

XIX ICRC
 RAPPORTEUR PAPER FOR SESSIONS SH5, SH6, AND SH7

FORBUSH DECREASES
 GEOMAGNETIC AND ATMOSPHERIC EFFECTS
 COSMOGENIC NUCLIDES

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This report is an attempt to give an overview and synthesis of recent developments that have occurred in the areas of Forbush decreases, Geomagnetic and Atmospheric Effects, and Cosmogenic Nuclides. Emphasis is laid on those new results and ideas which were presented in sessions SH5, SH6, and SH7 (and, if related to the abovementioned areas, also in sessions SH9 and SH10) at this conference, but some other relevant developments are discussed as well.

The complexity of the three areas and the large number of contributed papers (see Table 1) quite necessarily lead to a very personal selection of the highlights. And although this report is more comprehensive in some points compared to my oral presentation at the conference it is not a summary of the contributed papers in the abovementioned fields. My enthusiasm about new results and ideas may in addition cover some of the associated important problems. I would like to apologize for this bias. I also make my apologies to all the colleagues whose work is not mentioned explicitly in this report.

Table 1 Number of Contributed Papers in Sessions SH5, 6, 7, 9, and 10

	in Conference Papers	presented at Conference
SH 5	20	9
SH 6	18	8
SH 7	14	13
SH 9	16	11
SH10	8	3

1. Forbush decreases (Fds) have been a topic on each Cosmic Ray Conference since their discovery - and there is no evidence that this situation will change in the near future. They play a major - if not the dominant - role in the 11-year modulation of the galactic cosmic rays (see e.g. McKibben, 1981), they are associated with significant perturbations in the interplanetary medium and of the earth's magnetosphere, but the explanation of the physical processes involved has been an open question for debate for many years.

The first comprehensive review about Forbush decreases was published by Lockwood (1971). A summary of the pre-conference knowledge about Fds can be found e.g. in Iucci et al. (1984), and many of the most recent results have been published in the Proceedings of the International Symposium on Cosmic Ray Modulation in the Heliosphere, held in Morioka, Japan, August 21-25, 1984. An updated review paper on Fds including the latest developments is at present in preparation by Agrawal (1985).

Forbush decreases apparently occur at random, with a tendency to be more frequent and to have a larger amplitude during the increasing and maximum phase of the sunspot cycle. In the morphology of Fds different classifications have been proposed in the past. At present two types of Forbush decrease events with different characteristics are distinguished according to their origin (Shah et al., 1979): sporadic (non-recurrent) and recurrent (27-day period) decreases. Sporadic Forbush decreases have their origin in solar flares accompanied by type IV radioemission, occurring either on the visible or invisible hemisphere of the Sun (SH5.1-4), whereas recurrent decreases are generally related to long-lived corotating high speed solar wind streams associated with coronal holes (Venkatesan et al., 1982).

The classical Fd as recorded e.g. by a mid-latitude neutron monitor (NM) has a cosmic ray intensity-time profile as shown schematically in Figure 1. Starting immediately after a storm sudden commencement (the geomagnetic signature of the arrival of an interplanetary shock) the cosmic ray intensity decreases rapidly, typically about $\sim 5\%$ (but up to several 10%) within a few hours. This decrease is then followed by a slow recovery lasting in the order of one week. Several hours prior to the fast decrease, some Fds show a distinct pre-increase with an amplitude of about 0.4% (SH5.1-22). In many cases the descending phase of a Fd exhibits a clear two-step structure (Barnden, 1973; SH5.1-5) with two consecutive decreases in the cosmic ray intensity of approximately the same amplitude. The time period of depressed cosmic ray intensity is usually characterized by a fine structure in the intensity-time profile, including an occasional short-time (post-)increase during the minimum

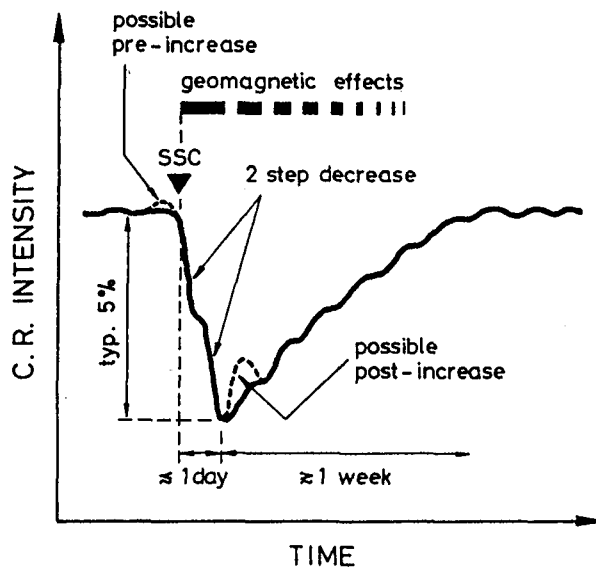


Fig. 1 The classical Forbush decrease

intensity phase (SH5.1-3). The entire event is associated with anisotropies, and for the analysis of Fds using cosmic ray data sampled on or near the earth it is also important to note that in particular the initial phase is subject to more or less pronounced geomagnetic effects. The modulation function of Fds, $F(R)$, is often approximated by $F(R) \propto R^{-\gamma}$ (with an upper limiting rigidity of 100 GV or more) where the spectral index γ has an average value of ~ 0.8 for sporadic and of ~ 0.4 for recurrent Fds (Nachkebia and Shatashvili, 1983). Another representation of the modulation function is given by $F(R) \propto \exp(-K/R^\gamma)$ with $0.2 \leq K \leq 1.0$ and $0.5 \leq \gamma \leq 0.9$ (e.g. Fenton et al., 1984). It was suggested at this conference by Sakakibara et al. (SH5.1-6), however, that a spectral form of fractional power type $(R^{-\gamma_1}(R+R_c)^{-\gamma_2})$ yields actually a more suitable representation of the rigidity dependence of Fds than power type or power-exponential type descriptions. For "hard" Fds during 1978-1982, i.e. for Fds with a relative change in the vertical muon intensity of more than 0.05% at the Sakashita underground telescopes (median primary rigidity $R_m = 330 - 567$ GV), they found $\gamma_1 = 0.37$, $\gamma_2 = 0.89$, and $R_c = 10$ GV. For "soft" Fds the corresponding values are $\gamma_1 = 0.77$, $\gamma_2 = 1.02$, and $R_c = 14$ GV.

