Using water vapor isotopes as a tracer for cloud-aerosol-precipitation studies

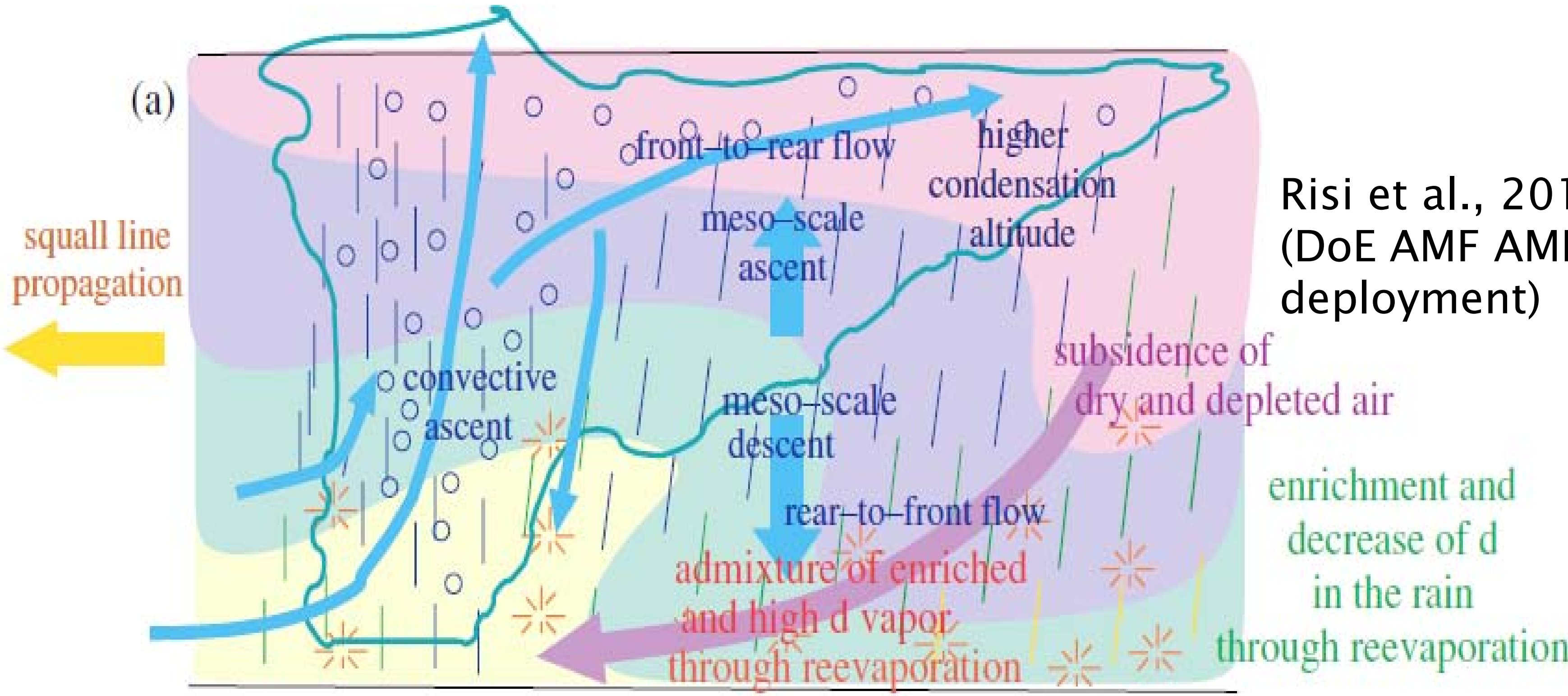
David Noone[1], Marc Ficsher[2], Sebastien Biraud[2], Margaret Torn[2]

[1]Dept. Atmospheric and Oceanic Sciences and
Cooperative Institute for Research in Environmental Sciences
University of Colorado

[2]Lawrence Berkeley National Laboratory

Outline

- New science opportunities because in situ measurements of isotope composition of vapor
- Isotopes record what happened to the water vapor and where it came from
    - Indicator of water source/origin
    - Indicator of cloud processes
- *Give theoretical basis, show a few examples*

