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 ***

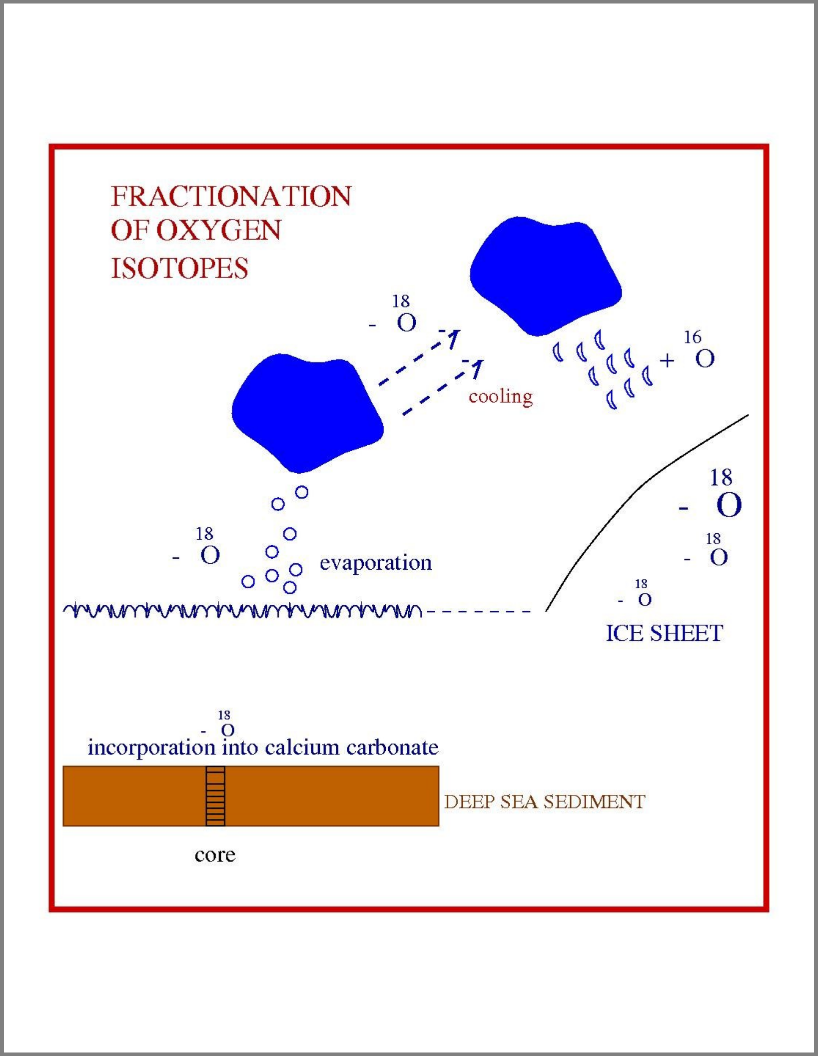
How to deal with uncertainty?

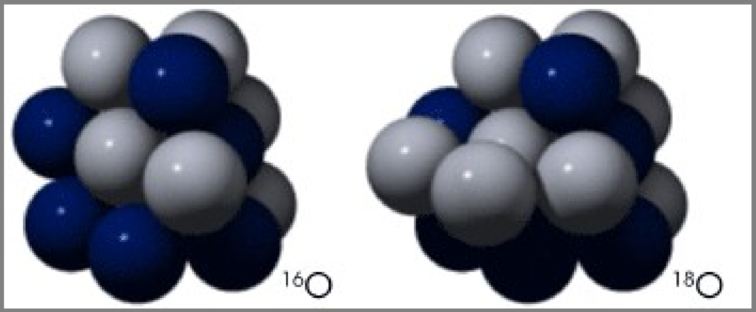
- Scientific theories and understanding
- Conceptual models
- Computational models
- Look to the Past: observations of past and present

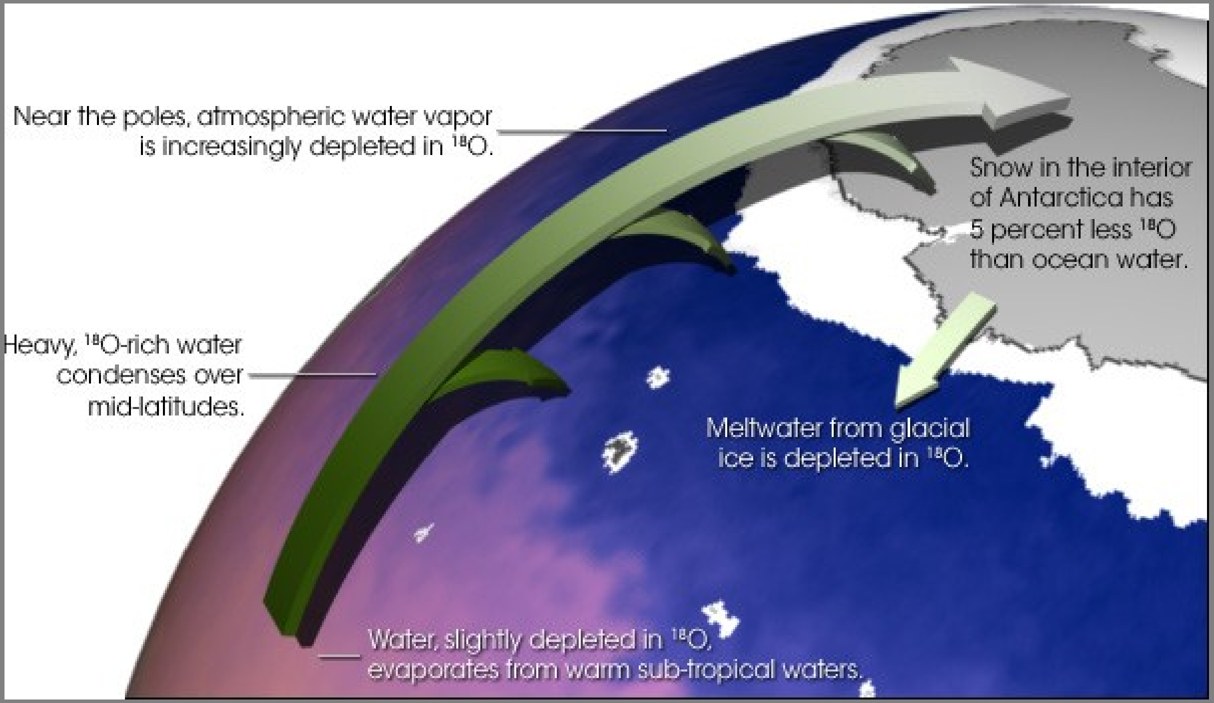
How do we decipher the past?