One of the most significant features of the flare-associated Fds is the so-called East-West asymmetry: Fds related to solar flares in the eastern or central region of the solar disk exhibit larger amplitudes and longer recovery times than Fds related to solar flares on the western part of the solar disk. The present knowledge about the interplanetary perturbations associated with sporadic Fds within heliocentric distances of a few AU has been summarized by Iucci et al. (1984) and is shown in Figure 2. The front perturbation is a driven shock with a heliolongitudinal extent of about 100° . This shock is followed by a magnetic blob and a high-speed plasma cloud of about 0.5 AU average radial dimension at the orbit of the earth, emitted in a short time interval of usually less than 15 hours immediately after the beginning of the type IV burst. The Fd-modulated region is included between two

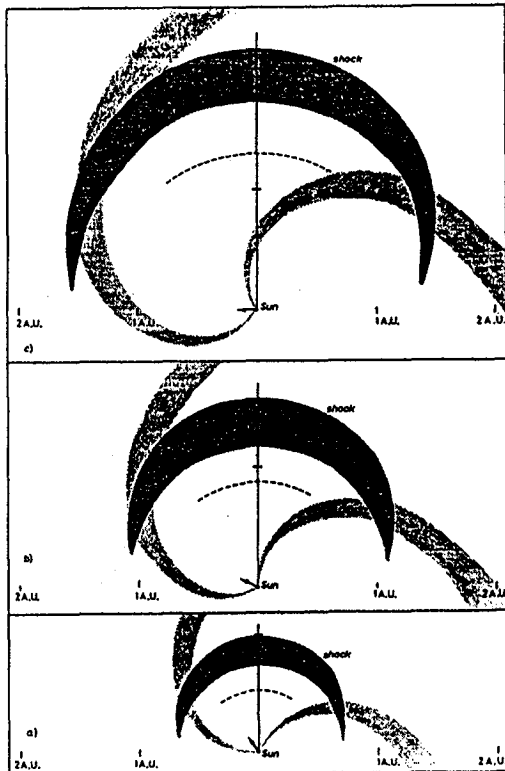


Fig. 2 Sketch on the ecliptic plane in a stationary frame of reference of the space-time evolution of a FD-producing interplanetary perturbation at three different times after the time t_0 of the type IV solar flare (SF). The flare region, indicated by the arrows, was located on the straight line at time t_0 . Regions of enhanced IMF are indicated by the shaded areas (■ front perturbation, □ corotating lateral perturbations). The flare ejecta plasma is located between the shock and the dashed line. a) 2.5 days b) 4.5 days c) 6.5 days after the SF (from Iucci et al., 1984)

corotating boundary streams. Significant progress has been made during the last years in the understanding of the propagation of shocks in the interplanetary medium. Using either MHD theory (e.g. Wu et al., 1983) or by modelling the shock simply as a blast wave in the reference frame of the moving solar wind (Smart and Shea, 1985) it became possible to predict the arrival of a shock at the earth after a solar flare with an accuracy of 1-2 hours. Many of the associated problems were discussed recently at the STIP Symposium on Retrospective Analyses and Future Coordinated Intervals held in Les Diablerets, Switzerland, June 10-12, 1985, and will be published in the proceedings of that meeting (Shea and Smart, 1985).

In order to understand the physical processes responsible for the transient modulation of the cosmic ray intensity correlation studies with parameters describing the interplanetary medium are of crucial importance, and corresponding results can be found in several contributions to this conference (SH5.1-5, SH5.1-9, SH5.1-11, SH5.1-12, and SH5.1-13). Figure 3 taken from paper SH5.1-5 is an example for the Fd on September 29, 1978. As can be seen this Fd shows a distinct two-step decrease. The interplanetary magnetic field (IMF) data and the solar wind plasma parameters indicate that the first step begins with the shock passage at the earth. The second step is connected to the entry of the earth into a region with an enhanced magnitude of the interplanetary magnetic field and with a loop-like field configuration. This conclusion is in agreement with results obtained by Badruddin et al. for other shock-associated Fds (SH5.1-12). In a statistical analysis of the flare-associated Fds in the period 1964-1982 Iucci et al. (SH5.1-5) determined the separate contributions of the shock front and of the following magnetic perturbation to the amplitude of the first and second step of Fds as a function of the associated solar flare longitude. The corresponding result is shown in Figure 4. The polar diagram in this Figure represents (for 1 AU) the helio-longitudinal dependence, relative to the flare longitude, of the total amplitude of Fds (normalized to a maximum value of 1) together with the corresponding amplitudes of the first and second step. It can be seen that only the second step exhibits a pronounced east-west asymmetry, probably due to the longitudinal asymmetry of the magnetic perturbation following the shock.

Thomas and Gall (1984) recently showed in a theoretical study that a radially propagating perturbation similar to the one existing at the front edge of the Fd-modulated region is able to prolong the containment of cosmic ray particles behind it, leading to an additional adiabatic cooling of these particles and, therefore, to Fds in the sunward region of interplanetary space connected magnetically with the perturbation front. On the other hand, continuing previous work (and beyond a similar attempt by Badruddin et al. (SH5.1-12)) Iucci et al. (SH5.1-5) succeeded in relating empirically the total amplitude and the amplitudes of the two individual steps of Fds quantitatively to a perturbation parameter describing the strength of the front edge perturbation in the interplanetary medium made up by the shock and the magnetic blob effect, whereas the strength of the perturbation at the western boundary was found to be not correlated with the amplitude of Fds (not associated with type IV flares). These results are considered

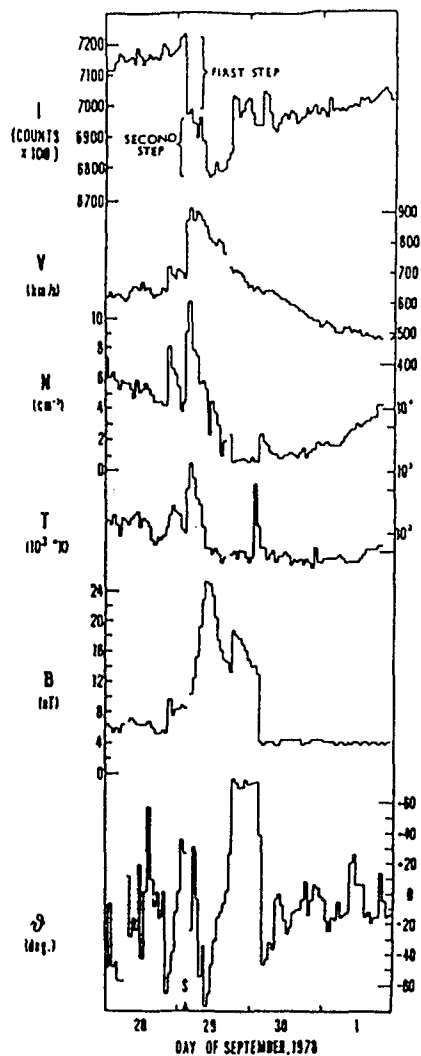


Fig. 3 Example for the time behaviour of a two-step Fd and of associated parameters of the interplanetary medium (SH5.1-5)

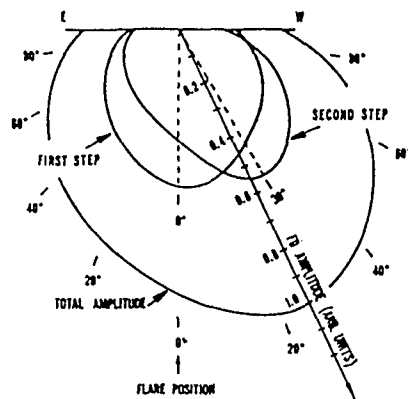


Fig. 4 Polar diagram representing the heliolongitudinal dependence, relative to the flare longitude, of the total amplitude of Fds together with the amplitudes of the first and second step (SH5.1-5)

to be important clues for the understanding of the mechanisms responsible for the cosmic ray density depression inside the Fd-modulated region.

