EGU 2020

CR2.2: Present and palaeo-perspectives on ice-sheet dynamics: data, models and comparisons

May 5th, 2020

Simulated last deglaciation of the Barents Sea Ice Sheet primarily driven by oceanic conditions

Accepted for publication in Quaternary Science Reviews

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Outline

- Study area and scientific motivations
- Ice sheet model description and simulations setup
- Last deglaciation of the Barents Sea Ice Sheet:
  - Key results from our simulations
  - Model/DATED-1 comparison
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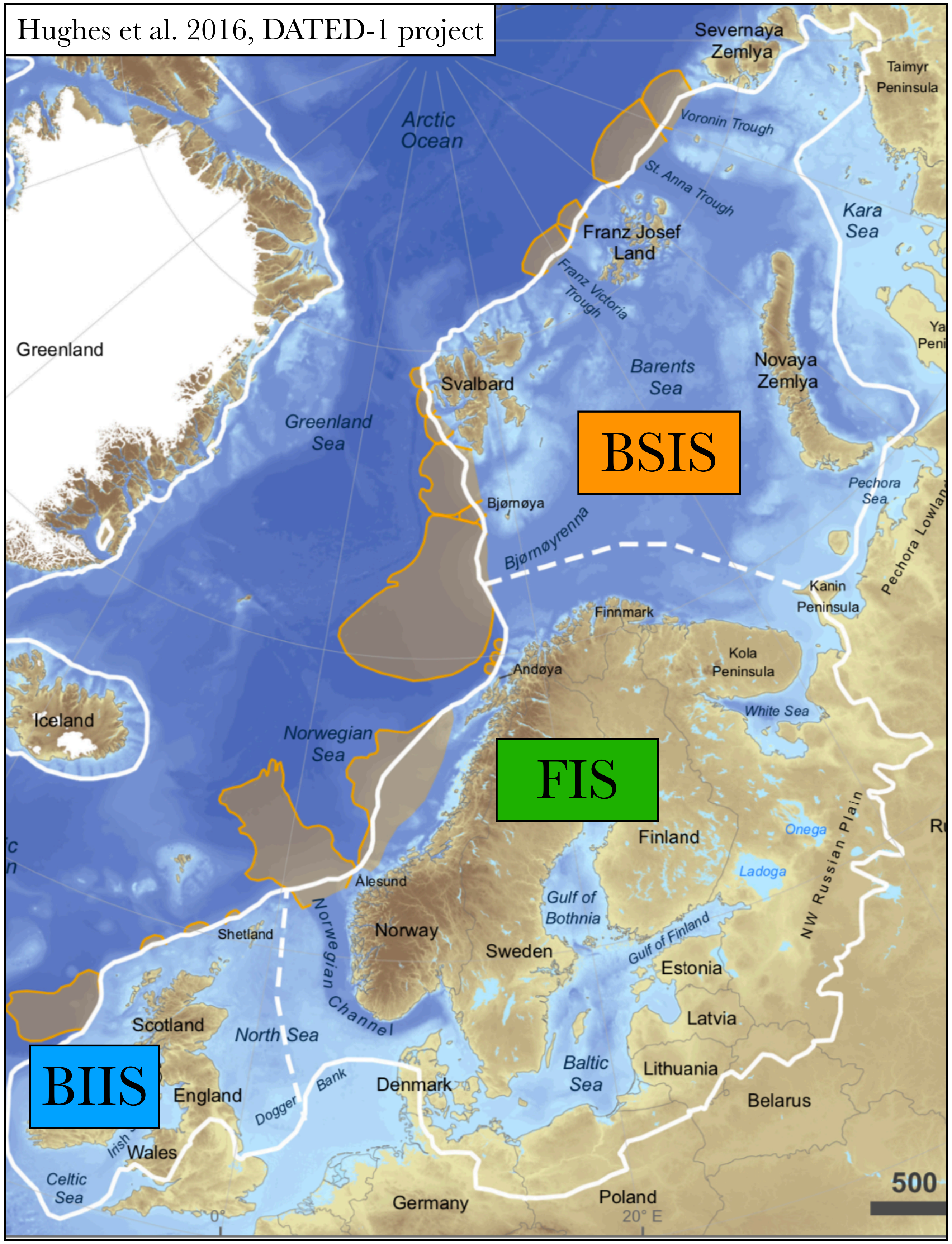
Eurasian ice sheet complex during the LGM

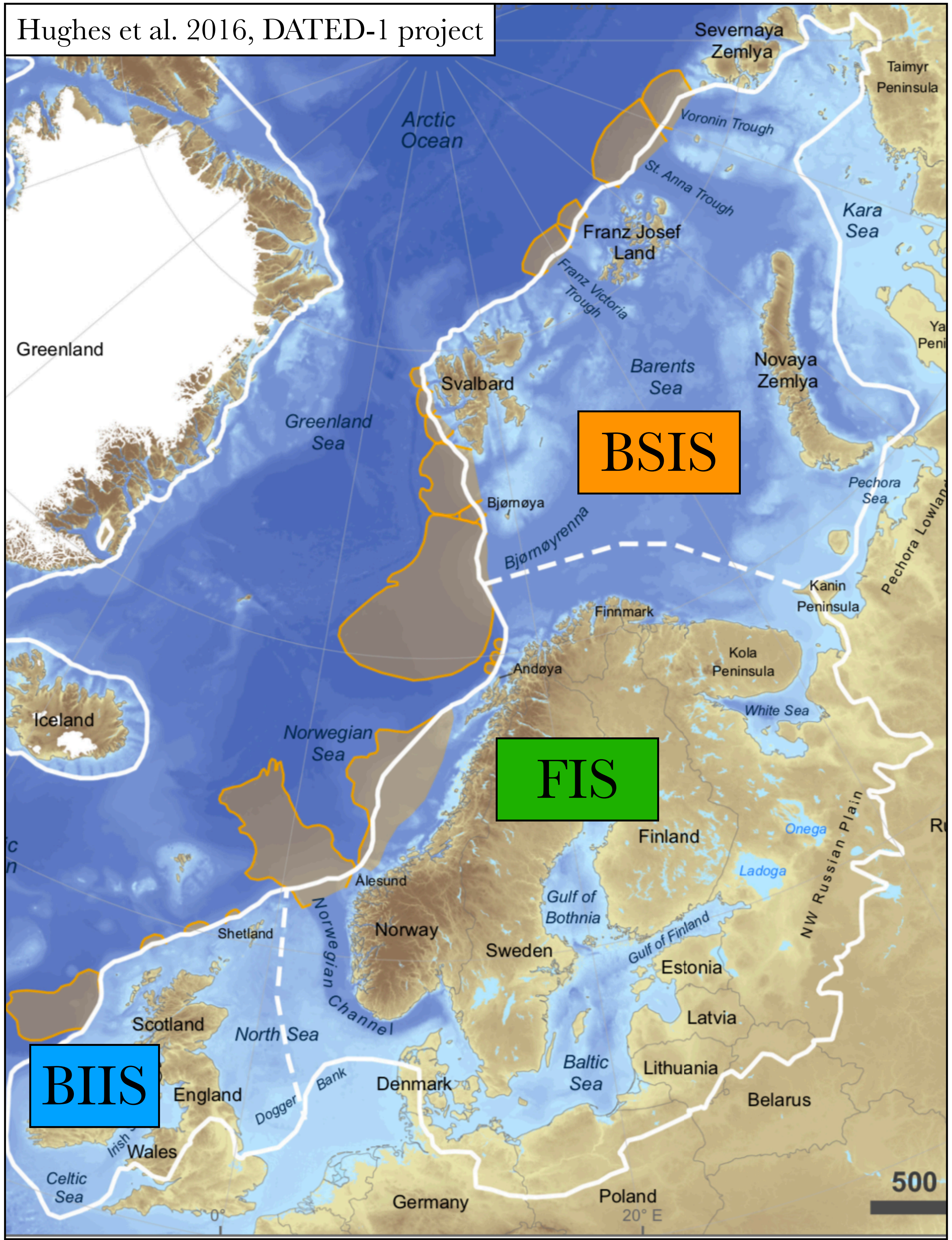


LGM, around 21,000 yr BP:

Eurasian Ice Sheet complex (20–24 m SLE)

- British-Irish Ice Sheet (~2 m SLE)
- Fennoscandian Ice Sheet (~15 m SLE)
- Barents Sea Ice Sheet (~7 m SLE)

Eurasian ice sheet complex: observations



LGM, around 21,000 yr BP:

Eurasian Ice Sheet complex (20–24 m SLE)

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DATED-1 archive, Hughes et al. 2015:

- time-slice reconstructions of EISc between LGM and 10,000 yr BP;
- Collection of existing chronological data (marine/terrestrial) till Jan. 1st, 2013

The last Eurasian ice sheets – a chronological database and time-slice reconstruction, DATED-1

