

Recent retreat of Greenland's marine terminating glaciers has a lasting impact on velocity and mass loss during the 21st Century



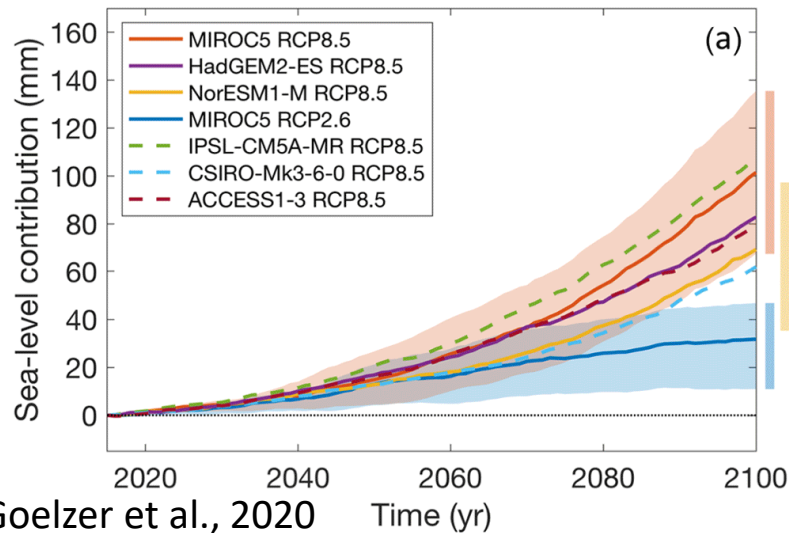
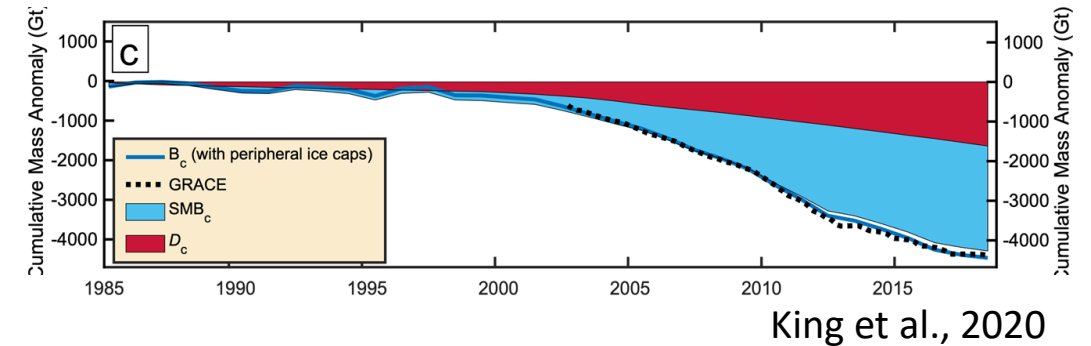
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Background

- Greenland Ice Sheet (GrIS) is losing mass through
 - Negative surface mass balance
 - Discharge into ocean through ice dynamics



- And it will continue to lose mass in the future
 - (1) Due to future climate change → temperature/SMB anomalies relative to present day
 - (2) Dynamic adjustment to past changes (i.e. the *committed response*, Price et al., 2011)

- In the ISMIP6 projections for Greenland (Goelzer et al., 2020), a control simulation was removed from each projection, i.e. the projected sea level rise only accounts for (1), and does not include (2).
- How do we account for this missing component?
 - Add the control back in? – issues of model drift between models
 - Extrapolate current mass loss rates? – but effects of past retreat diminish over time
 - Find the committed response?

