Quantifying uncertainty in future projections of ice loss from the Filchner-Ronne Ice Shelf System

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Introduction

Mass loss from the Antarctic Ice Sheet is the main **source of uncertainty in projections** of future sea-level rise, with important implications for coastal regions worldwide. **Enhanced melt beneath ice shelves could destabilise** large parts of the ice sheet, and further increase ice loss. Despite advances in our understanding of feedbacks in the ice sheet-ice shelf-ocean system, future projections of ice loss remain poorly constrained in many parts of Antarctica. In particular, there is **ongoing debate surrounding the future of the Filchner-Ronne Ice Shelf** (FRIS) region. The FRIS has remained relatively unchanged in recent decades, but an **increase in air and ocean temperatures in the neighbouring Weddell Sea**, could force rapid retreat in the near future. Indeed, previous modelling work has suggested the **potential for widespread infiltration of warm water** beneath the ice shelf in the second half of the twenty-first century, leading to a drastic **increase in basal melting** [1].

Objectives

1. Estimate **potential mass change** from the Filchner-Ronne region through to the year 2300
2. Assess the **uncertainty** associated with mass change **projections**, and determine which **model parameters drive this uncertainty**

Method

Here, we use the ice flow model Úa alongside an implementation of the PICO ocean box model [2,3] to understand the key physical processes and model variability in future projections of sea-level rise from the FRIS region. To this end we use an uncertainty quantification approach (Figure 1) and the UQLAB toolset.

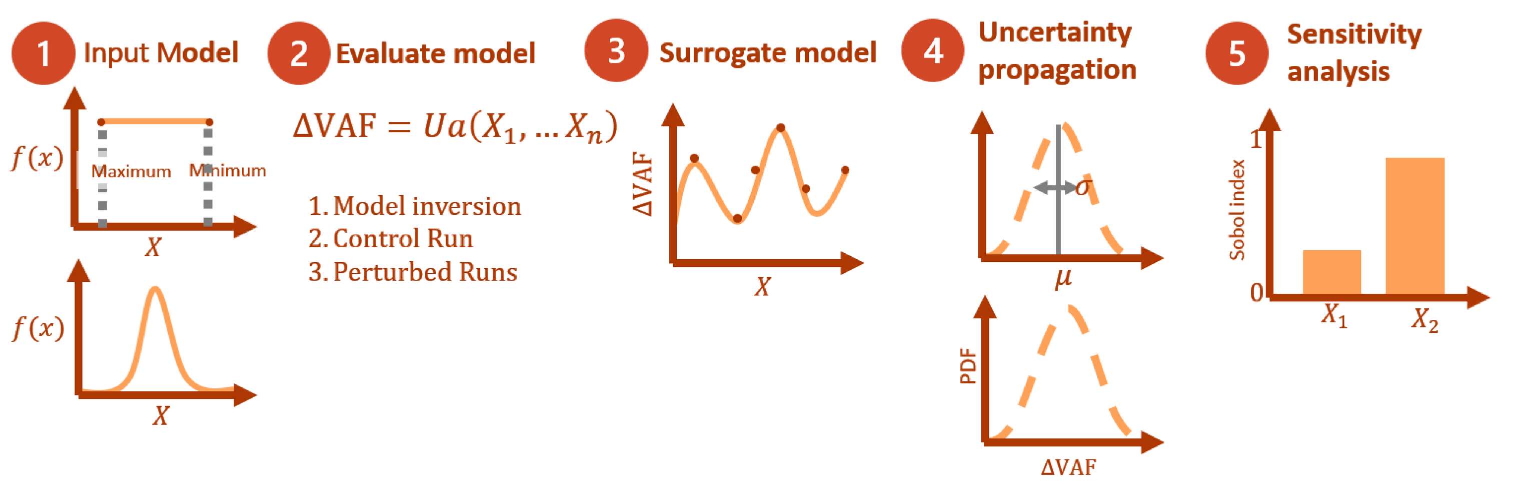

Figure 1: Uncertainty quantification methods summary. First we set prior probability distribution functions (PDFs) of each of our parameters (see Figure 3). We then extensively and randomly sample from these PDFs and evaluate the ice flow model. Each model evaluation includes a model inversion (to initialise to observations), a control forward run (as a reference), and four perturbed forwards runs, one for each RCP scenario. These four sets of simulations are then used to train four surrogate models, which are used to propagate uncertainty and assess the sensitivity of our projections to uncertainties in each of our input parameters.

