



Long Term Average Observation of First Two Harmonics of Cosmic Ray Daily Variation

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Abstract: Cosmic ray daily variation is directly related with changes in interplanetary conditions. The significant and systematic deviations in the amplitude and phase of the diurnal, semi-diurnal variation of cosmic rays from the average values is due to strong geomagnetic and solar activity. The amplitudes and phases (time of maxima) of first two harmonics of cosmic ray daily variation show 11/22 years variability. In the present study the observational values of 22nd and 23rd cycle for various harmonics, particularly at neutron monitor energies have been used to compare their characteristic values. As the latitude of NM station gets higher, the phase gets delayed, that is, the phase shifted to the later hour. For first harmonic we also observed that for both the stations the time of maxima shifted to earlier hours during solar minima (II-Quadrant) for solar cycle 22 and for solar cycle 23, the time of maxima shifted to later hours. The amplitudes are found to be larger for maxima and for the descending phase of solar cycle for both the stations. The semi-diurnal amplitudes vary from the range of 0.01% to 0.08%. However, the spread of phases is larger, in comparison to diurnal anisotropy. The spread is to be found much larger during the high solar activity period. The time of maxima for KIEL station spreads in I and IV quadrant.

Keywords: Cosmic rays, solar activity, diurnal variation, annual average vector, harmonic dial.

I. Introduction

The discovery of cosmic rays opened up a new window to add various dimensions of interplanetary space. The different kinds of time -variations of primary cosmic radiation operating over different scales of times are the solar flare increase lasting over a period of minutes to an hour or more, the Forbush decrease lasting over a period of a fraction of a day and recovery over days and the long term change in intensity, the daily variation of Cosmic-Ray Intensity etc. The daily variations in the cosmic-ray intensity arise from spatial anisotropies in interplanetary space. The anisotropy appears generally to be due to two principal processes, one a modulation equivalent to a pair of oppositely directed positive and negative sources, and the other a negative virtual source approximately oriented along the garden hose direction towards the Sun [10]. In addition to the prominent diurnal component, the daily variation is composed of at least two more contributions of lesser amplitudes, i.e., semi-diurnal and tri-diurnal components. Cosmic ray daily variation is directly related with changes in interplanetary conditions. The significant and systematic deviations in the amplitude and phase of the diurnal, semi-diurnal and tri-diurnal variation of cosmic rays from the average values is due to strong geomagnetic and solar activity. The amplitudes and phases (time of maxima) of first three harmonics of cosmic ray daily variation show 11/22 years variability. In general, two techniques have been involved to study the solar daily variation: the Fourier series (harmonics) and the power spectral methods. The power spectral method provides excellent estimates of the amplitude of the diurnal anisotropy independent of any phase shifts in the daily anisotropy. In contrast, the Fourier analysis yields reliable measures of the amplitude and phase on a day-to-day basis, provided the time-series is reasonably stationary. The average diurnal anisotropy before 1970 was essentially time-invariant ([1],[3]) and was accounted for in terms of the convection-diffusion model [2]. The balance between convection and diffusion generates an energy independent anisotropic flow of cosmic ray particles.

Long-term variations of the cosmic ray diurnal anisotropy have been examined using neutron and muon monitor data for all days ([4],[5]) and for only geomagnetically quiet days in a year ([12],[13]). The total diurnal anisotropy consists of two modulation components, one related to the ~ 22-year solar magnetic cycle and the other to a ~11-year solar activity cycle ([5],[14]) they observed that for a wide range of rigidities, the direction of the ~22-year component was roughly perpendicular to the average diurnal anisotropy vector and along 162° east of the Earth-Sun line, deviating significantly from the IMF direction and the ~11-year component was essentially due to the variation in the upper cut-off rigidity. Energetic particles in the interplanetary space walk randomly in irregularities of the large-scale IMF when irregularities are moving with the solar wind velocity. The distribution function determined by a Fokker-Planck equation describes the time

evolution of the probability density function of the position and momentum of particle. In addition to the convection and diffusion, CRs experience two additional effects. One of them is the acceleration or deceleration. Solar wind plasma is expanding in free space and compressing at the shocks near the planets or in the interplanetary space. Modulation of GCR in the inner heliosphere is controlled by convection in solar wind, diffusion, particle drifts and adiabatic energy losses ([6],[11]).

