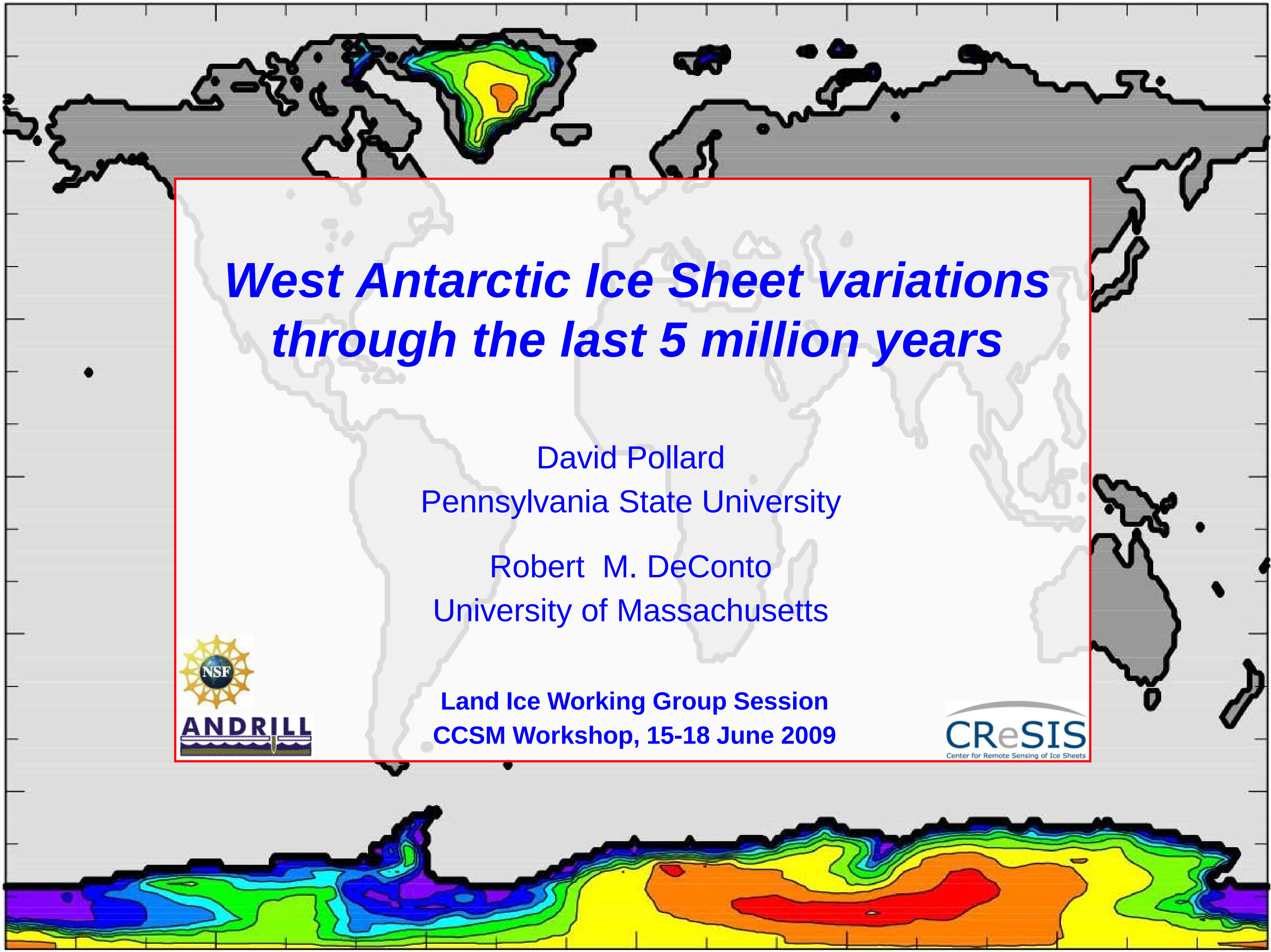

West Antarctic Ice Sheet variations through the last 5 million years

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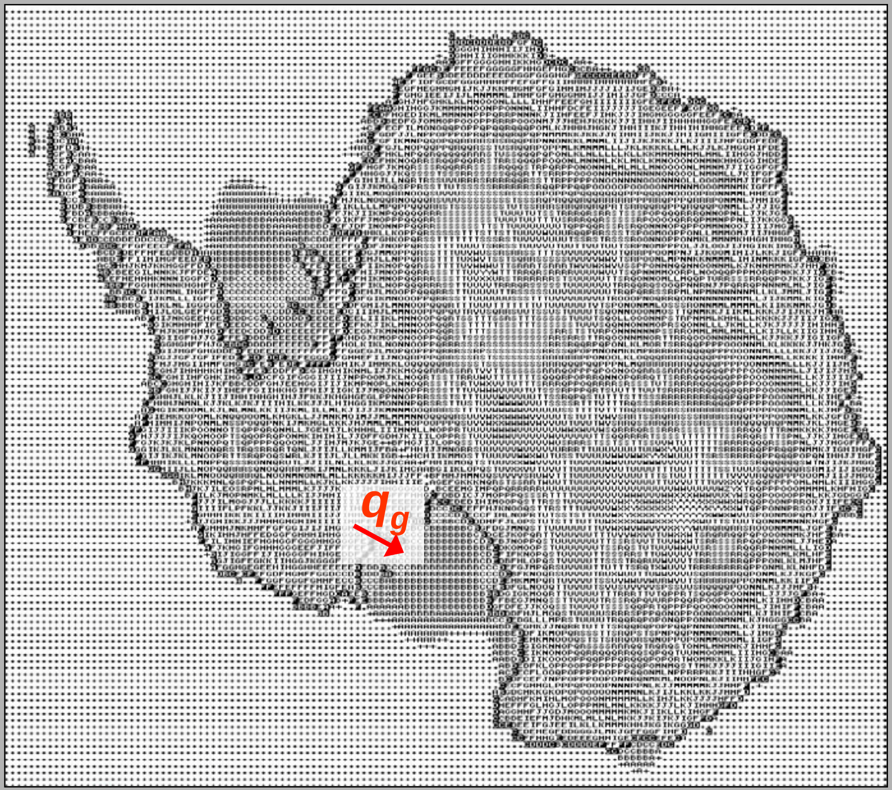
Land Ice Working Group Session
CCSM Workshop, 15-18 June 2009

