

An aerial photograph of a massive glacier system, showing intricate patterns of ice and dark sediment. The glacier flows from the top left towards the bottom right, where it meets a body of water. The water is a deep blue-green color, and several small icebergs are visible floating on its surface. The text "Ice and climate: learning from an uncertain past" is overlaid in white, serif font in the upper-middle section of the image.

Ice and climate: learning from an
uncertain past

**Should we worry about climate
change?**

**What should we do about climate
change?**

**Why are there no clear answers?
????????????????????**

There is no 100% certain answer

**Uncertainty is
unavoidable when
dealing with
climate (and most
environmental)
systems**



Why: fundamental sources of unpredictability

- ◆ Nonlinearity
- ◆ -> Sensitivity to initial conditions
- ◆ -> Time-delayed response
- ◆ Feedbacks between diverse components
- ◆ Cross-scale linkages



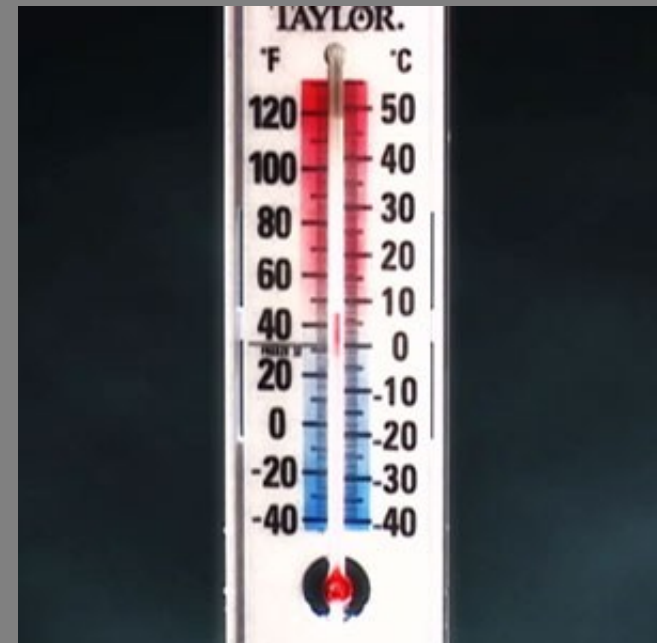
*** All characteristics of the climate system ***

How to deal with uncertainty?

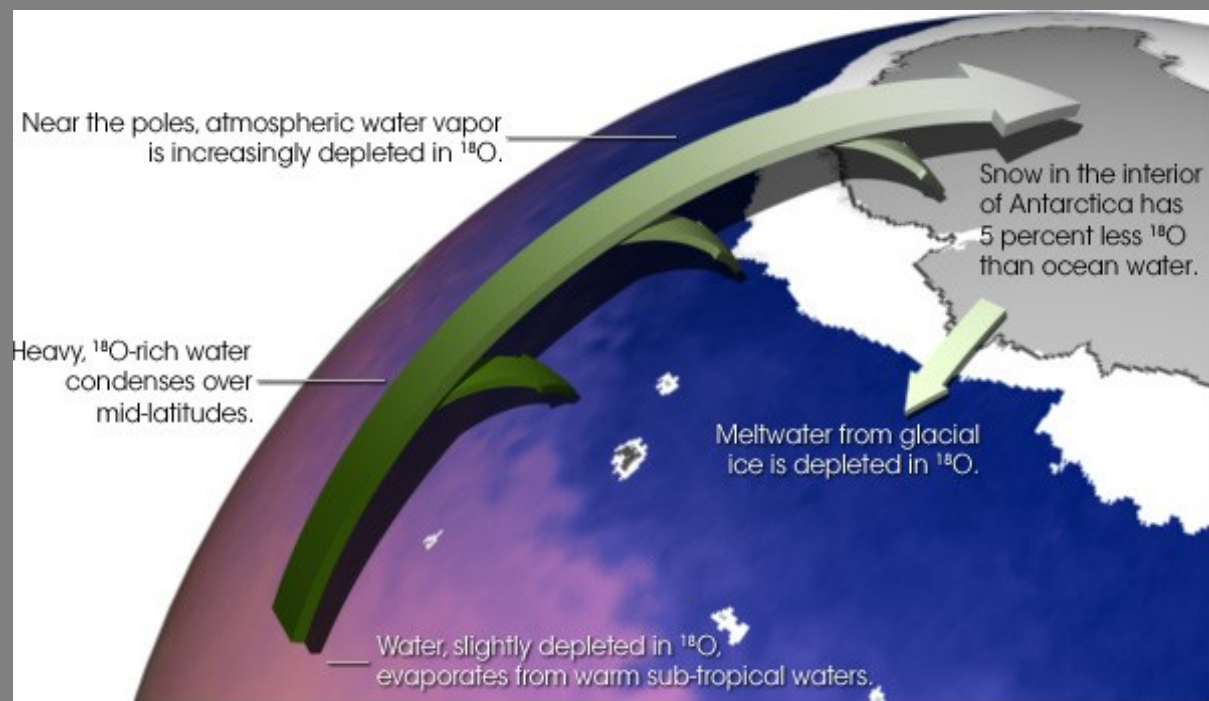
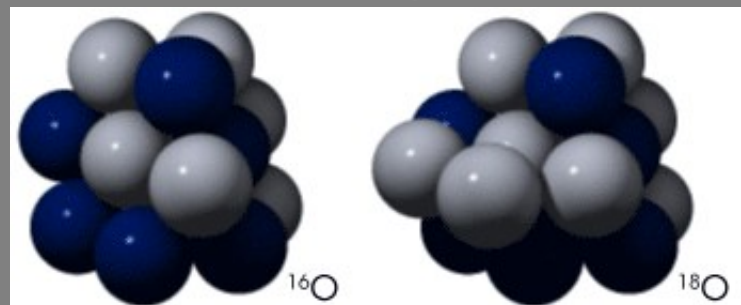
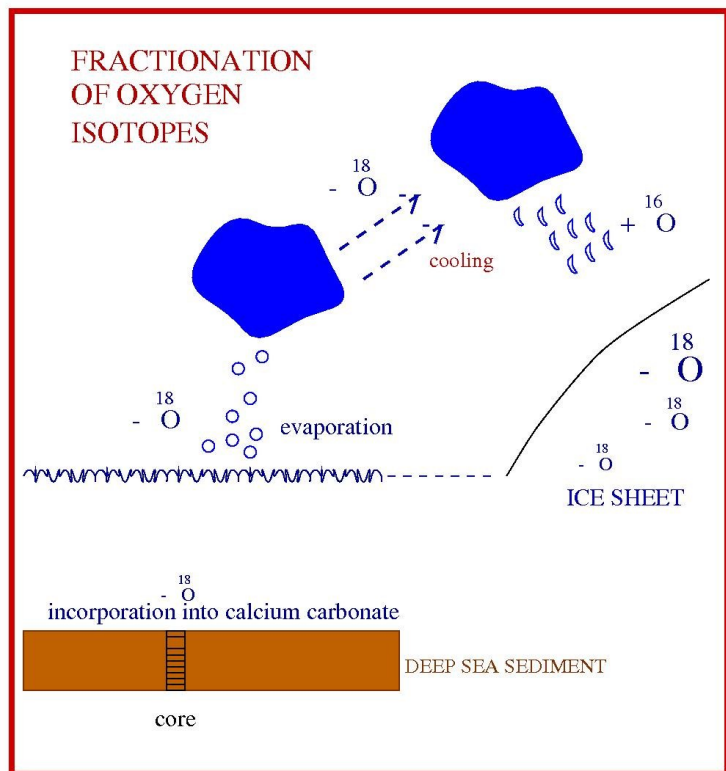
- ◆ Scientific theories and understanding
- ◆ Conceptual models
- ◆ Computational models
- ◆ Look to the Past: observations of past and present

How do we decipher the past?

Need measuring sticks for temperature, sea level,...



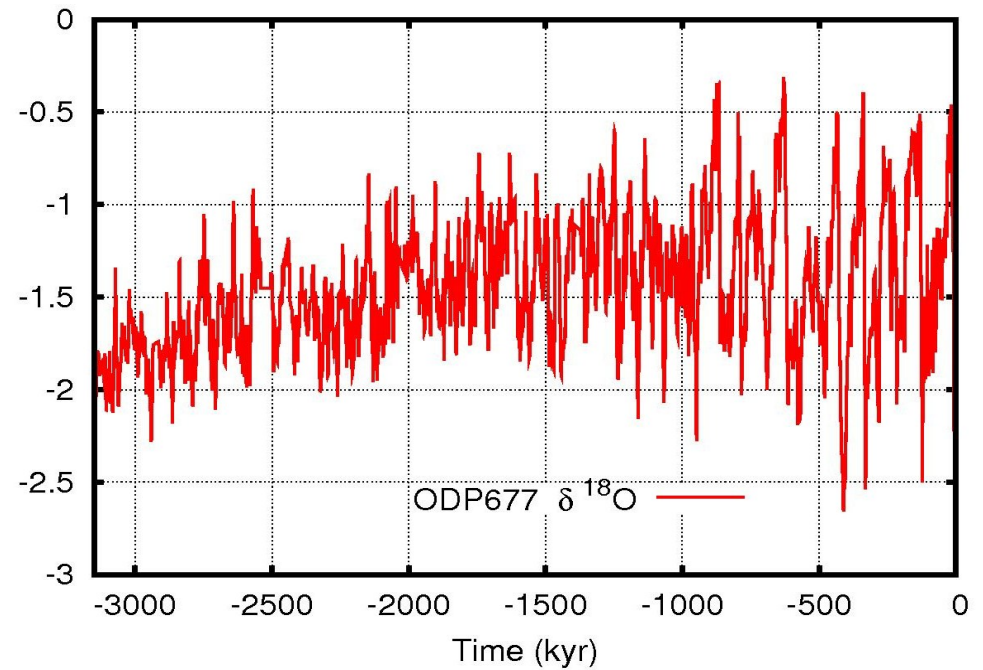
How do we decipher the past: Oxygen isotope measuring stick



How do we decipher the past?



