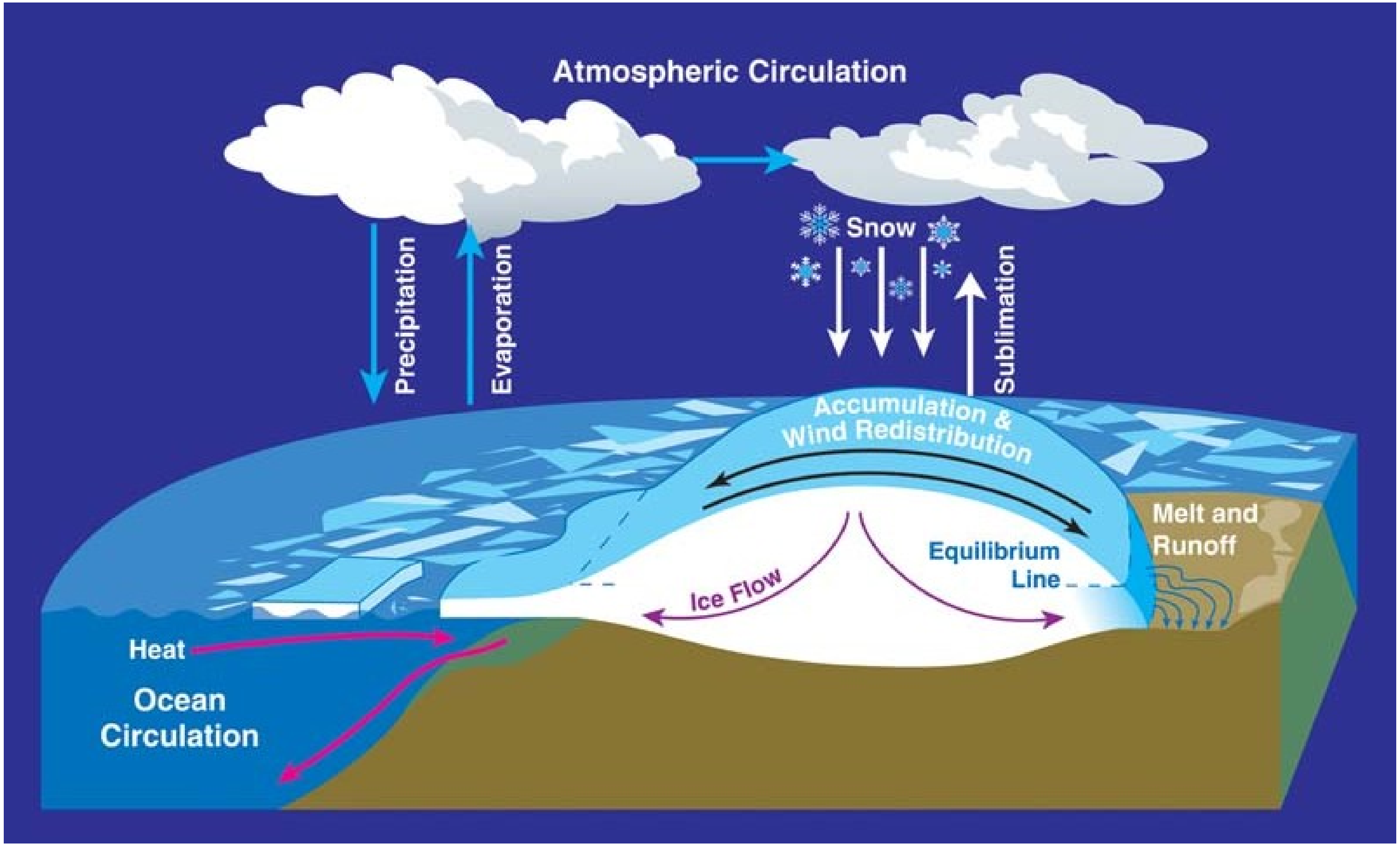
Predicting the sea-level contribution of the Greenland and Antarctic ice-sheets

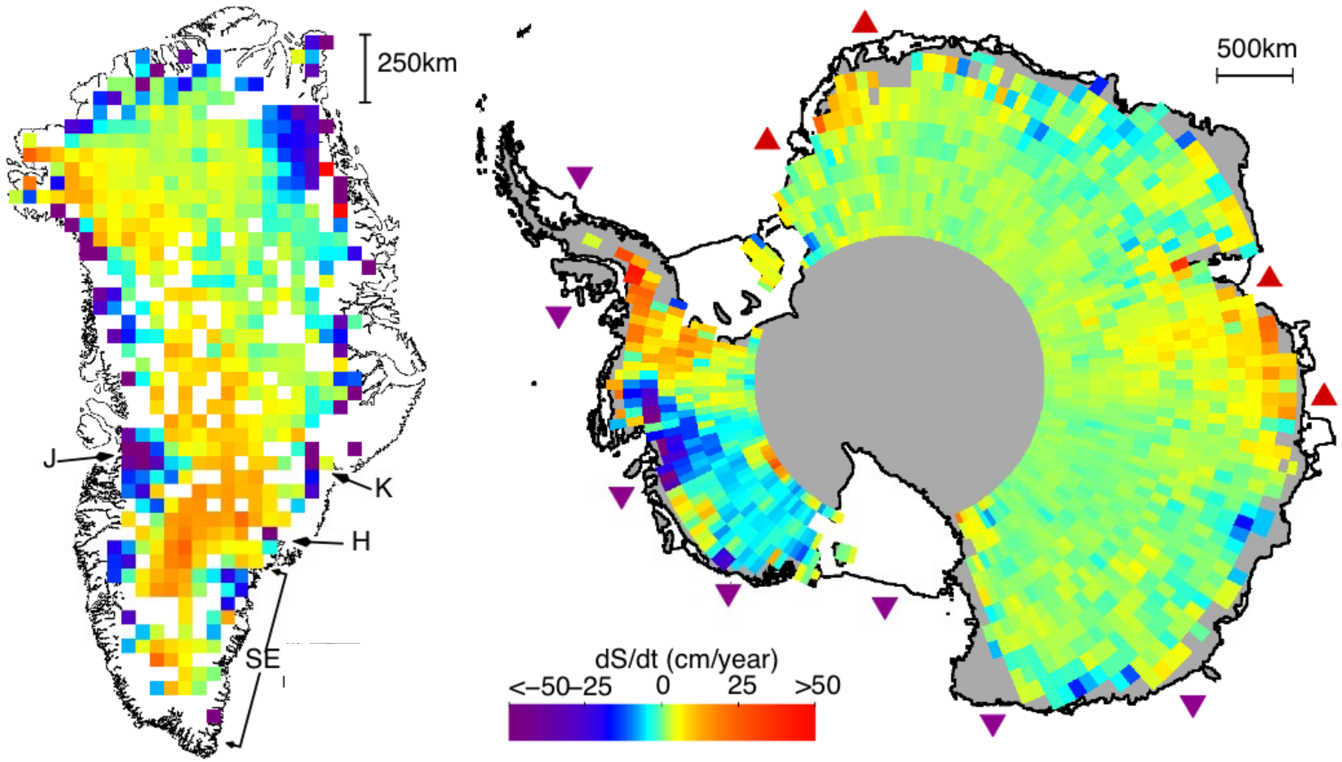
Jonathan Gregory[1,2]
1 Walker Institute for Climate System Research,
Department of Meteorology, University of Reading
2 Met Office Hadley Centre, Exeter
with many thanks to Richard Alley

