SH 3.6.04

Cosmic Ray Survey to Antarctica and Coupling Functions for Neutron Component Near Solar Minimum (1996-1997) 2. Meteorological Effects and Correction of Survey Data

N. Iucci[1], G. Villoresi[2], L.I. Dorman[3], and M. Parisi[1]

[1]*Dipartimento di Fisica "E. Amaldi", Università "Roma Tre", 00146 Rome, Italy*

[2]*IFSI/CNR, c/o Dipartimento di Fisica, Università "Roma Tre", 00146 Rome, Italy*

[3]*IZMIRAN, 142092 Troitsk, Moscow Region, Russia; Technion, Haifa and ICRC of TAU, Tel Aviv, Israel*

Abstract

We present an analysis of the atmospheric effects influencing the counting rate of a NM-64 neutron monitor and bare neutron counters utilized during the latitude survey performed in 1996-1997 from Italy to Antarctica and back. We determine the influence of Bernoulli effect on the evaluation of atmospheric mass and the effect of sea-state on the neutron counting rate, by using the data recorded during the time spent in Antarctic region (cut-off rigidity $R_{cp} \leq 1$ *GV*); then, accurate values of atmospheric pressure coefficients are computed. The survey data are corrected for the above effects; atmospheric pressure coefficients changing with cut-off rigidity are computed by combining previous findings together with our determinations at $R_{cp} \leq 1$ *GV*. It is estimated the temperature effect on the NM counting rate; the survey data are corrected by using the sea-level temperature during the expedition and the data of atmospheric temperature vertical distribution measured by NOOA-9 and NOOA-10 satellites.

1 Introduction:

In SH.3.6.24 we presented the cosmic ray (CR) data recorded by a NM and 2 bare neutron counters (BC) during the latitude survey to Antarctica on in the period December 1996-March 1997. For an accurate determination of latitude effect and coupling function of the CR nuclear active component, as measured by a NM, it is necessary to apply corrections due to meteorological variations. We use the 3-hourly intensity data corrected for time variations in the flux of primary CR. We analyze the following effects:

-variations in the air mass over the detector (atmospheric absorption effect); this mass is derived from the atmospheric pressure by using the actual value of gravitational field *g*, and applying the correction for the relative velocity between the barometric sensor linked to the ship and the atmosphere (Bernoulli effect);

-inclination of the neutron detector relative to the horizontal plane produced by sea waves (sea-state effect);

-changes in the temperature of atmospheric layers as a function of time and geographic latitude.

2 Bernoulli Effect on Measurements of Atmospheric Mass:

The influence on atmospheric pressure measurements of Bernoulli effect caused by wind flows in the atmosphere (see review in Dorman 1963, 1972, 1974) leads to estimate smaller values in the vertical mass *M* of air, as determined by measurements of the dynamic air pressure *P*. The relation between *M* and *P* is:

$$M(\varphi,\lambda) = \frac{P g_o}{P_o g(\varphi,\lambda)} \cdot 1033.2 \quad (g \cdot cm^{-2}), \qquad (2.1)$$

where φ is the geographic latitude and λ the geographic longitude; P_0 =1013 *hPascal* the normal air pressure, g_o=980.6 cm/s^2 the standard Earth's gravitational acceleration and, according to Uotila (1957),

$$g(\varphi,\lambda) = 978.0516\left(1 + 0.0052910 sin^2\varphi - 0.0000059 sin^2 2\varphi + 0.0000106 cos^2\varphi cos2\left(\lambda + 6^o\right)\right). \qquad (2.2)$$

We used 5-min data of wind speed *W* with respect to the ship and determined for each 3-hourly interval the average value $\left\langle W^2 \right\rangle = (1/36)\sum_{j=1}^{36} W_j^2$. The correction for Bernoulli effect can be written as:

$$\Delta M_b = f \cdot M_b = \frac{f(1/2)\rho\left\langle W^2 \right\rangle}{g(\varphi,\lambda)}, \quad (2.3)$$

where $\rho = \rho_0 PT_0/P_0T$, ρ_0 is the density of air near sea level at normal conditions $P_0=760\ mmHg$, $T_0=290^0\ K$, and P, T are the average pressure and temperature for each 3-hourly interval. In (2.3) the coefficient $f<1$ accounts for the fact that in low atmosphere the wind action is mainly limited to some fraction (up to 3-4 *km*) of total atmospheric layer. $\left\langle W^2 \right\rangle$ data are available until February 13, 1997 when the wind sensor was damaged. After February 13 $\left\langle W^2 \right\rangle$ (in $m^2 \cdot s^{-2}$) has been evaluated by means of the sea-state index F_S, being $\left\langle W^2 \right\rangle = 12.2F_S^2 - 41.2F_S + 73.2$ (correlation coefficient $R = 0.852 \pm 0.016$), as determined in the previous period of survey (December 20, 1996-February 13, 1997).

