A Synoptic Approach to Sun-Weather Investigations

by

John M. Wilcox

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Abstract

The advantages of a regular program of daily observations of the magnetosphere, ionosphere and atmosphere are described. Such synoptic observations may be one of the best routes to understanding the physical mechanisms involved in sun-weather influences. Some specific examples of such observations are given.

A SYNOPTIC APPROACH TO SUN-WEATHER INVESTIGATIONS*

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Most geophysical investigations can be classified either as relating to discrete events on a limited temporal and spatial scale, or to synoptic analysis on a broad and comprehensive scale. In this paper we discuss the latter approach, and suggest that additional observations are needed in order to realize the full potential of this method.

It is clear that extra-terrestrial causes may influence many phenomena in the magnetosphere, ionosphere and atmosphere. We will give several examples involving the influence of the solar magnetic sector structure (Wilcox, 1968), which can clearly be seen in the observed interplanetary magnetic field near the earth. This field typically has a polarity away from the sun for several consecutive days, followed by an abrupt change to a polarity toward the sun for the next several consecutive days, and so on. A narrow current sheet in interplanetary space separates the regions of opposite field polarity. This separation is called a sector boundary, and typically is swept past the earth by the solar wind within a few tens of minutes.

Many extra-terrestrial quantities are influenced by the sector structure, such as the magnitude of the interplanetary magnetic field, the solar wind velocity, density and temperature, the flux of solar energetic particles, the cosmic ray flux, solar extreme ultraviolet irradiance, etc. In addition there are terrestrial effects from other classes of phenomena such as flare-related shock waves in the inter-

*Excerpted from Invited Lecture delivered at Chapman Conference on Atmosphere - Ionosphere - Magnetosphere Interactions at Yosemite, California, February 1976.

planetary medium that are not directly related to the sector structure. For brevity we will restrict the discussion to a few examples of sector-related terrestrial phenomena. Some specific observations are discussed in order to clarify the discussion. Many other observations of equal or greater merit are not mentioned.

A considerable influence of the solar sector structure on tropospheric vorticity has been found by Wilcox et al. (1974), as illustrated in Figure 1. Hines and Halevy (1975) have suggested that this effect may be caused by a modulation of the timing of natural meteorological processes by the solar influence.

In the polar cap regions of the earth there is an interesting topological asymmetry related to the polarity of the interplanetary magnetic field. When the interplanetary field is directed away from the sun it is possible to have connection between interplanetary field lines coming from the sun and geomagnetic field lines in the northern polar cap. Geomagnetic field lines leaving the southern polar cap could connect to interplanetary field lines that are swept by the solar wind to the outer solar system. When the interplanetary field has polarity toward the sun the role of the northern and southern polar caps is reversed.

Yeager and Frank (1976) have found a "remarkable" effect in low-energy electron intensities at large distances over the northern polar cap, using spacecraft observations. They found high intensities for away polarity sectors and low intensities for toward polarity sectors, as shown in Figure 2. We see that when the magnetic topology is such as to provide a good connection between the sun and the northern polar cap (i.e. away sector polarity), the electron intensity over the polar cap is considerably increased. Although the energy densities associated with the electrons observed by Yeager and Frank are small, the sector-related variation in these intensities (and perhaps in other particle fluxes yet to be discovered) may influence variations in other aspects of the magnetosphere, ionosphere and atmosphere.

As a final example of polar cap variations related to the sector structure we mention the well-known discovery by Svalgaard (1968) and by Mansurov (1969) that the daily variation of the vertical component of the geomagnetic field observed near the geomagnetic pole reverses when the sector polarity reverses.

The influence of the sector polarity extends down to mid-latitudes. Mishin et al. (1975) and Svalgaard (1976) have discussed the equivalent current system shown in Figure 3. This current system consists of two oppositely directed vortices with equatorial foci near dawn and near dusk. When the sector polarity reverses the currents in the two vortices also reverse.

It was possible to discover and investigate the effects described above because continuous observations of the relevant physical quantities were available over intervals of many months or years. It seems quite possible that some of the fundamental properties of the magnetosphere, ionosphere and atmosphere may be organized by the sector structure in a manner analogous to the cases already described. For the most part the required synoptic observations of the fundamental quantities do not exist and are not presently being taken. By fundamental quantities we mean densities, temperatures, pressure, composition, electric and magnetic fields, etc.

