Observations of the isotopic composition of vapor and condensed water in the tropical tropopause layer

Harvard ICOS/HOxotope
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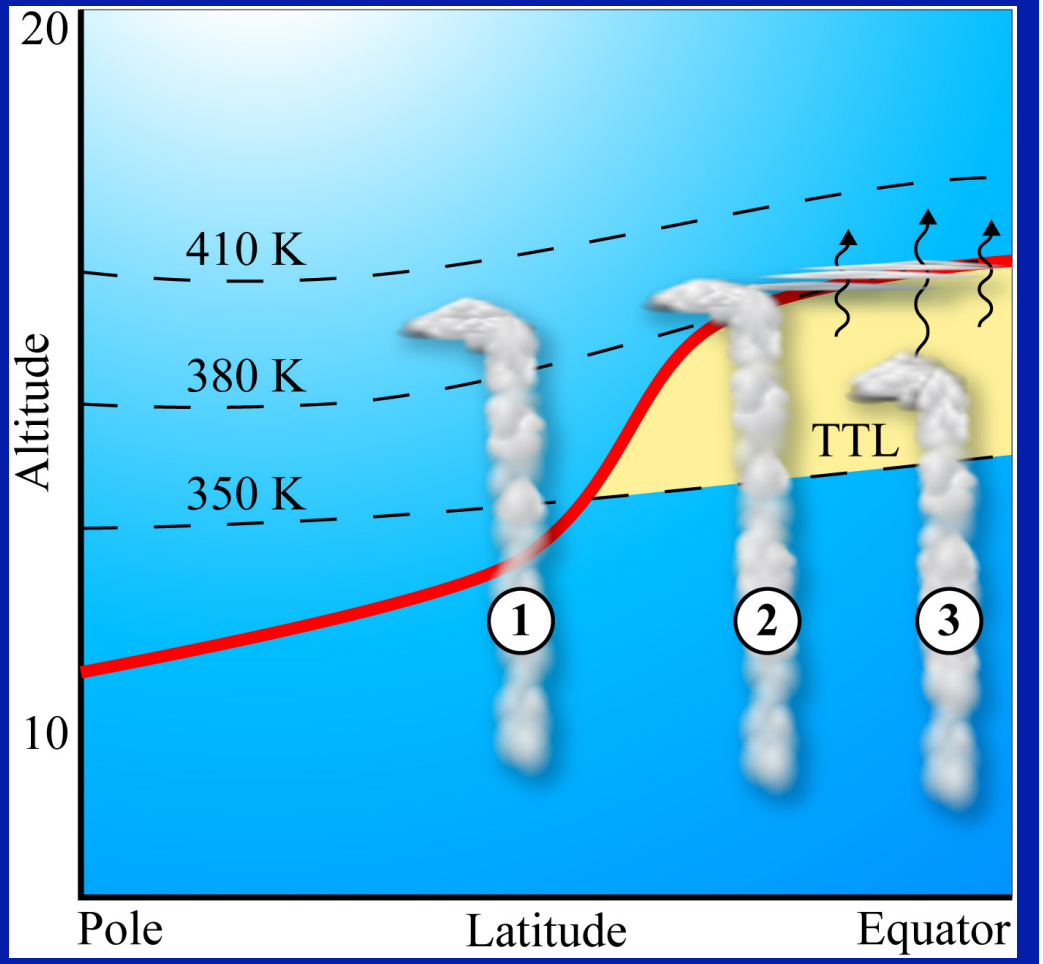
Hydration pathways

H_2O and H_2O isotopes observations can be used to quantify:

1) Ice lofting and convective outflow above 380 K in mid-lats
2) Ice lofting into the tropical stratosphere
3) Convective influence in the TTL

