Using measurements and model simulations to understand the cause of the seasonal variation in the oxygen isotopic composition of precipitation along the western US Coast

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Thanks to:

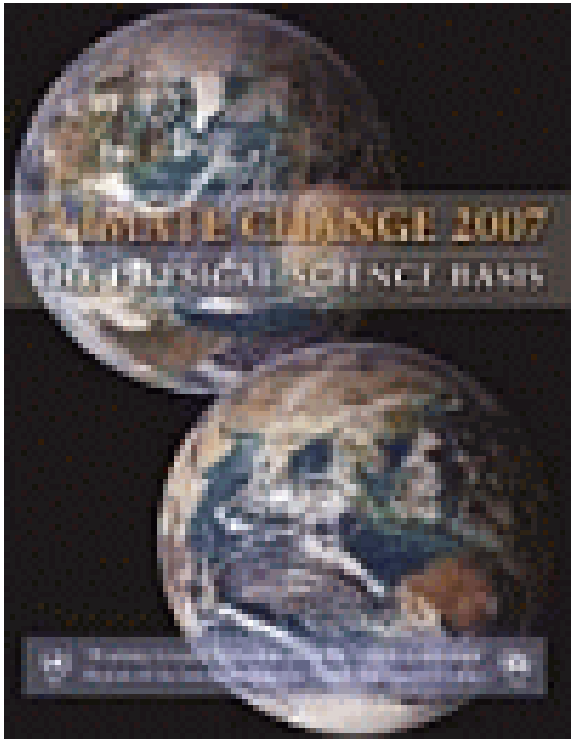
Chris Lehmann, Brenda Riney, Miguel Rincon, Mengfan Zhu, and Lisa Kanner

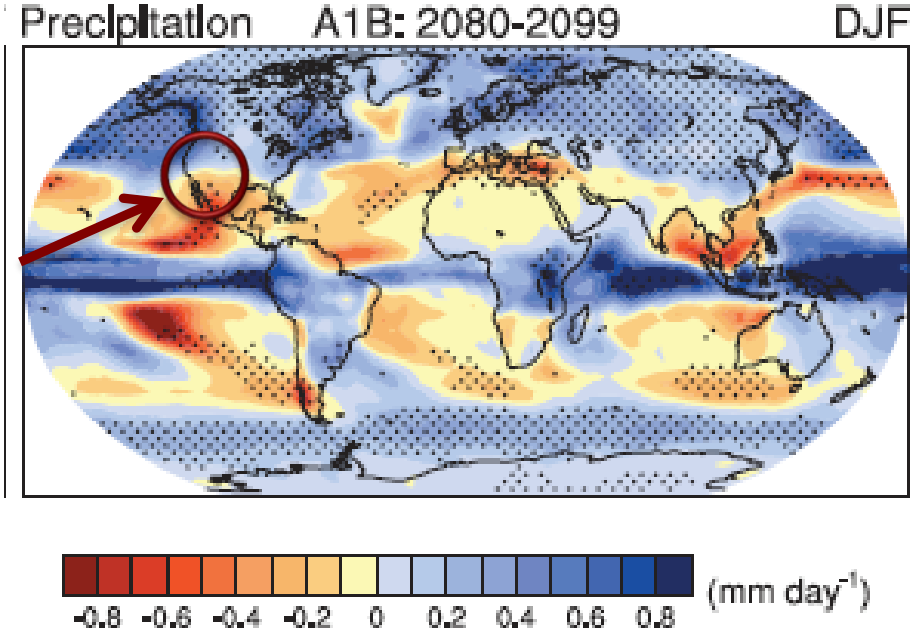
Overview

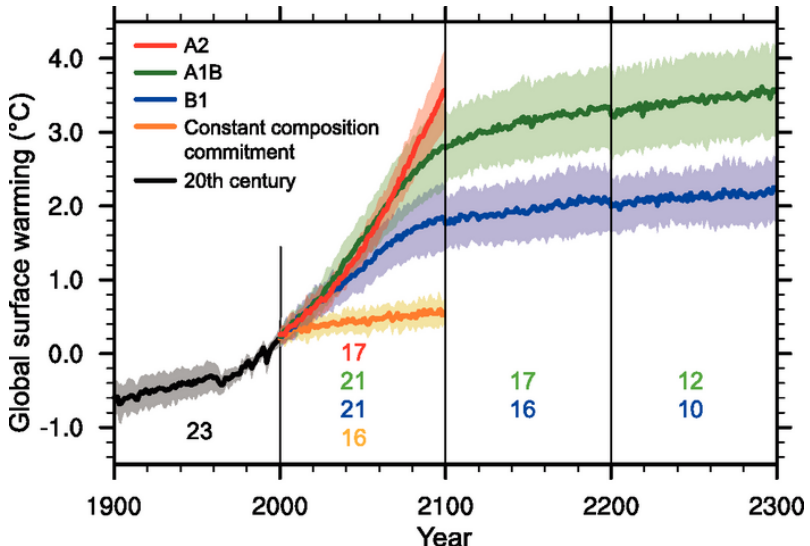
- Motivation
- NADP data
- Atmospheric Model and Experiments
- Tagging experiments
- Conclusion

Motivation

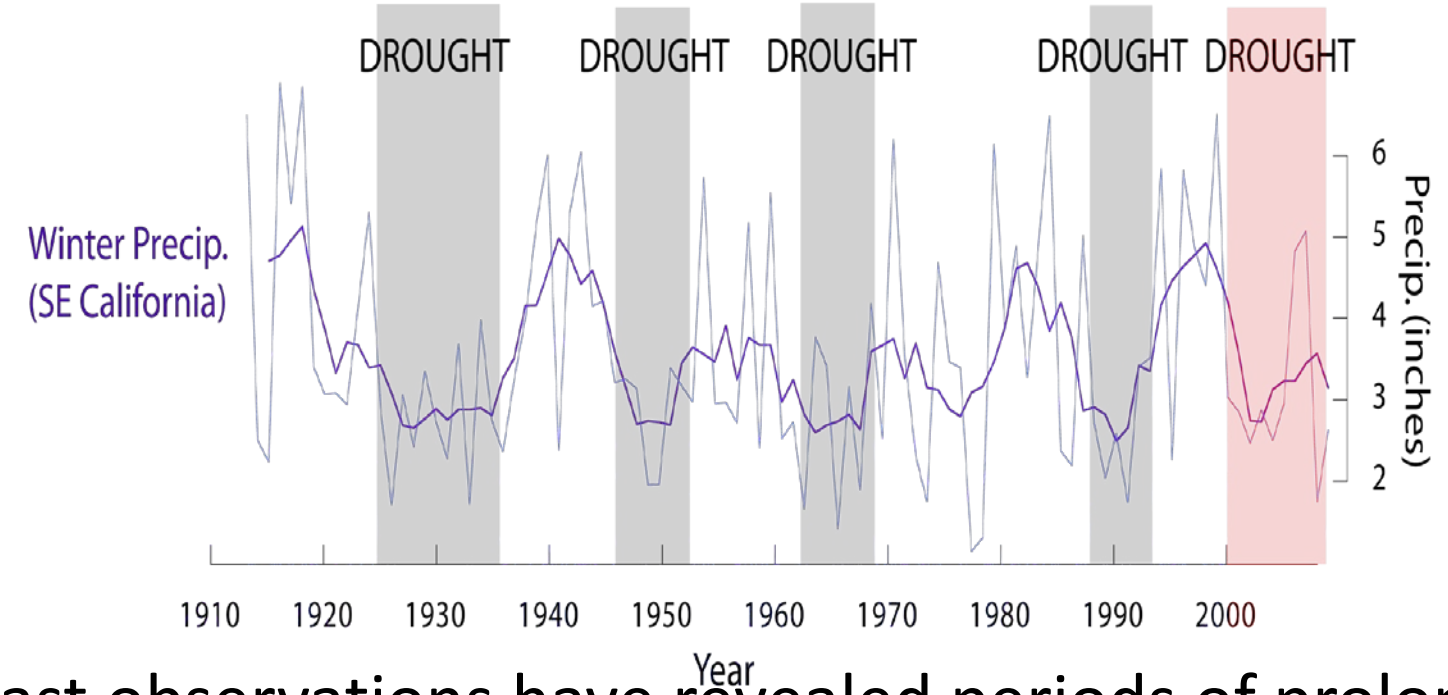
The Intergovernmental Panel on Climate Change reported:
“The most consistent results from the majority of the current generation of models show, for a future warmer climate, a poleward shift of storm tracks in both hemispheres.”







Research Project



- Past observations have revealed periods of prolonged drought in the western US.
- Our research group recently got funded by the NSF for a 5 year project to better understand atmospheric controls on protracted periods of drought in the western US.

