Measurements the Stable Isotopologues of Water Vapor at Mauna Loa for Monitoring the Atmospheric Water Cycle

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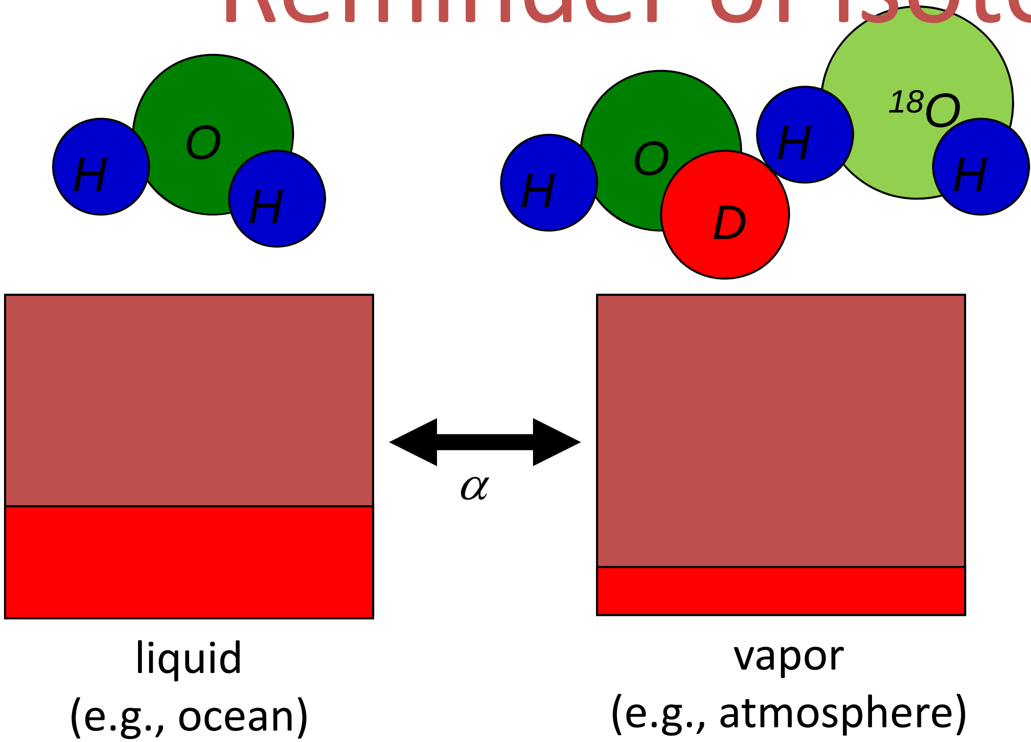
Overview

- Why isotopes?
- Understanding budgets
  - Isotopes provide additional constraint
- Measurements at Mauna Loa
  - Raw data (δD, not ^{18}O today)
  - Budget analysis (quick taste)
  - Sources of water (it's not evaporation!)
- *Next steps*

Noone, D., 2008: An isotopic evaluation of the factors controlling low humidity air in the troposphere. J Climate, in review.

Noone and 13 others, 2009: Identification of moistening and dehydration processes in the North Pacific subtropical dry zone from continuous water isotopologue measurements at Mauna Loa, J G R, in prep.

Reminder of isotope physics



Ratio of HDO to H_2O

Measured as a difference from ocean water.

$$\delta = \frac{R}{R_{ocn}} - 1$$

Two simple isotope models…

Condensation

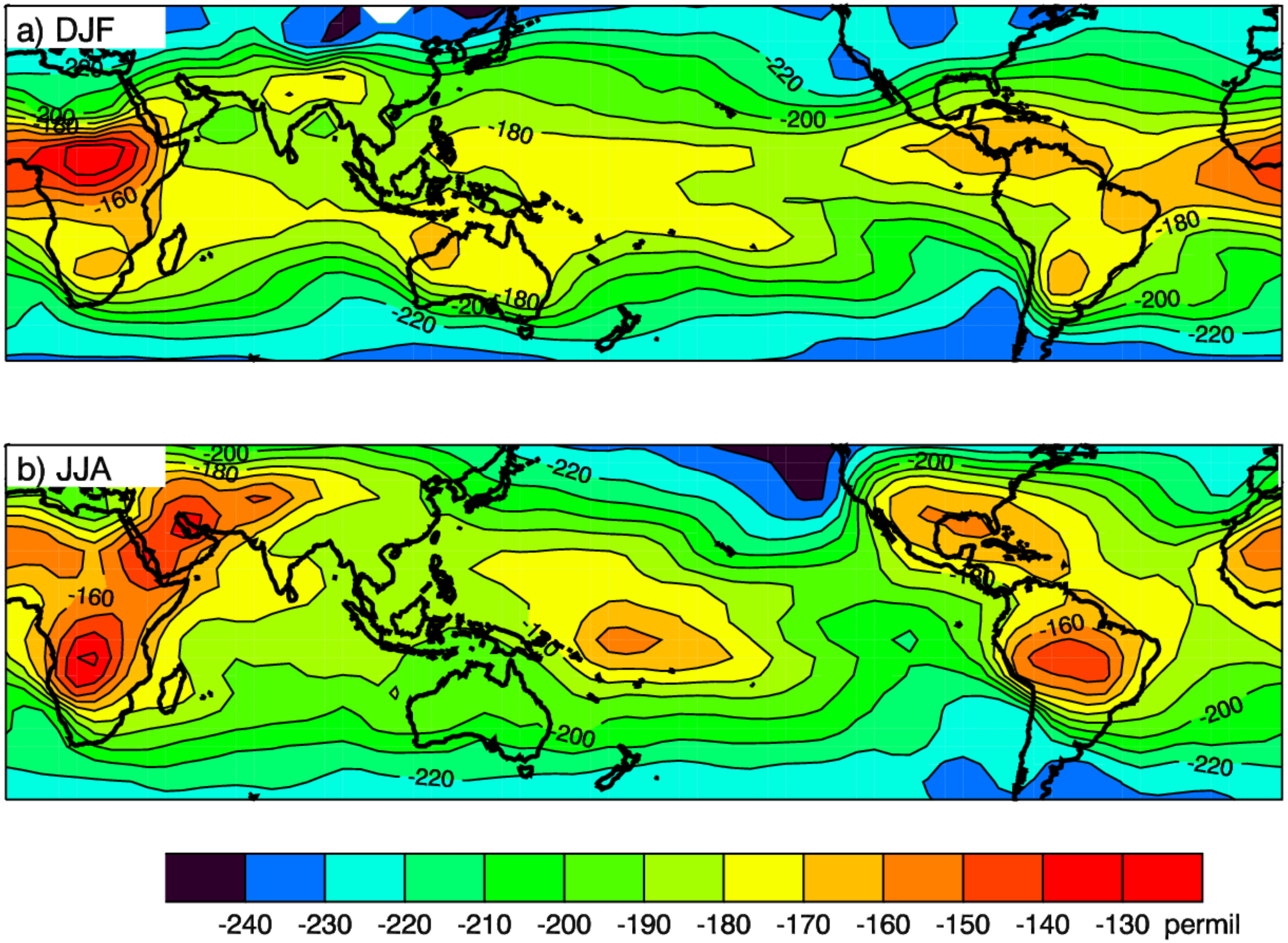
Vapor becomes depleted as heavy removed preferentially

Evaporation

Returns to isotopic composition of the (ocean/land) source.

