Simulating the Greenland Ice sheet over two glacial cycles:

Sensitivity to sub-shelf melting and relative sea level

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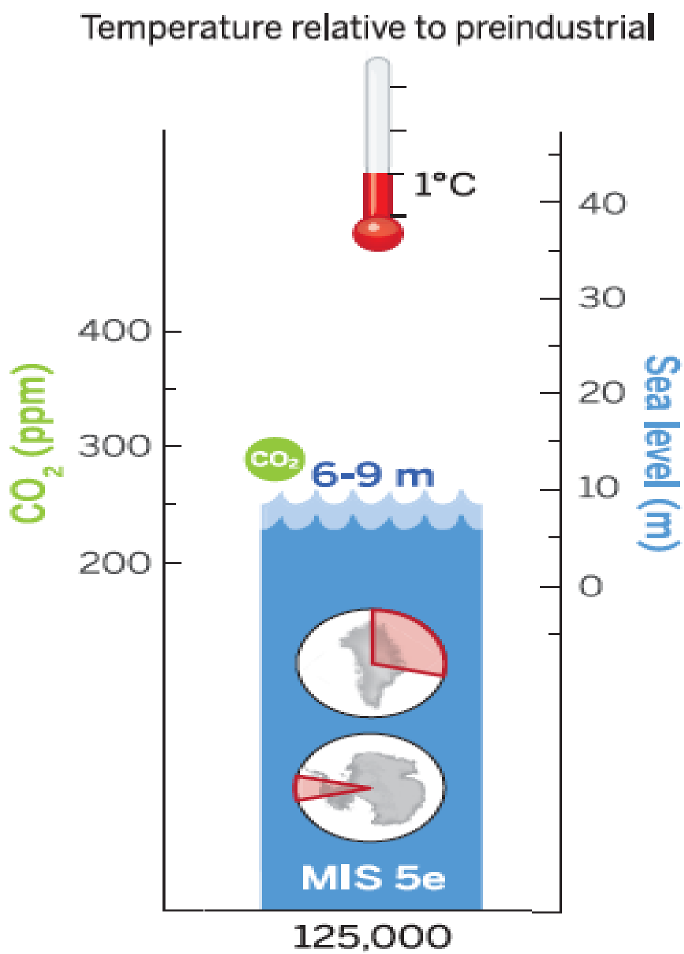
Aim 1: GrIS contribution to Eustatic Sea Level

Last Interglacial

GrIS: 0.6-3.5m



Dutton et al,Science, 2015

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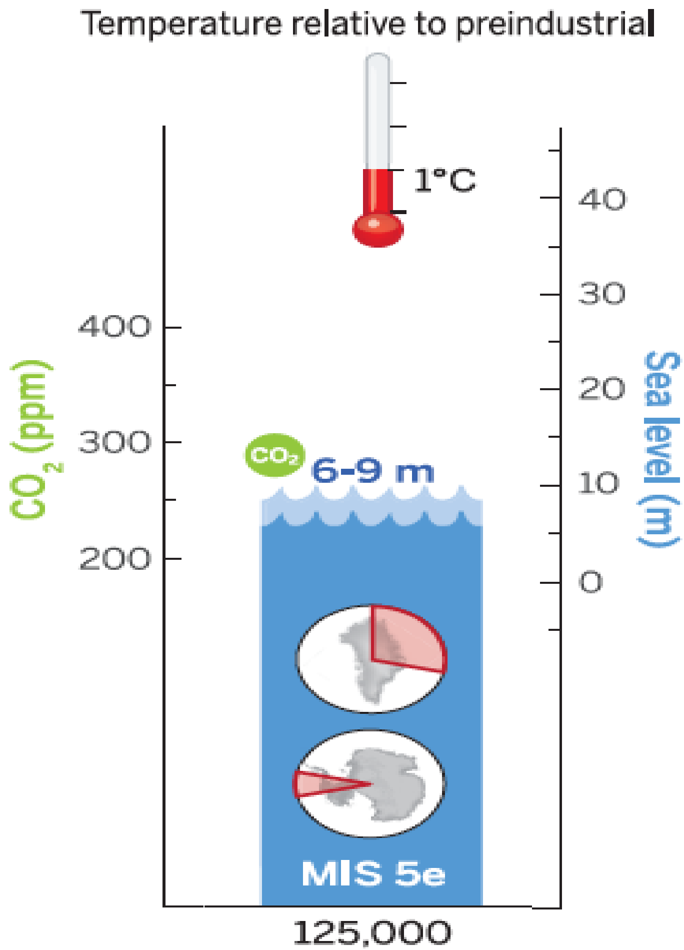
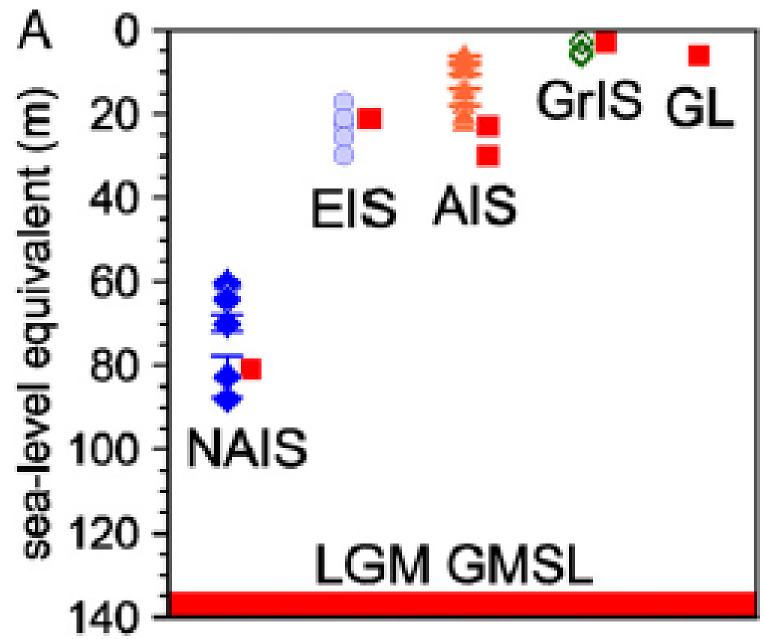


Dutton et al,Science, 2015

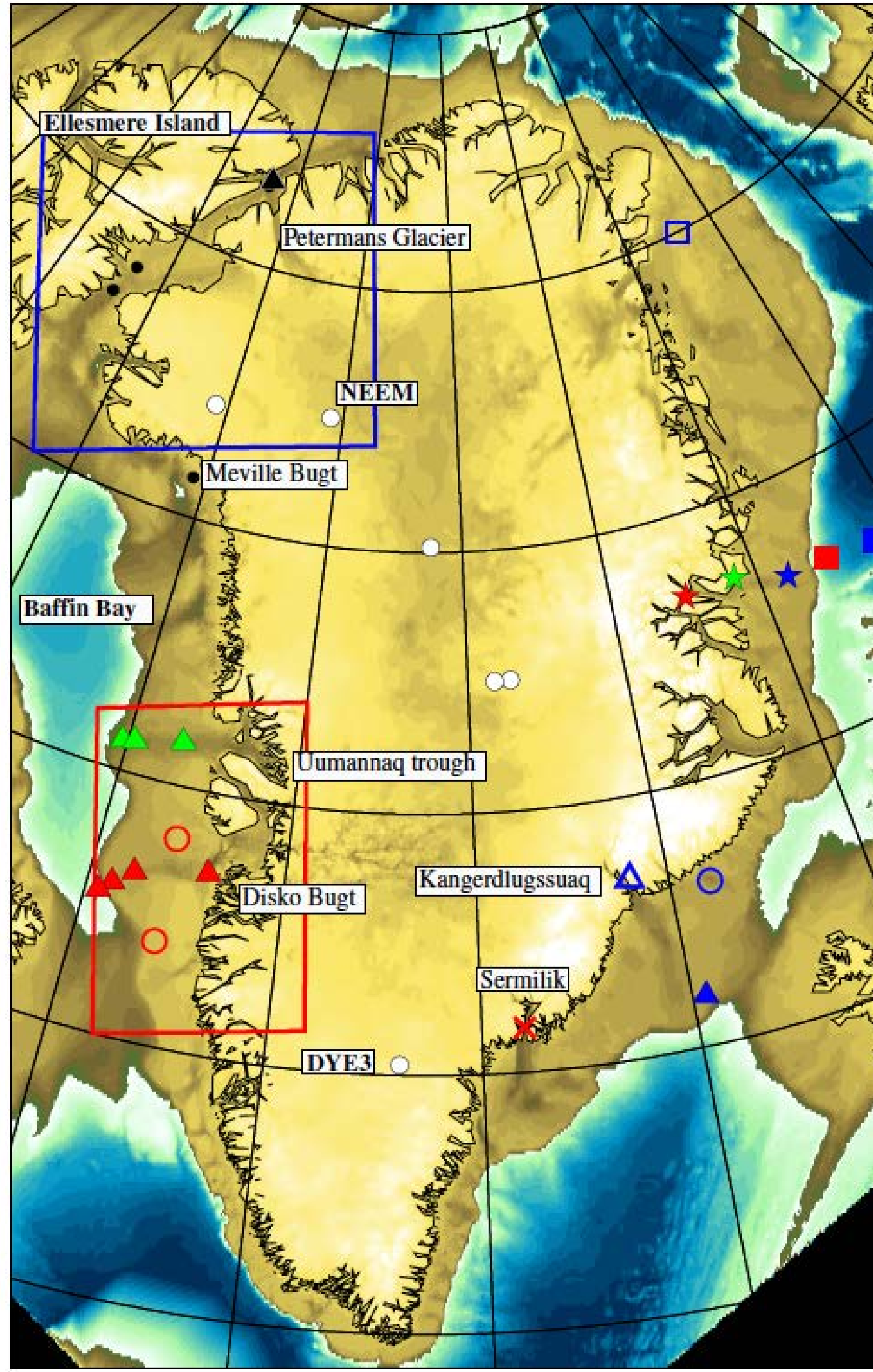
Last Glacial Maximum



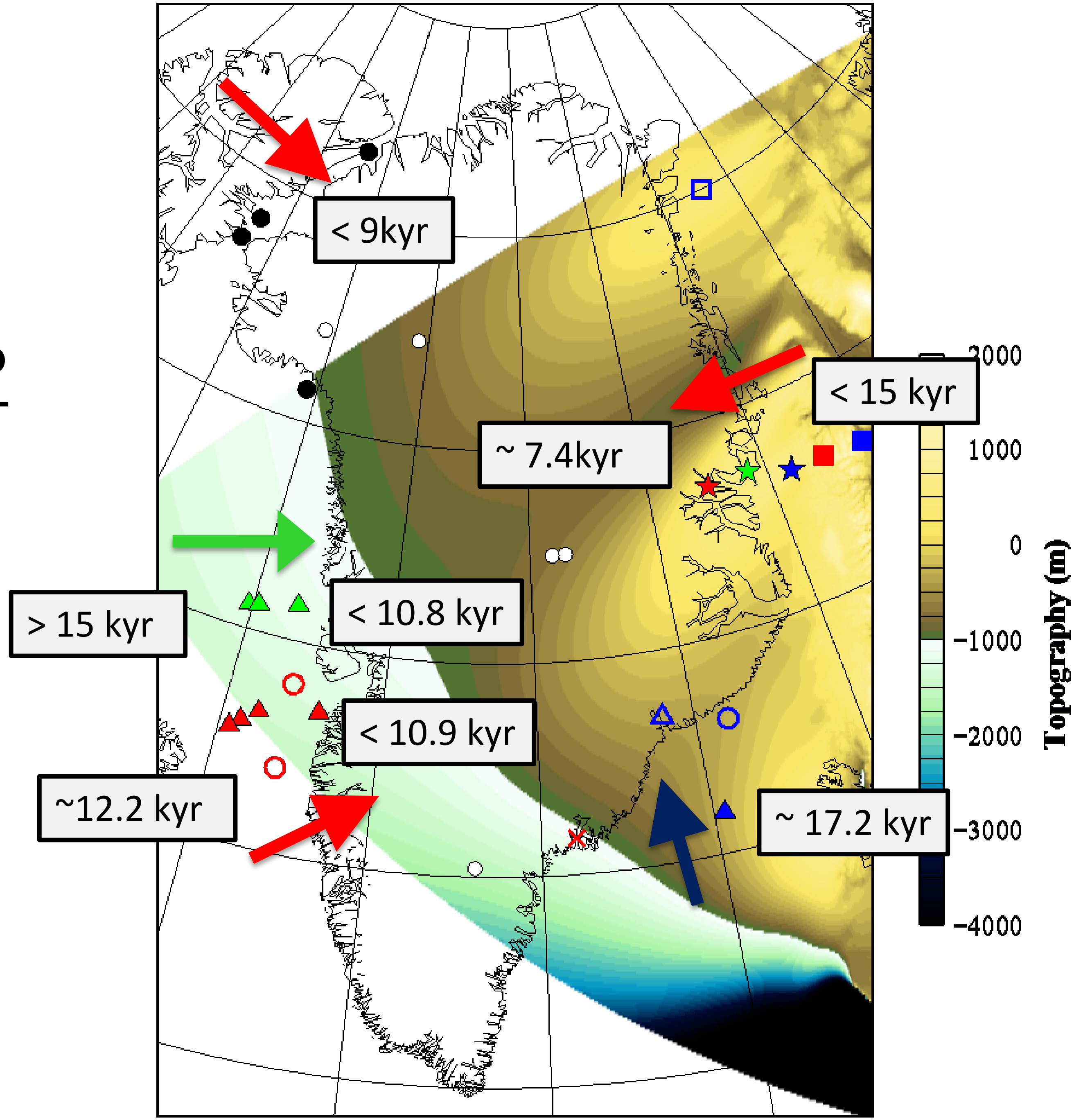
GrIS: 5m

Clark +Tarasov,PNAS, 2014

Aim 2: How large was the sheet at glacial maximum?



