IMF-SENSE-DEPENDENT COSMIC RAY ANISOTROPY PRODUCED FROM DIFFUSION-CONVECTION IN HELIOSPHERE

K. Nagashima*, K. Munakata and R. Tatsuoka

*Cosmic Ray Research Laboratory, Nagoya University
Nagoya 464, Japan
Department of Physics, Nagoya University, Nagoya 464, Japan

1. Introduction. An IMF-sense-dependent first order anisotropy of solar origin, which is produced perpendicularly to the ecliptic plane from the radial density gradient, was first pointed out by Swinson.

In addition to this anisotropy, the existence of IMF-sense-dependent higher order anisotropies has recently been suggested by Munakata and Nagashima(1), based on the simulation of cosmic ray diffusion-convection in the heliomagnetosphere.

In this paper, we discuss the characteristics of the daily variations caused by the IMF-sense-dependent 2nd order anisotropy obtained on the same condition as adopted by Munakata and Nagashima(1). A brief comparison of these variations with observations will also be made in order to demonstrate their existence.

2. Daily Variation and its Seasonal Variation. Munakata and Nagashima obtained a stationary cosmic ray anisotropy of solar origin which is expressed in the IMF-polar-coordinate system defined at any point fixed in space(cf. fig.1), as

$$\eta(r,p)=\sum_{n=1}^{\infty}\sum_{m=0}^{n}\{\eta_n^{mc}(r,p)\cos m\Phi'+\eta_n^{ms}(r,p)\sin m\Phi'\}P_n^m(\cos\Theta'), \qquad (1)$$

where the angles Θ' and Φ' express the incident direction of cosmic rays with momentum p at a point r, and $P_n^m(\cos\Theta')$ is the semi-normalized associate Legendre function(3).

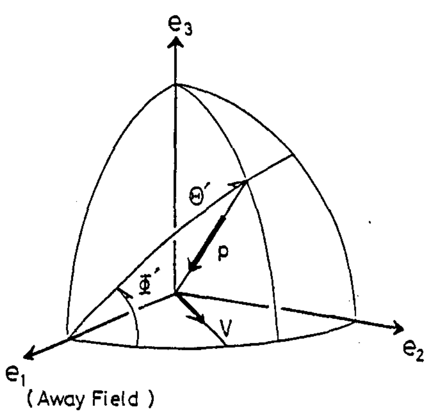


Fig. 1. The IMF-POLAR-COORDINATE SYSTEM.
p: Momentum of particle.
V: Solar wind velocity.
e_l : Unit vector in the direction of "away" magnetic field.
e_3 : Unit vector in the direction of $e_l \times V$.
$e_2 = e_3 \times e_l$.

The terms with coefficients η_n^{ms} in eq.(1) are called IMF-sense-dependent terms, because η_n^{ms} 's change their sign according to the sense of IMF. The IMF-sense-dependent 2nd order anisotropy is composed of two kinds of term ($\eta_2^{ms}P_2^m(\cos\Theta')\sin m\Phi'$; m=1,2) which are not symmetric for an arbitrary rotation around any axis. This anisotropy produces two kinds of daily variation at the Earth; one is a solar(SO) diurnal variation and the other is an extended sidereal($SI_{1/2}$) semi-diurnal variation(2).

The solar diurnal variation changes the sign for a sign change of the geographic latitude($\frac{\pi}{2}-\theta$) of the viewing direction of the telescope. We call this type of variation the north-south(N-S) asymmetric type or $P_2^1(\cos\theta)$-type. For the positive and negative polarity states, fig.2(a) shows the dependence of the solar diurnal space harmonic vector [2] on the diffusion parameters (λ_0 and a_λ) which are related to the scattering m.f.p (λ) as,

$$\lambda=\lambda_0(R/\mathrm{GV})\exp\left(\frac{r-r_e}{33\mathrm{a.u.}}\right)(1+a_\lambda\cos\theta_H). \quad (2)$$

In the equation, R is the cosmic ray rigidity, r_e=1a.u. and θ_H is the heliographic co-latitude. In fig.2, the arabic numerals express the values of a_λ and the roman numerals I and II express, respectively, the cases of λ_0=0.016a.u. and λ_0=0.032a.u.