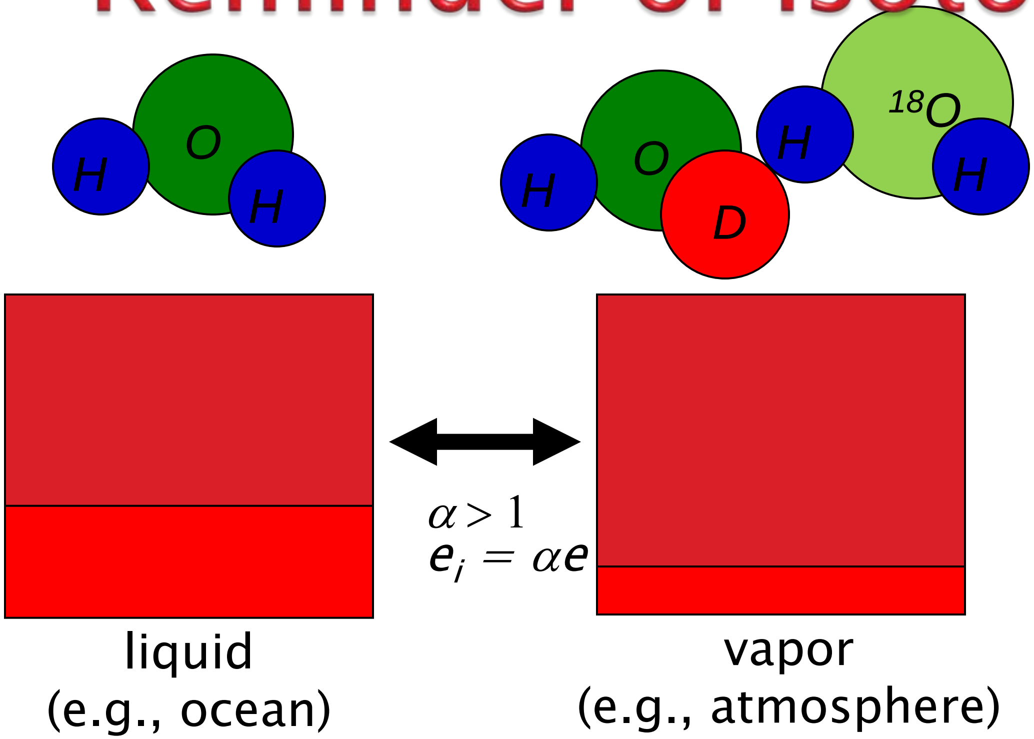


Risi et al., 2010 (DoE AMF AMMA deployment)

"Zipser" inspired cloud dynamics

What is the air motion?
What is the hydrometeor motion?
What are the microphysical exchanges?
Each aspect has an isotopic "tag" which helps analysis

Reminder of isotope physics



Ratio of HDO to H_2O

Measured as a difference from ocean water.

Equilibrium fractionation about 8 times stronger for 18O relative to ^{2}H

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

Two simple isotope models…

Condensation

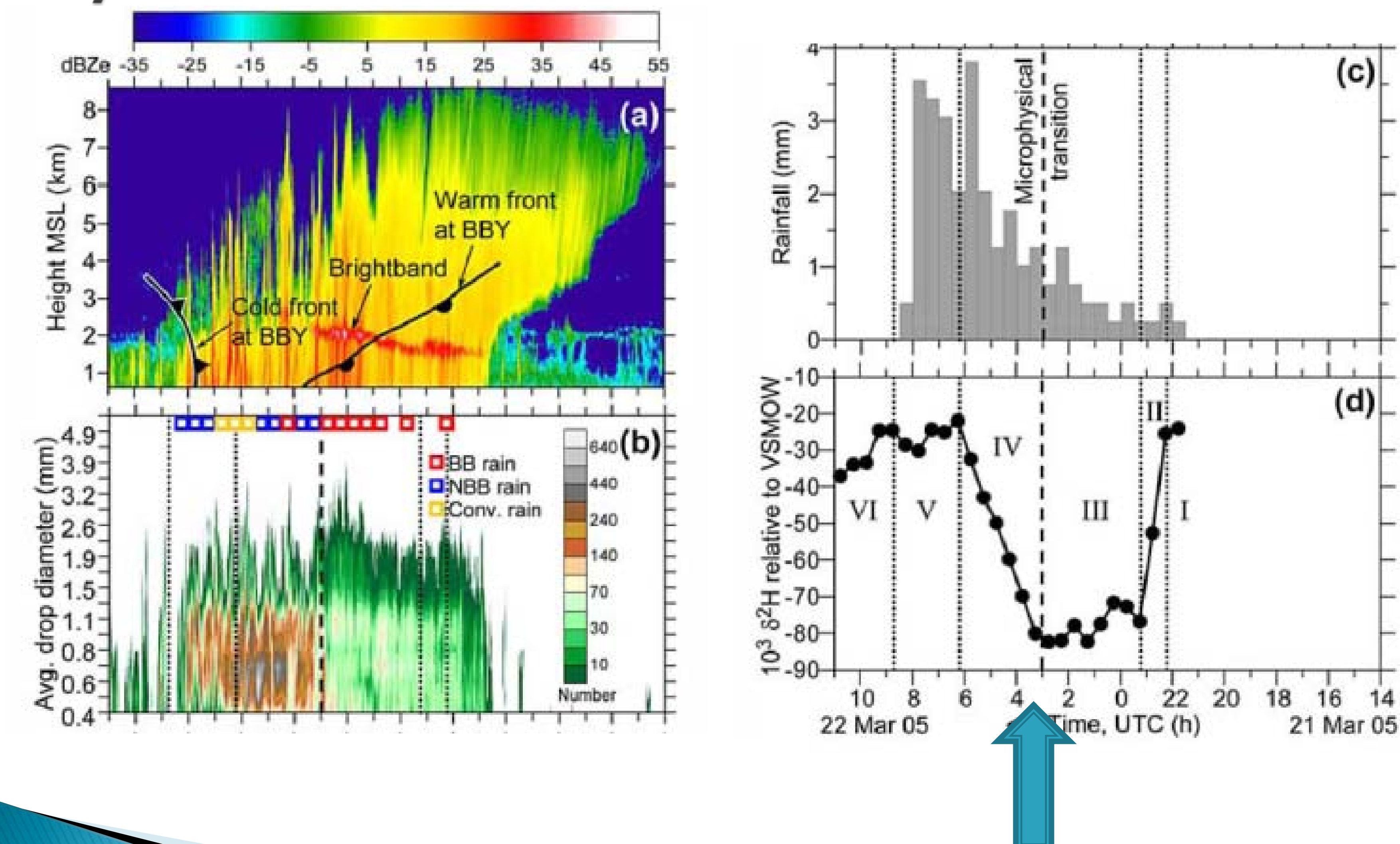
Vapor becomes depleted as heavy removed preferentially