Ice-sheet processes



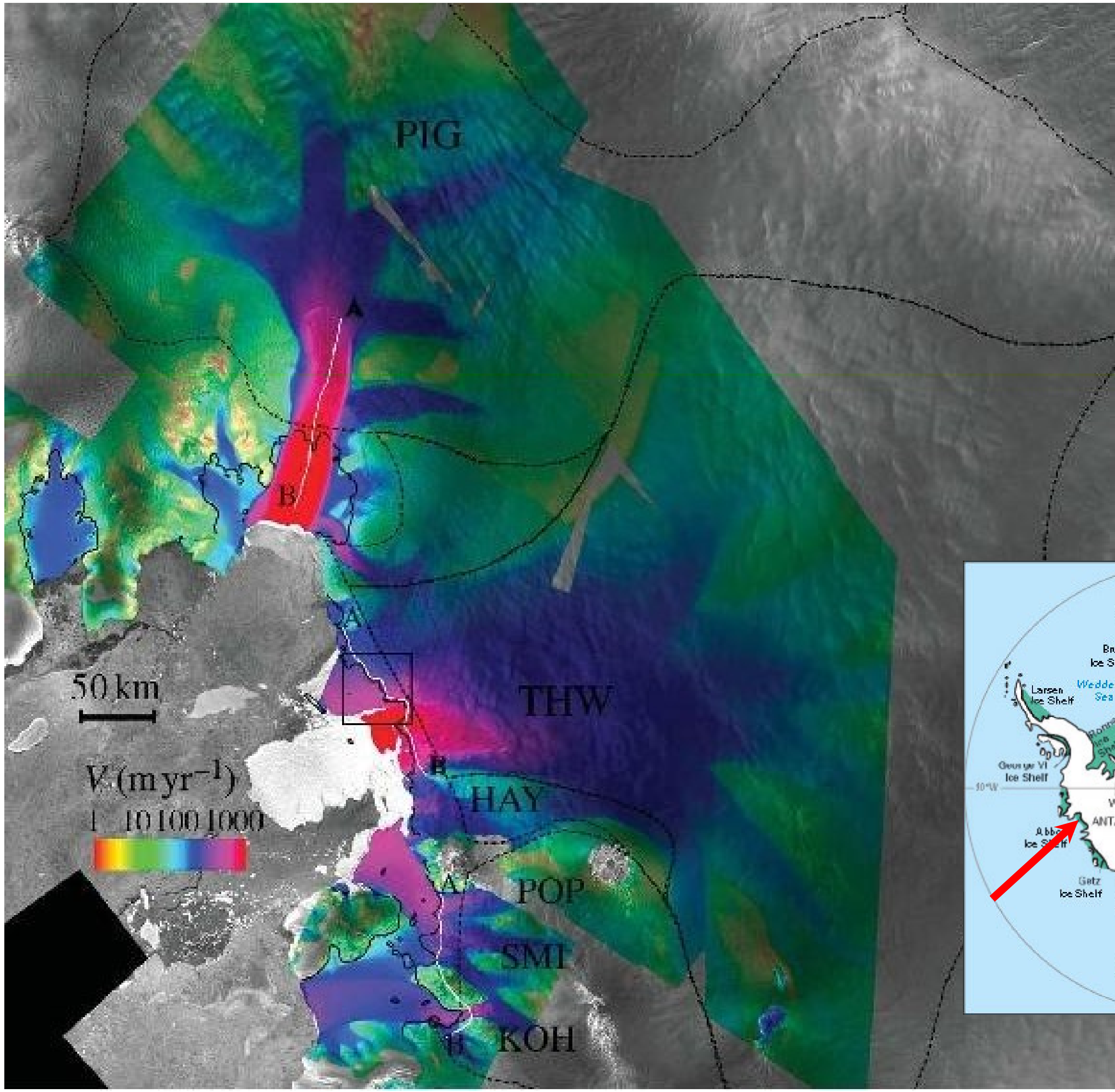
NASA

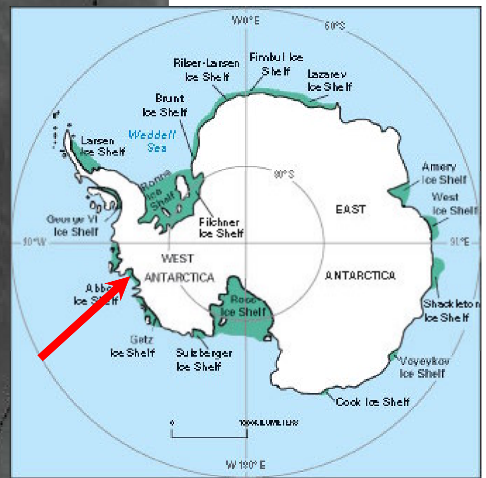
Recent ice-sheet thickness change



Flow speed has increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior of the ice sheets. The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or loss of floating glacier tongues. [Mass] losses from the ice sheets of Greenland (0.21±0.07 mm yr^{-1}) and Antarctica (0.21±0.35 mm yr^{-1}) have *very likely* contributed to sea level rise over 1993 to 2003 (3.1±0.7 mm yr^{-1}).

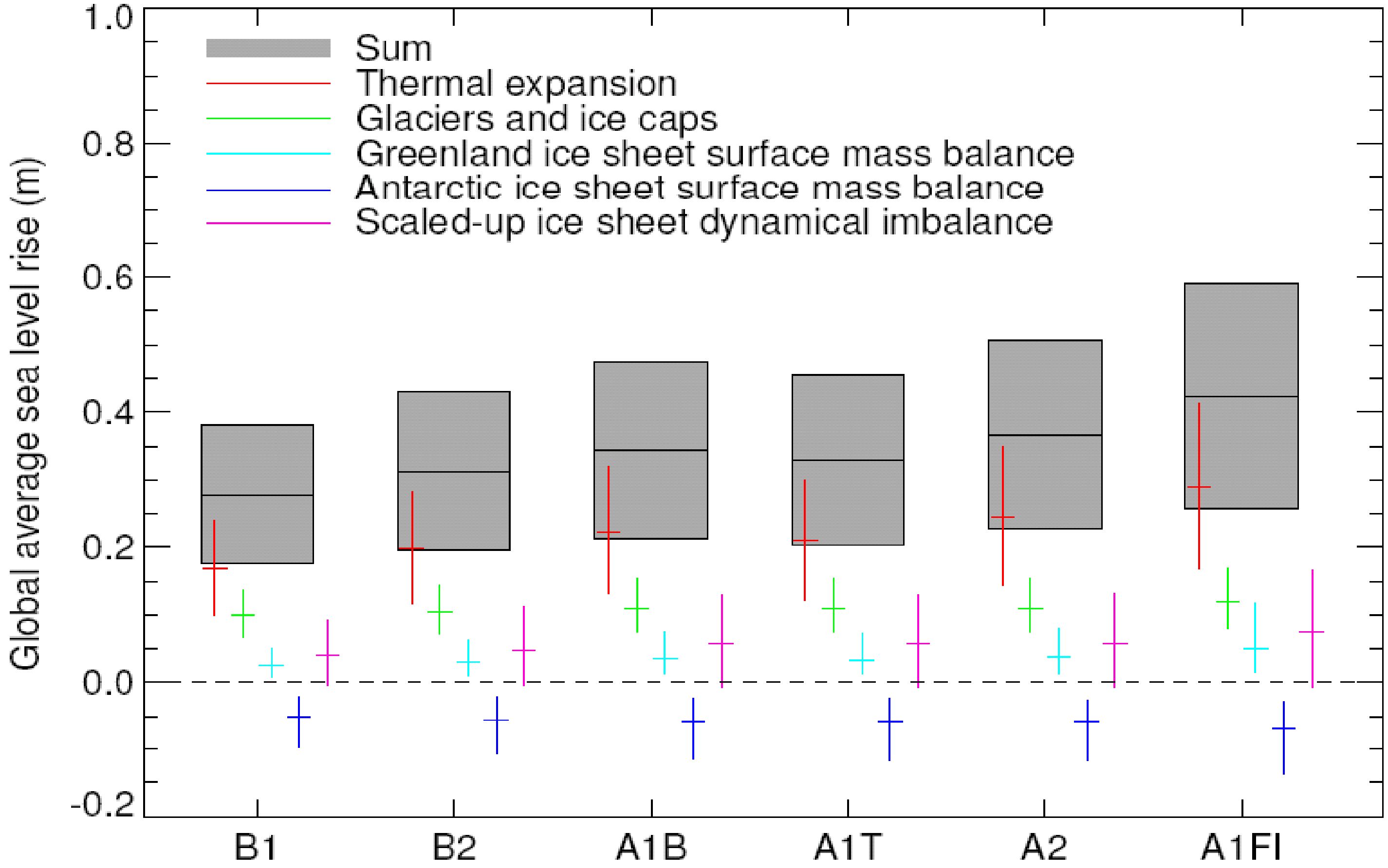
Ice-streams in Pine Island Bay, West Antarctica





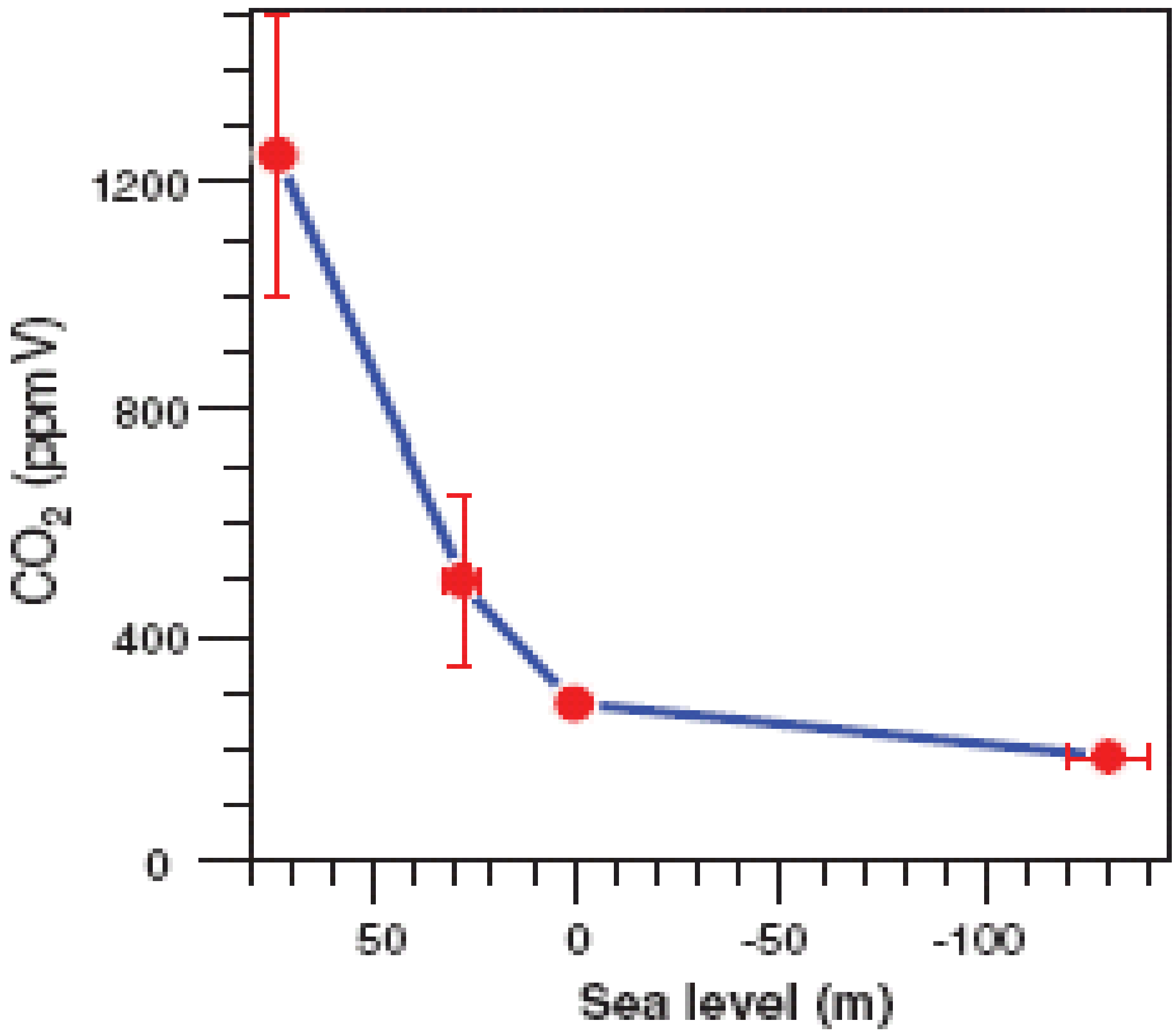
Rignot in Payne et al. (2006)