Aim 3: When did the Ice sheet retreat?



Method

- Use a SIA-SSA Ice sheet model 'IMAU-ICE'
- Simulate the GrIS from 238 kyr BP to PD

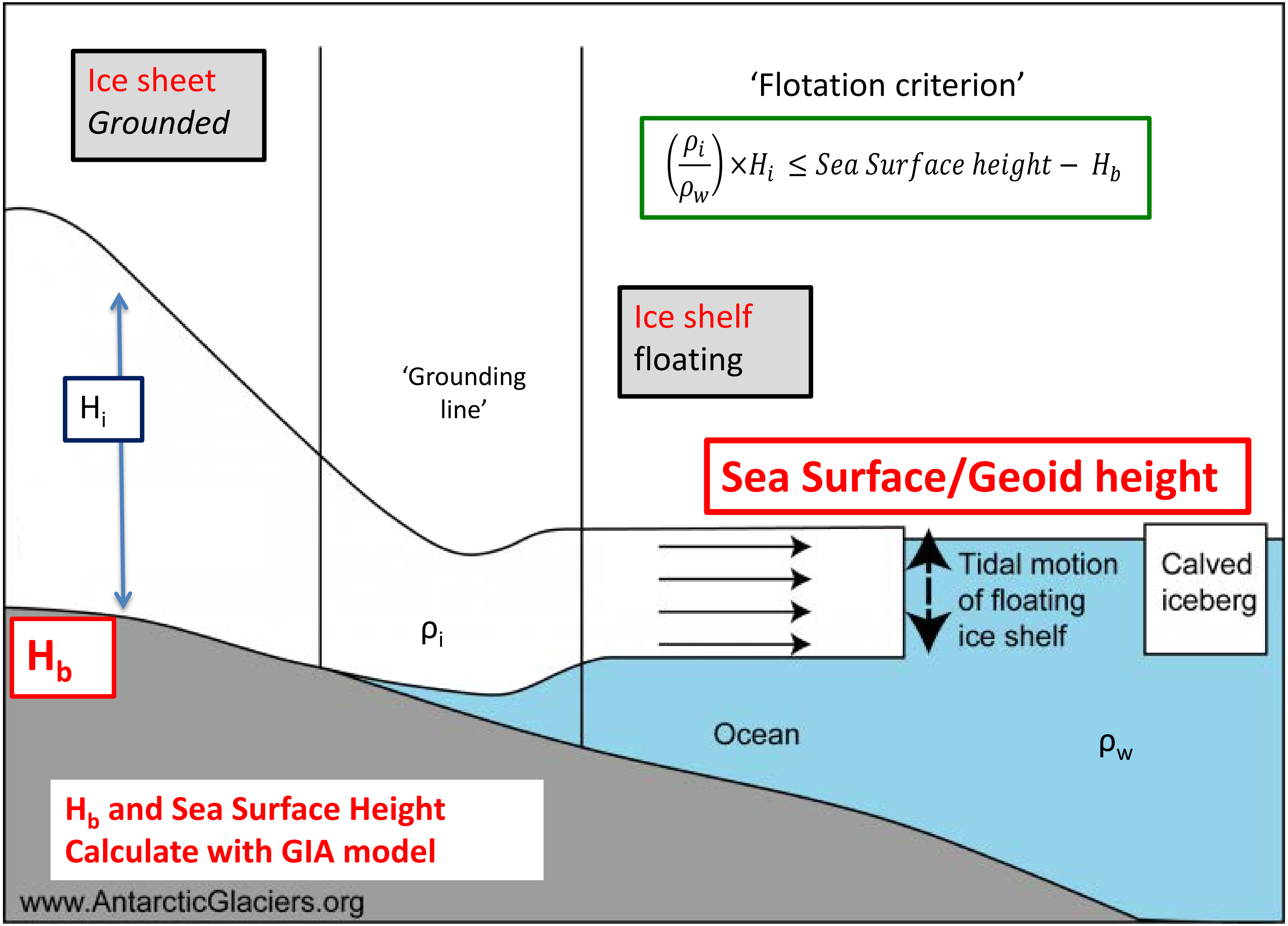
Investigate

- parameterisation for sub shelf melting related to changes in palaeo water depth
- Offline RSL forcing – GIA model – palaeo water depth

- Suite of ~ 300 simulations
- 11 final viable combinations

Can we address the 3 proposed questions

Background: Ice sheet – Ice shelf model



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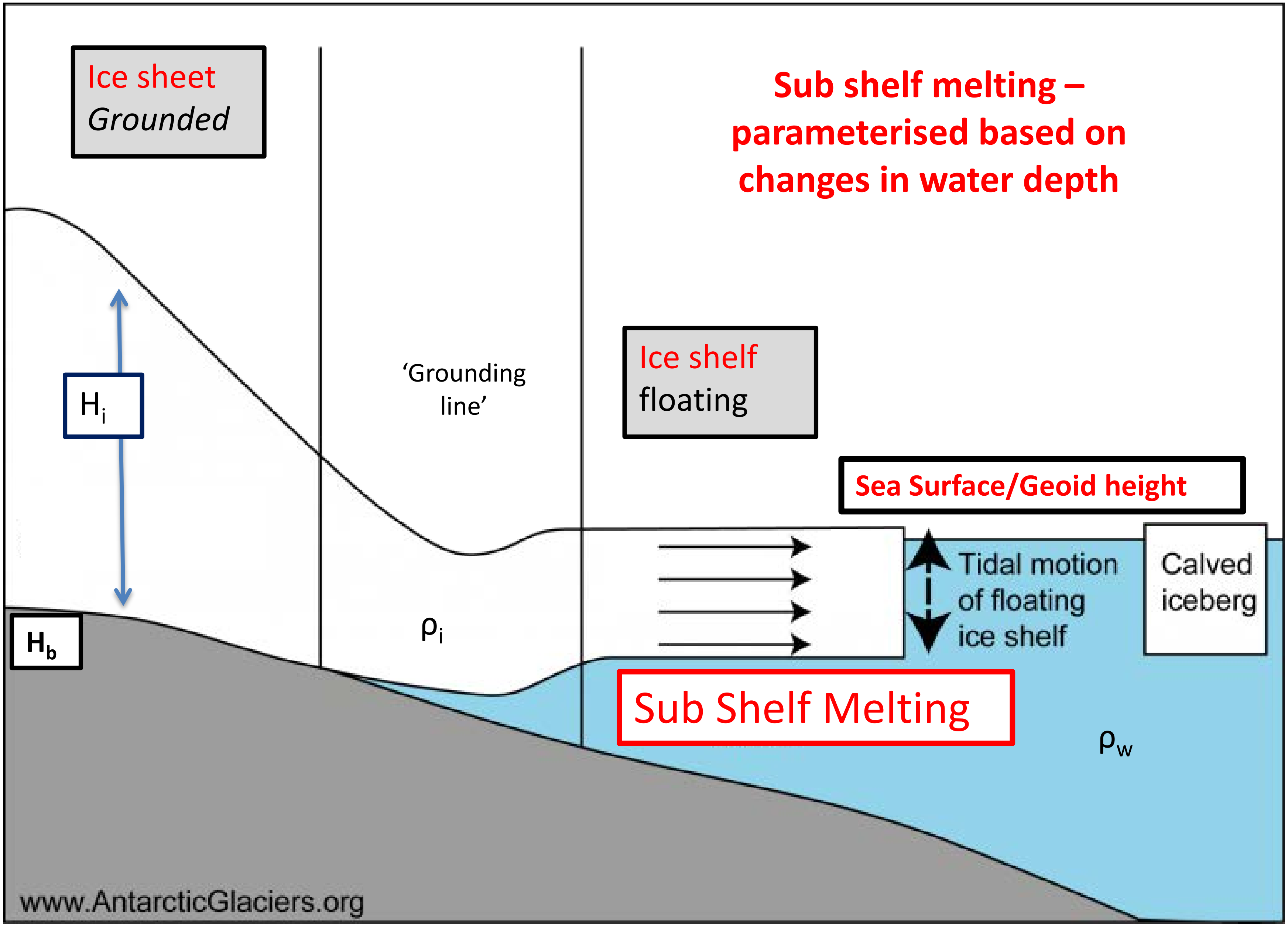
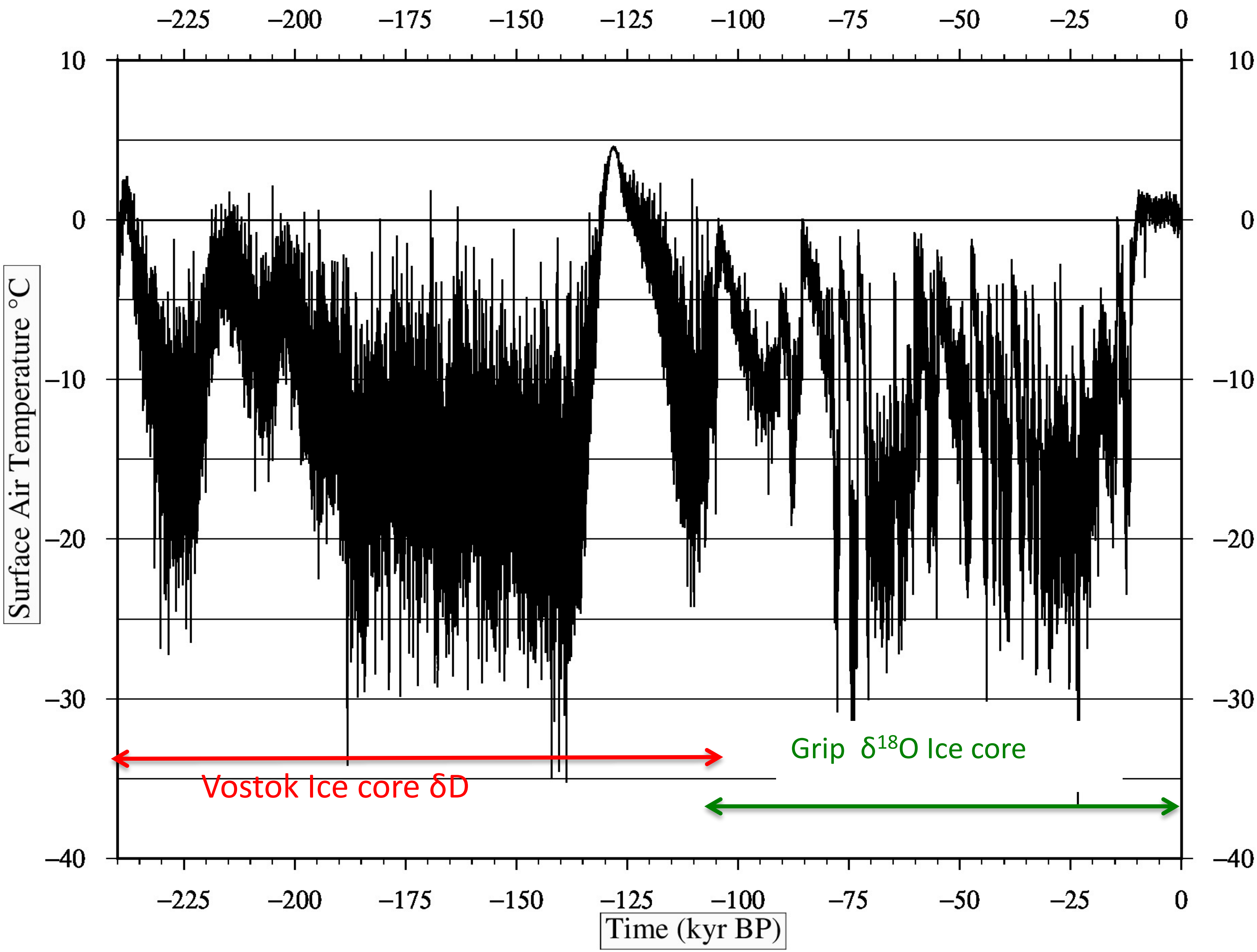