ANNA L. C. HUGHES, RICHARD GYLLENCREUTZ, ØYSTEIN S. LOHNE, JAN MANGERUD AND JOHN INGE SVENDSEN

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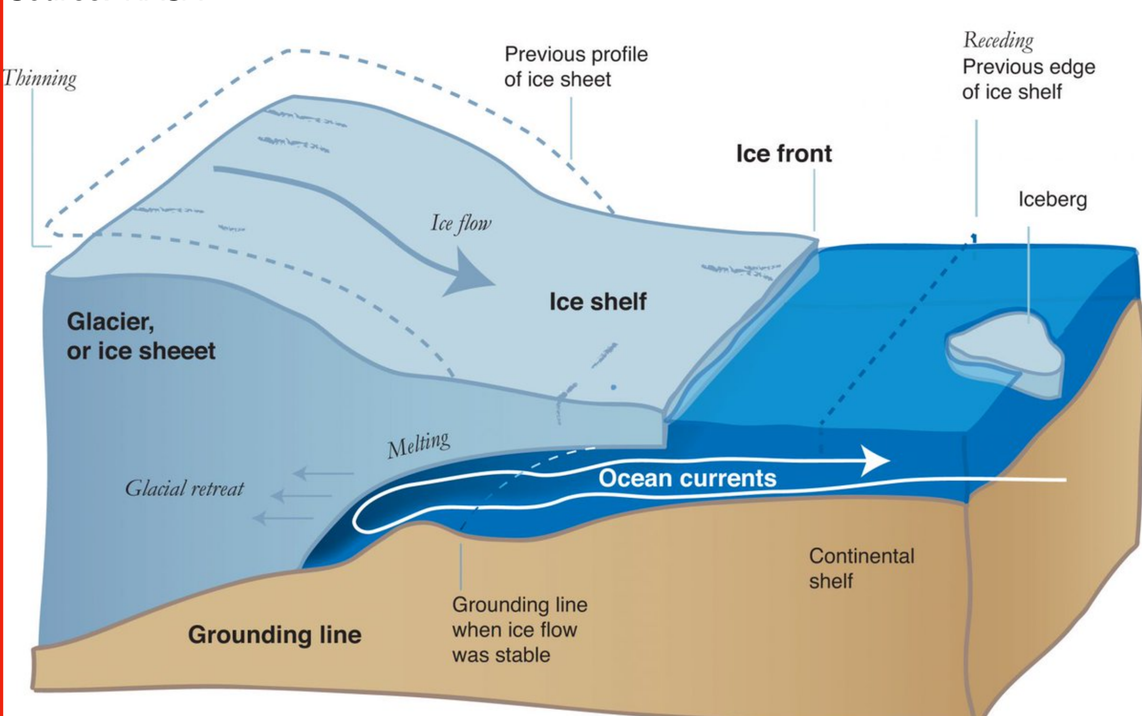
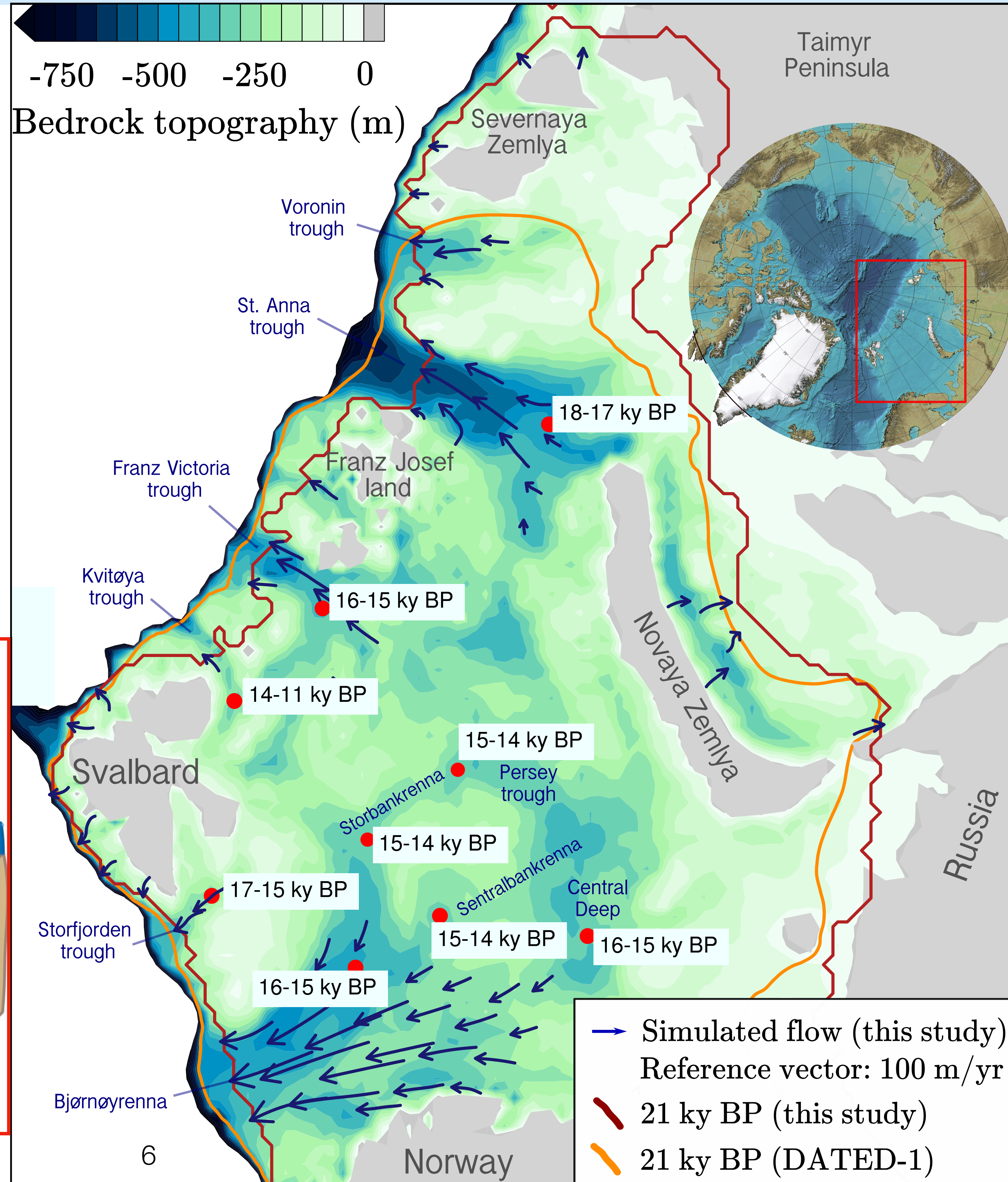
Barents Sea ice sheet: bathymetry, ice dynamics

Barents Sea Ice Sheet:

- almost entirely marine-based;
- grounded on rel. shallow shelf;
- drained by several ice streams flowing in glacial troughs;
- resting on retrograde bedrock: potentially prone to MISI: Marine Ice Sheet Instability

Source: NASA





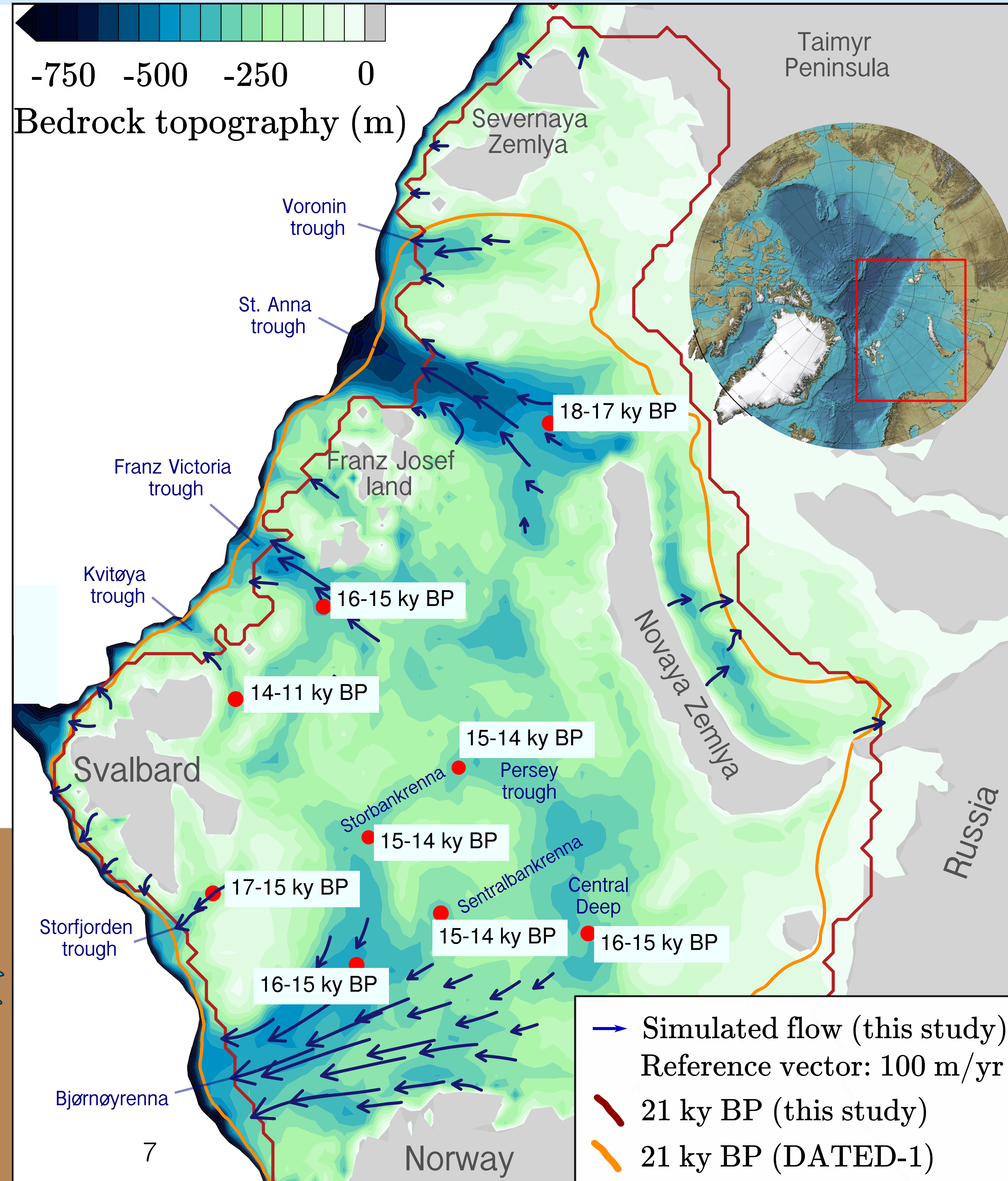
Barents Sea ice sheet: bathymetry, ice dynamics

Barents Sea Ice Sheet:

- almost entirely marine-based;
- grounded on rel. shallow shelf;
- drained by several ice streams flowing in glacial troughs;
- resting on retrograde bedrock: potentially prone to MISI;

Similar to present-day WAIS (Mercer, 1970)

Siegert, 2002



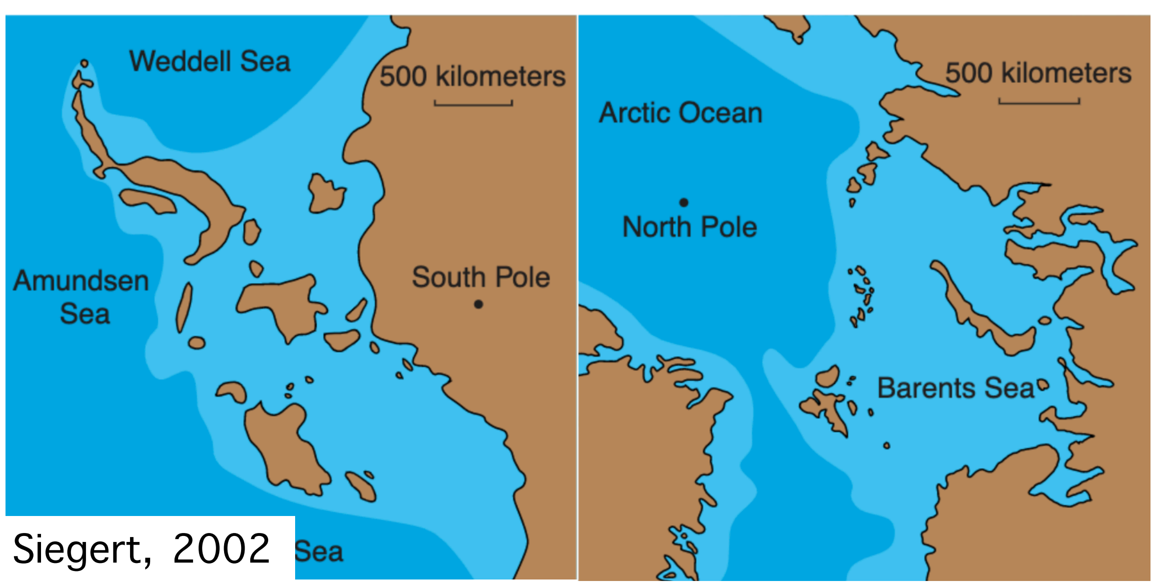
Main scientific question of this study

West Antarctic Ice Sheet:

- ~3.3 m SLE (Bamber et al. 2009);
- almost entirely marine-based;
- resting on retrograde bedrock: MISI has been observed/simulated;

Ocean melting under ice shelves:

- primary cause for WAIS mass loss;
- trigger for dynamic instabilities (MISI, loss of buttressing)



Siegert, 2002

Observations limited to past decades:

need to understand processes on glacial timescales (100/>1000 yrs)

What is role played by ocean melting in driving the last deglaciation of the Barents Sea Ice Sheet?

