A new saturation model for quasi-linear gyrokinetic turbulent transport

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The findings of an investigation into the properties of the three dimensional (3D) saturated fluctuation intensity of the electric potential in gyrokinetic turbulence simulations is presented. Scans in flux surface elongation and Shafranov shift are used to isolate the tokamak geometric dependencies. The intensity of the saturated potential fluctuations required in order to compute exact fluxes by a quasilinear method is determined using linear eigenmodes computed with the same gyrokinetic code as the turbulence simulation. This method eliminates the uncertainties from approximate linear eigenmodes, flux surface averaging and radial wavenumber summation in the determination of the required potential intensity for the quasi-linear flux calculation to be exact. A model of this "quasi-linear intensity" is constructed using the linear eigenmode properties and the geometry shape functions obtained from the 3D intensity spectrum. The new quasi-linear transport model computes the poloidal wavenumber spectrum of the electron and ion energy fluxes with unprecedented accuracy. A systematic procedure for building the saturation model from sub-models of the radial wavenumber spectral width and the non-linear mixing rate of the potential fluctuation spectrum is developed. New insights are gained into the way zonal flow mixing saturates ion-scale turbulence by controlling the radial wavenumber width of the turbulence. The verification and calibration of the new quasi-linear transport model with a large database of gyrokinetic turbulence simulations is presented. A modification to the overall multiplicative factor of the model is found to be necessary to improve the fit to scans of the temperature and density gradients and safety factor to this database. The error in the fit of the quasi-linear fluxes of electron and ion energy fluxes is significantly better than for previous saturation models. The spectral shift model for the impact of equilibrium ExB velocity shear and the zonal flow mixing model for electron-scale turbulence are both revised to be compatible with the new quasi-linear intensity model. The models for the loss of bounce averaging and electron collisions in the TGLF reduced linear gyro-fluid equations are changed to improve the linear eigenmode accuracy.