Abrupt climate change and the oceans

EPS131, Introduction to Physical Oceanography and Climate
Dept of Earth and Planetary Sciences, Harvard University
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Outline:

1. Glacial climate, observations of DO & Heinrich events
2. Welander flip-flop
3. The sea ice amplifier
4. Ice shelf collapse: hydrofracturing
5. Ice sheet collapse:
    1. Basal melting (binge-purge)
    2. Marine Ice Sheet Instability (MISI)

The Glacial world/ ice cores

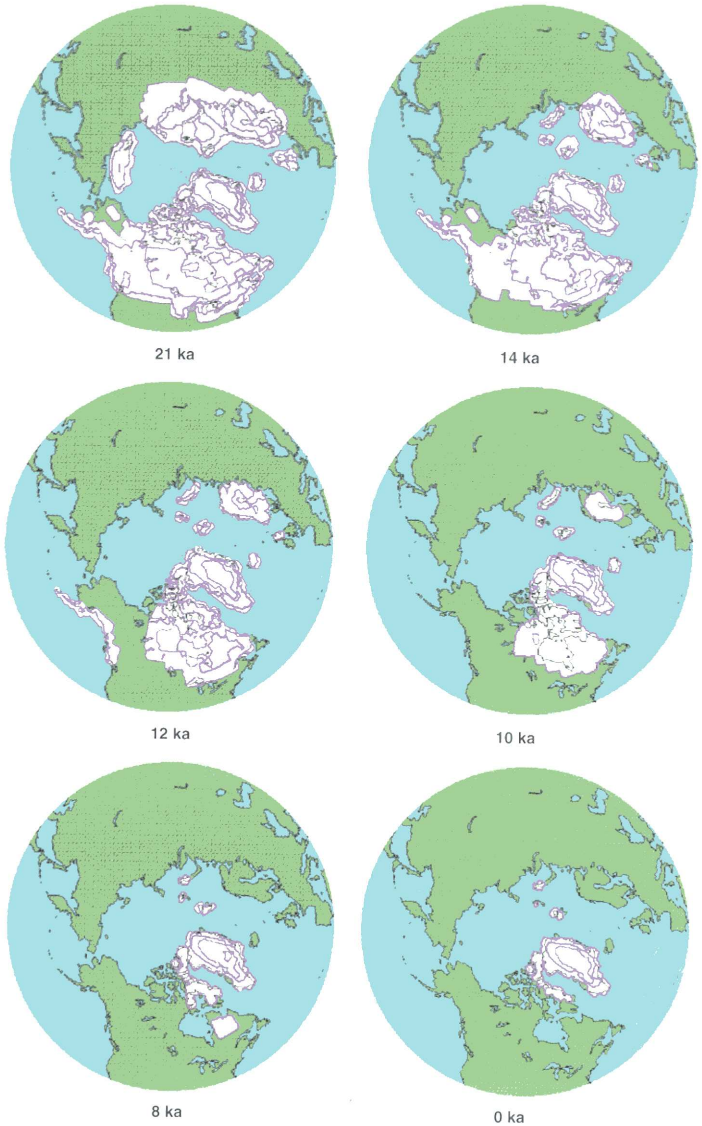


Fig. 4. Thickness isopachs for the ICE-4G model for a sequence of times beginning at Last Glacial Maximum at 21 ka and ending at the present. The contour interval is 1 km.

SCIENCE • VOL. 265 • 8 JULY 1994

← Ice sheet elevation: 2-3 km, sea level drop: 120 meter

Ice core taken out of drill, Byrd, Antarctica (L. Thompson)

Dansgaard-Oeschger events

D/O events

Dansgaard-Oeschger events: abrupt warming events seen in Greenland ice cores; occur every ~1500 years, last a few hundred years;

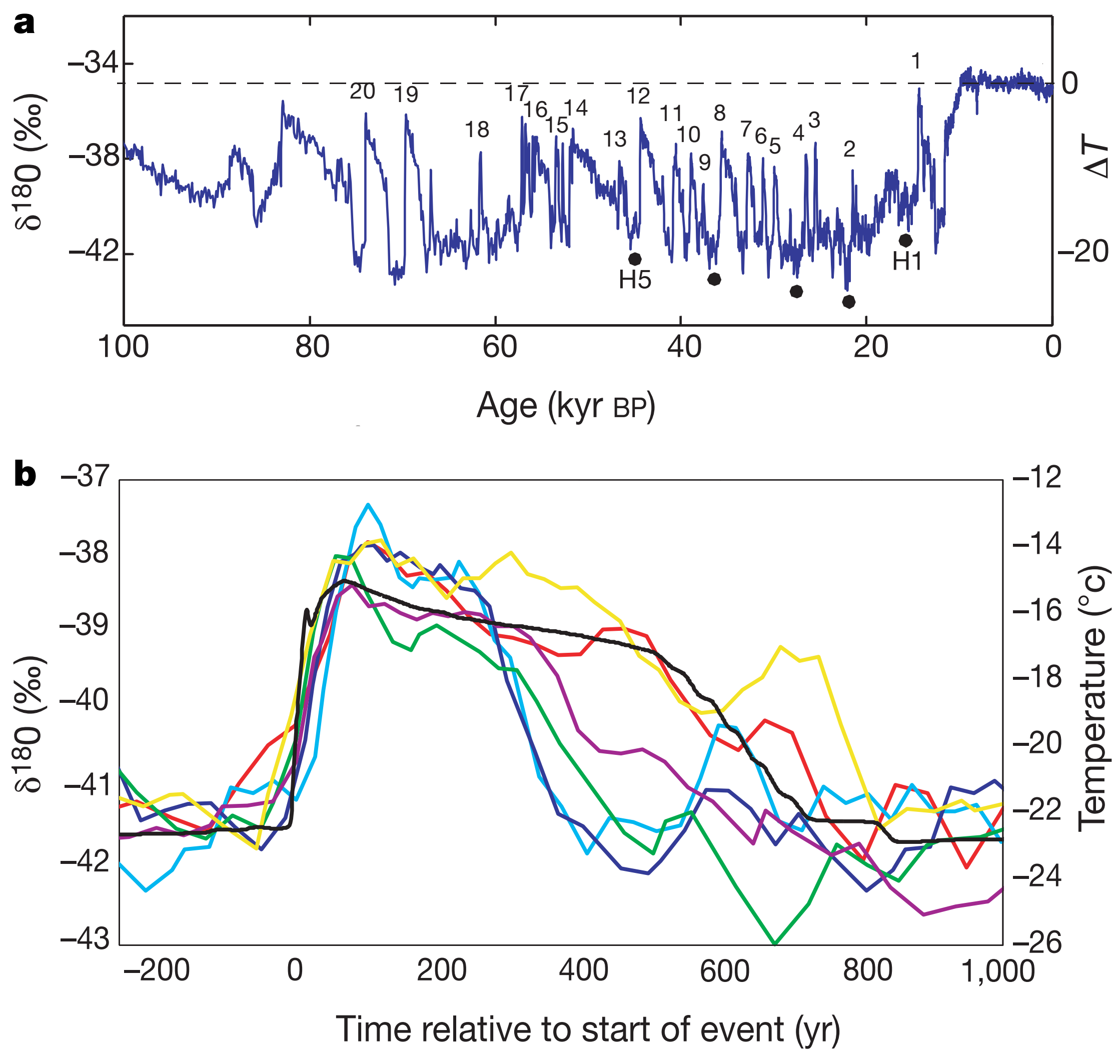
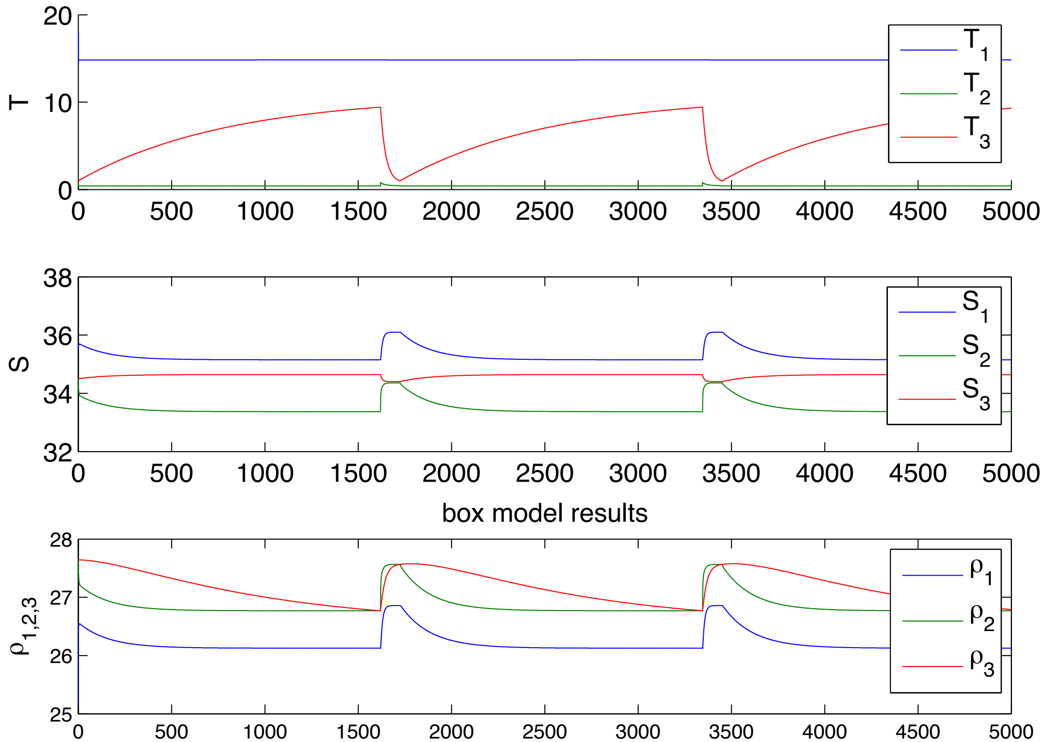


