On the Evolution of Dynamical Complexities in Space Environment Over Four Solar Cycles 1964 – 2008

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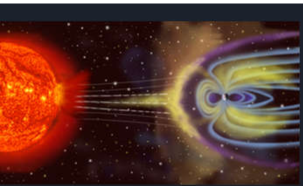
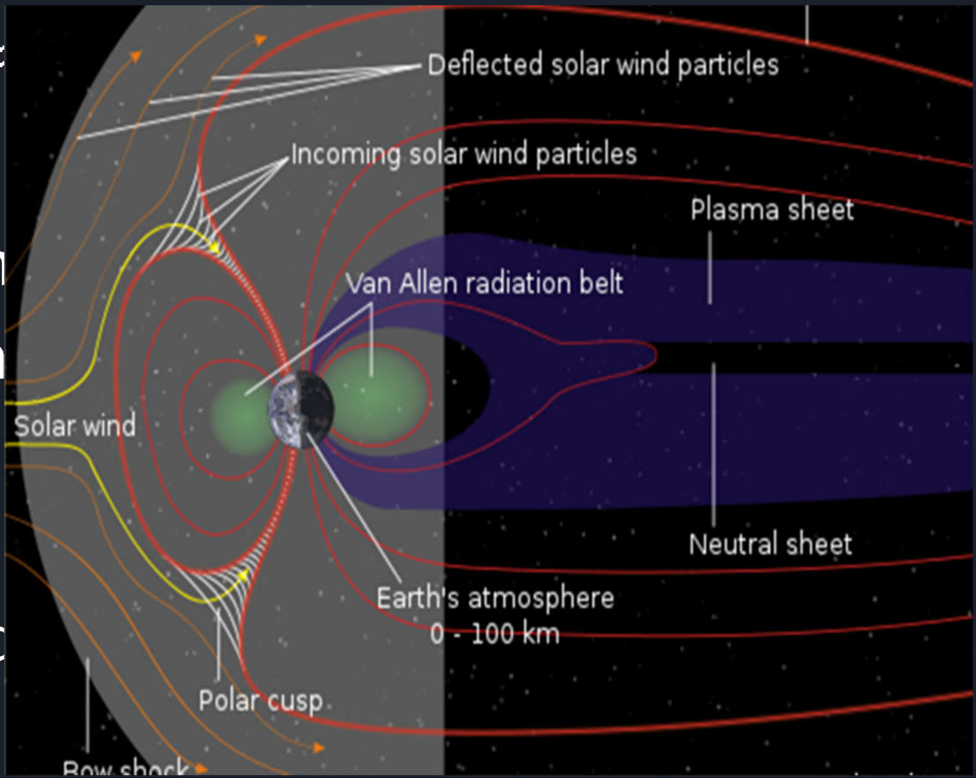
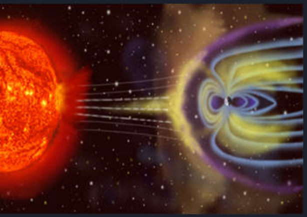


Geospace

- Geospace refers to the region of the outer space near Earth
- Geospace basically span through region of space which goes from the solar photosphere to the mesosphere of the Earth
- It is a complex system composec of several nonlinearly coupled subsystems (Donner et al, 2019)



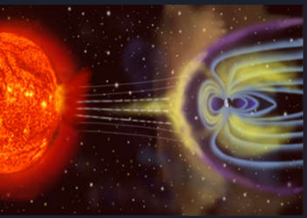


Dynamical complexities

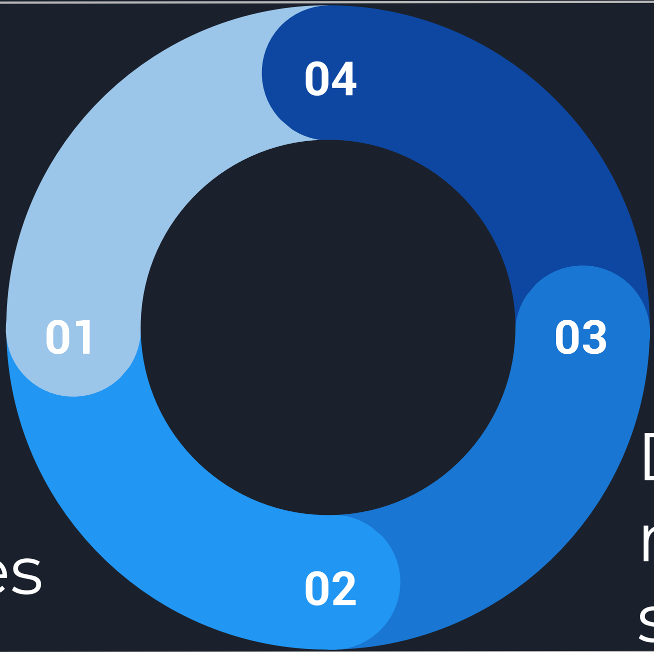
01 Linear approach cannot sufficiently capture the dynamics of complex systems, hence, the use of nonlinear techniques

02 Nonlinear techniques do not make assumption about the underlying probability distribution and are designed to capture the underlying dynamics.