Uncertain Parameters

We investigate the influence of eight model parameters on projections of mass change from the FRIS (Figure 3). The first two parameters relate to our **model inversion (initialisation)**, in which we optimise the misfit between observed and modelled velocities by minimising a cost function and estimating parameters of **basal slipperiness** (C) **and ice rheology** (A). C is estimated using a Weertman sliding law, with exponent m which determines the nonlinearity of the basal sliding law, and Glen's Flow law with exponent n which determines the nonlinearity of the ice rheology. Appropriate values for m and n remain uncertain but reasonable bounds have been proposed which act as the bounds for our prior distributions (Figure 3).

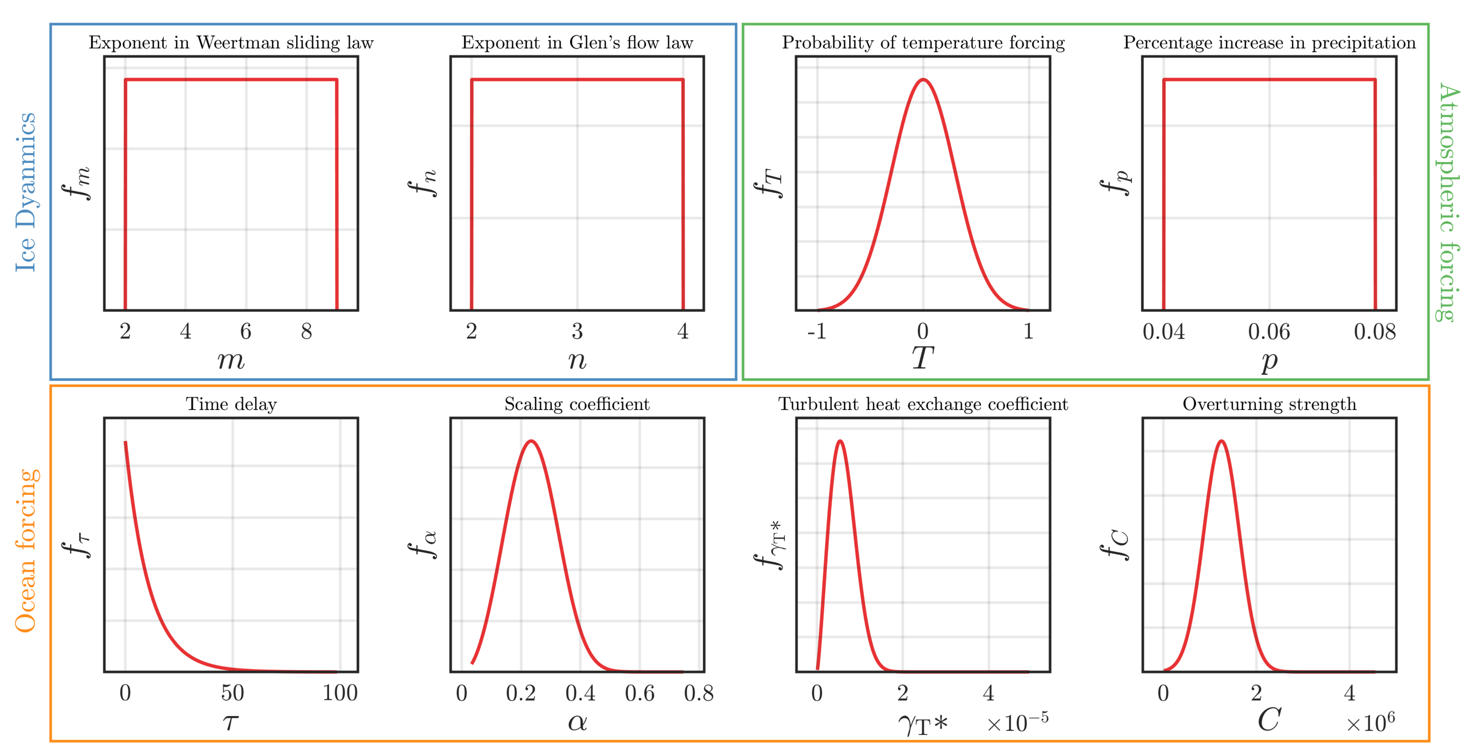

Figure 2: Probability distributions for uncertain parameters included in our analysis, grouped by ice dynamics (blue rectangle), atmospheric forcing (green rectangle), and ocean forcing (orange rectangle). For each parameter, x-axes show the parameter bounds, and red lines show the probability distribution functions. The distributions of the four ocean forcing parameters are outputs from our Bayesian analysis (A1) in which we optimised the parameter distributions using observations of basal melting beneath the Filchner-Ronne ice shelf.