General model setup



General model setup

→ **Input** topography and ice sheet thickness – *Bamber et al,2013*

→ **Input** Climate parameters – adapted from the Racmo2 dataset

→ **Surface Air Temperature Forcing** - *Helsen et al,2013*

- Ran 20x20km
- Each simulation ran for 100 kyr to reach equilibrium: match to present day observations
- SMB – influence of topo on SMB - SMB-gradient method *Helsen et al,2013*

- 'Weertman-type sliding law' relates ν_b - basal velocity to τ_b^p basal shear stress

$$\nu_b = A_s \frac{\tau_b^p}{Z^q}$$

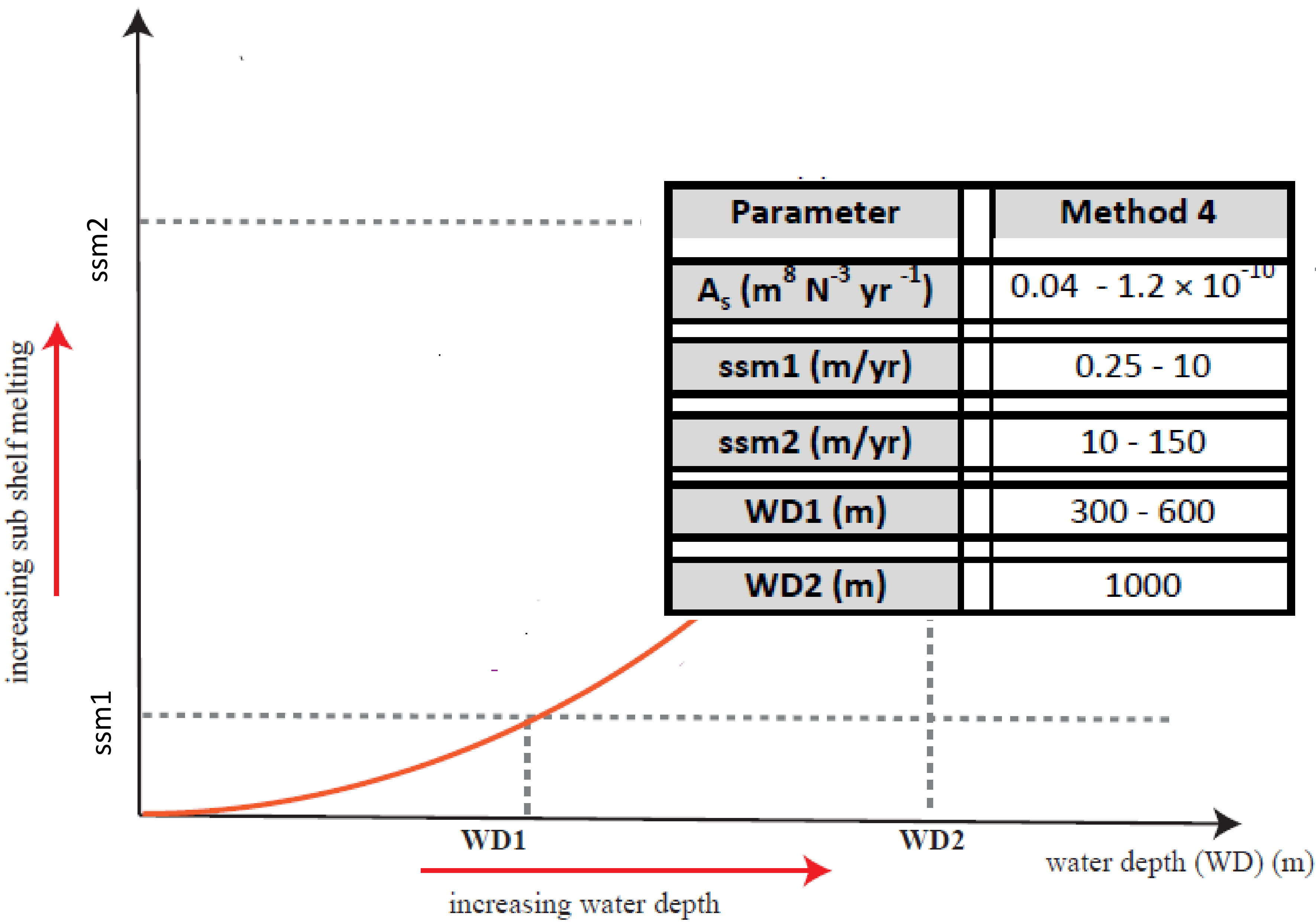
A_s : 0.04 $\times 10^{-10}$ and 1.8 $\times 10^{-10}$ $m^8 N^{-3} yr^{-1}$.

Sub Shelf Melt Parameterisation

- Looked into four different parameterisation

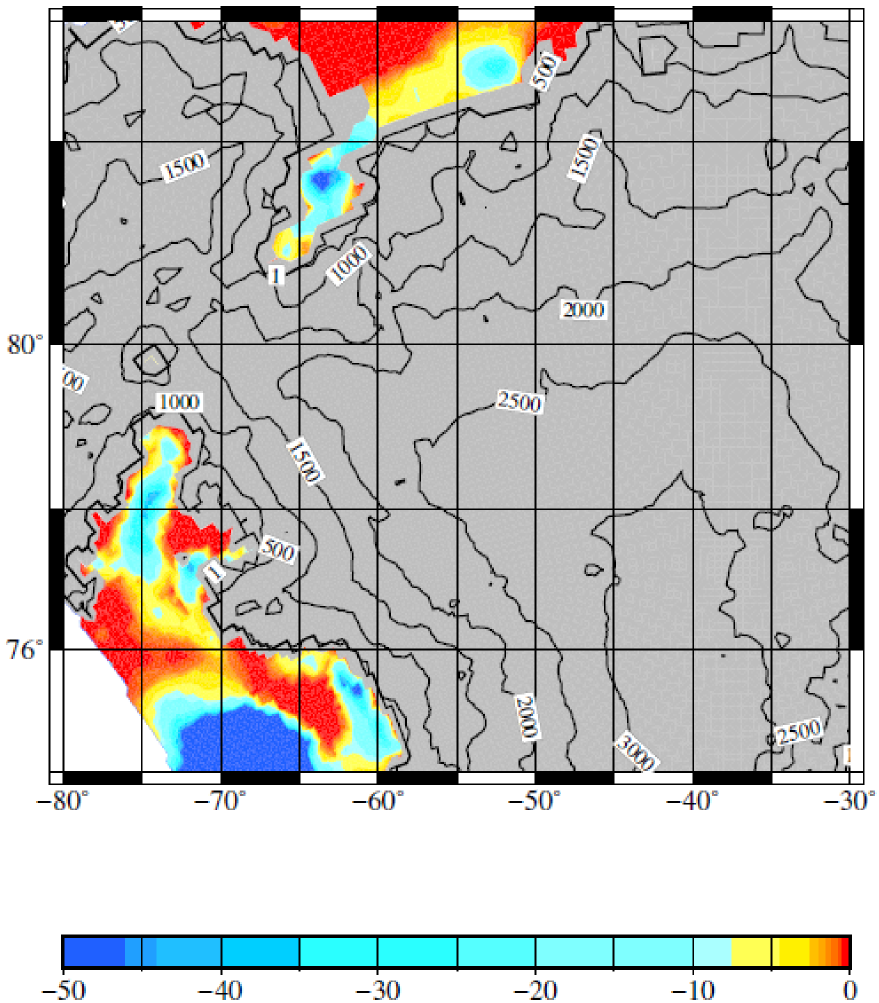
- Increase in palaeo water depth – increase in ssm

Method 4: Exponential ssm

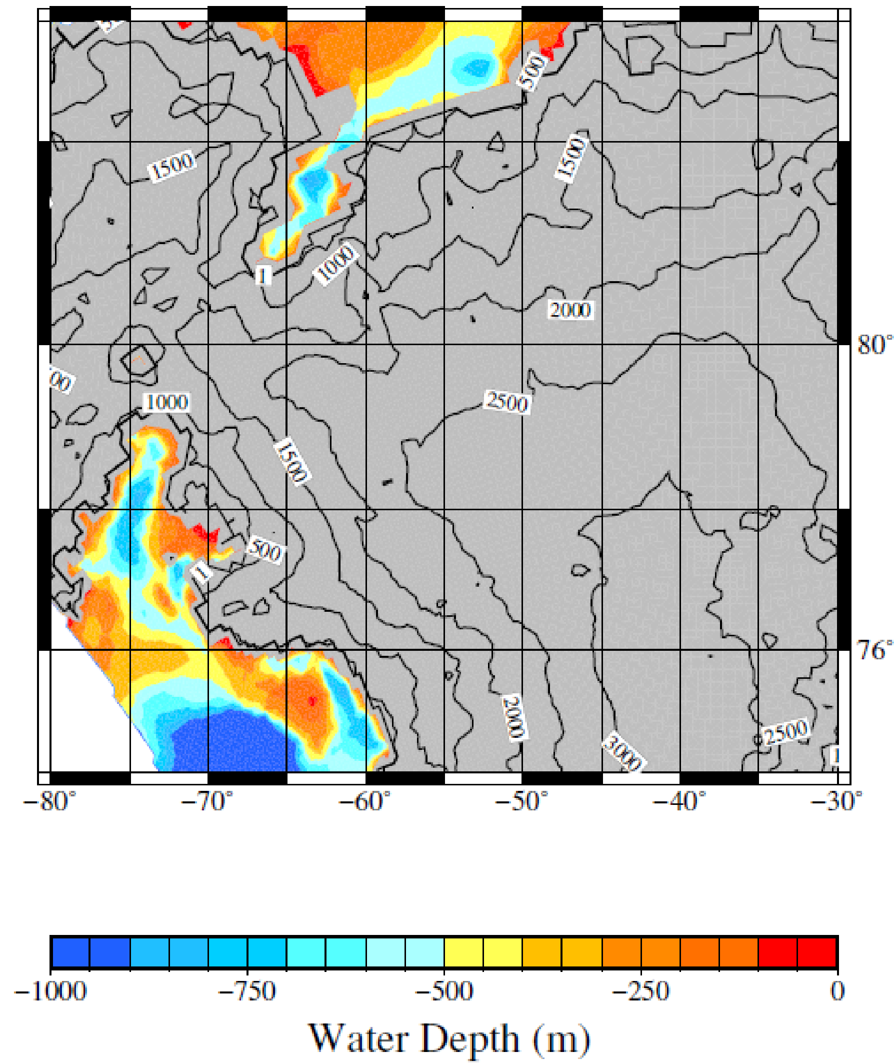


Parameter	Method 4
A_s ($m^8\ N^{-3}\ yr^{-1}$)	$0.04 - 1.2 \times 10^{-10}$
ssm1 (m/yr)	0.25 - 10
ssm2 (m/yr)	10 - 150
WD1 (m)	300 - 600
WD2 (m)	1000