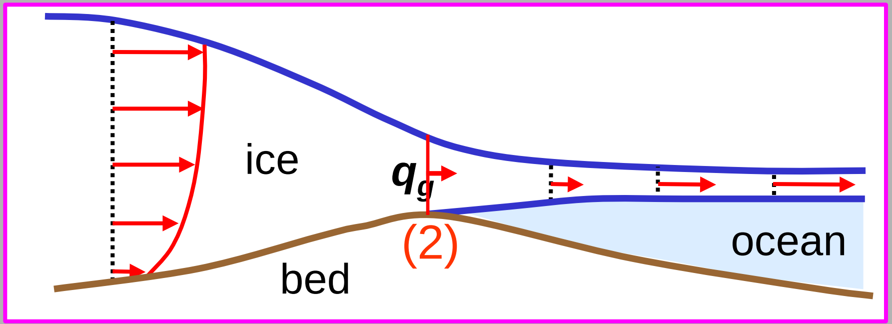
Outline

Antarctic ice sheet model applied to last 5 Myr

- New model features, prescribed climate forcing
- Results compared with ANDRILL sediment core record
- Other topics: ice streams, last deglaciation

Features in 3-D ice sheet-shelf model





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

PLUS:

1) Heuristic combination of the 2 scaled equations for shearing and stretching flow (~grounded vs. floating ice velocities)

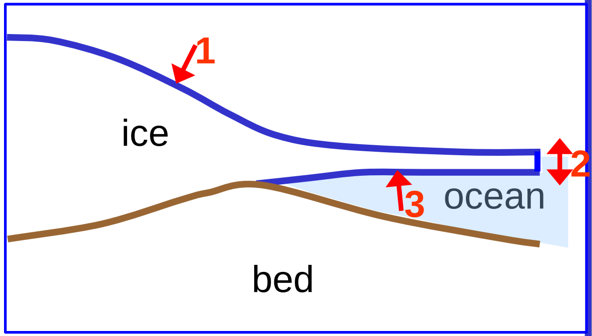
2) C. Schoof's (2007,JGR) parameterization of flux across grounding lines. Allows realistic grounding-line migration and ice-shelf buttressing

$$q_g = u_g h_g = A\, h_g^{\left(\frac{m+n+3}{m+1}\right)}$$

h_g = thickness, u_g = velocity, q_g = flux

Climate forcing needed for last 5 million years

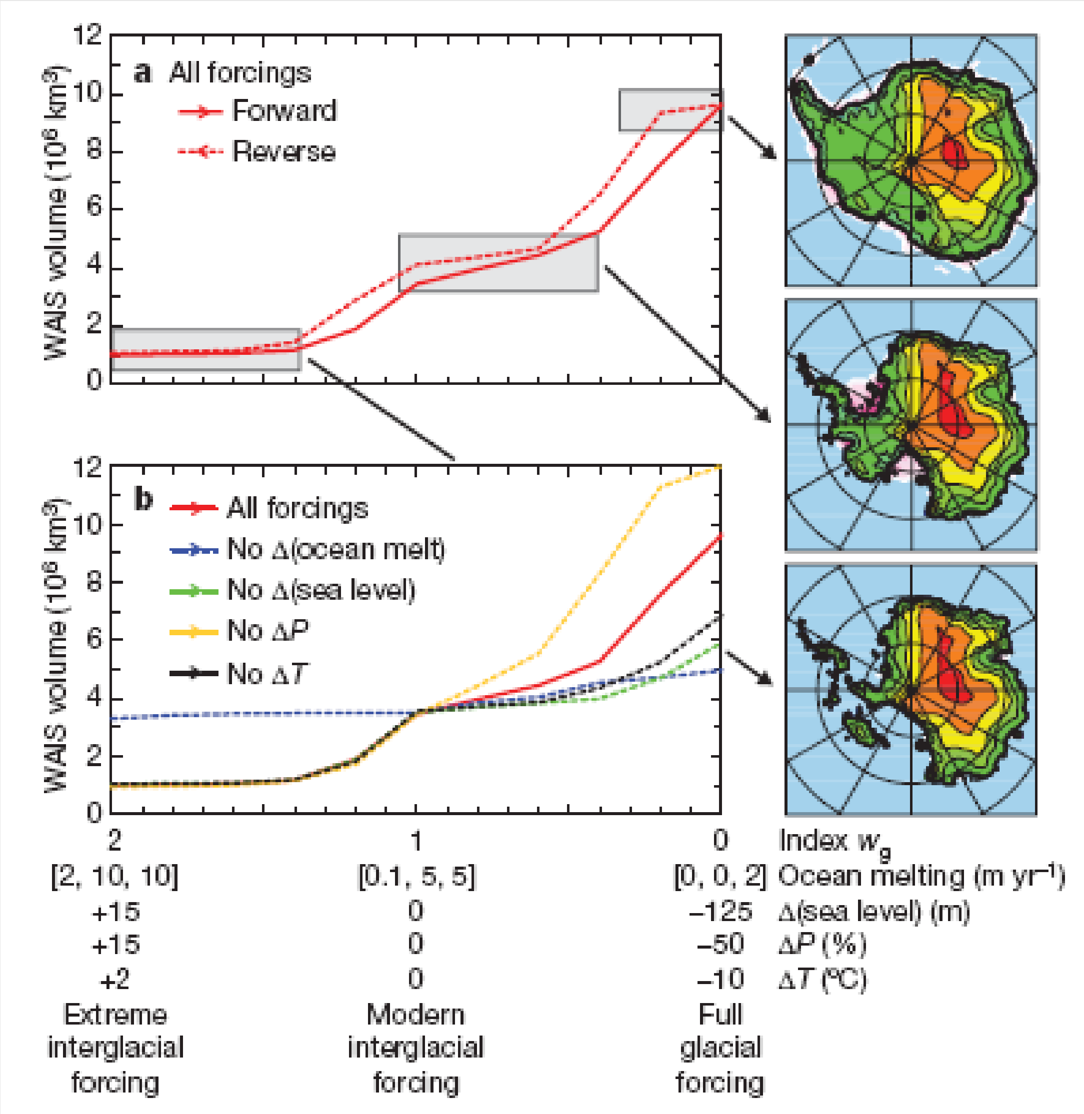
- Three forcing fields must be provided to drive any ice-sheet-shelf model:
  1. Surface mass balance
  2. Sea level
  3. Sub-ice-shelf oceanic melt