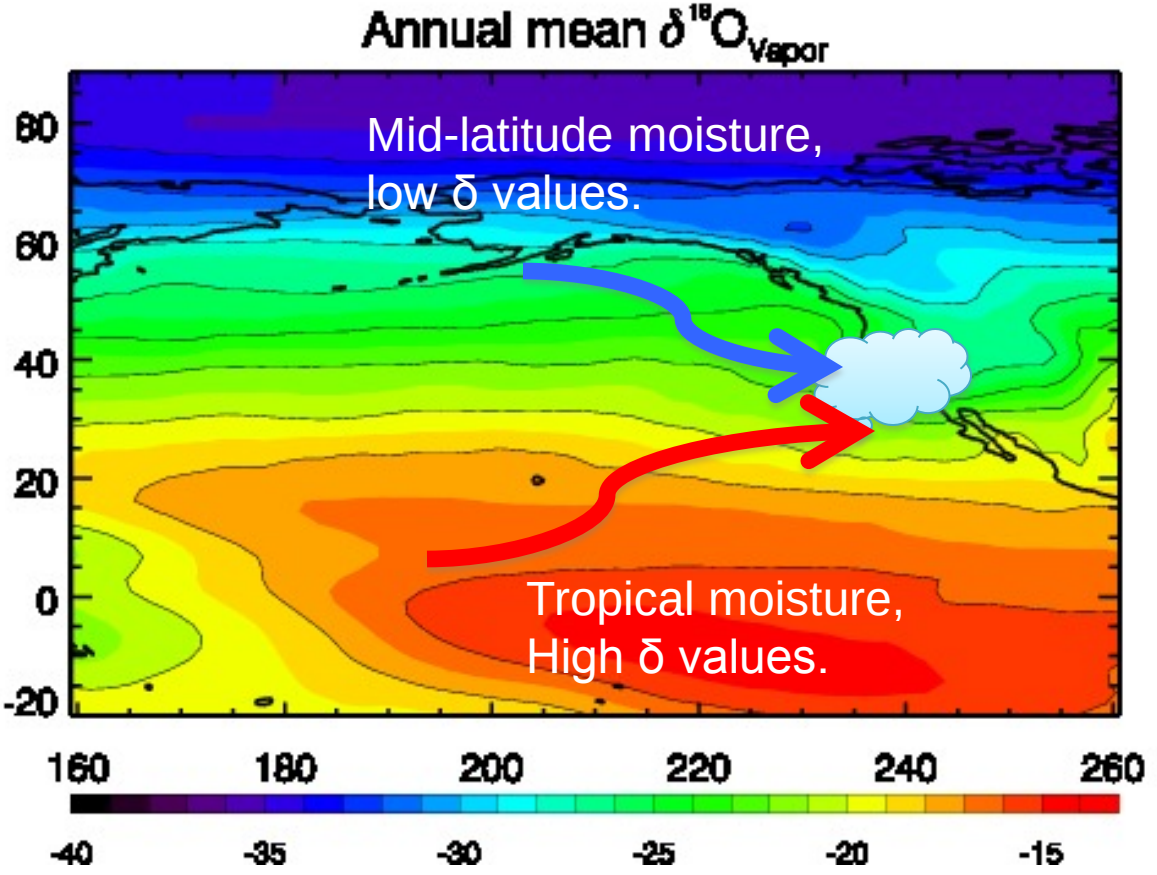
Isotope Tracers

Isotopes in water are believed to trace atmospheric circulation (Berkelhammer et al., 2012)

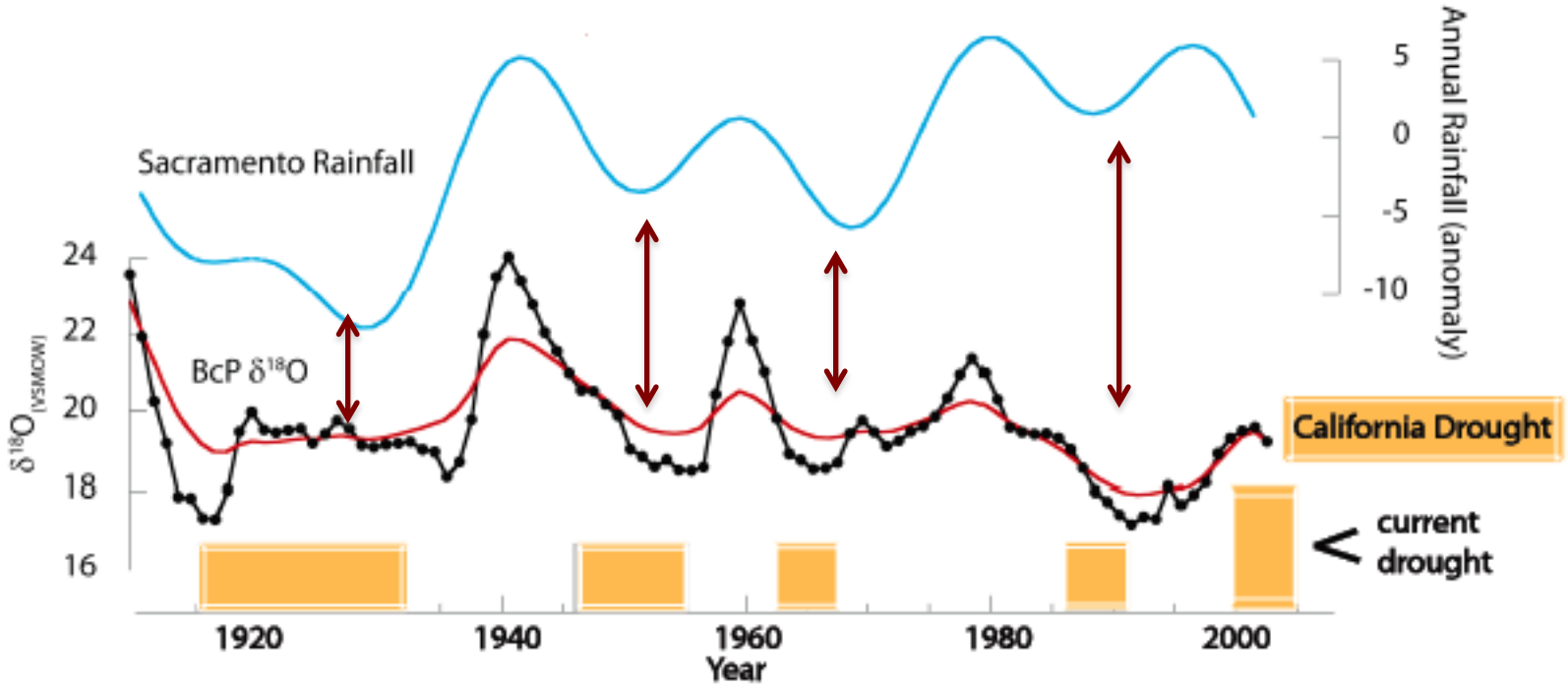
$$R = \frac{H_2{}^{18}O}{H_2{}^{16}O}$$

Heavy to light isotope ratio

$$\delta = \left(\frac{R}{R_{STANDARD}} - 1 \right) \times 1000$$



Previous drought and isotopes



Previous drought coincided with periods of low $\delta^{18}O$ of tree cellulose, which is thought to record precipitation.

