Using Satellite Based Measurements of Water Vapor and its Isotopes to Quantify Water Cycle Sources and Processes

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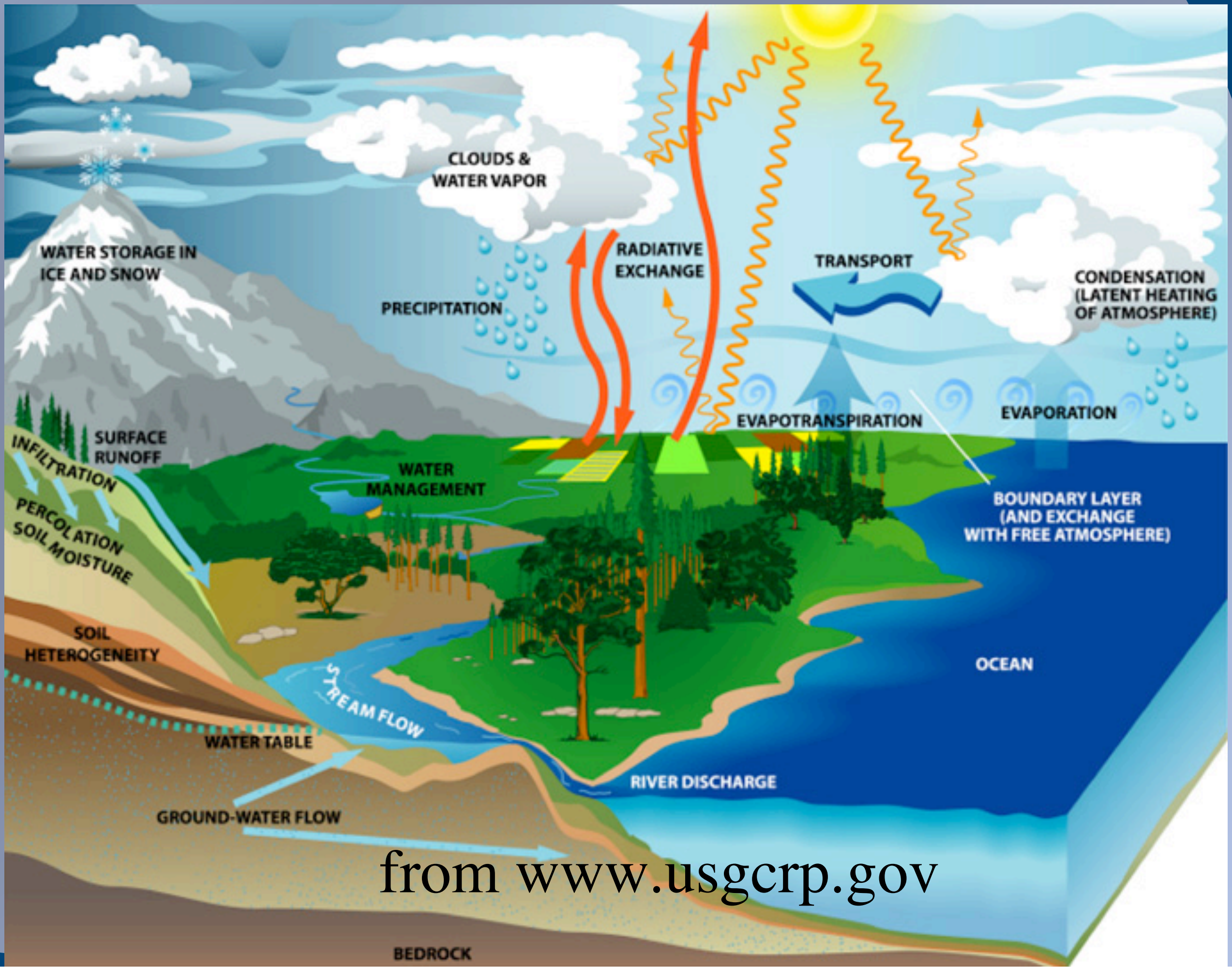
What are the water vapor feedbacks, or alternatively, what is the radiative response to changes in the water cycle?

