Uncertainty Quantification for Ice Sheet Science and Sea Level Projections

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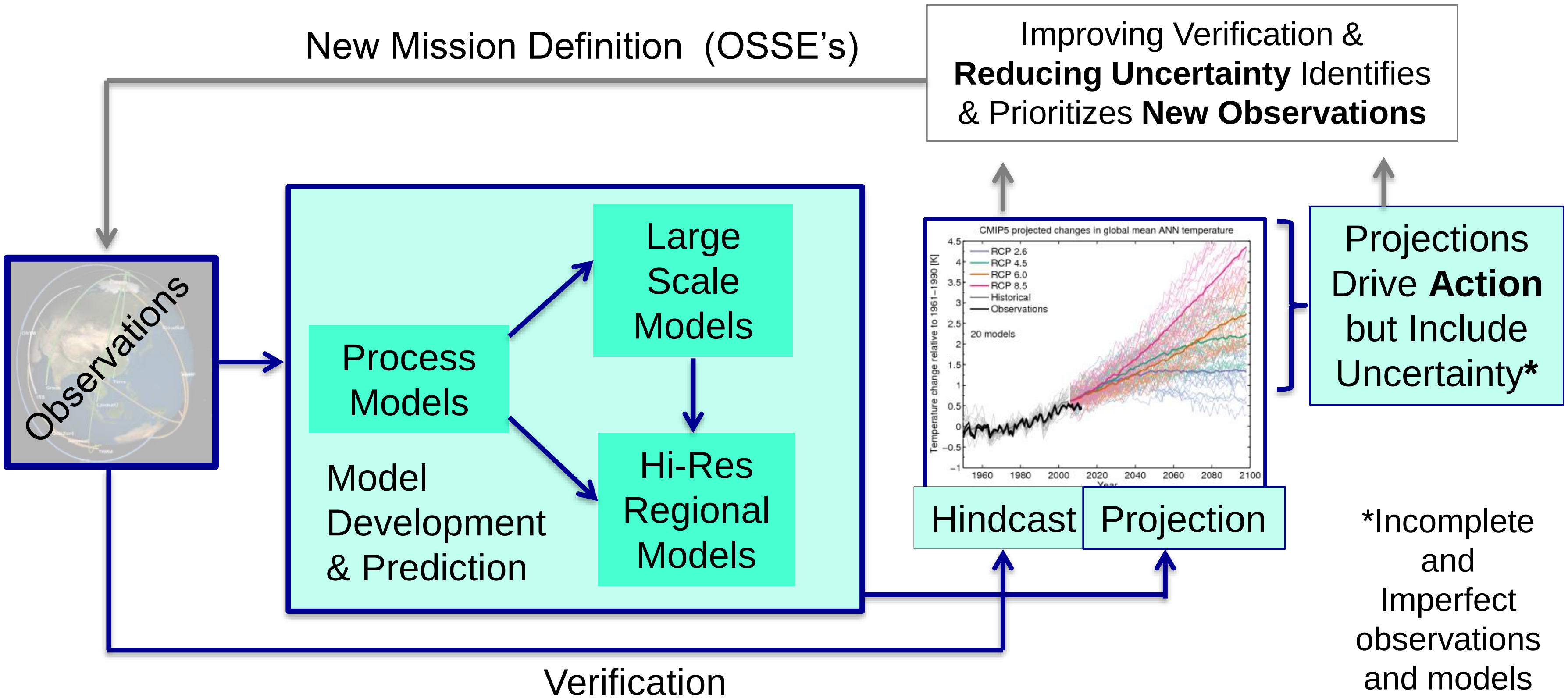
Motivation

- Two (originally uncoupled) questions:

1. Why can't we do a better job of quantitatively assessing and optimizing new measurements impact on understanding of the climate system?
   - Significant improvement in quantitatively tracing from measurement to instrument design via system engineering approaches
   - Extend to "science system engineering" at higher level of abstraction
2. Why can't we have smaller uncertainties in sea level rise by 2100?
   - Range from ~20 cm to ~200 cm

JPL Physics based model/prediction/observing optimization framework

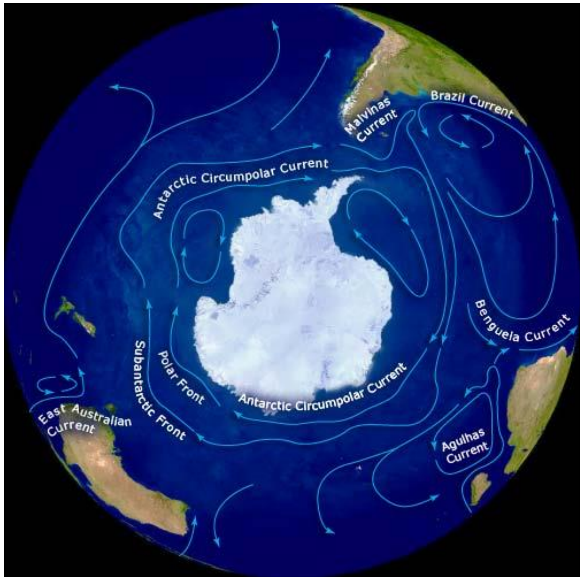


Better quantitative characterization of these complex systems through the application of system engineering and uncertainty quantification methods would enable:

