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Cosmic Ray Survey to Antarctica and Coupling Functions for Neutron Component Near Solar Minimum (1996-1997) 1. The Latitude Survey

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Abstract

During the 1996-97 austral summer, it was operated a 3NM-64 neutron monitor on board the ship "Italica" to record cosmic ray neutron intensities in seas from Italy to Antarctica and back. Moreover, the flux of thermalized neutrons was measured by 2 bare BF_3 counters. We describe the experiment, present a data quality assurance analysis, correct the data for primary cosmic ray variations, and compute the vertical cut-off rigidities along the survey route by using the actual representation of the total geomagnetic field and by taking into account the penumbra effect. In two parallel papers meteorological effects are investigated; geomagnetic effects and North-South asymmetry are evaluated and coupling functions are computed.

1 Introduction:

The technique of latitude surveys of cosmic ray (CR) nucleonic component is the most reliable method to calibrate the "CR geomagnetic spectrometer" and to determine the coupling functions necessary for studying time variations of the primary CR spectrum by the data of the neutron monitor station network (see review in Dorman 1974, 1975 and Nagashima, Sakakibara, & Murakami 1989; Potgieter et al. 1980a,b; Moraal et al. 1989; Stoker 1993; Stoker & Moraal 1995; Bieber et al. 1997; Villoresi et al. 1997). Moreover, by latitude surveys it is also possible to control the evaluation of geomagnetic cut-off rigidities and detect geomagnetic anomalies (see Stoker 1995; Stoker et al. 1997; Clem et al. 1997). However, to receive reliable latitude effects of CR nucleonic component it is necessary to apply refined analysis techniques on the original data registered along the survey. In this paper we describe the latitude survey experiment performed on board the ship "Italica" during 1996-1997, in the frame of the Italian Antarctic Research Program, and present a data quality assurance analysis; we correct the data for primary CR variations and compute the vertical cut-off rigidities along the survey route.

2 Description of the Experiment:

The experiment has been installed inside an *ad hoc* constructed container. The intensity of high-energy CR nucleonic component was detected by a standard 3NM super neutron monitor (counters *N1*, *N2*, *N3*). The thickness of the lateral polyethylene slabs was increased from the usual 7 cm to 14 cm to achieve a better shielding of the detector from neutrons produced by CR interactions with surrounding matter. Over the 3NM, on the extreme left and right sides, two additional BF_3 counters without lead and polyethylene (bare counters *B1*, *B2*) have been utilized for recording the background flux of thermalized neutrons. This low-energy component gives information on locally produced thermalized neutrons, whose flux depends on changes in the distribution and composition of environmental matter, and on the presence of radioactive elements in soil, rocks and atmosphere.

The following data have been recorded at 5-minute intervals:

-geographic position and universal time (provided by a GPS);

-atmospheric pressure by a high precision device utilizing a vibrating cylinder transducer (resolution 0.01 *mb*, precision 0.1 *mb*, stability 0.1 *mb* per year) and by an additional pressure sensor (0.2 *mb* resolution);
-internal and external temperature and internal relative humidity;
-the values of high and low voltages;
-the integral 5-min value of CR intensities measured by each counter (*N1*, *N2*, *N3*, *B1*, *B2*);
-speed and direction of wind (provided by a parallel experiment).

The 5-min data have been utilized only for data quality checking. The complete data analysis is based on 3-hourly data. Information on sea-state strength have been obtained twice a day from the ship's records; 3-hourly values have been computed by linear interpolation.

3 Quality Assurance Procedures, Pre- and Post-Survey Measurements:

The behavior of the NM and BC neutron detectors and of the whole instrumentation utilized during the latitude survey has been controlled for 7 days before the survey and for 7 days after. The detectors operated inside a container which was located near the village of Colli (φ=41.67*N*, λ=13.52*E*, 230 *m* a.s.l.), ~80 *km* Southeast of Rome, in an industrial area where the experiment has been assembled. CR records of monitors operating in Colli have been compared with the contemporary data of the Rome 17NM detector (cut-off rigidity ≈6.2 *GV*, φ=41.91*N*, λ=12.5*E*). We performed the correlation between the 3-hourly values of the logarithm of CR intensity I and the mass of vertical air column M: $\ln(I)=\beta M+b$ (see Table 1).

