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Different facets of dynamical complexity in the magnetosphere - A recurrence perspective

Veronika Stolbova (1,2), Reik V. Donner (1,3), Jonathan F. Donges (4,5), Marina Georgiou (6), Georgios Balasis (6), Stelios Potirakis (7), Jürgen Kurths (1,2,8)

(1) Research Domain IV – Transdisciplinary Concepts& Methods, Potsdam Institute for Climate Impact Research, Potsdam, Germany, (2) Department of Physics, Humboldt University, Berlin, Germany, (3) Department of Biogeochemical Integration, Max Planck Institute for Biogeochemistry, Jena, Germany, (4) Research Domain I – Earth System Analysis, Potsdam Institute for Climate Impact Research, Potsdam, Germany, (5) Stockholm Resilience Centre, Stockholm University, Sweden, (6) Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, Greece, (7) Department of Electronics, Technological Education Institute (TEI) of Piraeus, Greece, (8) Institute for Complex Systems and Mathematical Biology, University of Aberdeen, UK

Modern human civilizations rely to a great extent on the proper functioning of infrastructures such as communication and electrical power generation and supply. Natural hazards present an ongoing threat to these infrastructures. Whereas earthquakes, storms and other types of disasters associated with the Earth's internal dynamics have mostly local to regional effects, severe magnetic storms (most prominently those following strong solar eruptions) and related phenomena have the particular potential of affecting large parts of the globe at once (in case of damaging communication infrastructures relying on satellite transmissions, they even have global hazardous potential). In order to better understanding the variations between quiescence and activity phases of the Earth's magnetic field, the complex structure of fluctuations of magnetic field strength needs to be carefully analyzed.

In this work, we utilize the powerful framework of recurrence analysis for studying the properties of the Earth's magnetosphere during one year of observations including several quiescence and activity phases. Specifically, we apply several measures of recurrence quantification analysis (RQA) and recurrence network analysis (RNA) to hourly values of the disturbance storm-time (Dst) index for the year 2001. Both RQA and RNA have recently shown their great potentials for tracing variations in dynamical complexity in non-stationary models as well as real-world time series, including various applications to geoscientific problems. Here, both frameworks are used for the first time to study the complex signatures of magnetospheric fluctuations during non-storm and storm conditions.

Our results reveal that recurrence characteristics provide excellent tracers for changes in the dynamical complexity along non-stationary records of geomagnetic activity. In particular, trapping time (characterizing the typical length of "laminar phases" in the observed dynamics) and network transitivity (associated with some generalized notion of effective attractor dimension) allow very good discrimination between activity (magnetic storms) and quiescence phases. By performing a receiver-operating characteristics (ROC) analysis, we demonstrate that the performance in the latter task is superior to many previously considered characteristics like Hurst exponent or symbolic dynamics based entropy concepts, with the exception of entropy measures based on distances in phase space (like the recurrence concept) such as sample and approximate entropy. Our results suggest the great potentials for further utilization of recurrence-based measures for tracing temporal changes in the dynamical complexity of magnetospheric variability.