22-YEAR CYCLE OF THE UPPER LIMITING RIGIDITY OF DALY WAVES

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Abstract. The method of calculating energy losses along regular particle trajectories is applied to obtain the predicted cosmic ray anisotropies from 200 to 500 GV. The tilt angle of the interplanetary neutral sheet varies to simulate a 22-year cycle magnetic cycle. The calculated values of solar diurnal and semidiurnal, and siderial diurnal intensity waves are compared with observations.

1. Introduction. Earlier we suggested (Erdős and Kóta 1979, 1980) that the cosmic ray anisotropies observed at underground energies can be interpreted in terms of regular particle motion in the Interplanetary Magnetic Field (IMF) incorporating a wavy neutral sheet. At high rigidities, the effects of small-scale irregularities should be negligible and, being the dominant large-scale feature of the IMF, the wavy neutral sheet plays the decisive role.

In this paper we investigate how cosmic ray anisotropies change during a 22-year magnetic cycle. We consider the 200 - 500 GV range which represents the high rigidity tail of the modulation spectrum. The state of the heliosphere changes in a complex way during a solar cycle. From this complexity, the only feature we consider here is the variation of the inclination of the tilted heliospheric neutral sheet. The tilt angle is minimal around solar minimum and increases with increasing solar activity (Thomas and Smith 1981). As a crude approximation, we simulate the 22-year cycle by simply changing the tilt angle.

2. The Model. The IMF model and the method of calculation are described in detail elsewhere (Erdős and Kóta 1979, 1980, 1981). Briefly, a conventional Parker spiral field is applied with a 5 gamma field strength at the earth. The wavy neutral sheet dividing the opposite polarities is given by

$$\sin\theta = \sin\alpha \cdot \cos(\varphi + r) \qquad (1)$$

where θ and φ are heliographic latitude and longitude, respectively, r is heliocentric distance in units of AU. The tilt angle, α, gives the maximum latitudinal excursion of the neutral sheet. The configuration of away polarity above the sheet and toward polarity below the sheet will be referred to as $A > 0$.

We note that equation (1) does not exactly correspond to a tilted plane at the sun. Calculations were also carried out for a tilted plane of 90° inclination. This case of indefinite A, where the two configurations merge, will be labelled with 90*.

The theoretical results to be presented always give the full free-space anisotropy that would be observed by an equatorial observer in the absence of geomagnetic deflection. Calculations do not include the Compton-Getting effect due to the orbital motion of the earth.

3. Results. In this paragraph we briefly report on the daily intensity waves predicted for 200, 300 and 500 GV at various values of the tilt angle, α.

The harmonic dial of the solar daily variation calculated for 200 GV is shown in Figure 1. For comparision, Figure 2 (taken from Benkő et. al., 1984) shows the year-to-year daily vectors observed by the Budapest underground telescopes (median energy: 180 GeV) in the period of 1976 (A>0, low solar activity) to 1983 (A<0). We find a remarkable agreement if correction is made to the 1.5 hr geomagnetic deflection, the Compton-Getting effect due to the earth's orbital motion, and the cos $47^o \approx 0.68$ attenuation factor due to the 47^o N geografical latitude of the station.

The amplitudes of the solar daily waves calculated for 200, 300 and 500 GV are shown in Figure 3.

The predicted harmonic dial of the semidiurnal variation of 200 GV cosmic rays is shown in Figure 4, while the calculated amplitudes are given in Figure 5. A charge asymmetry can clearly be seen: for A > 0, an earlier phase and a smaller amplitude is to be expected. These findings are in general agreement with numerous observations (see, for example, Morishita et. al., 1984).

As expected, the phase of the sidereal daily wave was always found to be close to either 6 hr or 8 hr, depending on the polarity of the magnetic sector. Figure 6 gives the calculated sidereal amplitudes. Our theoretical results suggest a hard energy spectrum; the spectrum of the sidereal variation turns out markedly harder than the solar diurnal and semidiurnal spectra. This finding also suggests that a sidereal variation of solar origin may still be present at rigidities where solar diurnal and semidiurnal waves already diminish. Thus, in searching for a genuine galactic anisotropy of cosmic rays one should be cautious in establishing the upper rigidity limit of the heliospheric effects.

References:

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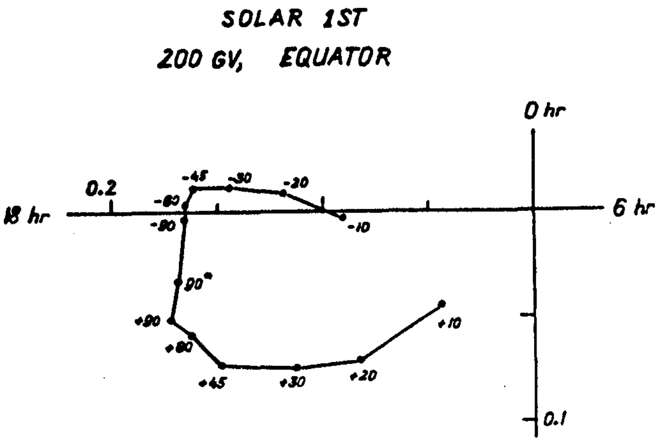

Figure 1. Calculated harmonic dial of the solar daily waves of 200 GV cosmic rays. Numbers stand for the tilt angle, α, in degrees (negative values refer to A < 0).

