Long-Term Datasets for the Understanding of Solar and Stellar Magnetic Cycles
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Heliospheric Modulation of Cosmic Rays and Solar Activity during Solar Cycles 22-24

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Abstract. We have studied, the relationship between monthly variations of average counting rates of cosmic ray intensity (CRI) at Moscow super neutron monitoring station with mid cut-off rigidities ($\sim 2.42\ GV$), and the solar radio flux at $10.7cm$ ($F10.7$) and sunspot number (SSN) during the solar cycles $22-24$. The $F10.7cm$ ($2800\ MHz$) and SSN is an excellent indicator of solar activity for the study period. We have investigated the patterns of long-term and mid-term periodicities of SSN and $F10.7$, using Fast Fourier Transform (FFT) technique. We have observed the time-lag between ascending phase of CRI with $F10.7cm$ and SSN during solar cycles $22-24$.

Keywords. Solar Activity (SSN, F10.7 cm), Cosmic Ray Intensity (CRI)

1. Introduction

The Sun oriented several phenomena are continuously occurring on the surface of the Sun, like solar flares, coronal holes, coronal mass emission,SSN etc. The sunspot number (SSN) is a photospheric index of solar activity and solar radio flux at 2800 MHz has also been quantified in the form of solar activity. Sunspots number is the oldest parameter of solar activity parameter, but 2800 MHz (10.7 cm) solar flux parameter is available from since 1947. The effect of convection is due to the outflow of the solar wind, which can reduce the cosmic ray intensity (CRI) at any point of the heliosphere. The cosmic ray intensity (CRI) modulation is controlled by global solar activity, which affects the conditions of the cosmic rays (CRs) propagation within the heliosphere. The heliospheric effect of cosmic rays is encountering a turbulent solar wind with an embedded heliospheric magnetic field (HMF). The anisotropy variations of the cosmic ray intensity are only observed in the heliospheric region and can be easily detected by ground-based detectors, Heber *et al.* (2006). In the long -term, periodicity presents the 11 years sunspot cycle (Schwabe cycle) and for short-term, periodicity $\sim 27\ days$ is the most important, Forbush (1958). The variations in solar activity have established periods of about $\sim 27\ days$ and $\sim 11\ years$, and between these, it is called the mid-term periodicity, Modzelewska *et al.* (2013), Singh *et al.* (2018).

2. Method and Data Analysis

The monthly pressure-corrected data CRI are available at the mid cut-off rigidities of neutron monitoring station Moscow ($\sim 2.42\ GV$) (http://cosmicrays.oulu/readme.html). The monthly values of sunspot numbers (SSN) and solar radio flux ($F10.7cm$) are taken from National Geophysical Data Centre (NGDC) (http://www.ngdc.noaa.gov/ngdc.html). We have used the error bar for normalized cross-correlation between SSN and $F10.7cm$ with CRI, for all possible time-lags in the ascending phase during solar cycles $22-24$

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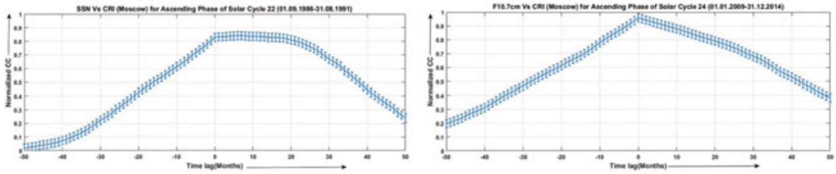

Figure 1. Cross-correlation coefficients as a function of time-lag between CRs with SSN and F10.7cm, for the ascending phase of solar cycles 22- 24.

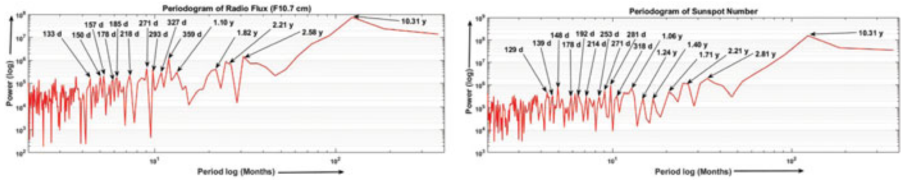

Figure 2. Periodogram analysis of the monthly data for SSN, and F10.7cm by fast Fourier transformation technique during the combined solar cycles 22-24

(1986 − 2016).We have predicted periodicities of SSN and $F10.7\ cm$; by the periodogram of Fast Fourier Transform (FFT) technique.

3. Results and Discussion

Figure1 shows the cross-correlation, time-lag, and their statistical errors bar between solar activity (SSN and F10.7cm) with CRI for the ascending period of 1986 – 2016. The value of the cross-correlation coefficient with 95% significance level at top of the curve is almost flat and their time-lags of the study period. It is observed that during the ascending phase a positive time-lag implies that the recovery of the solar activity (such as SSN and F10.7cm) is faster than the CRI. The time-lags between CRI and SSN for ascending phase of solar cycle 22 is remarkably large and reaches $0 - 18$ months with a correlation coefficient ($R = 0.830 - 0.821$), and for cycle 23,$0 - 14$ months with ($R = 0.828 - 0.820$), and for cycle 24,$0 - 12$ months with ($R = 0.832 - 0.825$). The solar radio flux (F10.7cm) shows the maximum correlation with zero time lags for the ascending phase of solar cycle 24 ($R = 0.953$), and for solar cycle 22 ($R = 0.918$), and for solar cycle 23 ($R = 0.928$).Therefore we conclude that the maximum of the SSN and F10.7cm, do not coincide exactly with the minimum of the CRs (CRI), indicating that there is a time-lag between these time series.

Figure 2 shows, the periodogram of FFT for monthly average data of SSN and F10.7 cm has been calculated periodicity for combined solar cycles 22-24 (1986 – 2016). We have investigated the long-term periodicity of SSN and F10.7 cm is $\sim$ 10.31 years. The power spectra shows the periods for SSN and F10.7 cm in Reigertype is ($\sim 120 - \sim 192d$), and intermediate-term is ($\sim 214 - \sim 327d$), and Mid-term is ($\sim$ 1.10$-\sim$ 2.81 years), and the quasi-annual period for SSN is$\sim 382d$ and for F10.7cm$\sim 359d$, by spectral decomposition methods of FFT. We have reported that the significant period of SSN is$\sim$ 1.24 *years* and it is the change of rotational speed near the base of convection zone for the period 1986-2016.

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