit seem to indicate F-region reflection from the path midpoint at 300 kilometers. The returned echo appears similar to those returned from extensive aurora curtains and may represent blobs of ionization oriented along the earth's magnetic field.

The reduction of vertical incidence ionospheric sounding records, or ionograms, to profiles of electron density as a function of true height, is being carried out at Pennsylvania State University by E. R. Schmerling, where an extension is used of the matrix method developed by Budden. Records from Washington, D.C., Panama, and Talara and Huancayo, Peru, have been reduced to individual profiles and read off to give the density at every 20 kilometers of true height. From examination of the 1957 data it has been discovered that the shape of the F-2 layer rarely corresponds to a parabola, an approximation sometimes used previously, and that there is a striking increase in electron density at night, particularly at Huancayo and Panama, where the layers rise at night and decrease in thickness.

Reduction of electron density profiles for many stations at scattered intervals (rather than more comprehensive coverage at a few stations) has been carried out at the National Bureau of Standards, Central Radio Propagation Laboratory, Boulder, Colo., by the same method to determine the instantaneous horizontal distribution of electron density at a series of fixed heights over the United States. Applications include the interpretation of radio data from satellites or other sources within or beyond the ionosphere, the determination of ray paths for radio waves reflected at oblique incidence from the ionosphere, the study of regional anomalies, and the study of large traveling disturbances.

Other ionospheric scatter effects are being studied in a cooperative program under the supervision of K. L. Bowles and R. S. Cohen (Central Radio Propagation Laboratory, National Bureau of Standards), with the South American participating committees of Argentina, Brazil, Chile, Ecuador, and Peru. Six circuits, in which transmission is affected by ionospheric scatter of obliquely incident 50 megacycle waves, have been established by the Central Radio Propagation Laboratory to span the geomagnetic equator and provide east-west control data. The variability in daytime scattering along these paths has been found to correlate with the presence of equatorial sporadic-E. There is further correlation with intensity variations of the horizontal component of the earth's magnetic field. Since these are in turn associated with the equatorial electrojet, these propagation studies are helping to define the relation between equatorial sporadic-E ionization and the equatorial electrojet. On the other hand, nighttime scatter signal seems to be correlated with the