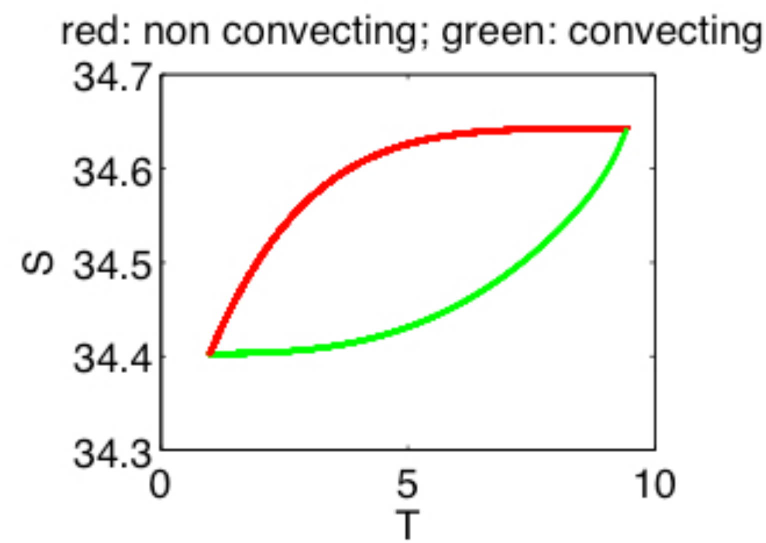
Figure 4 Abrupt climate changes in Greenland ice-core data. **a**, d[18]O from GRIP core, a proxy for atmospheric temperature over Greenland. Dansgaard±Oeschger (D/O) warm events (numbered). Heinrich events H1-H5 marked by black dots. **b**, Time evolution of recent D/O events taken from a (3, light blue; 4, dark blue; 5, purple; 6, green; 7, orange; 10, red). Many D/O events show the characteristic slow cooling phase after the initial warming, followed by a more abrupt temperature drop. Some events are much longer but still show this general characteristic (for example, nos 8, 12, 19, 20). A modeled D/O event in black (North Atlantic air temperature).

Ganopolski Rahmstorf 2001

D/O-like AMOC oscillations, “flushes”



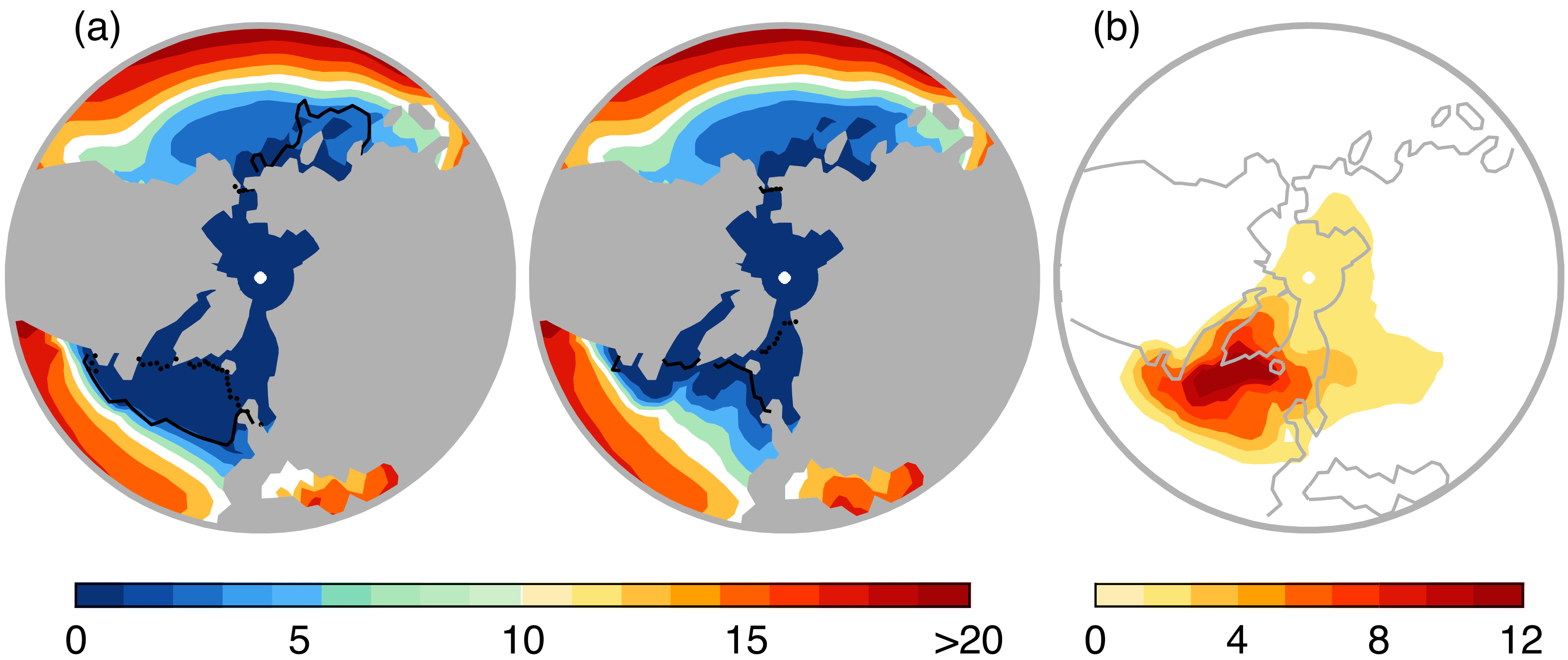
Temperature, salinity and density of all 3 boxes



T-S phase space

Winton 1993 model, based on Matlab code on course webpage

D/O due to weak AMOC variability amplified by sea ice changes?

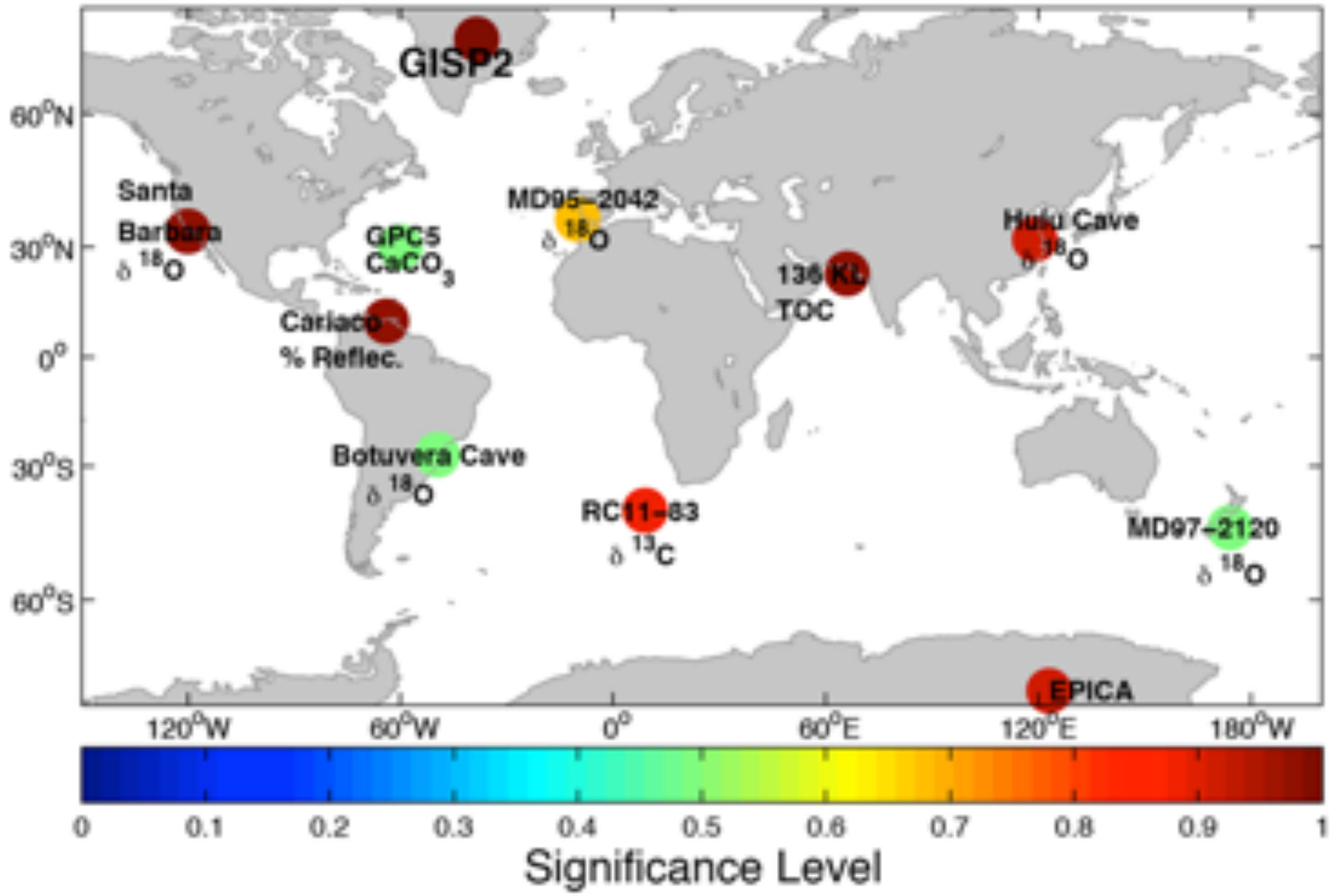


Comparison of LGM and reduced sea ice scenario I. (A) Annual mean sea surface temperature boundary conditions (deg C) for LGM (left) & reduced sea ice scenario (right). Maximum (February) and minimum (August) sea ice extents are indicated with the solid and dotted lines. Scenario I has a maximum sea ice extent equivalent to LGM perennial ice cover, and a minimum sea ice extent equivalent to the modern day perennial ice cover. ice thickness is 2 m, typical value for Arctic today. (B) The difference in surface air temperature between the two simulations (degrees C).

Li, Battisti, Schrag, Tziperman, 2005

D/O teleconnections: observations

Remote relationships with DO events: test for covariance between time-uncertain series



Significance of covariance between GISPII and remote proxies of climate, accounting for time uncertainty.

