EUROPEAN FUSION DEVELOPMENT AGREEMENT

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Benchmarking Tokamak Edge Modelling Codes

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1. INTRODUCTION

Edge modelling codes are currently used to understand and interpret the results ofpresent day tokamaks, and for predictive modelling in support of engineering design of existing, as well as future, tokamaks, e.g. ITER. It is therefore crucial to compare the existing codes, and to understand, document and resolve the differences between them, whether these arise from differences in underlying physics approximations or choices of numerical treatment.

A programme for comparing edge modelling codes is underway, starting with D without drifts, D with drifts, D+C without drifts, and, finally, D+C with drifts. The codes currently being compared are SOLPS (”B2.5-Eirene”) [1–5], EDGE2D-NIMBUS [6–9] and EDGE2D-EIRENE, all with Monte-Carlo neutrals; and SOLPS (”B2.5”) [10–15] and UEDGE [16], with fluid neutrals. In order to remove one possible source of differences in the codes, all of the codes are using the same grid (the standard grid generated by the JET GRID2D [6] or, for some test cases, an orthogonal grid generated by UEDGE). Significant effort has also gone into ensuring that the boundary conditions and transport coefficients are equivalent for all of the codes.

2. RESULTS

In comparing SOLPS (”B2.5-Eirene”) and EDGE2D-NIMBUS, the initial results were very different, but were soon brought closer together [17] by 1. ensuring that both codes used the same kinetic electron and ion heat flux limiters (the “standard” default parameters are different in the two code packages); 2. matching the gas puffing position used to control the separatrix density (the one code used a distributed gas puff, the other started with a point source); 3. matching the core boundary conditions in terms of “recycling” the neutrals absorbed at this boundary into ions.

Figure 1 shows in the left panel the effect of parallel electron and ion heat flux limiters, and in the right panel, the final good agreement between the two codes (and also that the choice of a 5-pt or 9-pt stencil did not seem to make a difference under these conditions), in both cases by plotting the electron temperature at the outer target, for cases where the upstream separatrix electron density was feedback controlled by a gas puff to $0.5\times10^{19}\mathrm{m}^{-3}$. This quantity was chosen because 1. it tends to be a very sensitive indicator of differences between runs; 2. it is physically important, playing a key role in determining power fluxes to the target, as well as influencing the energy of incoming ions by its effect on the sheath potential and so impacting physical sputtering; 3. it is experimentally measurable and so is important when comparisons to experimental results are made; 4. the outer target rather than the inner was chosen because the outer target is usually more critical in power fluxes. The agreement as a function of density is not always as good as this, but the agreement remains satisfactory for higher densities, and the trends are similar (for example, for the $1.5\times10^{19}\mathrm{m}^{-3}$ upstream electron density case, the electron temperature peak was within 10%, but the profile was shifted a few cm’s; this is thought to be caused by differences between the atomic physics in NIMBUS, used with EDGE2D, and EIRENE, used with SOLPS and is under further investigation in the framework of an effort to couple EDGE2D to EIRENE).

The comparison of the codes using a fluid treatment for the neutrals has, somewhat surprisingly, been more difficult than for the codes using a kinetic treatment of the neutrals. The current status of the comparison (for an orthogonal mesh) can be seen in the left panel of figure 2. As with the earlier SOLPS/UEDGE-NIMBUS work, the initial comparisons showed fairly large disagreements, which have largely been eliminated by: 1. using pressure driven diffusion of neutrals in both codes; 2. identified a factor of $\sqrt{2}$ in the expressions for the calculation of the neutral flux limiters; 3. implementing the same method of calculating the neutral D's and χ's in both codes; 4. using an orthogonal mesh; 5. switching off a term in UEDGE that was not implemented in SOLPS accounting
for an energy transfer from electrons to ions associated with molecular break-up; 6. using the same ion energy recycling coefficient; 7. adding an option to UEDGE to use Balescu rather than Braginskii and an option for SOLPS to switch from its standard formulation based on Balescu to the Braginskii formulation originally used in UEDGE; 8. using the same atomic physics.

This last point turned out to be particularly significant, figure 2 shows in the right panel the effect of changing the atomic physics assumptions in the SOLPS simulations. Of particular importance were the rates associated with charge exchange between neutral and ionized D, figure 3 left, which shows some of the rates that were "available" to the codes. Of somewhat smaller importance in the parameter range explored were the electron cooling rates, shown in the right panel of figure 3.

DISCUSSION

While this sort of code-code benchmarking is somewhat thankless work, it is, we believe, crucial. In addition to fixing "bugs" in the codes, it also brings to the forefront some of the "hidden" assumptions or physics choices that have been made. In the above results, the role of the kinetic flux limiters was found to be important: these codecode comparisons cannot say what the "right" answer is in these circumstances, but can highlight the importance of a better understanding of the flux limits. Another important issue identified was the role of atomic physics—an area where the typical modeller might not appreciate that choices made 20 years ago in a code are still having an impact today. The ADAS '96 data set [18], augmented by more recent charge exchange data, is probably the'"best" routinely available data.