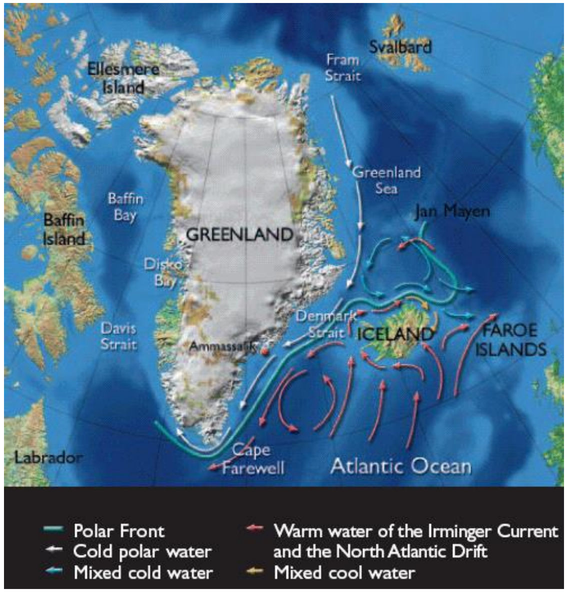
- Improved *science analysis* results
- Improved *science traceability* for optimizing measurement system (mission and instruments) design
- Improved *prioritization* of missions and instruments

Models

Antarctica



Greenland



ISSM

- Ice Sheet System Model
- Adjoint capabilities
- UQ analysis using DAKOTA framework

ECCO2/MITgcm

- Estimating the Circulation and Climate of the Ocean
- Adjoint capabilities

Adjoint capability enables easy integration of real or simulated observations for parameter estimation.

Multi-step Process

Parameter values applied as constant values for 100 yr durations

- Step 1 – single parameter sensitivity experiments
  - Ocean/ice melt rate; viscosity; basal drag; Surface Mass Balance
- Step 2 – Initial Monte Carlo analysis
  - varying most influential parameters from step 1, over extreme (high SLR) min/max range
  - 1 and 2000 partition runs - equal area
- Step 3 – refined Monte Carlo analysis
  - More credible parameter mix/max for next 100 yrs
  - 27 “smart” partitions – designed around drainage basins and climate regions
- Step 4 – scenario driven / time evolved parameter change
  - Future work

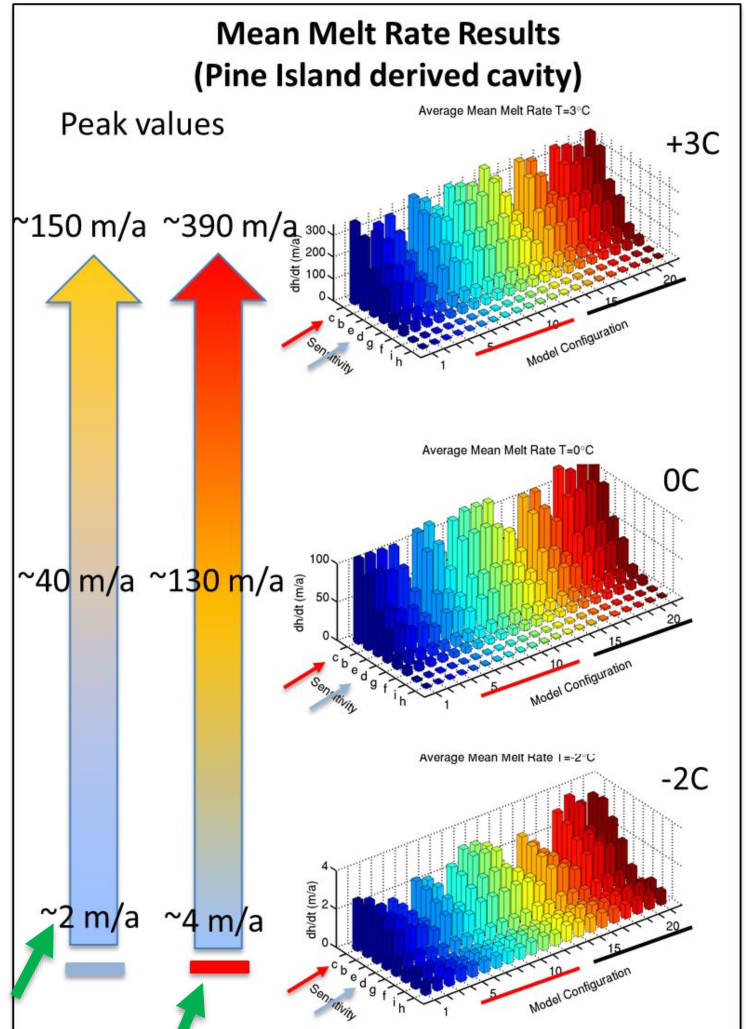
Each AIS UQ Monte-Carlo Experiment: Varied 4 parameters, 200 values each, 800 runs total for each experiment

