Water isotopes and the general circulation

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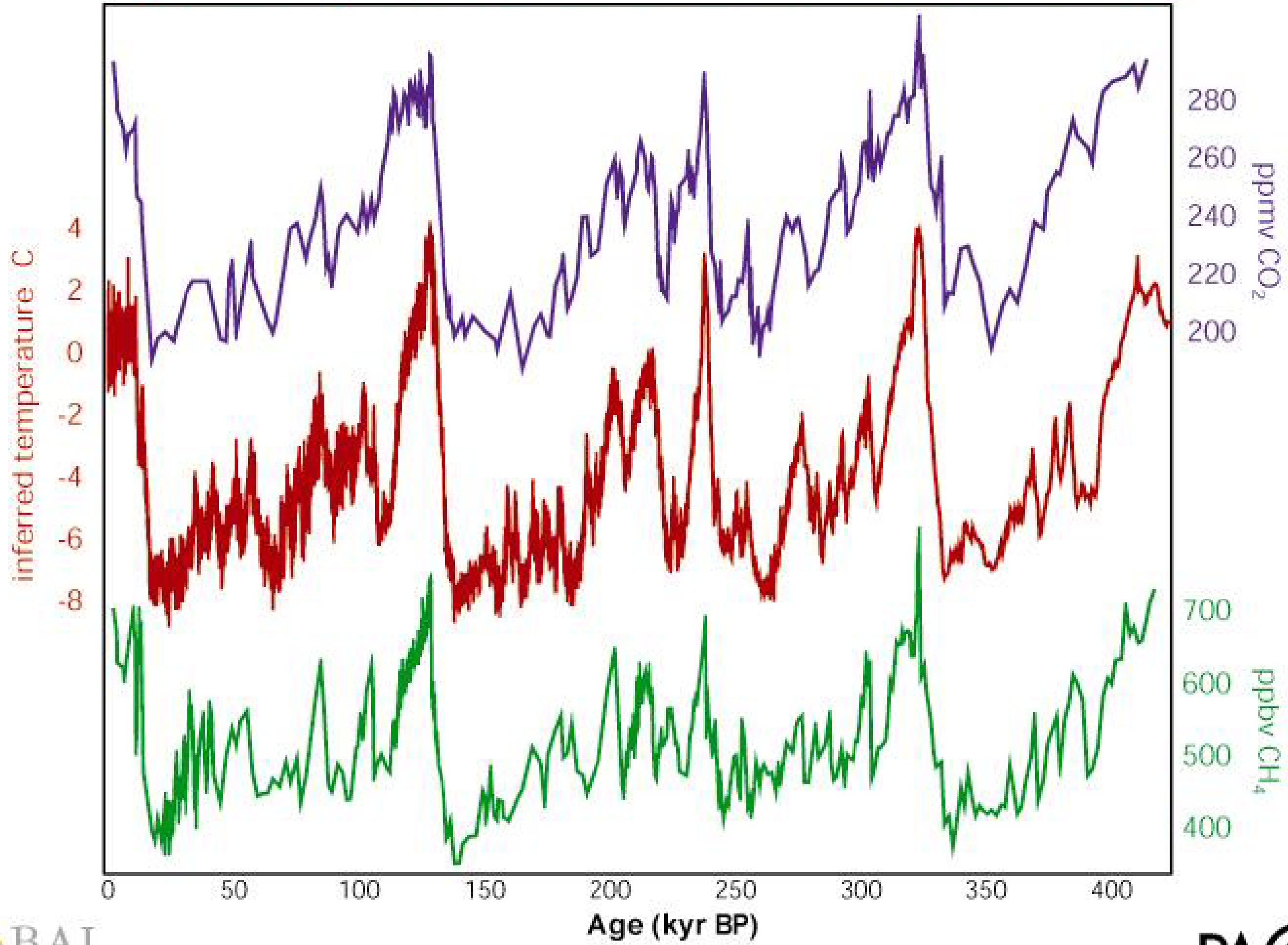
Overview

- Evidence of variation in the circulation of ocean and atmosphere from ice cores
- Water isotope cycles
- Review of idealized isotopic fractionation
- Expression of isotopic fractionation in nature
- Attributing signals to source, rainout and temperature
- More complete view of atmospheric circulation, and hydrology
- Isotope signals of variation in circulation

- Relationship between large scale ocean state and atmospheric circulation as reveled from isotope records

4 glacial cycles recorded in the Vostok ice core



GLOBAL CHANGE IGBP

J.R. Petit et al., *Nature*, **399**, 429Ð36, 1999.

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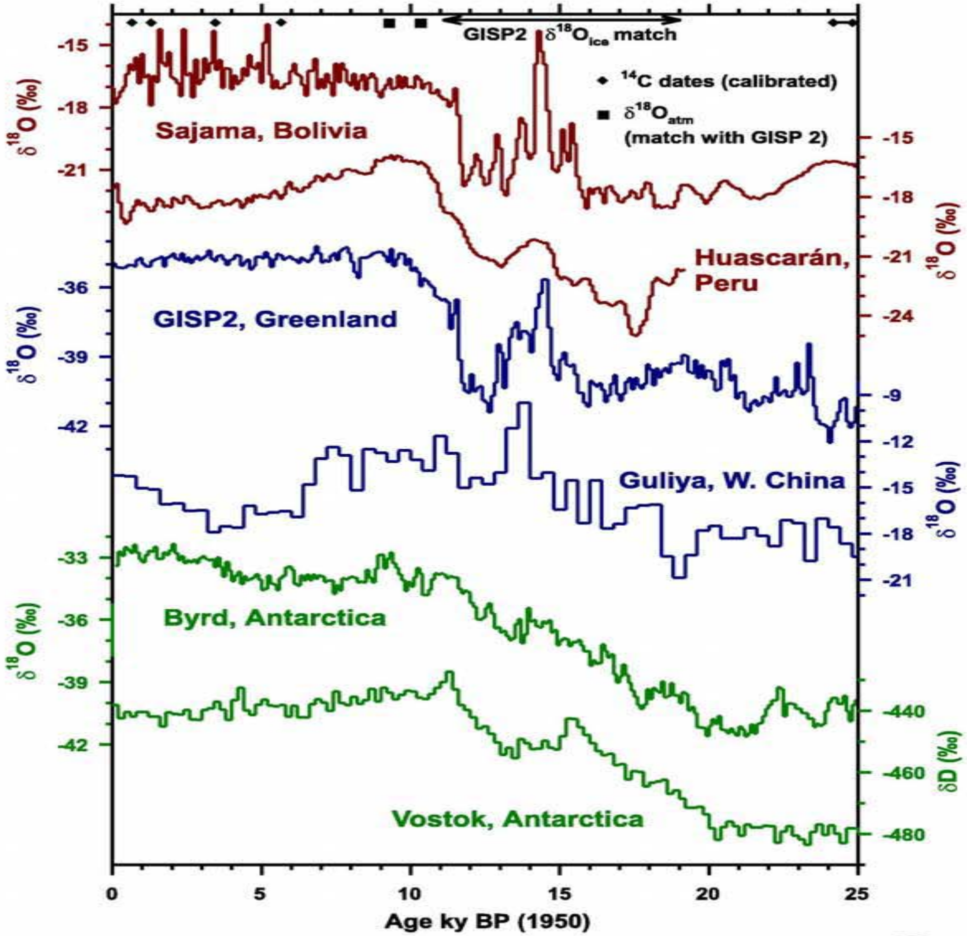
CIRES

Ice Cores from the Tropics Greenland and Antarctica



Thompson, L. (1998)
Science, **282**, 1858 - 1864.

