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OVERVIEW OF SOLAR-TERRESTRIAL PHYSICS PHENOMENA FOR THE RETROSP--ETC(U)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A summary of the significant solar-terrestrial events that occurred during the Retrospective World Interval of 20 March - 5 May 1976 has been prepared using data available at the present time. Although this period occurred at solar minimum, it was an active interval - one in which the principal events were associated with solar activity in a region at Carrington Longitude approximately 45°. (This active center was designated McMath Plage 14143 during solar rotation 1639 and renumbered McMath Plage 14179 during solar rotation 1640). Among the events summarized are the following:

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(1) solar activity during the period 20-23 March 1976 from a region behind the eastern limb of the sun;

(2) a large geomagnetic storm with intense mid-latitude auroral activity on 26 March;

(3) moderate solar particle intensities at the Earth from 26 through 31 March; and

(4) a ground-level solar cosmic ray event on 30 April having a very hard spectrum.

AFGL-TR-77-0211

Overview of Solar-Terrestrial Physics Phenomena for the Retrospective World Interval of 20 March - 5 May 1976

by

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ABSTRACT

A summary of the significant solar-terrestrial events that occurred during the Retrospective World Interval of 20 March - 5 May 1976 has been prepared using data available at the present time. Although this period occurred at solar minimum, it was an active interval - one in which the principal events were associated with solar activity in a region at Carrington Longitude ~45°. (This active center was designated McMath Plage 14143 during solar rotation 1639 and renumbered McMath Plage 14179 during solar rotation 1640). Among the events summarized are the following:

(1) solar activity during the period 20-23 March 1976 from a region behind the eastern limb of the sun;

(2) a large geomagnetic storm with intense mid-latitude auroral activity on 26 March;

(3) moderate solar particle intensities at the Earth from 26 through 31 March; and

(4) a ground-level solar cosmic ray event on 30 April having a very hard spectrum.

Introduction

During the 18th Plenary Meeting of COSPAR held in Varna, Bulgaria in 1975, members of the Study of Traveling Interplanetary Phenomena (STIP) Project recommended two intervals for special studies. STIP Interval I was scheduled for September and October 1975. STIP Interval II was planned for early 1976 with the final dates of 15 March - 15 May being selected after the successful launch of Helios 2 on 15 January 1976.

Both of these intervals occurred during solar minimum, as illustrated by the graph of observed and "smoothed" sunspot numbers shown in Figure 1. In fact, statistical "sunspot minimum", defined by the minimum in a weighted 13-month average of the Zürich sunspot number, apparently occurred in March 1976, although the observed sunspot number for this particular month was the highest monthly value in a 17-month period (September 1975 - January 1977). To be specific, the period 20 March - 5 May 1976 was very active for solar minimum. Activity took place in a region at Carrington Longitude ~45° that was associated with several interplanetary and terrestrial disturba...

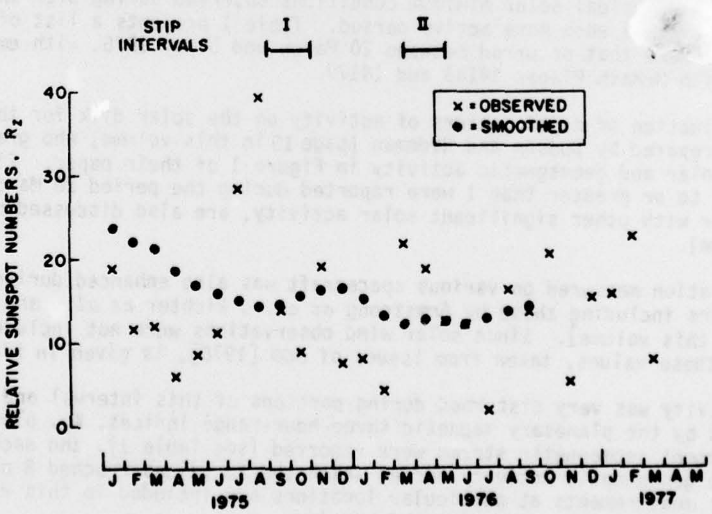

Fig. 1. Observed and smoothed sunspot numbers for the period January 1975 through March 1977. The time periods of the STIP Intervals are indicated by the bars at the top of the figure.

