Response of the Antarctic ice sheet to increased ice-shelf oceanic melting

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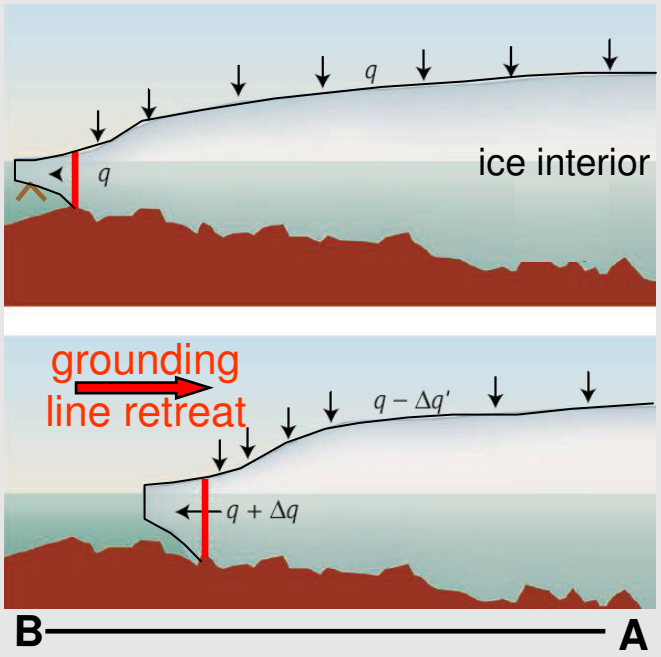
WAIS/FRISP Workshop, September 27-29, 2009

ANDRILL

NSF

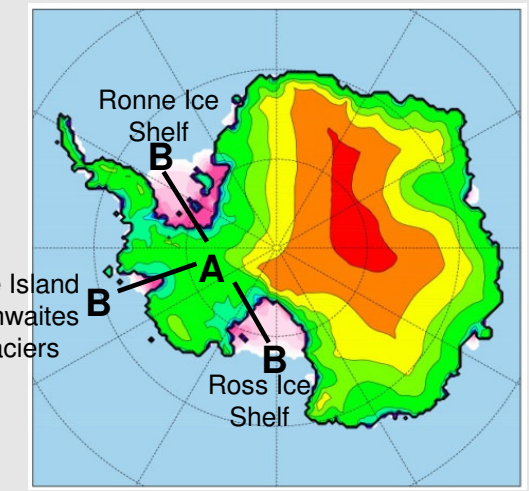
CReSIS
Center for Remote Sensing of Ice Sheets

Grounding-Line Retreat Instability



- Ice velocities across the grounding line…
  - are slowed by ice-shelf buttressing
  - increase strongly with g.l. depth $\left(h_g^{\frac{m+n+3}{m+1}} \right)$
- So, if ice-shelf buttressing is lost, and the bed deepens upstream...then possibility of runaway retreat !

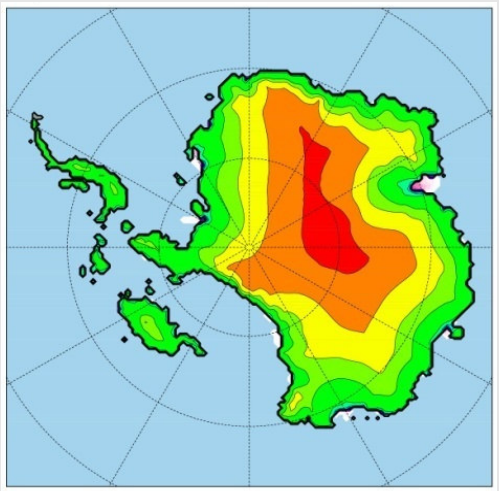
Weertman (1976, Nature); Mercer (1978, Nature); Schoof (2007, JGR)