GLOBAL IGBP CHANGE

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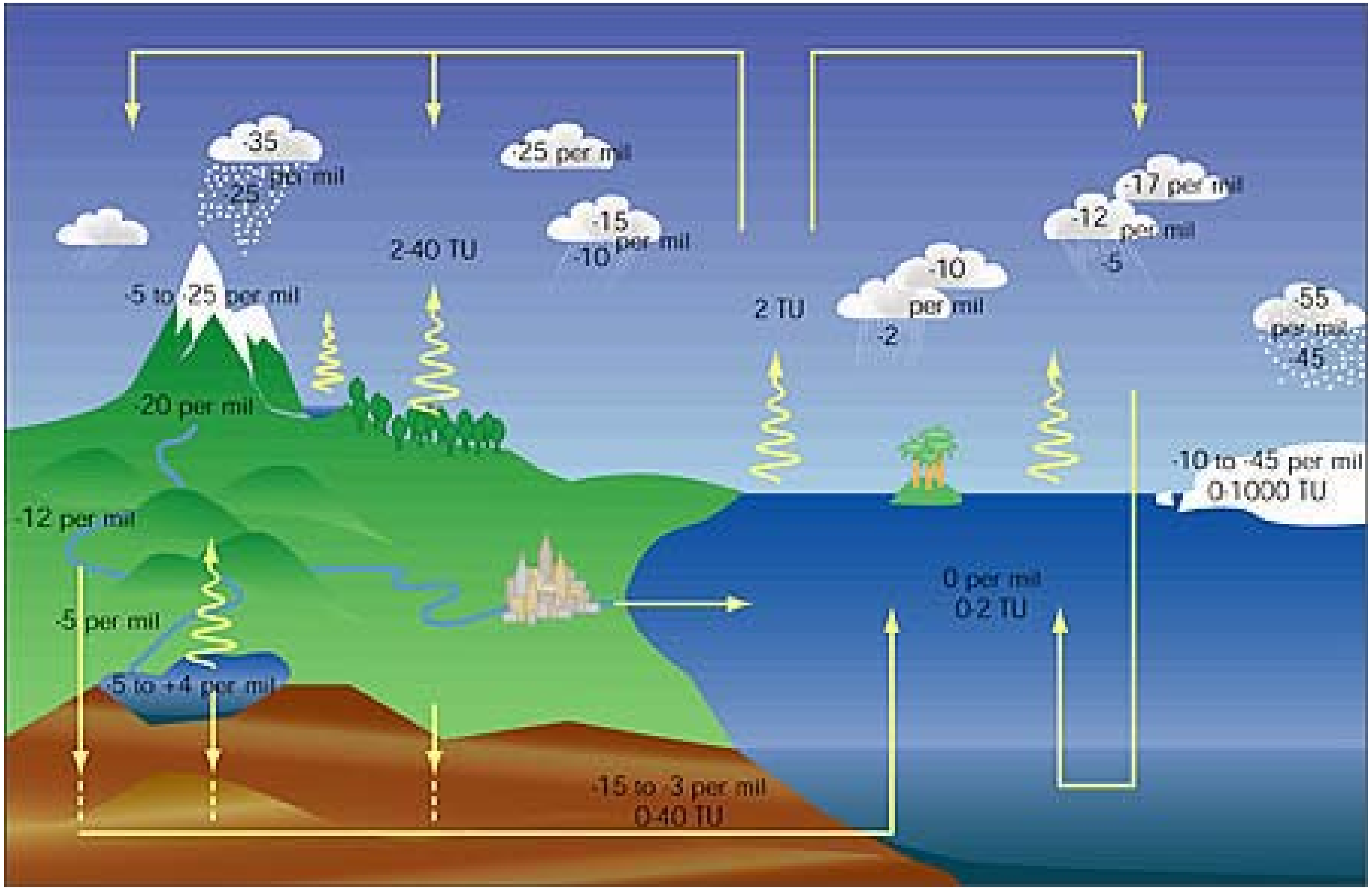
2.1

CIRES

paos

Hydrologic cycle and isotopic exchange



"Delta values" $\delta^{18}O = (R/R_{standard}-1)x1000$ R = moles of $H_2{}^{18}O$/moles of $H_2{}^{16}O$

CIRES

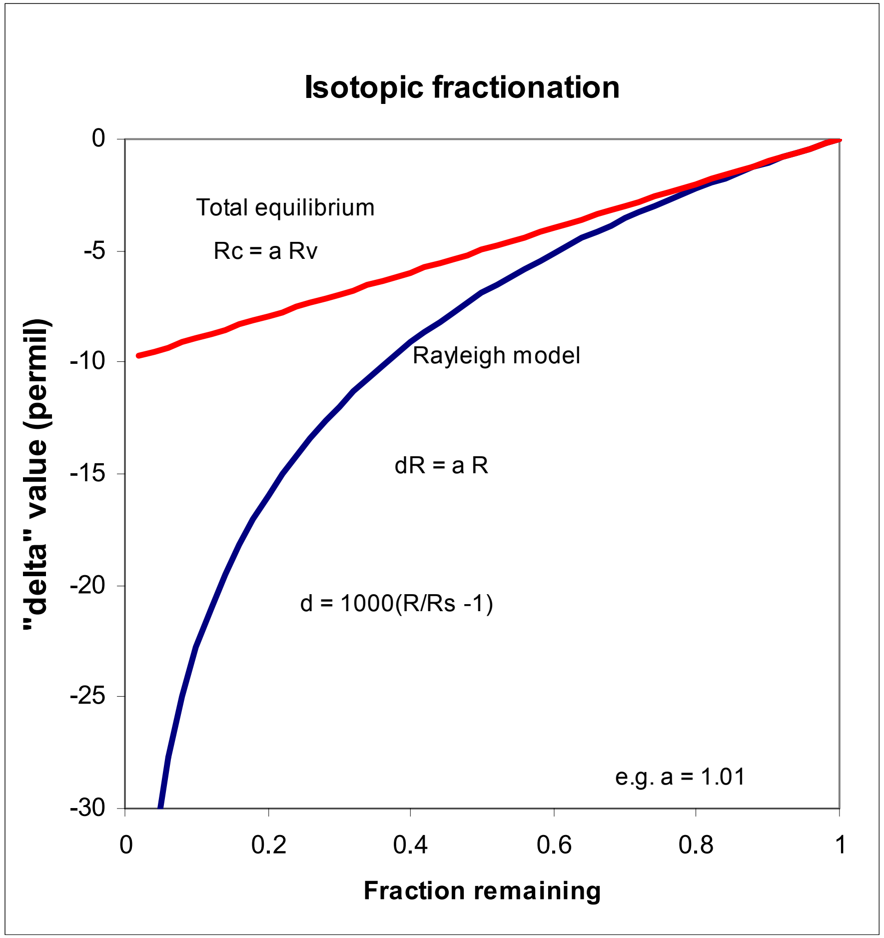
paos

Isotopic fractionation

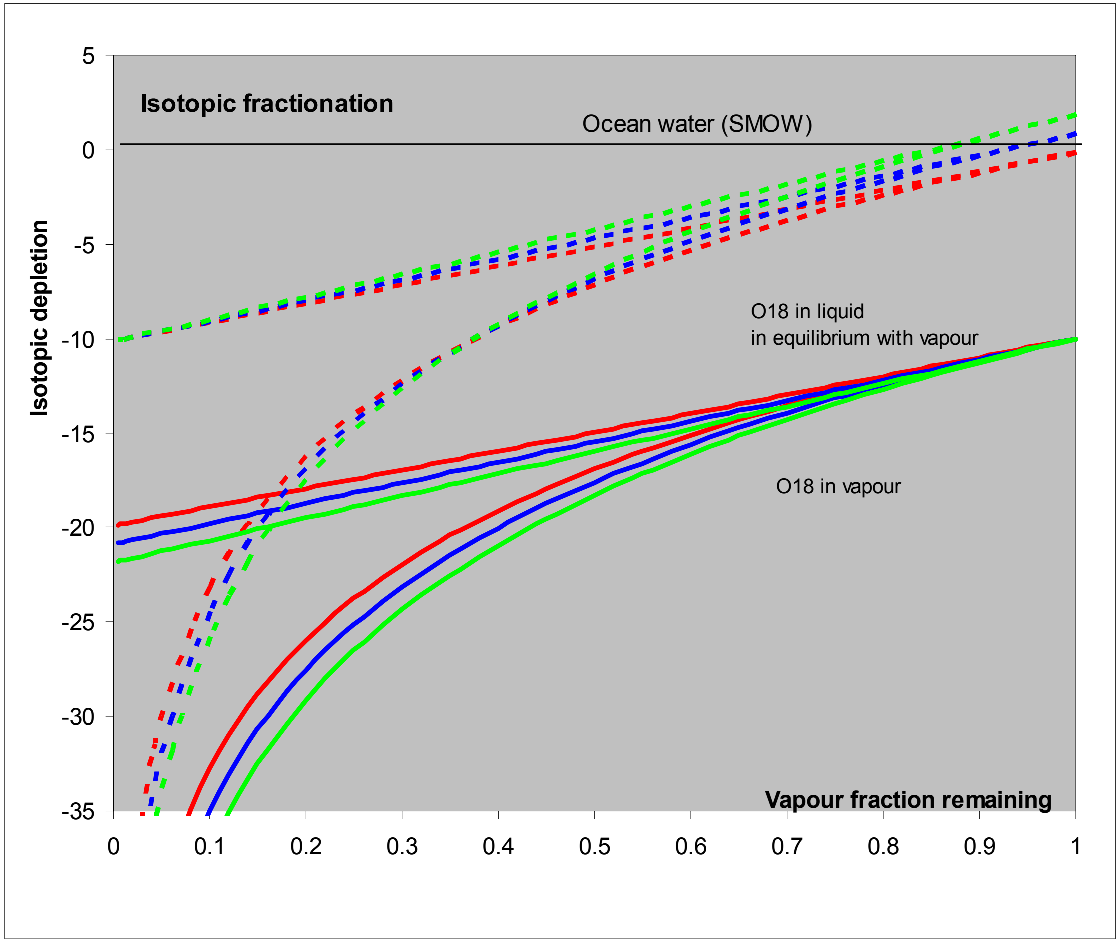
The substituted molecule is slightly heavier, allowing a different partitioning of energy between translational, vibration and rotational states. Isotopic fractionation is a quantum mechanical effect.

Liquids (and solids) have additional vibration states due to intermolecular forces.