AR4 projections of sea level rise by 2090-2099



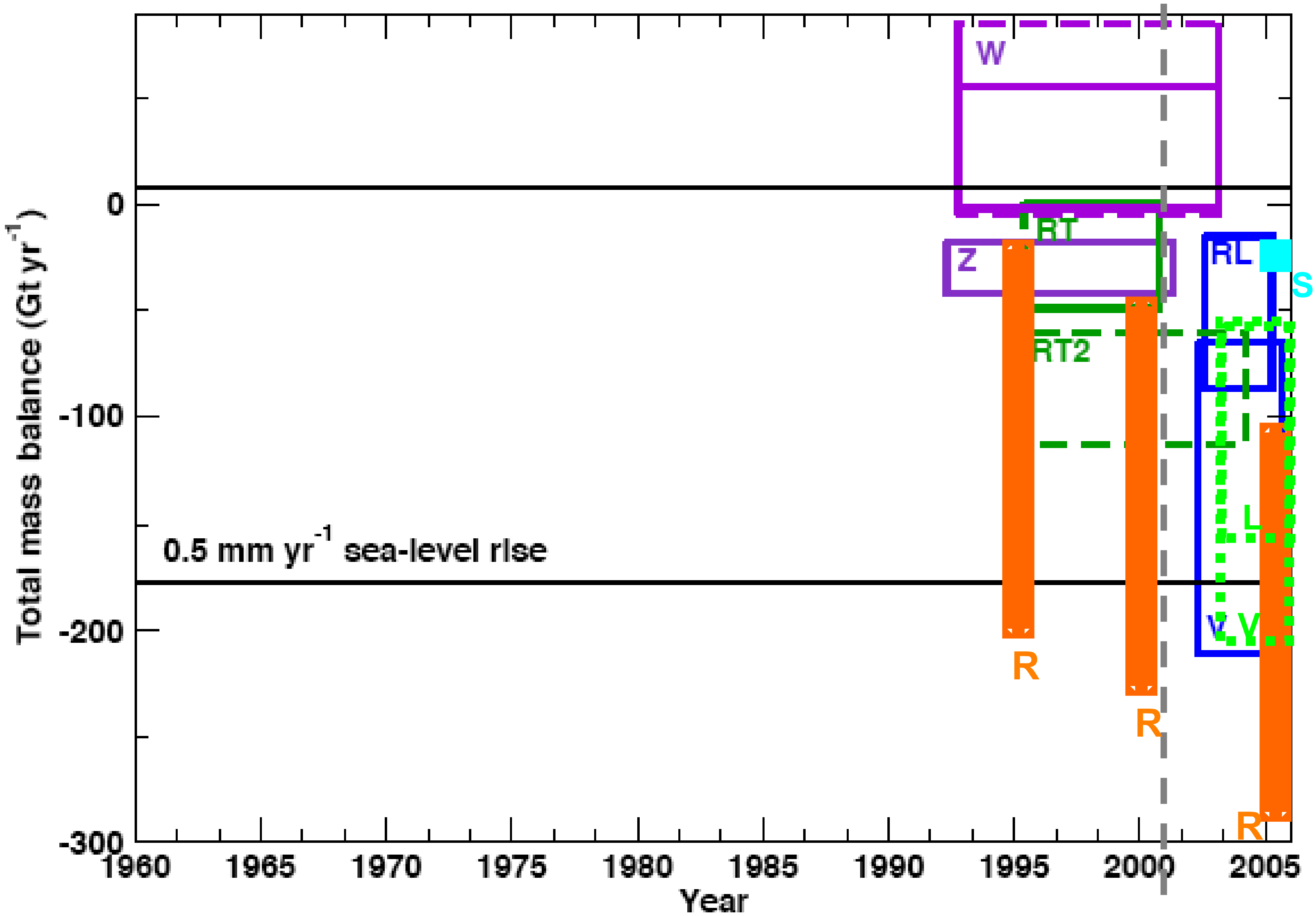
The projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future. … Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise.

Relationship between CO_2 and ice volume



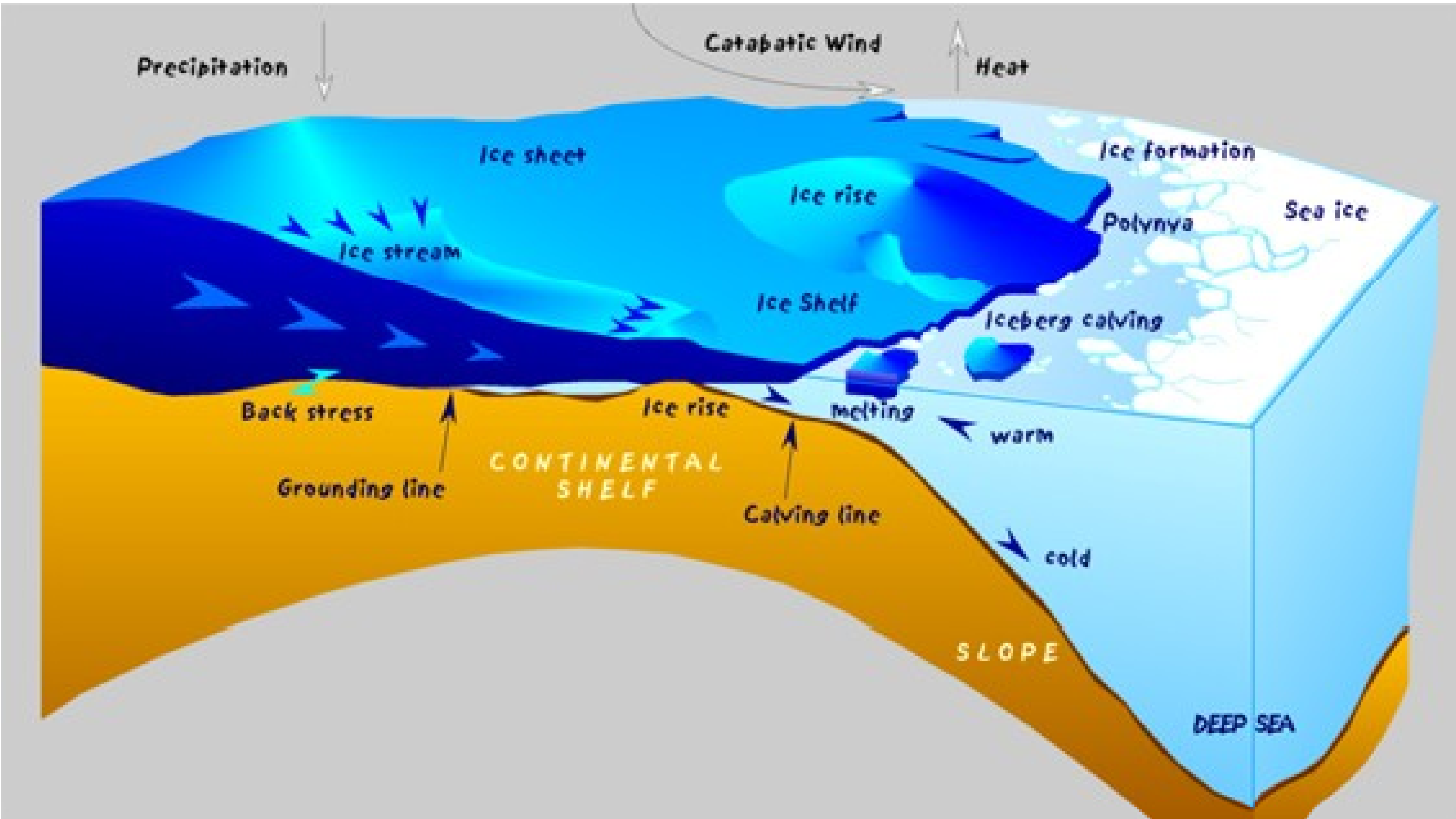
Alley et al. (2005)

Antarctic mass balance



Alley et al., 2007, Ann. Glac.; Shepherd and Wingham, 2007, Science; Rignot et al., Nature, 2008; Velicogna, Luthcke, AGU 2007