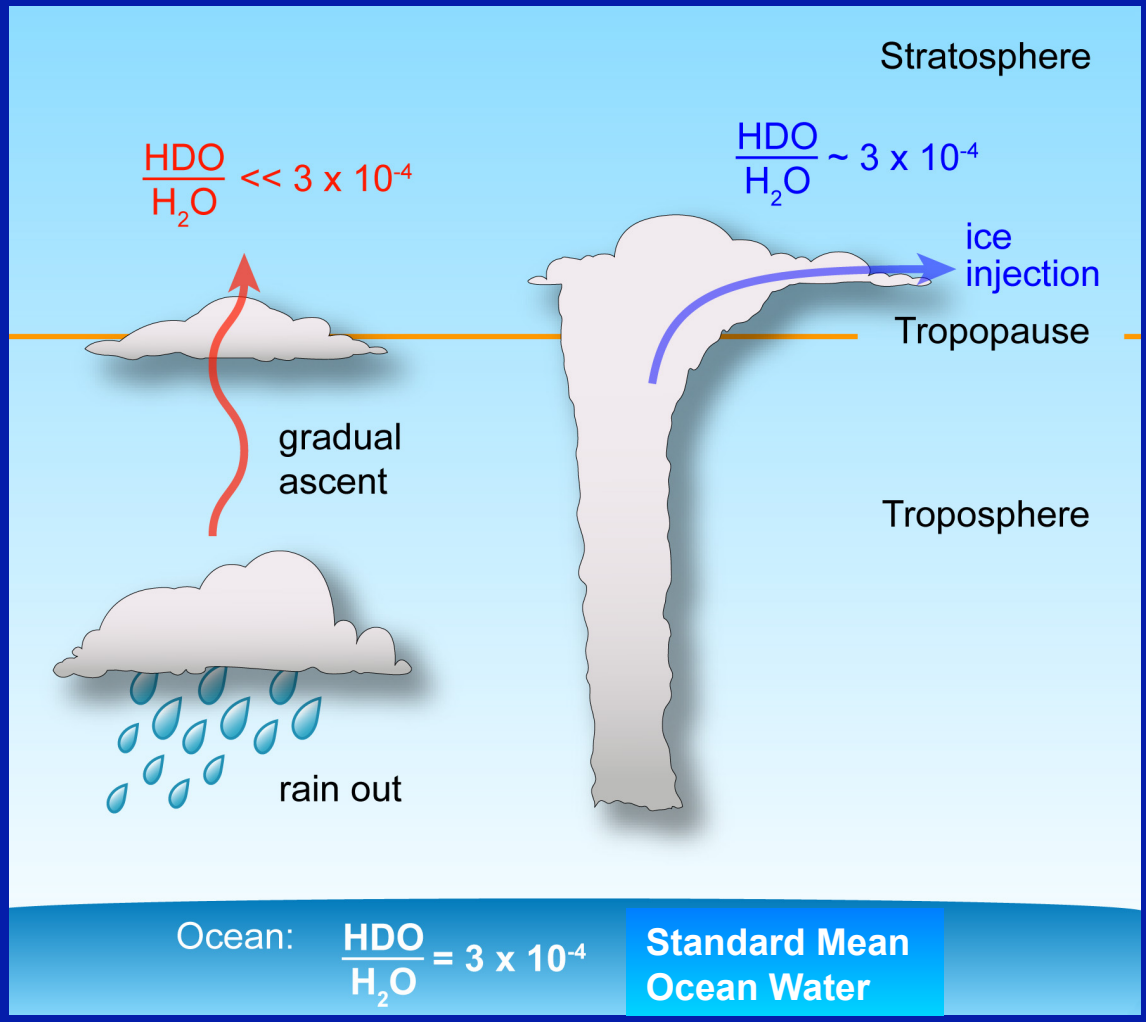
The isotopically heavy stratosphere indicates that the sum of 1 – 3 is significant.

What is the relative contribution of these pathways?



Water isotopes as tracers of Convection

- HDO condenses more readily than H_2O
- Rainout leads to HDO depletion
- Ice injection can make the stratosphere “Heavy”
- *In situ* water isotope measurements can offer a tracer for the condensation history of air parcels



$\delta D = 1000 (HDO/H_2O/SMOW – 1)$

ICOS Isotope Instrument

- Mid-IR absorption spectroscopy using new cavity-based technique
- *(Integrated cavity output spectroscopy)*
- Enhanced sensitivity (x 40) because of 4 km optical path
- Multiple species (H_2O, HDO, $H_2{}^{18}O$, $H_2{}^{17}O$, CH_4)