Basal Melt Rate Sensitivity

Ocean warming at ice interface potentially important for large SLR cases

- Ice shelf cavity interface water temperature increase of 2° C can result in 20x to 30x increase in melt rate
  - Credibility / Likelihood of 2° C rise in Southern Ocean ice boundary water in next 100 yrs is very low, but impact is high

- Measurement and prediction of evolution of AIS ice cavity interface water temperature and knowledge of heat exchange coefficient is important for constraining future worst-case SLR



Current best estimate heat exchange coefficients

High end heat exchange coefficients

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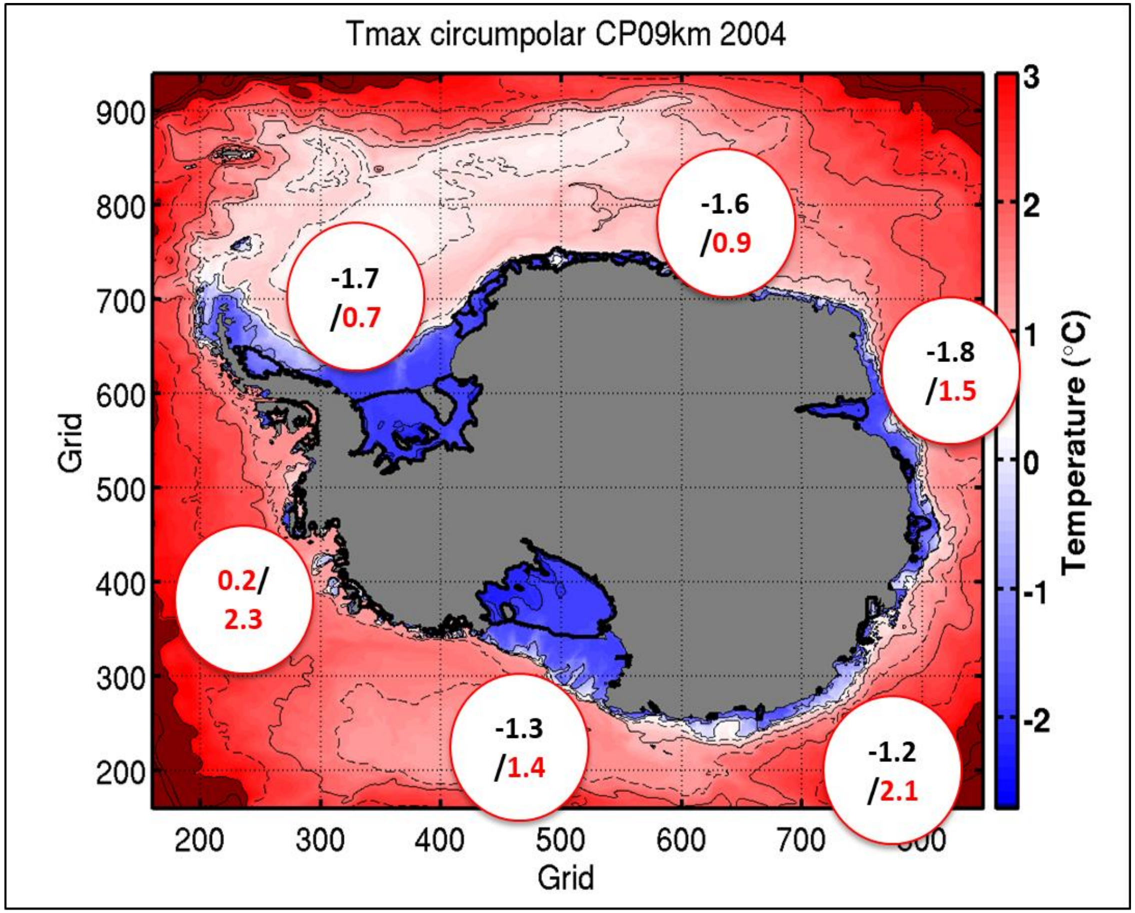
How warm can it get?