03 Previous studies using nonlinear approaches have yielded interesting results Rabiu et al, 2015; Ogunjo et al. 2017



Objectives

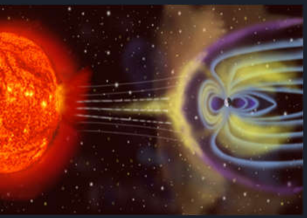


Examine the complexity in the magnetosphere

Compare the complexity measures with mean values

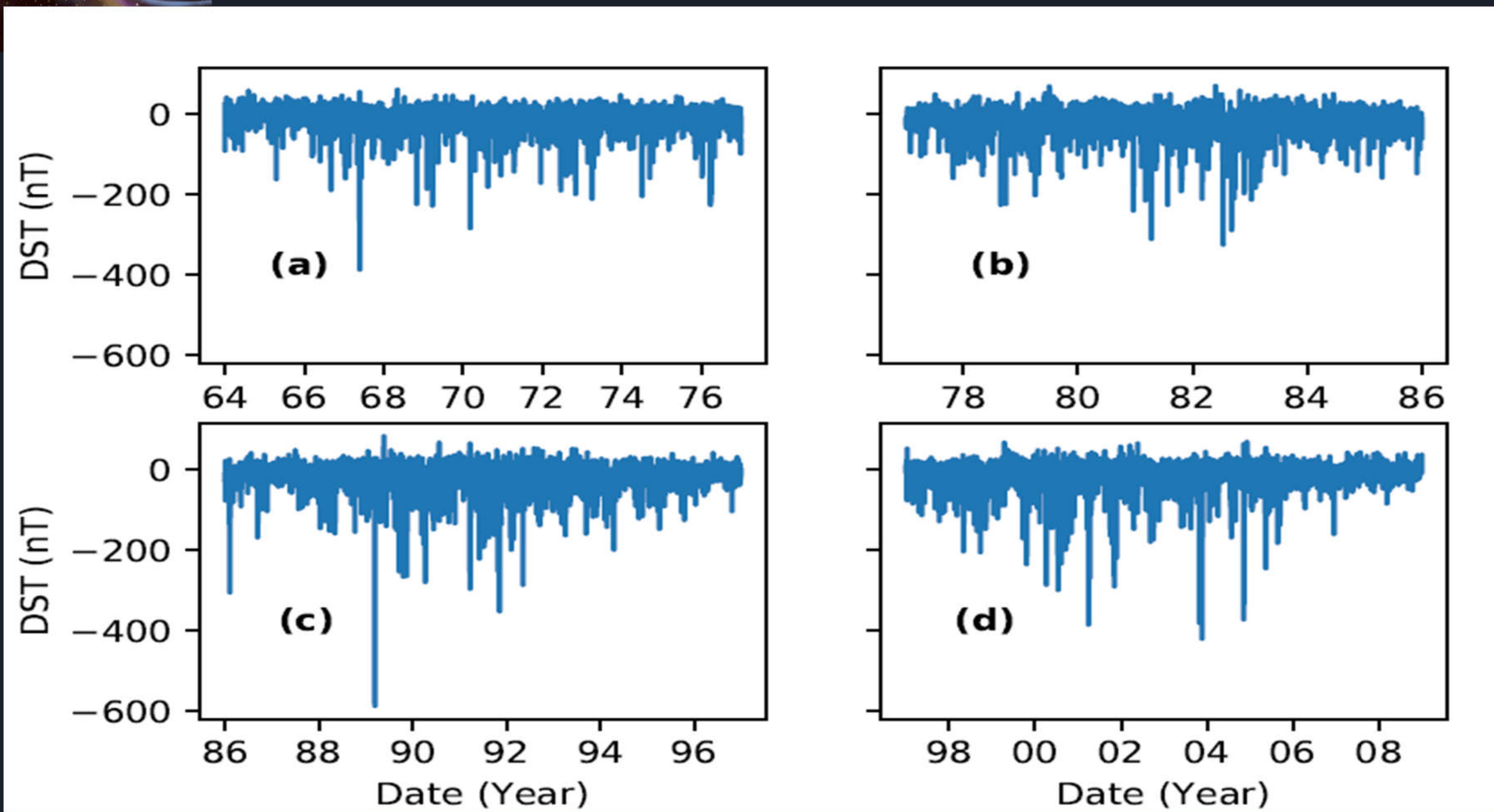
Determine multifractal structures in the magnetosphere