On the other hand, the extended sidereal semi-diurnal variation is N-S symmetric or $P_2^2(\cos\theta)$-type and represents the annual variation of the solar semi-diurnal variation whose yearly average is zero. This space harmonic vector [2] is also shown in fig.2(b).

It is noteworthy that these two kinds of vector show remarkable polarity state dependences (cf. fig.2).

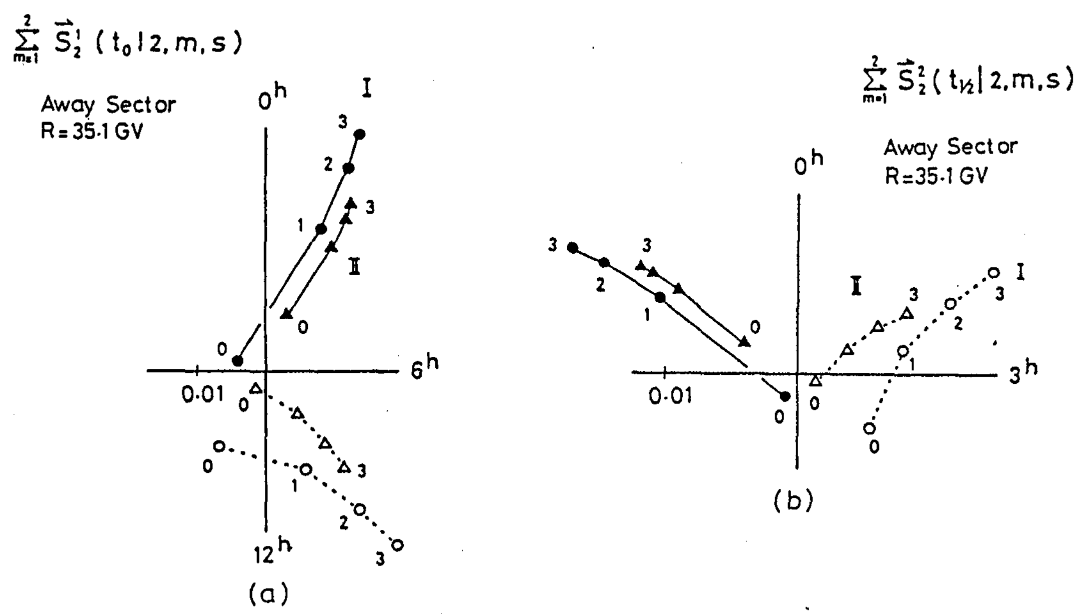


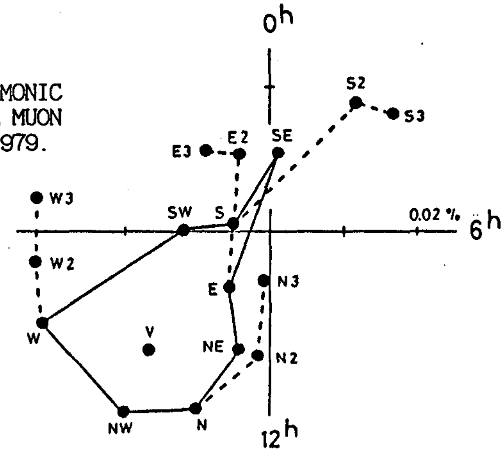
Fig. 2. PARAMETER DEPENDENCE OF THE (a) SOLAR DIURNAL AND (b) EXTENDED SIDEREAL SEMI-DIURNAL SPACE HARMONIC VECTOR IN THE AWAY SECTOR.
The solid and open symbols represent the positive and negative polarity states, respectively.

3. Comparison with Observations. Fig.3 shows the observed *SO* difference vectors(T-A) between the corresponding harmonic vectors in the toward(T) and away(A) sectors in the positive polarity state(1971-1979) of the multi-directional muon telescope at Nagoya. In the figure, the symbols(V,N,S,E,...) denote respectively the 17 directional component telescopes [4].

The theoretical *SO* vectors to be compared with the observed vectors are shown in fig.4 and are obtained by assuming that the phase of space harmonic vector is 0hr [4].