- Use empirical parameterizations for modern (1-3), and past (1-2)

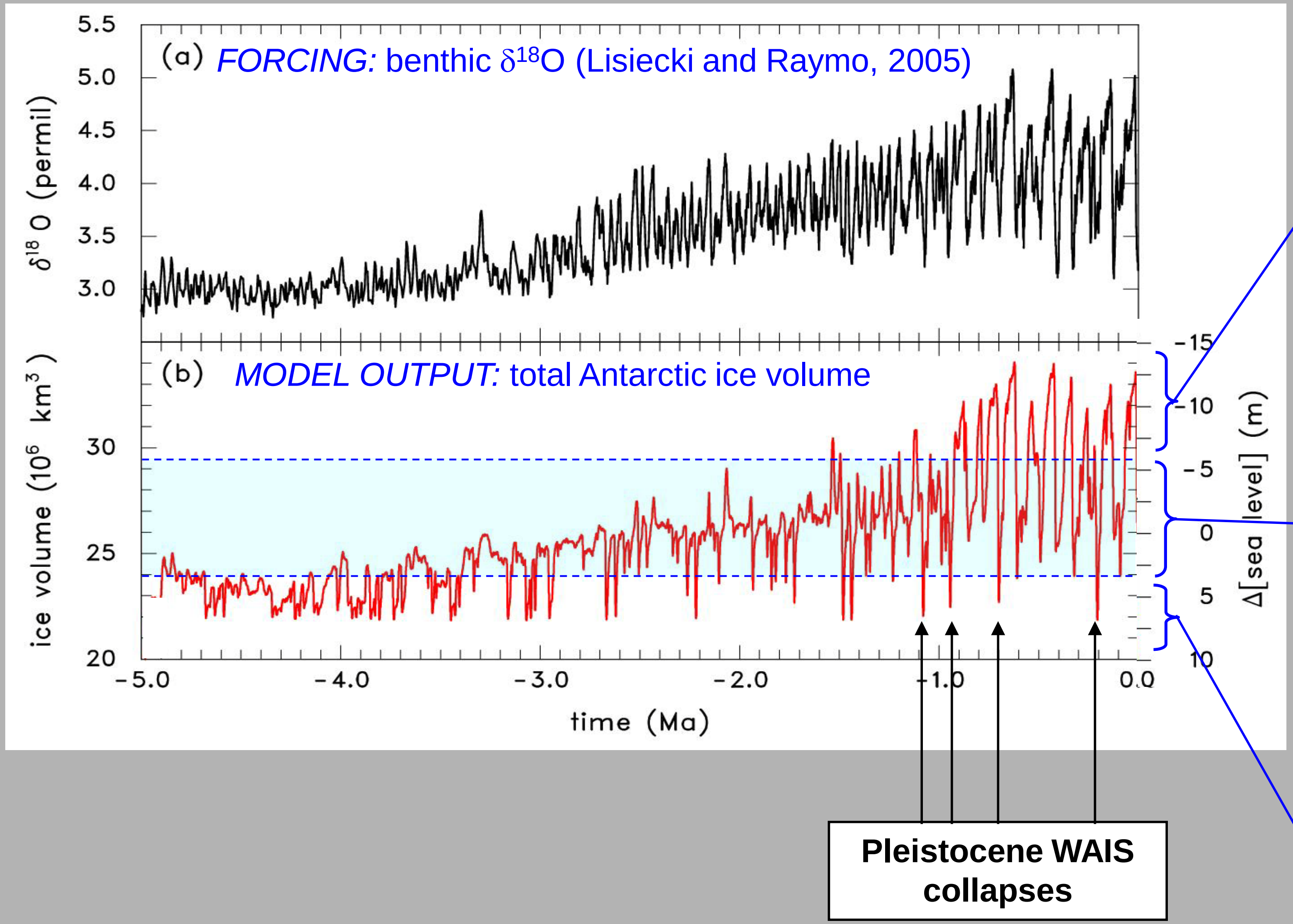
- Past variations of sub-ice oceanic melting (3) are assumed to be controlled by far-field changes*, proportional to deep-sea-core benthic $\delta^{18}O$ record

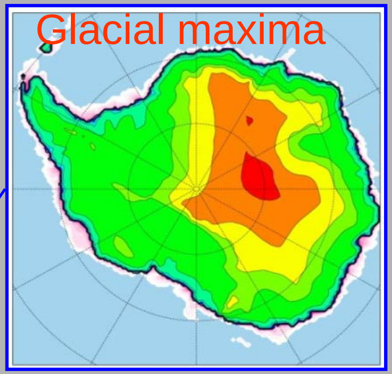
* via thermohaline circulation for instance…not dominated by local orbital insolation. Our reasoning is based on last deglacial sequence ~15 to 0 ka.