Evaporation

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

Conditions under which condensation occurs is different from the conditions when evaporation occurs – thus "tags"

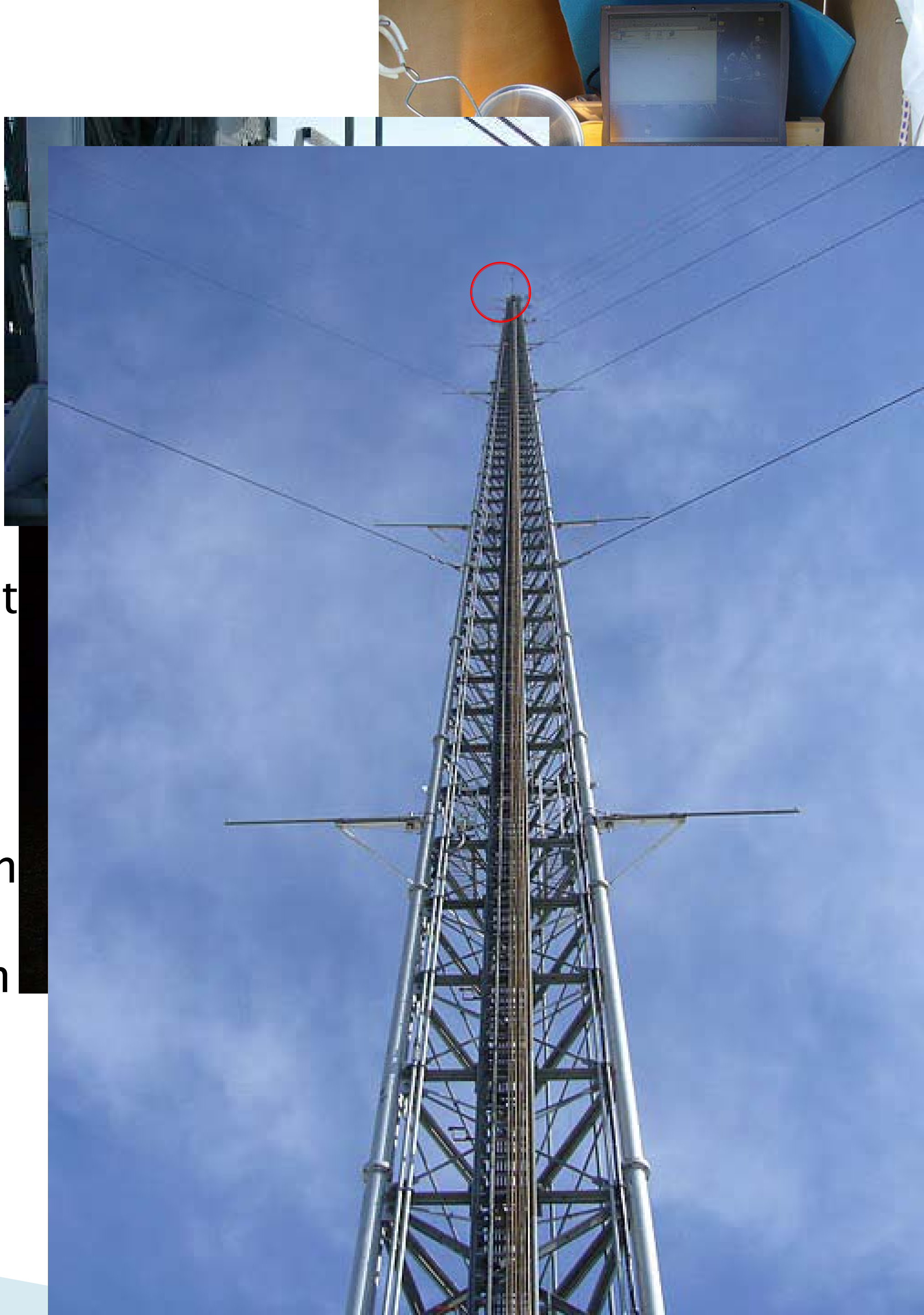
Isotopic composition and cloud dynamics

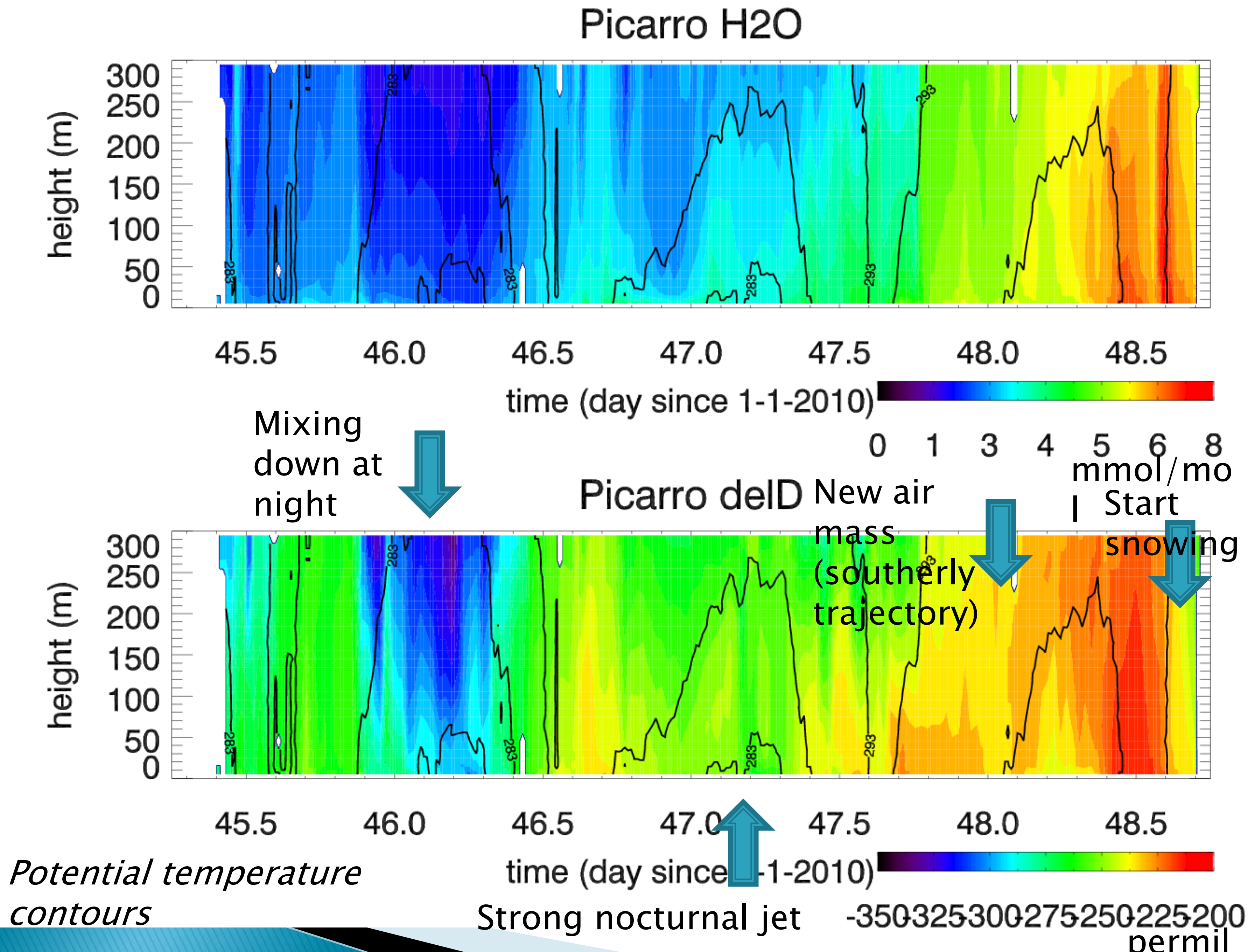


Coplen et al., 2008

Experiment

- Mounted a Picarro Water Vapor Isotope Analyzer on the BAO instrument carriage.
- Along with additional sensors
- LiCor open path CO_2/H_2O, temperature, pressure, sonic wind)
- Every 15 minutes, elevator went up or down for about 4 days (Feb 15-18, 2010)
- Ascent takes 8m50s, decent 8m30s
- Data mapped to high resolution profiles
- 312 profiles 0-300 meters with approximately 5-20 meter resolution (depending on instrument response)

