Core-Edge Coupling: developments within the EFDA Task Force on Integrated Tokamak Modelling.

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Introduction

Power exhaust is a key problem in ITER and other future tokamaks. One of the critical ingredients in solving this problem is radiative cooling, with a combination of core and divertor radiation. For a reactor concept based on radiative cooling, it is crucial to ensure consistency between the core plasma and the Scrape-Off Layer. In [1], three approaches for core-edge coupling were described: **mediated**, where the edge codes are used to provide boundary conditions for the core codes on the basis of fitting coefficients to the results of a number of edge runs; **direct** where the edge and core codes are directly coupled; and **avoided** where the edge code is extended all the way to the centre of the plasma. In that paper coupling was avoided by extending the edge calculation to include the core plasma. In this work we consider the problem of coupling core and edge transport codes within the EFDA Task Force on Integrated Tokamak Modelling using **direct** coupling.

Coupling codes can introduce a number of problems: (i) a disparity in time-scales, (ii) a mismatch in physics assumptions, (iii) the complexity of dealing with separate codes, (iv) possible mixed-language programming, and (v) scheduling the interaction between the coupled codes.

The core-edge coupled system does introduce a disparity in time-scales, with a characteristic time-scale for the core being an energy confinement time or longer (seconds for ITER), whereas the Scrape-Off Layer (SOL) typically has a time-scale of milliseconds with some phenomena being even faster. Another disparity is the computational complexity: the transport solver for the core is typically a 1D (radial) code solving a set of reaction-convection-diffusion equations evolving the density, toroidal momentum and energies for the species considered; the edge transport solver is typically a 2D (radial and poloidal with toroidal symmetry assumed) or 3D code solving for the density, parallel momentum and energies for the species considered and is typically considerably more expensive computationally. In the case of the core, it is often the case that the impurity species are split off from the main ion species, and only the density equations are solved for the various impurity charge states.

Given the disparity in time-scales and complexity, the necessity of core-edge coupling should be critically assessed for each physics problem. An important class of applications are, however, simplified if the goal is to find a consistent steady state solution between the core and edge codes, and it is that problem that is addressed here.

The EFDA Task Force on Integrated Tokamak Modelling (ITM-TF) is building a framework for combining different codes to perform simulations that go beyond the capabilities of any single code. This is being done by standardizing the information to be transferred between different classes of codes, and then adapting the individual codes to accept and provide these standardized information objects (called Consistent Physical Objects, CPOs[2]). This approach minimizes the changes that need to be introduced into any code, while maximizing the range of possible workflows that can be performed.

Other work in this area can be found in [3] and Senichenkov *et al*, this conference.

Results

The edge 2D transport code (SOLPS)[4] was coupled with a workflow based on a core main plasma transport code (European Transport Solver, ETS)[5] and a core impurities transport code. In this work the "Fortran" version of the ETS workflow was used; simultaneously effort has been ongoing in developing the planned multi-language version of the workflow using Kepler[6]. This version includes the core transport code (ETS), an impurity code developed within the framework of the ITM-TF, the equilibrium code HELENA[7] and simple models for particle and energy sources as well as transport coefficients.

A Python program was written to import an equilibrium for an ASDEX Upgrade shot (#17151) and store the necessary information in ITM equilibrium and limiter CPOs. The same Python program calculated a bounding surface that separated the calculation domains between the core and edge codes (in the examples here, at 95% of the normalized poloidal flux), figure 1. This information was then used by the HELENA equilibrium code, together with an initial guess as to temperature and density profiles, to calculate the equilibrium for the core transport codes. The ETS workflow was then run until converged, using an initial guess as to the boundary conditions at the core-edge interface. The same initial equilibrium information was used to create the SOLPS grid. Figure 1 shows the combined grids, as well as the limiter information, with