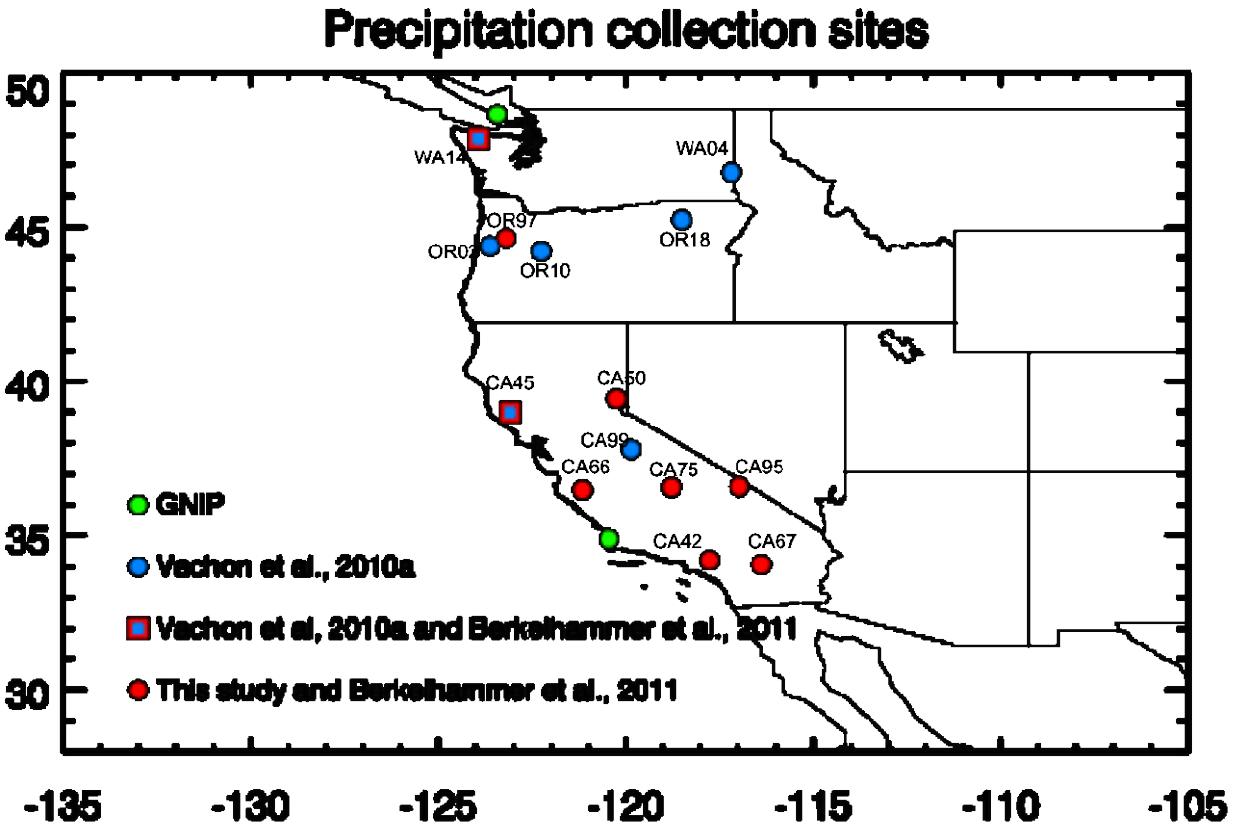
Our initial interpretation of this record was that extended periods of drought were due to a lower fraction of moisture from the tropics.

Stations used to gather data

We gathered data from a total of 16 stations.