Ice sheet model simulations of the last deglaciation of the Barents Sea Ice Sheet, taking into account ocean melting

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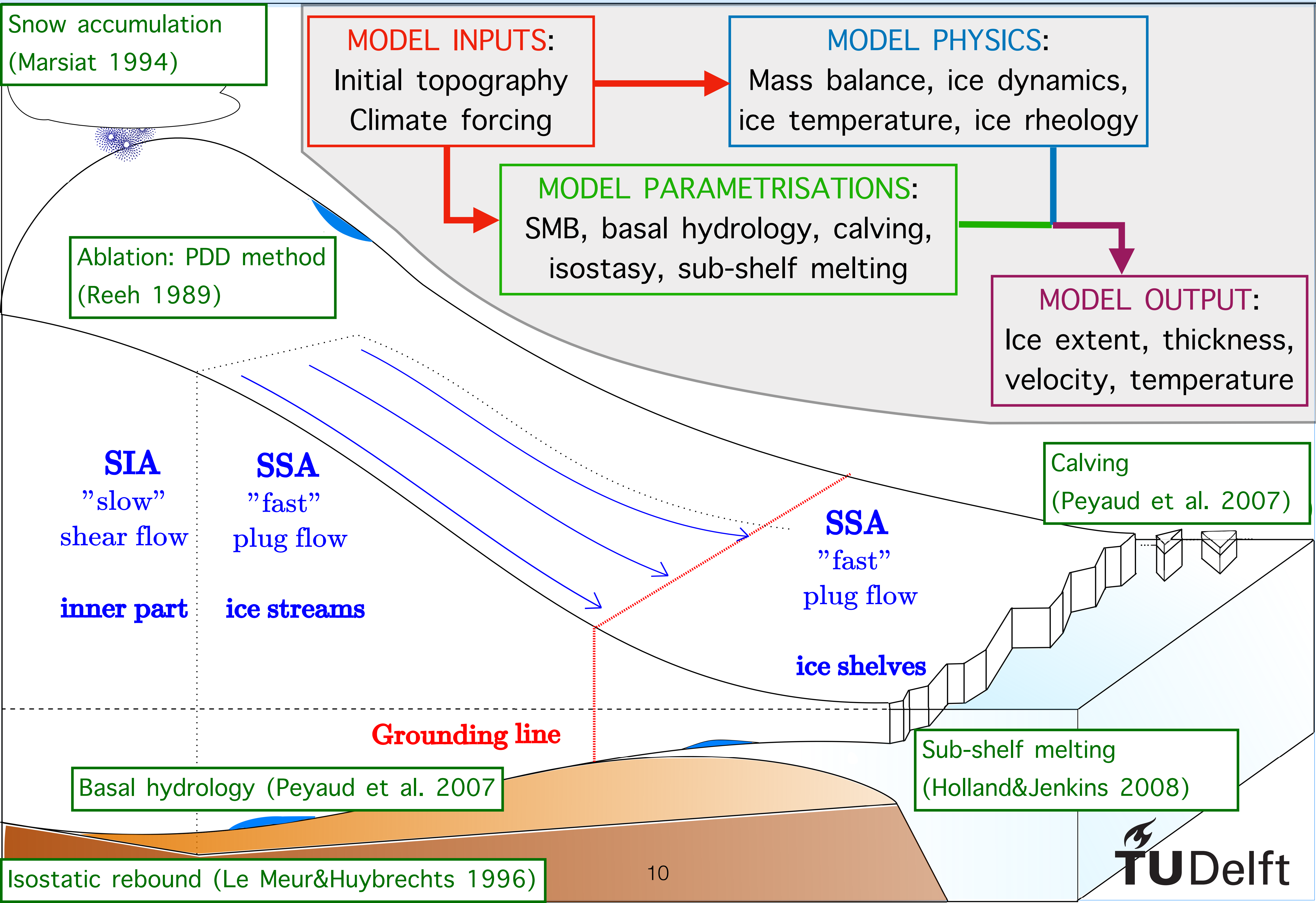
GRISLI ice sheet model (Ritz et al. 2001): overview



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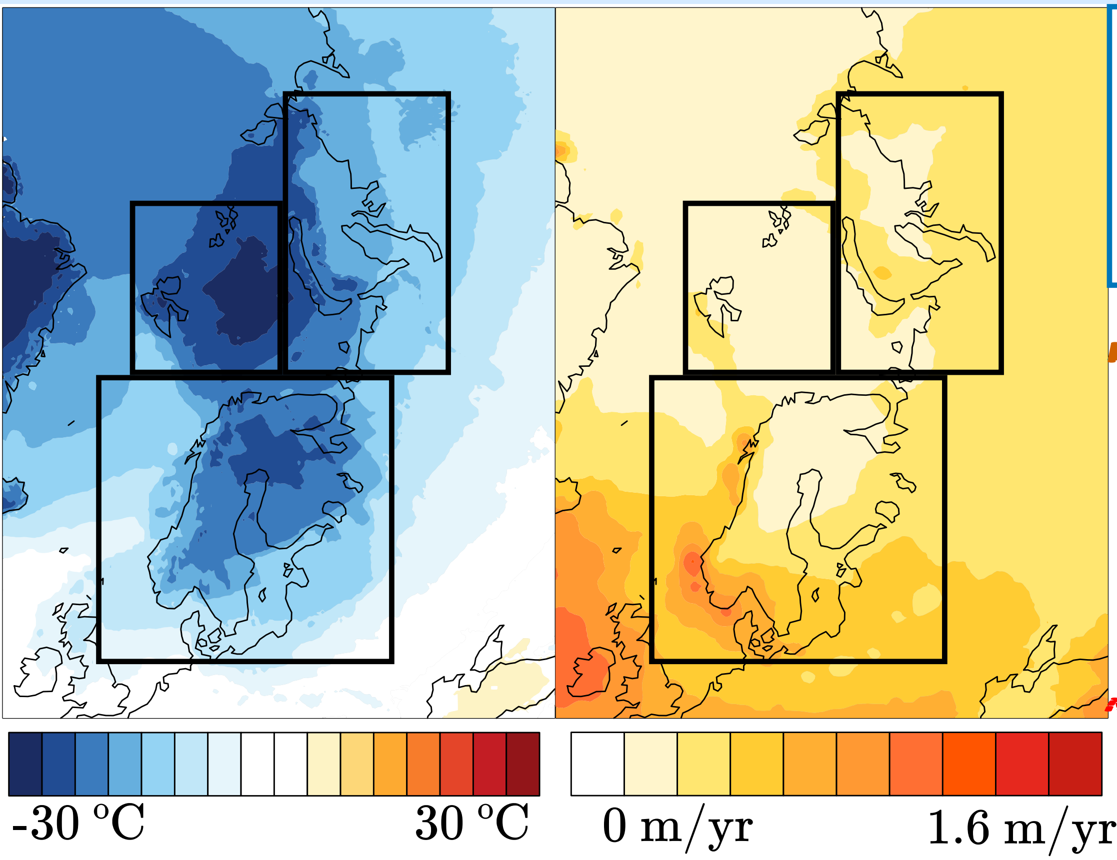
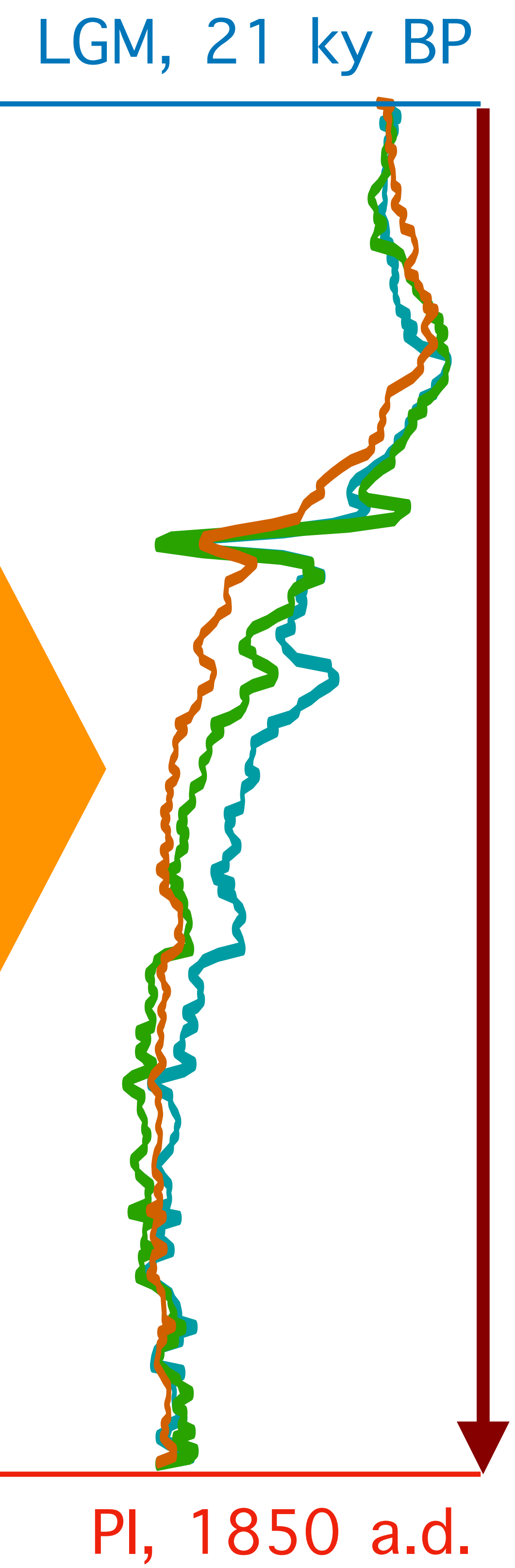
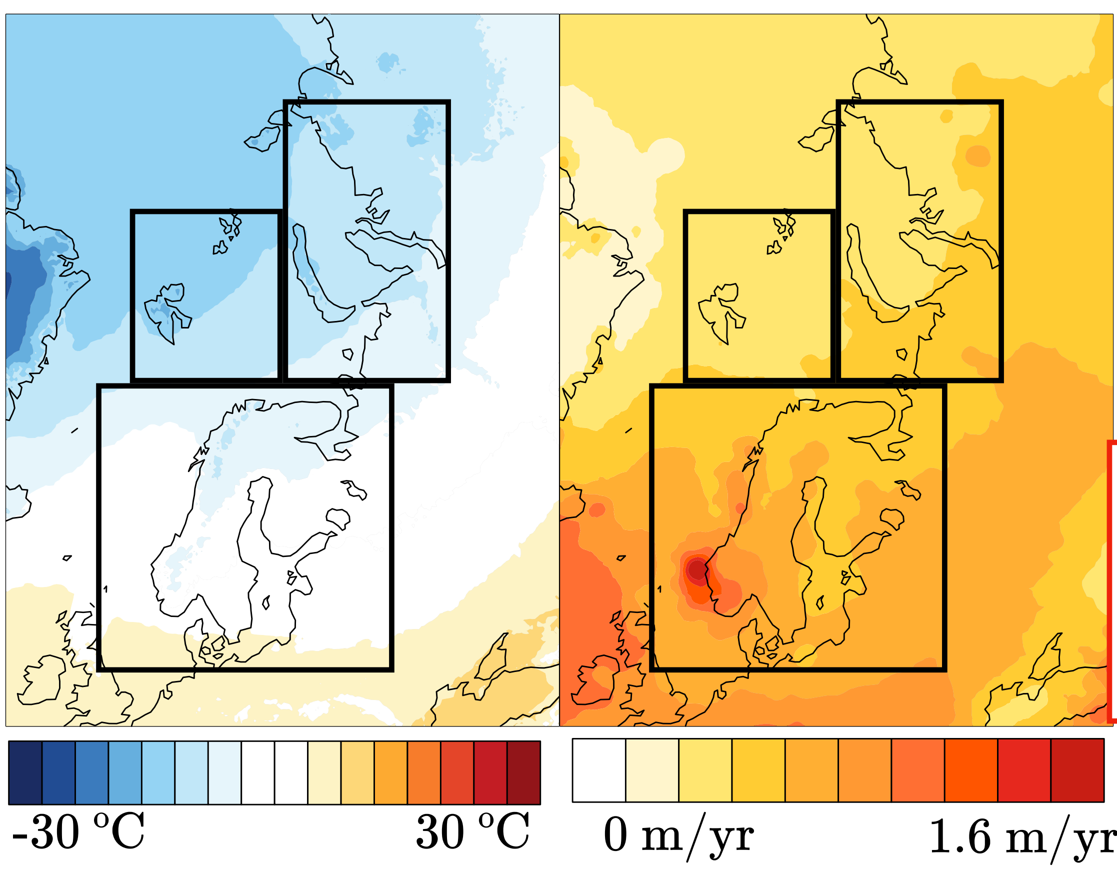
Transient simulations design: climate forcing



