LATITUDINAL GRADIENTS OF COSMIC RAYS AND THE POLARITY REVERSAL OF THE HELIOSPHERIC MAGNETIC FIELD A PRELIMINARY EVALUATION

G Newkirk, Jr
National Center for Atmospheric Research, Boulder, Colorado

J A Lockwood
University of New Hampshire, Durham, New Hampshire

M Garcia-Muñoz
and
J A Simpson
University of Chicago, Chicago, Illinois

1 Introduction A central uncertainty in understanding the propagation and modulation of galactic cosmic rays is whether or not the cross-field drift of particles in the large-scale heliospheric magnetic field plays an important role (Burlaga, 1983, Jones, 1983) Studies of measured differences in various cosmic ray properties between epochs having positive and negative polarity of the heliospheric field have led to inconclusive results A major uncertainty is the interpretation to be placed on differences in behavior between successive solar cycles separated by approximately 11 years, accidental differences from cycle to cycle may be confused with differences which are truly dependent upon the polarity of the field

Since theoretical models of cosmic ray propagation including drifts predict the presence of an unambiguous latitudinal gradient of particle flux with respect to the heliospheric current sheet, one might expect that observation of this parameter could provide a means of resolving the question However, neither analyses of the latitudinal gradient at one rigidity (Newkirk and Fisk, 1985) nor of the rigidity dependence of this parameter during the last solar minimum (Newkirk *et al*, 1985) have done so The reason for this failure is that models both with and without large-scale drifts can be adjusted within reasonable limits to provide agreement with the observations

However, if drift effects are significant, the gradient of cosmic rays with respect to the current sheet should exhibit a *strong* sensitivity to the polarity of the large-scale magnetic field in the heliosphere (Jokipii and Kopriva, 1979, Kota and Jokipii, 1982) For example, at 2 GV and an inclination of the current sheet to the solar equator of 30°, the latitudinal gradient should increase from -3% AU^{-1} in the 1969-80 cycle to -13% AU^{-1} in the 1980-90 cycle Even though the current sheet is usually more complex than a plane inclined to the solar equator and the observations represent the average of a variety of inclinations, this four-fold increase in the magnitude should provide unambiguous evidence for the importance of drifts Naturally, models without drifts are insensitive to the polarity of the large-scale field

This investigation provides preliminary answers to the questions (1) Does the latitudinal gradient change as predicted by the drift-dominated models? and (2) Does the rigidity dependence of the latitudinal gradient display any sensitivity to the polarity of the field?

2 Data Analysis Our approach is to examine the gradient of cosmic ray flux in ecliptic latitude with respect to the current sheet at 1 AU for equivalent epochs before and after the reversal of the large-scale solar magnetic field in late 1980 We use synoptic K-coronameter observations to locate the position of the coronal current sheet, which we assume projects radially out to 1 AU according to the locally observed solar wind speed The methodology is described in detail in Newkirk and Fisk (1985) and Newkirk *et al* (1985) Cosmic ray fluxes between 0 9 GV and 35 GV (see Table) provide the basic data The epochs chosen for the comparison are DOY 1 1971 to DOY 250 1972 and DOY 1 1983 to DOY 140 1984 Both periods include the early recovery stage of cosmic ray modulation and occur when the configurations of polar coronal holes and the current sheet were roughly similar (Figure 1) Daily mean fluxes were used throughout the study and, since we are concerned with the steady-state distribution of cosmic rays, days when the

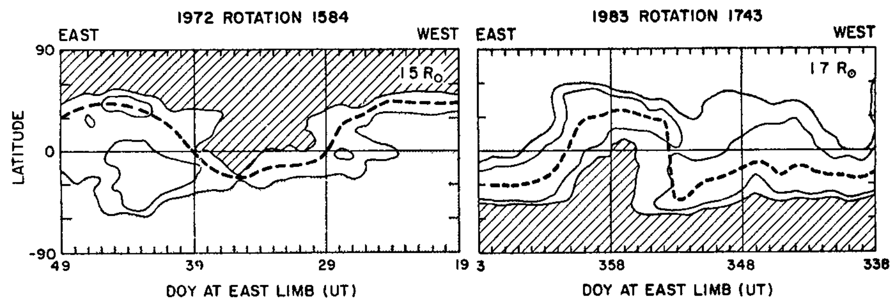

Fig 1 Synoptic contour maps of the polarization-brightness product of the K-corona allow the "band of coronal streamers" and the assumed location of the coronal current sheet (heavy dashed) to be located for typical rotations in 1972 and 1983 For clarity only two contour levels are shown Cross hatched and stippled areas indicate positive and negative magnetic polarities of the dominant magnetic field in the polar coronal holes as inferred from either a potential extrapolation of the photospheric fields or the polarity of the interplanetary field During both epochs, the current sheet extends up to 35° from the equator

interplanetary medium was disturbed or when solar energetic particles contaminated the record were excluded from the analysis For the purposes of this study we have defined as disturbed any day influenced by a classical Forbush decrease in the Mt Washington neutron monitor data Days contaminated by solar energetic particles were identified in the IMP (> 106 MeV) channel and, to insure homogeneity, the same days were eliminated from all three records