In several papers the effect of "magnetic clouds", "magnetic cloud-like structures", and different types of high-speed solar plasma streams on cosmic ray intensity and anisotropies was discussed. Badruddin et al. (SH5.1-12) investigated the influence of three classes of magnetic clouds - shock associated clouds, stream interfaces and cold magnetic enhancements - on cosmic ray intensity. In paper SH5.1-4 Iucci et al. identified 31 short-term increases (with time duration less than 24 hours and amplitudes up to 5%) in the galactic cosmic ray intensity during Fd events of the period 1966-1977. All these increases

occurred after the passage of the compression region following the shock. They were associated with a magnetically perturbed, high velocity, low density and low temperature region in space for which in 7 cases the "magnetic cloud structure" according to the classification proposed by Burlaga (1984) could be determined. No satisfactory explanation for these observational results is, however, available yet.

The significance of periodic short-time cosmic ray intensity fluctuations for the analysis and the understanding of modulation processes has long been recognized (Dhanju and Sarabhai, 1967). A review of different techniques and applications in this field was recently published by Dorman and Libin (1984). Corresponding results were presented at this conference in papers SH5.1-7, 14, 17, and 18. By using the maximum entropy method Vainikka et al. (SH5.1-7) performed a spectral analysis of the cosmic ray intensity recorded at 9 neutron monitor stations during the large Fd of July 13-14, 1982, which was already discussed to some extent at the 18th ICRC in Bangalore (Agrawal, 1983). During the decrease phase of this Forbush event the analysis confirms the existence of a persistent oscillation with a time period of about 2 hours and an amplitude of 1-3%. This oscillation can be associated with a similar periodicity observed at the same time in the magnetospheric magnetic field. During the recovery phase the cosmic ray intensity showed a 3% variation with a time period of about 10 hours. Unfortunately, no correlation of these two periodic cosmic ray intensity variations with characteristic parameters of the interplanetary medium has yet been done and, therefore, their real origin is still unclear. Another very interesting result is discussed by Gulinsky et al. in paper SH5.1-18. Using 5-minute, 1- and 2-hour values of a large number of ground-based detectors, these authors investigated the cosmic ray power density spectrum for quiet time periods, periods with solar flares, and Fds during the years 1977-1982. Beside the known application of relating the cosmic ray power spectral density to the power density spectrum of IMF fluctuations, Gulinsky et al. demonstrate that the short-time cosmic ray variations in the GeV range also reflect the presence of large-scale perturbations in the interplanetary medium. As illustrated in Figure 5 which is based on the NM-registrations at Utrecht and Kerguelen for the time period September 7-23, 1977, the authors show that the spectral index γ in the range $10^{-6} \leq f \leq 10^{-4}$ Hz of the cosmic ray power density spectrum $P(f) = B \cdot f^{-\gamma}$ starts to increase significantly at least 18 hours prior to the onset of the Fd which occurred on September 21, 1977, whereas the quantity B decreases. In another study Sakai and Kato (SH5.1-14) found a pronounced periodicity in the cosmic ray intensity observed at Akeno with a time period of about 37 minutes during 1300-1900 UT on April 25, 1984, just one day prior to the Fd of April 26. It seems, therefore, that short-time cosmic ray fluctuations as observed by ground-based detectors are a suitable tool to probe the large-scale perturbations in the interplanetary medium and their approach to the earth.

There were some arguments in the past whether or not the characteristic properties of Fds such as the rigidity dependence (i.e. the modulation function) or the average recovery time are affected by the reversal of the solar magnetic field (as it occurred e.g. in 1980 for the last time). In this respect it was pointed out at this

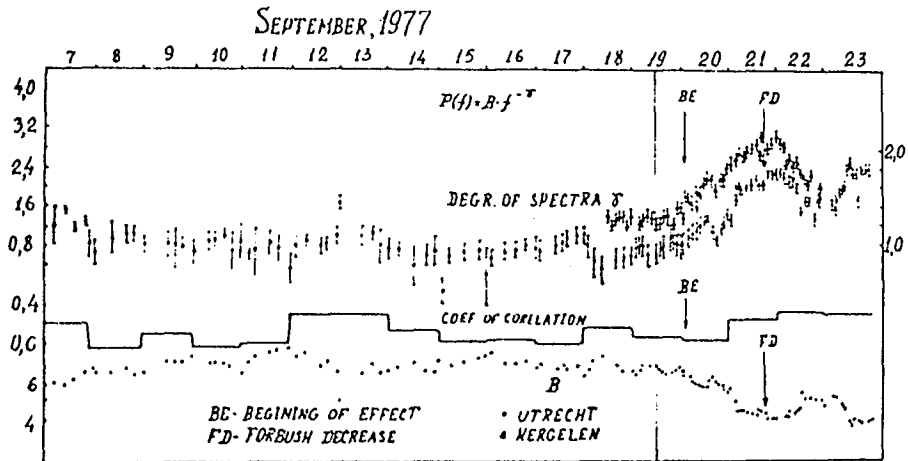
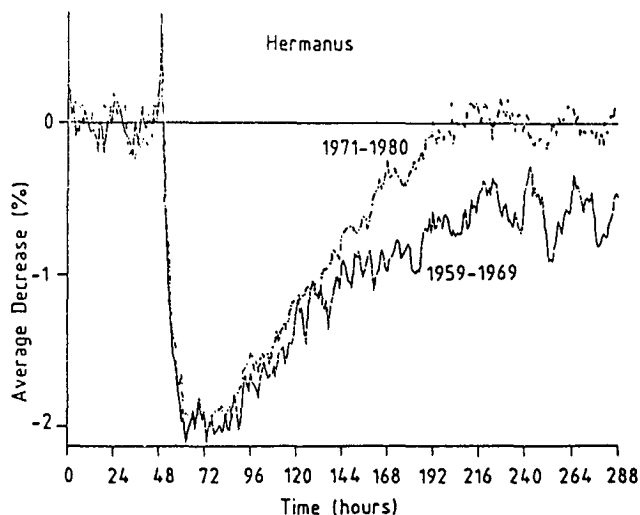


Fig. 5 Time dependence of the power spectrum of cosmic ray scintillations, $P(f) = B \cdot f^{-\gamma}$ ($f \leq 10^{-4}$ Hz) as determined by Gulinsky et al. (SH5.1-18) for the time period 7-23 September, 1977. The spectral index γ (top curve) starts to increase at least 18 hours before the arrival of a perturbation in the interplanetary medium at the earth and the beginning of the Fd on September 21, 1977, whereas B (bottom curve) decreases.