It is anticipated that this period of enhanced solar activity, coming as it did during solar minimum, will be studied by many researchers. Indeed, even while scientists were submitting their data for publication in this report, several of them were analyzing their own results for presentation at the L. D. de Feiter Memorial Symposium on the Study of Traveling Interplanetary Phenomena held in conjunction with the XX COSPAR Meeting in Tel Aviv, Israel, in June 1977. These papers will be published in the conference proceedings.

STIP Interval II - General Observations

The dates for STIP Interval II were selected primarily because of the possibility of obtaining extensive and heretofore unavailable particle, plasma, and magnetic field observations from two space probes close to the sun. These probes, namely, Helios 1 and Helios 2, both underwent perihelion passage during this interval. The orbits of these two probes are shown in Figure 2.

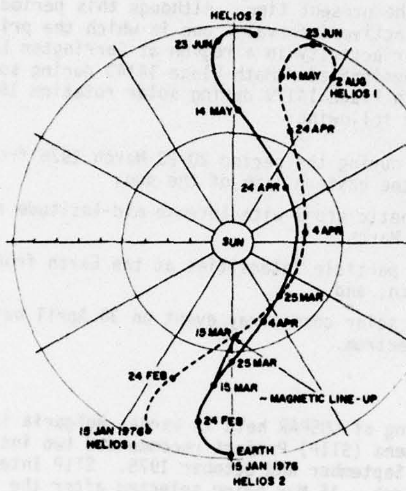

Fig. 2. The orbits of the Helios 1 and 2 space probes with respect to a fixed Sun-Earth line. The time period is from 15 January to August 1976.

In contrast with the typical solar minimum conditions observed during STIP Interval I [Shea *et al.*, 1977], STIP Interval II was a much more active period. Table 1 presents a list of some of the major solar-terrestrial phenomena that occurred between 20 March and 5 May 1976, with emphasis on those believed associated with McMath Plages 14143 and 14179.

An excellent evaluation of major centers of activity on the solar disk for the period 20 March - 5 May 1976 has been prepared by Dodson and Hedeman [page 10 in this volume] who graphically illustrate the daily values of solar and geomagnetic activity in Figure 1 of their paper. Eight solar flares with importance equal to or greater than 1 were reported during the period 20 March - 5 May 1976, and these flares, together with other significant solar activity, are also discussed by Dodson and Hedeman [page 10 in this volume].

Particulate radiation measured on various spacecraft was also enhanced during this period, as shown in several papers including those by Armstrong *et al.*, Richter *et al.*, and Kunow *et al.*, [pages 145, 141, and 134 in this volume]. Since solar wind observations were not included in the data submissions; a plot of these values, taken from issues of *SGD* [1976], is given in Figure 3.

Geomagnetic activity was very disturbed during portions of this interval and very quiet at other times, as illustrated by the planetary magnetic three-hour-range indices, Kp, plotted in Figure 4. Three sudden commencement geomagnetic storms were reported (see Table 1), and each was followed by a period of disturbed geomagnetic activity during which the Kp values reached 8 or greater. Several papers on geomagnetic measurements at particular locations are included in this report as well as papers on various ionospheric effects during this period.

Table 1

List of Significant Solar-Terrestrial Phenomena (20 March - 2 May 1976)

