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Sidereal daily variation in the cosmic ray intensity

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Abstract: The sidereal daily variation is investigated by using the continuous observation data of ground and underground (7, 20 and 60 m w.e.) muon cosmic ray intensities for the 1972 to 2002 period. The results obtained are discussed in the light of the supposed sources of heliospheric and galactic origin.

Introduction

Daily variations of cosmic ray (CR) intensity in the sidereal time is of great interest to study the heliosphere geometry and a portion of cosmic radiation anisotropy of galactic origin in the range of low energy. The investigation of sidereal-daily variations is carried out in a wide energy range with the neutron monitors, ionization chambers, muon telescopes and also with EAS arrays [1]-[3].

In [1] the authors mark two types of anisotropy of sidereal variations: one of them is of galactic origin with the minimum near 12 h local sidereal time (LST), and another one is directed from the heliomagnitosphere tail (tail-in anisotropy), which is characterized by an acute peak with the maximum at 06 h LST.

The study of sidereal anisotropy with the help of neutron monitor data showed [2] that there exists an anisotropy from the head part of the heliosphere with the maximum at 18 h LST (helionose-in anisotropy). In the same work the coexistence of three types of sidereal-daily variation anisotropy was discussed in detail. The data were analyzed in the epochs of different polarity of the general solar magnetic field and in the periods of active and quiet Sun. Investigations were carried out with ionization chambers ($60 \div 100$ GeV), neutron monitors (~ 20 GeV) and underground muon telescopes ($\sim 200 \div 700$ GeV). The anisotropy from the heliosphere tail was observed in all energy ranges ($20 \div 700$ GeV), from the head part of the heliosphere - in the region of low and mean energies ($20 \div 100$ GeV), and the galactic anisotropy is observed in the region of mean and high energies ($60 \div 700$ GeV). The anisotropy, directed from the heliospheric tail, predominates in the active periods of solar cycle at the positive polarity of magnetic field of the Sun.

The "tail-in" anisotropy is maximum during the December solstice, when the Earth is the nearest the heliomagnitosphere tail and almost disappears during the June solstice.

Data analysis and discussion

In the present work the CR muon component data of the telescopes at 0, 7 and 20 m w.e. in the vertical (V) and at 30° angle to the south (S) and north (N) relative to the zenith at the Yakutsk station ($\lambda = 62^\circ N, \phi = 130^\circ E$) obtained during 31 years ($1972 - 2002$) are used. The accuracy of registration in years at these levels and for all directions for the observed registration period is not equivalent. Poor statistics falls on 1970s. The data of telescope at a depth of 60 m w.e. are also used only for the vertical direction because of poor statistics.

Fig 1 presents the sidereal- and antisidereal-daily variations in vertical (a), south (b) and north (c), respectively. It is seen from these Figures that the phase of sidereal-daily variations observed doesn't change with the depth of registration but depends on the direction of particle arrival. The amplitude of sidereal-daily variation observed also depends on the direction. The phase of the antisidereal-daily variation observed for the vertical direction shifts to the earlier time with the depth of registration. It should be noted the strong dependence of phase of this variation on the direction of registration.

Fig. 2 gives sidereal-daily and antisidereal-daily variations for the South-North difference after taking into account of geomagnetic field influence. Both variations in phase and amplitude doesn't strongly differ from each other, and such a property doesn't change with a depth. It should be noted that these variations are free from the atmospheric influence.

Table 1 lists the amplitudes and phases of the first harmonics of sidereal-, antisidereal- and solar-daily variations observed for the South-North difference after taking into account of geomagnetic field influence.

It is supposed that the daily variation observed in the sidereal time reflects the really existing anisotropy in the siderical coordinate system and the spurious variation is caused by the modulation of solar-daily variation. Contributions of atmospheric and other noise in the sidereal time are excluded by the differences of S-N telescopes.

The modulation of solar variations is described as follows:

$I(t) = A_0[1 + \alpha\cos(\omega_\odot t - \omega_\odot t_{year})]\cos(\omega t - \omega t_{max})$.

Here A_0 is the average amplitude of solar-daily variation, α is a relative depth of its annual variation, $\omega_\odot$ is a frequency corresponding to the period of 1 year, ω is a frequency corresponding to the period of 1 day, t_{year} is a season of the year (time is counted of the vernal equinox), when the amplitude of solar-daily variation is maximum, t_{max} is the maximum time of solar-daily variation.