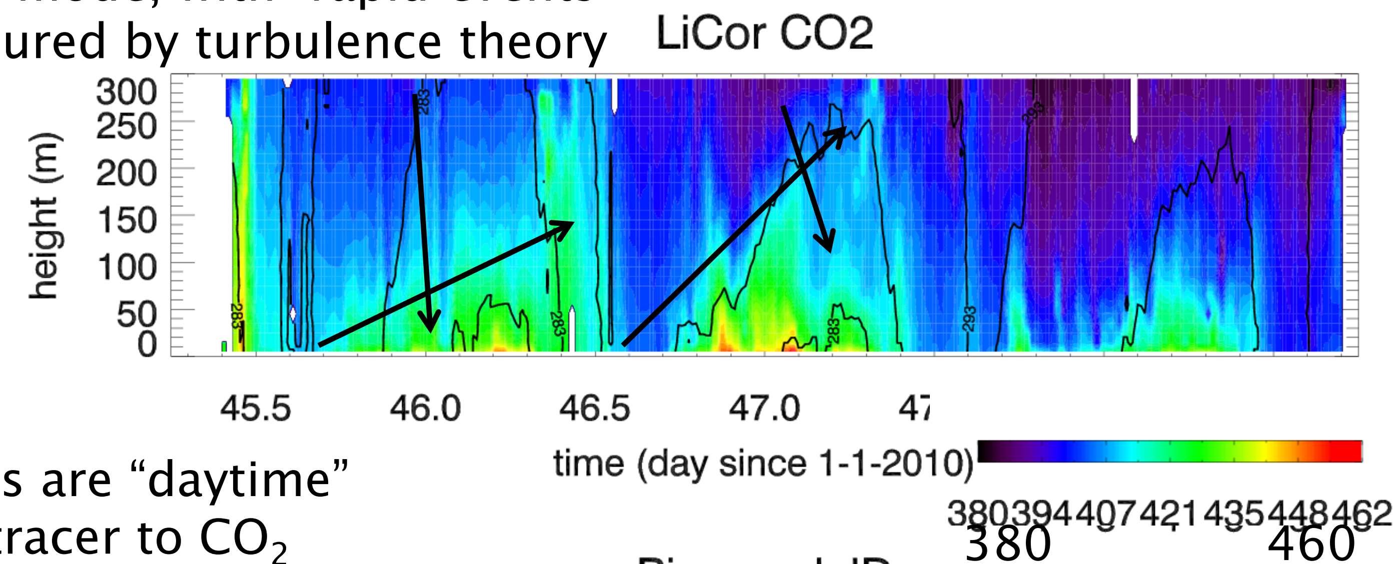




Picarro H2O
height (m)
300
250
200
150
100
50
0
283
293
45.5
46.0
46.5
47.0
47.5
48.0
48.5
time (day since 1-1-2010)
0 1 3 4 5 6 8
mmol/mol
Mixing down at night
Picarro delD
New air mass (southerly trajectory)
Start snowing
height (m)
300
250
200
150
100
50
0
283
293
45.5
46.0
46.5
47.0
47.5
48.0
48.5
time (day since 1-1-2010)
-350-325-300-275-250-225-200
permil
Potential temperature contours
Strong nocturnal jet