Apply cavity specific potential temperature increase to cavity melt temperature sensitivity, to get estimated melt rate upper bound for ~50-100 year horizon

- Warm Circumpolar Deep Water (CDW) that is forced onto the continental shelf mainly drives present-day melt in high-melt areas
- How do melt rates change if CDW makes it onto the shelf for present-day "cold" ice shelves?

Figure: *Present temperature maximum and potential future temperature maximum given by nearby CDW.*



Top: cy 2004-2008 mean Temperature maximum in cavity
Bottom: Temperature maximum of Circumpolar Deep Water

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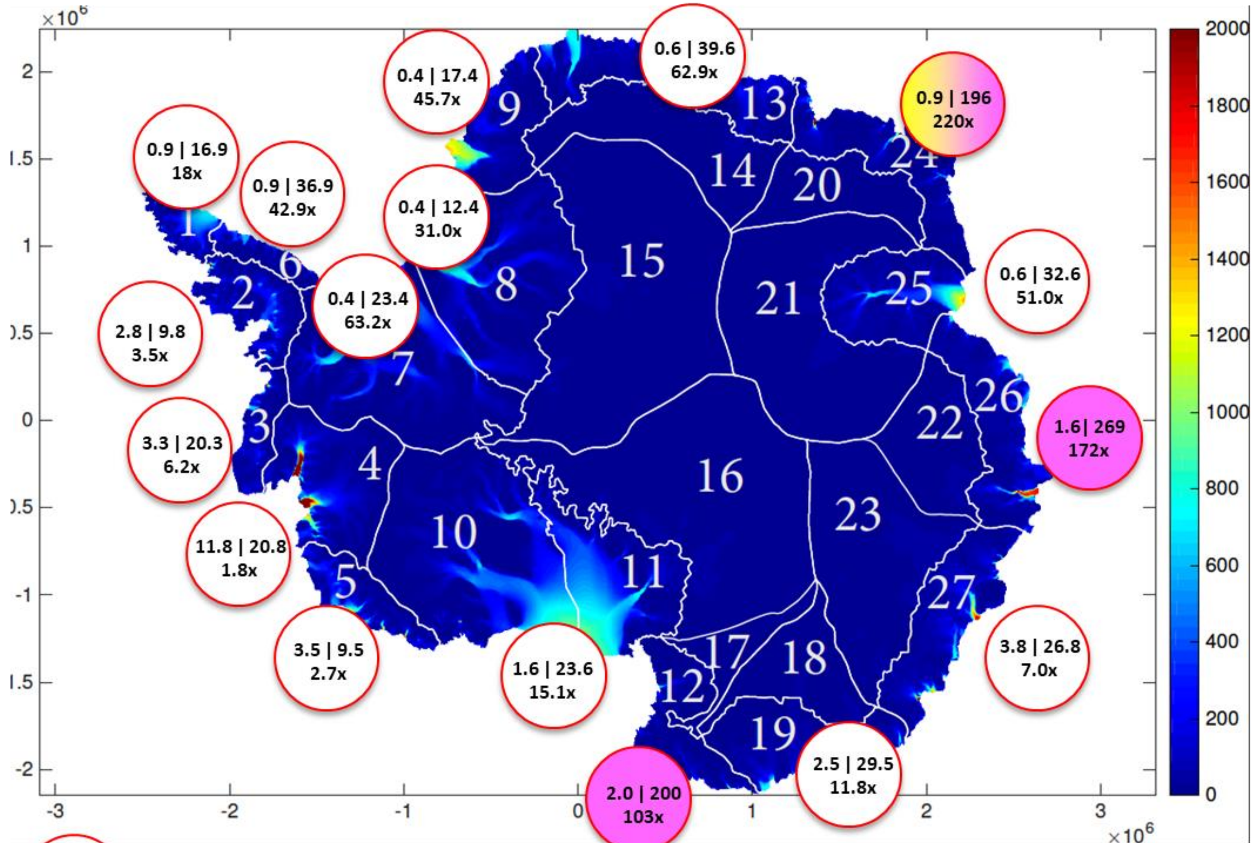
What are potential (realistic) melt rates?

Apply cavity specific potential temperature increase to cavity melt temperature sensitivity, to get estimated melt rate upper bound for ~50-100 year horizon

- Determine melt rates based on current CDW temperatures around Antarctica
- Apply a multiplier to present-day melt rates to raise up to “realistic” melt rate potential