Date 1976	Time (UT)	Event
March 20	0203	Type II radio burst at the east limb (Culgoora)
	2257	Type II radio burst at the east limb (Culgoora)
		Note: Solar wind velocity enhancement on 9 April observed by Pioneer 10 (9.7 AU, 147° east of the Sun-Earth line).
23	0450	X-ray enhancement, east limb (OSO-8)
	0837-0841	Solar flare (S05, E90; McMath Plage 14143; SB)
	0840-1900	X-ray enhancement (GOES-1)
	0841	Type II and Type IV radio bursts (IZMIRAN, Moscow)
	0842	Type IV radio burst (Dürnten)
	0907-0945	Solar flare (S07, E90; McMath Plage 14143; SN)
	1100	Many loops observed in H-alpha, SE limb (Ramey)
26	0233	Sudden commencement geomagnetic storm (Ap=138)
28	1840	Onset of X-ray enhancement, 1-8Å (GOES-1)
	1905-2021	Solar flare (S07, E28; McMath Plage 14143; 1B)
	1915	Onset of 8800 MHz solar noise burst. Maximum at 1934 UT with flux density of 3719 flux units (Sagamore Hill)
	1921-1950	Type II radio burst (Harvard)
	1925-1939	Type IV radio burst (Sagamore Hill)
	1931-2400	Type IV radio burst (Boulder)
31	1103	Onset of X-ray enhancement, 1-8Å (SMA/GOES)
	1138-1350	Solar flare (S07, W09; McMath Plage 14143; 1N)
	1153-1512	Type IV radio burst (Dürnten)
	1356-1407	Solar flare (S08, W09; McMath Plage 14143; SF)
	1437-1442	Solar flare (S10, W03; McMath Plage 14143; SN)
	1445-1508	Solar flare (S11, W08; McMath Plage 14143; SF)
April 1	0255	Sudden commencement geomagnetic storm (Ap=107)

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Date 1976	Time (UT)	Event
April 30	2043	Onset of X-ray enhancement, 1-8Å (GOES-1)
	2047-2218	Solar flare (S08, W46; McMath Plage 14179; 1B)
	2047	Onset of 2800 MHz solar noise burst at Ottawa. Maximum at 2109 UT with flux density of 1670 flux units.
	2103-2130	Type IV radio burst (Sagamore Hill)
	2107-2129	Type II radio burst (Harvard)
	2120-2125	Onset of GLE (Inuvik, Canada, neutron monitor)
	2125-2130	Onset of PCA (Thule, Greenland; Cape Zhelaniya and Dixon Island, USSR)
	2130	Onset of 6-10 MeV protons observed on SMS/GOES
May 1	0130	Maximum PCA at Thule, Greenland (2.7 dB)
2	1829	Sudden commencement geomagnetic storm (Ap=58 on 2 May; Ap=94 on 3 May)

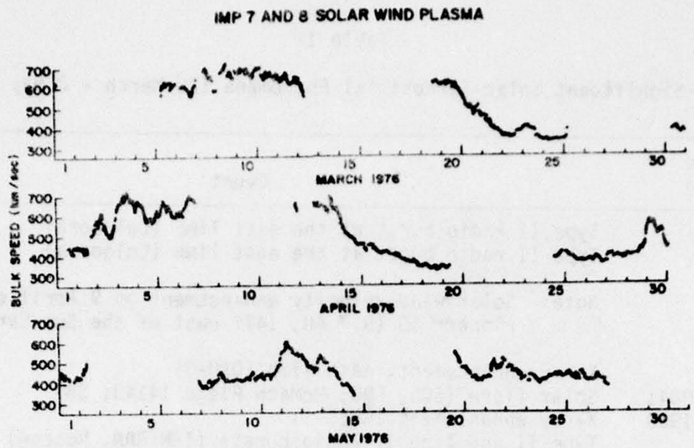

Fig. 3. Solar wind bulk speed measurements observed by the Earth-orbiting spacecraft IMP 7 and IMP 8 for the period 1 March through 31 May 1976. These data, from the MIT plasma probe, were published in *SGD* [1976].