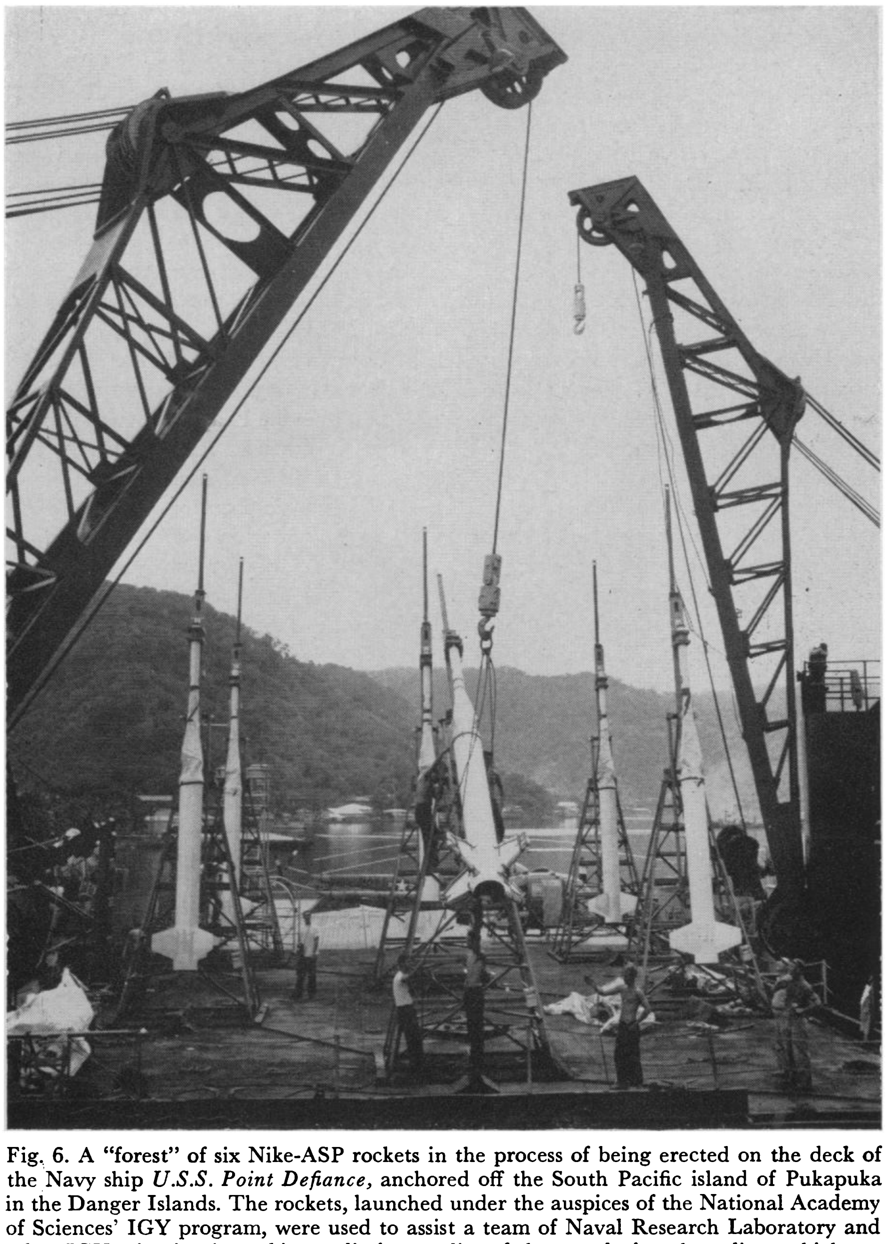

Fig. 6. A "forest" of six Nike-ASP rockets in the process of being erected on the deck of the Navy ship *U.S.S. Point Defiance,* anchored off the South Pacific island of Pukapuka in the Danger Islands. The rockets, launched under the auspices of the National Academy of Sciences' IGY program, were used to assist a team of Naval Research Laboratory and other IGY scientists in making radiation studies of the sun during the eclipse which occurred 12 October. In this first use of high-altitude rockets for astrophysical eclipse measurements, five were launched within a span of 40 minutes; two of these were in the air simultaneously during the total eclipse. Telemetering time averaged close to eight minutes per rocket. A sixth rocket was fired on 13 October, when a solar flare occurred following the eclipse. This rocket carried radiation measuring instruments to an altitude of 140 to 150 miles, exceeding all previous records for rockets launched from shipboard. [U.S. Navy]

presence of disturbed conditions in the F-region observed as equatorial spread. The knowledge that the nighttime transmission scattering probably occurs at 130- to 180-kilometer levels suggests that some of the spread-F and some of the long-path scatter signals at night are caused by the same ionospheric irregularities in the region from 130 to 180 kilometers in height.

