Jet Propulsion Laboratory
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Potential Antarctic contribution to sea level and associated uncertainties in ice sheet model forcing

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We use the
Ice Sheet System Model (ISSM)
to model ice flow, ice thermal properties, and
migration of floating ice grounding lines

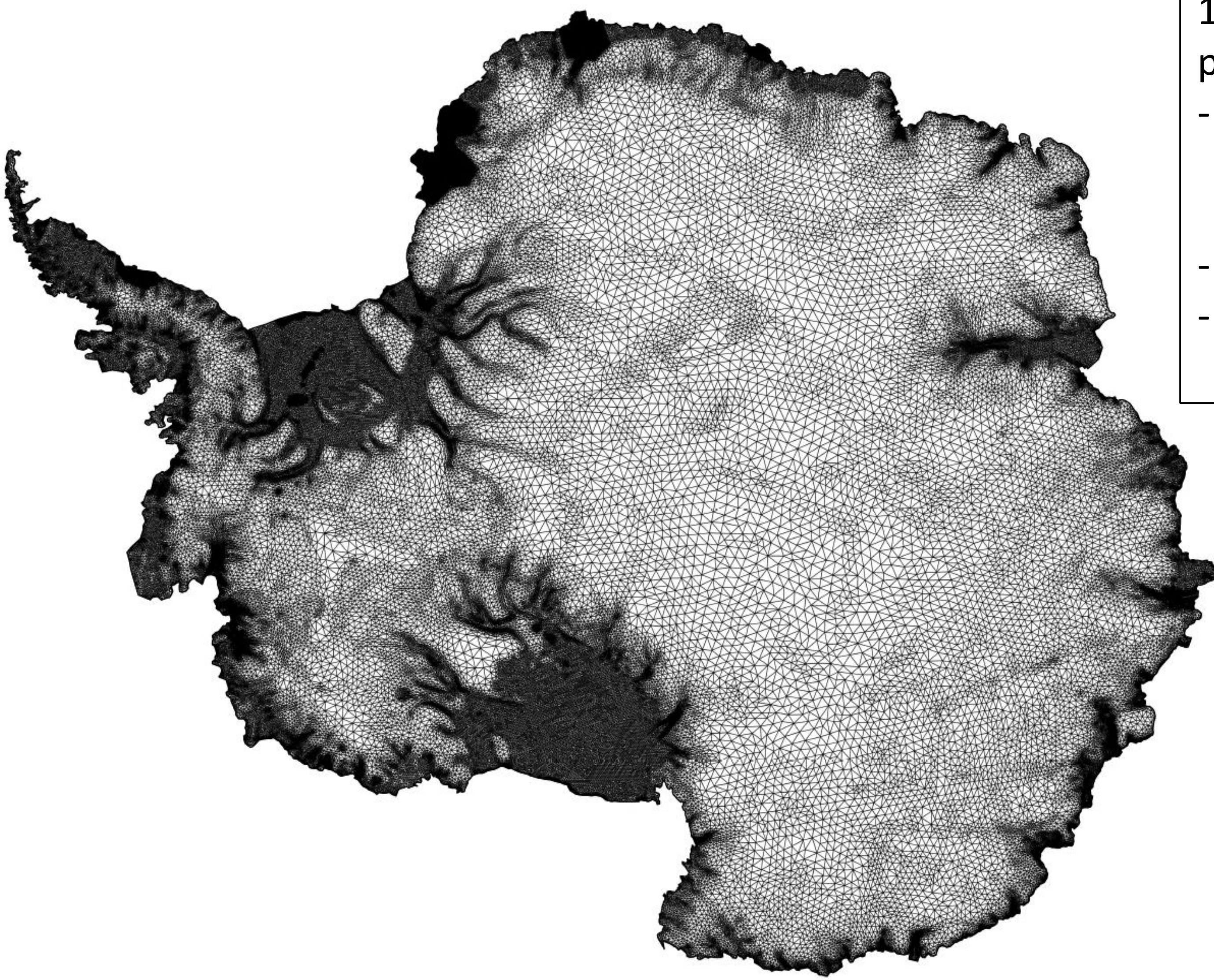
and

the ISSM-DAKOTA framework
for uncertainty quantification analyses

Ice Flow Model:

ISSM Antarctica (AIS)

ISSM-AIS uses a finite element, anisotropic triangular mesh

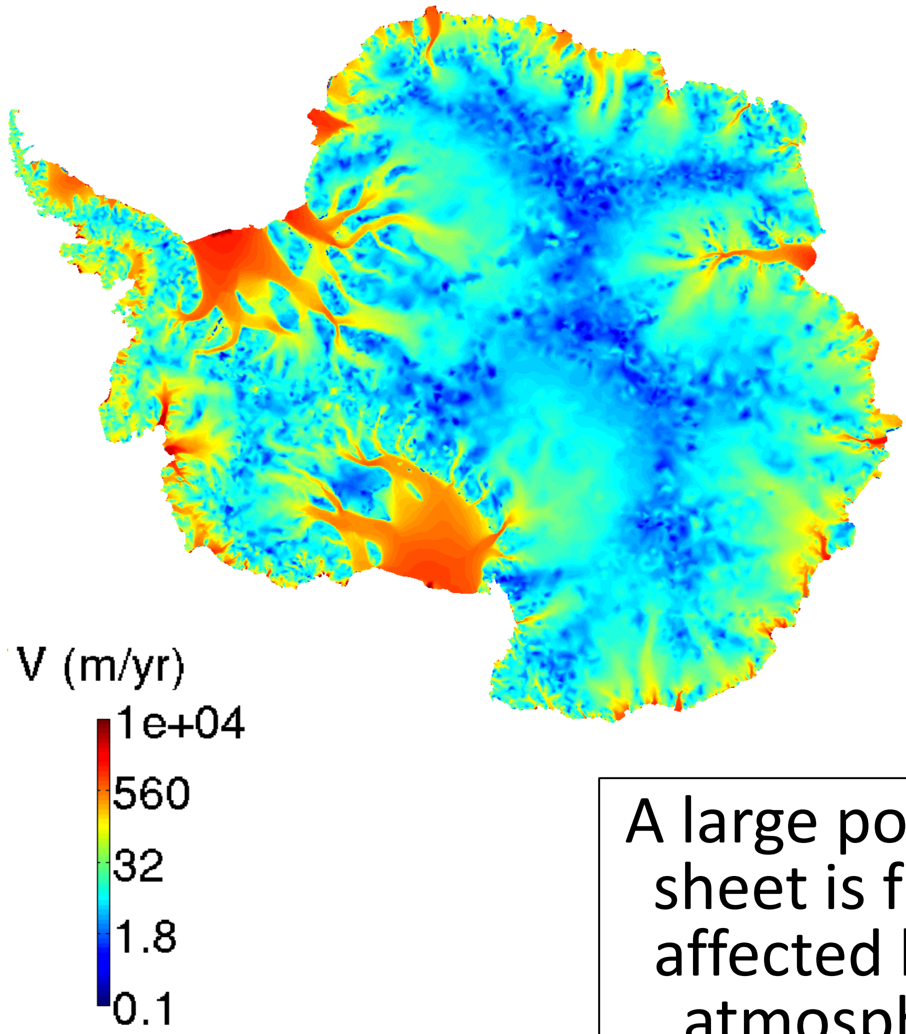


187,447 finite elements per layer:

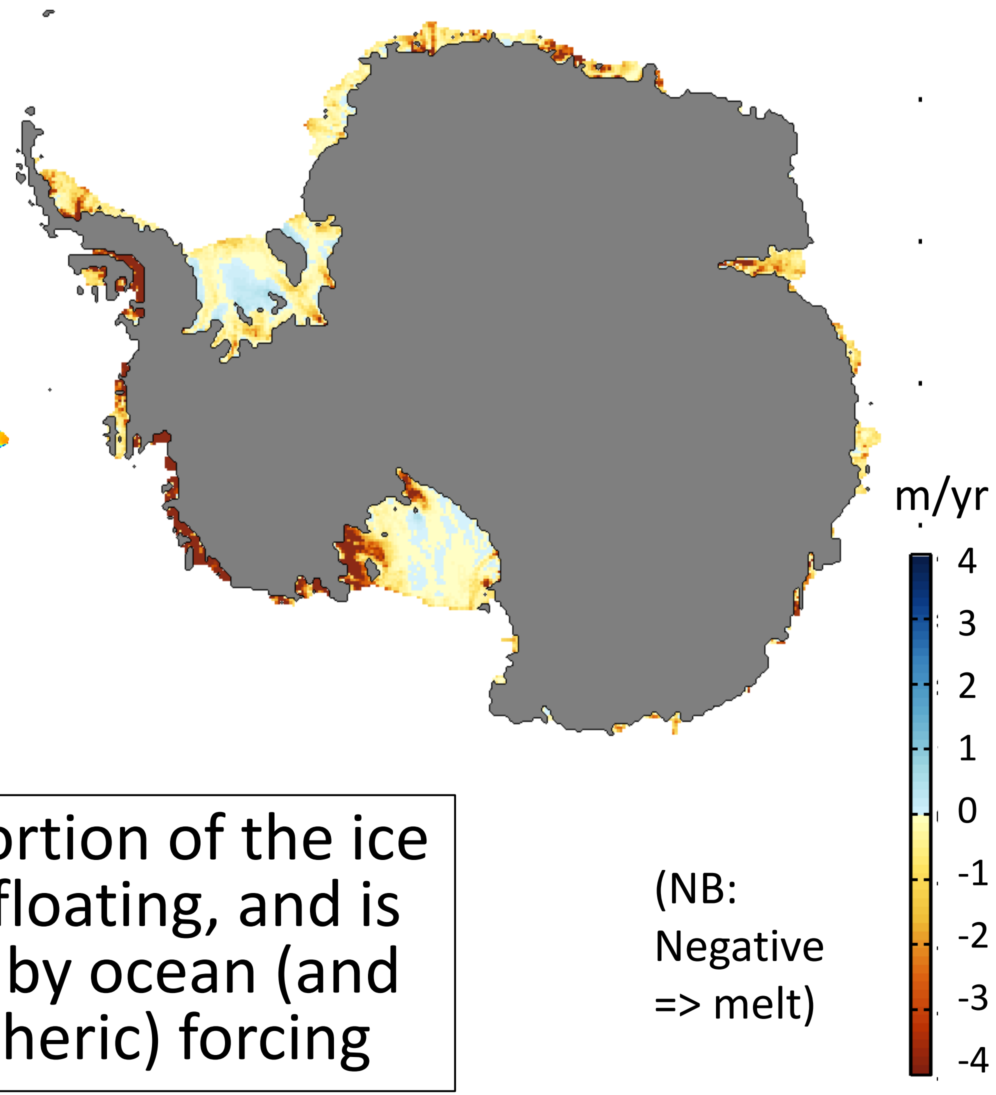
- 1 km resolution along the coast and at shear margins
- 50 km at the divides
- At least 8km on floating ice

Higher spatial resolution is used where we have strong shear and for floating ice