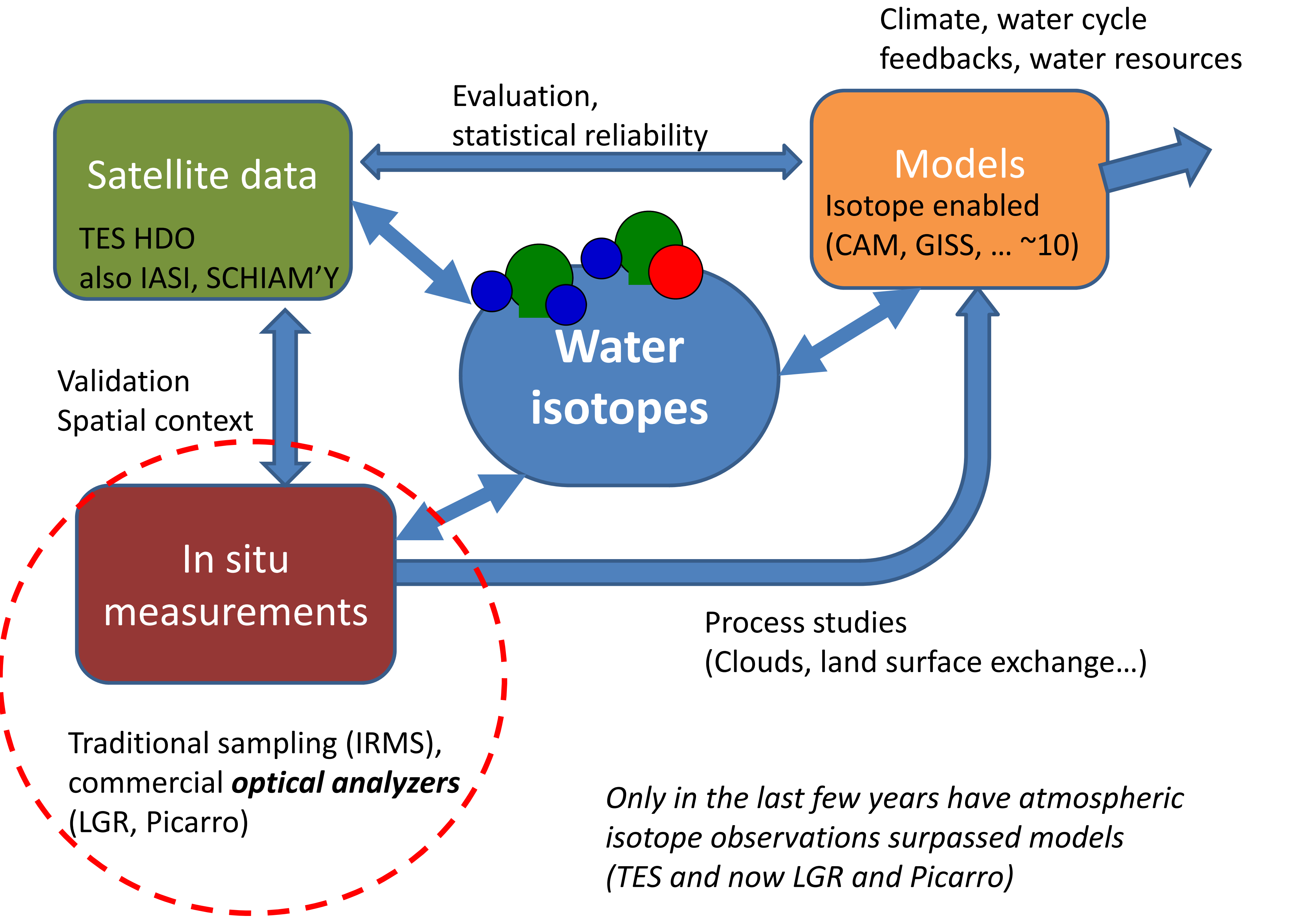
Conditions under which condensation occurs is different from the conditions when evaporation occurs

TES δD climatology (850-500 hPa)



December 2004 – March 2008

Brown et al., in prep, Helliker and Noone in press, Noone, et al., in prep., Brown et al., 2008, Worden et al., 2007, Worden 2006



Climate, water cycle feedbacks, water resources
Evaluation, statistical reliability
Satellite data
TES HDO
also IASI, SCHIAM'Y
Models
Isotope enabled (CAM, GISS, … ~10)
Water isotopes
Validation
Spatial context
In situ measurements
Process studies
(Clouds, land surface exchange…)
Traditional sampling (IRMS), commercial optical analyzers (LGR, Picarro)
Only in the last few years have atmospheric isotope observations surpassed models (TES and now LGR and Picarro)

HAVAIKI 2008

Hawaii Atmospheric Vapor Isotope “Knowledge” Intercomparison

PIs: David Noone (U. Colorado) and Joe Galewsky (U. New Mexico)

Objectives

1. Test optical analysers
   JPL, Picarro, Los Gatos Research
2. Provide validation opportunity for TES and IASI HDO
3. Science objectives
   Understand hydrology of dry zones

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Manish Gupta

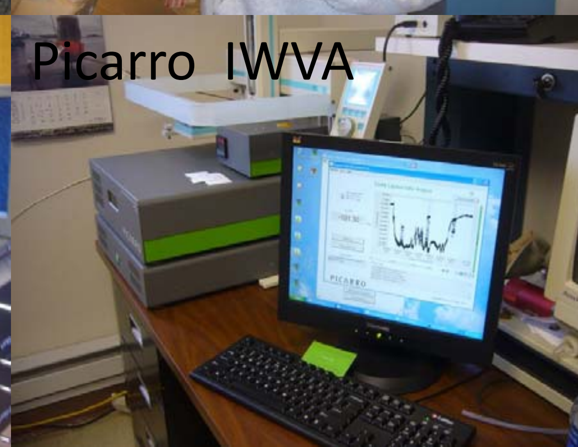
Picarro
Eric Crosson
Priya Gupta
Aaron van Pelt