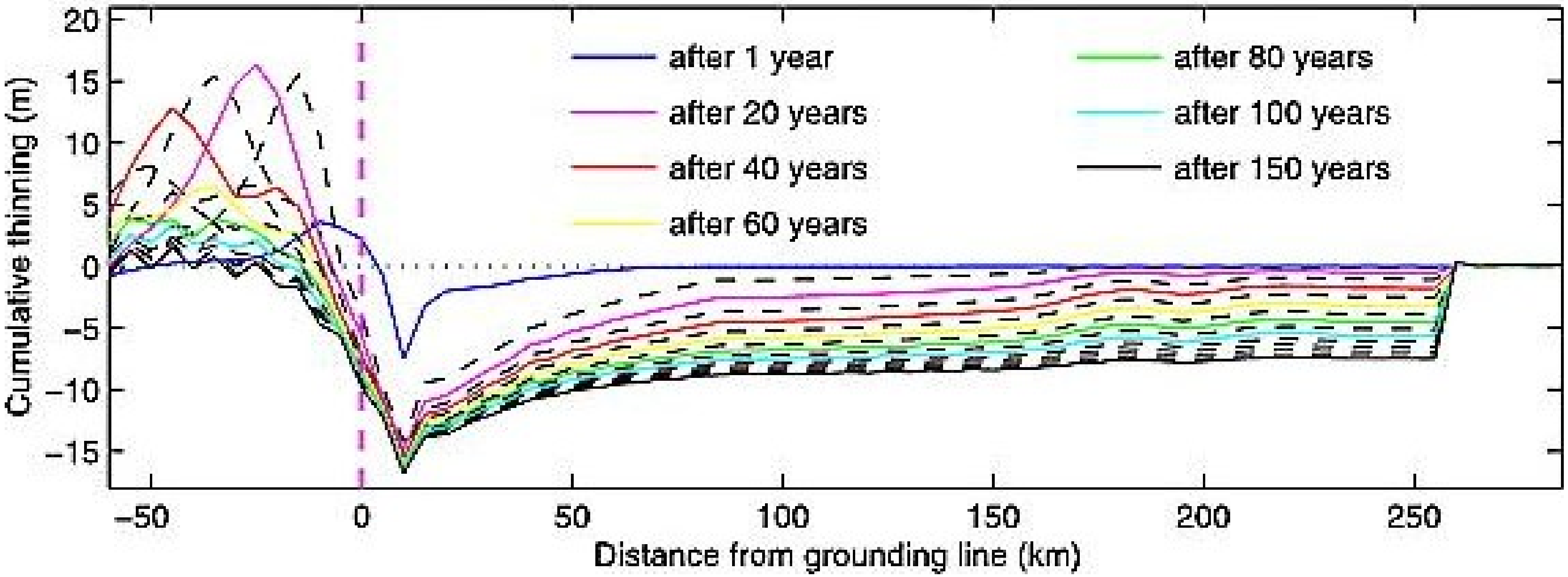
Ice-sheet processes



Antarctic coast with glaciological and oceanographic processes

Without the ice rise, this ice shelf would be unstable

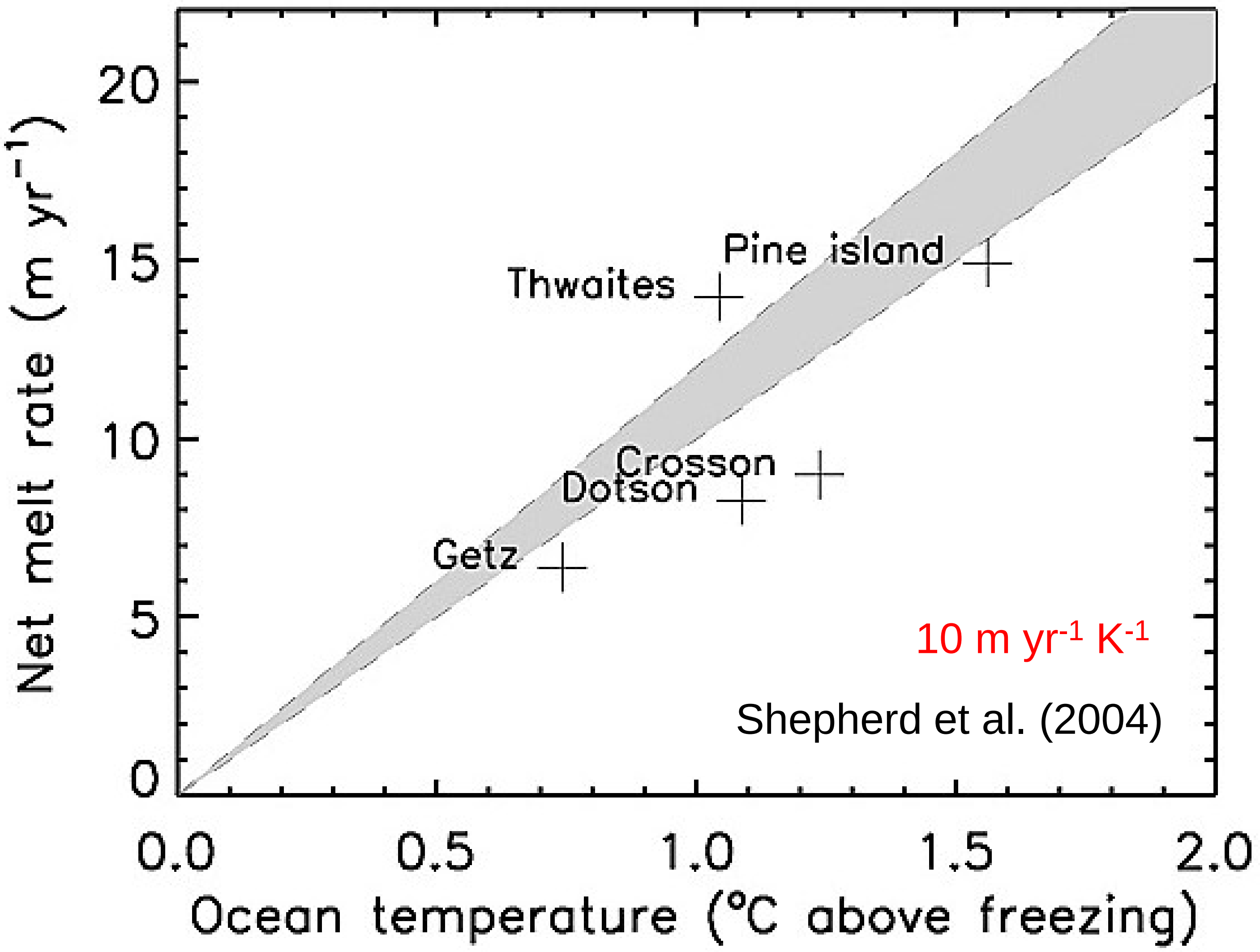
Modelling reaction of an ice-stream to reduced restraint



Payne et al. (2004)

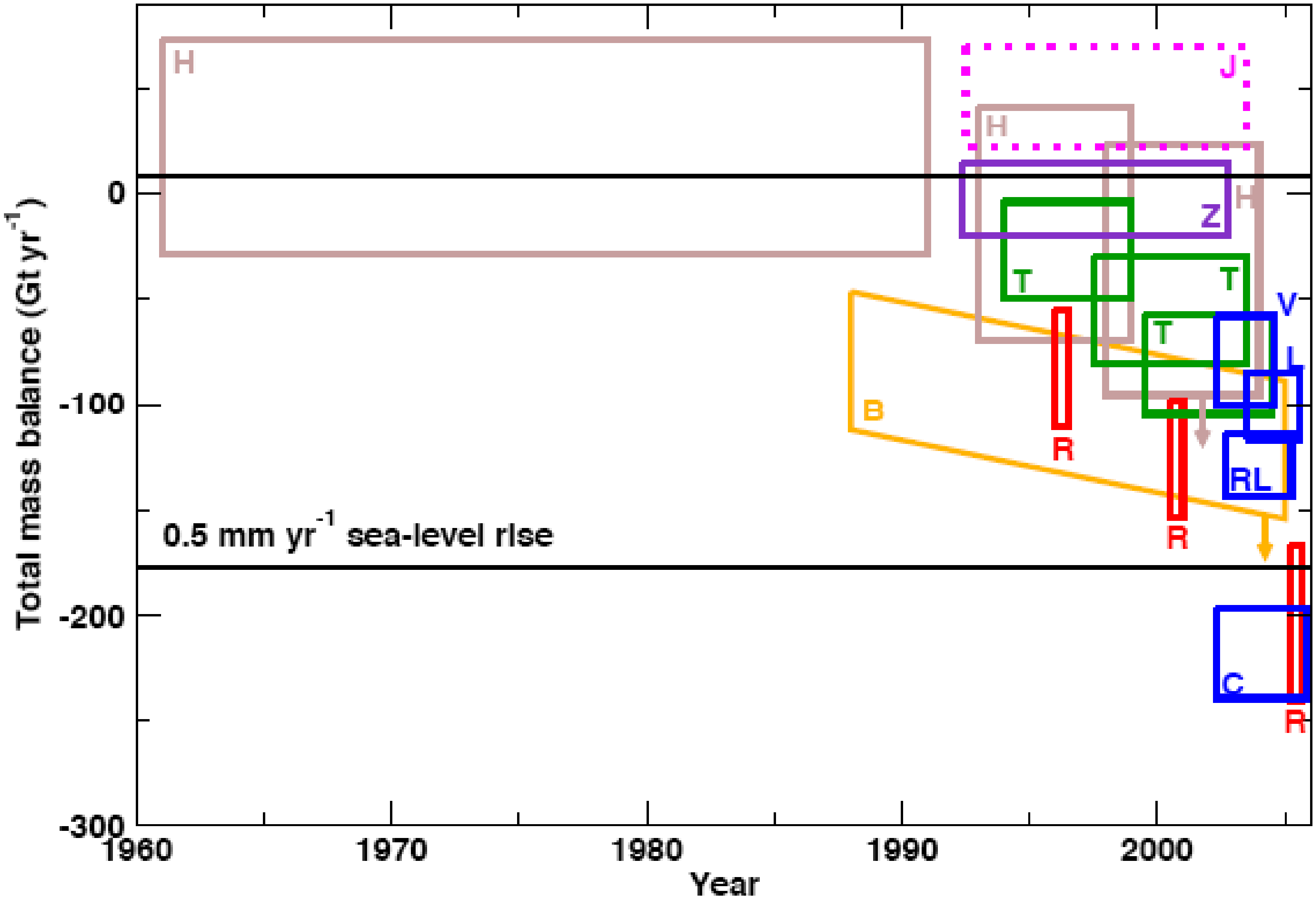
We need models of continental ice-sheets
including dynamics of ice-streams and ice-shelves

Warming ocean promotes basal melting



We need models relating ice-shelf basal melting to large-scale oceanography

Greenland mass balance



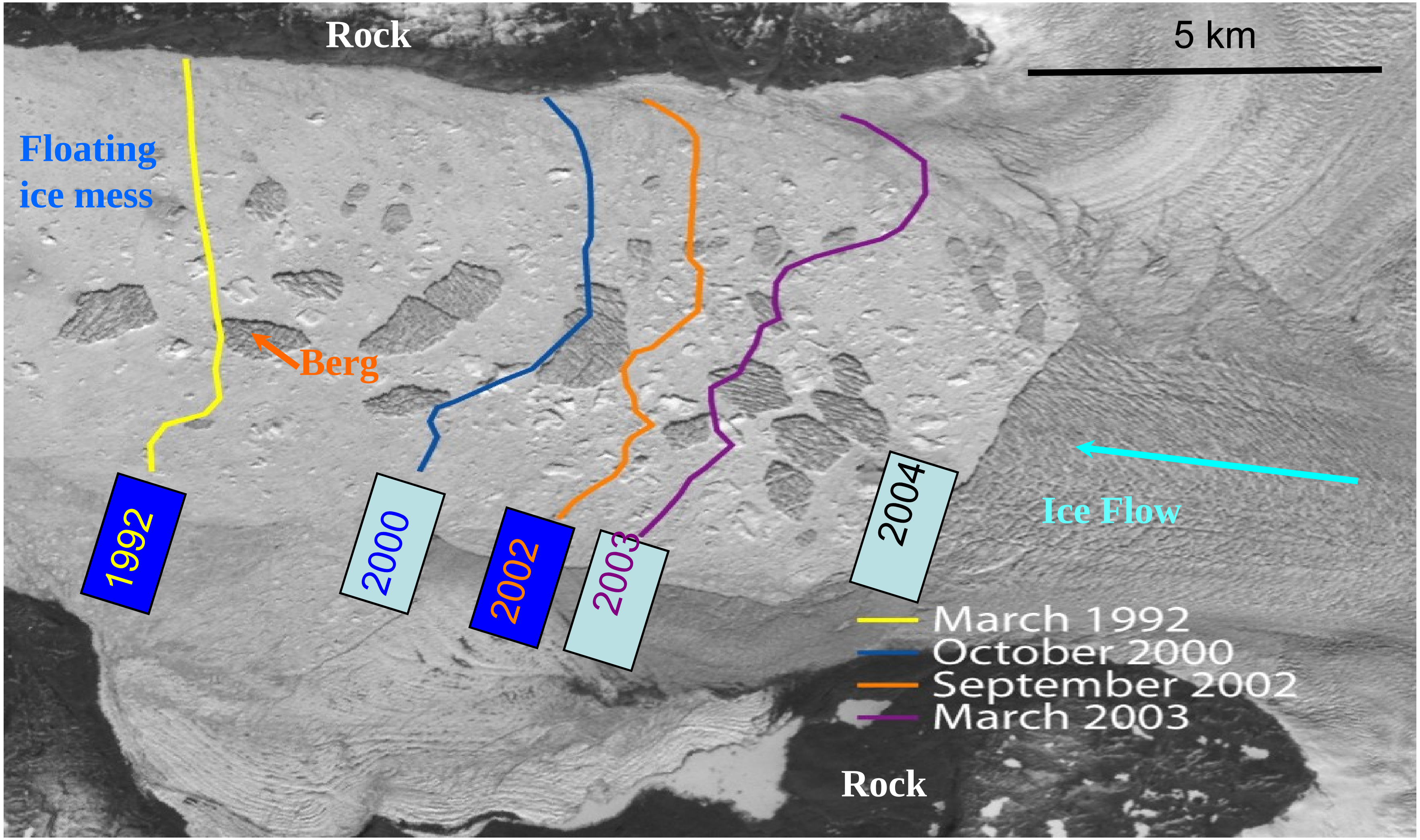
Alley et al., 2007, Ann. Glac.