The initial question posed by this benchmarking effort, which was to resolve differences between the codes when applied to reproduce the same set of tokamak discharges, can now be answered with some confidence. That is, although the codes used quite different numerical schemes and implementations, when the underlying physical assumptions (including "hidden" ones) and discharge parameters are chosen to be the same, the codes give remarkably similar answers. This exercise thus improves our confidence and understanding of those essential tools for data interpretation and design of future experiments.

This work is still ongoing – the next stage is to complete the D-only, fluid neutral comparisons. After that (and to some extent this has already started), is the comparison of D+C. On a longer time scale, the treatment of drifts in the various codes will be compared.

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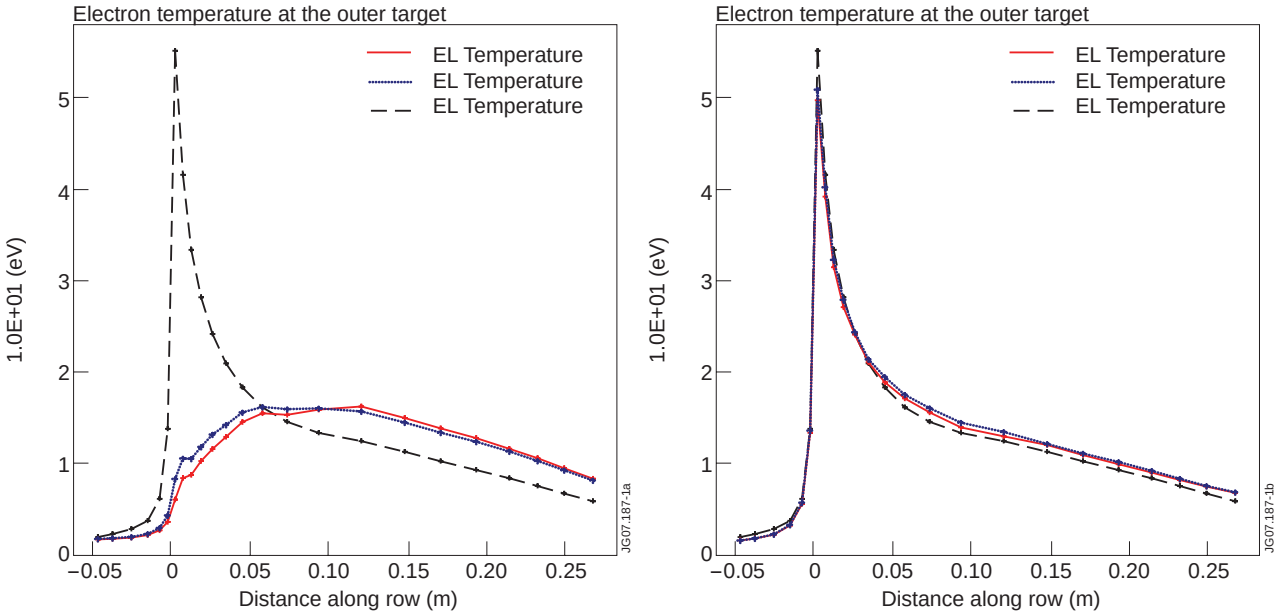

Figure 1: Left: SOLPS runs with differing choices of electron and ion parallel heat flux limiters: 0.15, 0.2 and 10. Right A comparison of EDGE2D-NIMBUS simulations (with 5- and 9-pt stencils) with SOLPS.

