Dynamical Complexity and Information Transfer in Geospace

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Traditionally, the studies of space physics, space weather and geophysics have employed a wide range of analysis tools ranging from physics-based models to empirical models. The coupled system of solar wind - magnetosphere - ionosphere - ground is well known to be nonlinear and complex. However, many space physicists are not trained in nonlinear techniques, and still rely on more traditional approaches, such as linear correlation analyses. On the other hand, real advances in the field can be gained with nontraditional approaches that take into account nonlinear and complex dynamics, including information theory and causal inference (see e.g., Balasis et al., 2023). Here, we present results from the application of complex system approaches to radiation belts in the magnetosphere and geomagnetically induced currents (GICs) on the ground. In Manshour et al. (2024) the patterns of interactions between the solar wind, geomagnetic activity and radiation belt electrons have been investigated. We have found a significant information transfer from solar wind, geomagnetic activity and fluxes of very low energy electrons (54 keV), into fluxes of relativistic (470 keV) and ultra-relativistic (2.23 MeV) electrons. We have presented evidence of a direct causal relationship from relativistic into ultra-relativistic electrons, which points to a local acceleration mechanism for electrons energization. In Boutsi et al. (2025) block entropy analysis of the GIC activity indices at middle-latitude European observatories around the St. Patrick's Day March 2015 intense magnetic storm and Mother's Day (or Gannon) May 2024 superintense storm has been performed. We have found that the GIC index values were generally higher for the May 2024 storm, indicating elevated risk levels. Furthermore, the entropy values of the SYM-H and GIC indices were higher in the time interval before the storms than during the storms, indicating transition from a system with lower organization to one with higher organization. These findings, including the temporal dynamics of the entropy and GIC indices, have highlighted the potential of this method to reveal pre-storm susceptibility and relaxation processes.

References:

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