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Coupled neoclassical-magnetohydrodynamic simulations of axisymmetric plasmas[1]

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Neoclassical effects (e.g., the bootstrap current and neoclassical toroidal viscosity [NTV]) have a profound impact on many magnetohydrodynamic (MHD) instabilities, including tearing modes, edge-localized modes (ELMs), and resistive wall modes. High-fidelity simulations of such phenomena require a multiphysics code that self-consistently couples the kinetic and fluid models. We present the first results of the DK4D code, a dynamic drift-kinetic equation (DKE) solver being developed for this application. In this study, DK4D solves a set of time-dependent, axisymmetric DKEs for the non-Maxwellian part of the electron and ion distribution functions (f_{NM}) with linearized Fokker-Planck-Landau collision operators. The plasma is formally assumed to be in the low- to finite-collisionality regimes. The form of the DKEs used were derived in a Chapman-Enskog-like fashion, ensuring that f_{NM} carries no density, momentum, or temperature. Rather, these quantities are contained within the background Maxwellian and are evolved by an appropriate set of extended MHD equations. We will discuss computational methods used and benchmarks to other neoclassical models and codes. Furthermore, DK4D has been coupled to a reduced, transport-timescale MHD code, allowing for self-consistent simulations of the dynamic formation of the ohmic and bootstrap currents. Several applications of this hybrid code will be presented, including an ELM-like pressure collapse. We will also discuss plans for coupling to the spatially three-dimensional, extended MHD code M3D-C^1 and generalizing to nonaxisymmetric geometries, with the goal of performing self-consistent hybrid simulations of tokamak instabilities and calculations of NTV torque.

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