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Coarse-graining phase-space in delta-f Particle-in-Cell (PIC) simulation[1]

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Particle weights in a δf PIC simulation slowly grow in time even after the turbulent fluxes reach a steady state. This can eventually lead to discrete particle noise at long times. We present a solution to this problem. Growing weights are the result of balancing the flux in a truly collisionless simulation. Collisions as currently implemented in PIC models via Monte-Carlo do not reduce the growing weight problem [2]. Since weight growth is manifestation of phase-space filamentation, the weight level can be reduced by simply periodically coarse-graining the distribution function in phase space. A five-dimensional phase-space grid is used to facilitate the coarse-graining procedure (CGP). δf is periodically deposited on the 5-D grid, then re-evaluated at the particle position using interpolation. Any discontinuity of δf in time arising from CGP is reduced by resetting only a small fraction of the particle weight. CGP effectively introduces dissipation into the otherwise dissipation-less PIC method. An estimate of the numerical diffusion due to this smoothing procedure is provided in the limit of large particle number. CGP is demonstrated to effectively suppress the long-term increase of the particle weights in ITG simulations, while keeping the turbulent flux unchanged. Spectral analysis indicates that the reduction in particle weights is mainly due to the elimination of the short scale structures in the density fluctuations. Large scale density fluctuations that account for the turbulent fluxes are not affected. We have implemented CGP in the GEM code and applied it to the study of beta-scaling of turbulent transport in core plasmas, as well as, the simulation of edge plasmas with strong density and temperature gradients. Both of these problems were previously difficult to model in flux-tube simulations.

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[2]Y. Chen and S. E. Parker, J. Comput. Phys. 220 839 (2007)