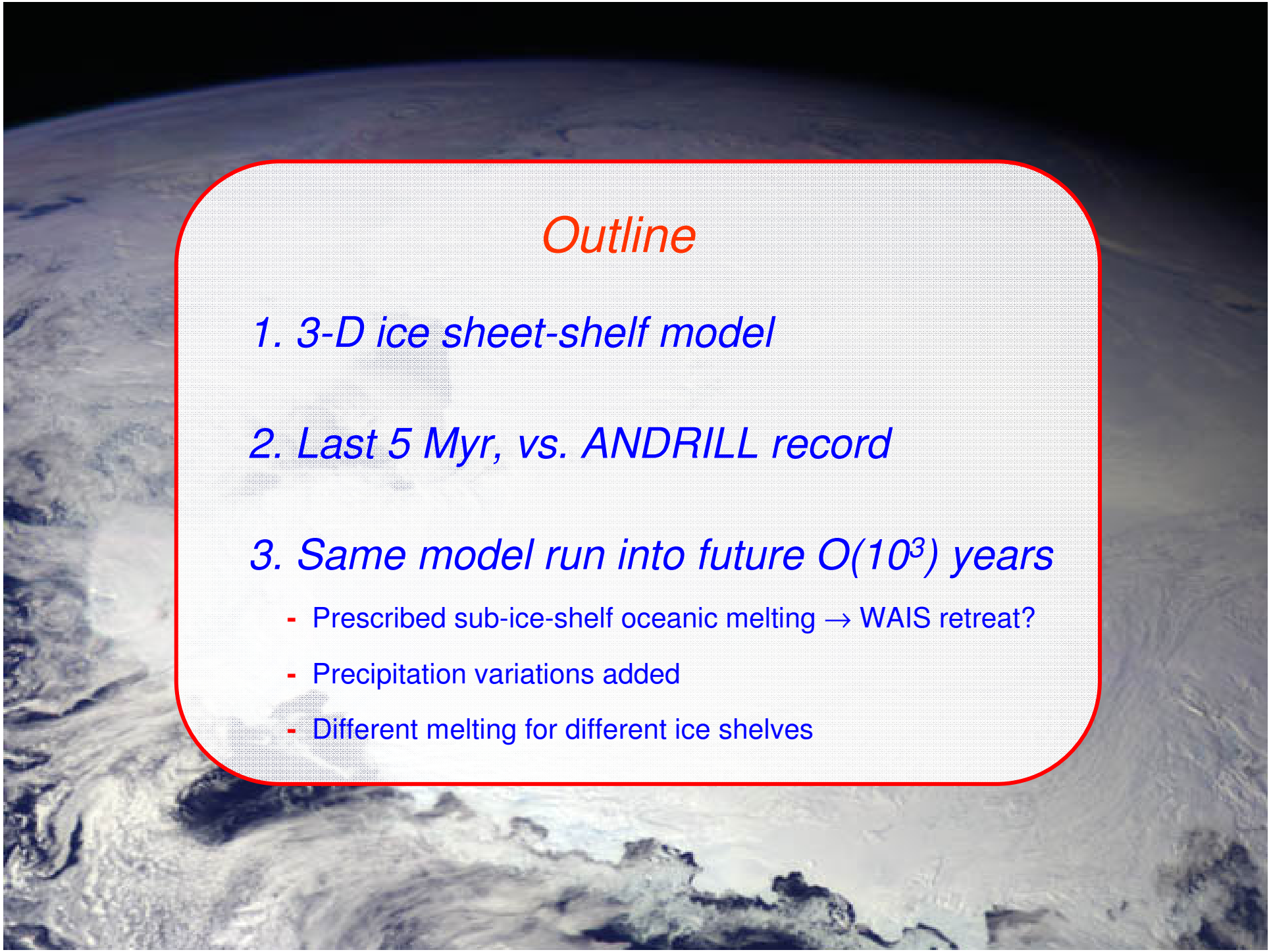


?

in 100 years?

in 1000+ years?