Jakobshavn Isbrae, West Greenland

Discharge from many major Greenland ice streams (outlet glaciers) has accelerated markedly.

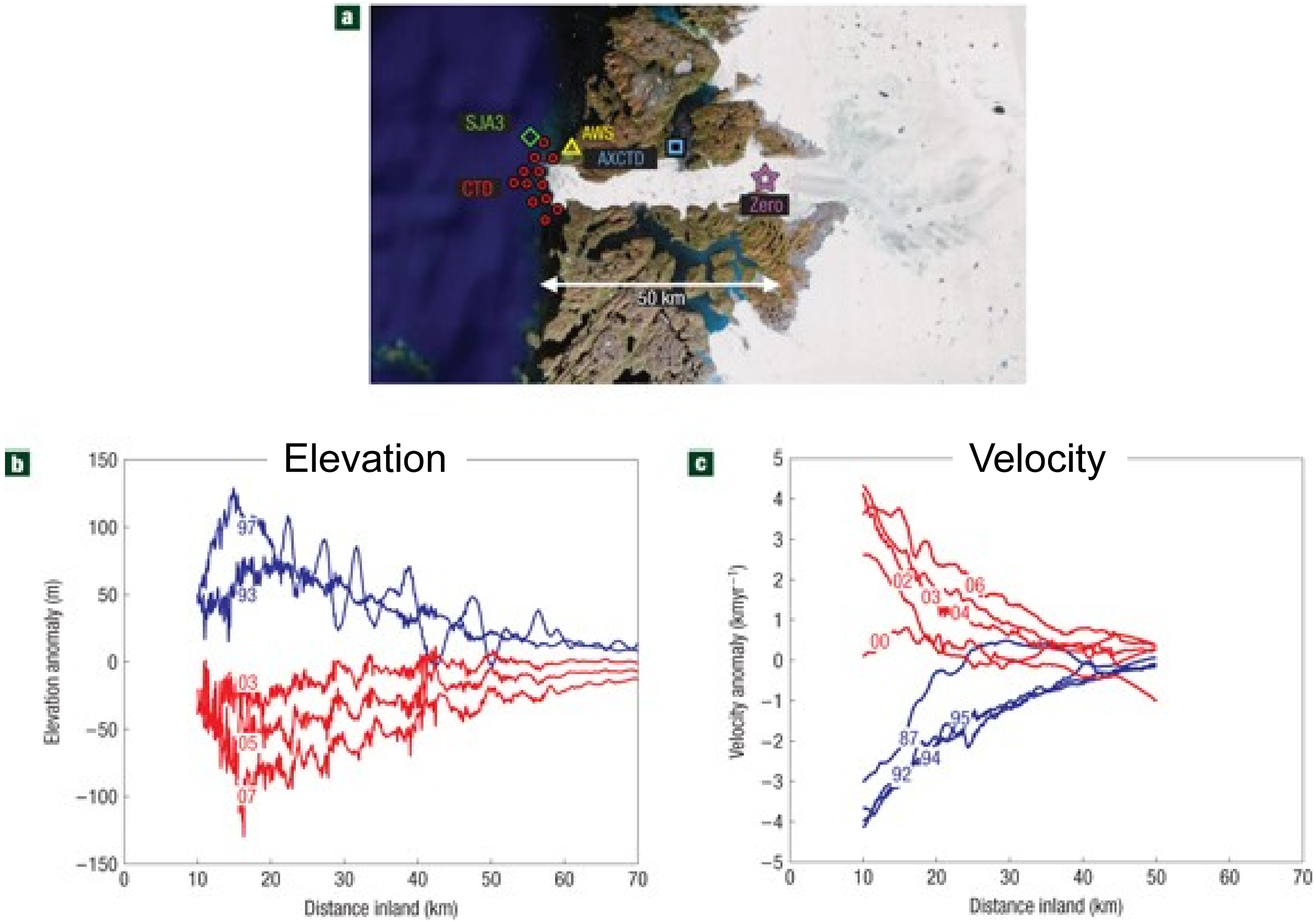
Source: Konrad Steffen, Univ. of Colorado

Jakobshavn Isbrae, West Greenland



Retreat with speed doubling during ice-shelf loss (Alley et al., 2005).

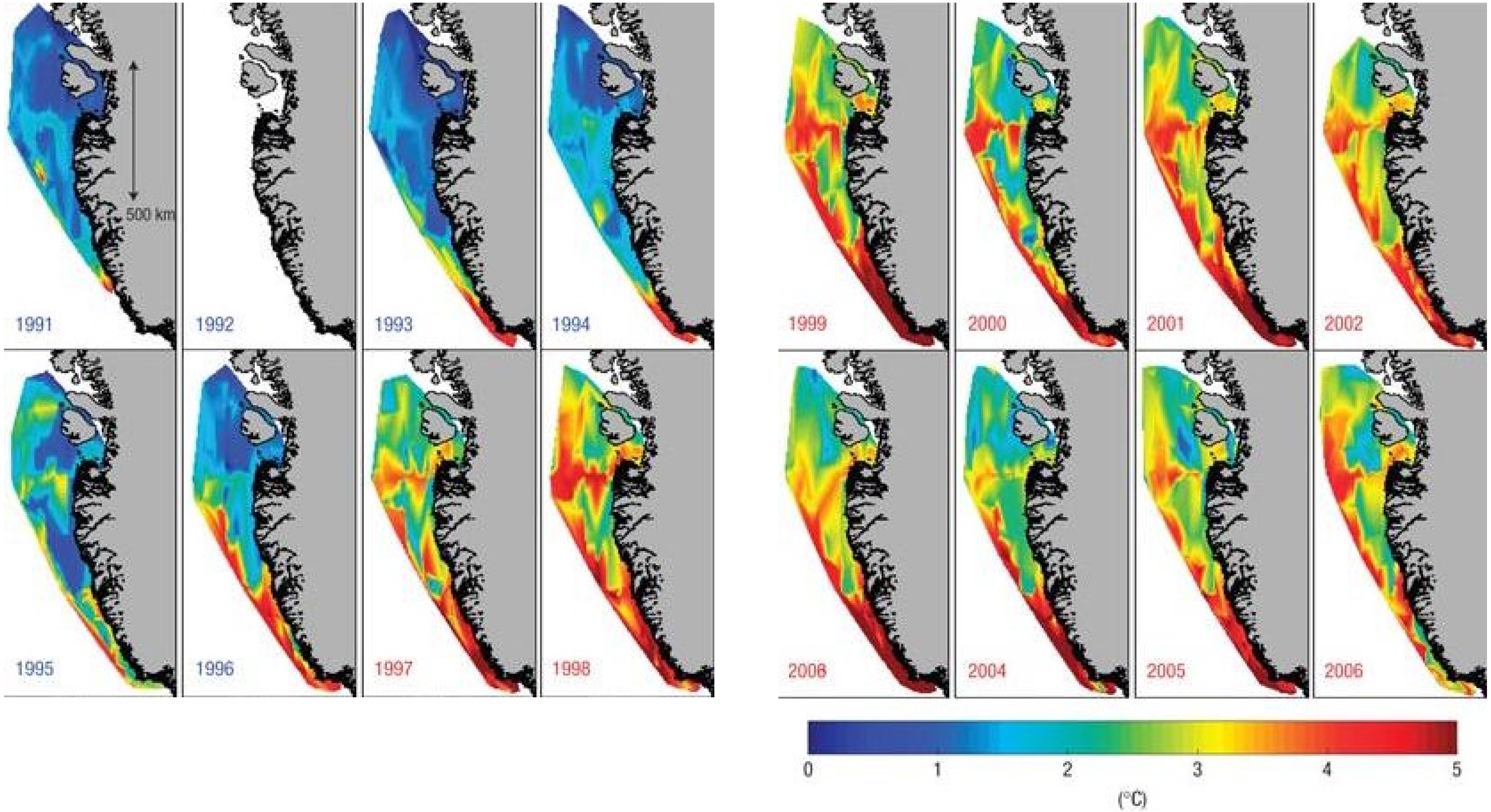
Jakobshavn Isbrae, West Greenland



Holland et al. (2008)

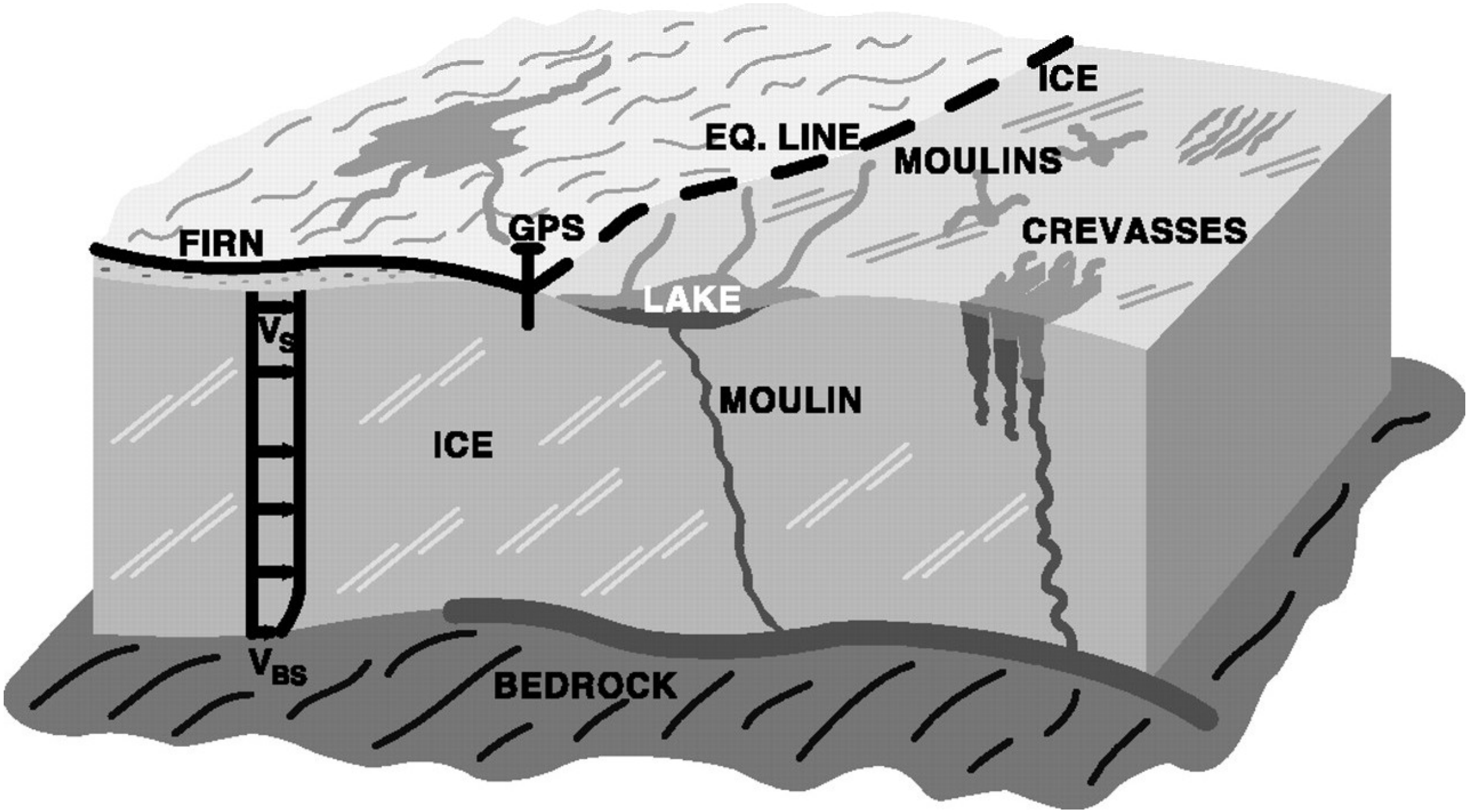
Jakobshavn Isbrae, West Greenland

Water temperature, 150-600 m depth-averaged



Holland et al. (2008)