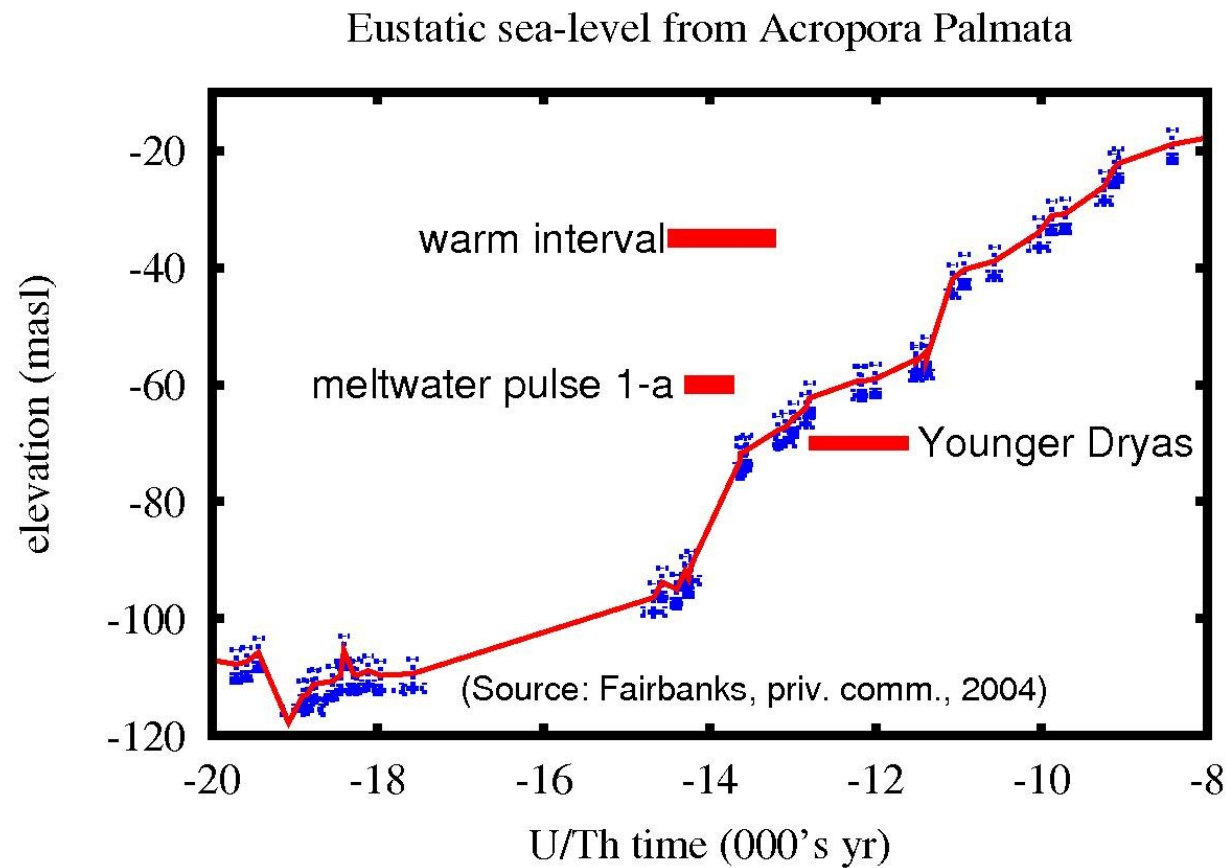
- Ocean drilling: Deep history stored in mud



What time of day is this and how does this relate to the changing seasons and ice age cycle?



Another measuring stick for SEA-LEVEL



200 years ago

Nobody knew about past large-scale glaciation
over North America or Europe

200 years ago



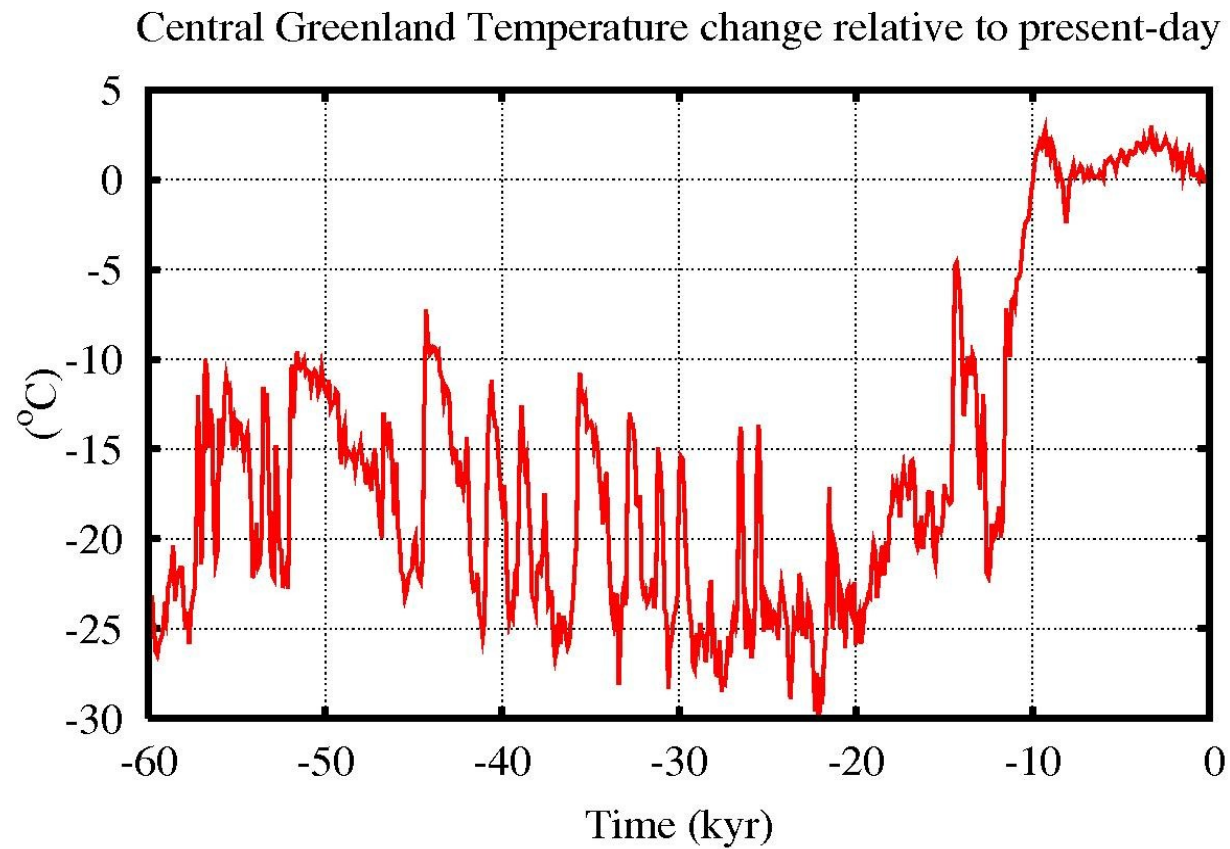
- Louis Agassiz first proposed the existence of continental glaciation over Europe in 1837
- How did he figure this out?

200 years ago

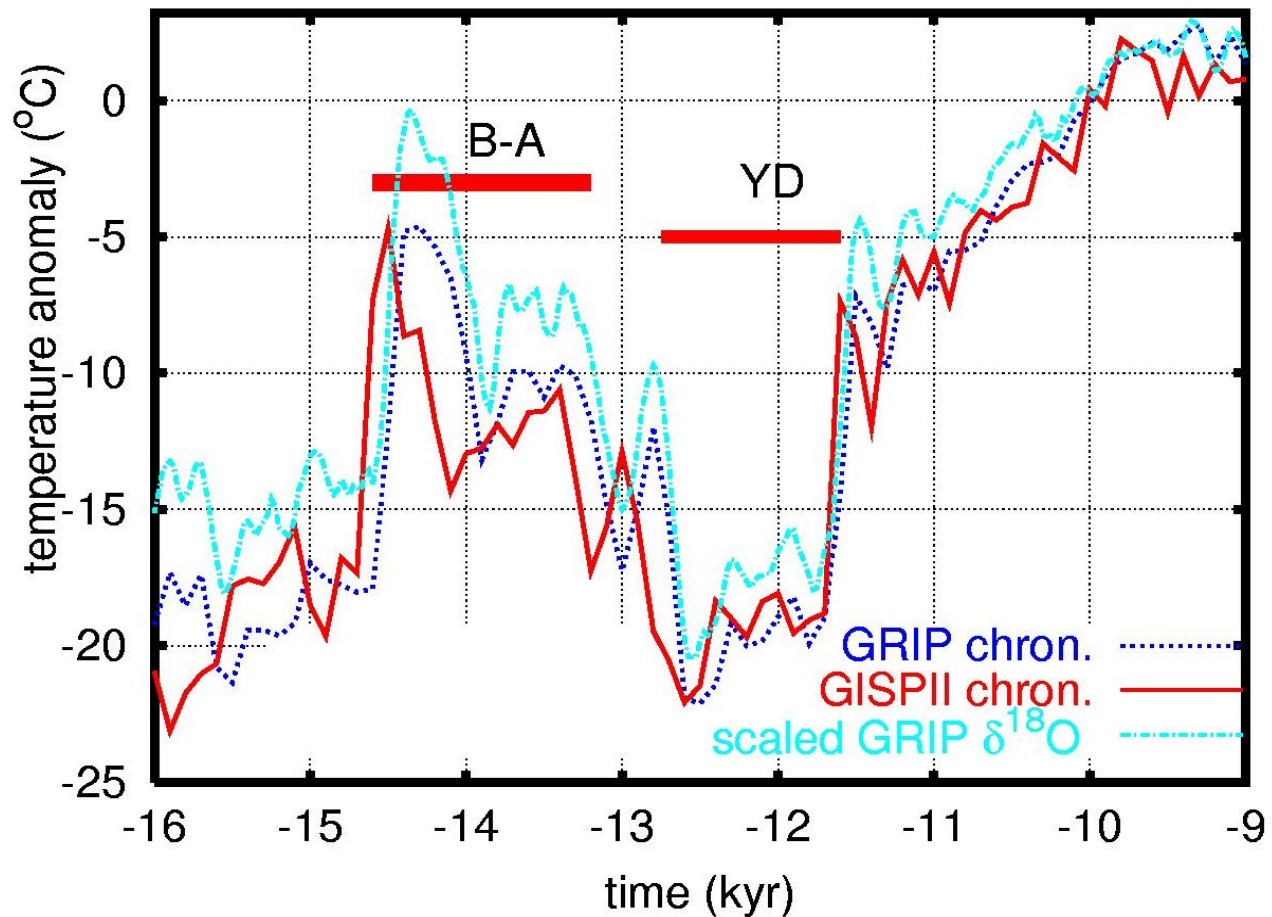


- Louis Agassiz first proposed the existence of continental glaciation over Europe in 1837
- How did he figure this out?
 - Drumlins
 - Erratics
 - Eskers