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

How do we decipher the past: Oxygen isotope measuring stick

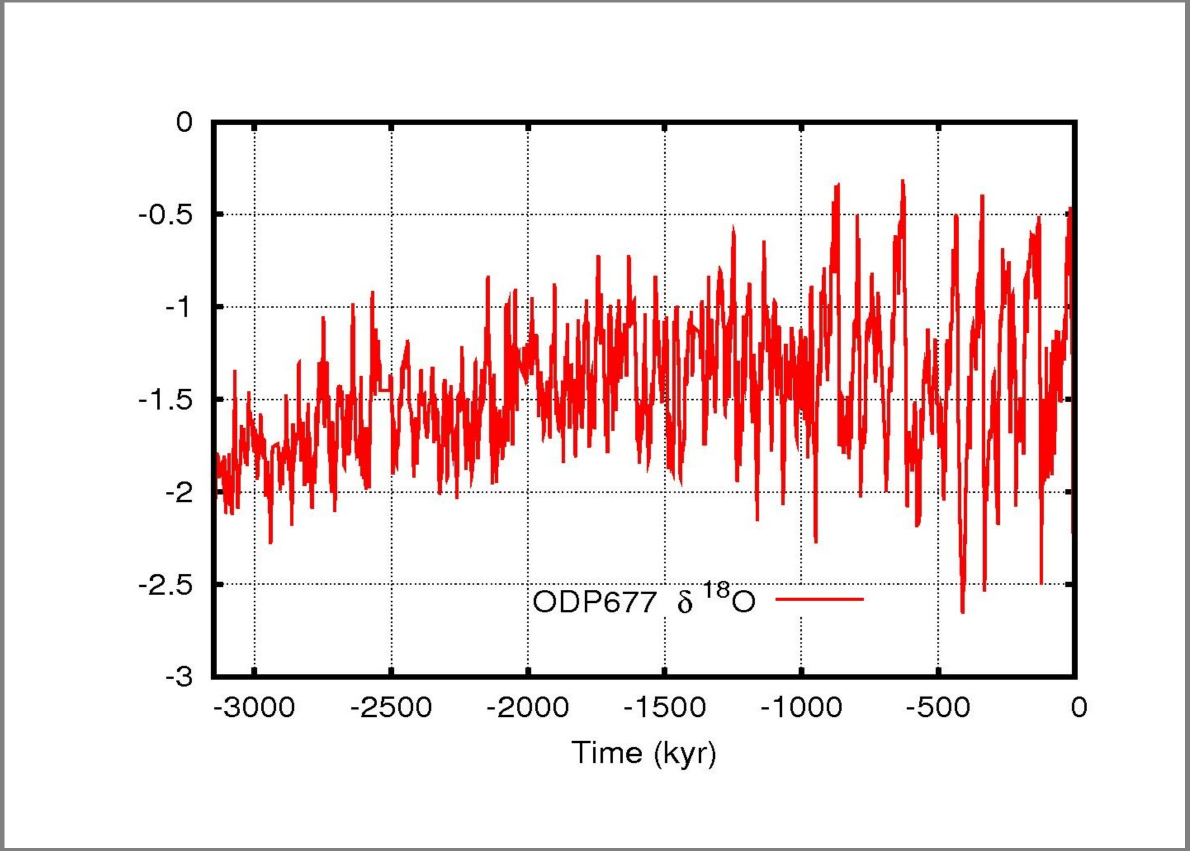






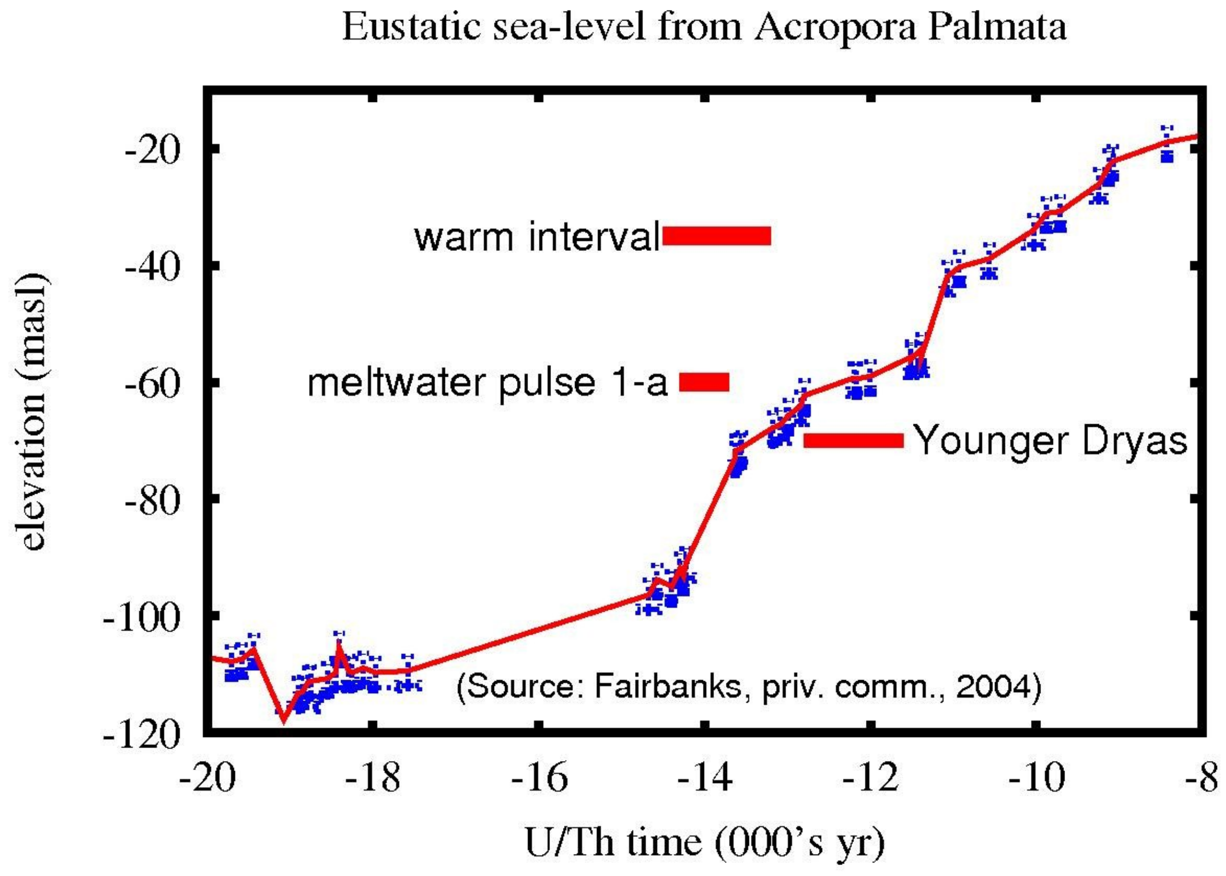
How do we decipher the past?