Such synoptic observations of fundamental quantities in the magnetopshere, ionosphere and atmosphere would be very helpful to future sun-weather investigations. By synoptic observations we mean basically observations on a time scale of one per day, although in some cases twelve- or three-hour observations might be helpful. We recommend that wherever possible existing equipment and future equipment be used once a day to obtain synoptic observations of the fundamental quantities. Some examples are given below.

Incoherent scatter radar observations can yield profiles of electron density, electron temperature, and ion temperature versus height above the station. Data are normally obtained between heights of about 200 and 700 kilometers. "These ionospheric observations are not typically made routinely, but rather during preselected time periods, or as needed, because radar installations that can make these observations are expensive to operate and can be used for many kinds of research" (Environmental Data Service, 1976). We recommend that once each day the incoherent scatter radar should be used to obtain height profiles of electron density and temperature and ion temperature. The time of day for the synoptic observations should be chosen at the time of an extremum in the daily variation of the quantities, since the quantities tend to be slowly changing with time near an extremum. In this way a small increment in priority and support for synoptic observations might yield considerable physical returns.

As an example of this approach, it is planned at Siple Station (Helliwell, 1975) to make this kind of synoptic observation using a VLF transmitter, riometer, magnetometer, auroral photometer, and similar equipment. This schedule should be supported and adhered to at all stations having the capability for coordinated multiple observations.

Observations of the atmospheric electric field in clear weather obtained with small aircraft (Markson, 1976) both through vertical profiles and constant altitude records near 10 kilometers may measure a global property of atmospheric electricity. Such observations have usually been related to short time intervals of particular interest. We recommend that such observations should be performed once per day at a time near the maximum of the daily variation during a continuous interval of at least a year or two. Synoptic geomagnetic observations have revealed a great deal about the terrestrial environment. The analogous synoptic geoelectrical measurements have been comparatively neglected, but might reveal a similar wealth of information. For example, Reiter (1976) has reported observations of the atmospheric electric field and the air-earth current density at a high mountain observatory through the present sunspot cycle. A clear influence of the solar sector structure on these quantities has been found, as shown in Figure 4.

Continuous spacecraft observations of cirrus cloud cover on a global basis could be very helpful, since a solar influence on cirrus cloud formation has been suggested as a possible mechanism. In this connection we should emphasize the availability of the data on a global basis with a spatial resolution of perhaps 5° latitude by 10° longitude. It appears that the necessary spacecraft observations may already exist, but the reduction of the data into a form useful for sun-weather investigations has not yet been done.

The relatively rapid response time associated with the Space Shuttle should make it possible to study particular patterns in atmospheric response that may be proposed as mechanisms. Shuttle observations might emphasize the northern hemisphere winter, since this has been the most responsive situation studied. However, the possibility to compare the two hemispheres could be most helpful. One might want to emphasize the longer flights planned for the Shuttle, and continuous synoptic observations during the flights. For example, an atmospheric x-ray emission experiment (Goldberg et al., 1975) planned for the Shuttle has two modes of observation, field imaging or point source. It would seem desirable that once or twice each day the instrument be operated for synoptic observations in the field imaging mode, in addition to whatever more specialized observations might be obtained.

Continuous observations through at least the next eleven-year sunspot cycle of the nearby interplanetary medium should be obtained with spacecraft to provide information on the extra-terrestrial causes for terrestrial effects. Interplanetary quantities of interest include the solar wind velocity, density, temperature and composition, the vector interplanetary magnetic field, energetic particle fluxes through a wide range of energies, and wave observations. The Heliocentric Spacecraft of the International Sun-Earth Explorer Project is a good example of the kind of spacecraft required. The Heliocentric Spacecraft remains on the earth-sun line at a distance of about 0.01 astronomical units from the earth. The interplanetary observations should be made available in real time to facilitate forecasting of terrestrial disturbances. This would feedback into the research process by alerting investigators to make more extensive and closely spaced observations at critical times.

Large-scale synoptic observations of the sun should be continued and improved. The priceless series of daily synoptic maps of the photospheric magnetic field obtained at Mt. Wilson Observatory must be continued for many years. Other solar observatories should be encouraged to maintain synoptic observing programs. I may even recommend that the synoptic observations of large-scale magnetic and velocity fields at the Stanford Solar Observatory should be continued.