II. Data and Method of Analysis

In the present analysis, we have derived the annual mean values of amplitudes and phases of the diurnal and Semi diurnal variation of cosmic ray intensity variation for the period of 1986-2010 covering solar activity cycle 22 and 23 for Beijing and Kiel neutron monitor stations. The amplitudes and phases of diurnal variations are derived using the technique of harmonic analysis. We have used pressure and temperature corrected hourly neutron monitor data for Kiel (2.32Gv), Beijing (10.09Gv) neutron monitor stations. The amplitudes and phases of the harmonics of cosmic ray daily variation have been obtained on day to day basis for the whole period of solar cycles 22 & 23, starting from 1986 to 2010. A 24 hours moving average technique is also adopted to remove the long-term trend. The annual average for each station after rejecting the universal time affected days are identified. The vector addition diagram and harmonic dial representations are used in the study. These are quite important to observe the complete variability in cosmic ray daily variation from year to year on long term basis.

III. Result and Discussion

The vector addition technique is applied to derive the long-term behavior of diurnal anisotropy. We have drawn the annual average vectors of diurnal variation for the periods of 1986 to 2010 using the Beijing and Kiel neutron monitors data as shown in figure 1 (a, b). In these figures, the annual average values for diurnal vectors have been plotted for the entire period of study. We also studied the amplitude (%) and phase (Hrs.) variations for both of the stations covering solar cycle 22 and 23. Similar to diurnal anisotropy, we have again done the similar vector addition analysis for semi-diurnal variation of cosmic rays using the Beijing and Kiel neutron monitors data. Figures-2(a, b) show the annual average vectors of semi-diurnal components of cosmic ray daily variation for the period of 1986 to 2010. Annual averages used in this analysis are deduced from using the Beijing and Kiel neutron monitors data. In these figures the annual values for semi-diurnal vectors have been plotted end point to end point for the entire period of study in the form of vector addition diagram. The average values are shown in figure by the dashed lines for both Beijing and Kiel stations. The average values of Beijing and Kiel stations for First and Second Harmonics have been calculated which are as follows:

	Annual average amplitude		Annual average phase	
Station	Beijing	Kiel	Beijing	Kiel
I-Harmonic	$R_1 = 0.211\%$	$R_1 = 0.26\%$	$\theta_1 = 173^\circ$	$\theta_1 = 205^\circ$
II-Harmonic	$R_2 = 0.029\%$	$R_2 = 0.032\%$	$\theta_2 = 12^\circ$	$\theta_2 = 3^\circ$

There is a remarkable correspondence in the changes of the diurnal component for both the stations. We have found smaller amplitudes during the lower Sunspot activity period and substantially larger amplitudes during the high Sunspot solar activity periods. We noticed that the amplitudes are significantly larger in solar cycle 23 than that of solar cycle 22.

The harmonic dial vector analysis of the annual average values for the first and second harmonics at low and high latitude neutron monitor stations for the period of 1986 to 2010 is carried out for Beijing and Kiel shown in the fig.3(a, b) and 4(a, b) respectively. For first harmonic, we also observed that for both the stations the time of maxima shifted to earlier hours during solar minima (II-Quadrant) for solar cycle 22 and for solar cycle 23, the time of maxima shifted to later hours. The amplitudes are found to be larger for maxima and for the descending phase of solar cycle for both the stations. Similar results have been reported by many other investigators ([1],[8],[5],[7],[9],[15]). The semi-diurnal amplitudes vary from the range of 0.01% to 0.08%. However, the spread of phases is larger, in comparison to diurnal anisotropy. The spread is found to be much larger during the high solar activity period. The time of maxima for KIEL station spreads in I and IV quadrant but for low latitude station Beijing, we find that the phase spreads in all quadrants which needs further investigation.

