

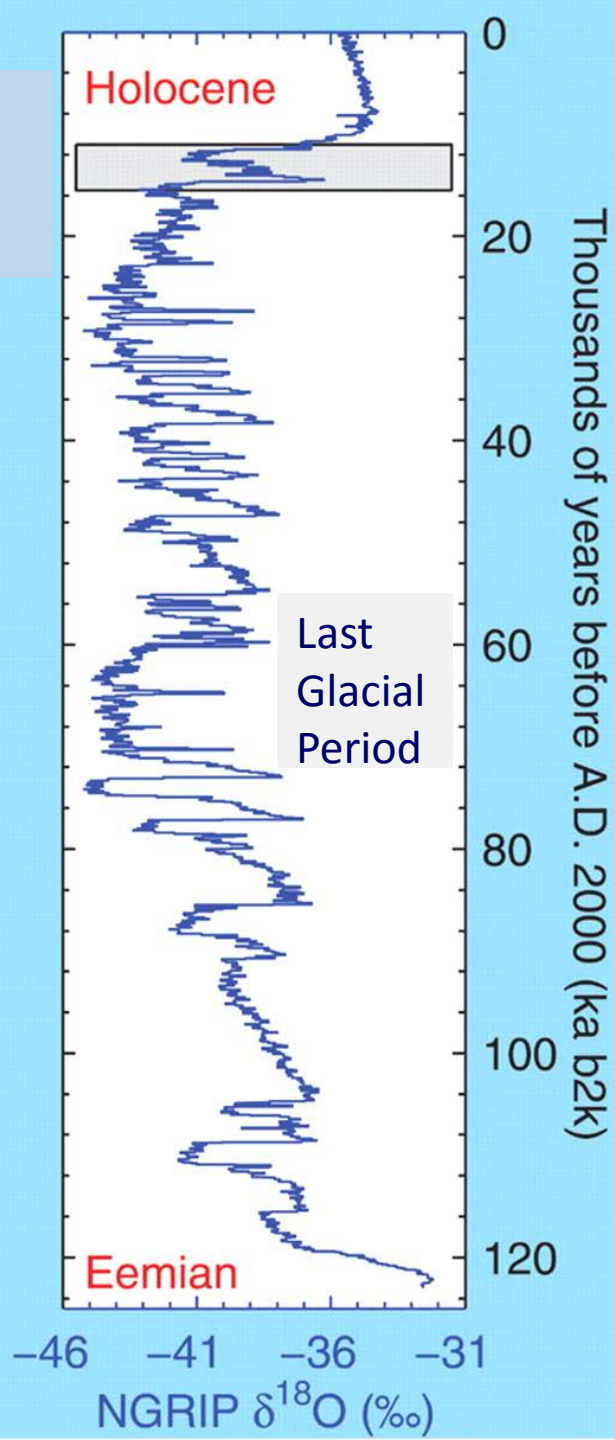
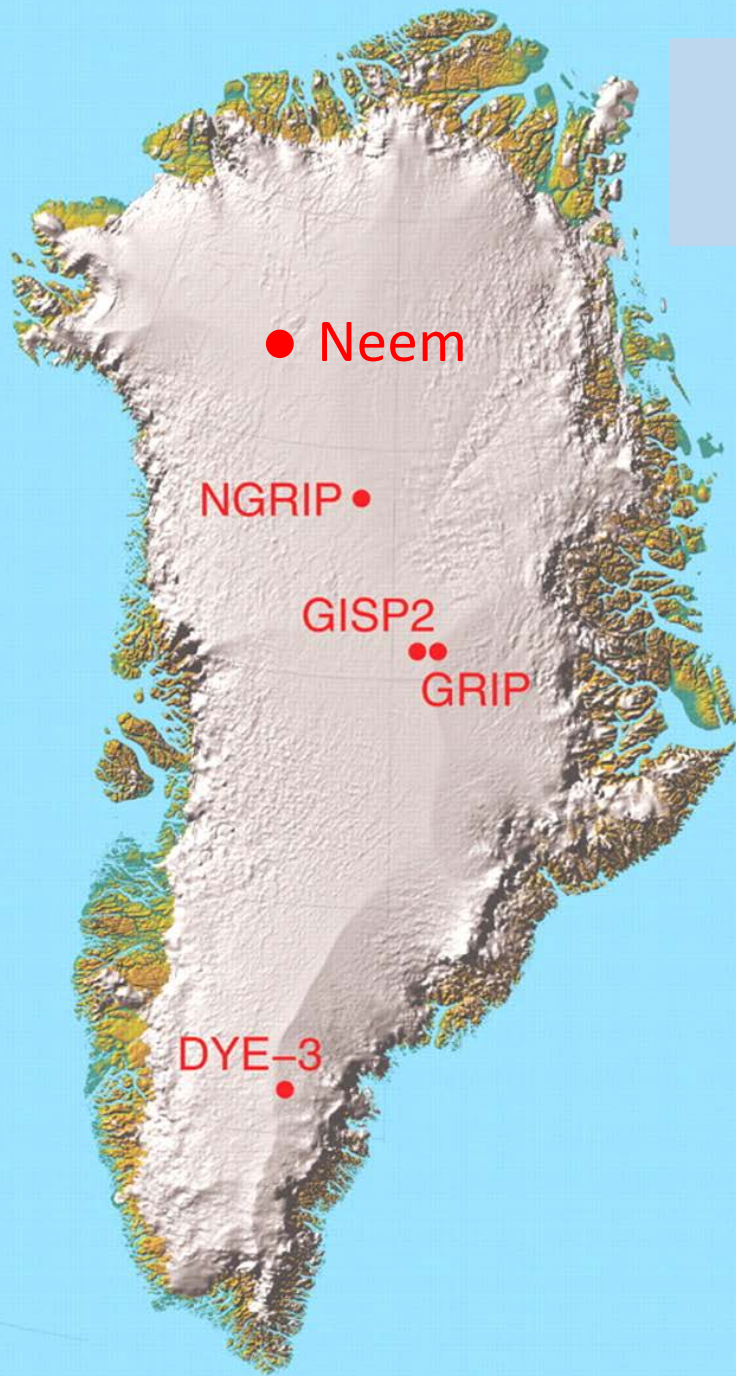
The background of the slide is a photograph of a glacier. The ice is layered, with prominent vertical blue streaks (icebergs) and horizontal white layers (moraine deposits). The overall color palette is light blue and white, with some darker brownish-grey spots where the ice is more heavily eroded or contains more sediment.

Modelling Isotope Tracers in the Laurentide Ice Sheet through the Last Glacial Cycle

Shawn Marshall, University of Calgary

Reasons to Model Ice Sheet Isotopes

Within Greenland and Antarctica, $\delta^{18}\text{O}$ and δD offer additional internal ice sheet constraints for models of ice sheet and climate history (i.e. via ice cores)



Reasons to Model Ice Sheet Isotopes

Within Greenland and Antarctica, $\delta^{18}\text{O}$ and δD offer additional internal ice sheet constraints for models of ice sheet and climate history (i.e. via ice cores)

At LGM, oceans were enriched by ca. 1‰ in ^{18}O ; $\delta^{18}\text{O}$ of the ice sheets needs to be done to equate this to ice sheet volume at LGM

- This is usually assumed to be -30‰
- The evolution of ice sheet $\delta^{18}\text{O}$ (t) is even more interesting, and offers potential constraints.

Passive Tracers in Ice Sheet Models

Following Clarke & L'homme (2002, 2005)

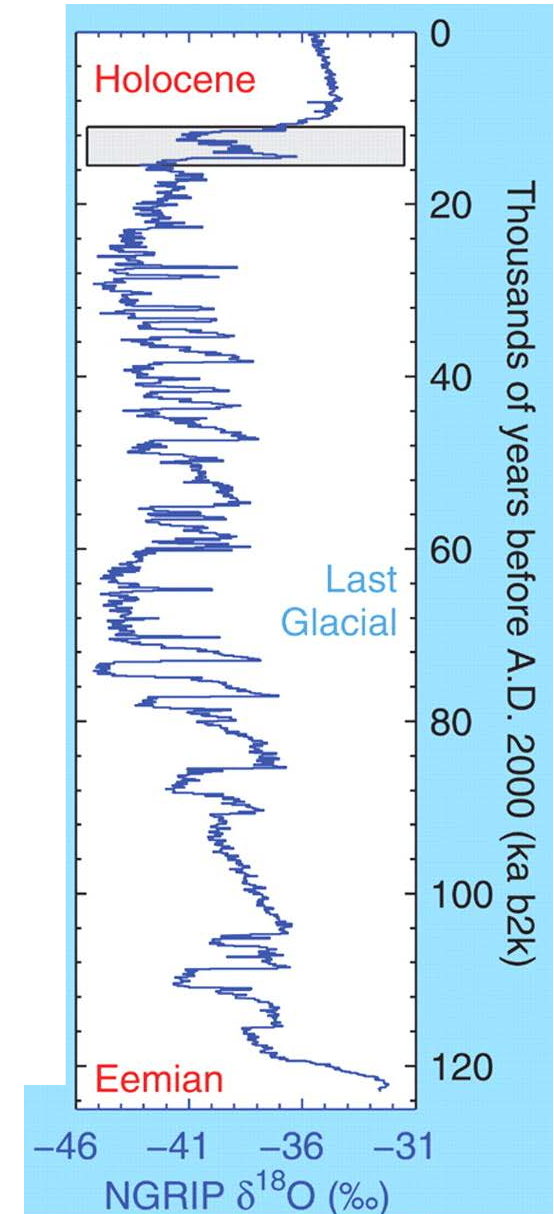
- Lagrangian tracer of ice origin and age (x,y,z)
i.e. can query any part of the ice sheet for (x_0,y_0,z_0,t_0)
- Next you need estimates of $\delta^{18}\text{O}$ (and/or δD) of precipitation at (x_0,y_0,z_0,t_0) , to map $\delta(x,y,z)$
- Typically in ice sheet models, $n_z \sim 20$, so e.g. $\Delta z \sim 150$ m, too coarse for a synthetic ice core. Hence it is necessary to interpolate $\delta(z)$.
- Finally, diffuse the interpolated $\delta(z)$ profile.

Passive Tracers in Ice Sheet Models

Application to Greenland:

Precipitation $\delta^{18}\text{O}$ is somewhat constrained, since we ~know $\delta(x_0, y_0, z_0, t_0)$ at ice core sites.