The relative configuration of the observed vectors in fig.3 bears a striking resemblance to that of $P_2^1(\cos\theta)$-type not to that of $P_1^1(\cos\theta)$-type (N-S symmetric) shown in fig.4.

Fig. 3.
SOLAR DIURNAL "TOWARD-MINUS-AWAY" HARMONIC VECTORS (T-A) OBSERVED BY MULTI-DIRECTIONAL MUON TELESCOPE AT NAGOYA FOR THE PERIOD OF 1971-1979.



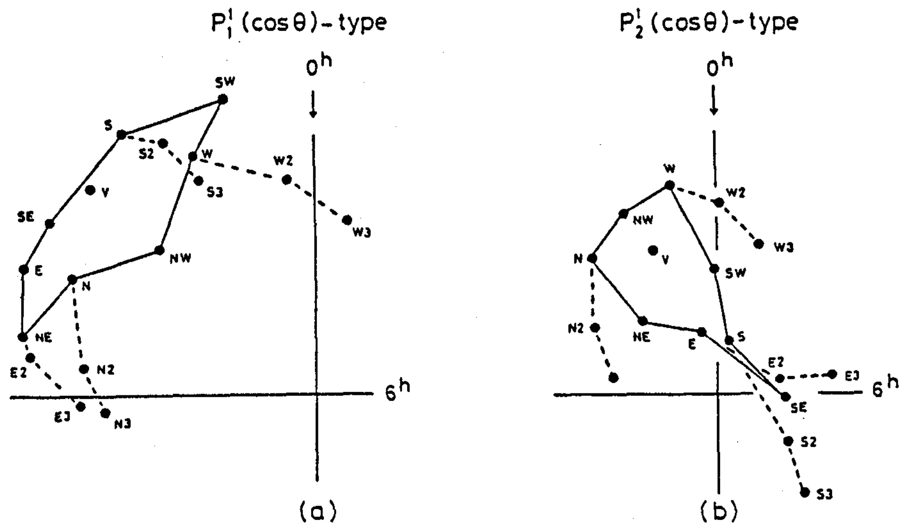


Fig. 4. RELATIVE CONFIGURATION OF EXPECTED DIURNAL HARMONIC VECTORS OF $P_1^1(\cos\theta)$- AND $P_2^1(\cos\theta)$-TYPE FOR COMPONENT TELESCOPES OF MULTI-DIRECTIONAL MUON TELESCOPE AT NAGOYA.
The spectrum of the vector is assumed to be of power-type $[(R/10GV)^{0.5}]$ with upper limiting rigidity (100GV).

In addition to the above solar diurnal variation, the present anisotropy produces also $SI_{1/2}$ vector. Fig.5 shows the T-A vectors in positive polarity state, and the theoretical vectors are shown in fig.6 in the same manner of fig.4. Although the observed vectors $SI_{1/2}$'s are not very significant statistically, their relative configuration is systematic and bears a resemblance to that of $P_2^2(\cos\theta)$-type in fig.6(a) not to that of $P_3^2(\cos\theta)$-type (N-S asymmetric).

In fig.5, we show also the observed $AS_{1/2}$ vectors which must be very small (~ one sixth) in comparison with $SI_{1/2}$ vectors from the theoretical point of view(2). The observed vectors $AS_{1/2}$'s are evidently small as expected.

These comparison with observations strongly suggest the existence of the 2nd order IMF-sense-dependent anisotropy. For confirmation, however, detailed analysis of the observed vectors SO and $SI_{1/2}$ is required.

4. Conclusion. It has been demonstrated that an IMF-sense-dependent 2nd order anisotropy is produced by the diffusion-convection of cosmic rays in the heliomagnetosphere. The result implies that the anisotropy cannot be expressed only by the pitch angle($\mu=\cos\Theta'$) with respect to the IMF-axis (cf. eq. (1)). In this respect, it is not suitable to discuss the 2nd and 3rd order anisotropies, based on the diffusion equation with respect to the pitch angle[5].