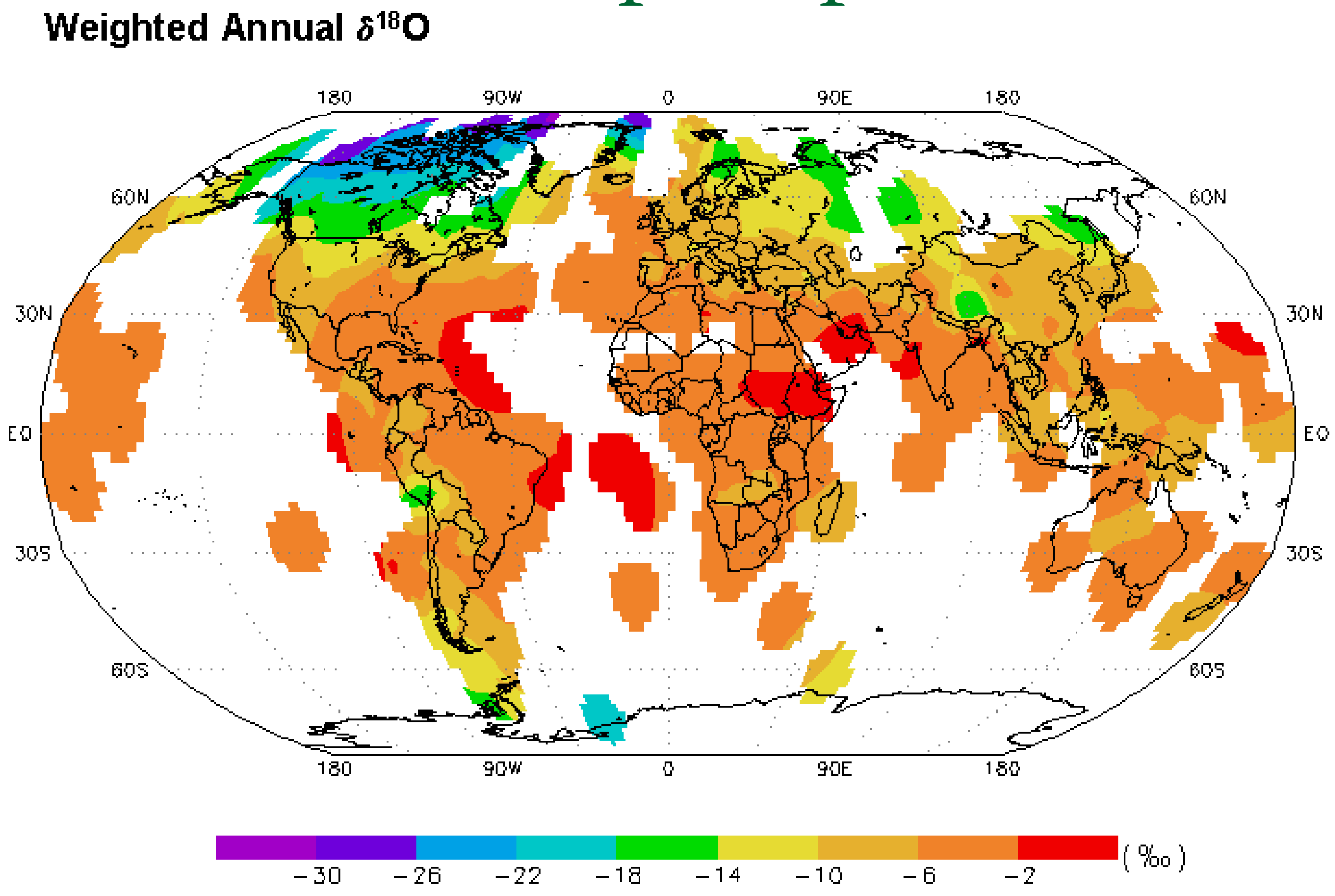
So, for the same energy fewer of the heavy isotopes can be liberated from a liquid surface (at 25°C, 1 percent fewer). The ***liquid is enriched***, the ***vapor is depleted***.



Distillation: vapor and condensate

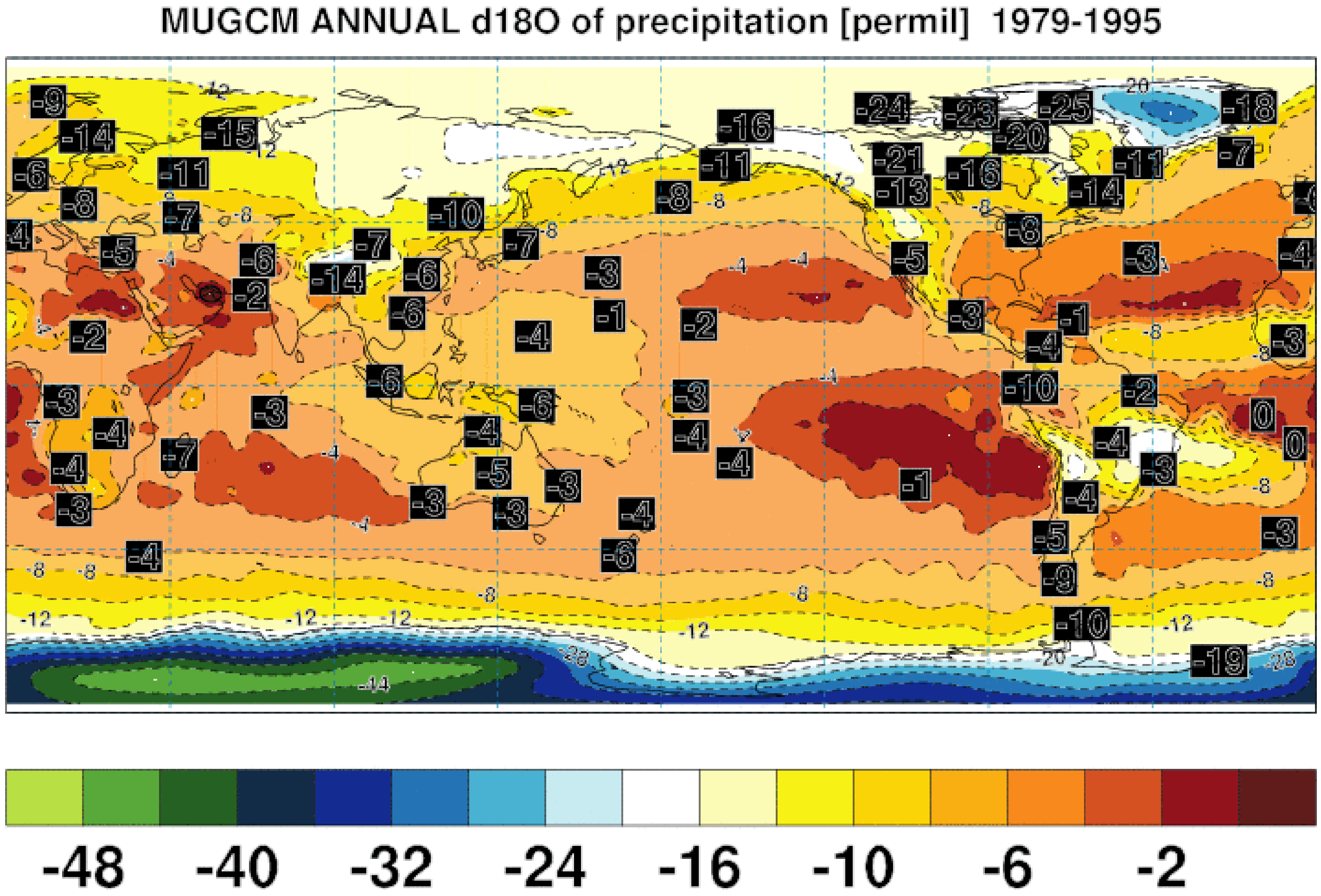


Observed ^{18}O in precipitation



IAEA/WMO Global Network for Isotopes in Precipitation

Modeled ^{18}O in precipitation



Noone and Simmonds, *J. Climate*, 2002

Closer look at Rayleigh distillation

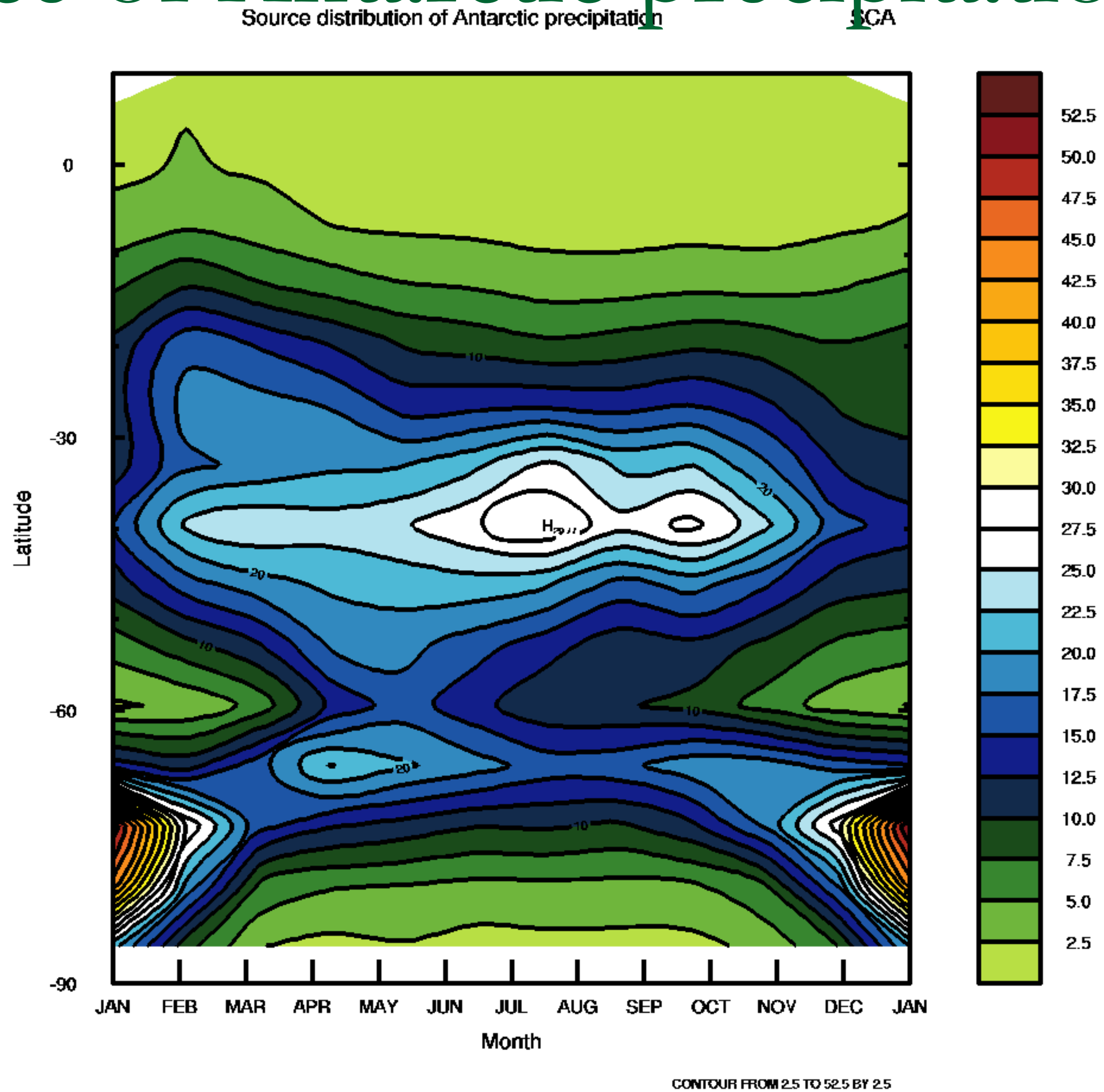
- $R = R_0 F^{\alpha-1}$
  F is the "rainout"
  α is the fractionation factor