Variation in complexity over different solar cycles



RESULTS

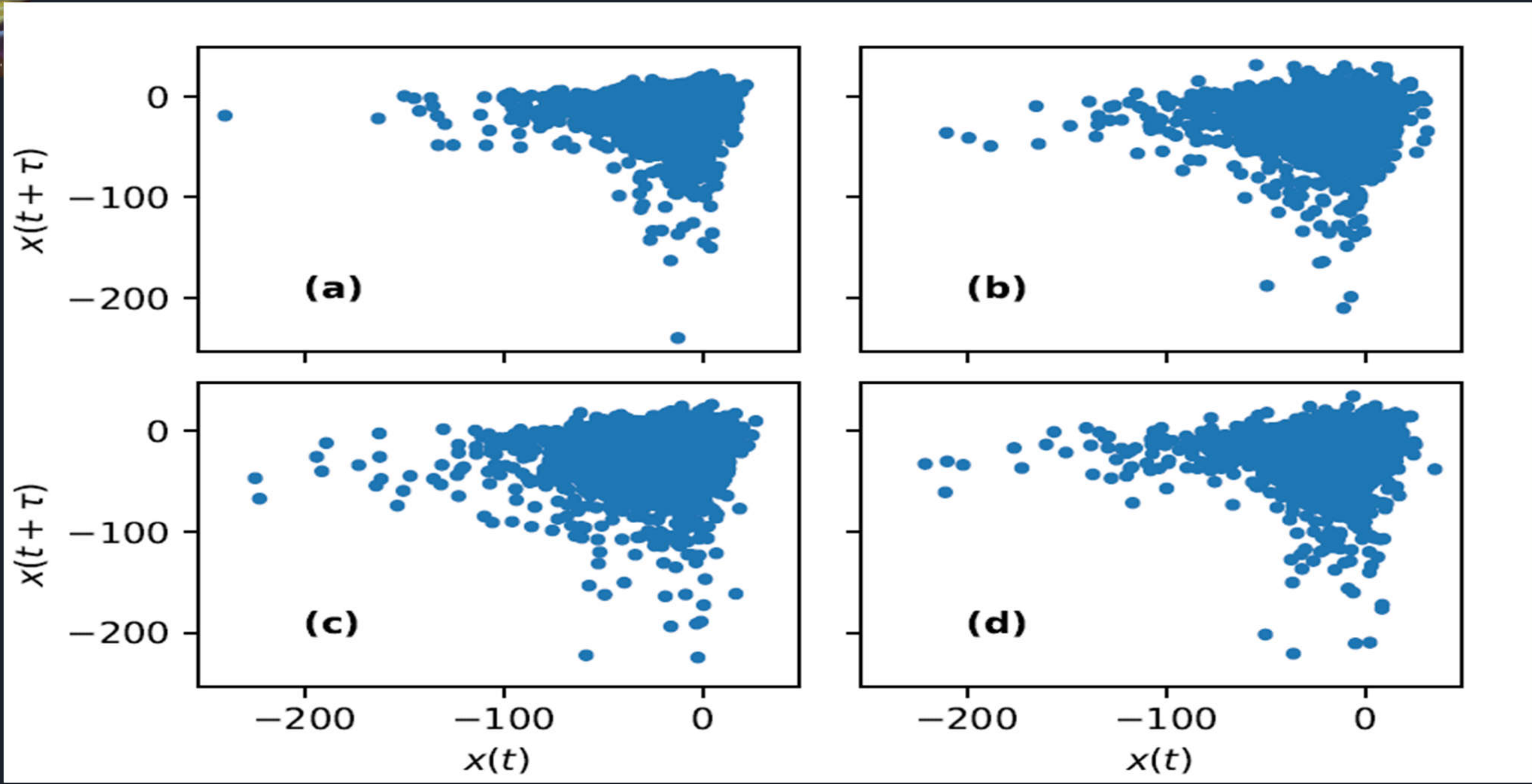
Time series over 4 solar cycles



Each solar cycle contains storms of different categories.

Time series of Dst values over each of the four solar cycles under consideration (a) 20 (b) 21 (c) 22 (d) 23

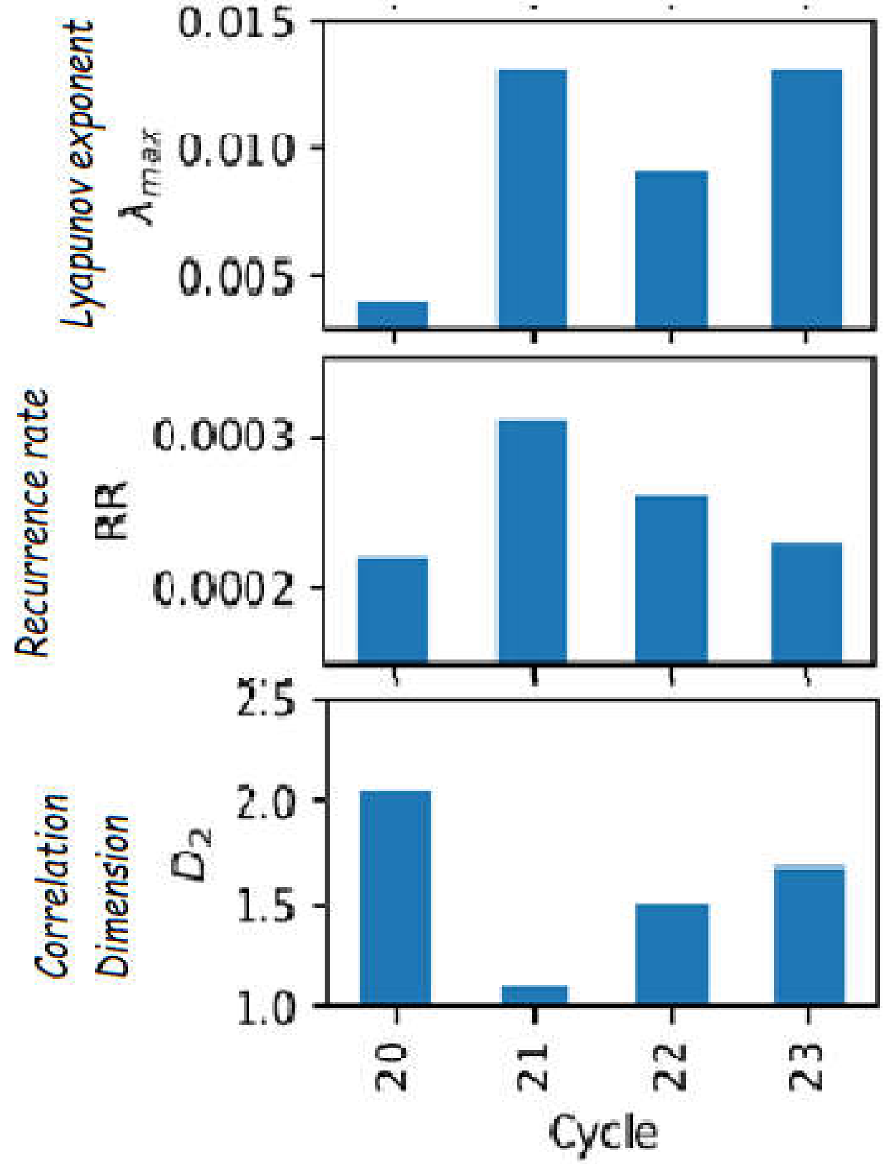
Phase space trajectories for each solar cycle