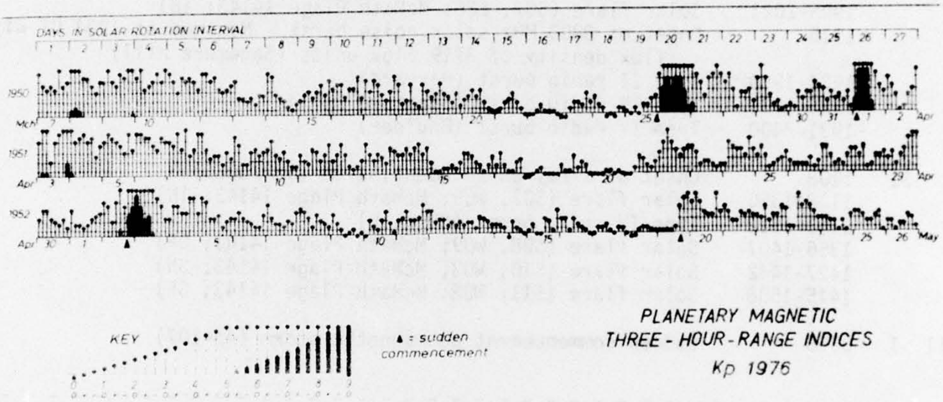

Fig. 4. Planetary magnetic three-hour-range indices, Kp, for the period 7 March through 26 May 1976. The rotation numbers given on the left-hand side of this figure are Bartels rotation numbers and not the solar rotation numbers referred to in the text of this paper.

Cosmic ray measurements are also included, not only because of a ground-level solar cosmic ray nt that occurred on 30 April, but also because of neutron monitor data (measurements of ≥ 500 MeV tons) having long been used as an indicator of interplanetary and geomagnetic phenomena. The ative cosmic radiation intensity for this period, as measured by the Deep River neutron monitor, shown in Figure 5.

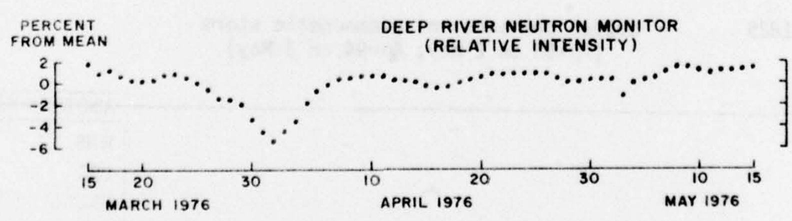

Fig. 5. Graphical display of the relative cosmic ray neutron monitor intensity as measured by the Deep River, Canada, neutron monitor for the period 15 March - 15 May 1976. The daily average intensity was used to determine the points on this figure; the mean is the average value for this entire period.

In addition, other solar-terrestrial physics observations during this interval, such as solar radio data, riometer data, and aeronomy measurements, are included in this report. Although many of the presentations contain data for the entire interval, the majority of these contributions contain data for one or more specific events throughout this period. When studied in their entirety, all of these data should allow researchers to investigate well-separated solar phenomena at sunspot minimum, inasmuch as the number of possible solar sources of the various interplanetary and terrestrial phenomena is drastically reduced from the count occurring near solar maximum.

Significant Events During STIP Interval II

Events of 20 March 1976. Type II radio bursts recorded by the Culgoora, Australia, radioheliograph and radio spectrograph at 0203 and 2255 UT on 20 March 1976 were attributed by Nelson and McLean [page 90 in this volume] to activity 55° and 44° behind the eastern limb of the sun, respectively. These authors concluded that the source of these Type II radio bursts was McMath Plage 14143 (as numbered on solar rotation 1639). Figure 6 illustrates the position of various space probes and the location of McMath Plage 14143 on 20 March 1976. Unfortunately, during this time period, there were no observational data from the Pioneer 9 space probe - measurements that could have confirmed the existence of an interplanetary shock associated with the Type II radio bursts on 20 March.

