

# Transport modelling of a plasma current scan discharge set of ASDEX Upgrade for application to current ramps

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## Introduction

In a previous work [1] a comprehensive study of transport during current ramps has showed some limitations of modelling when it comes to predicting temperature profiles at low currents, due to poor description of edge-like turbulence physics. Here we address the problem from a different perspective, tackling steady-state cases with different plasma currents, such that effects from transients are avoided. A validation study of the recently developed TGLF model [2] against the experiment and the GLF23 model [3] is performed. The main focus here will be on electron temperature profile.

## Set-up of a current scan database for transport simulations

The discharges are selected to provide relevant variation in  $q_{95}$ , as shown in figure 1(a), with purely Ohmic heating (L-mode regimes), and with auxiliary NBI heating (resulting in H-mode regimes). For 0.8 and 1 MA cases, different line averaged plasma densities are considered, as shown in figure 1(b). The time slices for the modelling are taken during the stationary flat-top

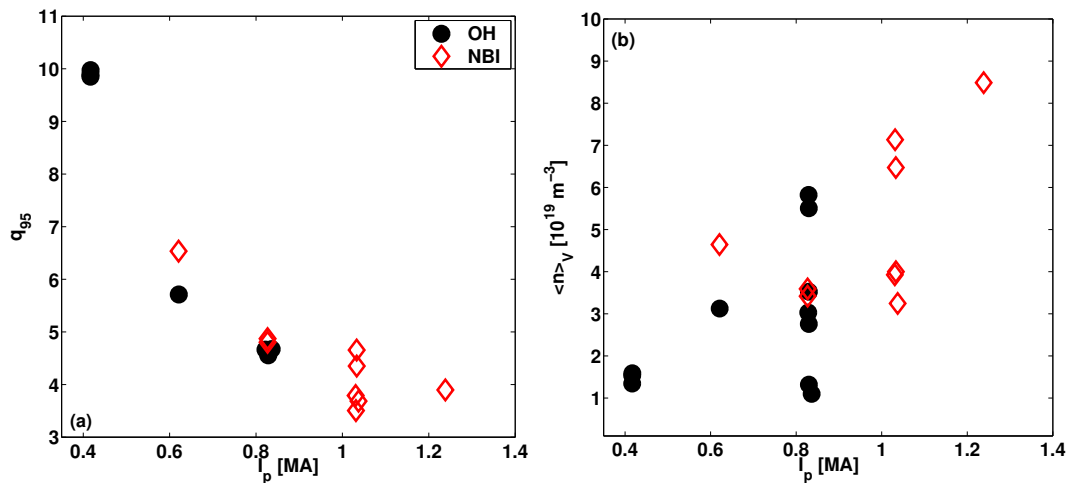


Figure 1: a) Values of  $q_{95}$  versus  $I_p$  for the selected database. Both Ohmically heated (OH) and NBI heated (NBI) plasmas are considered; b) Volume averaged density  $\langle n \rangle_v$ .

phase. The electron density profile is obtained from Thomson scattering, while the electron temperature is obtained from an ECE radiometer. When available, the ion temperature profile is obtained from CXRS, otherwise either from two neutral particle analyzers, or from prescribed profiles which are chosen to match the total energy content of the plasma. The transport simulations are performed with the ASTRA code [4]. The electron and ion temperatures are evolved,

while the density is prescribed. The transport is calculated inside  $\rho_V = 0.9$ , where  $\rho_V = \sqrt{V/V_b}$ , and  $V$  is the volume enclosed by a flux surface.

### Numerical results of quasi-linear transport modelling

Predicted electron temperature profiles  $T_e$  are shown in figure 2(a) for six cases at different  $I_p$  and  $\langle n \rangle_V$ , versus  $\rho_V$ . The agreement between the two models and the experimental data

