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Coupling Functions for NM-64 and NM Without Lead Derived on the Basis of Calculated Apparent Cutoff Rigidities for CR Latitude Survey from Antarctica to Italy in Minimum of Solar Activity

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Abstract: In [1] were calculated the apparent cut-off rigidities for the backward route (Antarctica-Italy) of the CR latitude survey performed on a ship *Italica* during 1996-1997 solar minimum. These computations were done on the basis of results of trajectory calculations for inclined cut-off rigidities for various azimuth and zenith angles (0°, 15°, 30°, 45°, 60°) and azimuth directions changing from 0° to 360° in steps of 45°. The information on integral multiplicities of secondary neutrons detected by neutron monitor in dependence of zenith angle of incoming primary CR particles have been also used. This information is based on the theoretical calculations of meson-nuclear cascades of primary protons with different rigidities arriving to the Earth's atmosphere at zenith angles 0°, 15°, 30°, 45°, 60° and 75°. By using this information and data of CR latitude survey from Antarctica to Italy in minimum of solar activity we determine coupling functions for NM-64 and BC (NM without lead).

Principles of the data corrections method

The method used is principally based on a thorough evaluation of several meteorological and geomagnetic effects. **Corrections for meteorological effects include:**
(i) determination of the atmospheric-absorbing mass, by taking into account the effect of wind (Bernoulli effect) on barometric data, as well as the variation of gravitational acceleration g with geographic position;
(ii) determination of atmospheric absorption coefficients appropriate to the current solar cycle phase and their variability with cutoff rigidity;
(iii) evaluation of intensity changes due to latitudinal and temporal variations in the temperature distribution of the atmospheric column; and
(iv) estimate of intensity variations due to the tilt effect of the neutron monitor (sea-state effect).
Interplanetary and geomagnetic effects to be considered are:
(i) correction for isotropic temporal fluctuations in the primary CR;
(ii) correction for CR north-south asymmetry in the interplanetary space;
(iii) determination of cutoff rigidities for a vertical particle incidence by taking into account the penumbra effect, and of apparent cutoff rigidities by taking into account the contribution of nonvertical incidence; and
(iv) correction for temporal variations of the CR east-west effect caused by the asymmetric shielding mass around the neutron detectors.
Fig. 1 shows the individual contributions of each effect on NM data correction during the survey period. Results given in Fig. 1 indicate that all these effects should be taken into account, since the amplitude of each corrections is much greater than the statistical limits of the data:
(i) up to 40% for changes in atmospheric absorbing mass (including ~3% effect for Antarctica-to-Equator change in g and up to 1.3% for the wind effect);

(ii) up to about 1.2% in the case of the NM (2.5% in the case of the BC) for the sea-state effect;
(iii) 1% for Antarctica-to-Equator change in atmospheric temperature effect; and
(iv) up to 1% for North-South anisotropy.

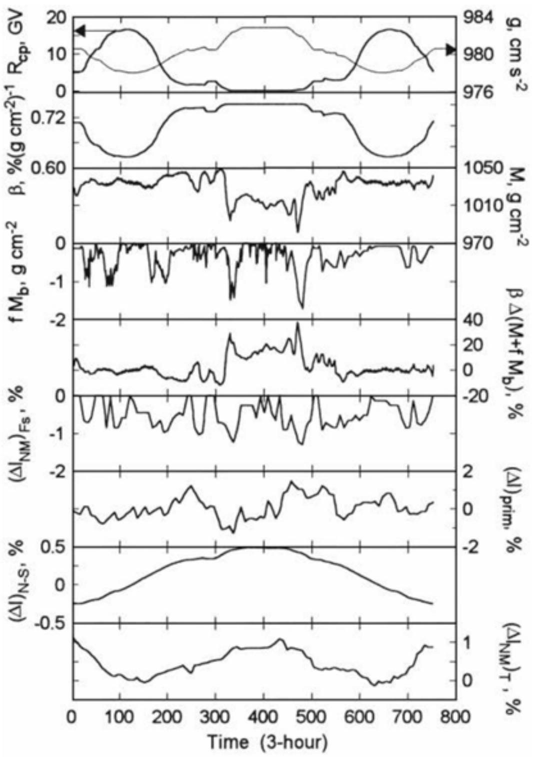

Figure 1: Summary for NM data corrections. From top to bottom: cutoff rigidity R_{cp} and g (in the same panel); atmospheric absorption coefficient β, atmospheric mass M, wind effect on atmospheric mass fMb, the effect of atmospheric mass (M + fMb) changes on counting rate; the sea-state effect on counting rate (for 2BC the effect is 2 times larger); the effect of CR isotropic primary variations; the effect of CR North-South asymmetry; and the effect of atmospheric temperature changes on the counting rate.

The dependences of the NM and BC intensities on the apparent cutoff rigidity

Corrected experimental data on the dependence of the NM normalized intensity at sea level upon R_{ap} found in [1] are presented in Fig. 2, and for BC – in Fig. 3.