Daily synoptic spacecraft observations of the far ultraviolet solar irradiance (Heath et al, 1975) could be a vital link in a sun-weather mechanism. Such full disk observations have not been of primary interest to many of the solar physicists involved in previous spacecraft programs, and therefore these observations have not received sufficient priority. This deficiency should be rectified.

A complete understanding of the coupling between the sun and the earth cannnot be obtained without three-dimensional information on the intervening medium, i.e. out-of-ecliptic spacecraft missions. Solar energetic particle propagation and cosmic ray trajectories are much influenced by the interplanetary magnetic field at latitudes away from the solar equator. A significant terrestrial influence may come from solar features extended away from the sun at non-equatorial latitudes. For example, a magnetic sector boundary has been observed to make a 90° angle with the solar equator at the photosphere. This angle decreases with increasing distance from the sun (Svalgaard et al., 1975), until near the orbit of earth the angle between the sector boundary and the extended solar equatorial plane may be only 15° or 20°, as shown in Figure 5. This suggests that the solar sector structure that covers a wide range of latitudes on both sides of the solar equator in the photosphere has been squashed to a much more limited range of latitudes at the orbit of the earth. Synoptic observations of the interplanetary medium out of the ecliptic during several years are needed to resolve such questions. Of course the radio scintillation observations that give information on solar wind properties out of the ecliptic should be continued. Further discussion of out-of-ecliptic physics and spacecraft is available in Wilcox (1973) and Page (1975).

The examples given in this paper are illustrative rather than inclusive. The synoptic method of observations and analysis suggested here may lead to a considerable advance in our understanding of solar-terrestrial physics, including not the least sun-weather effects.

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Figure Captions

Figure 1 Average response of the vorticity area index (the area of all the low pressure troughs in the northern hemisphere) about times when solar magnetic sector boundaries were carried past the earth by the solar wind. Sector boundaries were carried past the earth by the solar wind on day 0. The analysis includes 53 boundaries during the winter months November to March in the years 1964 to 1970. The standard error of the mean (error bar) was calculated after subtracting a 27-day mean centered on each sector boundary, to remove long-term trends. The deviations corresponding to the individual boundaries are consistent with a normal distribution about the mean. (after Wilcox et al., 1974)

Figure 2 In the bottom panel, comparison of interplanetary sector polarities and electron intensitites within the Northern polar cap region. Shaded bars denote sectors with interplanetary magnetic fields directed away from the sun. The two bar graphs at the top of the figure are the observed polarities of the interplanetary magnetic fields from in situ measurements and the inferred polarities from ground-based magnetometry at polar magnetic latitudes. (after Yeager and Frank, 1976)

Figure 3 External equivalent ionospheric current system for effect in mid-latitudes of the polarity of the interplanetary magnetic field. The system shown is found during away polarity under average conditions. For toward polarity the current directions reverse. The contour interval is 5×10^3 ampere. (after Svalgaard, 1976)

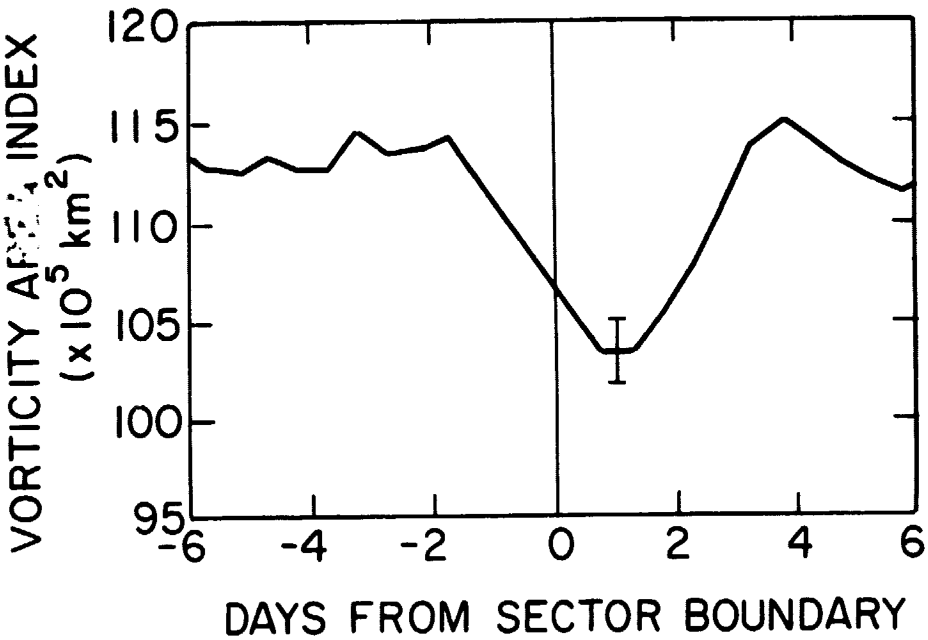
Figure 4 Superposed epoch analysis of atmospheric electric field E and air-earth current density I (both recorded at Zugspitze Peak Observatory, 3 km a.s.l., above the exchange layer, on fine-weather days) around days with passages of the sector structure boundary of the interplanetary magnetic field. -/+: field direction change towards/away from the sun; +/-: vice versa.