Actually we only really know $\delta(t_0)$. The spatial origin of ice at a given depth in an ice core is unknown. One can assume it is the same as modern, or one can use an ice sheet model to refine estimates of (x_0, y_0, z_0)



Passive Tracers in Ice Sheet Models

Application to Greenland

Another option is to rely on Dansgaard for estimates of $\delta(x_0, y_0, z_0, t_0)$ – really this means $\delta(T)$:

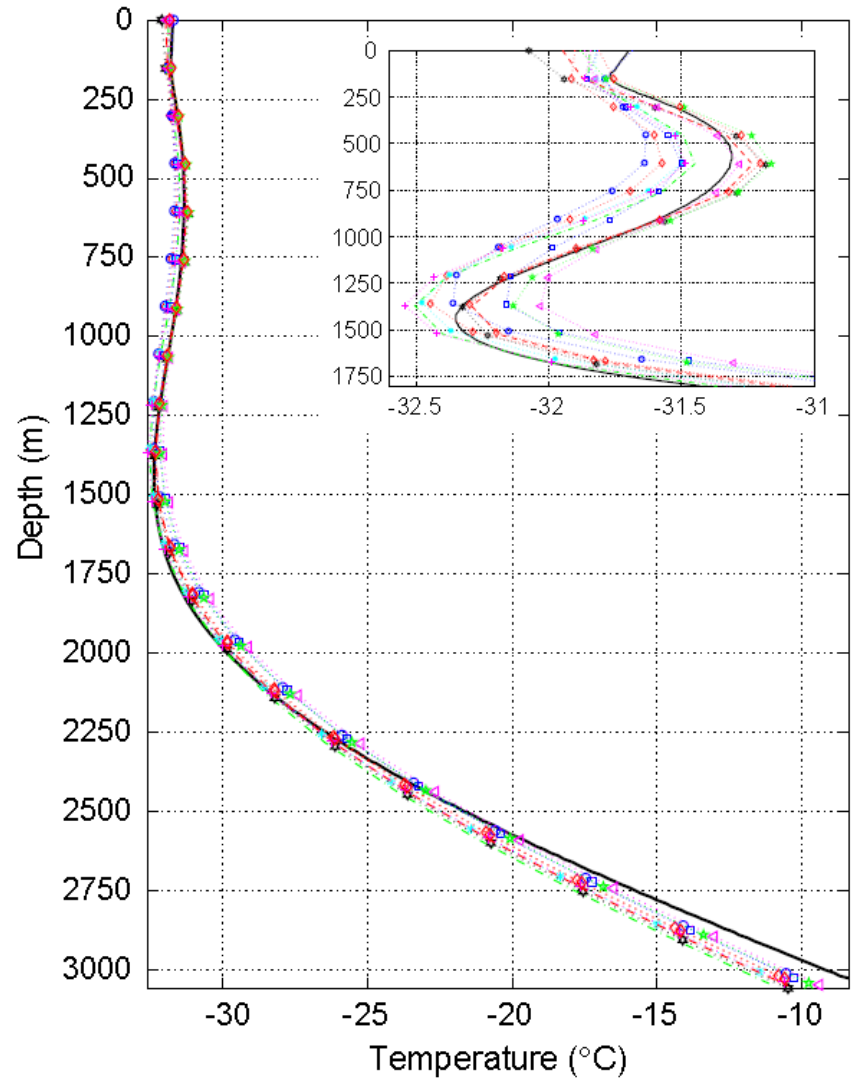
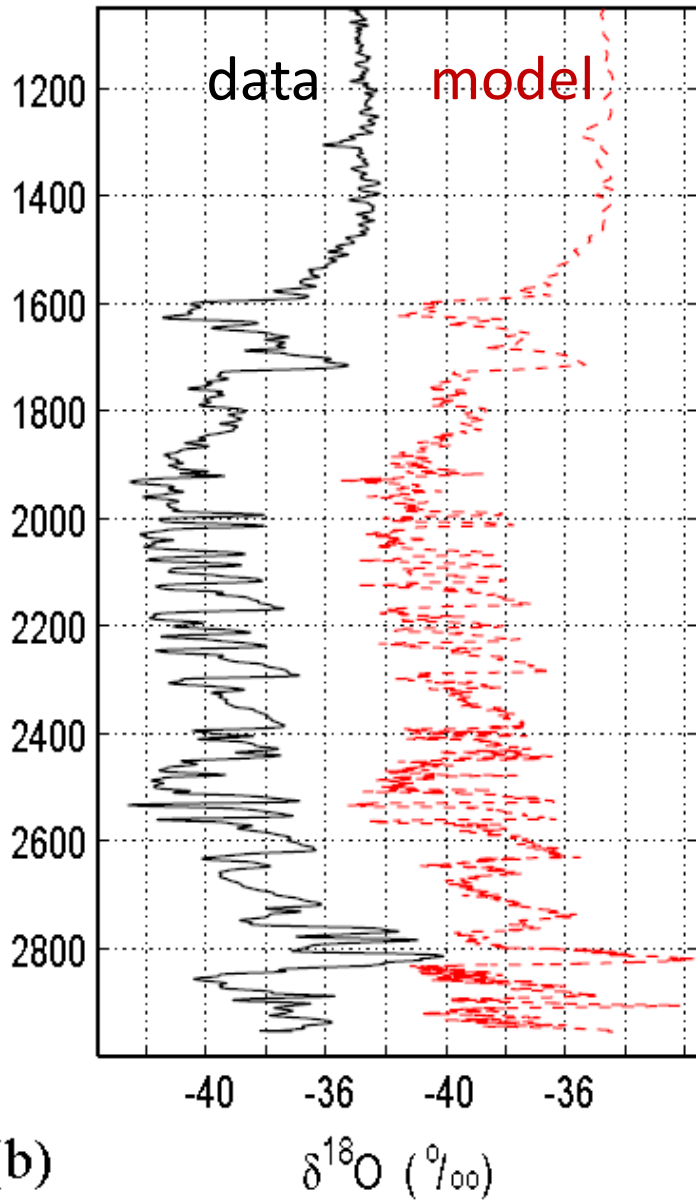
i.e. transfer function based on modern day

$$\delta_{18m} = 0.69 \delta t_a - 13.6 \text{‰}$$

This assumes stationarity and assumes that we can model past temperatures $T(x_0, y_0, z_0, t_0)$ with some confidence (climate model or ice core based).

Example for Greenland

GRIP ice core $\delta^{18}\text{O}$ and $T(z)$



Some questions and limitations

There is circularity here, in the modeling of Greenland ice cores based on Greenland ice cores

We need more spatial information for precipitation $\delta^{18}\text{O}$ and changes in seasonality of precipitation, moisture pathways, etc. through the glaciation – i.e., not just the modern δ - T relation

Some questions and limitations

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Post-depositional melt effects on $\delta^{18}\text{O}$?

The effects of meltwater percolation on the seasonal isotopic signals in an Arctic snowpack

Tara MORAN, Shawn MARSHALL

Journal of Glaciology, Vol. 55, No. 194, 2009

Isotope thermometry in melt-affected ice cores

T. Moran,¹ S. J. Marshall,¹ and M. J. Sharp²

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, F02010, doi:10.1029/2010JF001738, 2011



Isotopes in this ice core reveal how glaciers responded to climate change more than 100,000 years ago.

CLIMATOLOGY

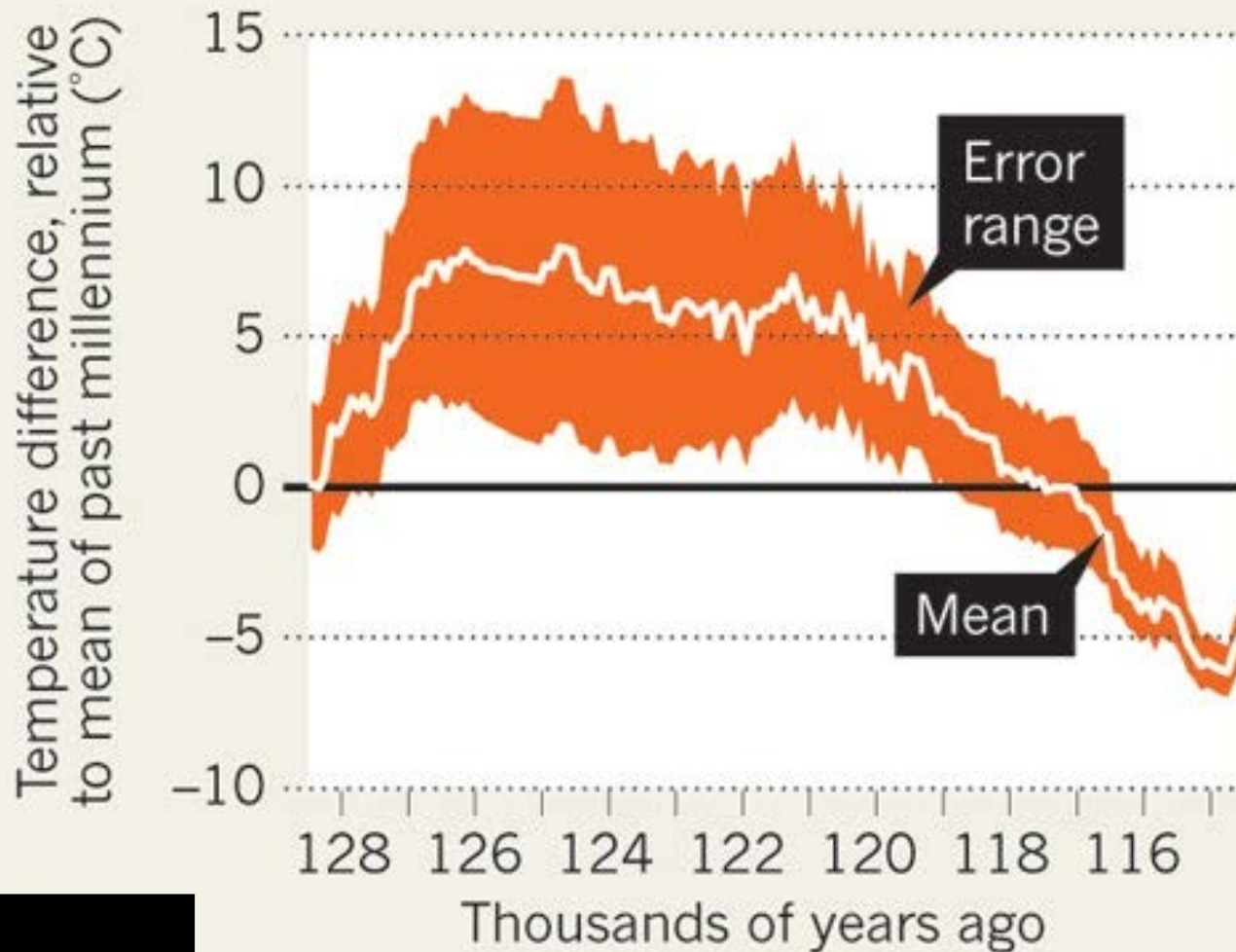
Greenland defied ancient warming

But Antarctic glaciers may be more vulnerable than thought.

*Nature
News,
2013*

WARM SPELL

The Eemian interglacial period (130,000–115,000 years ago) began with a burst of climate warming — but this caused only a modest shrinkage of the ice sheet that covered Greenland at the time.