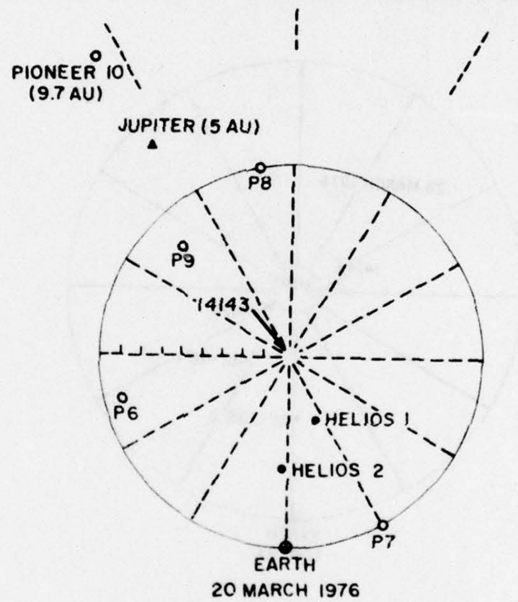

Fig. 6. Positions of important space probes and the planet Jupiter relative to the Sun-Earth line on 20 March 1976. The area within 1 AU is drawn to scale. The radial positions of Jupiter and Pioneer 10 are not drawn to scale, but their angular location is accurate. The Pioneer space probes within 1 AU are designated by the letter P and the appropriate number. The location of McMath Plage 14143 is indicated by the arrow.

The IMP 7 and IMP 8 solar wind observations during March, April, and May 1976, illustrated in Figure 3, show that a high-speed solar wind stream was observed at the earth from 6 to 12 March, returning again from 4 to 7 April. In a preliminary examination of the daily solar wind peak speed samples from the Pioneer 10 spacecraft, located at 9.7 AU, Wolfe [private communication] has confirmed that this same high-speed stream was apparently also observed by the Pioneer 10 space probe.

Events of 23-31 March 1976. McMath Plage 14143 was observed in X-rays by the OSO 8 satellite by 1200 UT on 22 March when this region was still ~20° behind the eastern limb of the sun. By 0450 UT on 23 March, this region was the major source of X-ray emission on the visible disk, and it continued to be the dominant X-ray source on the sun throughout its transit ["2-30 keV X-ray Data from OSO-8," page 187 in this issue]. At 0837 UT on 23 March, flare activity occurred in McMath Plage 14143 on the eastern limb of the Sun, just as this region was becoming visible from the Earth. This activity is discussed by Dodson and Hedeman [page 10 in this volume]. Akinjan *et al.* [page 48 in this volume] report that an analysis of the radio spectra data obtained by Soviet observatories shows that the radio event, with onset at 0841 UT on 23 March, was a complex set of Type II and Type IV radio bursts.

The positions of the two principal active regions on the visible solar disk on 23 March are shown in Figure 7. Unfortunately, the location of McMath Plage 14143 was not ideally situated for efficient particle detection at the Earth, whereas plage 14127, at W57, was in a good position for efficient particle transport along the interplanetary magnetic field lines to the Earth. Solar particle fluxes at the Earth were enhanced from 23 through 31 March at energies greater than 40 MeV [*SGD*, 1976]. Helios 1 and Helios 2 also observed solar particle flux increases during this time period that Kunow *et al.* [1977] ascribe to the activity in McMath Plage 14143; the >51 MeV proton channel on Helios 2 recorded the highest flux observed during the entire STIP Interval ["MeV Protons, Alpha Particles and Electrons as Observed Aboard Helios 1 and 2 during STIP Interval II," page 134 in this volume]. The Helios space probe data will be a very valuable tool in ascertaining the solar coronal and interplanetary particle propagation conditions during this period.

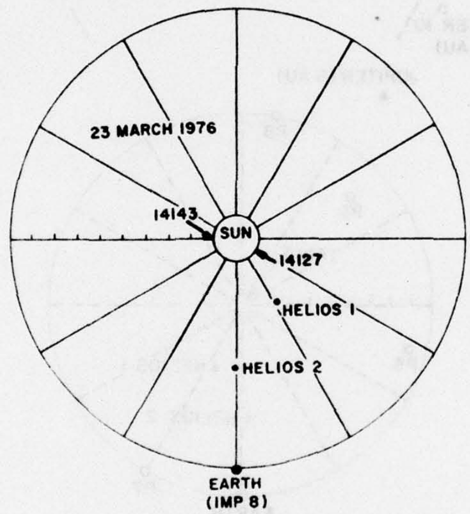

Fig. 7. Positions of the Helios 1 and Helios 2 space probes relative to the Sun-Earth line on 23 March. The locations of McMath Plage 14143 and McMath Plage 14127 are indicated by arrows.

