# COSMIC RAY INTENSITY VARIATIONS OBSERVED AT MATSUSHIRO (220 M.W.E. IN DEPTH)

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ABSTRACT

Cosmic ray data from Matsushiro underground station have been analyzed for four years (1981-84). It is found that a marked semi-annual intensity variation has been observed in this period. Solar diurnal and semi-diurnal variations have also been observed. After correcting for the spurious sidereal diurnal variation arising from the anisotropy responsible for the solar semi-diurnal variation (Nagashima et al., 1983), it is found that the corrected siderial diurnal variation is consistent with those so far reported.

1. Introduction. Deep underground observation of the cosmic ray intensity variation provides valuable information as to the nature of modulation in the heliosphere. Matsushiro underground cosmic ray station has been in operation since Aug. 1980 at the depth of 220 m.w.e. (Yasue et al., 1981a). The median primary rigidity of the vertical telescope is about 700 GV (Fujimoto et al., 1984), and its counting rate is $2.1 \times 10^4$/h. The analyses of the observed intensity variations of the vertical telescope for four complete years (1981-84) are presented.

2. Semi-annual intensity variation. At the Paris Conference, we have reported that the most part of the unexpectedly large barometric coefficient ($\sim$-0.05%/mb) observed at deep underground stations (Humble et al., 1979; Yasue et al., 1981b) can be attributed to the atmospheric temperature effect (Yasue et al, 1981b). In this report, we present another phenomenon which also seems to be caused by the atmospheric temperature effect. Fig. 1 shows the monthly averaged intensity varia

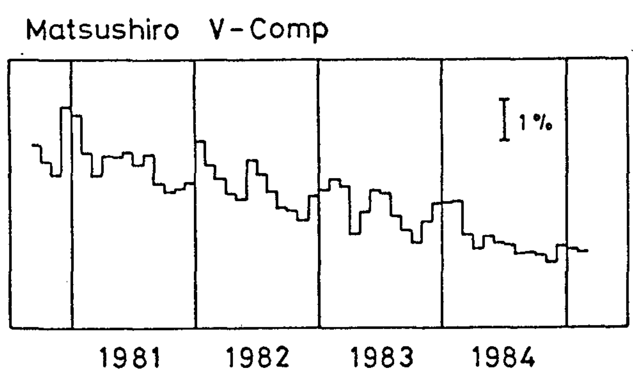


Fig.1 Monthly averaged intensity variation.

tion of the vertical telescope (abbreviated as V-Comp) observed at Matsushiro. In the figure, we can notice a marked semi-annual intensity variation superposed on a gradual intensity decrease. The intensity decrease (about 1 % per year) may be due to the decrease in detector efficiency of the scintillation counters (Ueno, private communication). The semi-annual intensity variation takes the maximum value both in summer and in winter. Such a variation has not been observed at the shallower underground stations than Matsushiro (Ueno et al., 1979). The most part of this variation can be explained quantitatively in terms of the variation of the upper atmospheric temperature (Sagisaka, 1984).

3. Observed daily variations. Fig. 2 shows the daily variations of V-Comp (top) and atmospheric pressure (bottom) averaged over four years (1981-84) for solar (SO), sidereal (SI) and anti-sidereal (AS) time. Cosmic ray data are not corrected for pressure. In the figure, V-Comp shows not only significant SI daily variation but also SO and AS daily variations. It is noted, however, that the atmospheric temperature effect described in the previous section may contaminate also the daily variations.

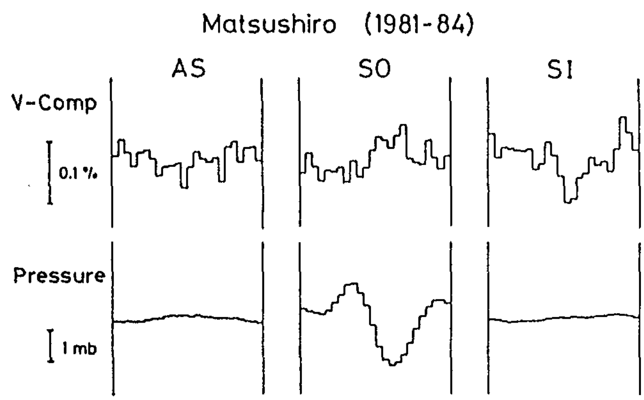


Fig.2 Averaged daily variation of V-Comp and atmospheric pressure for solar(SO), sidereal(SI) and anti-sidereal(AS) time.

We can find in Fig. 2 that the daily variations of pressure in SI and AS time are negligibly small (about one-tenth) compared with that in SO time. This fact implys that we may reasonably assume that the influence of the atmospheric effects becomes serious only in SO time and can be neglected in SI and AS time.