Surface Velocities



Ice Shelf Basal Mass Balance



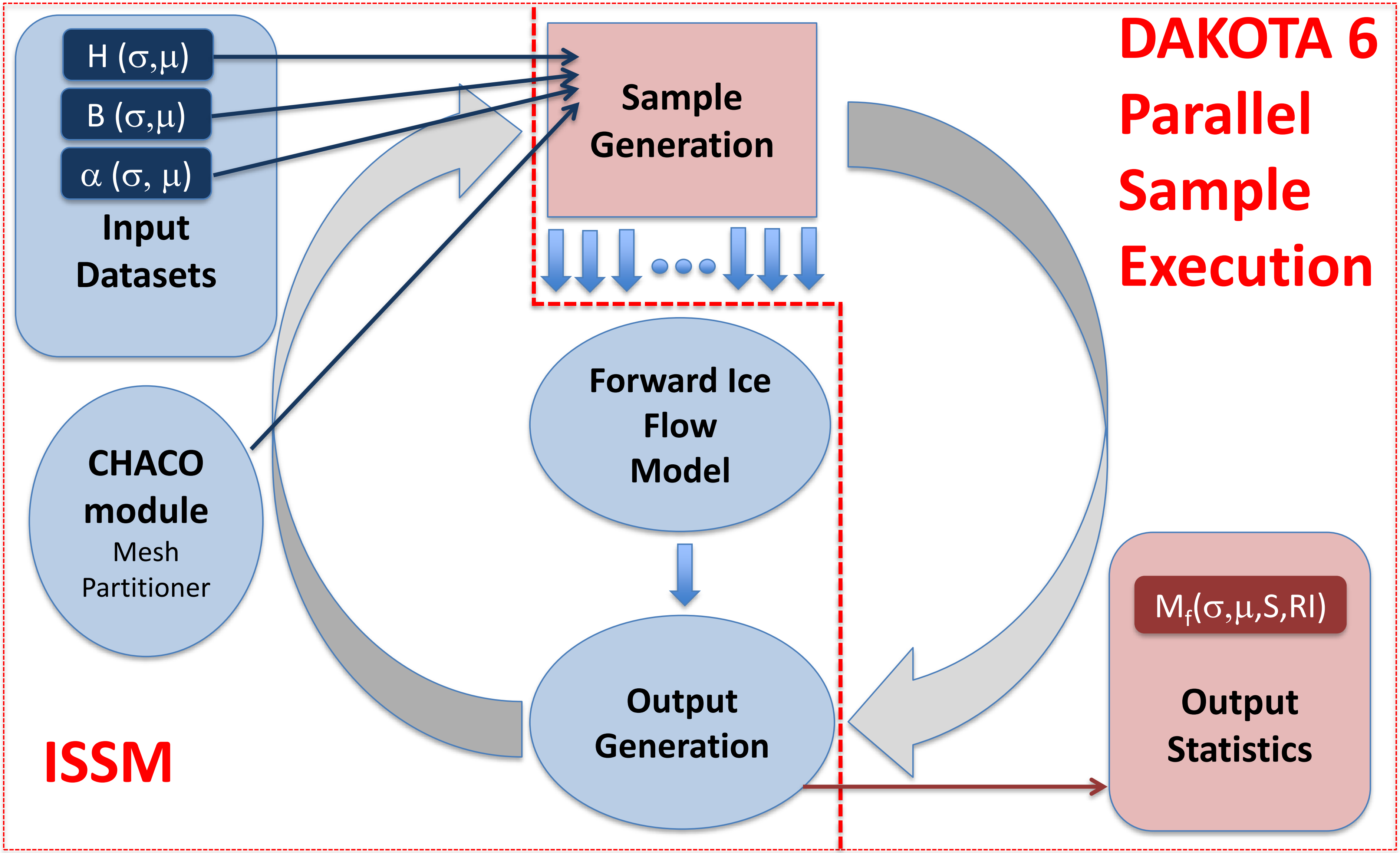
(NB: Negative => melt)

A large portion of the ice sheet is floating, and is affected by ocean (and atmospheric) forcing

Uncertainty Quantification Techniques:

ISSM-DAKOTA FRAMEWORK

Design Analysis Kit for Optimization and Terascale Applications (DAKOTA) software is embedded into ISSM



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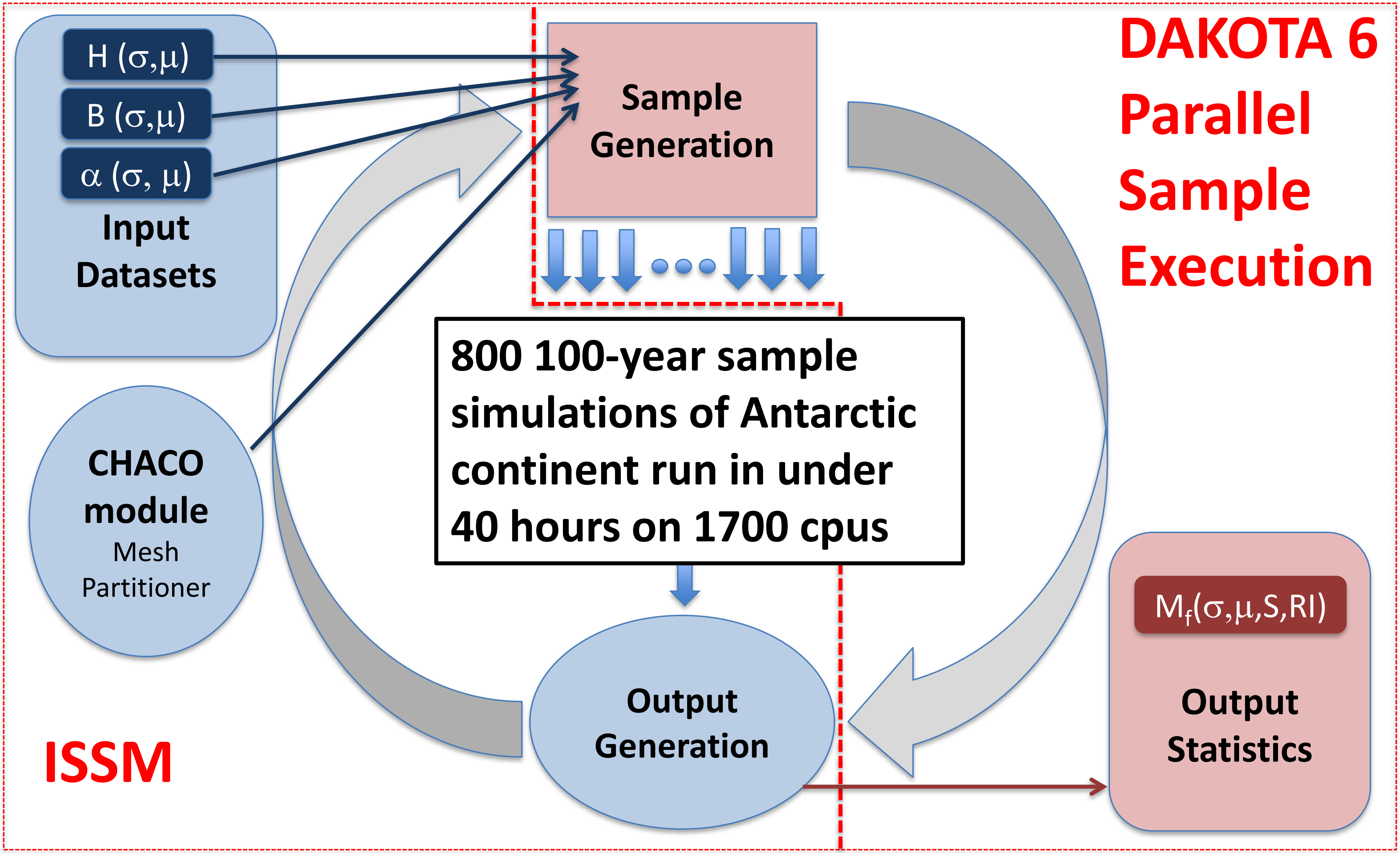


Continental-Scale Utility of

SAMPLING ANALYSIS

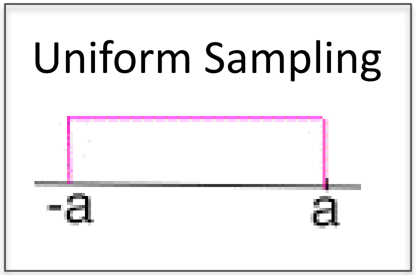
What are the sources of uncertainty in projected extreme changes in regional 100-year Sea Level Equivalent (SLE) contribution from Antarctica?

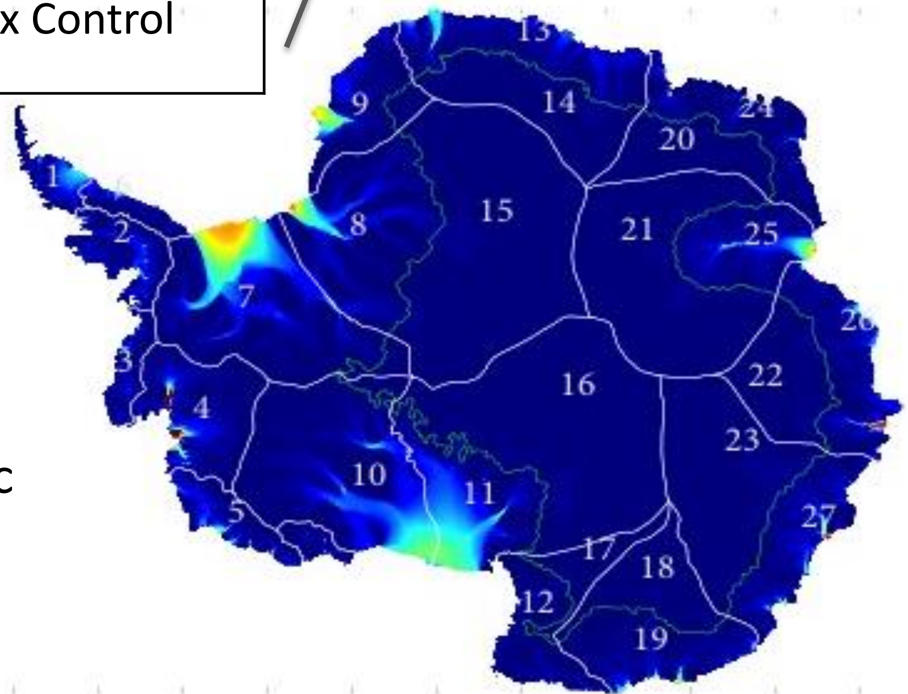
FORCING, 100-year forward run forced with constant:

- Surface mass balance: from RACMO2 (mean annual 1979-2010).
- Ice shelve melt rates: from mean annual ECCO2-MITgcm 150-layer 9 km (2004-2013)

We sample four variables in ISSM-AIS with extreme values, using uniform sampling over 27 geographically-based partitions for 100 year period

Parameter/Forcing	**Min**	**Max**
Ice Shelf Melt	Minimum annual melt rates (ECCO2-MITgcm)	10 x Mean annual melt rates
Basal Drag	40% of Control	Control value
Ice Viscosity	60% of Control	Control value
Accumulation	50% of Control	2 x Control





27 Geographic Partitions

We sample four variables in ISSM-AIS with extreme values, using uniform sampling over 27 geographically-based partitions for 100 year period