Outline

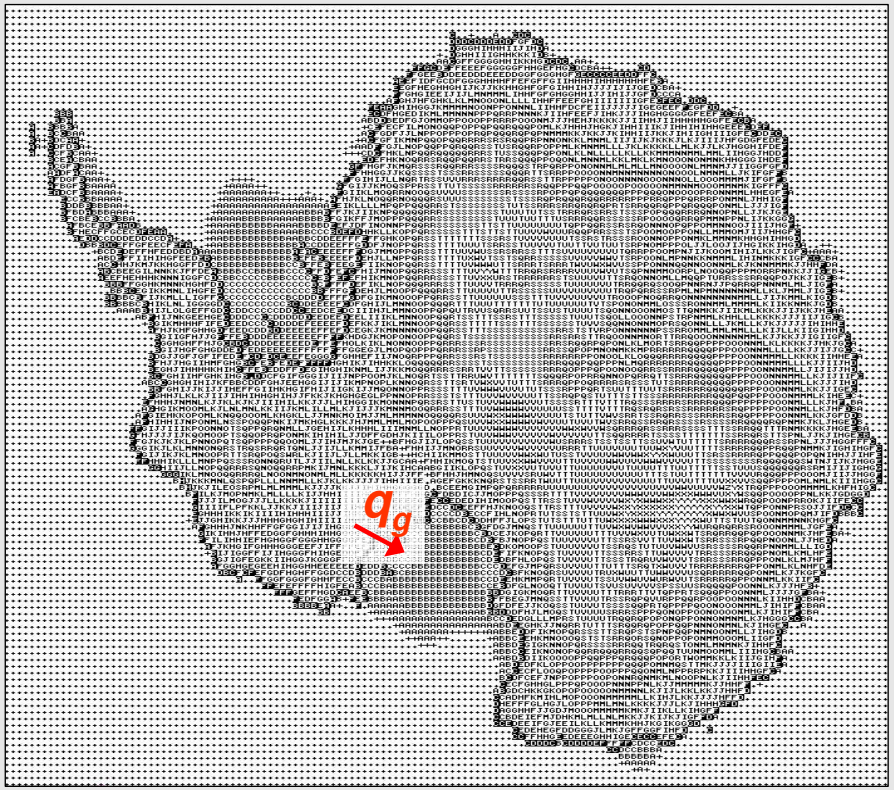
1. 3-D ice sheet-shelf model

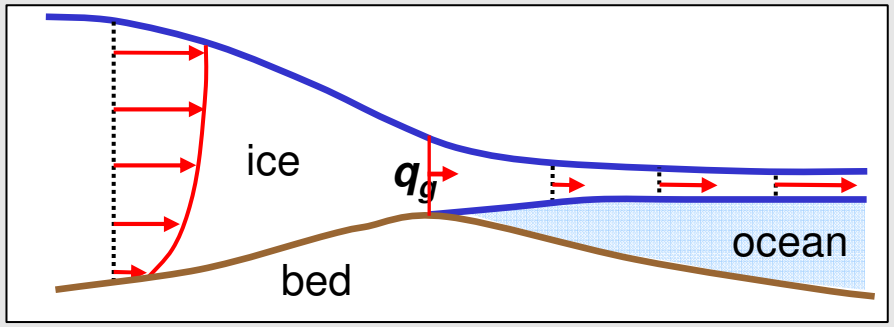
2. Last 5 Myr, vs. ANDRILL record

3. Same model run into future O(10^3) years

- Prescribed sub-ice-shelf oceanic melting → WAIS retreat?
- Precipitation variations added
- Different melting for different ice shelves

Features in ice sheet-shelf model





Predicts ice thickness, temperature, bedrock elevation. 40 km grid size. Follows standard model lineage…

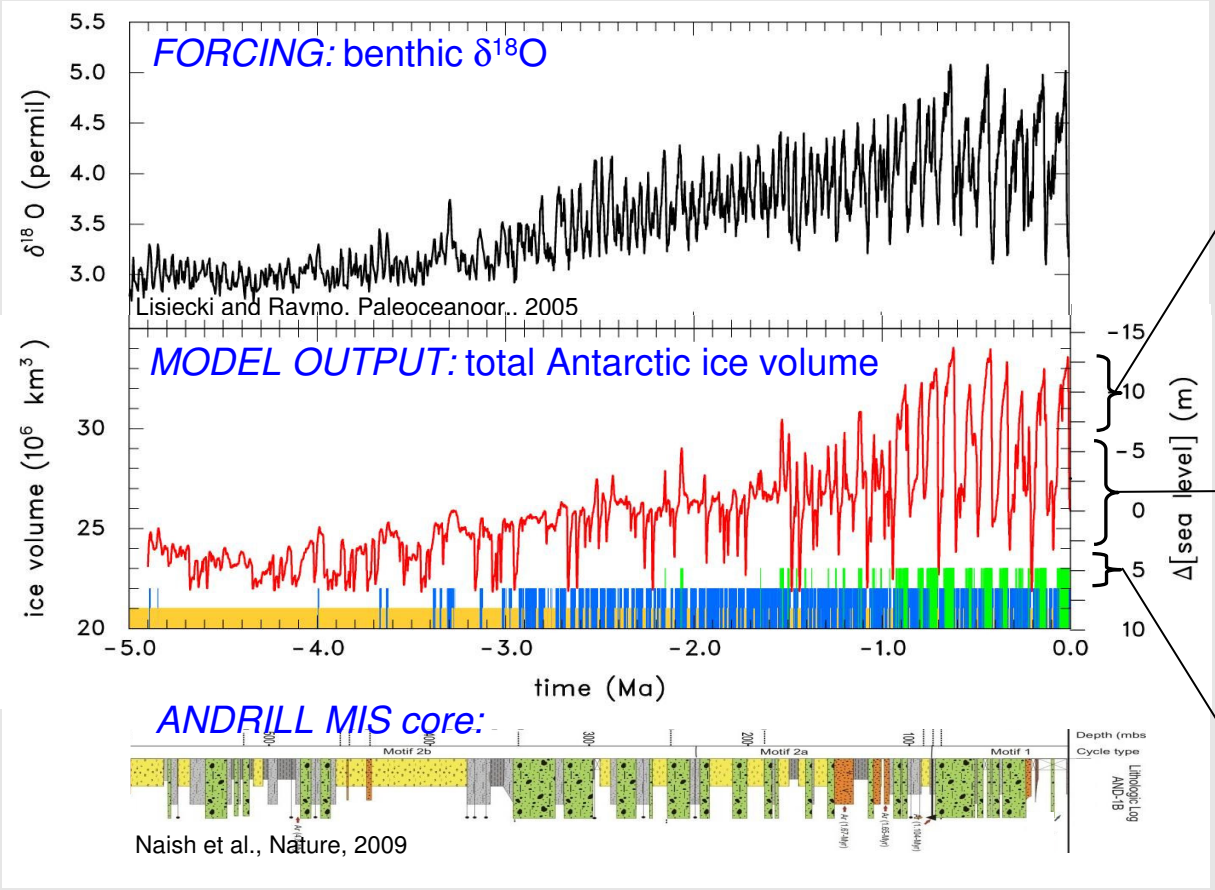
PLUS:

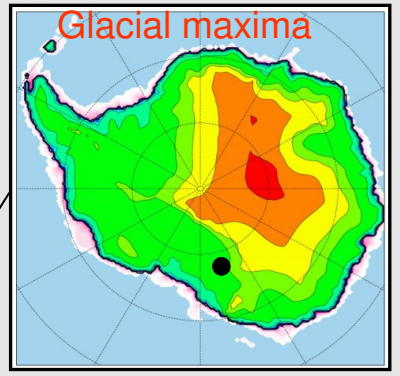
1) Hybrid combination of the 2 scaled equations for shearing (grounded interior) and stretching (floating/stream) ice flow