TEMPERATURE: Inferred from Greenland ice core

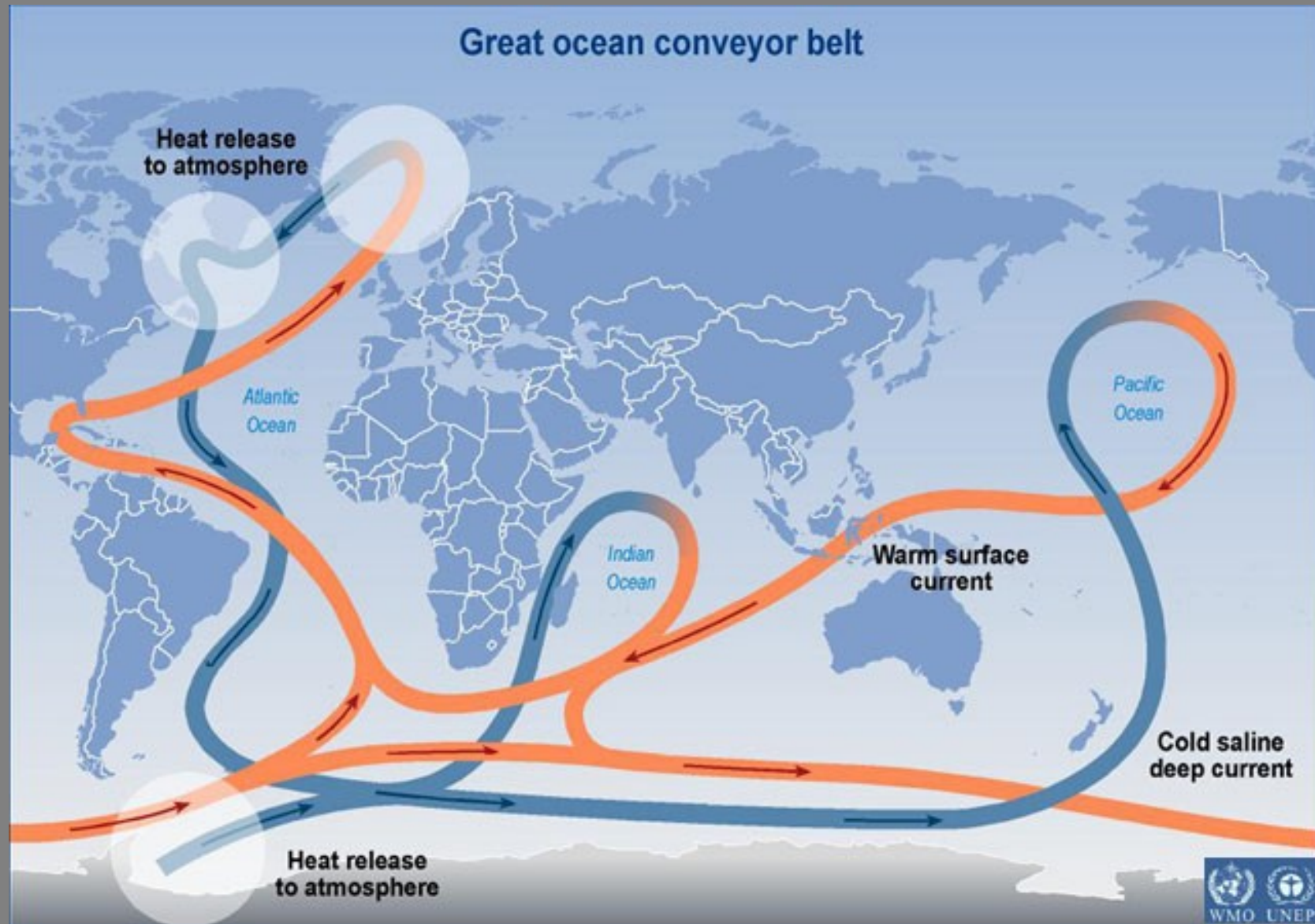


Jumping climate



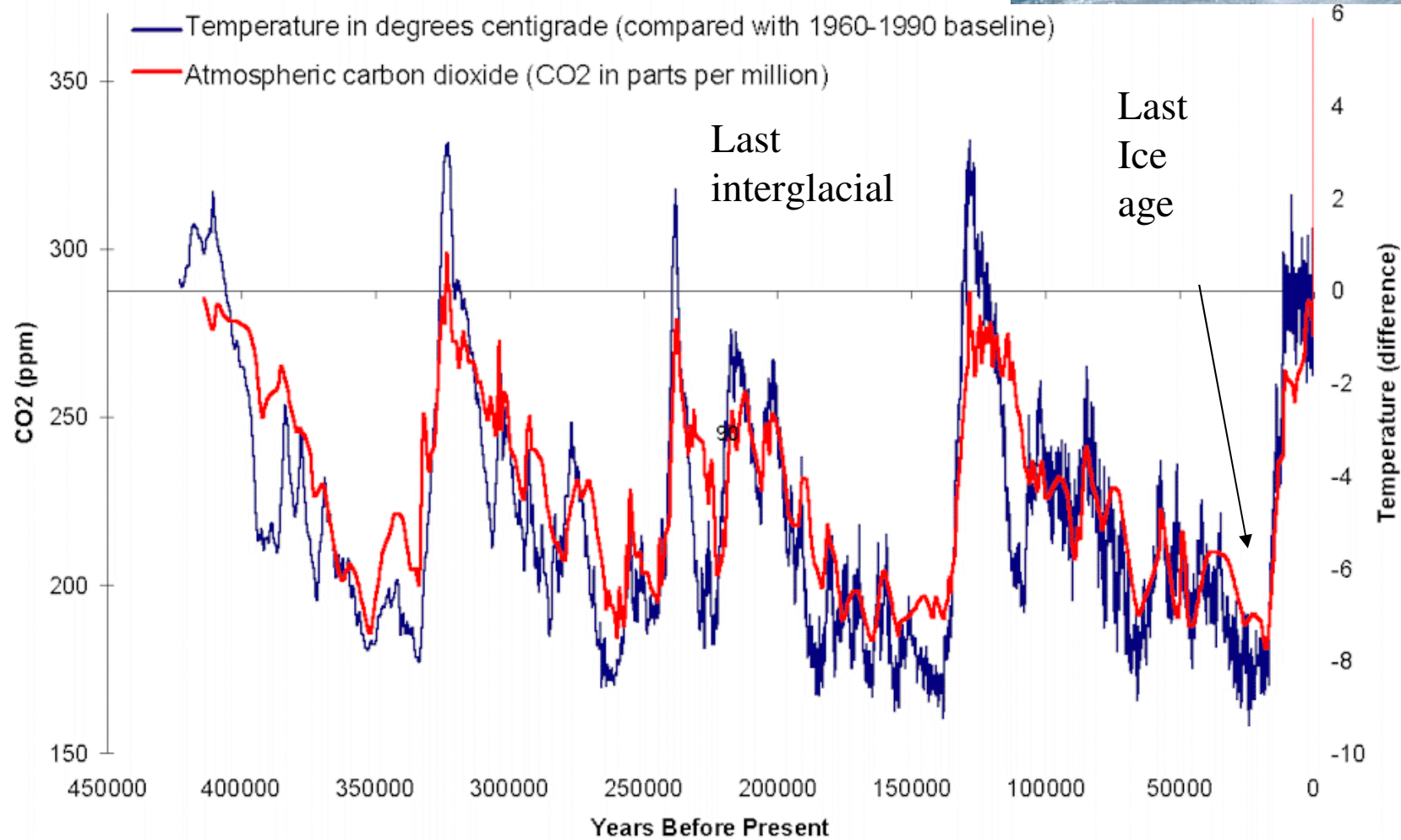
(from Tarasov and Peltier, 2003)

Ocean thermohaline circulation



What about CO₂?

