Partial ring currents and cosmic ray magnetic cutoff rigidity variations

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cutoff rigidity variations of European mid-latitude stations during the September 1974 Forbush decrease

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Neutron Monitor data of the September 1974 Forbush decrease have been analysed in order to investigate changes in cutoff rigidities at European mid-latitude stations. Based on a best fit of theoretical and experimental coupling functions the expected variations of the cosmic ray intensity for Jungfraujoch have been calculated from the counting rates of the stations Kiel and Utrecht. From the comparison of these results with the measurements hourly values for the cutoff variations have been deduced. For Jungfraujoch the analysis shows maximum changes in cutoff rigidity of $\pm 1.0 \pm 0.3$ GV on September 15, between 1500 and 1900 UT.

4.1 INTRODUCTION

In studies of primary spectral variations during Forbush decreases based on Neutron Monitor data one must account for perturbations in the geomagnetic field as a cause of considerable changes in cutoff rigidity. Therefore possibilities for an experimental determination of cutoff variations have been examined by several authors. A review of the different techniques has been given in a previous paper by Debrunner et al. (1973), who have also proposed a special method for mid-latitude stations. Not mentioned was the work of Louis (1972) which represents, just as the treatise of Dorman (1974), a comprehensive study of variations in cutoff rigidity during magnetic storms. In a recent paper Agrawal et al. (1974) suggested that during the complex of events in August 1972, a sudden increase in cosmic ray intensity coinciding with a geomagnetic storm with $D_{st}=200 \gamma$ on August 4, was caused by a lowering of the cutoff rigidity. Here as well as in the work of Louis, quantitative results are given but detailed indications on accuracy are missing and the time resolution is rather poor. In the present paper variations of the cutoff rigidity at Jungfraujoch during the September 1974 event are analysed based on hourly Neutron Monitor data of Kiel and Utrecht. All these stations have nearly the same asymptotic directions of viewing, which is a necessary condition for our method of analysis.

On September 13, 1974, a decrease in cosmic ray intensity started as indicated in figure 1. On September 15, 1343 UT a storm sudden commencement (S.S.C.) occurred, probably due to a complex of solar flares on September 13 starting between 1458 and 1513 UT in McMath regions 13224 and 13225 (Solar Geophysical Data, prompt reports, October, November 1974) and was followed by a strong geomagnetic storm and sharp Forbush decrease at very high latitude stations. However for Kiel the intensity remained practically constant for several hours whereas at other mid-latitude stations (Utrecht, Doubrdes, Zugspitze, Jungfraujoch and Rome) an increase in intensity was recorded. The intensity at Zugspitze and Jungfraujoch reached a maximum of $+1.0\%$ and $+1.5\%$ respectively relative to the average cosmic ray intensity of September 4-8, 1974, which was used as reference level. As this observed intensity increase shows an ‘inverse’ latitude effect, which is expected up to $R_e \approx 7$ GV from theoretical...
considerations of cutoff changes, the only possible cause for this effect is a lowering of the geomagnetic cutoff rigidity. An increase due to energetic solar particles or an anisotropy would show a normal latitude effect and can therefore be excluded. Also on this basis the behaviour of the recordings from Kiel and the other mid-latitude stations can be explained. As the cutoff rigidity at Oulu is less than the atmospheric cutoff, this station records the true Forbush decrease.

Fig. 4.1. Relative variations of the total counting rates, with respect to the reference level of September 4-8, 1974, for the stations Rome (ROM), Jungfraujoch (JUN), Zugspitze (ZUG), Dourbes (DOU), Utrecht (UTR), Kiel (KIE) and Oulu (OUL).

4.2 ANALYSIS OF THE EVENT

During a Forbush decrease the primary cosmic ray spectrum is generally described by

$$\psi(R,t) = [1 + \delta \psi(R,t)] \cdot \psi_0(R)$$

$$= [1 + \pi(t) \cdot R^{\gamma(t)}] \cdot \psi_0(R)$$

where $\psi_0(R)$ is the undisturbed primary differential rigidity spectrum.

Taking into account a possible simultaneous change $\Delta R_c(t)$ of the effective cutoff rigidity $R_c$, the relative variations of the counting rate of a Neutron Monitor at atmospheric depth $h$ are then given by

$$\delta N(h,R_c,t) = \int_{R_c}^{R_c + \Delta R_c(t)} W(h,R,R_c) \, dR + \int_{R_c+\Delta R_c(t)}^{\infty} W(h,R,R_c) \cdot \delta \psi(R,t) \, dR$$

For September 1974 the normalized coupling functions $W(h,R,R_c)$ have been deduced from our best fit differential response functions (Flückiger, 1974).