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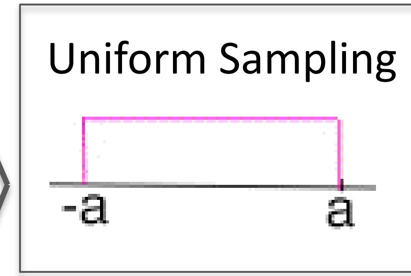
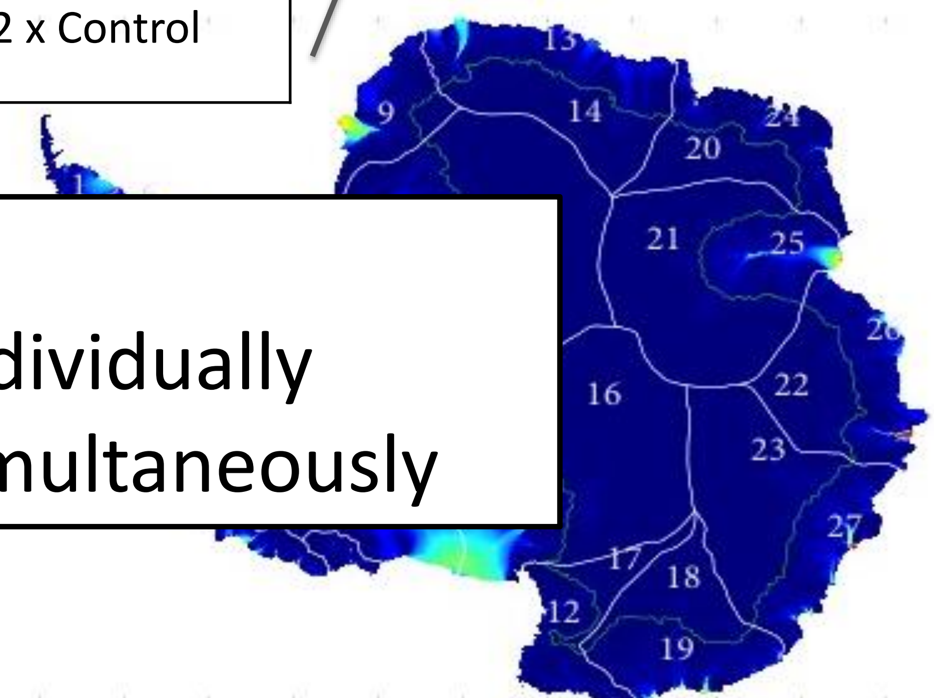


STRATEGY

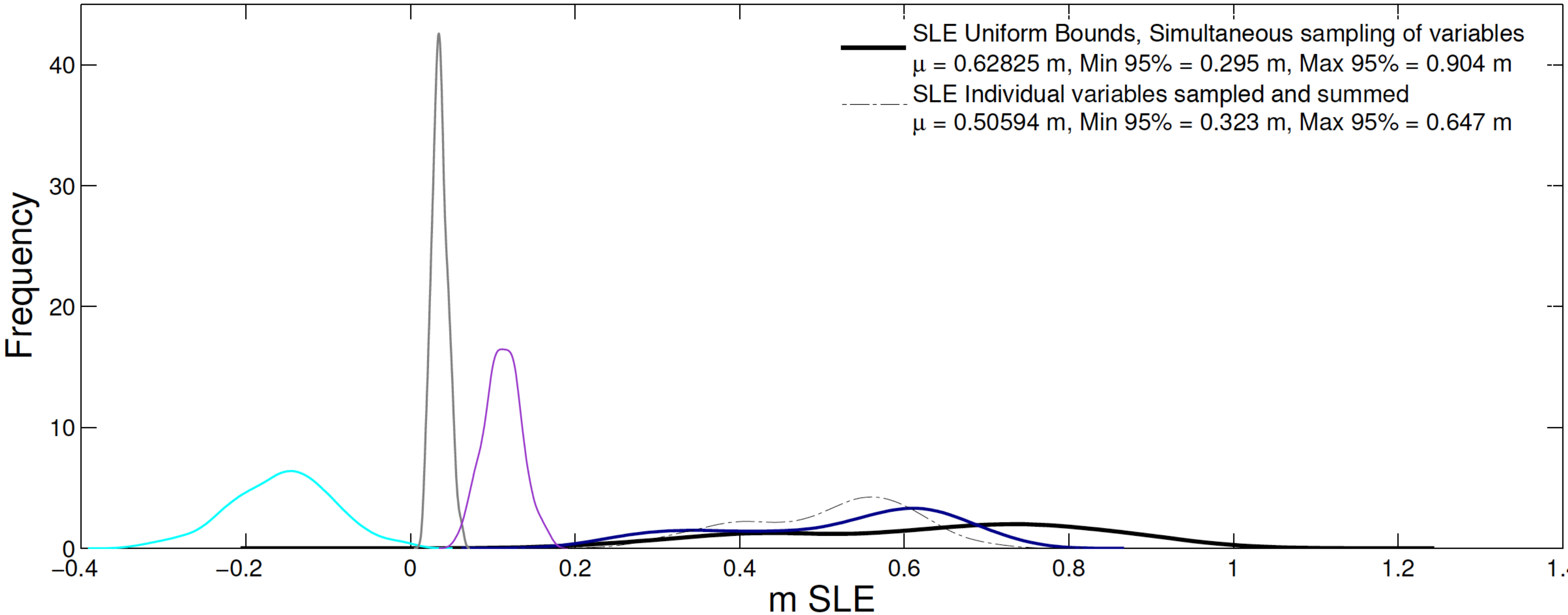
⇒Sample variables Individually

⇒Sample variables simultaneously



Partitions

Sampling of individual variables independently highlights that ice shelf melt is a dominant contributor to sea level



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[Schlegel et al., *Cryosphere*, submitted]

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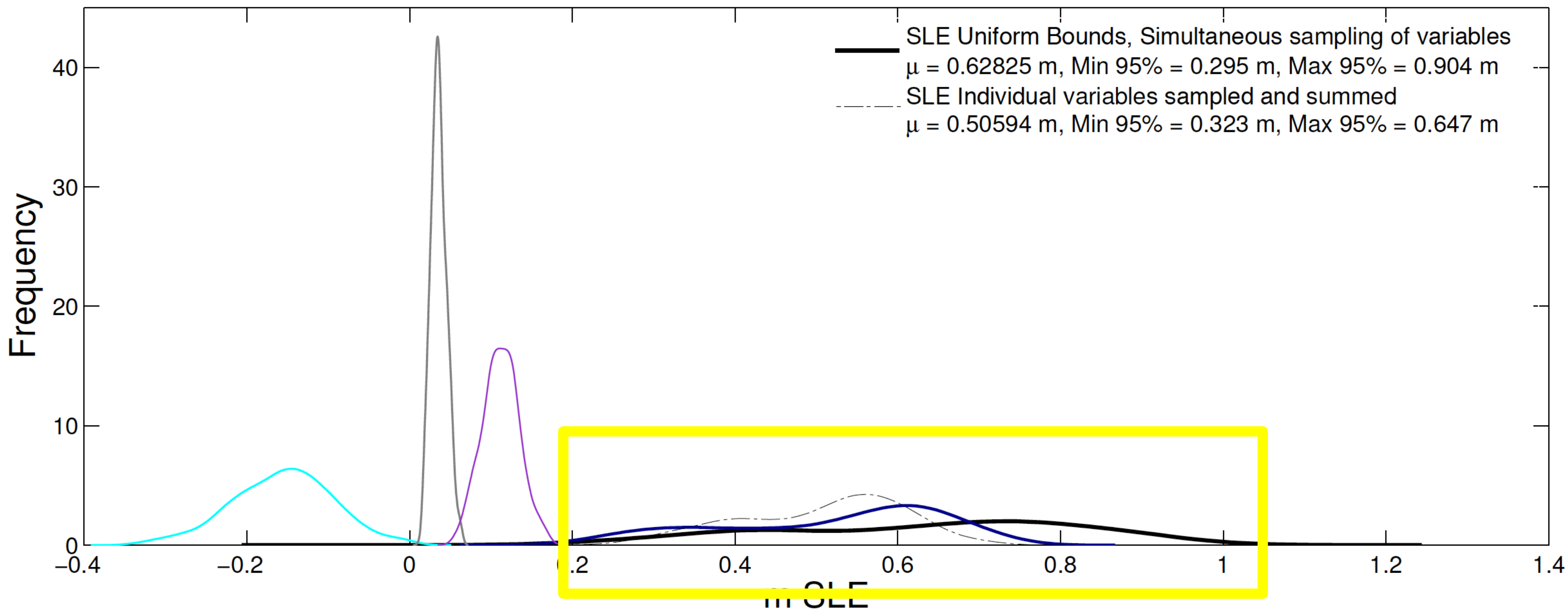