Method 4: Exponential ssm

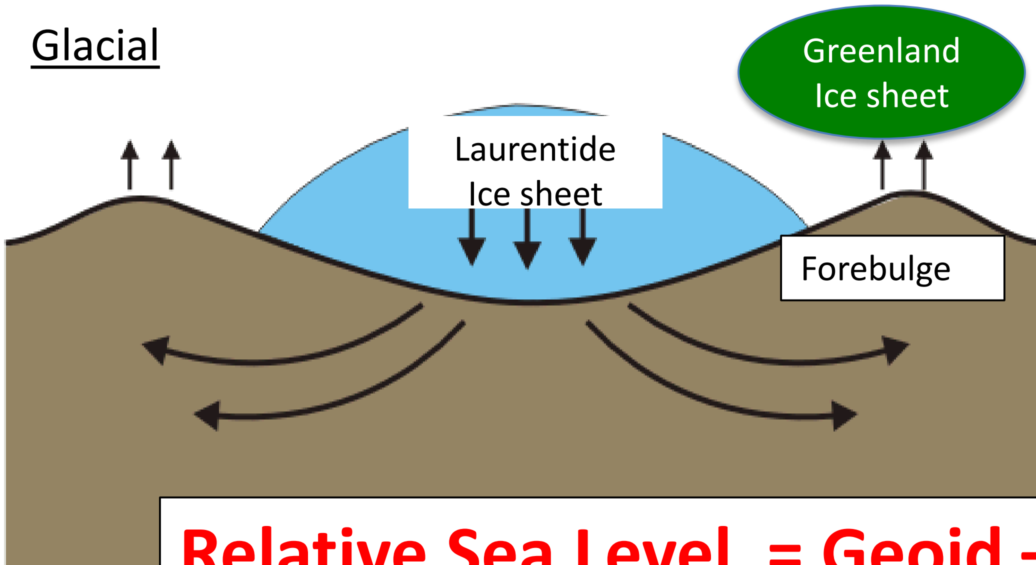


Sub shelf melting (m/yr)



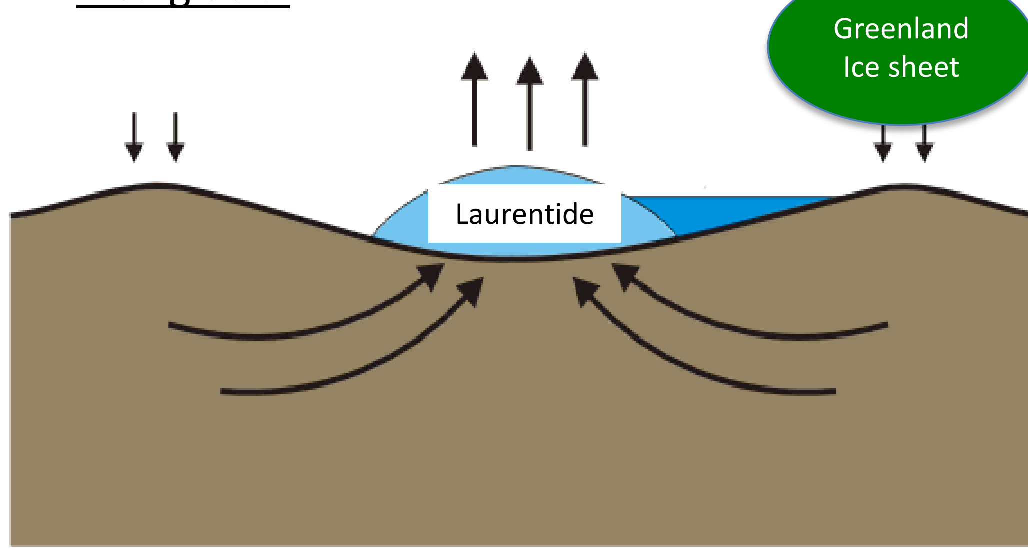
Relative Sea Level forcing

Glacial



Relative Sea Level = Geoid – Solid Earth

Interglacial



Relative Sea Level forcing

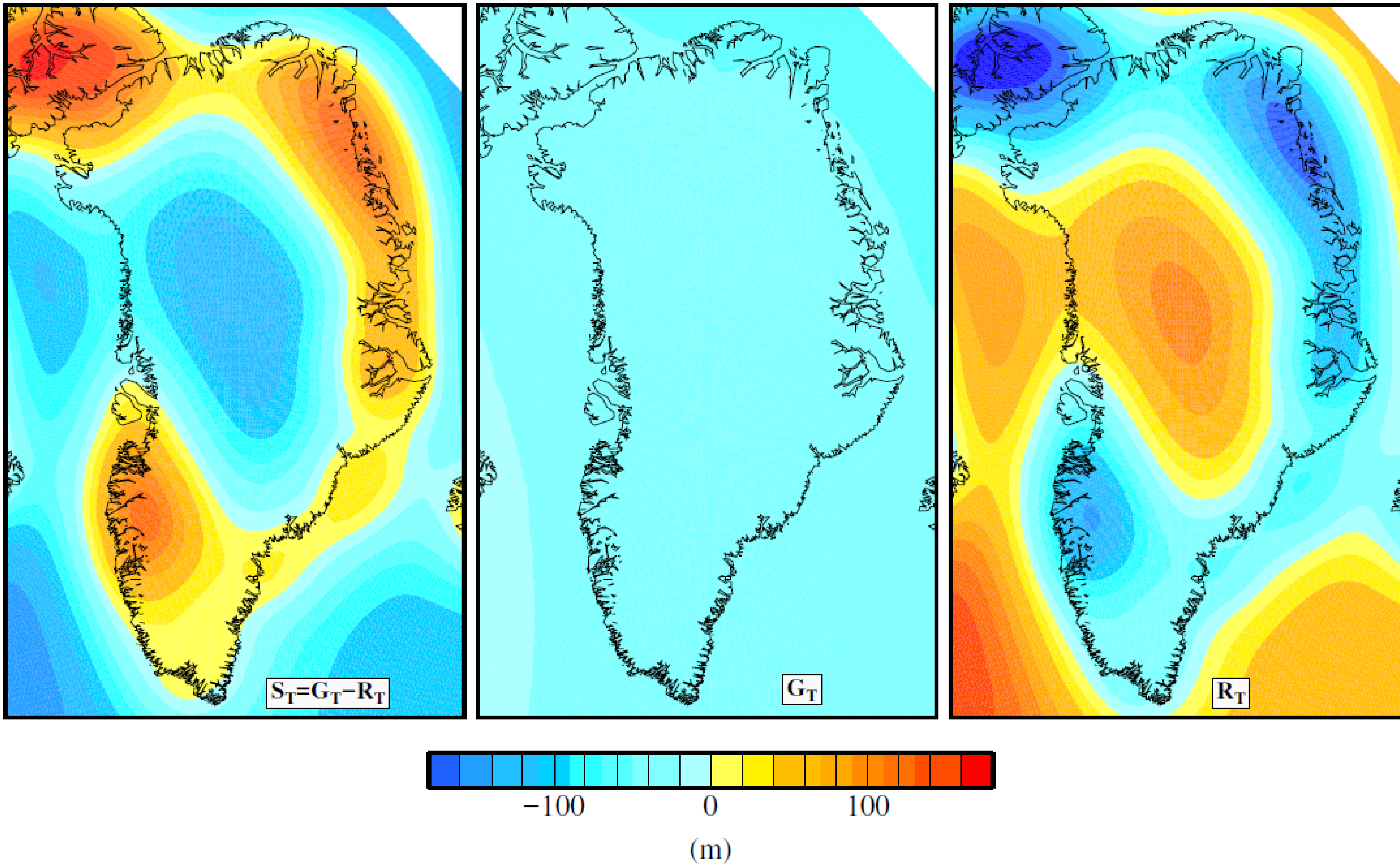
$$S(\theta, \psi, t) = G_T\,(\theta, \psi, t) - R_T\,(\theta, \psi, t)$$

$G_T\,(\theta, \psi, t)$ Vertical perturbation of the geoid

$R_T\,(\theta, \psi, t)$ Vertical perturbation of the solid earth surface

Relative Sea Level = Sea Surface – Solid Earth

Total Signal



Relative Sea Level forcing

$$S(\theta,\psi,t) = \left(G_L\,(\theta,\psi,t) + G_{NL}\,(\theta,\psi,t)\right) - \ (R_L\,(\theta,\psi,t) + R_{NL}\,(\theta,\psi,t))$$

Separate into:

- LOCAL component - due to GrIS

$$G_L(\theta,\psi,t) \qquad R_L(\theta,\psi,t)$$

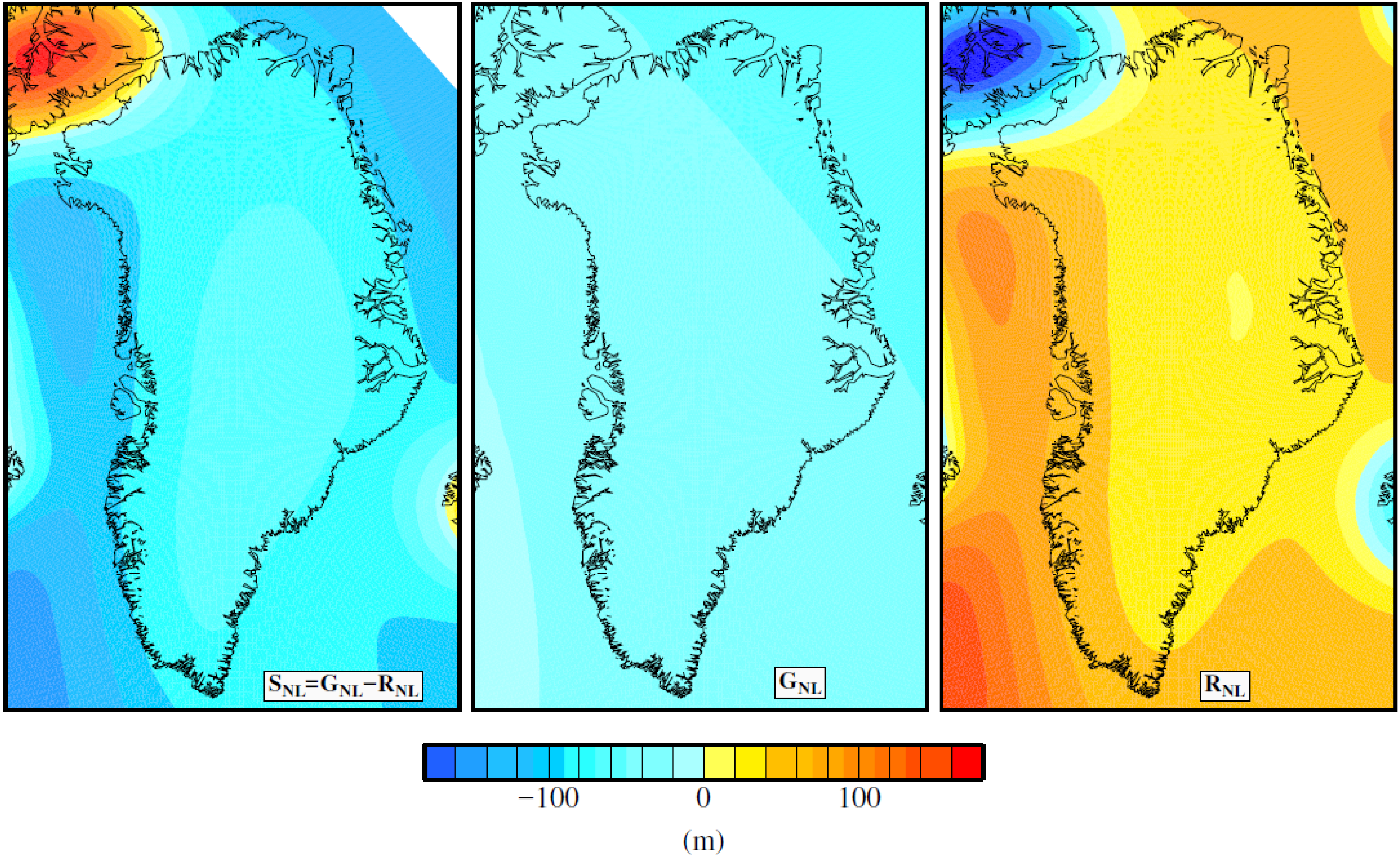
- NON-LOCAL component - primarily due to Laurentide Ice sheet

$$G_{NL}(\theta,\psi,t) \qquad R_{NL}(\theta,\psi,t)$$

- To calculate the NON-LOCAL component – use GIA model

Relative Sea Level = Sea Surface – Solid Earth

Non – Local



Relative Sea Level forcing

$$S(\theta,\psi,t) = \left(G_L\,(\theta,\psi,t) + G_{NL}\,(\theta,\psi,t)\right) - \,(R_L\,(\theta,\psi,t) + R_{NL}\,(\theta,\psi,t))$$

