SH 4.2-5

DRIFT AND OBSERVATIONS IN COSMIC-RAY MODULATION. II.

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1. Introduction

In Part 1 (SH4.2-4) we have quantitatively shown that our drift model can simultaneously fit the observed 1965-66 and 1977 electron and proton spectra, in contrast with spherically symmetric models. We interpret this result as evidence of a charge-sign dependent effect due to particle drift. Using the same set of parameters, we could also simulate a shift in the phase and amplitude of the diurnal variation in the cosmic-ray (CR) intensity by reversing the polarity of the interplanetary magnetic field (IMF).

In this paper, again using the same set of parameters, we show that drift can cause significant differences in the radial and latitudinal dependence of cosmic rays for consecutive solar minimum periods. We also searched the literature for additional modulation features related to the IMF polarity reversal and therefore relevant to determining the role of particle drift in the modulation of cosmic rays.

2. Model Calculations

Using the parameters of Part 1, we calculated the radial and latitudinal dependence of the 100 MeV proton intensity for two consecutive solar minimum periods. The radial dependence, with the radial gradient G_r in %/AU, is shown in Fig. 1a. The latitudinal dependence, with the latitudinal gradient G_θ in %/degree, is shown for 1 AU and 20 AU in Fig. 1b and Fig. 1c respectively. For the D(+) period (1976), G_r remains almost constant for most of the heliosphere with a rapid increase near the boundary, and G_θ almost identical at 1 AU and 20 AU. For the D(-) period (1965), G_r is overall larger and decreases toward the boundary, while G_θ differs significantly for the two drift cases at 1 AU, and at 20 AU. (Note the difference in the intensity for the two drift solutions at 1 AU and 20 AU). The general behavior of the density gradients displayed in Fig. 1a-c is a feature of all drift models.

One of the best manifestations of the effect of drift becomes apparent when the transport equation is solved using θ-(polar angle) dependent Gaussian spectra at the outer boundary instead of the full θ-independent interstellar spectrum. By shifting these spectra (half-width of 10°) consecutively in 10° intervals from the heliospheric poles to the equator, the results shown in Fig. 2 were obtained. Protons reaching Earth from a particular region on the outer boundary are expressed as percentage of those that would have reached Earth if a full interstellar spectrum was used. The calculations were repeated for increasing values of the parallel diffusion coefficient $K_\parallel$ with other parameters unchanged. Solution (b) in Fig. 2 corresponds to the solutions in Fig. 1a-c. (Note that $(K_\parallel)_o$ is a constant in the expression for $K_\parallel$ given by Potgieter and Moraal, 1985). These results show, in contrast with the no-drift case, that drift causes positively charged particles reaching Earth to predominantly come from the outer equatorial regions during a D(-) period (1965), but from the outer polar regions when the IMF changes polarity. A factor 3 increase in $K_{\parallel}$ extends this region to include mid-latitudes, while the situation remains virtually unchanged for the D(-) period. In general these calculations show that oppositely charged particles should traverse different regions of the heliosphere (Part 1). Another implication is that the (anti) correlation between variations in the CR intensity and solar activity parameters should exhibit a 22-year cycle.

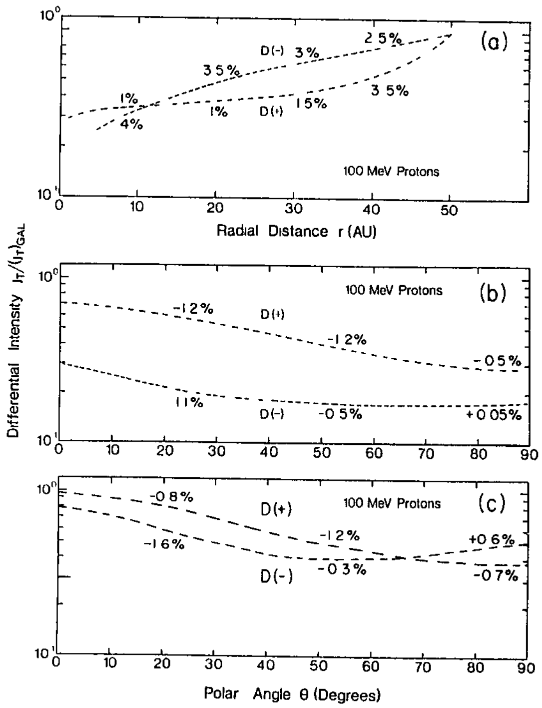

Fig. 1: (a) The radial dependence in the equatorial plane (Θ = 90°), (b) the latitudinal dependence at 1 AU and (c) at 20 AU, of the 100 MeV proton intensity. (The differential gradients are in %/AU; -latitudinal gradients are in %/degree).

