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# Two-way spatial coupling of magnetohydrodynamic and particle-in-cell methods for plasma simulation

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Simulating solar plasmas is very challenging because they have a wide range of scales, and different physics models apply at different scales. Magnetohydrodynamic (MHD) simulations are very efficient in describing and predicting the dynamics of solar plasmas at scales larger than the ion gyro-radius. However, they miss the kinetic effects at small scales which play a crucial role in several important phenomena, like magnetic reconnection. On the other hand, fully kinetic simulations are more computation-intensive and cannot handle large simulation domains or long-time evolution. One way to overcome this difficulty is to simulate the plasma kinetically only in regions where kinetic effects are important, and simulate the rest of the plasma with MHD. In this work, we describe such a method of two-way (forward and backward) coupling of the MHD code MPI-AMRVAC with the kinetic particle-in-cell (PIC) code iPic3D. In forward coupling, information from MHD is used to provide initial and boundary conditions to the PIC code. In backward coupling, moments of the velocity distribution function from the PIC simulation are used to update the MHD variables. We implement this scheme in 2D simulations where a rectangular PIC region is embedded within the MHD simulation domain. We will describe how the information is passed between the two codes, the time-stepping algorithm of this coupling, and the parallelization strategy of this coupling. We will show results of crucial tests like the energy conservation of this method and the propagation of Alfven waves, whistler waves, and fast magnetosonic waves through the embedded PIC domain. We will show simulations of the standard Geospace Environmental Modeling (GEM) challenge where the PIC-region is embedded around the X-point of reconnection. In all these cases the coupling works satisfactorily and indicates that it is suitable for future multi-scale and multi-physics simulations of waves and reconnection relevant for solar system plasmas.