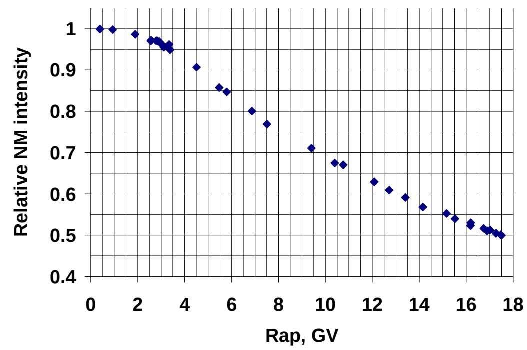

Figure 2: Normalized daily NM intensity as a function of apparent cutoff rigidity R_{ap} for return surveys.

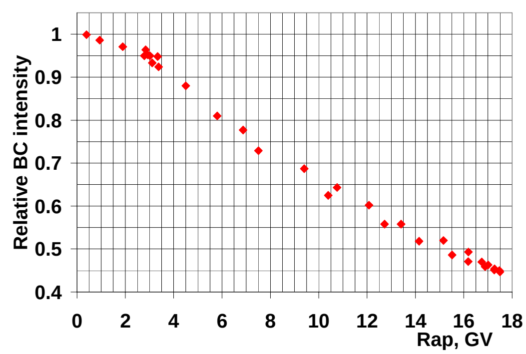

Figure 3: Normalized daily BC intensity as a function of apparent cutoff rigidity R_{ap} for return surveys.

To give an analytical description of normalized NM intensity versus R_{ap} we use the function introduced in [2]:

$$I_{NM}\left(R_{ap}\right)/I_{NM}(0) = 1 - \exp\left(-\alpha_{NM} R_{ap}^{-k_{NM}}\right). \quad (1)$$

Constants α_{NM} and k_{NM} we obtain as regression coefficients of the best fit linear correlation followed from Eq. 1:

$$\ln\left(-\ln\left(1 - I_{NM}\left(R_{ap}\right)/I_{NM}(0)\right)\right) = -k_{NM}\ln\left(R_{ap}\right) + \ln\left(\alpha_{NM}\right) \quad (2)$$

For BC data (see Fig. 3) we applied the same procedure as for NM.

The results of the determination of constants α_{NM} and k_{NM} for data in Fig. 2 as well as α_{BC} and k_{BC} for data in Fig. 3 are shown in Fig.4. We used only data for $\ln(R_{ap}/1\text{GV}) \geq 0.5$, but finally check results for all data.

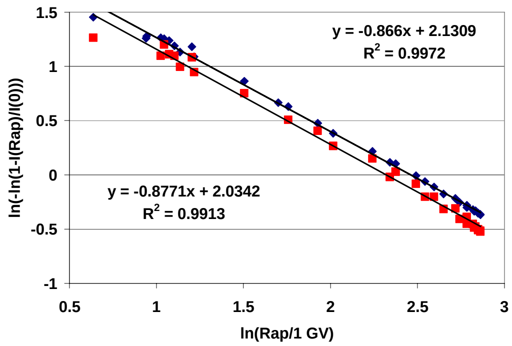

Figure 4: Determination of parameters α and κ for NM (top right) and BC (bottom left).

From Fig. 4 follows that for NM data

$$\alpha_{NM} = \exp(2.1309) = 8.422, \quad k_{NM} = 0.866 \quad (3)$$

with correlation coefficient CC = 0.9986, and for BC data

$$\alpha_{BC} = \exp(2.0342) = 7.646, \quad k_{BC} = 0.877 \quad (4)$$

with CC = 0.9956. With these constants we calculate NMtheor and BCtheor for all R_{ap} and compare with all observation data. Results are shown in Figs 5 and 6.

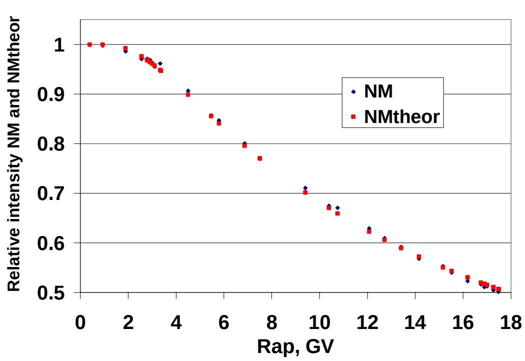

Figure 5: Relative intensity NM and NMtheor in dependence from R_{ap}; CC = 0.9997.

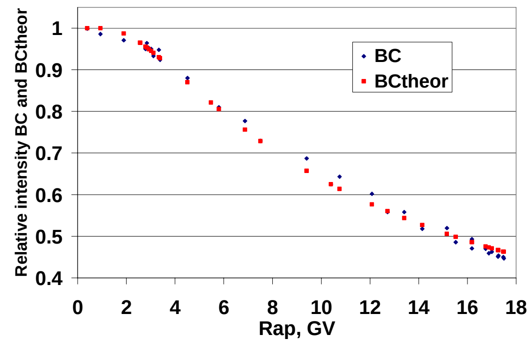

Figure 6: Relative intensity BC and BCtheor in dependence from R_{ap}; CC = 0.9979.