- 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

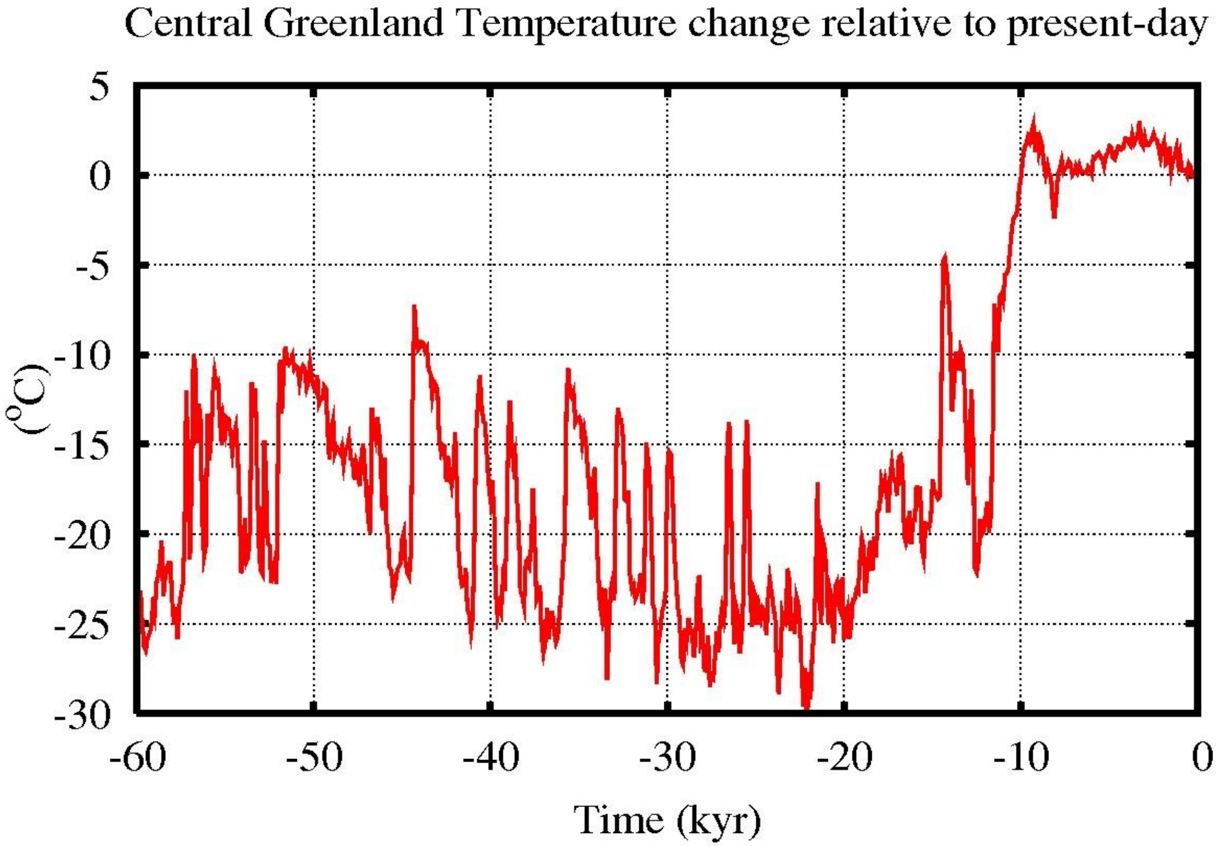
200 years ago

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

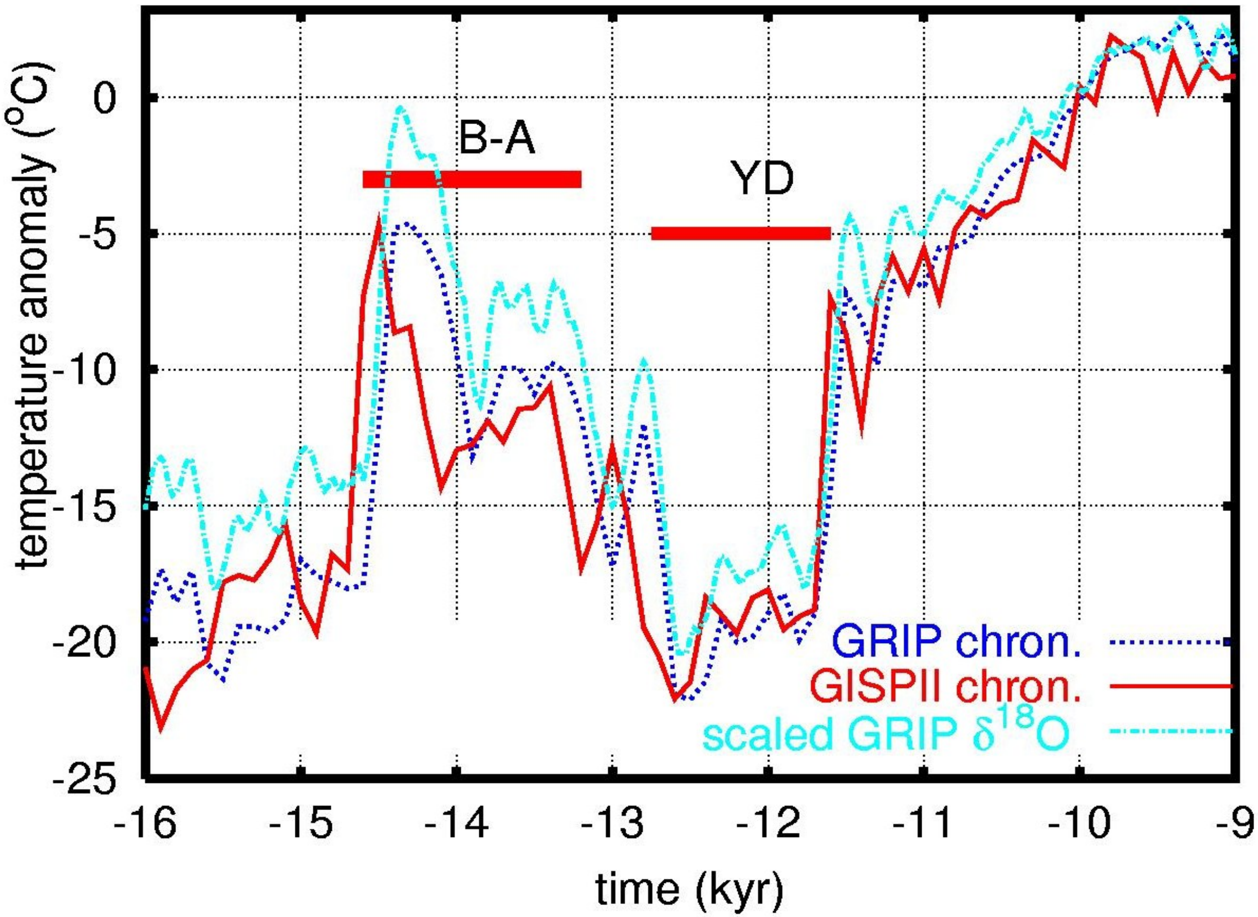
200 years ago

- 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

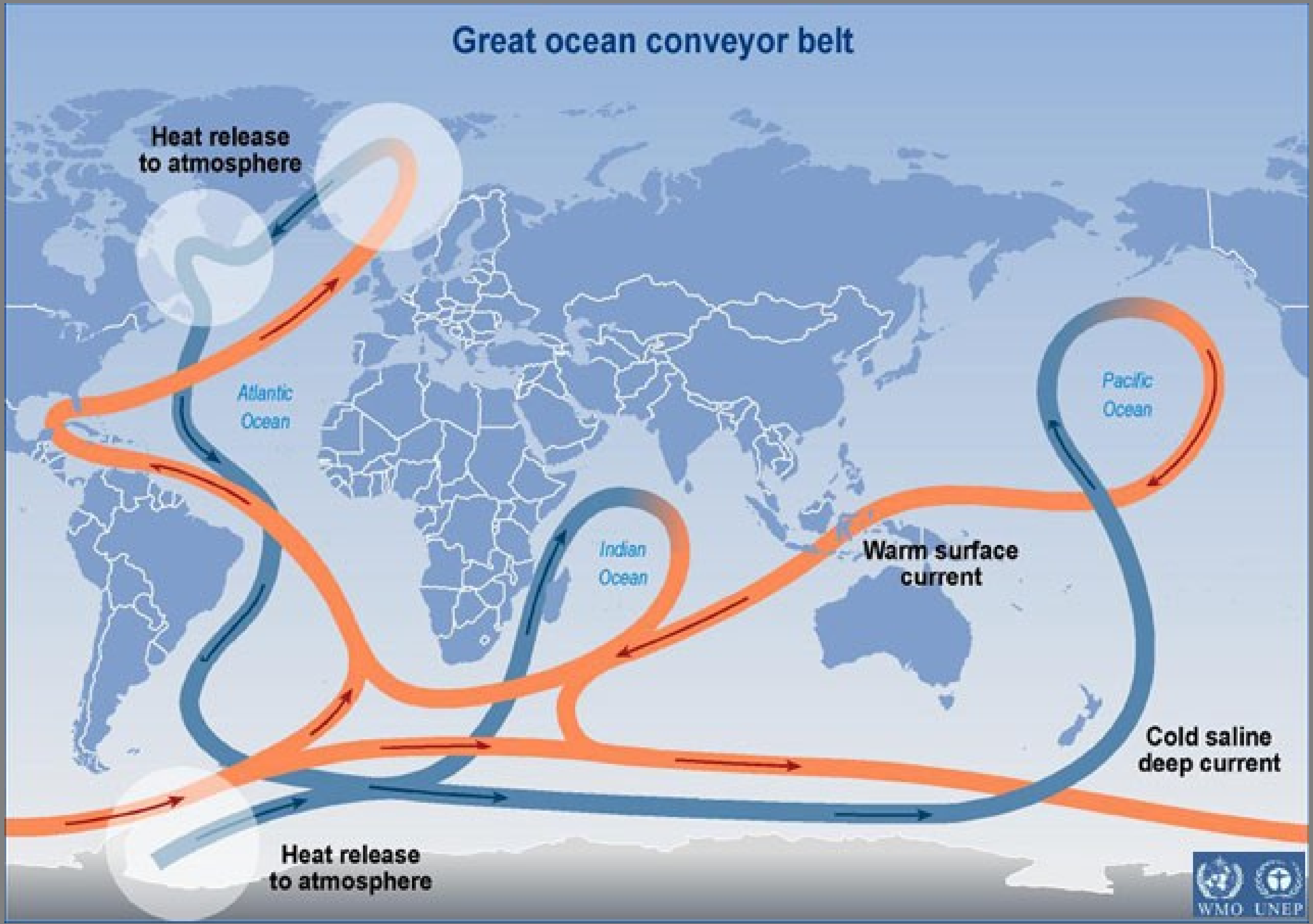


Jumping climate



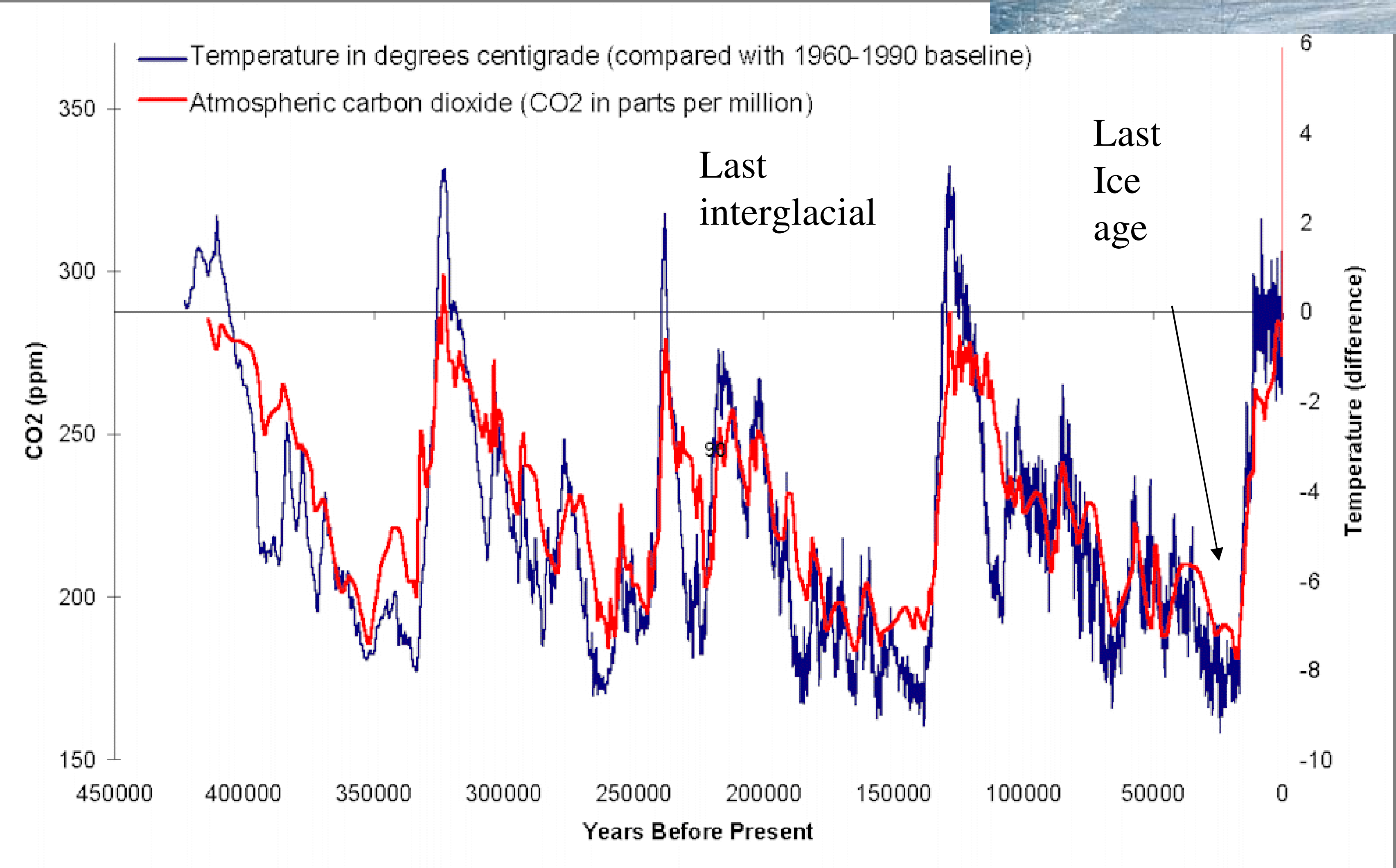
(from Tarasov and Peltier, 2003)

Ocean thermohaline circulation



What about CO_2?