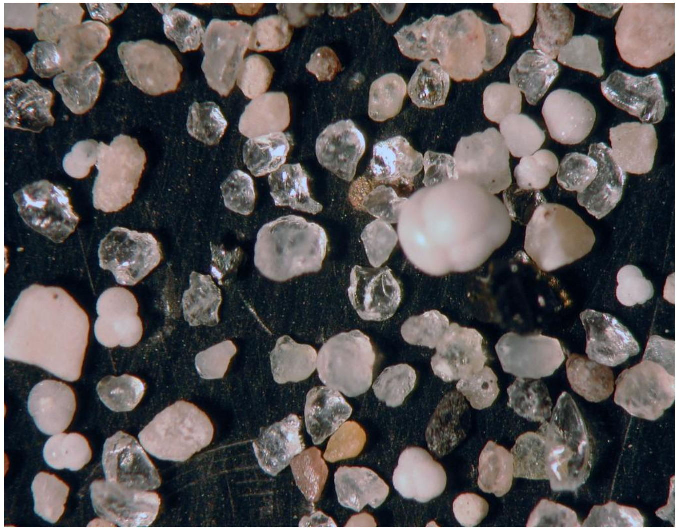
Heinrich events

Heinrich Events: Observations

Typical N. Atlantic marine sediment core

Typical marine sediment (Forams, etc.)

Ice rafted debris (IRD)



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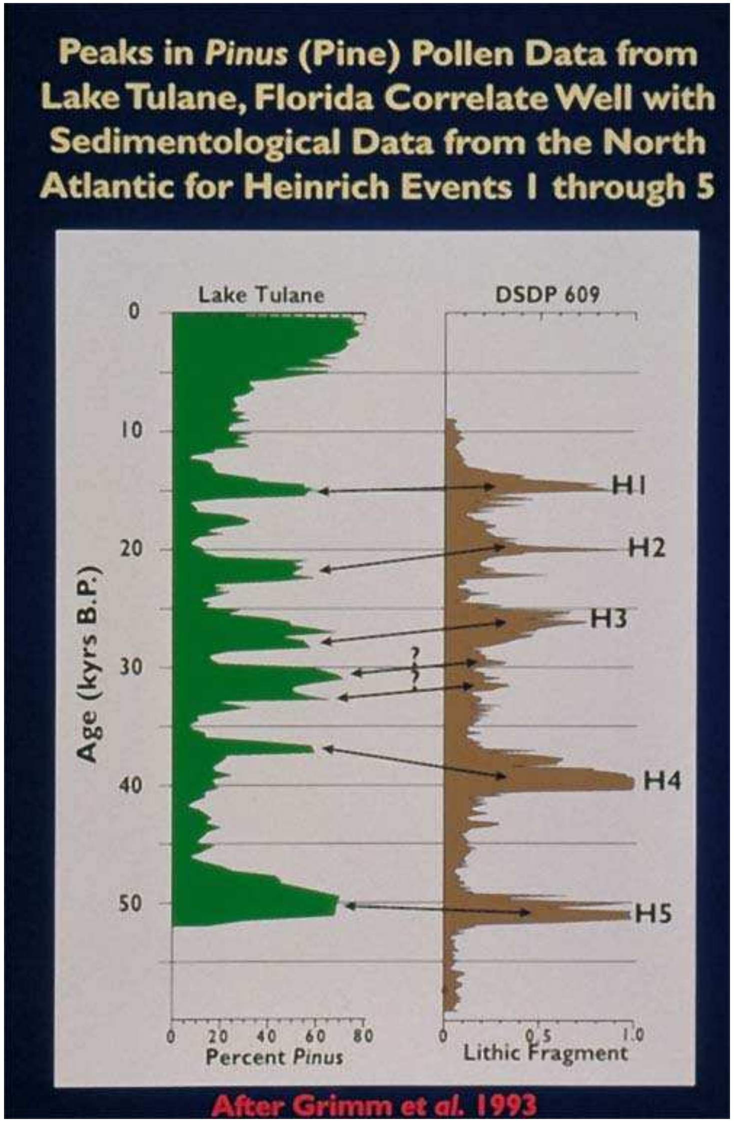
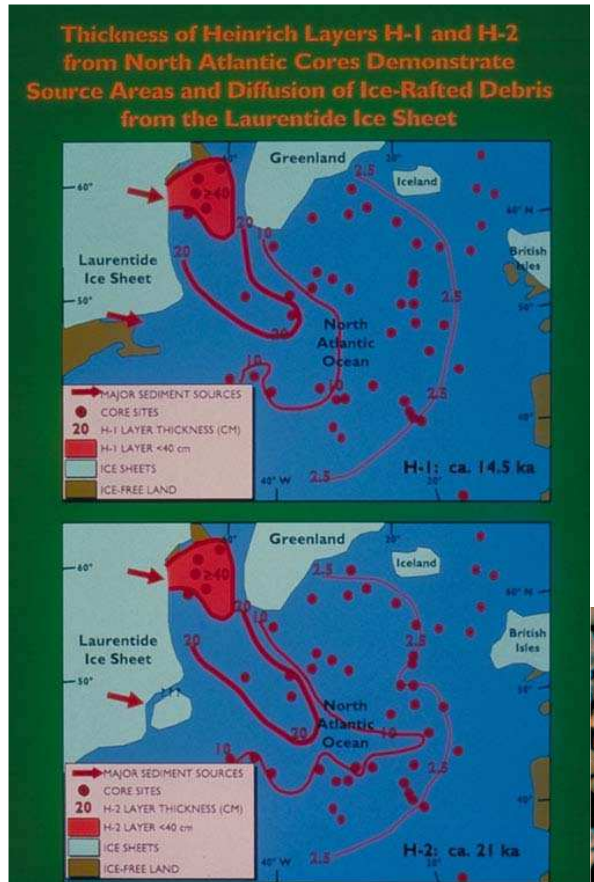
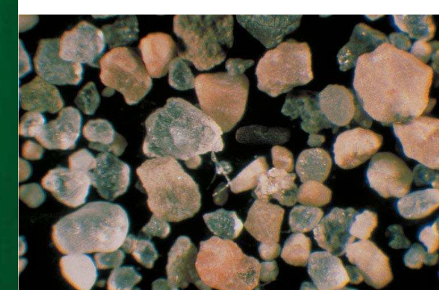


← (right panel) ice rafted debris layers marking Heinrich events: major glacier discharge events from Laurentide ice sheet to North Atlantic, every 7-10,000 years.

(http://www.ncdc.noaa.gov/paleo/slides/)





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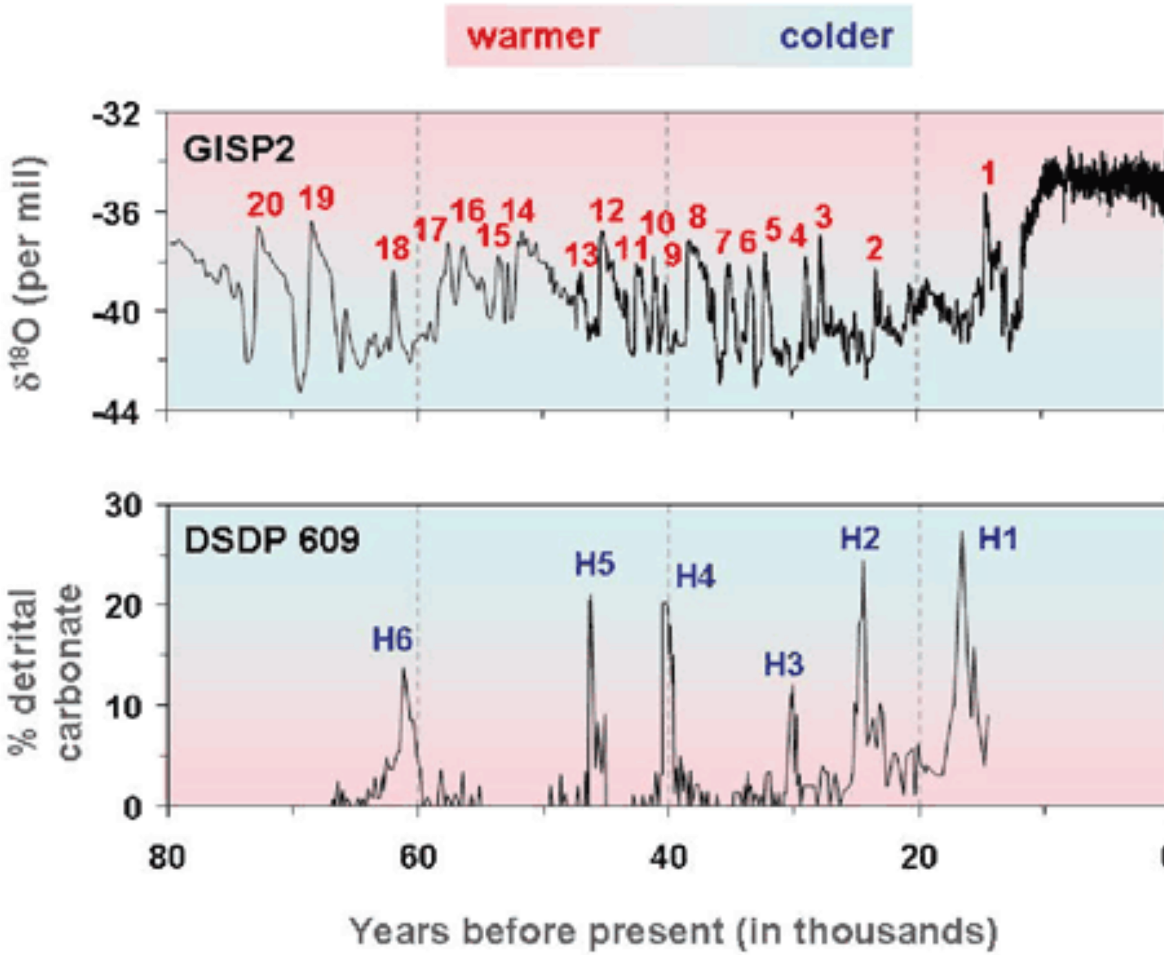
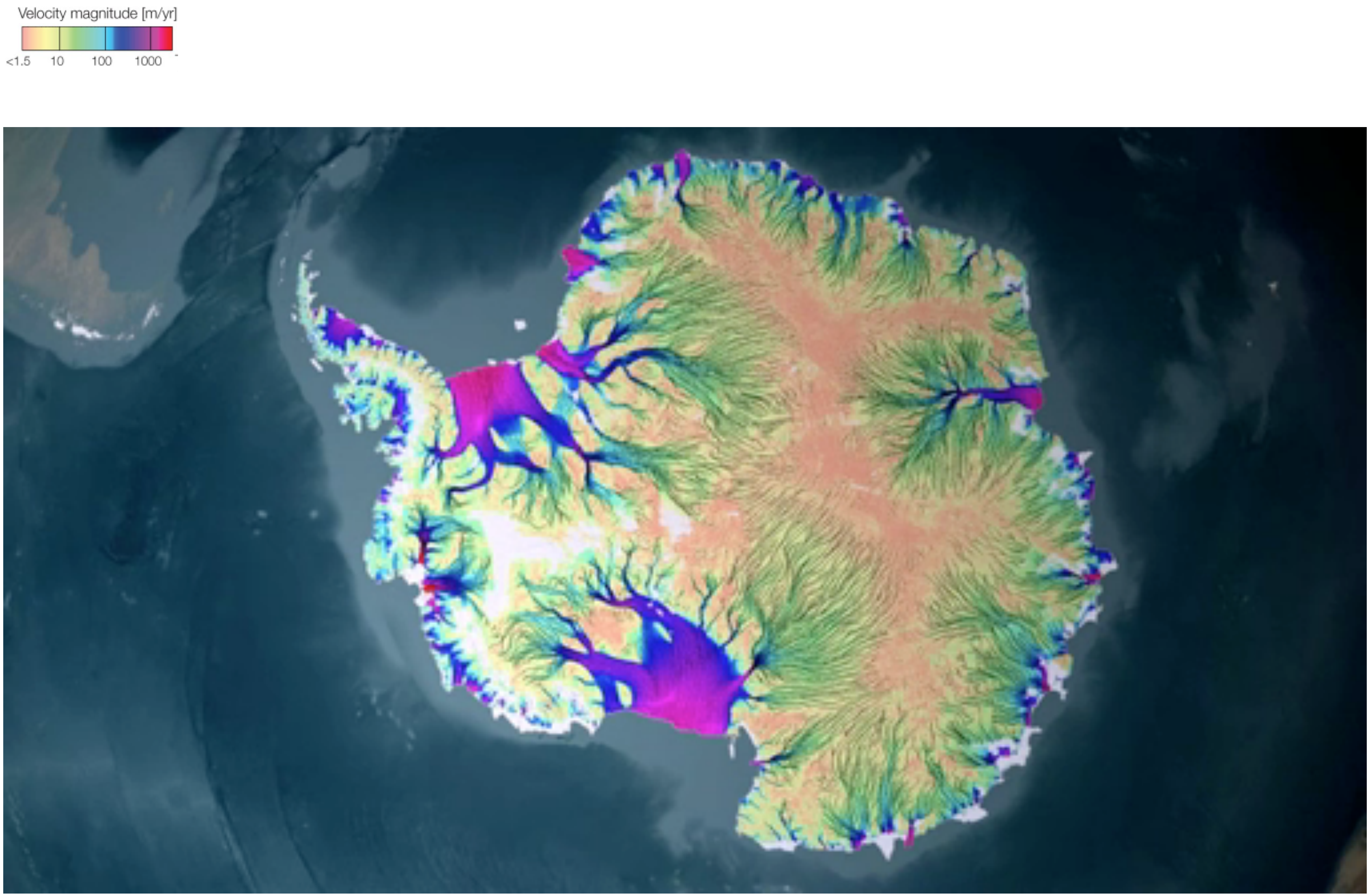