LGM simulated climate
IPSL-CM5A-LR GCM
Braconnot et al. 2012

Regional indexes based on TraCE-21ka: transient climate simulation of last 21,000 years (Liu et al. 2009)





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Transient simulations design: sub-shelf melting

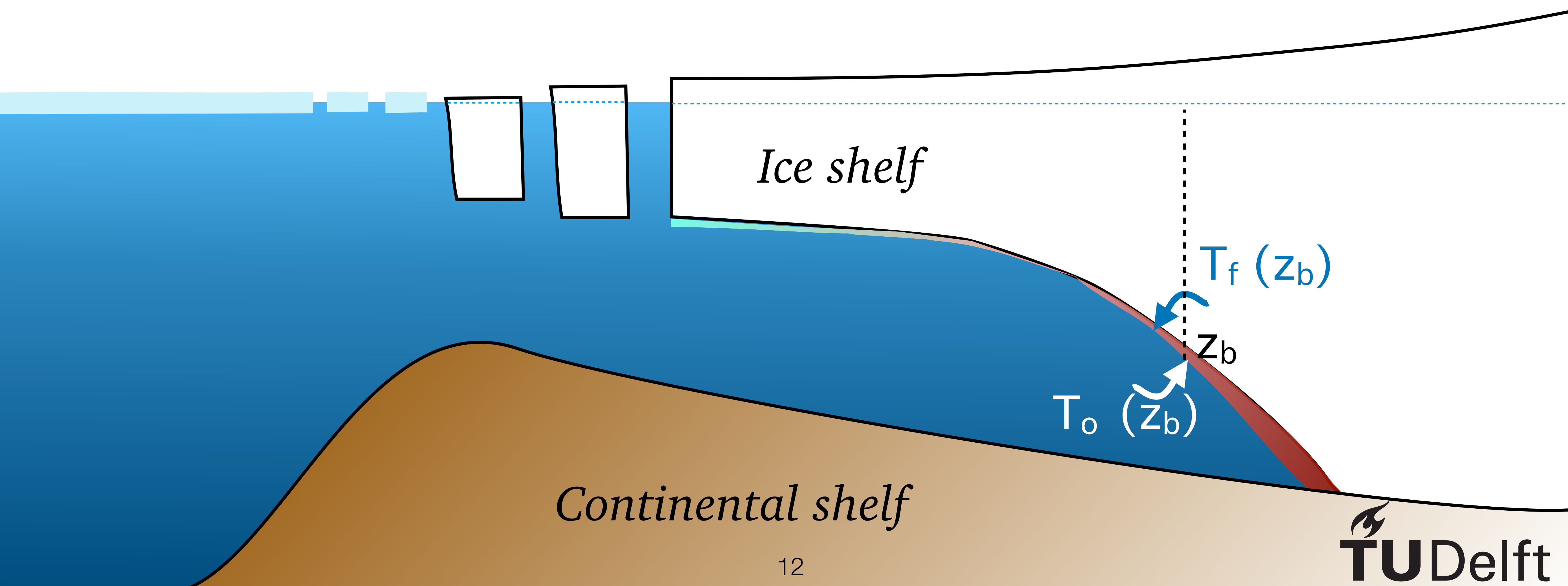
Sub-shelf melting formulation (Holland&Jenkins 2008):

Two-equations formulation based on heat exchange at ice-ocean boundary

$$B_m(z_b) = \frac{\rho_o c_{po} \gamma_t F_m \cdot \left(T_o(z_b) - T_f(z_b)\right)^2}{L_i \rho_i}$$

$$T_f(z_b) = 0.0939 - 0.057 \cdot S(z_b) + 7.64 \cdot 10^{-4} \cdot z_b$$

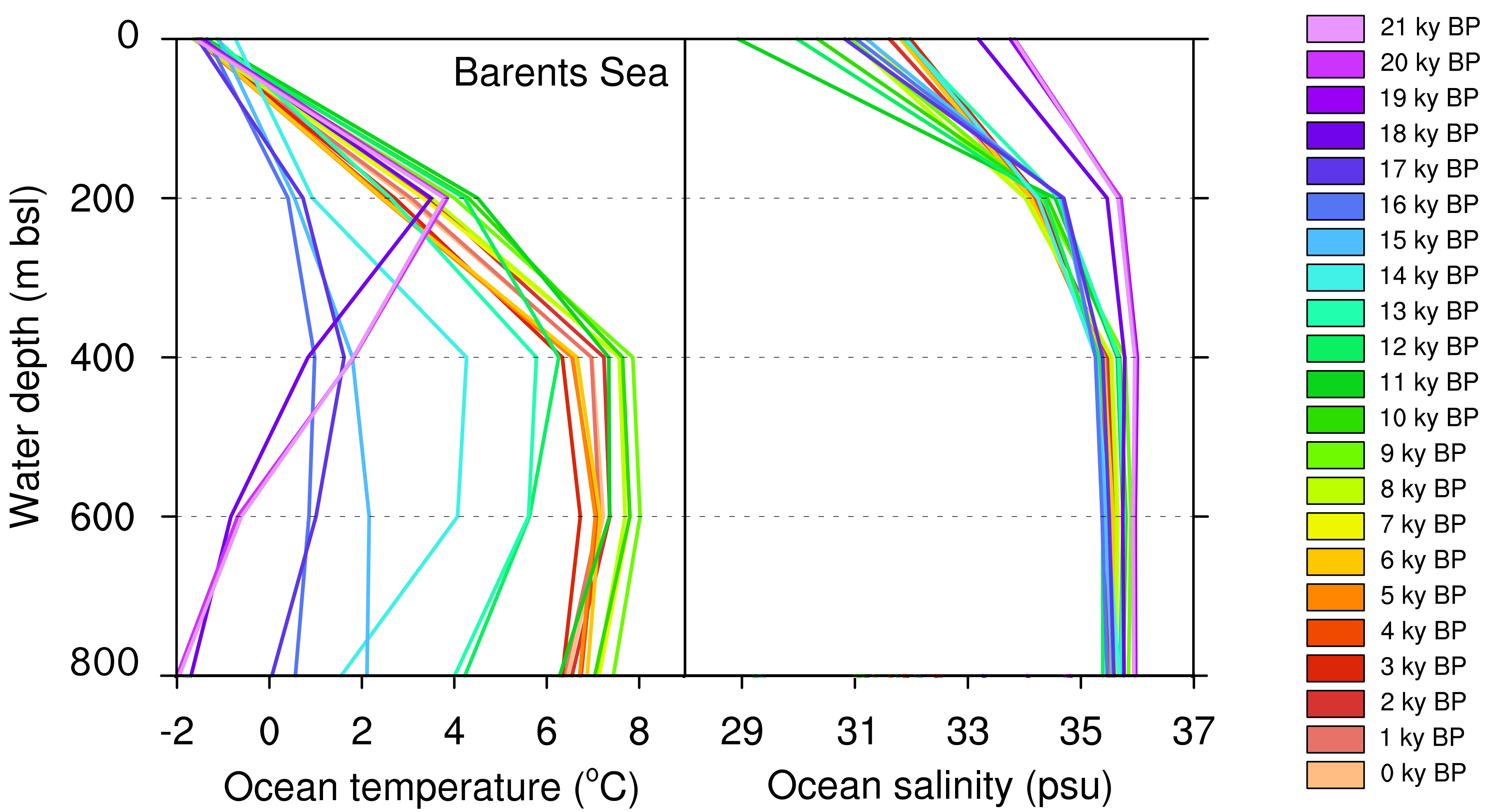
We need ocean temperature, salinity to force the parametrisation during the simulation

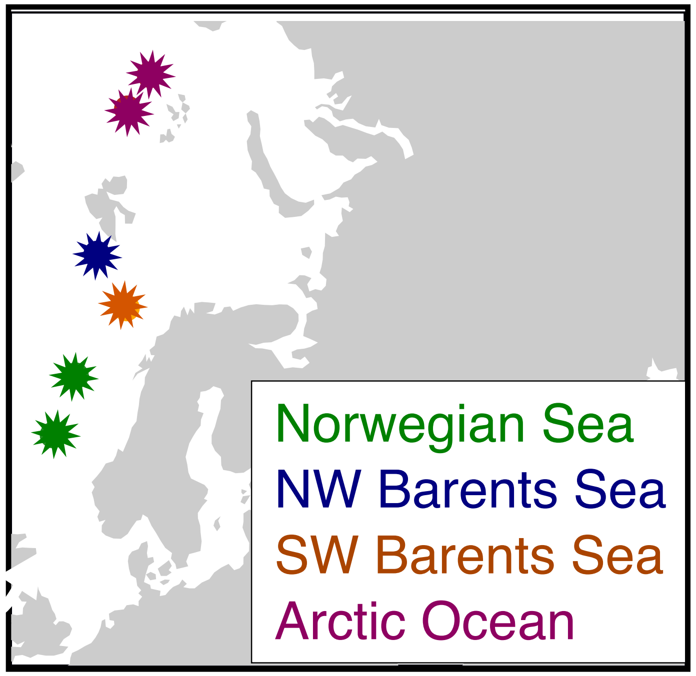


Transient simulations design: ocean forcing

We need ocean temperature, salinity to force the parametrisation during the simulation

Regional ocean temperature and salinity profiles based on TraCE-21ka transient climate simulation of last 21,000 years (Liu et al. 2009)





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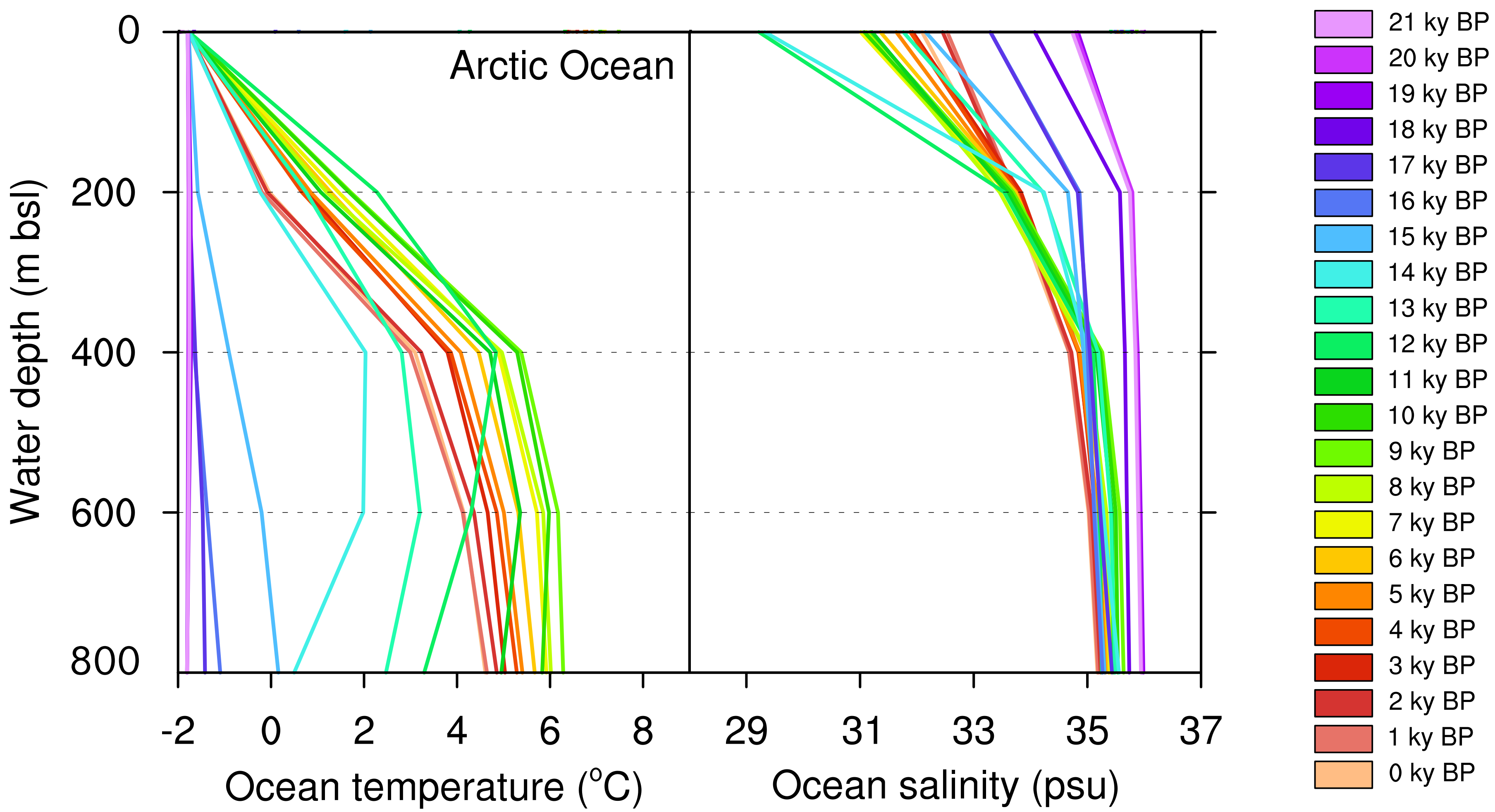