2 from GNIP and

14 from NADP



Analyzing NADP samples

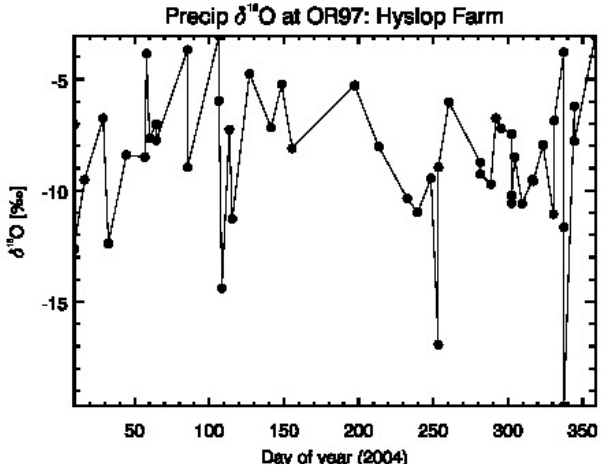
NADP precip samples

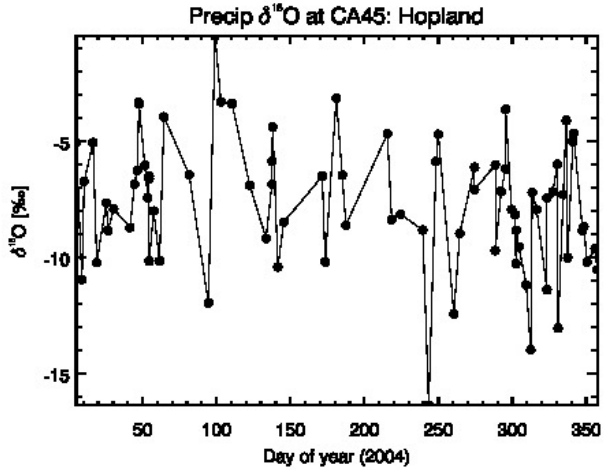
+

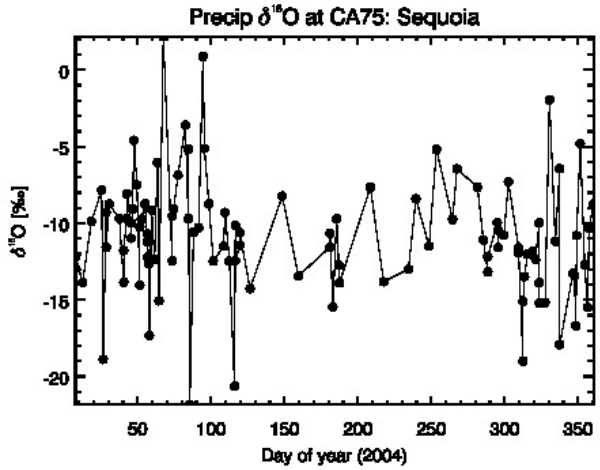
Ring down spectrometer

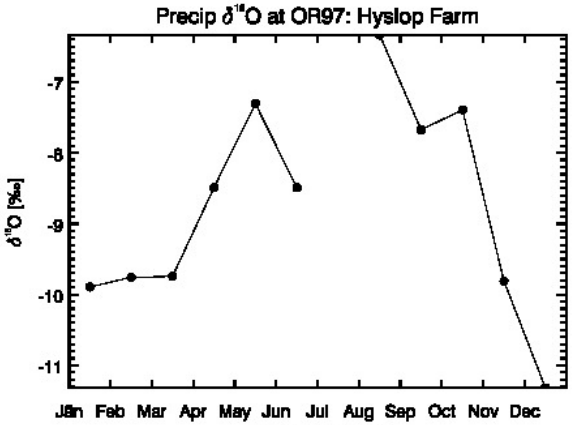
= δ

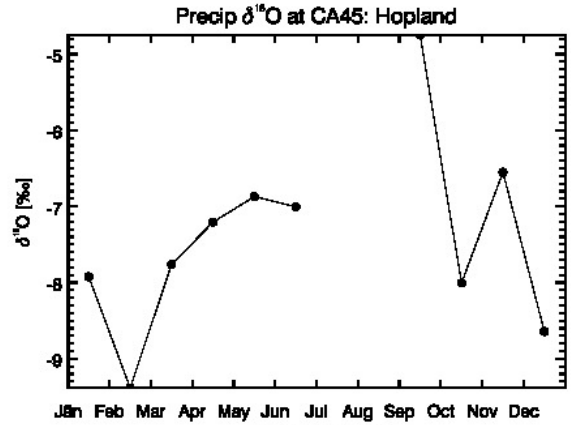
Time Series of isotope data

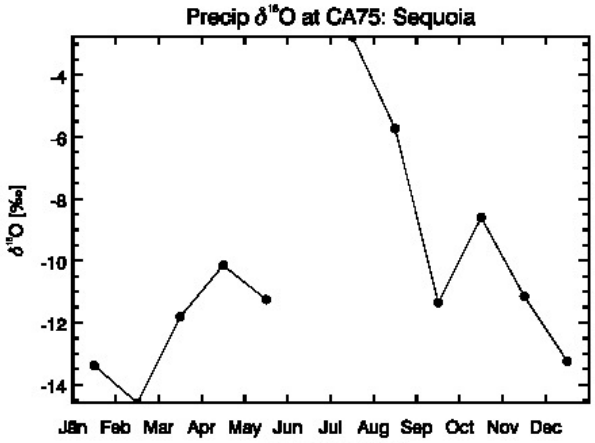




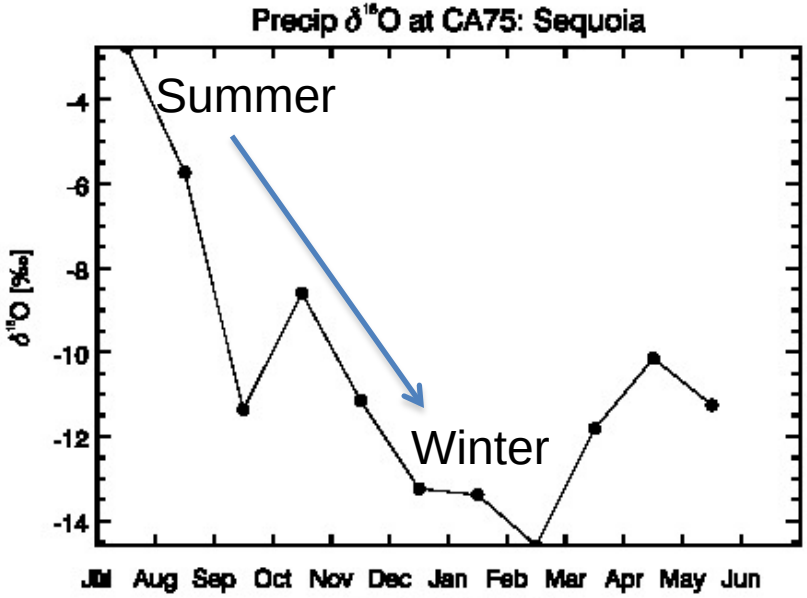


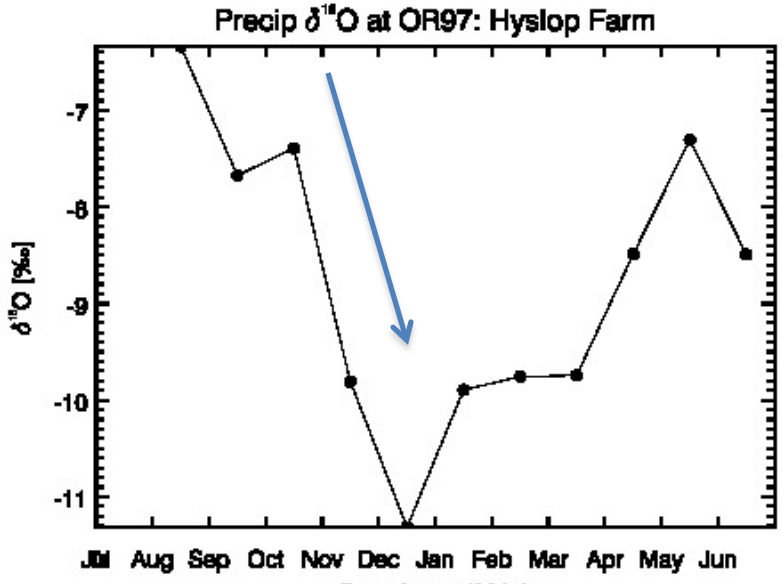






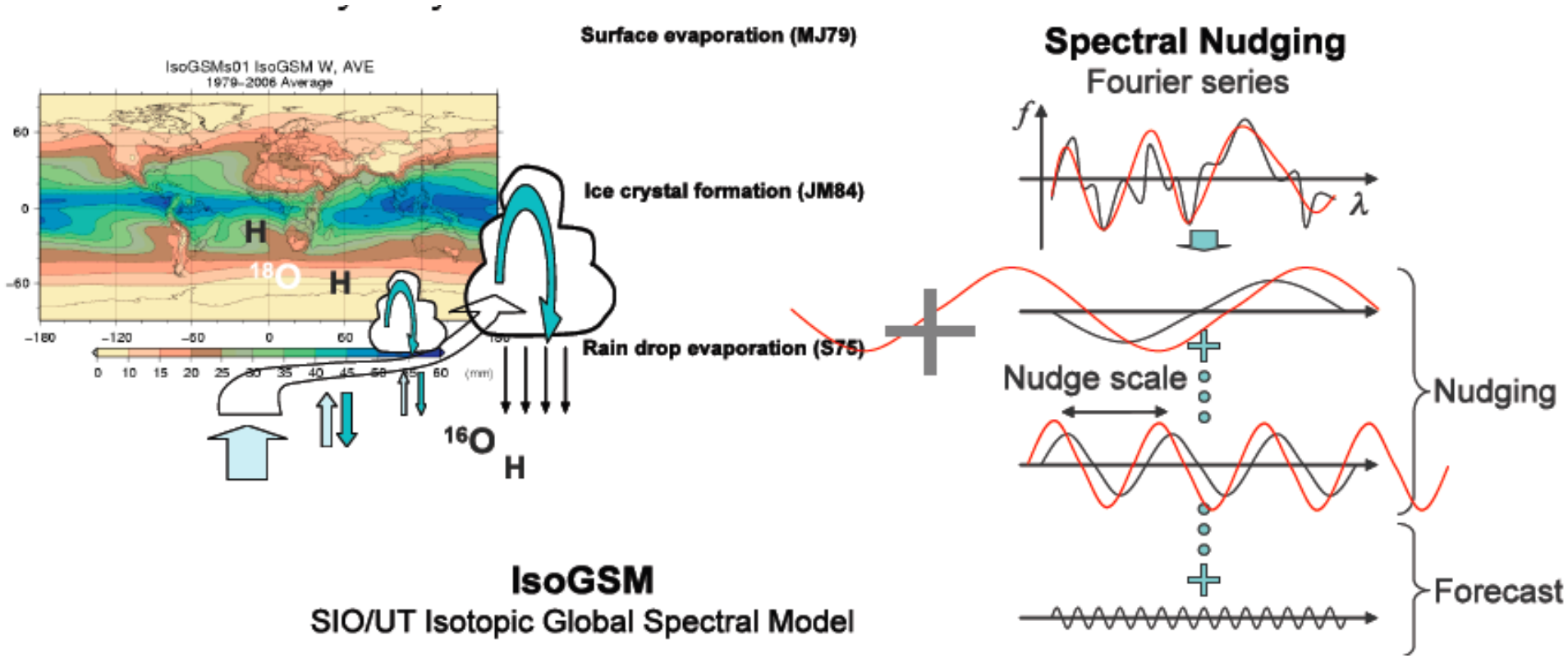
The seasonal drop in isotopes



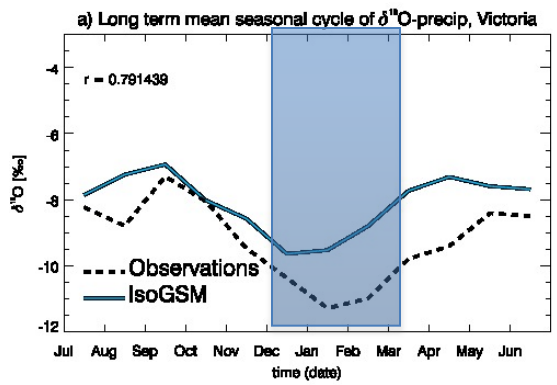


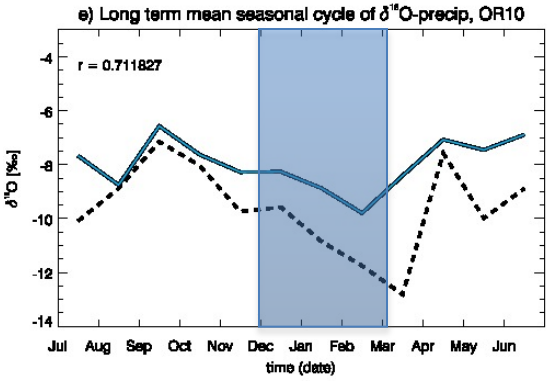
- Observations from the GNIP and NADP reveal a seasonal drop in δ values during the fall/winter.
- What causes this drop?
  - Temperature?
  - Rainout
  - Source changes

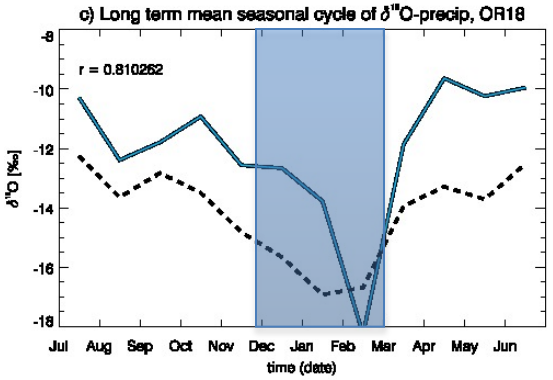
IsoGSM

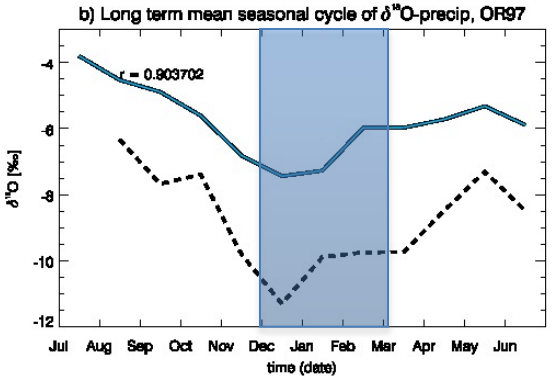


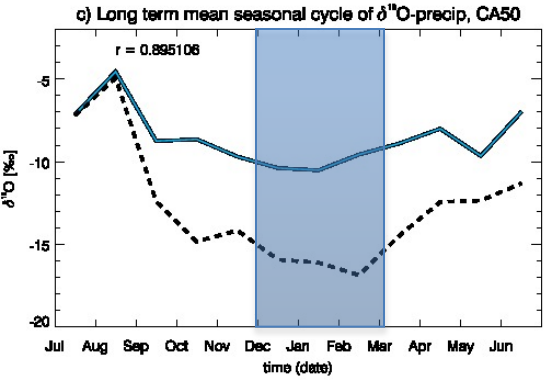
- We have used IsoGSM to answer this question.
- IsoGSM is an atmospheric GCM that is equipped with isotope tracers.
- The model also uses a spectral nudging technique that allows it to be constrained by observed wind fields