3 Nature and Evaluation of Sea-State Effect on the NM Counting Rate:

The sea-state effect, experimentally investigated by Bieber et al. (1995), is analyzed with regards to its physical nature. Let us call $2F(\theta)d\theta$ the flux of nuclear active CR particles approaching sea level at zenith angle between θ and $\theta + d\theta$ and integrated over azimuth angle. The flux integrated over all zenith angles on an horizontal NM with effective surface S will be $2\,S \cdot F(\theta)d\theta$ and the total counting rate will be:

$$I_o = 2S\int_0^{\pi/2} F(\theta)\cos(\theta)\varphi(\theta)d\theta = 2S\int_0^{\pi/2} F(\theta)\Psi(\theta)d\theta\,, \quad (3.1)$$

$\varphi(\theta)$ being the average probability to detect a neutron approaching at zenith angle θ . $F(\theta), \varphi(\theta), \Psi(\theta)$ are even functions, and $F(\theta)$ goes rapidly to zero for $\theta = \pi/2$. If the NM is inclined by an angle θ_o , assuming that almost horizontal CR are fully absorbed by the inclined ship and for sufficiently small θ_o values,

$$I(\theta_o) - I_o \cong \theta_o^2 S\int_0^{\pi/2} F(\theta)\Psi''(\theta)d\theta - S\int_{\pi/2-\theta_o}^{\pi/2} F(\theta)\Psi(\theta+\theta_o)d\theta = \Delta I_1 + \Delta I_2\,. \quad (3.2)$$

For the most likely condition of $\varphi(\theta)$ slowly changing with θ , *i.e.* for $\varphi'(\theta) \cong 0$ and $\Psi''(\theta) \cong -\Psi(\theta)$, the decrease in counting rate due to the geometrical effect of rotation of the NM by the angle θ_o will be:

$$\Delta I_1/I = (I(\theta_o) - I_o)_1/I_o \cong -\theta_o^2/2\,. \quad (3.3)$$

In case of harmonic rolling motion of the ship, $\theta_o = \theta_m \cos\omega T, \left\langle \theta_o^2 \right\rangle = \theta_m^2/2$, the average effect will be:

$$\left\langle \Delta I_1/I \right\rangle \cong -\theta_m^2/4\,. \quad (3.4)$$

The second integral ΔI_2 in (3.2), representing the decrease in counting rate produced by half CR flux approaching the monitor with zenith angle $\theta > \pi/2 - \theta_o$ (absorption effect through the inclined ship), is negligible and, for $\theta_o \le 0.2$, *i.e.* for $\alpha = \pi/2 - \theta \le \theta_o \le 0.2$ we can approximate $F(\theta)$ and $\Psi(\theta)$ as:

$F(\theta) \propto cos^k\theta = sin^k\alpha \cong \alpha^k$, with $k \ge 2$,

$\Psi(\theta) \propto \cos(\theta + \theta_o) = sin(\alpha - \theta_o) = sin\alpha \cdot cos\theta_o - cos\alpha \cdot sin\theta_o \cong (sin\alpha - sin\theta_o) \cong \alpha - \theta_o$,

and, as a consequence, being γ a constant of some units:

$$\langle \Delta I_2/I \rangle \cong -\frac{\gamma}{2}\int_0^{\theta_o} \alpha^{k+1} d\alpha = -\frac{\gamma}{k+2}\cdot\frac{\theta_o^{k+2}}{2} < -\frac{\gamma}{4}\cdot\frac{\theta_o^4}{2} \cong -\frac{\gamma}{16}\cdot\theta_m^4. \quad (3.5)$$

By taking into account the relations (3.2), (3.4) and (3.5) we obtain for $\theta_m \leq 0.2$

$$\langle \Delta I/I \rangle = \langle \Delta I_1/I \rangle + \langle \Delta I_2/I \rangle \cong \langle \Delta I_2/I \rangle \cong -\theta_m^2/4. \quad (3.6)$$