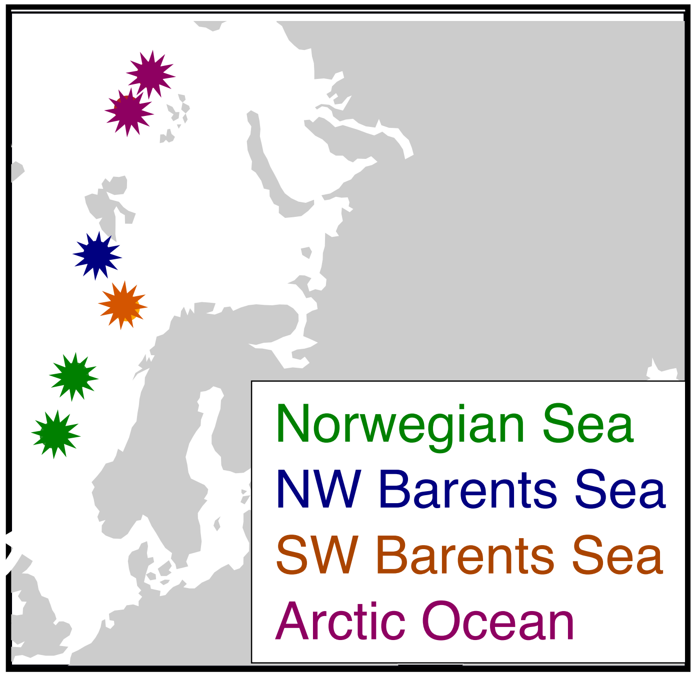

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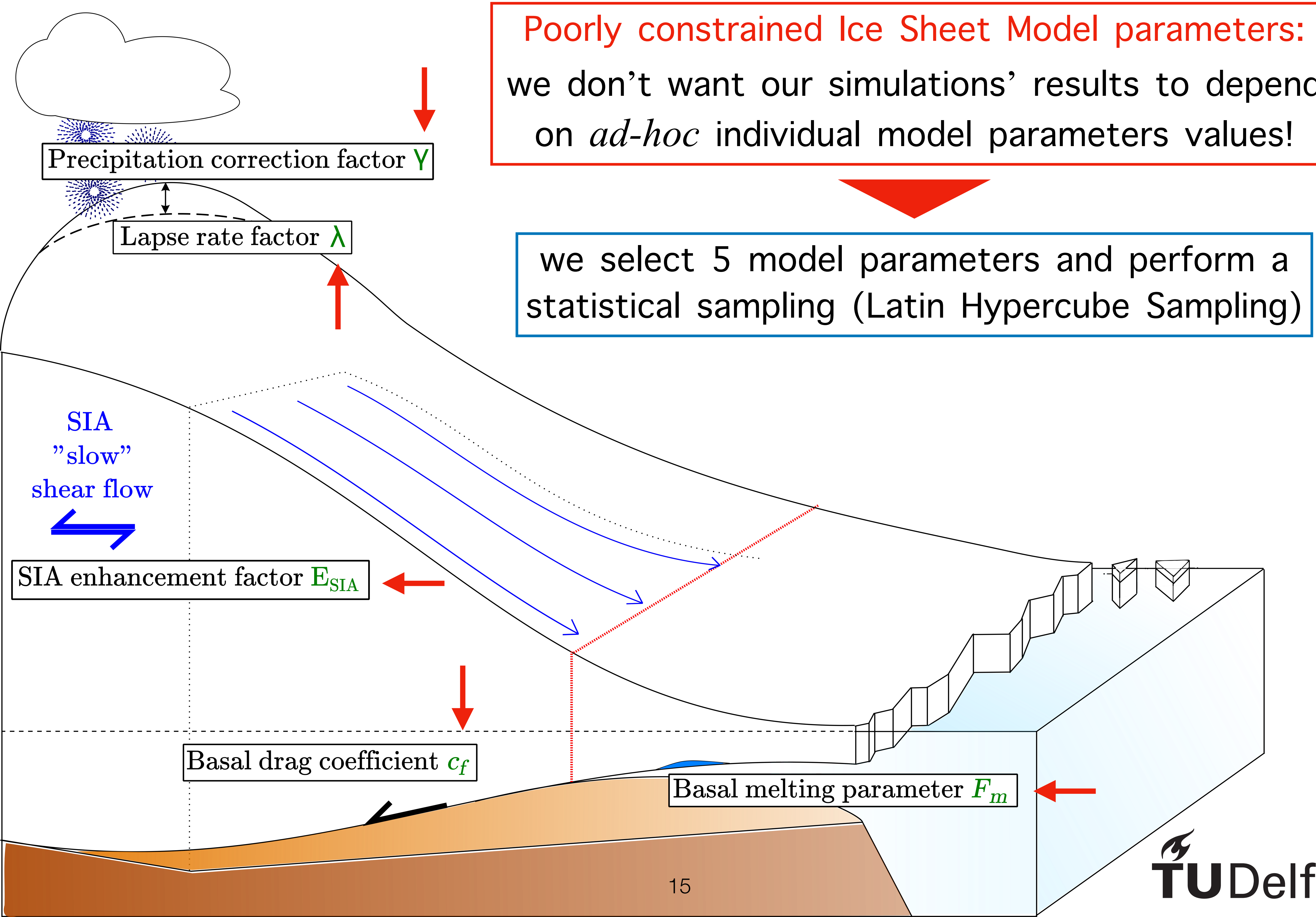
Statistical ensemble of simulations: LHS approach

Poorly constrained Ice Sheet Model parameters:

we don't want our simulations' results to depend on *ad-hoc* individual model parameters values!

we select 5 model parameters and perform a statistical sampling (Latin Hypercube Sampling)



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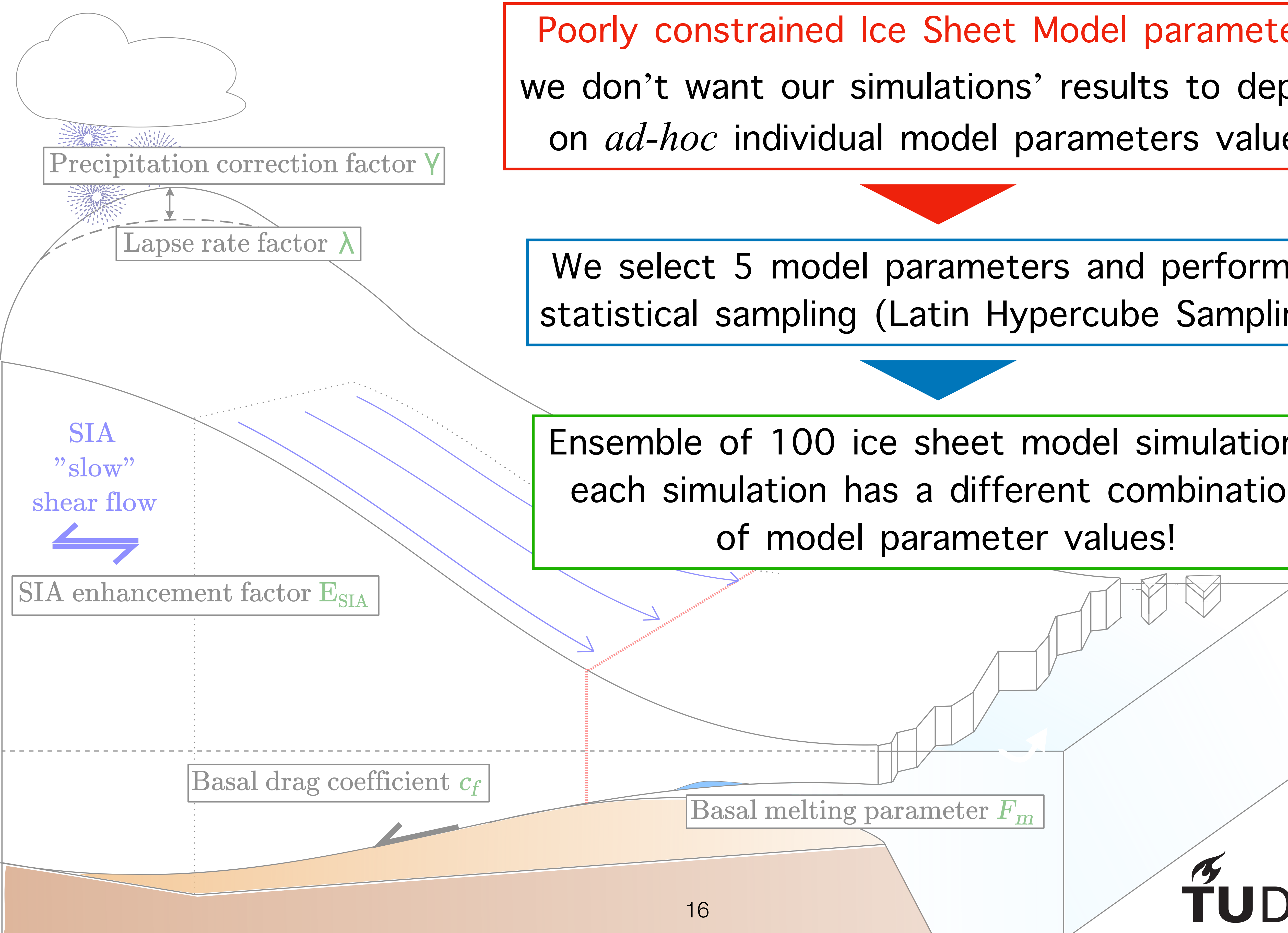
Ensemble of 100 ice sheet model simulations: each simulation has a different combination of model parameter values!



