Characterizing nonlinear processes in simulations of turbulent space plasmas

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Natural collisionless plasmas, such as the solar wind, can be characterized in terms of their turbulence properties, which are often taken from a framework focused on universal properties, such as power spectra with power law slopes. Improving data analysis (higher resolution and multi-spacecraft) has led to a refined picture in which characteristic plasma scales play a role. For example, recent observational work has concentrated on the transition from inertial, fluid-like scales to scales where particle kinetic processes (either ion or electron) become relevant. At the same time, this transition has been much studied with kinetic simulations which can capture important kinetic effects but which are large enough to cover some of the inertial range. These simulations remind us that turbulence in a collisionless plasma has a complex network of processes involving particle energization and magnetic field topology, such as magnetic reconnection, kinetic instabilities and wave-particle interactions, as well as nonlinear wave-wave processes. We present results from a number of hybrid PIC simulations (kinetic ions with electron fluid) of solar wind turbulence that illustrate various aspects of this complex system. Simulations of the relaxation of a system of multiple current sheets show turbulent-like behaviour with forward and inverse cascade. However, detailed characterization of the intermittency and topological evolution using cancellation analysis shows that the system does not attain a state of fully developed turbulence. Simulations initialised with long wavelength Alfvénic fluctuations develop many of the power law spectral features observed in the solar wind, and we show examples of comparisons between such simulations and data. We also use the simulations to understand the role of magnetic reconnection in the evolution of the turbulence, and its connection to intermittency. Finally, we discuss how the particle distribution can be characterised in the turbulence in terms of diffusion (both classical and anomalous), and the fragmented energy release sites associated with reconnection.