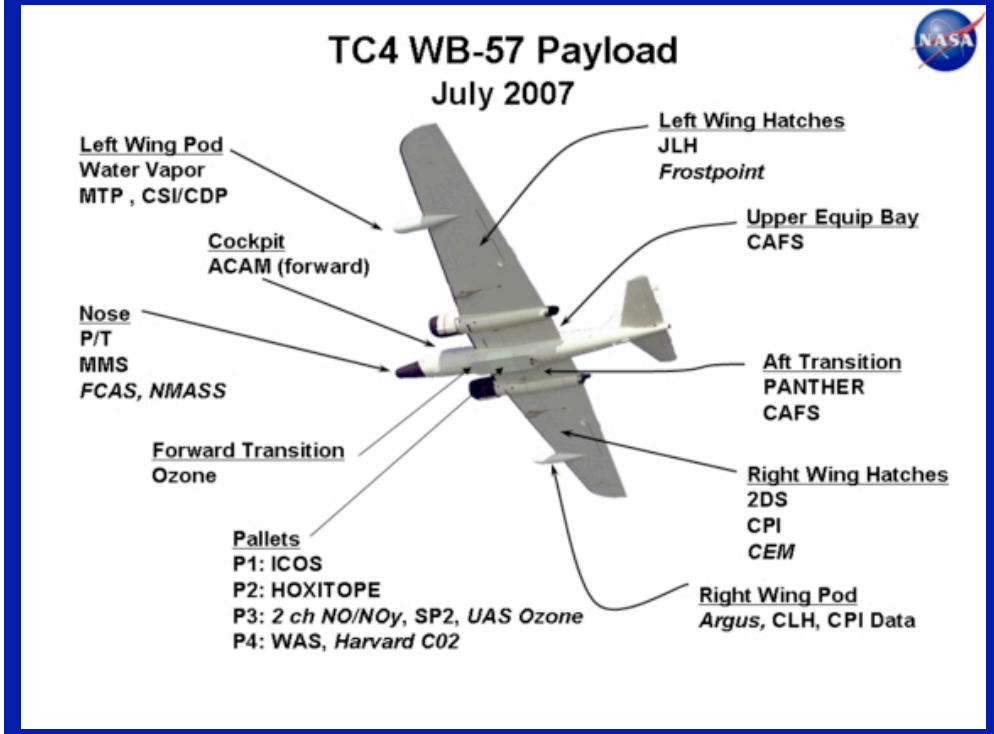
D.S. Sayres, *et al., in prep.*

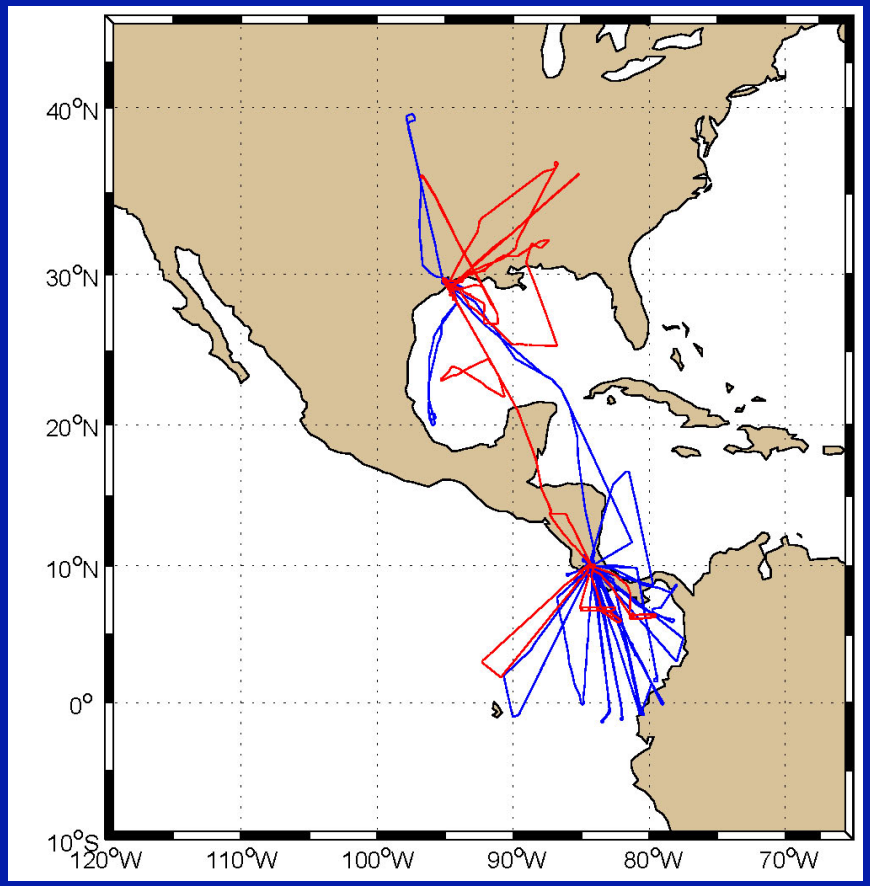
Hoxotope total water isotope instrument

- Photofragment laser-induced fluorescence of OH and OD
- *(Heritage of Harvard HOx instrument)*
- Contamination-free sampling (HO_X radicals lost on wall contact)
- Improved sensitivity (x 2-10) over conventional techniques

