Improved Algorithms for Continuum/Vlasov Gyrokinetic Codes

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We discuss various possible improved algorithms for continuum/Vlasov gyrokinetic codes such as GS2[1, 2], GENE[3], and GYRO[4]. While these recently-developed codes are quite sophisticated and generally work fairly well in their studies of microturbulence in tokamaks and other plasmas, there are several improvements that could be explored. These codes solve the nonlinear electromagnetic gyrokinetic equation for the particle distribution function $f(\vec{x}, v_\parallel, v_\perp, t)$ using a range of finite-difference and spectral techniques and various treatments of the geometry. Here we focus on the GS2 code (http://gs2.sourceforge.net), which employs a fully implicit treatment of the linear (parallel) dynamics[2] and pseudo-spectral evaluation of nonlinear terms[1] in general geometry flux-tube coordinates.

Vlasov codes are potentially susceptible to a long-known recurrence problem, in which the phases between the distribution function f at various velocities, which become decoherrent due to phase-mixing/Landau-damping, might become coherent again. In a low collisionality plasma, avoiding this recurrence can require very high velocity space resolution. Here we explore using a hypercollisionality operator, which smooths out small scales in $f(v)$ while preserving larger scale features (which determine density, momentum, energy, etc.). Hypercollisionality models thus can provide a tunable level of approximation, so that gyrofluid-like efficiencies can be achieved at lower velocity resolution, while higher resolution can be used to check convergence. In practice, the recurrence problem is not as severe in codes like GS2 as one might first think, for several reasons. First, cylindrical coordinates are used in velocity space so that the grid spacing in $v_\parallel$ is non-uniform, which reduces the likelihood of all phases becoming coherent. Second, there is usually some dissipation in the algorithms, such as the loss associated with the shearing of f to high k_x as particles stream along sheared magnetic fields and eventually exit the simulation (though trapped particles are still susceptible).

We have developed a fast iterative implicit algorithm that works well in tests in a linear local gyrokinetic code. Implicit treatment of f given the potentials is almost trivial in the gyrokinetic equation, but the potentials also need to be implicit. Our iterative algorithm employs a physics-based preconditioner, with Padé approximations for the plasma response matrices, which is the expensive part of GS2's original implicit algorithm[2]. Other potential improvements include the usage of higher-order finite differencing for the parallel dynamics, averaging some of the terms in the gyrokinetic equations over finite-size cells, and higher order time stepping. Finally, sub-grid turbulence models can be useful for reducing the required spatial resolution.

References

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