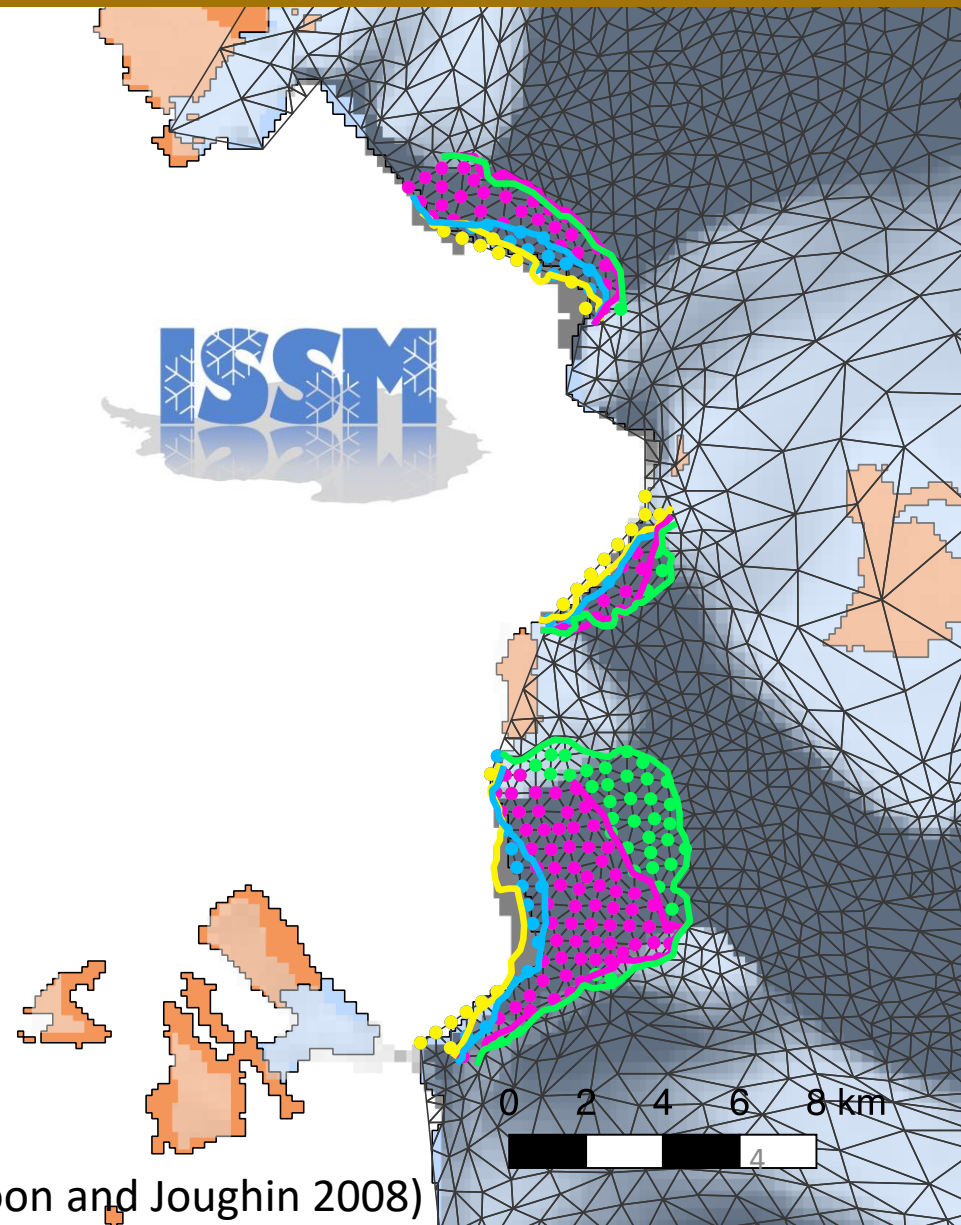
Aims

1. Model the committed dynamic response of the Greenland Ice Sheet to recent terminus retreat
 - Assess the implications for ISMIP6
2. Explore uncertainty in the response, and constrain it using Bayesian Calibration
3. Determine which regions have the largest and most uncertain committed response

