Quasi-Linear transport model EDWM: Update and benchmarking

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The purpose of this work is to improve the fidelity of the quasi-linear EDWM [1] fluid model by introduction of correction factors benchmarked against non-linear gyro-kinetic models. As performance of a tokamak fusion plasma is largely determined by turbulent transport, it is crucial to model this process accurately. The simulations with the greatest physics fidelity that are currently employed to analyse turbulent transport in tokamak plasma are based on gyro-kinetic theory. However, the computing cost associated with running gyro-kinetic codes is still prohibitive for routine analysis of tokamak discharges. Consequently, models with additional simplifications have been developed, mainly based on the quasi-linear approach. Although, the quasi-linear models have proven to give solid physics result, the physics fidelity of the reduced models is not up to the standard of gyro-kinetic codes in all areas, especially not when it comes to non-linear effects such as zonal flows and turbulence spreading. In this work we benefit from gyro-kinetic simulations to introduce and calibrate enhancements/corrections to EDWM. In particular, five areas where enhancements/corrections can be applied are studied: (I) a new poloidal wave number filter; (II) a correction factor for the role of collisionality; (III) an adjustment of the balance between the electron and ion heat fluxes; (IV) a correction factor for the scaling of the turbulent transport with the safety factor q, and (V) a new rule for the saturation of the fluctuation level (mainly to adapt to the updated poloidal wave number filter).

EDWM is a quasi-linear model and solves the linear dispersion relation, hence it does not get the saturated quantities directly as in the non-linear case. Quasi-linear theory connects the linear growthrates, real frequency and other plasma parameters to the saturated quantities, such as the electrostatic potential by assuming that saturation occurs when the convective ExB non linearity is balanced by the linear growthrate. However, as this is an non-linear phenomena, called drift wave mixing, the expression for the electrostatic potential can not properly be expressed by quasi-liner theory and an description of poloidal wavenumber dependency is needed. We construct an expression for the electrostatic potential from the original EDWM saturation, calculated at the correlation length, to determine the saturation level, and a filter, $f(k_y)$ containing all poloidal wave dependency.

$$|\hat{\phi}|^2 = \frac{4\gamma_a^2}{\omega_{Dea} R^2 k_a^2} f^2(k_y) \tag{1}$$

Here k is the wavenumber, ω_{De} is the electron diamagnetic drift frequency, γ the linear

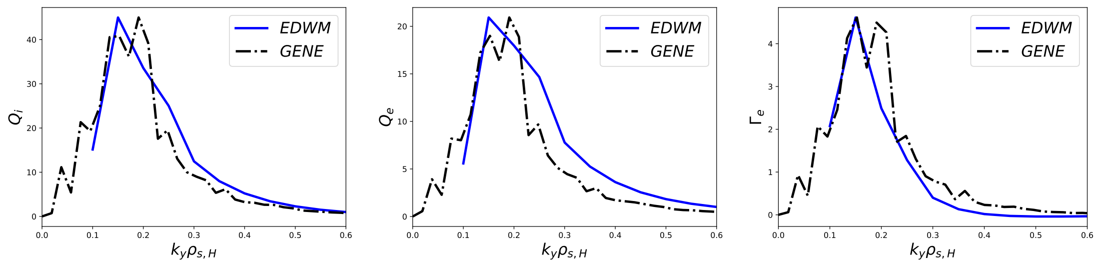

Figure 1: Comparison of fluxes of ion energy (a), electron energy (b) and particle flux (c) between a nonlinear GENE simulation and new EDWM for JET discharge 91544 at $\rho_t = 0.8$.

growthrate, R the major radius and "a" denotes the value of the parameters at the the correlation length scale. The shape of f has been determined by comparing with the spectral shape from 17 non-linear simulations with the gyro-kinetic code GENE [2]. There are two simulations from AUG, three from DIII-D and twelve from JET including both H- and L-mode plasmas. The JET simulations include three hydrogen plasmas, the majority have deuterium as main ion species. Analysis indicated that the zonal flow velocity dominate the saturation mechanism for the turbulent transport with which are in agreement with previous studies [3]. Hence, the correlation length scale is determined by the maximum value for γ/k_y, the length scale for of the zonal low velocity. An example of the effect of the filter are shown in Figure (1), compared with Gene's spectral shape. EDWM capture the spectral shape for all transport channels in a satisfactory way. The magnitude of the EDWM fluxes have been normalized with maximum level from the GENE simulations.

The EDWM collision operator is described in detail in [4] and it works well at low and high collisionalities, however at intermediate collisionality it is not as proficient. We aim to update the EDWM collision operator by benchmarking it for the GA standard case against the gyro-fluid model TGLF [5] and linear simulations with GENE. This is done by investigation the zero flux peaking factor (ZF PF), the normalized density gradient which causes the turbulent particle transport to have zero flux. As it is sensitive to the collisionality it is suitable for the collision operator tuning. We have calculated the ZF PF at different fractions of the "natural" collision frequency and compare the results