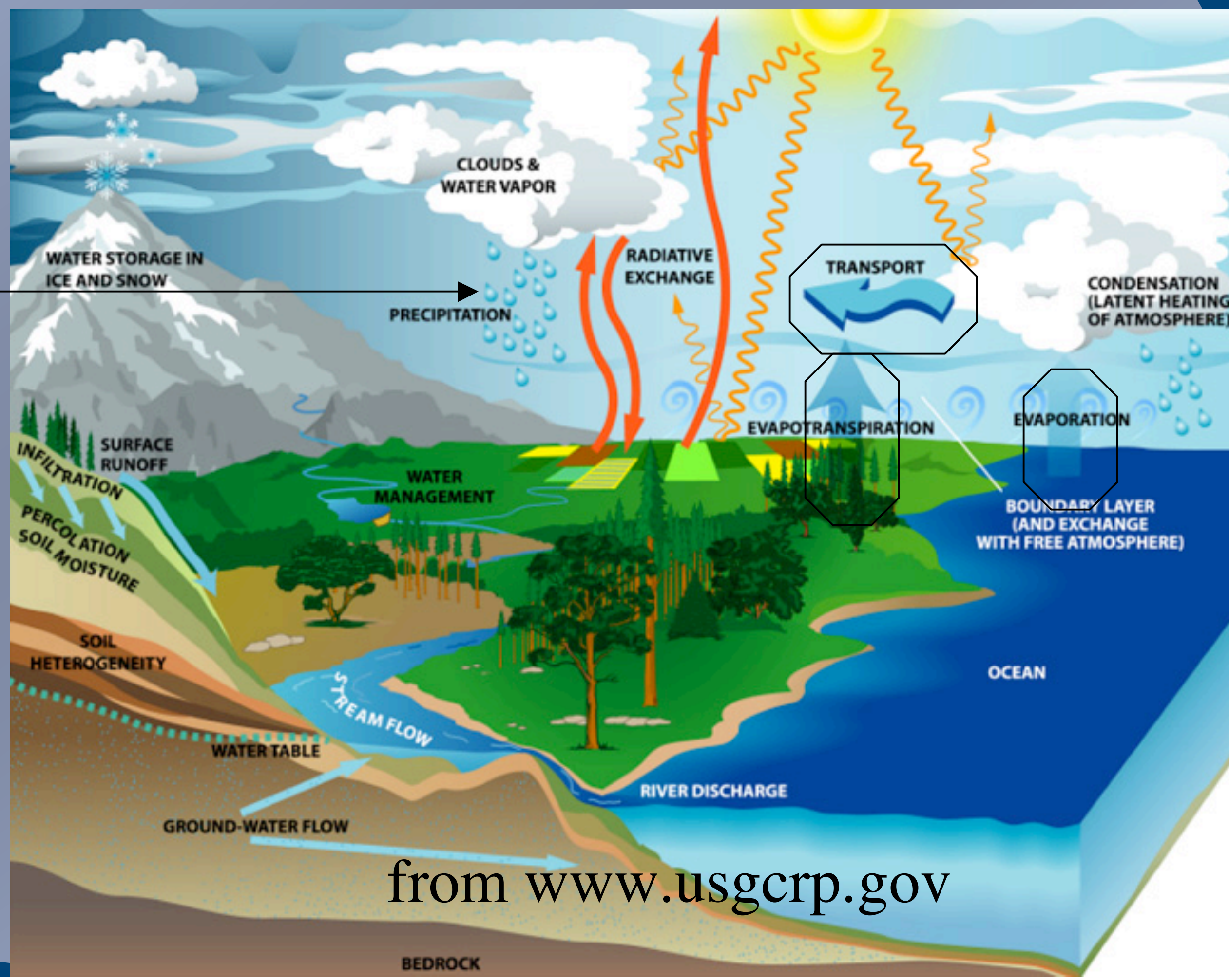
- Vertical distribution of water in its different phases affect the incoming and outgoing radiation in different ways
- Understanding the feedbacks or radiative response to changes in the water cycle require characterization of these distributions as well as the exchanges between phases of water and the sources of this water
- Hydrology focused satellite instruments and in situ measurements are typically of the distribution of water in its different phases and use these distributions (as well as ancillary information) to infer exchange efficiency between the phases
- Uncertainties in these measurements significantly affect estimates of the distribution of exchange processes



from www.usgcrp.gov

How will water availability change with a changing climate?

Precipitation depends on distribution of moisture sources and moisture processing during transport



from www.usgcrp.gov

Global uncertainty of P-E still ~10% and regional uncertainties much higher

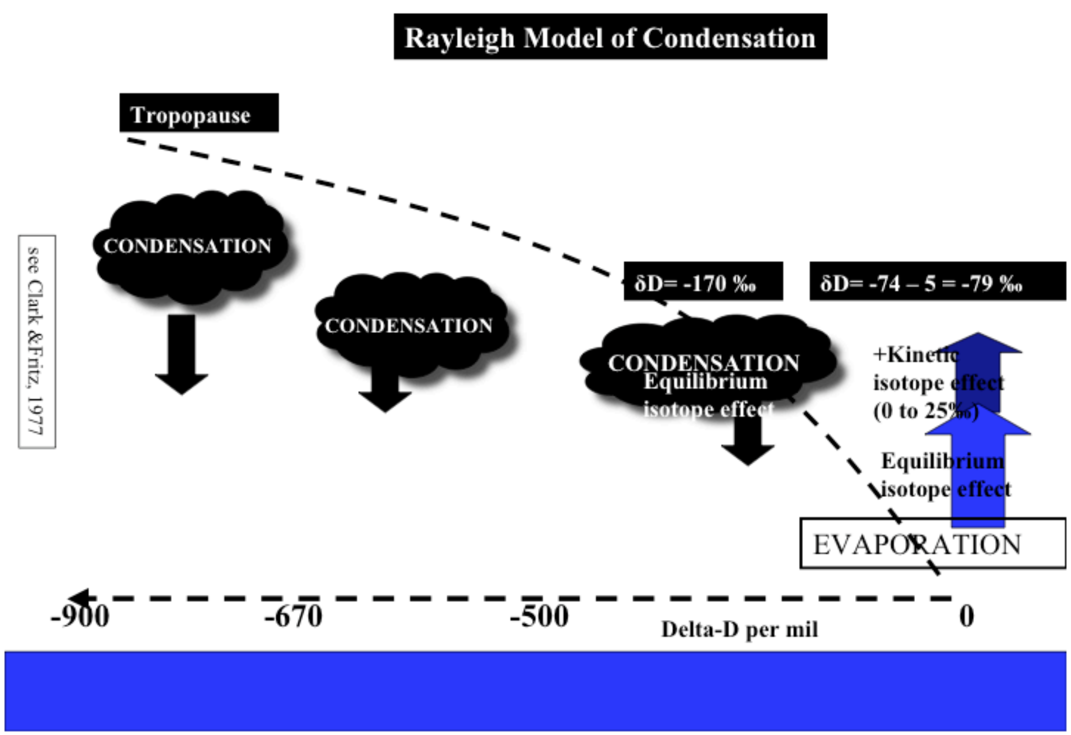
(e.g., Wentz et al., Science 2007 and refs therein)

