SH 3.6.25

Cosmic Ray Survey to Antarctica and Coupling Functions for Neutron Component Near Solar Minimum (1996-1997) 3. Geomagnetic Effects and Coupling Functions

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Abstract

We present the sea-level latitude effect of two components of cosmic ray radiation obtained by a survey conducted by ship from Italy to Antarctica and back during 1996-1997 solar minimum. High energy atmospheric neutrons were detected by a 3NM-64; thermalized atmospheric neutrons by 2 bare BF_3 counters. The internal consistency of data and stability of detectors, the investigation of meteorological effects and data correction are presented in two parallel papers, together with the computation of updated vertical cut-off rigidities corrected for penumbra effect (R_{cp}). In the present paper the effect on survey data of North-South asymmetry of cosmic ray flux in near-Earth space is evaluated and data correction is applied; apparent cut-off rigidities (R_{cp}^{ap}), which take into account the contribution of inclined particles to the counting rate, are estimated. A small Forward-Backward effect is found and explained by the influence of an asymmetric shielding structure around the monitor. The latitude dependencies (*i.e.* neutron intensities *vs.* cut-off rigidity) and associated coupling functions are computed for both monitors and compared. The NM latitude dependence obtained for this solar minimum is found to be almost identical to that obtained by other authors in the previous solar minimum. The absence of the so-called "crossover" effect, when comparing coupling functions of subsequent solar minimums, is discussed on the light of cosmic ray intensity changes observed by neutron monitor stations.

1 Introduction:

During 1996-1997 solar minimum we conducted a cosmic ray (CR) latitude survey on a ship of Italian Antarctic Research Program, measuring neutron intensity on seas by a 3NM-64 and a 2BC (bare BF_3 counters) detectors. In SH.3.6.24 and SH.3.6. 04 we presented the survey data corrected for a number of effects: (i) small variations of CR primary origin by using the data of the neutron station network; (ii) meteorological effects, including atmospheric mass absorption (by taking into account Bernoulli effect), sea-state and temperature effects. Cut-off rigidities R_{cp} of vertically incident CR particles have been computed for every day, for the corresponding average geographic location of the ship, by taking into account penumbra effect; the 3-hourly values have been obtained by interpolation. In this paper we analyze the dependencies of NM and BC neutron intensities on cut-off rigidity and compute the associated coupling functions. We correct the data for the small North-South anisotropy in the primary CR flux. Also the so-called "apparent" cut-off rigidities R_{cp}^{ap} (see Clem et al. 1997) are computed in dipole approximation by taking into account the contribution of particles reaching the detector from sufficiently inclined directions.

We compare the survey data recorded in different hemispheres and in different directions (from Italy to Antarctica and vice versa) to verify the computation of R_{cp} and of R_{cp}^{ap}, and to make clear possible shielding effects due to asymmetric mass distribution on the ship around NM.

2 Correction for North-South Asymmetry of CR in Interplanetary Space:

CR latitude survey data are influenced by the small North-South (N-S) asymmetry of CR distribution in the interplanetary space. Belov et al. (1990) found that the amplitude of N-S asymmetry in NM intensity is $A_{NS} \leq 1\%$ ($A_{NS}>0$ when $I_N>I_S$ and $A_{NS}<0$ when $I_N<I_S$). The CR intensity distribution at the Earth caused by the N-S asymmetry with amplitude A_{NS} can be described as $I(\varphi,t)=A_{NS}(t)\sin\varphi$, where $A_{NS}(t)=[I(\pi/2,t)-I(-\pi/2,t)]/[I(\pi/2,t)+I(-\pi/2,t)]$, being φ the geographic latitude ($\varphi>0$ in northern hemisphere and $\varphi<0$ in southern). Let us consider the case of N-S asymmetry changing with time during the survey. A recent study of Belov et al. (1995) showed that $A_{NS}(t)$ has a seasonal variation with maximum ≈+0.5% in May-Aug. and minimum ≈-0.5% in Dec.-Mar. We used these results for our survey data, by assuming that this seasonal variation is about the same in all years. During the survey period (December-March), the expected $\Delta I/I$ caused by the almost constant N-S asymmetry was computed and used for data correction (see Figure 1).