IV. Conclusion

1. The amplitudes and phases of first two harmonics are calculated for the period of 1986 to 2010, using the hourly values of Beijing and Kiel neutron monitor stations. We found a remarkable correspondence in the changes of diurnal and semi-diurnal components for both the stations.
2. We applied the vector addition technique and harmonic dial representation for the diurnal and semi-diurnal amplitudes and phases of cosmic rays intensity variation observed for the same period.
3. For first harmonic, we observed that for both the stations the time of maxima shifted to earlier hours during solar minima for solar cycle 22 and for solar cycle 23, the time of maxima shifted to later hours. The amplitudes are found to be larger for maxima and for the descending phase of solar cycle for both the stations.
4. The semi-diurnal amplitudes vary from the range of 0.01% to 0.08%. However, the spread of phases is larger, in comparison to diurnal anisotropy. The spread is found to be much larger during the high solar activity period.

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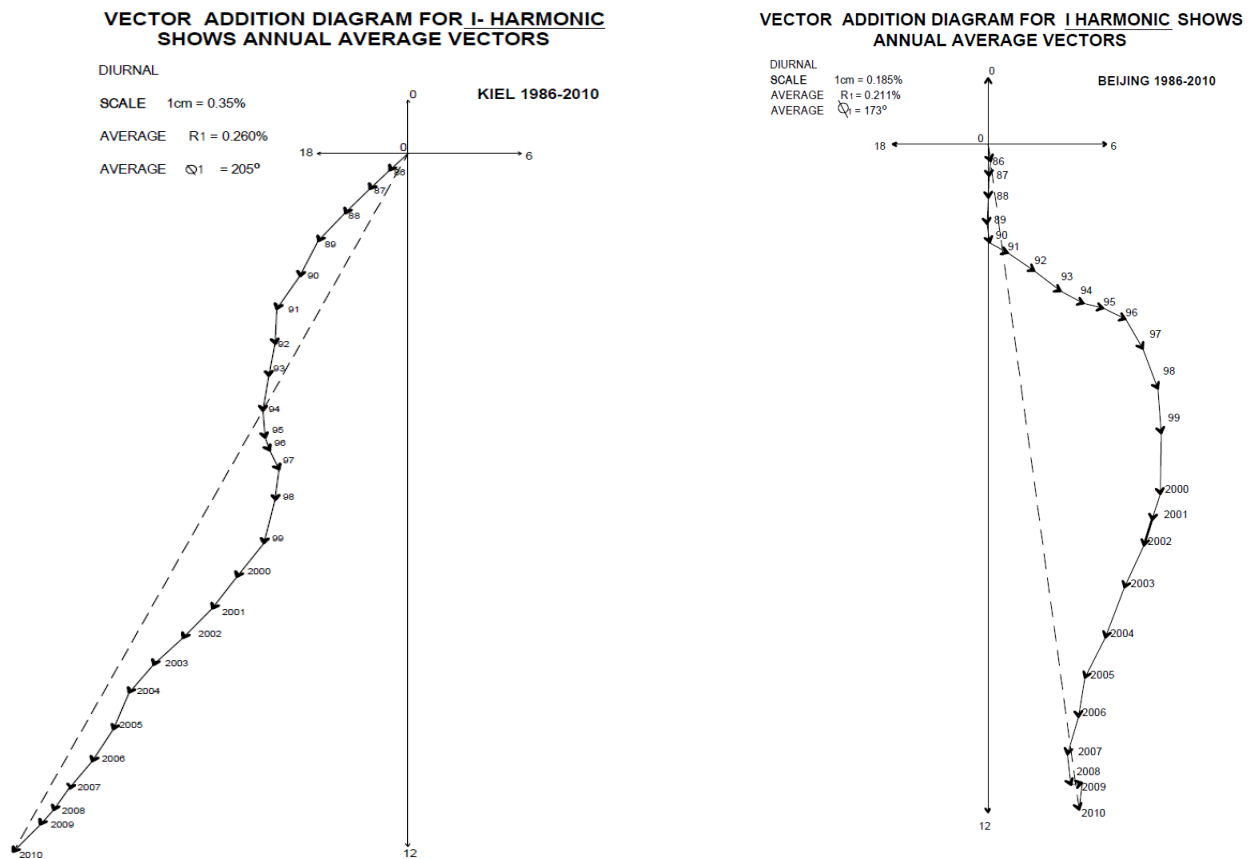