Model simulations

- ISSM initialized to 2007 ice sheet
- Transient simulations (2007-2100)
 - Parameters varied within an ensemble framework:
 - Basal friction coefficient
 - Ice viscosity/temperature
 - SMB: to represent climatic variability
 - 137 ensemble members in total
 - For each of the 137 ensemble members:
 - Control simulation
 - Perturbed simulation → retreat imposed based on observed terminus position (2007-2105)
 - No additional future climate forcing included

Terminus positions (Moon and Joughin 2008)

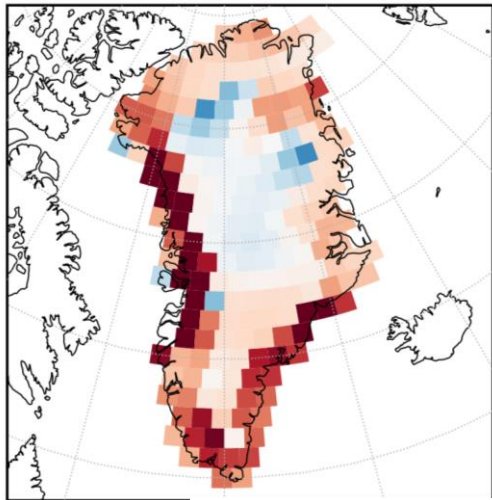


Bayesian calibration using GRACE data

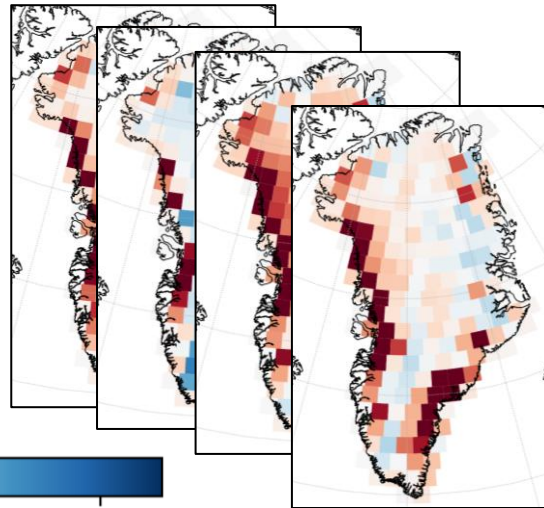
- Each ensemble member (j) is scored (s) on its ability to match modelled mass change (f) with observations from GRACE (z).
- This score accounts for observational and model structural error (σ).
- Mass loss is aggregated over basins (i) in order to make the comparison
- Normalised scores are used to weight the probabilistic projection of sea level rise (next slide)

$$s_j = \exp \left[-\frac{1}{2} \sum_i \frac{(f_i^j - z_i^j)^2}{(\sigma_i^j)^2} \right]$$

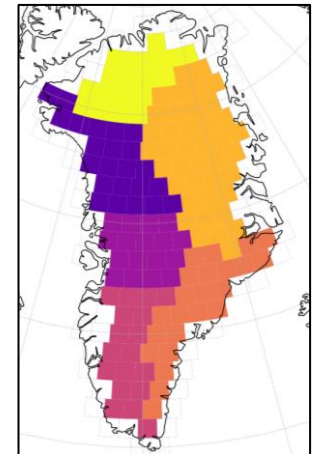
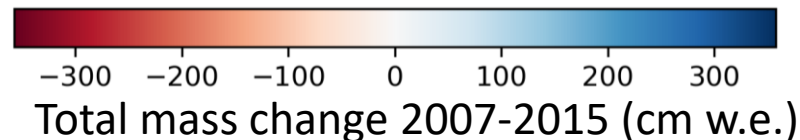
GRACE L1B mass trends (z)



Examples of mass trend from model ensemble members (f^j)