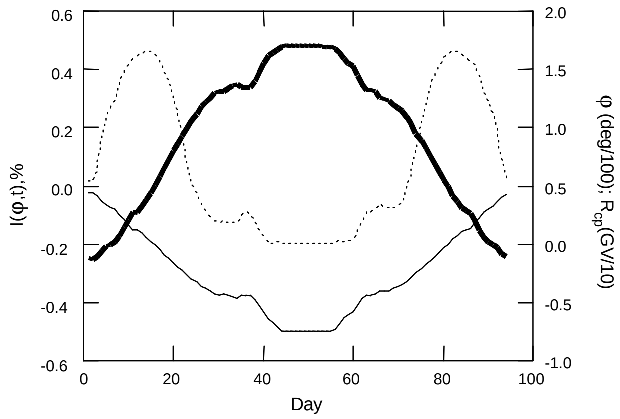

Figure 1: $\Delta I/I$ due to N-S asymmetry (thick line), φ (thin line) and R_{cp} (broken line) during the survey

3 The Dependences of Corrected Intensities upon Cut-off Rigidities:

In Figure 2 we show for NM and BC the dependencies of the 3-hourly corrected values of $J = I/I_0$ (I_0 is the average intensity at R_{cp}<1.0 GV)) on R_{cp} for southern (S) and northern (N) hemispheres, separately for forward (F) (from Italy to Antarctica) and backward (from Italy to Antarctica) (B) surveys.

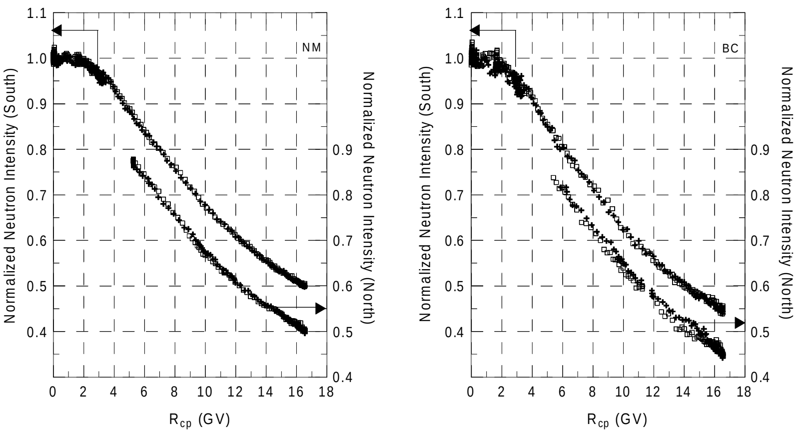

Figure 2: $J_{NM}(R_{cp})$ & $J_{BC}(R_{cp})$ for F(□) and B(+) routes separately for N and S hemispheres

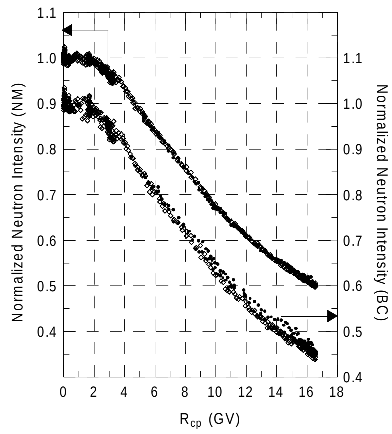

Figure 3: $J_{NM}(R_{cp})$ & $J_{BC}(R_{cp})$ for N (•) and S (◊) hemispheres

For NM it appears that the difference in J_{NM} between F and B surveys is very small; only in N hemisphere for $R_{cp} \cong (9\div11)$ GV a systematic difference of ≅ 1 % is observed, while for BC the effect has a larger amplitude ≅ 3 % and covers a wider rigidity interval (9÷15) GV. This anomaly (F-B effect) could be caused by the 180° rotation with the ship of the asymmetric distribution of matter on the NM and BC, relative to the asymmetric distribution of cut-off rigidities (so-called East-West effect). The normalized intensity data $J_{NM}(R_{cp})$ and $J_{BC}(R_{cp})$ are shown in Figure 3 separately for N and S hemispheres. For BC a great discrepancy is observed between N and S curves, while for NM the N and S data are in full agreement.