Figure-1(a, b) Mean annual diurnal vectors for the period 1986 to 2010 for Beijing and Kiel. The length of the vector gives the amplitude and the angle, with respect to the given axes of coordinates, gives the hour of maximum.

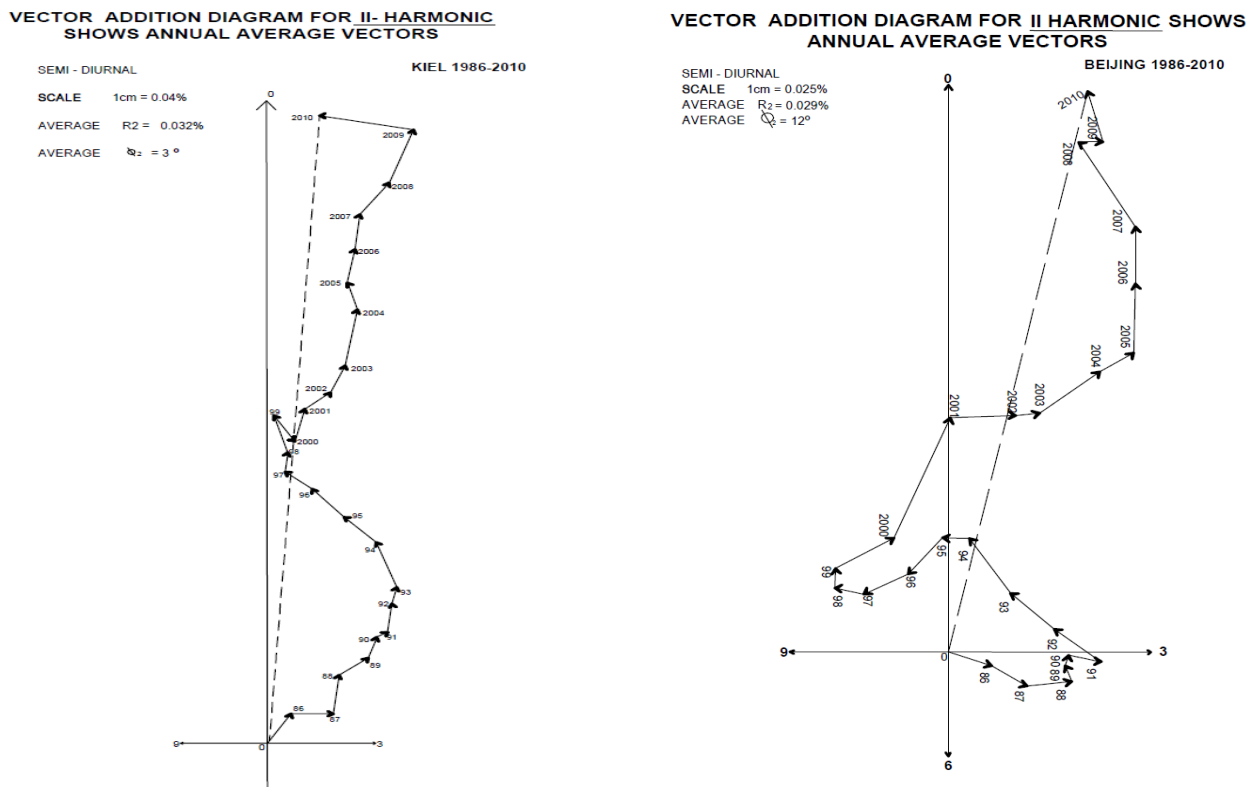


Figure-2(a, b) Mean annual semidiurnal vectors for the period 1986 to 2010 for Beijing and Kiel. The length of the vector gives the amplitude and the angle, with respect to the given axes of coordinates, gives the hour of maximum.