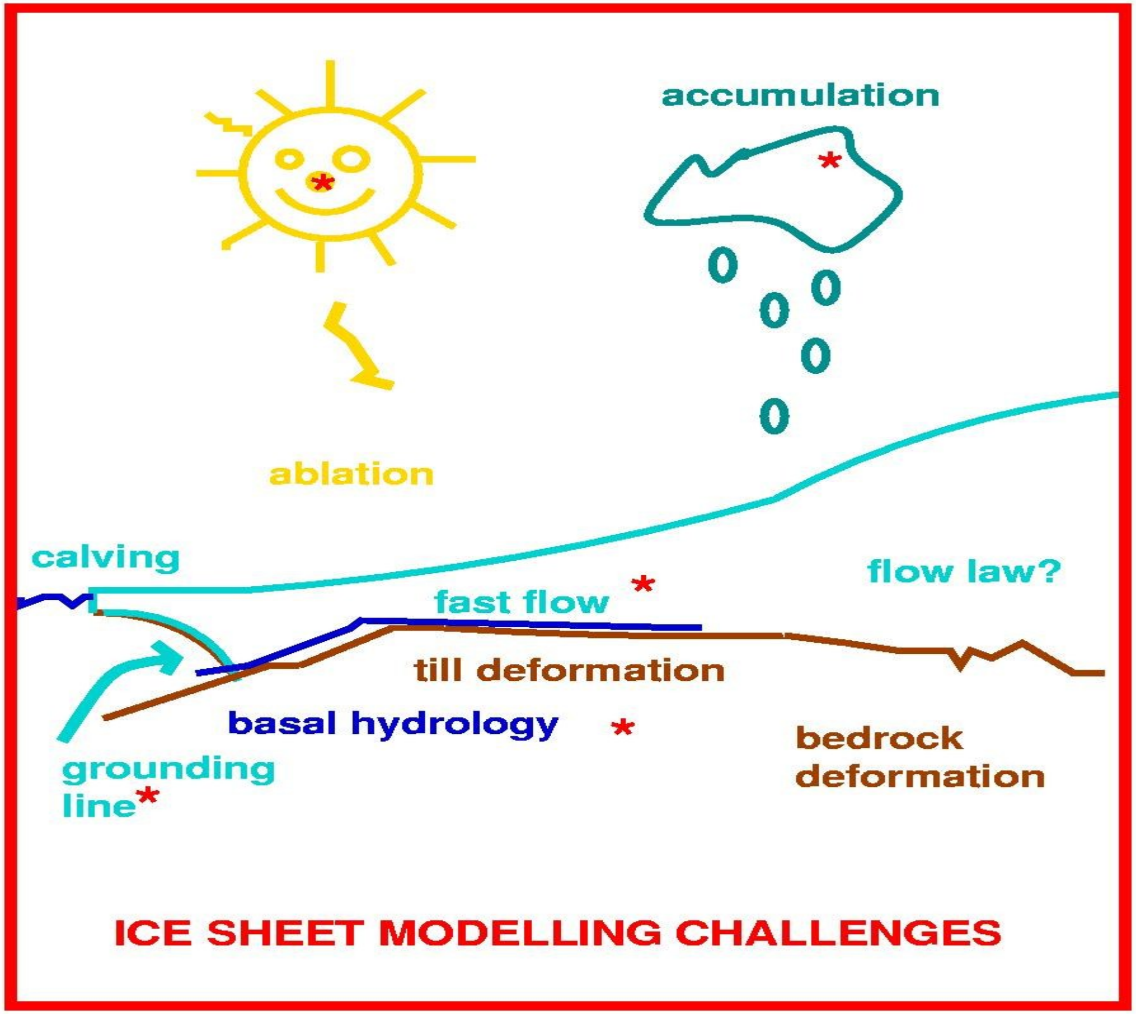
Vostok Ice Core Record



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

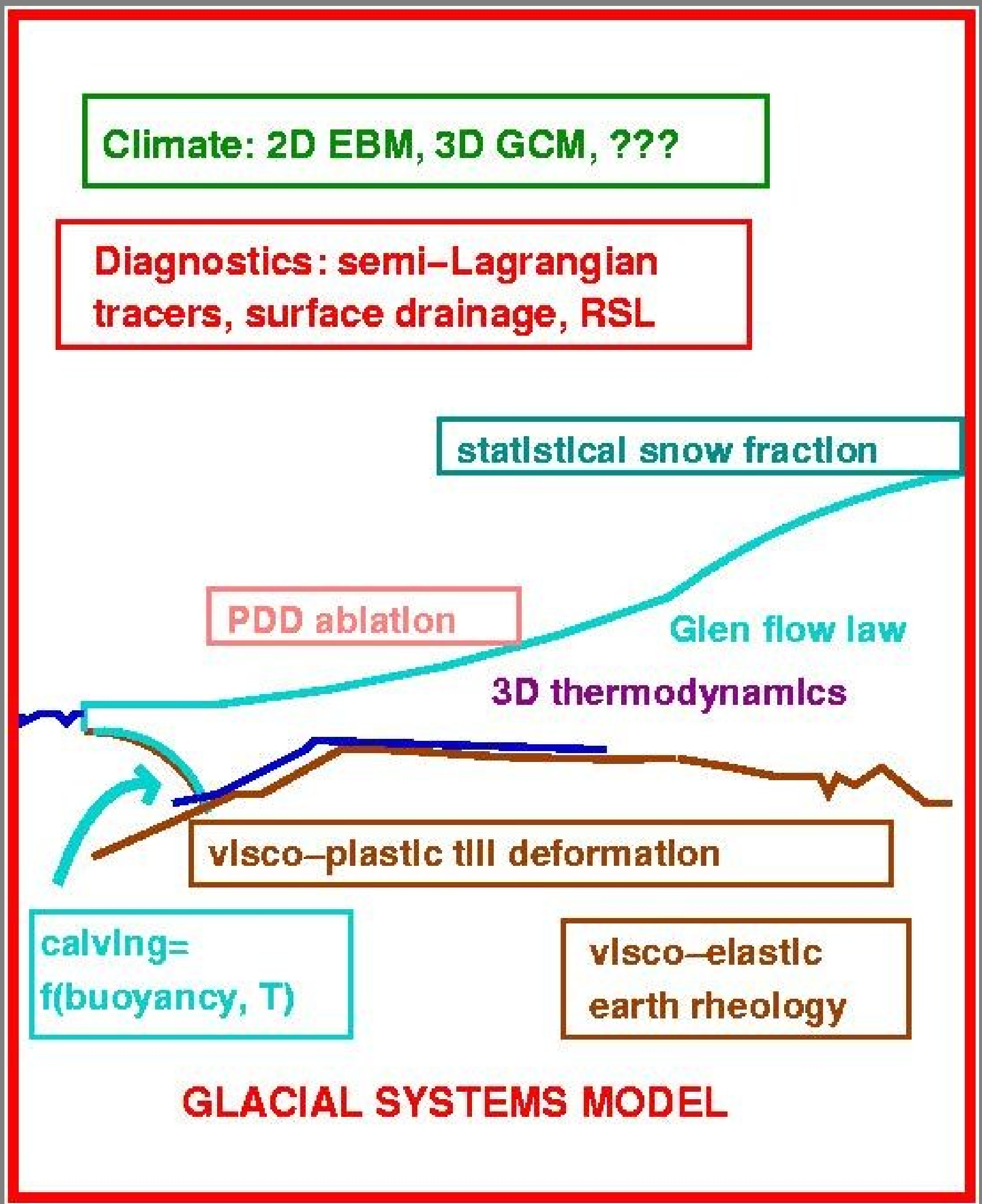
Models

The Glacial System




To predict the future of such systems we need models
And we need to test them against the past
B.Beauchamp

Glacial Systems Model (GSM)



