FIRST SOLPS-ITER WIDE GRID SIMULATIONS OF THE ITER BURNING PLASMA SCRAPE-OFF LAYER

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One of the key issues for next step fusion reactors is how the energy from the confined plasma will distribute over the different plasma-facing components (PFC). On the one hand, the heat loads on the divertor targets and other material surfaces should stay below engineering limits [1], while on the other surface sputtering should be low enough to have modest impact on the core plasma, particularly in view of the new ITER re-baseline in which tungsten (W) replaces beryllium as main chamber armour [2].

To date, the majority of high-fidelity simulations of the ITER burning plasma boundary and divertor plasma have been performed with the SOLPS suite of codes, and notably the SOLPS-ITER version hosted by the ITER Organization [3]. Until now, these SOLPS studies have been restricted to numerical grids extending from the pedestal region to the last flux surface in the scrape-off layer (SOL) on which field lines still connect continuously from inner to outer divertor targets (usually corresponding to the “second separatrix” of the lower single null divertor configuration). Plasma parameters in the regions between the second separatrix and the first wall were approximated using decay profiles from the simulation region, while particle and energy fluxes were assumed to reach the real surfaces unchanged, allowing recycling, sputtering and heat loads to be calculated, but leading to large uncertainties. This can be overcome if the grids can be extended to the walls, as is the case, for example with the SOLEDGE3X code, using which simulations have been recently performed for ITER non-active phase operations [4] and even for a few neon (Ne)-seeded burning plasma cases [5]. This capability has now been introduced in SOLPS-ITER following a multi-year program to develop a wide unstructured grid approach [6].

First test wide grid simulations with the code were performed for EAST using SOLPS-ITER3.2.0 [7] and, as reported here, are now extended to the ITER Ne-seeded baseline scenario at P_{SOL} = 100 MW (see Fig. 1a for the numerical grid). The primary aims of this first numerical study are the realistic description of the plasma flows in the far-SOL and production of plasma backgrounds for the calculation of W sputtering and migration by other codes. For the first time for such a scenario, convergence of SOLPS-ITER 3.2.0 was attained with the equation for the electrostatic potential included in the calculations (which also include coupling with the Eirene code for kinetic neutrals). To obtain these results several modifications were made compared to the code described in [6]: the flux limiting coefficients were upgraded in the far-SOL regions with extremely low collisionality; the boundary conditions were improved to ensure numerical stability; several other stability issues were resolved. Drift contributions were turned off both in the particle and current balance, so that the neoclassical solution for the radial electric field inside the separatrix could not be reproduced. Nevertheless, inclusion of the current balance in the SOL and divertor private flux regions (PFR) provides an opportunity to calculate thermoelectric currents and the distribution of the electrostatic potential, determined mainly by the electron parallel momentum balance. The self-consistent sheath potential drop obtained in the calculations can be of importance for future sputtering modeling.

Anomalous transport coefficients in the far-SOL were chosen based on physical analysis of filamentary transport [8,9], consistent with experimental observations. Such considerations indicate appropriate values of particle diffusivity in semi-detached scenarios of ~$2\,m^2/s$. Its value has been scanned in a series of simulations in which the radial profile of $D_\perp$ is increased from a magnitude typical for near-SOL calculations used in previous standard grid code runs ($D_\perp = 0.3\,m^2/s$ [1]), up to $5\,m^2/s$ and $10\,m^2/s$ in the far-SOL to try and reproduce the density shoulders often observed experimentally in high density H-mode operation on current devices [10]. As usual, the heat conductivity transport coefficients were increased proportionally (with a ratio $\chi_\perp/D_\perp$ ~3). The near-SOL, described here by parameter L, is defined as the region over which transport is set to low values and has been fixed at 1 cm or 3 cm, as a proxy for the “breakpoint” seen experimentally (for which there is not yet a clear physics basis) between the near and far-SOL density or power flux profiles. In all simulations, the Ne seeding is set by a feedback scheme to achieve a prescribed separatrix concentration (for these first runs set to $C_{Ne} = 0.4\%$ or $C_{Ne} = 1.2\%$).

