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Quasilinear turbulent transport modeling with semi-empirical and mixing-length-like saturation rules

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Understanding and predicting particle and heat transport are important to obtain high-performance fusion plasmas. Since transport phenomena are dominated by turbulence especially for tokamak plasmas, detailed descriptions of underlying turbulence physics are required to predict kinetic profiles accurately, but introducing the detailed descriptions to transport models leads to an increase in the computational cost. In order to tackle the issue, a neural-network (NN) based approach has been undertaken and NN-based transport models are now available [1, 2]. Our previous study has also presented another one, which is named DeKANIS, and it has originally been developed for particle transport [3]. The present DeKANIS covers heat transport as well, giving turbulent particle and heat fluxes for electrons in a quasilinear limit as $\bar{\Gamma}_\mathrm{e} = \bar{D}(R/L_{n_\mathrm{e}} + C_\mathrm{T} R/L_{T_\mathrm{e}} + C_\mathrm{P})$ and $\bar{Q}_\mathrm{e} = \bar{\chi}_\mathrm{e}(R/L_{T_\mathrm{e}} + C_\mathrm{N} R/L_{n_\mathrm{e}} + C_\mathrm{HP})$, respectively. Here, $\bar{D}$, $\bar{\chi}$, R/L_n and R/L_T are the particle and heat diffusivities in proportion to the fluctuation amplitudes and the density and temperature gradients, respectively, and all of them are non-dimensional. The right-hand side of the flux expressions is composed of the diagonal (diffusion) and off-diagonal (pinch) components, which are quantitatively determined by estimating the diffusivities ($\bar{D}$ and $\bar{\chi}$) and the pinch term coefficients (C_T, C_P, C_N and C_HP). Predicting the decomposed fluxes could be helpful to understand formation mechanisms of kinetic profiles.

DeKANIS estimates the pinch term coefficients with a NN, which has been trained to reproduce those given by linear calculations of local flux-tube gyrokinetic codes. On the other hand, there are two ways to estimate the diffusivities. First one makes the NN reproduce semi-empirically evaluated $\bar{D}$, as well as the pinch term coefficients. Here, the training dataset has been constructed based on JT-60U H-mode core plasmas and $\bar{D}$ has been evaluated with the experimental particle flux $\bar{\Gamma}_\mathrm{e,exp}$. The remaining $\bar{\chi}_\mathrm{e}$ can be calculated to satisfy the Onsager symmetry between the off-diagonal terms of the particle and heat fluxes: the saturation level of the fluctuation amplitude is estimated based on $\bar{\Gamma}_\mathrm{e,exp}$, without the experimental heat flux $\bar{Q}_\mathrm{e,exp}$. The model using the saturation rule is referred to as DeKANIS-1.

The second way uses a mixing-length like model to estimate the diffusivity. In this paper, the following expression [4] is used: $\bar{D} = 1.86 \times 10^4 (\bar{\gamma}/\bar{k}_\theta^2)^{1.5} \bar{L}_\mathrm{ZF}^{-2.71}$, where $\bar{\gamma}$ and $\bar{k}_\theta$ are the normalized local maximum linear growth rate and the poloidal wavenumber corresponding to $\bar{\gamma}$, and $\bar{L}_\mathrm{ZF}$ is the residual zonal flow level. To use the mixing-length-like model, the NN has been trained to reproduce $\bar{\gamma}$, $\bar{k}_\theta$ and $\bar{L}_\mathrm{ZF}$ that are given by the gyrokinetic linear calculations, as well as the pinch term coefficients. As to $\bar{\chi}_\mathrm{e}$, the Onsager symmetry is applied. The model using the mixing-length like expression is referred to as DeKANIS-2. Examples of $\bar{\Gamma}_\mathrm{e}$ and $\bar{Q}_\mathrm{e}$ predicted by DeKANIS-1 and -2 are shown in figure 1, and the two models are found to reproduce the fluxes to a similar degree. These models give fluxes in $\sim 10^{-3}$ second with a single CPU, which is much faster than the conventionally used transport models.

While DeKANIS-1 uses the NN constructed with the JT-60U experimental value, DeKANIS-2 uses the NN based only on the linear gyrokinetic calculations. The latter one can, therefore, be applicable to a wide range of plasma parameters including those of other devices by modifying the mixing-length like model. More sophisticated models such as that shown in [5] will be introduced, and the validity will be discussed in the conference.

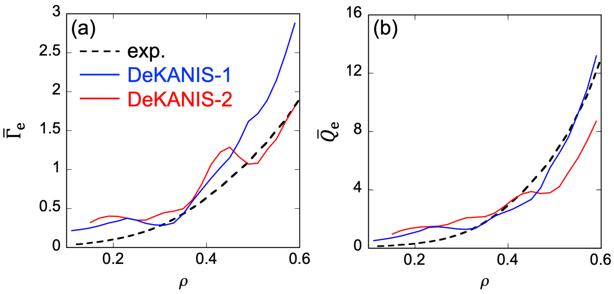

Figure 1: Radial profiles of the electron (a) particle and (b) heat fluxes predicted by two types of DeKANIS with the experimental ones. Here, the plasma in question is not included in the NN training dataset.

References

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