Nature
News, 2013

Passive Tracers in Ice Sheet Models

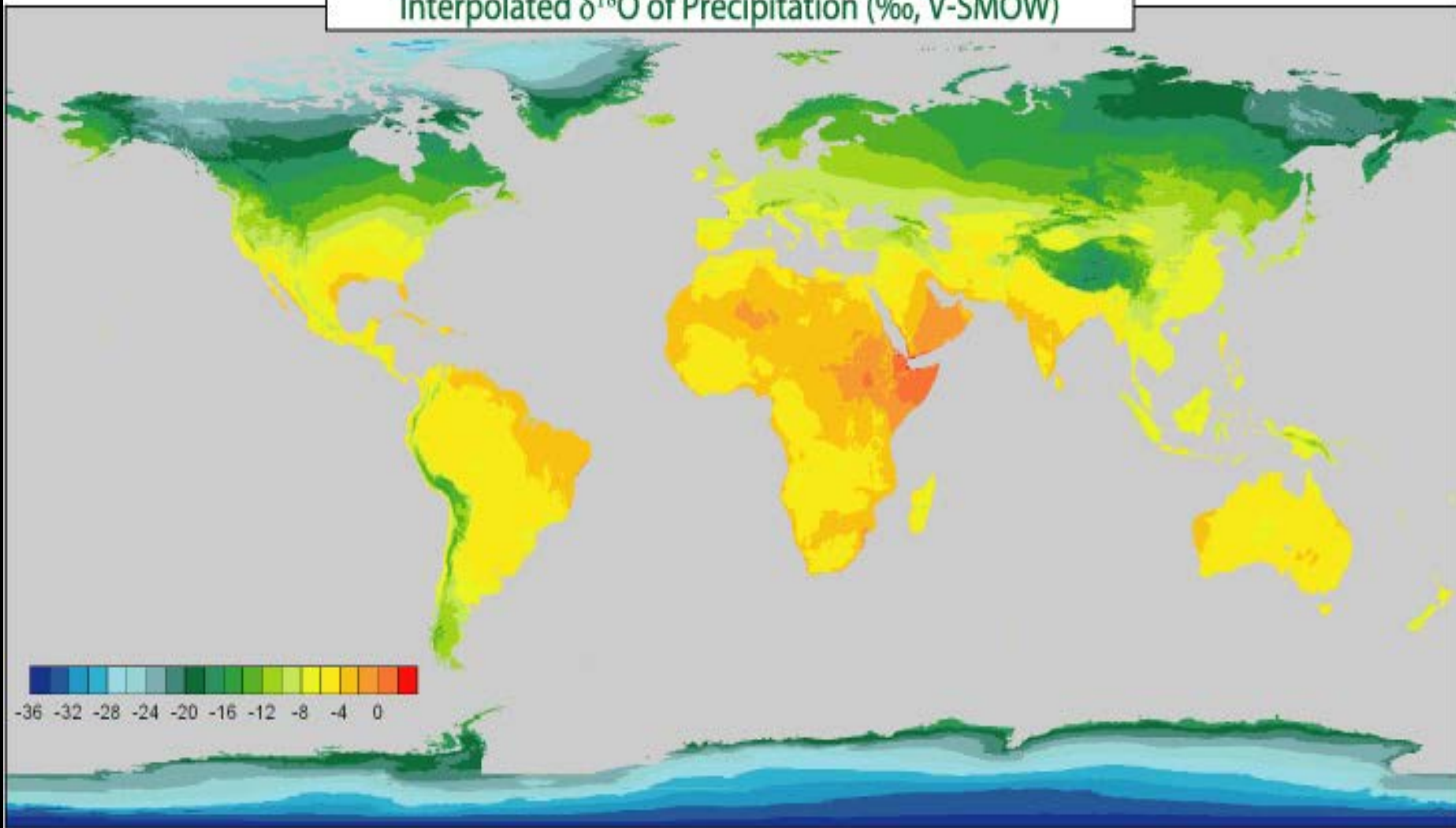
Application to the Laurentide Ice Sheet:

Here we really don't know $\delta(x_0, y_0, z_0, t_0)$.

Options:

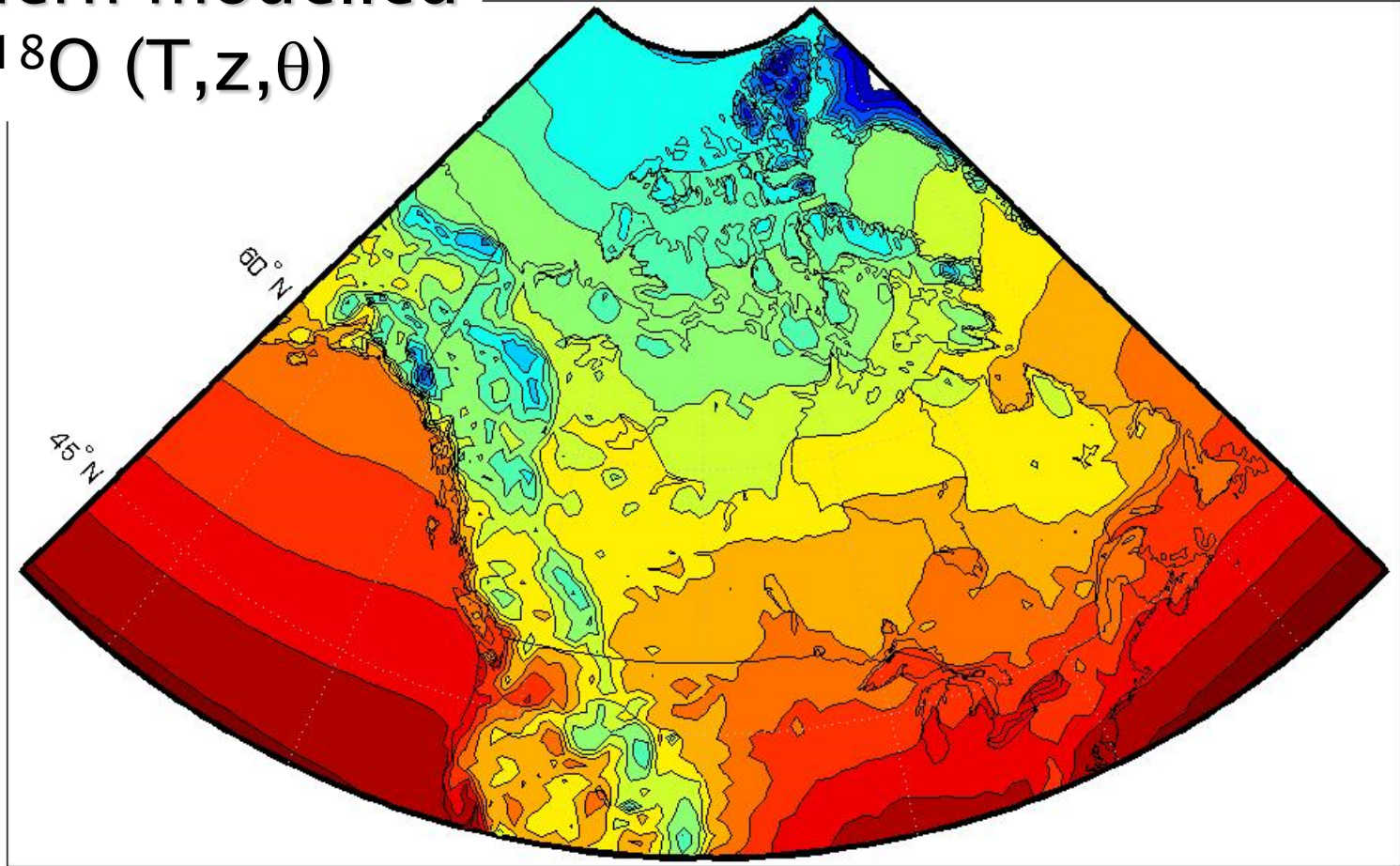
- transfer function based on modern day
- independent isotopic model, e.g. Rayleigh
- isotope-enabled GCM

Interpolated $\delta^{18}\text{O}$ of Precipitation (‰, V-SMOW)



Modern modelled

$\delta^{18}\text{O}$ (T,z, θ)



$\delta^{18}\text{O}$ (precipitation)