Measurements of the isotopic composition of water help constrain the tropospheric moisture budget by providing information about the condensation and evaporation history as well as the source regions

Characteristics of isotopes:

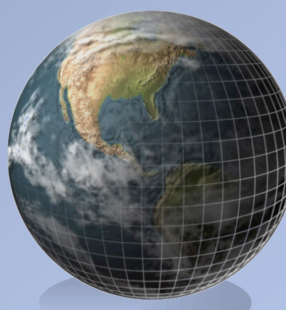
Lighter isotopes preferentially evaporate. Heavier isotopes preferentially condense.

The isotopic composition of ocean waters and vapor evaporated from the ocean is well known which helps mark the water source of the observed air parcel

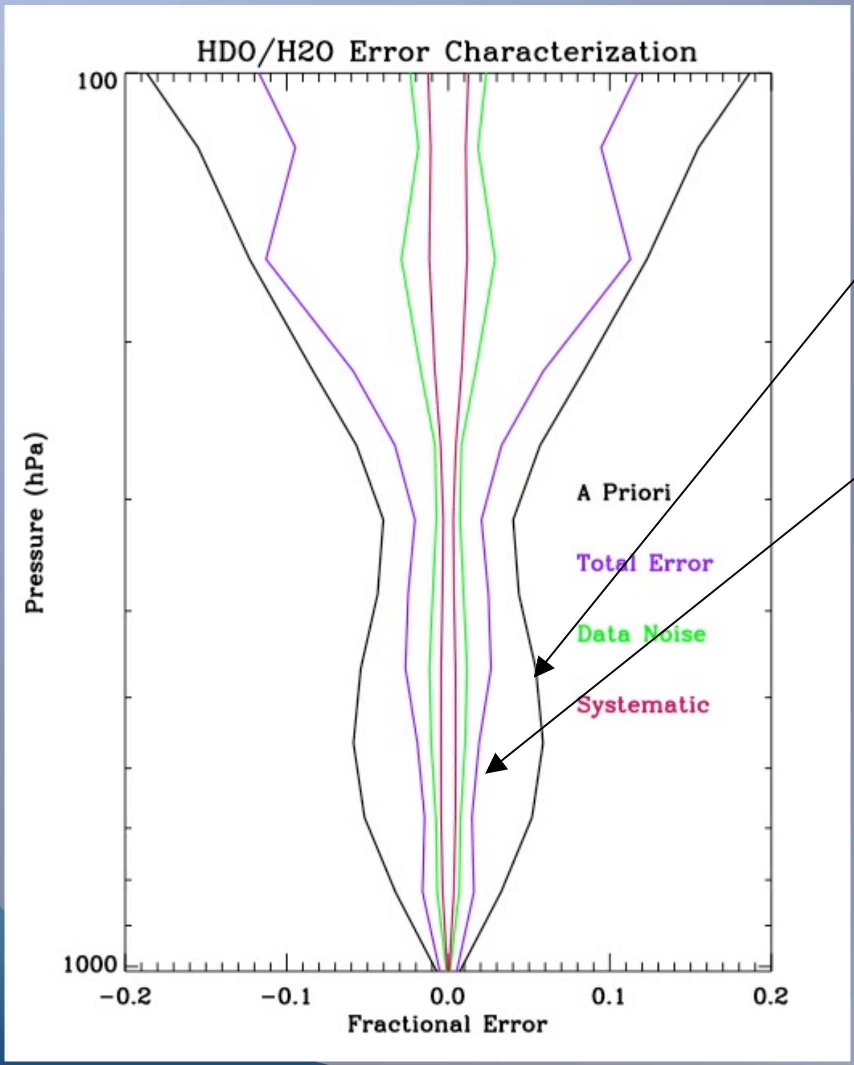


Reference for water isotopes is the Standard Mean Ocean Water (SMOW) = 3.1 x 10^{-4} HDO/H_2O

$$\delta D = 1000\left(\frac{HDO}{H_2O} / SMOW - 1\right)$$



Description of errors: Use of Simultaneous HDO/H_2O Retrieval Minimizes Error of H_2O on HDO and Vice Versa:



5% A Priori Uncertainty in the HDO/H_2O ratio (we now know this is too conservative)

~1.5% A Posteriori Uncertainty in the HDO/H_2O ratio

Initial Comparison of TES data, models, and aircraft observations of the subtropical free troposphere indicate a 5% bias correction needed