Cryogenic traps

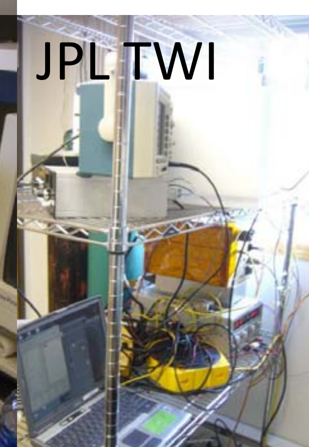
Vacuum flasks

http://cires.colorado.edu/science/features/vapor/

LGR WVIA



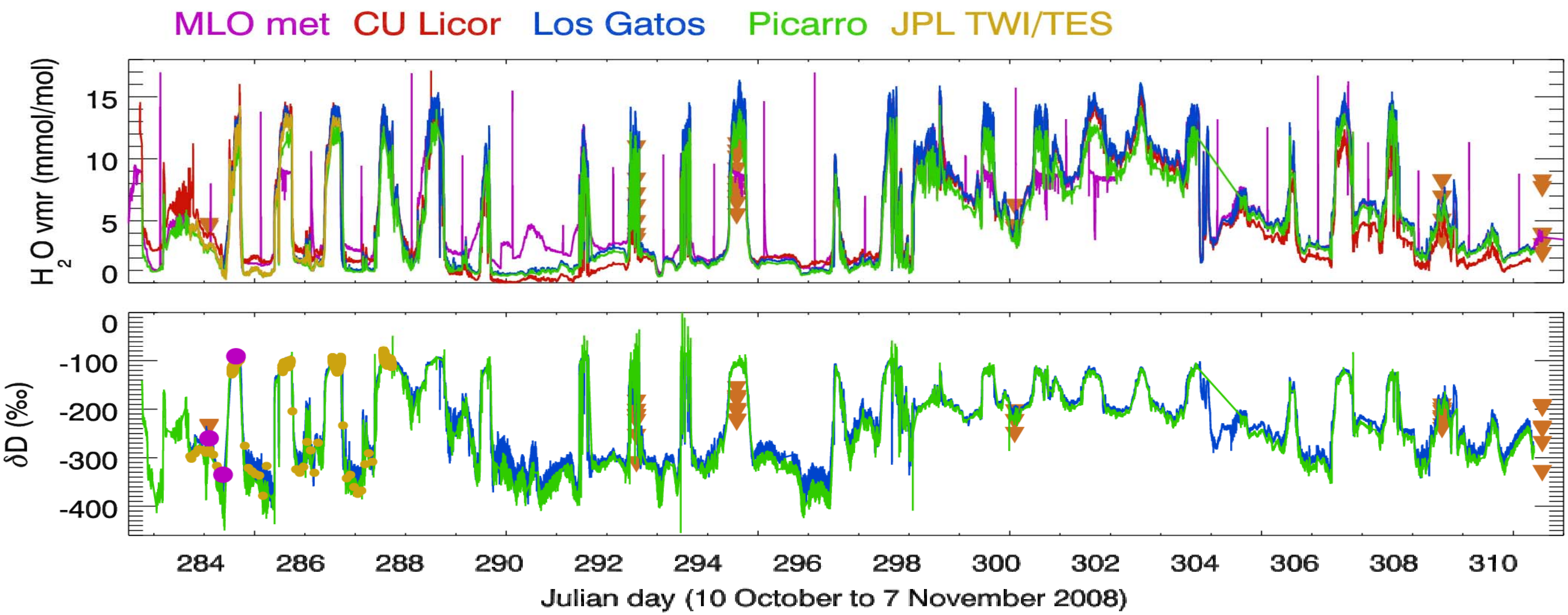
Picarro IWVA



JPL TWI

Inlet

Water and isotopes at Mauna Loa



General agreement between instruments

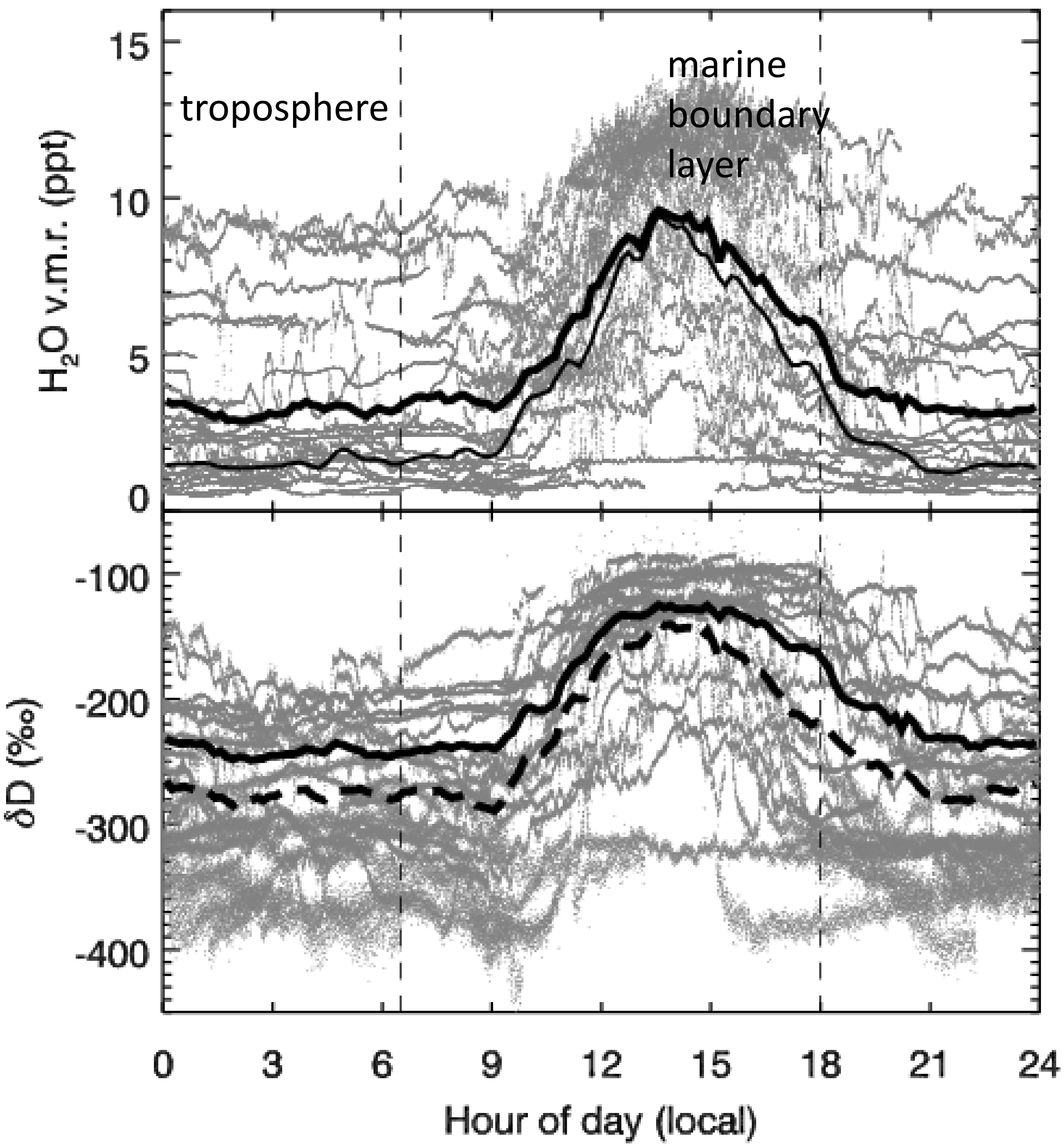
Some differences in details

Dominant diurnal cycle

Very dry night (free troposphere)

