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Advancing plasma turbulence understanding through a rigorous Verification and Validation procedure: a practical example

PAOLO RICCI, Centre de Recherches en Physique des Plasmas - Ecole Polytechnique Fédérale de Lausanne

The methodology used to assess the reliability of numerical simulation codes constitutes the Verification and Validation (V&V) procedure. V&V is composed by two separated tasks: the verification process, which is a mathematical issue targeted to assess that the physical model is correctly solved, and the validation, which determines the consistency of the code results, and therefore of the physical model, with experimental data. In the present work, a V&V procedure, rigorous and unparalleled in plasma physics, is presented and applied showing, through a practical example, how it can advance our physics understanding of plasma turbulence. Bridging the gap between plasma physics and other scientific domains, in particular the computational fluid dynamics community, a rigorous methodology for the verification of a plasma simulation code is presented, based on the method of manufactured solution and Roache's grid converge index. This methodology assesses that the model equations are correctly solved, within the order of accuracy of the numerical scheme, and provides a rigorous estimate of the uncertainty affecting the numerical results. Two-dimensional and three-dimensional verified simulations of the basic plasma physics experiment TORPEX are then performed, and rigorously validated against the experimental data. The validation procedure allows progress in the understanding of the turbulent dynamics in TORPEX, by pinpointing the presence of a turbulent regime transition, due to the competition between the resistive and ideal interchange instabilities.