XX | YY
AAx

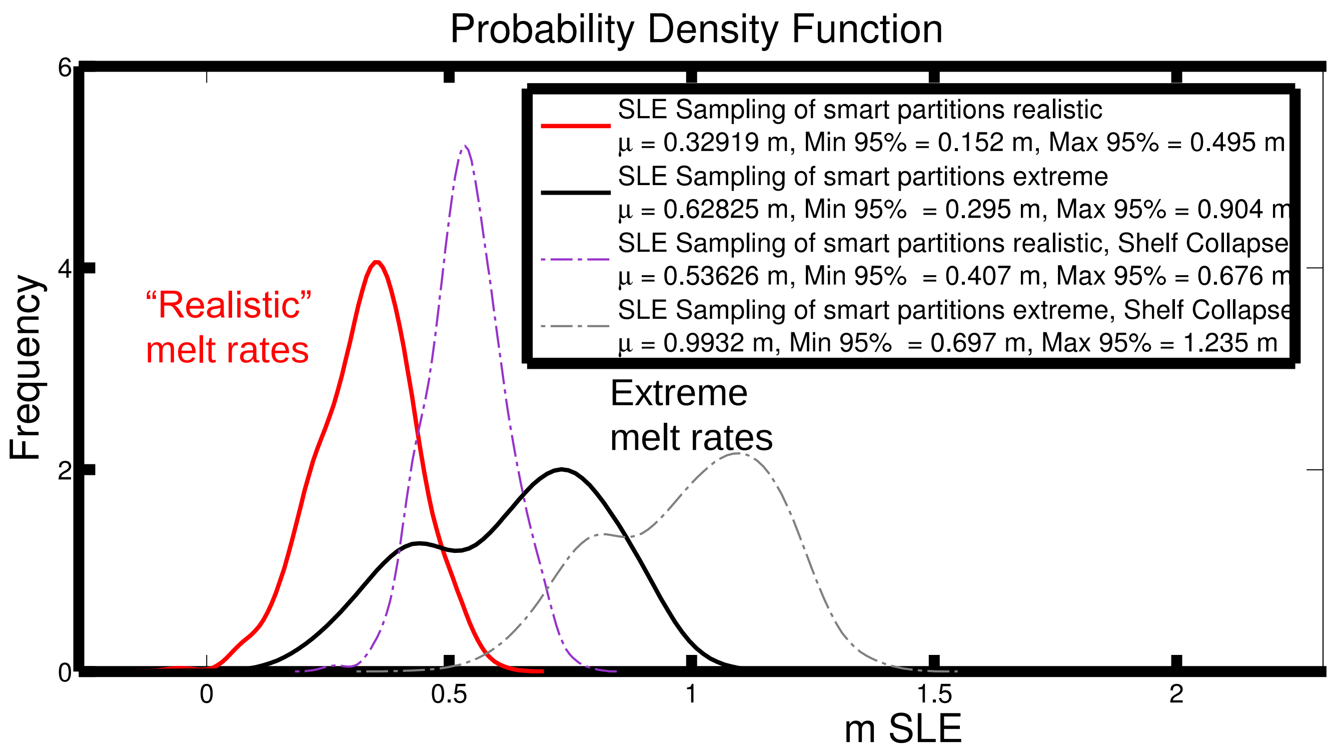
XX / YY / AA = current estimated meltrate (m/yr) per model / upper bound predict (m/yr) / multiplier over current estimate

Model predict for current conditions is factor of 2x or greater different from current observations

Model predict for future conditions is very large (>100m/yr)– grid resolution or other modelling artifact

Figure: *Melt rate multiplication factors derived from the CDW temperatures, which give a more realistic heterogeneous distribution vs. uniform increases of rates.*

Antarctica UQ Run – Extreme vs. Realistic Worst Case



Examples of parameter range differences for "realistic" vs "extreme" runs (% relative to control, which is "best estimate of current conditions"):
Basal drag: (-15 to -25%) to (+15 to 25%); 0 to -40%
Viscosity: (-5 to -10%) to +5%; -60% to 0
Melt rate: 0 to (2x to ~200x) ; 0 to 10x

Figure: *Results from 100-year Antarctica Uncertainty Quantification runs. Text summarizes parameters varied. PDF of sampling experiments, comparing sampling of extreme bounds (black) with realistic bounds (red) over smart partitions. We also include curves resulting from sampling of the same model, but with the collapse of all its ice shelves instantaneously at the beginning of the simulation. The collapsed shelves model is sampled with extreme bounds (grey) and with realistic bounds (purple). SLE = Sea Level Equivalent net mass loss (above flotation).*