Ice streams: Ice Velocities for the Antarctic Ice Sheet



Rignot et al. 2011

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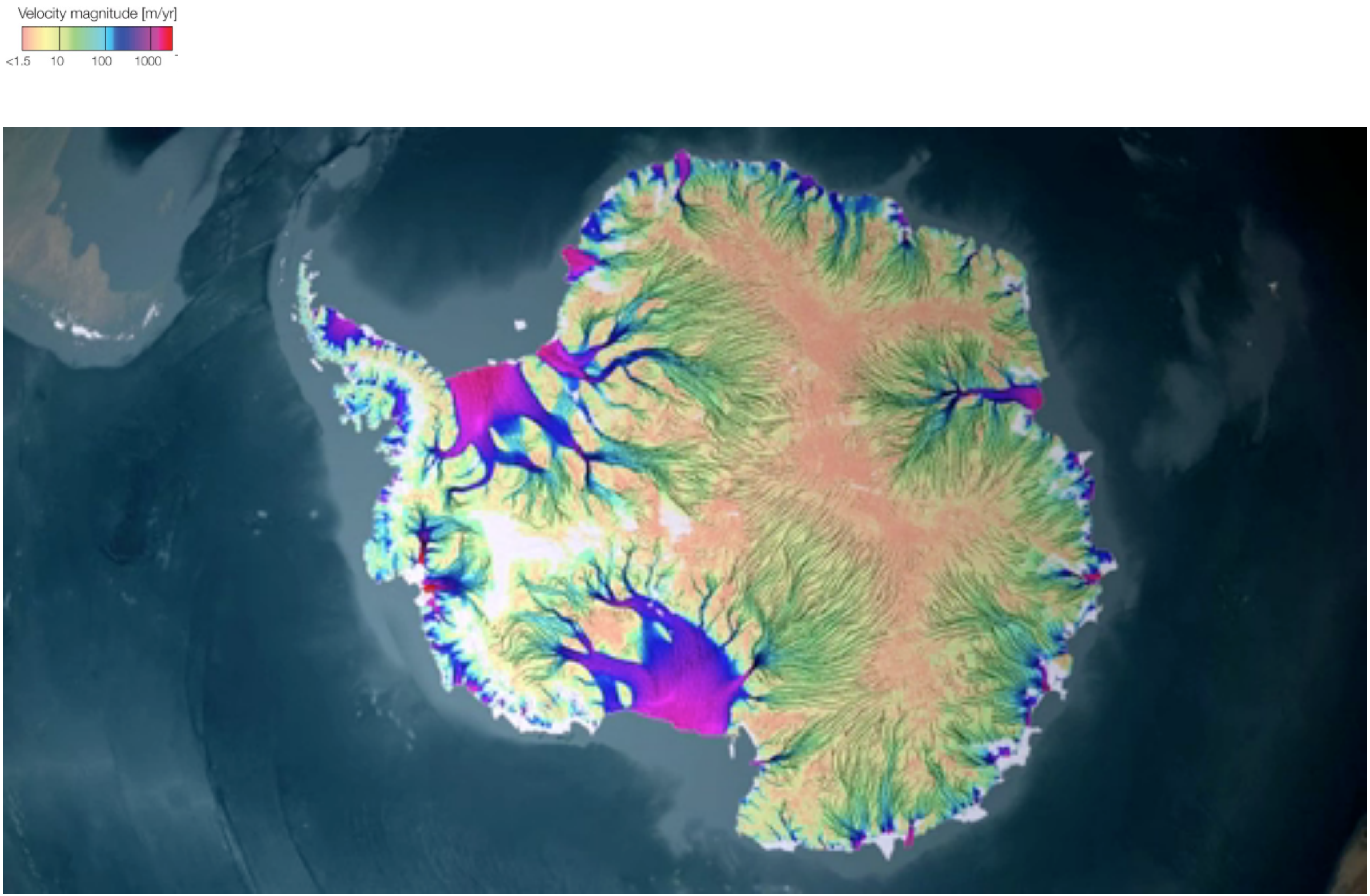

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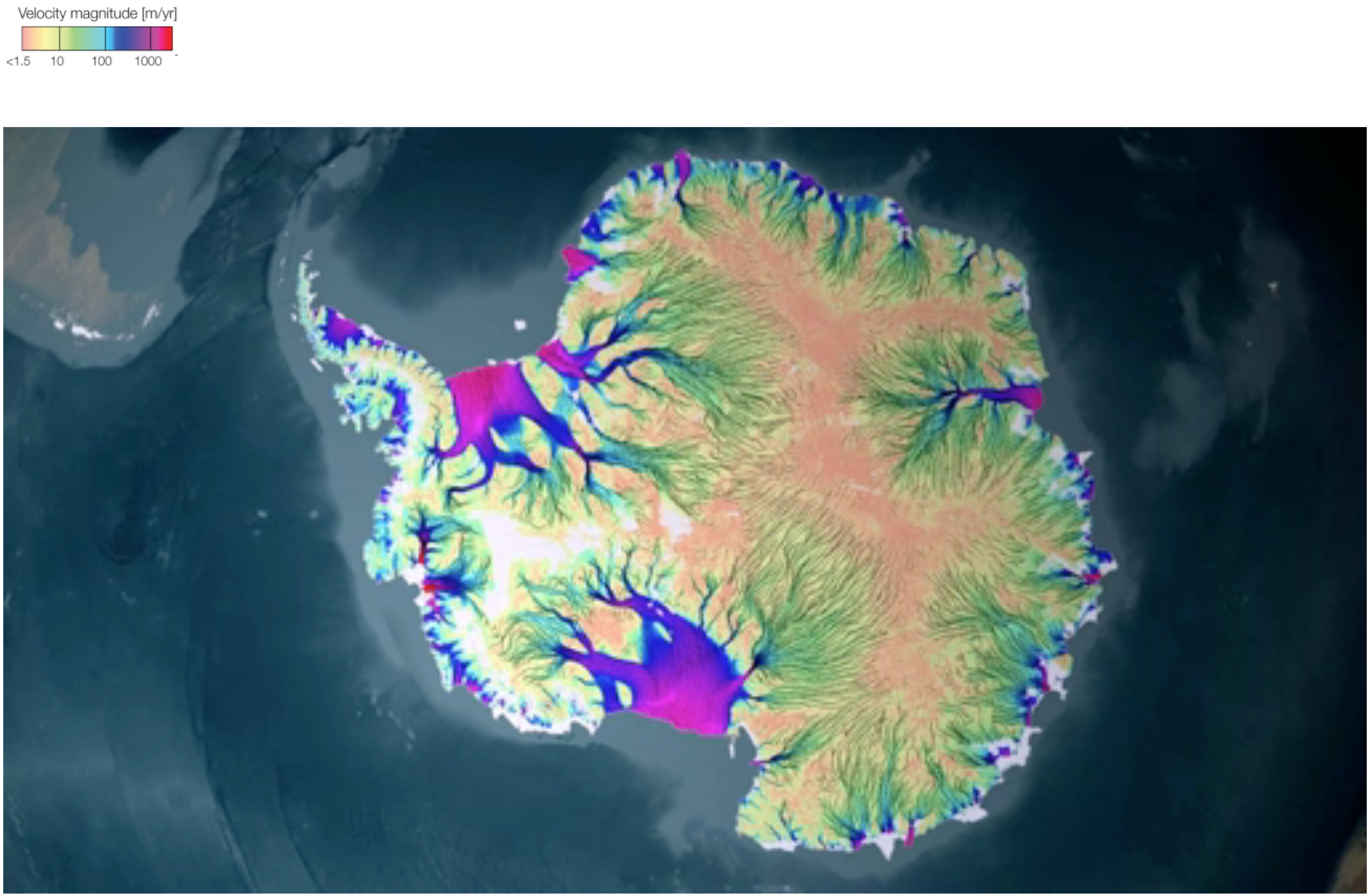