There was a major geomagnetic disturbance on 26 March with a sudden commencement at 0233 UT. The major geomagnetic storm that followed produced an Ap value of 138, making it the fifth highest value of the 20th solar cycle. Intense auroras were observed at a number of mid-latitude locations. Figure 8 is an image of the auroral forms observed at 0925 UT on 26 March. The intense aurora in this figure extends to 58° corrected geomagnetic latitude, indicating a tremendous expansion of the earth's polar cap.

The solar flare that erupted <1905 UT on 28 March was an apparent particle producer, as evidenced by the discrete impulsive increase observed on the IMP 7 and IMP 8 spacecraft at all energies published in *SGD* [1976]. Although Helios 1 did not appear to detect a major particle increase associated with this event, Helios 2 did observe a sudden impulsive increase on all energy channels. Once again the value of the Helios data in aiding our understanding of solar particle propagation conditions in the Sun-Earth region is indicated. Another major sudden commencement geomagnetic storm occurred at 0255 UT on 1 April with an Ap value of 107, and auroras were reported at some mid-latitude locations [*SGD* 1967].

Fig. 8. DMSP satellite image of the moderately bright continuous aurora plus discrete arcs and bands observed on 26 March 1976. In this reverse image the aurora appears black. A background geographic coordinate grid for 100 km altitude has been superposed on the image for reference. The equatorward edge of the bright continuous aurora corresponds to a corrected geomagnetic latitude of 5[illegible] The vertical dashed line designates the satellite subtrack which passes [illegible] the equatorward edge of the aurora at 0925 UT. The satellite is in a dawn-dusk orbit; the sunset terminator appears to the left of the image.

Event of 30 April 1976. McMath Plage 14143 returned to the eastern limb of the solar disk on 20 April 1976, at which time it was designated as McMath Plage 14179. On 29 April the frequency of subflares in this region increased markedly ["Overall Evaluation of Major Centers of Activity on the Solar Disk, 20 March - 5 May 1976," page 10 in this volume]. The major flare from this region, at 2047 UT on 30 April (classified as importance 1B), was accompanied by major X-ray and radio emission. This flare is of particular interest because it was the source of a ground-level solar cosmic ray event. From examination of the neutron monitor data from 10 locations, the earliest onset of relativistic protons appears to lie between 2120 and 2125 UT at Inuvik, Canada. Figure 9 shows that its 12% increase was the largest. Comparison of the relative increases at a number of stations having essentially atmospheric cutoff rigidities implied that the relativistic particle flux in this event was quite anisotropic (see Figure 9). In particular, note the relative increases at Inuvik and Goose Bay, Canada. At lower energies an impulsive increase in the electron and proton fluxes was observed on the IMP 8 satellite ["Solar and Interplanetary Particles Observed in the Interval 20 March through 5 May with IMP 8," page 145 in this volume].

In the polar cap a maximum absorption of 2.7 dB was measured by the Thule, Greenland, riometer ["Riometer, Magnetometer, and VLF Ionosonde Data from the Polar Cap, 21 March - 8 May 1976," page in this volume], although "spikes" in the riometer measurements at several Soviet stations indicated maximum absorption values of $\sim$5.0 dB ["Polar Cap Absorption Event of 30 April - 3 May 1976 by the Riometer Data at the Soviet Arctic and Antarctic Stations," page 248 in this issue]. The relatively modest low-energy particle increase observed by IMP 8, the comparatively small riometer absorption, and the ground-level neutron monitor increase indicate a very hard particle spectrum. Magnetometer records show a sudden commencement geomagnetic storm occurred at 1829 UT on 2 May, followed by major disturbances for the next 24 hours.