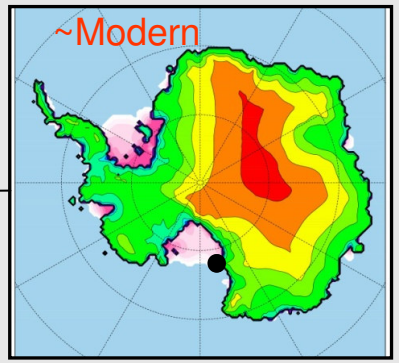
2) C. Schoof's (2007,JGR) parameterization of flux across grounding lines (q_g). Allows realistic grounding-line migration and ice-shelf buttressing

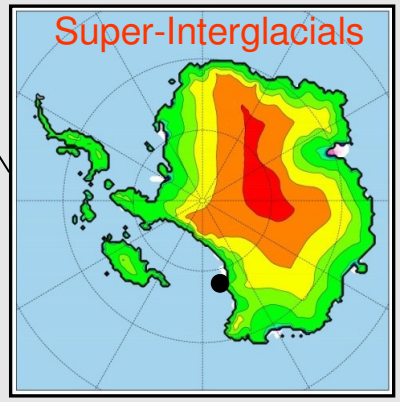
3) Simple parameterizations of forcings:
   - sea level
   - surface mass balance and temperature
   - sub-ice-shelf oceanic melt rate

Model Antarctic ice volume, last 5 million years





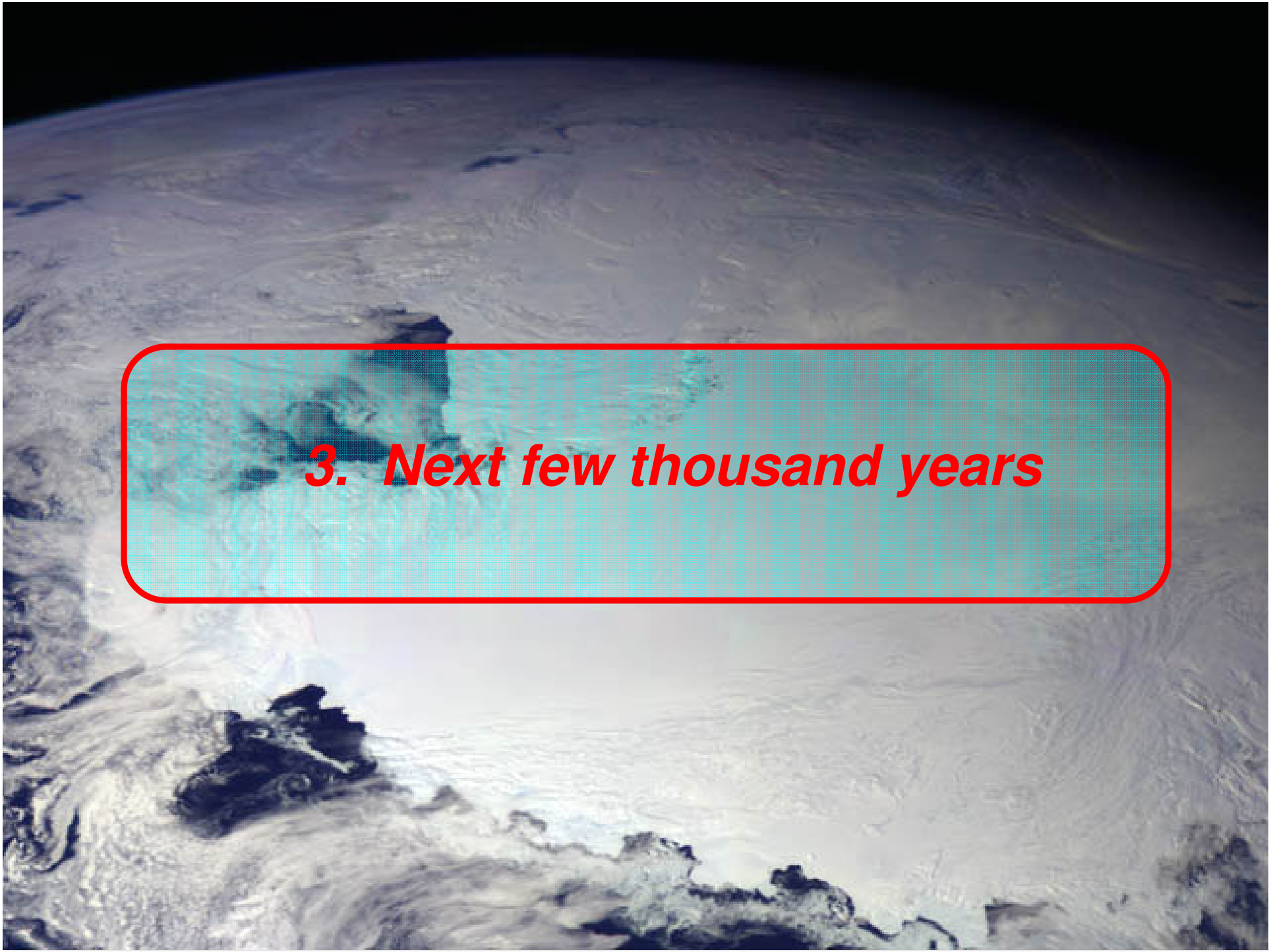




pink = floating ice shelves

Closest model grid point and ANDRILL core agree:

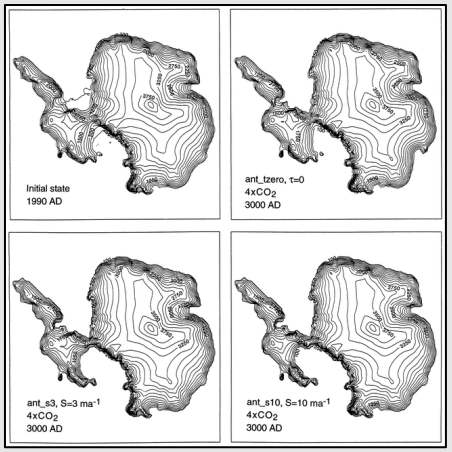
- ~5 to 3 Ma: Long periods with open ocean
- ~3 to 1 Ma: Cooling trend
- ~1 to 0 Ma: Current glacial cycles


3. Next few thousand years

Future WAIS Collapse? – previous work

- Previous 3-D ice sheet-shelf models have found that:
  - Sub-ice-shelf oceanic melting is likely to be dominant, via shelf thinning → loss of buttressing → marine instability
  - Melt rates of a few meters per year under large shelves ⇒ marine WAIS collapse in O(10^3) years

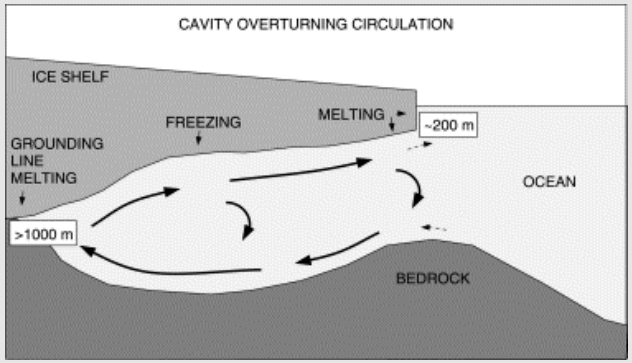
Huybrechts and de Wolde, J. Clim., 1999



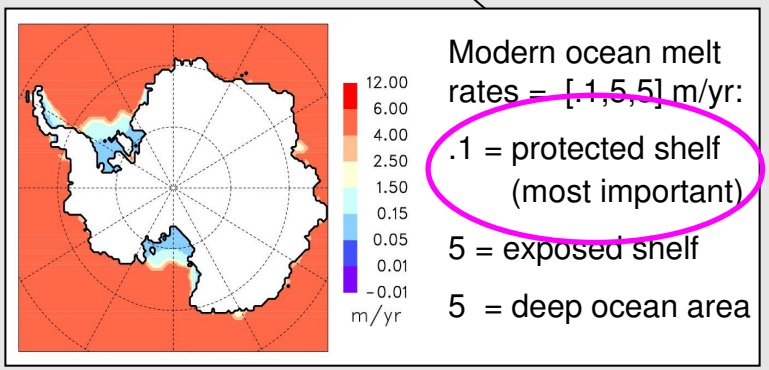
Also:
Warner and Budd (Ann. Glac., 1998);
Swingedouw et al. (GRL, 2008)

- We add:
  - Schoof (JGR, 2007) grounding-line flux treatment
  - "Validation" vs. ANDRILL Plio-Pleistocene and last deglaciation

- Future scenarios of oceanic melting are not yet available.
  We use a simple parameterization, and prescribed step-function increase