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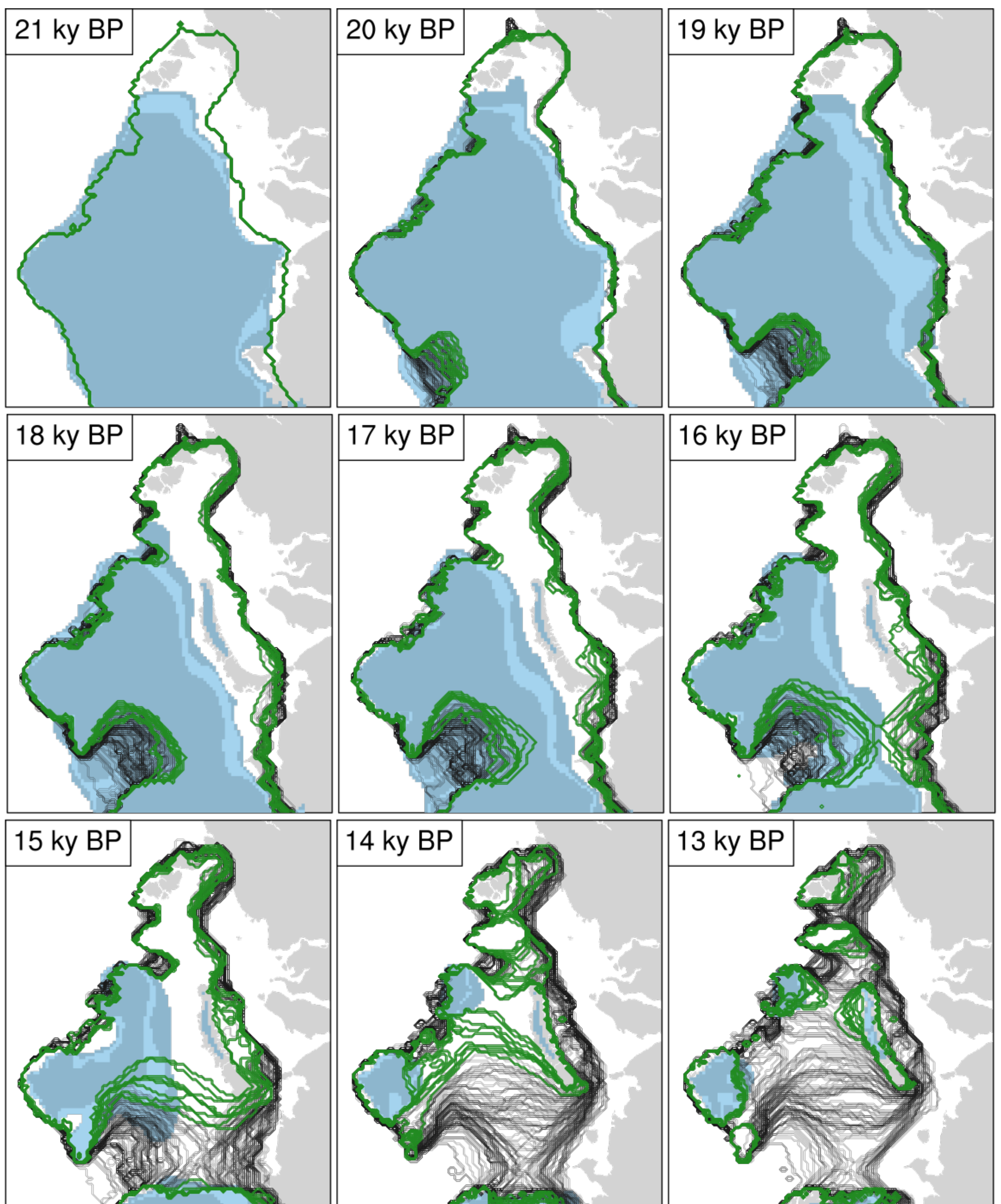
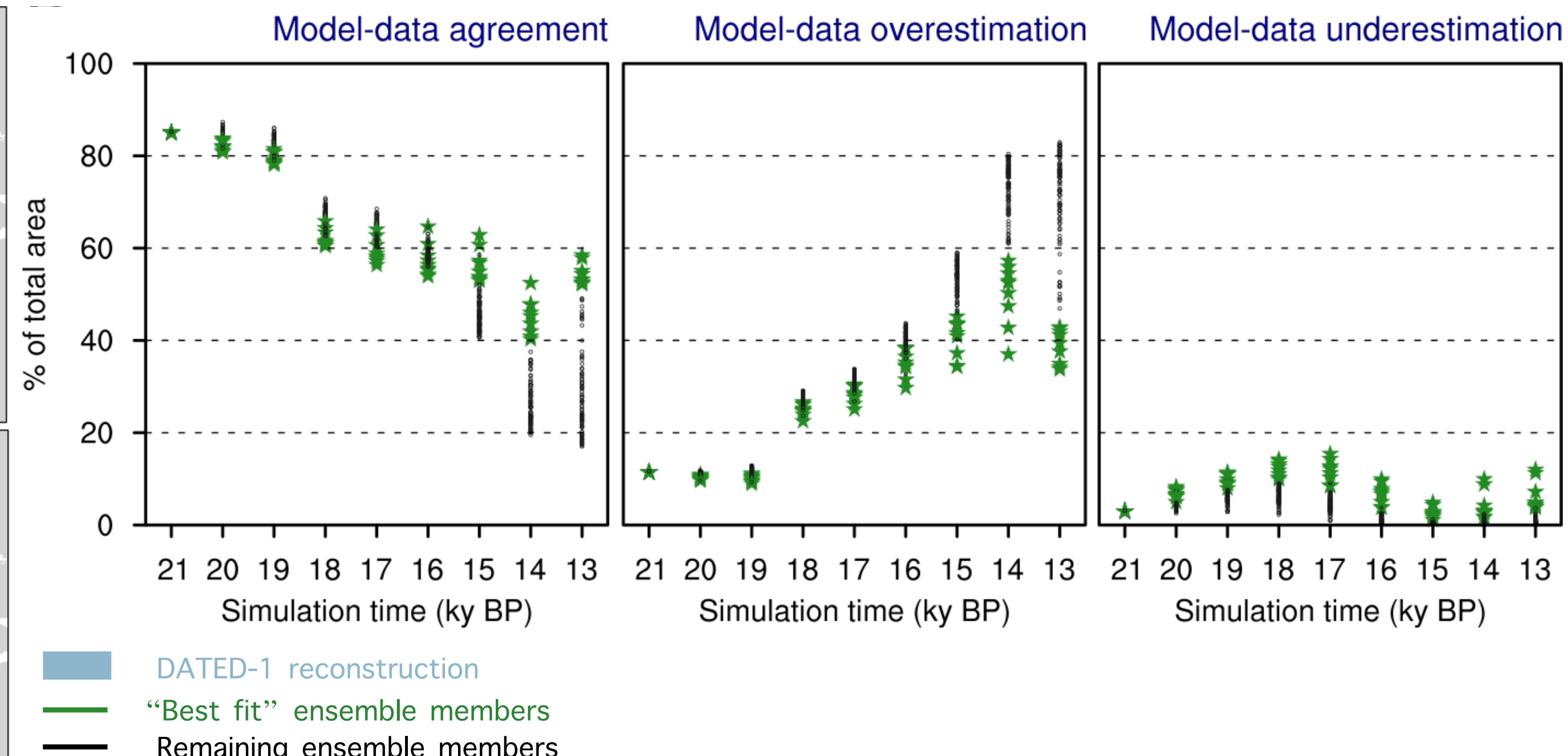
Model/data comparison: "admissible simulations"

Ensemble of 100 ice sheet model simulations: each simulation has a different combination of model parameter values!

Direct comparison between simulated/DATED-1 ice extent (21-13 ky BP)





9 "admissible simulations" showing the best model/data agreement are used to construct min-avg-max simulated deglaciation scenarios

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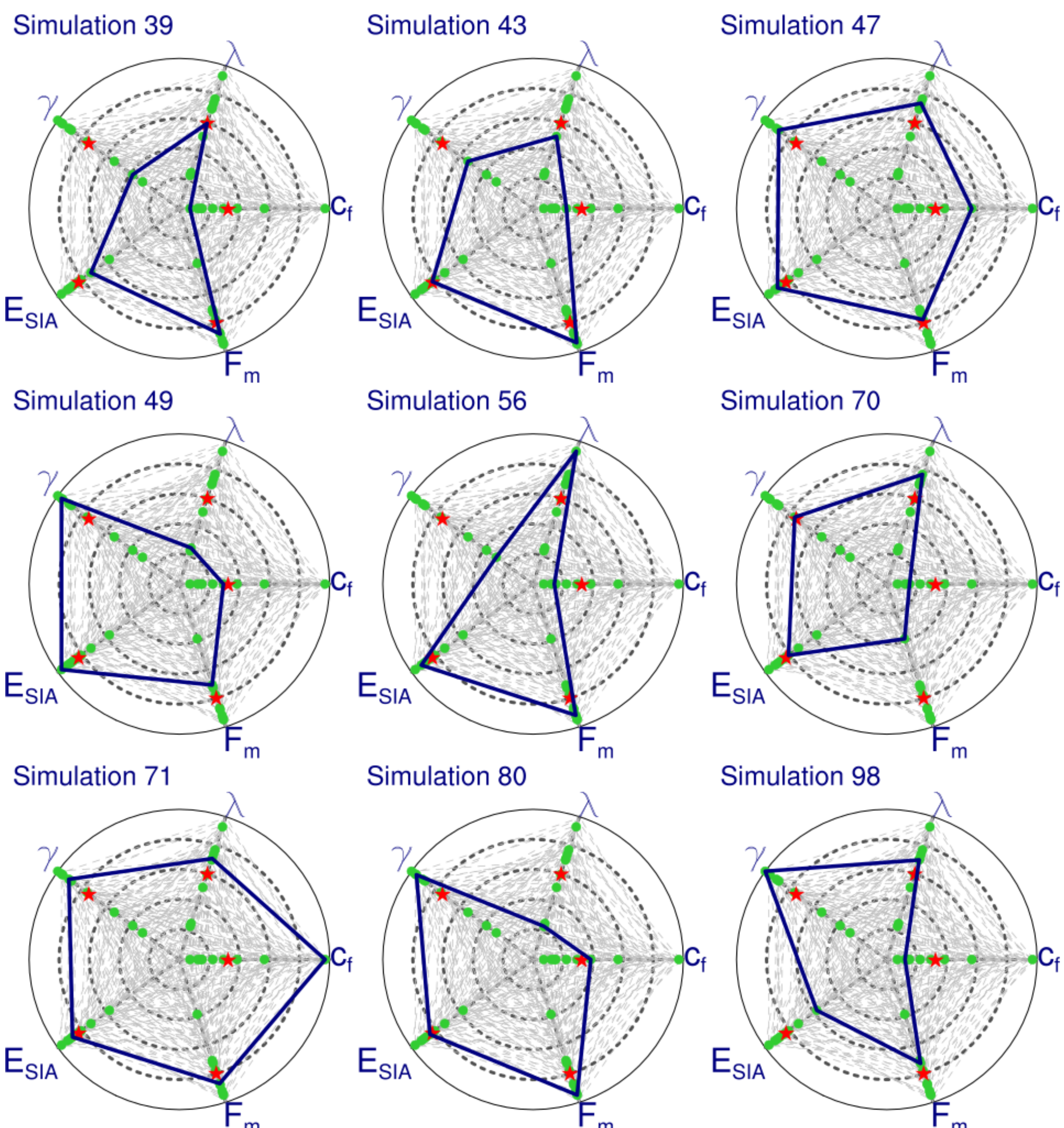
Model parameter values in "admissible simulations"

9 simulations ("best fit") showing the best model/data agreement: distribution of the parameter values compared to original range of values?