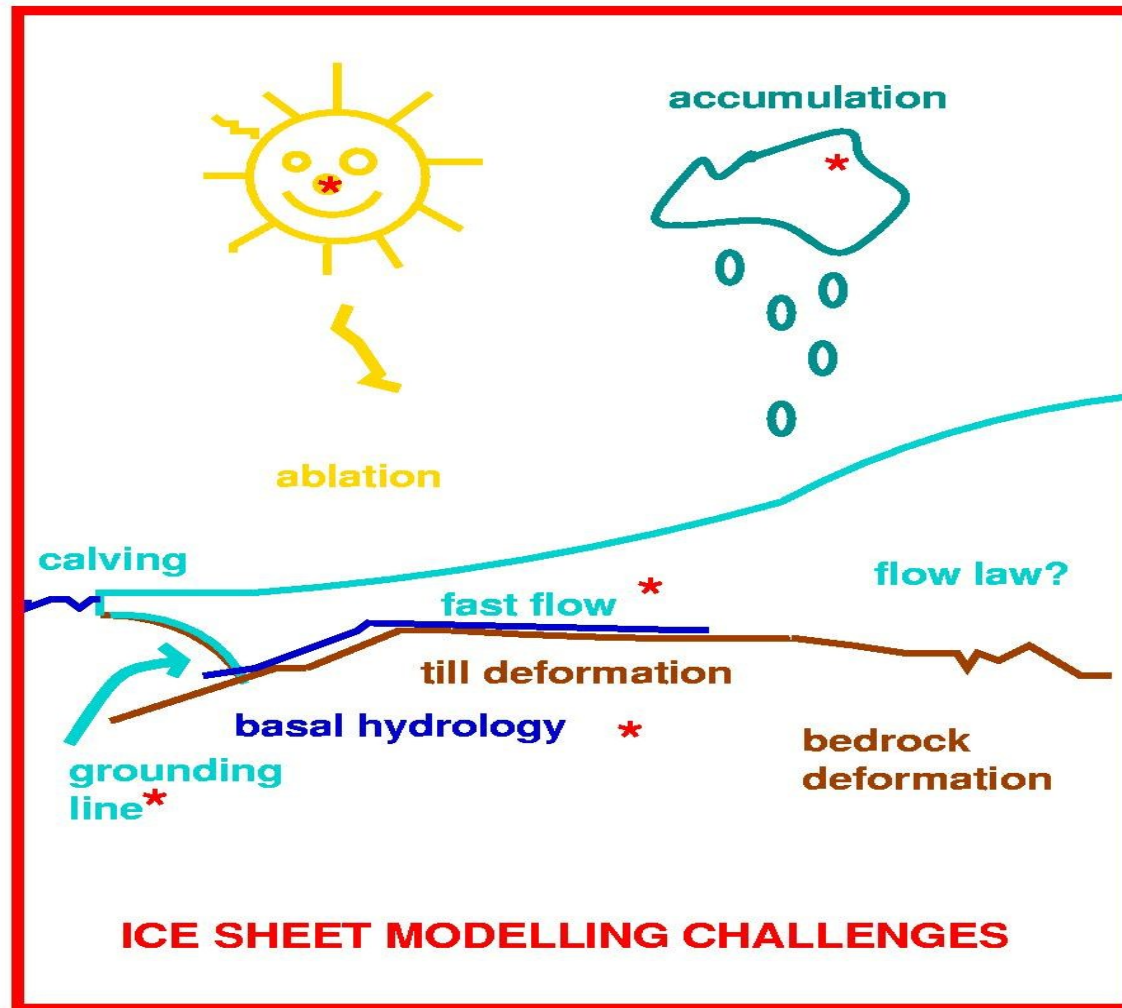
Vostok Ice Core Record



**How to get from observations of the
past to predicting the future?**

Models

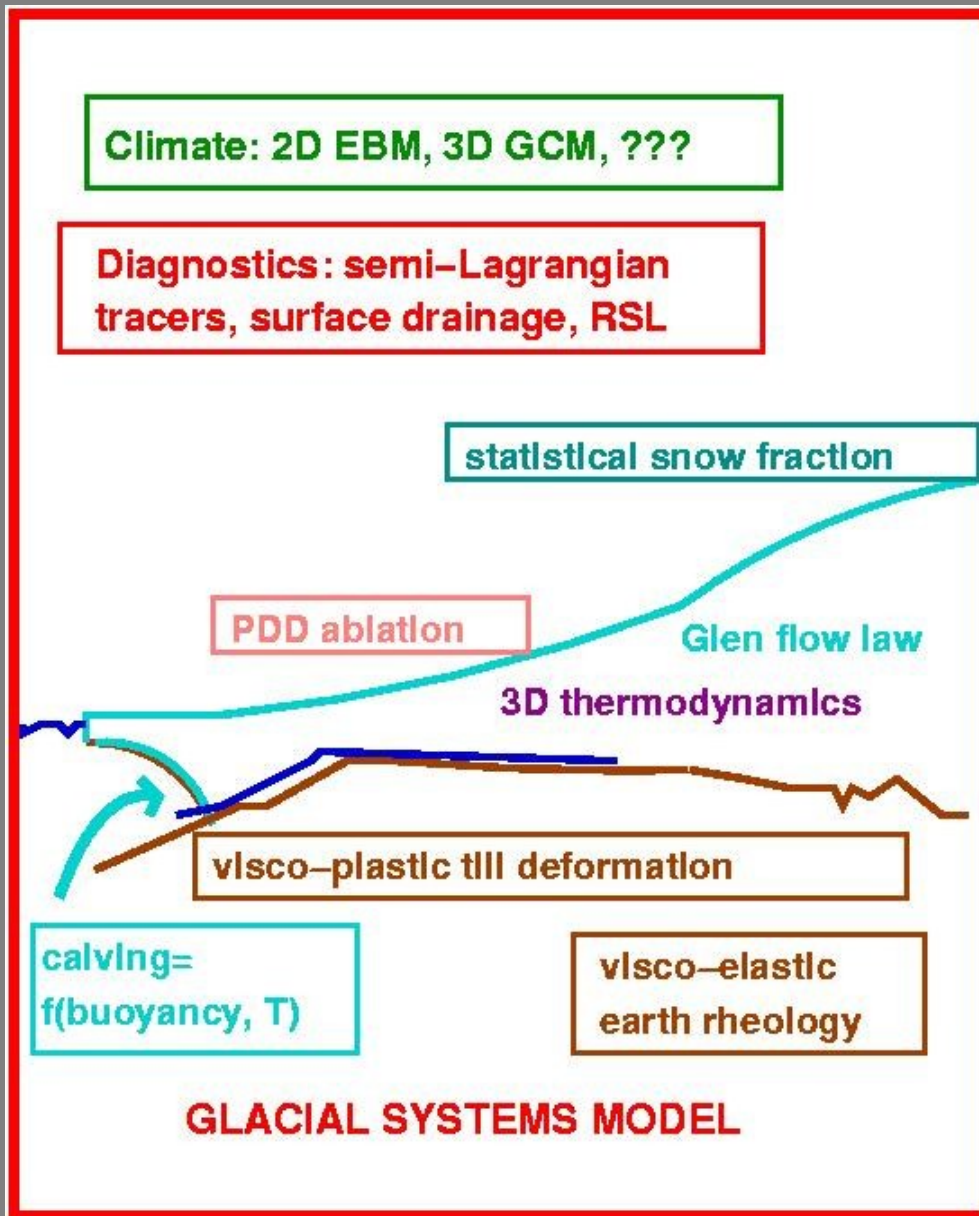
The Glacial System



**To predict the future of such
systems we need models**

**And we need to test them against
the past**

Glacial Systems Model (GSM)



Some GSM equations

- ice thickness ($H(\vec{r}, t)$) evolution computed from vertically integrated continuity equation for ice mass:

$$\frac{\partial H}{\partial t} = -\nabla_h \cdot \int_{z_b}^h \vec{V}(z) dz + G(\vec{r}, T) \quad (1)$$

- Ice velocity field $\vec{V}(\vec{r}, t)$ from Glen flow rheology

$$\vec{V}(\vec{r}) = \vec{V}_b - 2(\rho_i g)^n \{ \nabla_h(h) \cdot \nabla_h(h) \}^{(n-1)/2} \nabla_h(h) \cdot E \int_{z_b}^z A(T^*(z')) (h - z')^n dz'$$

- Ice temperature ($T(\vec{r}, t)$) from energy conservation

$$\rho_i c_i(T(\vec{r})) \frac{\partial T(\vec{r})}{\partial t} = \frac{\partial}{\partial z} \left\{ k_i(T(\vec{r})) \frac{dT(\vec{r})}{dz} \right\} - \rho_i c_i(T(\vec{r})) \mathbf{V}(\vec{r}) \cdot \nabla T(\vec{r}) + Q_d(\vec{r})$$

- Bedrock elevation R under load L from convolution with Greens function Γ :