- α is a function of temperature
- F depends on large scale circulation and thermal state
- Both have temporal dependence

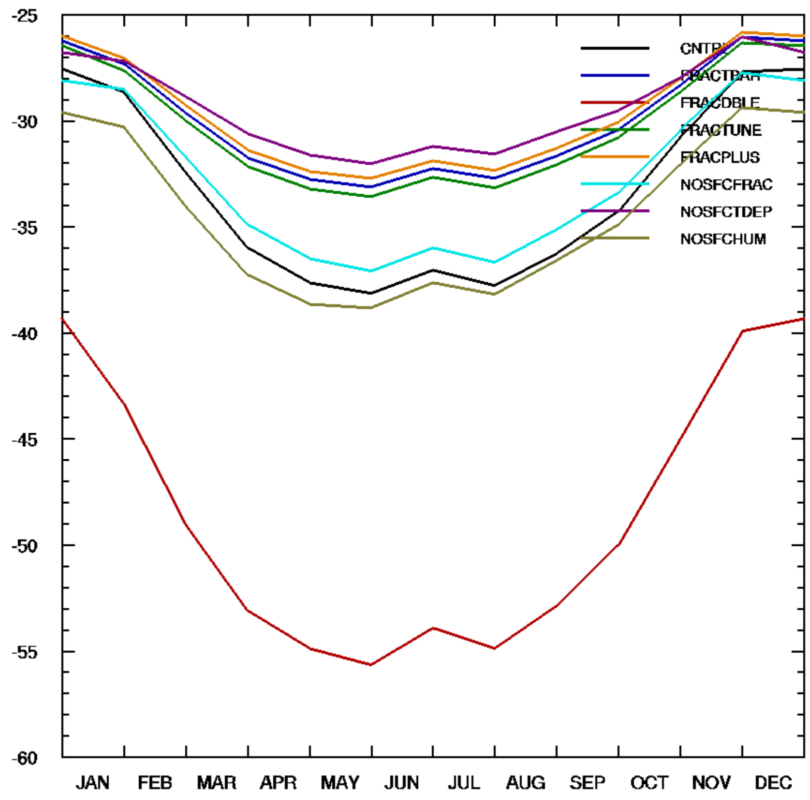
How much of isotope signal in polar snow is due to:

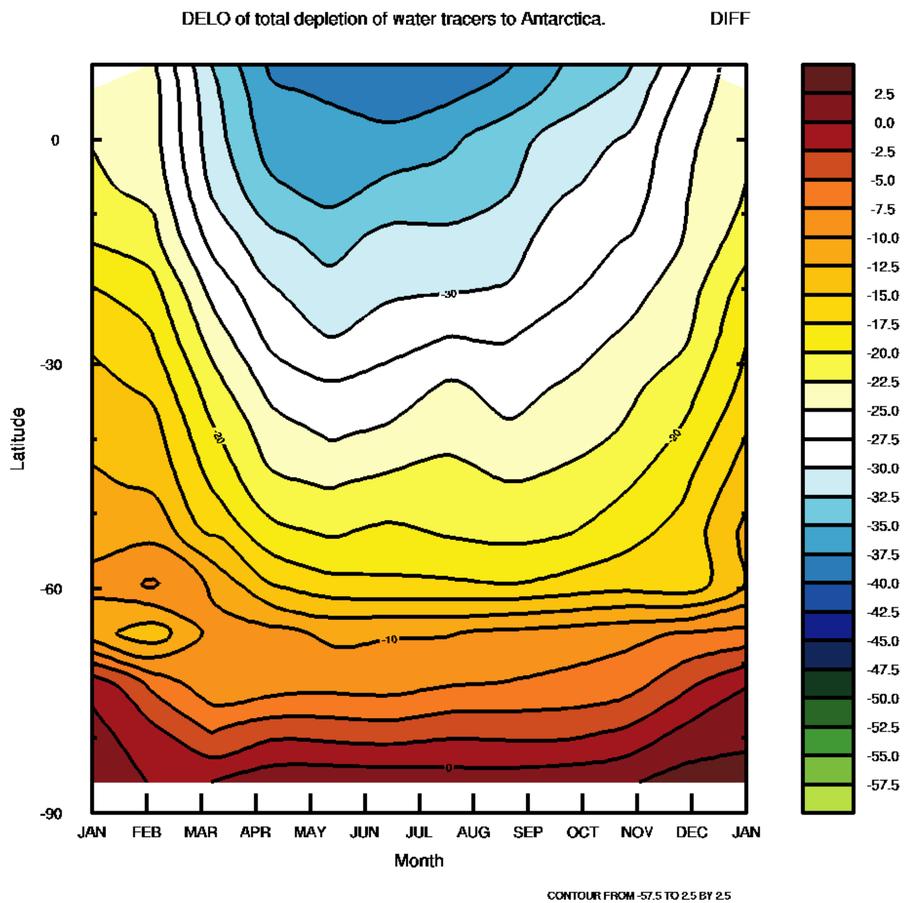
1. change in condensation temperature (α)
2. change in rainout
3. change in F is due to change in source conditions