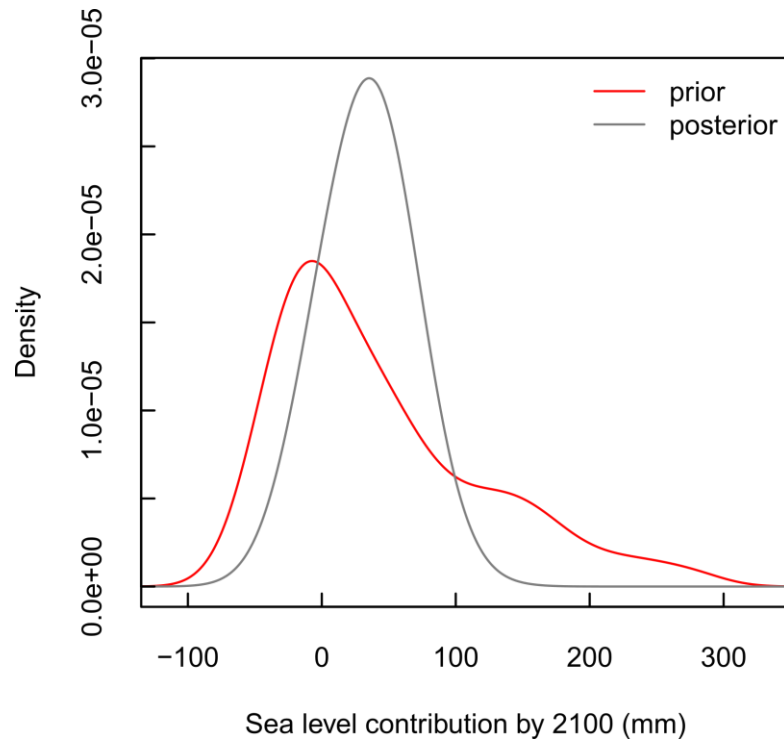


Basins (i)

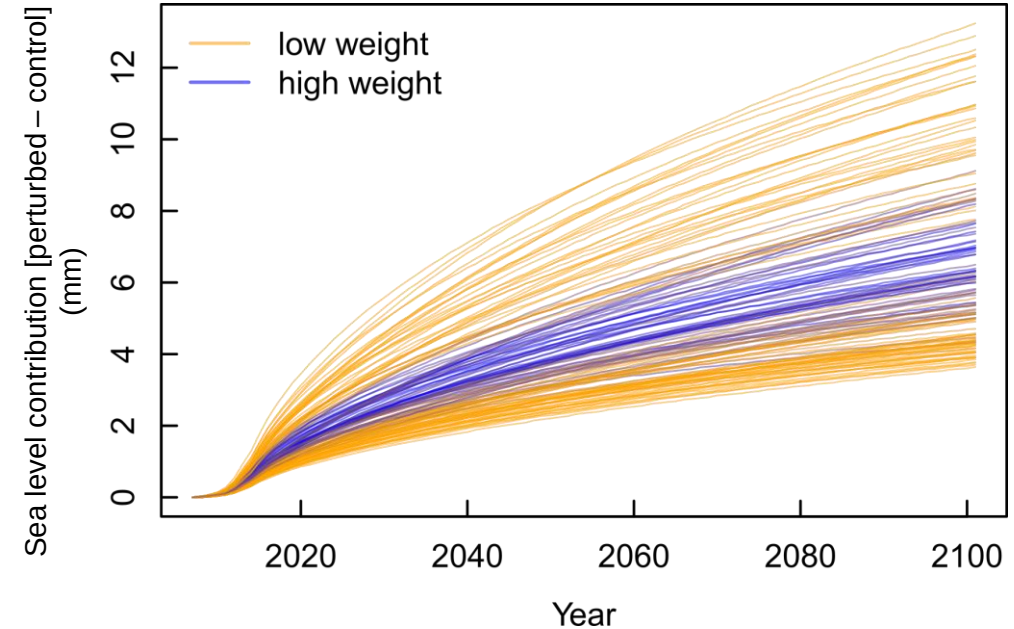


(Thanks to
Bryant Loomis,
NASA GSFC)