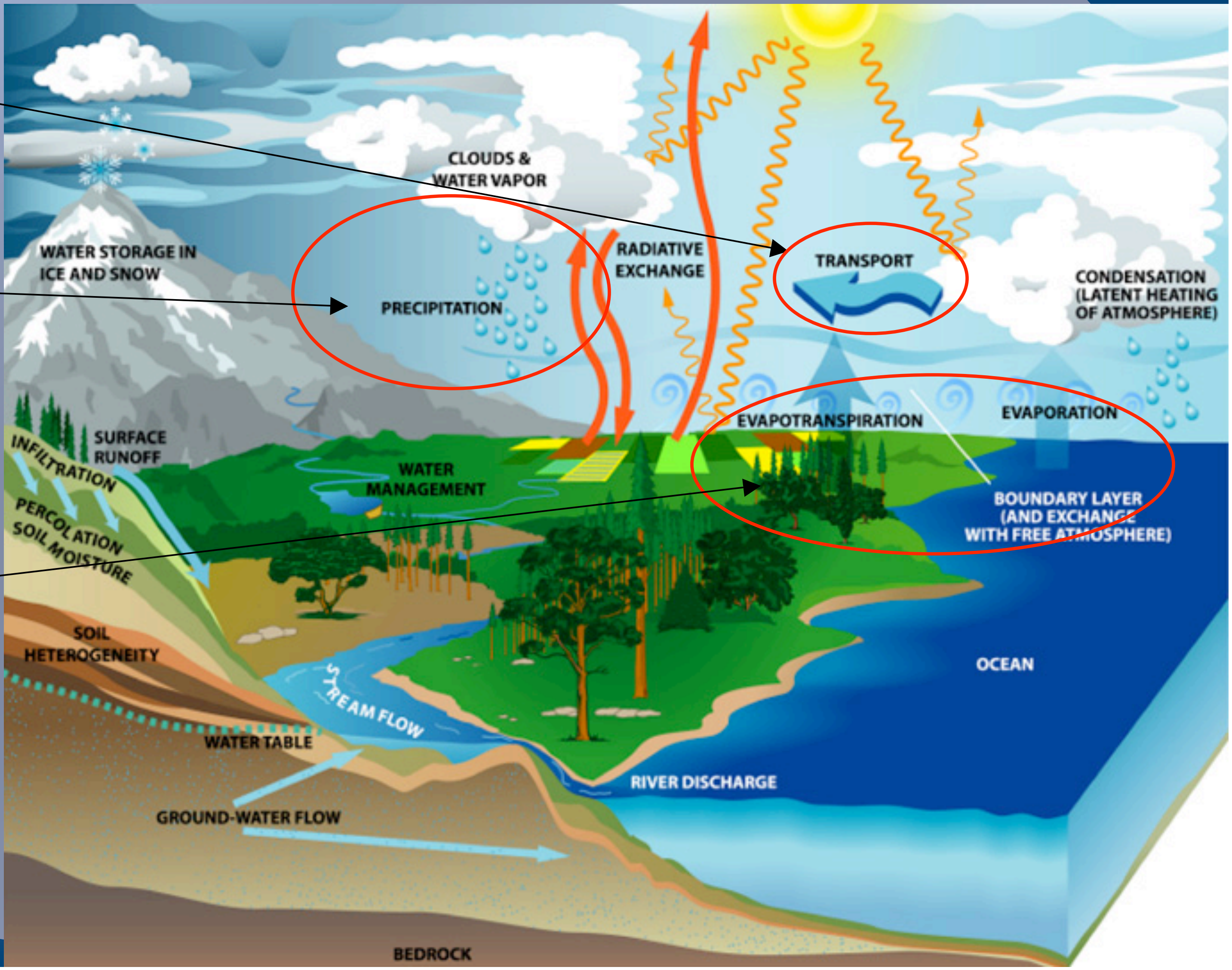
See Worden et al., 2006 for more details on error calculation

Global TES tropospheric water isotope observations can primarily examine…..

Transport of vapor

Efficiency that vapor is converted to precipitation and back again

Exchange from PBL to free troposphere



Isotopic composition of vapor is more depleted at high latitudes as vapor is lost to precipitation