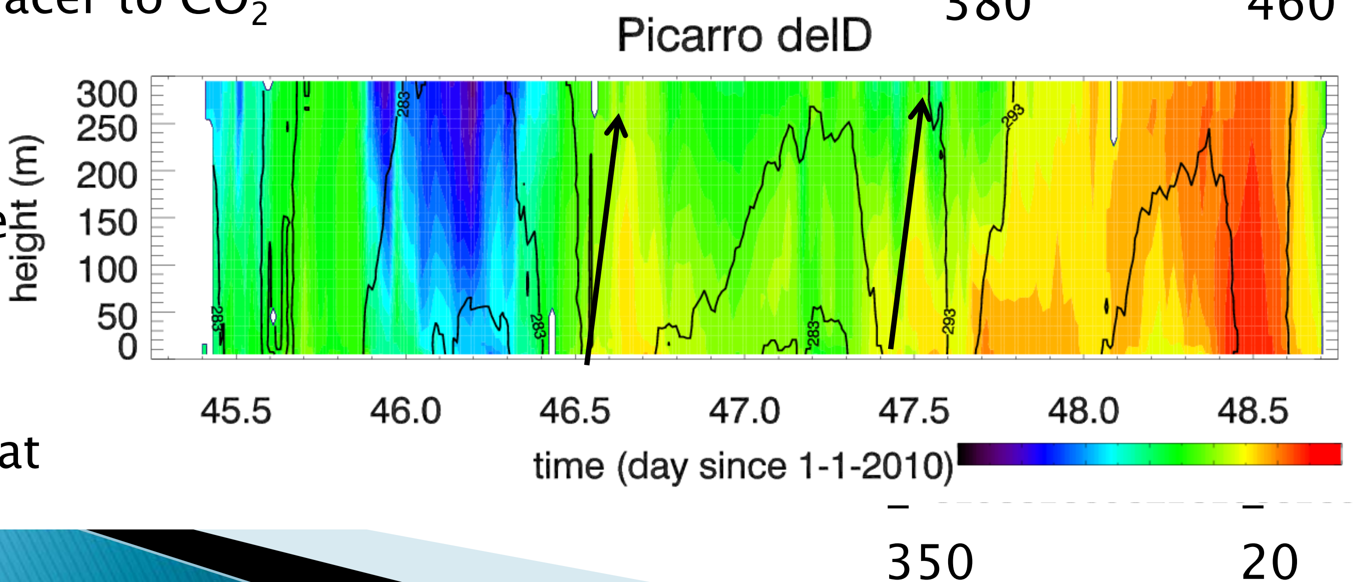
Intermittency of mixing

Slope mixing mode, with “rapid events”
Not well captured by turbulence theory

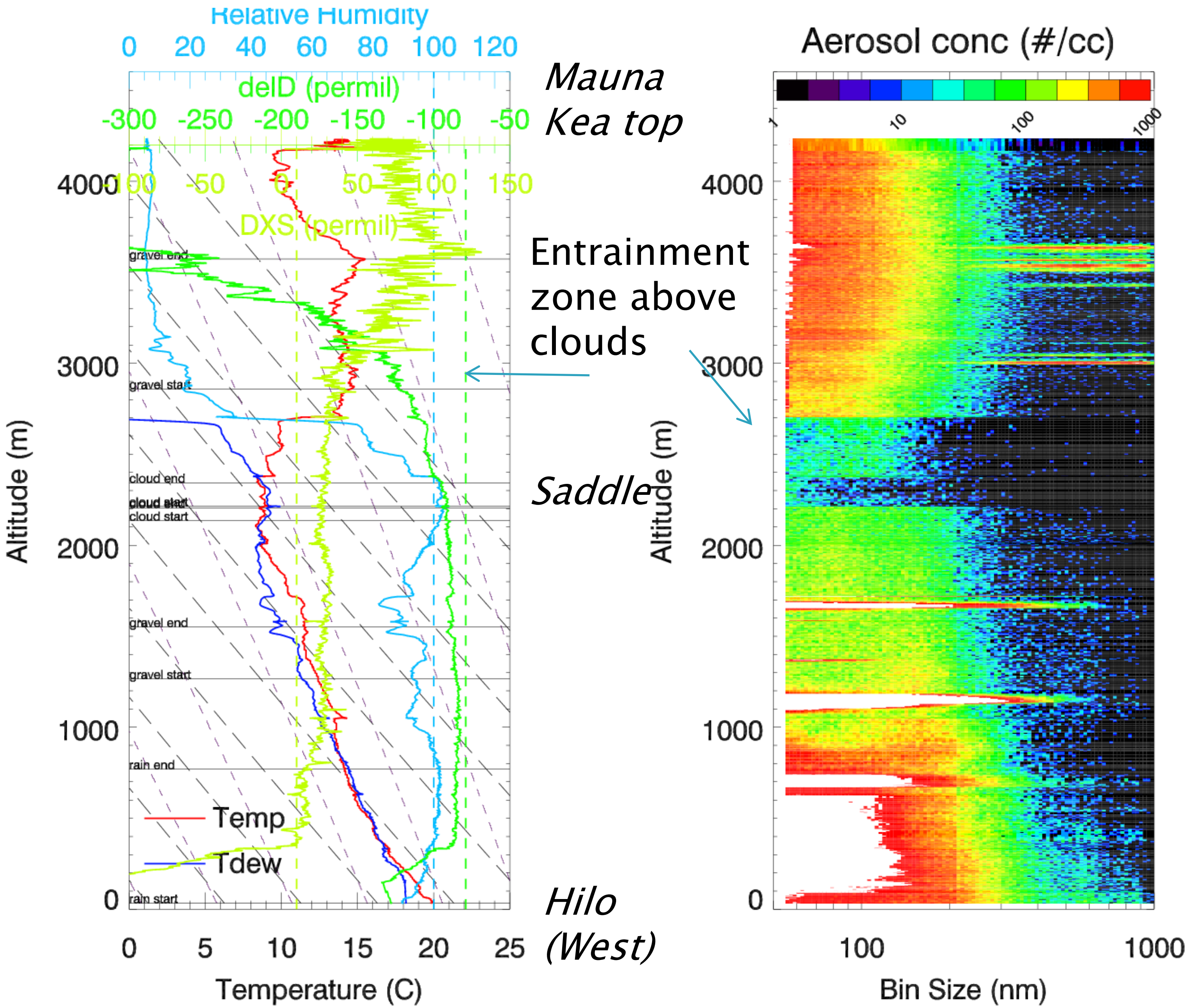