Source of Antarctic precipitation

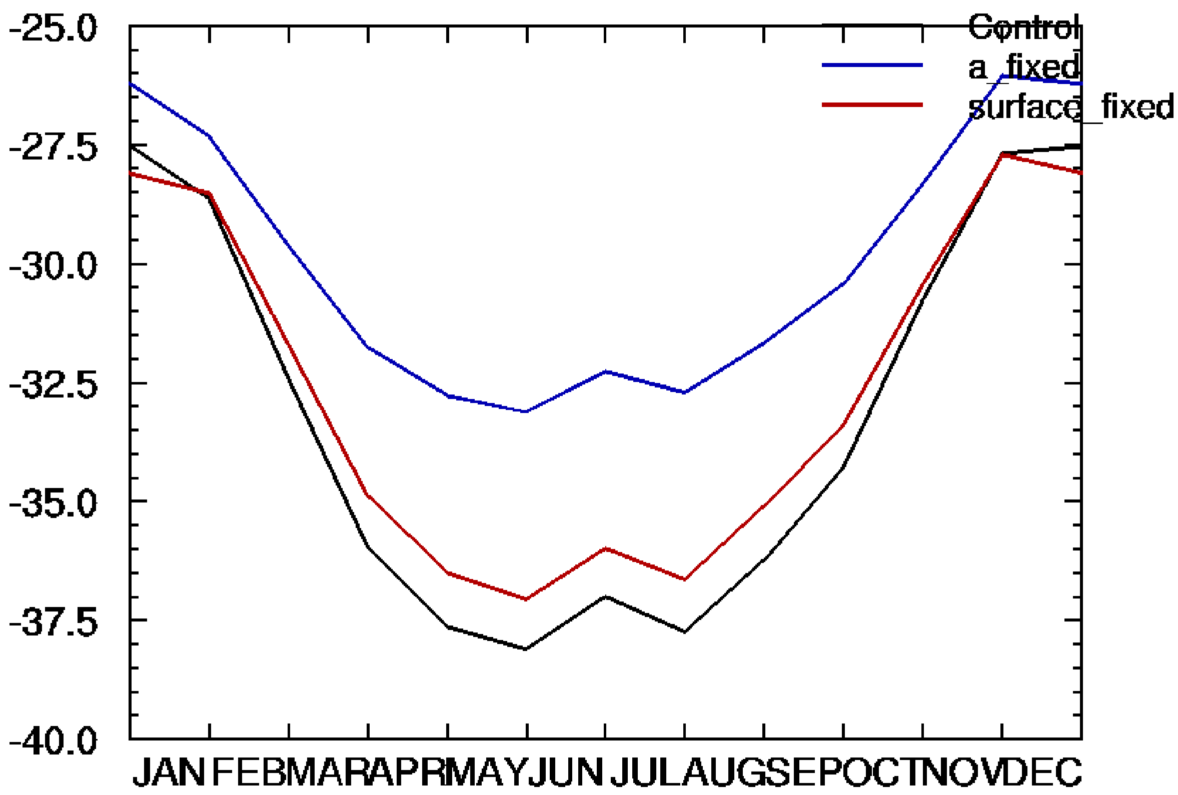


^{18}O at source and depletion en route





Rainout vs condensation temperature



Amplitude of cycle

10.6 permil

Variation in condensation temperature accounts for

3.7 permil

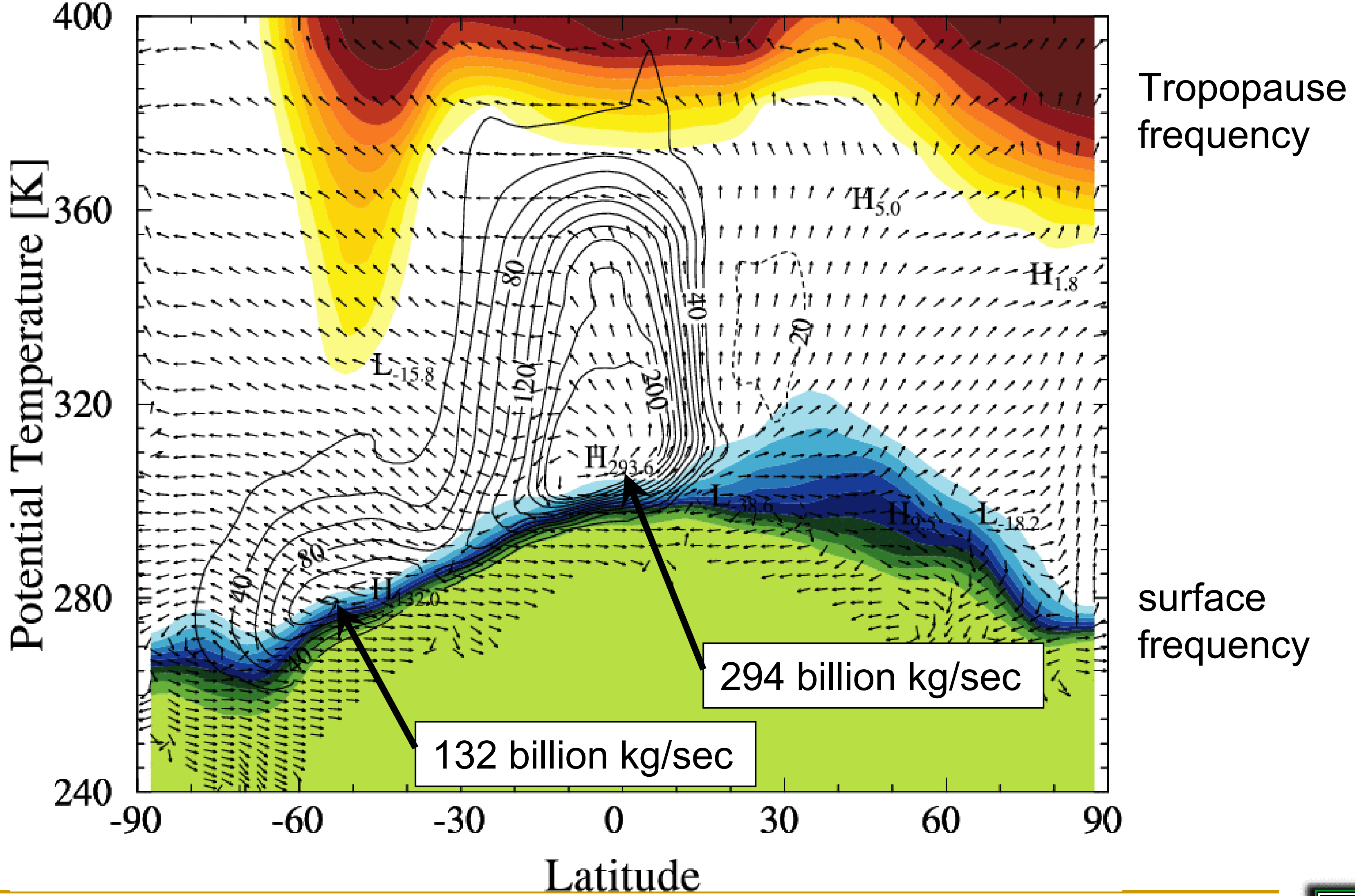
Variation in source temperature

1.7 permil

Variation in rainout

4.6 permil

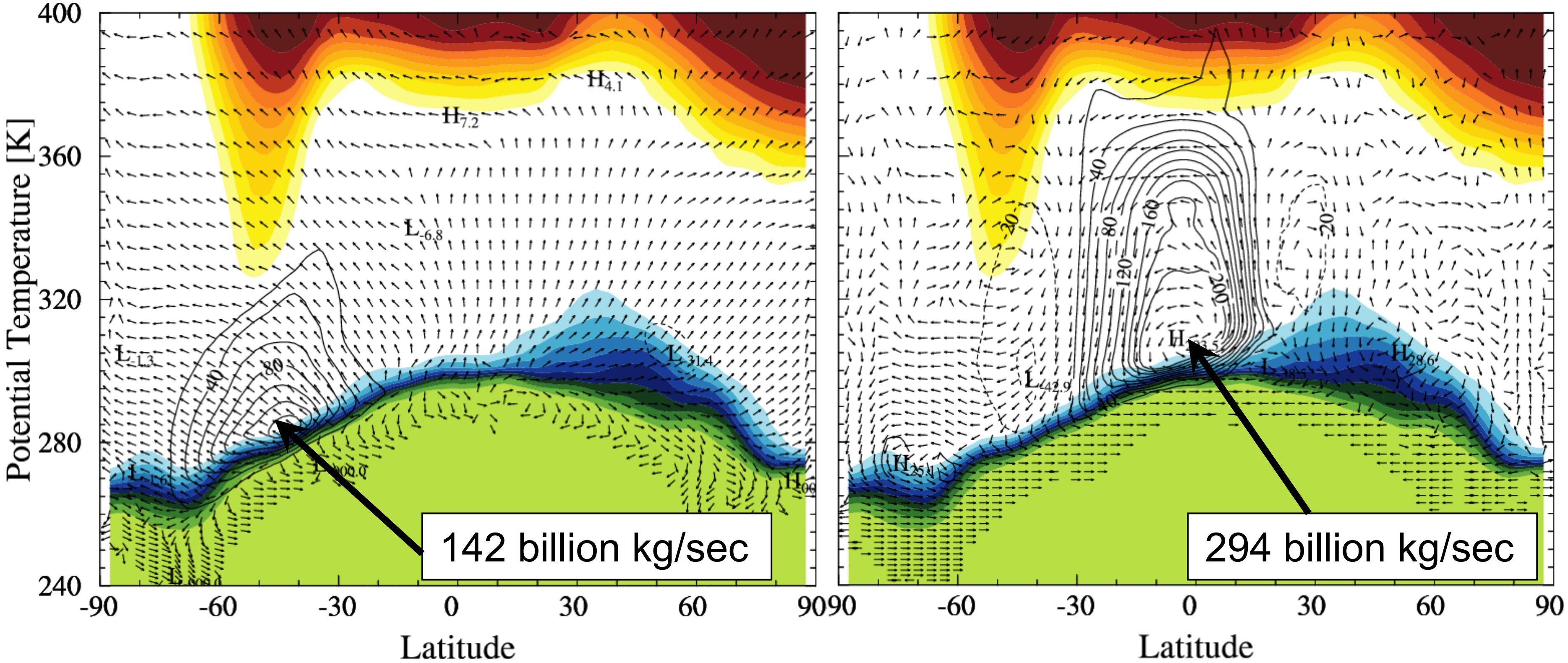
Lagrangian mass circulation (July)