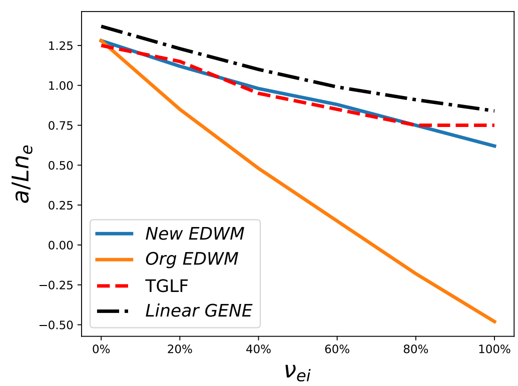

Figure 2: Zero Flux peaking factor for GA standard case.

in Figure (2). TGLF and linear GENE show a similar dependence on the collisionality with a small offset. Original EDWM is in agreement in the collisionless limit, however at larger fractions the result diverge from TGLF and GENE. New EDWM solves this by multiplying the collision frequency with a factor of 1/3. The result for new EDWM is the orange line in Figure (2) and it is well matched with the other codes.

Original EDWM yields too low electron heat flux compared to its ionic counterpart. In order to investigate this problem, we compared the fluxes provided by EDWM with the fluxes from the 17 GENE simulations. We calculated the ratio between the ion and electron heat flux. The result showed that on average the electron heat flux is about a factor 2.88 too low in original EDWM. This factor have been added to electron heat flux for the new EDWM. Result of the ratios for the new EDWM are displayed in Figure (3) and are more satisfactory.

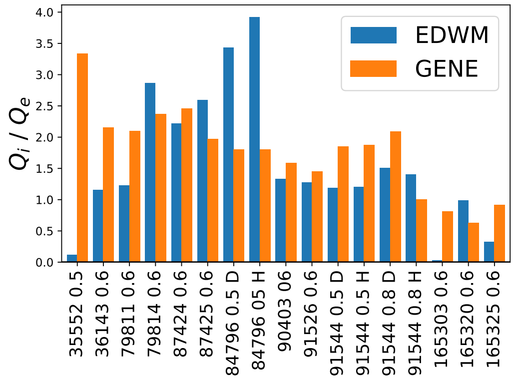

Figure 3: Ratio for Q_i/Q_e for 17 GENE and new EDWM simulations.

Original EDWMs' response to the safety factor has been updated in the new version by comparing with safety factor scans done with the gyro-kinetic code GYRO [6]. Results show that a stronger dependency is needed which will lead to a larger transport in the outer regions of typical plasma discharges. The reason for the additional safety factor dependence is to model the spectral shift with safety factor which are seen in non-linear gyro-kinetic simulations [7]. We have compared our simulations with EDWM with safety factor scans which have been performed with the GA standard case, with $\hat{s} = 1$ and $\hat{s} = 1.5$, and the TEM1 case. From the simulations it is clear that the GYRO simulations has a stronger dependency which EDWM does not capture. The heat fluxes also have a larger discrepancy between GYRO and EDWM. Hence, we have added a different coefficient for the particle and heat fluxes in the implementation of the new EDWM. The average different dependency between the EDWM result and GYRO database are as follow: particle flux; 0.09 and heat flux, 0.77. These two coefficient have been implemented as power law corrections for the safety factor on the fluxes which EDWM provides. The new version of EDWM are shown for the heat fluxes for the GA standard case with $\hat{s} = 1$ in Figure (4).

The last improvement we present in this paper is the normalization level for the fluxes. As the original EDWM normalization level was with 5 poloidal wavenumber instead of 11 and without the updates presented, the level need to be adjusted. We have performed the normalization

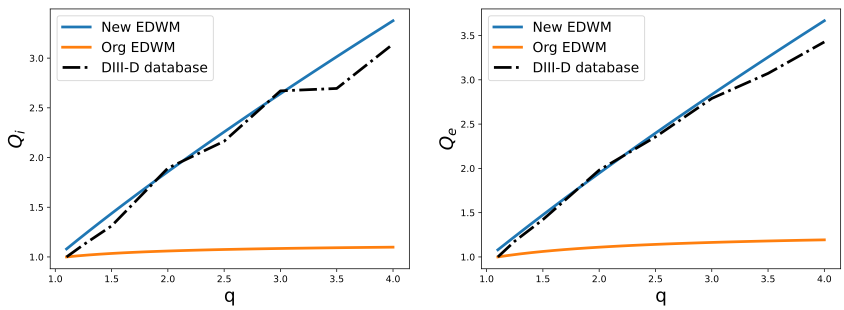

Figure 4: Safety factor scan for EDWM GA standard case with $\hat{s} = 1$ compared with original EDWM and the new version of EDWM.

comparing EDWM fluxes with those from 17 GENE simulations. The results for the EDWM and GENE ratio are presented in Table (1). EDWM overpredicts all fluxes, which is mainly due to the increase poloidal wavenumbers. The results indicate that the fluxes in EDWM should be lowered with a factor of 4.17 to get the same results as GENE. This factor has been added to the new version of EDWM.

For future work the new version of EDWM will be implemented in a integrated modelling tool such as ETS, JINTRAC, ASTRA etc. It is important to perform predictive simulations to verify that the new EDWM capture the complex interplay between different properties in the plasma in a self consistent treatment.

Flux	EDWM/GENE
Q_i	3.60
Γ_e	4.85
Q_e	4.06

Table 1: The average ratio for the fluxes of the new EDWM divided with GENE.

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