For the lowest diffusivities in the scan, the results obtained on the extended grid are close to those found on the standard grid in the common region of modeling, (Fig.1(b)). For higher transport only the wide grid modeling is reliable. Figure 2 compiles profiles of selected parameters along the first wall poloidal contour and the electron density profiles at the outer midplane (OMP) for the 8 code runs which form this first ITER study with the wide grid code. For the highest value of $D_\perp$ the characteristic density width in the far-SOL has increased by a factor ~3, but this value also leads to an increase of the ionization source inside the separatrix and very high far-SOL ion temperatures. For lower values, typical of those estimated based on the simple model of filamentary transport and for modeling of semi-detached regimes of modern tokamaks, the far SOL transport does not significantly affect the plasma parameters inside the separatrix. Importantly, the flow of main ions and seeded impurity to the wall at the outer and inner midplanes increases by a factor ~100 as $D_\perp$ increases from 0.3 – 2.0 m^2/s. Whilst T_e decreases with scale length comparable to that of the density, T_i falls considerably more slowly. This can be understood from simple considerations of radial and parallel transport balance in the sheath-limited regime, characteristic of the far-SOL plasma. Thus λ_{Ti} can exceed 10 cm, leading to high (of the order of several tens of eV) values of T_i at the wall. The Ne ion average charge state at the wall, an important parameter determining the strength of the wall sputtered W source, is in the range $<Z_{Ne}>$ = 5-8 at the inner and outer midplanes for the runs with increased far SOL diffusivities and somewhat lower ($<Z_{Ne}>$ = 2-3) for lower cross-field transport.

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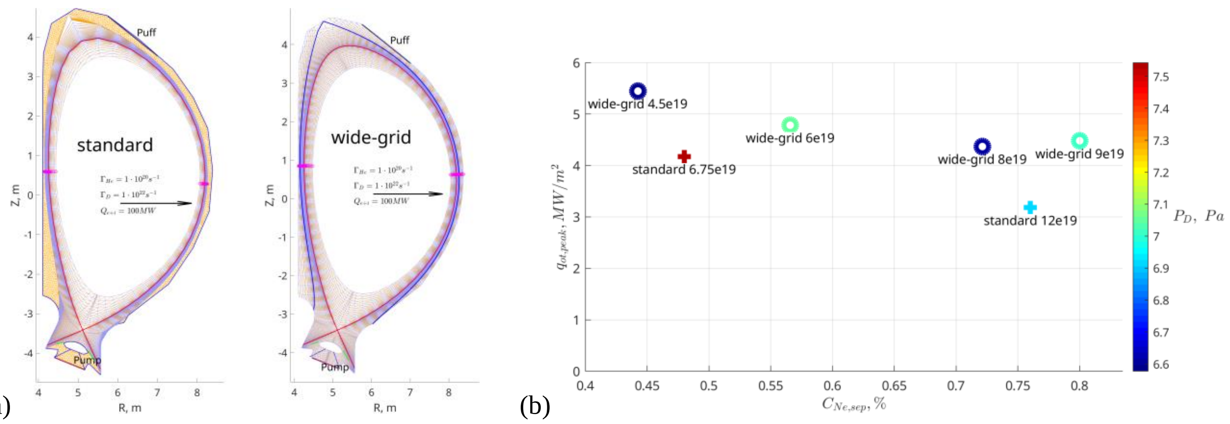

Fig.1. (a) Computational domains for the standard and wide grid simulations. The plasma mesh is shown in purple and the green lines in the PFR cross the cells where deuterium neutral pressure P_D is calculated. (b) Peak outer target plasma heat flux density versus C_{Ne} . The colorbar gives the neutral pressure in the private flux region according to the definition used in [1].

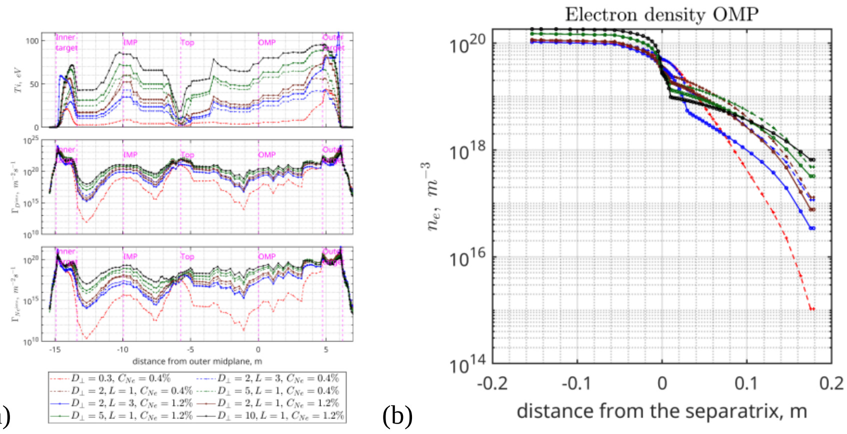

Fig. 2. (a) Profiles of ion temperature, deuterium and Ne ion flux along the wall; (b) electron density at the OMP for different transport coefficients in the far SOL.