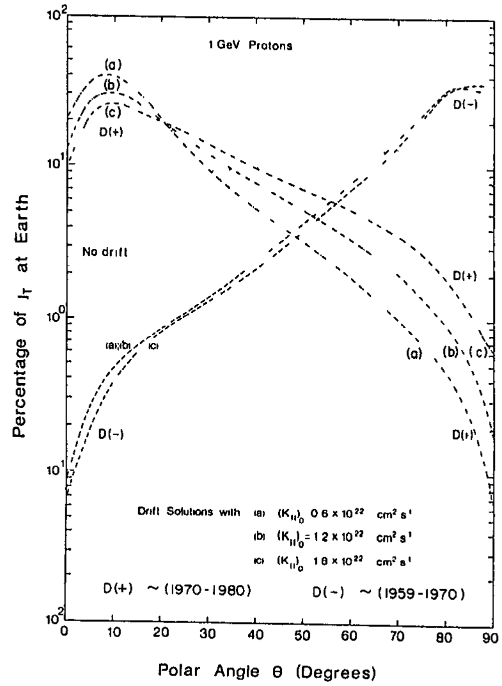

Fig. 2: The calculated percentage of 1 GeV protons reaching Earth from a particular region at the outer boundary for the two drift cases compared to the no-drift situation. The equatorial plane is at Θ = 90°.

3. Discussion of Results and Observations

Fig. 1a-c show that drift can cause significant differences in the radial and latitude dependence of cosmic rays during consecutive solar minimum periods. Compared to our results, the observed integral latitudinal gradient (Decker et al., 1984) is as yet inconclusive about the role of drift. Jokipii (1984), however, by carefully simulating the exact observational conditions near the neutral sheet using a three-dimension drift model, found excellent agreement with the results of Newkirk and Fisk (1985), who studied the statistical dependence of CR intensity on the distance from the neutral sheet.

Less encouraging are observed integral radial gradients recently reported by Webber and Lockwood (1985) and McKibben et al. (1985). The radial gradient seems to decrease since 1981, which is not expected from a drift point of view. It also appears that our model predicts the radial gradient too small for the 1976 solar minimum period. Since both the radial and latitudinal gradients are rather insensitive to parameter variations in drift models, these observations may become an interesting challenge to these models. It is also a complicating factor in explaining the role of drift concerning the anomalous components. However, the near constancy of the integral radial gradient observed before 1980, despite large changes in solar activity (Webber and Lockwood, 1985), is consistent with our model, but not with time-independent spherically symmetric models. In these models a direct relation exists for variations in $K_{\parallel}$ and the radial gradient.

Potgieter et al. (1980) calculated neutron monitor differential response functions from latitude survey data for 1954, 1965 and 1976, and found that the 1965 response function deviates significantly from those for 1954 and 1976. Using the parameters of Part 1, which fit the low-energy 1965-66 and 1977 proton and electron data, we could not simulate the observed large difference between the corresponding response functions, although we obtained a split in the right direction. The complicating factor here is that the low-energy proton fluxes were higher in 1976-77 than in 1965, while the neutron monitor counting rates were lower in 1976-77 compared to 1965.

Another relevant observation is the change in direction of the annual wave vector, derived from the yearly variations in CR intensity, in 1958-59 and again in 1968-69 (e.g., Antonucci et al., 1978; Nosaka, et al., 1984). Whether drift effects are the predominant cause of this observation, is not yet clear and has to await more detailed studies.

From 1972-77 the CR intensity was an extended, rather flat plateau preceded by a fast recovery over 2 years in 1970-72. (See the correlation study of Akasofu et al., 1985 regarding this period). During the 1965 solar minimum the intensity was peaked, preceded by an extended recovery period of $\sim$ 7 years. This behavior is consistent with the feature of drift models that the proton intensity is less sensitive to variation in modulation parameters during a D(+) cycle (1970-80) compared to the 11-years before and after this period (Jokipii and Thomas, 1981; Kota and Jokipii, 1983; Potgieter and Moraal, 1985).