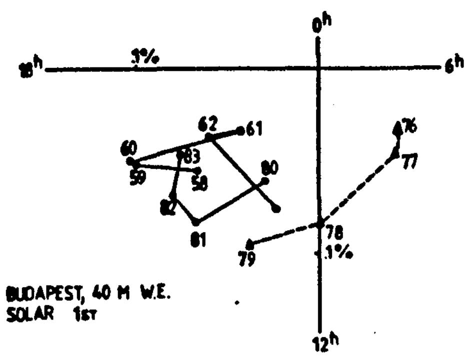

Figure 2. The Budapest solar daily vectors without geomagnetic correction. Numbers stand for the year of observation. Results are grouped according to the polarity state (triangles and dashed lines refer to A > 0).

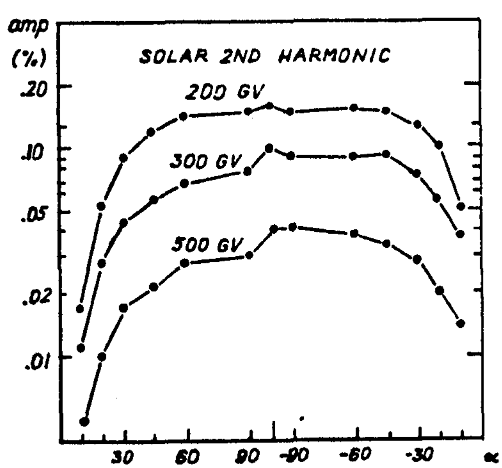

Figure 3. Calculated amplitudes of the solar daily vectors of 200, 300 and 500 GV cosmic rays vs the tilt angle, α , in degrees. (Negative values of α refer to A < 0.)

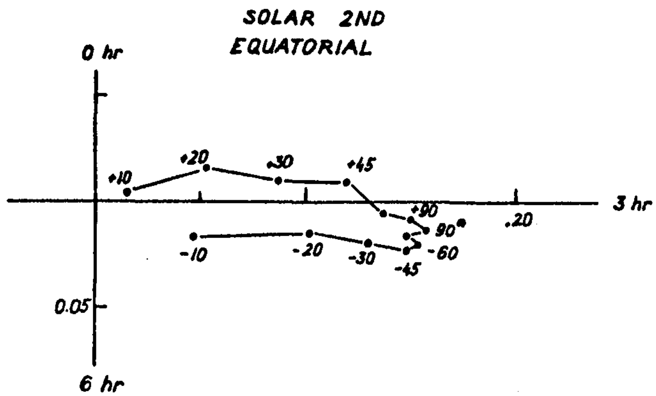

Figure 4. Same as Fig. 1., for semidiurnal vectors.

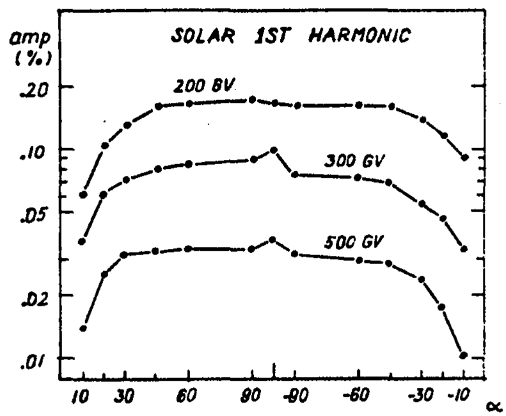

Figure 5. Same as Fig. 3., for semidiurnal vectors.

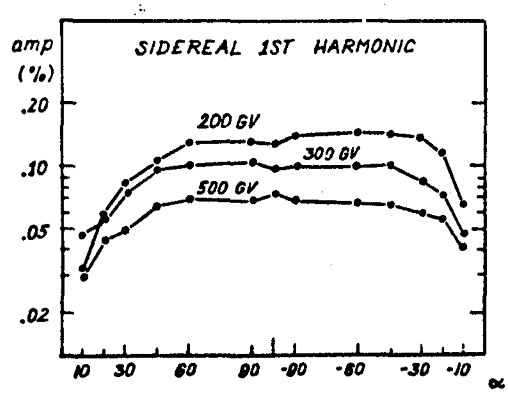

Figure 6. Same as Fig. 3., for sidereal daily vectors.