MUGCM, R21L9, 5 years

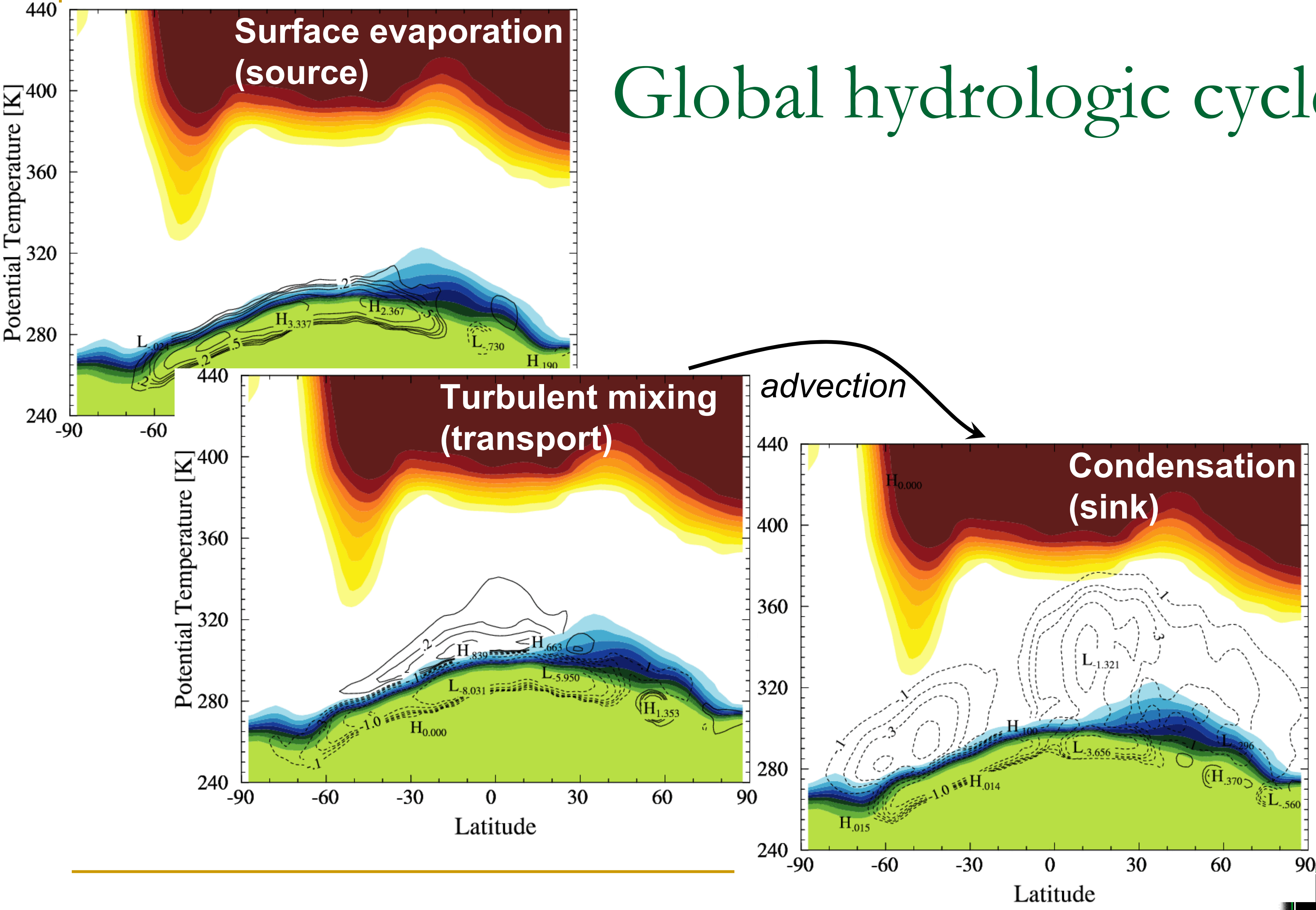
Zonal mean and eddy circulation

Perpetual July simulation (360 day average)

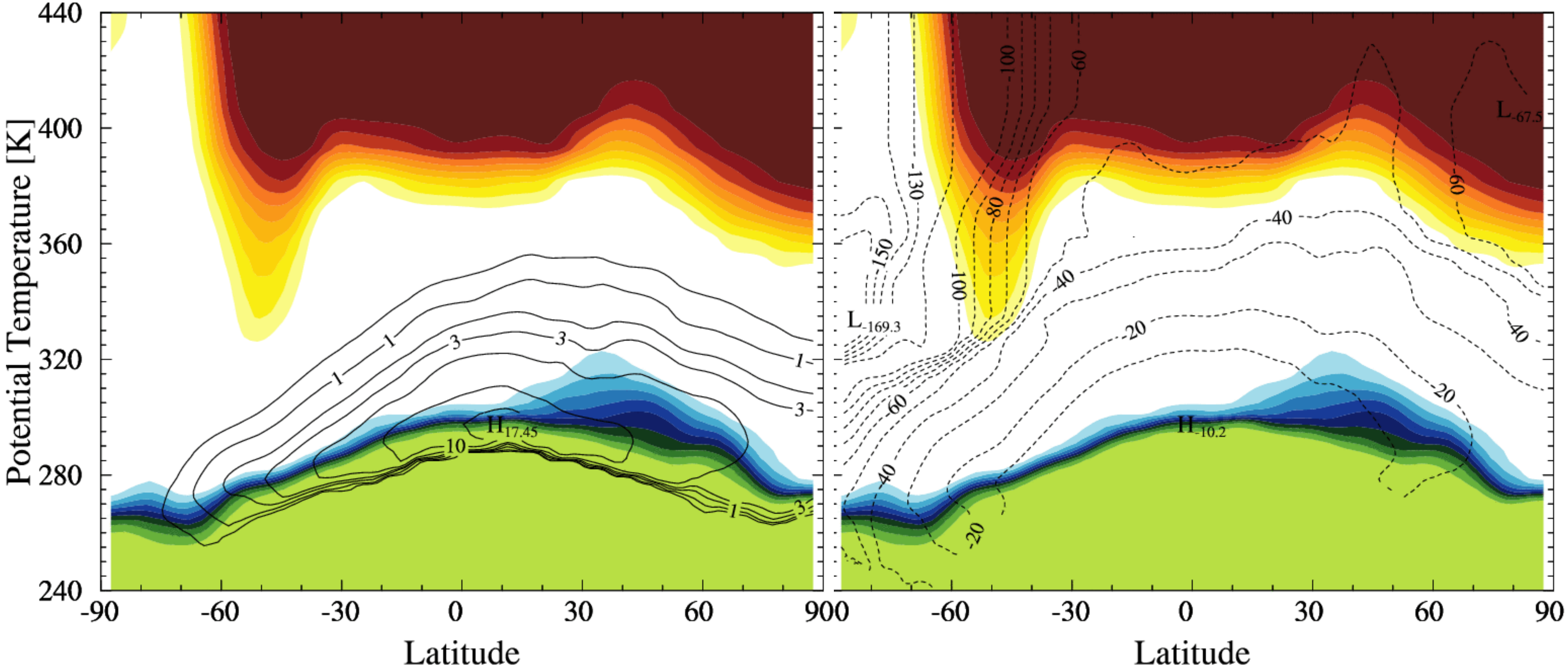


1. Eddies remove air mass from subtropics
2. Equatorward return flow below mean height of surface
3. Summer circulation very different

Global hydrologic cycle



Water vapor and isotopic depletion



Given conditions at “source”, depletion represents competition between:

1. Distillation in isolation (temperature, temperature gradient/condensation)
2. Entrainment of non-depleted water (humidity, stratification/sheer)

Can we deduce changes in circulation from ice core isotope records?

- Changes in transport pathways
- Condensation history (thermal structure)
- Ventilation of boundary layer
- Conditions at evaporation

- Two key quantities are equator to pole temperature gradient, and the vertical thermal stratification

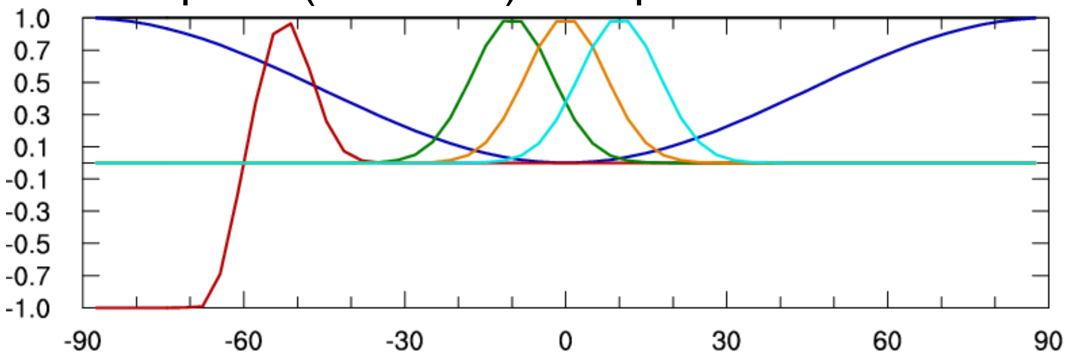
Isotopic depletion and overturning

- Water vapor transported aloft by symmetric overturning in tropics and eddy induced circulation at mid-latitudes
- Water source must be "tropical" PLUS mixture from local PBL (mixing CAN allow total replacement of water mass en-route)
- Variations in overturning associated with moist processes (thus isotopic fractionation) as well as transport

Can isotopes tell us directly about hemispheric circulation?

Can isotopes tell us about the role of water vapor in global energetics?

- GCM experiment to modify different parts of the circulation to quantify effect on polar (Antarctic) isotope.