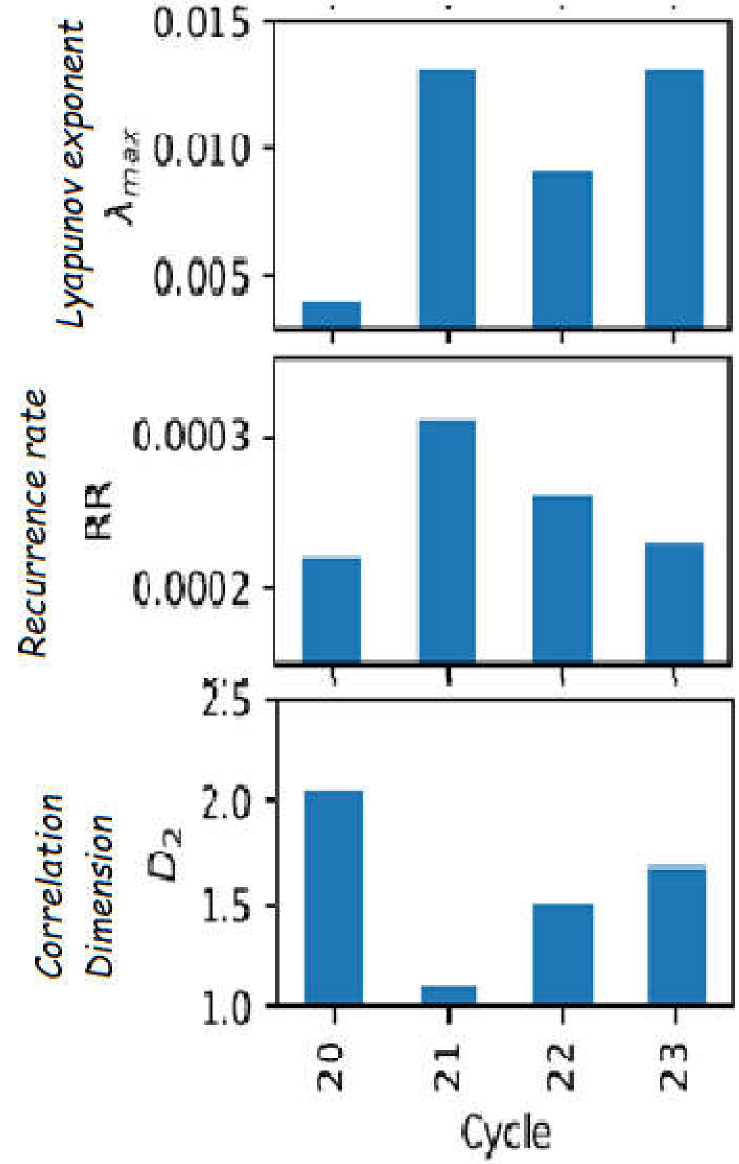


Phase space reconstruction of Dst signals in different solar cycles using Taken's embedding theorem. (a) 20 (b) 21 (c) 22 (d) 23