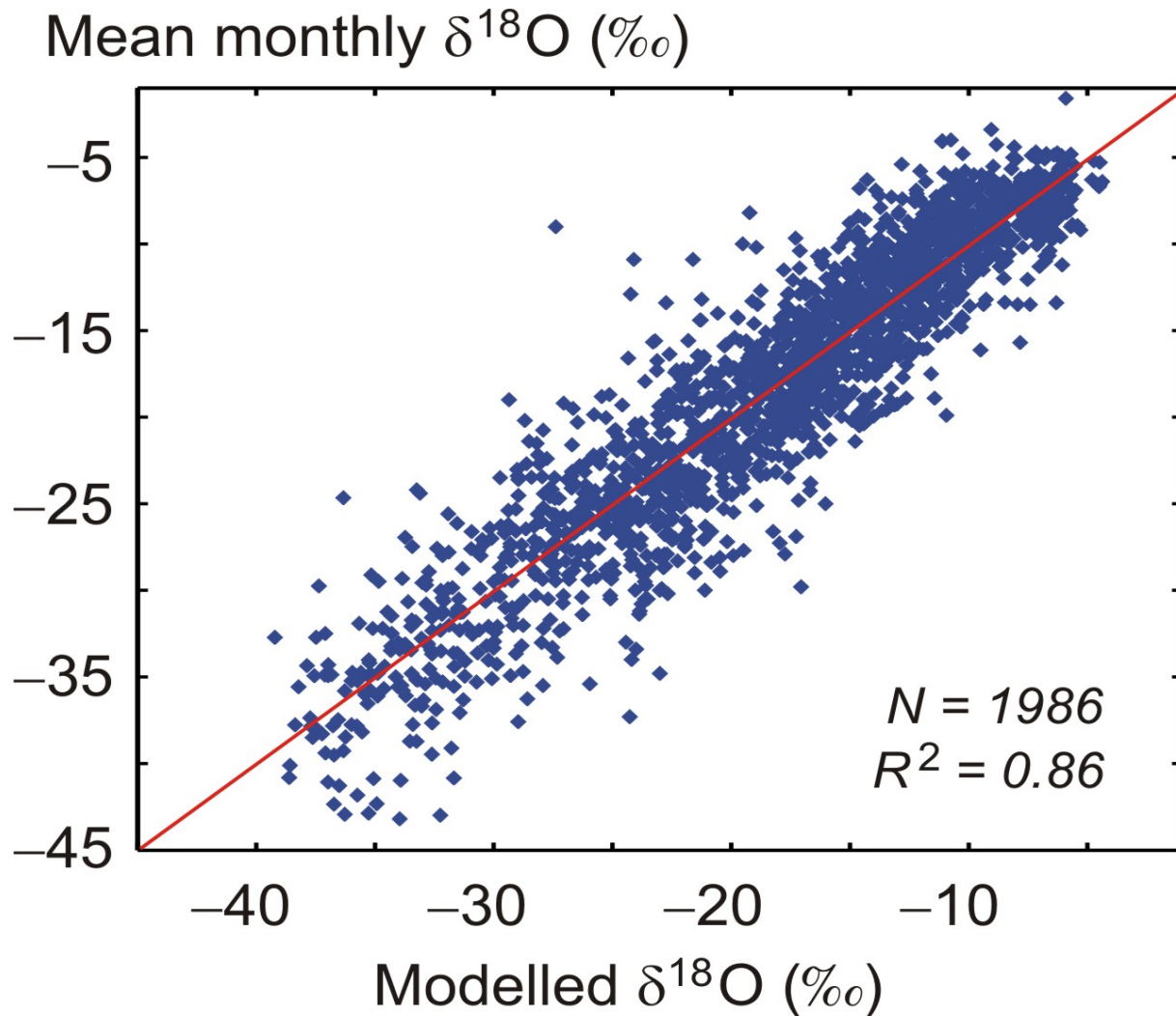
present day

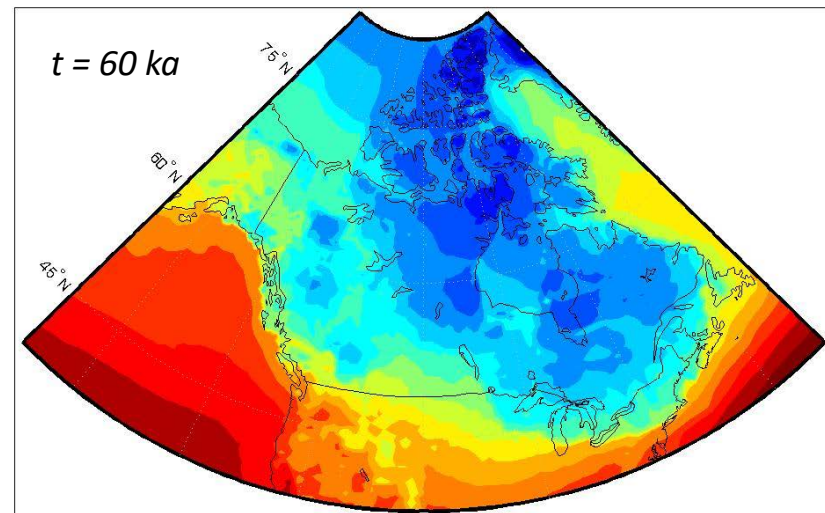
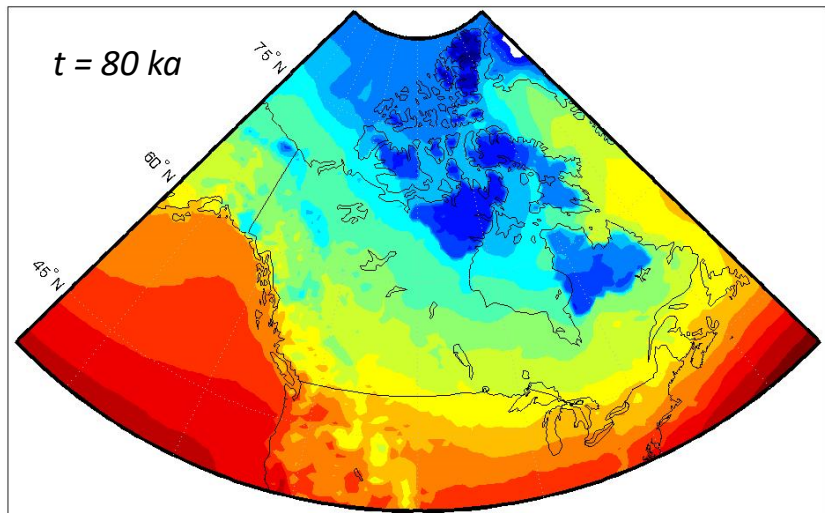


-45 -40 -35 -30 -25 -20 -15 -10

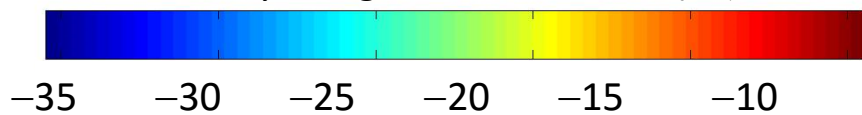
Precipitation $\delta^{18}\text{O}$ in Canada

Observed vs. modelled: $\delta^{18}\text{O}$ (T, θ, z)

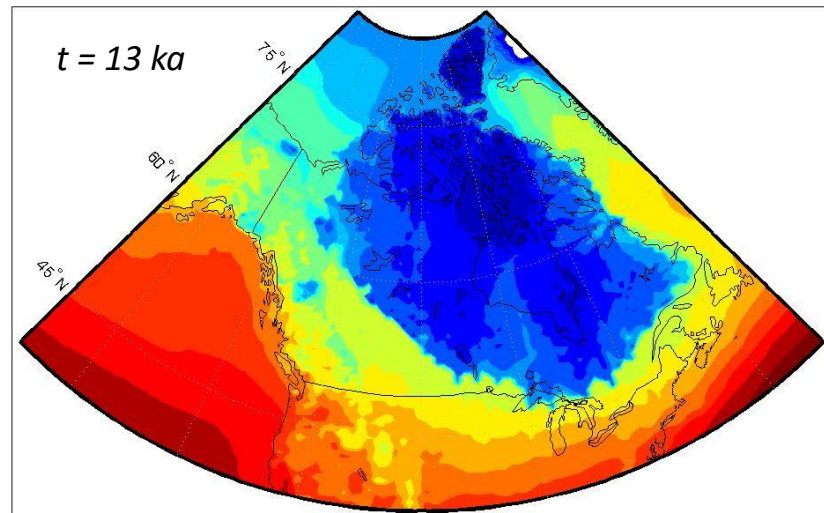
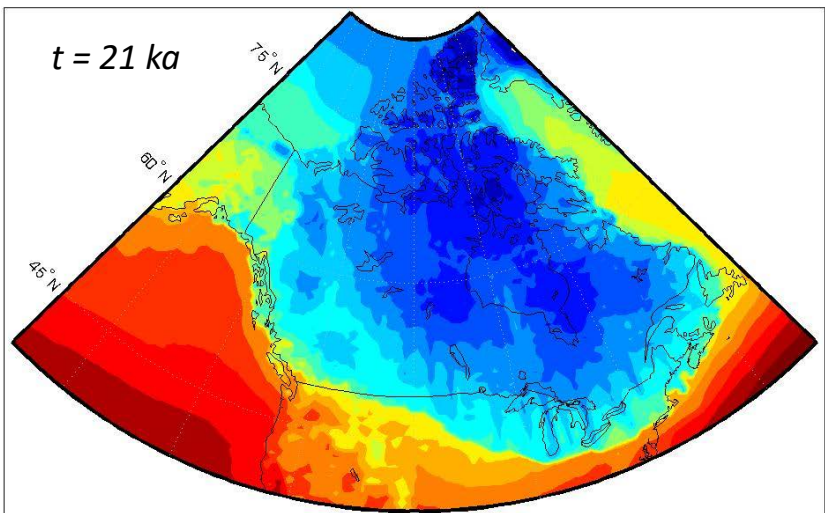
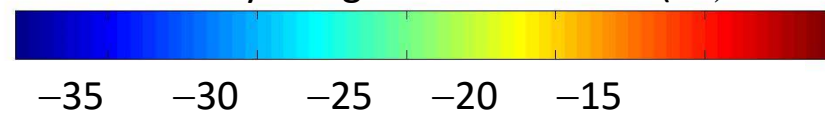




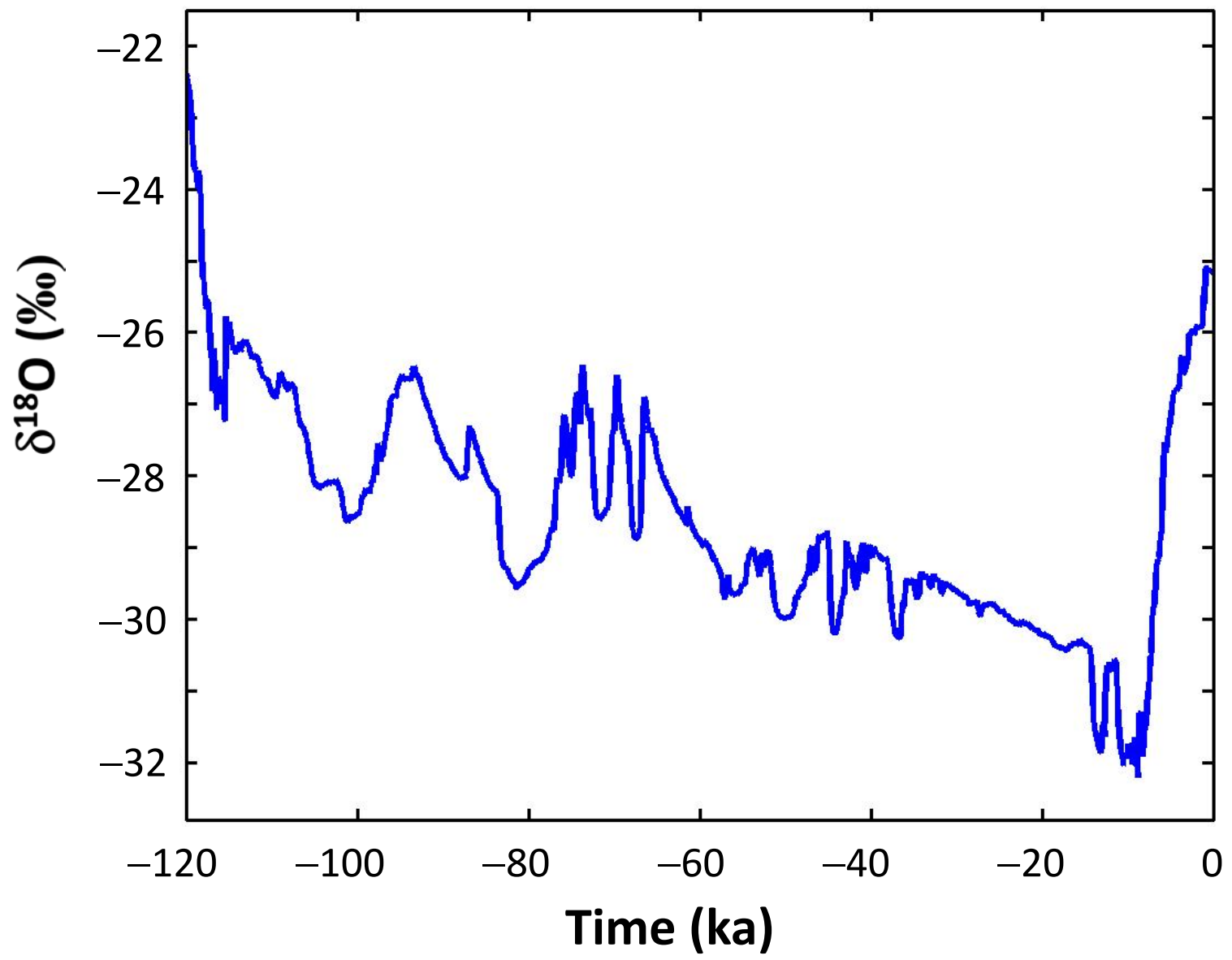
Vertically-integrated mean $\delta^{18}\text{O}$ (‰)