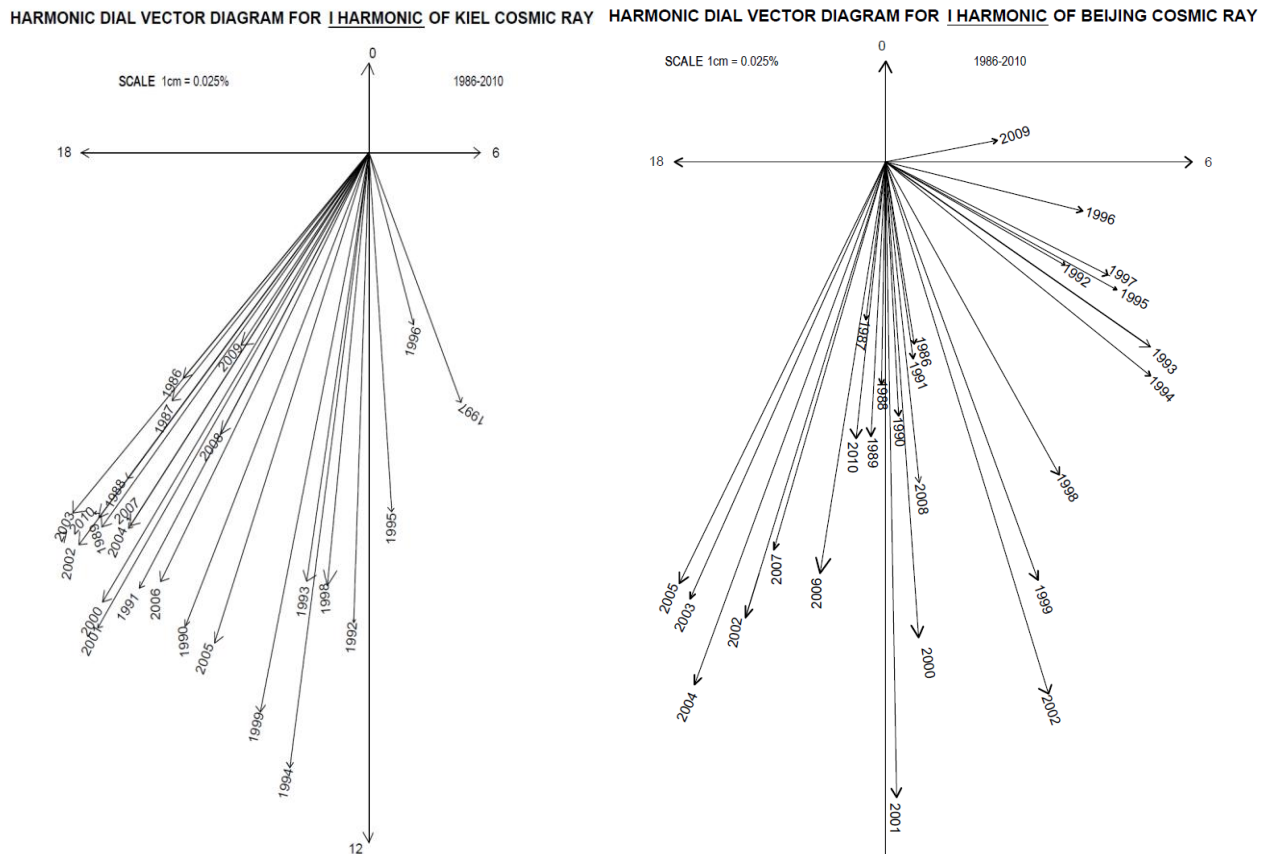


Figure-3(a, b) The harmonic dial representation of the annual average values for the first harmonics for Beijing and Kiel neutron monitor stations for the period of 1986 to 2010.