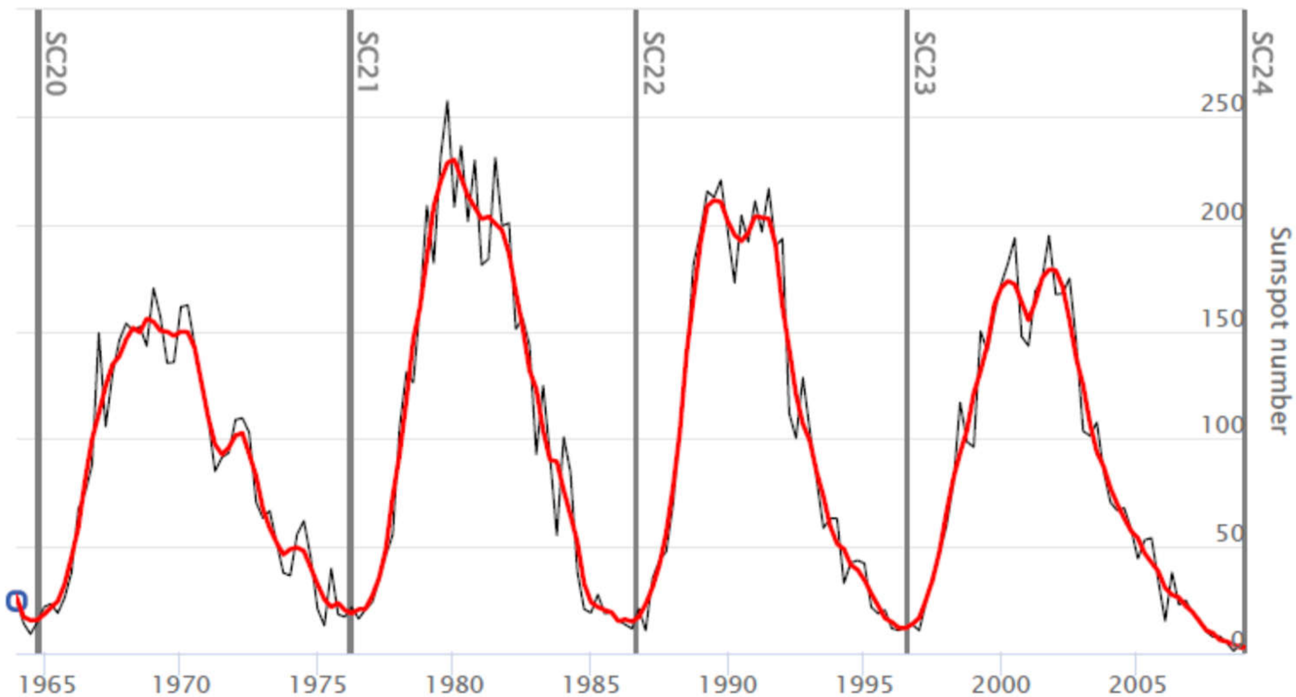
Nonlinear analysis of daily Dst values using:

- embedding delay (τ),
- embedding dimension (m),
- Sample Entropy (SpEn),
- Lyapunov exponent (λmax),
- recurrence rate (RR).
- correlation dimension (D2),





Order of chaoticity 20 > 23 > 22> 21



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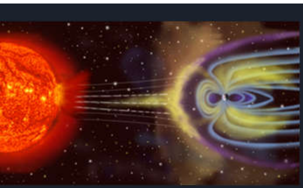
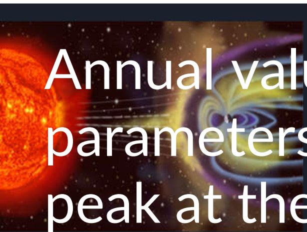


Nonlinear analysis of daily Dst values using:

- embedding delay (τ),
- embedding dimension (m),
- Sample Entropy (SpEn),
- Lyapunov exponent (λmax),
- correlation dimension (D2),
- recurrence rate (RR).

✓ The complexity in each solar cycle was estimated.

✓ our results showed that the most and least chaotic solar cycles are 20 and 21, respectively.

