Gyrokinetic simulation tests of quasilinear and tracer transport

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Abstract

A nonlinear gyrokinetic simulation code is used to test the *quasilinear transport approximation* (QLTA) with a simulated nonlinear spectral (potential field) intensity. Two common forms of the QLTA are defined. The first uses the linear *mode spectrum* [mQLTA] and the second uses the complete *frequency spectrum* [fQLTA] for the nonlinear spectral intensity. The mQLTA is tested via two-step linear then nonlinear simulations convoluting a *quasilinear weight* with a nonlinear field intensity *spectral weight* to get the quasilinear transport in comparison with the actual nonlinear transport. The fQLTA is tested via one-step simulations that have ion and electron "plasma species" at full densities and "tracer species" at negligible densities (and making no contribution to the Poisson field solve equation). If the tracer and plasma gyrokinetic equations are identical, then so are their respective energy and particle diffusivities. Comparing tracer and plasma (actual) diffusivities, when the tracer equation nonlinearity is deleted, provides a quantifiable test of the fQLTA form. The mQLTA preserves ambipolarity but the two-step test includes only the leading linear normal modes at each wave number. The one-step test of the fQLTA subsumes all normal modes but precludes ambipolar particle flow. The mQLTA and fQLTA quasilinear weights (per normal mode) are shown to be identical for a commonly used (but unphysical) mode frequency line width model. In successful cases, quasilinear diffusivities are typically 1.4-1.8 [1.2-1.4] larger than actual diffusivities for mQLTA [fQLTA]. The QLTA is expected to make best predictions in the ratios of energy and particle flows. Electron to ion energy flow ratios are well approximated but both forms of the QLTA appear to breakdown most evidently for ratios of particle to energy flows in cases with strongly pinched (and impractically large) particle flows. An example of the so-called *passive tracer diffusivity*, which includes only linear and nonlinear $E \times B$ motion, is given for comparison with actual diffusivities.