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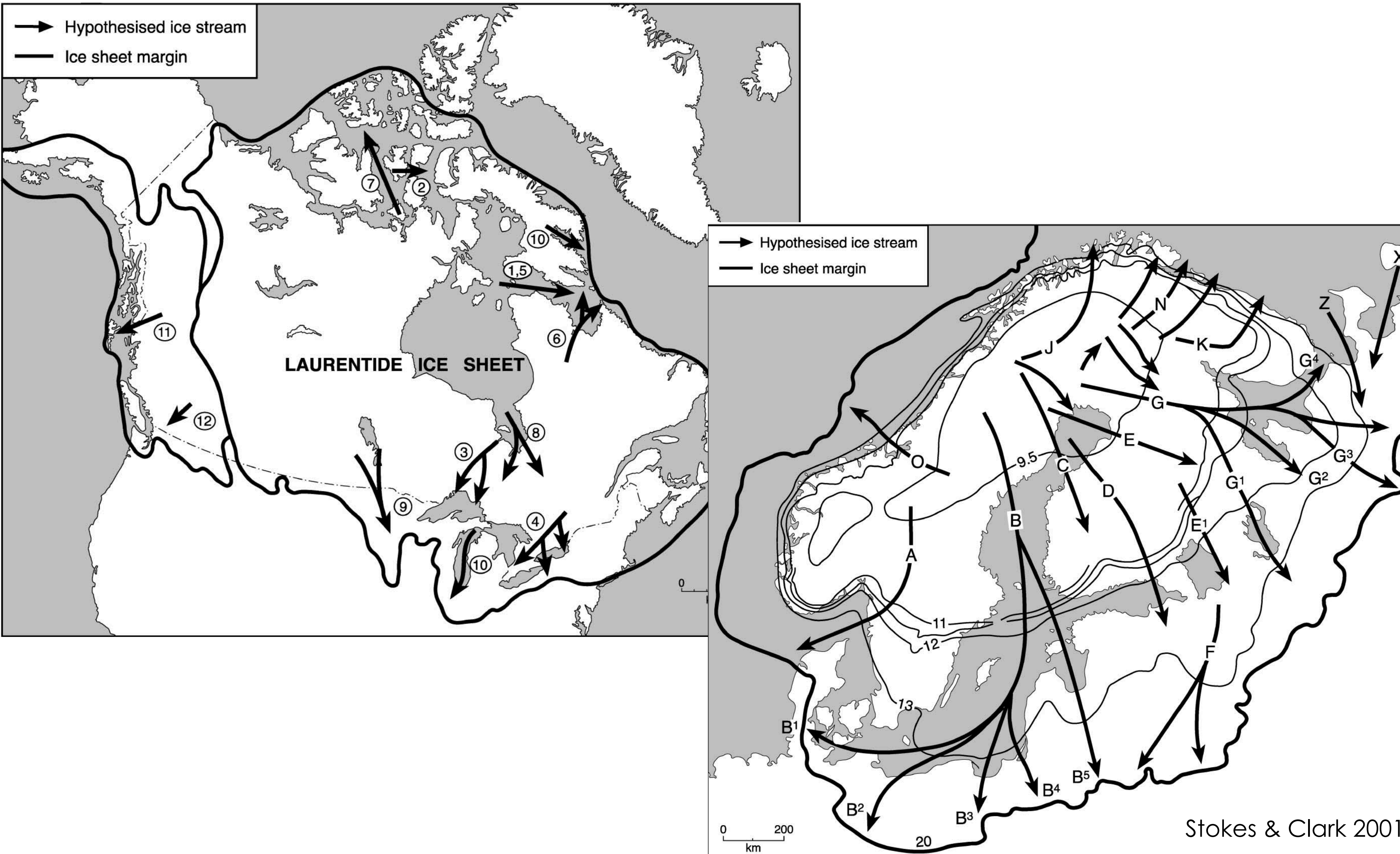
Proposed Paleo-Ice Streams



Hypothesis 1: MacAyeal's (1993) Binge-purge oscillator

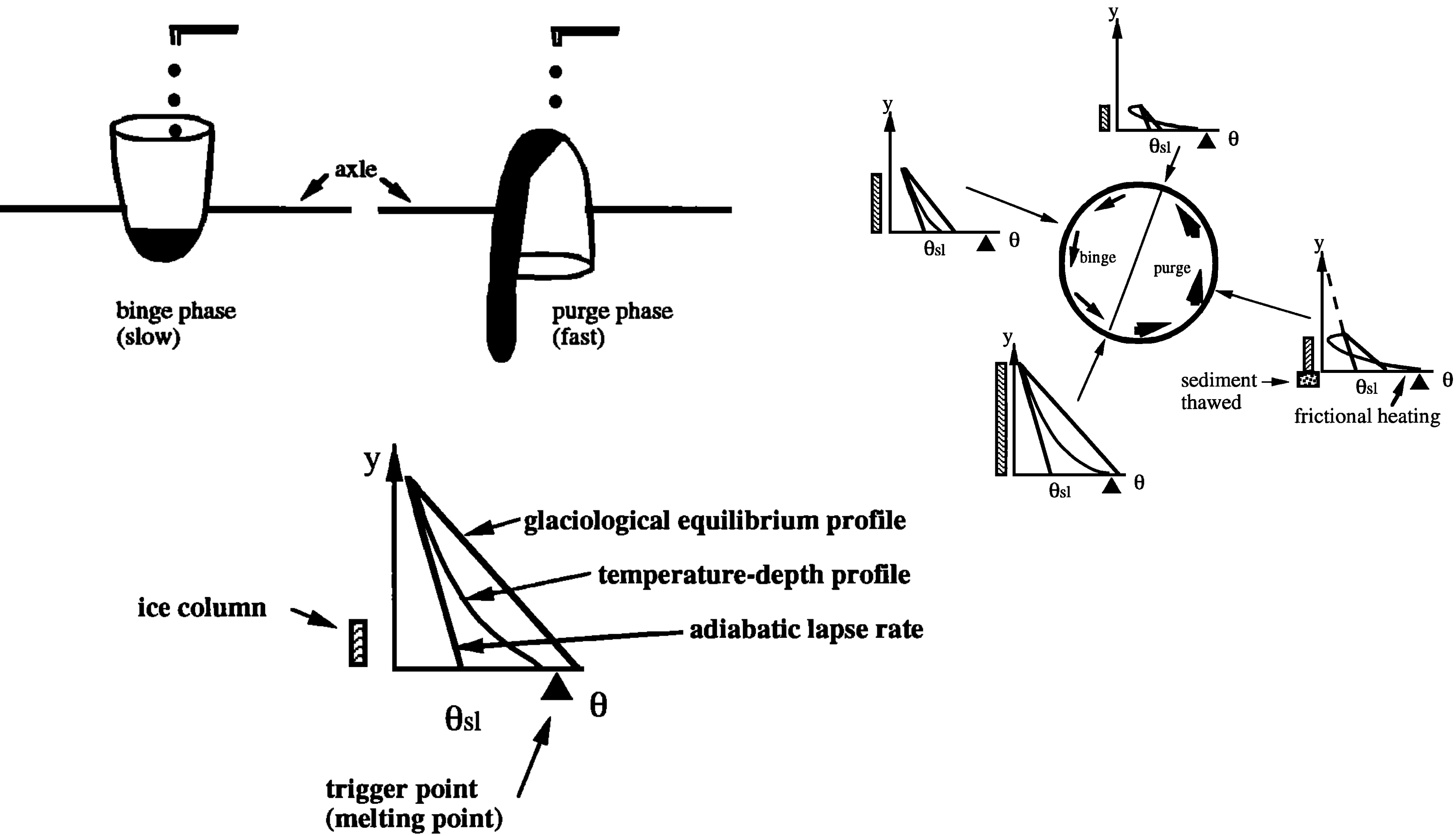
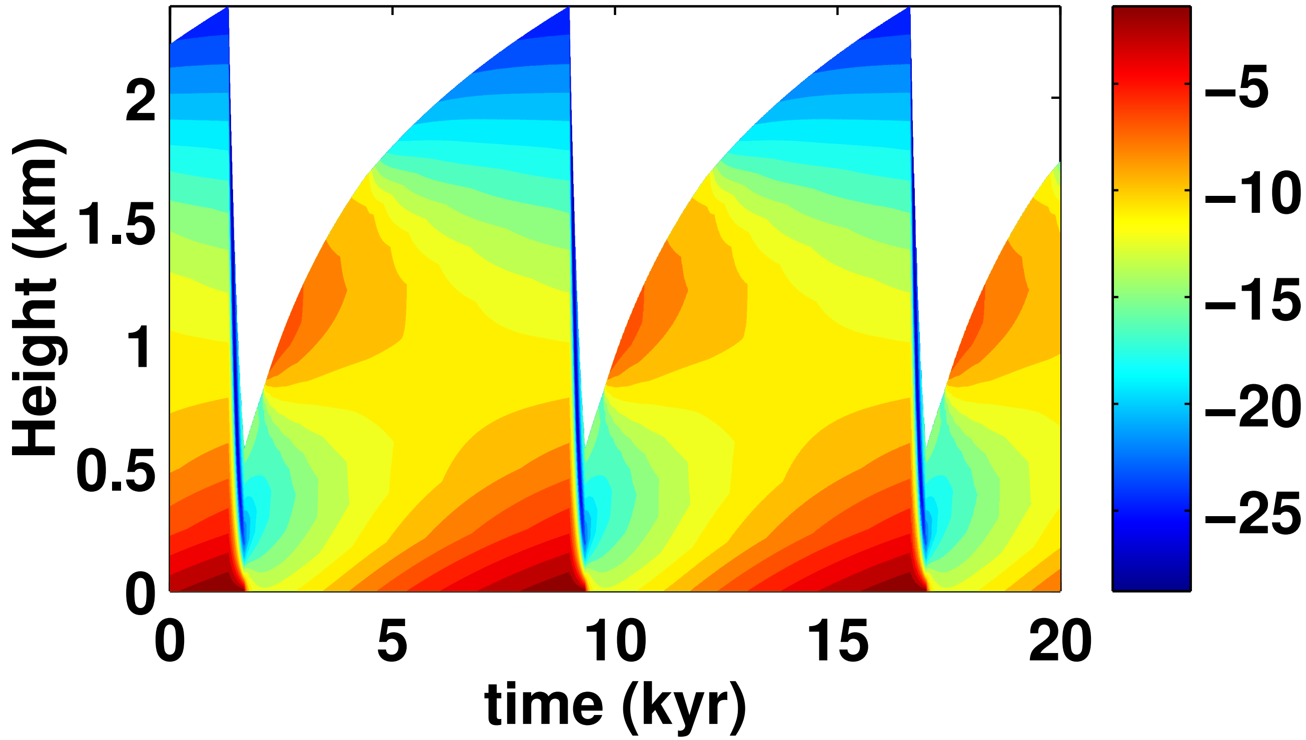