Lubrication of ice-sheet flow by surface meltwater



Zwally et al. (2002)

Supraglacial meltwater lake in Greenland

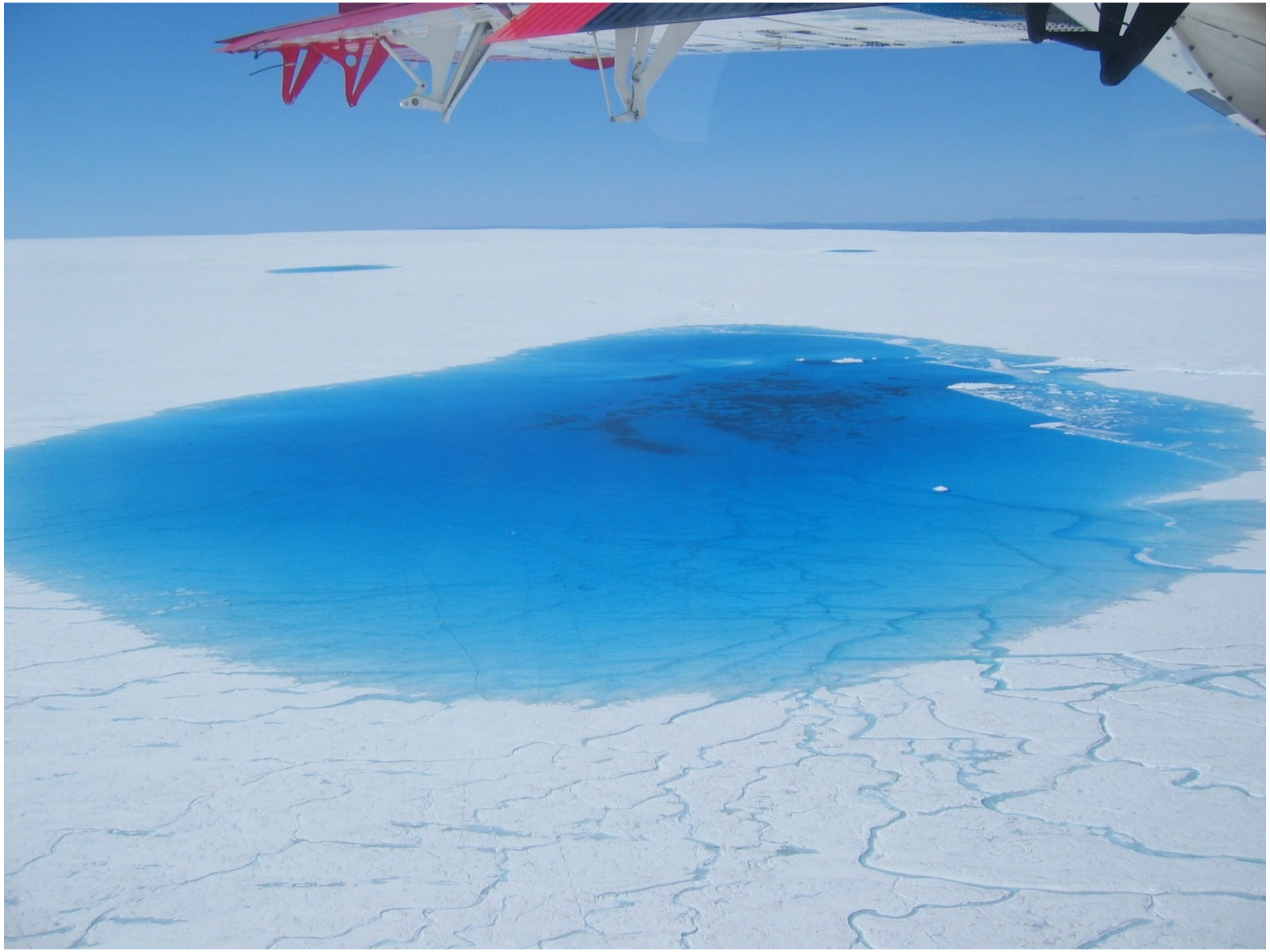


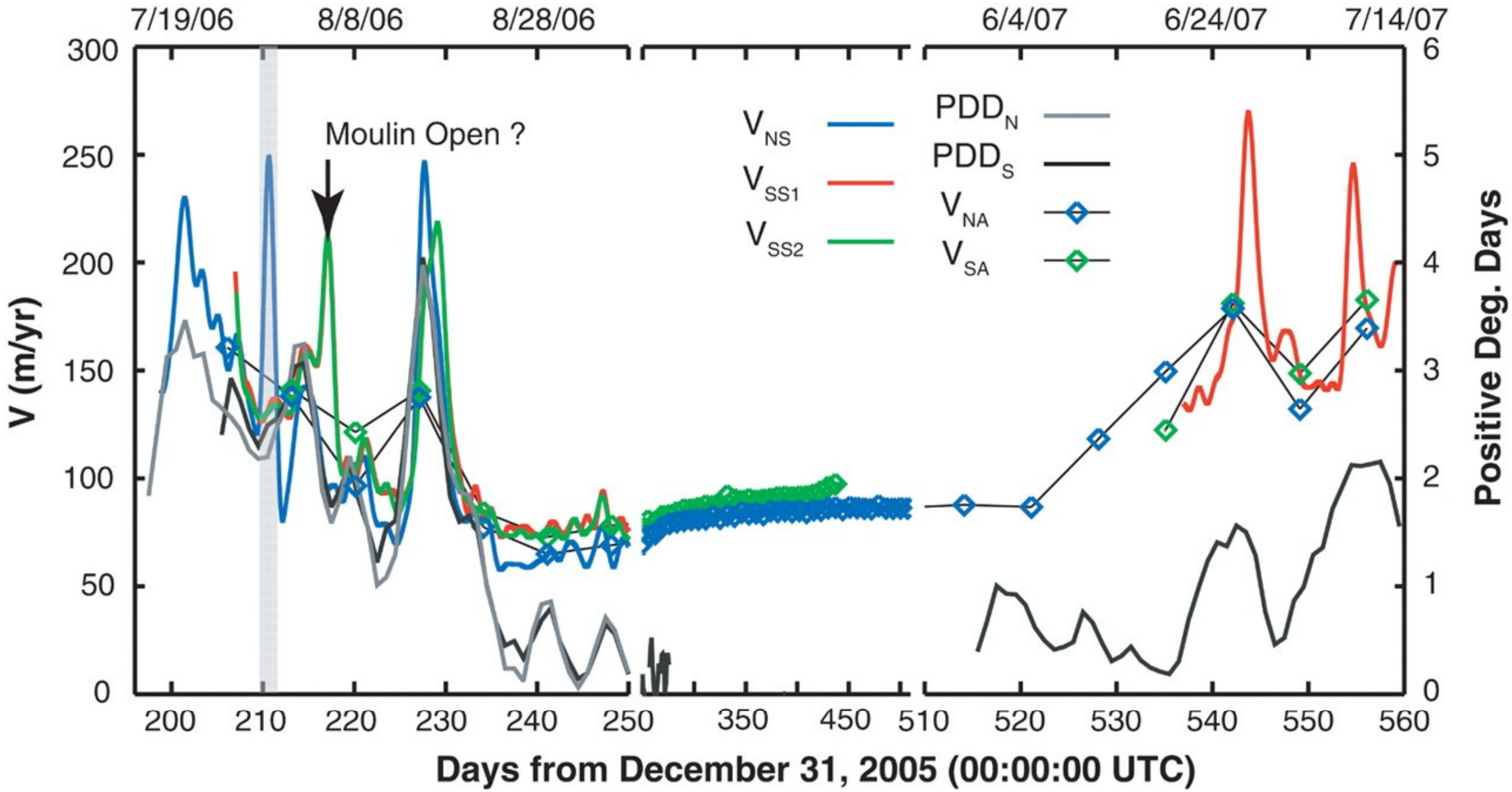
Photo courtesy Ian Joughin (copyright 2008)

Drainage of meltwater lake to the ice-sheet bed

Spectacular confirmation: observed lake drainage through new fracture to bed, with >Niagara Falls for an hour, uplift of several meters

Das et al., 2008

Lubrication of ice-sheet flow by surface meltwater



Velocity speed up when there is large surface melting and during lake drainage. Only a few % averaged over a large area and whole year. Joughin et al. 2008

Lubrication of ice-sheet flow by surface meltwater

Central Greenland frozen to bed, with almost no basal motion.

Thawing a frozen bed increases motion, perhaps 2x as a first estimate.