Some GSM equations

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

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

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

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

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

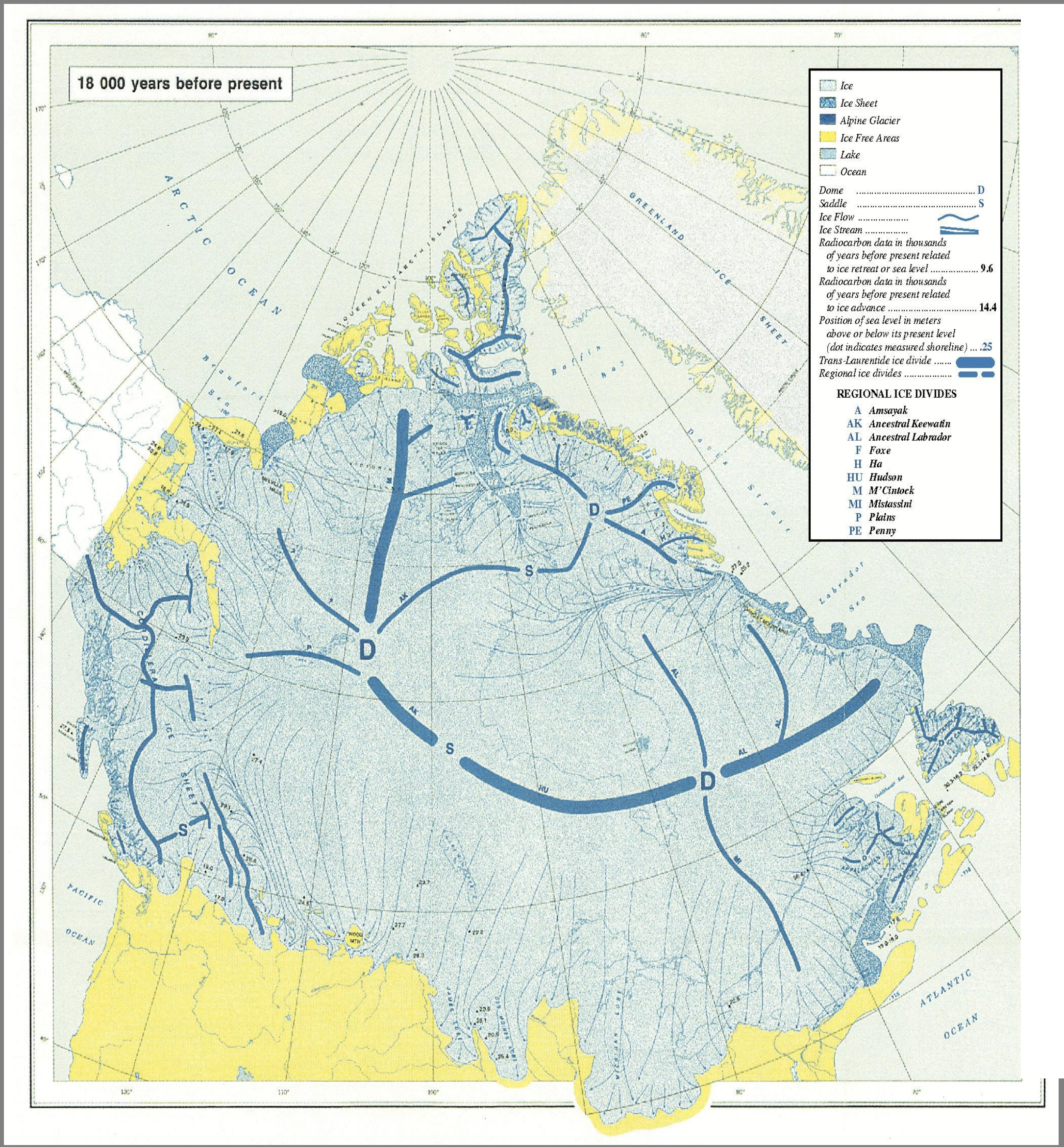
$$\rho_i c_i(T(\vec{\mathbf{r}}))\frac{\partial T(\vec{\mathbf{r}})}{\partial t} = \frac{\partial}{\partial z}\left\{k_i(T(\vec{\mathbf{r}}))\frac{dT(\vec{\mathbf{r}})}{dz}\right\} - \rho_i c_i(T(\vec{\mathbf{r}}))\mathbf{V}(\vec{\mathbf{r}})\cdot\nabla T(\vec{\mathbf{r}}) + Q_d(\vec{\mathbf{r}})$$

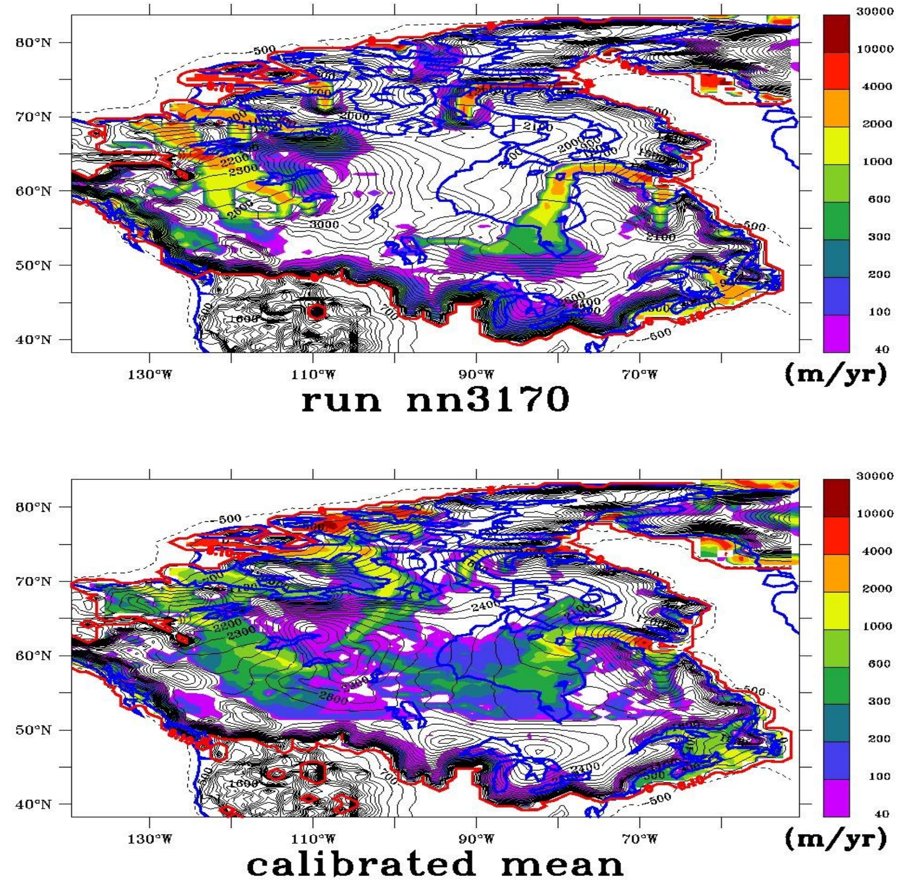
- Bedrock elevation R under load L from convolution with Greens function Γ:

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

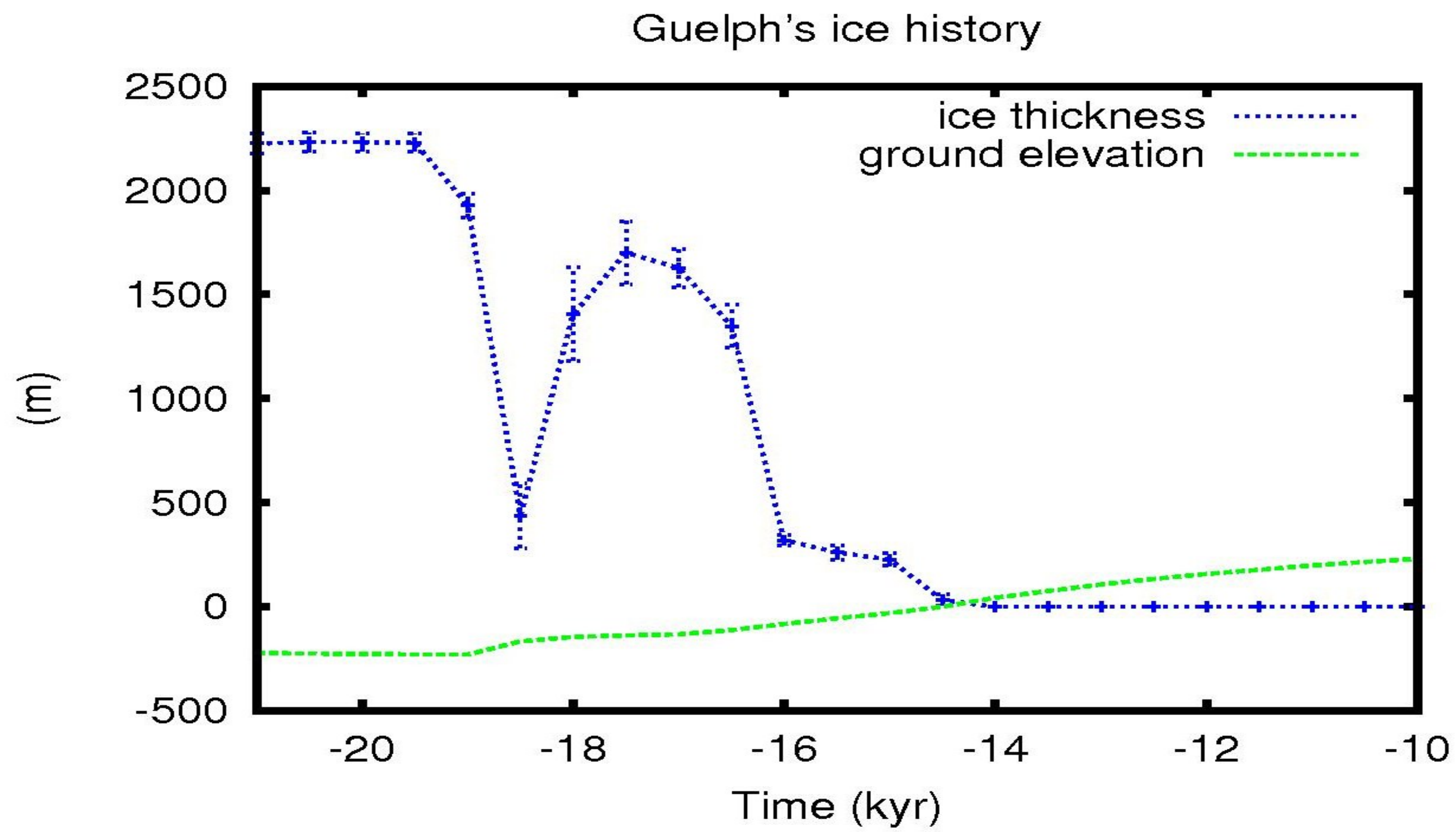
Reminder: Reality

Conceptual and computer model

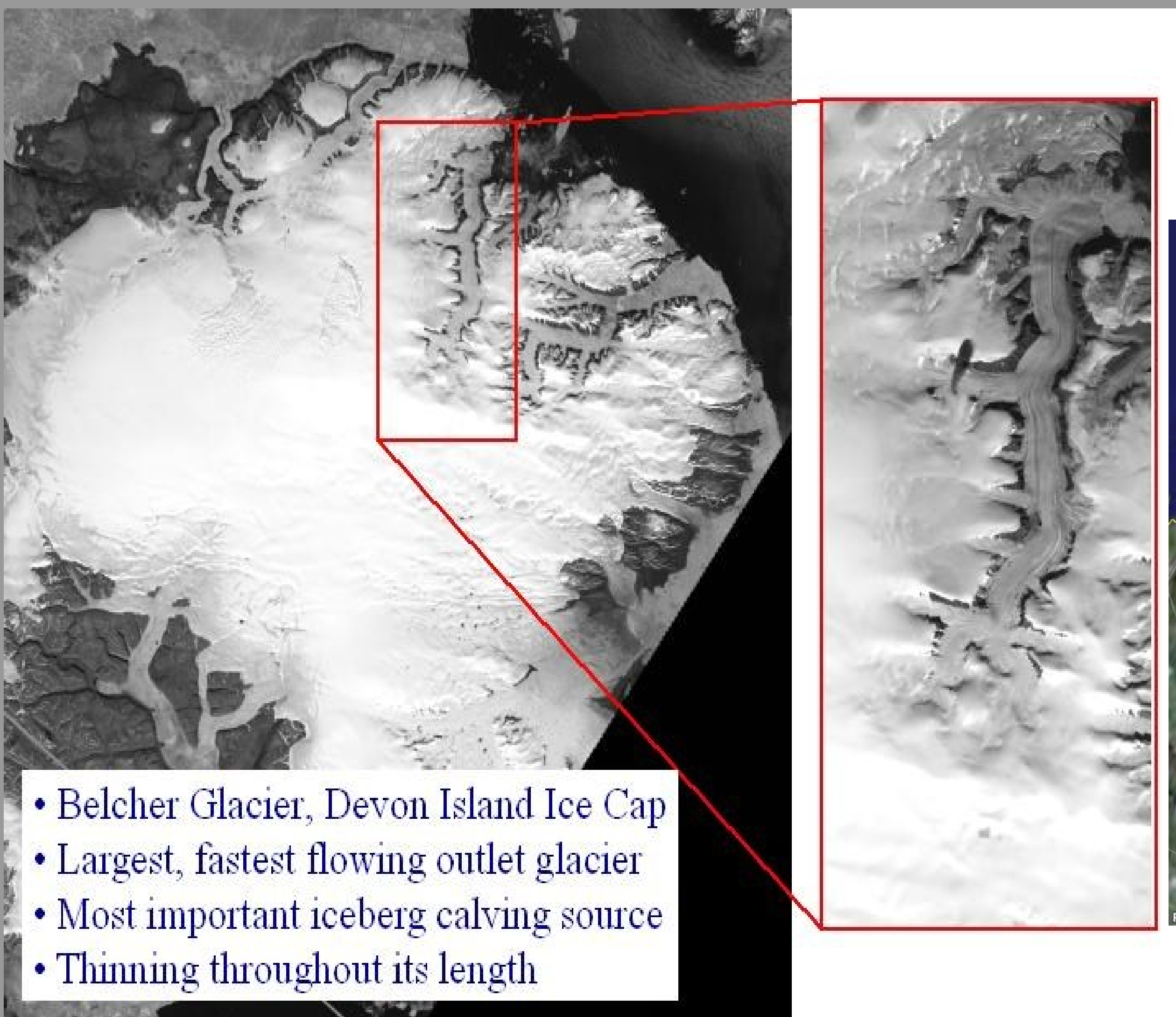




Interpreting models



Study site: Belcher Glacier



Lateral moraine and entrained boulders


Hanging out by a glacial mediterranian

The critical qualities for being a good scientist

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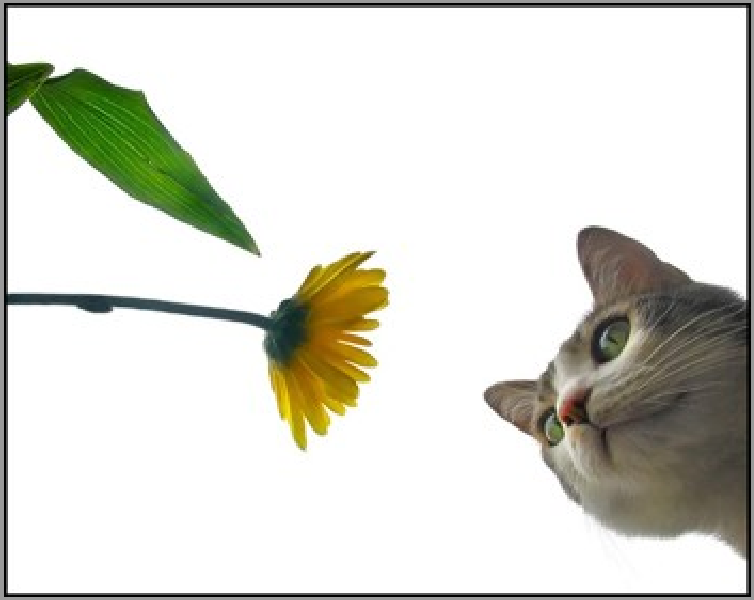
What I think: Curiosity and being able to ask the right questions (and perseverence/stubborness)



Why did this happen?
How does it work?