Fig. 2. A conceptual view of the temperature-depth profile $\theta(y)$ in an ice column during the binge/purge cycle of the Laurentide ice sheet. Vertical elevation from the base of the ice column is denoted by y and θ represents temperature. The annual average sea level atmospheric temperature is denoted by θ_{sl}. The melting temperature of ice is represented by the black triangles. The four graphs surrounding the central circle display the sequence of states through which the ice column evolves during a complete cycle. Time passage is represented by counterclockwise progression through the sequence of graphs.

Hypothesis 1: MacAyeal's (1993) Binge-purge oscillator

- Laurentide Ice Sheet (*LIS*) thickens due to snow accumulation (**binge stage**); geothermal heat is trapped at the base of thick & insulating *LIS*
- Geothermal heating melts glacier base, reduces bottom friction ➨ ice sheet slides into North Atlantic ocean (**purge stage**)
- Thiner glacier allows geothermal heat to diffuse out, base refreezes, cycle repeats



Glacier (`LIS'') height as function of time during a few Heinrich cycles. colors indicate temperature within ice sheet.

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MacAyeal (1993a): climate forcing not likely to play a role based on temperature diffusion argument; **However:** there are other mechanisms: Moulins, Accumulation of melt water in ice shelf cracks, collapse & elimination of buttressing/back-pressure

https://www.youtube.com/watch?v=-EMCxE1v22I&t=1s

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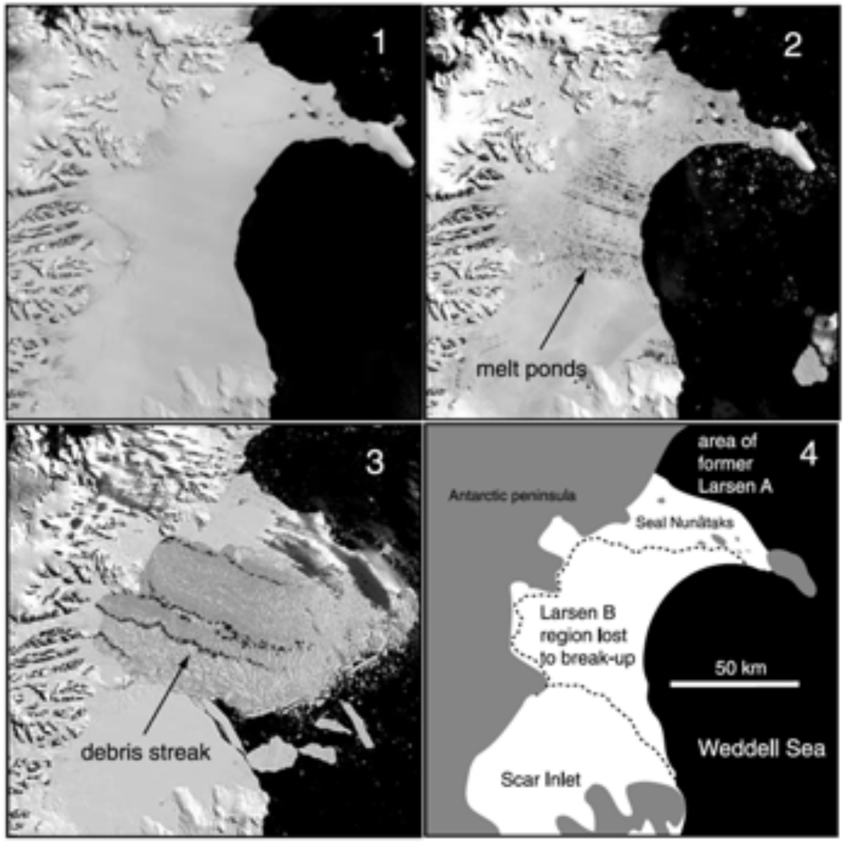
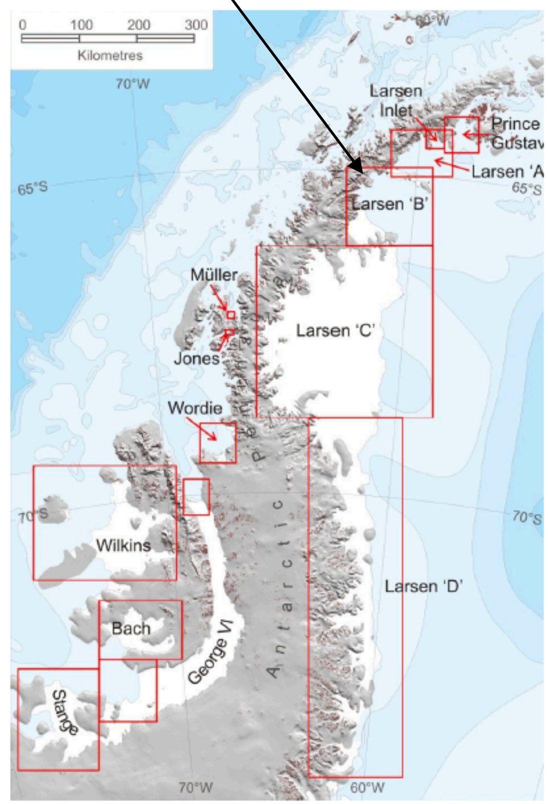
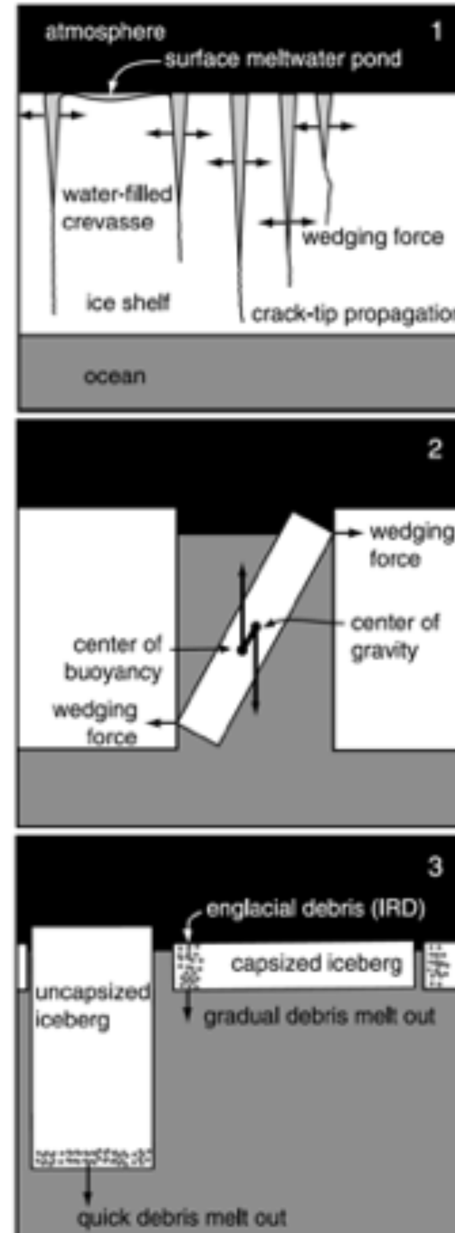
Hypothesis 2: Catastrophic ice shelf break up

Larsen B collapse, March 2002



Mechanism: hydro-fracture



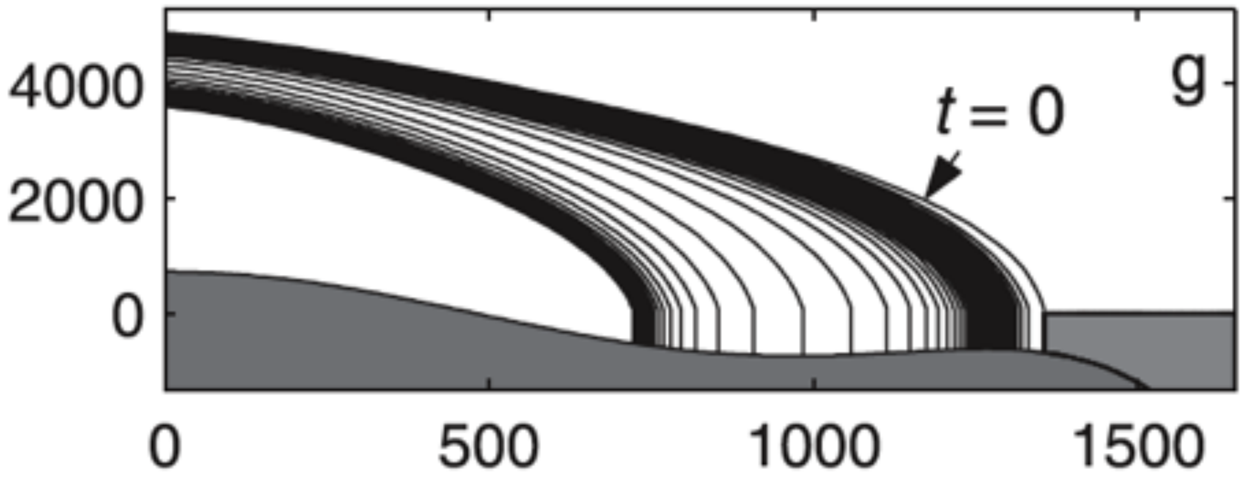


expected signature: no large sea ice level change

(Hulbe et al, 2004)