Boundary layer during daytime

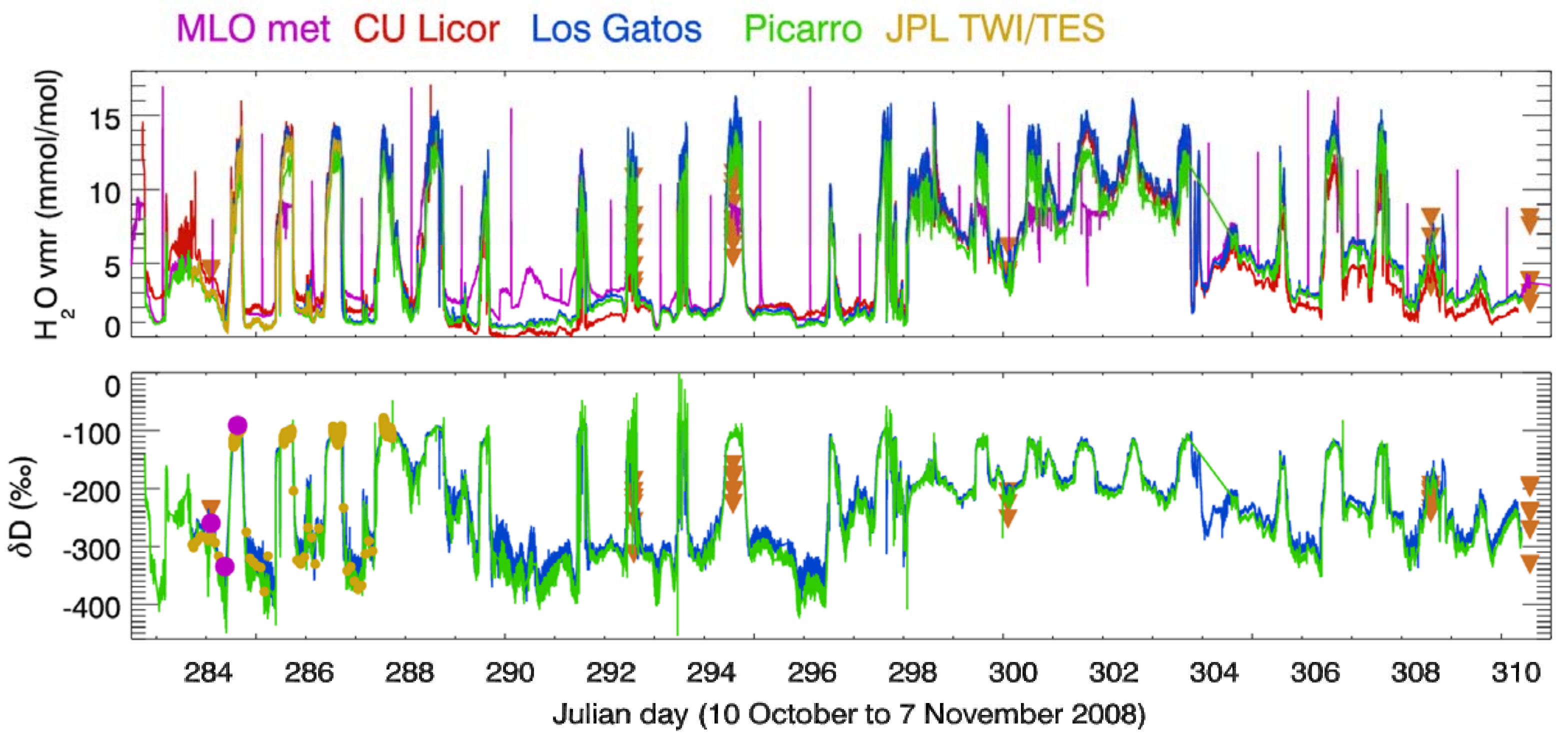
Noone et al., JGR, in prep,



Notice difference in shape:
This is where the information from isotopes resides.

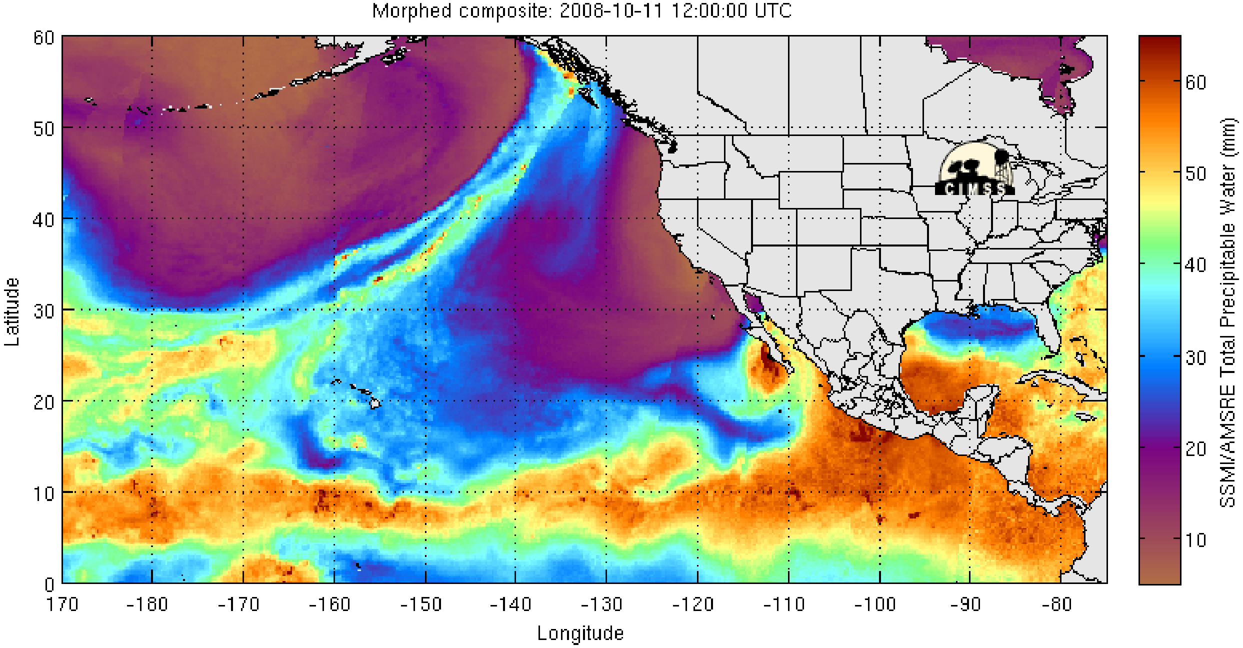
Enormous!