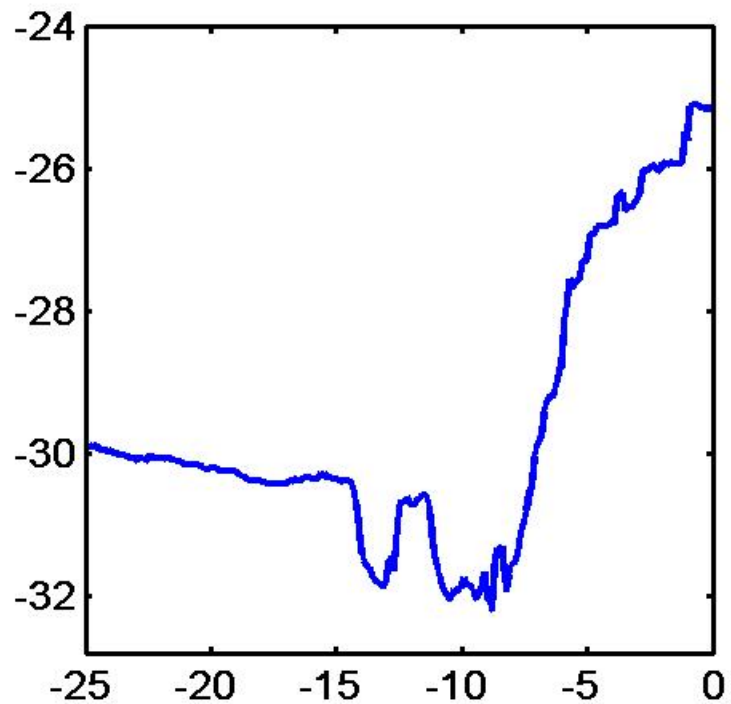
Vertically-integrated mean $\delta^{18}\text{O}$ (‰)



Mean $\delta^{18}\text{O}$ of the North American ice sheets (‰)

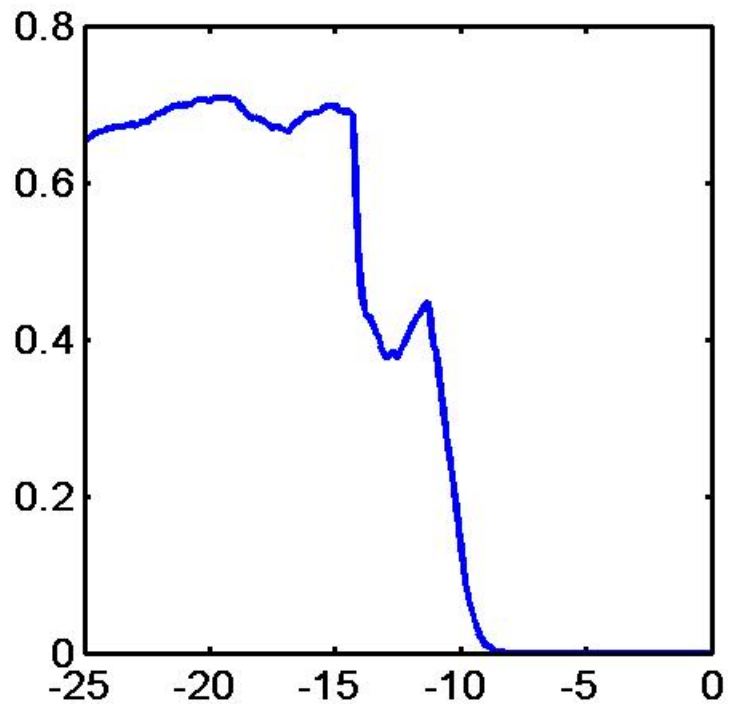


Ice sheet $\delta^{18}\text{O}$ (‰)



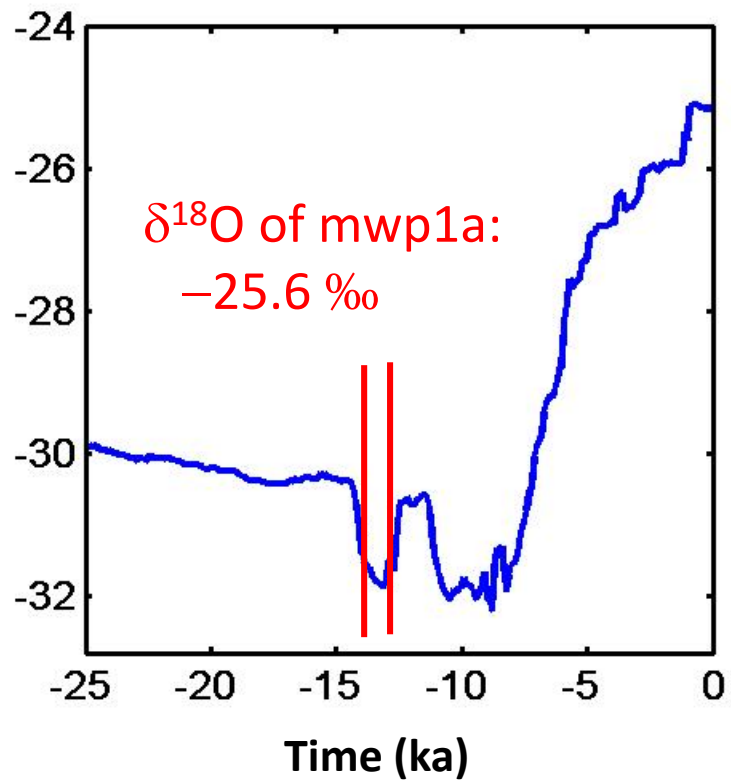
Time (ka)

Marine $\Delta\delta^{18}\text{O}$ (‰)

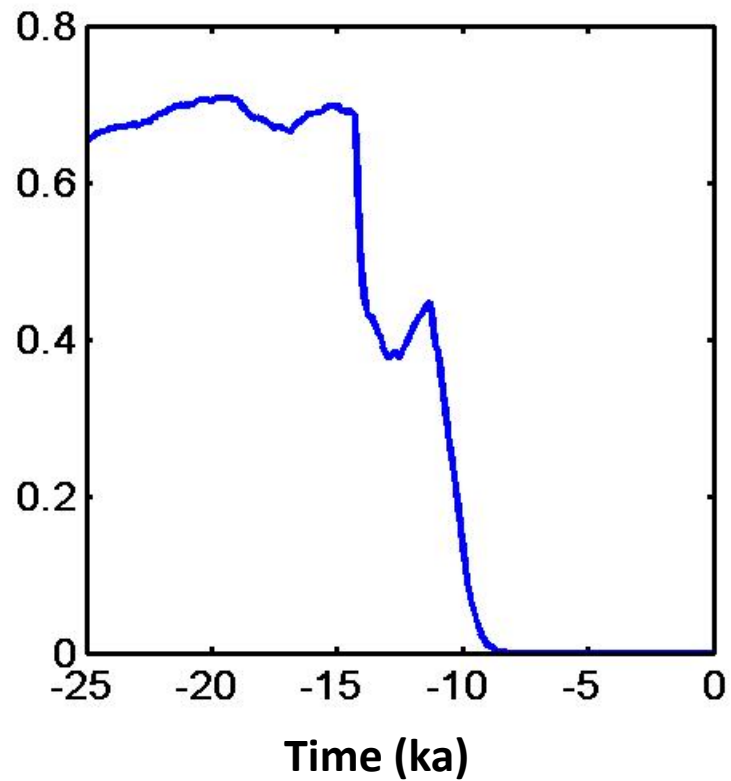


Time (ka)

Ice sheet $\delta^{18}\text{O}$ (‰)



Marine $\Delta\delta^{18}\text{O}$ (‰)



Proxies documenting Laurentide $\delta^{18}\text{O}$ values?



SUBGLACIAL LIS
CONCRETIONS AT
CANTLEY
(over Grenvillian
Precambrian
marbles)

Age of concretions:
 22.2 ± 1.3 ka
(TSD/U-Th)

$\delta^{18}\text{O}_{\text{calcite}} \sim -25\text{‰}$

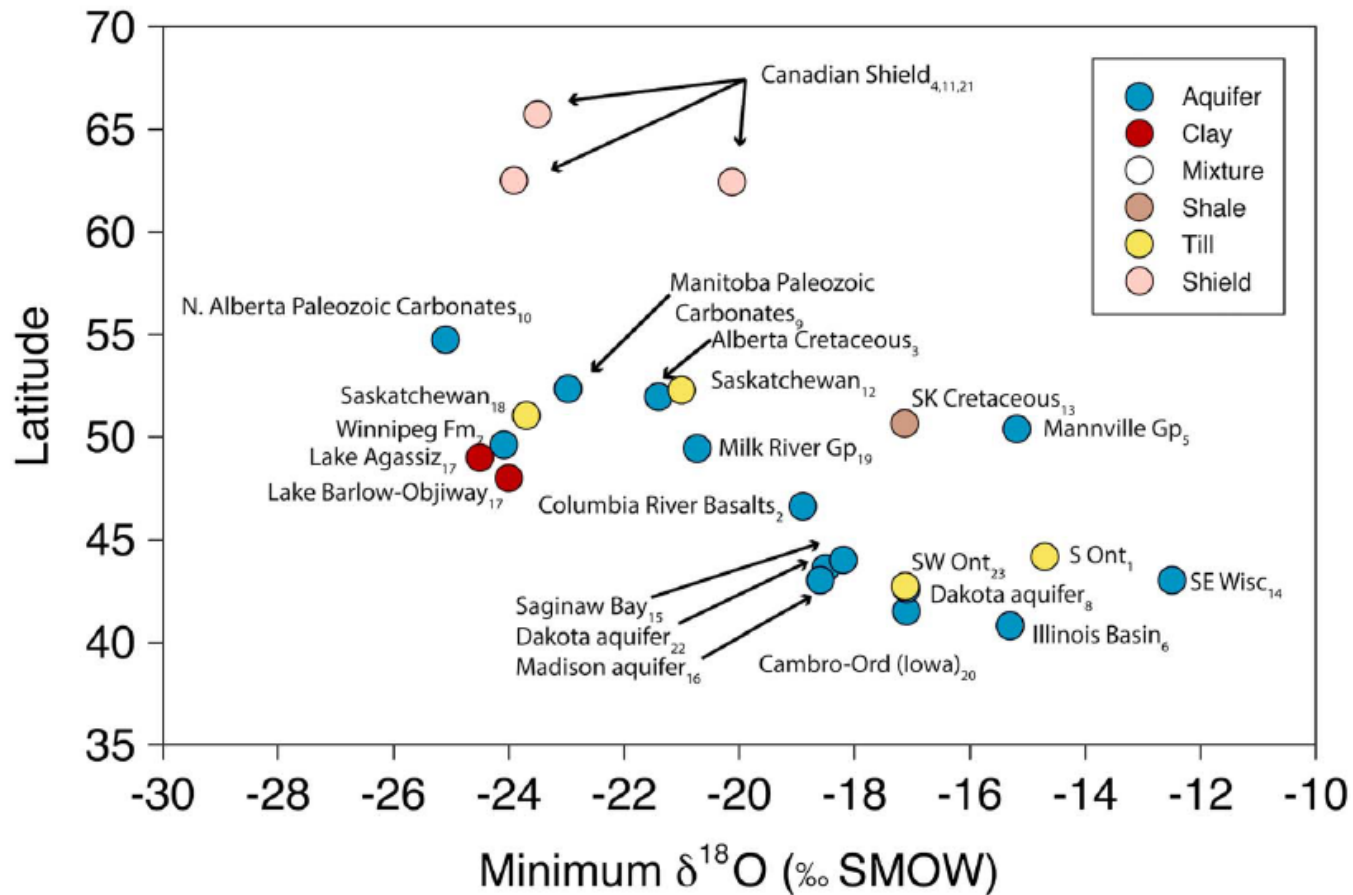
with $T \sim 0^\circ\text{C}$, $\delta^{18}\text{O}_{\text{water}} \sim -30\text{‰}$

