PISCEES: Ice Sheet Model Experiments for Evaluating Sea Level Rise

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We've used CISM-Albany and DAKOTA to conduct a demonstration of the end-to-end workflow for quantifying the uncertainty in the expected sea-level rise during the 21st century. There are several steps to the workflow, requiring different computational tools. In the previous year, we presented preliminary results for Bayesian calibration of the ice sheet model parameters for the current (equilibrium) configuration. Here, we show progress on the step of propagating model uncertainties through the dynamic evolution of the ice sheet.

- From an "ad hoc" optimized / initialized 4 km GIS run (Figure 1), we "relaxed" the initial condition by running forward in time for ~100 years. This initial condition is referred to as the MAP point.
    - Subsequent experiments will use a model initialized with adjoint-based optimization
- We generated a suite of Karhunen-Loeve Expansion (KLE) modes used to perturb the "MAP point" beta field ($\bar{\beta}$, in the equation below). These serve as an approximation of the uncertainty in the MAP point beta field. For now, these KLE modes were generated as eigenvectors of an exponential covariance kernel based on the x and y coordinates of the GIS geometry (Figure 2).
- Using Latin hypercube (LHC) sampling from a uniform [-1,1] distribution and K=10 KLE modes (ξ_k), we generated an ensemble of 66 alternate realizations of the beta field:

$$\beta(\omega) = \bar{\beta} + \sum_{k=1}^{K} \sqrt{\lambda_k}\boldsymbol{\phi}_k \xi_k(\omega)$$

- The CISM-Albany model was propagated forward in time for 50 years for each ensemble member. Figure 3 shows the effect of the perturbed beta field on the soliution for one of these cases, and Figure 4 shows the effect on SLR for each of them.

