Verification of Gyrokinetic codes: theoretical background and applications.

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In fusion plasmas the strong magnetic field allows the fast gyro motion to be systematically removed from the description of the dynamics, resulting in a considerable model simplification and gain of computational time. Nowadays, the gyrokinetic (GK) codes play a major role in the understanding of the development and the saturation of turbulence and in the prediction of the consequent transport. The realistic description of a burning plasma provides problems of increased complexity, which involve the interaction among MHD modes, turbulence and energetic particles and which represent a hard computational challenge. Present prediction capabilities strongly depend on the reliability of gyrokinetic codes in parameter domains in which limited verification has been performed so far, e.g. for radially global simulations at high β, which are required for advanced fusion reactor scenarios.

In this work, we present a new and generic theoretical framework and specific numerical applications to test the validity and the domain of applicability of existing GK codes. For a sound verification process, the underlying theoretical GK model and the numerical scheme must be considered at the same time, which makes this approach pioneering. At the analytical level, the main novelty consists in using advanced mathematical tools such as variational formulation of dynamics for systematization of basic GK code's equations to access the limits of their applicability. At the first instance, the indirect verification of numerical scheme is proposed via the Benchmark process. The derivation of the gyrokinetically reduced Maxwell-Vlasov model from the variational formulation of dynamics guarantees, first of all, its energetic consistency. In addition, it provides access to the systematic derivation of conservation laws for energy and momentum, which can further be interpreted as transport equations[1,2].

In the fusion community, the particle in cell (PIC) and the Eulerian methods are the most often employed to solve the GK equations. In this work, specific examples of code verification are presented for two GK codes: the multi-species electromagnetic version of the ORB5 [3], and the radially global version of GENE (Eulerian) [4]. Of course, the proposed methodology can be applied to any existing GK code. In order to get a systematic comparison at the analytical level [5], we establish a hierarchy of reduced GK Vlasov-Maxwell equations using the generic variational formulation [6]. Then, we derive and include the models implemented in ORB5 and GENE inside this hierarchy. At the computational level, detailed verification of global electromagnetic test cases based on the CBC (CYCLONE Based Case) are considered, including a parametric β-scan covering the transition between the ITG to KBM and the spectral properties at the nominal β value [8].

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