Further Developments of the Edge Transport Simulation Package, SOLPS

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Abstract. The continuing development of the SOLPS package of codes is described, together with some examples of results.

1. Introduction

Development of the SOLPS suite of codes has continued since the last IAEA conference with further refinement of the drift and current terms in B2–SOLPS5.0 (B2.5), the development of a version of B2 implementing dynamic grid adaptation (B2–SOLPS6.0), the development of an interpretive version of B2, the coupling of B2 to a turbulence code, and the implementation of time-dependent boundary conditions and transport coefficients. These developments have allowed new physics to be simulated and compared to experiment.

2. Background

The SOLPS (Scrape-Off Layer Plasma Simulation) suite of codes consists of

1. a 2-D multi-fluid plasma code, B2 (the original version [1,2] was further developed at Garching, and then replaced by a newer version [3] which was further modified [4–6])
2. a 3-D multi-species Monte-Carlo neutrals code, Eirene [7]
3. B2–Eirene, from the coupling of B2 and Eirene [8, 9]
4. a grid generator, Carre [10]
5. a graphical display program for setting up new configurations, DG
6. a plot program for plotting the plasma state
7. a set of scripts and programs for plotting the time-development of the plasma

and is one of the standard tools used to simulate the edge plasma of present day machines, as well as to make predictive runs for planned machines (ITER [11–16], KSTAR, SST, HT7-U). Three versions of the SOLPS package exist: SOLPS 4.0 (using the older B2) is still in use where analysis started before the release of SOLPS 5.0; the current standard

SOLPS 5.0 (in two variants: a development version in St. Petersburg, the "Russian" version, and the release version, the "German" version) and the yet-to-be released SOLPS 6.0 with mesh adaptation.

3. Determination of anomalous transport

The value of the anomalous radial heat and particle transport is an important input into the edge transport codes, and usually enters as particle and thermal diffusivities, D and χ. At the last IAEA meeting [17] a technique for deriving these directly from experiment was shown (see also [18, 19]), here an alternative technique is demonstrated where the transport coefficients are obtained from a "first principles" turbulence code by coupling the two together [20, 21]. Two variants of the coupling are possible. **"Direct coupling"** where the codes are called alternately, with the plasma background being calculated by the transport code, which then passes them to the turbulence code, which then calculates the fluxes of particles and energy, and then passes these fluxes to to the transport code which uses them (in the the form of transport coefficients) to update the profiles. **"Indirect coupling"** parameterizes the output from the turbulence code over the range of expected plasma conditions, and then this parameterization is used by the transport code. Both methods have been implemented: the first gives rise to "noise" from the turbulence code (similar to that found when coupling a fluid plasma code to a Monte-Carlo neutrals code), and so, for parametric studies, the second has been more actively pursued.

4. Modeling of electric fields and currents in the edge plasma

The impact of electric fields and the corresponding drifts are important for the redistribution of plasma and impurities in the edge plasma. The radial electric field in the vicinity of a separatrix may be responsible for the transition into the improved confinement regime (L-H transition). Therefore, effects associated with the electric field should be included in the transport codes. The 2–D problem of the calculation of the self-consistent electric field is complicated since the electric field is determined by various mechanisms of perpendicular conductivity. Rather subtle effects such as diamagnetic currents, different components of the viscosity tensor, inertia and collisions with neutrals determine the transverse current, and, therefore, the current distribution and self-consistent electric fields in the edge plasma.

These effects were included in the B2–SOLPS5.0 code [4–6]. Simulations [22–26] give the dependence of the radial electric field on the local and global plasma parameters. The shear of the radial electric field, which is responsible for the transition to an improved confinement regime, is a linear function of a local ion temperature and the local average toroidal velocity and is inversely proportional to the toroidal magnetic field. The scaling for the L-H transition threshold agrees with the experimental H-mode scaling of ASDEX Upgrade. The radial electric field shows no bifurcation and is close to the neoclassical electric field with the toroidal rotation contribution determined by the radial anomalous transport of the toroidal momentum. The fine structure of the electric field at the separatrix and its dependence on toroidal magnetic field inversion was also analyzed.

Additionally the radial electric field in biasing experiments and the ensuing effective conductivity has also been analysed [27], as well as the impact of drifts on impurities [28].

The effects of electric fields and currents have also been examined for the island divertor configuration [29], Alcator C-Mod [30] and are being pursued for JET and ASDEX Upgrade.