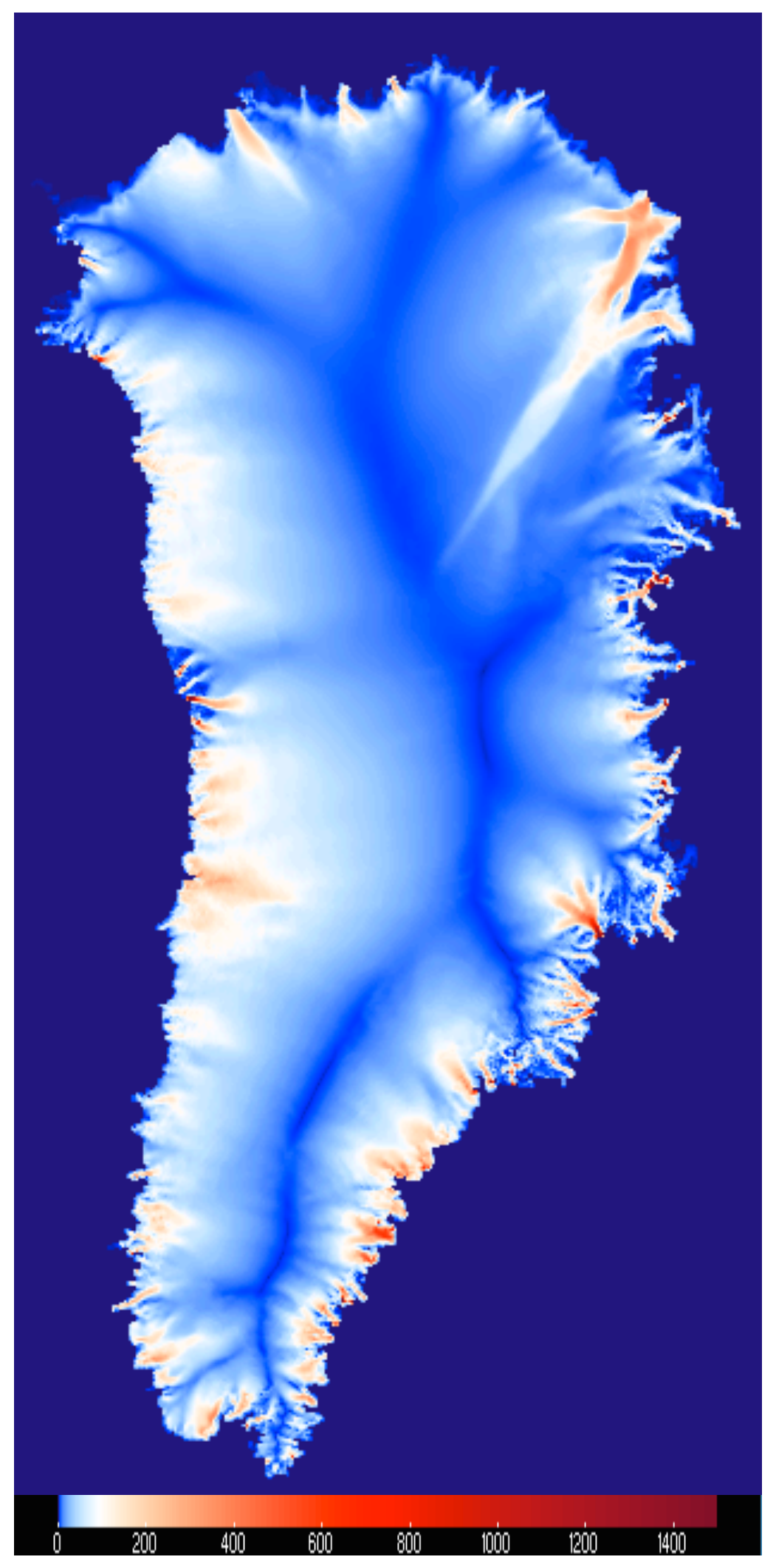


Figure 1. Velocity field from the initial condition, using the MAP point β field.

