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Causality and information transfer in interactions of solar wind, radiation belts and geomagnetic field

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Understanding physical processes that drive dynamics of the radiation belts - the high-energy charged particle population trapped by the geomagnetic field in the inner magnetosphere, is of great importance for science and society. In fact, this population dynamically interacts with the solar wind and geomagnetic field over various temporal and spatial scales, and can have significant impacts on its surrounding environment, including hazards to satellites and astronaut health. Understanding the relevant acceleration mechanisms of these particles can help not only to uncover the underlying physics, but also to improve our ability to predict and to protect. Despite numerous attempts over several decades, unfolding the dynamics of interactions in such systems is still one of the challenging research areas and has not yet been achieved, due to the complex and nonlinear underlying physics of the radiation belts. However, information theory is not constrained by such limitations and has proven itself to be a powerful non-parametric approach to discover the causal interactions among different nonlinear complex systems, and can be considered complementary to physics-based approaches. In this work, we apply entropy-based causality measures such as conditional mutual information to determine the information transfer between various variables including different solar wind parameters and geomagnetic activity indices obtained from NASA's OmniWeb service and omnidirectional electron fluxes from the MagEIS units onboard Van Allen Probe B in the outer radiation belt, ranging in energy from a few keV to several MeV. We find significant information flow from low energy electrons into high energy ones as well as from some solar wind/geomagnetic field parameters into electron fluxes of various energies. We are confident that our results provide great prospects for future targeted research on the dynamical mechanisms underlying radiation belts dynamics.

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