We use **RCP temperature anomalies** (ΔT_g) from MAGICC 6.0 through to 2300 and randomly select forcing between 25 and 75% quantiles of the ensemble mean using the temperature probability value T. Precipitation change is forced: $P = A_{obs} \times \exp(p \cdot \Delta T_g)$ with respect to initial RACMO2.3 [4] surface accumulation (A_{obs}). Given that temperatures are not projected surpass $0°C$ by 2300 (and thus we do not force surface melt) in this region, **increases in snowfall are likely to be an important control on mass change**. However, the **percentage increase per degree of warming** (p) **remains unknown** but is proposed to range between $4 - 8\%$ across Antarctica [5].

RCP temperatures are used to **force ocean temperature changes** ($\Delta T_o(t)$) in the ocean box model using a time delay (τ) and scaling coefficient (α) as $\Delta T_o(t) = \alpha \cdot \Delta T_g(t - \tau)$ [6]. Two additional physical parameters in the ocean box model control the **strength of basal melting** beneath ice shelves, the turbulent heat exchange coefficient γ_{T*} and the strength of the overturning circulation C [2,3]. While some values have been proposed [2,6], the probability distributions (PDFs) these parameters remain unknown. We **optimised parameter PDFs** using observations of basal melt rates (see A1) and used posterior distributions as input to our uncertainty analysis (Figure 3).

Initial Results

- Initial results indicate that the FRIS could have a predominantly **negative contribution to sea level rise (mass gain)** over the next ~ 300 years. Increases in ocean temperatures and thus rates of basal melt beneath the ice shelf may not outweigh increases in precipitation. Despite this, **some parameter combinations cause grounding line retreat**, particularly around the Moller and Institute ice streams.