The exponent $\gamma$ may vary from event to event (e.g. Lockwood, 1971) and even during an event (Aldagorova et al., 1973). Since nearly all experimentally obtained values for $\gamma$ fall in the range $0.0 < \gamma < 1.6$ with errors in the order of 0.8, the exponent $\gamma$ was varied in this analysis from 0.4 to 1.4 in steps of 0.2.
For each \( \gamma \) the amplitudes \( \eta (t) \) were determined for the stations Kiel and Utrecht. The spectra so obtained have been used to calculate the relative variations of the total counting rate at Jungfraujoch, \( \delta N^J(t) \), for \( \Delta R_c^J = 0 \). The differences between observed and theoretical variations were attributed to cutoff changes.

Numerical values for the variations \( \Delta R_c^J(t) \) have then been determined. Taking into account the theoretical latitude dependence of \( \Delta R_c \) (Obayashi, 1959), the cutoff changes of Kiel and Utrecht \( \Delta R_c^K(t) \) and \( \Delta R_c^U(t) \) have been calculated from \( \Delta R_c^J(t) \). The same computing process was then repeated using the changed cutoff rigidity for the three stations until the variation of the altered value of \( R_c^J \) was less than 0.01 GV.

Figure 2 shows the resulting mean values of \( \Delta R_c^J(t) \) computed with \( \gamma = 0.8 \) for September 13-18, 1974.

As a check we treated the data from Oulu and Dourbes in the same way as the Kiel and Utrecht data. The results for the cutoff changes at Jungfraujoch are in close agreement with those obtained from Kiel and Utrecht measurements. As an additional check the cutoff changes for Zugspitze and Rome were calculated with measurements from Oulu, Kiel, Utrecht and Dourbes. These results show the expected latitude dependence of the cutoff variations as compared with \( \Delta R_c \) for Jungfraujoch.

For the determination of the accuracy in the deduced cutoff variations we must account for errors in the coupling functions, inaccuracies in the exponent \( \gamma \), statistical errors of the measured counting rates as well as for the errors introduced by pressure corrections. A discussion on reliability of our method has already been given in a previous paper (Debrunner et al., 1973). Following the same procedure the relative errors in \( \Delta R_c^J(t) \) due to unreliabilities in the coupling functions have been determined to be in the order of \( \pm 30\% \). As has also been found the errors in \( \gamma \) cause a mean inaccuracy in the determination of cutoff variations of \( \pm 0.10 \) GV. The uncertainties due to inaccuracies in the Neutron Monitor data are of the order of \( \pm 0.1 \) GV. Thus the maximum value of \( |\Delta R_c^J(t)| \) given in figure 2 has an error of \( \pm 0.3 \) GV.
4.3 DISCUSSION OF RESULTS

Cutoff variations during a Forbush decrease are thought to be due to a ring current with a magnetic moment opposite to the intrinsic geomagnetic moment. We therefore compared our results on cutoff changes with the hourly values of the index D$_{st}$ (Sugiura, 1975), which are a measure for the ring current field near the earth (e.g. Akasofu, 1963).

From the D$_{st}$ values it is also possible to deduce theoretical cutoff variations (e.g. Obayashi, 1959). These calculated values for the cutoff rigidity changes at Jungfraujoch are also given in figure 2. The comparison between the theoretical and experimentally deduced values of the variations of cutoff rigidity shows reasonably good agreement.

Furthermore there seems to be a maximum sensitivity in cutoff variations around 1600 hours local time when the asymptotic directions for low rigidities are in the geomagnetic tail, a phenomenon we also observed in our analysis of the July 1974 Forbush decrease. This has also been noticed by Hatton (1962) and may be due to an asymmetric ring current as pointed out by Yoshida et al. (1968). However further research is needed for a better understanding of these effects.

4.4 CONCLUSIONS

During the September 1974 event the effective vertical cutoff rigidity of Jungfraujoch was considerably lowered with a maximum variation $\Delta R_{J}^V = -1.0 \pm 0.3$ GV between 1500 and 1900 UT on September 15. The magnitude of the changes are in reasonable agreement with the theoretical values calculated from D$_{st}$ and with values for similar events cited in the literature (e.g. Freier, 1962; Hatton et al., 1962; Wolfson et al., 1967; Yoshida et al., 1968; Nobles et al., 1968).

We also concluded from this analysis as shown in figure 2 that cutoff changes may last for long periods of the order of days.

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4.6 REFERENCES


Sugiura, M. 1975, private communication.