SST anomalies

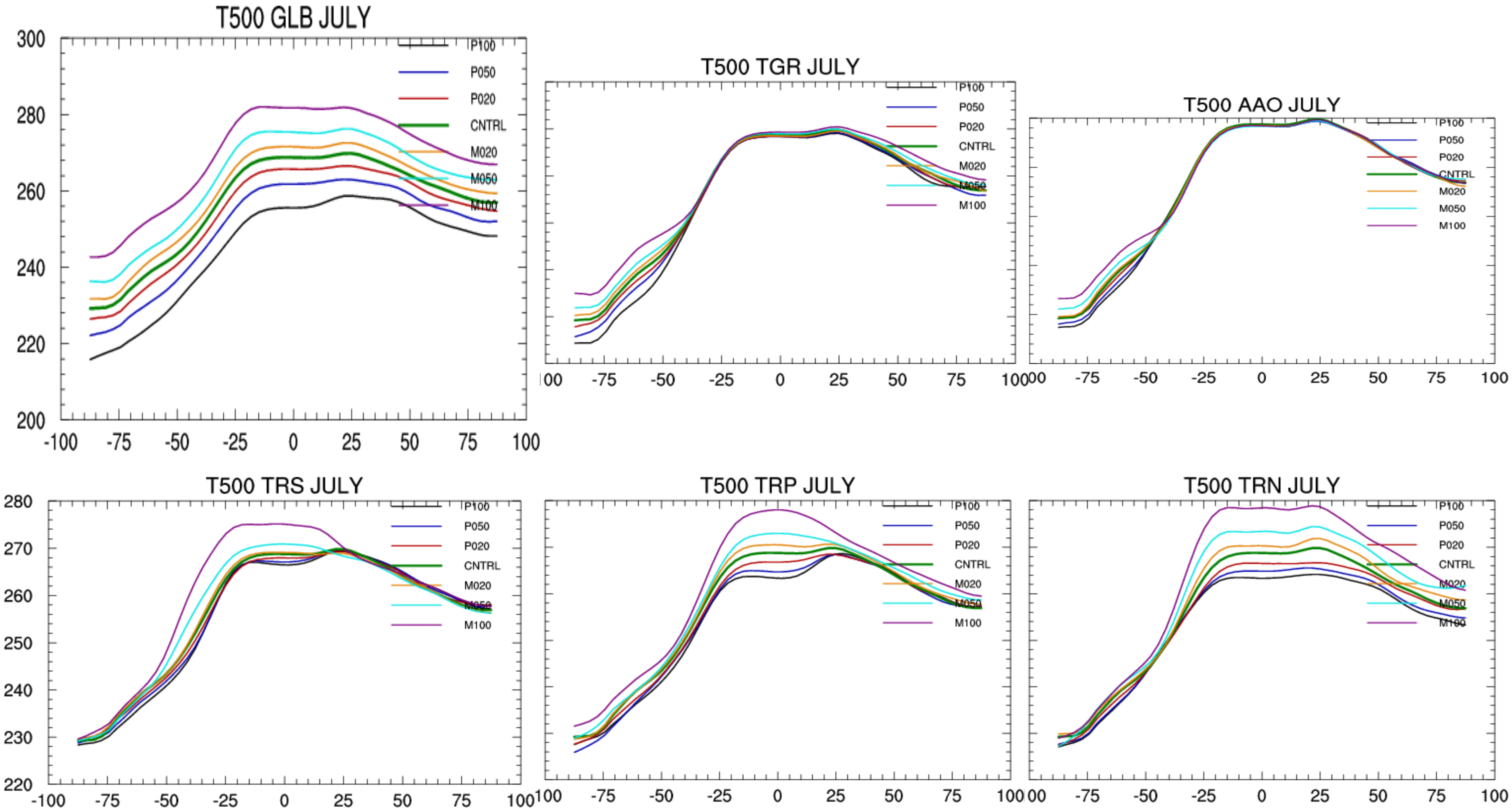
- Global mean
- "J2" temperature gradient
- AAO/storm track shift
- Tropical (10S, 0, 10N)

