Towards robust prediction of the dynamics of the Antarctic ice sheet :

Uncertainty quantification of sea-level rise projections and grounding-line retreat with essential ice-sheet models

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Abstract

Recent progress in the modelling of the dynamics of the Antarctic ice sheet has led to a paradigm shift in the perception of the Antarctic ice sheet in a changing climate. New understanding of the dynamics of the Antarctic ice sheet now suggests that the response of the Antarctic ice sheet to climate change will be driven by instability mechanisms in marine sectors. As concerns have grown about the response of the Antarctic ice sheet in a warming climate, interest has grown simultaneously in predicting with quantified uncertainty the evolution of the Antarctic ice sheet and in clarifying the role played by uncertainties in predicting the response of the Antarctic ice sheet to climate change.

Essential ice-sheet models have recently emerged as computationally efficient ice-sheet models for large-scale and long-term simulations of the ice-sheet dynamics and integration into Earth system models. Essential ice-sheet models, such as the fast Elementary Thermomechanical Ice Sheet (f.ETISh) model developed at the Université Libre de Bruxelles, achieve computational tractability by representing essential mechanisms and feedbacks of ice-sheet thermodynamics through reduced-order models and appropriate parameterisations. Given their computational tractability, essential ice-sheet models combined with methods from the field of uncertainty quantification provide opportunities for more comprehensive analyses of the impact of uncertainty in ice-sheet models and for expanding the range of uncertainty quantification methods employed in ice-sheet modelling.

The main contributions of this thesis are twofold. On the one hand, we contribute a new assessment and new understanding of the impact of uncertainties on the multicentennial response of the Antarctic ice sheet. On the other hand, we contribute new methods for uncertainty quantification of geometrical characteristics of the spatial response of physics-based computational models, with, as a motivation in glaciology, a focus on predicting with quantified uncertainty the retreat of the grounded region of the Antarctic ice sheet.

For the first contribution, we carry out new probabilistic projections of the multicentennial response of the Antarctic ice sheet to climate change using the f.ETISh model. We apply methods from the field of uncertainty quantification to the f.ETISh model to investigate the influence of several sources of uncertainty, namely sources of uncertainty in atmospheric forcing, basal sliding, grounding-line flux parameterisation, calving, sub-shelf melting, ice-shelf rheology, and bedrock relation, on the continental response on the Antarctic ice sheet. We provide new probabilistic projections of the contribution of the Antarctic ice sheet to future sea-level rise ; we carry out stochastic sensitivity analysis to determine the most influential sources of uncertainty ; and we provide new probabilistic projections of the retreat of the grounded portion of the Antarctic ice sheet.

For the second contribution, we propose to address uncertainty quantification of geometrical characteristics of the spatial response of physics-based computational models within the probabilistic context of the random set theory. We contribute to the development of the concept of confidence sets that either contain or are contained within an excursion set of the spatial response with a specified probability level. We propose a new multifidelity quantile-based method for the estimation of such confidence sets and we demonstrate the performance of the proposed method on an application concerned with predicting with quantified uncertainty the retreat of the Antarctic ice sheet.

In addition to these two main contributions, we contribute to two additional pieces of research pertaining to the computation of Sobol indices in global sensitivity analysis in small-data settings using the recently introduced probabilistic learning on manifolds (PLoM) and to a multi-model comparison of the projections of the contribution of the Antarctic ice sheet to global mean sea-level rise.

Key-words : Uncertainty quantification, probabilistic projections, confidence sets, essential ice-sheet models, Antarctic ice sheet.