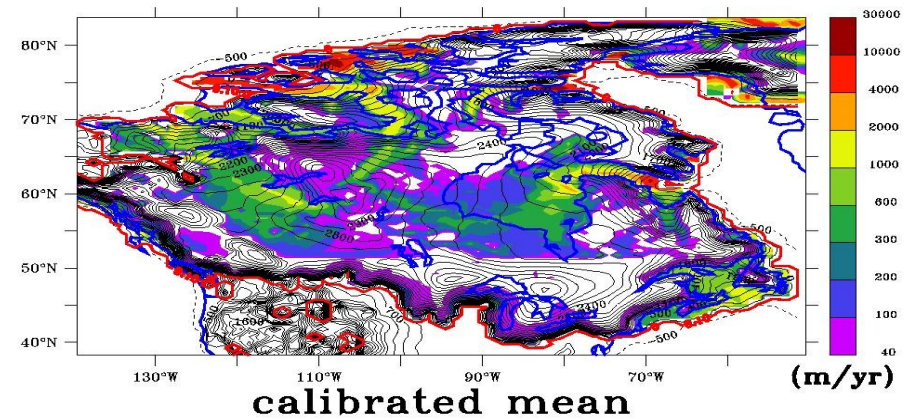
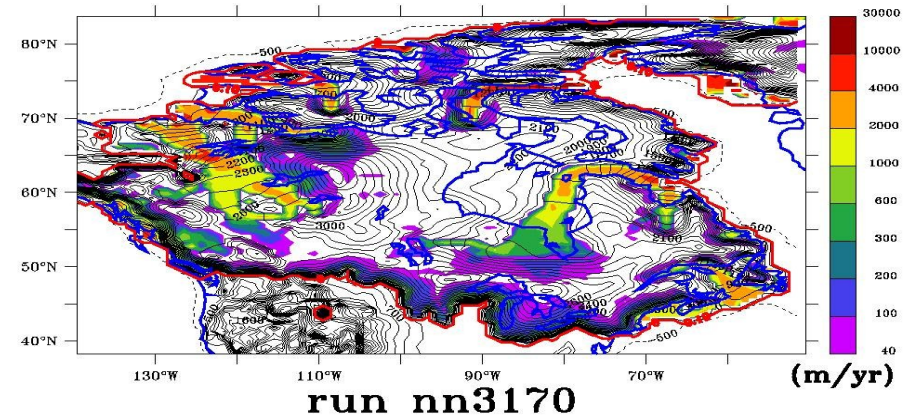
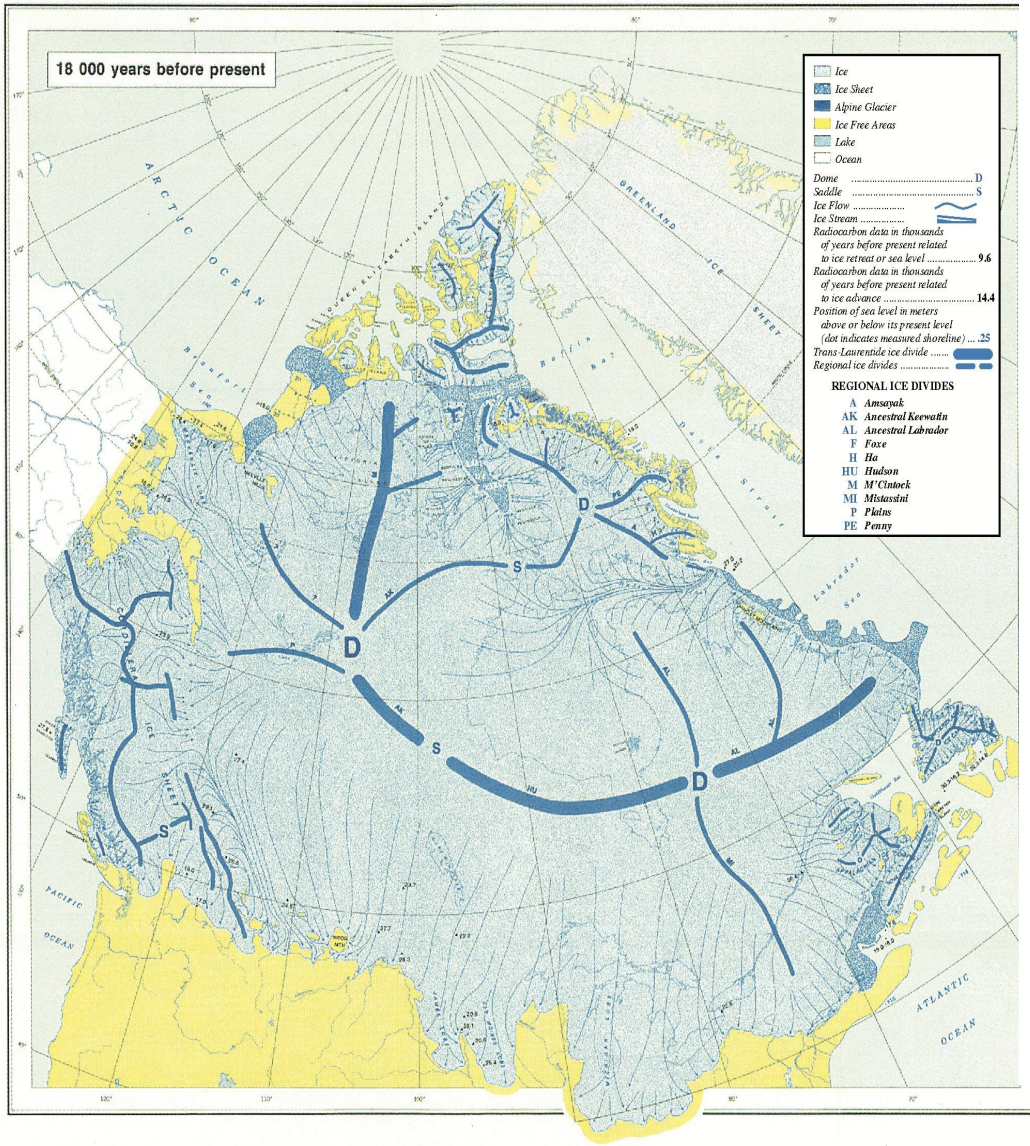
$$R(\theta, \psi, t) = \int_{-\infty}^t \int_{\Omega} L(\theta', \psi', t') \Gamma(\gamma, t - t') d\Omega' dt'$$

