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Cosmic Ray Modulation and the Heliosphere

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Abstract. We reproduce the long term temporal variations of galactic cosmic ray intensity applying a semi-empirical 1-D diffusion-convection model. We use a shell-like model in which each magnetized shell modulates the cosmic ray intensity during its travel from the Sun to the heliospheric boundary. The cosmic ray intensity at the Earth's orbit is the result of the successive dynamic influence of all shells between the Earth and the heliospheric boundary. Our results are in very good agreement with ground-based observations from Climax and Huancayo cosmic ray stations.

1 Introduction

In this work we divide the heliosphere into magnetic shells that propagate from the inner to the outer heliosphere. A magnetic shell carries its own interplanetary magnetic field frozen in the solar wind plasma. The cosmic ray intensity at 1 AU is modulated from all the magnetic shells that have previously passed from 1 AU and for that given moment travel to the heliospheric boundary, being the heliospheric termination shock. The extend of the heliosphere is assumed to vary with time following the varying pressure of the solar wind (Exarhos and Moussas, 1999a). Using 1 day mean values of the solar wind plasma and magnetic field measurements at 1 AU, we reproduce the temporal variations of the galactic cosmic ray intensity at neutron monitor energies (approximately above 3 GeV) and compare them with ground based neutron monitor data for the last three solar cycles.

2 Analysis

A semi-empirical 1-D diffusion-convection model, based on the concept of magnetic shells, is used to reproduce the galactic cosmic ray intensity at 1 AU. We assume that a magnetic shell at a heliospheric distance r, with an average velocity u and magnetic field $B(r)$, modulates the cosmic ray intensity by a factor

$$f(r) = exp(-\gamma u B(r)) \tag{1}$$

The parameter γ is chosen to give a cosmic ray intensity pattern as close as possible to the observed one (Exarhos and Moussas, 2001). We do not include the rigidity dependence of the modulating factor since we reproduce the integrated cosmic ray intensity over all particle rigidities. The exponential form of the modulating factor, that we use in this model, is based on the steady state diffusion-convection equation (Parker, 1965; O'Gallagher, 1975) and on the form of the diffusion coefficient which is proportional to $1/B^{\alpha}$ (Chih and Lee, 1986). We assume $\alpha = 1$, a value previously used by Perko and Burlaga (1992), Le Roux and Potgieter (1992a,d, 1995) and Potgieter and Le Roux (1992a,b, 1994).

The cosmic ray intensity at 1 AU is the result of the modulation of each magnetic shell between 1 AU and the heliospheric termination shock. Thus the cosmic ray intensity I_{1AU} at 1 AU is calculated as the product of the modulating factors $f(r_i)$ of each shell from $r = 1AU$ to $r = R_{TS}$, R_{TS} the termination shock radius.

$$I_{1AU} = I_{R_{TS}} f(1AU)...f(r_i)...f(R_{TS}) \tag{2}$$

We assume that the cosmic ray intensity $I_{R_{TS}}$ at the termination shock is equal to the unmodulated cosmic ray intensity I_o. Our results, compared with the Climax and Huancayo cosmic ray count rates, seems to reproduce very well the observed cosmic ray intensity, regardless of the magnetic field polarity changes and the solar activity. We do not include in our model the particle drifts and the adiabatic losses (see Zhang 1999a,b for a detailed analysis of adiabatic losses).

We fit our results to the Climax and Huancayo data by setting $\gamma = 1.4 \times 10^{-5}$ and $\gamma = 0.6 \times 10^{-5}$ respectively. We use defferent values of γ because the recorded count rates of each station depend on the geomagnetic cut-off rigidity of the station and the specific yield function $S(P)$, P being the