Science offers the chance to encounter curious individuals

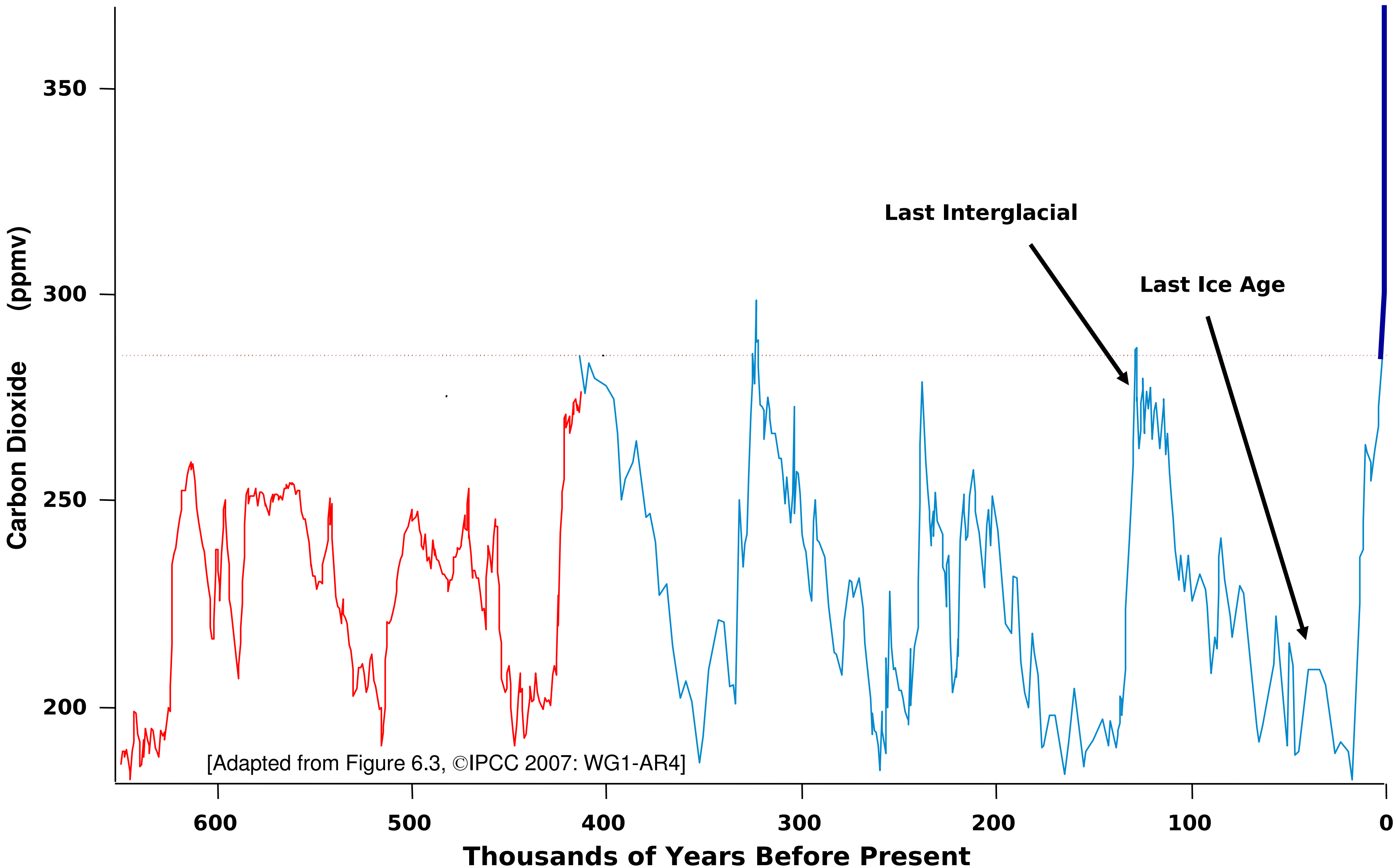

I did not really want a skylight

Where much of the uncertainty is

Personal Learning

- Hydrology (water flow) matters on glaciers


So what about the future?



Ice ages are not random. They are 'forced' (by earth's orbital clock…. changes in the sunlight received).

Humans are 'forcing' the system in a new way. CO_2 increases are mainly due to fossil fuel burning. CO_2 has not been this high in more than half a million years.

Other climate system tipping points

- Amazon
- Permafrost & methane
- Marine methane (hydrates)
- Marine CO_2
- Coral reefs
- Sea-ice: done deal for Arctic

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

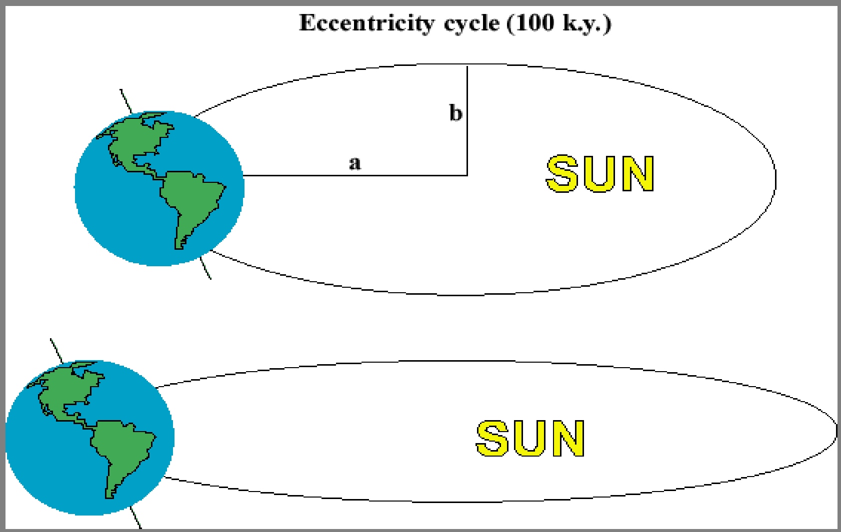
Precautionary Principle: Uncertainty is not an excuse for inaction

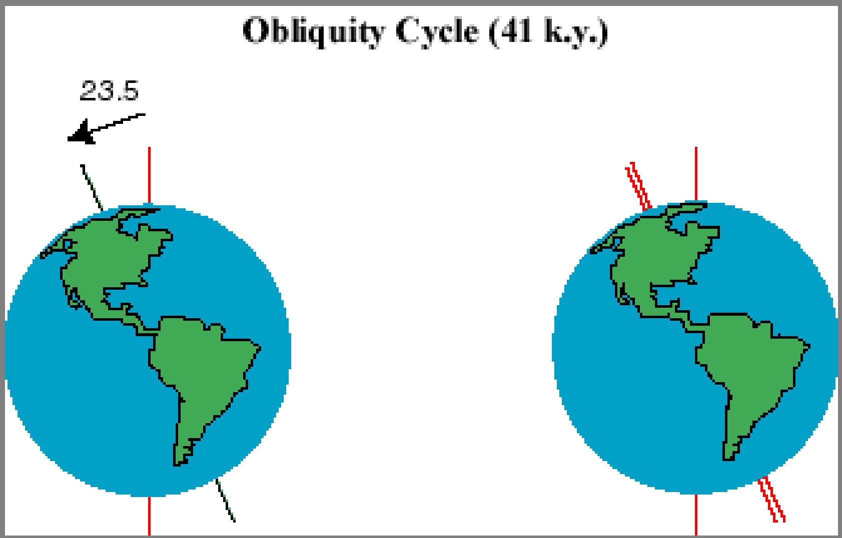
Questions?

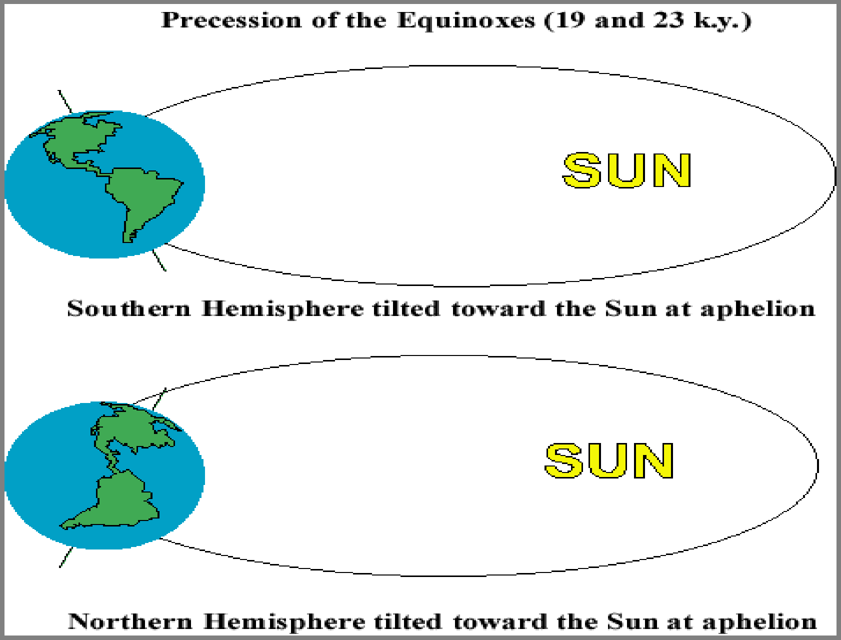
Questions

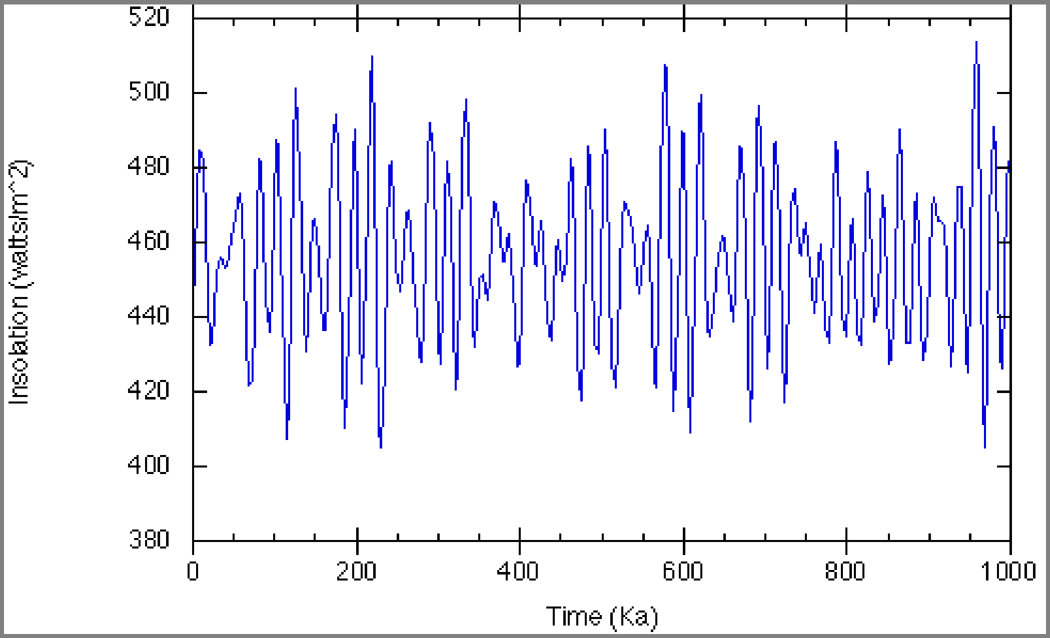
- What drove the 100kyr ice age cycle?
  - What caused CO_2 to change?
- What caused the fast changes in climate seen in the Greenland ice core record?
- How fast can the West Antarctic and Greenland Ice Sheets loose ice?

