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Time delays in the functional relation of heat transport coefficients, turbulences, and zonal flows in gyrokinetic simulations

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Understanding and controlling turbulent transport are key issues toward realization of nuclear fusion generation in magnetically confined plasma researches. Although nonlinear gyrokinetic simulation is used to estimate turbulent transport level quantitatively, it demands huge computational costs. Therefore, it has been tried to construct simplified transport models to predict transport levels in gyrokinetic simulations with reduced computational costs. In the turbulent transport, zonal flows play an important role to decide the transport levels [1]. In previous works [2,3], the functional relation among time averages of turbulences, zonal flows, and ion heat transport coefficients were proposed for stellarators and tokamaks from a phenomenological perspective.

Recently, we reported that the time series data of turbulent fluctuation T, zonal flow amplitude Z, and transport coefficient χ, which are obtained from the ITG gyrokinetic simulations by GKV code [5], has certain structure in the parameter space which consists of T, Z, and χ [4]. The structure can be represented by a nonlinear functional relation among T, Z, and χ,

$$\tilde{\chi}_{\mathrm{i}}^{\mathrm{Model}}(t) = \frac{C_1 T(t)^{\alpha}}{1 + C_2\sqrt{Z(t)}/T(t)}.$$

Here normalized ion heat transport coefficient is denoted by $\tilde{\chi}_{\mathrm{i}}$. The coefficients (C_1, C_2, α) were determined by nonlinear fitting method using Nelder-Mead simplex method [7] with various initial parameters to avoid multiple local minima [3]. The functional relation for time series data provides higher accuracy than the original function.

For a relation between turbulence and zonal flow, predator-prey relation had been discussed [6]. On the other hand, our functional model has not been reflected the predator-prey relation. In order to discuss such relation for our model, we consider "time delay" between each evolution of T, Z, and χ. We artificially introduce the time delays, Δt_T and Δt_Z. The model function can be presented as

$$\tilde{\chi}_{\mathrm{i}}^{\mathrm{Model}}(t, \Delta t_T, \Delta t_Z) = \frac{C_1 T(t-\Delta t_T)^{\alpha}}{1 + C_2\sqrt{Z(t-\Delta t_Z)}/T(t-\Delta t_T)}.$$

The figure shows the *root mean squared percentage error*, RMSPE, for the case of $R_0/L_{T_{\mathrm{i}}} = 15.0$. We can find that there exists a minimum point in $\Delta t_T > \Delta t_Z$. Therefore, if we construct the predator-prey like relation with the time delay $\Delta t_{TZ} = \Delta t_T - \Delta t_Z$, the accuracy of our functional model relation can be improved.

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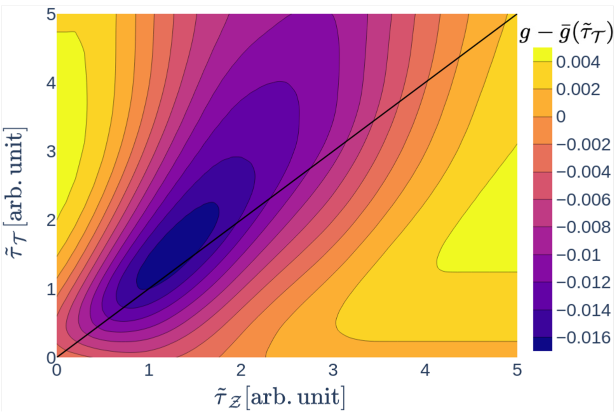

Figure: Contour map of errors for $R_0/L_{T_{\mathrm{i}}} = 15.0$, where g is RMSPE, the average value of A is denoted by $\bar{A}$, and Δt is normalized by $R_0/v_{t_{\mathrm{i}}}$. The black line shows $\Delta t_T = \Delta t_Z$.