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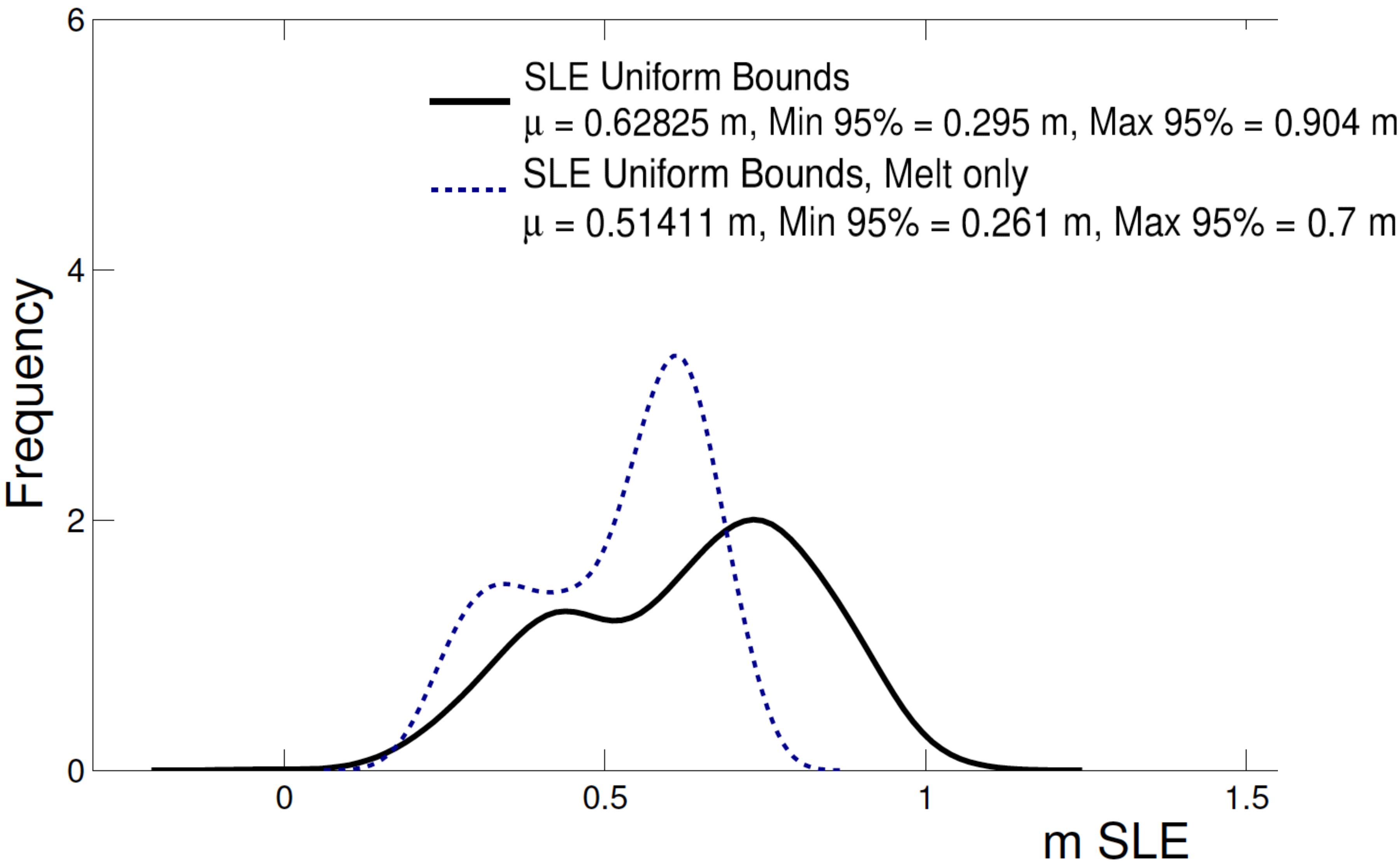
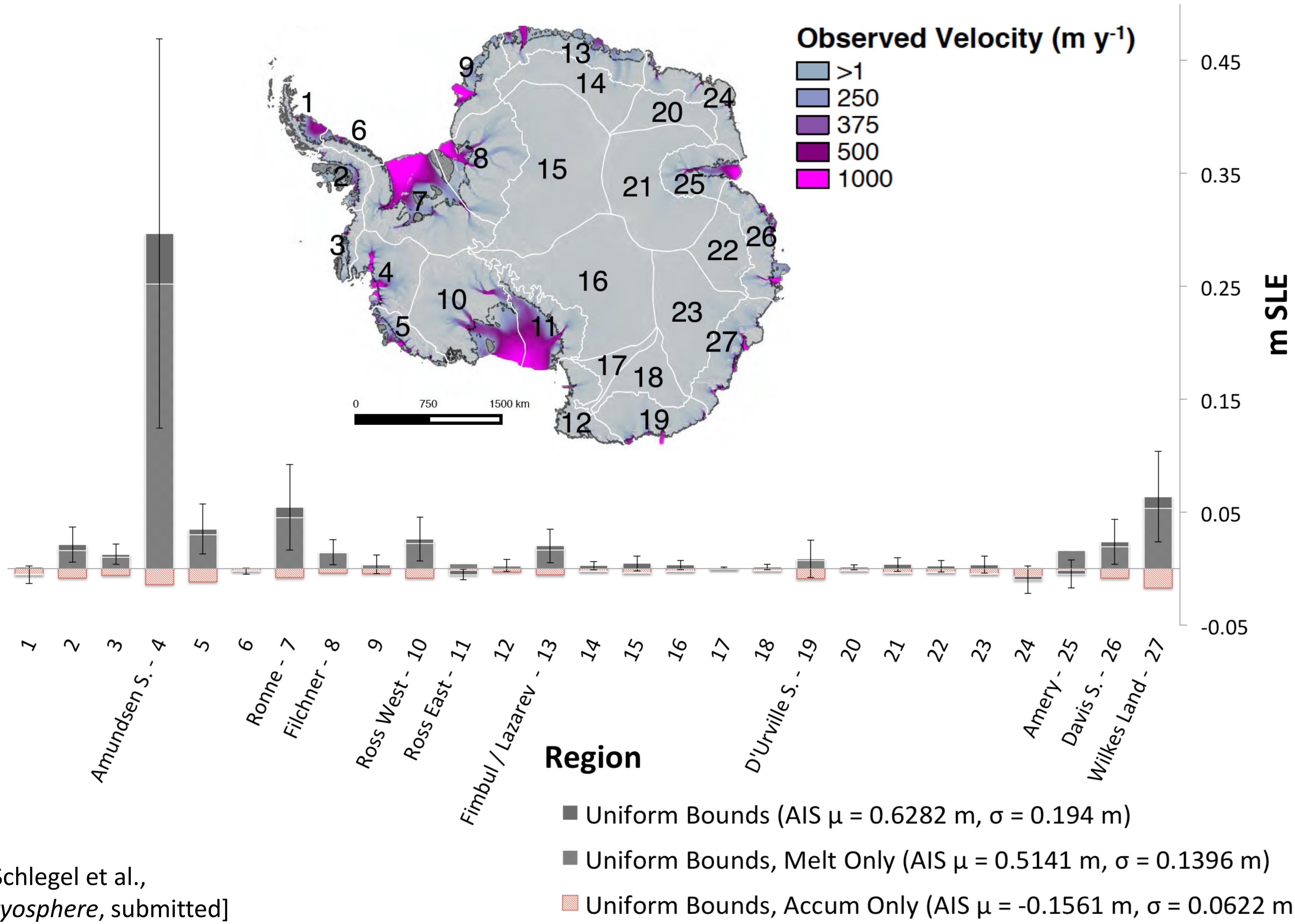
Ice Shelf Melt is responsible for a majority of the spread, and for the complex, bimodal distribution



Regional Analysis:

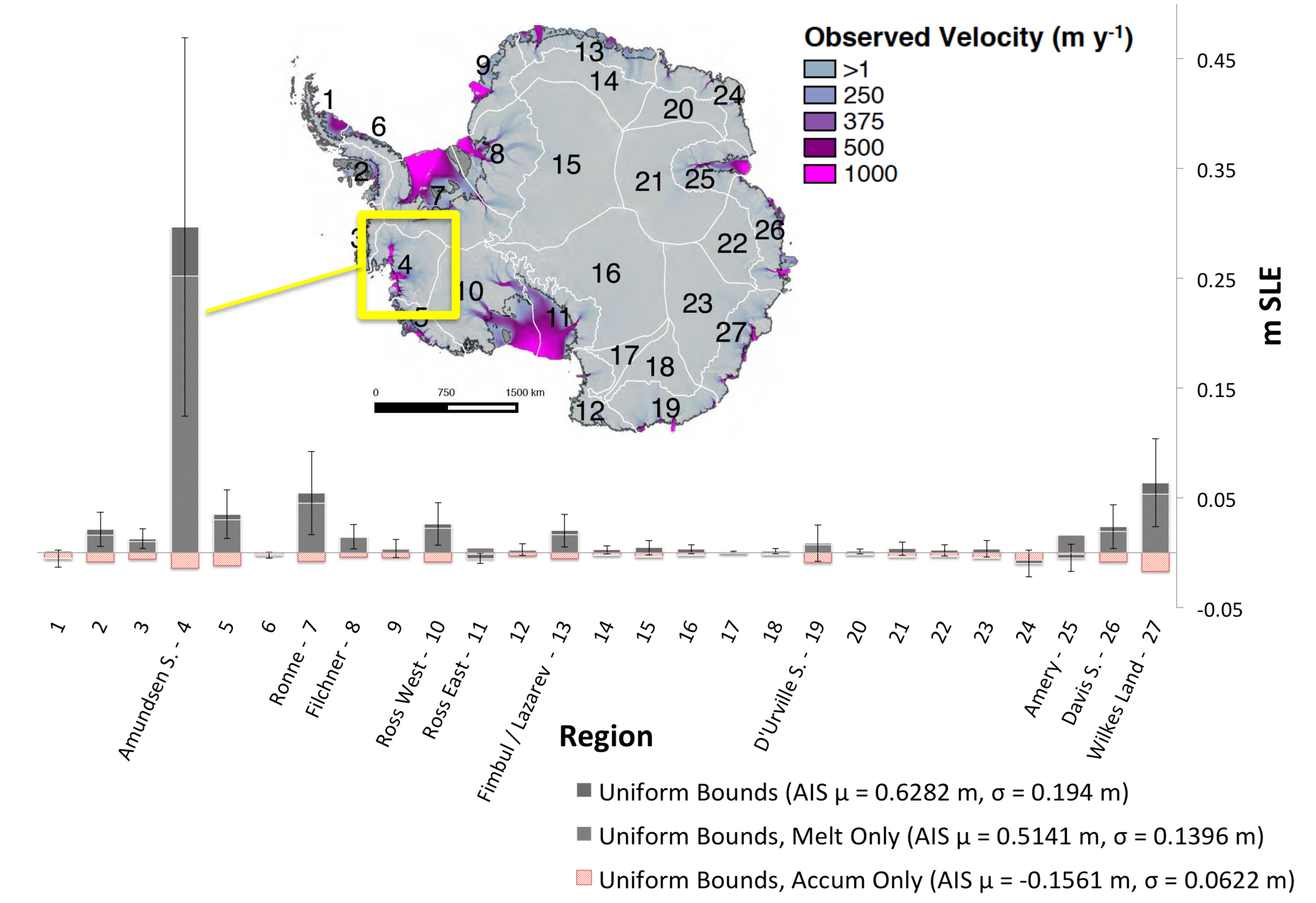
UNCERTAINTY IN SEA LEVEL CONTRIBUTION

Regional analysis reveals that ice shelf melt rates for one basin are largely responsible for uncertainty in ISSM 100-year sea level contribution

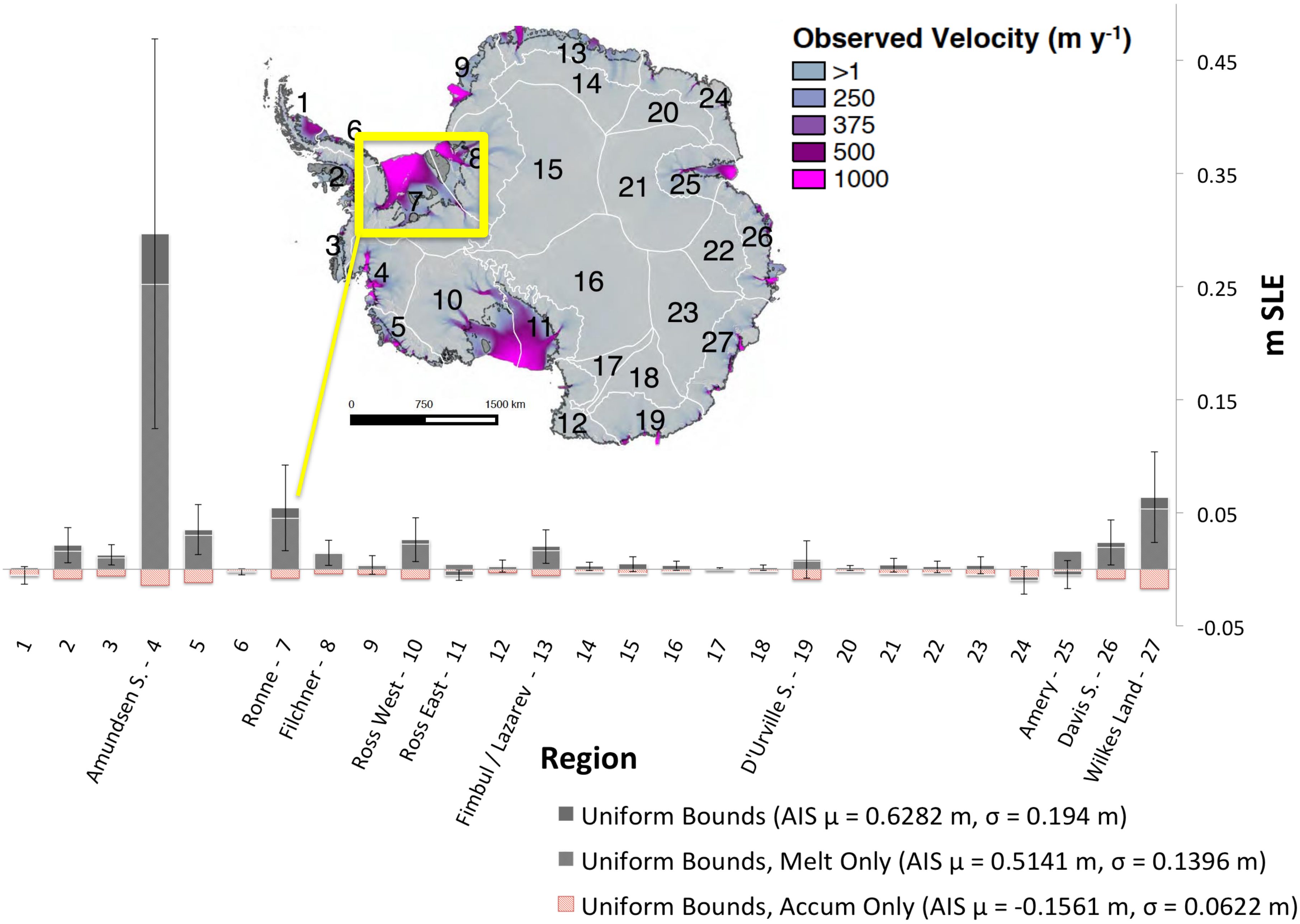


[Schlegel et al., *Cryosphere*, submitted]