Table 1: Atmospheric absorption coefficients β and corresponding correlation coefficients R

Monitor	Before Survey		After Survey	
	β (%/$g.cm^{-2}$)	R	β (%/$g.cm^{-2}$)	R
Rome 17NM	0.661±0.008	-0.9958±0.0007	0.690±0.013	-09909±0.0016
Colli 3NM	0.665±0.010	-0.9944±0.0010	0.694±0.019	-0.9806±0.0034
Colli BC	0.613±0.021	-0.971±0.005	0.610±0.040	-0.904±0.016

The efficiency of NM and BC detectors before and after survey has been checked by comparing the contemporary data registered in Colli and in Rome (17NM-64). The comparison was done on pressure corrected data because of different pressure variations in the two sites due to the 80 *km* relative distance and to the difference in altitude. The ratio NM-Colli/17NM-Rome appears to be stable within the pure statistical fluctuations: 0.1833±0.0006 before survey and 0.1839±0.0007 after survey (the ratio before/after is 0.997±0.005). The average value of the ratio BC-Colli/17NM-Rome is 0.01052±0.00014 before survey and 0.01019±0.00012 after survey (the ratio before/after is 1.032±0.019). These results show that the efficiency of NM remained stable within 0.5% along the survey time.

4 The Latitude Survey:

On Dec. 19, 1996, in Ravenna (300 *Km* NE of Rome on Adriatic Sea), the container was installed on the upper deck of the ship "Italica" to reduce CR shielding effects. In direction opposite to the ship's motion the zenith angle $45^0 \div 90^0$ was partially shielded by an upper structure. On Dec. 21 the ship sailed from Ravenna to Antarctica. The Antarctic Base "Terranova Bay" was reached on Feb. 2, '97. The ship returned to Ravenna on Mar. 26, '97. In Figure 1 we show the ship route which was about the same in the two ways.

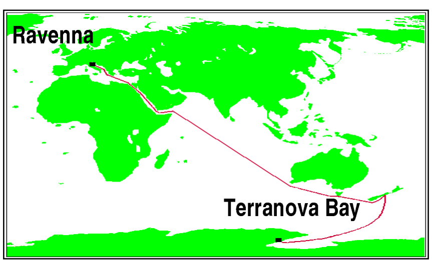

Figure 1: The survey route

5 Quality Assurance Procedures, Internal Tests:

In Figure 2 we show the time-series of original 3-hourly data for the total period of measurements for separate counters. The central counter *N2* of the 3NM has the highest counting rate, as expected. The ratios $r_K = I_{NK}/\Sigma I_{NK}$ (k=1, 2, 3), I_{B1}/I_{B2} and I_{BC}/I_{NM} are shown in Figure 3. Ratios r_2, r_3 show small regular variations with time which correspond to regular changes with latitude, indicating differences of about 1% in the overall latitude effect of individual NM counters; different shielding, different electronic dead-time and α particle contamination could originate such small effect. The behavior of I_{BC}/I_{NM} indicates that the latitude effect of BC is ~10% bigger than for NM, being BC more sensitive to lower energies. The effect on I_{BC} of changes in surrounding masses and in local radioactivity is visible in the I_{BC}/I_{NM} ratio in periods when the ship was in ports or in their proximity.