a,b: Complete interval from May 1964 through Febraury 1975, i.e. one total solar cycle;

c,d: Interval of maximum solar activity 1967 through 1971, only.

(After Reiter, 1976).

Figure 5 Schematic summarizing various observations of the inclination of sector boundaries to the solar equator. Short line segments indicate the inclination of the boundaries and are marked with the inclination angles to the left of the solar disk and with the heliocentric distances to the right. The lower panel shows the inclination, i, as function of heliocentric distance. (after Svalgaard et al., 1975)



VORTICITY AREA INDEX
(x 10^5 km^2)
120
115
110
105
100
95
-6
-4
-2
0
2
4
6
DAYS FROM SECTOR BOUNDARY

Figure 1

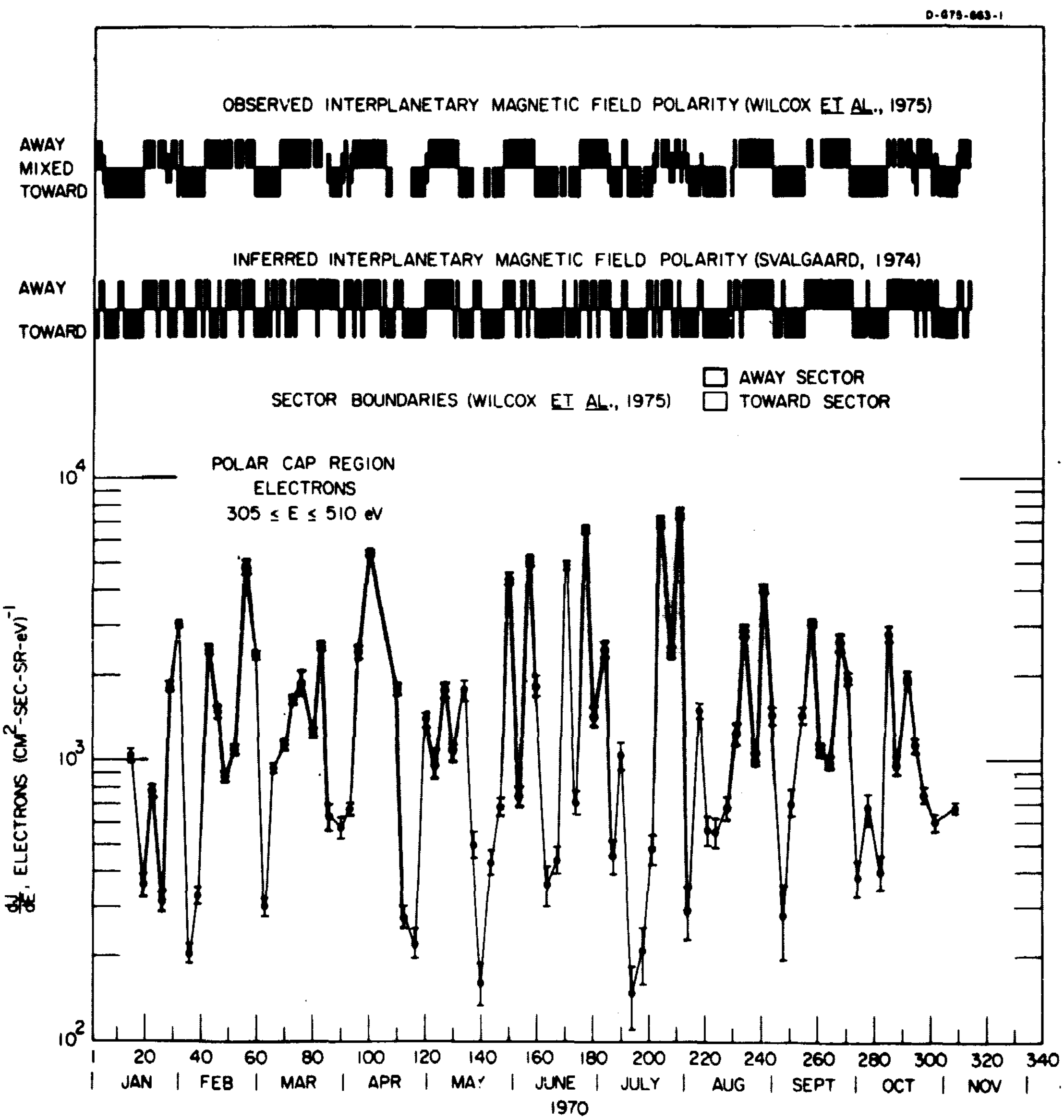

D-075-663-1
OBSERVED INTERPLANETARY MAGNETIC FIELD POLARITY (WILCOX ET AL., 1975)
AWAY
MIXED
TOWARD
INFERRED INTERPLANETARY MAGNETIC FIELD POLARITY (SVALGAARD, 1974)
AWAY
TOWARD
SECTOR BOUNDARIES (WILCOX ET AL., 1975)
AWAY SECTOR
TOWARD SECTOR
POLAR CAP REGION
ELECTRONS
305 ≤ E ≤ 510 eV
dJ/dE, ELECTRONS (CM²-SEC-SR-eV)⁻¹
10⁴
10³
10²
1 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340
JAN FEB MAR APR MAY JUNE JULY AUG SEPT OCT NOV
1970