conference by Jain et al. (SH5.1-15) that during 1980 both the number and the magnitude of Fds was anomalously small compared to the high level of sunspot and solar flare activity. Fenton et al. (1984) performed an analysis of several shock-associated Fds during 1976-1983. Although their analysis was based on a rather limited number of comparable events, it appeared to these authors that the functional form of the Forbush-type decrease process is essentially the same now as it was during solar cycle 20. It was possible for them to conclude, however, that the rigidity dependence of the Fd is different from that of the long-term solar cycle changes during cycle 21 as it was earlier. Lockwood et al. (SH4.1-9) in a study of the intensity recovery of Forbush-type decreases as a function of heliocentric distance and its relationship to the 11-year variation arrived at the conclusions that the average recovery time t_r from transient decreases at 1 AU is energy independent and t_r is ~ 5 days, that t_r is essentially the same before and after the solar magnetic field reversal in 1980, and that t_r is constant through the solar modulation cycle. Apparently in contrast to these conclusions a remarkable result was presented by Moraal and Mulder (SH5.1-2). These authors compared the "average Fd", as observed by a specific NM during the years 1971-1980 with the corresponding "average Fd" of the years 1959-1969. The results which are consistent for different NM stations are illustrated in Figure 6 for Hermanus. They show a clear difference in the recovery phase. During 1971-1980 the cosmic ray intensity recovers to the pre-Fd level within 7 days after the onset of the decrease whereas during 1959-1969 even after 10

Fig. 6
The "average" Forbush decrease as observed with the neutron monitor at Hermanus during the time periods 1959-1969 (solid curve) and 1971-1980 (dashed curve). According to Moraal and Mulder (SH5.1-2) the difference in the recovery phase may be due to the drift effect.



days it is still significantly below this level. Although additional tests have to be performed to support their explanation the authors consider this effect as due to "drift", i.e. to the differences in the drift velocity field in the 1970 to 1980 IMF configuration with respect to the 1959-1969 configuration. It will certainly be most interesting to see the further development of this study.

2. Geomagnetic effects The geomagnetic field acts as a natural spectrometer for cosmic ray particles and it is, therefore, a "key instrument" in cosmic ray research. In order to relate the cosmic ray observations near or on earth to the cosmic ray flux in space, however, the transport of cosmic rays through the geomagnetic field must be understood in detail. Cutoff rigidities, asymptotic directions and/or entry points of cosmic ray particles to the magnetosphere have to be known accurately. The early work on cosmic ray motion in axially symmetric representations of the earth's magnetic field was limited to analytic considerations (Störmer, 1930; Lemaitre and Vallarta, 1936). Today, cutoff rigidities and asymptotic directions are determined almost exclusively by computer simulation of cosmic ray particle trajectories using elaborate mathematical representations of the magnetic field within the magnetospheric cavity. As a consequence of this evolution, and in order to avoid possible misinterpretations, the cosmic ray cutoff terminology needed a re-evaluation. At this conference, a final set of new definitions for use in theoretical and experimental cosmic ray studies was suggested by the experts in the field (Cooke et al., SH6.1-11).

Due to the secular changes in the geomagnetic field the trajectory calculations yielding cosmic ray cutoff rigidities and asymptotic directions have to be repeated periodically. For the Epoch 1955, 1960, and 1965 geomagnetic field models tables including the results of these calculations for the worldwide network of cosmic ray stations and/or a five degree by fifteen degree world grid have been published in the

past (e.g. Shea and Smart, 1975a, b). At present, calculations for Epoch 1980 by Shea, Smart, and co-workers are about to be completed. First results were already presented at the 18th ICRC (Shea et al., 1983a,b; Shea and Smart, 1983), and a comprehensive set of tables will again be published as an AFGL-report in the near future (Shea and Smart, 1985).

If uncertainties of the order of 5% can be accepted simple estimating procedures can be used to evaluate cosmic ray cutoff rigidities and asymptotic directions. In paper SH6.1-12 Shea et al. present useful relationships employing the McIlwain L-parameter to estimate the vertical cutoff rigidities for the twenty-five year period 1955-1980. For the effective vertical cutoff rigidity, R_c , the corresponding relation is $R_c = 16.237 L^{-2.0353}$ GV. Flückiger et al. (1983, and SH6.1-13) discuss a method of estimating the change in the asymptotic directions of approach for vertically incident cosmic ray particles due to storm-time as well as secular variations in the geomagnetic field from a reference set of directions at a specific epoch by considering the corresponding change in the geomagnetic cutoff rigidity.

It is of considerable interest to evaluate the primary cosmic ray flux which is able to reach a satellite in earth orbit. The evaluation requires the knowledge of the geomagnetic cutoffs for all four pi steradians of possible arrival directions at every point along the spacecraft orbit. It involves in general a large number of trajectory calculations, and special computer techniques have been devised to scan the rigidity/zenith-angle space efficiently for allowed arrival directions (Cooke, 1981; Humble et al., 1983). It is possible to summarize the results of such calculations on a unit sphere of access which graphically describes the access of primary cosmic ray particles to the satellite. In the upper hemisphere of the allowed portion of this sphere the cosmic ray cutoffs can be ordered by application of Störmer theory in offset dipole coordinates (Smart and Shea, 1977). In paper SH6.1-14 of this conference Humble et al. present an empirical method to model the occluded portion of the downward hemisphere representing arrival directions which are forbidden due to the earth's cosmic ray shadow effect. Figure 7 illustrates some of their results for a satellite at an altitude of 400 km and at three locations.

Although theoretically the earth's cosmic ray shadow prohibits the arrival of all primary cosmic ray particles from directions represented by the occluded part of the downward hemisphere, reality can be different. An example for this was also given at this conference by Beaujean et al. (SH10.1-6,7) who reported on heavy cosmic ray measurements made aboard Spacelab-1. A stack of CR-39 plastic track detectors was exposed to the cosmic radiation at 250 km altitude during 10 days. As a part of the stack was rotated one revolution within 7 days the impact time of most of the particles could be correlated with the orbit position and thus with geomagnetic field parameters. In their analysis of heavy particles with charge $Z \geq 6$ in the energy range 50-150 MeV per nucleon the authors find 36 geomagnetically forbidden particles among a total of 365. Six of these particles arrived from below the horizon. It is interesting to note that these forbidden particles