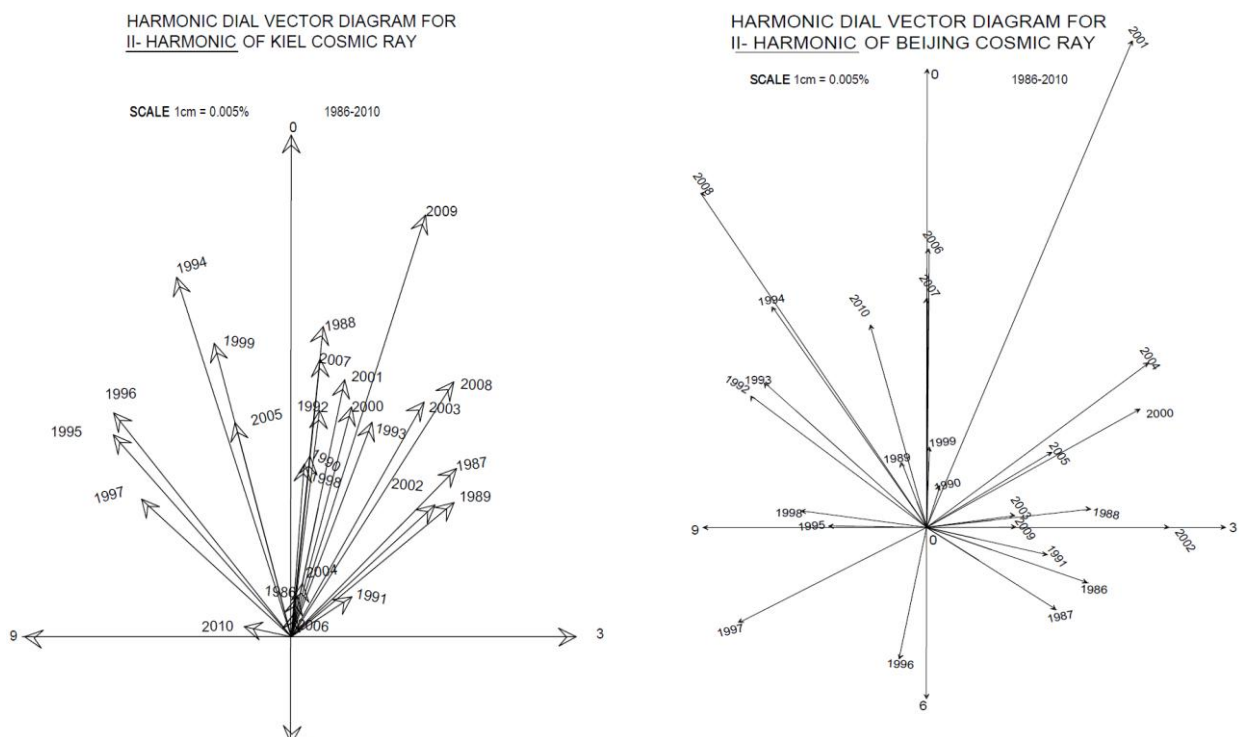


Figure-4(a, b) The harmonic dial representation of the annual average values for the second harmonics for Beijing and Kiel neutron monitor stations for the period of 1986 to 2010.