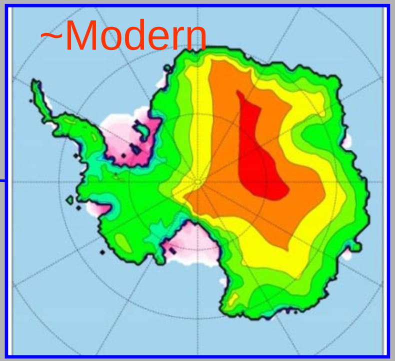


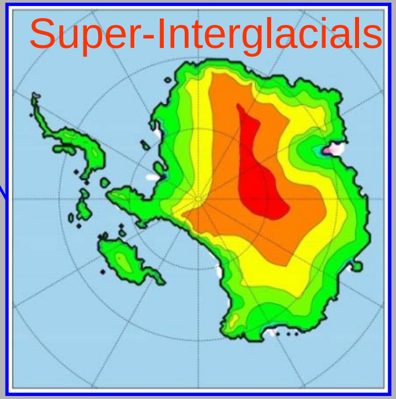
Pollard and DeConto, 2009

Model Antarctic ice volume, last 5 million years

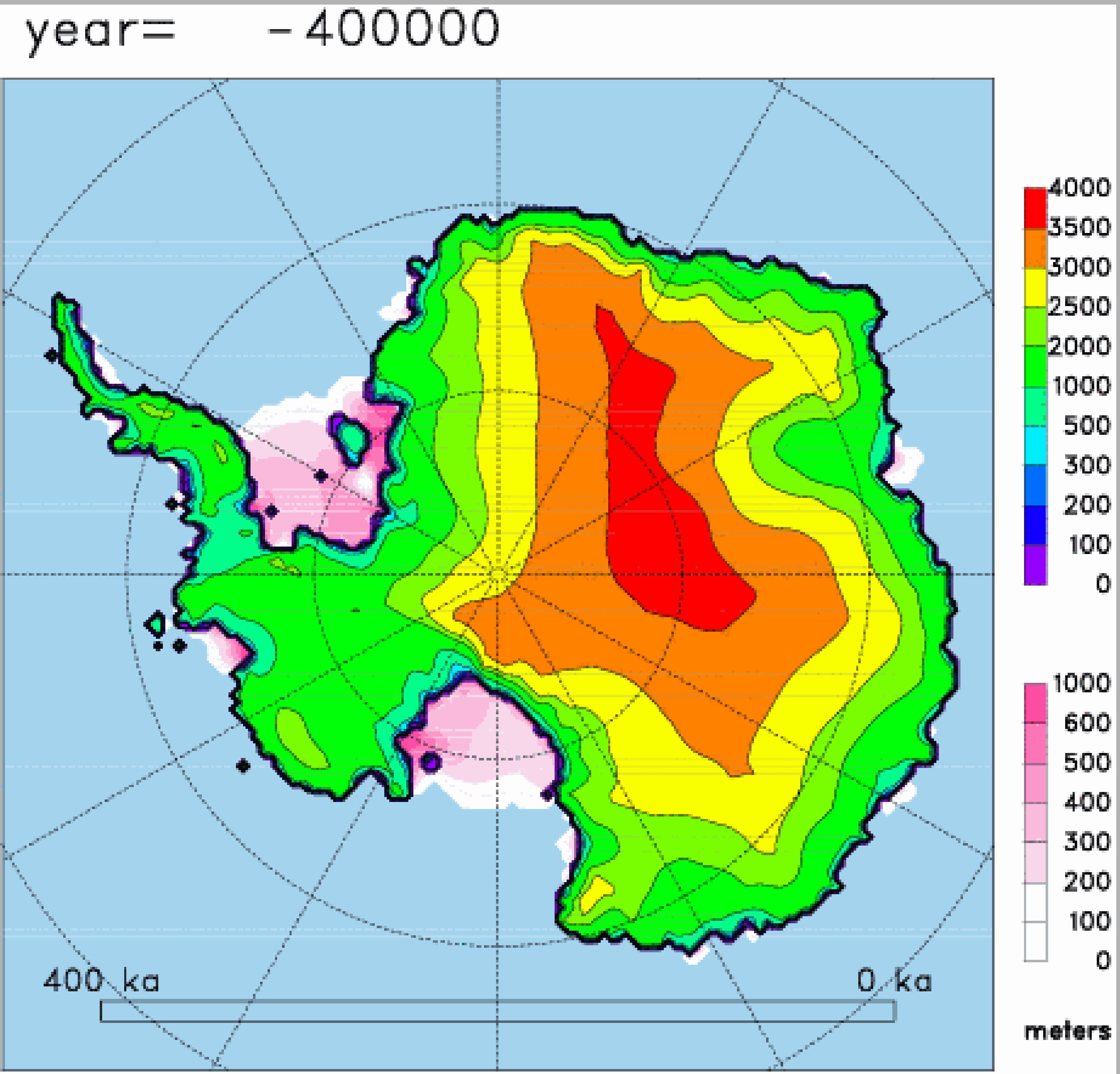


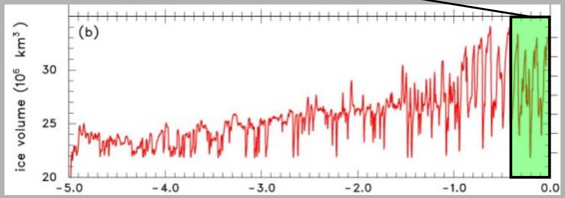






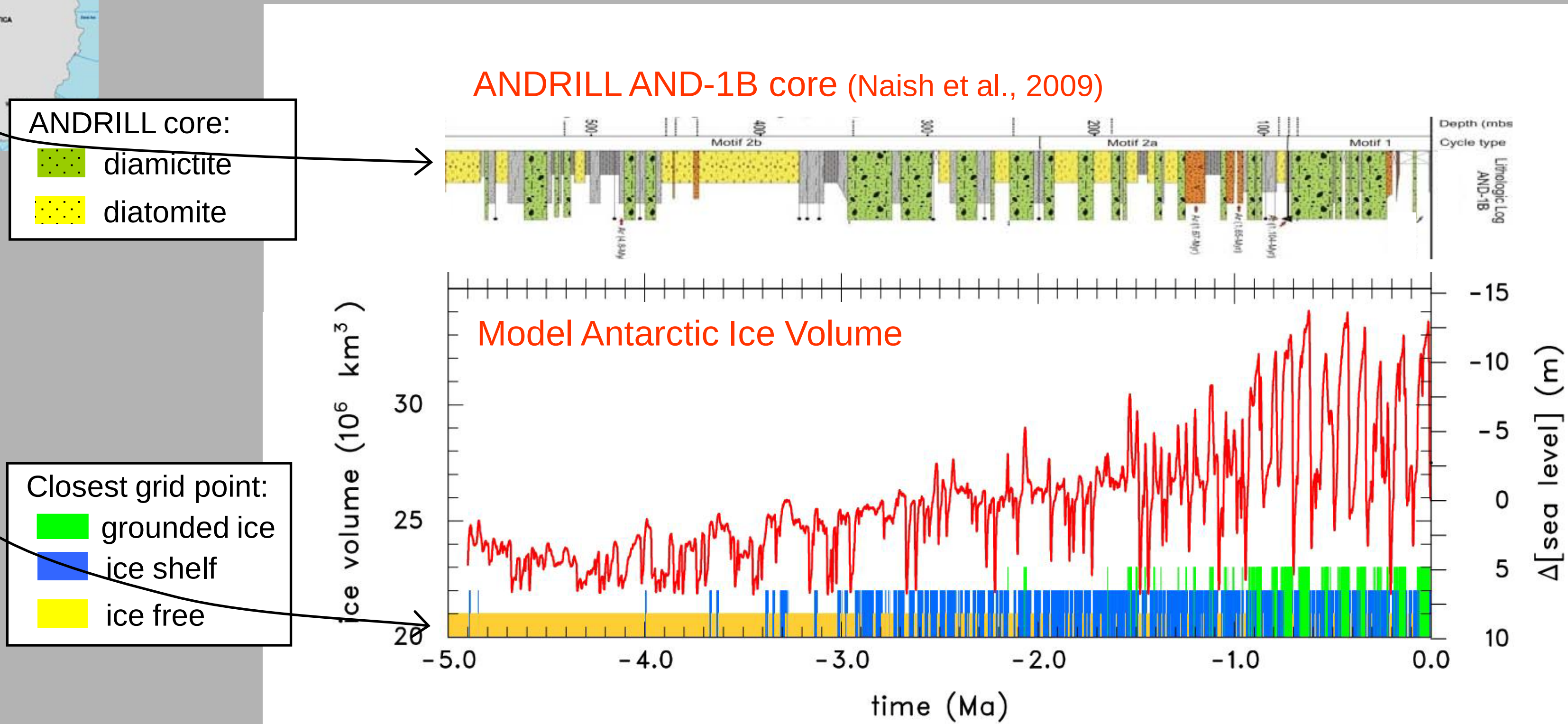
Ice elevations (thickness if floating), last 400,000 years





- EAIS is ~stable, WAIS varies