We could not do continuous measurements of θ_m on the ship, but it was possible to do some determinations of $\theta_m \cong 0.20 \div 0.21$ for sea-state strength $F_s \cong 8$ and to derive the empirical relationship:

$$F_S \cong 750 \cdot \theta_m^2/4 \quad (3.7),$$

and to obtain for NM, according to (3.6) and (3.7):

$$\left(\langle I(F_S)\rangle - I_o\right)/I_o = K_{NM}\cdot F_S \cong -1.3\cdot 10^{-3}\cdot F_S. \quad (3.8)$$

4 Determination of Atmospheric Absorption, Bernoulli and Sea-State Effects in Antarctic Region ($R_{cp} \leq 1$ GV):

In Antarctic region (R_{cp}≤1 GV) the high variability of M, W^2 and F_S allowed to estimate β (atmospheric absorption coefficient), f, and K for NM, in spite of the fact that W and F_S are well correlated and usually they are more effective during low-M regime. By multiple correlation analysis among lnI, M, F_S and $1/2\rho W^2$, we found a wide region in the coordinate system (β, f, K) in which the correlation coefficients are very high and not statistically different. For this reason it was necessary to determine the total contribution of Bernoulli and sea-state effects by comparing data having similar $\langle M \rangle$ and great variations in W^2 and F_S. For NM the assessment of the two separate effects has been done by: (i) determining K by (3.8) and (ii) computing f (by simple difference procedure). For BC, being already determined the coefficient f by the analysis of NM data, it was possible to evaluate the sea-state effect through the estimate of global (sea-state plus Bernoulli) effect. For both detectors we computed the value of β by correlation between the corrected M and $\ln I$ data. Table 1 shows the results of our analysis.

Table 1: Summary of the evaluation of Bernoulli, sea-state and barometric effects for NM and BC detectors in Antarctic region ($R_{cp} \leq 1GV$) in the period January 27÷February 18, 1997

Neutron Detector	NM-64		BC	
Bernoulli (*Bern.*) effect Sea-state (F_S) effect	$f = 0.3$ $\Delta I/I = K_{NM}F_S = -1.3\cdot 10^{-3}\cdot F_S$		$f = 0.3$ $\Delta I/I = K_{BC}F_S = -2.5\cdot 10^{-3}\cdot F_S$	
Barometric effect	β (%/g/cm^2)	R	β (%/g/cm^2)	R
Original Data	-0.722±0.007	-0.992±0.006	-0.726±0.013	-0.985±0.012
Data corrected for *Bern.*	-0.737±0.006	-0.994±0.005	-0.740±0.012	-0.987±0.007
Data corrected for *Bern.* & F_S	-0.751±0.005	-0.995±0.005	-0.766±0.011	-0.991±0.009

5 Correction of Survey Data for All Meteorological Effects:

In Figure 1 we show a summary of all corrections applied on survey data on 3-hourly basis.

- The vertical atmospheric mass M+fM_b has been computed according to (2.1), (2.2), (2.3), with f=0.3.
- The correction for sea-state effect was applied by the results of Table 1, by assuming that the sea-state effect, evaluated in Antarctic region, is the same at different latitudes.

- The correction for atmospheric absorption effect has been applied by utilizing the dependence of atmospheric absorption coefficient on cut-off rigidity obtained for the period of minimum solar activity by Carmichael & Bercovitch (1969) and Bachelet et al. (1972), by taking into account our determination in Antarctic region. This dependence was approximated by the Dorman (1969) function:

$$\beta = \beta_o\left(1 - \exp\left(-\alpha R_{cp}^{-k}\right)\right), \quad (5.1)$$

where $\beta_o = -0.751\% / g / cm^2$, $\alpha = \exp(1.74395) = 5.69 \pm 0.03$, $k = 0.411 \pm 0.002$

- NM data have also been corrected for temperature variations in different atmospheric layers by using the Dorman (1957, 1972), Dorman et al. (1990) model. Temperature data measured by satellites NOAA-9 and 10 during 1985-88 have been used, together with temperature data recorded on the ship, to have continuous information on the time variations of atmospheric temperature distribution and to account for the effect of meteorological perturbations in the lower atmospheric layers.