Reminder: Reality

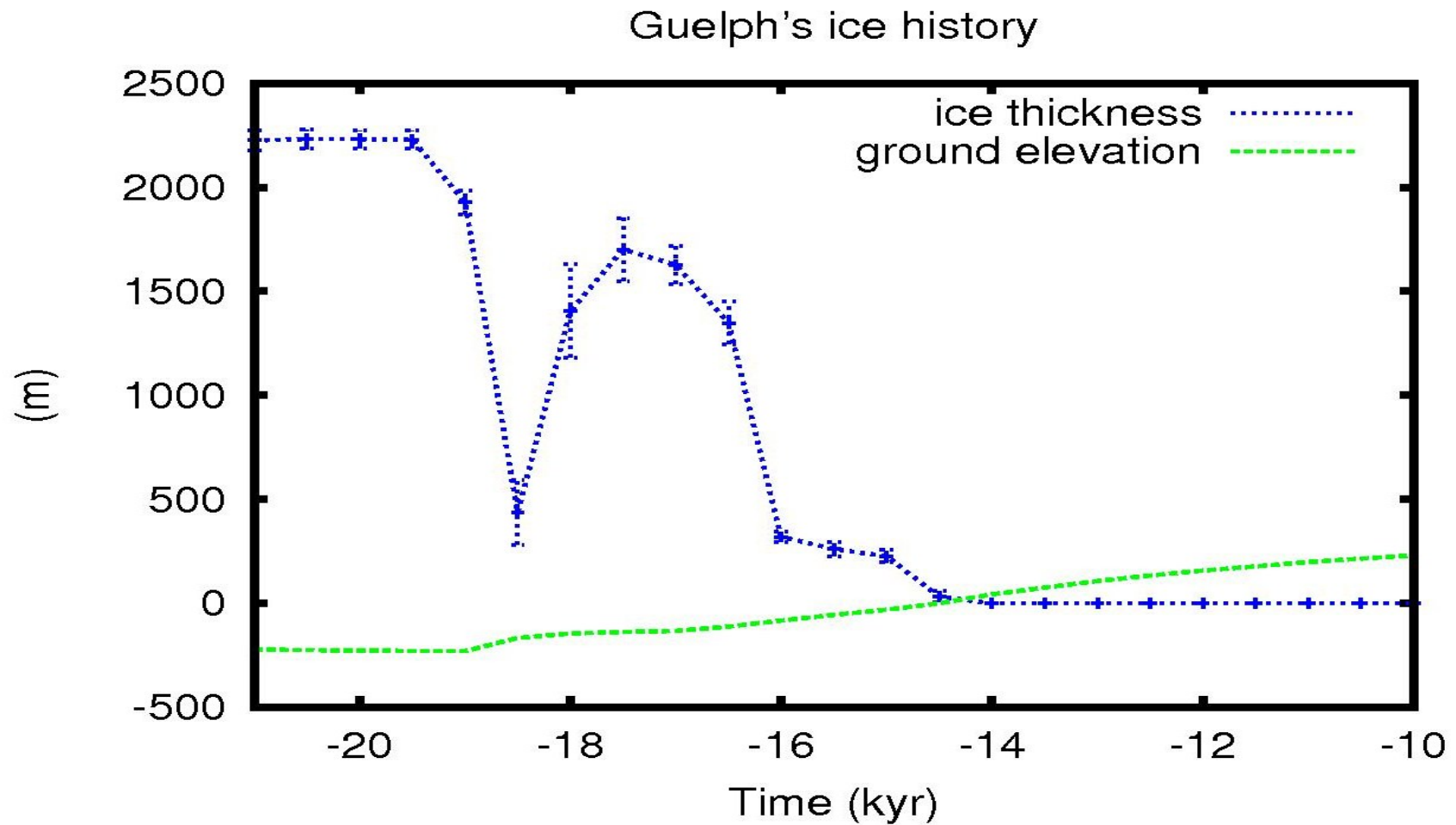


B. DeYoung

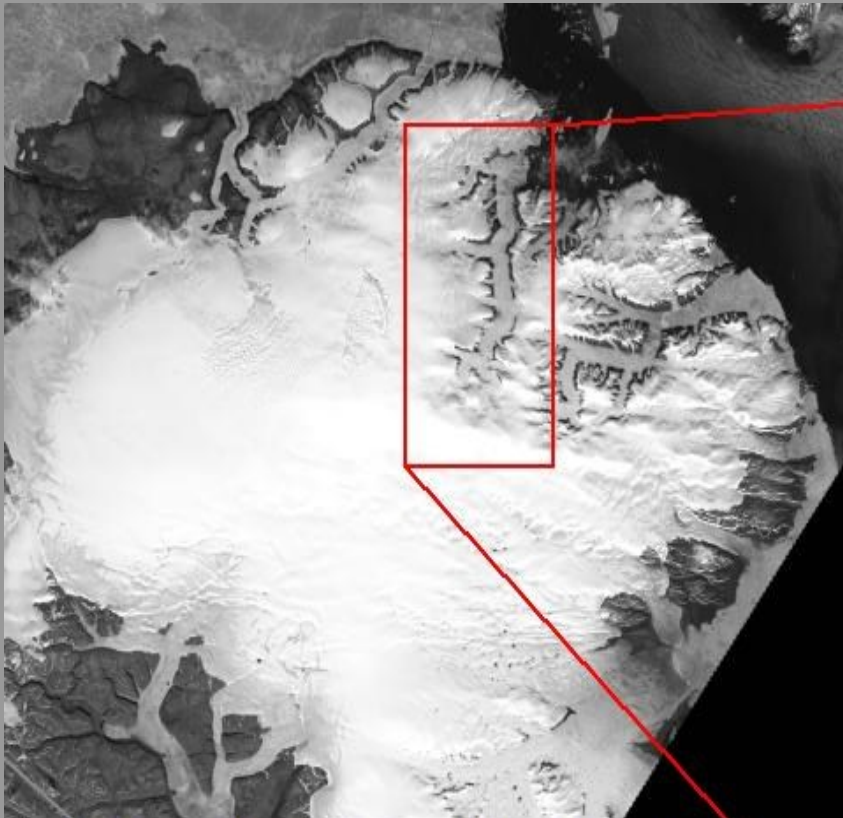
Conceptual and computer model



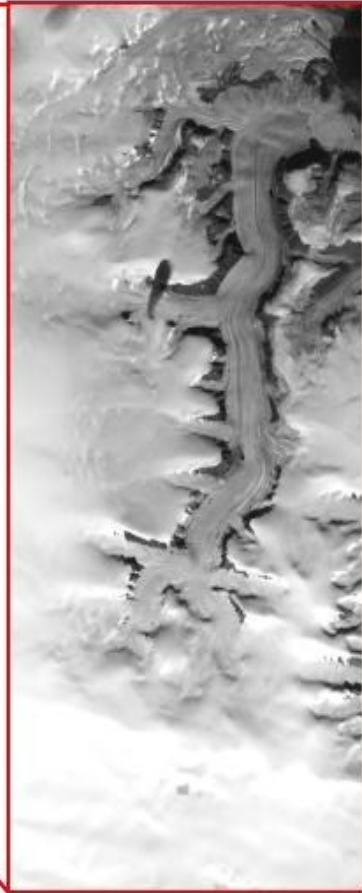
Interpreting models



Study site: Belcher Glacier



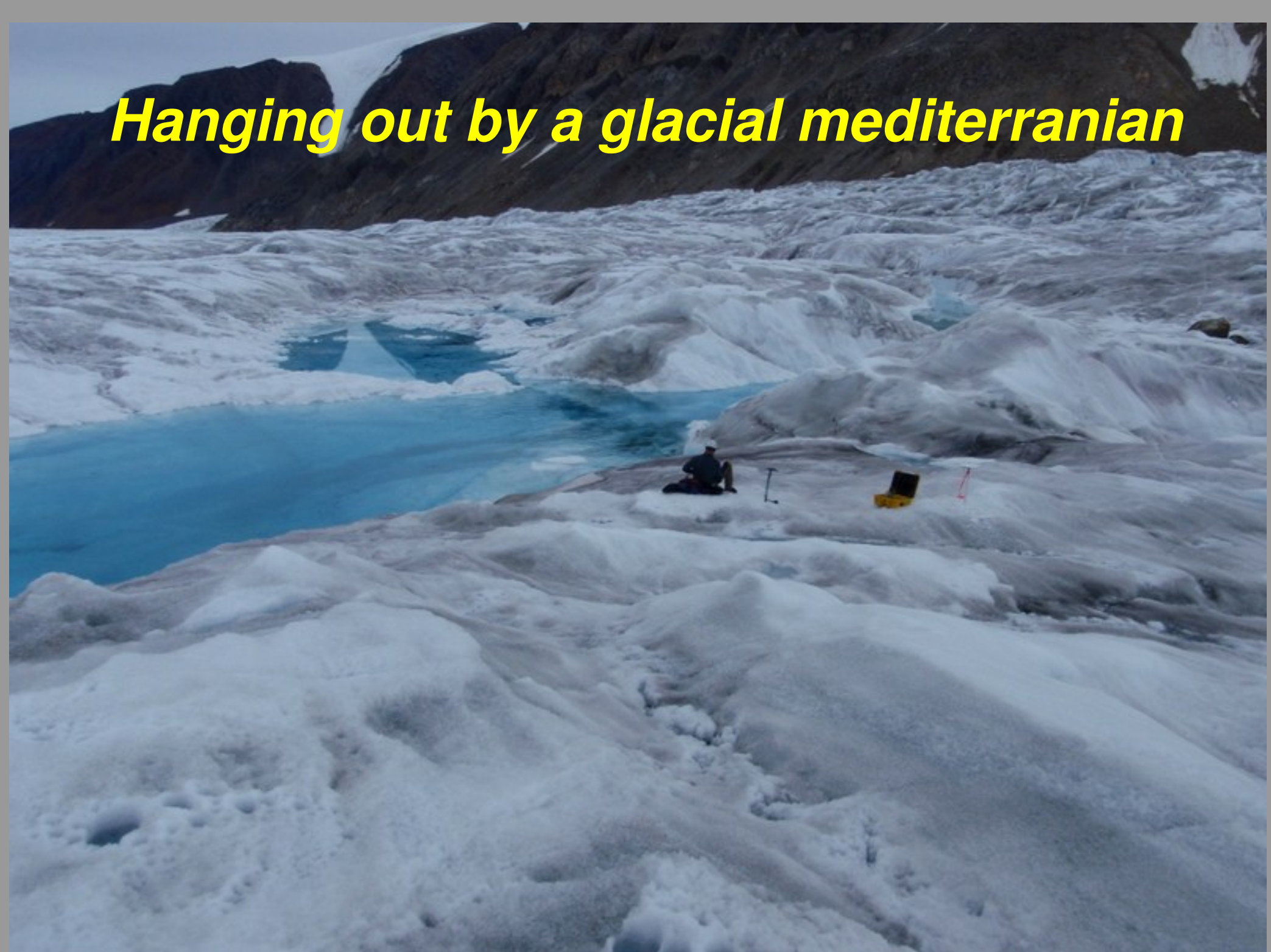
- Belcher Glacier, Devon Island Ice Cap
- Largest, fastest flowing outlet glacier
- Most important iceberg calving source
- Thinning throughout its length



Lateral moraine and entrained boulders



Hanging out by a glacial mediterranean



The critical qualities for being a good scientist

What do you think?



The critical qualities for being a good scientist

What I think: Curiosity and being able to ask the right questions (and perseverance/stubbornness)

Why did this happen?
How does it work?



A photograph of a snowy landscape with a trail of footprints leading through the snow. The snow is white and appears to be a deep, soft layer. The footprints are dark and lead from the foreground towards the background, curving slightly to the right. There are some small, dark patches of vegetation or rocks visible through the snow. The lighting is bright, creating soft shadows and highlights on the snow's surface.

***Science offers the chance to encounter
curious individuals***





I did not really want a skylight





Where much of the uncertainty is





Personal Learning

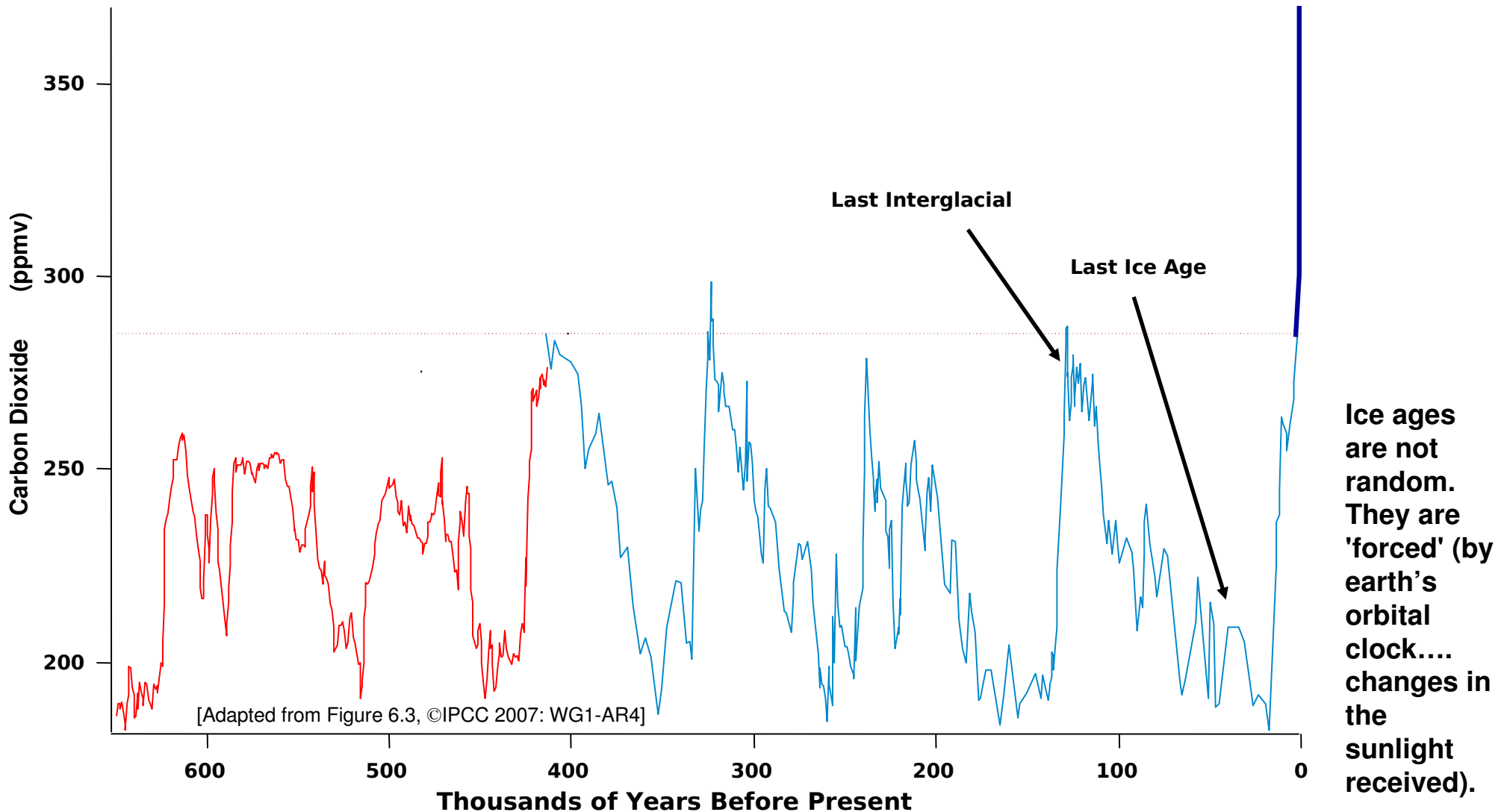
- Hydrology (water flow) matters on glaciers







So what about the future?