Hillaire-Marcel et al, CJES, 1979

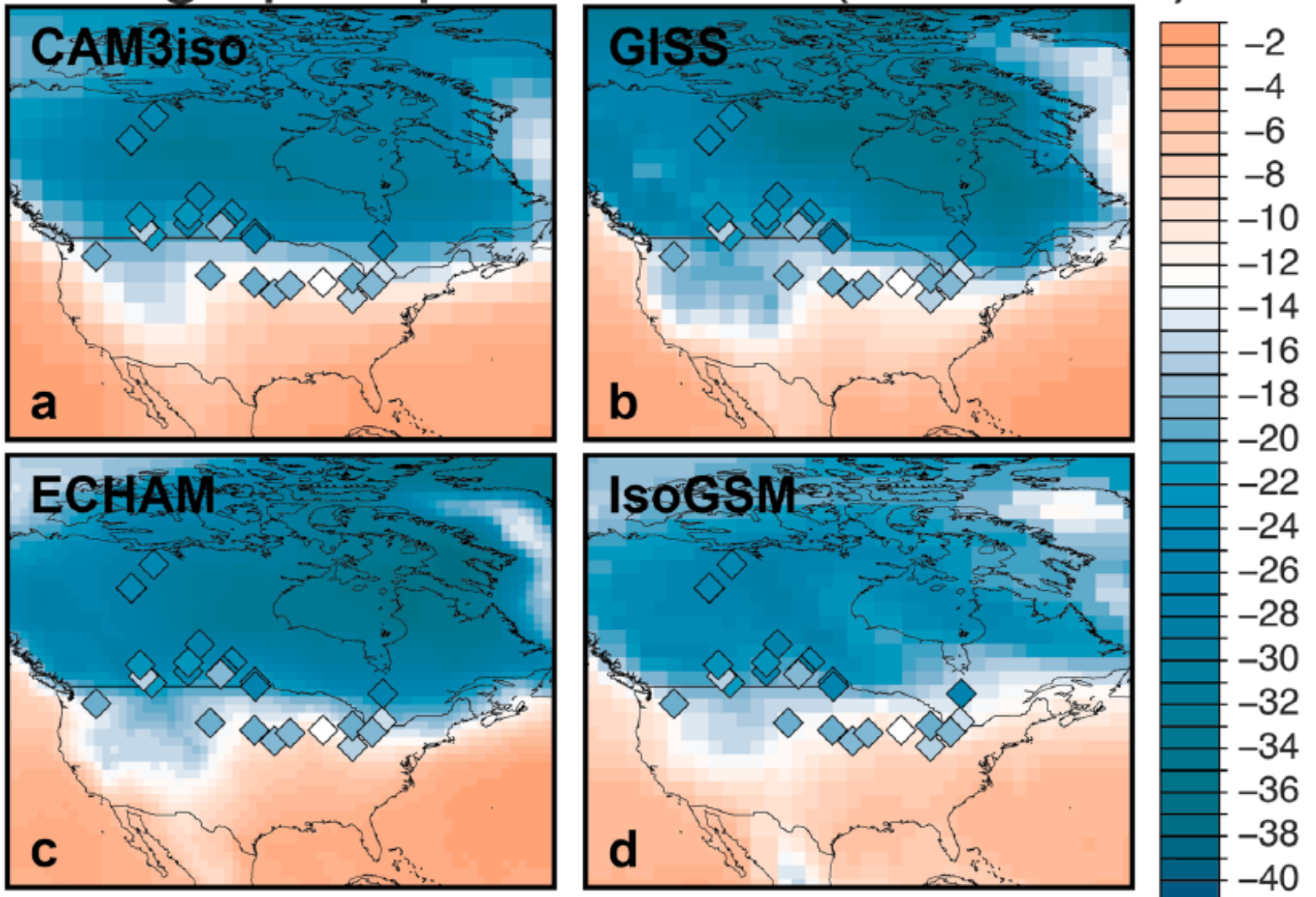
Hillaire-Marcel & Causse, QR, 1989

The isotopic composition of the Laurentide Ice Sheet and fossil groundwater

Grant Ferguson¹ and Scott Jasechko²



Ice age precipitation $\delta^{18}\text{O}$ (‰ SMOW)



Summary and Preliminary Conclusions

Advances should be possible through isoCESM: complete the loop on the global hydrological and water isotope cycles.

Maybe need to think about $\Delta\delta$ for this, depending on atmospheric model biases.

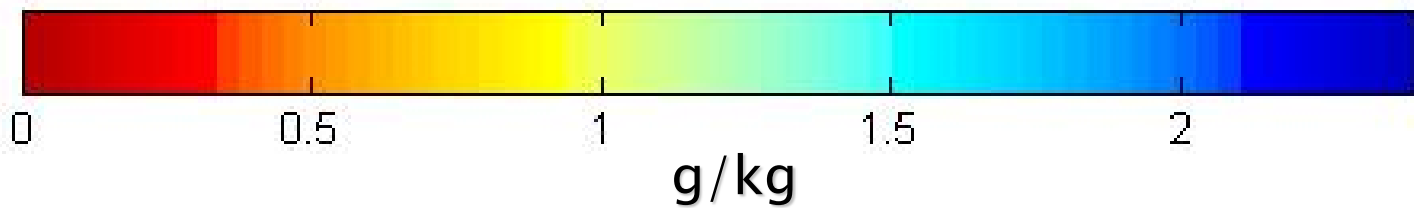
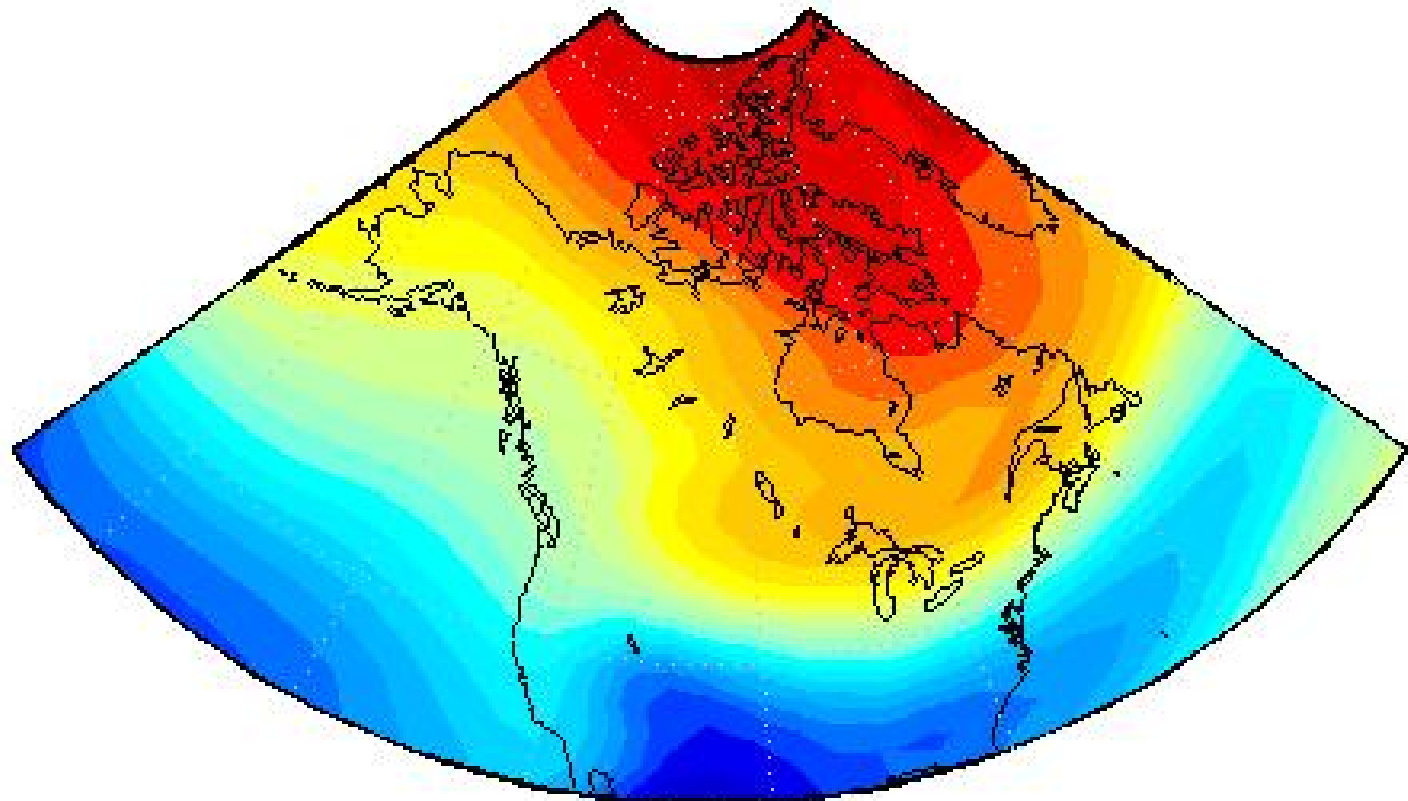
Challenge: how to treat transient δ of precipitation over many kyr, or a glacial cycle?

