Reliable Waveform Relaxation Convergence Estimates for Atmosphere-Ice-Ocean Coupling

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Abstract

Climate models are large, coupled codes solving nonlinear systems of partial differential equations. We focus on the atmosphere, ocean, and sea ice components, which are coupled at the sea surface via boundary conditions. Coupling algorithms used in practice correspond to a single step of iterative Schwarz waveform relaxation (WR) methods. Not iterating is computationally cheap but introduces numerical coupling errors which can be substantial [1]. Coupling error reduction is directly linked to the convergence factor of the WR iteration. We are therefore interested in reliably estimating the latter.

To this end, we recently contributed with the WR convergence analysis of a simplified model for thermodynamical atmosphere-ice-ocean coupling: in essence, coupled heat equations with discontinuous material parameters and nonstandard interface boundary conditions [2]. In this talk, we compare the results from this analysis to WR convergence results we obtain with a coupled single column climate model: the EC-Earth AOSCM, which uses the same coupling setup as its host model, EC-Earth. Our analysis in [2] explains observed fast WR convergence in ice-free simulations. When sea ice is present, WR in the EC-Earth AOSCM converges much faster than the analysis predicts. This discrepancy can be reduced by modifying the sea ice component in the simplified model. We also show how discontinuities in the EC-Earth code can slow down numerically observed WR convergence. Our work illustrates that simplified models and established WR analysis techniques are useful tools to understand WR convergence for state-of-the-art atmosphere-ice-ocean codes.

References

[1] Valentina Schüller et al. "Quantifying coupling errors in atmosphere-ocean-sea ice models: A study of iterative and non-iterative approaches in the EC-Earth AOSCM". In: *Geosci. Model Dev.* 18.22 (Nov. 2025), pp. 9167–9187. ISSN: 1991-9603.

[2] Valentina Schüller, Philipp Birken, and Hanna Kjellson. "Analysis of bulk interface conditions for atmosphere-ice-ocean coupling". In: *DD29 Proceedings*. Dec. 2025. DOI: 10.5194/gmd-18-9167-2025.