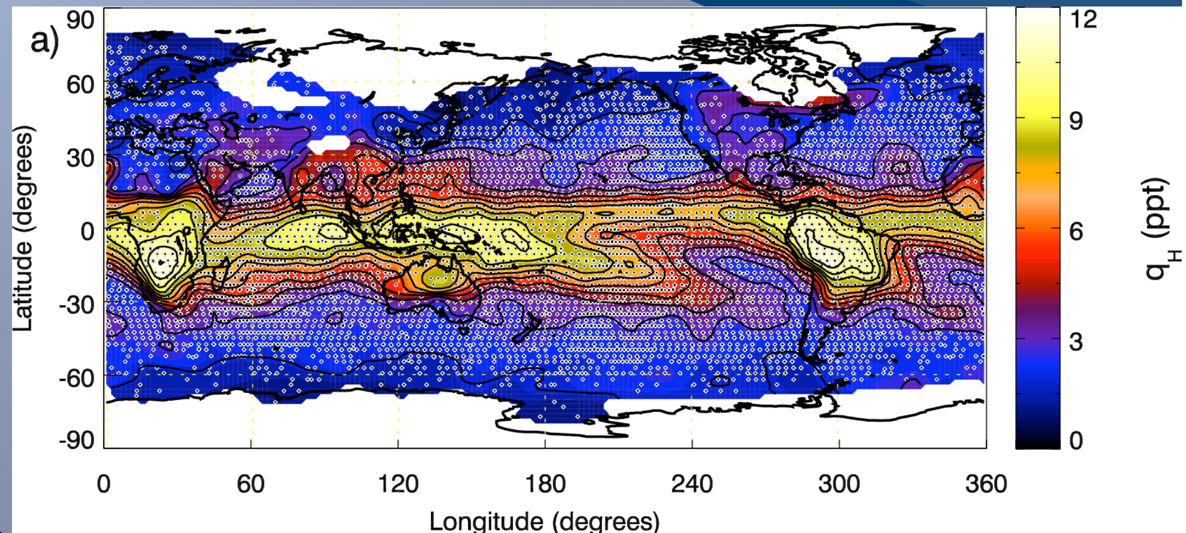
Relatively enhanced isotopic composition over land: signature of convective lofting of boundary layer vapor and evapo-transpiration

(e.g. Salati et al. 1979)

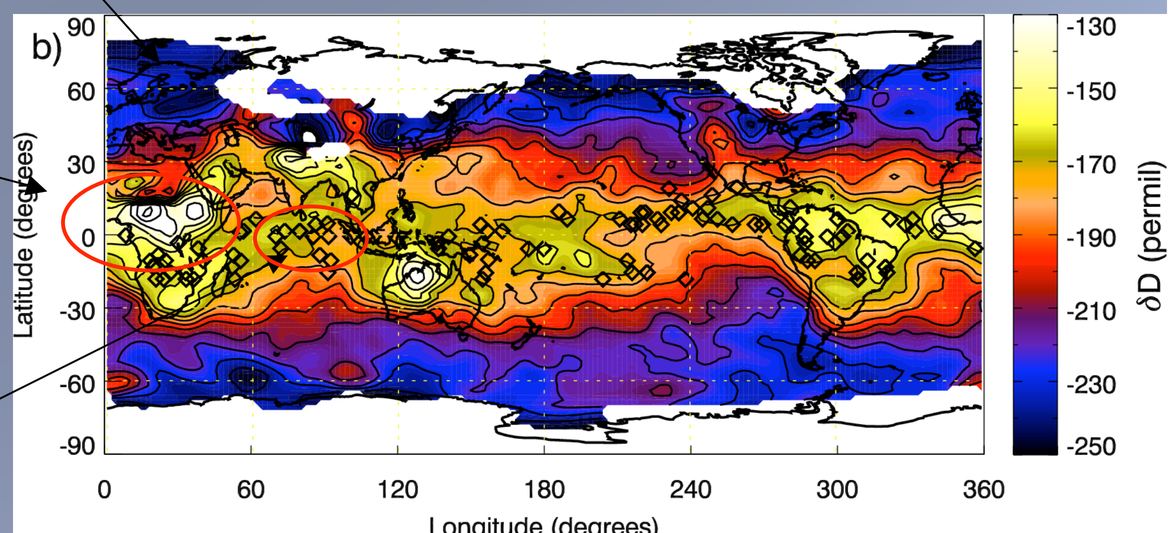
Isotopic Composition relatively low in regions of high rainfall indicate recycling of depleted vapor back into cloud systems (Diamonds)

(e.g. Lawrence et al. 2004, Risi and Boni 2008)