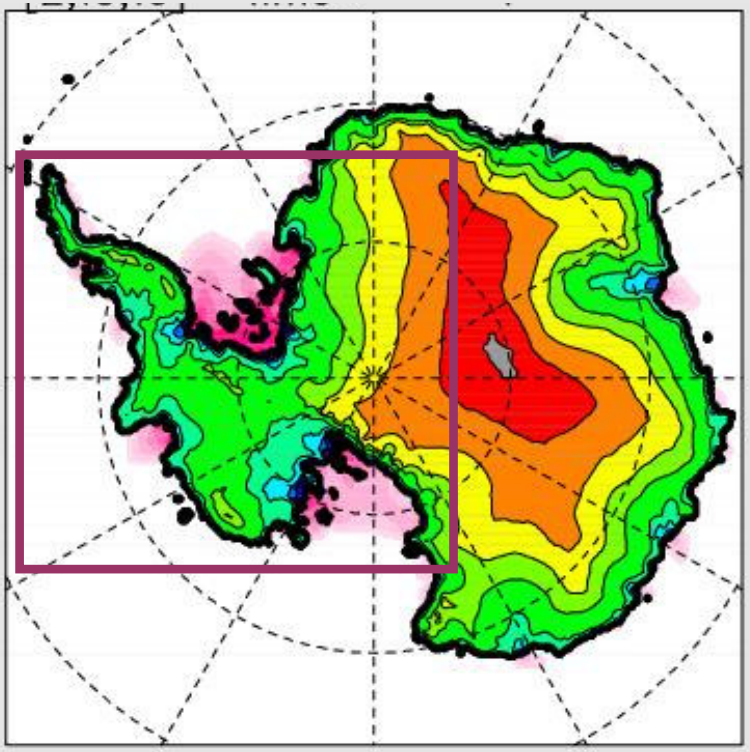


Beckmann and Goose, Ocn. Mod., 2003

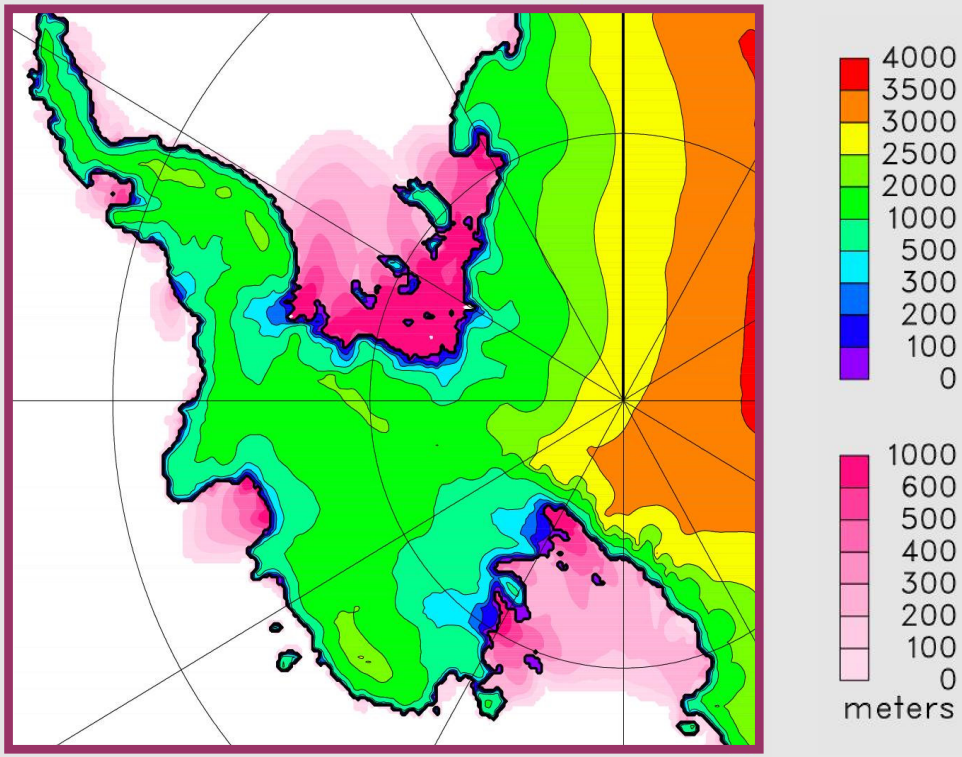


Nested domain over West Antarctica

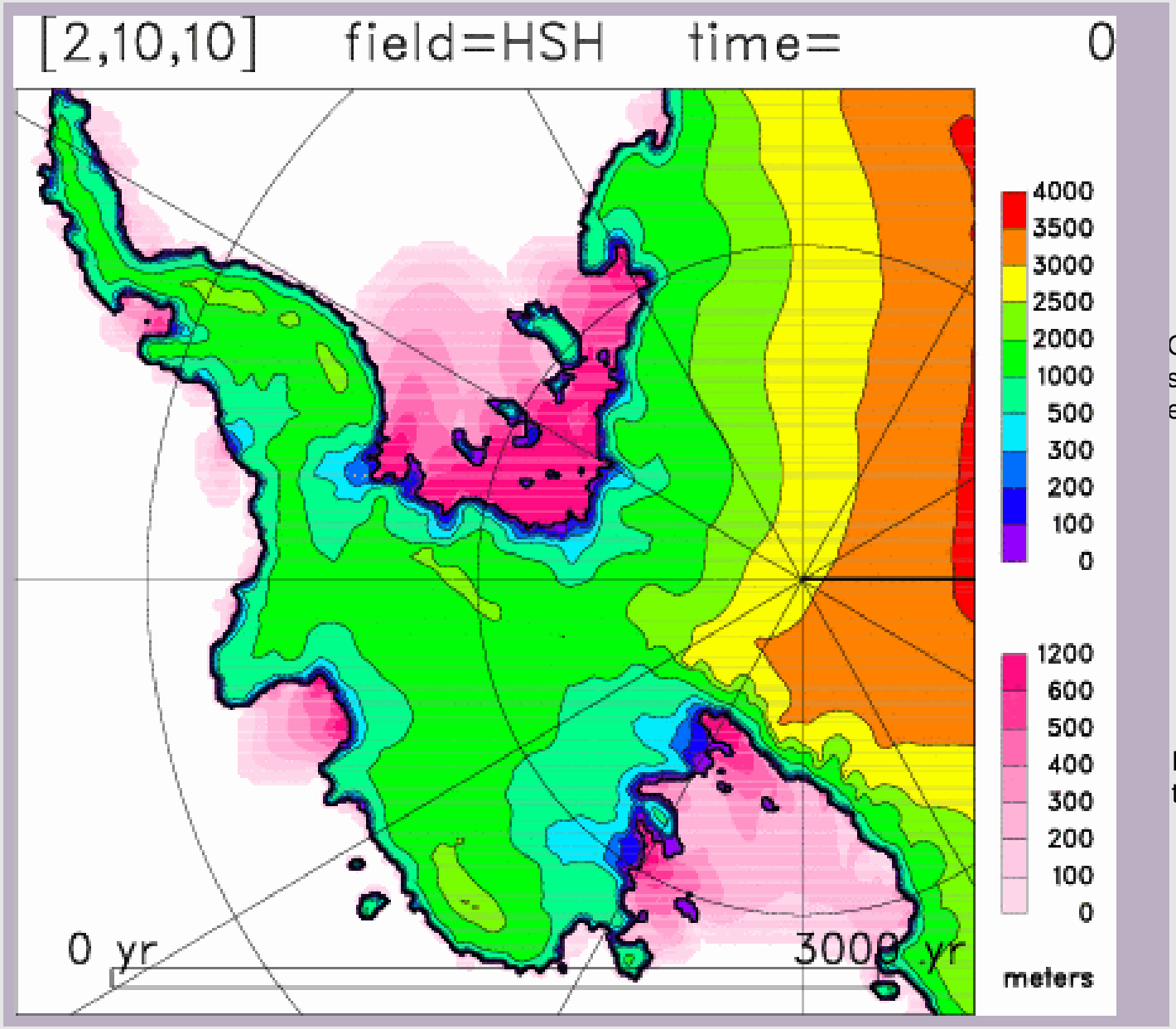