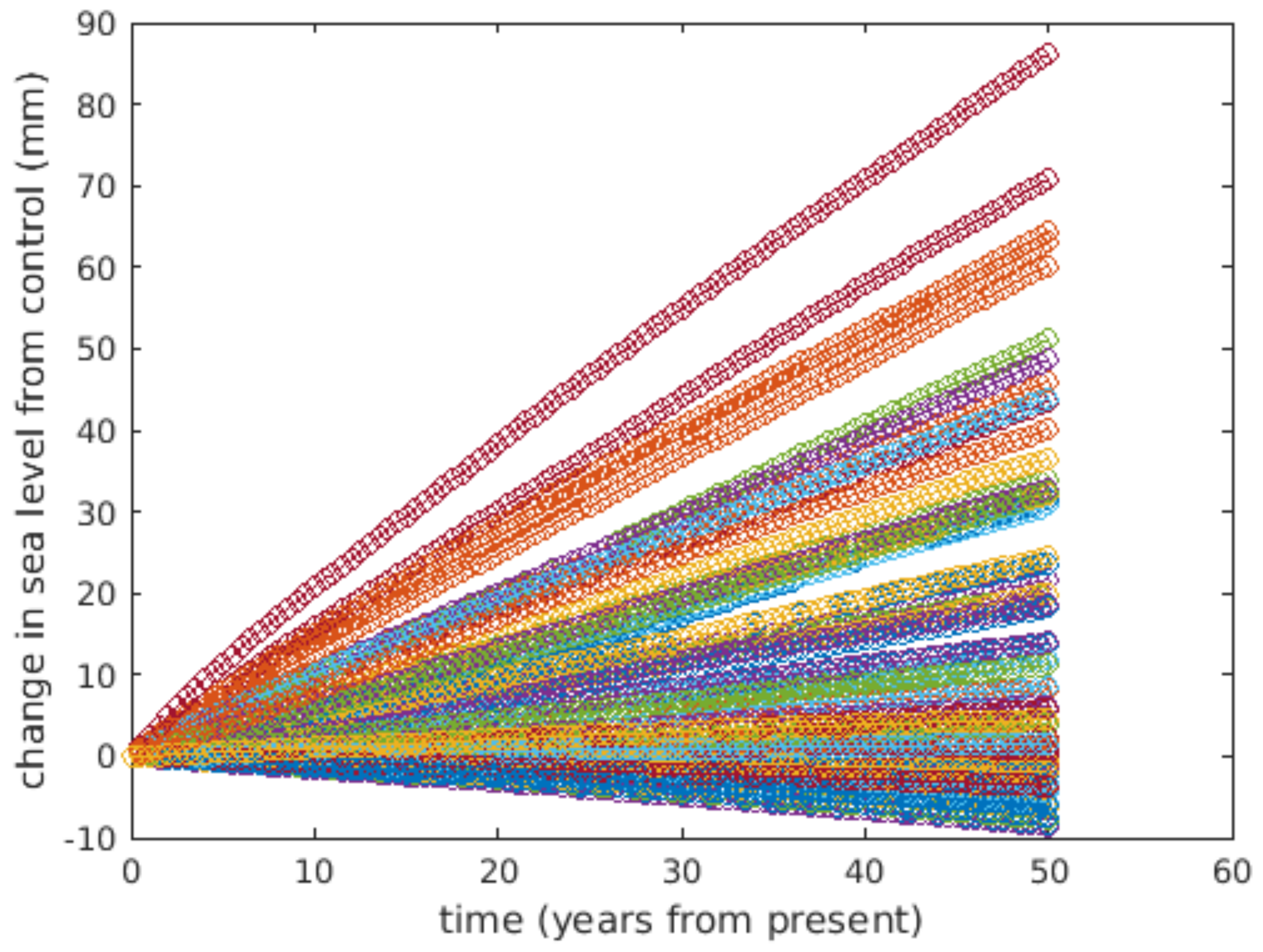


Figure 4: SLR distribution – compared to MAP point -- from the ensemble of 66 high fidelity simulations with varying β fields. All 66 runs ran to completion out-of-the-box on Hopper, providing evidence of the robustness of the CISM-Albany code.