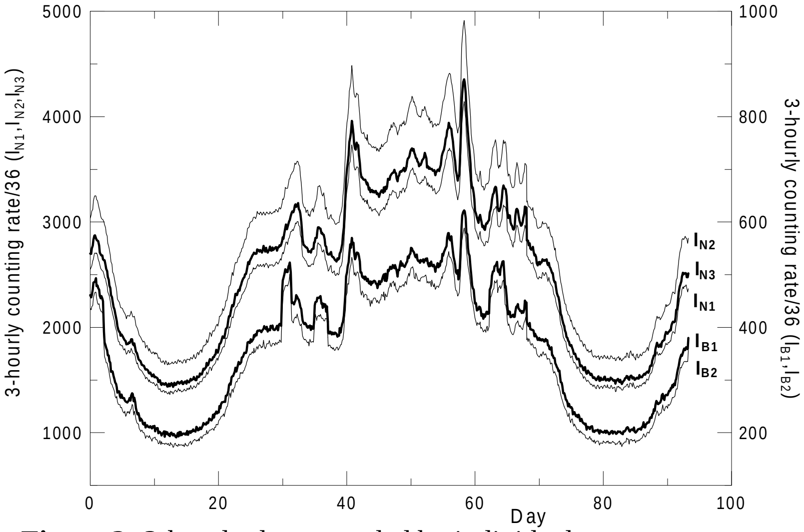

Figure 2: 3-hourly data recorded by individual counters

6 Computation of Vertical Cut-offs:

Cut-off rigidities of vertically incident CR have been computed by trajectory numerical method for every day, for the corresponding average geographic position of the ship. The total Earth's magnetic field has been considered as the sum of fields generated by both internal (represented by the Gaussian series with IGRF-95 coefficients -IAGA Division V, Working Group 8, 1996- up to n=10, extrapolated to the epoch of survey) and external sources (represented by the Tsyganenko, 1989 model for K_P=0, according to the 'quiet' solar-interplanetary conditions observed during the period of survey). For each point we computed the upper cut-off rigidity R_c and the effective cut-off rigidity R_{cp}, which takes into account the effect of penumbra for flat CR spectrum (see Shea, Smart, & Carmichael, 1976). From the R_{cp} daily values we determined the R_{cp} for each 3-hourly average position of the ship by interpolation from daily data, by taking into account the average geographic coordinates of each 3-hourly interval.

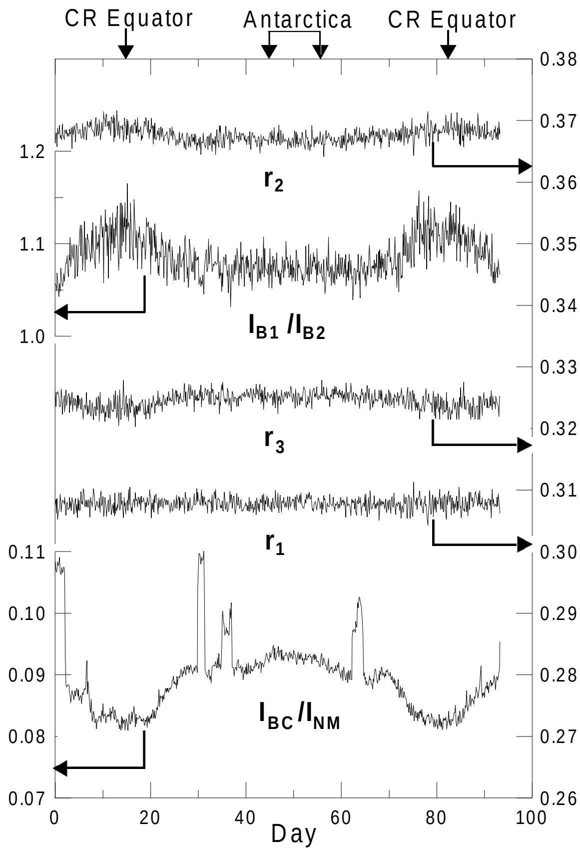

Figure 3: Comparative behavior among sections and detectors

7 Corrections for CR Primary Variations:

The latitude survey data have been corrected for primary variations occurred during the survey time; *i.e.* they have been referred to a definite primary condition. The whole period of survey was inside solar minimum and characterized by very small CR time variations. To optimize the correction for primary variations, we used the synoptic changes shown by the whole network of sea-level stations (about 20 NM-64 detectors), by choosing the average intensity during the whole survey time as reference level. For each day a correction factor has been computed by interpolation between stations having R_{cp} values as close as possible (at least one lower and one higher) to the R_{cp} value of the ship for that day. The correction has been applied on daily values to avoid contamination produced by diurnal anisotropy. Therefore, residual changes due to CR short-term oscillations and diurnal variations are present in the 3-hourly survey data.

8 Summary and Conclusions:

We presented the design and realization of the latitude survey experiment conducted on board the ship "Italica" of the Italian Antarctic Program during the austral summer 1996-1997. Two neutron detectors, a standard 3NM-64 and 2 bare counters were in operation on the ship. The analysis of data recorded before, during and after the survey showed that the data quality was enough accurate to assure the determination of reliable coupling functions for neutron monitor intensity for 1996-1997 solar minimum. We computed cut-off rigidities of vertically incident CR particles, by using the IGRF95 geomagnetic field model and its secular variation, as well as the Tsyganenko (1989) model for the external sources. The data have been corrected for primary variations occurred during the survey time.

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