Shea and Smart (1981) found a correlation coefficient of -0.86 between the geomagnetic aa-index - a measure of disturbance in the ecliptic plane - and the CR intensity for the years around 1965. For this period Aldagarova et al. (1979) found that the CR intensity correlates best to coronal green line (CGL) intensity in the -20° to +20° heliolatitude range. However, for the years around 1976, Shea and Smart found a correlation coefficient of +0.28 and Aldagarova et al. the best correlation for +30° to +50°, and to a lesser extent for -20° to -30° heliolatitude. In combination these observations indicate that during a D(+) cycle (1976), variations in the CR intensity correlate better with solar activity parameters in a much wider heliolatitude range compared to a D(-) period (1965) when cosmic rays are predominantly transported to the inner heliosphere via the equatorial regions. (See also Jokipii, 1981). The same conclusion can be reached from the observations of Nagashima and Morishita (1980), Pandey et al. (1983) and Vernov et al. (1983), despite different data and techniques used by them. These observations are consistent with our calculations shown in Fig. 2 and the drift velocities shown in Part 1.

4. Summary and Conclusion

In Part 1 we discussed two key observations relevant to determining the relative importance of drift in cosmic-ray modulation. In the present paper, using the same set of parameters, we have illustrated the significant effect of drift on the radial and latitudinal dependence of cosmic rays for consecutive solar minimum periods. Compared with the integral radial gradient observed in 1976 (Webber and Lockwood, 1985), the calculated value seems too small. A detailed comparison will however have to await the forthcoming solar minimum. The same applies to the latitudinal gradient which is as yet inconclusive about drift effects.

Searching the literature for observations related to the IMF polarity reversal (in addition to Part 1), we found distinct difference in neutron monitor response functions for consecutive solar minimum periods, and also in the annual variations of cosmic rays observed before and after polarity reversals. Whether drift is the predominant effect is however not yet clear. We also found several reports which indicate better correlation between variations in the cosmic-ray intensity and solar activity parameters (e.g., the corona green line intensity) over a much wider range of heliolatitude during 1970-80 compared to before this period. These observations are consistent with drift models according to which cosmic ray protons primarily come via the polar regions during a D(+) period (1970-80), but primarily via the equatorial regions during D(-) periods. The observed peak vs. plateau in cosmic-ray intensity for the years around 1965 and 1976 respectively is also consistent with the general feature of drift models according to which the proton intensity is more sensitive to changes in modulation conditions during 1970-80 compared to before 1970.

5. Acknowledgements

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References

Akasofu, S.I., et al., 1985, J. Geophys. Res., 90, 4439.
Aldagarova, Kh.Z., et al., 1979, Proc. 16th ICRC (Kyoto), 3, 343.
Antonucci, E., et al., 1978, Ap. J., 220, 712.
Decker, R.B., et al., 1984, Ap. J., 278, L119.
Jokipii, J.R., 1981, Geophys. Res. Lett., 8, 837.
Jokipii, J.R., 1984, Proc. Int. Symp. C.R., Morioka, Japan.
Jokipii, J.R., and Thomas, B., 1981, Ap. J., 243, 1115.
Kota, J., and Jokipii, J.R., 1983, Ap. J., 265, 573.
McKibben, R.B., et al., 1985, Ap. J., 289, L35.
Nagashima, K., and Morishita, I., 1980, Plant. Space Sci., 28, 195.
Newkirk, G., and Fisk, L.A., 1985, J. Geophys. Res., 90, 2391.
Nosaka, T., et al., 1984, J. Geomagn. Geoelectr., 36, 73.
Pandey, P.K., et al., 1983, Proc. 18th ICRC (Bangalore), 3, 91.
Potgieter, M.S., et al., 1980, South Afr. J. Phys., 3, 90.
Potgieter, M.S., and Moraal, H., 1985, Ap. J., in press.
Shea, M.A., and Smart, D.F., 1981, Adv. Space Res., 1, 47.
Vernov, S.N., et al., 1983, Proc. 18th ICRC (Bangalore), 3, 187.
Webber, W.R., and Lockwood, J.A., 1985, Paper SH4.3-1, this conference.