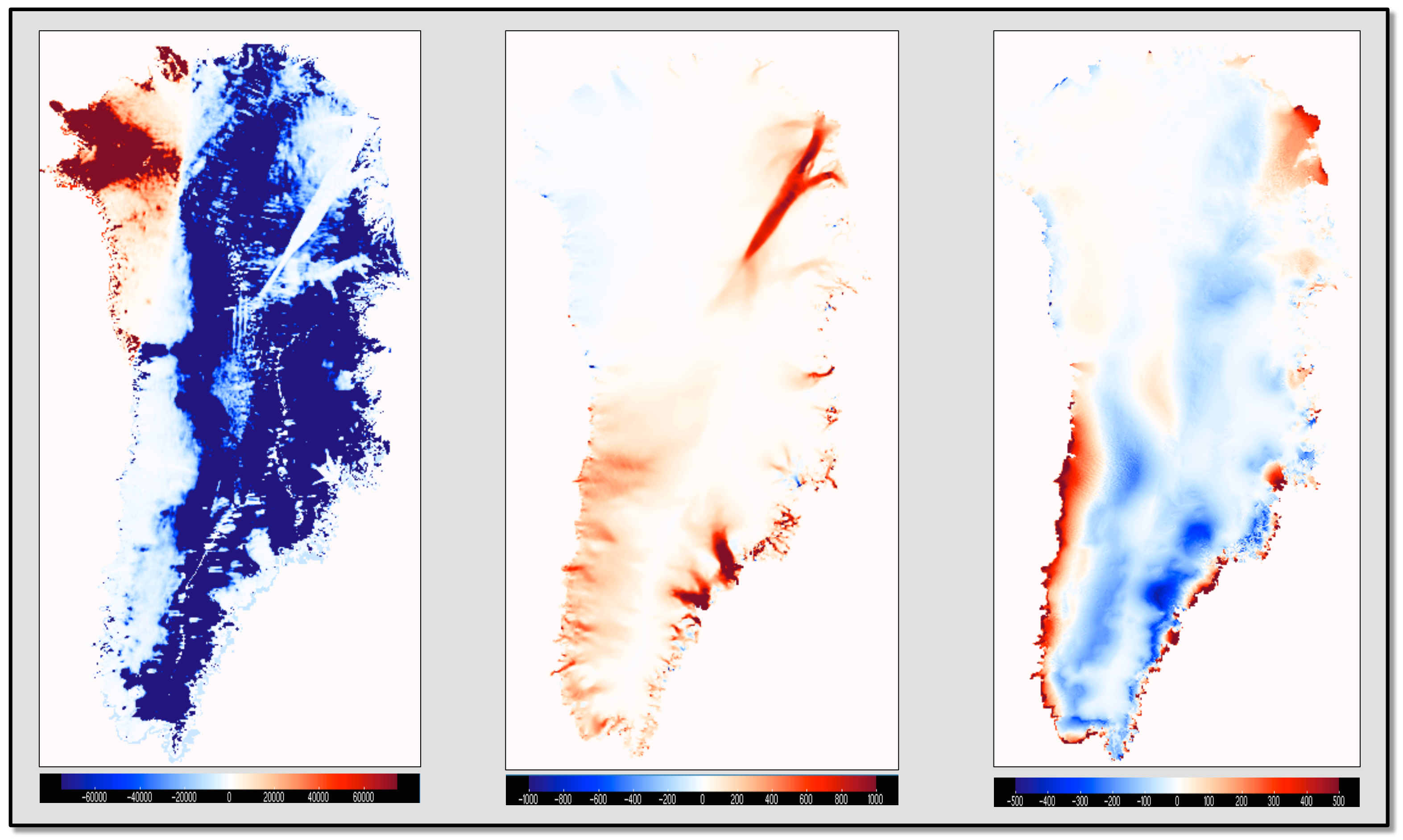
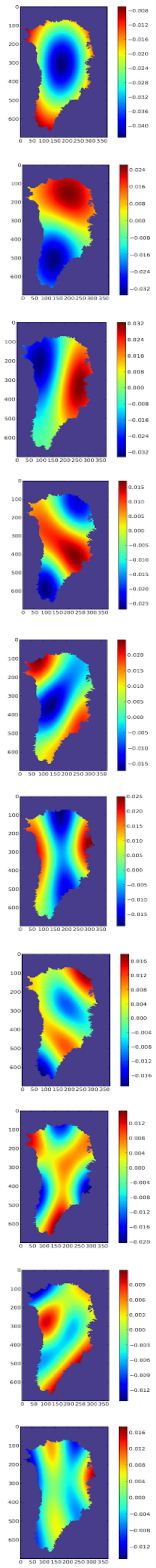


Figure 3: Perturbation to β (left - Pa yr/m) and the resulting change in the velocity field (center - m/yr) and ice thickness (right - m) at the end of the 50 yr run, for a single ensemble member. From the size of the changes over 50 yrs, you can see that some of the perturbations were quite large (thickness changes in the right panel are >500 m in places). It's encouraging that CISM-Albany was able to do 50 yr integrations after such large perturbations.

Figure 2: KLE modes (with decreasing energy content from top to bottom)



End-to-End workflow for quantifying the uncertainty in the possible changes in sea level in the future two centuries

Q: How do uncertainties in the basal traction parameter β affect projections of sea level rise?