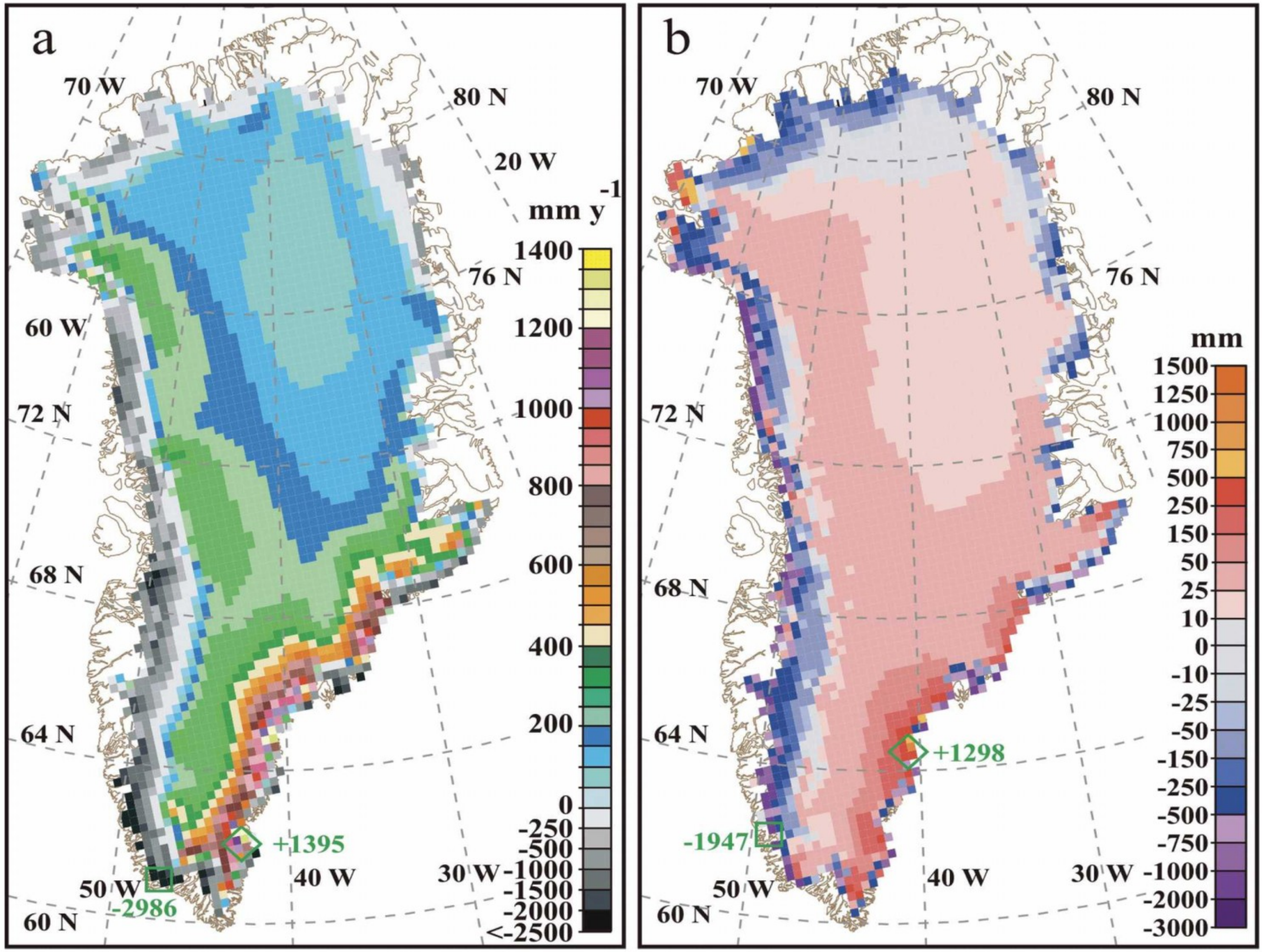
Time for advective-diffusive propagation of surface temperature and snowfall changes to bed: 10^3-10^4 yr.

Time for surface meltwater reaching bed to have similar effect: ~ 1 hour.

Hence inland expansion of surface melting may accelerate ice discharge and rate of mass loss (10s%, Parizek and Alley, 2004).

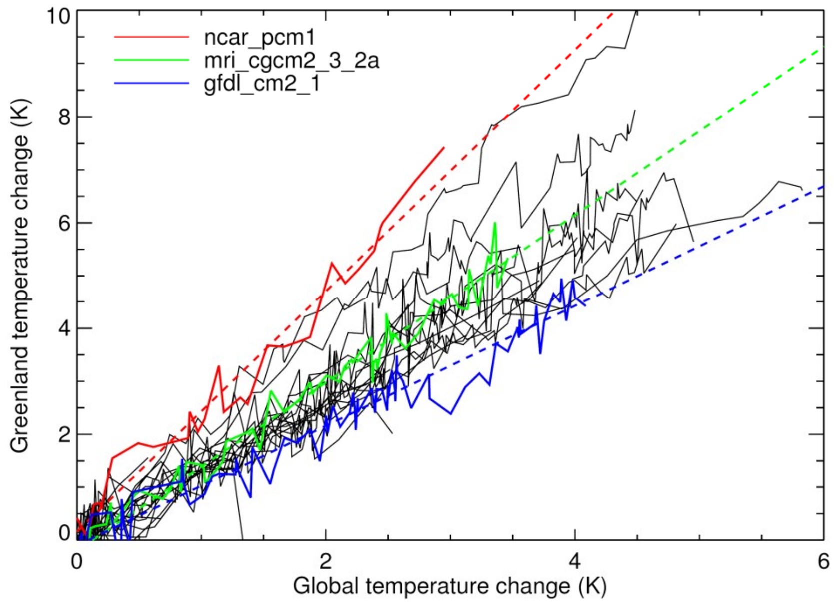
Greenland surface mass balance

Annual average | Change over 1988-2004

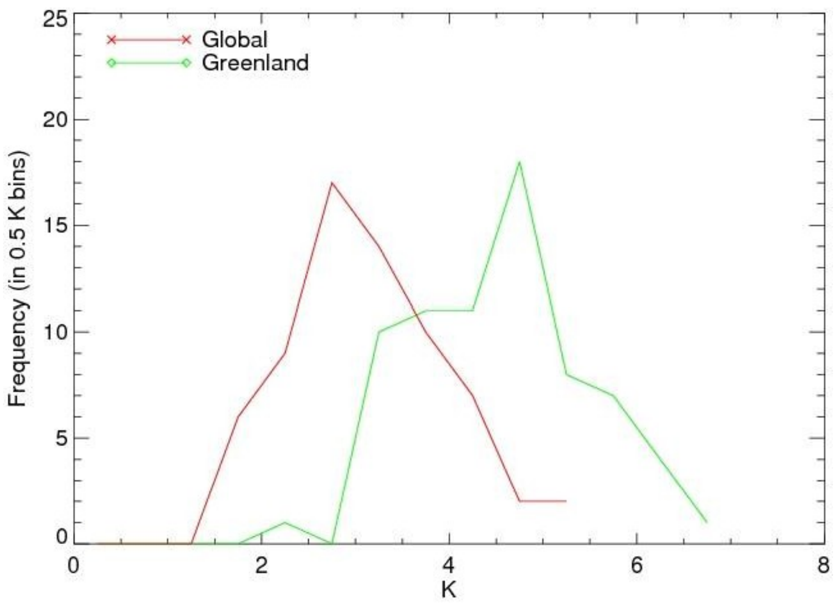


Box et al. (2006)