Continental Antarctica, 20 km grid



Nested WAIS, 10 km grid



Ocean melt = 2 m/yr for interior shelves
0 to 3000 yr



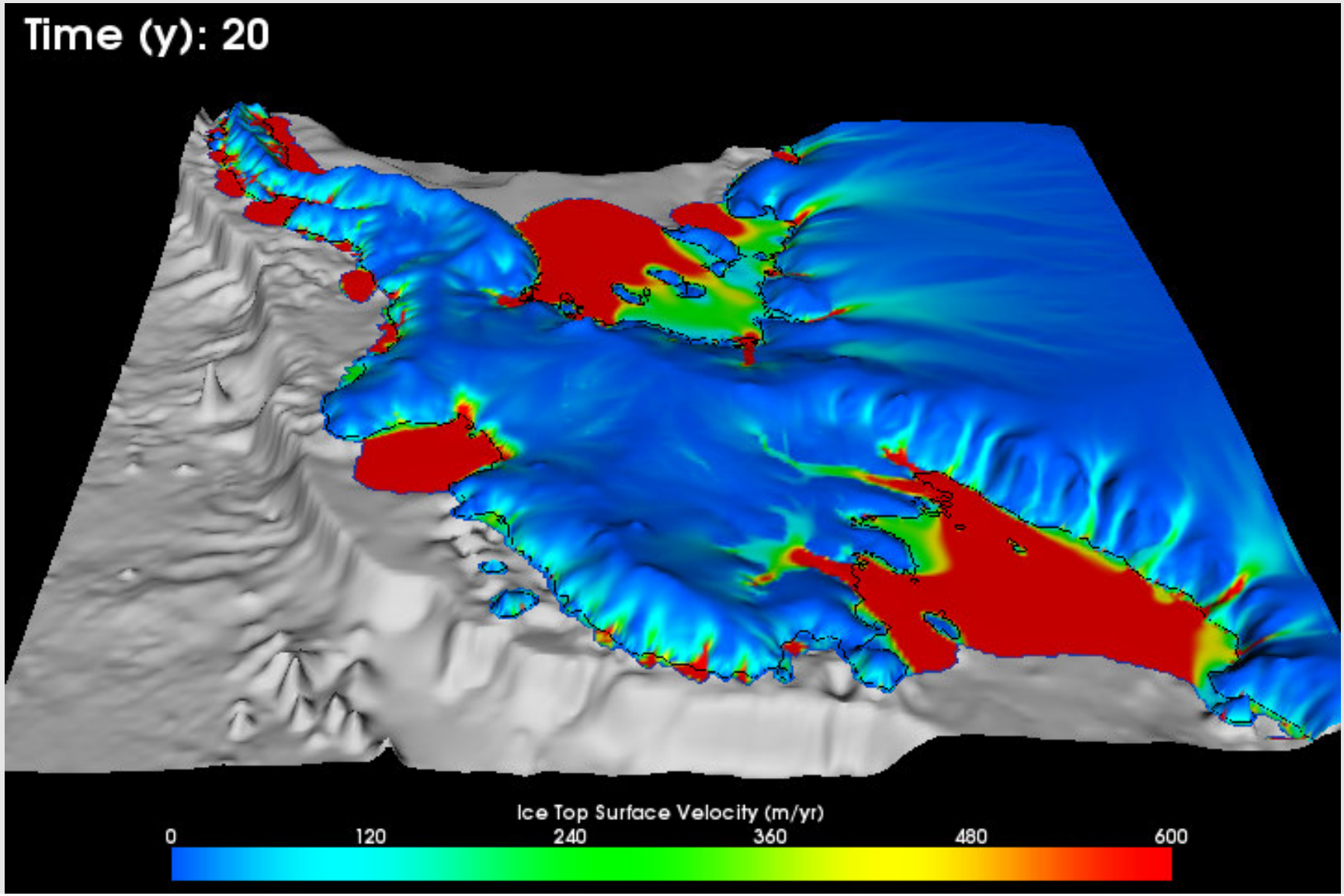
Grounded ice surface elevation (m)