- WAIS retreats are short-lived, sudden
- WAIS sectors vary in unison, “one-dimensionally”

ANDRILL vs. closest model grid point



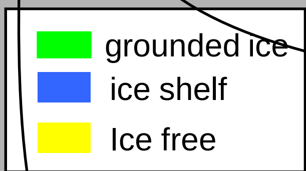
Closest model grid point and ANDRILL core agree:

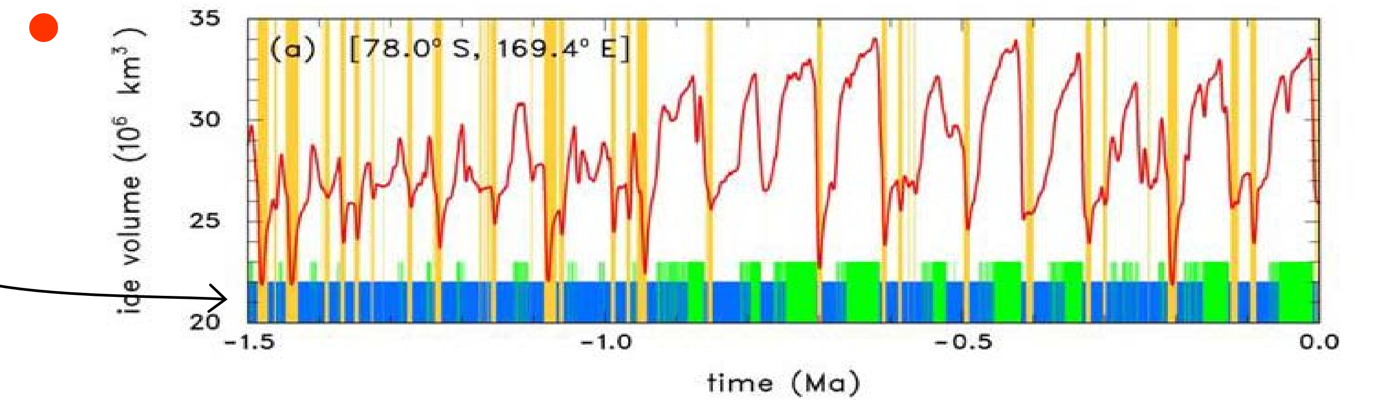
- ~5 to 3 Ma: Long periods with open ocean
- ~3 to 1 Ma: Cooling trend
- ~1 to 0 Ma: Current glacial cycles