From the above expression is seen that only the amplitude modulation is taken into account. This expression contains harmonics with three frequencies: ω, $\omega + \omega_\odot$, $\omega - \omega_\odot$, which can be named as variations in solar, sidereal and antisidereal time. The time of all three variations is counted from 00 h LT in the point of autumnal equinox. Thus,

$I(t) = A_0\cos(\omega_\odot t - \omega t_{max}) + A\frac{\alpha}{2}\cos[(\omega + \omega_\odot)t - (\omega t_{max} + \omega_\odot t_{year})] + A\frac{\alpha}{2}\cos[(\omega - \omega_\odot)t - (\omega t_{max} - \omega_\odot t_{year})]$.

In order to find a spurious variation in the sidereal time it is necessary to use information on antisidereal variation observed. The amplitudes of both variations are the same, and phases differ by the sign of value $\omega_\odot t_{year}$. Because the phase ωt_{max} is determined from the solar-daily variation, then the phase $\omega_\odot t_{year}$ can be obtained from the antisidereal variation and substituted into the expression for the spurious variation in the sidereal time.

Knowing the parameters of the observed solar-, sidereal- and antisidereal-daily variations for the South-North difference after the correction for the geomagnetic field with the help of above expression one can estimate the value of spurious and true sidereal-daily variations. It is seen from Table 2 that the amplitude of true sidereal anisotropy is $0.052 - 0.063\%$ at the depths of $0 \div 20$ m w.e. with the maximum time within $0 - 1,5$ h.

We have also estimated the value of sidereal-daily variation of atmospheric origin(see Table 3). It is seen that on the Earth's surface the sidereal variation of the atmospheric origin changes depending on the direction of the particle arrival in amplitude within $0,013 - 0,018\%$ and in phase within $2,8 - 3,3$ h. At the depth of 7 m w.e. and lower the sidereal-daily variation of atmospheric origin is practically absent.

Conclusions

The assumption that the solar-daily variation undergos the amplitude modulation allows to estimate a true sidereal anisotropy and spurious sidereal-daily variation of modulation and atmospheric origin correctly. A true sidereal anisotropy and spurious sidereal-daily variation of modulation character in value do not almost differ. The time of maximum of true sidereal anisotropy on the average at all registration levels is equal to 0,7 h. The sidereal-daily variation of atmospheric origin should be taken into account only for the muon telescopes located on the Earth's surface. The atmospheric contribution into the sidereal anisotropy is insignificant at depths more than 7 m w.e.

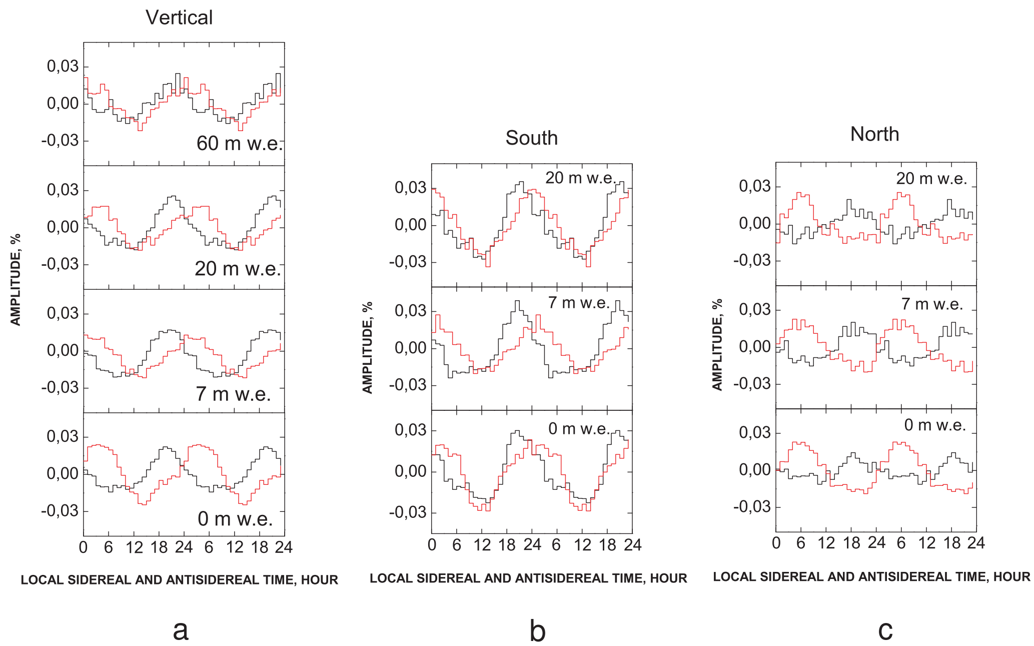

Figure 1: Observed sidereal-daily (black line) and antisidereal-daily (red line) variations in the local sidereal and antisidereal time for various registration levels.