- NON-LOCAL – derived from GIA model

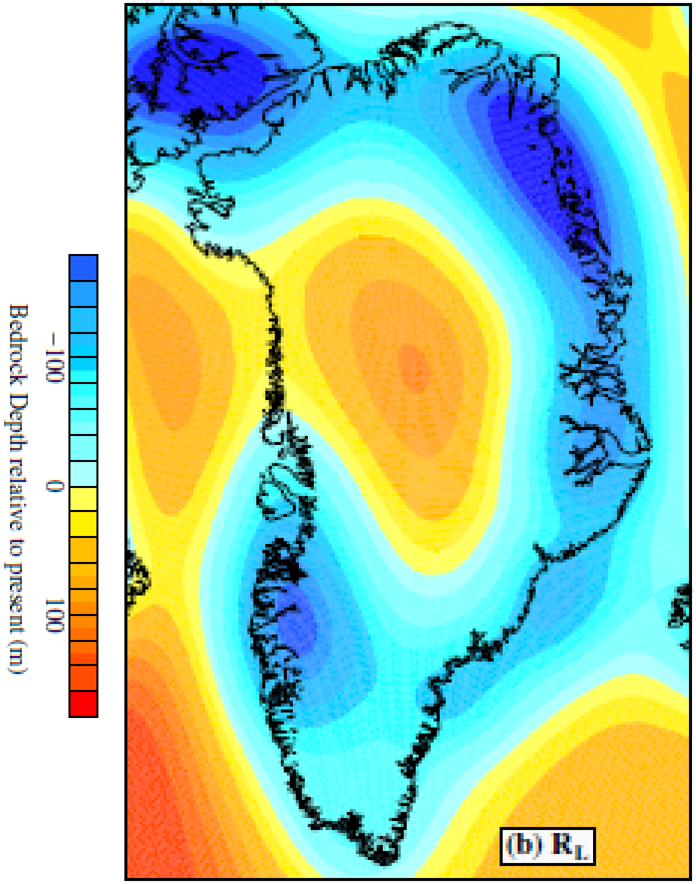
- LOCAL component - GrIS == IMAU-ICE model

$$G_L(\theta,\psi,t) \qquad R_L(\theta,\psi,t)$$

Relative Sea Level forcing

For the LOCAL signal: IMAU-ICE: calculate $R_L(\theta,\psi,t)$ - ‘ELRA’ method.

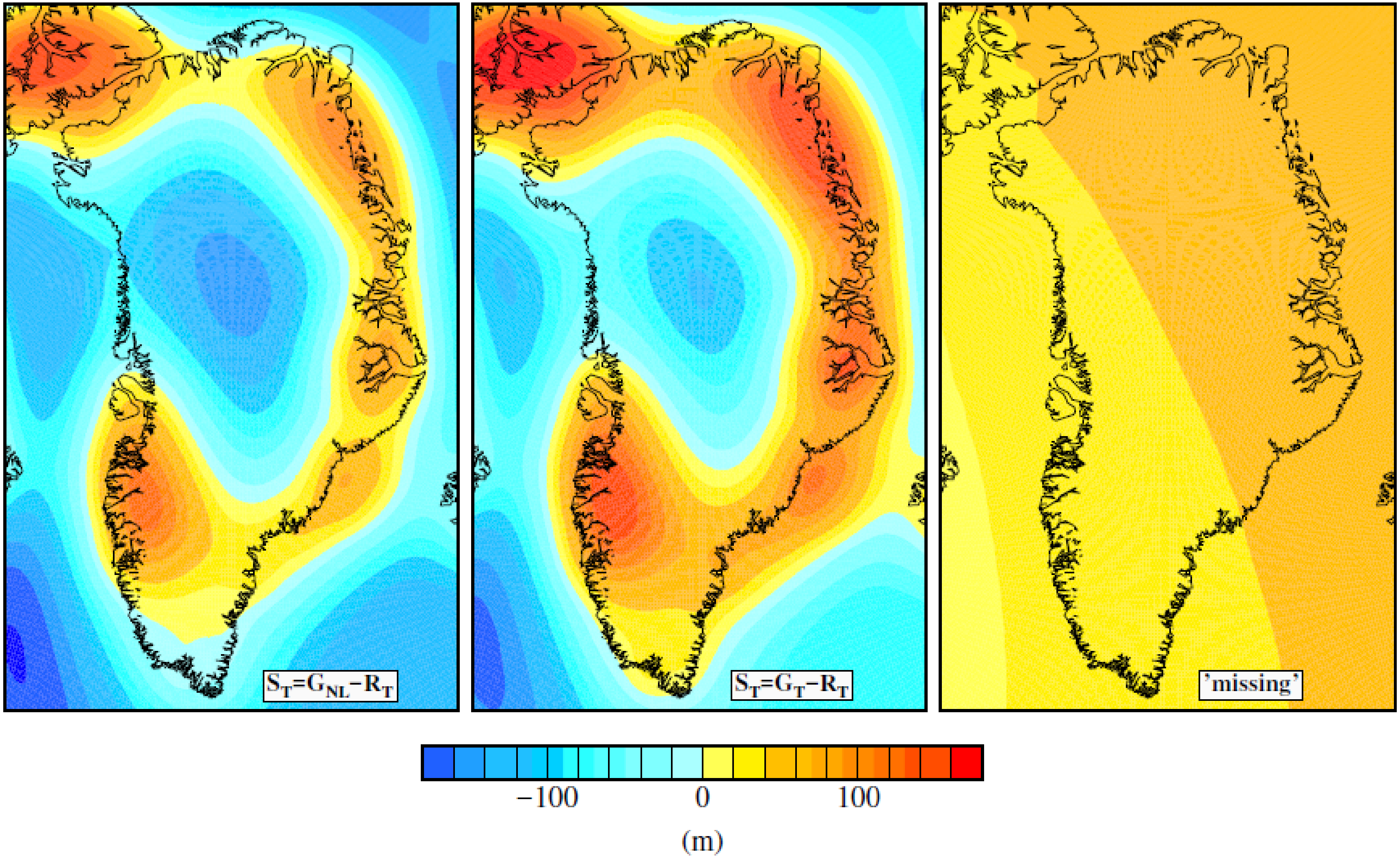
$$S(\theta,\psi,t) = \left(G_{NL}\,(\theta,\psi,t)\right) - \left(R_L\,(\theta,\psi,t) + R_{NL}\,(\theta,\psi,t)\right)$$



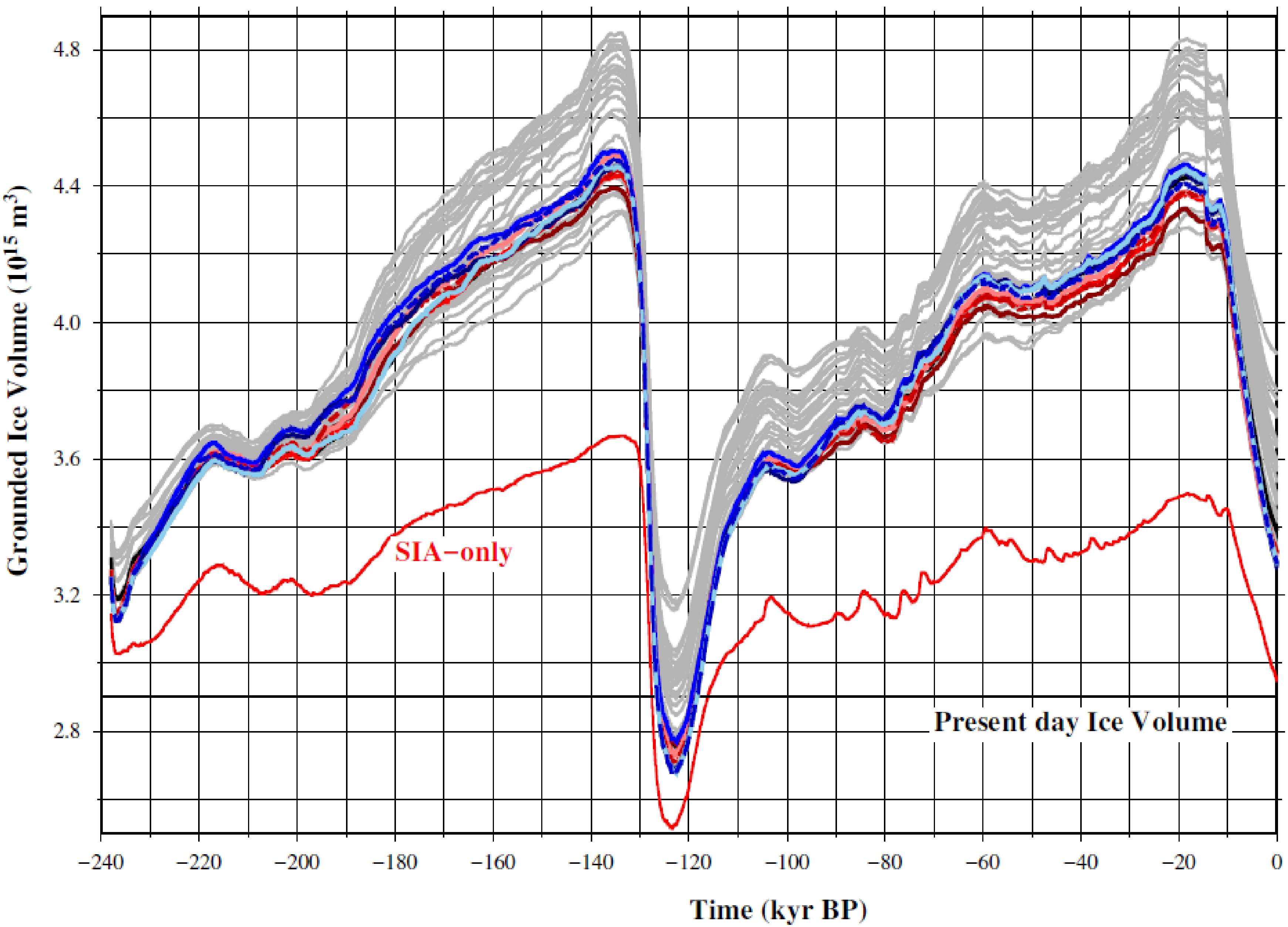
- Still missing the LOCAL Geoid signal
- No mechanism in IMAU-ICE to calculate

Relative Sea Level forcing:

$$S(\theta,\psi,t) = \left(G_{NL}(\theta,\psi,t)\right) - \left(R_L(\theta,\psi,t) + R_{NL}(\theta,\psi,t)\right)$$