4. Solar daily variation. The heavy solid lines in Fig. 3 show the 1st and 2nd harmonic vectors of the daily variation (SO) of V-Comp shown in Fig. 2. The error circles are the standard error of each mean vector estimated from the dispersion of yearly vectors. In the following, we try to estimate SO harmonic vectors caused by the temperature effect. By analyzing observed data from multi-directional

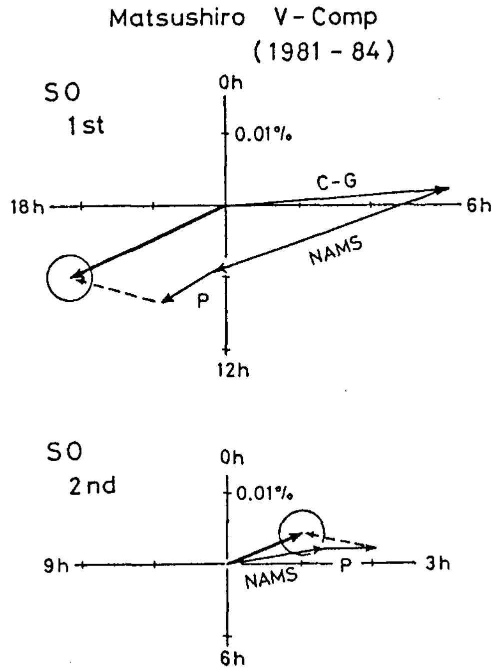


Fig. 3 Solar 1st and 2nd harmonic vectors.

muon telescopes at Nagoya and underground telescopes at Misato and Sakashita (NAMS) in the period of 1978-83, Ueno et al. (1984) and Morishita et al. (1984) determined, respectively, the characteristics of the anisotropies responsible for the solar diurnal and semi-diurnal variations. Assuming those anisotropies obtained by them, and using the coupling coefficients (Fujimoto et al, 1984), we can estimate the expected solar diurnal and semi-diurnal variations at Matsushiro in this period. The obtained vectors are shown in Fig. 3 with the vectors 'NAMS'. These vectors are free from the atmospheric effects. The vectors 'P' in the same figure show SO 1st and 2nd harmonics produced from the daily variation of the atmospheric pressure shown in Fig. 2. Here, we assume the genuine barometric coefficient of -0.01%/mb (Sagisaka et al., 1979). The vector 'C-G' in Fig. 3 shows the 1st harmonic vector originated from the Compton-Getting effect due to the Earth's revolution around the Sun. Composing the above vectors on the respective harmonic dials, and comparing the resultant vectors with the observed ones, we can obtain the residual vectors (dashed line) shown in Fig. 3. One might expect that these vectors are produced from the atmospheric temperature effect. (It is noted that other unknown vectors, one of which may be originated from the galactic anisotropy (Nagashima et al., 1982), might also be included in these vectors.)

5. SI and AS daily variations. It is emphasized that the solar daily variation is observed even at this depth (220 m.w.e.) in this period. As has been described by Nagashima et al. (1983, 1985), the second order solar anisotropy responsible for the observed semi-diurnal variation produces the AS 1st harmonic vector with the phase of 0h, due to the tilt of the spin axis of the Earth to the ecliptic plane. The present observation seems to support his expectation. Namely, the observed AS vector in Fig. 4 seems to be interpreted as the side-band vector produced from the 2nd order anisotropy at 3h-21h. In this case, another side-band vector (spurious sidereal vector) should be observed according to his theory. This vector can be derived from the observed AS vector (Nagashima et al., 1983), and is shown by the dashed line (amplitude and phase of the vector is 0.014% and 19.4h, respectively) on the SI harmonic dial (see Fig. 4). If we subtract this spurious SI

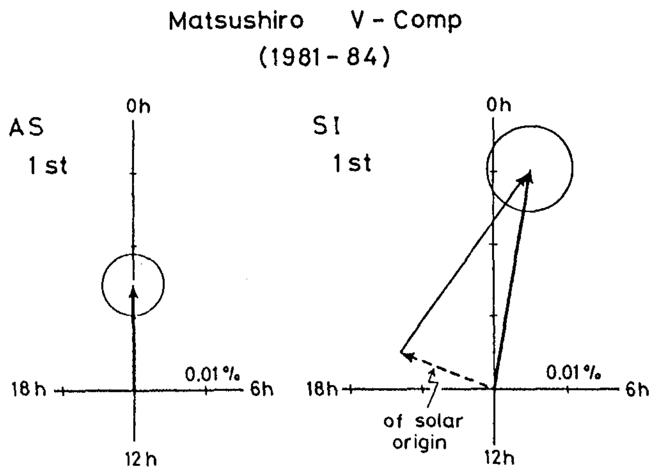


Fig.4 Sidereal and anti-sidereal harmonic vectors.

vector from the observed SI vector, we can obtain the true SI vector of galactic origin. The resultant vector has the amplitude of 0.031% and the phase of 2.3h. The present result seems to be consistent with those so far reported (Nagashima et al., 1985).

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