Hypothesis 3: Abrupt retreat of grounding line across a retrograde bottom slope (Marine Ice Sheet Instability/ MISI)

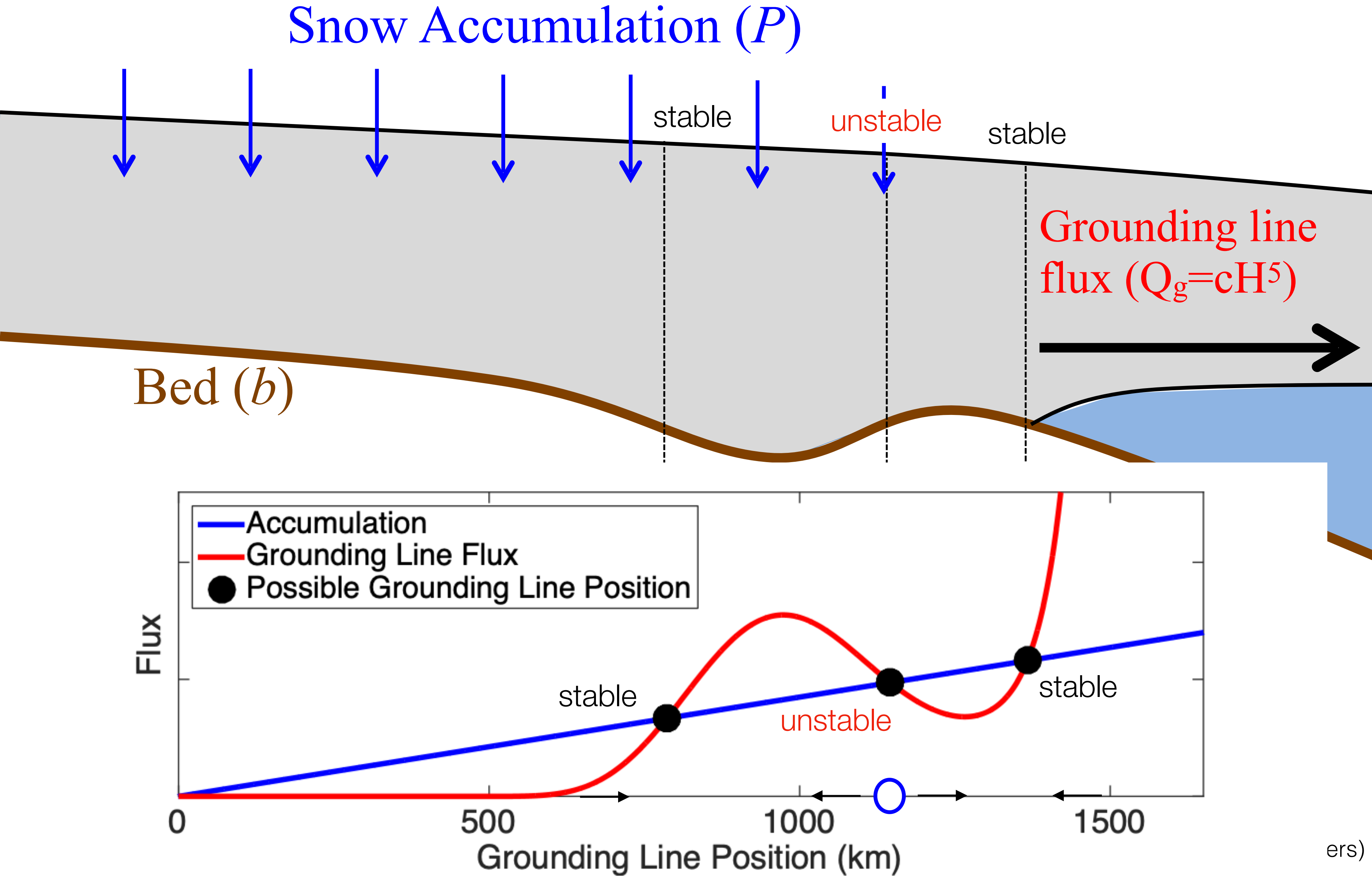
(Weertman, 1974; Schoof, 2007)



scenario 1: ocean melting at grounding line placing it upstream of unstable point

Marine Ice Sheet Instability (MISI)
scenario (1): melting by a warmer ocean

from Alex Robel



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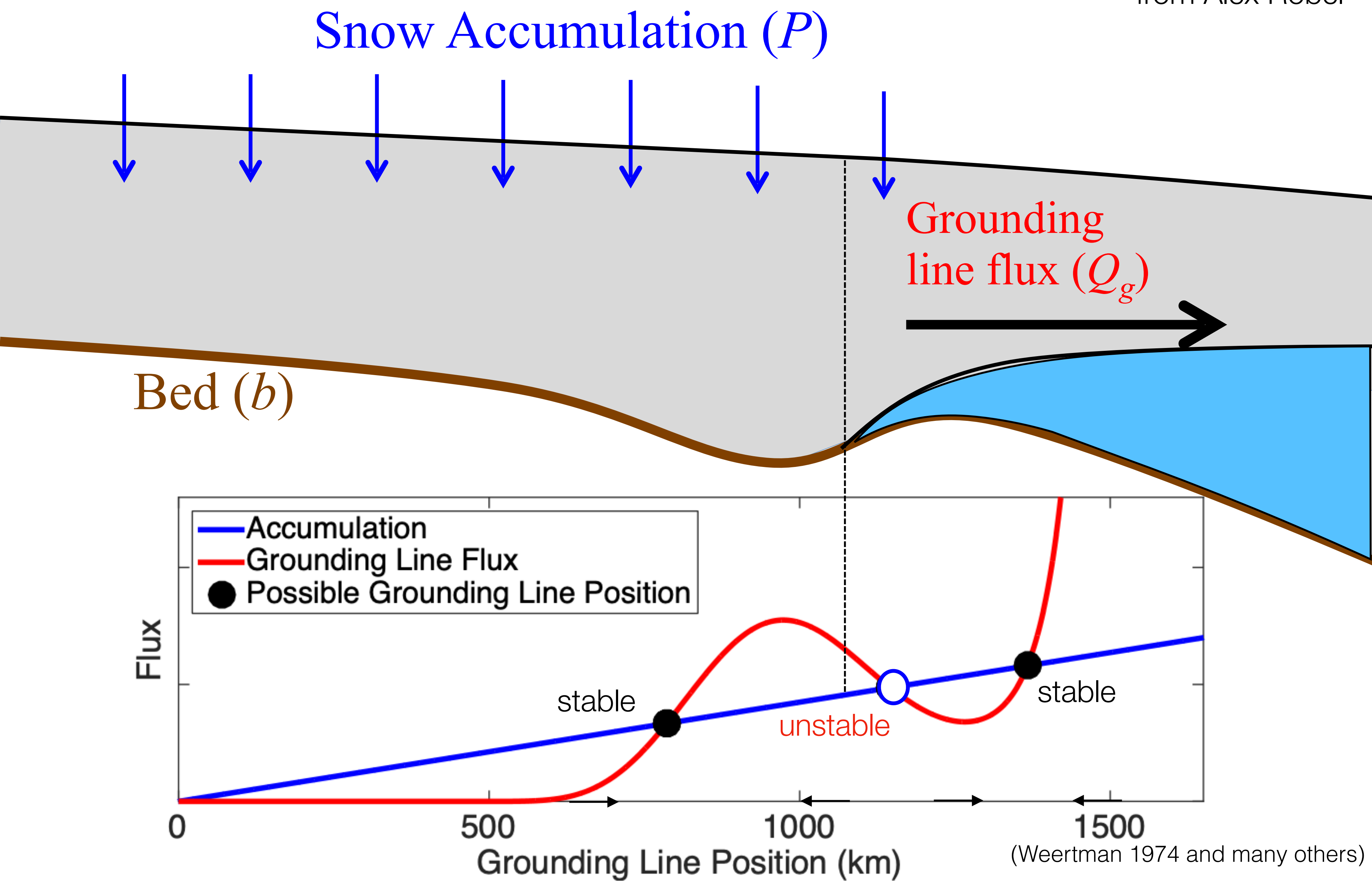

(Weertman 1974 and many others)