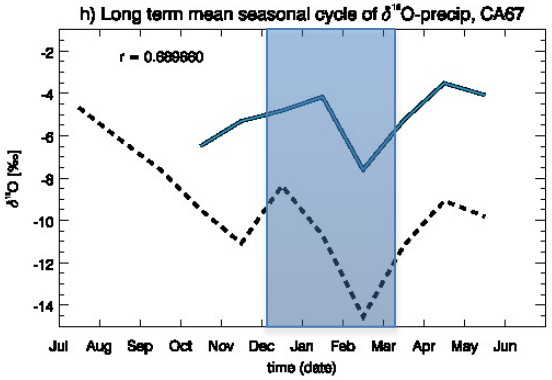


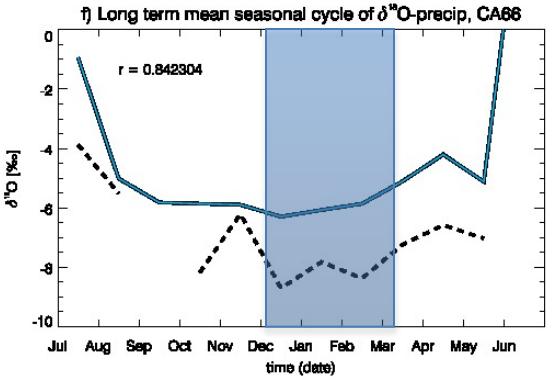










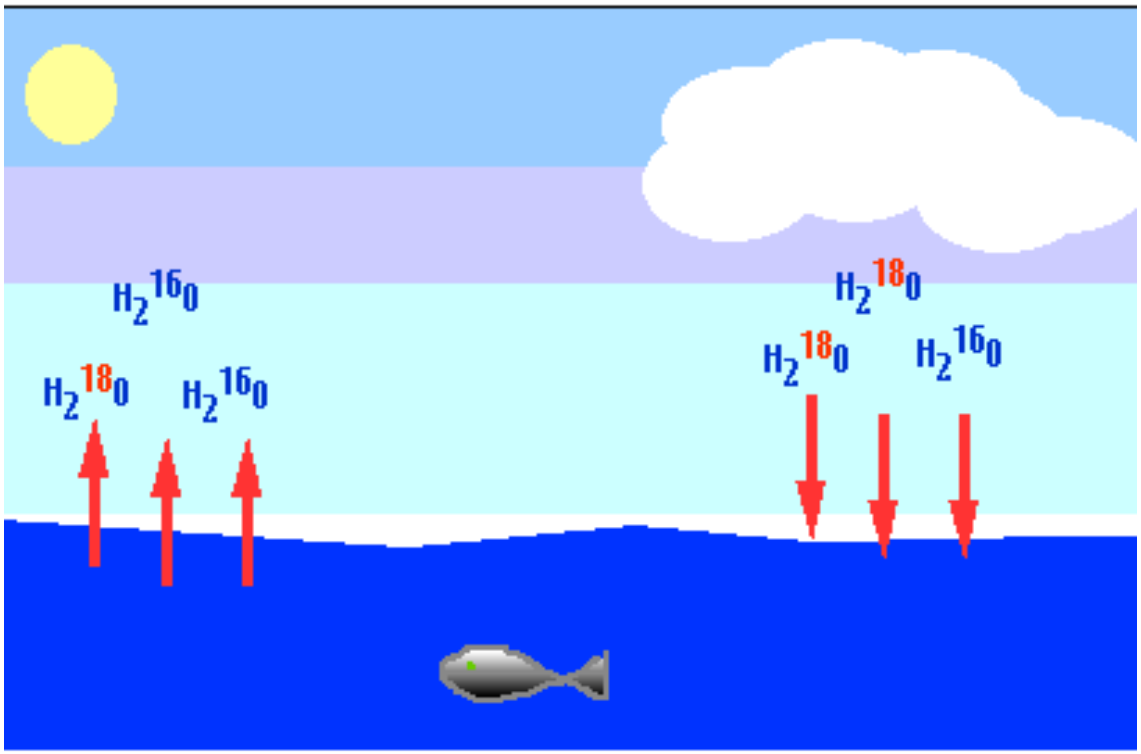


Our data and the model

- Model does reasonably well at many locations
- IsoGSM captures winter drop in δ values.

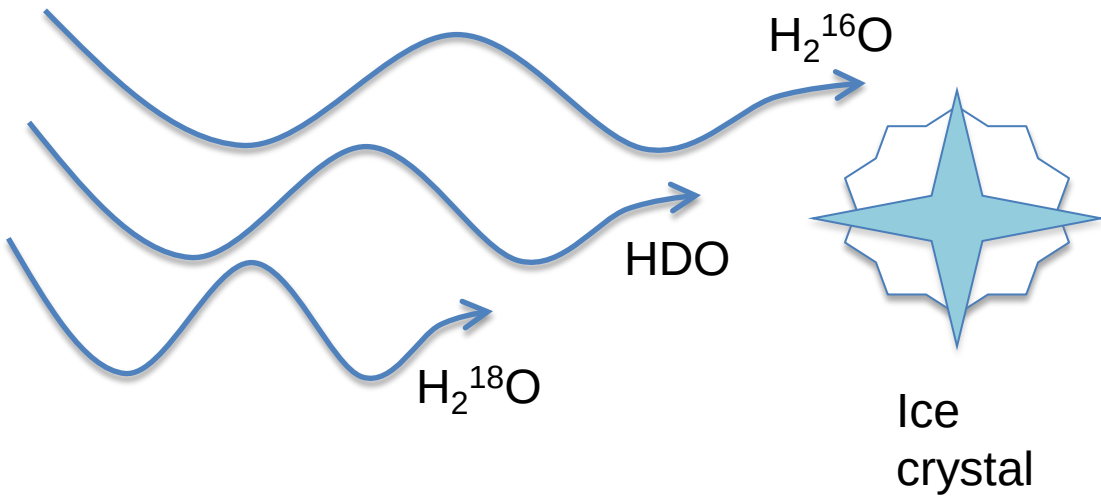
Equilibrium fractionation of isotopes

- Lighter isotopes are preferentially evaporated from the ocean.
- Heavier isotopes are preferentially condensed in the atmosphere.
- These are both temperature dependent.



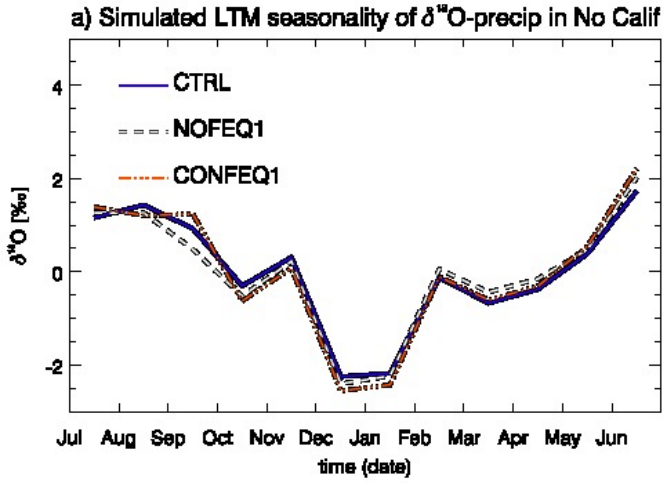
Kinetic fractionation of isotopes

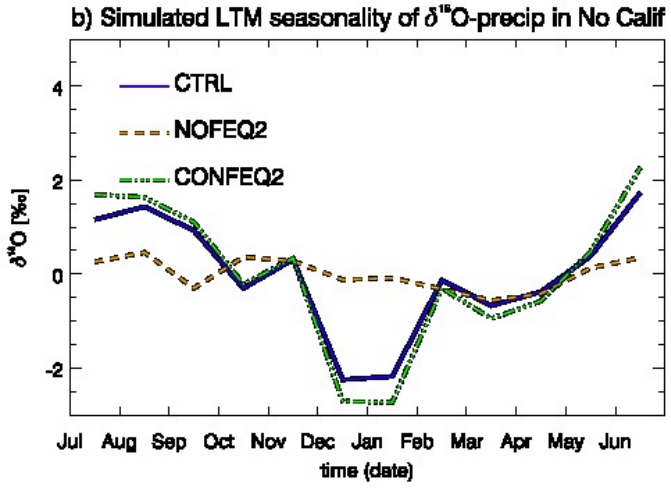
- Differences in molecular diffusion rates cause kinetic fractionation.
- This occurs for:
  - Ocean evaporation
  - Raindrop evaporation
  - Vapor deposition onto ice crystals