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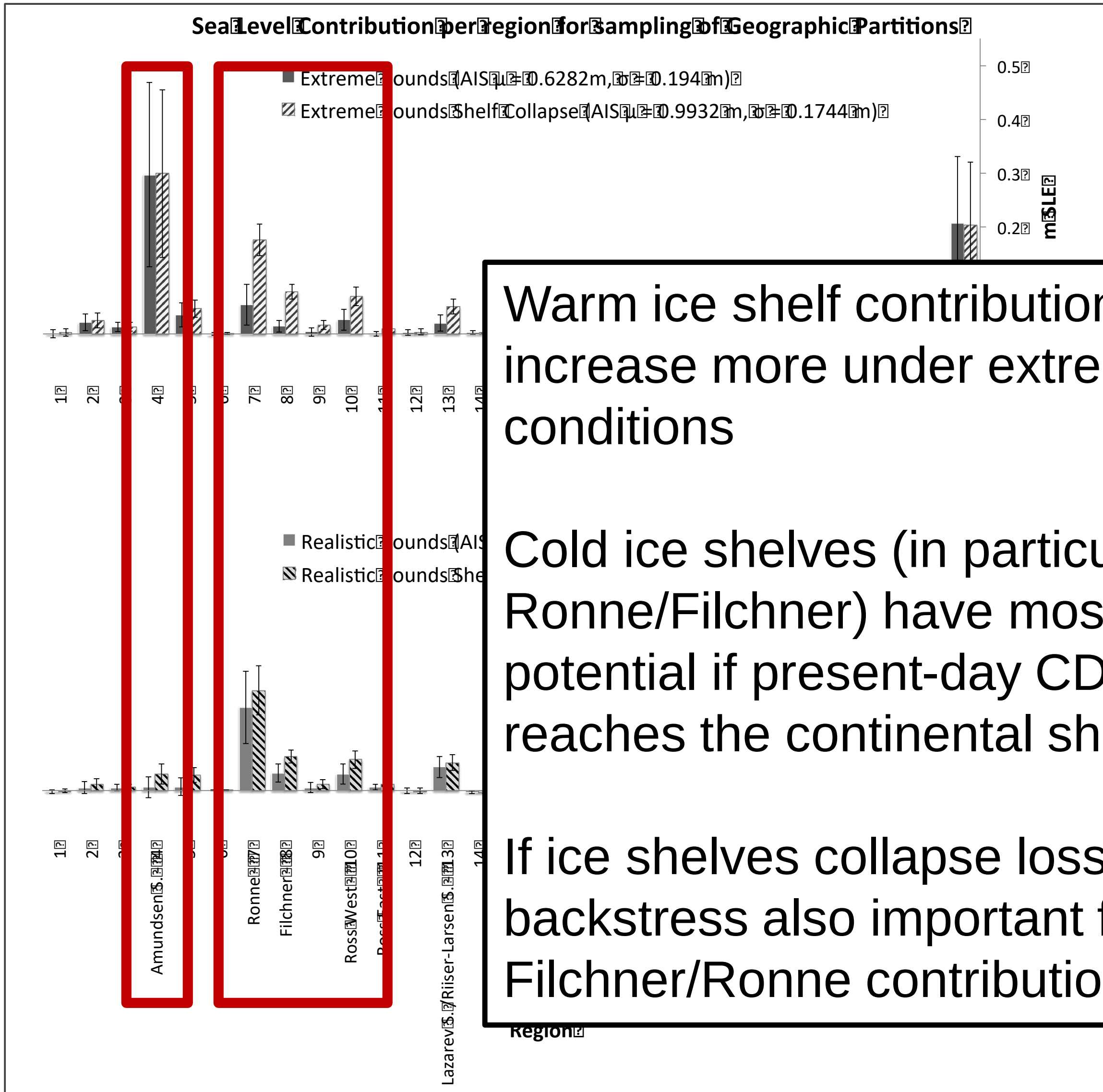

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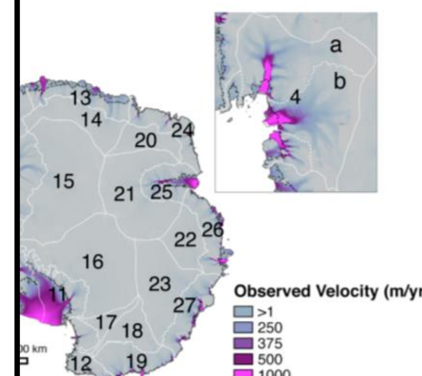
Warm ice shelf contributions increase more under extreme conditions

Cold ice shelves (in particular, Ronne/Filchner) have most potential if present-day CDW reaches the continental shelf

If ice shelves collapse loss of backstress also important factor for Filchner/Ronne contribution

mparison of impact of rcing (top) vs. more cing (bottom) on sea bution by glacier.