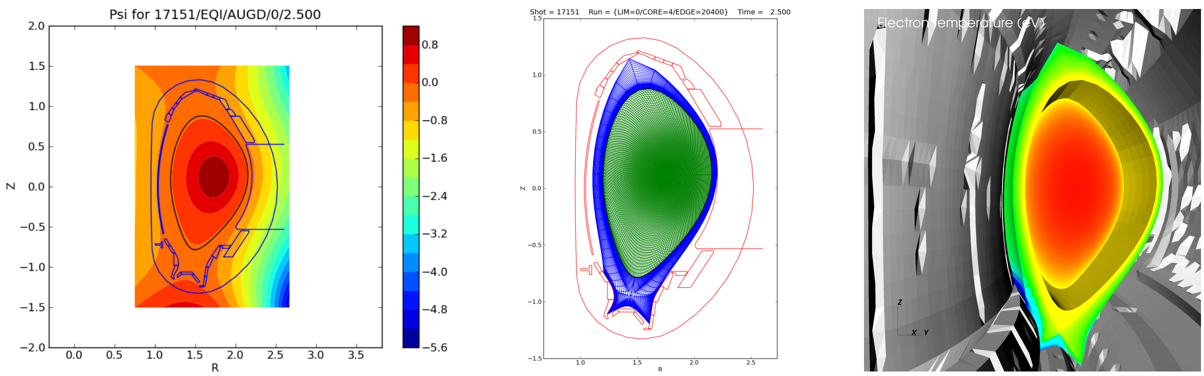

Figure 1: Left, AUG shot 17151 at 2.5s showing the poloidal flux and the 95% flux surface. Centre, the combined core and grids for the same shot. Right, combined results from the core and edge simulations (showing the electron temperature), together with a representation of the AUG wall.

all data derived from ITM-TF CPOs. Then the two codes were called alternately and each run individually until converged, with information about the boundary conditions transferred from one code to the other with the use of two Python programs, until convergence of the workflow was achieved.

In setting up the information transfer between the core and edge codes, a number of choices need to be made: (i) the mapping between species handled by the codes (SOLPS treats neutrals and all charge states of the ions; the ETS workflow distinguishes between "main" ions for which a full set of transport equations is solved, but no ionization or recombination reactions are treated, and "impurity" ions for which only the density equations are solved, but where ionization and recombination are treated); (ii) the direction of the coupling: whether fluxes or values are passed; in these cases values of density and temperature were passed from SOLPS to the ETS, and the ETS returned energy and particle fluxes; and (iii) the mapping from the 1D inner boundary of the SOLPS computation to the single point forming the ETS boundary (averaging temperature/densities or integrating fluxes).

For the most complicated case described here, SOLPS treated all of the charge states of D, He, C, Ar and Ne (including the neutrals), a total of 42. The ETS treated D^+ and He^{+2} as main ions, and the core impurity code treated the individual charge states of C, Ar and Ne. The core codes did not, in this case, treat the neutrals and SOLPS used a zero-flux boundary condition for these. SOLPS also used a zero-flux boundary condition for all of the charge states of C, Ar, Ne and for He^{+1}. The results for the electron temperature and density, and the convergence, are shown in figure 2.

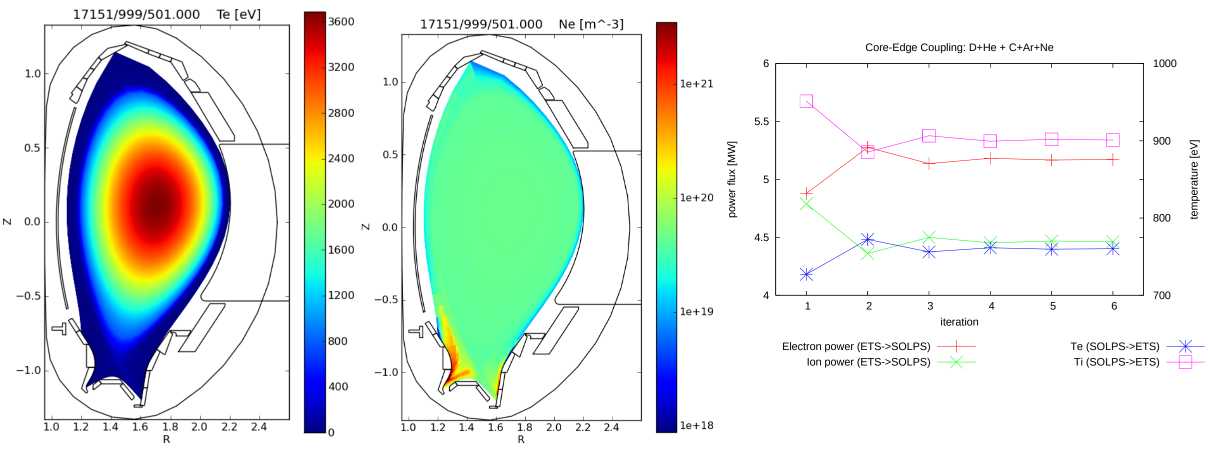

Figure 2: Plots of Te and ne for the final state of the D+He + C+Ar+Ne case, as well as a plot showing the convergence with iteration number of the boundary powers and temperatures.

Discussion

Coupling of an edge transport code and a core transport code has been demonstrated for the particular case of steady state and multiple impurities, using the ITM-TF infrastructure (standardized inputs/outputs as CPOs). This work will be extended to treat time-dependent cases and to make use of the Kepler simulation manager for orchestrating the workflow.

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