TES H_2O Nov - Jan 2005



TES Delta-D (550-800 hPa) Nov - Jan 2005

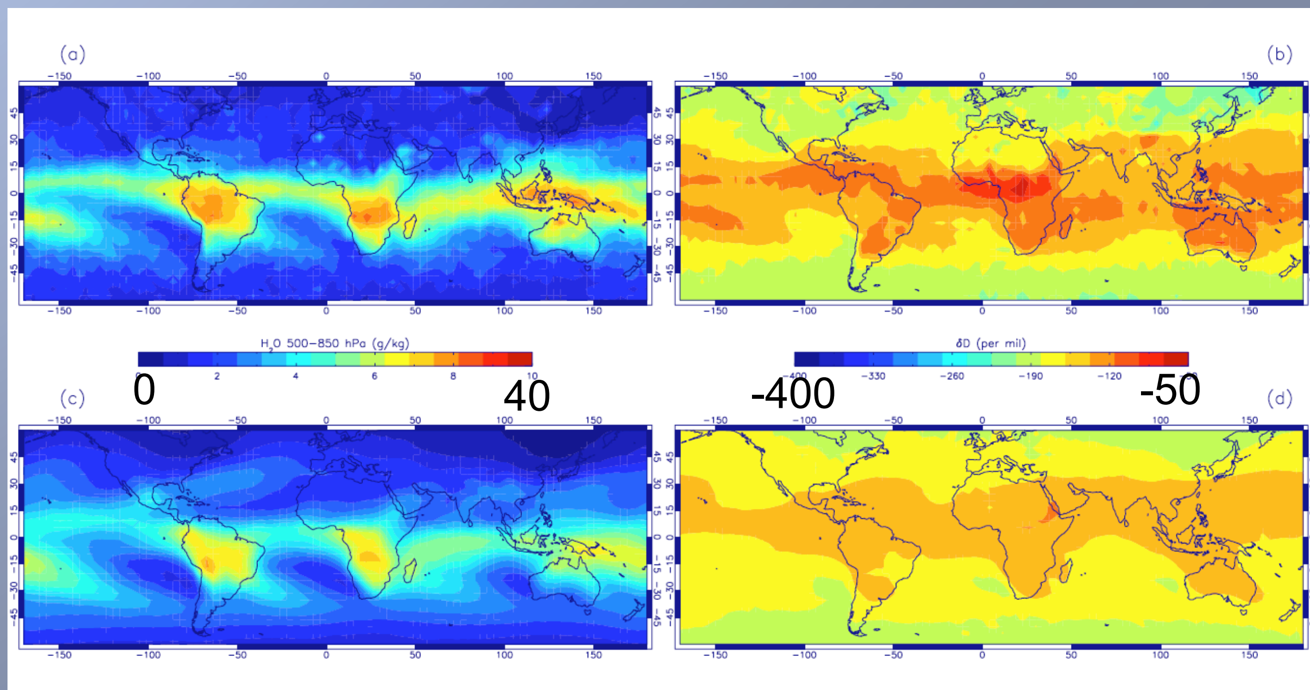


From Worden, Noone, Bowman et al. Nature, 445, 528-532, 2007

Comparison between TES and NCAR CAM with Isotopes

TES H_2O (g/kg)

TES δD (per mil)



CAM H_2O

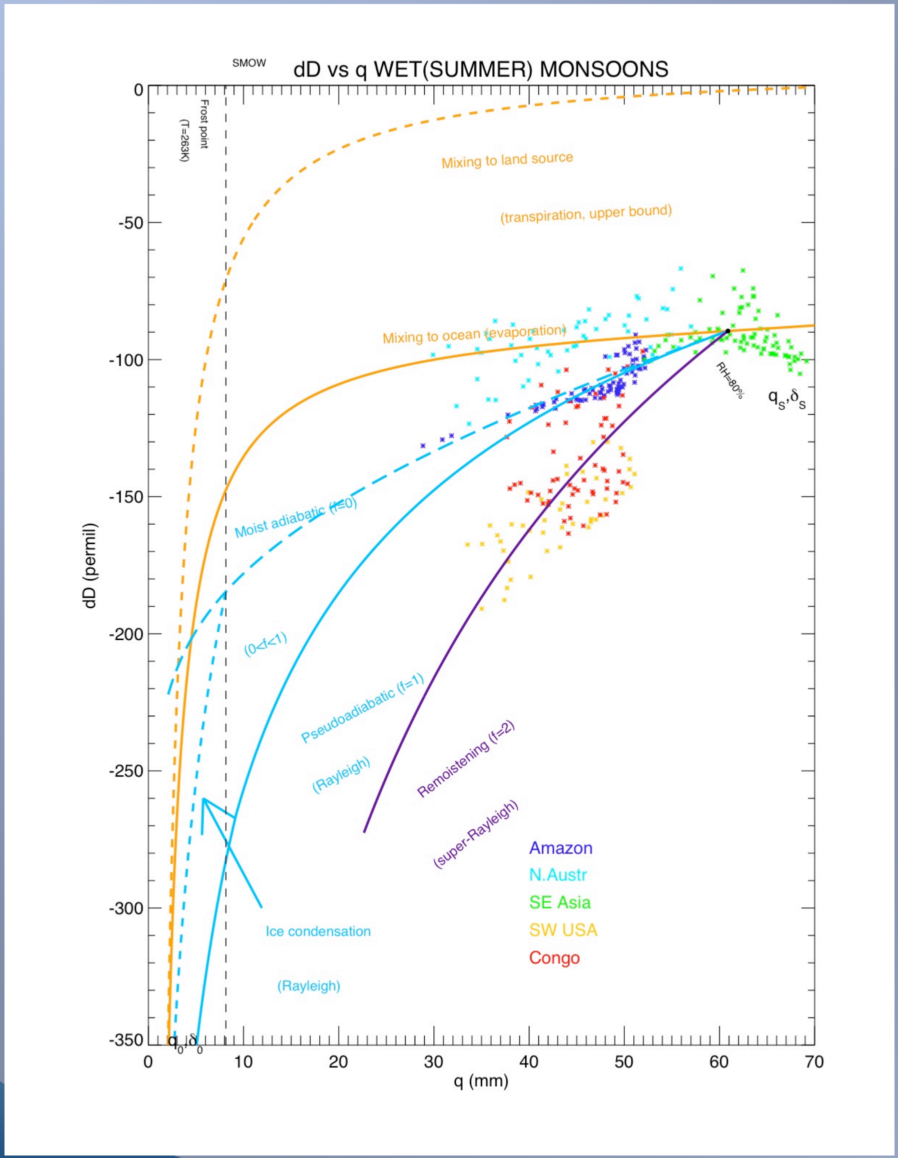
CAM δD

- *TES observation operator applied to model.*
- *The variability in tropics consistent, but peak latitude values from the NCAR CAM is different from that of TES.*
- *Not enough mixing due to sub-grid scale convection*