Naish et al., 2009, Nature

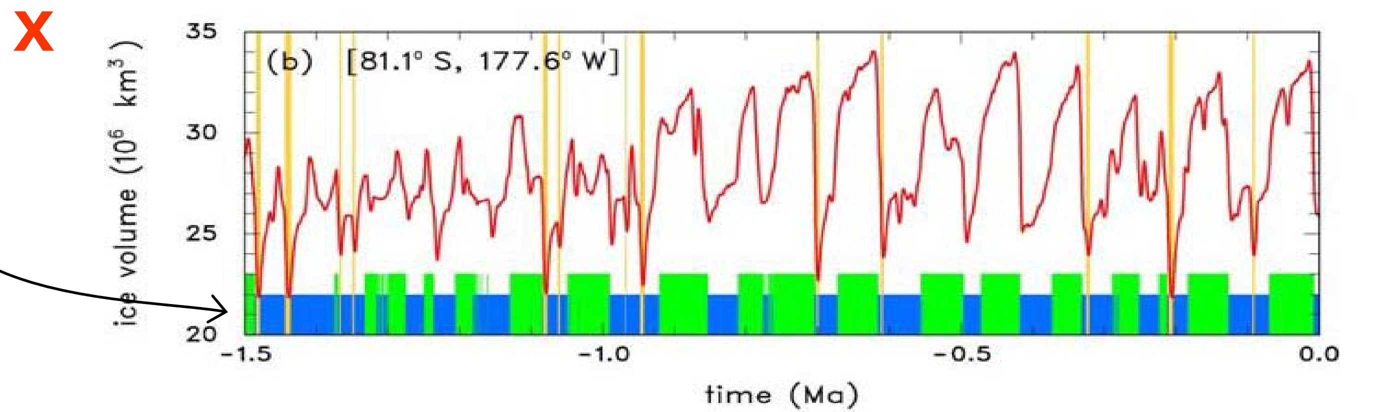
Pollard and DeConto, 2009, Nature

ANDRILL represents WAIS extent





Ice-free conditions at ANDRILL site (●) ⇔ partial WAIS retreats

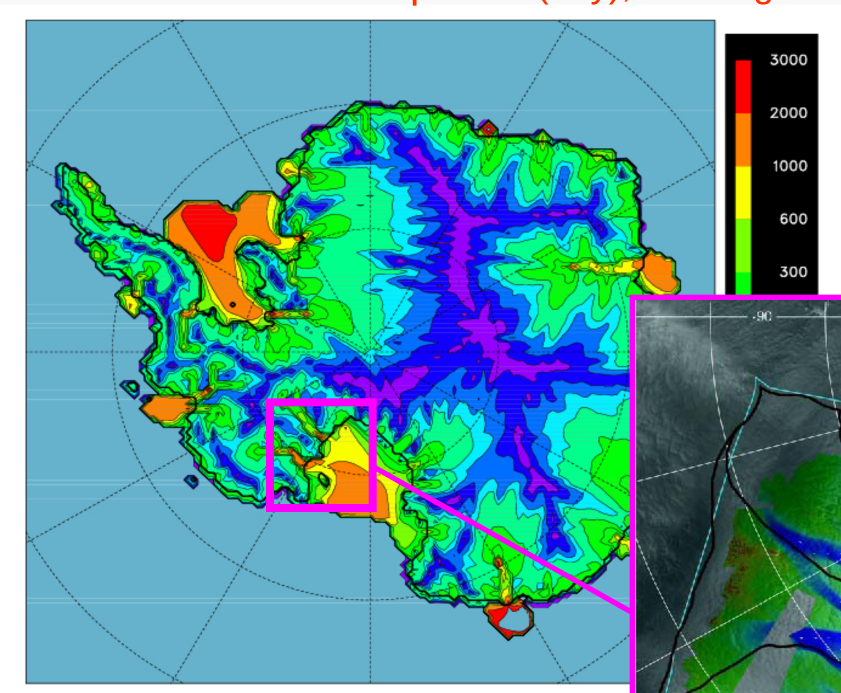


- Sites closer to WAIS (X) could better identify WAIS *collapse,* assuming enough accomodation space, little erosion ***(BUT HARD TO FIND?)***


Other topics: (1) Ross ice streams
(2) Last deglacial retreat

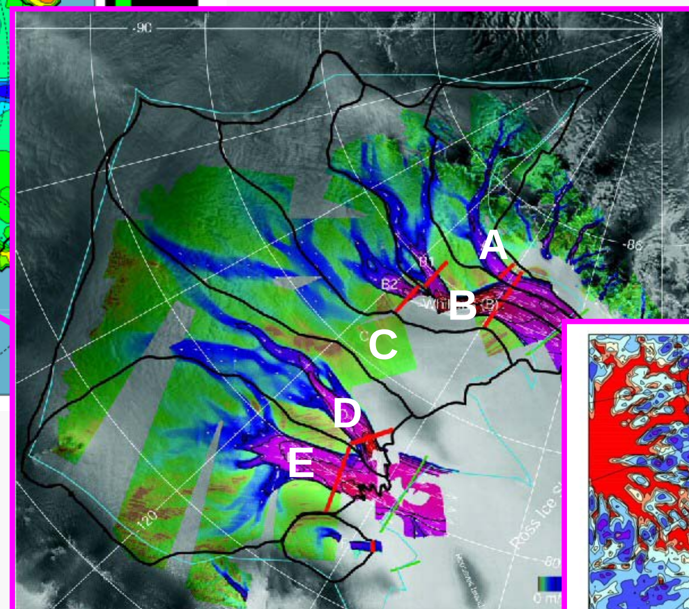
Resolving WAIS ice stream networks: Nested model