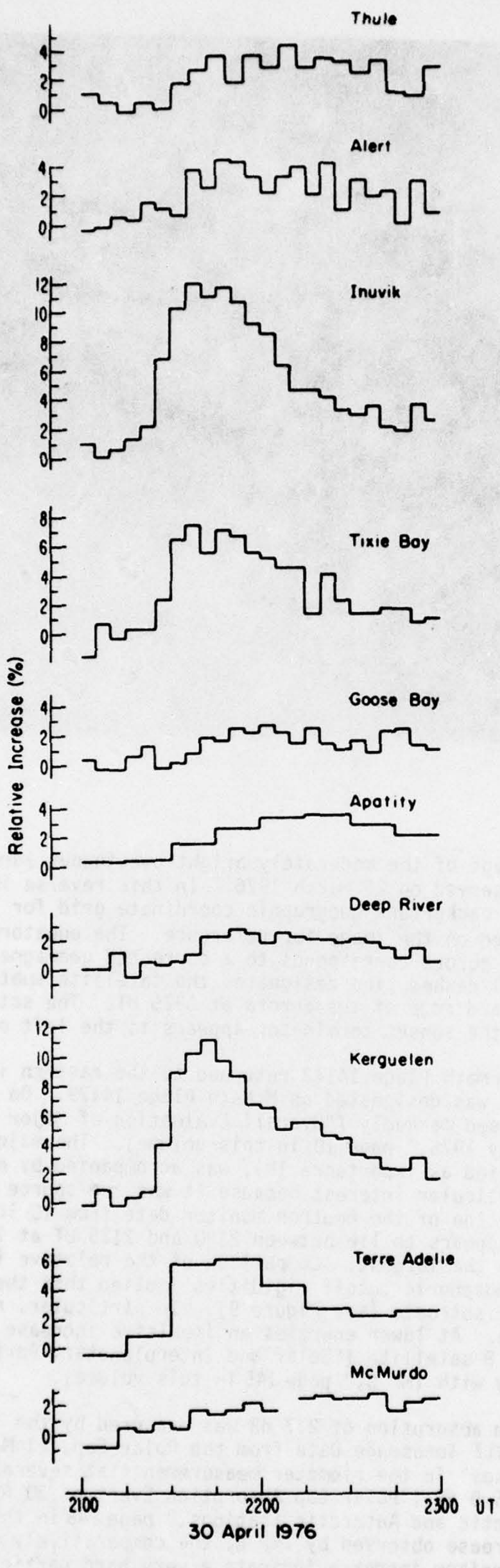

Fig. 9. Relative neutron monitor increases at 10 stations having essentially atmospheric cutoff.

The positions of the Helios space probes on 30 April are shown in Figure 10 together with the position of McMath Plage 14179. Although the flare position was favorably situated for efficient particle propagation from the Sun to the Earth, its location was ∿110° to the east of the Sun-Helios line. This event was observed on both the Helios 1 and Helios 2 space probes, although the time-intensity profile differed markedly between the two satellites ["MeV Protons, Alpha Particles and Electrons as Observed Aboard Helios 1 and 2 during *STIP Interval II*," *page 134 in this volume*]. This impulsive, well-isolated, relativistic solar cosmic ray event should also offer a unique opportunity to study solar particle propagation in the solar corona and in the interplanetary medium.

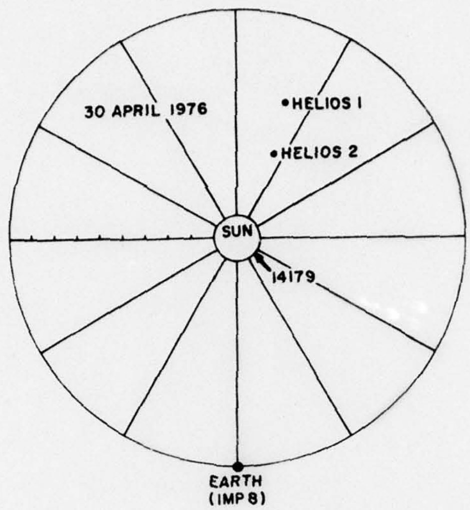

Fig. 10. Positions of the Helios 1 and Helios 2 space probes relative to the Sun-Earth line on 30 April. The location of McMath Plage 14179 is indicated by the arrow.

Summary

STIP Interval II was a coordinated period of observations that coincided with statistical sunspot minimum. Ironically, during this period, there were several exceptional solar events that resulted in the designation of a Retrospective World Interval for the period 20 March - 5 May 1976. The solar activity; the interplanetary particles, fields, and plasmas; and the geomagnetic activity that occurred during this period provide measurements of relatively isolated solar particle and plasma emissions during solar minimum.

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