Instruments sensitive < 1 permil

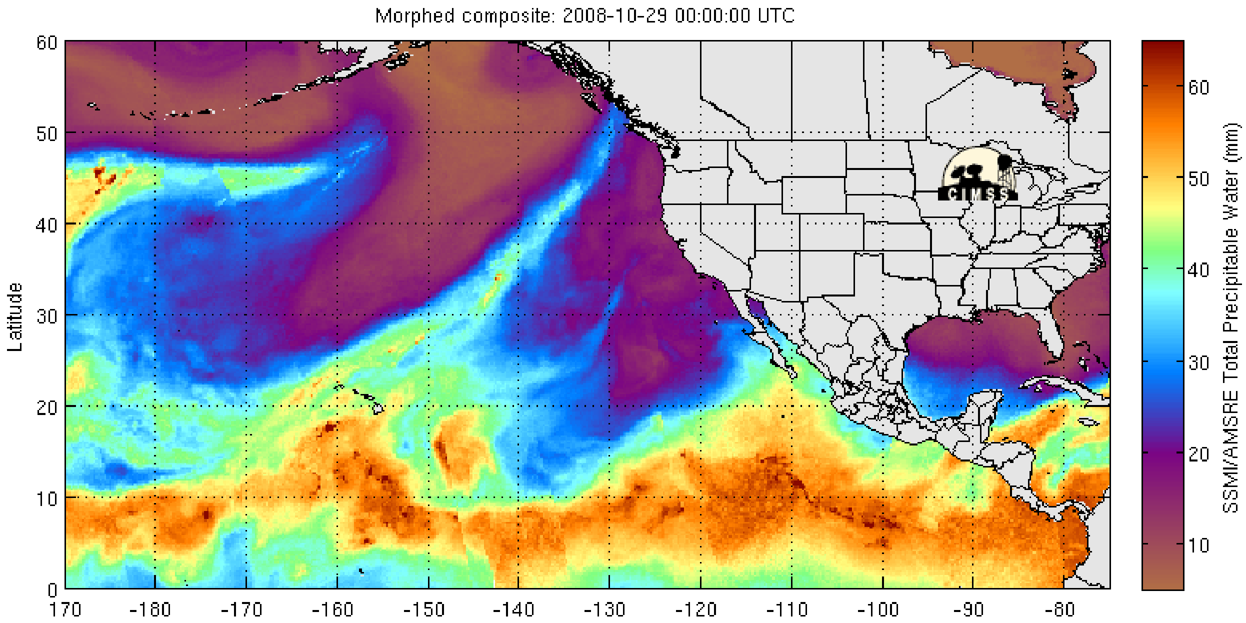


Noone et al., JGR, in prep

Column precipitable water

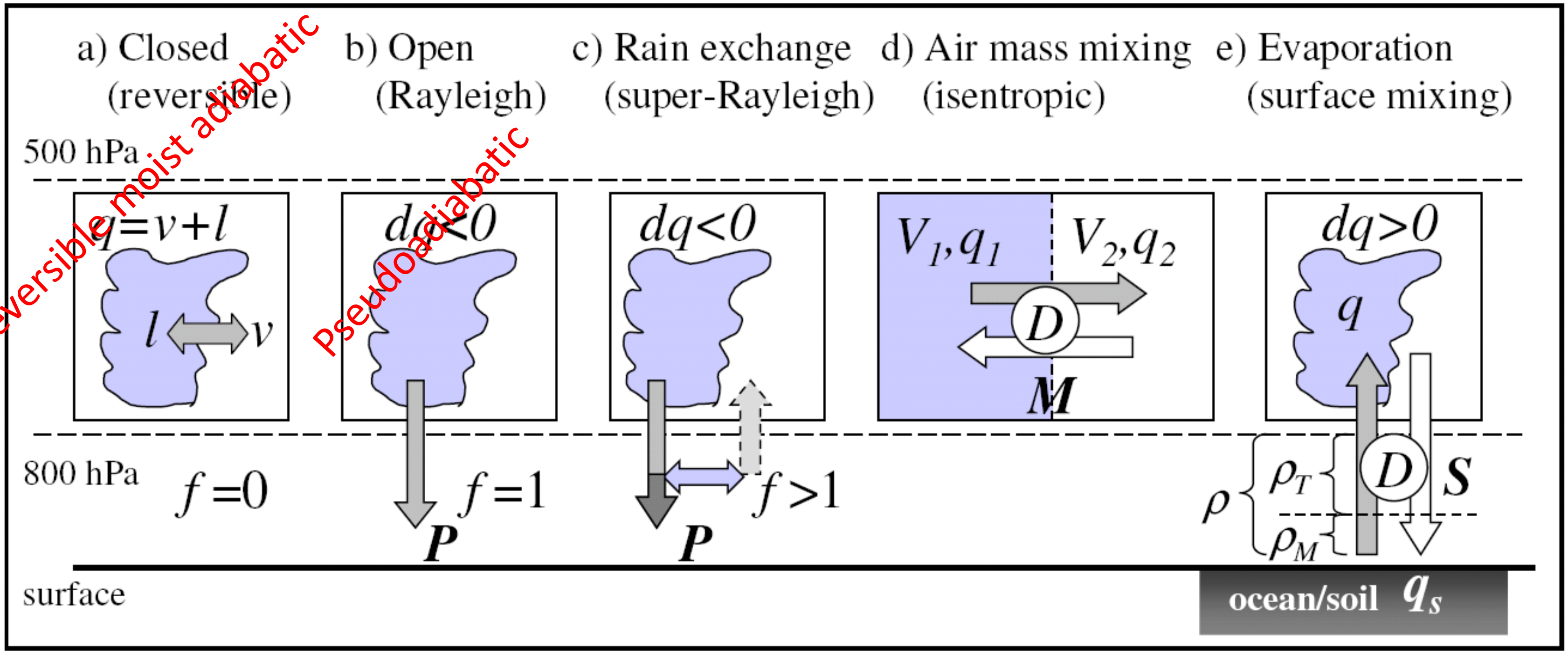


Dry, subtropical nights



Moist, “river” outflow

Theoretical guidance: box budgets



Condensation

$$(\delta - \delta_0) = (\alpha - 1)\ln\left(\frac{q}{q_0}\right)$$

$$\alpha = \frac{\alpha_e}{\alpha_e(1 - f) + f}$$