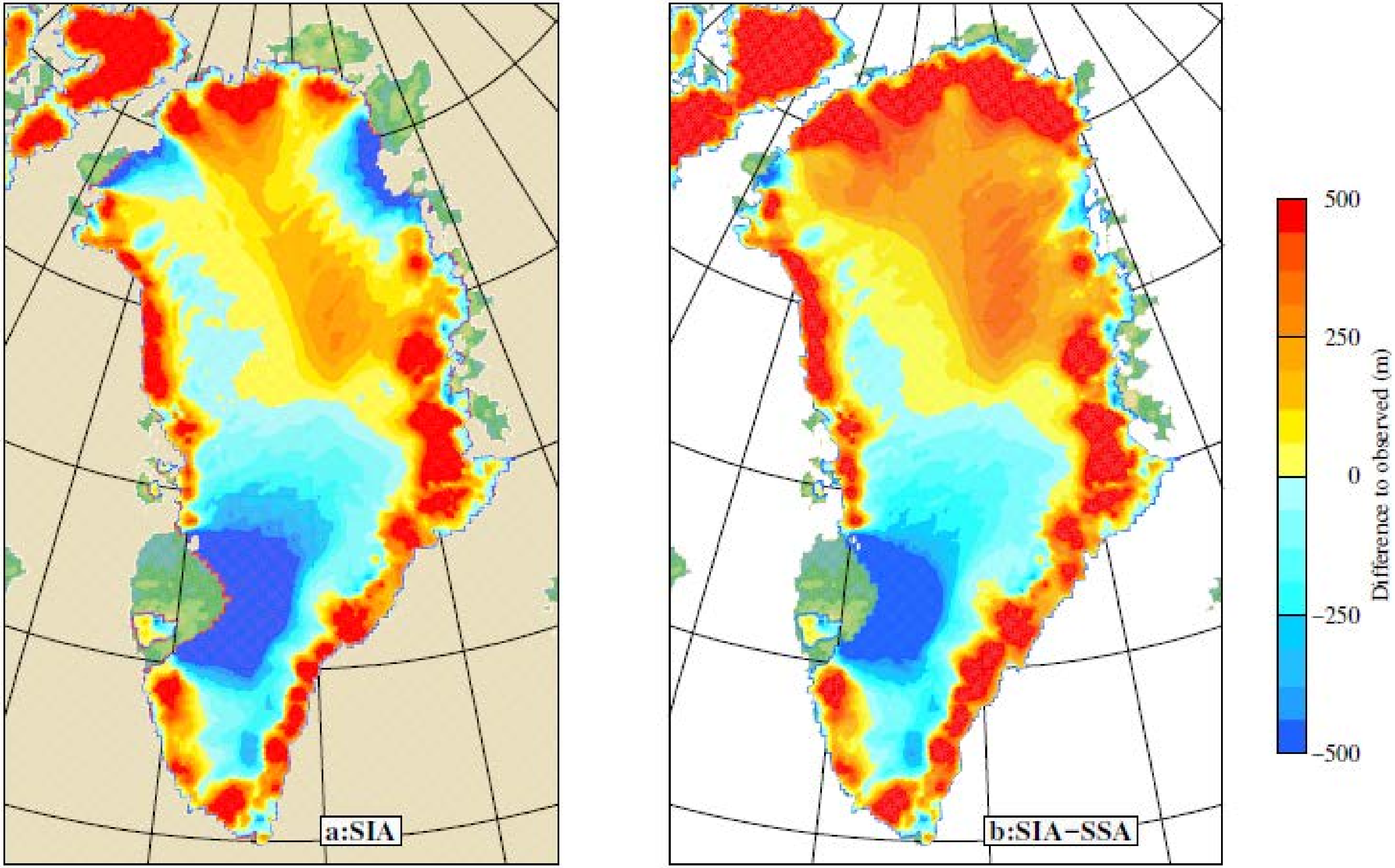


Results

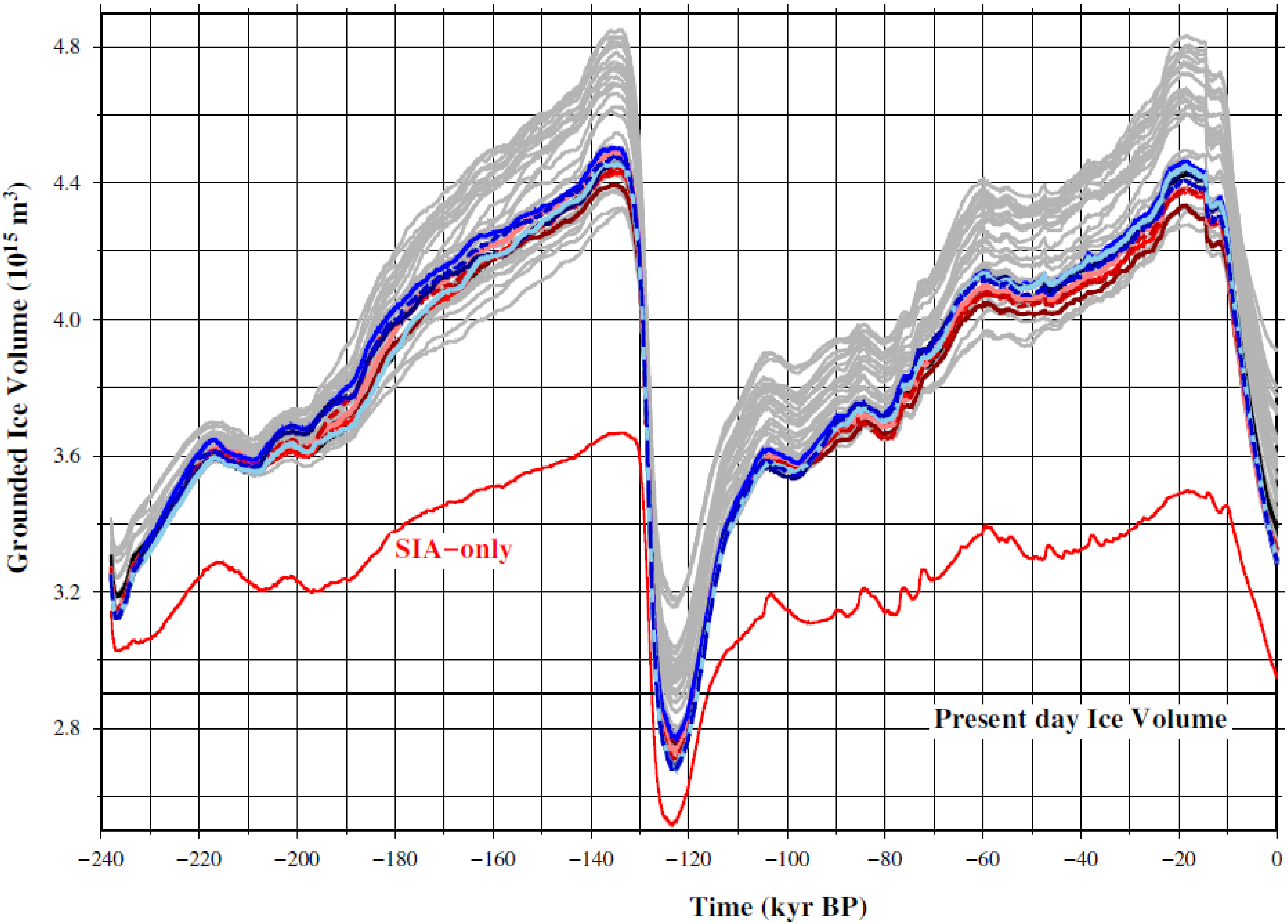


Grounded Ice Volume (10^{15} m^3)
4.8
4.4
4.0
3.6
3.2
2.8
SIA−only
Present day Ice Volume
−240
−220
−200
−180
−160
−140
−120
−100
−80
−60
−40
−20
0
Time (kyr BP)

Results: Present day extent



Results:



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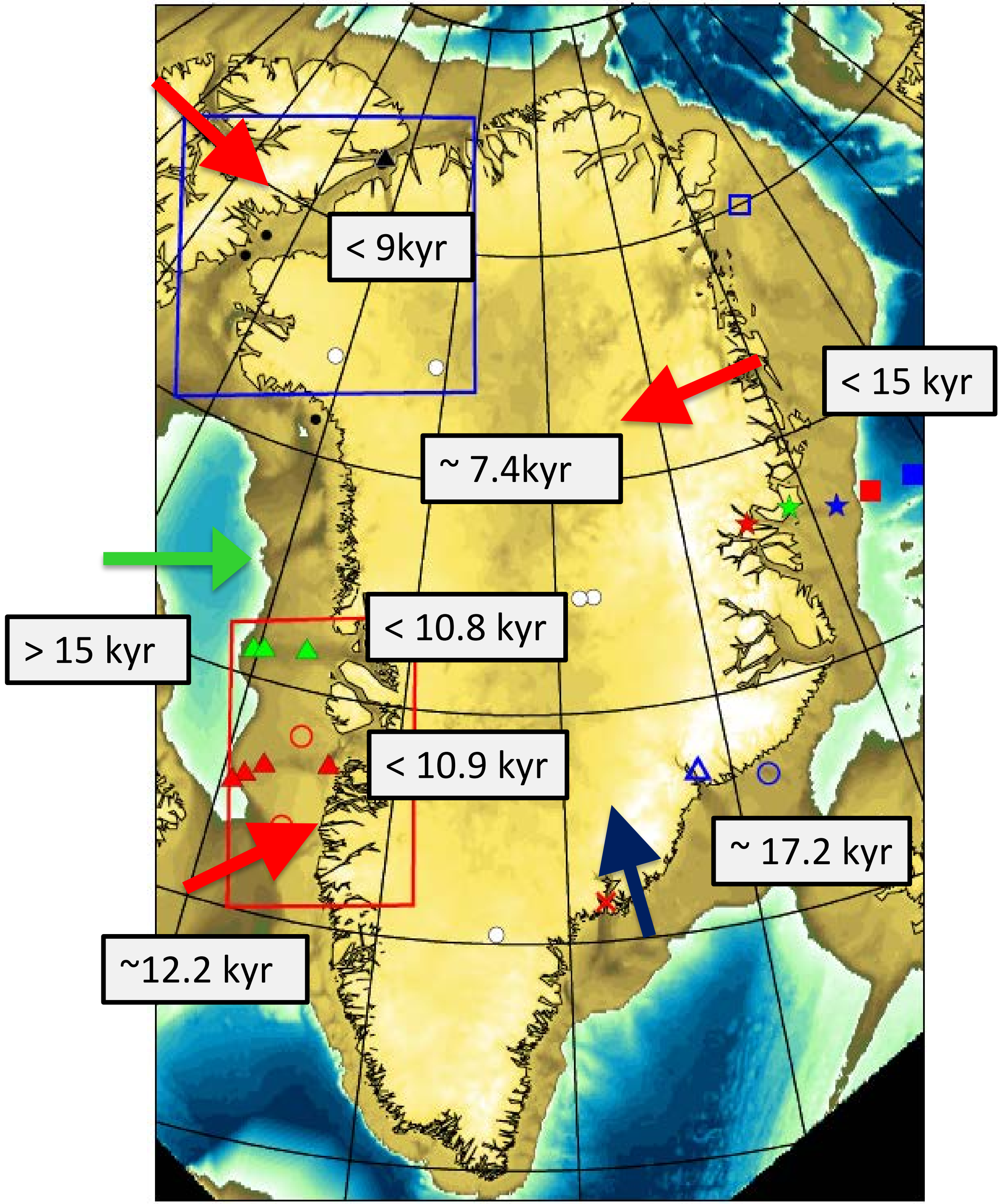
Recap:

Aim 2: How large was the sheet at glacial maximum?

Aim 3: When did the Ice sheet retreat?



