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Characterizing Sub-Grid-Scale Effects on Plasma Turbulence in the Earth's Magnetosheath: Contribution to Generalized Ohm's Law

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In plasma physics, one of the main obstacles to unravelling the mechanisms responsible for energy transfer between electromagnetic fields and plasma particles is the multiscale nature of plasma phenomena. In this context, plasma turbulence plays a fundamental role because it transports energy across spatial scales from the energy injection scales (large-scales) down to small-scales at which energy is dissipated. One of the key open challenges in plasma turbulence research is understanding how the small-scale turbulent dynamics couple into and influences the large-scale behavior of the system and how that influences the energy budget and energy transport at system scales. One approach to address this challenge is to employ so-called Large Eddy Simulations (LES), where the large scales of the system are directly simulated, and the small-scale unresolved dynamics are parameterized using Sub-Grid-Scale (SGS) models. However, the appropriate SGS models for describing collisionless plasma systems with large scale separations remain poorly constrained. In nearly collisionless space plasmas, such SGS models might include both the effects of unresolved MHD-like nonlinear dynamics as well as unresolved multi-fluid and kinetic effects. However, modelling highly nonlinear phenomena is a nontrivial task and the accuracy of the LES depends on how well the SGS phenomena are modeled.

In this work, we employ a series of Vlasov-Hybrid and fully kinetic Particle-in-Cell (PIC) simulations modelling conditions similar to turbulence in Earth's magnetosheath to characterize and constrain the SGS effects appropriate for turbulent collisionless plasmas. We particularly focus on the SGS effects described within the generalized Ohm's law terms, which can describe effects such as, for example, turbulent resistivity and dynamo effects. We estimate the relative contribution from the SGS terms ($\Sigma\tau$ in Eq. 1) in the generalized Ohm's law to the total electric field in our simulations.

$$E + u \times B = R + \sum \tau \qquad (1)$$

We also establish the dependence of the SGS terms on plasma beta (Fig1) as well as their dependence on resolved quantities such as the magnetic field, electric current density, and plasma vorticity. We also explore dependence on quantities associated with compressibility and hall physics. Since electric fields strongly contribute to plasma particle energization, our results are relevant for better understanding the cross-scale energy transfer and estimating the SGS contribution to the energy budget. Moreover, our results provide important insight for the future modelling of large-scale turbulent plasmas such as the Earth's magnetosphere, the solar wind, solar and stellar atmospheres, and other astrophysical systems.

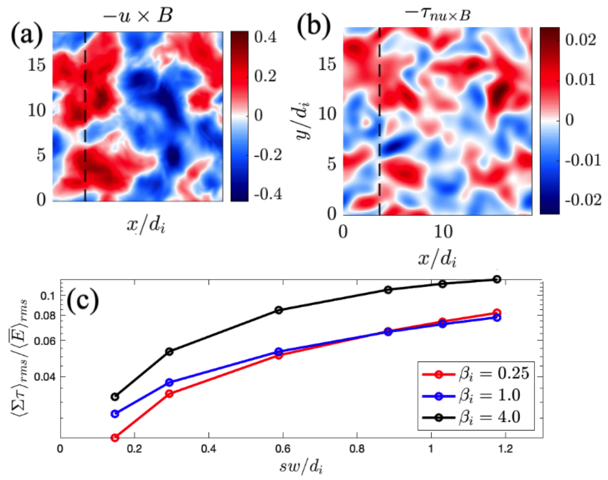

Fig. 1 Resolved and unresolved contributions to the generalized Ohm's law. Dependence with scale filter and plasma beta

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