5. Grid adaptation

We developed a version 6.0 of the 2–D multispecies plasma fluid code B2, where a flexible dynamic grid adaptation module has been added. The method followed in this case involves the creation of two grid structures. A fine 2–D mesh produced from the magnetic flux surface structure serves as a scaffolding on which a rougher, adaptable mesh is constructed depending on the physical situation. The conditions for grid refinement/coarsening involve normalized gradients of the plasma parameters and are checked at regular intervals. The algorithm and its numerical implementation are described in detail in [31, 32]. This new version is fully backwards-compatible with SOLPS5.0, and includes the same physics.

The new code version allows one to simulate localized and/or time-dependent phenomena by dynamically increasing the grid density in the zone of interest without a strong increase of CPU runtime [32], thus enabling a more realistic modelling of such features as detachment fronts, MARFEs or ELMs.

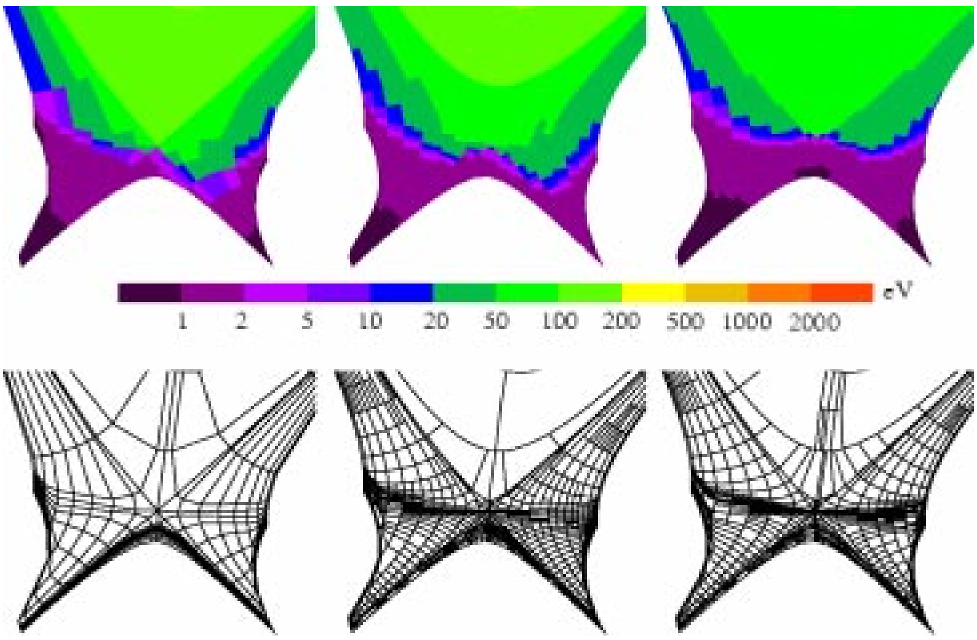

Figure 1: Comparison of electron temperature results and respective grids without (left) and with (center) grid refinement, plus with increased gas puffing (right). The detachment front is clearly much better resolved where grid refinement takes place, although the general plasma behaviour is essentially the same. With increased gas puffing, the detachment front moves upwards away from the plate and the region of grid adjustment follows this motion.

6. Additional changes

In addition to the above-mentioned drift terms, the code package has also been enhanced by: 1. the addition of code to ensure accurate particle balance needed for some pumping scenarios (into SOLPS 4.0 [13] and also into the SOLPS 5.0 version) 2. the preparation of a SOLPS 5.0 manual [33] (in continuing development); 3. the preparation of a set of course notes on SOLPS [34]

7. Some additional physics results

The SOLPS code package has been used to model the compression of deuterium and helium for ASDEX Upgrade [35] as well as to explore power asymmetries during ELMs [36].

Increasing use is also being made of the SOLPS package to model JET [37–39].

8. Plans

Further code development and integration is planned: 1. the new version of Eirene which includes photon transport and uses dynamic memory allocation will be coupled; 2. the "Russian" version of the B2 code (with a more complete set of equations but with the older, staggered grid formulation of the momentum equation) will be merged with the "German" version (which, in addition to a cell-centered treatment of the momentum equation, has provision for a wider variety of geometries — limiter, single null, double null, stellarator island); 3. the possible inclusion of additional kinetic effects in the SOL; 4. the possible extension of the drifts to deeper into the core region raises issues related to the validity of the equations in the banana regime — additional kinetic corrections might be needed to stabilise the code; 5. the possible extension to include additional surface physics effects; 6. additional physics could also rise when using the code for very low aspect ratio tokamaks. In conjunction with the JET activities [38], an effort to benchmark the three edge codes used for JET will be pursued. It is also planned to extend the use of the interpretive version of the B2 code, B2.5-I, to other tokamaks.

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