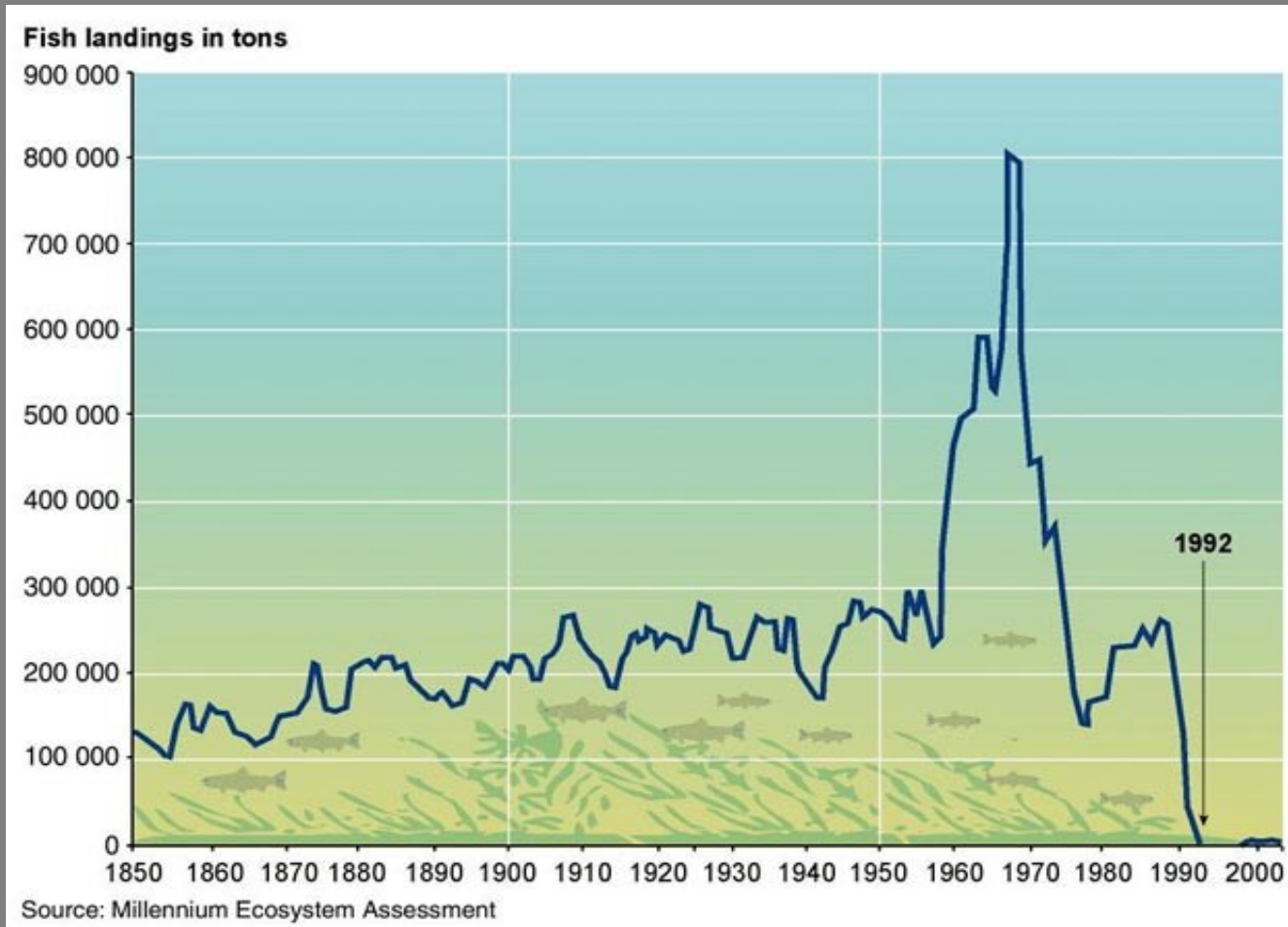


Humans are ‘forcing’ the system in a new way. CO₂ increases are mainly due to fossil fuel burning. CO₂ has not been this high in more than half a million years.

Other climate system tipping points

- ◆ Amazon
- ◆ Permafrost & methane
- ◆ Marine methane (hydrates)
- ◆ Marine CO₂
- ◆ Coral reefs
- ◆ Sea-ice: done deal for Arctic

The result of policy based on linear response when applied to fundamentally non-linear systems



***Precautionary Principle: Uncertainty is
not an excuse for inaction***

Questions?



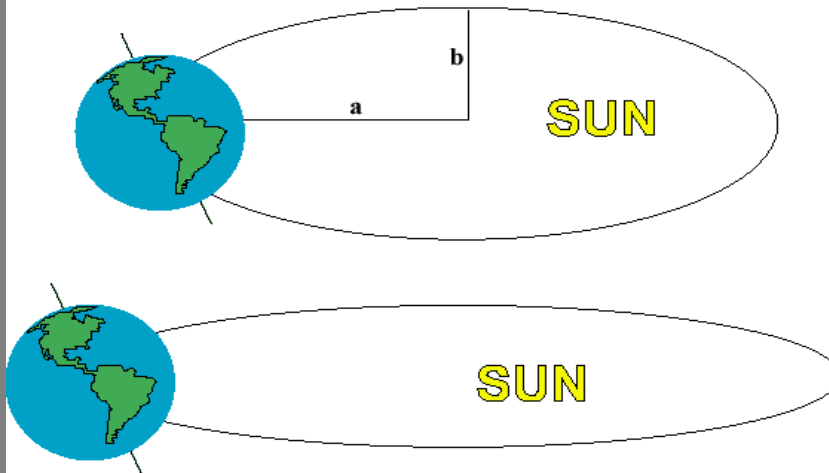
Questions

- What drove the 100kyr ice age cycle?
 - What caused CO₂ to change?
- What caused the fast changes in climate seen in the Greenland ice core record?
- How fast can the West Antarctic and Greenland Ice Sheets loose ice?

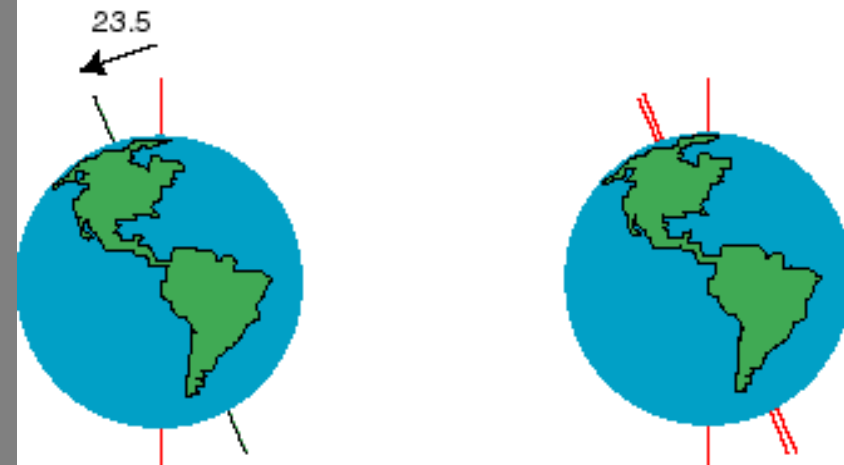


Why the ice age (glacial) cycle?

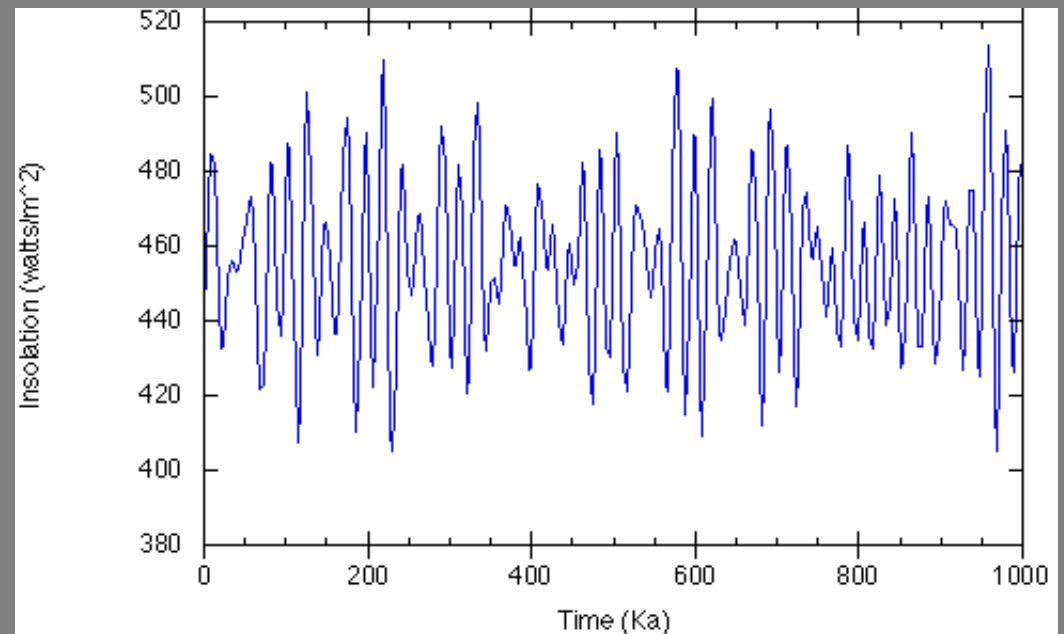
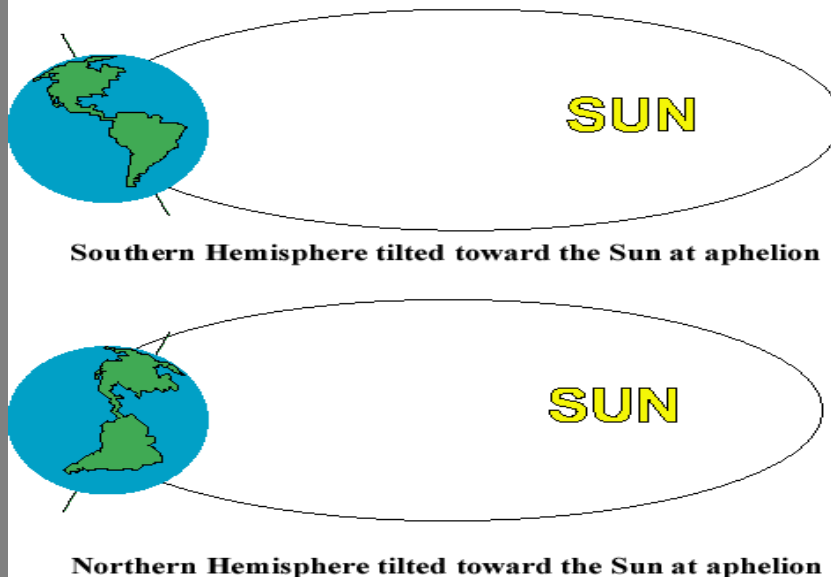
Eccentricity cycle (100 k.y.)



