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Sensitivity-based Uncertainty Quantification for plasma edge codes: status and challenges

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Plasma edge codes like SOLPS-ITER [1] are currently the main tools for interpreting exhaust scenarios in existing experiments, and for designing next step fusion reactors like ITER and DEMO. These codes typically couple a multi-fluid model for the plasma with a kinetic model for the neutral particles. While the former is implemented in a (deterministic) Finite Volume setting, the latter is solved with (stochastic) Monte Carlo (MC) methods, making simulations computationally expensive. Moreover, several sources of uncertainty are present throughout the complex simulation chain: starting from the magnetic equilibrium reconstruction, which forms the basis for the plasma mesh; going over unresolved physical phenomena requiring closure terms and related parameters, such as anomalous transport coefficients; and finally, a plethora of uncertain input parameters, such as atomic physics rates or boundary conditions. Therefore, uncertainty quantification (UQ) for model validation with plasma edge codes appears a challenging task, which is presently precluded by the high computational costs.

In this contribution, we show how adjoint sensitivity analysis enables UQ for plasma edge codes, discussing the main achievements so far, and the remaining issues and challenges. The adjoint sensitivity analysis is based on Algorithmic Differentiation (AD), which provides floating-point accurate sensitivities for complex codes in a semi-automatic way. Such sensitivities are then fed to gradient-based optimization methods, which are employed to solve the backward UQ problem, also known as parameter estimation or model calibration. Casting this estimation into a Bayesian Maximum A Posterior (MAP) setting, we consistently account for information and uncertainties from different diagnostics [2]. The main limitation of this framework is that currently only an approximate fluid neutral model can be employed. The more accurate MC model requires dealing with statistical noise in the sensitivity computation. We show that this can be accommodated in a discrete adjoint setting [3] and report on first results employing AD. Finally, we show how a combination of finite differences and adjoint sensitivities, also known as an in-parts adjoint technique, allows sensitivity propagation throughout the whole simulation chain, including magnetic equilibrium reconstruction [4].

[1] S. Wiesen et al. (2015), J. Nucl. Mater. 463, 480-484.
[2] S. Carli et al. (2021), Contrib. Plasma Phys. 62 (5-6), e202100184.
[3] W. Dekeyser et al. (2018), Contrib. Plasma Phys. 58, 643-651.
[4] M. Blommaert et al. (2017), Nuclear Materials and Energy 12, 1049-1054.

Speaker's Affiliation

KU Leuven, Leuven

Member State or IGO/NGO

Belgium

Primary author: CARLI, Stefano (KU Leuven)

Co-authors: DEKEYSER, Wouter (KU Leuven, Department of Mechanical Engineering); HORSTEN, Niels (KU Leuven); BLOMMAERT, Maarten (KU Leuven); BAELMANS, Tine

Presenter: CARLI, Stefano (KU Leuven)

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