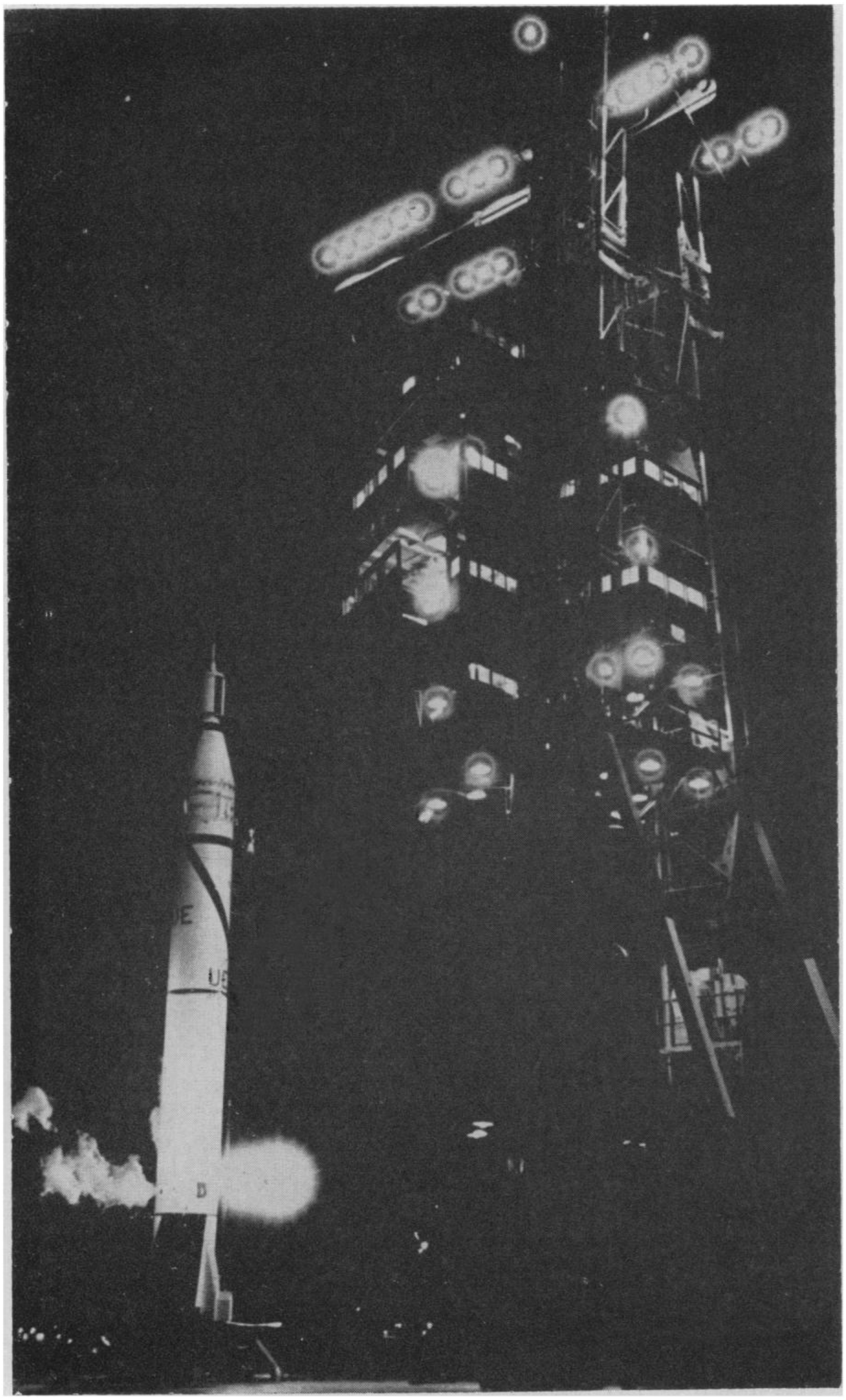

Fig. 7. The gantry crane, the lighted structure at right, is withdrawn in preparation for the launching of the Jupiter-C rocket (at left) at Cape Canaveral, Florida, at 10:48 P.M., EST, 31 Jan. 1958. This rocket placed the first U.S.-IGY earth satellite in orbit, seven minutes after firing. The satellite carried instrumentation to record data on cosmic rays, micrometeorites, and internal and skin temperatures, designed at the University of Iowa, the Air Force Cambridge Research Center, and the California Institute of Technology's Jet Propulsion Laboratory, respectively. The Jupiter-C rocket was jointly developed by the Army Ballistic Missile Agency and the California Institute of Technology's Jet Propulsion Laboratory and was launched by the Army Ballistic Missile Agency. [U.S. Army]

Rockets and Satellites

While rockets and satellites are only tools, albeit powerful ones, for *in situ* studies of phenomena in the high atmosphere and space, they have represented an important area of IGY activity and have stood in the international program as distinct efforts. Seven nations engaged in rocketry studies (Australia, Canada, France, Great Britain, Japan, the United States, and the U.S.S.R.) while two (U.S. and U.S.S.R.) launched satellites. More than 300 research sounding rockets of various types were fired, seven satellites were launched successfully, and one deep-space probe (Pioneer I) covered some one-third the distance toward the moon.

The quantity of data gathered by research sounding rockets was appreciable. Of great general interest were the studies of x-rays discovered by H. Friedman and his associates (Naval Research Laboratory) at times of solar flares in the lower, D-region of the ionosphere. It now appears this x-radiation creates the increased ionization which leads to radiocommunications blackouts at times of solar activity. X-rays, Friedman reports, increase with solar flare activity, while ultraviolet radiation does not, although measurements have not been made during the initial period of onset of flares. Moreover, during the eclipse of last October, Friedman employed rockets for the first time in such a study (see Fig. 6) and detected x-rays during total eclipse while ultraviolet radiation was completely absent, giving the first direct evidence that x-rays originate in the sun's corona, whereas ultraviolet radiation was absent during total eclipse. These experiments are significant not only because they add to our fundamental knowledge of the upper atmosphere and solar processes, but because the information sheds light on problems of the radio propagation.