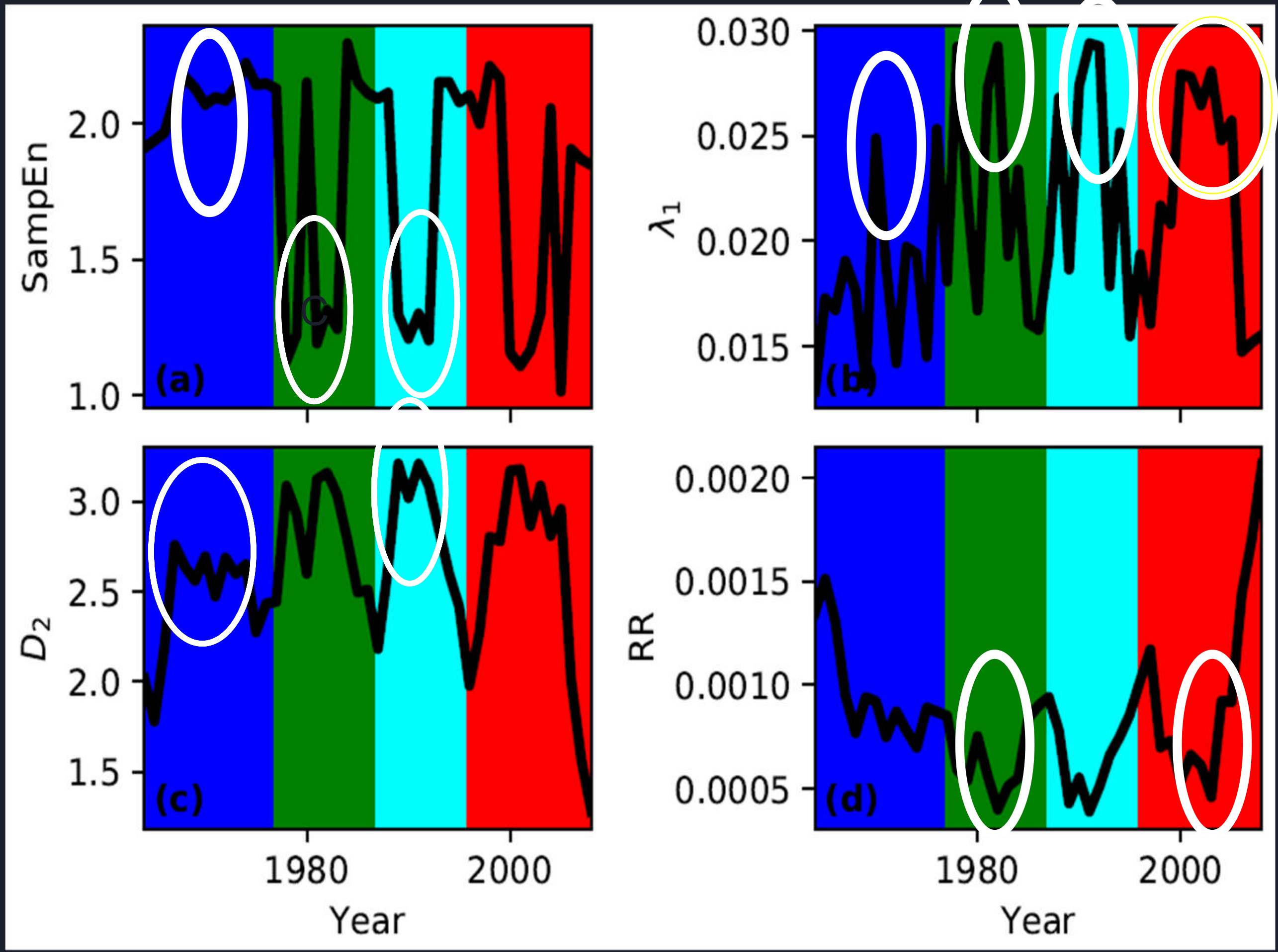


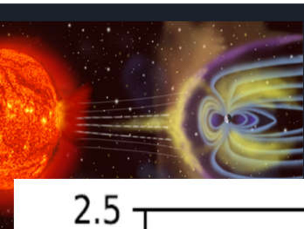
Temporal variations - Solar cycle

Annual values of chaotic parameters were found to peak at the maximum of the solar cycle.

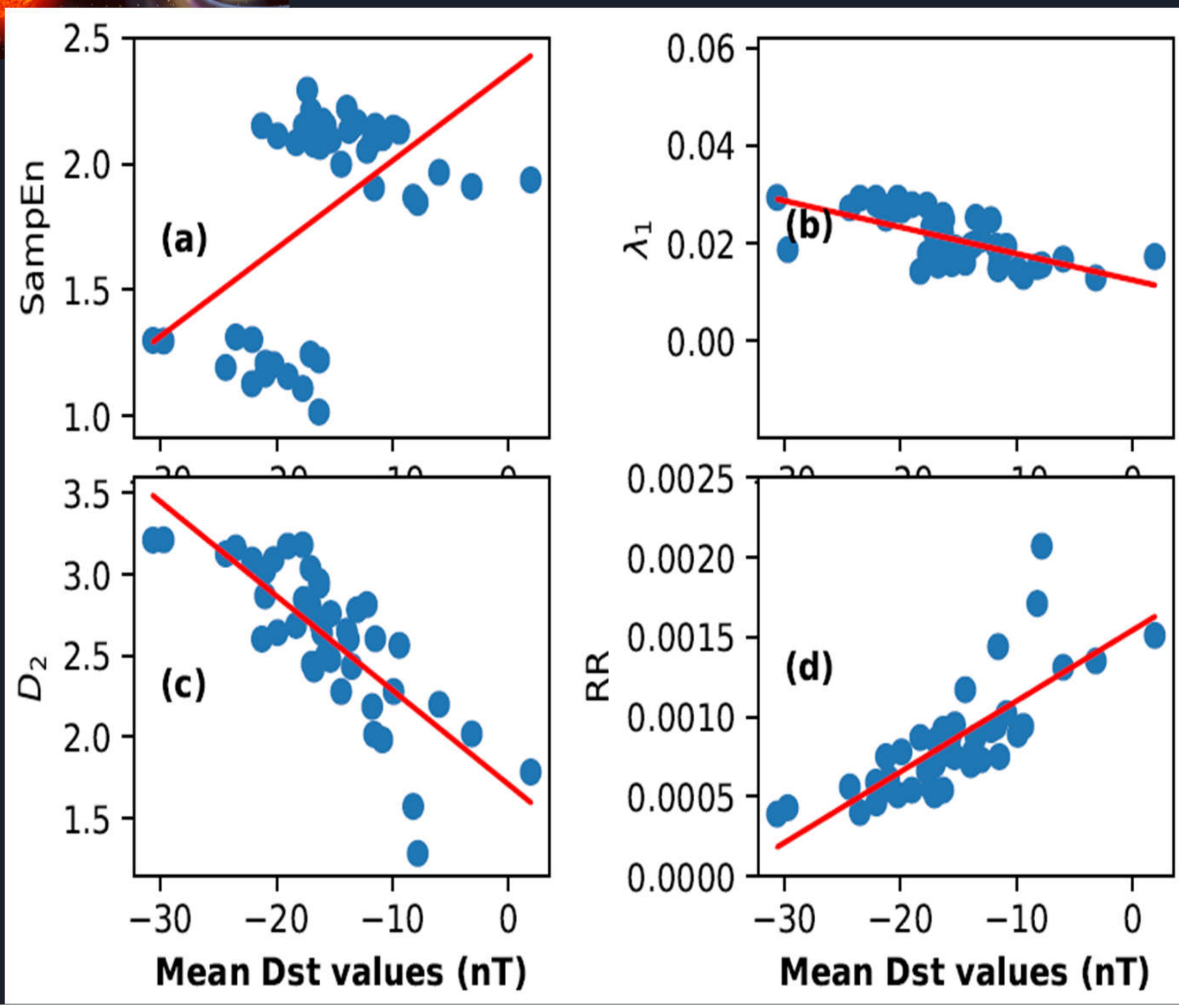
This suggests that solar activity increases the complexity of the Dst values. There are other peaks within the solar cycles which we are still trying to understand.