Results

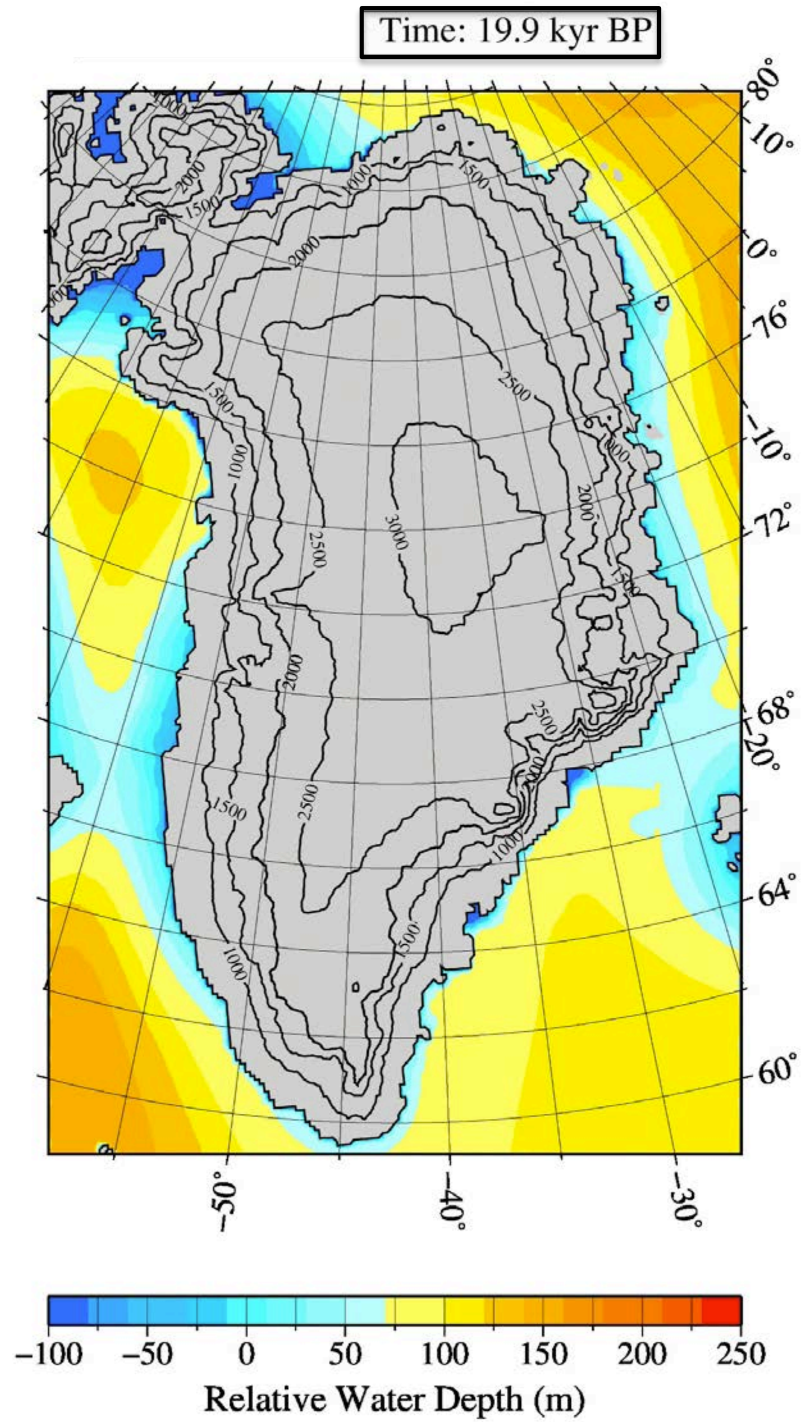
- **LGM IV**: 2.61m
- **PD IV**: 3.31×10^{15} m^2
- 19.9 to 14.9 minimal change

South

- Retreat – readvance – retreat
- Timings related to SAT

North

- One period of retreat
- Sensitive to choice of ssm
- Highly variable timings



Summary Points

- Reconstruct GrIS over two glacial cycles

Q1 – Eustatic Sea Level (ESL) contribution

- LIG ESL = 1.5m, decrease ~ 0.5m relative to SIA only
- LGM ESL = 2.6m, increase of 1.5 m

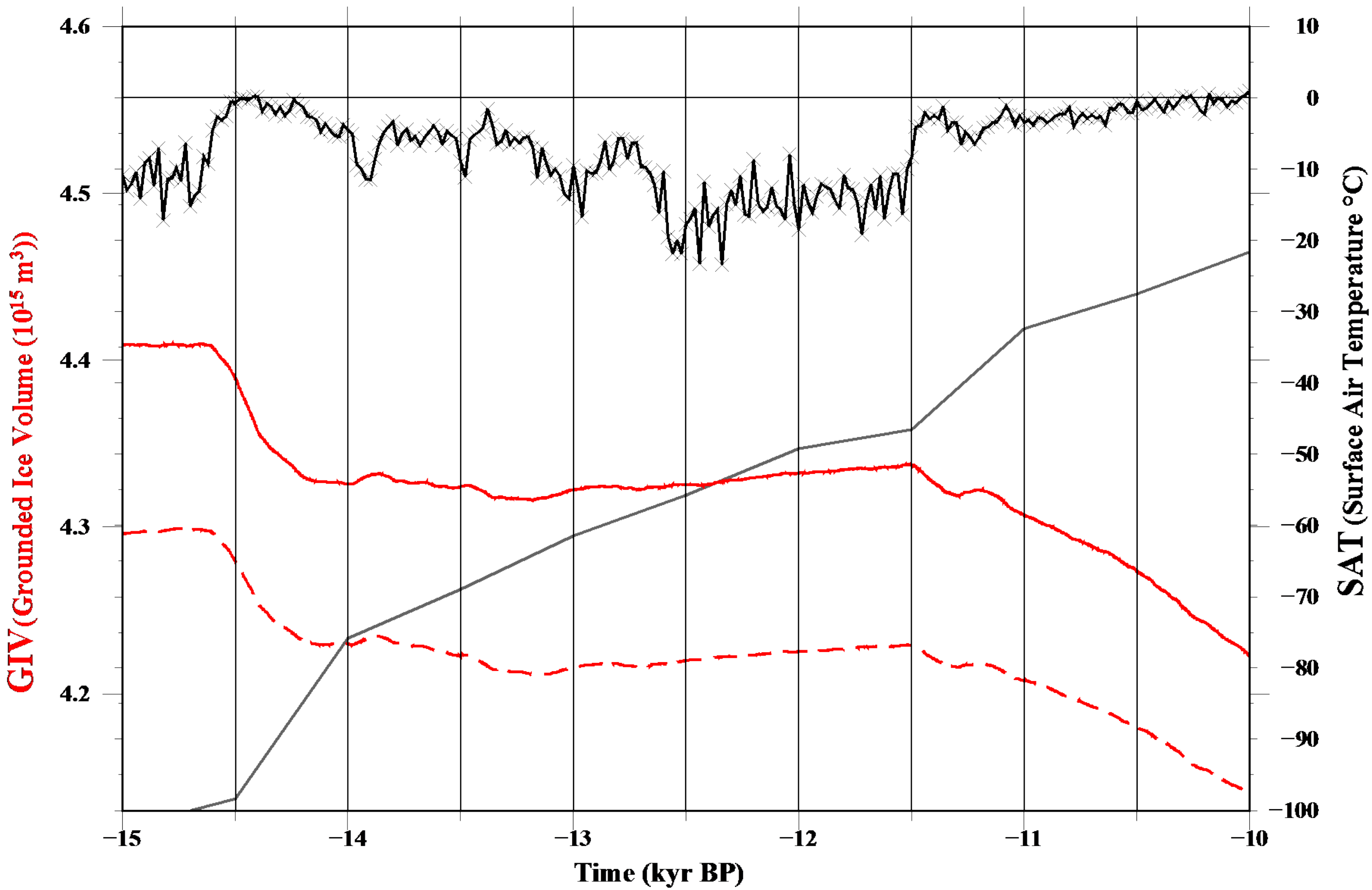
Q2 – Simulate a large GrIS

- Extends out onto continental shelf and across the Nares Strait
- Mismatch to the observations still remain

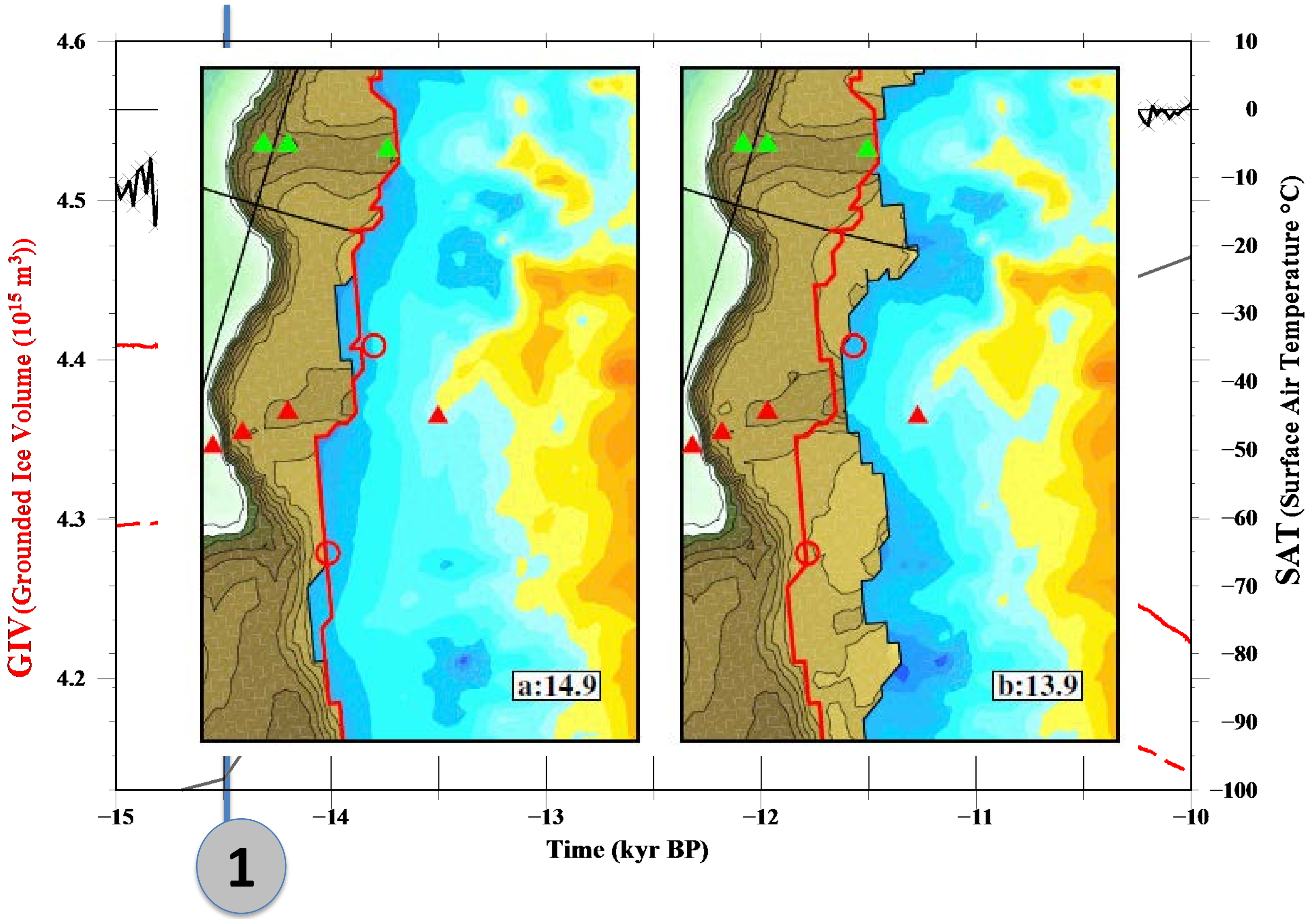
Q3 – Timing of Retreat

- SW Retreat – driven primarily by SAT, secondary ssm
- NW – retreat driven by RSL and ssm- sensitive to the timing of the LIS deglaciation