4 Forward-Backward Effect and Apparent Cut-off Rigidities:

The observed F-B effect in N hemisphere could be caused by the CR East-West asymmetry together with a non-symmetric distribution of matter around the NM. By geographic coordinates we computed the average azimuth angle of the ship's direction and the distribution of cut-off rigidities for CR arriving at different zenith and azimuth angles. Being the main asymmetry in the matter distribution due to a higher structure in the back of ship, the F-B effect should be mainly caused by the difference in cut-off rigidities of CR arriving to the monitor at different zenith angles θ from front of ship, $R_f(\theta,t)$ and from back, $R_b(\theta,t)$:

$$A_{fb}(\theta,t)=2(R_f(\theta,t)-R_b(\theta,t))/(R_f(\theta,t)+R_b(\theta,t)). \quad (4.1)$$

We did a general analysis of this effect, including an evaluation for different zenith angle intervals (zenith zones) of the asymmetry in CR cut-off rigidities and of the related weights in the counting rate of a NM detector. If the higher structure in the back of ship would shield only 1/3 of particles coming inside the western or eastern region of zenith zone at $\theta>37.5^0$, it will be enough to explain the F-B effect on the NM counting rate. For BC also the additional generation of neutrons in the shielding structure could be important, that producing a bigger F-B effect than for NM, in agreement with the observations.

As for the F-B effect, we can compute the so-called "apparent" cut-off rigidities (see Clem et al. 1997) by taking into account cut-off rigidities not only for vertical incident particles, but also for inclined primary particles with different weights in dependence of zenith angle θ:

$$R_{cp}^{ap}(R_{cp})d\theta \approx \sum_i \left\langle R_{cp}(\theta_i \div \theta_{i+1})\right\rangle \left\langle W\left(R_{cp},\theta_i \div \theta_{i+1}\right)\right\rangle, \quad (6.1.1)$$

where $\left\langle R_{cp}(\theta_i \div \theta_{i+1})\right\rangle$ is the cut-off rigidity averaged over azimuth angle in the zenith zone $\theta_i \div \theta_{i+1}$ and $\left\langle W\left(R_{cp},\theta_i \div \theta_{i+1}\right)\right\rangle$ is the normalized relative weight of this zone. As for the F-B we determined the normalized zenith angle distribution of neutrons arriving to the NM, under the hypothesis of CR isotropic distribution over the atmosphere, we will use here these results for calculating R_{cp}^{ap} along the ship route. We determined the expected weights of different zenith zones in dependence of R_{cp} and the inclined cut-off rigidities for different zenith zones from 6 additional azimuth directions Front-Left, Left, Left-Back, Back-Right, Right, and Right-Front relative to the ship orientation (directions Front and Back have been already considered in the F-B effect). In Figure 4 we show the final results of this computation for all 3-hours of survey; they agree with the Clem et al. (1997) average results obtained by using the local geomagnetic field for selected sites.

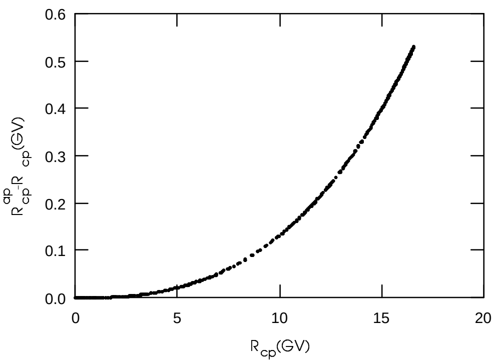

Figure 4: $R_{cp}^{ap} - R_{cp}$ *vs.* R_{cp}

5 Coupling Functions for NM and BC:

The experimental data on the dependence of normalized intensity $J(R_{cp})$ have been presented in Figure 3 for NM and BC. In these data the F-B effect is eliminated by averaging the data of forward and backward routes. The Dorman (1969) function was used for the analytical description:

$$J\left(R_{cp}\right)=I\left(R_{cp}\right)/I_o=\left(1-\exp\left(-\alpha R_{cp}^{-k}\right)\right). \quad (5.1)$$

α and k are determined as regression coefficients of the best fit of the linear correlation, for ln $R_{cp} \geq 1.5$,:

$$\ln(-\ln(1-J(R_{cp})))= -k\ln(R_{cp})+\ln(\alpha). \quad (5.2)$$

In Table 1 we show the α and k values for NM and BC obtained by using data of southern hemisphere which cover the whole cut-off rigidity range. The normalized coupling function will be:

$$W(R)= \alpha k R^{-(k+1)}\exp(-\alpha R^{-k}). \quad (5.3)$$

Table 1: α, k and correlation coefficient $\Re$ for NM and BC obtained for R_{cp} and R_{cp}^{ap} dependencies