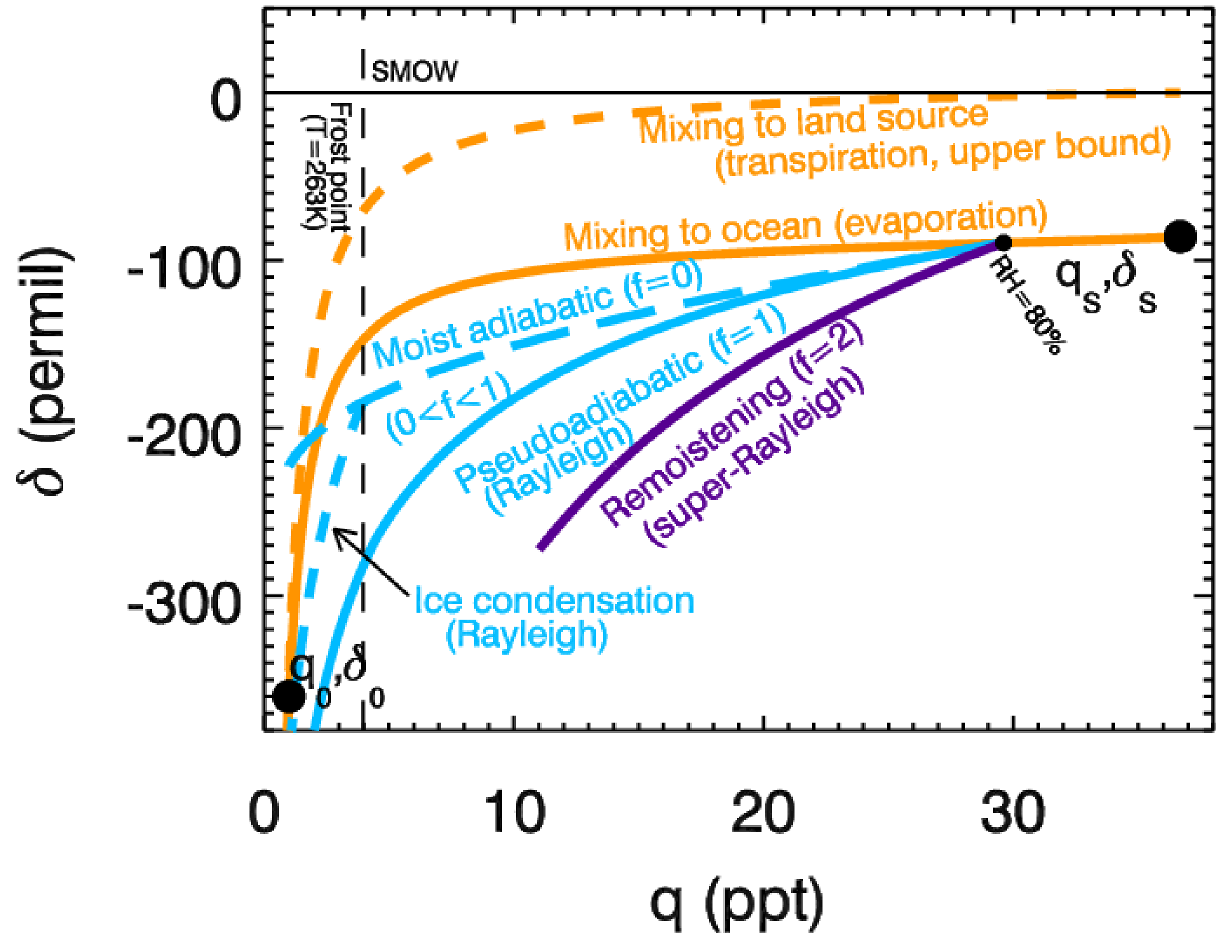
Mixing/hydration

$$\delta \approx \frac{R}{R_s} - 1 = -\left[\hat{q}\left(\hat{\delta} - (1 - H)\right)\right]\frac{1}{q} - (1 - H)$$

$$H = \left(\hat{q}_i - q_{i,0}\right)\left[\hat{q} - q_0\right]^{-\eta}$$

Noone, J, Climate, in review

Framework for interpreting HDO



(Noone, in review)

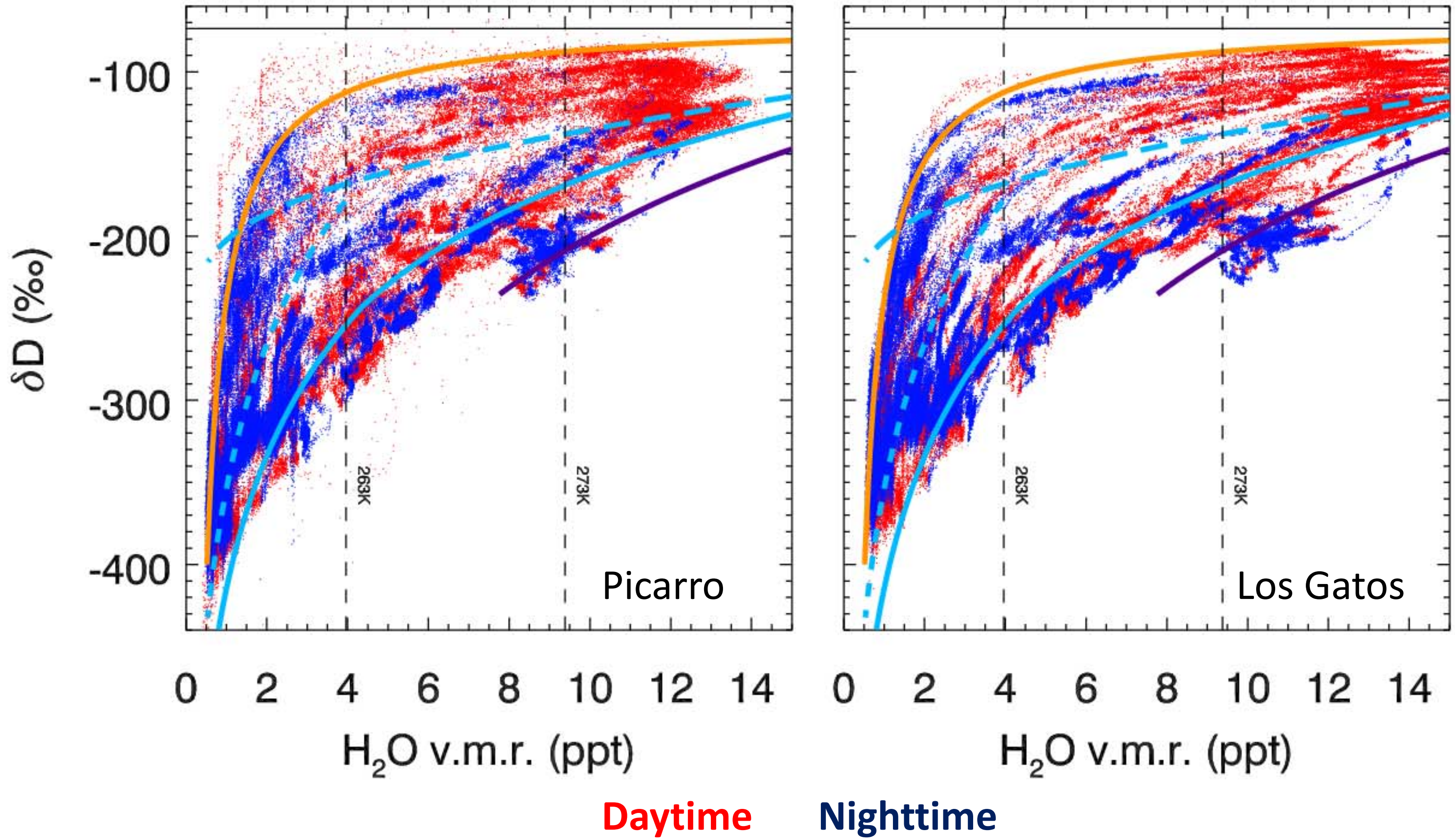
"6 easy pieces"