Regional analysis reveals that ice shelf melt rates for one outlet are largely responsible for uncertainty in ISSM 100-year sea level contribution



Regional analysis highlights three regions contributing the largest uncertainty to estimates of AIS sea level contribution



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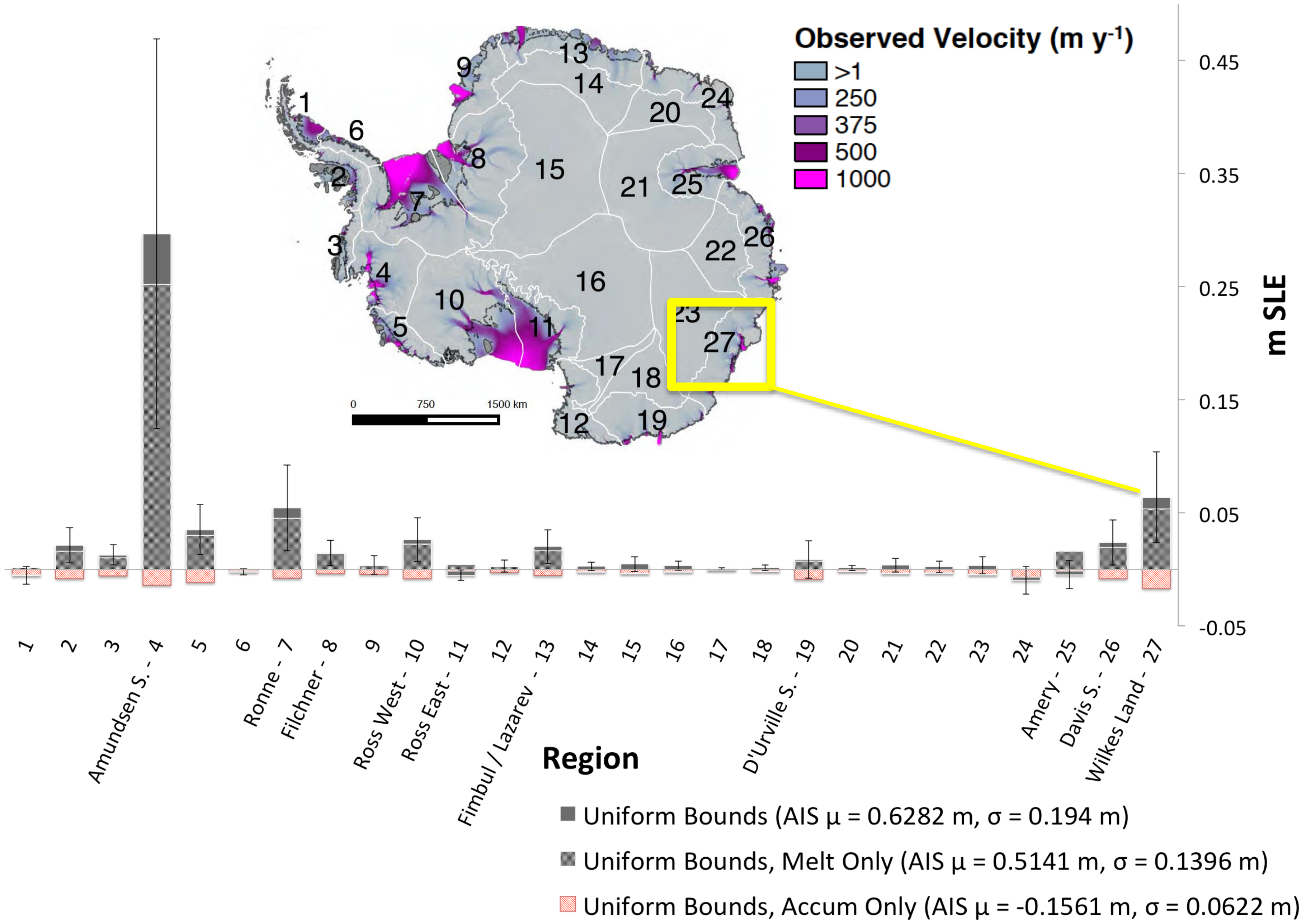
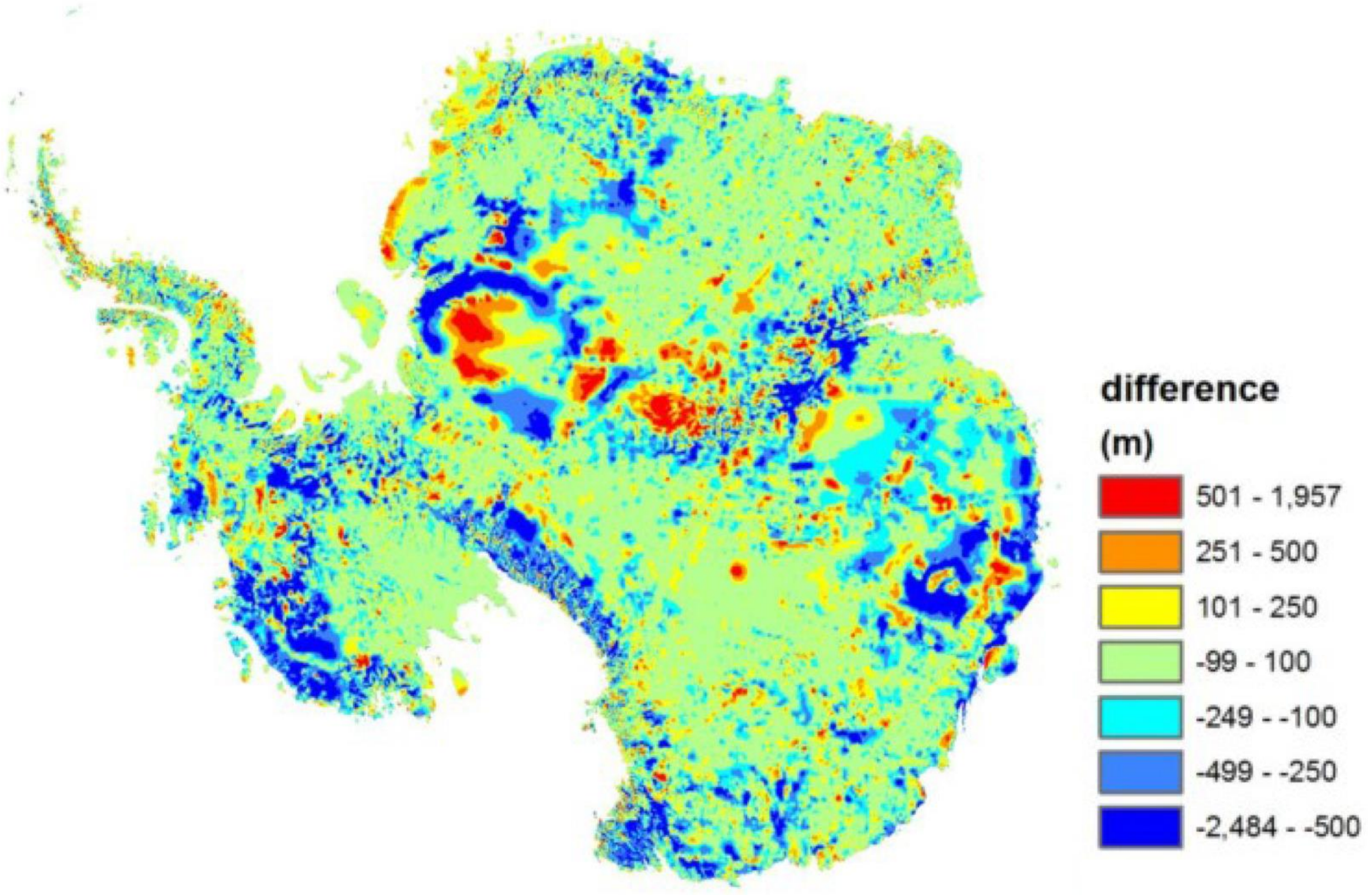


Additional Analysis:

UNCERTAINTY DUE TO BEDROCK TOPOGRAPHY

Antarctica Extreme Uniform Sampling:
Effect of bed topography over 100 years

Bedmap2 to Bedmap1



[Fretwell et al., *Cryosphere*, 2013]