Dep.	α_{NM}	k_{NM}	$\Re$ for all NM data	α_{BC}	k_{BC}	$\Re$ for all BC data
R_{cp}	10.275±0.023	0.9615±0.0021	0.99937	9.694±0.037	0.9954±0.0038	0.99884
R_{cp}^{ap}	9.916±0.021	0.9393±0.0020	0.99939	9.344±0.036	0.9725±0.0037	0.99887

Coupling functions computed for NM and BC for R_{cp} dependence are shown in Figure 5 together with the relative standard errors. BC detector is significantly more sensitive to smaller primary energies than NM, as expected. We also show the NM coupling functions for R_{cp} and R_{cp}^{ap} dependencies and the comparison, for R_{cp} dependence, between our NM coupling function and the 1986-87 one (Moraal et al. 1989).

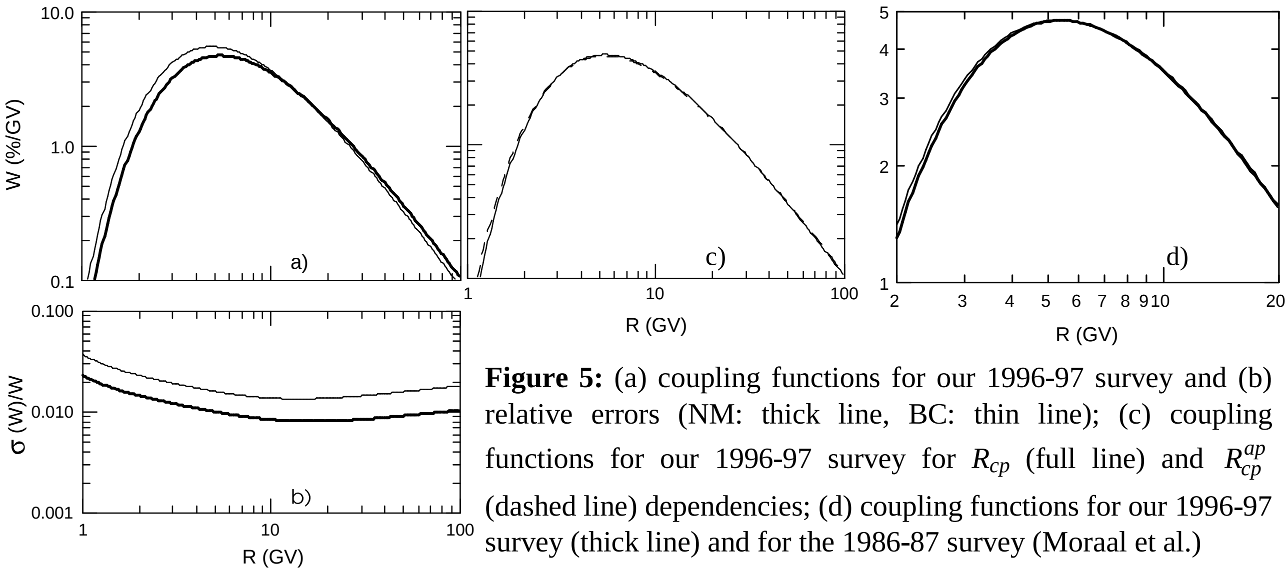

Figure 5: (a) coupling functions for our 1996-97 survey and (b) relative errors (NM: thick line, BC: thin line); (c) coupling functions for our 1996-97 survey for R_{cp} (full line) and R_{cp}^{ap} (dashed line) dependencies; (d) coupling functions for our 1996-97 survey (thick line) and for the 1986-87 survey (Moraal et al.)

A negligible "crossover" effect is found when comparing the 1986-87 and 1996-97 coupling functions and it is opposite to the large crossover found by Bieber et al. (1997) when comparing the 1986-87 survey with their 1995 survey. It is important to note that the CR intensity at high latitude during the 1995 survey was lower by 0.3÷1% than during our 1996-1997 survey. The NM station data may help in disentangling the problem of crossover. A difference in coupling functions, as reported for subsequent solar minimums in previous papers, would correspond to an anomalous difference δI=3÷4% between the intensity changes observed in successive solar minimums by stations at very low cut-offs and stations at cut-offs near the crossover point ≈(6÷7) *GV*. The behavior of NM stations appears to be inconsistent (δI≅0.5%) with a crossover effect, and supports the similarity of 1986-87 and 1996-97 coupling functions found in this paper.

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