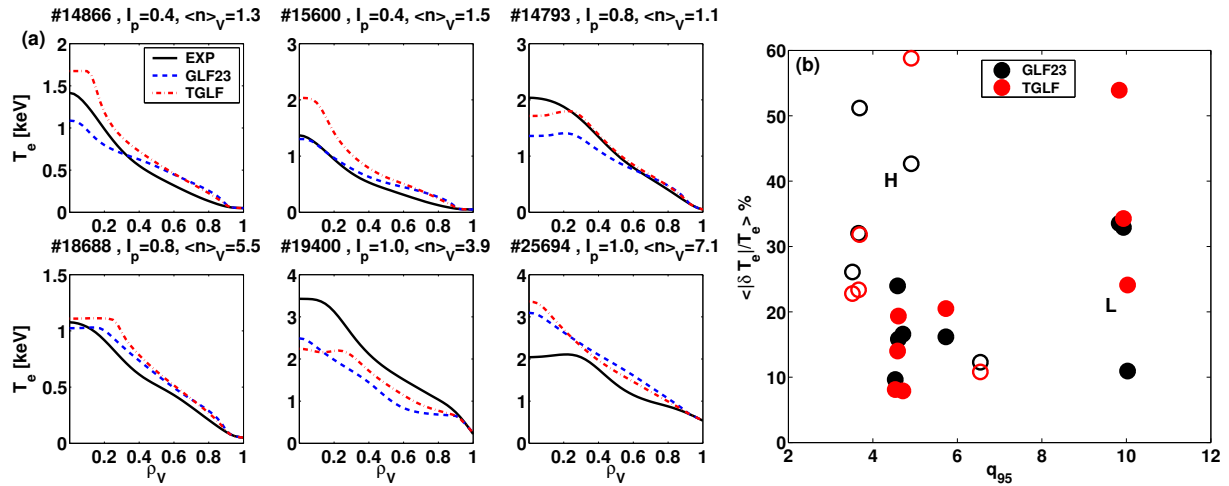


Figure 2: a)  $T_e$  profiles compared between experimental (EXP), GLF23 prediction (GLF23) and TGLF prediction (TGLF), for six cases; b) Overall relative error in electron temperature profile predictions: comparison between GLF23 and TGLF. L-modes are represented by solid symbols, H-modes by empty symbols.

is rather good, although several issues, which cause the observed discrepancies, remain to be investigated. In particular, in the edge region transport is underestimated by both GLF23 and TGLF in the cases at 400 kA. In contrast, it seems to be overestimated in the case #19400. The overall error, defined as the radial integral of the discrepancies, is shown in figure 2(b) for all the simulated cases. TGLF is close to the experiment when the overall error is small, i.e. when the edge is correctly reproduced. On the other hand, when the discrepancy in the edge is large, TGLF tends to produce a larger error. The reasons TGLF tends to give lower core transport than GLF23, especially in presence of a strong trapped electron mode drive, can be seen in the different descriptions of trapped electron physics, between the two codes. TGLF has been vastly extended and carefully checked to match kinetic closures over a wide range of parameters. It could be that the impact of collisionality is rather strong and maybe one of the main reasons for the discrepancy.

### Numerical results of non-linear gyrofluid calculations

The gyrofluid code GEM [5] provides non-linear calculations. Moreover, it uses an optimization procedure that allows profiles to evolve such that the heat fluxes are prescribed (from ASTRA results in this case), by running exponential averages in the saturated phase. The code is used to study transport in the outer plasma region for the current ramp-up of discharge #26328, at a time slice with low current ( $\sim 550$  kA,  $q_{95} \sim 8.5$ ). The time traces of the calculated  $T_e$  (figure 3, left) and  $T_i$  (figure 3, right) are shown. As can be seen from the evolution, the time

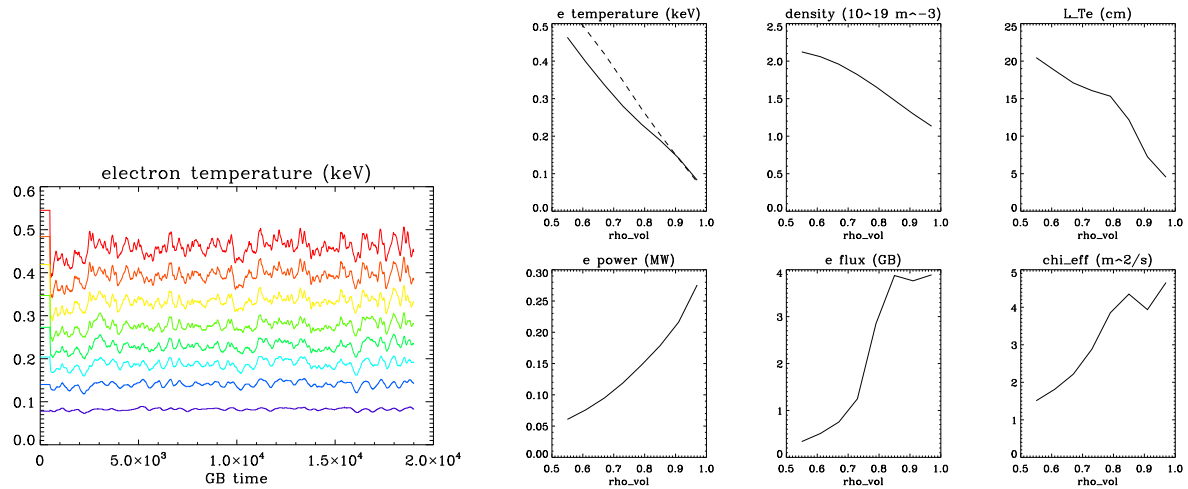


Figure 3: (left) Time traces of  $T_e$  at different radial locations (deep blue is around  $r/a \sim 0.95$  and light red is around  $r/a \sim 0.55$ ). Time is shown in units of  $L_\perp/c_s$ ; (right) profiles of  $T_e$  (dashed line is initial condition),  $n_e$ ,  $L_{Te}$ , input power to electrons, electron flux, and effective energy diffusivity.

evolved profile of the electron temperature is not very different from the initial condition (comparing the solid and dashed line of the top-right subplot of figure 3, right). In contrast, the ion temperature shows a discrepancy which causes  $T_i \sim T_e$  at  $\rho_V \sim 0.5$  and the edge  $T_i$  normalized gradient is almost doubled in magnitude (comparing the solid and dashed line of the top-right subplot of figure 4, right). Note that GEM does not include trapped-electrons, however in the