Model surface ice speeds (m/y), 40 km grid

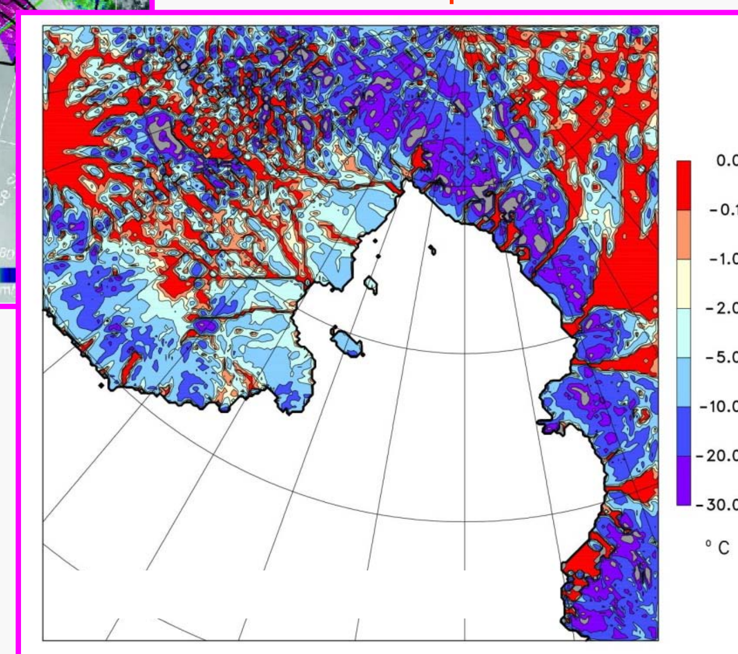


Observed speeds

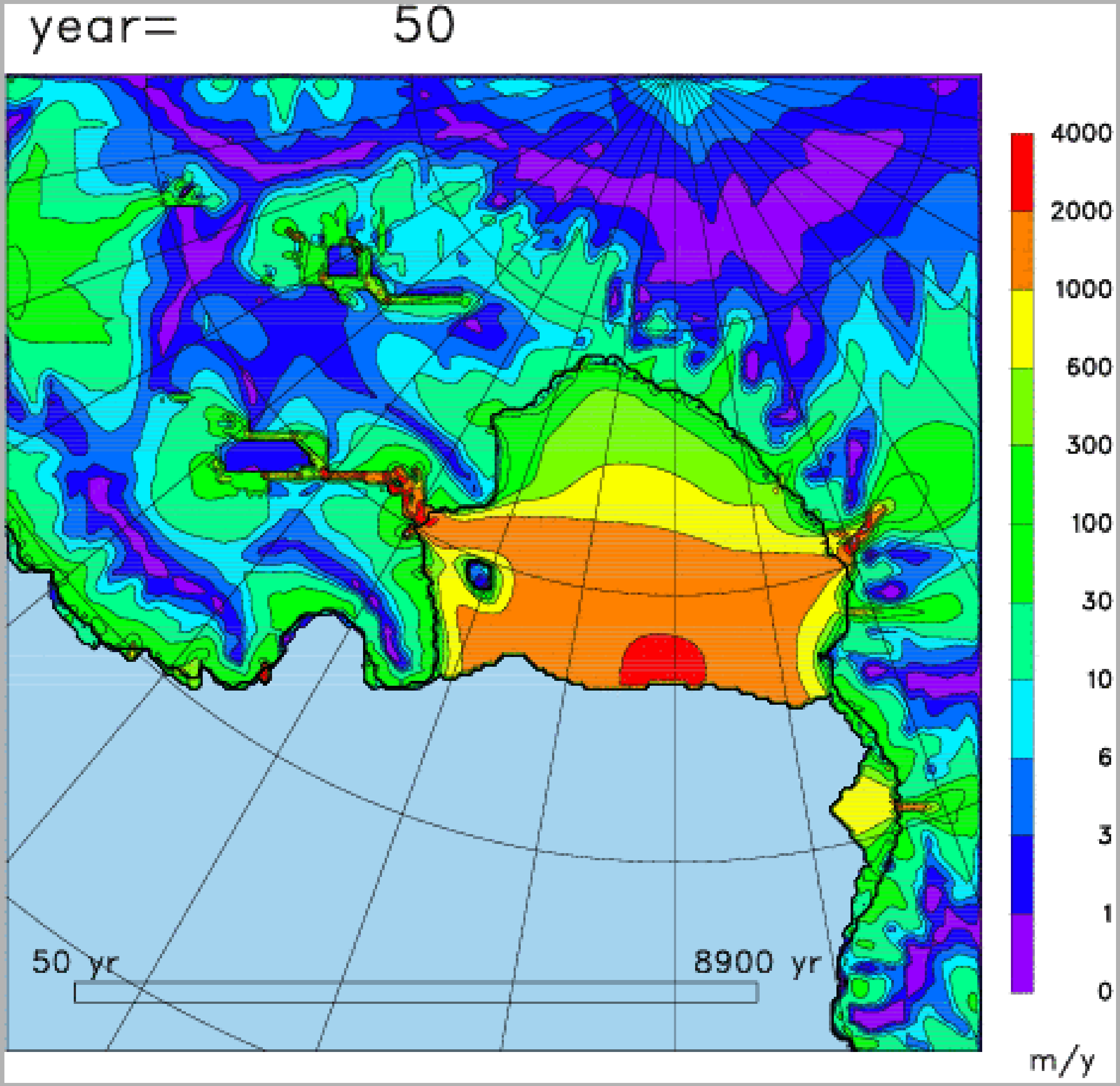
(I. Joughin, U. Washington, in C. Raymond, Science, 2002)

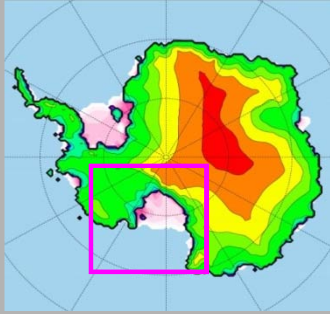


Nested model, 10 km grid, basal temperatures



Nested-model ice stream fluctuations, 100's to 1000's yr time scales





Reminiscent of observed !