Collaboration with David Noone (U. of Colorado, and Gavin Schmidt GISS)

J Lee et al., in prep

Identifying processes controlling Monsoon Precipitation



Amazon vapor is relatively "fresh" and can be linked back to water source after simple condensation processes

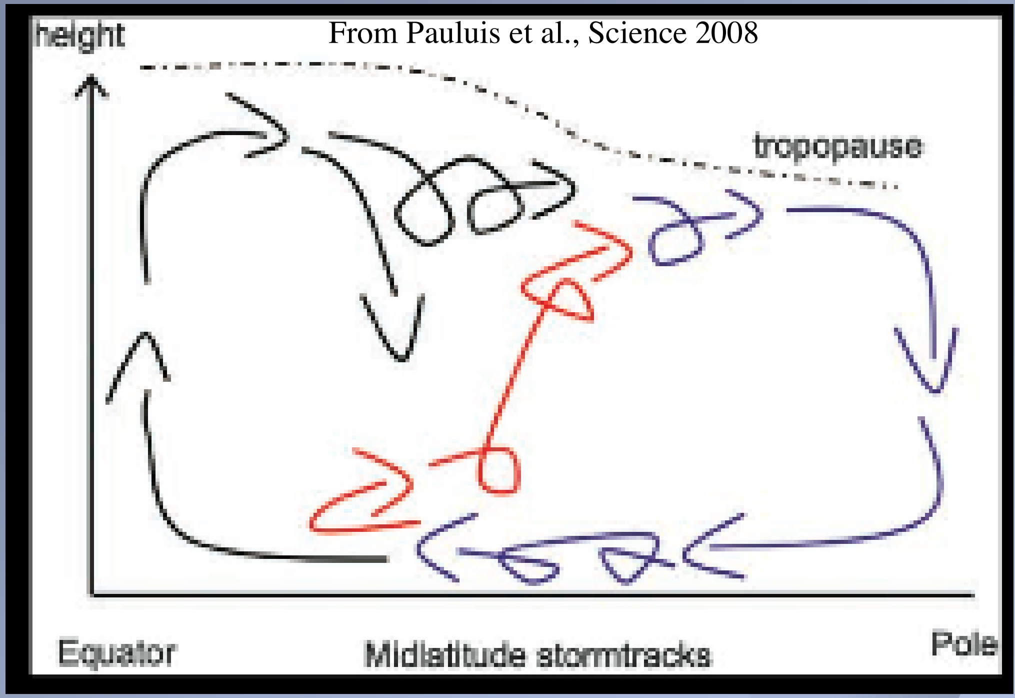
Monsoon regions over the Congo and Western USA show significant re-evaporation

Vapor over Asian monsoon is very fresh and also shows signature of evapo-transpiration

Estimating Moisture Sources, Sinks, and Transport at High Latitudes

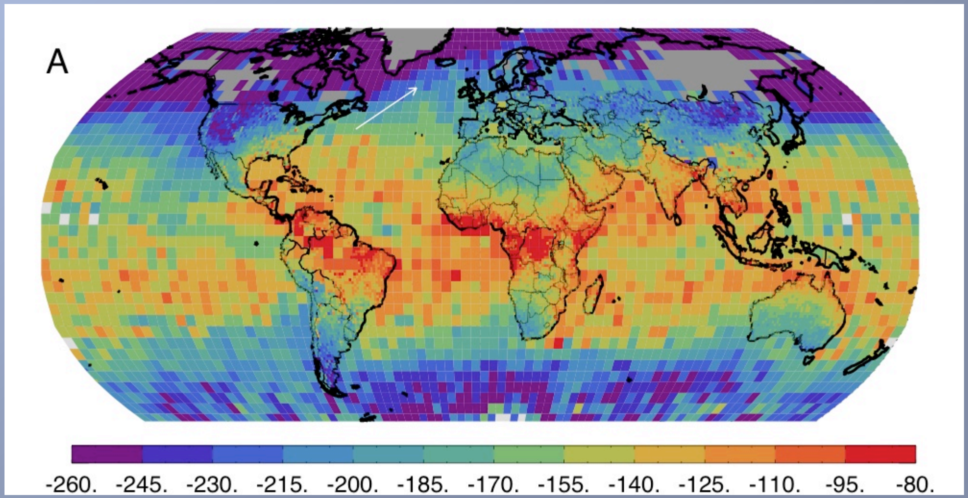
Use 2-D model with averaged wind fields to retrieve moisture sources and sinks by matching latitudinal gradients of H2O and delta-D to the 2-D model