Water isotopes are “daytime” complement tracer to CO_2

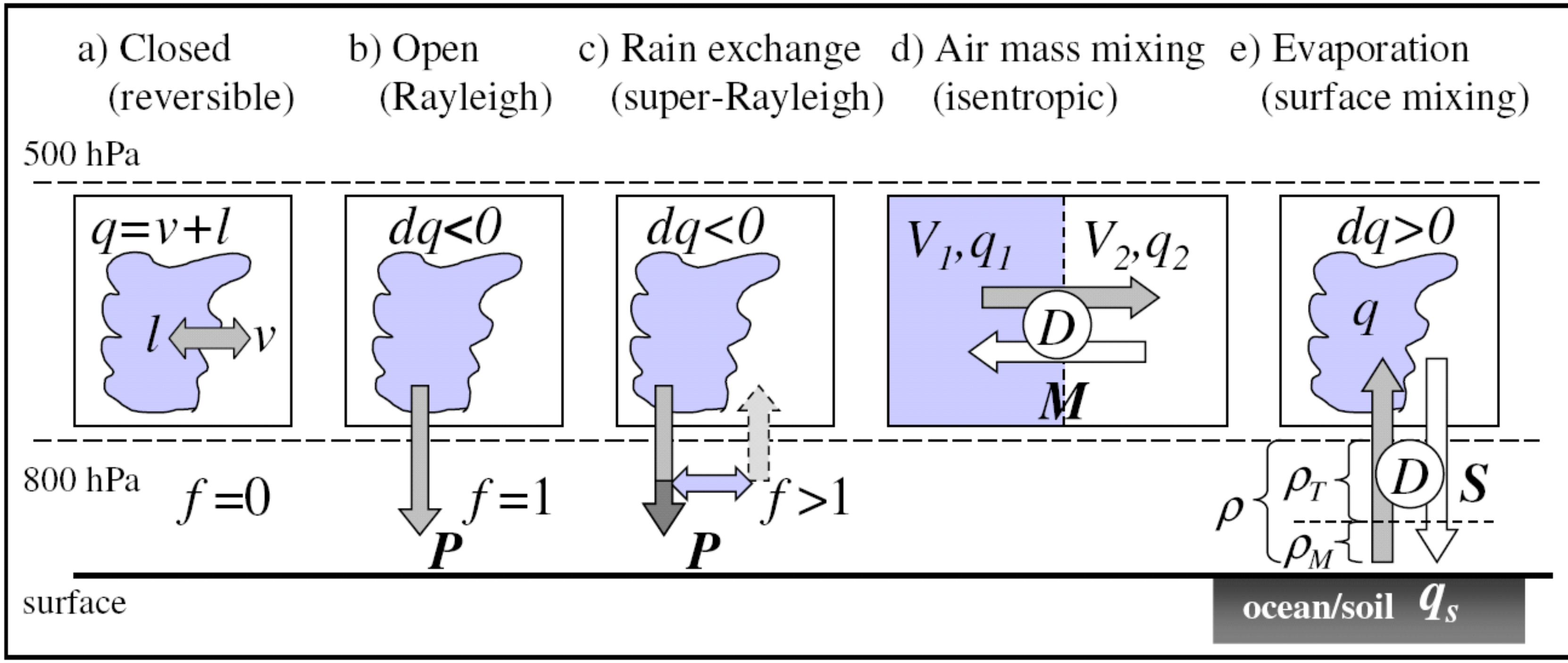
Solving PBL equation can give mixing rate and PNL height. (See Noone and Risi – in prep, or at AGU)