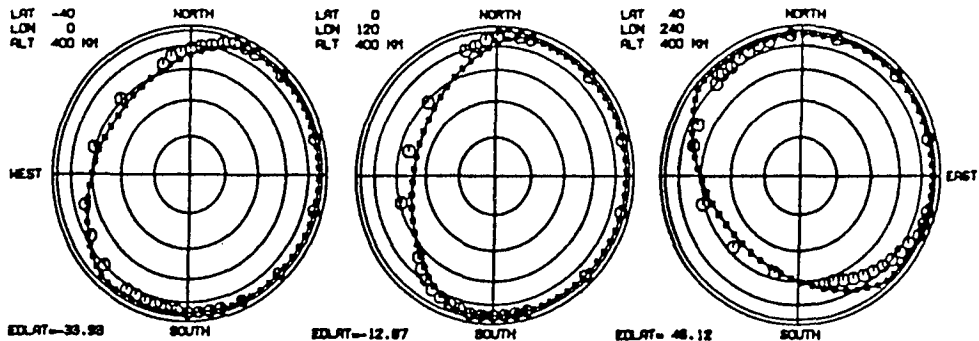


Fig. 7 Projections of the downward hemisphere of access for a satellite orbiting at 400 km altitude, at the locations 40°S/0°E, 0°S/120°E, and 40°N/240°E (Humble et al., SH6.1-14). The concentric rings represent 15° projections from the spacecraft equator to the nadir direction. Arrival directions which are completely forbidden to galactic cosmic radiation of any energy are represented by the area enclosed by the large dots in each projection. Open dots indicate where the maximum accessible zenith directions were determined by the cosmic ray trajectory-tracing method. The lines connecting the small solid squares indicate the results obtained according to the empirical model.

appeared between $\sim 49^\circ$ and $\sim 57^\circ$ geomagnetic latitude, with a concentration in the southern hemisphere between the geographic longitudes $\sim 30^\circ\text{E}$ and $\sim 200^\circ\text{E}$.

The appearance of forbidden particles could be due to a temporary change in the geomagnetic field. The variation of cosmic ray cutoff rigidities during magnetic storms is well established. The maximum absolute effect occurs at mid-latitudes. Local time asymmetries were found to be correlated with longitudinally asymmetric changes in the low latitude magnetic field which are generally attributed to the presence of a partial ring current (e.g. Dorman, 1974; Debrunner and Flückiger, 1977; Arens, 1978; and references therein). In a recent study based on data of the worldwide network of neutron monitors Kudo et al. conclusively demonstrate that the amplitude of the transient cosmic ray increase associated with the depression of the cutoff rigidity during severe geomagnetic storms strongly depends on local time, and that its maximum phase is found in the evening sector (Kudo et al., 1984; SH5.1-8). According to Flückiger et al. (1985) it appears that at any time, t , during geomagnetically active periods the changes in the cosmic ray cutoff rigidity, ΔR_c , at low and mid-latitudes can be related to the weighted sum of the changes in the horizontal component of the equatorial surface magnetic field, ΔH_{eq} , sampled at intervals of one hour in local time, t_L , from 0 to 7 hours to the east of the specified location:

$$\Delta R_c(R_c, t_L, t) \approx \sum_{n=0}^7 g_n(R_c) \cdot \Delta H_{eq}(t_L + n, t)$$

with $g_n(R_c)$ denoting weighting factors in dependence of the cutoff rigidity, R_c , derived from trajectory calculations. But cosmic ray cutoff rigidities not only change during magnetic storms. In paper SH5.1-14 Sakai and Kato show that in general the power spectral density of cosmic rays in the frequency range of 10^{-4} - 10^{-3} Hz correlates positively with the fluctuations of the geomagnetic field (represented by the Dst parameter) around $1.2 \cdot 10^{-4}$ Hz, indicating a rather dynamic character of the geomagnetic effects on cosmic rays. The diurnal variation of cutoff rigidities was established a long time ago, and in several publications the cutoff rigidities at high latitudes were evaluated theoretically as a function of local time using a magnetic field model including the tail of the magnetosphere (e.g. Smart et al., 1969). In paper SH6.1-10 Tyasto and Danilova describe a new theoretical study on the daily variation of cutoff rigidities at mid-latitudes. Based on trajectory calculations using a model of the magnetospheric

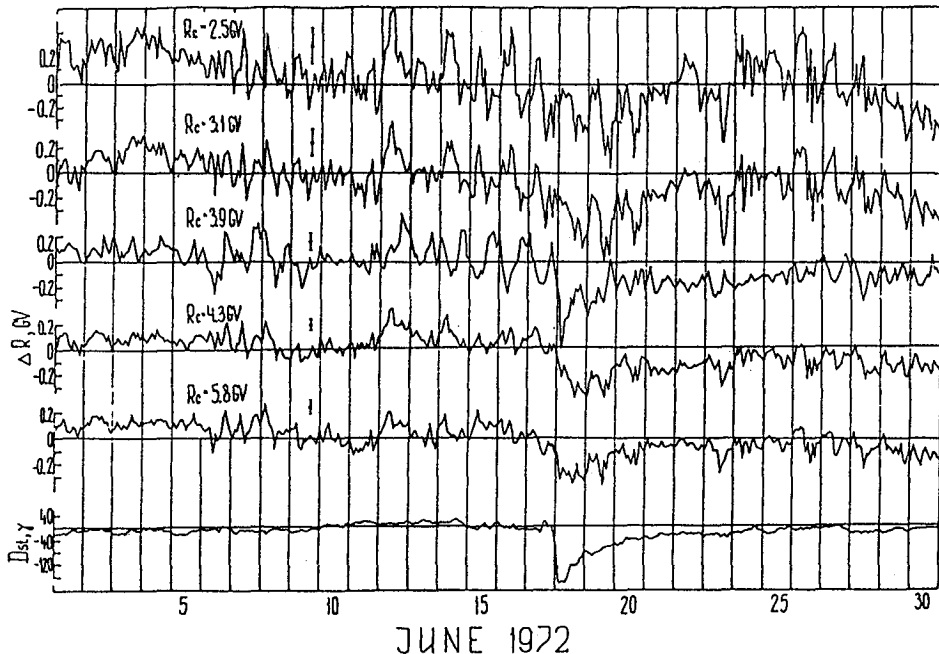


Fig. 8 Variations of the cutoff rigidity, ΔR_c , during June 1972, as determined by Dvornikov et al. (SH6.1-21) for five groups of cosmic ray stations (Kiel and Utrecht, $R_c = 2.5$ GV; Dourbes and Lindau, $R_c = 3.1$ GV; the Sayan spectrograph complex, $R_c = 3.9$ GV; Hafelekar, Zugspitze, Jungfrauoch, $R_c = 4.3$ GV; Rome and Pic-du-Midi, $R_c = 5.8$ GV), and Dst parameter (bottom curve).

magnetic field worked out recently by Tsyganenko and Usmanov (1982) they arrive at the conclusion that even during magnetically quiet time periods the magnetospheric effects lead to daily variations in the vertical cutoff rigidities of 0.15 GV at Moscow (cutoff rigidity $R_c = 2.48$ GV) and 0.02 GV at Mt. Norikura ($R_c = 12.0$ GV). It is interesting to compare these values with results given in paper SH.6.1-21. In this paper Dvornikov et al. discuss an experimental study in which they determined for the first time the cutoff rigidity variations at five middle and lower latitudes for the time period 1 May - 30 June, 1972, i.e. for two entire months! The analysis was based on data of 34 world network stations and a newly developed method of "spectrographic global survey". Figure 8 shows the results obtained for June 1972. Although some caution may be appropriate in accepting the absolute values of these results it is quite certain that this study provides new insight in the diurnal behaviour of cosmic ray cutoff rigidities.