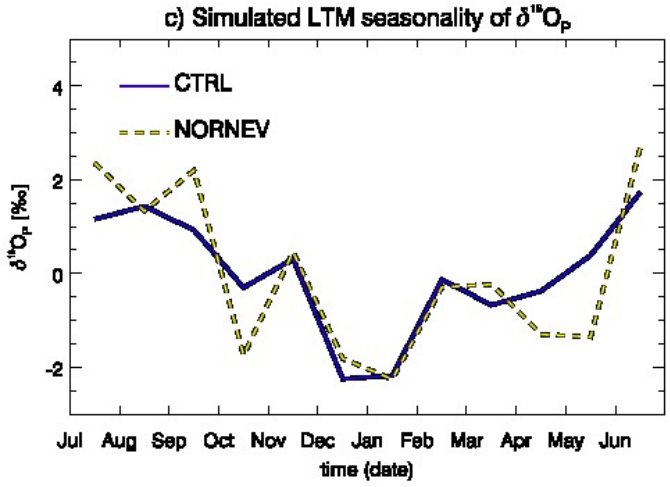


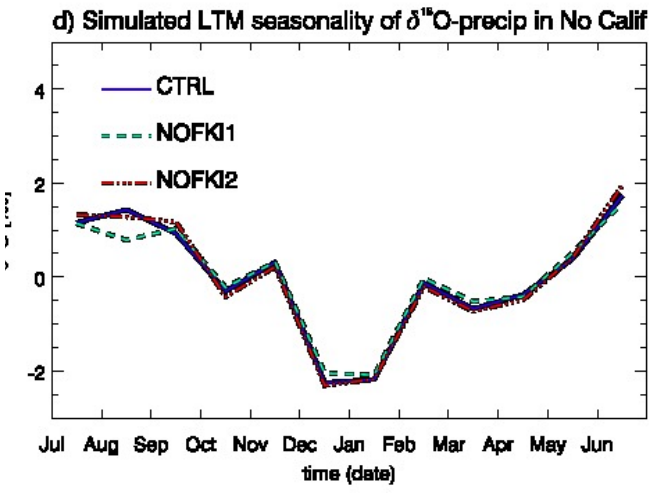
We conducted sensitivity experiments that individually removed these fractionation factors in the model.

Results of sensitivity experiments



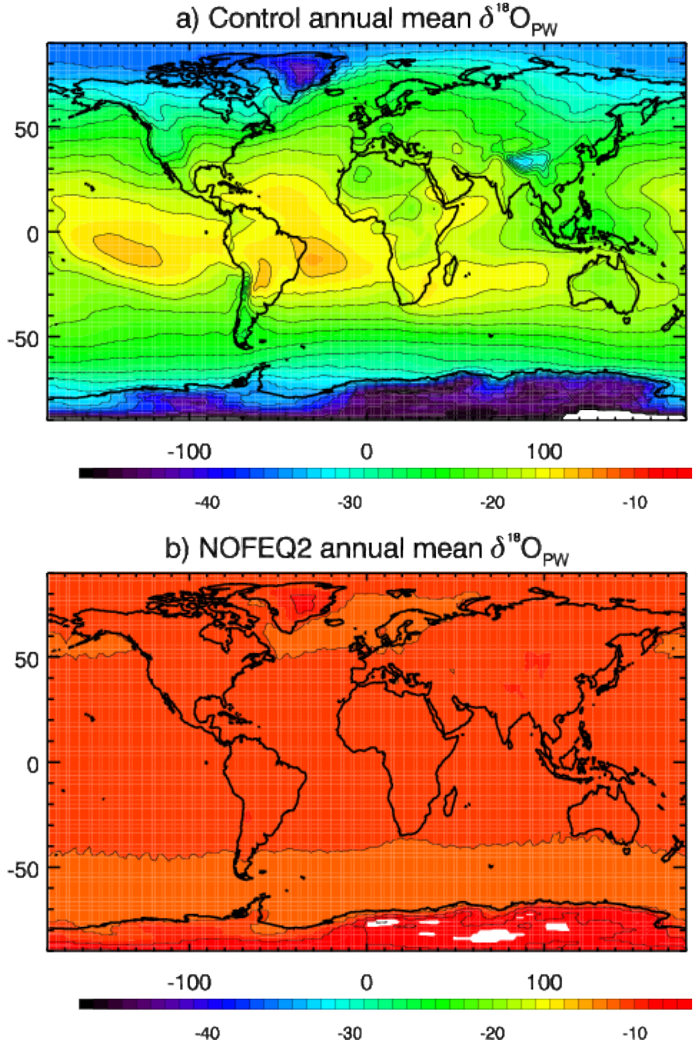




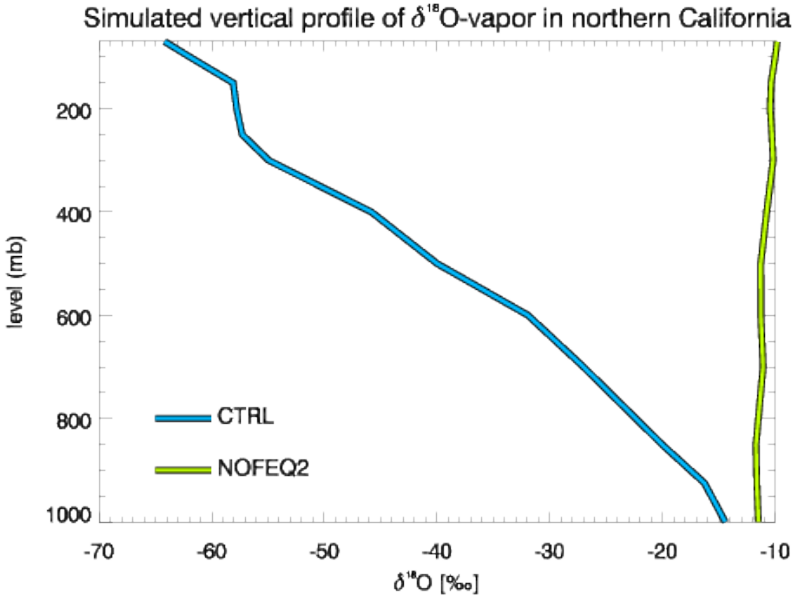


- Results from the NOFEQ2 simulation showed the clear reduction in the seasonal cycle.
- This indicates that equilibrium fractionation during condensation is causing the seasonal cycle.

What happened in the experiment

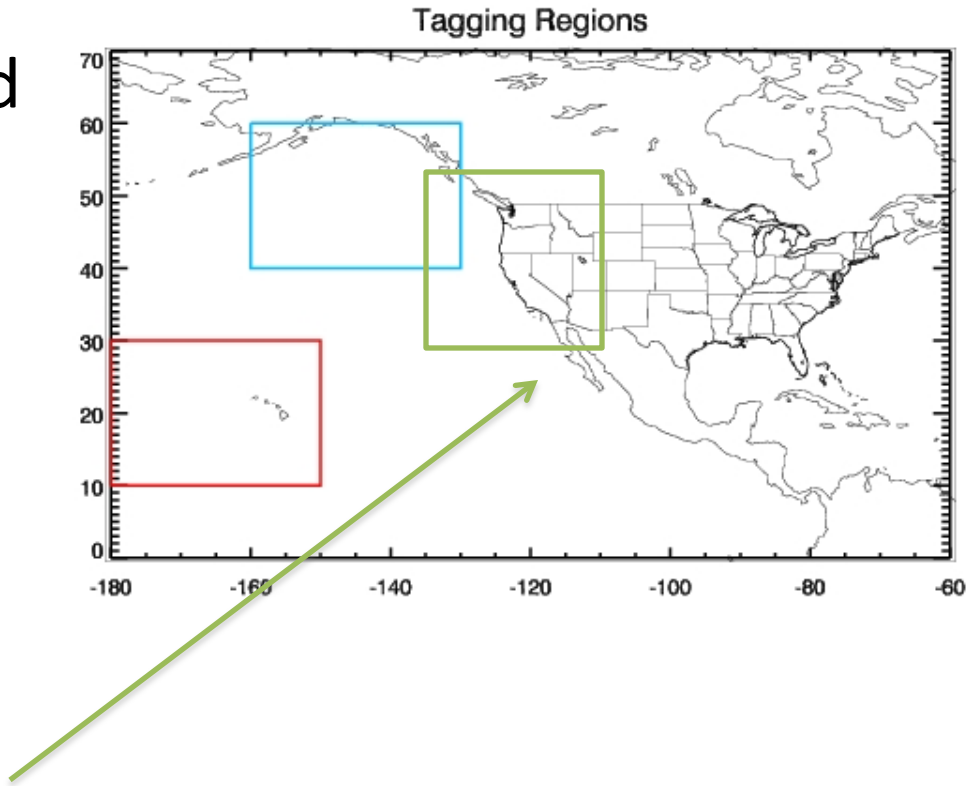


- Both horizontal and vertical gradients were reduced.