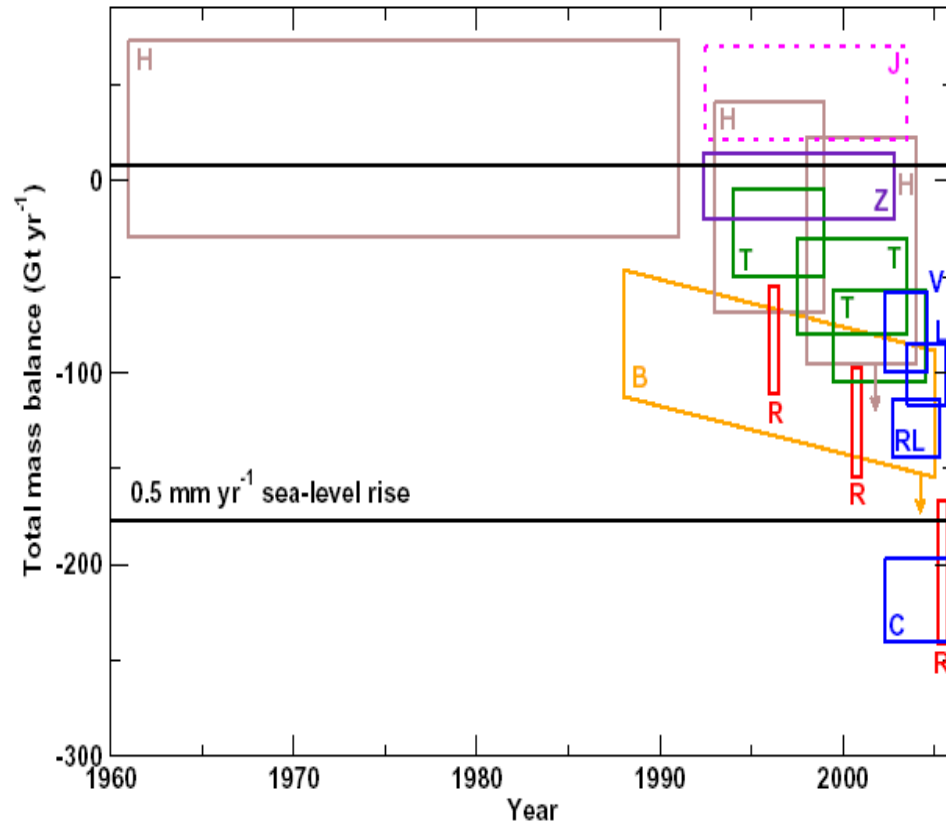
Obliquity Cycle (41 k.y.)



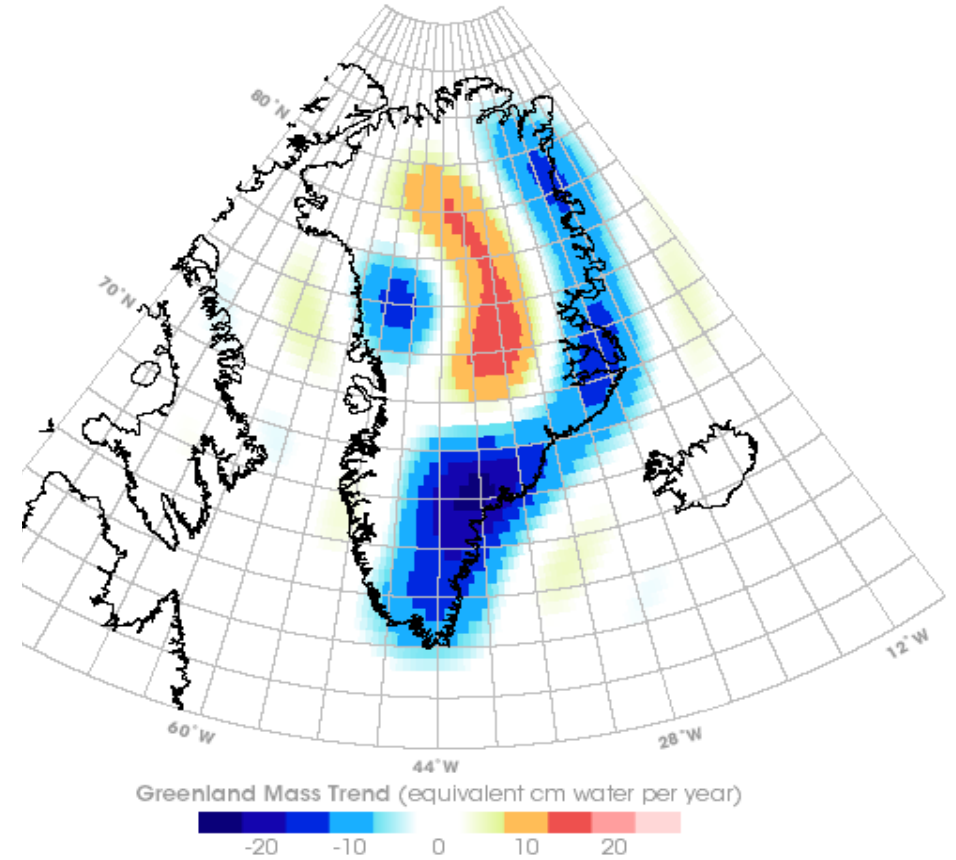
Precession of the Equinoxes (19 and 23 k.y.)



Greenland's changing mass-balance



Alley et al., *Annals of Glaciology*, 2007



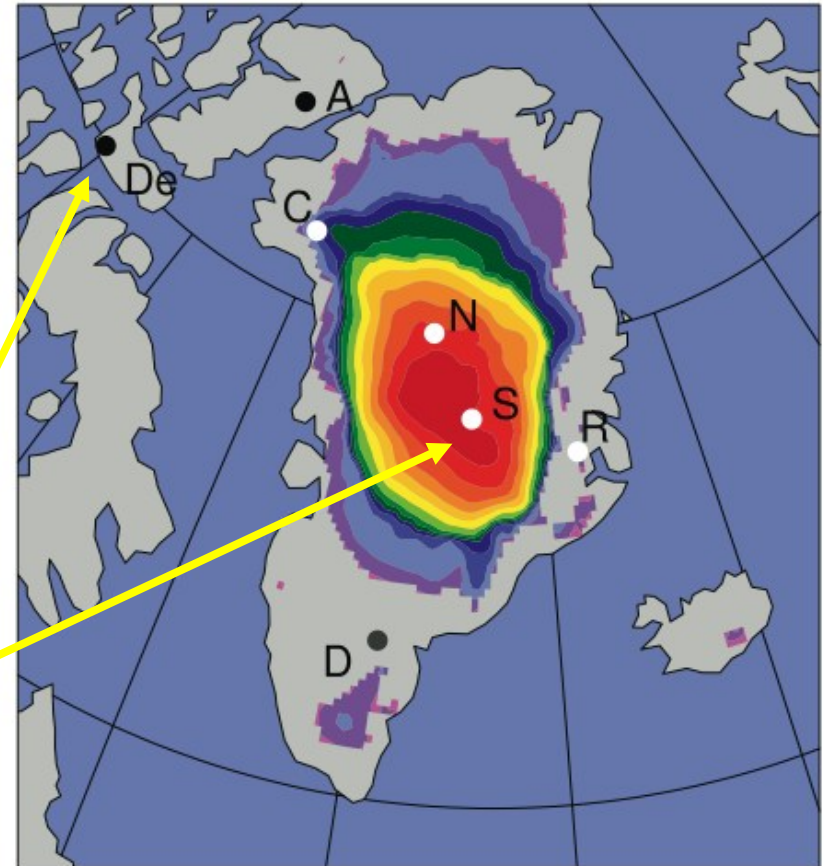
Luthcke et al, *Science*, 2006

Past Change in The Greenland Ice Sheet

The last time polar regions were significantly warmer (by 3-5°C) than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 m of sea level rise.

White and black dots show drill sites where ice older than 125,000 years is and is not found.

Annual Ice Thickness and Extent at Last Interglacial



m

Relative sea-level (RSL) data



RSL data sites