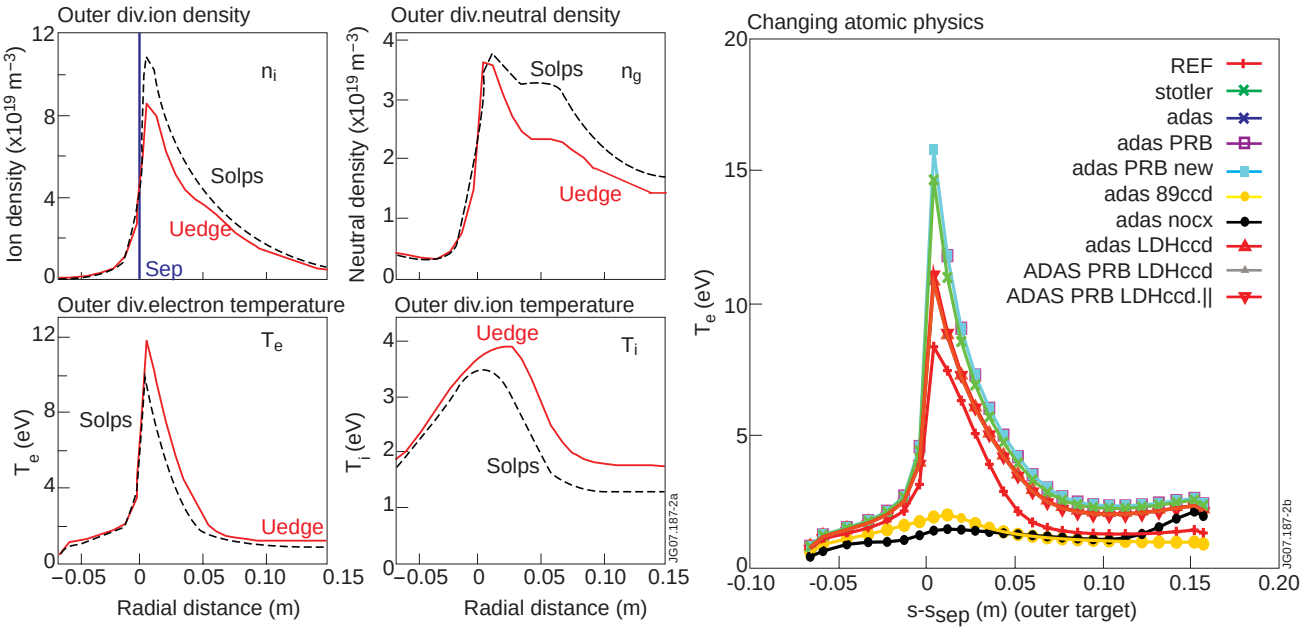

Figure 2: Left: comparisons of SOLPS and UEDGE. Right: SOLPS runs with differing choices for the atomic physics.

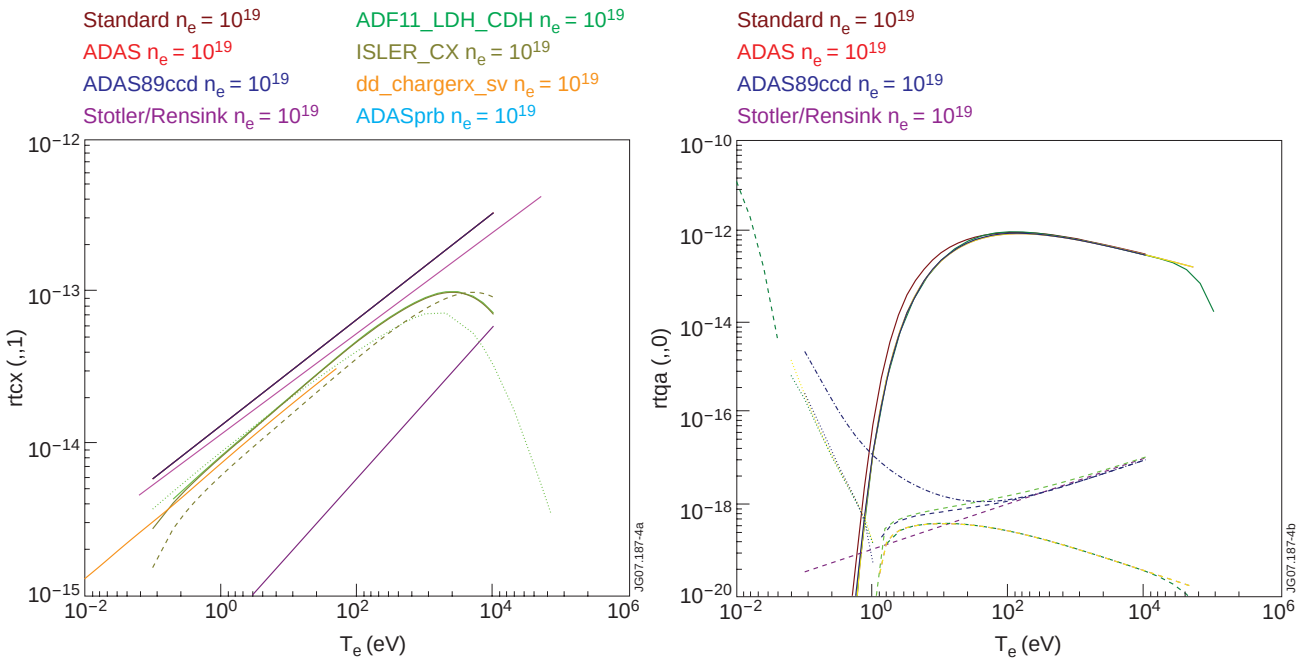

Figure 3: Atomic physics rates. Left: charge exchange rate coefficient as a function of temperature for an electron density of $1\times10^{19}m^{-3}$. Right: The electron cooling rate coefficient as a function of temperature for an electron density of $1\times10^{19}m^{-3}$.