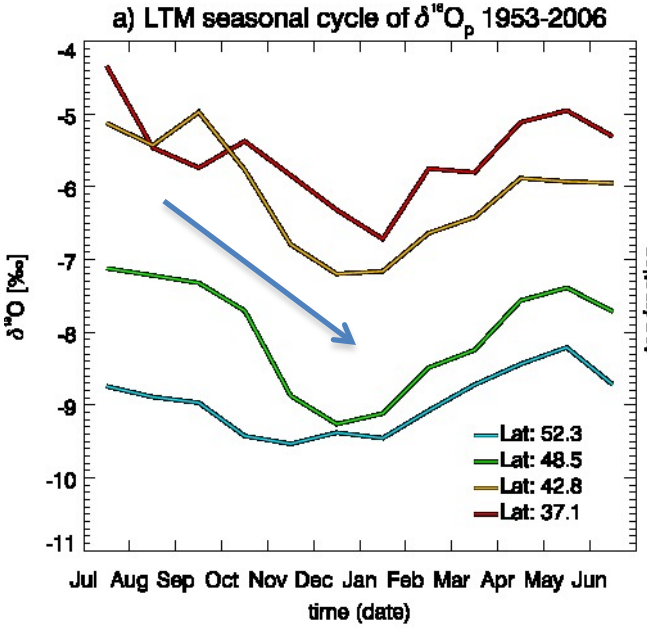


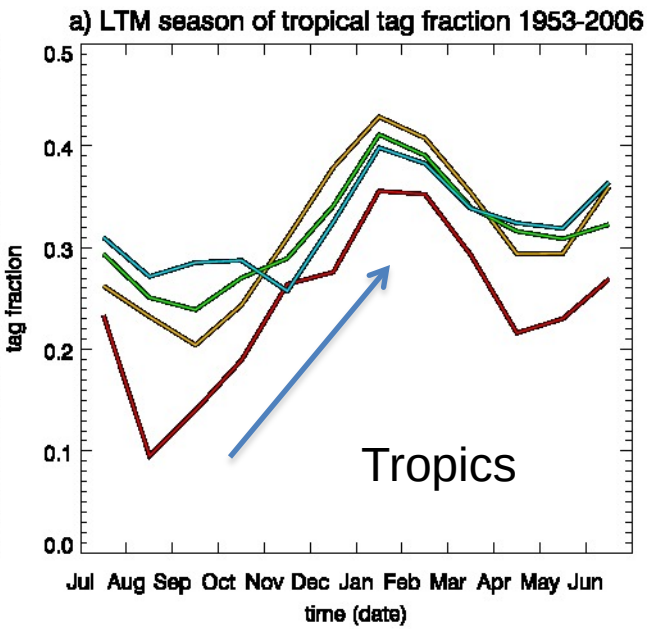
Tagging simulations

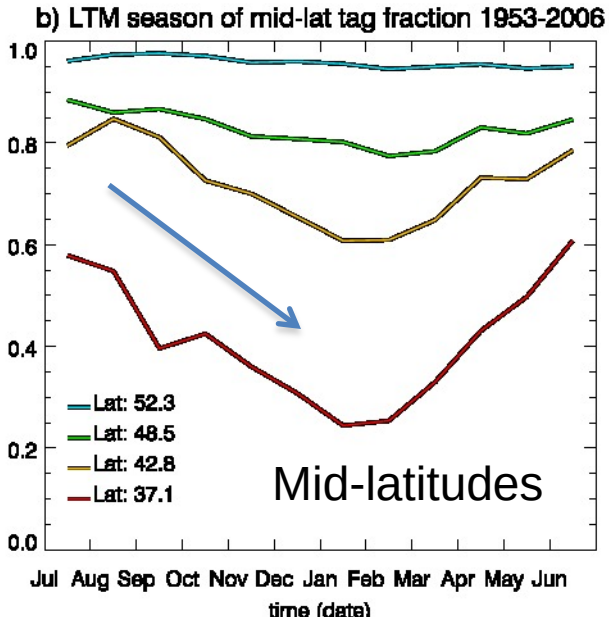
- TAGLAT: Tag tropical and middle latitude moisture.
  TAGZ: Tag lower level (below 0.8 sigma level) and upper level (above 0.8 sigma level) vapor.



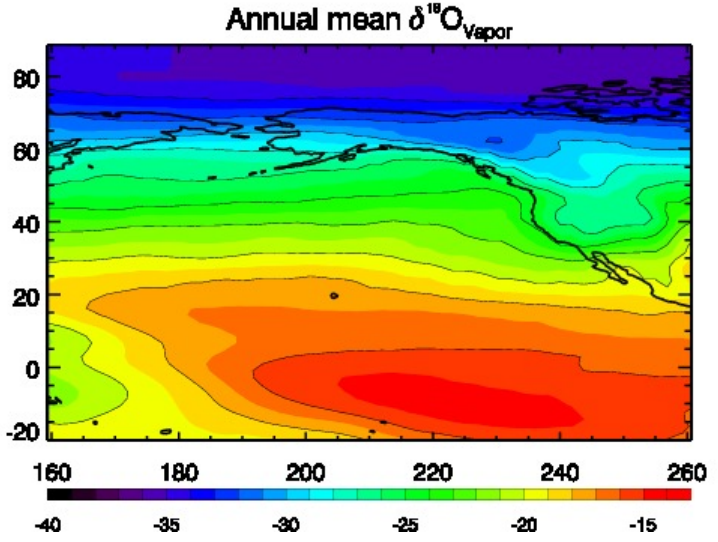
Tropical vs Mid-latitude moisture



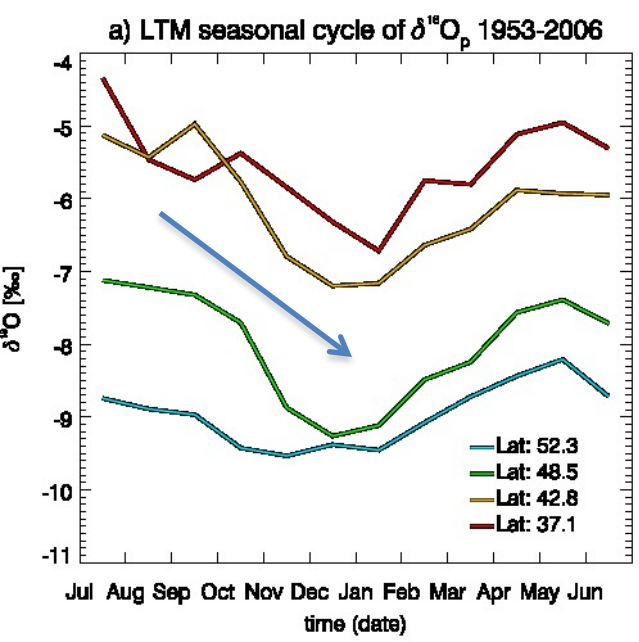


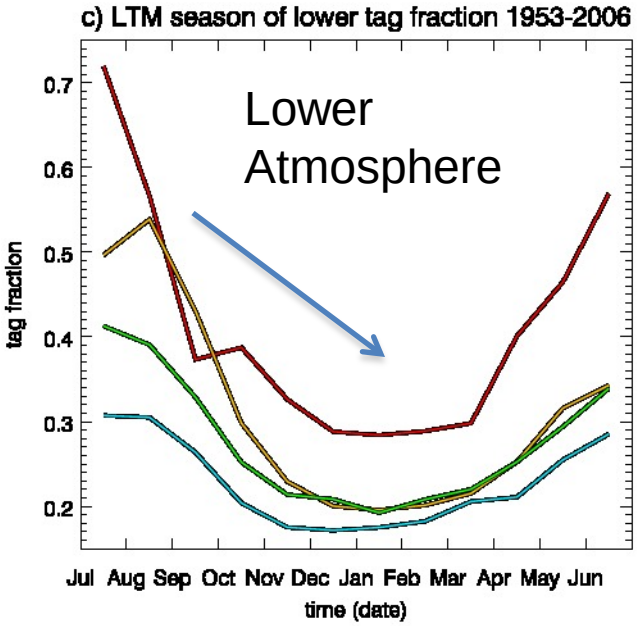


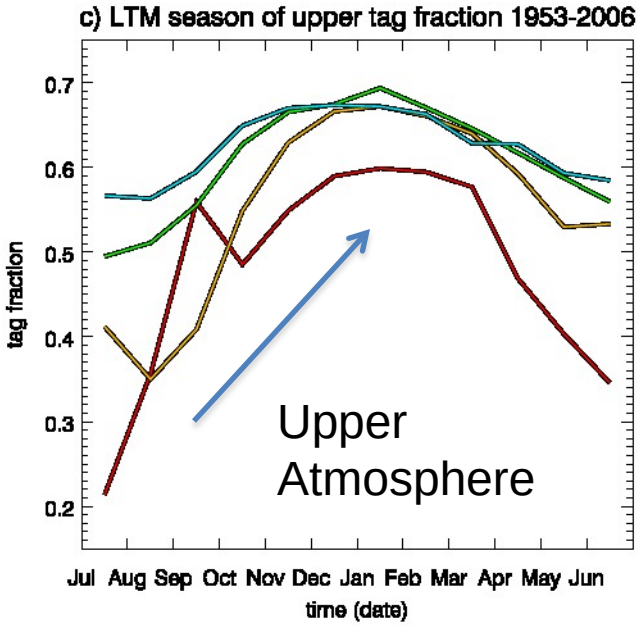
- More tropical moisture rains out in the west during winter.
- This is inconsistent with the horizontal gradient