Data

Surface velocity $\mathrm{v} = \hat{\mathrm{v}} + \varepsilon_{\mathrm{v}}$

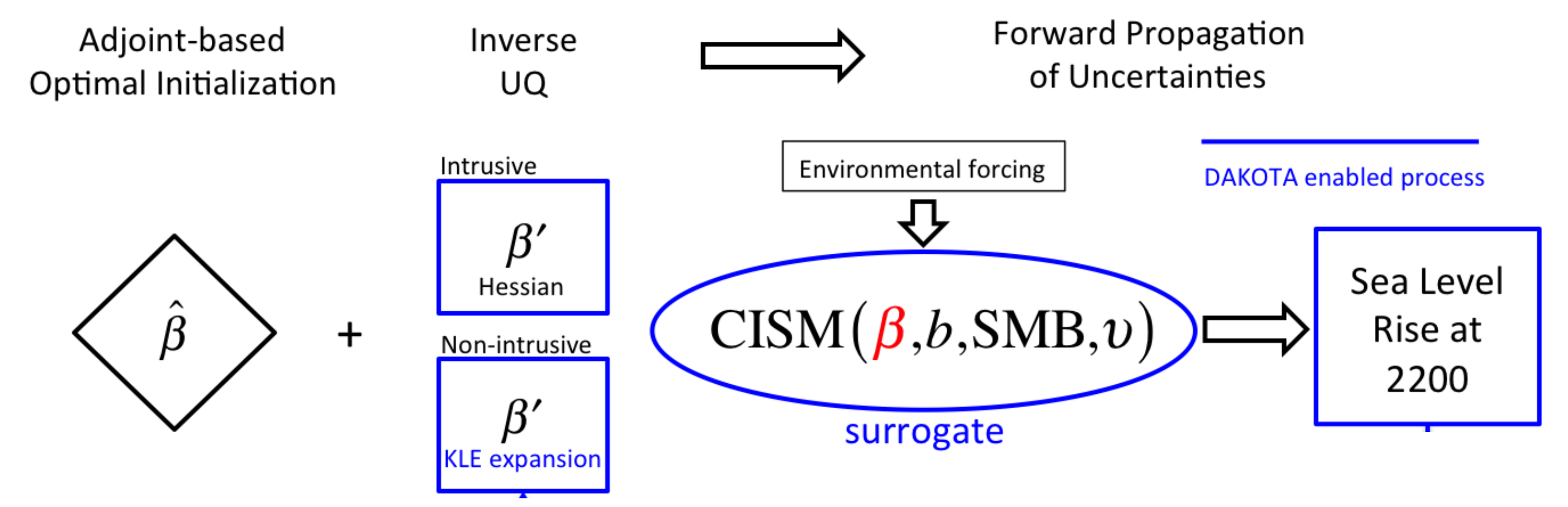
Surface elevation $h = \hat{h} + \varepsilon_h$

Bed topography $b = \hat{b} + \varepsilon_b$

Uncertain parameters

basal traction $\beta = \underset{\text{MAP estimate}}{\hat{\beta}} + \underset{\text{uncertainty}}{\beta'}$