Each with amplitude ±1, 2, 5, 10

74 GCM simulations – 360 day perpetual July

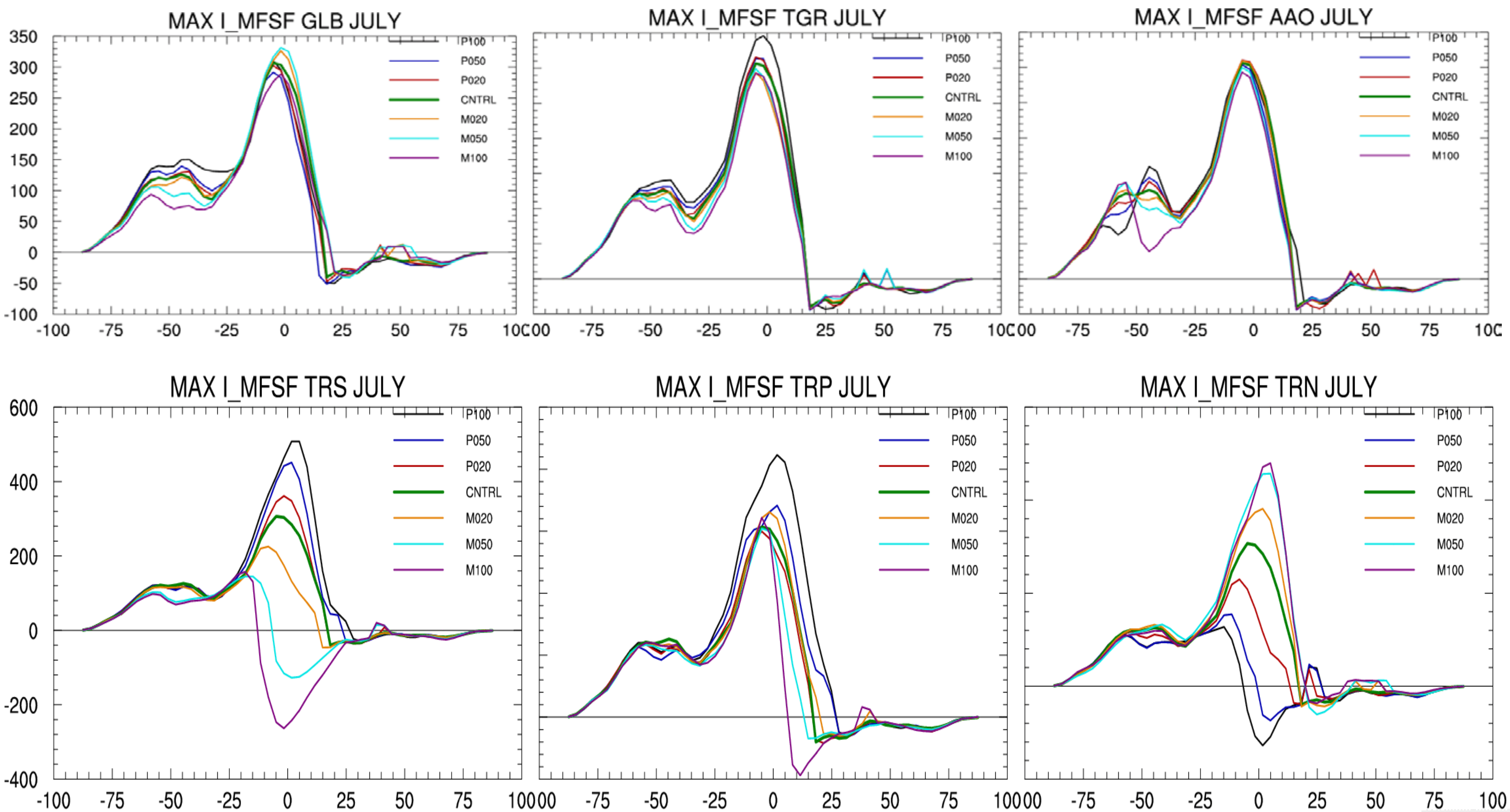
Overview of model responce

500hPa temperature



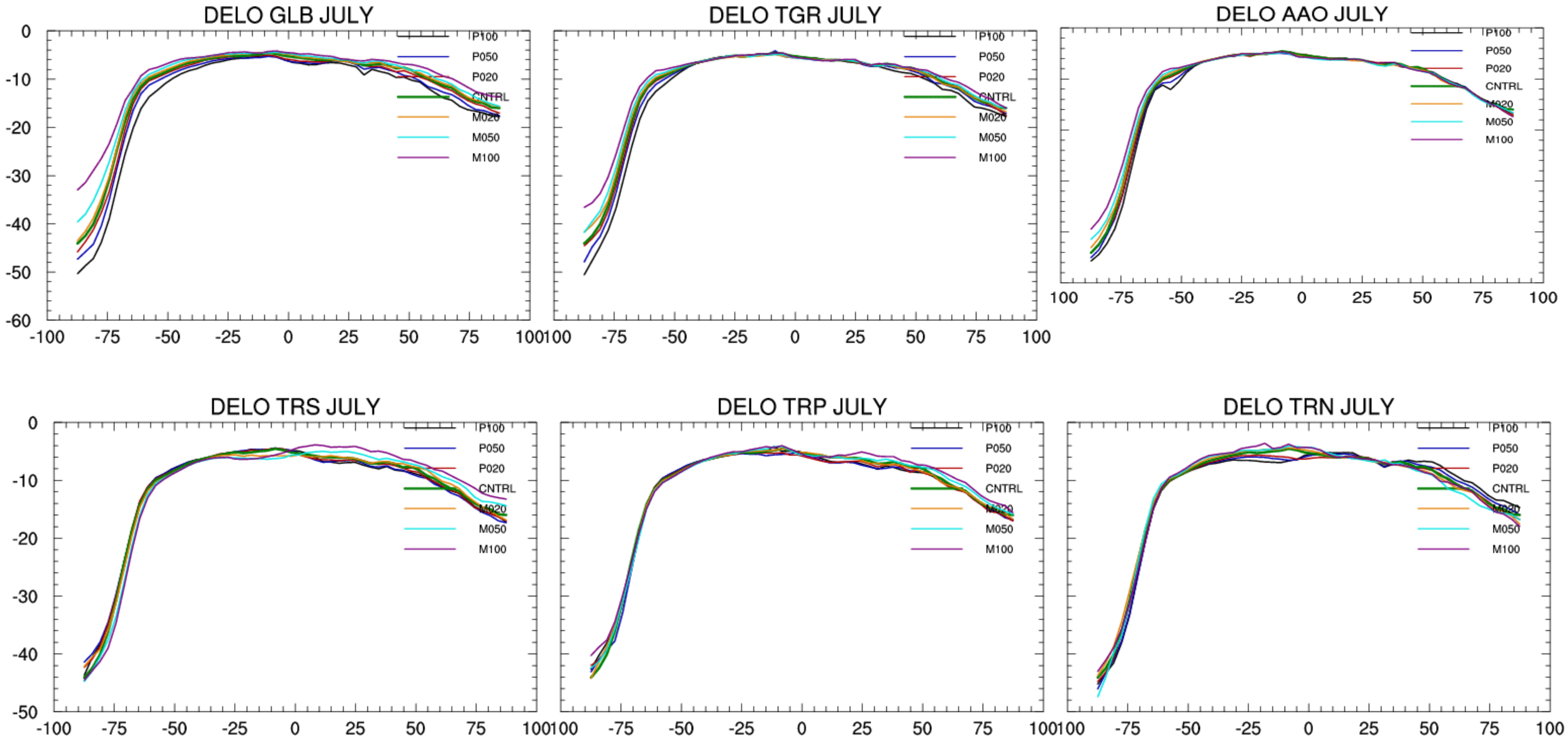
Circulation response

Southward mass transport in poleward moving branch

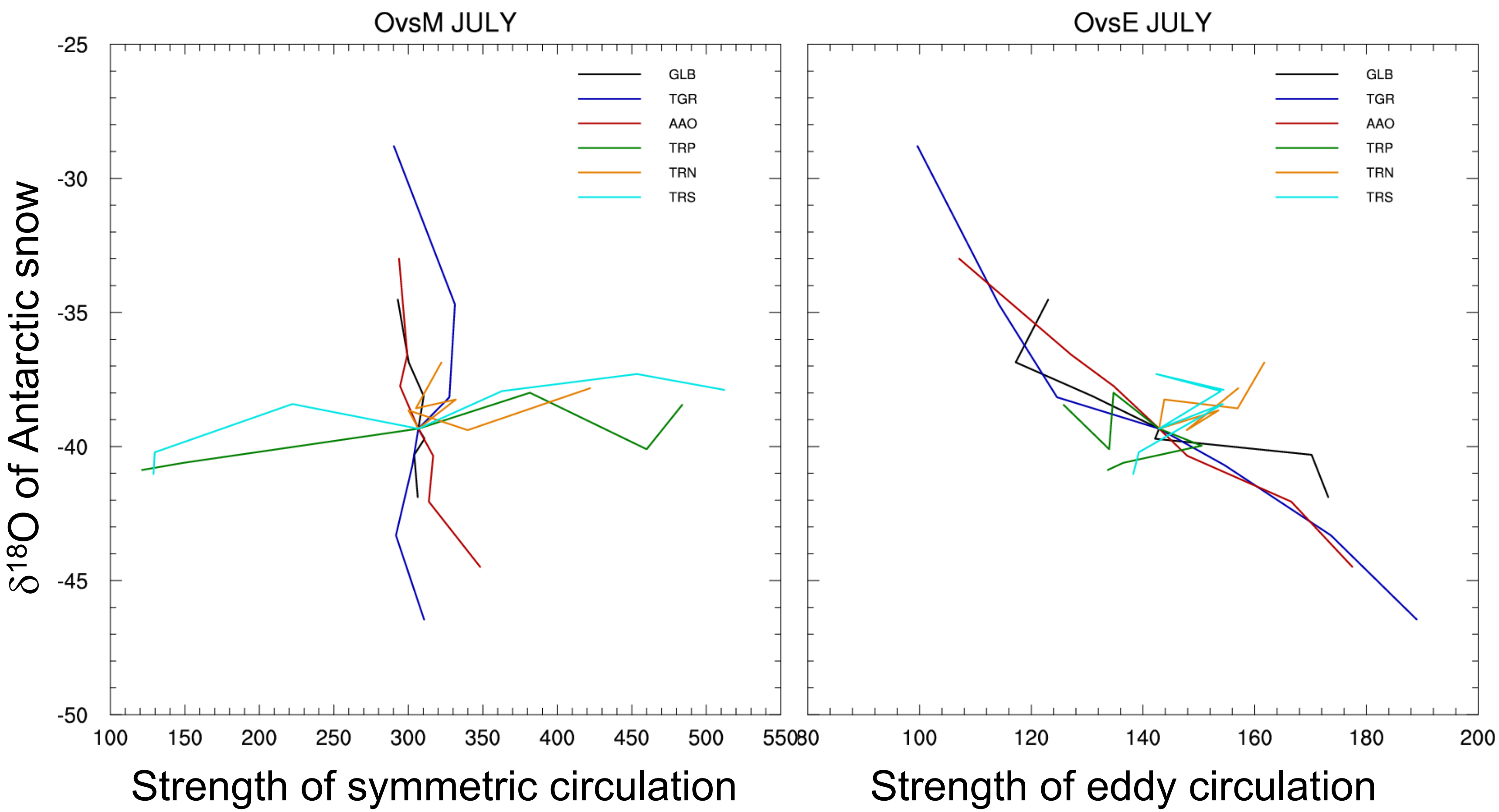


Isotopic response

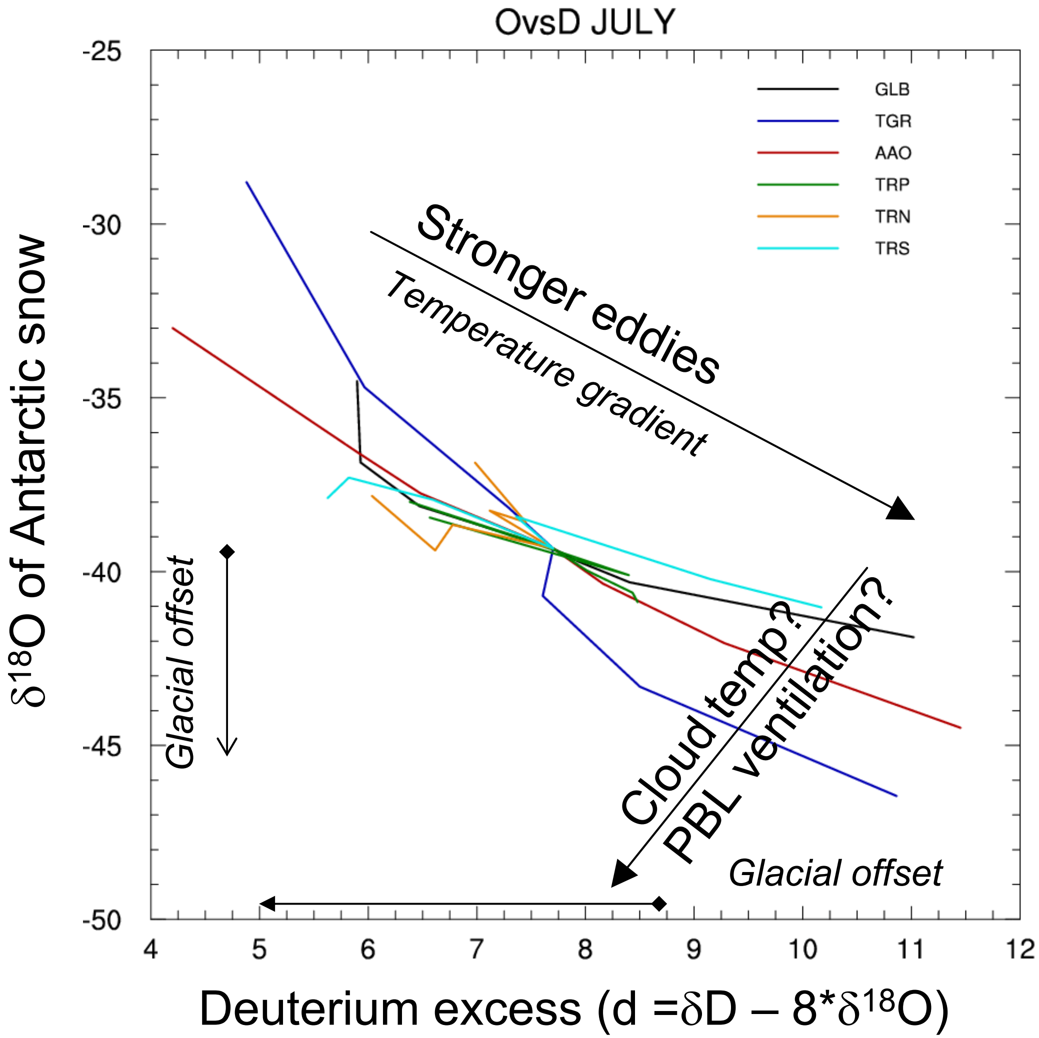
δ18O in precipitation



Isotopic variations due to circulation



A new approach for reconstruction?



Conclusions

- Polar records have remarkable little dependence on tropical circulation (need eddies to remove vapor from tropics)
- Stronger eddies means greater long-range transport and more vigorous distillation
- From these experiments, can not distinguish between amount of distillation, temperature of condensation, and changes in fractionation at source.
- However, interpretation of isotopic records as "temperature" is overly simplistic, and the records are indeed more valuable

Final remarks

- Understand the transport of water, as it is constrained by the general circulation (role of latent sensible heat transport given momentum balance).
- As it is this which imparts the isotopic signal, we need to know this association for proxy interpretation
- Winter greater long-range transport, summer more turbulent mixing in mid/high latitudes.
- Importance of eddy vs symmetric transport seasonal dependence, and changes could lead to unrecognized bias in present proxy interpretations.
- Need to develop more comprehensive (physically based) method for past climate reconstruction to exploit the richness of the isotopic archives