Very powerful analytic tool since constrains ***system***

Two things to worry about:

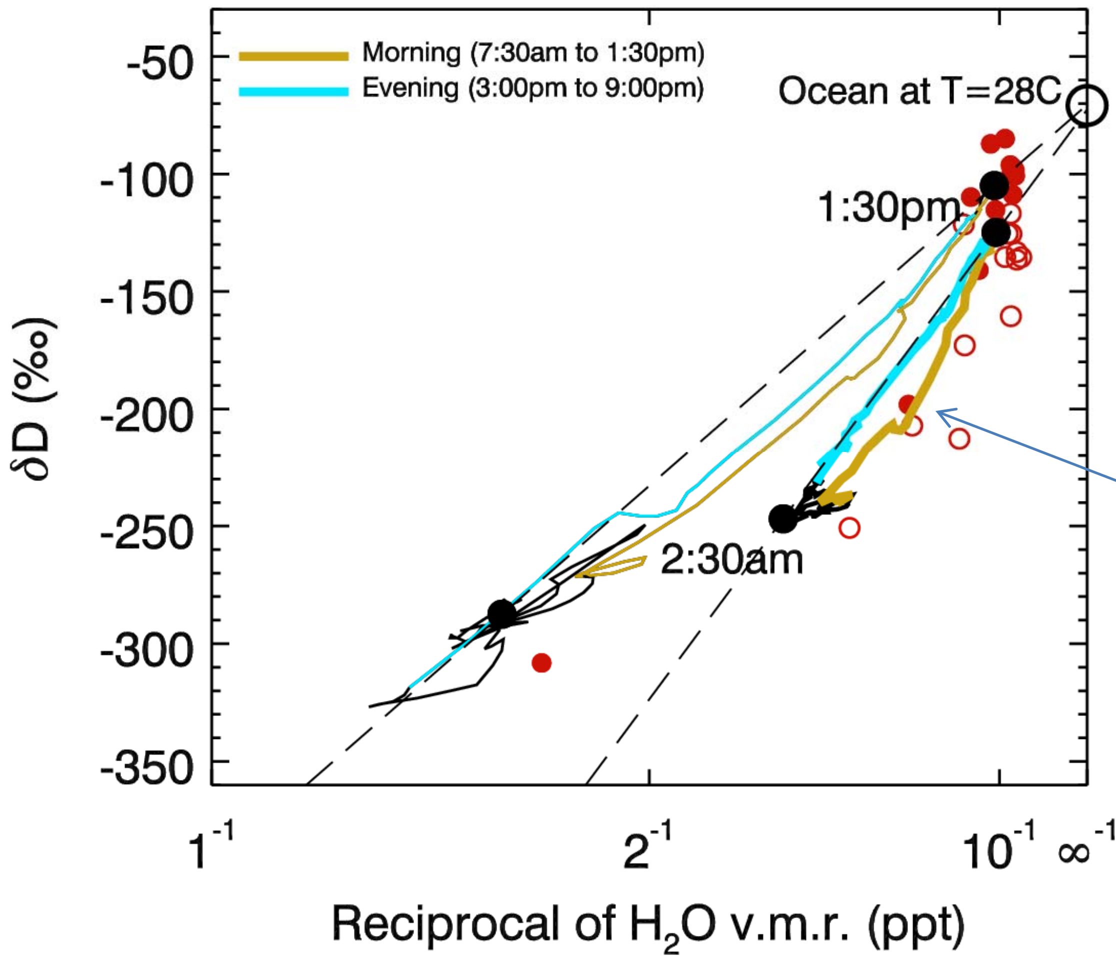
1) What is source composition? (end members, balance of sources)

2) What is *slope*? (rainfall efficiency, type of cloud)



Measurements immediately confirm theory!
Thus theory can be used to interpret data.
Key aspect is that it is a 2 dimensional problem, to give a cycle.

The source for diurnal cycle



Collapse of the MBL in the evening is simple mixing.

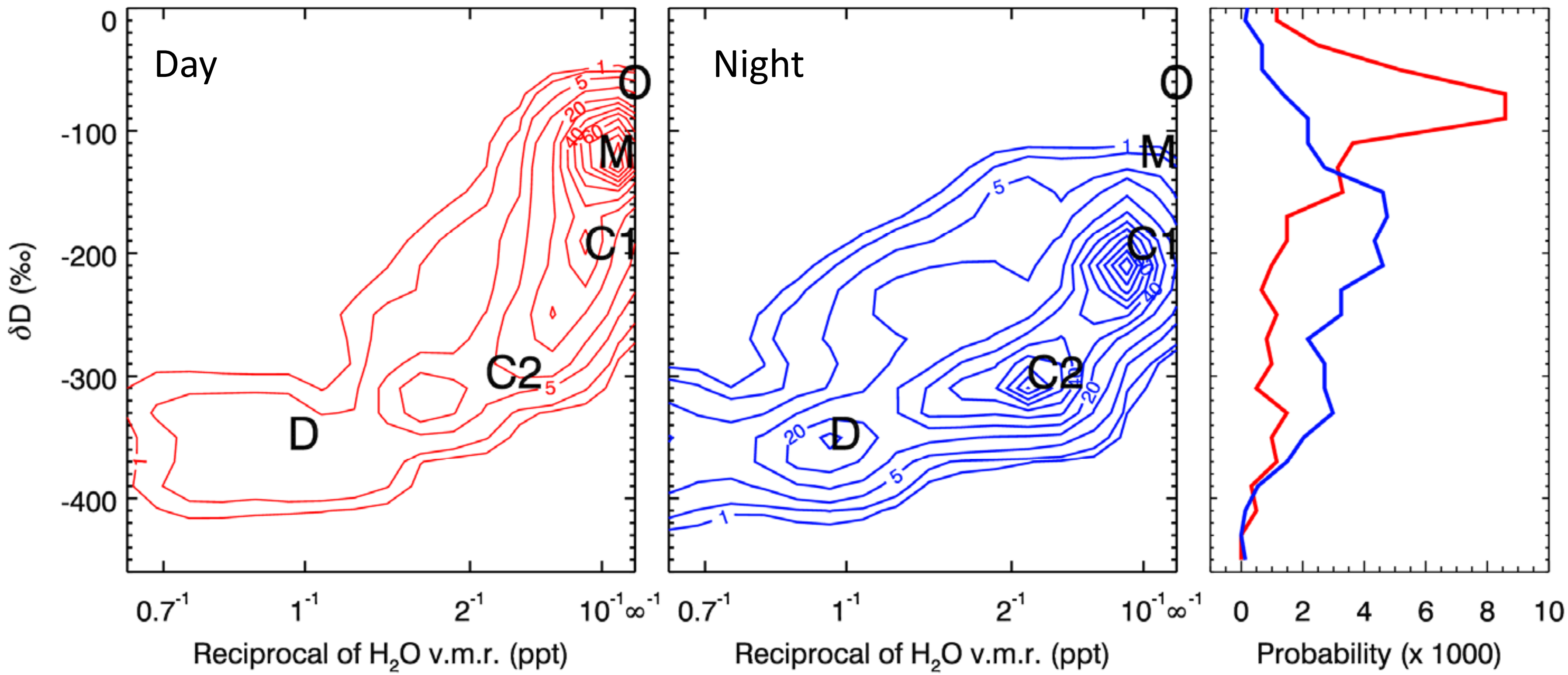
Daytime growth has a "third" reservoir: boundary layer clouds

