COSMIC RAY NORTH-SOUTH ANISOTROPY 1961-1983

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ABSTRACT

Measurements from neutron monitors in Thule (Greenland) and McMurdo (Antarctica) have been used to determine yearly values of the cosmic ray north-south anisotropy over the period 1961-1983. The results strongly suggest that superposed upon the mean anisotropy of 0.05% is a solar cycle variation of amplitude 0.03%. No evidence for a dependence of the anisotropy upon polarity of the solar poloidal magnetic field is found.

1. Introduction. Detailed information on the spatial distribution of cosmic rays in the heliosphere is essential for testing theories of the solar cycle modulation of galactic cosmic rays. An invaluable tool for probing the spatial distribution is the steady-state north-south anisotropy of cosmic rays, which has been found to be intimately related to the cosmic ray radial gradient (Swinson, 1969; Bercovitch, 1970; Iucci and Storini, 1972; Yasue, 1980; Pomerantz et al., 1982). Most investigations of this effect, however, have been limited to intervals of a few years, or else have combined data from many years, such that yearly variations were not evident. As a result, possible solar cycle or solar polarity dependences of the north-south anisotropy, and hence of the radial gradient at > 1 GV rigidities, are not well determined.

With the availability of neutron monitor data from north and south polar stations from 1961 to the present, an interval of more than 2 solar cycles, a comprehensive analysis of long-term changes in the north-south anisotropy is now feasible. The information gained through this analysis will provide important observational constraints that models of cosmic ray modulation must satisfy.

2. Results. Previous investigations of the steady-state north-south anisotropy have typically reported magnitudes ~ 0.1% or less. In order to extract this exceedingly small signal from the neutron monitor data, the method of analysis was designed with these goals in mind: (1) to reduce the effect of unrelated cosmic ray variations of much larger amplitude, (2) to take into account possible systematic variations in the relative efficiencies of the north and south polar detectors, and (3) to obtain reliable error estimates, which are essential for proper interpretation of the results. In essence, the method involved calculating, separately for toward and away polarity of the interplanetary magnetic field, the ratio of counts recorded at Thule to counts

recorded at McMurdo. The anisotropy was calculated for each solar rotation period from these ratios and from the relative efficiency of the two detectors, which was also determined separately for each solar rotation period. Finally, a yearly average of the anisotropy and an error estimate were calculated from this set of solar rotation values.

Results of the analysis appear in Figure 1, where yearly averages of the north-south anisotropy ξ_{NS} are plotted with $\pm$ 1σ error bars. By convention, ξ_{NS} is taken to be the value determined for toward sector polarity, with a positive value indicating that the observed cosmic ray intensity was larger at the north polar station than at the south polar station. With this convention, a positive value of ξ_{NS} is expected if the anisotropy arises from a positive radial gradient.

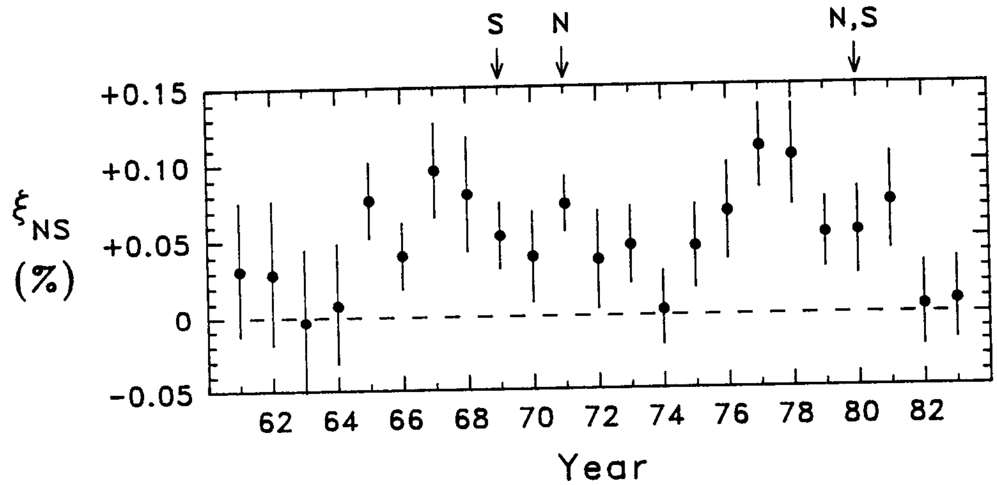

Fig. 1. Cosmic ray north-south anisotropy over a period of two solar cycles, as determined from neutron monitor observations at Thule and McMurdo. Arrows indicate years in which the sun's north (N) and/or south (S) pole changed magnetic polarity.

Note that there is no a priori reason that the method of analysis would preferentially yield positive values of anisotropy over negative ones. Thus, Figure 1 provides strong support for the interpretation that the steady-state north-south anisotropy results from a positive radial gradient via the $\bar{B} \times \bar{\nabla} n$ drift, with most points indicating positive values of anisotropy that differ significantly from zero.