Committed sea level response



- Committed sea level contribution from perturbed simulations (includes dynamics + SMB)
- Red line = uncalibrated (prior)
- Grey line = calibrated (posterior)
- Scores down-weight extreme simulations
- The mode of the distribution shifts to the right (higher sea level contribution)

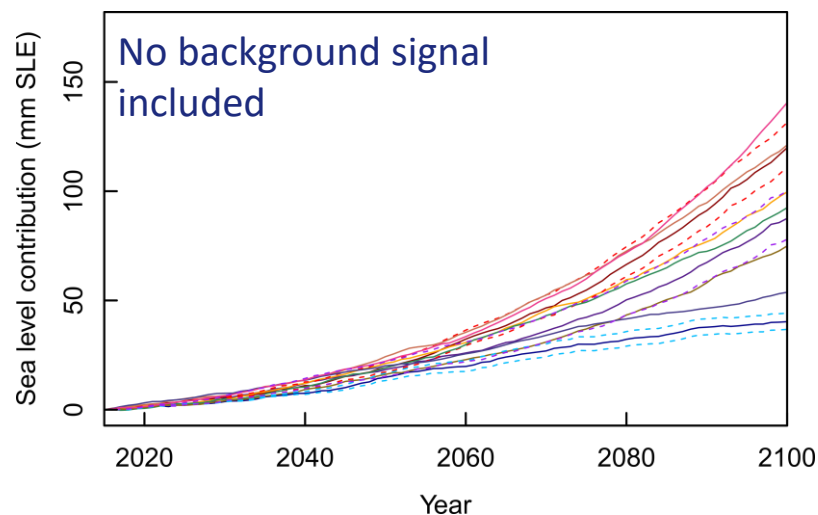
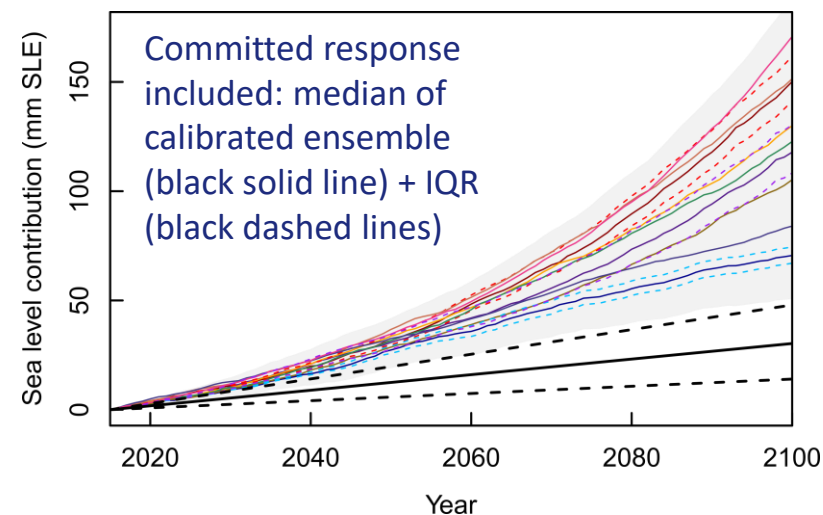


- Cumulative sea level contribution over the 21st Century in response to glacier retreat between 2007 and 2015 (perturbed - control simulations [i.e. SMB signal not included])
- Colours represent the weighting assigned to each ensemble member (blue = more successful at matching GRACE observations).
- Retreat of tidewater glaciers has a lasting impact on sea level rise, although rates decreases in the absence of continued retreat.