Why the ice age (glacial) cycle?

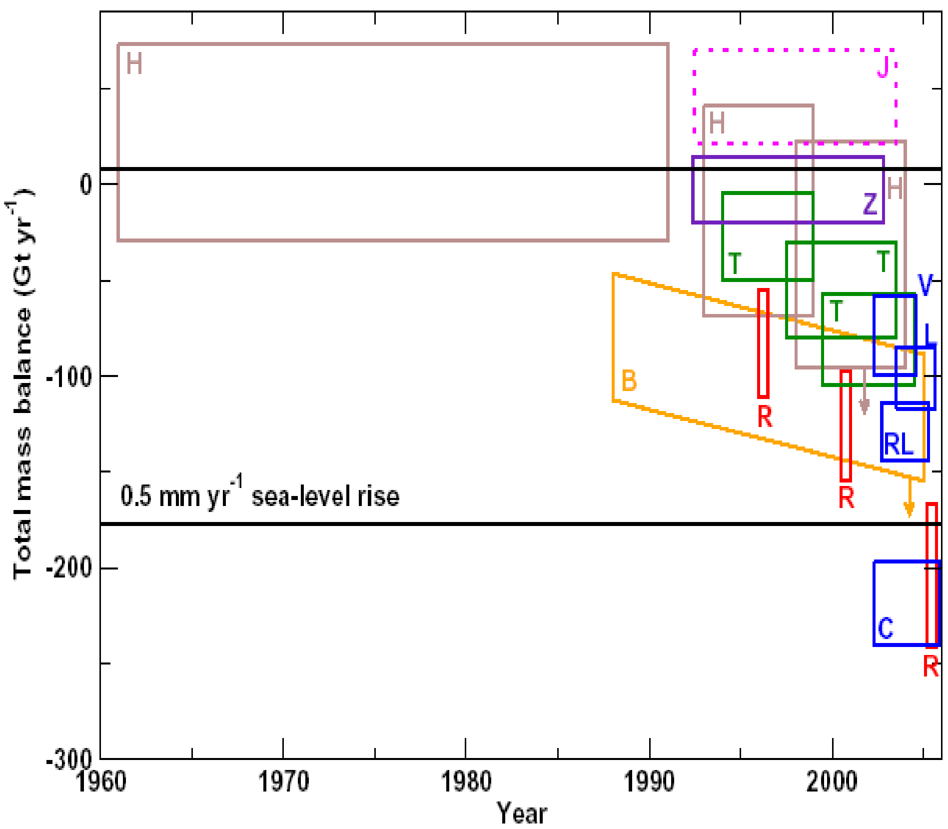




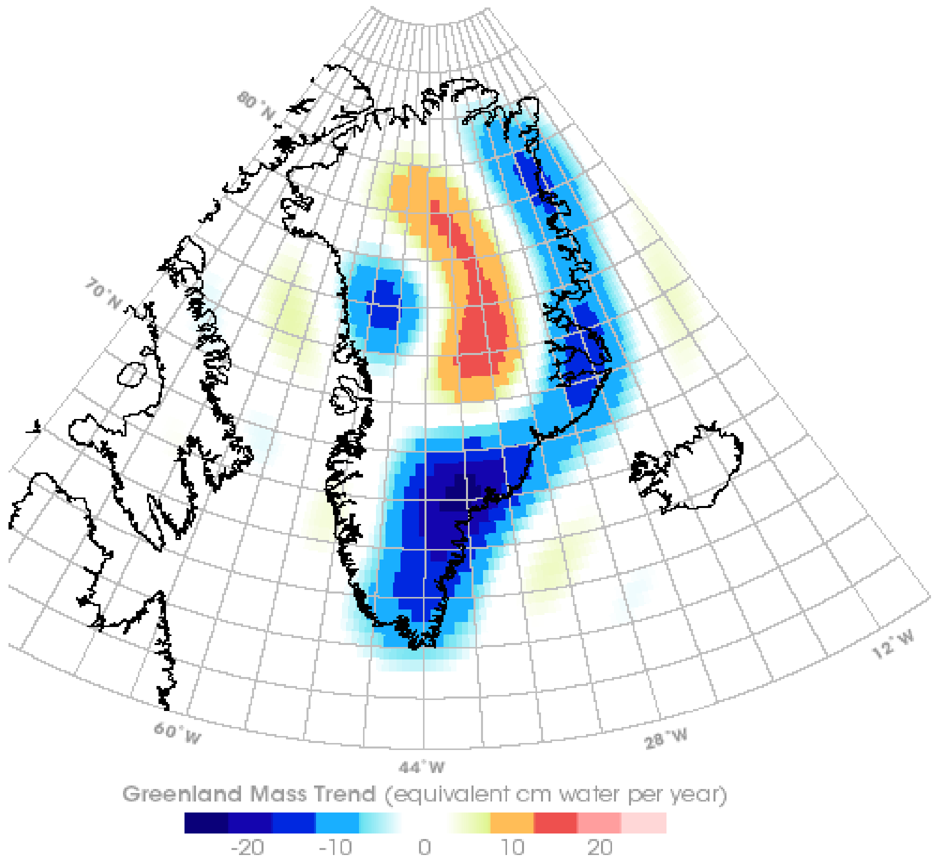




Greenland's changing mass-balance



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

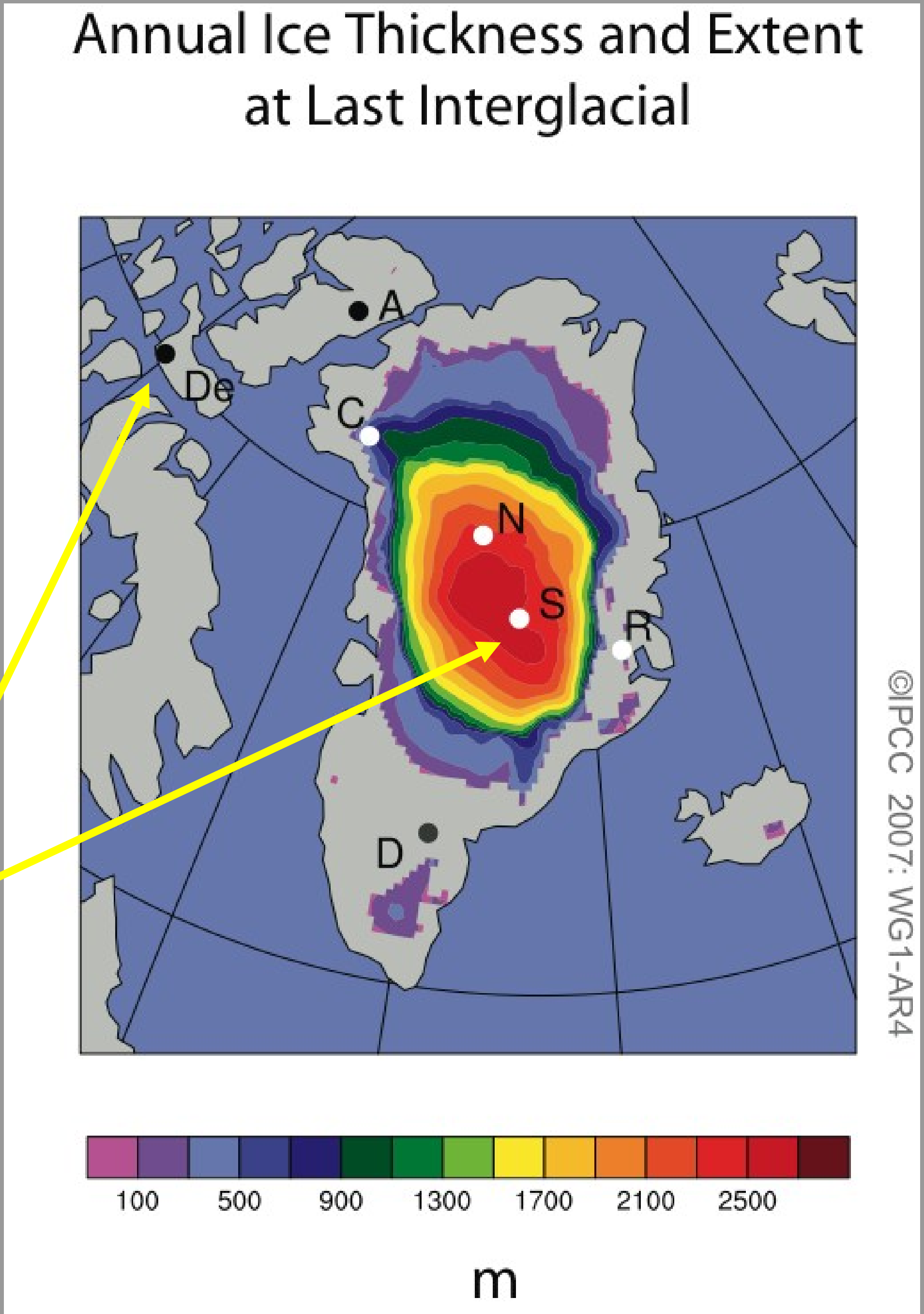


Luthcke et al, *Science,* 2006

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.



Relative sea-level (RSL) data