Conclusions

- Observing ice shelf melt rates (forcing and boundary conditions) essential for predicting Antarctica's contribution to sea level change
- Likely scenario for increased melt: warm CDW reaches the continental shelf
- Extreme melt (10x current rates) likely to increase warm ice shelf contributions most but less realistic
- "Realistic" melt rates (current CDW temperatures) affect cold ice shelves most (Filchner/Ronne)
- Ice shelf collapse affects Filchner/Ronne backstress
- Different climate scenarios ("extreme" vs. "realistic") can inform observing system plans

Additional details on importance of ice melt for the Antarctic contribution to sea level change:

GC24D-05: Uncertainties in the Antarctic Ice Sheet Contribution to Sea Level Rise: Exploration of Model Response to Errors in Climate Forcing, Boundary Conditions, and Internal Parameters

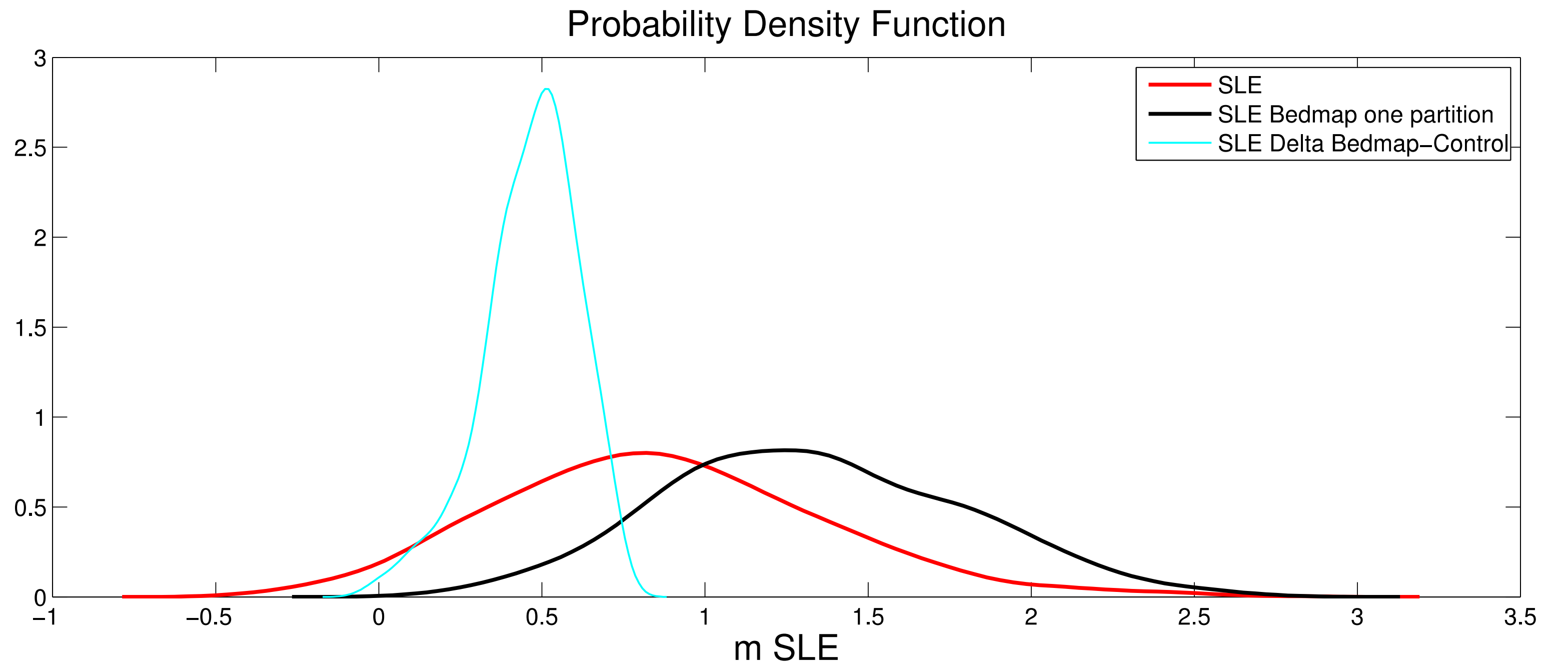
Nicole Schlegel, *Helene L Seroussi, Carmen Boening, Eric Y Larour, Daniel Limonadi, Michael Schodlok and Michael M Watkins*

Tuesday, 12 December 2017 17:20 - 17:40
New Orleans Ernest N. Morial Convention Center - 278-279

Thank you!

Uncertainties in Bedrock Topography

- Bedmap 1 vs Modified Bedmap 2: ~0.4m (~33%) mean SLR difference at 100yrs for extreme climate scenario
- Residual uncertainty in AIS topography is ~ Bedmap1 / Bedmap 2 correction
- **Completing high resolution bedmap of AIS is a quantifiably low risk / high pay-off measurement**



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Sea Level Rise Budget Implications

Pfeffer et al, 2008
Source for 2m upper bound in NCA. 1.1m of which comes from AIS + GIS

Table 3. SLR projections based on kinematic scenarios. Thermal expansion numbers are from (*22*).