However, the ability of the parameters to capture these peaks differ. Sample entropy did not adequately capture the peaks.





Correlation with mean values of Dst



The nonlinear measures were found to be linearly correlated with the mean values of Dst.

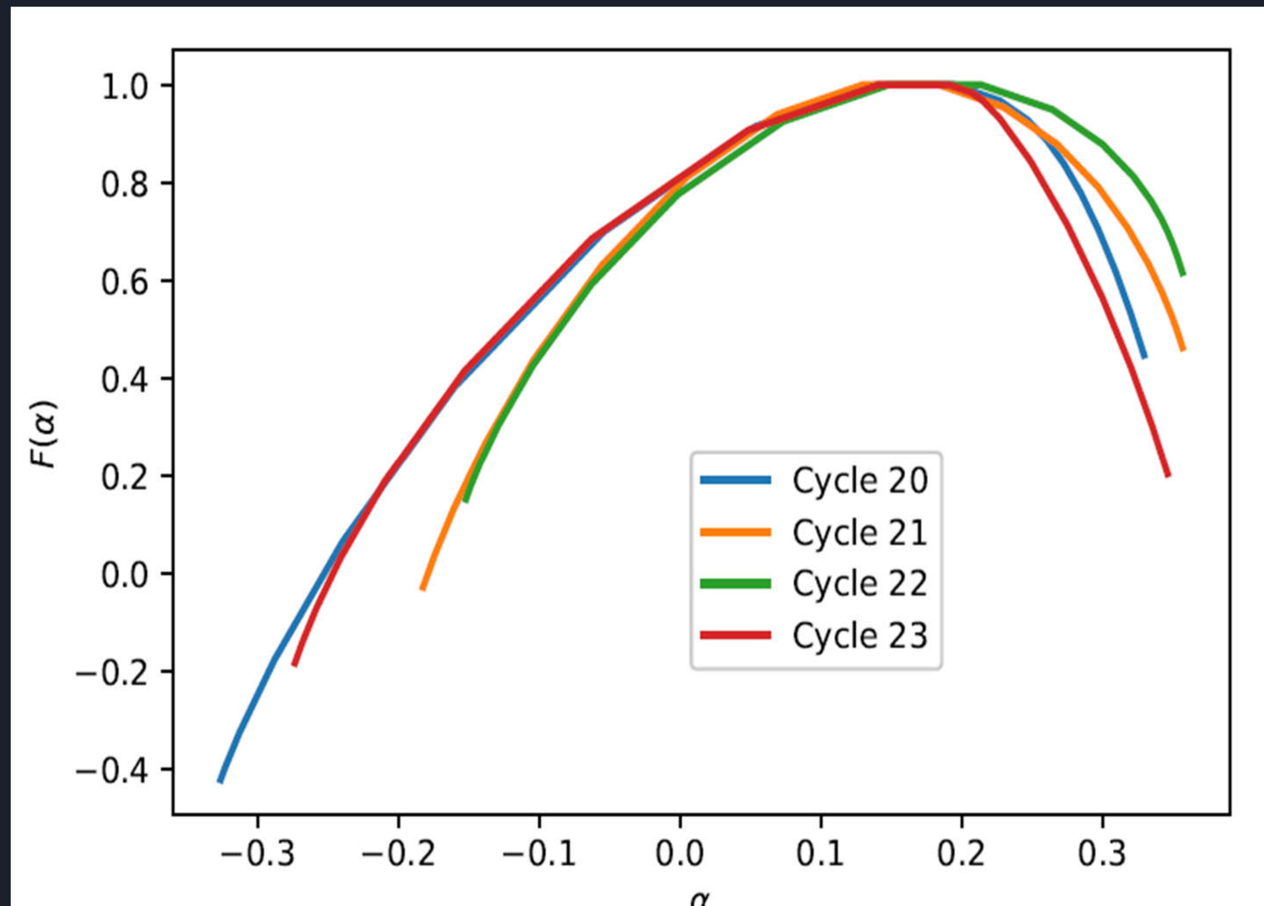
Significant correlation values of 0.5, -0.64, -0.8, 0.78 were found with Sample entropy, Lyapunov exponent, correlation dimension, and recurrence rates.

This showed that lower values of Dst correspond to stronger chaoticity.