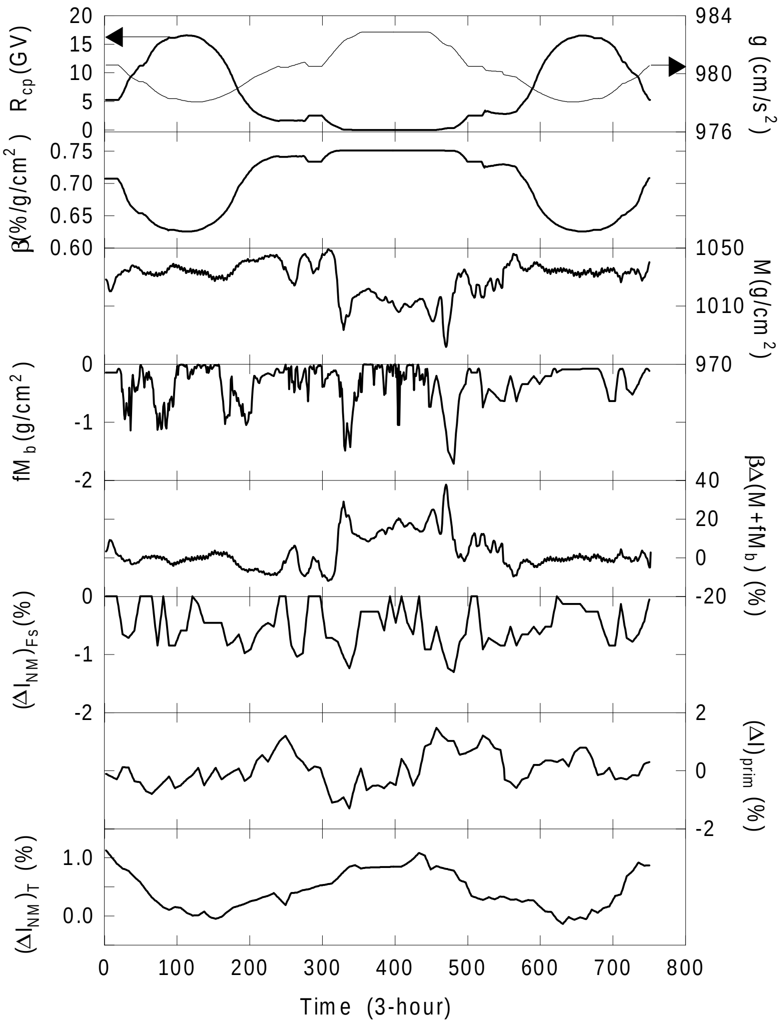

Figure 1: Meteorological effects on *I* and *M*, together with the changes in *g* and R_{cp} and the effect of CR primary variations

References

Bachelet, F., Iucci, N., Villoresi, G., & Zangrilli, N.L. 1972, Nuovo Cim. 11B, N. 1, 1

Bieber, J.W., Duldig, M.L, Evenson, P., Hall, D., & Humble, J.E. Proc. 24th ICRC (Rome, 1995) 4, 1078

Bieber, J.W., Evenson, P., Humble, J.E., & Duldig, M.L. Proc. 25th ICRC (Durban, 1997) 2, 45

Carmichael, H. & Bercovitch, M. 1969, Canad. J. Phys. 47, N. 19, 2051

Dorman, L.I. 1957, Cosmic Ray Variations (Moscow) (English translation: 1958, Wright-Patterson, Ohio)

Dorman, L.I. 1963, Cosmic Ray Variations and Space Research (Nauka, Moscow)

Dorman, L.I. Proc. 11th ICRC (Budapest, 1969) Invited Papers and Rapporteur Talks, p. 381

Dorman, L.I. 1972, Cosmic Ray Meteorological Effects (Nauka, Moscow)

Dorman, L.I. 1974, Cosmic Ray Variations and Space Exploration (Reading: North-Holland Publ. Co)

Dorman, L.I. 1975, Experimental and Theoretical Principles of CR Astrophysics (FIZMATGIZ, Moscow)

Dorman, L.I., Lagutin, A.A., & Chernyaev, G.V. Proc. 21th ICRC (Adelaide, 1990) 7, 81

Uotila, U.A. 1957, Inst. Geodesy, Photogrammetry and Cartography, Ohio State Univ., Columbus, Publ. 7