Analytical description of coupling functions for the NM and BC detectors

According to [2], if the dependence of any CR component relative intensity from cutoff rigidity can be described with a good accuracy by Eq. 1, the normalized coupling function will be

$$W(R) = \alpha k R^{-(k+1)} \exp\left(-\alpha R^{-k}\right), \qquad (5)$$

From Figs 5 and 6 follows that for NM and BC relative CR intensity the dependences from R_{ap} can be described by Eq. 1 with very good accuracy: CC = 0.9997 and 0.9979, correspondingly. It means that the normalized coupling function should be described with about the same accuracy by Eq. 5 with taking into account Eqs 3 and 4, correspondingly for NM and BC component. Results are shown in Figs 7 and 8.

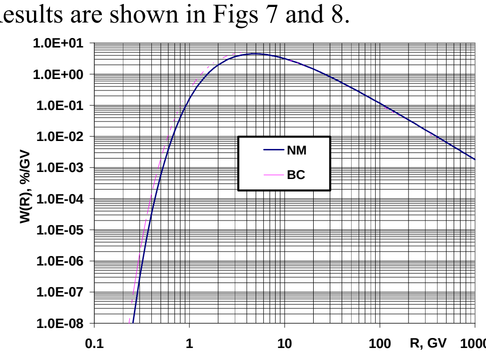

Figure 7: Normalized polar coupling functions for NM and BC according to backward route (from Antarctica to Italy) of the CR latitude survey performed on a ship *Italica* during 1996-1997 solar minimum.

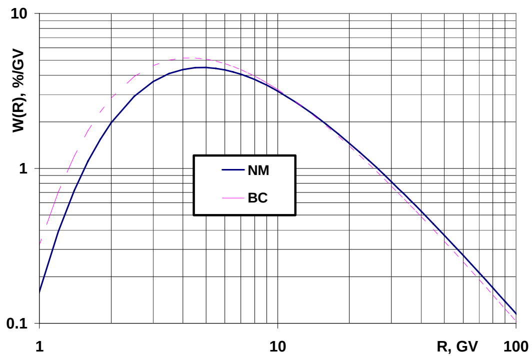

Figure 8: The same as in Fig. 7, but in most sensitive rigidity interval from 1 to 100 GV.

Comparison with previous results obtained by using effective vertical cutoff rigidities

In Fig. 9 are shown normalized coupling functions for NM and BC, obtained in [3-5] basing on the same experimental data, but using effective vertical cutoff rigidities R_{cp} instead of R_{ap}.

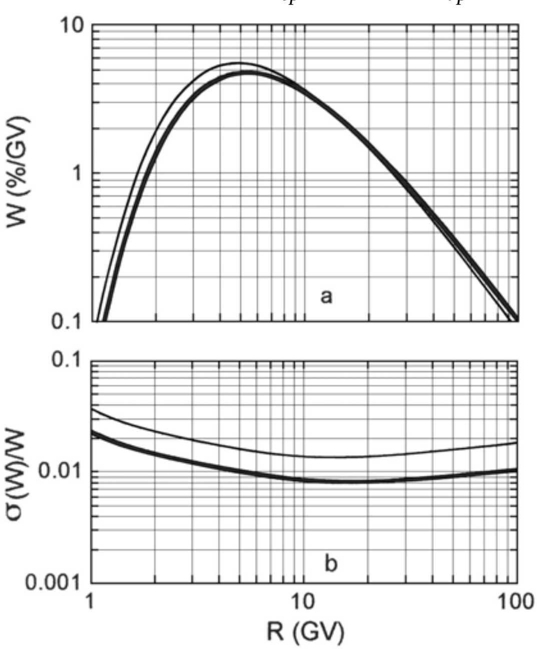

Figure 9: **(a)** Normalized polar coupling functions for NM (thick line) and BC (thin line) for 1996–1997 latitude survey Italy-Antarctica, obtained in [3-5] by using effective vertical cutoff rigidities.
(b) Relative errors of σ(W)/W for NM (thick line) and BC (thin line) in dependence of rigidity *R*.

In Fig. 9 are also shown estimated relative errors of σ(W)/W for NM and BC in dependence of rigidity *R*. About the same relative errors we estimated for coupling functions found above by using R_{ap}. The comparison of Fig. 8 with Fig. 9 shows some small differences: for NM the maximum is about 4.5 %/GV at *R* = 5 GV (Fig 9) and 5 %/GV at *R* = 5.5 GV (Fig 10); for BC the maximum is about 5 %/GV at *R* = 4.5 GV (Fig 9) and 5.5 %/GV at *R* = 5 GV (Fig 10).

Conclusion

Because in both cases we used the same experimental data, the mention differences should be caused only by the differences between R_{ap} and R_{cp} in dependence of latitude. And really, in [1] was shown that $R_{ap} - R_{cp}$ is negligible at high latitudes (low cutoff rigidities), but became significant at low latitudes (high cutoff rigidities) up to about 1 GV. These differences in R_{ap} and R_{cp} explain the small differences in coupling functions shown in Figs 8 and 9.

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