Uncertainty in projected change in Greenland surface mass balance

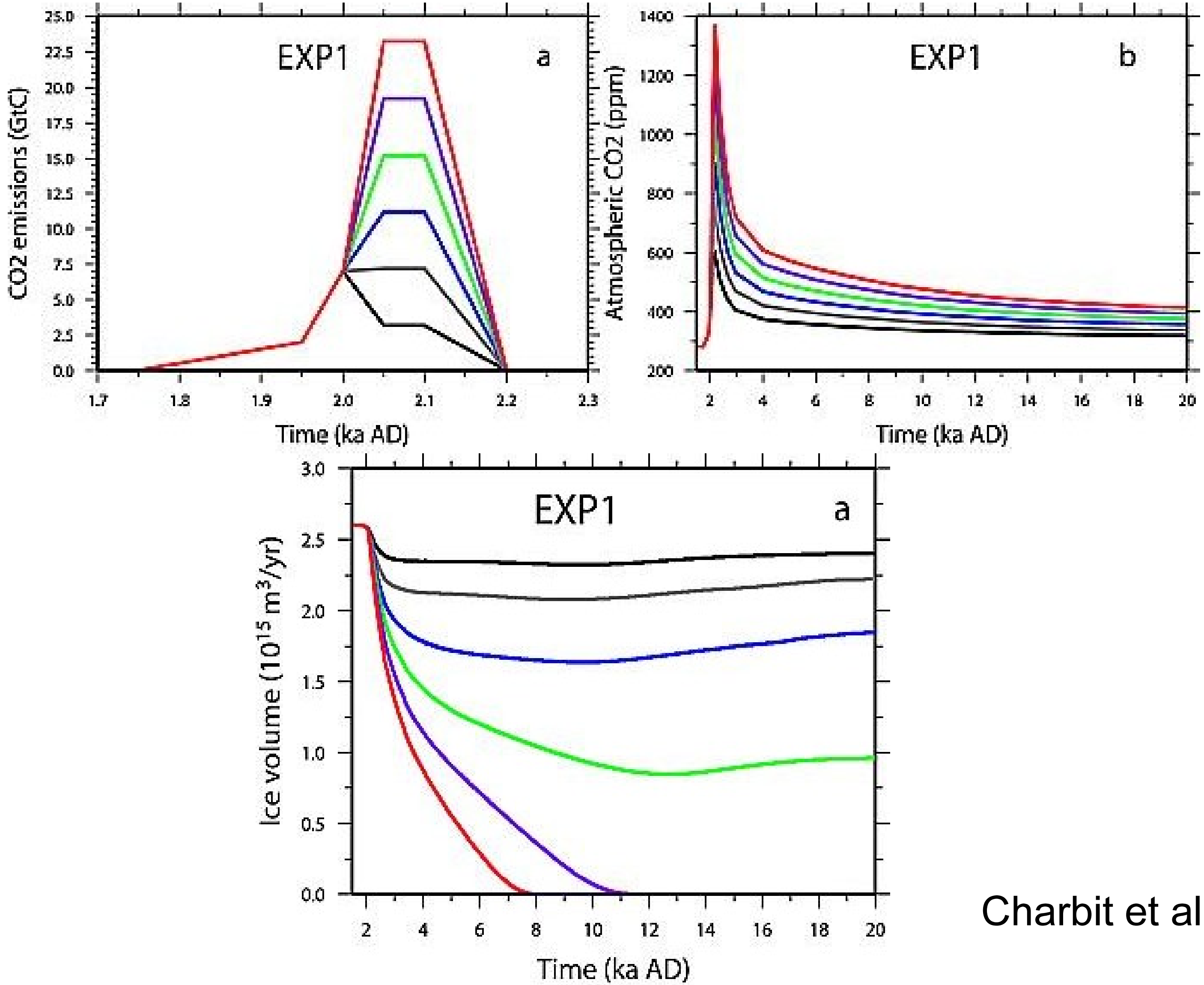


Threshold of sustainability



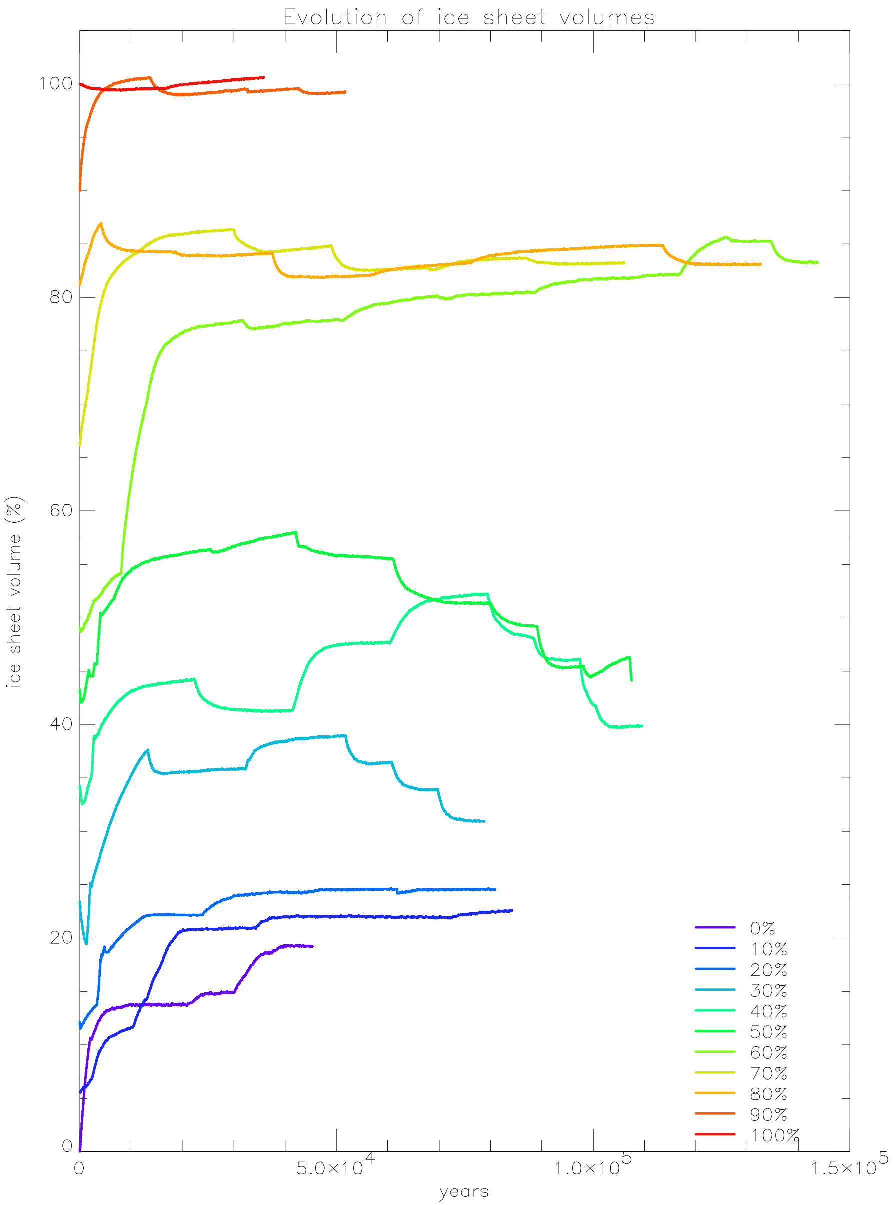
Gregory and Huybrechts (2006)

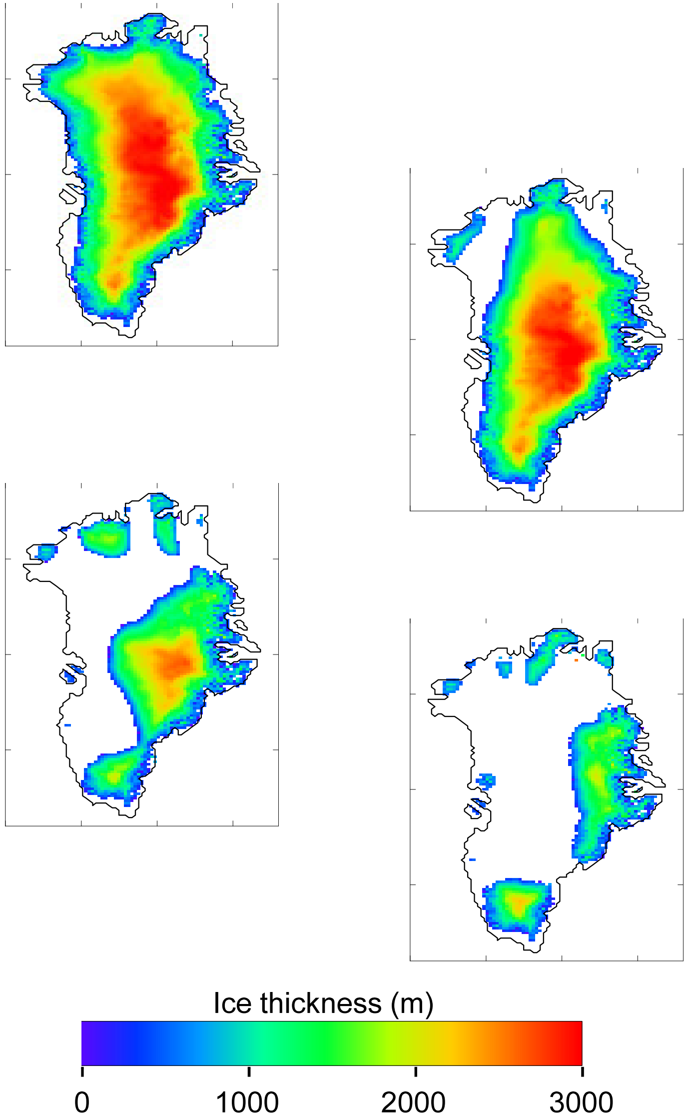
Irreversible loss of the Greenland ice sheet



Charbit et al. (2008)

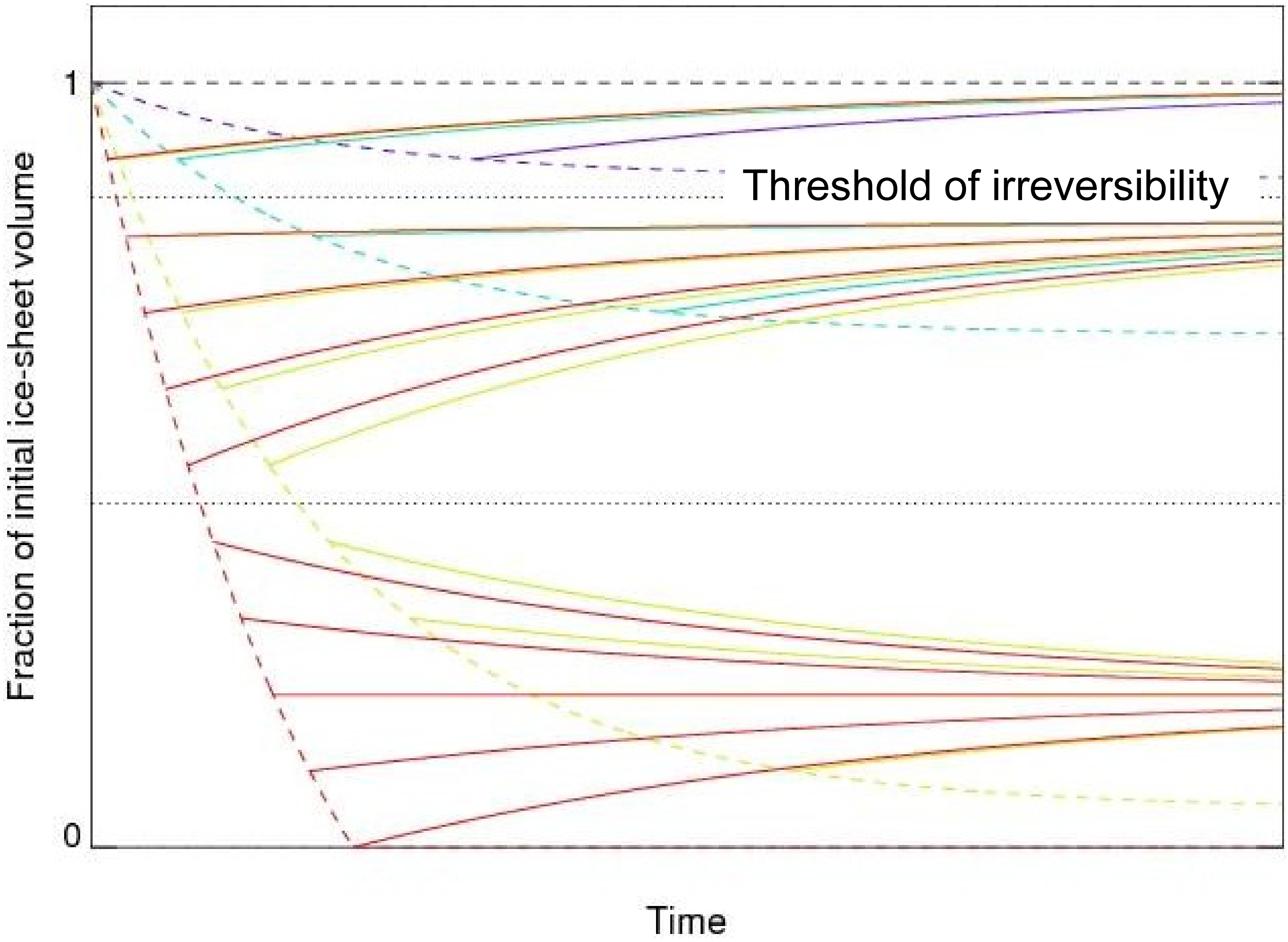
Irreversible loss and multiple states





Ridley et al. (submitted)

Irreversible loss of the Greenland ice sheet



Summary

The contribution of ice-sheets to future sea-level rise is very uncertain.

Accelerated ice-stream flow has been observed in both Antarctica and Greenland due to reduced ice-shelf buttressing, probably related to ocean warming.

People are working urgently on models of ocean—ice-shelf—ice-sheet interaction. Regional ocean warming will also be a challenge to predict.

Basal lubrication by surface meltwater commonly leads to accelerated flow in Greenland, but it is not generally a dominant effect. Increased surface melting could lead to modest additional ice discharge.

Change in Greenland surface mass balance will determine the long-term future of the Greenland ice sheet. There are large uncertainities in models of SMB and regional climate change.

Partial loss of the ice-sheet could become irreversible in O(100) years but there is huge uncertainty.