Extremely important ambient pressure, temperature, wind and density data were also obtained from rocket firings by groups at the Naval Research Laboratory, Geophysics Research Directorate, University of Michigan, and the Army Signal Research and Development Laboratory. One of the significant findings revealed that the distribution of atmospheric pressure and temperature at high latitudes differs from that at lower latitudes. The density of the atmosphere is under strong solar influence. There appear to be latitude, seasonal, and diurnal effects. These effects appear only at high altitudes above Fort Churchill, while none of these effects appear at lower latitudes.

A program at the State University of Iowa using balloon-borne rockets, called rockoons, had as its major purpose the measurement of total cosmic ray intensity over a wide range of geographic and geomagnetic latitudes during the present period of high solar activity. Special points of interest are (i) comparison of the intensity at upper atmosphere levels in high southern latitudes with intensity at high northern latitudes, and (ii) investigation of the location of the latitude "knee" in the Southern Hemisphere. Van Allen and his colleagues at Iowa report that flight data which have been read and reduced to date indicate that the total cosmic ray intensity at upper atmosphere levels in high southern latitudes is within 5 percent of that in high northern latitudes, and about 4.3 times as great as that near the equator. They also show that during the present period of high solar activity the latitude knee is found at a latitude lower than 50°S. Cosmic ray intensity at various altitudes is being systematically plotted against geomagnetic latitude.

Another aim of the Iowa research rocket program was precise measurement of the intensity of the terrestrial magnetic field to altitudes over 75 miles in the region of the equatorial electrojet. Van Allen obtained four satisfactory sets of data on magnetic intensity in the Line Islands at altitudes up to 84 miles, and flight data reduced during the IGY indicate new evidence for the existence of electric currents in the lower ionosphere. The full reduction of all four sets of flight data obtained in the Line Island area, when combined with the ground station measurements, is expected to yield illuminating information on the equatorial electrojet.

Several other Iowa experiments were conducted in the southern auroral zone. High-altitude measurements of the magnetic field were made for correlation with nearby antarctic observations. There were three successful magnetometer flights. Investigations were made here of the physical nature, intensity, and latitude distribution of the "soft radiation" associated with auroras. A flight at 70°48'S, 175°50'E was the only successful rocket flight of auroral instrumentation made in the zone. It encountered a high intensity of soft radiation resembling that studied extensively in the northern auroral zone during the rockoon expeditions from 1953 to 1957.

The most significant on-board satellite experiment to date now appears to be the work of Van Allen and his associates at the State University of Iowa, with radiation instrumentation on satellites 1958 alpha, gamma, and epsilon (commonly referred to as the Explorer satellites) (see Fig. 7). Satellite 1958 alpha led to the discovery of a zone of radiation in the high atmosphere. Van Allen reported that data from 1958 alpha and beta indicated that the radiation intensity of cosmic rays to 700 kilometers was as expected, but instrumental behavior beyond this range pointed to a great increase in intensity "totally inconsistent with cosmic ray expectations." The radiation was interpreted as corpuscular in nature.

More sophisticated instrumentation on 1958 epsilon provided added and better information. Van Allen and his colleagues believe it "is established that the great radiation belt around the earth consists of charged particles, temporarily trapped in the earth's magnetic field." They conjecture that the aurora is related to this trapped radiation and is caused by particle leakage from the belt. They suggest that solar plasma is the source of particles. These studies, in combination with other results of the IGY (the cosmic ray work, in particular), begin to relate a variety of atmospheric and spatial phenomena in an exciting and meaningful way, suggesting that major advances are in process of being made and formulated.

Many environmental studies were also carried out such as the temperatures of satellites (internal and skin) and exposure and behavior under micrometeorite bombardment. The solar batteries carried on 1958 beta have continued to operate since launching and have proved the feasibility of this source of power.

References and Notes

1. H. Odishaw, "International Geophysical Year: A report on the United States program," *Science* 127, 115 (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 only been made possible 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: Phillip W. Mange and Stanley Ruttenberg.
3. "An Interim Bibliography on the International Geophysical Year" (National Academy of Sciences, Washington, D.C., 1958, available from the Publications Office, at $1.00 per copy).
4. M. Nicolet, "Draft IGY Bibliography" (first and second issue) (CSAGI Secretariat General c/o Service du Rayonnement I.R.M., 3, Avenue Circulaire, Uccle, Belgium. Draft copies are not generally available; the completed bibliography will become available upon publication in the Annals of the IGY, published by the Pergamon Press).
5. A. L. Cullington, *Nature* 182, 1365 (1958).