Antarctica Extreme Uniform Sampling:
Effect of bed topography over 100 years

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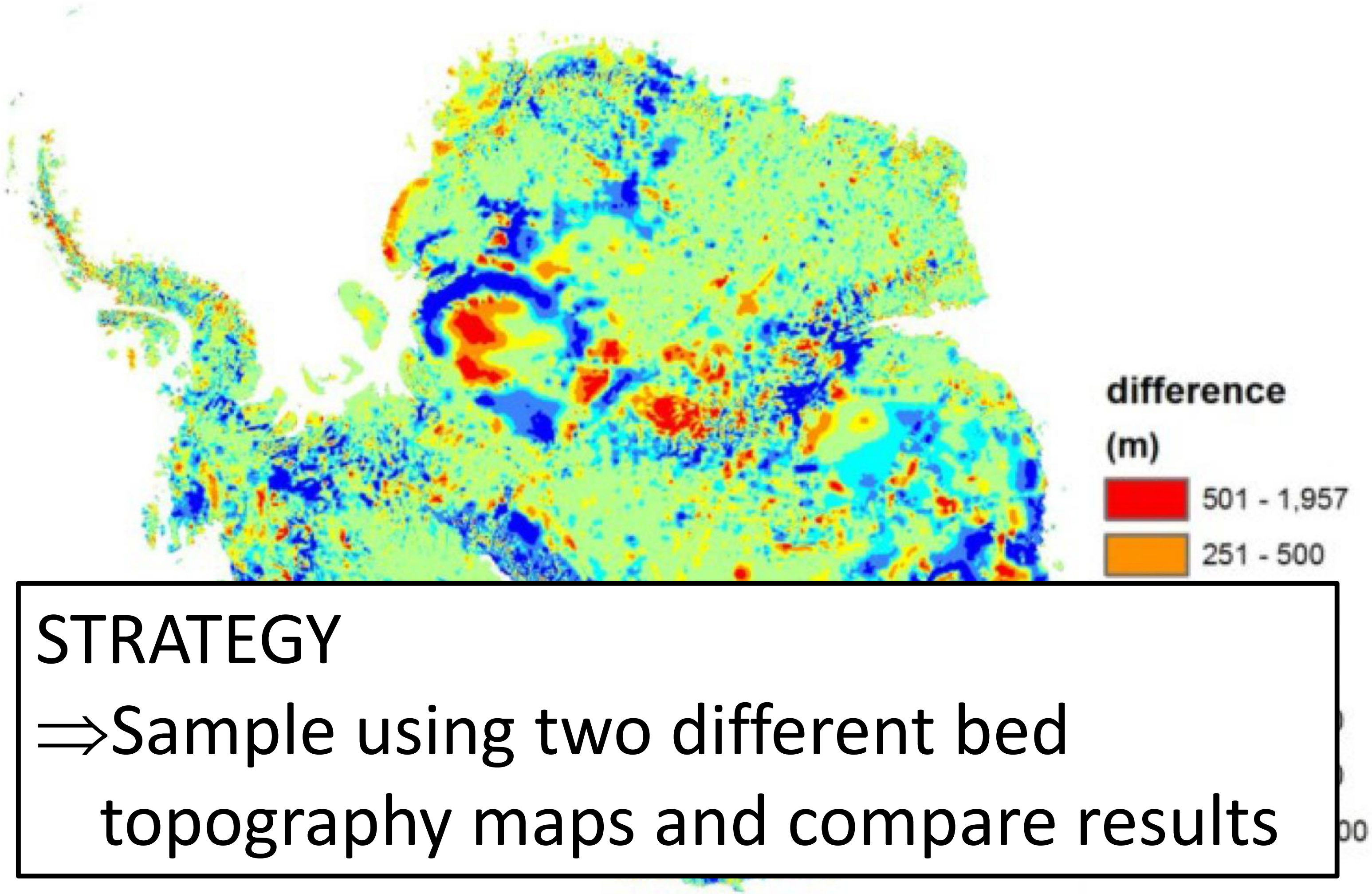
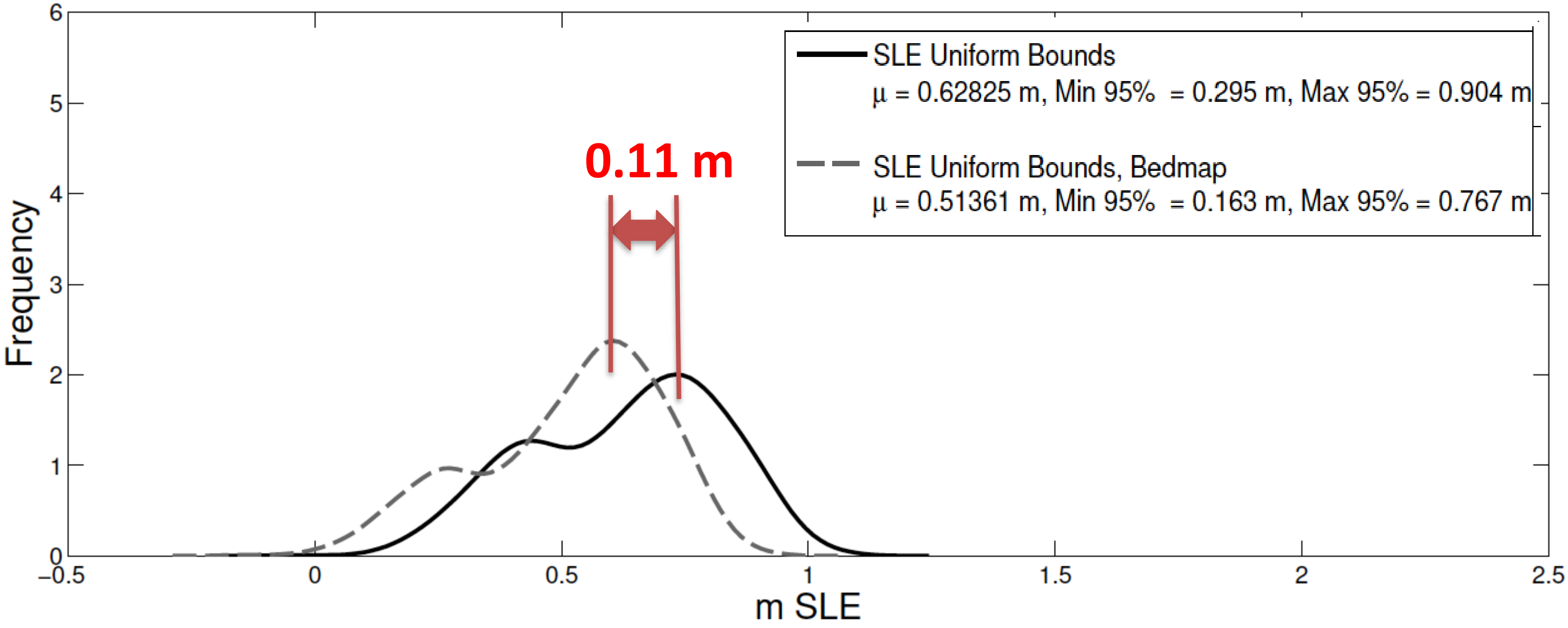


STRATEGY
⇒Sample using two different bed topography maps and compare results

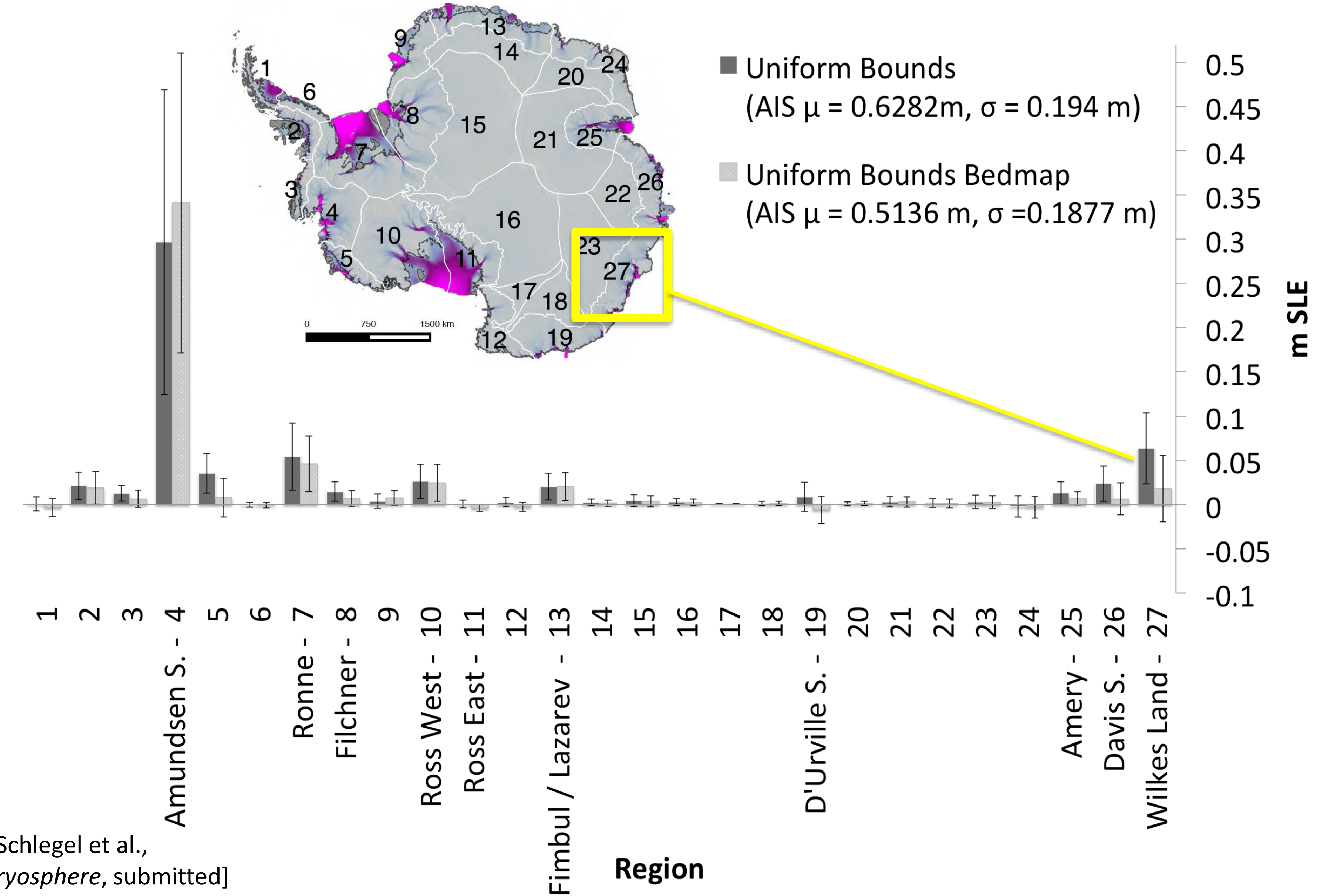
[Fretwell et al., *Cryosphere*, 2013]

Use of Bedmap1 topography instead of Bedmap2/Mass Conservation bedrock can lead to a ~20% underestimate in projection of sea level contribution



[Schlegel et al., *Cryosphere*, submitted]

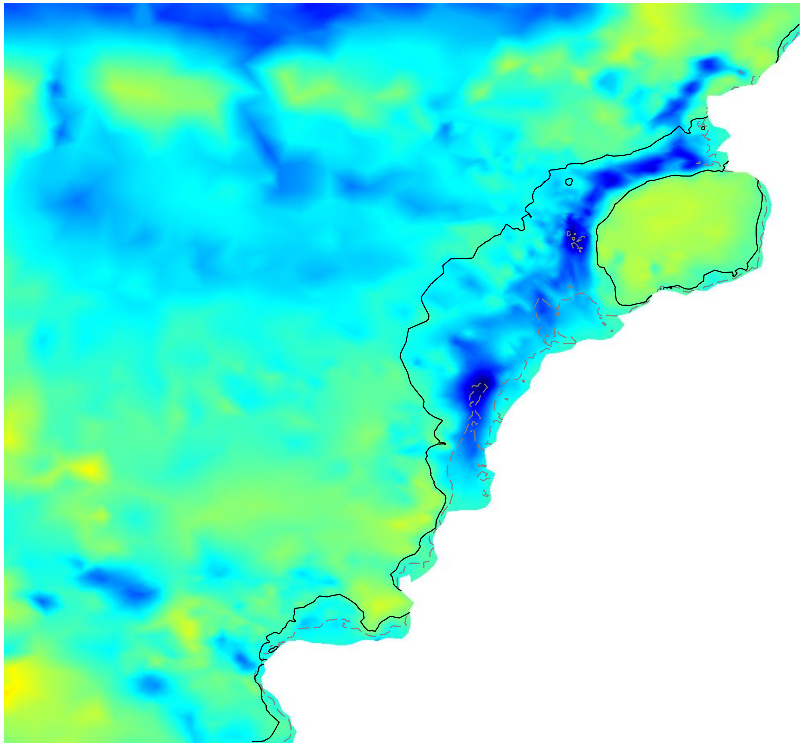
Regional analysis reveals that most outlets have a greater potential sea level contribution after an upgrade to newer bed topography



[Schlegel et al., *Cryosphere*, submitted]

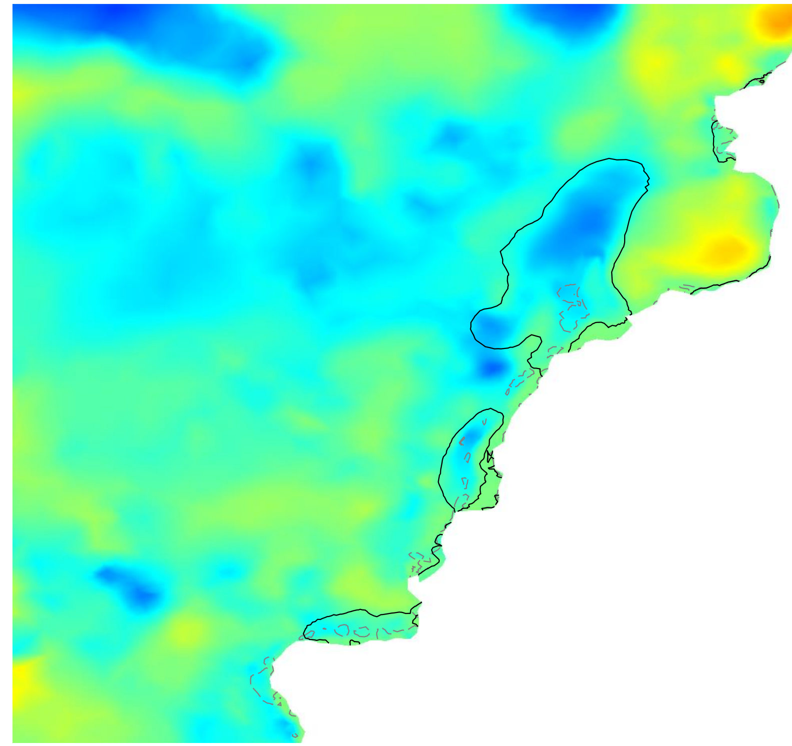
More refined bedrock topography increases the potential for interior grounding line migration in the majority of AIS ice shelves