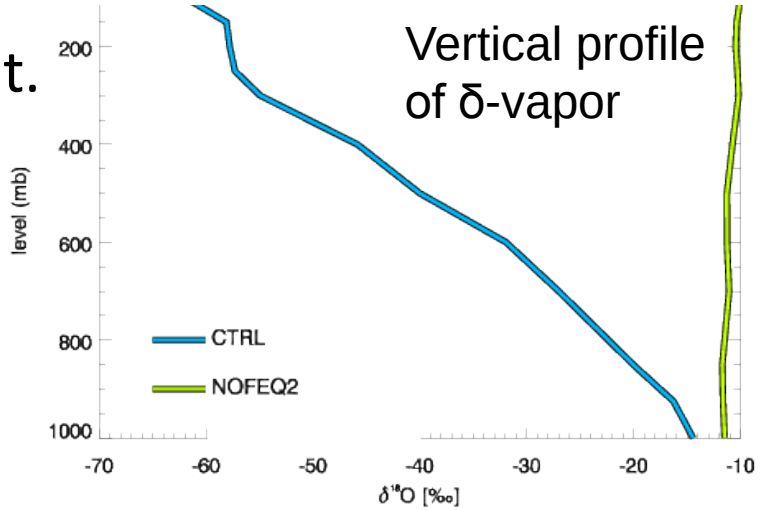
Low elevation vs high elevation



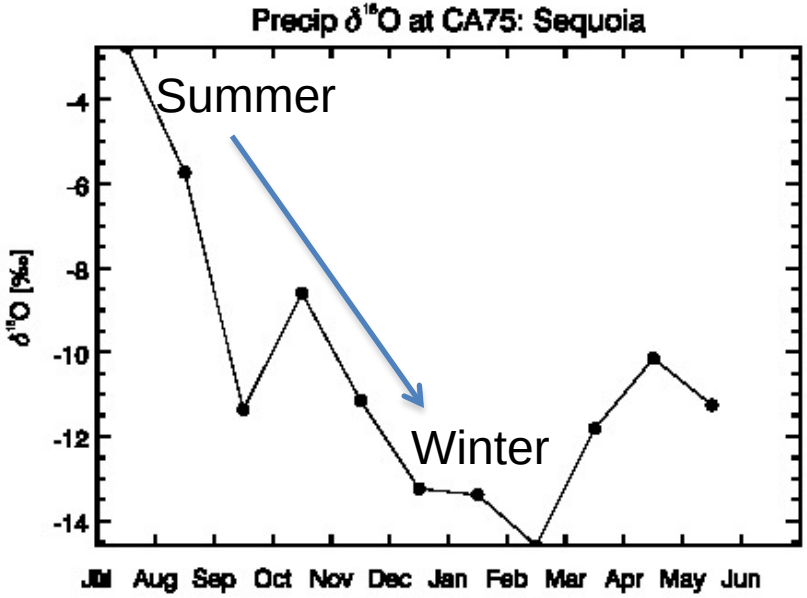


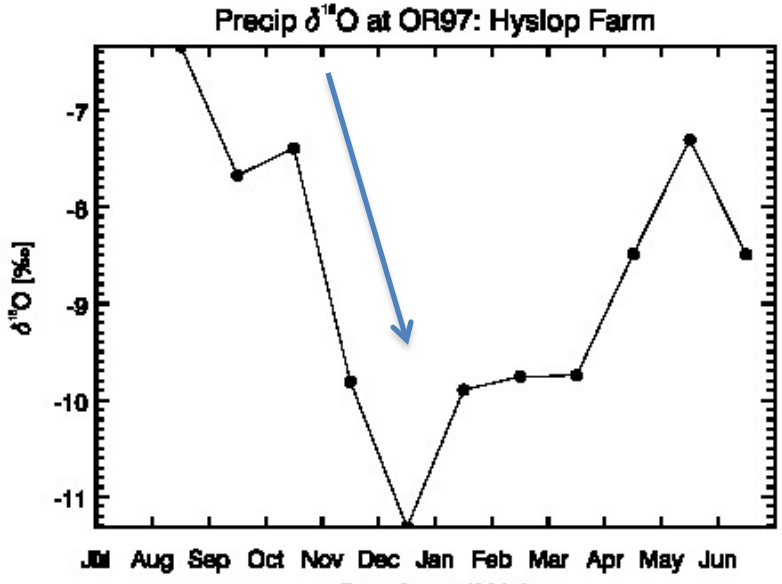


- Consistent with the vertical gradient.
- This could definitely be the cause.



The seasonal drop in isotopes

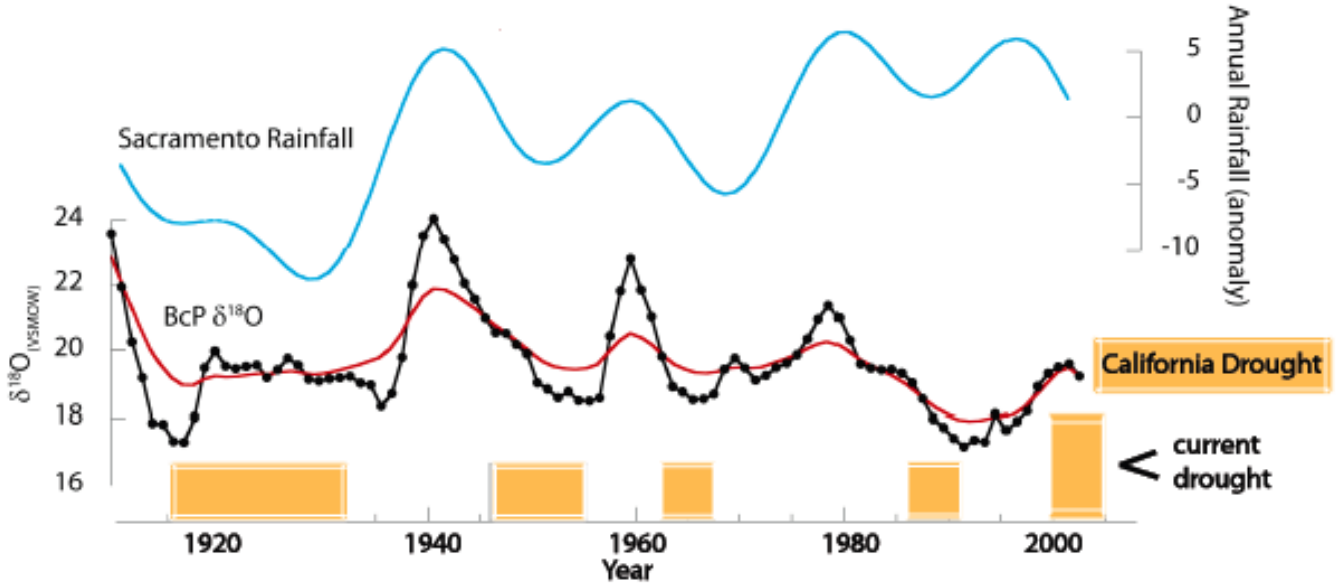




What causes this drop?

- Temperature?
- Rainout
- Source changes
- Seasonal changes in condensation height associated with variations in the wind fields.

Implications



- This effect from condensation height adds another layer of complexity when interpreting climate proxies based on isotopes in precipitation (i.e., $\delta^{18}O$ or δD values from tree cellulose, speleothems, or leaf wax *n*-alkanes).
- There is a strong possibility that these interannual variations are influenced by condensation height.

Conclusions and next steps

- We found that the seasonal variations in the isotopic composition of the precipitation appears to be dominated by condensation height along the western US coast associated with seasonal changes in the winds.
- Next question: Are these mechanisms true on interannual and interdecadal time-scales?
- What about other regions?

Citation: Buenning, N. H., L. Stott, K. Yoshimura, and M. Berkelhammer (2012), The cause of the seasonal variation in the oxygen isotopic composition of precipitation along the western U.S. coast, *J. Geophys. Res.*, *117*, D18114, doi:10.1029/2012JD018050