In recent years, considerable progress has been made in the development of quantitative magnetospheric magnetic field models. A review discussing the state of the art with a critical comparison of different field models is found e.g. in Walker (1979) and Walker (1983). Most of the models include the major magnetospheric current systems illustrated in Figure 9 (taken from Potemra, 1984), with the restriction that the effect of field-aligned currents is not yet taken into account adequately. All the models include the dipole tilt angle as an input parameter. The magnetospheric effects constitute an important extension of the theory of geomagnetic effects on cosmic rays, and they are of significance especially for polar latitudes. A review on cosmic ray cutoff calculations utilizing magnetospheric magnetic field models is found in Pfitzer (1979), where it is shown that the cutoff values using the most sophisticated field models agree with the measurements within the experimental uncertainties. Within the extended geomagnetic theory the points of entry, i.e. the locations where cosmic ray particles enter the magnetosphere with respect to their point of detection, as well as the pitch angle of approach, i.e. the angle between the direction of approach and the neighbouring IMF, became new useful theoretical tools. Recently, Gall et al. (1984) published an extensive catalogue (free copies were available during the conference) including approach directions and points of entry of cosmic rays for 67 higher latitude cosmic ray stations. Pfitzer (1979) summarized earlier calculations on entry points with the map given in Figure 10a indicating the regions through which protons enter the magnetosphere before they are observed at the polar cap. Experimental data concerning the access of solar flare particles to the high latitude regions of the earth are discussed e.g. by Engelmann et al. (1971), Mineev et al. (1983), Ilyin et al. (1983) and Biryukov et al. (1984). Figure 10b taken from Biryukov et al. (1984) shows the structure of the solar cosmic ray proton flux in the north polar cap for energies $E \geq 1$ MeV according to the "Intercosmos-17" and "Cosmos-900" data for November 22-25, 1977. It is obvious from Figure 10b that a distinct structure is present, but despite the somehow restricted geographical resolution it can also be seen that this structure does not well represent the patterns given in Figure 10a. It is quite probable that the real situation is strongly marked by the field aligned currents flowing into and away from the ionosphere at these

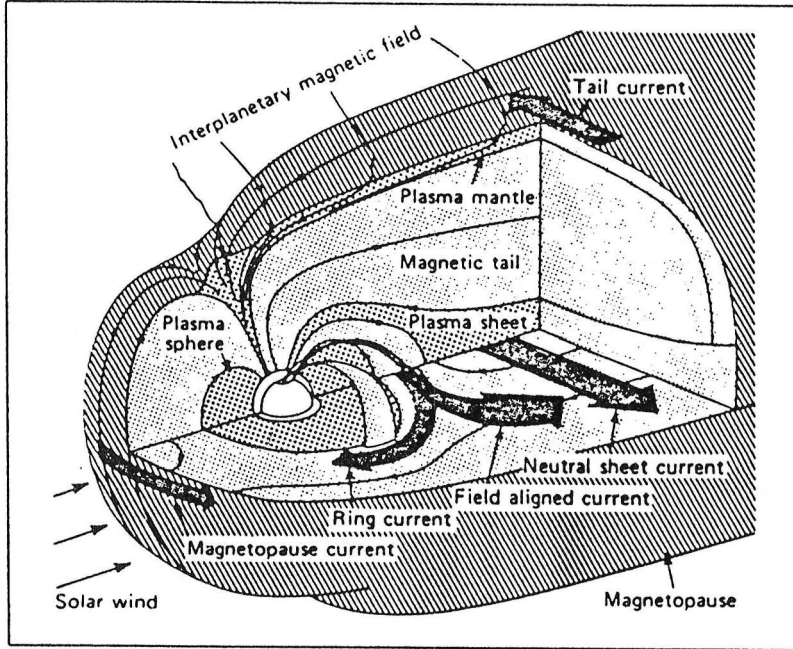


Fig. 9 The major magnetospheric current systems (Figure taken from Potemra, 1984)

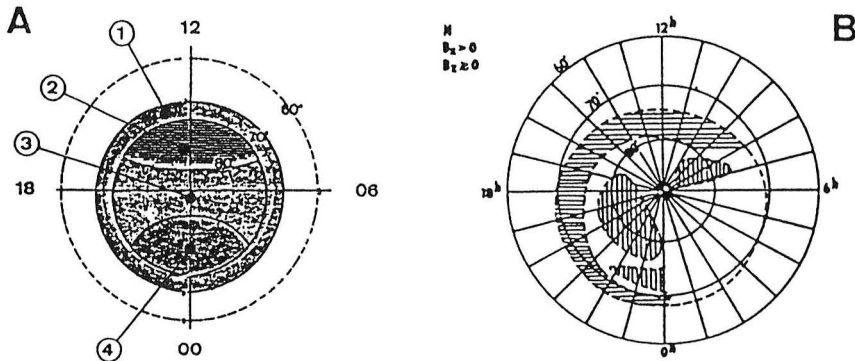


Fig. 10 Map of the polar cap showing the various regions corresponding to different entry points (to the magnetosphere) of protons observed at the polar cap

- a) theoretical result according to Pfitzer (1979). The entry locations are 1) daylight dawn, 2) direct access via cusps, 3) neutral sheet, and 4) lobes of tail
- b) experimental result given by Biryukov et al. (1984)

polar latitudes (see e.g. the reviews by Potemra, 1979, and Stern, 1983). New results on the access of solar cosmic ray particles to high latitude regions during quiescent and perturbed geomagnetic conditions are given in papers SH6.1-15 and SH6.1-16 (none of these two papers was actually presented at the conference). An illustration of these results is given in Figure 11, taken from Gorchakov et al. (SH6.1-15). The Figure shows the data from 3 channels of the Cerenkov detector on the low polar-orbiting satellite Cosmos-900 for the time interval 0845-1150 UT on November 22, 1977, which includes the abovementioned solar particle event starting at 1010 UT. Panel a refers to the quiet time period while panel b shows the measurements made during the solar particle event. It is important to realize that the comparisons of e.g. the equatorial penetration boundaries obtained from this kind of measurements (and as discussed in SH6.1-16) with theoretical results are a powerful tool to test the magnetospheric magnetic field models used in the calculations of cosmic ray particle transport at high latitudes.

