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Progress in first-principles simulation of SOL plasma turbulence and neutral atom dynamics with the GBS code

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The GBS code has been developed in the last few years to simulate plasma turbulence and neutral atom dynamics in SOL conditions. GBS advances the drift-reduced Braginskii equations for low-frequency plasma turbulence, solving at the same time a kinetic equation of neutral atoms by the method of characteristics. In GBS the plasma dynamics is evolved as the interplay between plasma sources (due to the neutral ionization and the plasma outflow from the tokamak core), turbulent transport, and plasma losses (at the limiter or divertor plates or through recombination processes). Therefore, the simulations evolve self-consistently both the plasma profile and its fluctuations, with no separation between the equilibrium and fluctuation scale lengths. A detailed study of the interaction of the plasma with the solid wall was carried out and, based on the kinetic results, a set of boundary conditions was found that were implemented in GBS at the sheath edge, where the drift-reduced Braginskii model loses its validity. The neutral module implemented in GBS represents the first-ever successful implementation of a self-consistent neutral solver within a first-principles turbulence code. The interaction of the plasma with the neutrals is taken self-consistently into account, by evaluating plasma source and energy losses due to ionization events, the drag due to charge-exchange collisions, and the recombination processes. GBS was verified by using the method of manufactured solutions, and it was validated against experimental data from several tokamaks worldwide, showing good agreement. In the present work, we focus on our recent insights on the neutral atom dynamics. We first illustrate the model that allows us to evolve at the same time plasma turbulence and neutral atom dynamics. Second, we describe our recent progress in the study of the transition from the sheath- to the conduction-limited regimes that was simulated in GBS by increasing the plasma density in the system. Thanks to the simulation results, we expanded and refined the so-called two-point model that is used to estimate the drop of electron and ion temperature along the magnetic field lines in the SOL. Third, we discuss the role of neutrals in setting the long scale length, dubbed shoulder, that is observed in the far SOL in the high density regime.

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