m w.e.	Sidereal		Antisidereal		Solar	
	Amp., %	Phase, h	Amp., %	Phase, h	Amp.,%	Phase, h
V 0	0.016±0.002	19.6±0.4	0.022±0.002	2.9±0.3	0.147±0.002	14.1±0.1
V 7	0.019±0.002	19.9±0.5	0.015±0.002	1.3±0.6	0.103±0.002	14.5±0.1
V 20	0.019±0.003	20.9±0.6	0.015±0.003	1.8±0.7	0.071±0.003	14.3±0.2
V 60	0.013±0.005	20.9±1.5	0.014±0.005	0.5±1.2	0.034±0.005	14.2±0.6
N 0	0.008±0.003	19.4±1.3	0.020±0.003	5.9±0.5	0.137±0.003	12.7±0.1
N 7	0.014±0.004	19.1±1.0	0.018±0.004	6.0±0.8	0.086±0.004	12.4±0.2
N 20	0.011±0.005	17.8±1.7	0.016±0.005	5.7±1.2	0.058±0.005	12.0±0.4
S 0	0.023±0.003	21.8±0.5	0.023±0.003	0.0±0.5	0.144±0.003	15.2±0.1
S 7	0.026±0.004	20.2±0.6	0.018±0.004	0.5±0.8	0.126±0.004	15.7±0.1
S 20	0.026±0.005	21.5±0.8	0.025±0.005	23.8±0.8	0.086±0.005	15.7±0.2
SN 0	0.035±0.004	21.1±0.4	0.050±0.004	18.9±0.3	0.166±0.004	17.3±0.1
SN 7	0.021±0.005	20.0±1.0	0.035±0.005	19.1±0.6	0.148±0.005	16.6±0.1
SN 20	0.026±0.008	21.6±1.1	0.032±0.008	20.4±0.9	0.083±0.008	17.1±0.4

Table 1: The observed sidereal-, antisidereal- and solar-daily variations.

m w.e.	Spurious		True	
	Amp., %	Phase, h	Amp., %	Phase, h
0	0.056±0.006	15.8±0.4	0.052±0.006	1.5±0.5
7	0.041±0.007	14.0±0.6	0.053±0.007	0.0±0.5
20	0.040±0.008	13.8±0.7	0.063±0.008	0.6±0.5

Table 2: The spurious and true sidereal-daily variations.

m w.e.	Vertical		South		North	
	Amp., %	Phase, h	Amp., %	Phase, h	Amp.,%	Phase, h
0	0.013±0.002	3.0±0.6	0.018±0.003	3.3±0.7	0.016±0.003	2.8±0.8
7	0.006±0.003	22.5±1.8	0.004±0.005	21.0±3.4	0.008±0.005	0.3±4.3
20	0.003±0.004	19.5±3.5	0.001±0.006	9.4±5.4	0.007±0.007	18.5±3.0

Table 3: The sidereal variation of the atmospheric origin.

Acknowledgements

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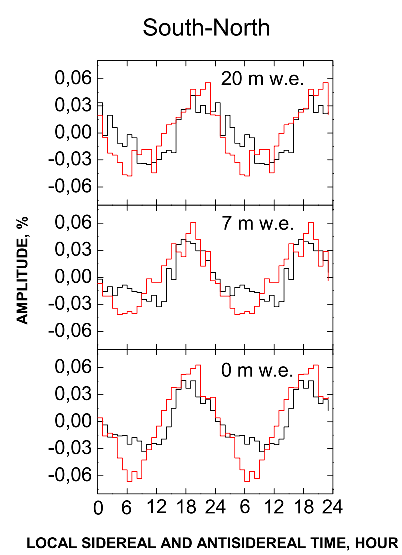

Figure 2: Sidereal-daily (black line) and anti-sidereal-daily (red line) variations in the local sidereal and antisidereal time for the South-North difference.