- Lapse rate, elevation correction and basal drag coefficient factor values spread across full interval length;
- SIA enhancement factor and sub-shelf melting coefficient values clustered at high end of full range intervals;

Symbol	"FE" Range	"FE" Avg	"AS" range	"AS" avg
λ	$[4 - 8.2]$	6.1	$[5.0 - 7.8]$	6.5
γ	$[0.03 - 0.1]$	0.065	$[0.05 - 0.1]$	0.082
E_{SIA}	$[1 - 5.6]$	3.3	$[3.6 - 5.4]$	4.8
c_f	$[1 - 10] \cdot 10^{-5}$	$5 \cdot 10^{-5}$	$[2 - 10] \cdot 10^{-5}$	$4 \cdot 10^{-5}$
f_m	$[0.005 - 1.5] \cdot 10^{-3}$	$0.8 \cdot 10^{-3}$	$[0.6 - 1.5] \cdot 10^{-3}$	$1.2 \cdot 10^{-3}$

Parameter values in individual simulation
Parameter values in "best fit" members
Average parameter values in "best fit" members
Parameter values in remaining members

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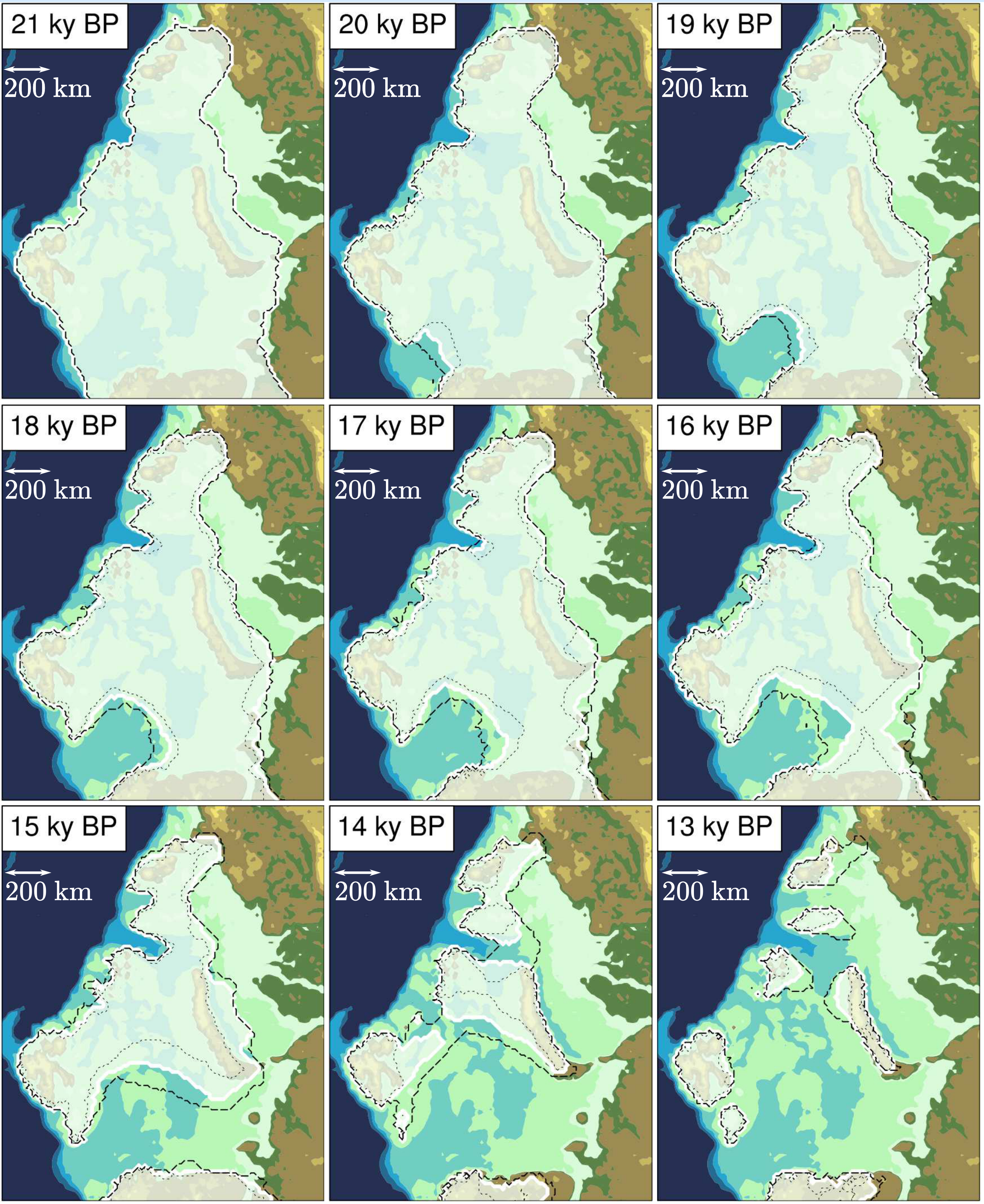
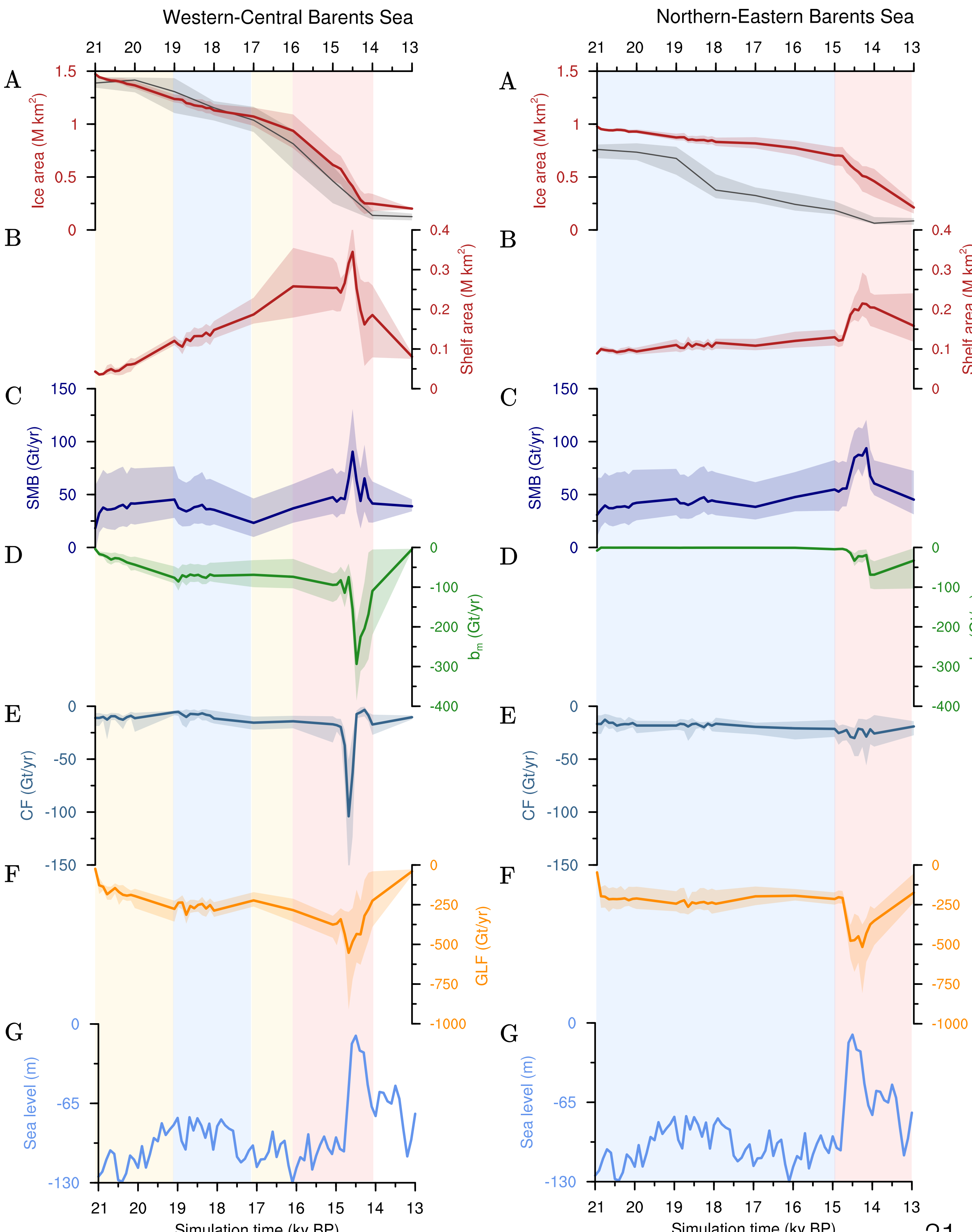
Last deglaciation of the Barents Sea ice sheet



Key results:

- Early retreat of western ice sheet margin in Bjornoyrenna between 21-18 ky BP;
- Late retreat of northern and eastern ice sheet margins after 15 ky BP;
- Collapse of Fennoscandian/Barents Sea ice sheet connection: 16-15 ky BP in max-avg, 17-16 ky BP in min scenarios;
- Final ice sheet collapse: 15-13 ky BP;
- Marked southwest-to-northeast deglaciation pattern;

Drivers of ice sheet retreat



Key results:

- Southwest-to-northeast deglaciation pattern due to different oceanic conditions in western/central and northern/eastern Barents Sea (slides 13-14);
- primary control of sub-shelf melting (panel D) on grounding-line discharge (panel F) and ice retreat (panel A);
- Prescribed eustatic sea level rise (panel G) amplify the impact of sub-shelf melting in western-central Barents Sea between 21-18 and 15-14 ky BP;
- Under low sub-shelf melting conditions, prescribed eustatic sea level rise (panel G) has little impact on ice retreat;