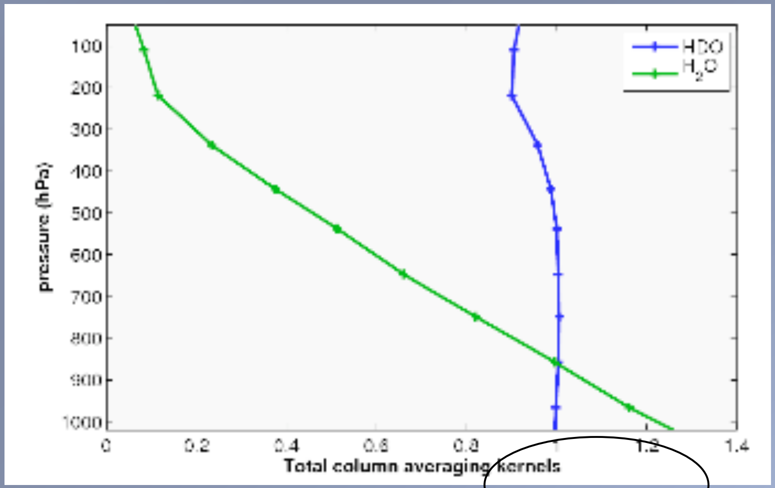
Collaboration with Eric Posmentier and Xiahong Feng at Dartmouth



Water Isotope Measurements form SCIAMACHY

Global Coverage using near IR reflected sunlight measurements provides sensitivity to water vapor isotopes in the PBL

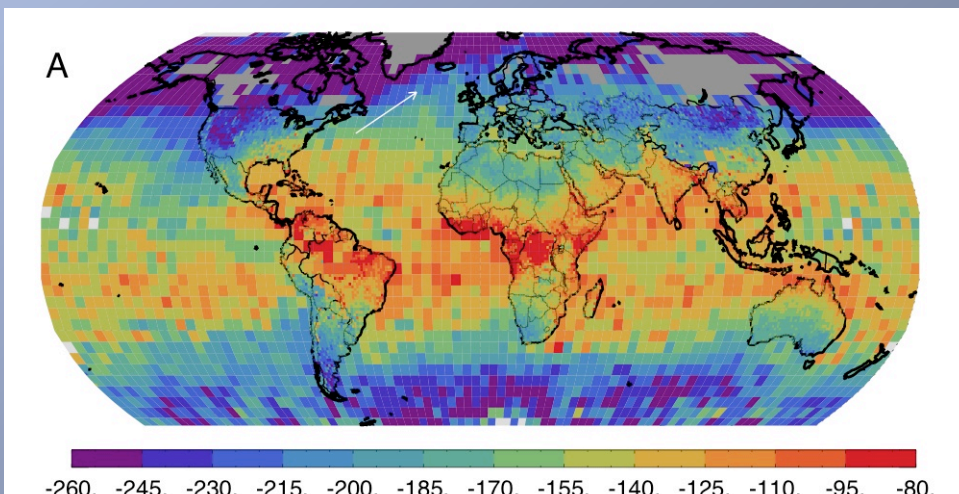


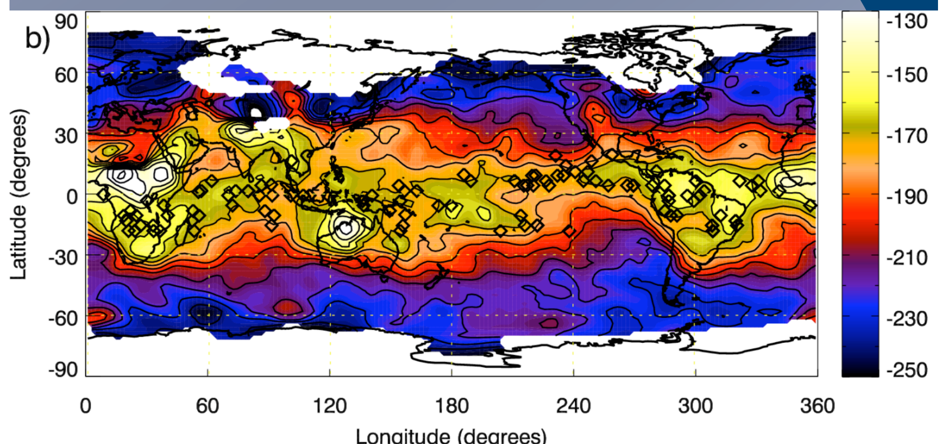


Frankenberg et al., 2009 Science Accepted

Best overall sensitivity to HDO/H2O ratio in PBL

Next Steps: Combine Sciamachy data with TES data to estimate mixing processes between PBL and Lower Troposphere as well as partition different terrestrial and ocean sources





Summary:

New global measurements of water vapor isotopes add a new dimension for quantifying tropospheric moisture sources and distribution of moist processes

These measurements can also improve understanding of the linkages between paleo-climate records of water isotopes to climate processes

Future Mission Concept:

Ideally we would like to quantify evaporation of vapor into the PBL, mixing between the PBL and free troposphere, cloud processes and precipitation, and impact of re-evaporation in upper troposphere on large-scale circulation and on tropospheric moisture

Vertically resolved measurements of H_2O and the HDO/H_2O ratio in the PBL, lower troposphere and upper troposphere, as well as cloud distributions can better characterize the distribution of these processes.

Idea: Multi-Spectral Approach to improve vertical resolution (example is PanFTS IIP, Stan Sander PI)

(a) Combine optically thick lines at ~1400 cm^{-1} with radiances near ~1200 cm^{-1} at TES spectral resolution to better resolve pressure broadening and reduce impact of interfering species

(b) Add near-IR radiance measurements to obtain total column capability, which in conjunction with profiling capability from IR should improve sensitivity to PBL (e.g., Worden et al., 2007)