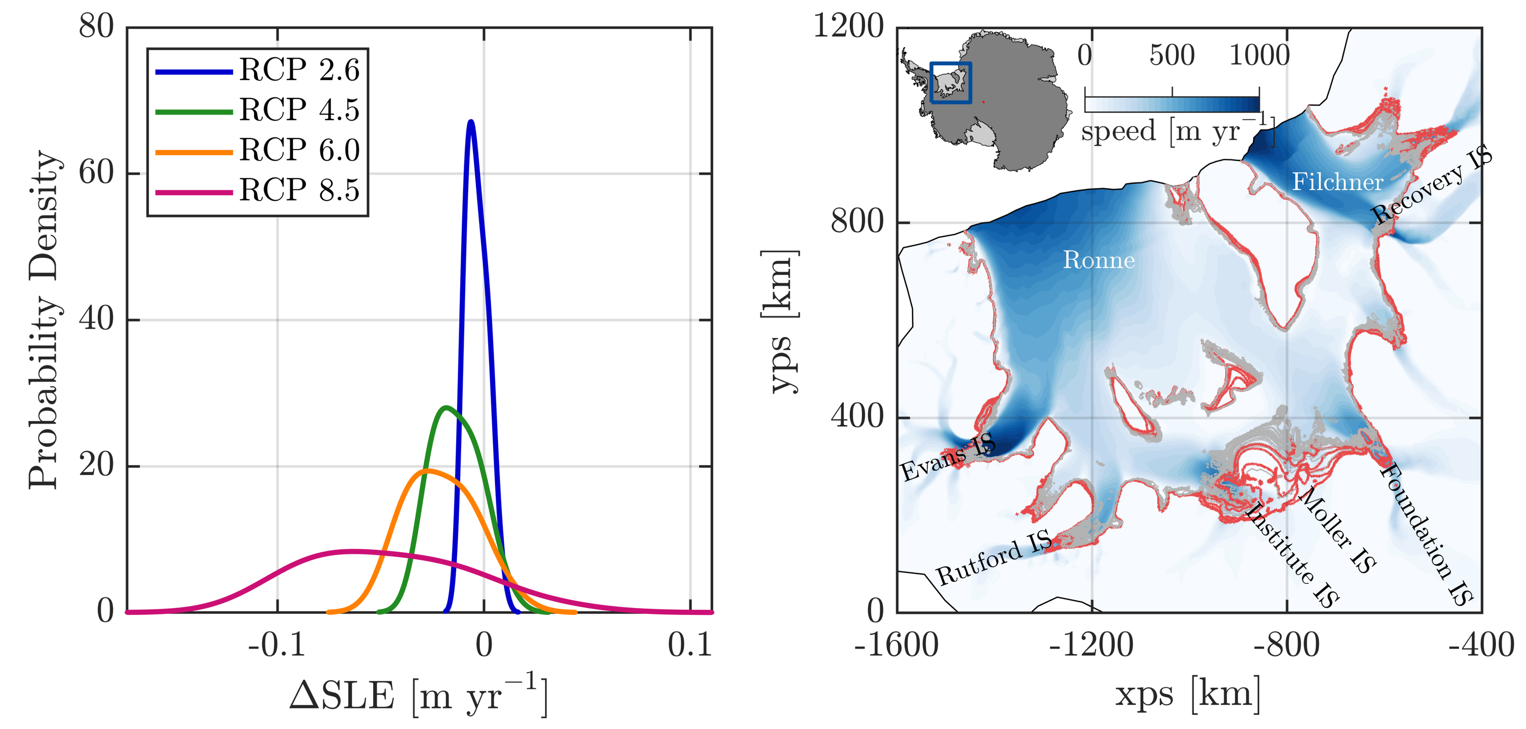

Figure 3: Initial results for a small sample of the parameter space evaluated to date ($N = 40$). Note: these results may change once the entire parameter space has been evaluated (~ 500 samples). Left panel shows probability distribution functions for change in volume above flotation in sea level equivalent [m yr^{-1}] for each of four RCP scenarios. Uncertainty in mass change in greatest for the higher warming scenarios (RCP 6.0 and 8.5). Right panel shows the FRIS and ice flow speeds. Grey lines are grounding line positions for 2300 under RCP8.5 forcing and have a negative contribution to SLR. The red lines show runs in which the grounding line retreats further, which suggests that some parameter combinations under this high warming scenario may force more substantial mass loss/postive sea level rise contribution from the FRIS.

A1. Bayesian optimisation of basal melt parameters

Distributions of model parameters that are unconstrained by observations could lead to wide and unrealistic uncertainty bounds on projections of sea level change. To improve PDFs for four hyperparameters (θ) used to force basal melting (Fig 3) we use Bayes theorem $\pi(\theta|Y) = \ell(\theta; Y)\pi(\theta)$ where the posterior PDF of θ given Y observations is equal to the likelihood (ℓ) of θ given Y multiplied by the prior PDF $\pi(\theta)$. To capture some spatial variability in melt rates, we optimise mean melt rates in each ocean box to observations [7]. Posterior point estimates show that melt rates in boxes two and three are now within the error of observations and total basal mass balance is closer to observations than using default values.

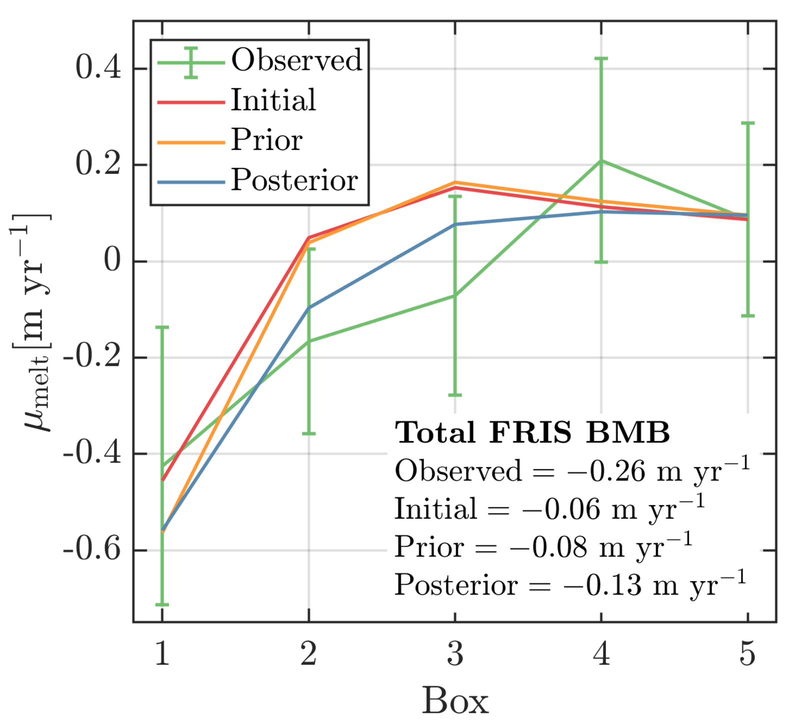

Figure 4: Melt rates for each PICO box. Values show total integrated basal mass balance for the entire ice shelf.

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