One option is to map $\delta(T)$ or $\delta(z,\theta,T)$ relationships for different ice sheet geometries, from snapshots

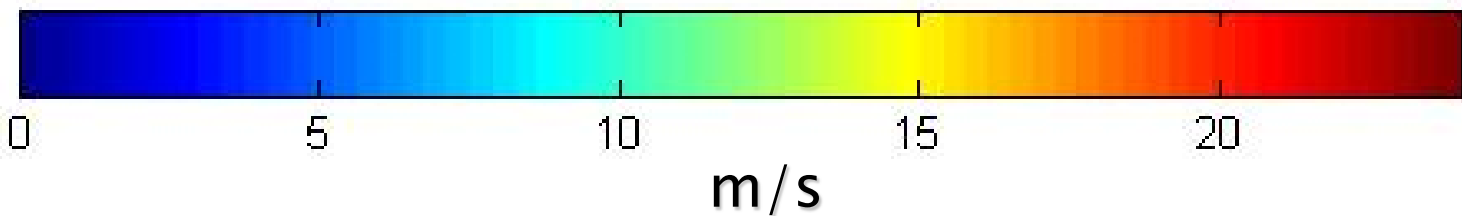
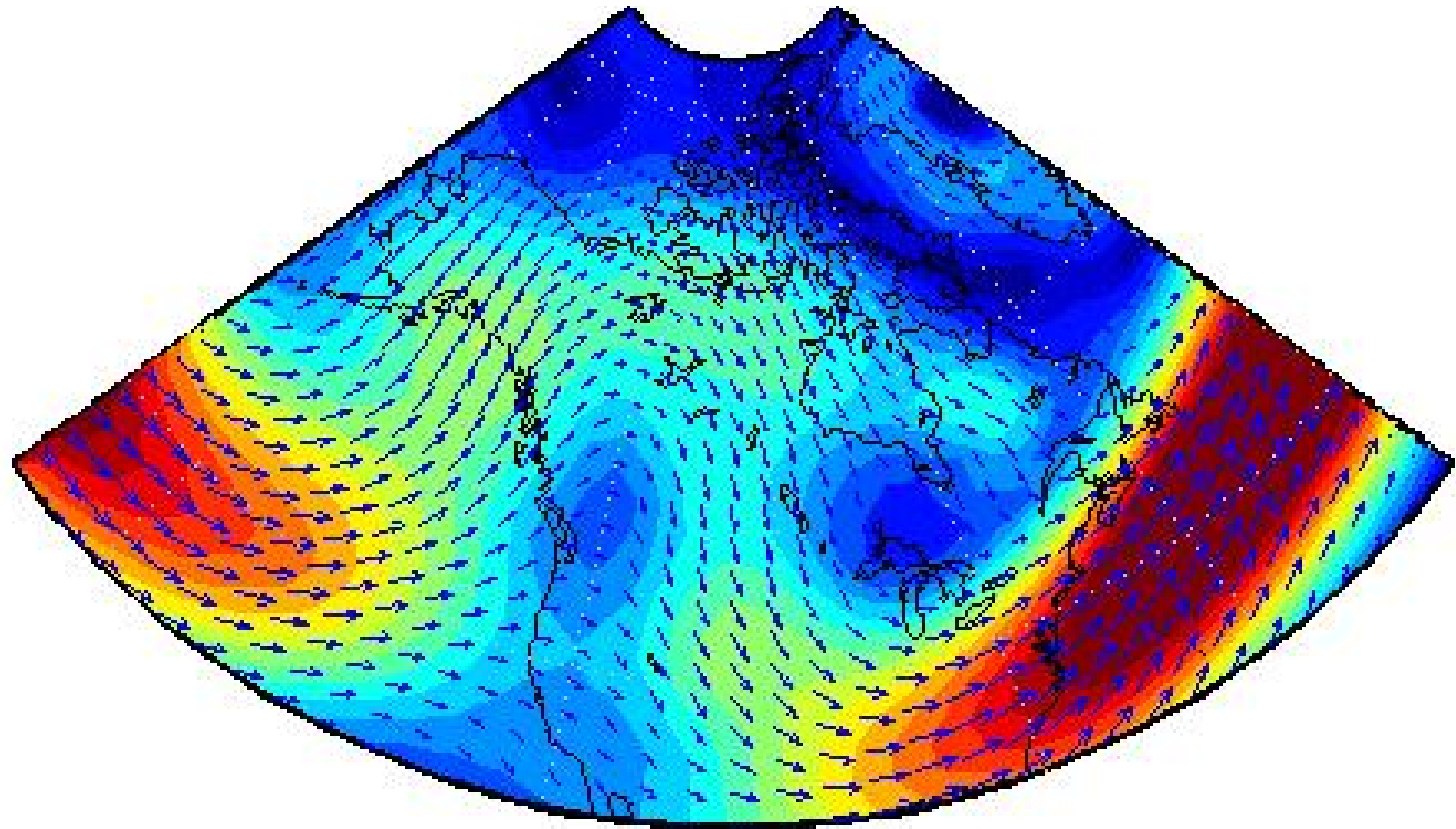
Questions



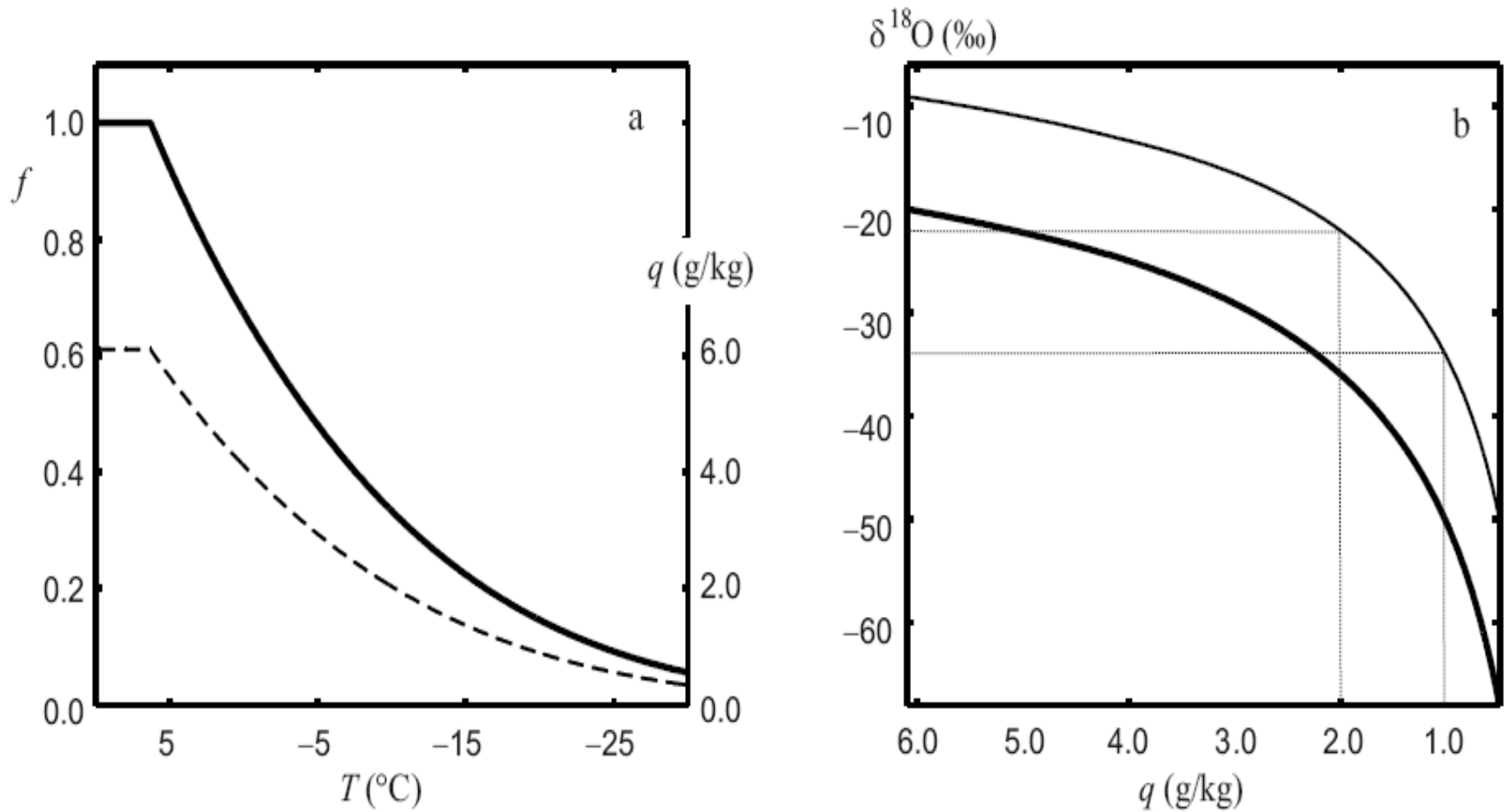
LGM 700-mb specific humidity

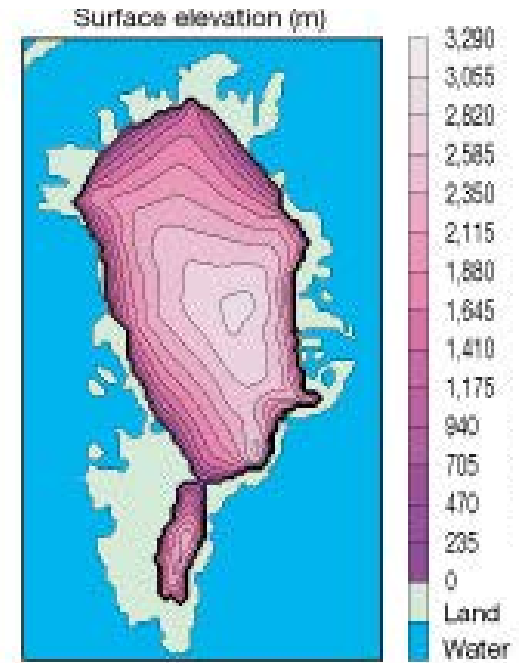
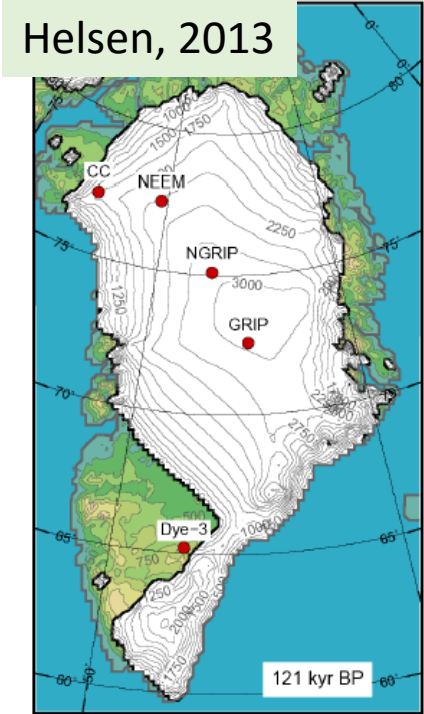
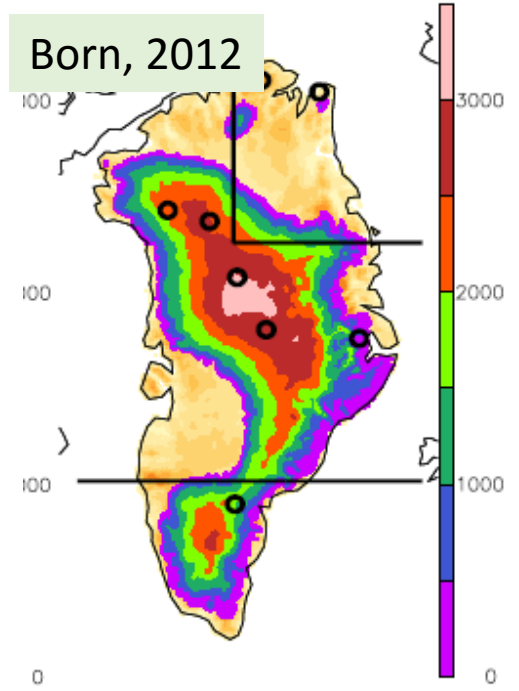
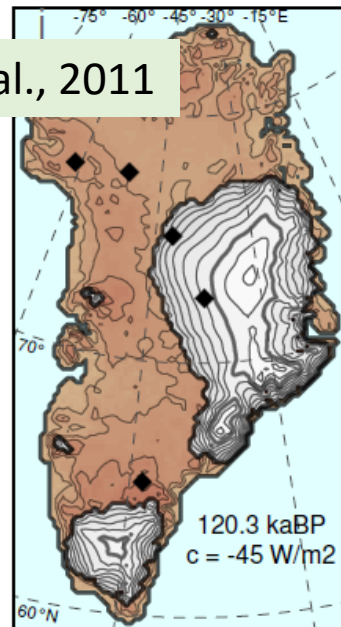
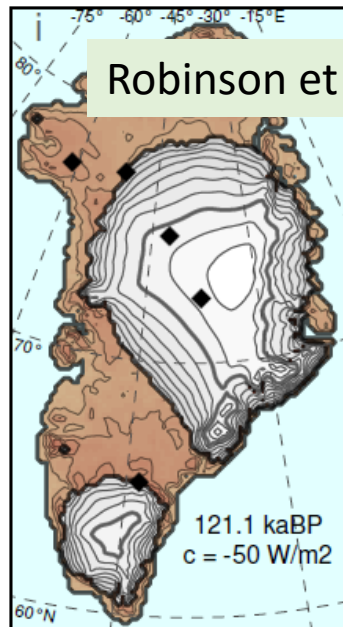
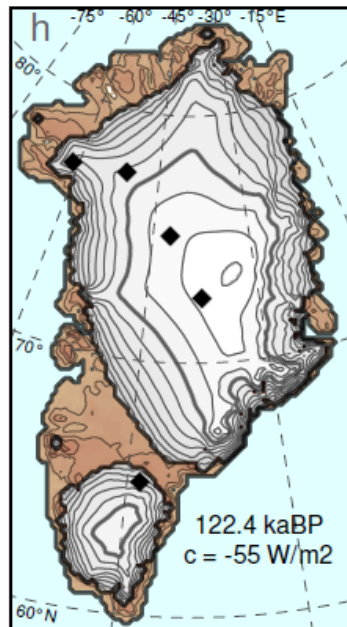