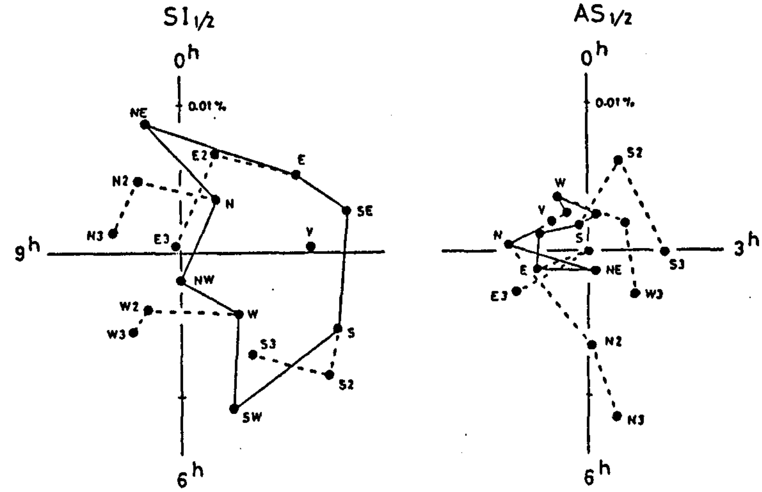


Fig. 5. EXTENDED SIDEREAL ($SI_{1/2}$) AND ANTI-SIDEREAL ($AS_{1/2}$) SEMI-DIURNAL "TOWARD-MINUS-AWAY" HARMONIC VECTORS (T-A) OBSERVED BY MULTI-DIRECTIONAL MUON TELESCOPE AT NAGOYA FOR THE PERIOD OF 1971-1979.

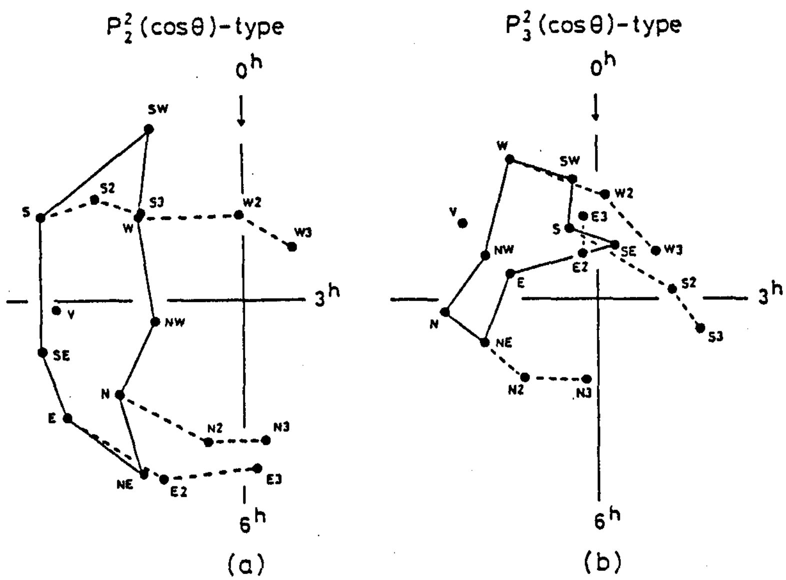


Fig. 6. RELATIVE CONFIGURATION OF EXPECTED SEMI-DIURNAL HARMONIC VECTORS OF $P_2^2(\cos\theta)$- AND $P_3^2(\cos\theta)$-TYPE FOR COMPONENT TELESCOPES OF MULTI-DIRECTIONAL MUON TELESCOPE AT NAGOYA.

The spectrum of the vector is assumed to be of power-type [$(R/10GV)^{0.5}$] with upper limiting rigidity (100GV).

References

(1) K. Munakata and K. Nagashima: *Proc. Int. Cosmic Ray Symposium* (Morioka, Japan, 1984), p.144; This Conference SH 4.5-1.

(2) R. Tatsuoka and K. Nagashima: This Conference SH 4.5-2.

(3) S. Chapman and J. Bartels: *Geomagnetism*, Vol.2 (Oxford, 1940), p.61; K. Nagashima: *Rep. Ionos. Space Res.*, Japan, **25**, 189 (1971).

(4) K. Fujimoto et al.: *Rep. of Cosmic-Ray Research Lab.*, No.9 (Nagoya Univ., 1984).

(5) J.W. Bieber and M.A. Pomerantz: *J.G.R. Lett.*, **10**, 920 (1983).