Floating Ice thickness (m)

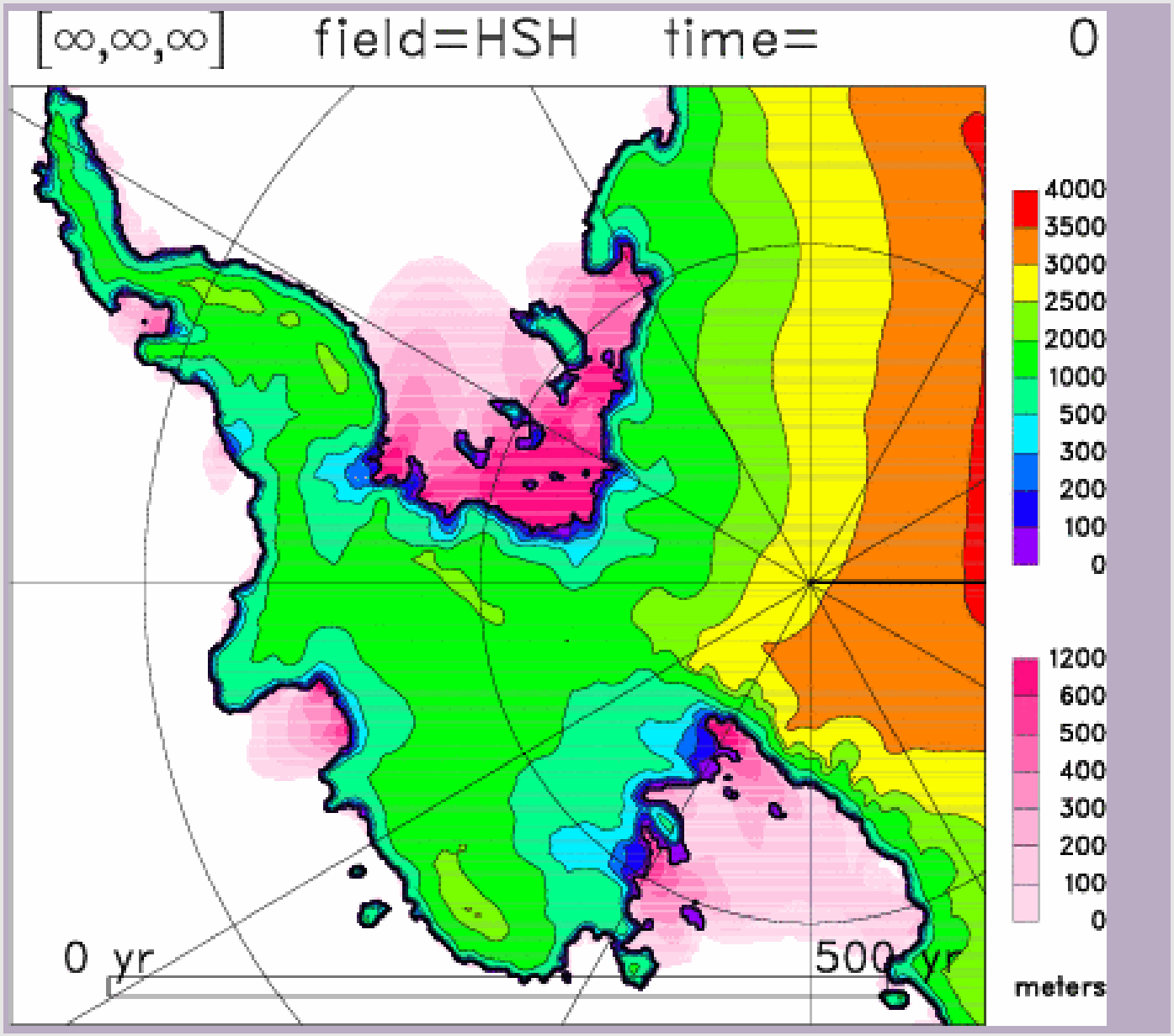
Ocean melt = 2 m/yr for interior shelves
0 to 4000 yr

Ice surface velocities (m/y)

Graphics by Chuck Anderson, EESI, Penn State



Ocean melt = “infinity”
0 to 500 yr



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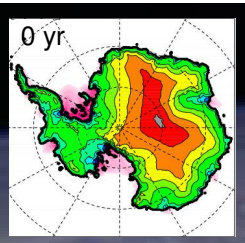
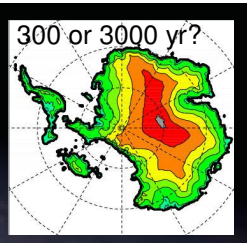
Floating Ice thickness (m)



Future WAIS summary



- **Given plausible future increases in sub-ice-shelf ocean melting, central WAIS is likely to collapse**

- **Time scale of collapse depends on magnitude of sub-ice ocean melt:**
  - 2 m/yr → ~3000 years, ∞ m/yr → ~300 years
  - What future melt rates for the major ice shelves?

    … Will need Regional Ocean Models and GCMs for projections.

    … Different rates for different embayments? Already ~30 m/yr for PIG-TG!

- **Net sea level contribution is reduced by future Antarctic snowfall (from ~3 m to 2 m?)**

- **Test with next generation higher-order higher-resolution ice models!**