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Limitations on a Kinetic Electron Closure for Extended Hybrid Electromagnetic Simulation of Drift Waves

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Nonadiabatic electron effects significantly modify the stability and concomitant turbulent transport of drift-waves in tokamaks. Incorporating electron kinetic and electromagnetic effects into gyrokinetic particle-in-cell drift-wave turbulence simulations is challenging. Previously we extended the electromagnetic hybrid scheme of Chen and Parker (fluid electrons and gyrokinetic ions)[1] to include a kinetic electron closure valid for finite $\beta m_{\rm i}/m_{\rm e} > 1$, where $\beta = 4\pi n T_{\rm e}/B^2$.[2] This scheme uses partially linearized (δf) drift-kinetic electrons whose number density moment is used to close the electron fluid momentum equation. The closure depends on a perturbation expansion of the electron response around the isothermal adiabatic fluid response.[3] The algorithm was successfully tested on kinetic shear-Alfvén waves, the ion-temperature-gradient instability, and the collisionless drift instability in an unsheared slab. This algorithm does *not* require that the mesh size perpendicular to $\boldsymbol{B}_0$ be smaller than the skin depth c/ω_{pe} and gives good results for $\beta m_{\rm i}/m_{\rm e} > 1$. However, this implementation of a kinetic-electron extended hybrid algorithm yields spurious results for linear ITG modes in sheared slab and toroidal geometries. Frequencies and growth rates are systematically wrong, and the δf electron weights grow too large. The inherent difficulty is the failure of the perturbation expansion around an adiabatic electron fluid response in the resonance layers near mode rational surfaces where the electrons are far from adiabatic and kinetic effects are not necessarily perturbative. The recent work of Chen, *et. al*[4] demonstrates a direct kinetic electron δf PIC algorithm that works at finite β and can resolve non-adiabatic electron kinetic behavior correctly.

This work is supported by the U.S. Department of Energy, Office of Fusion Energy Sciences, under Contract No. W-7405-ENG-48 at the University of California Lawrence Livermore National Laboratory and is part of the SciDAC Plasma Microturbulence Project.

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