Implications for ISMIP6 interpretation

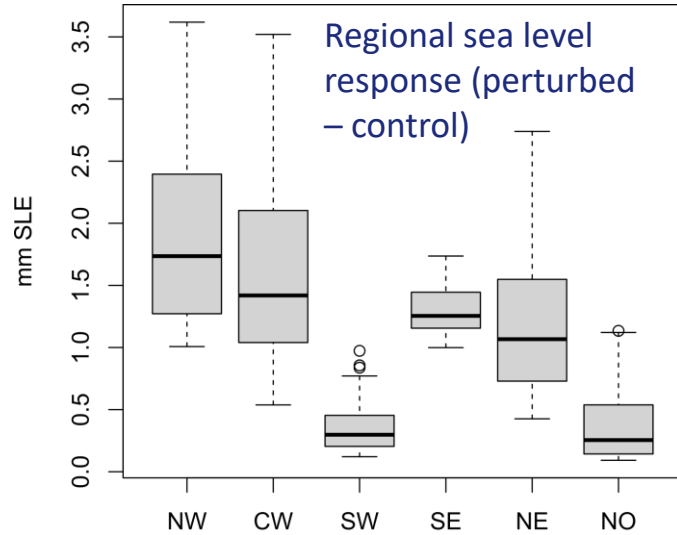
- The ISMIP6 Greenland results report the response of the ice sheet to future SMB and ocean temperature anomalies (Goelzer et al., 2020)
- How do we account for the background signal that are due to past changes (i.e. the committed response)?
 - Don't remove the control? Problem of model drift...
 - Extrapolate present day rates of mass loss? Overestimates loss...
 - Model the response to past change? Attempted here!

NASA GSFC
ISMIP6
projections



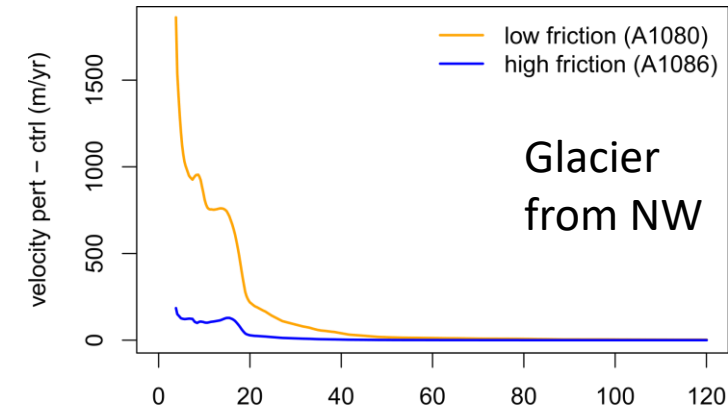
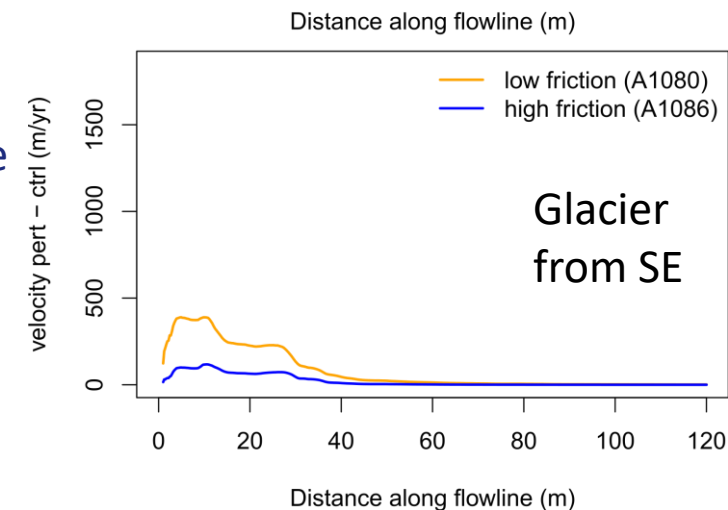
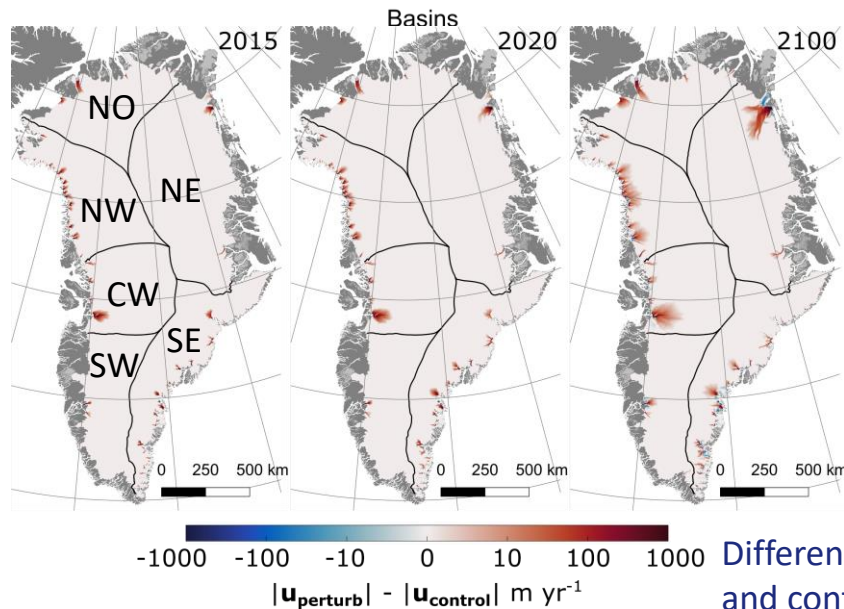
MIROC5.rcp85.Rmed
NorESM1.rcp85.Rmed
MIROC5.rcp26.Rmed
HadGEM2.ES.rcp85.Rmed
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MIROC5.rcp85.Rlow
ACCESS1.3.rcp85.Rmed
IPSL.CM5.MR.rcp85.Rmed
CSIRO.Mk3.6.rcp85.Rmed
CNRM.CM6.ssp126.Rmed
CNRM.CM6.ssp585.Rmed
MIROC5.rcp26.Rlow
MIROC5.rcp26.Rhigh
NorESM1.rcp85.Rlow
NorESM1.rcp85.Rhigh