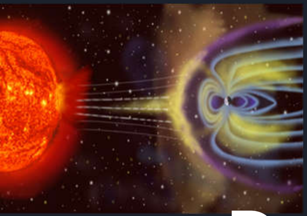
Multifractality

Multifractal Degree of Original, Surrogate and Shuffled Time Series

Cycle	Original series	Surrogate series	Shuffled series
Cycle 20	0.66	0.72	0.57
Cycle 21	0.54	0.68	0.55
Cycle 22	0.51	0.77	0.36
Cycle 23	0.62	0.84	0.47



The multifractal spectrum showed a right truncated inverted parabola. The strength of the multifractality across different solar cycles are in the order Cycle20 > Cycle23 > Cycle21 > Cycle22. The source of multifractality were found to be nonlinear correlations.



Conclusion

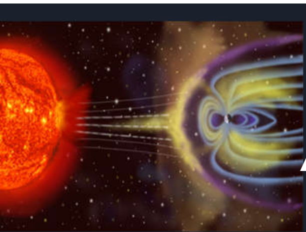
01 Dst values have short-term memory, are insensitive to small fluctuations, and are caused by nonlinear correlations

02 The more active a solar cycle is the less chaotic it is

03 The order of increasing complexity in the solar cycles is Cycle 21 < 22 < 23 < 20.

04 The peak of each solar cycle is associated with high chaoticity

05 Multifractality was observed in all solar cycles with the highest in Solar Cycle 20



Acknowledgments

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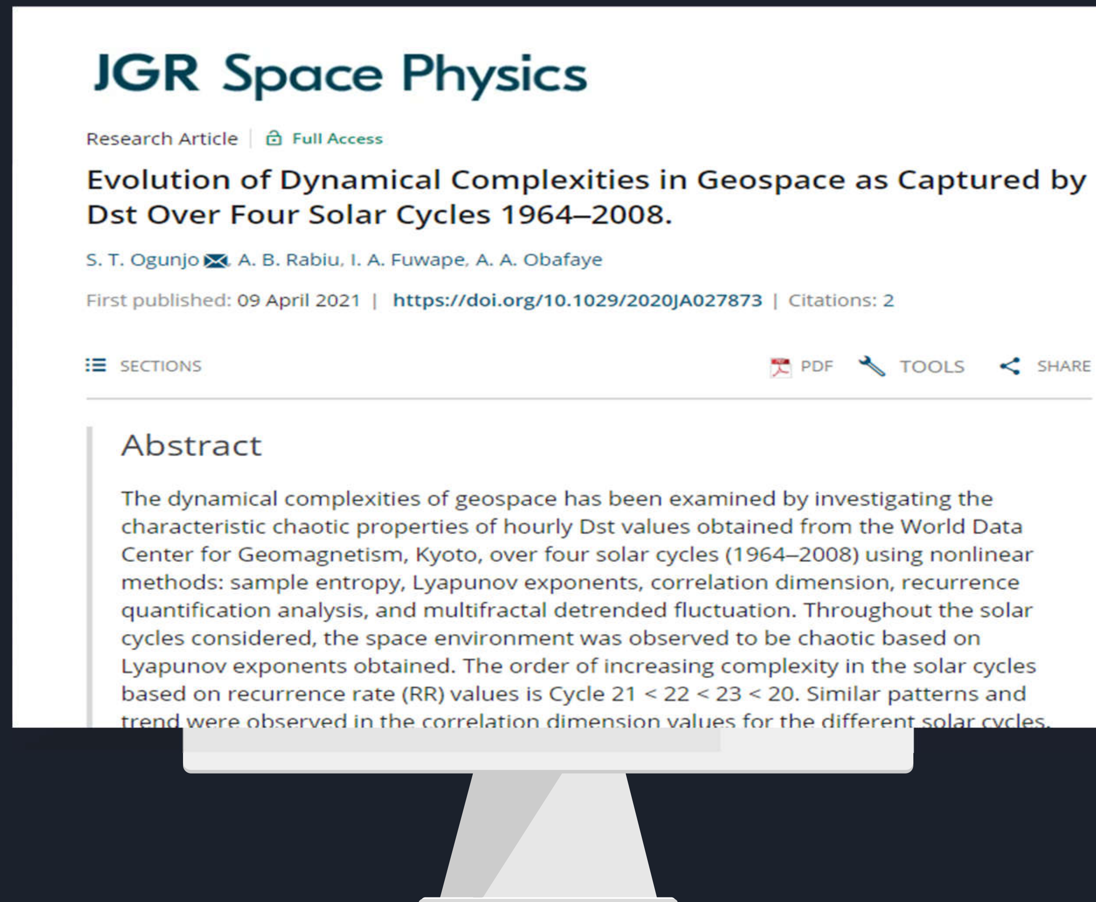

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Abstract

The dynamical complexities of geospace has been examined by investigating the characteristic chaotic properties of hourly Dst values obtained from the World Data Center for Geomagnetism, Kyoto, over four solar cycles (1964–2008) using nonlinear methods: sample entropy, Lyapunov exponents, correlation dimension, recurrence quantification analysis, and multifractal detrended fluctuation. Throughout the solar cycles considered, the space environment was observed to be chaotic based on Lyapunov exponents obtained. The order of increasing complexity in the solar cycles based on recurrence rate (RR) values is Cycle 21 < 22 < 23 < 20. Similar patterns and trend were observed in the correlation dimension values for the different solar cycles.

Thank you!