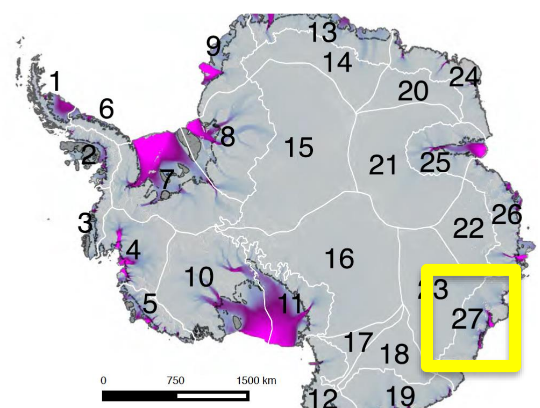
Bedmap2/Mass Conservation



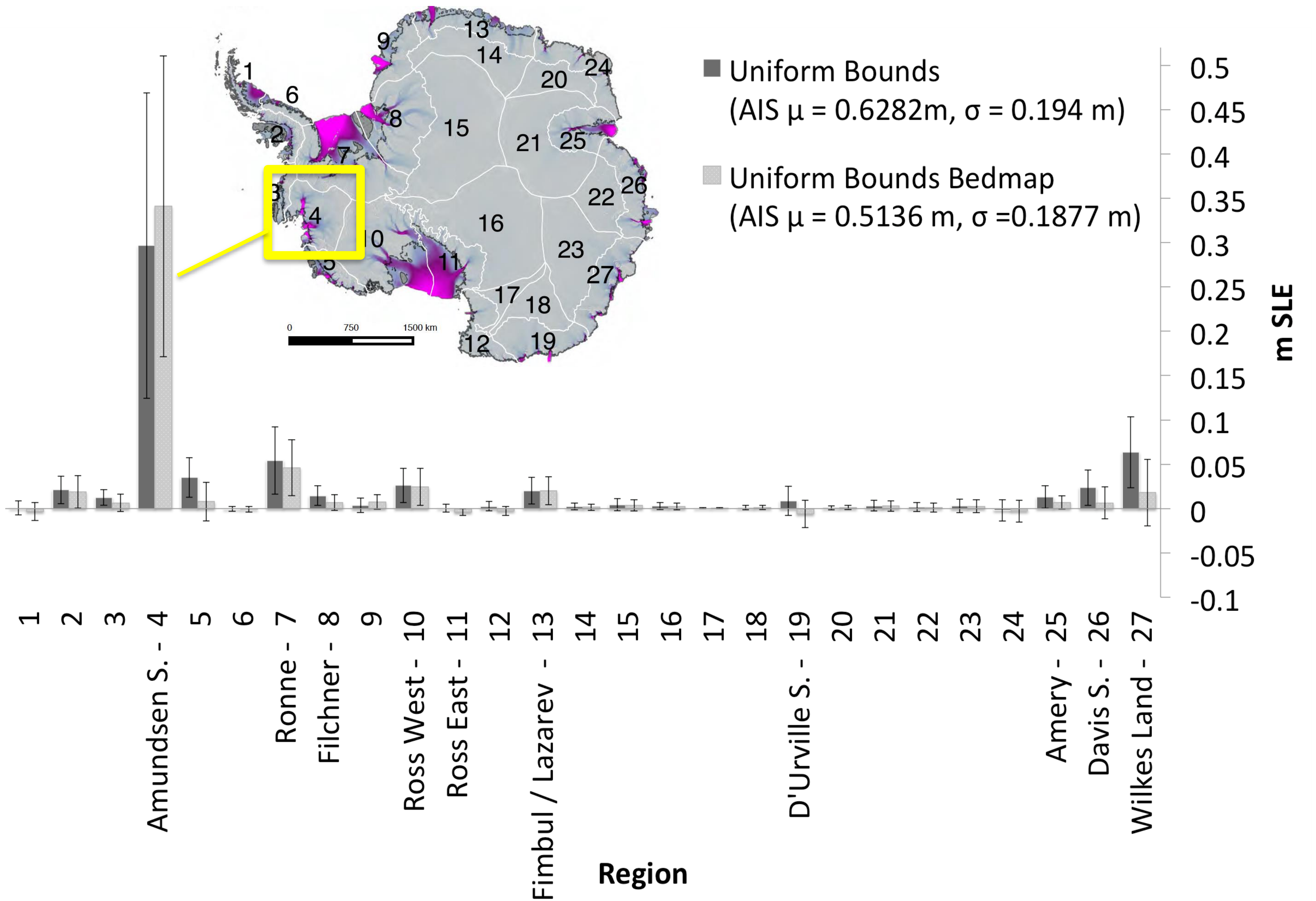
- - Initial Grounding Line
— Uniform Bounds Grounding Line at 100 years

Bedmap1



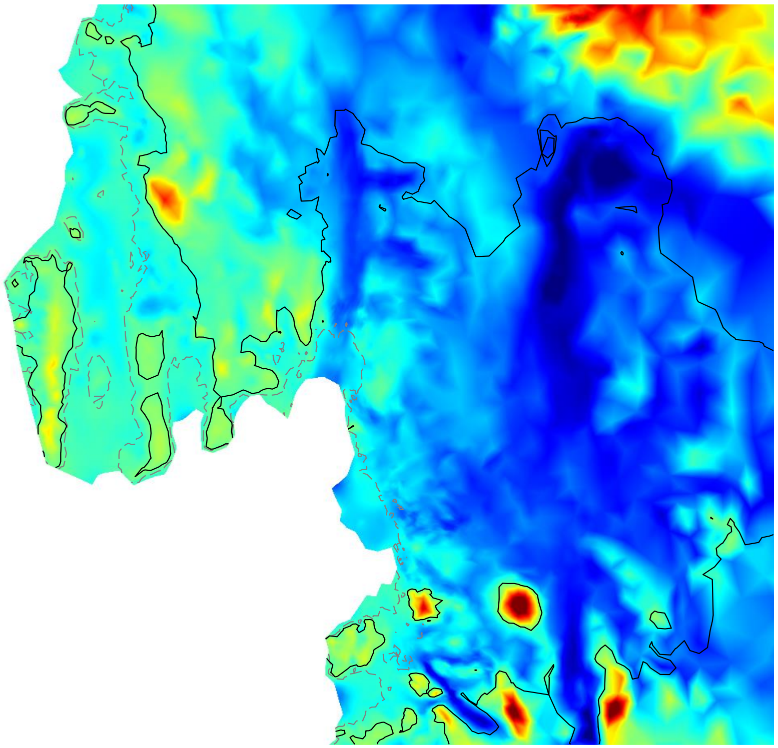


Amundsen Sea, the largest source of uncertainty, has a lower potential for sea level contribution after an upgrade to newer bed topography

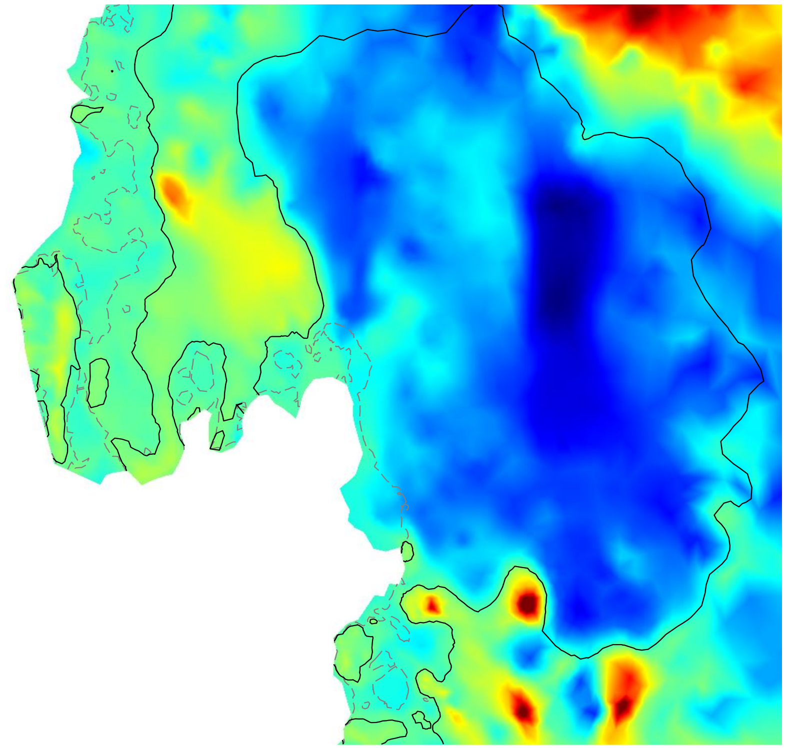


Pine Island Glacier, in contrast, has much less potential for interior grounding line migration with upgrade to Bedmap2/MC topography

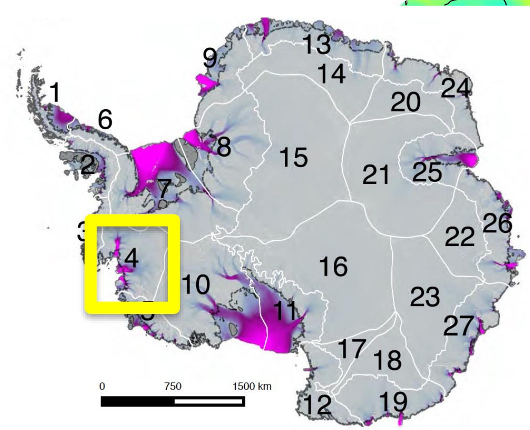
Bedmap2/Mass Conservation



Bedmap1



- - Initial Grounding Line
— Uniform Bounds Grounding Line at 100 years



Conclusions

We use uncertainty analyses to investigate how a continental ice sheet model of the Antarctic ice sheet responds to changes in forcing and boundary conditions.