3. Discussion.

Solar Cycle Variation of ξ_{NS}:

The value of the steady-state north-south anisotropy averaged over the 23-year period of this study is $\xi_{NS} = 0.052\%$. However, a possible solar cycle variation with period ~ 10 years is strongly suggested by Figure 1. To test this possibility quantitatively, the data of Figure 1 were assumed to be described by a constant plus a 10-year sinusoidal variation, with the phase and amplitude of the 10-year wave and the constant to be determined according to goodness-of-fit. The resulting constant term and wave amplitude were 0.053% and 0.028%, respectively, with the wave peaking in 1968 and 1978. Statistical tests indicate that there is only a 0.6% probability that a wave of this amplitude would occur by chance. Thus, a solar cycle variation of the cosmic ray north-south anisotropy is established with a high degree of confidence.

Effect of Drifts in Cosmic Ray Transport:

As illustrated in Figure 2, modulation models in which drifts play a predominant role predict that the radial profile of cosmic ray density will differ substantially between epochs of positive and negative polarity of the solar poloidal magnetic field (Jokipii and Kopriva, 1979). At a radial distance of 1 AU, the radial gradient -- i.e., the slope of the curves in Figure 2 -- is predicted to be substantially larger during epochs of negative solar polarity ($A < 0$) than during epochs of positive solar polarity ($A > 0$). This, in turn, would imply that the north-south anisotropy should show a corresponding dependence upon solar polarity.

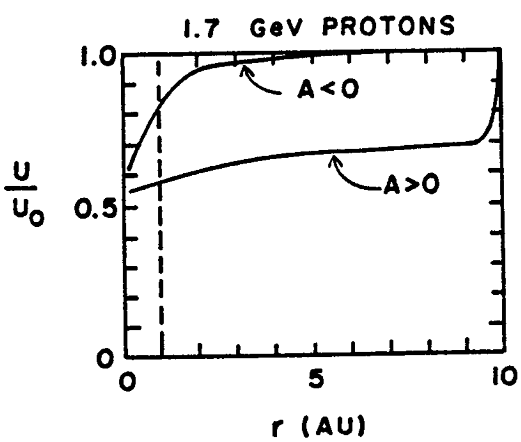

Fig. 2. Predicted relative intensity of cosmic rays as a function of radial distance (r) from the sun. Adapted from Figures 8 and 9 of Jokipii and Kopriva (1979).

The data of Figure 1 are inconsistent with this theoretical expectation. The average value of ξ_{NS} for the period 1961-1968, an epoch of negative solar polarity, was found to be 0.053%. Similarly, the value for the period 1972-1979, an epoch of positive solar polarity, was found to be 0.055%. A solar polarity dependence of the north-south anisotropy is not evident.

Cosmic Ray Radial Gradient:

The equations of cosmic ray transport permit information on the cosmic ray radial gradient to be inferred from a measurement of the north-south anisotropy. Since the relevant technique has been discussed by other investigators (e.g., Yasue, 1980), only results will be presented here. The average value of north-south anisotropy (0.053%) determined above corresponds to a radial gradient of 1.7%/AU at a rigidity of 10 GV, while the 10-year variation of the anisotropy suggests that the gradient actually oscillates between values ~ 0.8%/AU and ~ 2.6%/AU, the peaks occurring in 1968 and 1978. These inferred values of radial gradient appear to be generally consistent with recent spacecraft determinations of the integral radial gradient and its variation at lower energies (e.g., McKibben et al., 1985; Van Allen and Randall, 1985).

4. Acknowledgments. C. H. Tsao contributed significantly to the extensive computer analysis involved in this work. This research was supported by the National Science Foundation under grants ATM-8303758 and DPP-8300544.

References

Bercovitch, M., (1970), Determination of the heliocentric cosmic ray density gradient using neutron monitor data, Acta Physica Academiae Scientiarum Hungaricae, 29, Suppl. 2, 169.

Iucci, N., and M. Storini, (1972), The north-south anisotropy and the cosmic-ray radial gradient in the vicinity of the earth, Il Nuovo Cim., 10B, 325-333.

Jokipii, J. R., and D. A. Kopriva, (1979), Effects of particle drift on the transport of cosmic rays. III. Numerical models of galactic cosmic-ray modulation, Astrophys. J., 234, 384-392.

McKibben, R. B., K. R. Pyle, and J. A. Simpson, (1985), Changes in radial gradients of low-energy cosmic rays between solar minimum and maximum: Observations from 1 to 31 AU, Astrophys. J., 289, L35-L39.

Pomerantz, M. A., S. P. Duggal, A. J. Owens, M. F. Tolba, and C. H. Tsao, (1982), Cosmic ray north-south anisotropy: The role of the interplanetary magnetic field, J. Geophys. Res., 87, 10325-10330.

Swinson, D. B., (1969), 'Sidereal' cosmic-ray diurnal variations, J. Geophys. Res., 74, 5591-5598.

Van Allen, J. A., and B. A. Randall, (1985), Interplanetary cosmic ray intensity: 1972-1984 and out to 32 AU, J. Geophys. Res., 90, 1399-1412.

Yasue, S., (1980), North-south anisotropy and radial density gradient of galactic cosmic rays, J. Geomag. Geoelectr., 32, 617-635.