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

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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*
“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*
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
Mounted a Picarro Water Vapor Isotope Analyzer on the BAO instrument carriage.
Along with additional sensors
LiCor open path CO₂/H₂O, 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)
Potential temperature contours

Mixing down at night

New air mass (southerly trajectory)

Start snowing

Strong nocturnal jet

Picarro H2O
Slope mixing mode, with “rapid events” Not well captured by turbulence theory

Water isotopes are “daytime” complement tracer to CO₂

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

Mauna Kea top

Entrainment zone above clouds

Saddle

Hilo (West)
Theoretical framework

- Simple “box model” expectations for cloud provide a single measure of cloud precipitation efficiency.
Box model predictions (i.e., theoretical framework)

- Distinct air mass at start of snow storm
- Vapor residue from earlier storm

Example from tower
Blue: 10 m
Red: 300 m
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$_2$O 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