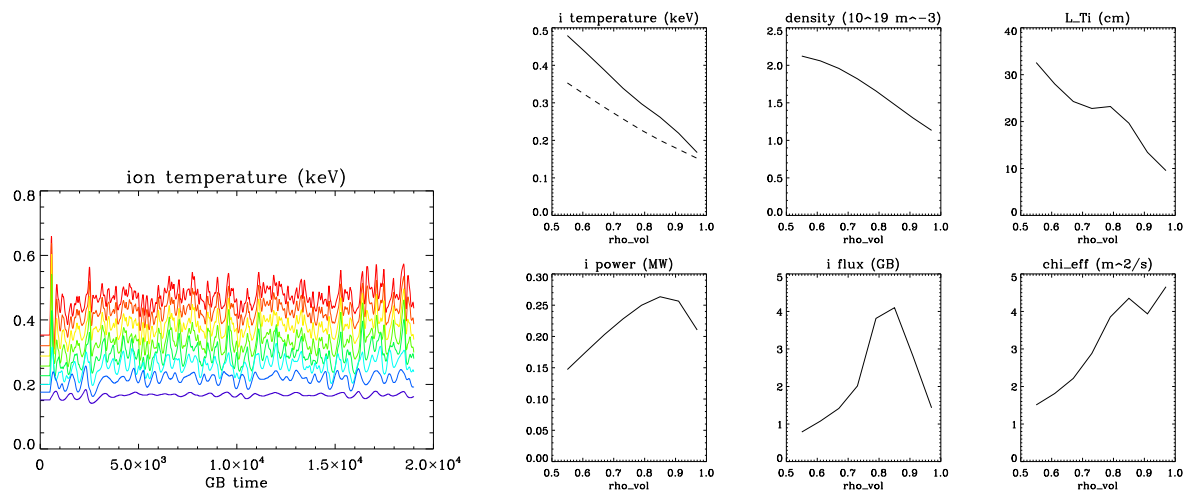


Figure 4: Same plots as in figure 3, but for the ion channel.

edge region it is believed that non-linear drift-wave physics should be the dominant player. Due to the large edge density gradient, ITG physics becomes marginal, which could be the reason why the ions are given a larger peaking than the initial condition. The TGLF simulation of this same case predicts a more peaked  $T_e$  profile and a similar  $T_i$  profile. However, due to the completely different nature of the physics content of the two codes, the fact that  $T_i$  predictions

are similar is a coincidence, which reasons will be investigated further. Note that the effective

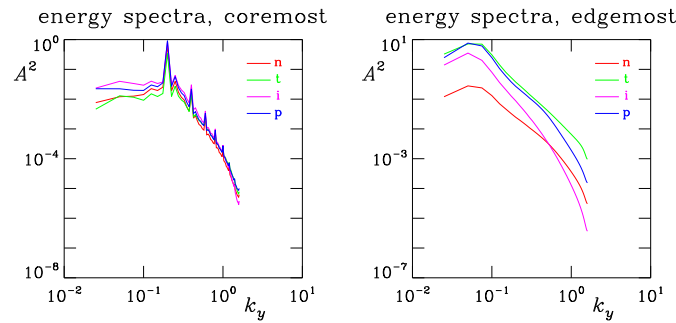


Figure 5: Turbulent spectra for the innermost location  $r/a = 0.55$  (left plot) and for the outermost location  $r/a = 0.95$  (right plot). Turbulent fields intensity are plotted versus the normalized wavelength  $k_y \rho_s$ .

energy diffusivity  $\chi_{\text{eff}}$  (bottom–right subplot of figure 3, right) are increasing from core to edge, which is normally the case for L–mode energy transport. This indicate that a sensitivity study of the profiles behaviour by changing the respective input power could say point out if the observed discrepancy is due to uncertainties on this parameter, rather than on the physic content of the model.

The time–averaged turbulent spectra are shown in figure 5 for (left) the innermost position  $r/a = 0.55$ , and for (right) the outermost position  $r/a = 0.95$ . While in the core region all turbulent fields amplitudes have a very pronounced peak at  $k_y \rho_s \sim 0.2$ , in the edge region most of the activity shifts down at  $k_y \rho_s \sim 0.05 - 0.07$ . These characteristics spectra are typically found in core–edge transition studies [6] and indicate that accounting for long wavelengths is essential.

## Conclusion and future developments

It has been shown that there is a strong sensitivity of the predictions on the behaviour of the model close to the plasma edge, in particular at low currents in L–mode, for both GLF23 and TGLF. TGLF is observed to predict more peaked  $T_e$  profiles at the same input power, in closer agreement with the experiment when the edge is correctly reproduced. It can be concluded that TGLF works better than GLF23 for core transport, however edge modelling is still an issue.

Electromagnetic non–linear gyro–fluid simulations are extremely helpful to understand the issue of core–edge transport coupling as also previously discussed in Ref. [6]. This is very promising work and will be further pursued.

## References

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