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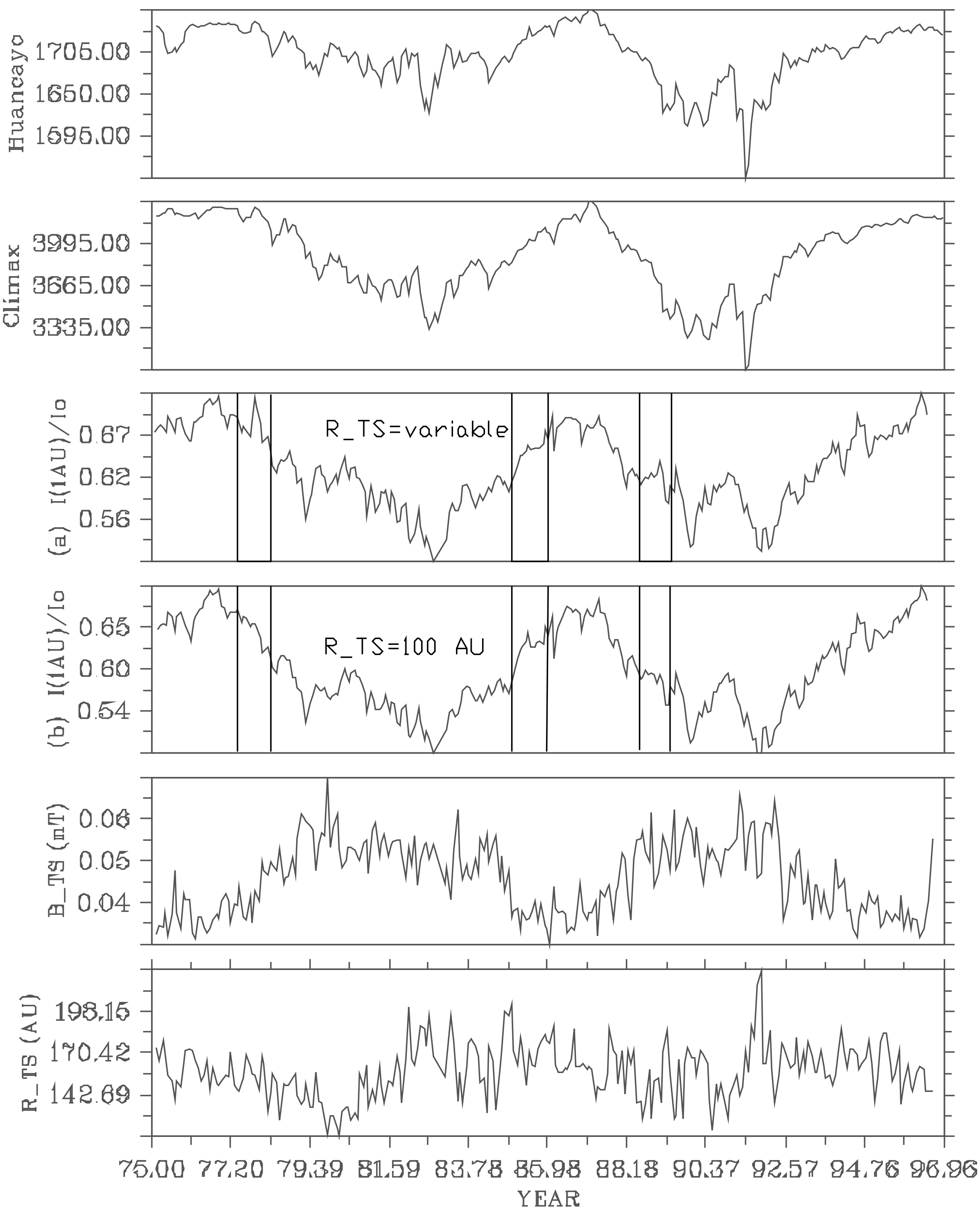

Fig. 1. The model cosmic ray intensity $I(1AU)$ normalized to the unmodulated cosmic ray intensity I_o.The recorded data from the Climax and Huancayo ground stations are shown for comparison. The last two panels are the interplanetary magnetic field B_{TS} extrapolated to the heliospheric termination shock and the termination shock radius R_{TS} respectively

particle's magnetic rigidity. Fig. 1 shows our results in combination with the recorded data from Climax and Huancayo ground NM stations. Fig. 1a shows the model results assuming a constant value of R_{TS} while in Fig. 1b we use a time varying value of R_{TS} (Axford, 1985; Exarhos and Moussas, 1999a), shown in the same figure. The differences between Fig. 1a and Fig. 1b seems to be small except from a few particular periods shown by the vertical dashed lines. In Fig. 1 is also displayed the temporal variations of the interplanetary magnetic field B_{TS} extrapolated at the time-varying heliospheric termination shock. The anti-correlation of B_{TS} with the cosmic ray intensity at 1 AU is very high and generally is much greater than the anti-correlation of B_{1AU} with the cosmic ray intensity (Exarhos and Moussas, 1999b).

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