3 Results Figure 2 contains an example of the profile of cosmic ray flux with respect to the heliospheric current sheet The scatter of the individual daily values indicates that considerable variation unrelated to the separation of the earth from the current sheet is present However, a least-means-square fit of the form

$$U = a_0 + a_1 \sin^2\lambda_{mg} ,$$

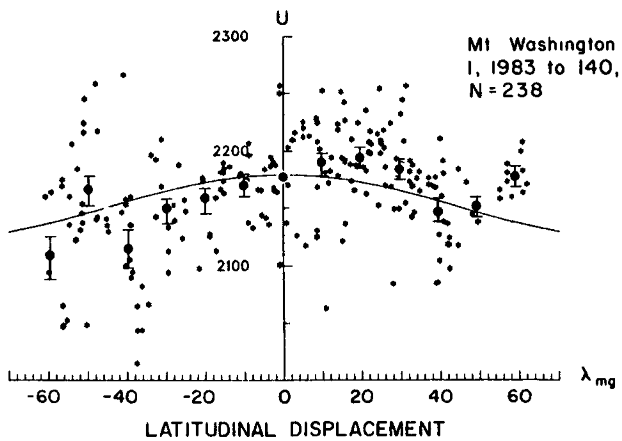

Fig 2 An example of the latitudinal variation detected in the individual daily values of cosmic ray flux (*) and in the means of each 10° interval (•) Range lines give the standard deviations of the means The smooth curve is the least-mean-square fit of the equation to the daily values For this example $a_0 = 2179 \pm 3$, $a_1 = -56 \pm 13$

where λ_{mg} is the inferred separation in ecliptic latitude between the Earth and the current sheet, is able to define the parameter a_1 with a precision of 20 to 30% for most cases. Of course, longer data intervals containing more points would produce a more precise result, however, the additional data are not yet available for the post-1980 interval and the pre-1980 interval has been limited deliberately to include approximately the same number of data points in both sets. The rela-

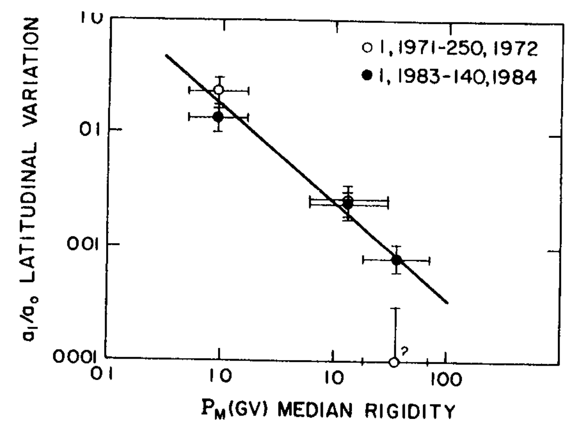

Fig. 3. The rigidity dependence of the relative latitudinal gradient $-a_1/a_o$ shows no significant difference between the 1971-72 and the 1983-84 intervals.

latitudinal gradients a_1/a_0 appear in the Table along with P_F, the probability that the coefficient a_1 is zero according to Fisher's F-test of the deviations of the daily points from the curve (Bevington, 1969). Although the data are noisy, all except the Huancayo value for 1971-72 are reasonably well established. The rigidity dependence of the latitudinal variation is displayed graphically in Figure 3. Vertical range lines indicate the standard error of estimate of the quantity a_1/a_0 while horizontal range lines delineate the limits within which 50% of the cosmic ray counting ray is generated. The straight line indicates the variation $P^{-0.72}$ estimated from a larger rigidity range for the four year period 1974-77 (Newkirk, *et al.* 1985).

Table
Parameters of the Cosmic Ray Monitors
and
Relative Latitudinal Gradients

Detector System	Reference	$P_M(GV)$	1971-72 $-a_1/a_o$	P_F	1983-84 $-a_1/a_o$	P_F
Huancayo	Simpson and Wang, 1970	35 (18-70)	0.001 ± 0.002	6×10^{-1}	0.008 ± 0.002	8×10^{-3}
Mt. Washington	Lockwood and Webber, 1967, 1979	13 (6-30)	0.026 ± 0.008	1×10^{-3}	0.024 ± 0.006	10^{-5}
IMP-8(106 MeV)	Garcia-Muñoz *et al.*, 1975	0.9 (0.5-1.7)	0.23 ± 0.07	5×10^{-4}	0.14 ± 0.03	2×10^{-5}

P_M = median rigidity (Newkirk, *et al.*, 1985), ( ) = 50% range

4 Conclusions and Discussion Within the statistical limits imposed by the currently available data and the noise inherent in the determination of the latitudinal gradient, no evidence for the expected change in the latitudinal gradient from pre-1980 to post-1980 epochs can be found In addition, the rigidity dependence of the gradient appears to be the same in the two epochs Thus, we can find no evidence for a sensitivity of the latitudinal gradient to the polarity of the large-scale heliospheric magnetic field such as has been predicted by models incorporating particle drifts

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