- C stoppage ~150 yr BP
- B,E stoppages 850-400 yr BP
- Fold in D ~1500 yr BP

(Rettzlaff and Bentley, 1993, J. Glac.; Hulbe and Fahnestock, 2007, JGR; Siegert et al., 2004, Science)

Fluctuations previously found in standard ice-sheet model:

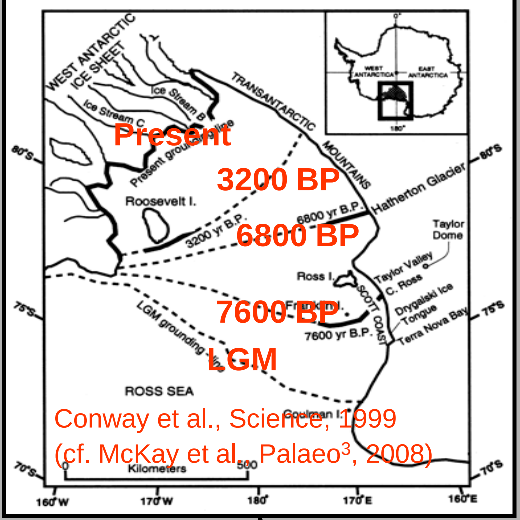
A.J. Payne, 1999, Clim. Dyn.

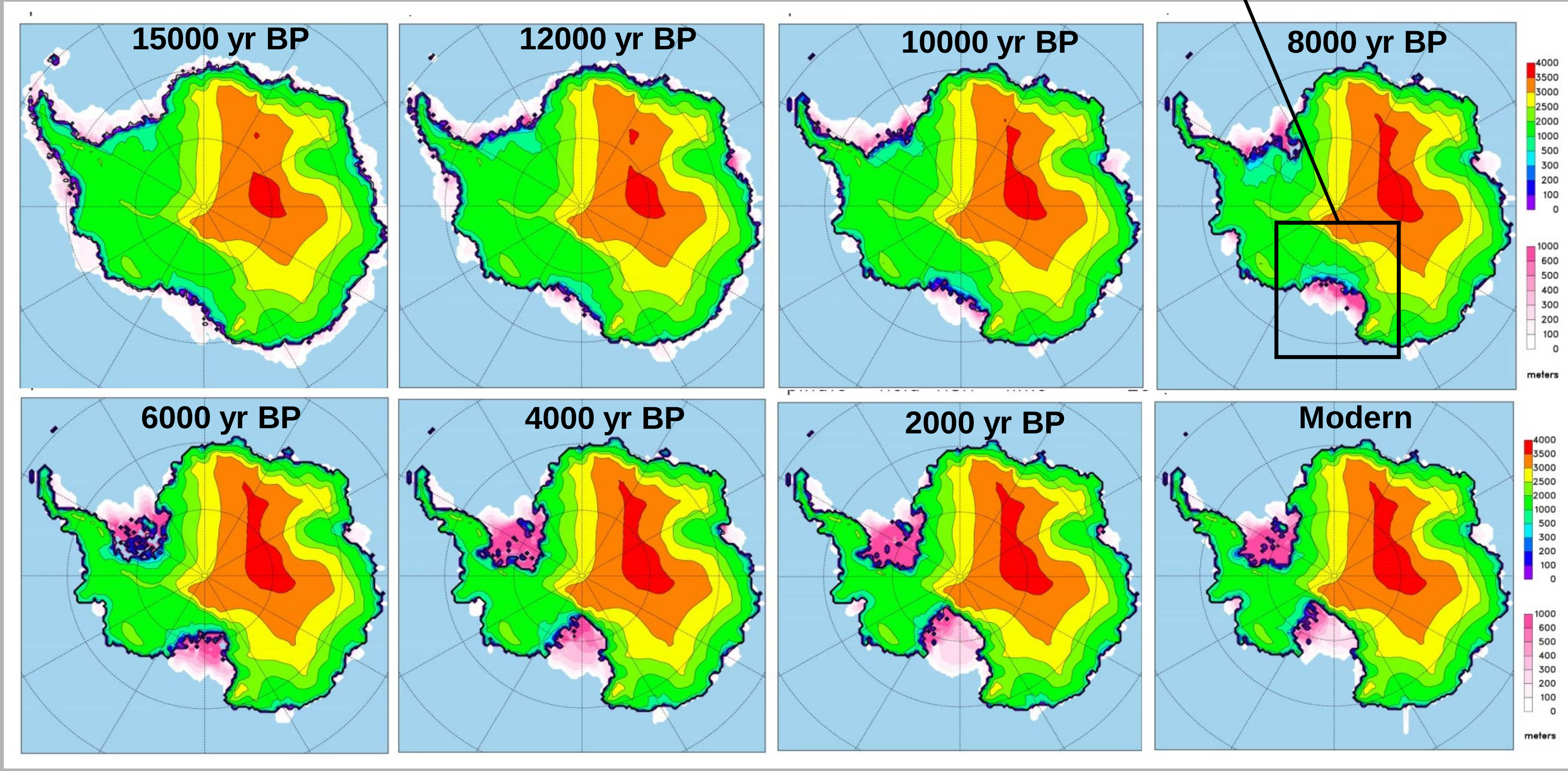
(cf. Hulbe and MacAyael, 1999, JGR; Jamieson et al., 2008, Geomorph.)

Grounding line retreat in Ross Embayment ~15 to 0 ka

- Good opportunity for model validation
- Need sub-grid ice-shelf pinning for best result

(Previous 3-D models: Budd et al., 1998; Ritz et al., 2001; Huybrechts, 2002; Philippon et al., 2006)





Summary

- ***Good "5 Ma" results:***

  ANDRILL core, LGM to modern, few WAIS collapses last ~1 Ma

- ***With central hypothesis:***

  { Paleo sub-ice oceanic melt ~ far-field $\delta^{18}O$ }

  Testable with A/OGCMs, regional ocean models

- ***Further improvements (modern-recent data):***

  Collapse timings last ~1 Ma, lower Siple Coast profiles,

  sub-grid pinning… *Nb: "5 Ma" results are robust…*

- ***Next Questions:***

  +20 m or more sea-level rise in Pliocene ~3 Ma?

  Very little Pliocene surface melting in our GCM! *cf.*