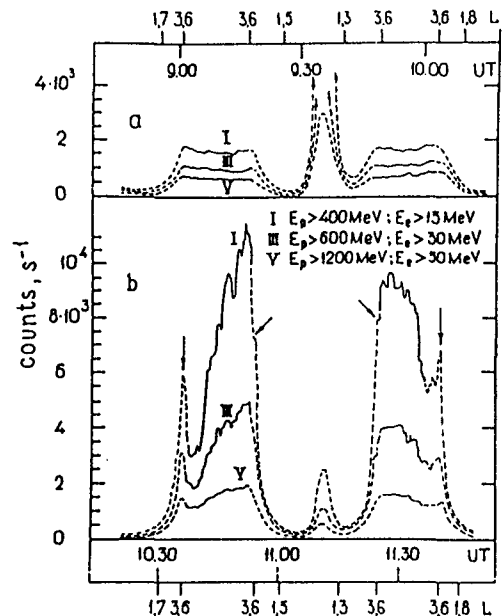


Fig. 11 The cosmic ray count rate as measured on November 22, 1977, with a Cerenkov counter aboard Cosmos-900 (Gorchakov et al., SH6.1-15):

- a) in the quiet time period prior to the solar particle event
- b) during the solar particle event

3. Atmospheric effects

It is quite obvious that the field of meteorological effects, cosmic ray secondaries in the atmosphere, and response functions of cosmic ray detectors is no longer the focal point of interest in cosmic ray research: only four papers out of nine were actually presented at the conference in this field (SH6.1-5, 7, 8, 18). And no reference to atmospheric effects was made, after all, in the oral version of this report. Here, however, I would like to mention at least three new developments.

The flux and energy spectrum of electron and proton albedo in the energy range between 20 MeV and 1000 MeV were measured systematically a long time ago by Verma (1967) over Palestine, Texas. The measurements of proton albedos were then extended to higher energies over the same

location by Pennypacker et al. (1973). Now for the first time the flux and the energy spectrum of low energy (30 - 100 MeV) albedo protons have been measured in a low latitude region, at 4 mb altitude, over Hyderabad, India (Verma and Kothari, SH6.1-8). Preliminary results of the balloon experiment which took place in December 1984 show that the spectrum of re-entrant albedo protons agrees well with the theoretical values evaluated previously (Kothari and Verma, 1983). However, the measured flux and spectrum of splash albedo protons seem to be somewhat higher than expected. Further data analysis including also the low (5 - 24 MeV) energy splash and re-entrant electron albedo spectrum will be done.

A comparative study of cosmic ray coupling coefficients for neutron monitor stations has been made recently by Mori and Nagashima (1984) in order to obtain the most appropriate response function and also "finally the most reliable information of cosmic ray solar modulation phenomena in space from the ground-based observations". The comparison covered the three response functions derived by Lockwood and Webber (1967), Nagashima (1971) and Aleksanyan et al. (1981). The conclusions obtained are not quite unambiguous, but Sakakibara et al. (Sakakibara et al., 1984; SH5.1-6) find that the response function derived by Nagashima is the most appropriate for the analysis of the rigidity dependence of Forbush decreases.

New results were presented, finally, in paper SH6.1-18 by Alexeyenko et al. concerning short-time (10 - 20 minutes time scale) perturbations of typically 1% in the ground-level cosmic ray intensity associated with meteorological phenomena, and which cannot be explained by pressure and temperature effects (at the level of observation). These perturbations have a long history, and they were already discussed at the 14th ICRC by Alexeyev et al. (1975). In the meantime, data from an experiment carried out with the Baksan E.A.S. array and an electric field meter added to the system allow a much more detailed analysis. The authors arrive at the conclusion that the correlation between these short perturbations observed in the ground-level cosmic ray intensity and the appearance of strong (>20 kV/m) electric fields in the atmosphere is established beyond doubt. They also suggest that the effect could be due to a mechanism based on the positive excess of muons if during the time periods of perturbed cosmic ray intensity the strength of the electric field at high altitudes is much larger than the one measured at the surface of the earth.

4. Cosmogenic Nuclides New experimental techniques such as the accelerator mass spectrometry, new methods of analysis as e.g. the cyclogram method of time series analysis, and "new isotopes" such as the ^{10}Be are in the process of revolutionizing this field. New possibilities for research are open now which up to some years ago one could only dream of, and the interdisciplinary character of the field, which was not small anyway, has been increasing enormously.

A comprehensive review paper on "Cosmic-Ray Record in Solar System Matter" including some of the new developments was published by Reedy et al. (1983). Raisbeck in his invited talk presented at this

conference gave an excellent overview of the history of the field, the main techniques and isotopes used today, and he discussed a few of the most interesting applications and ongoing activities. Reference is made, therefore, to the written version of his presentation included in this volume of the Conference Papers.

New techniques and new isotopes have also been proposed at this conference: Ninagawa et al. (SH9.1-16) described the application of a spatial distribution read-out system for thermoluminescence sheets (Yamamoto et al., HE7.1-7) in dating the terrestrial age of meteorites. Nishiizumi et al. (SH7.1-4) presented a new $^{129}\text{I} - ^{129}\text{Xe}$ method to obtain cosmic ray exposure ages and to study the average cosmic ray flux on a $10^7 - 10^8$ year time scale.

New theoretical studies on cosmogenic nuclide production by solar and galactic cosmic rays were discussed by Reedy (SH7.1-6, 7), Englert (SH7.1-9), and Zanda and Audouze (SH7.1-10), whereas the results of accelerator experiments on the contribution of secondary particles to the production of cosmogenic nuclides in meteorites were presented by Dragovitch and Englert (SH7.1-8). Because of the more fundamental character of these contributions, however, reference is made to the original papers for details.

The following discussion will be restricted to the problem of variations in the production rate of ^{14}C and ^{10}Be in the earth's atmosphere and their relation to solar modulation. In a recent paper Sonett (1984) showed that the 200-year periodicity in the time variations of atmospheric radiocarbon extends over the entire 8500-year La Jolla record and appears to be associated with a longer period between about 1500 and 2000 years. Beer et al. (1985a) find modulations with time periods of ~ 200 , ~ 500 and ~ 2000 years in both ^{14}C and ^{10}Be records between 3000 B.C. and 1100 A.D. As far as these long period variations are concerned they seem to be confirmed although their exact origin is still a matter of debate. Recent interest has focussed on the 11-year solar cycle in terrestrial records. Several studies (e.g. Damon et al., 1973; Baxter and Farmer, 1973; Burchuladze et al., 1980; Fan et al., 1983) on 11-year modulation effects in ^{14}C indicated a correlation between $\Delta^{14}\text{C}$ values and sunspot numbers, but in all the results cannot be considered conclusive. In recent papers it has been shown that the solar eleven year cycle is present in the series of ^{10}Be and $\delta^{18}\text{O}$ in ice cores as well as of thermoluminescence in sea sediments during the last millenia (Cini Castagnoli et al., 1984; Attolini et al., 1984; Beer et al., 1985b). As far as ^{14}C is concerned, Fan et al. (SH7.1-2) reported at this conference that from measurements in dated tree rings from 1824 - 1865 A.D. they find that, with the exception of the 1922 cycle, and with a delay of about five years, the $\Delta^{14}\text{C}$ values are anticorrelated with the sunspot numbers. The most interesting (and maybe also the most controversial) ^{14}C data, however, were presented at this conference by Kocharov et al. (SH7.1-14,15). Using scintillation equipment the radiocarbon content in dated tree ring samples from all over the Soviet Union was measured with an accuracy of 0.2 - 0.3% and with a time resolution of 1 year for the time period 1593 - 1981. They find a distinct 11-year periodicity in ^{14}C abundance before, and after the Maunder Minimum. A correlation analysis between the $\Delta^{14}\text{C}$ values