Figure 2

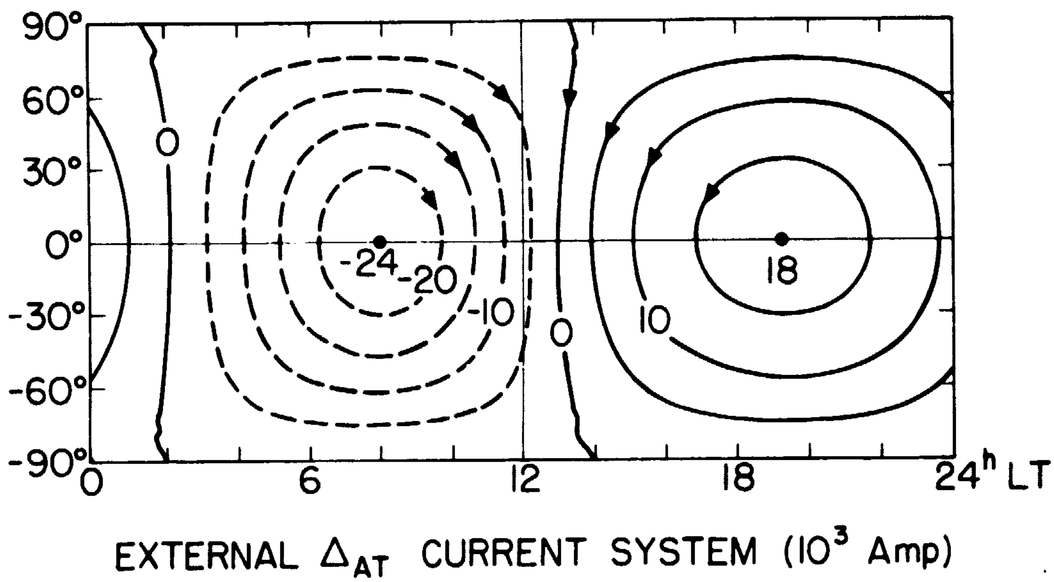
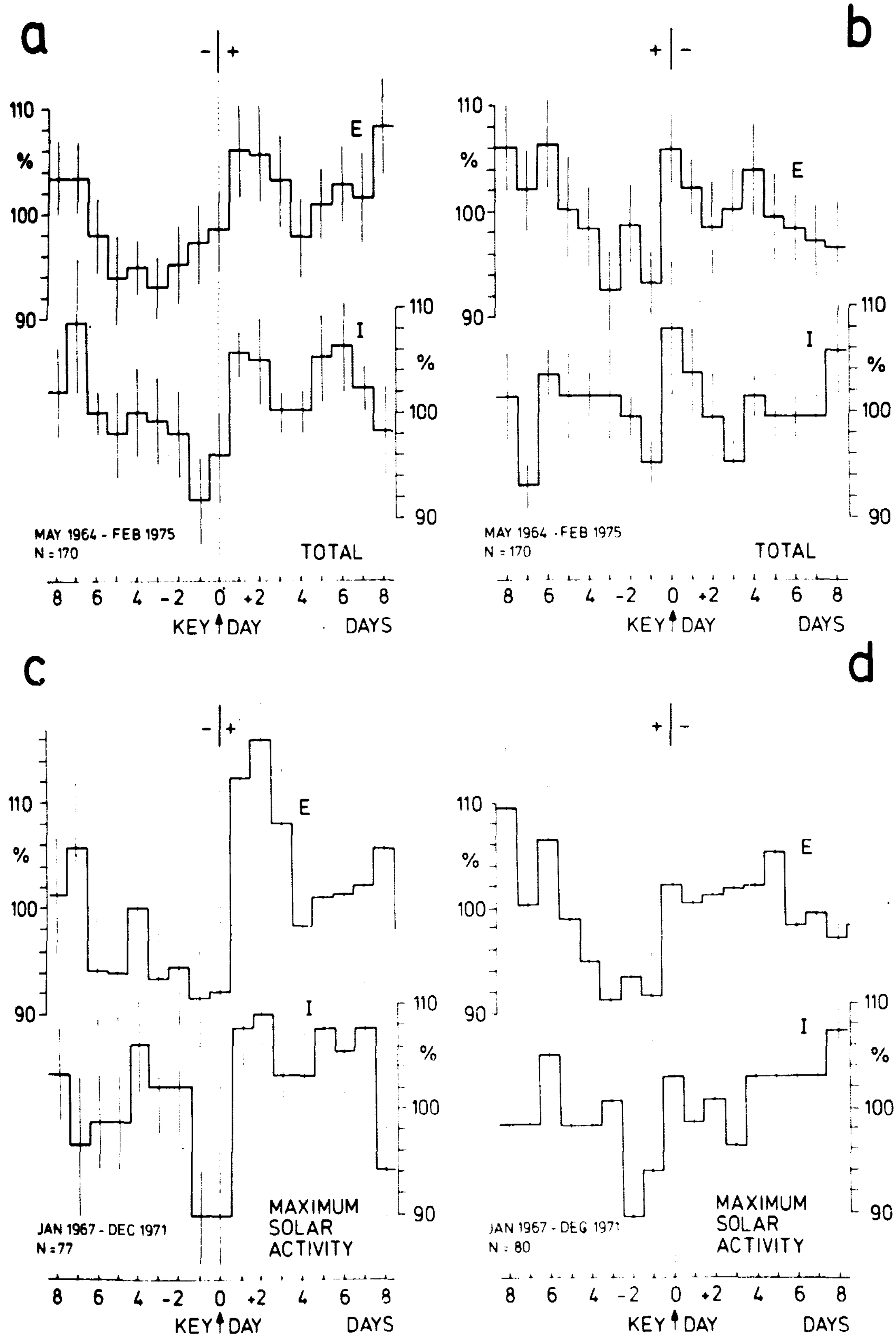

90°
60°
30°
0°
-30°
-60°
-90°
0
6
12
18
24h LT
0
-24
-20
-10
0
10
18
EXTERNAL ΔAT CURRENT SYSTEM (10³ Amp)

Figure 3



a
b
c
d
-|+
+|-
E
I
110
100
90
%
MAY 1964 - FEB 1975
N = 170
TOTAL
JAN 1967 - DEC 1971
N = 77
N = 80
MAXIMUM
SOLAR
ACTIVITY
8 6 4 -2 0 +2 4 6 8
KEY DAY
DAYS