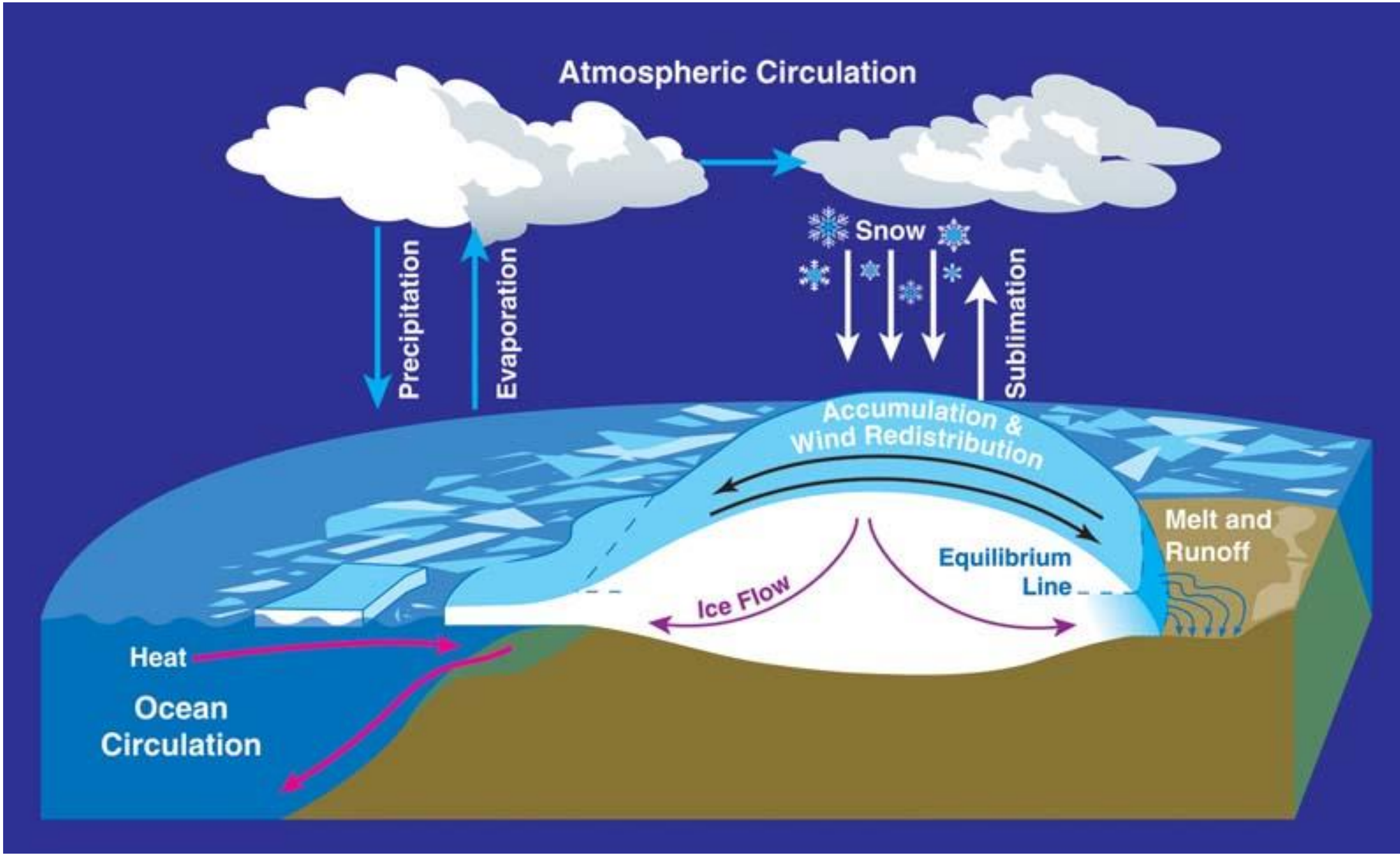
- Quantification of uncertainty helps us improve understanding of ice sheet model sensitivity to input error and uncertainties in projections

- Sampling analysis allows us to quantify how results vary within a parameter space
  - ➢ Antarctica Example
    - We investigate how variables affect model SLE uncertainty, including:
      - Melt, accumulation, basal drag, ice viscosity, and bed topography
    - We focus on experiments forced with extreme bounds: designed to encompass a large range of scenarios and push the model within physically plausible end member scenarios

✓ Ice shelf basal melt rate is a key contributor to SLE uncertainty.
✓ Uncertainties and sources of uncertainty vary regionally.
✓ Amundsen Sea, Ronne Ice Shelf, and coastal Wilkes Land are areas on which to focus in the future, in terms of observational and modeling efforts, including improvement of of bedrock topography maps.

Thank you!

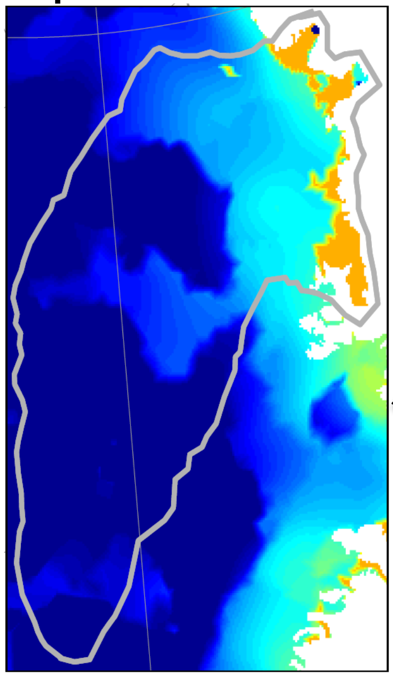
ISSM models the physics of ice flow and its response to changes in forcing and ice properties



(Credit: NASA)

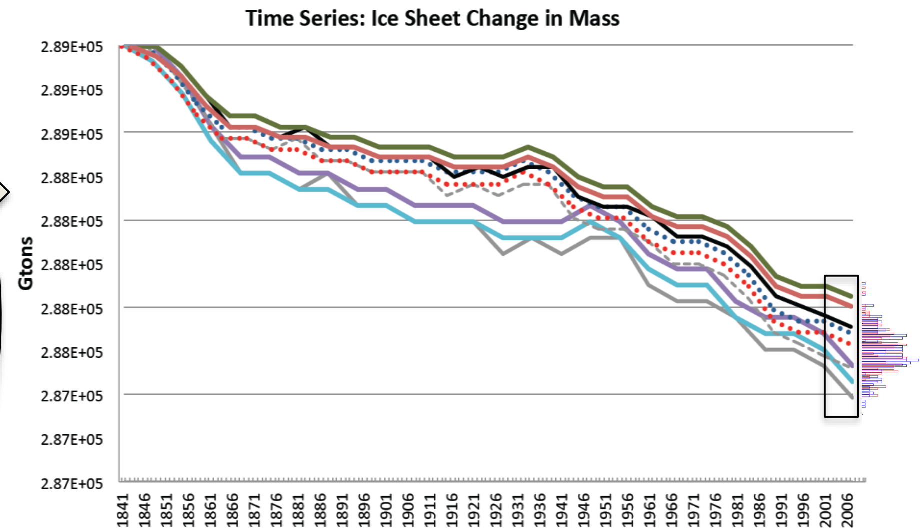
Sampling

Input: Standard Error

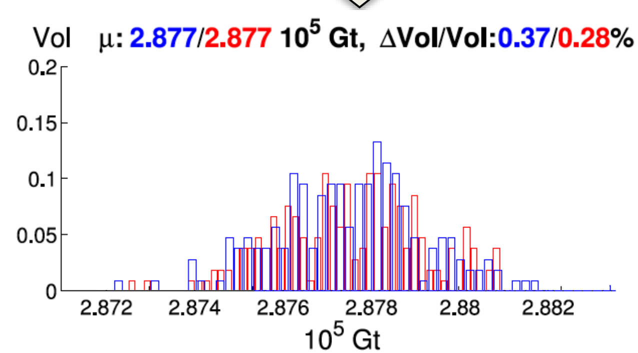


Random sampling of standard error, added to surface forcing

run many samples



Bin final values from all the runs



SAMPLING example:

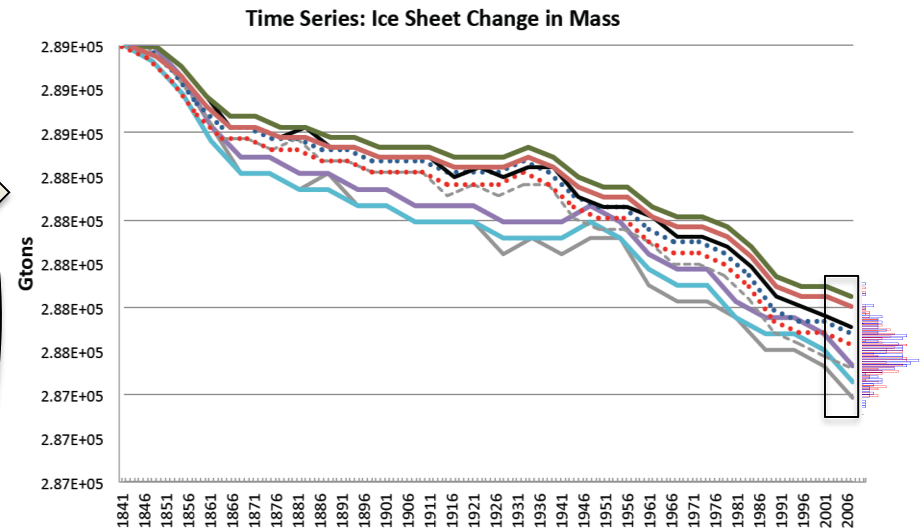
How is volume affected by random errors in surface climate within a range, +/– 3ε ? (where ε=standard error)

Sampling

Partitions

Random sampling of standard error, added to surface forcing

run many samples



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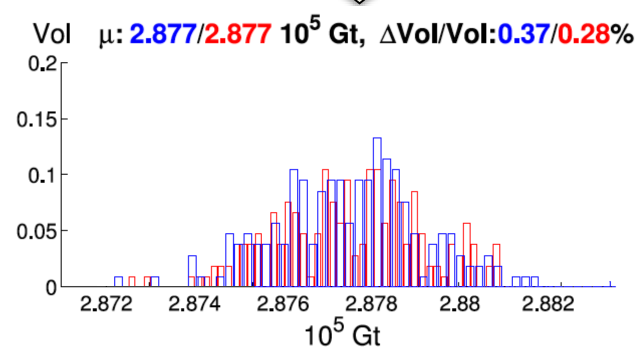

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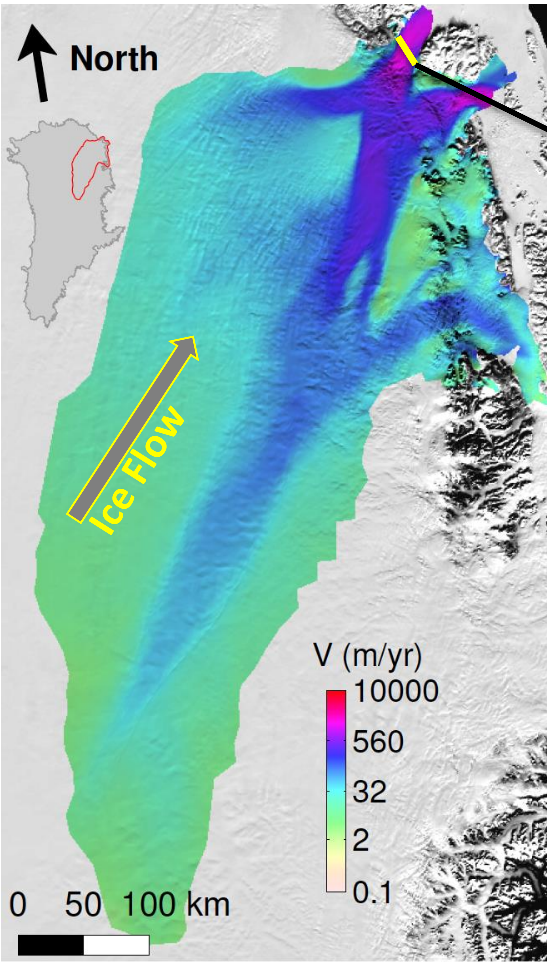
How is volume affected by random errors in surface climate within a range, +/– 3ε ? (where ε=standard error)

Sampling results for a single NEGIS flux gate

Modeled velocities



(Schlegel et al., *J. Geoph. Res*, 2015)

Modeled ranges in 79 North Ice discharge to ocean