UQ Workflow



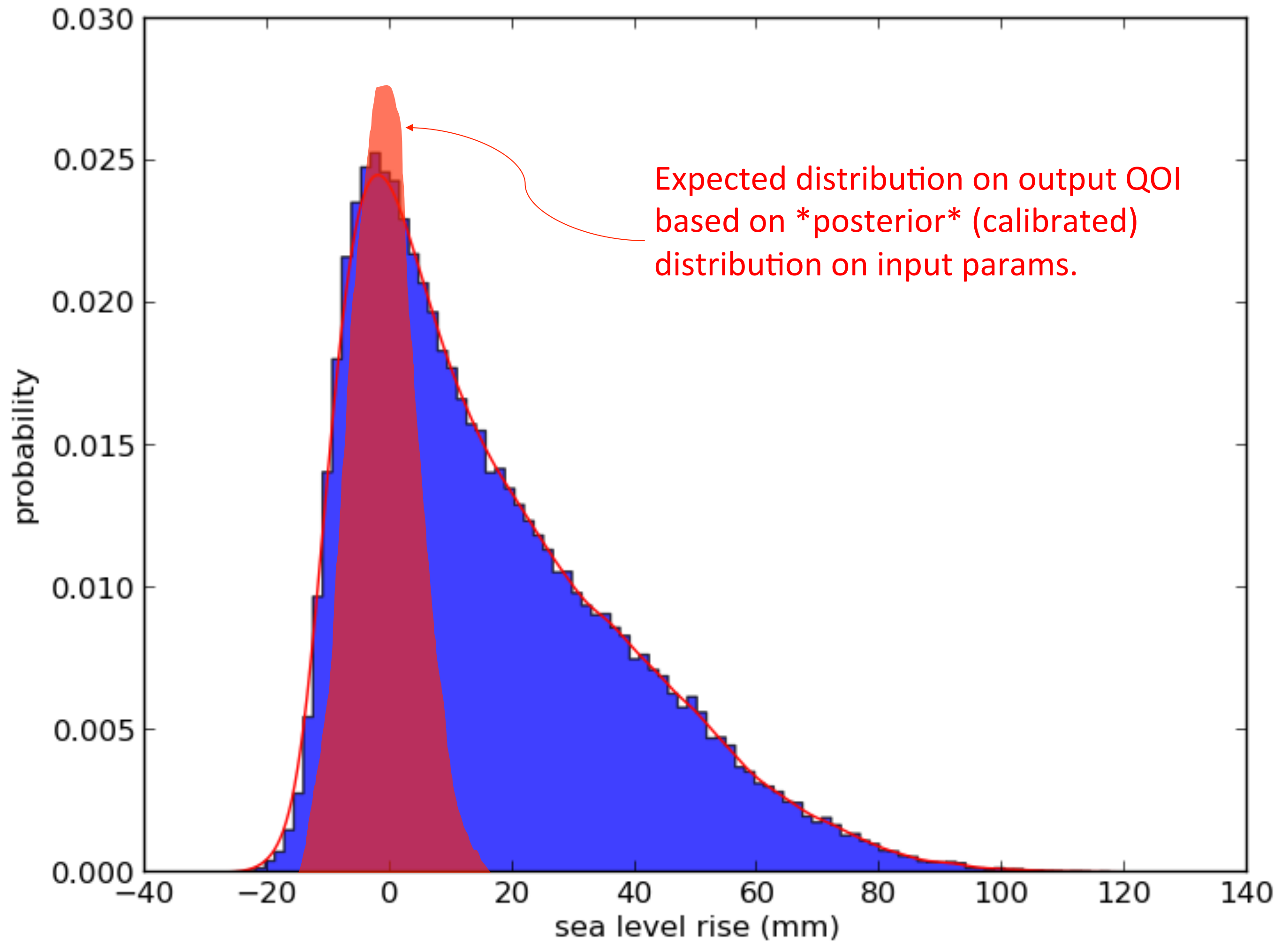


Figure 5: Probability Density Function (Blue) of SLR from the PCE emulator built using 66 high fidelity simulations (Figure 4). The PDF is generated by uniformly sampling the 10 dimensional KLE modes (priors). In Red, we have sketched what we expect what the SLR PDF will look like using posteriors from a calibration step. No environmental forcing is yet included.

Discussion

1) It is interesting to see how a uniform distribution on the input parameters translates to something much more skewed w.r.t. the model outputs. (Blue region in Figure 5)

- A larger fraction of the ice sheet currently has a beta value that forces no (or slow) basal sliding; that is, rapid sliding is confined to a small fraction of the ice sheet.
- A perturbation to the initial beta field that further increases β in areas where there is already very little sliding won't affect the output much … but decreasing beta in areas where there is currently little sliding has a very large effect, since the velocity in these regions will change significantly from the initial condition.
- Since we're sampling from a uniform distribution when perturbing beta, we'd expect to see a disproportionately large signal when reducing beta as opposed to increasing it.

2) Because of the roughness of the geometry data, dynamic evolution of our initialized models see large impulsive movements. What is the best way to create an initialied model that both respects the observational data and also behaves well enough that we can detect sensitivities to environmental forcings? In this study, we chose to integrate the tuned model for 100yrs to relax the solution as part of the initialization process.