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 ($\delta D$, not $^{18}O$ today)
  – Budget analysis (quick taste)
  – Sources of water (it’s not evaporation!)
• Next steps


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

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.

Ratio of HDO to H$_2$O

Measured as a difference from ocean water.

$$\delta = \frac{R}{R_{ocn}} - 1$$
TES δD climatology (850-500 hPa)

December 2004 – March 2008

Water isotopes

Satellite data
- TES HDO
- also IASI, SCHIAM’Y

Validation
- Spatial context

In situ measurements
- Traditional sampling (IRMS), commercial optical analyzers (LGR, Picarro)

Evaluation, statistical reliability

Models
- Isotope enabled (CAM, GISS, ... ~10)

Process studies
- (Clouds, land surface exchange...)

Climate, water cycle feedbacks, water resources

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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General agreement between instruments
  Some differences in details
Dominant diurnal cycle
  Very dry night (free troposphere)
  Boundary layer during daytime
Enormous!

Instruments sensitive < 1 permil

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

troposphere
marine boundary layer

Enormous!

Hour of day (local)

H₂O v.m.r. (ppt)

δD (%)
Noone et al., JGR, in prep
Column precipitable water

Dry, subtropical nights

Moist, “river” outflow
### Theoretical guidance: box budgets

<table>
<thead>
<tr>
<th>a) Closed</th>
<th>b) Open</th>
<th>c) Rain exchange</th>
<th>d) Air mass mixing</th>
<th>e) Evaporation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(reversible)</td>
<td>(Rayleigh)</td>
<td>(super-Rayleigh)</td>
<td>(isentropic)</td>
<td>(surface mixing)</td>
</tr>
</tbody>
</table>

#### Reversible moist adiabatic

\[ E_i = E_f + l(v + l) \]

#### Pseudoadiabatic

\[ \frac{dq}{q} < 0 \]

\[ \frac{dq}{q} > 0 \]

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**Surface**

<table>
<thead>
<tr>
<th>500 hPa</th>
<th>800 hPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f = 0 )</td>
<td>( f = 1 )</td>
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</table>

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**Condensation**

\[
(\delta - \delta_0) = (\alpha - 1) \ln \left( \frac{q}{q_0} \right) \\
\alpha = \frac{\alpha_e}{\alpha_e (1 - f) + f}
\]

**Mixing/hydration**

\[
\delta \approx \frac{R}{R_s} - 1 = -\left[ \hat{q} \left( \delta - (1 - H) \right) \right] \frac{1}{q} - (1 - H) \\
H = \left( \hat{q}_i - q_{i,0} \right) \left( \hat{q} - q_0 \right)^{-\eta}
\]

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Noone, J, *Climate, in review*
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)

(Noone, in review)
“6 easy pieces”
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

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

HAVAIKI

• 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 (CO₂, aerosols, …)
Deep anvil and cirrus cloud freezing

Shallow detrainment

Diabatic cooling

Diabatic heating

Radiative cooling

Eddies

MBL top

MLO

tropopause