LGM wind field (winter)

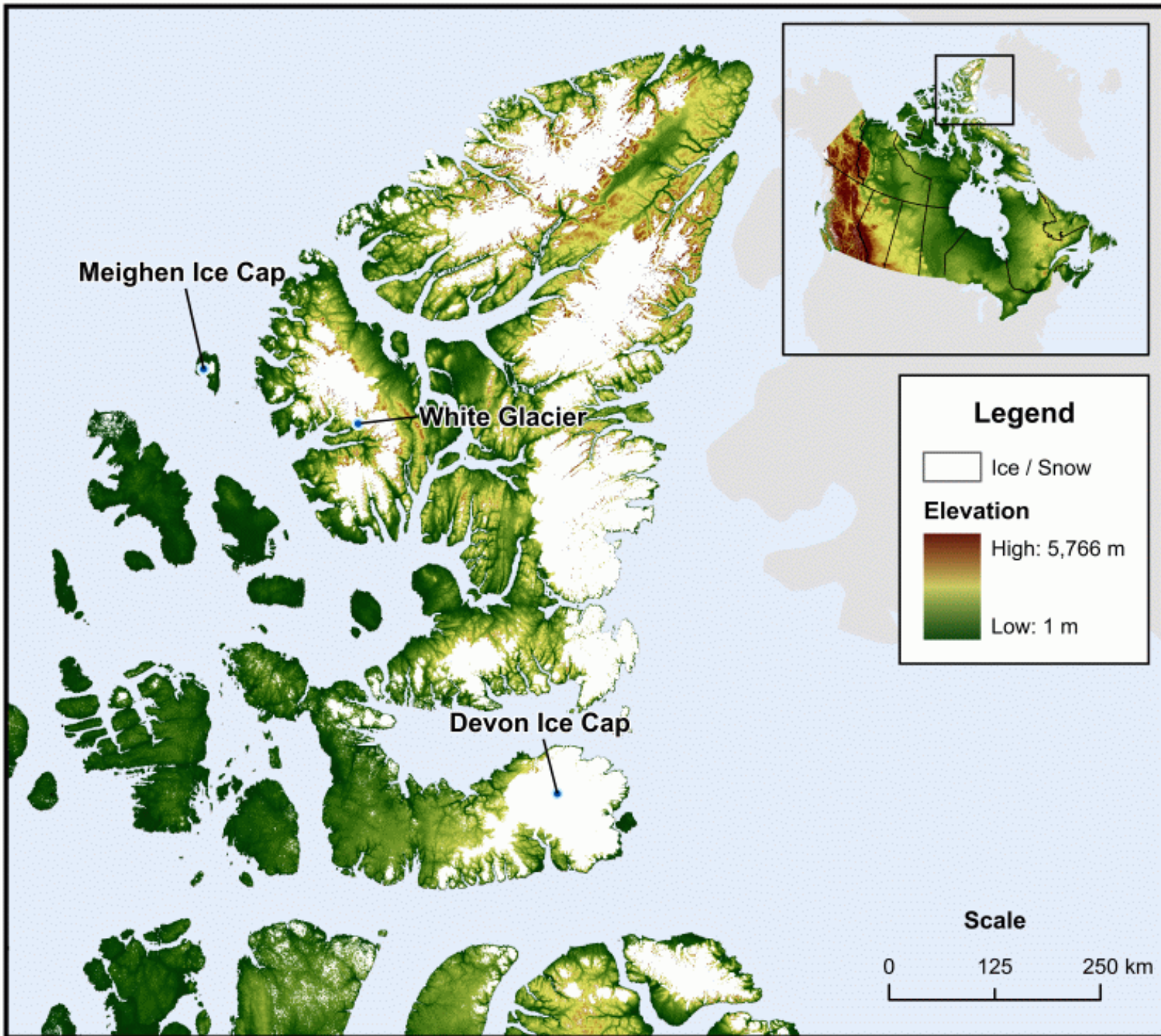


Modeling vapor transport and isotope fractionation





Cuffey and Marshall, 2000



**Q. What was the $\delta^{18}\text{O}$
of Laurentide Ice Sheet runoff ?**

Collaboration with Claude Hillaire-Marcel, Anne de Vernal, Garry Clarke & Andy Bush

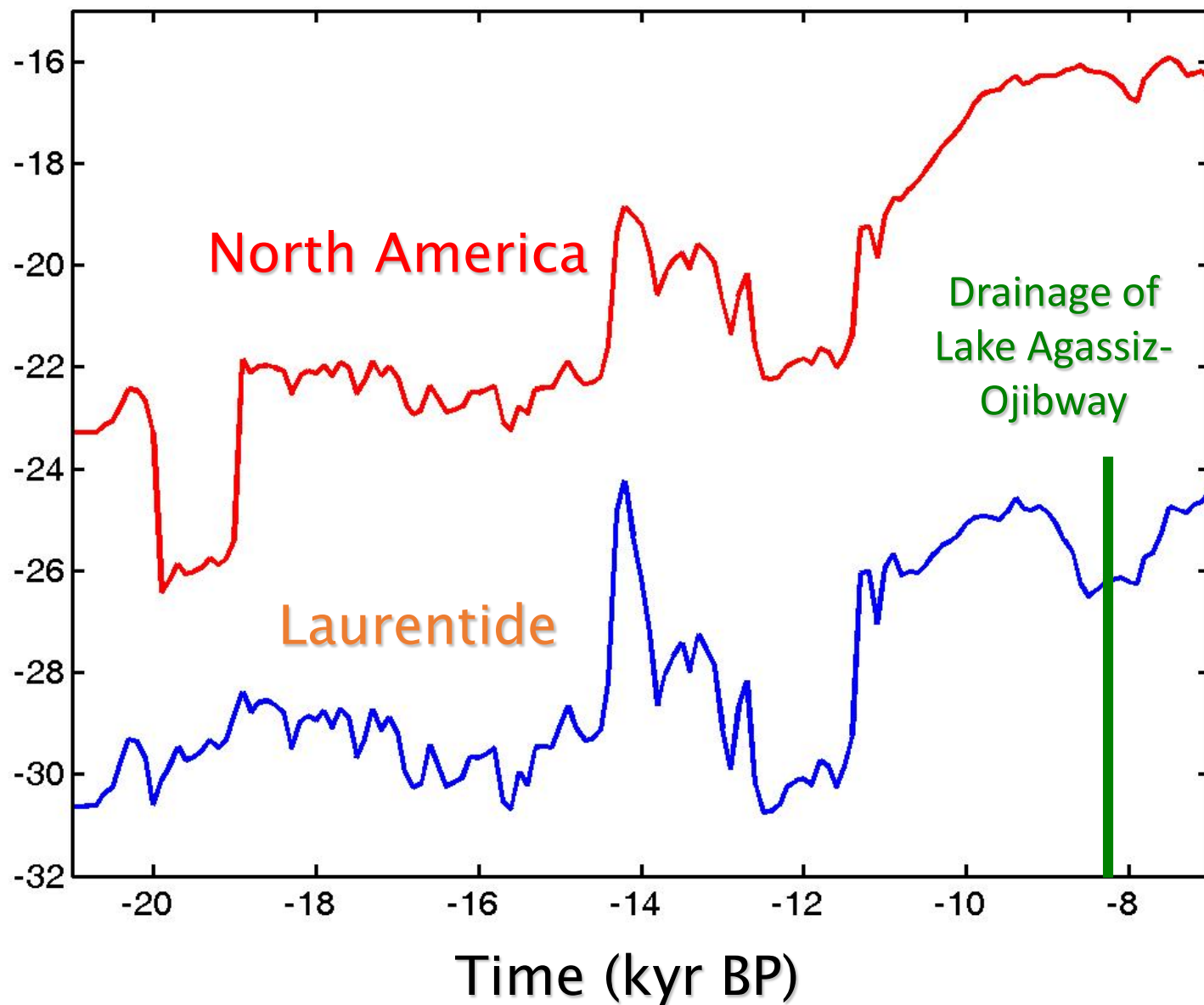
SE margin LIS meltwater...

Appr. -16‰

- *L. Erie ostracods, Fritz et al., 1975*

- *Glacial lake concretions, Hillaire-Marcel & Causse, 1989*

Mean modelled surface $\delta^{18}\text{O}$



SE margin LIS meltwater...

Appr. -16‰

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