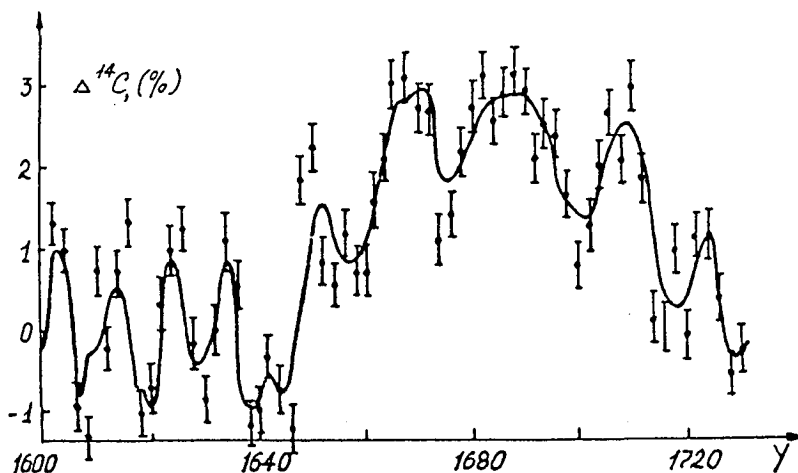


Fig. 12 $\Delta^{14}\text{C}$ data as obtained by Kocharov et al. (SH7.1-15) for the time period 1600-1730 A.D. (including the Maunder Minimum between 1645-1715 A.D.) from measurements of the radiocarbon abundance in dated tree rings.

and the Wolf sunspot number W yields a negative correlation with a time shift of about 4 - 5 years. This phase lag is in agreement with results obtained from calculations based on CO_2 -models if a 11-year periodicity in the ^{14}C production rate is assumed (e.g. Siegenthaler et al., 1980). The absolute amplitude of the effect, however, appears to be somewhat large compared to the results of the model calculations.

Of special interest are the results shown in Figure 12 concerning the time period of the Maunder Minimum. It is quite obvious that between 1645-1715 A.D. the $\Delta^{14}\text{C}$ level is enhanced and that its time profile does exhibit distinct variations. In comparison with data published by Stuiver and Quay (1980) it seems that between 1670-1710 A.D. the maximum $\Delta^{14}\text{C}$ values obtained by Kocharov et al. are about 40% larger, although the 3-year running means presented at the conference appeared to be quite consistent with an average $\Delta^{14}\text{C}$ -value of about 1.6% as given by Stuiver and Quay for this time period. Kocharov et al. translated the results shown in Figure 12 into ^{14}C production variations, sunspot numbers and intensity variations of the galactic cosmic rays within the rigidity range $0.5 \text{ GV} \leq R \leq 50 \text{ GV}$. It is emphasized that in general extreme care must be taken in interpreting this kind of data. The authors conclude that during the Maunder Minimum the 11-year solar cycle was very weak (if present at all) but that nevertheless the cosmic ray intensity was modulated, with good indications of a 20-22-year period. It is very interesting to compare this conclusion with the

results obtained by Beer et al. (1985b) who during the Maunder Minimum find periodicities in the ^{10}Be concentrations in polar ice cores varying from 9 to 11 years.

Mechanisms for further modulation of cosmic rays also in the absence of solar flares, as e.g. the effects of polar high speed recurrent solar wind streams have been discussed by several authors (e.g. Forman, 1978; Hundhausen, 1980; Fisk, 1979). Based on a statistical analysis of ^{10}Be , sunspot, geomagnetic, and aurora data Attolini et al. (SH7.1-1, 3) suggest that the modulation of ^{10}Be in polar ice is probably due to at least two main contributions: to one which is negative and in phase with the solar flare activity modulating the cosmic ray flux in Forbush-type decreases, and to one which is positive and in phase with the appearance of large wind streams originating at both polar coronal holes. From the analysis of Aurorae the authors furthermore conclude that the high latitude solar activity is related to a stable periodicity of 11.1 years whereas the low heliolatitude activity contributes to an oscillation of the solar cycle period between 10.8 and 11.4 years on a time scale of about 200 years.

5. Concluding Comments In conclusion the progress achieved in the areas of Forbush decreases, Geomagnetic Effects and Cosmogenic Nuclides, and possible directions of related research in the near future are summarized in the following (again very personal) comments:

In the field of transient variations correlation studies between cosmic ray measurements at 1 AU and other heliocentric distances and characteristic parameters of the interplanetary medium (e.g. solar wind speed, intensity and direction of the IMF, etc.) and especially with specific types of interplanetary perturbations (e.g. shock-associated clouds, stream interfaces, cold magnetic enhancements, etc.) have been very successful in yielding new knowledge about the structure of these modulating perturbations as well as their evolution in space and time. Experimental evidence has been found for substantial differences in the effects of the various types of interplanetary perturbations on cosmic rays, and for a dependence of these effects on the three-dimensional configuration of the interplanetary medium. More of these studies are needed especially in order to explain the physical processes involved. To a larger extent, these studies should also include anisotropy effects, they should definitely include the rigidity range above 10 GV, and they should be extended to all three dimensions of interplanetary space. It is expected that the ULYSSES out-of-ecliptic mission, a joint ESA-NASA project, will contribute substantially to these analyses, but unfortunately not before ~1988. The new experimental data also require an adaption of existing or the creation of new theoretical models - a comprehensive model for Forbush decreases explaining quantitatively all observational facts is still missing.

The area of geomagnetic effects has become the area of magnetospheric effects. Due to recent research great progress has been made especially in the experimental determination, the understanding and the theoretical modelling of changes in cosmic ray cutoff rigidities at low and mid-latitudes. Much work remains to be done as

far as high latitudes are concerned. In order to fully understand and to be able to simulate the (solar) cosmic ray particle access to the polar regions of the earth we need accurate models of the magnetospheric magnetic field. These models must include all major magnetospheric current systems (in particular the field aligned currents), and they should represent magnetically quiet time periods as well as different levels of geomagnetic activity. In the evolution of magnetospheric magnetic field models cosmic ray and magnetospheric physicists should work closely together since cosmic ray measurements are a powerful additional tool in the study of the perturbed magnetosphere.

In the field of cosmogenic nuclides, finally, exciting new results and developments follow in rapid succession. Thanks to new techniques and new isotopes the analysis of cosmic ray history has entered into a new dimension. Although many problems connected with experimental procedures, with data analysis, and in particular with the identification of climatic, meteorologic, transport and accumulation effects are still unsolved, the ^{14}C and especially the ^{10}Be isotopes in terrestrial records as well as the thermoluminescence in sediments are about ready to reveal the cosmic ray intensity-time profile at the earth for a time period of several thousand years back from now. And all those interested in larger time scales can expect a similar evolutionary progress in the near future from the analysis of meteorites, lunar samples, cosmic spherules and cosmic dust.

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