	SLR equivalent (mm)		
	Low 1	Low 2	High 1
Greenland			
Dynamics	93	93	467
SMB	71	71	71
Greenland total	165	165	538
Antarctica			
PIG/Thwaites dynamics	108		394
Lambert/Amery dynamics	16		158
Antarctic Peninsula dynamics	12		59
SMB	10		10
Antarctica total	146	128	619
Glaciers/ice caps			
Dynamics	94		471
SMB	80		80
GIC total	174	240	551
Thermal expansion	300	300	300
Total SLR to 2100	785	833	2008

Likely extreme upper bound - Our results indicate it is difficult to get this much ice out of GIS, even under extreme conditions

Reasonable but not extreme upper bound: Our results agree with there upper bounds given conservative, but not extreme, AIS parameters and boundary conditions. However, if un-expected / extreme conditions develop, AIS is capable of dynamically sourcing substantially more ice in 100 yrs (+1m)

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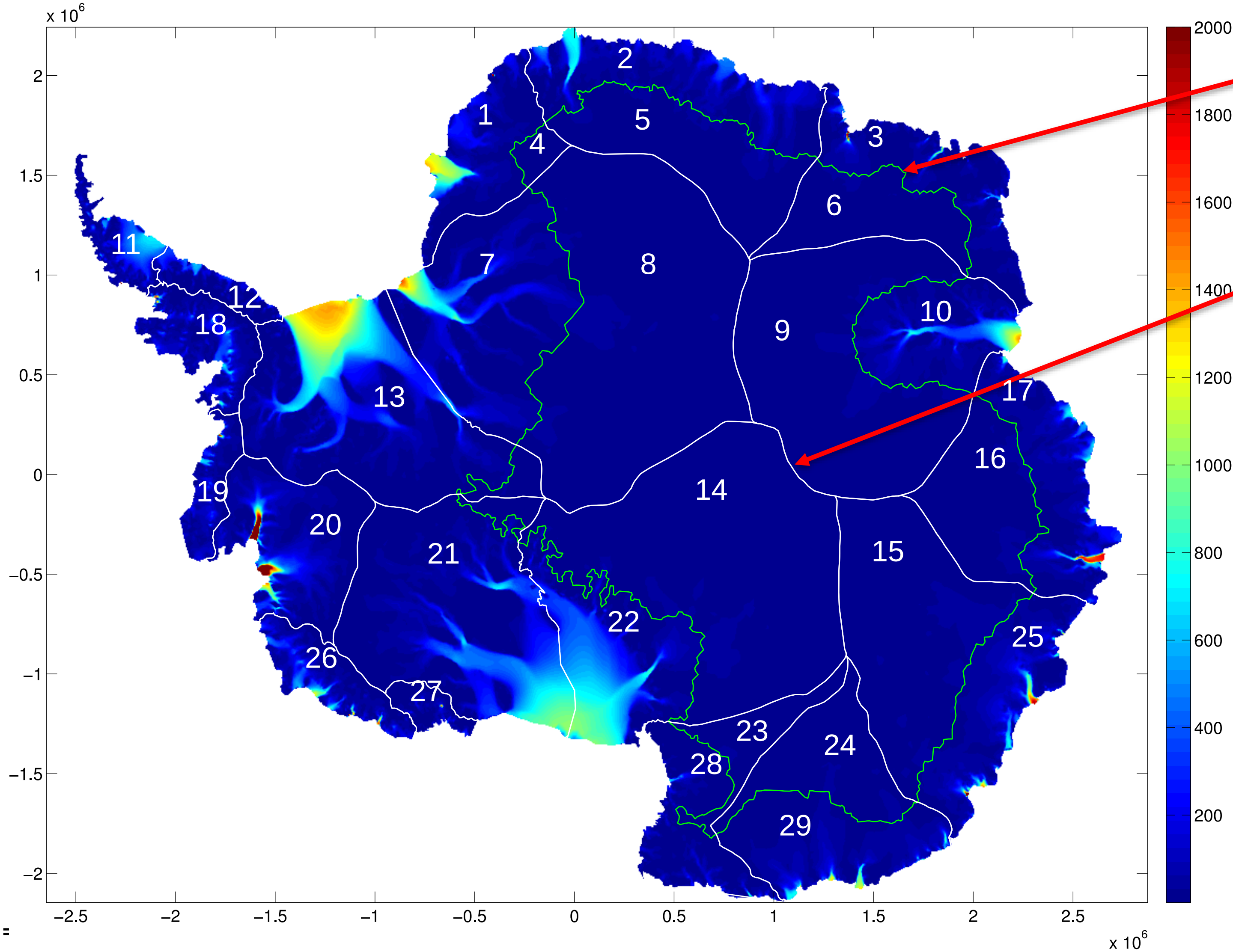
“Smart” Partitions



Climate split ~@2km based boundary

Drainage basin based boundary

Single Partition vs Smart Partitioning

- General effect is to **reduce the spread of sea level contribution** since now not all parts of AIS are assumed to have the same parameter values