Source is identified as evaporation of ocean water near 28°C (plus kinetic effects)

Similar to a "Keeling plot" used for $^{13}C/C$

Mean source, OK. What about sources for individual days/events?

What is the moisture source? (end member for mixing)



Daytime source – evaporation from the ocean (“O”)

Nighttime – detrainment from shallow convection (“C1”, “C2”)
(importantly, NOT evaporation)

Probability distributions only possible with high volume of data (satellite and in situ)

Conclusions

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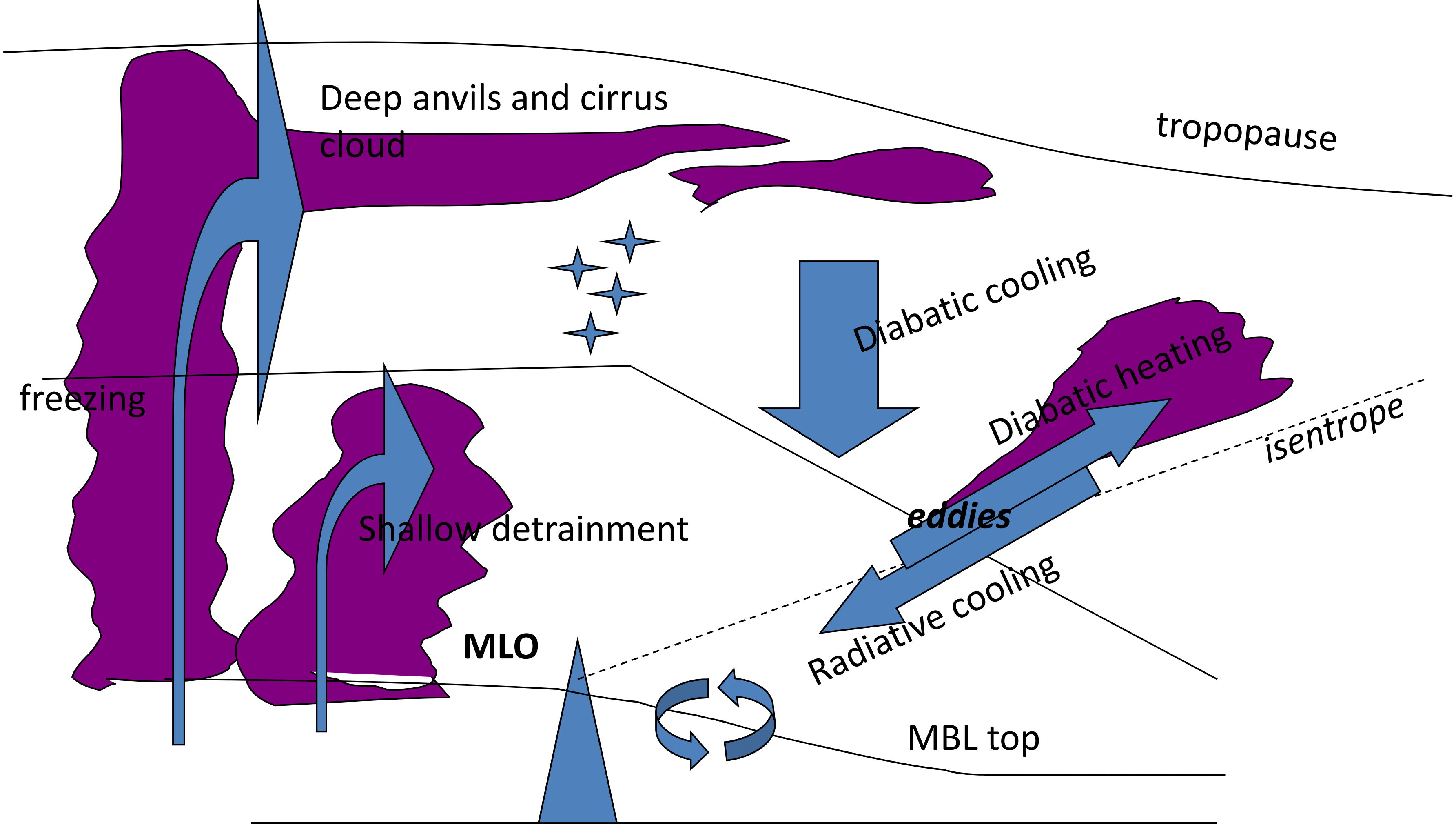
- Present generations of in situ analyzers are good for baseline measurements.
- They can achieve **laboratory precision** tied to established calibration standards in deployment
- Source of troposphere air is detrainment from convection *(not direct evaporation, as in the boundary layer)*

- Four field week test was a success, we're ready for longer records (and science)

More generally …

- Water vapor is the most important greenhouse gas
- The water cycle is changing in subtle ways associated with shifts in the budget terms
- Meteorological measurements don't capture the "why" well
- Isotopes capture processes (cloud type and source distribution)
- Useful to constraining mixing for other species (CO_2, aerosols, …)


Deep anvils and cirrus cloud
tropopause
Diabatic cooling
Diabatic heating
freezing
isentrope
eddies
Shallow detrainment
Radiative cooling
MLO
MBL top