Figure 4

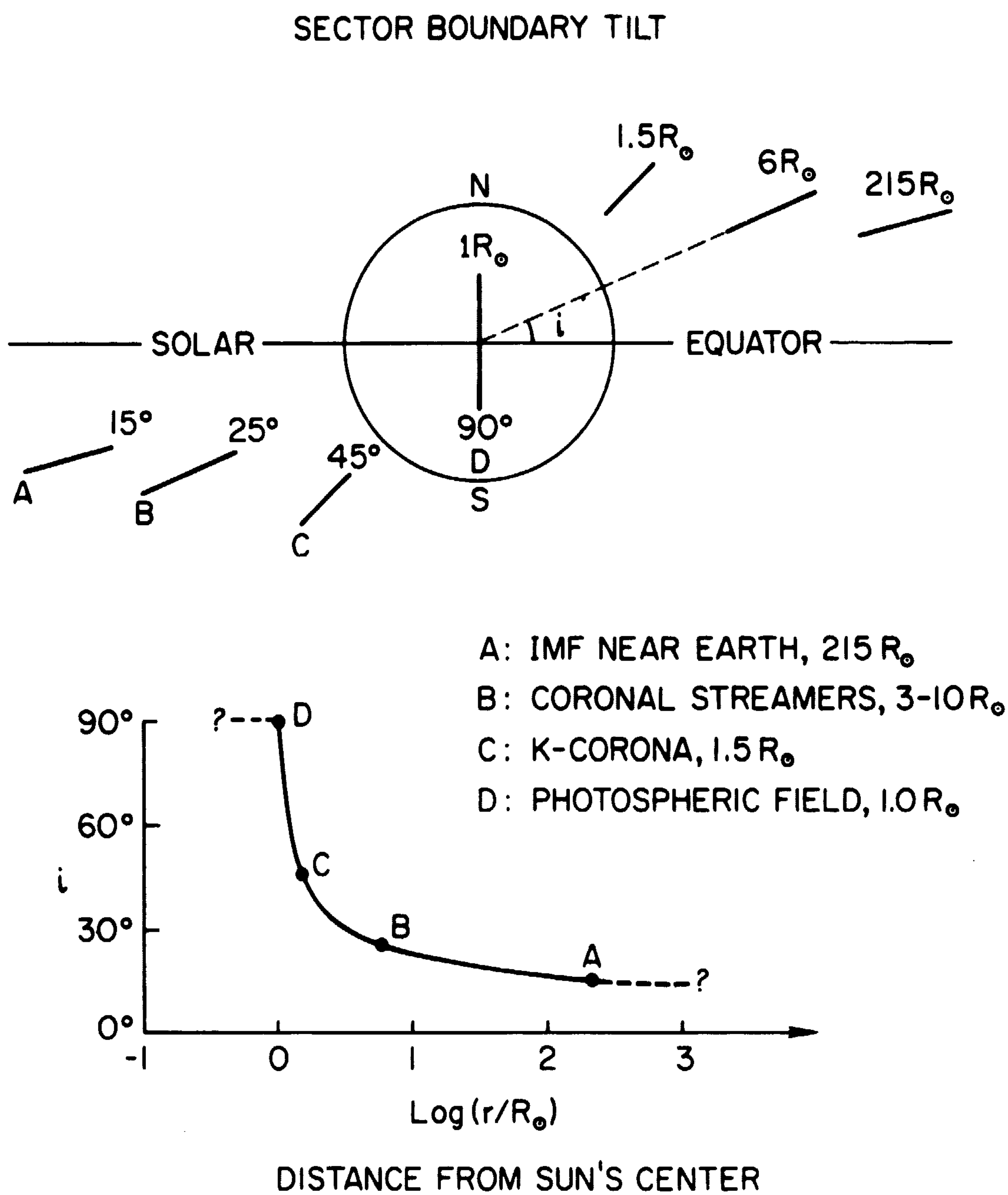

SECTOR BOUNDARY TILT
1.5R⊙
6R⊙
215R⊙
N
1R⊙
i
SOLAR
EQUATOR
15°
25°
45°
90°
D
S
A
B
C
A: IMF NEAR EARTH, 215 R⊙
B: CORONAL STREAMERS, 3-10 R⊙
C: K-CORONA, 1.5 R⊙
D: PHOTOSPHERIC FIELD, 1.0 R⊙
90°
60°
30°
0°
i
?
D
C
B
A
?
-1
0
1
2
3
Log (r/R⊙)
DISTANCE FROM SUN'S CENTER

Figure 5