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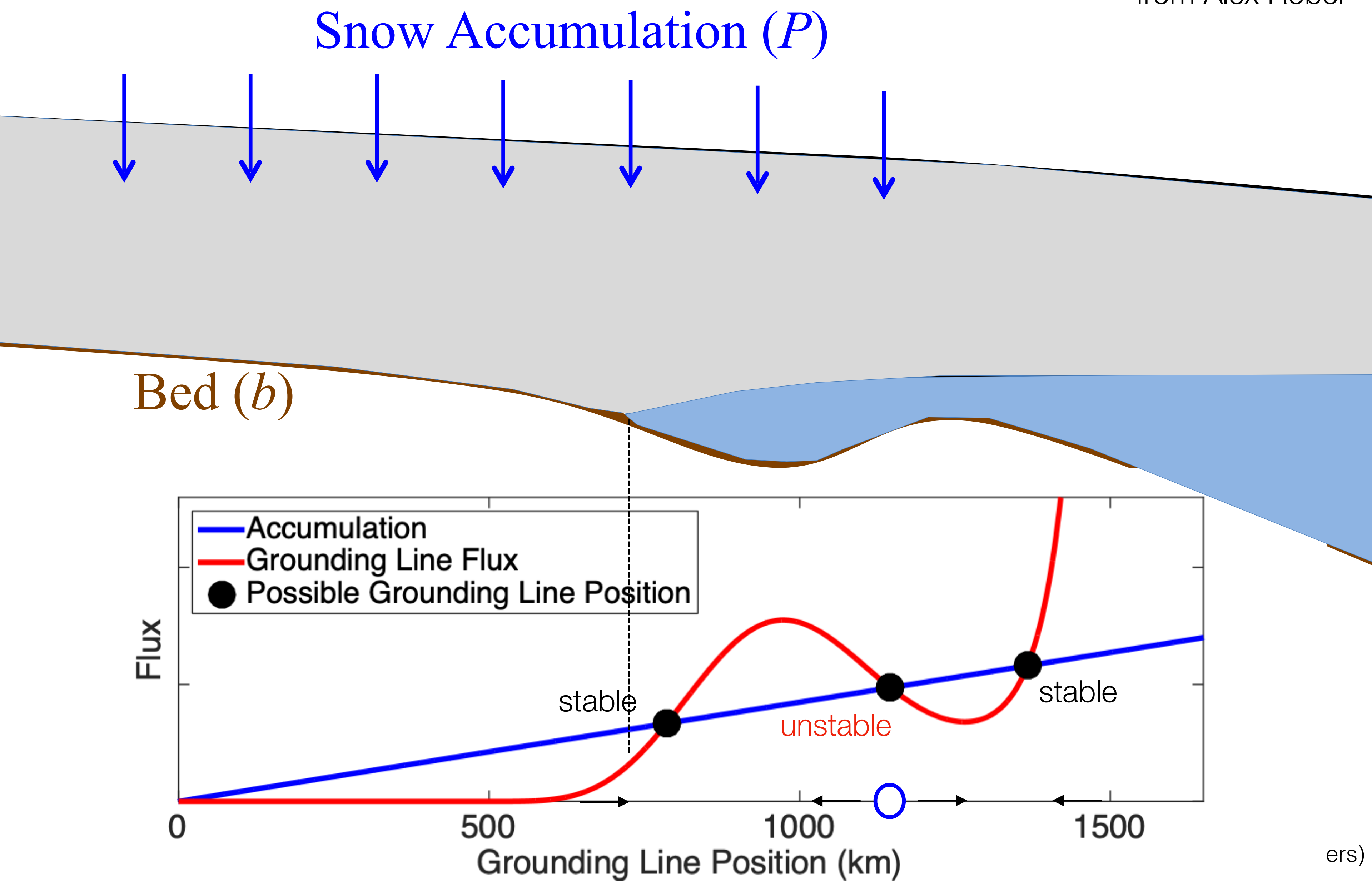
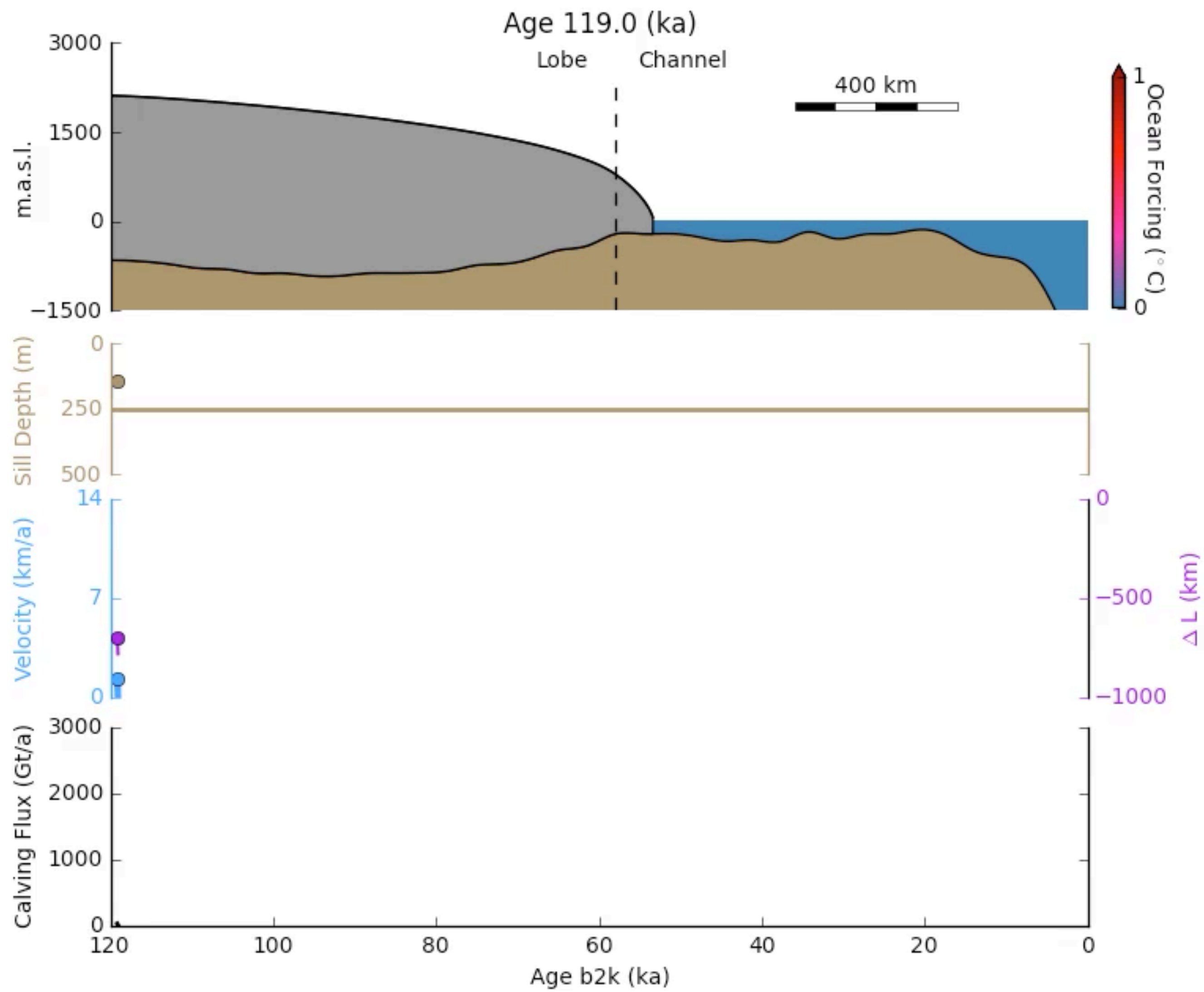


Heinrich events triggered by ocean forcing and modulated by isostatic adjustment

Jeremy N. Bassis[1], Sierra V. Petersen[2] & L. Mac Cathles[1,2]



Bassis et al 2017

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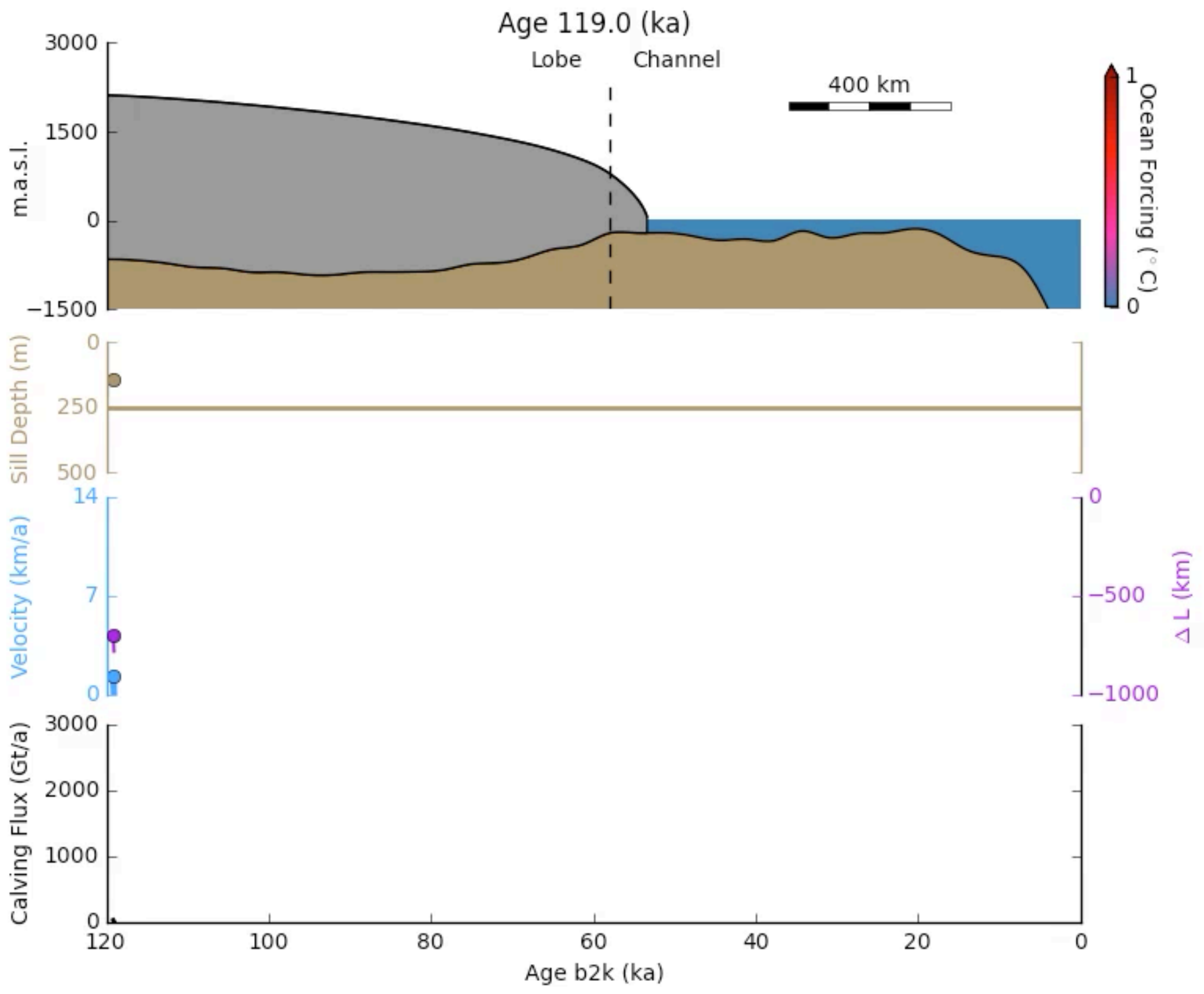

Bassis et al 2017

Conclusions: DO and Heinrich events

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- Synchronous collapses of different ice sheets: perhaps nonlinear phase locking through the ocean

The End