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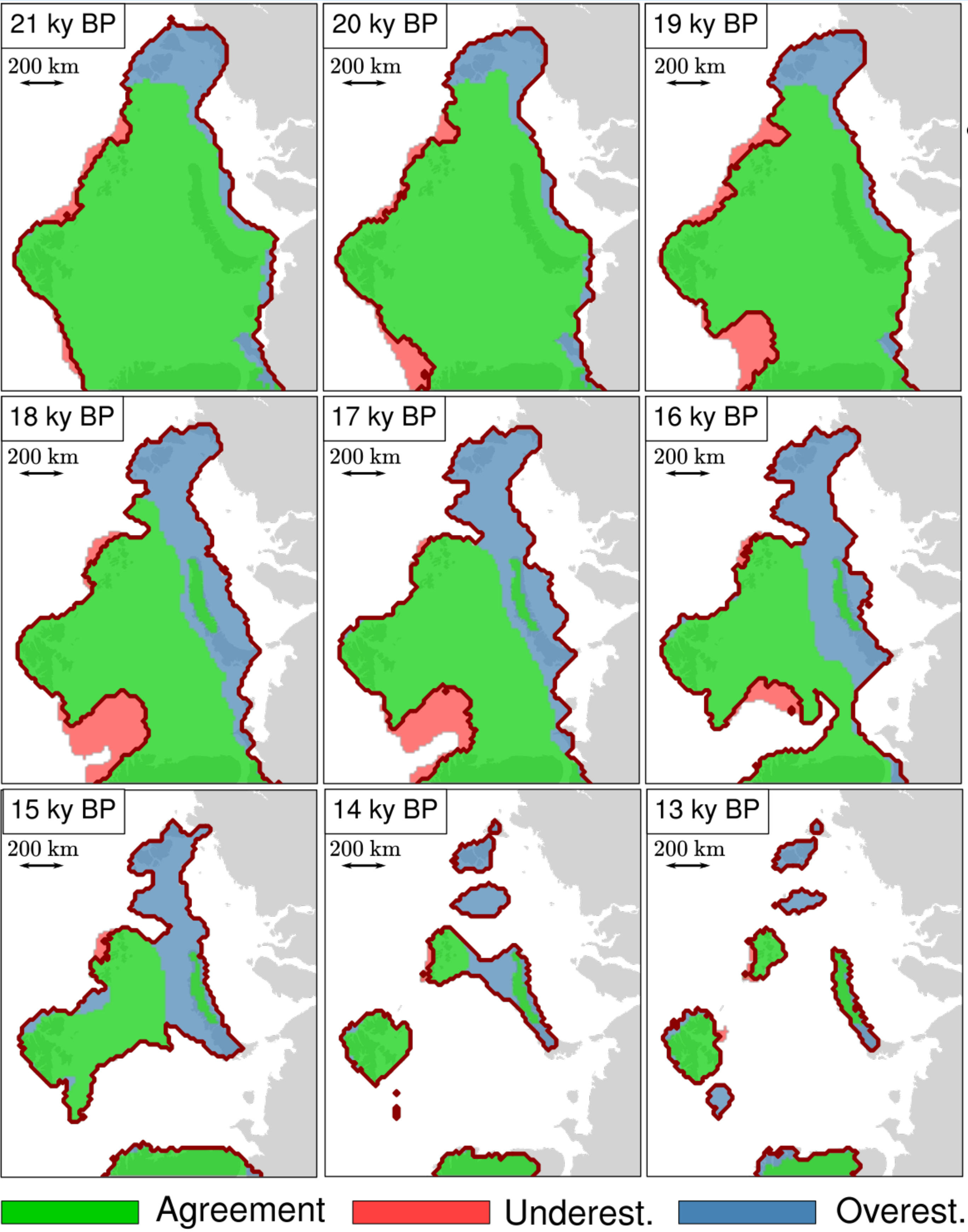
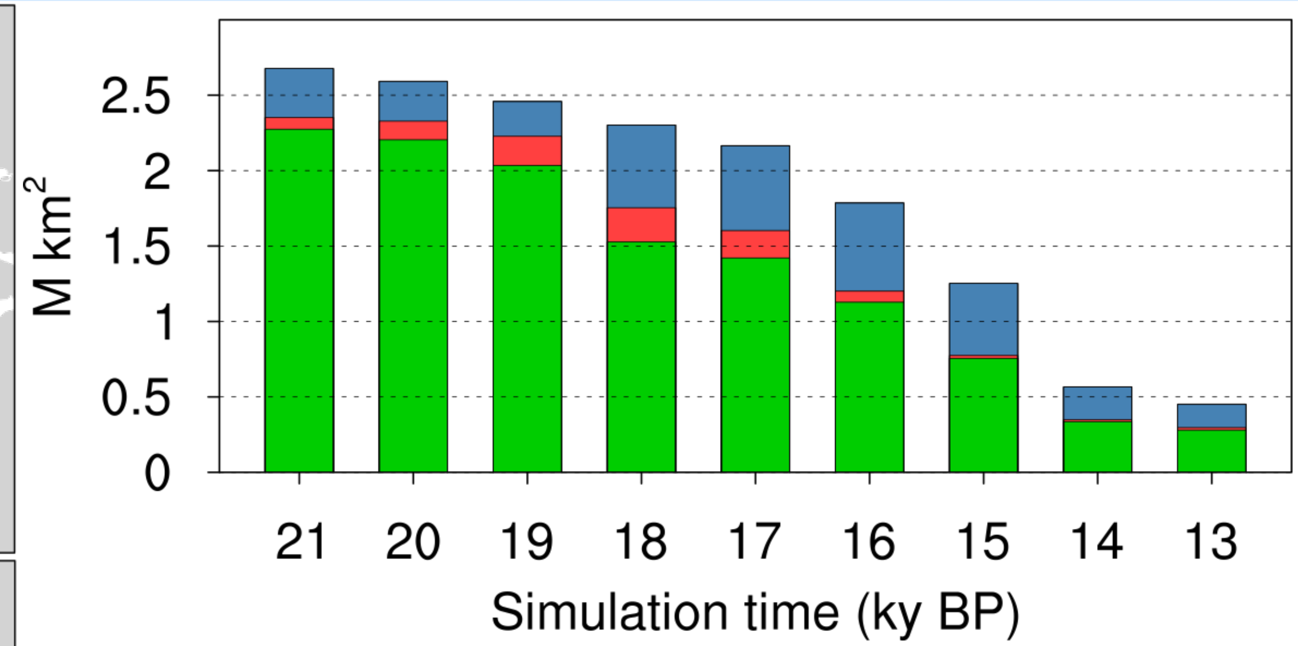
Model/DATED-1 comparison: overview





- ice extent underestimation at western ice sheet margin between 21-18 ky BP (red);
- ice extent overestimation at eastern ice sheet margin after 18 ky BP;
- model/data agreement in central/northern Barents Sea during the deglaciation:
  - ✦ collapse of FIS/BSIS connection (16-15 ky BP)
  - ✦ final ice sheet deglaciation (15-13 ky BP)

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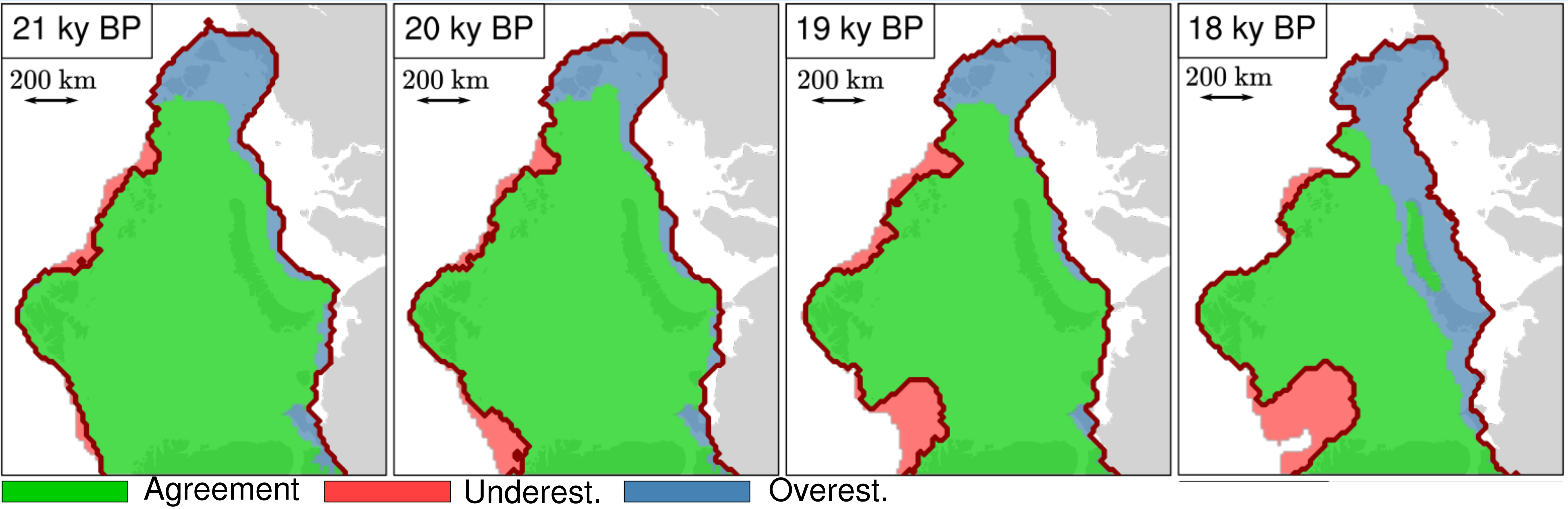
Ice extent underestimation between 21-18 ky BP



Early retreat of western margin not supported by DATED-1 reconstruction: what is causing this model/data mismatch?

- Trace21ka subsurface (200-400 m depth) ocean temperatures at western margin ~2-4 ^{0}C between 21-18 ky BP: possibly overestimated compared to proxy reconstructions;
- Trace-21ka ocean temperature warmer between 200-400 m depth than 400-800 m depth, thus higher sub-shelf melting values away from the grounding-line: in contradiction with ocean cavity circulation and plume models applied over Antarctic ice shelves;
- Overestimated extent of simulated Bjornoyrenna Ice Stream and relatively coarse horizontal resolution (20 km): amplified response to ice shelf thinning/sea level rise;

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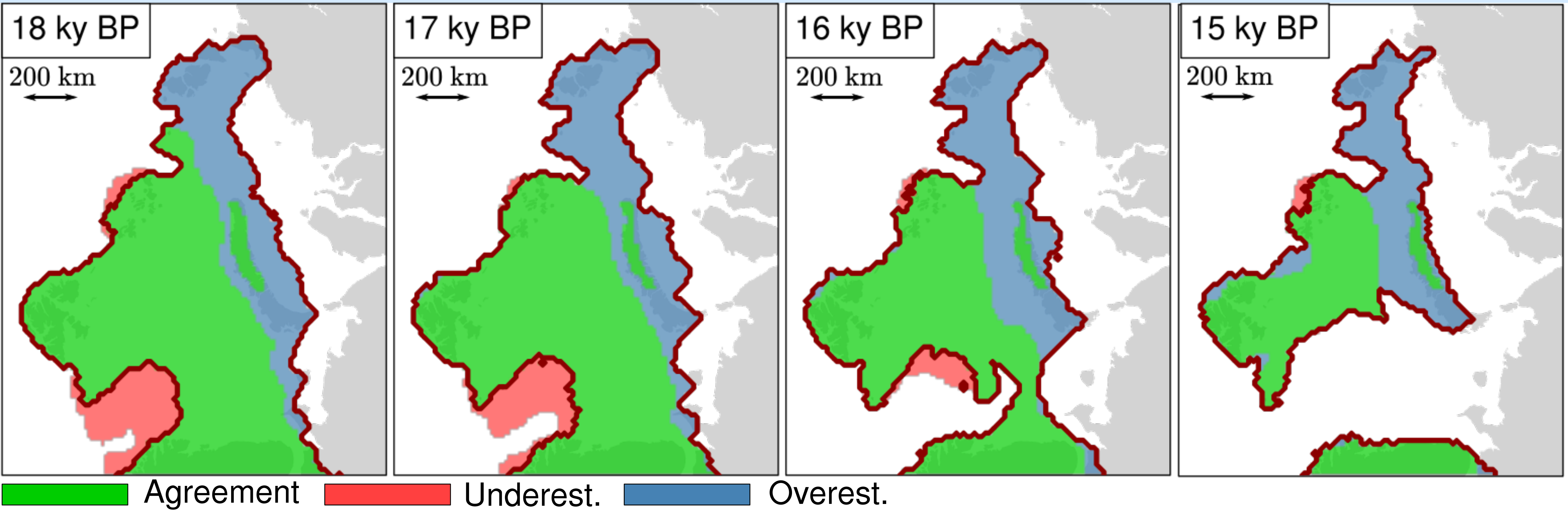
Ice extent overestimation between 18-15 ky BP



Eastern margin retreats later than suggested in DATED-1:
what is causing the model/DATED-1 mismatch?

- Atmospheric forcing extremely low until 15 ky BP at eastern margin: mechanisms of regional warming/enhanced seasonality neglected in climate forcing/PDD method;
- Sea level rise prescribed uniformly in our study: regional sea level rise could trigger initial ice retreat in spite of cold conditions (O'Cofaigh et al. 2019);
- However, limited data from eastern ice sheet margin (Hughes et al. 2016): model/data mismatch might be caused by uncertainties in DATED-1 reconstruction;

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- Simulated deglaciation of the Barents Sea Ice Sheet starts with retreat of the western margin between 21-18 ky BP, driven by ocean forcing and amplified by the prescribed eustatic sea level rise: mismatch with DATED-1 can be explained by warm 200-400 m depth ocean forcing during this time;

- Retreat of eastern ice sheet margin starts after 15 ky BP, much later than DATED-1 suggests: regional atmospheric warming and sea level rise might explain the mismatch, although DATED-1 highly uncertain for this margin;

- Timing of disintegration of the connection with Fennoscandian ice sheet (16-15 ky BP) and final ice sheet collapse (15-13 ky BP) are in agreement with DATED-1 reconstruction; both events primarily driven by ocean forcing, with sea level rise amplifying the ice sheet response between 15-14 ky BP;

- Sub-shelf melting has a strong control on the simulated grounding-line discharge, showing that a prolonged, gradual ocean warming is capable of triggering sustained grounded ice discharge over multi-millennial timescales, without including positive feedbacks such as MISI and MICI.

Conclusion

- Simulated deglaciation of the Barents Sea Ice Sheet starts with retreat of the western margin between 21-18 ky BP, driven by ocean forcing and amplified by the prescribed eustatic sea level rise: mismatch with DATED-1 can be explained by warm 200-400 m depth ocean forcing during this time;

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Thank you for the attention!

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