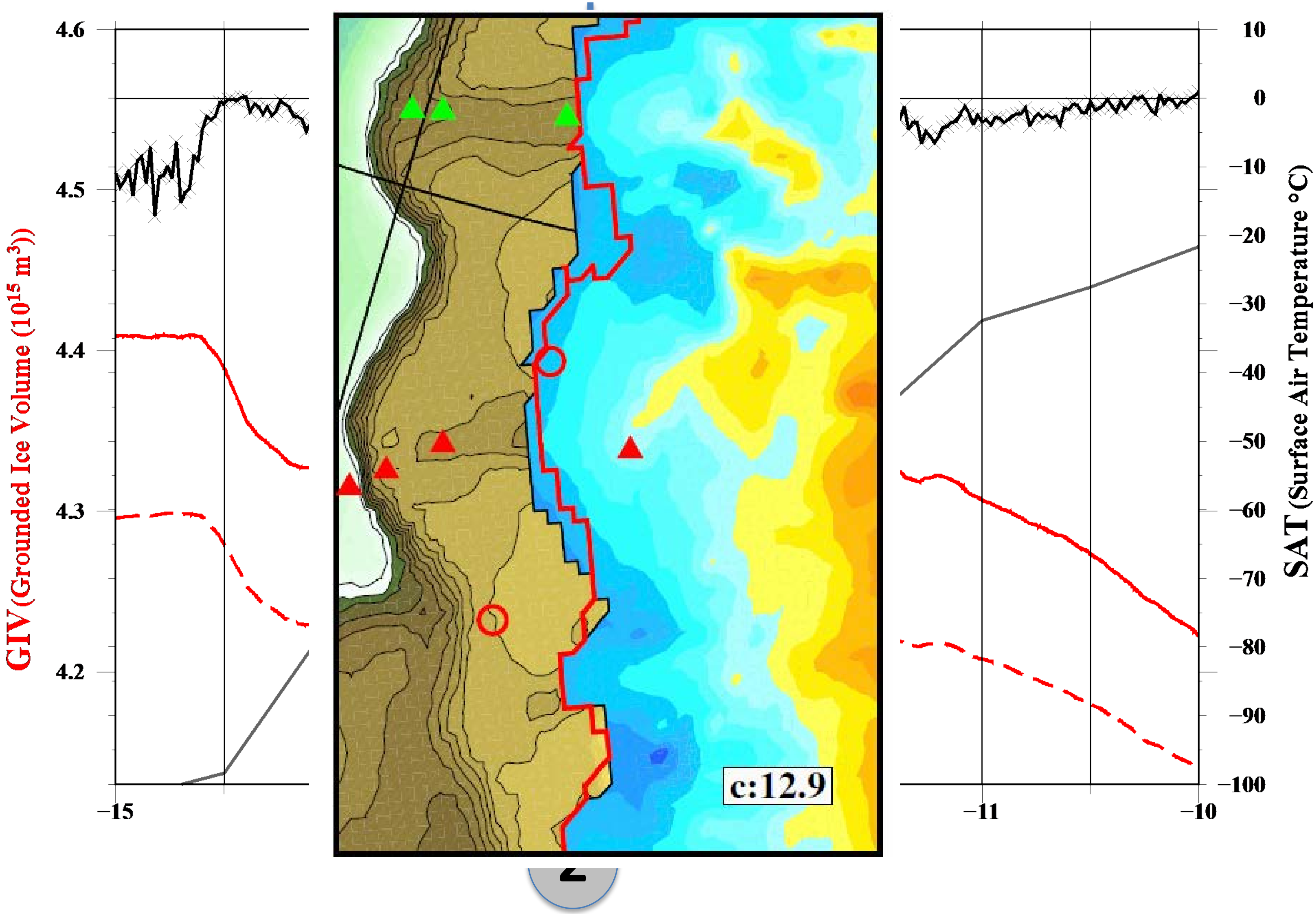
What drives the Spatial Variation in the retreat?



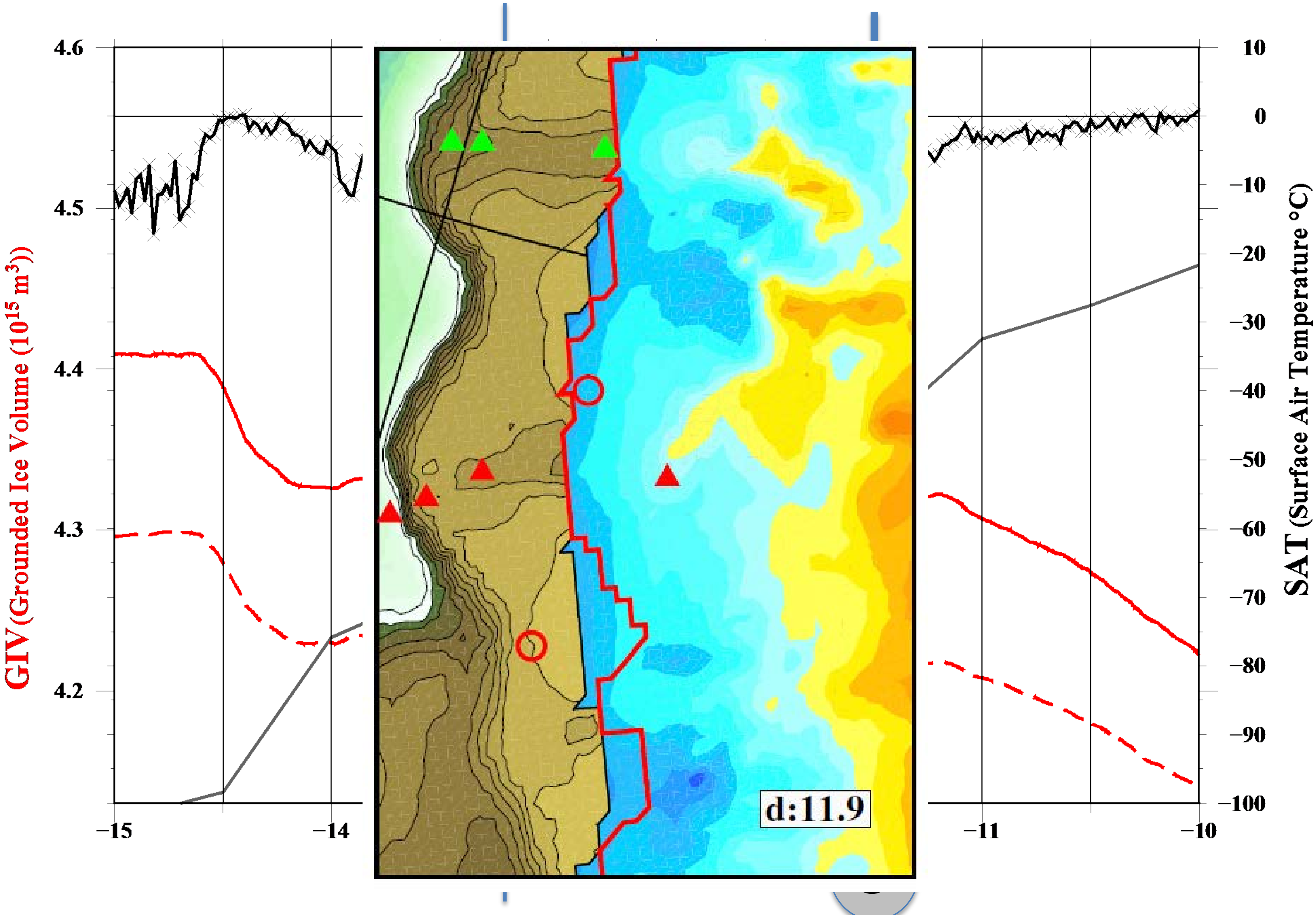
Between 14.7 and 13.9 - RETREAT



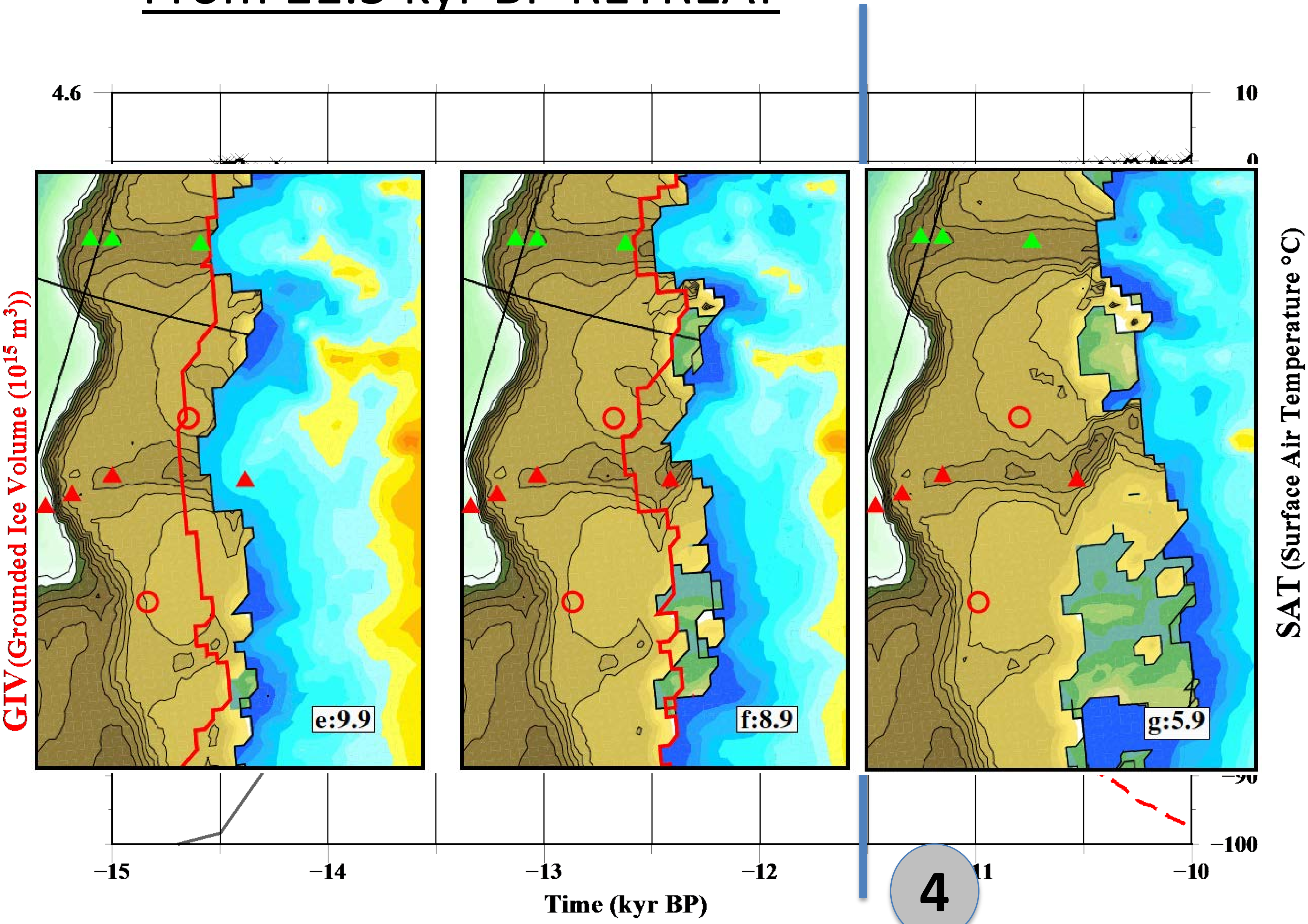
1 kyr stillstand



Between 12.9 and 11.5 kyr BP READVANCE



From 11.5 kyr BP RETREAT



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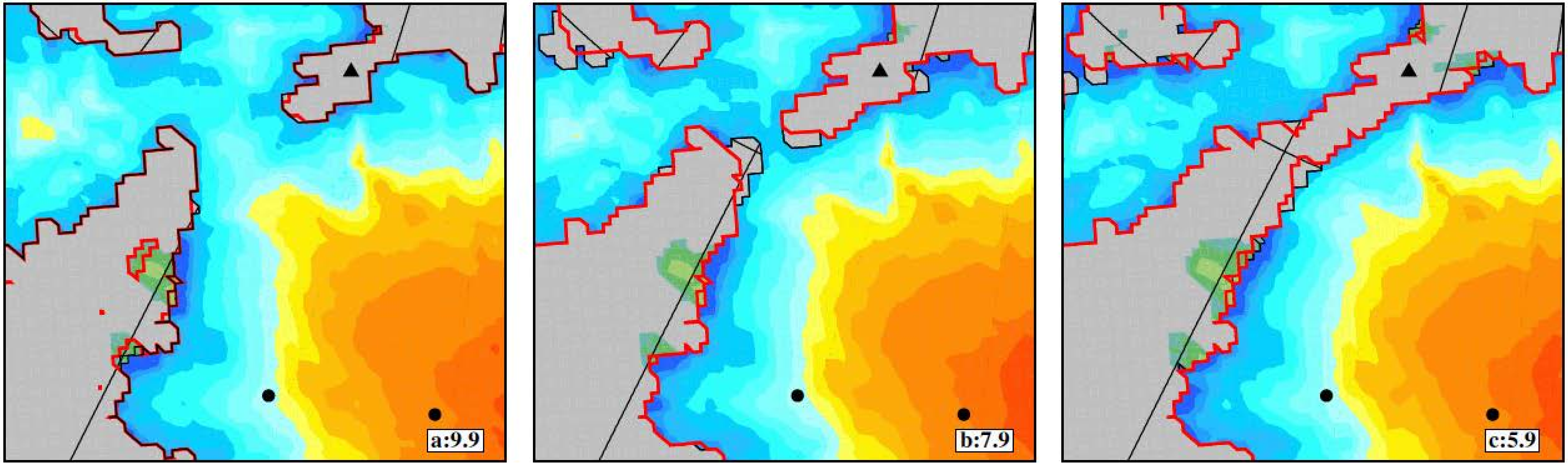
From 11.5 kyr BP: North West Margin



- Retreat between 7.9 and 6.9 kyr BP
- Timing – variable depending on ssm and RSL forcing

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