Profile from Hawaii: aerosol

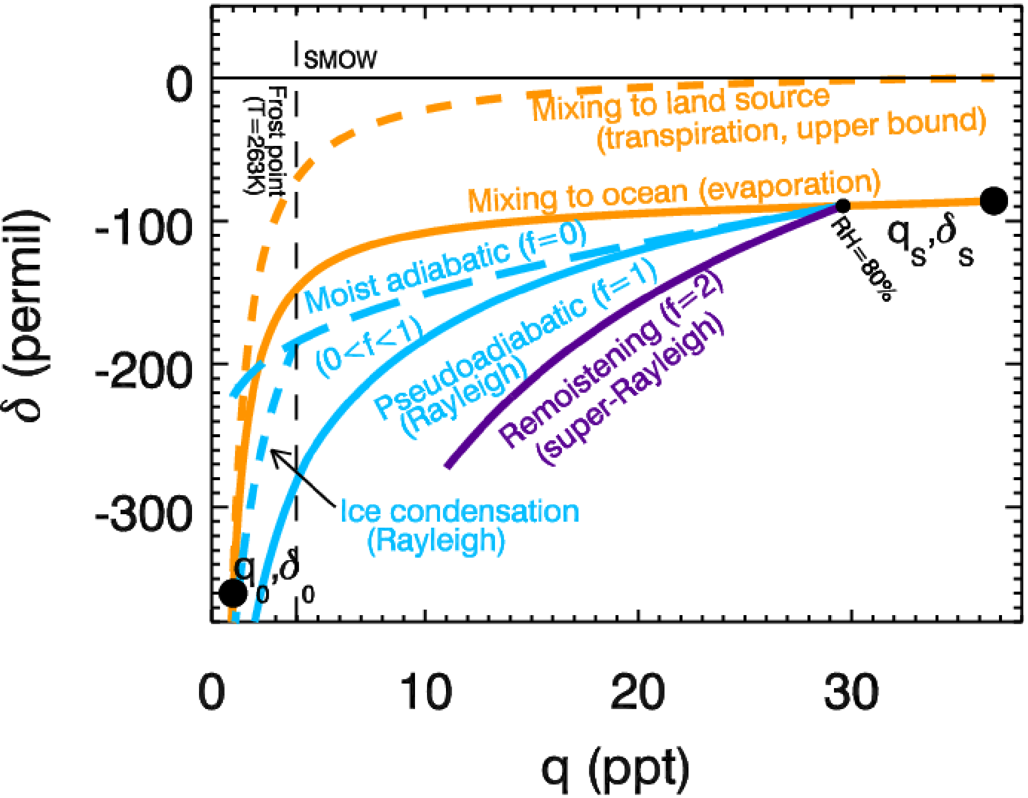


Theoretical framework

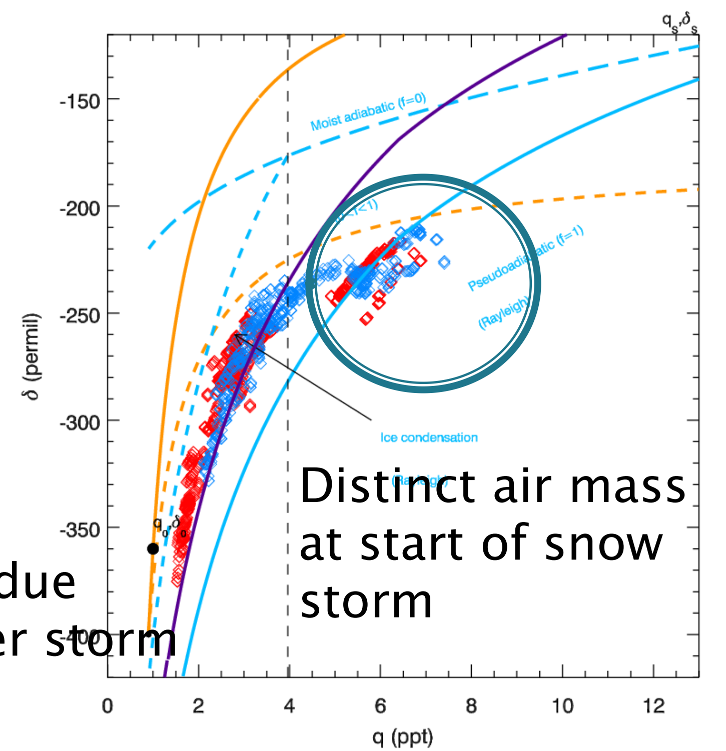


- Simple "box model" expectations for cloud provide a single measure of cloud precipitation efficiency.

Box model predictions
(i.e., theoretical framework)



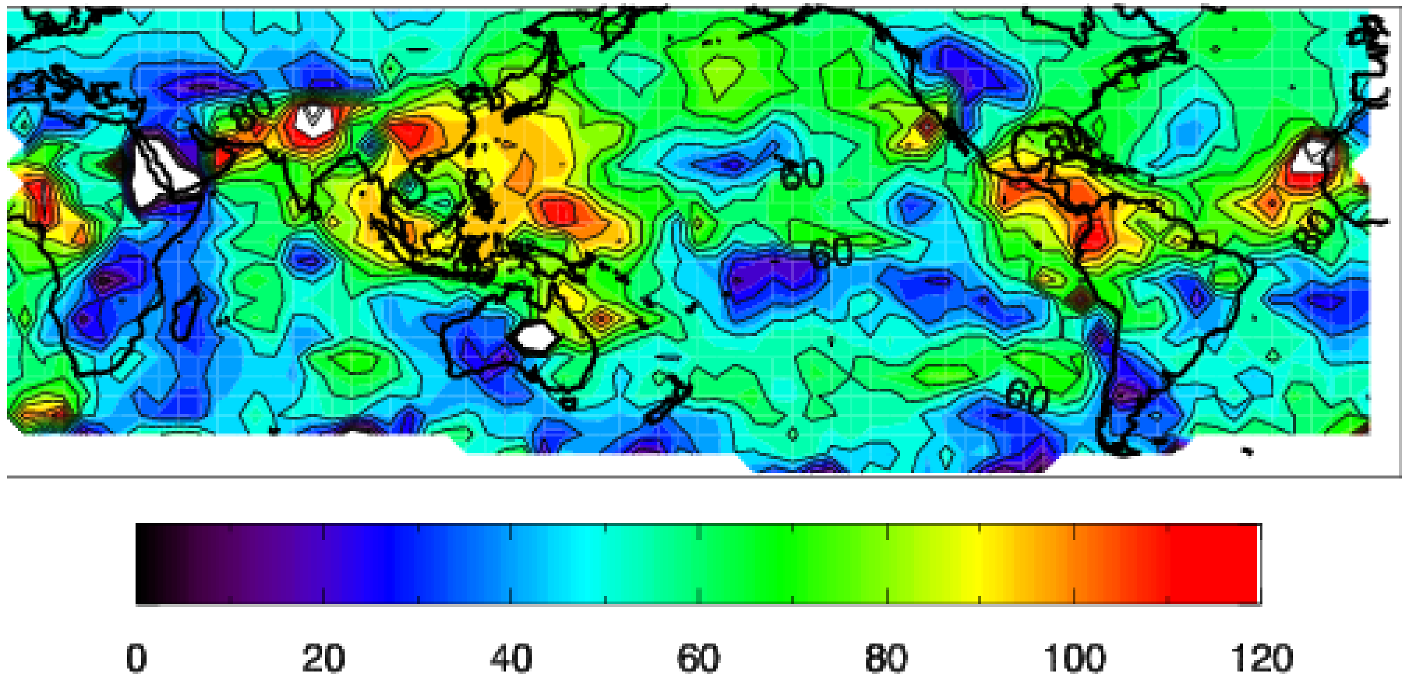
Example from tower
Blue: 10 m
Red: 300 m



Distinct air mass at start of snow storm

Vapor residue from earlier storm

“f”: Rainfall efficiency (JJA)



Using box models, applied to satellite data can deduce precipitation efficiency

Difference between reversible moist adiabatic conditions and pseudo adiabatic conditions is a measure of the rainfall efficiency.

i.e., The fraction of the water is removed from 850-500 hPa layer

(Adapted from Brown et al., 2010, in prep)

Conclusions

- Adds constraints to water budgets, …
  including ***what type of cloud processes***

- Combination of H_2O and isotopic measurements provides
  1) ***very clear signature of air mass mixing***
  (vertical, and distinct lateral air masses)
  2) **type/conditions of cloud and precipitation processes**
  (rain intensity, evaporation of falling rain)

- *Offers opportunity to get a direct measure of precipitation efficiency (in a bulk sense)*

- Clear advantages when combined with modern atmospheric instrumentation
  - Radar remote sensing
  - Boundary layer dynamics
  - Aerosol conditions
  - Surface water and carbon fluxes