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Dynamic complexity based analysis on the relationship between solar activity and cosmic ray intensity

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Abstract. The Earth's atmosphere is incessantly bombarded by energetic charged particles called cosmic rays (CR) which are having either solar or non-solar origin. Analysis based on information theoretic estimators can be effectively employed as a potential technique to analyze the dynamical changes in cosmic ray intensity during different solar cycles. In the present study, dynamical complexity based analysis using Jensen-Shannon divergence (JSD) has been employed which reveals the existence of some peculiar fluctuation properties in CRI flux at Jung neutron monitor station. JSD based dynamical complexity analyses confirm the existence of difference in dynamical properties of CR flux during solar cycles 20-21 and 22-23.

Keywords. Dynamical complexity, Jensen-Shannon divergence

1. Introduction

The variations in cosmic ray intensity (CRI) are continuously measured by ground station neutron monitors (NMs), operated at different geomagnetic cutoff rigidities, which are sensitive to energies of CRs. The flux rate of cosmic rays incident on the upper layers of Earth's atmosphere is modulated mainly by the solar wind. The 11-year solar cycle variations in CRI is anticorrelated with SSN (sunspot number) (Shuai Fu et al. 2021).

2. Data and Method

JSD can be considered as an information theoretic divergence estimator that measures the similarity between two distributions (Yin et al. 2020). When compared with the famous divergence estimator called Kullback-Leibler (KL) divergence, JSD is symmetric and is able to handle non-overlapped distributions thus leading to a smoother manifold. It is possible to determine the dynamical complexity derived from divergence measures of distributions (Schiepek and Strunk 2010). The dynamical complexity combines a 'fluctuation measure' which is sensitive to variations in amplitude or frequency of the time series and a 'distribution measure' which identifies the deviation of the data values from an ideal identical distribution over the range scale. The two measures are computed within a sliding window moving over the time series (for details regarding the method authors may refer to Kaiser 2017). Figure 1(a)-(d) shows the variation of JSD, dynamical complexity, SSN and CRI from which JSD has been calculated and the average dynamical complexity for different lags. While JSD varies between 0 and 1, the

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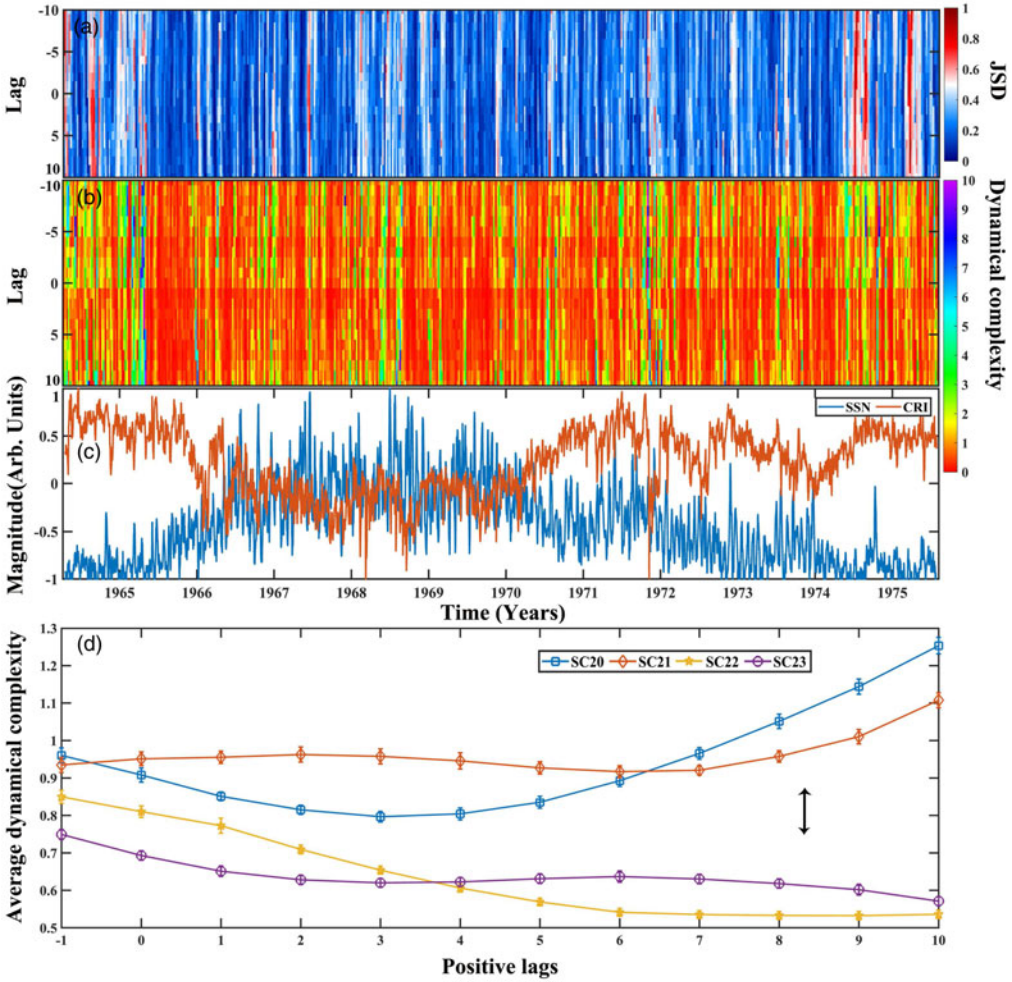

Figure 1. JS divergence analysis of solar cycle 20 for time lagged data at Jung: (a) JSD for lags -10 to 10, (b) Dynamical complexity for lags -10 to 10, (c) SSN and CRI variations for solar cycle 20, & (d) The variation of average dynamical complexity for solar cycles 20-23.

dynamical complexity varies between 0 and 10 with lower values being less complex and higher values show high degree of complexity.

3. Results and Conclusion

The variations in spectra during the periods of 1965, 1972, 1975 are due to higher divergence of associated distributions of SSN and CRI which in turn reflect in the dynamical complexity also. A peculiar bipartite pattern is seen for dynamical complexity between SC 20-21 and SC 22-23. Considering the 22-year Hale cycle, SC 20 and 21 mark the fall and rise periods with 1976 mark the minimum magnetic activity of the 22-year cycle. Similarly, SC 22 and 23 also characterize the descension and ascension periods where 1996 mark another magnetic minimum. This can also be interpreted on the grounds of earlier studies by Logachev et al. (2015). It is seen that there exists dynamical coupling in complexity of cosmic ray flux between 20-21 and 22-23 which is similar to the one reported for the proton data.

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References

Shuai Fu et al. 2021, *ApJS*, 254, 37.
Yin. Y., Wang, W., Li, Q., Ren, Z., and Shang, P. 2020, *Fluct.Noise Lett.*, 20, 2150013.
Schiepek, G. and Strunk, G. 2010, *Biol. Cybern*, 102, 197.
Logachev, Y.I., Bazilevskaya, G.A., Vashenyuk, E.V. et al. 2015, *Geomagn. Aeron.*, 55, 277.
Kaiser, T. 2017, *dyncomp: an R package for Estimating the Complexity of Short Time Series.*

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