Regional response



- Recent retreat results in a higher contribution in some regions than others:
 - NW has many tidewater glaciers → higher contribution
 - SW has fewer tidewater glaciers → lower response
 - Recent retreat of Petermann Glacier's (NO) long floating tongue has little impact on dynamics of grounded ice → lower response

Difference in velocity along flowlines between perturbed and control simulations at 2100



- Some regions have a more uncertain response than others:
 - E.g. spread of results across the ensemble are greater in NW than SE.
 - Glaciers in NW are more sensitive to changes in basal friction than the glaciers in the SE.

Difference in velocity between perturbed and control simulations

Conclusions

- Terminus retreat has a lasting impact on ice sheet dynamics and this needs to be accounted for in projections, e.g. ISMIP6 GrIS
- We have ever improving observational datasets that can help advance our ability to model past changes
- Bayesian calibration is one of the methods that can be used to constrain future projections
 - Future ISMIP efforts could use this method to ensure that model simulations adequately reproduce past change and remove the need to subtract the control simulation
- Some regions are more sensitive to parameter uncertainty than others

References

- Goelzer, H. et al. (2020) The future sea-level contribution of the Greenland ice sheet: a multi-model ensemble study of ISMIP6. *The Cryosphere*, 14(9), 10.5194/tc-14-3071-2020.
- King, M. et al. (2020) Dynamic ice loss from the Greenland Ice Sheet driven by sustained glacier retreat. *Communications Earth & Environment*, 10.1038/s43247-020-0001-2.
- Moon, T., Joughin, I. (2008) Changes in ice front position on Greenland's outlet glaciers from 1992 to 2007. *JGR*, 113, 10.1029/2007JF000927.
- Price, S. et al. (2011) Committed sea-level rise for the next century from Greenland ice sheet dynamics during the past decade. *PNAS*, 108(22), 10.1073/pnas.1017313108.