J. M. St.Clair, *et al., Rev. Sci. Instrum., 2008*

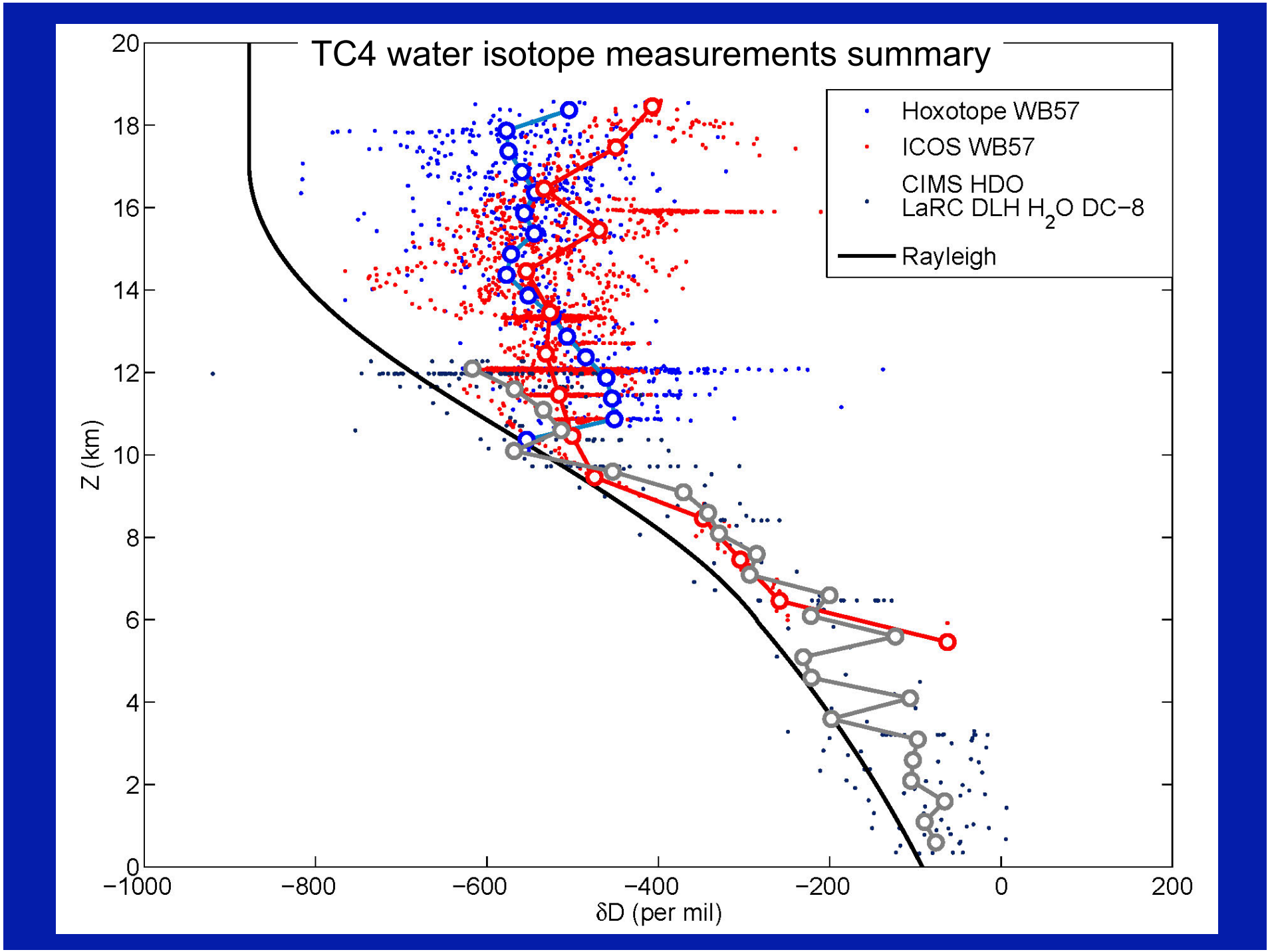
AVE_WIIF, CR_AVE, TC4





Blue Lines: CR-AVE Winter 2006

Red Lines: AVE-WIIF, TC4 Summer 2005 and 2007

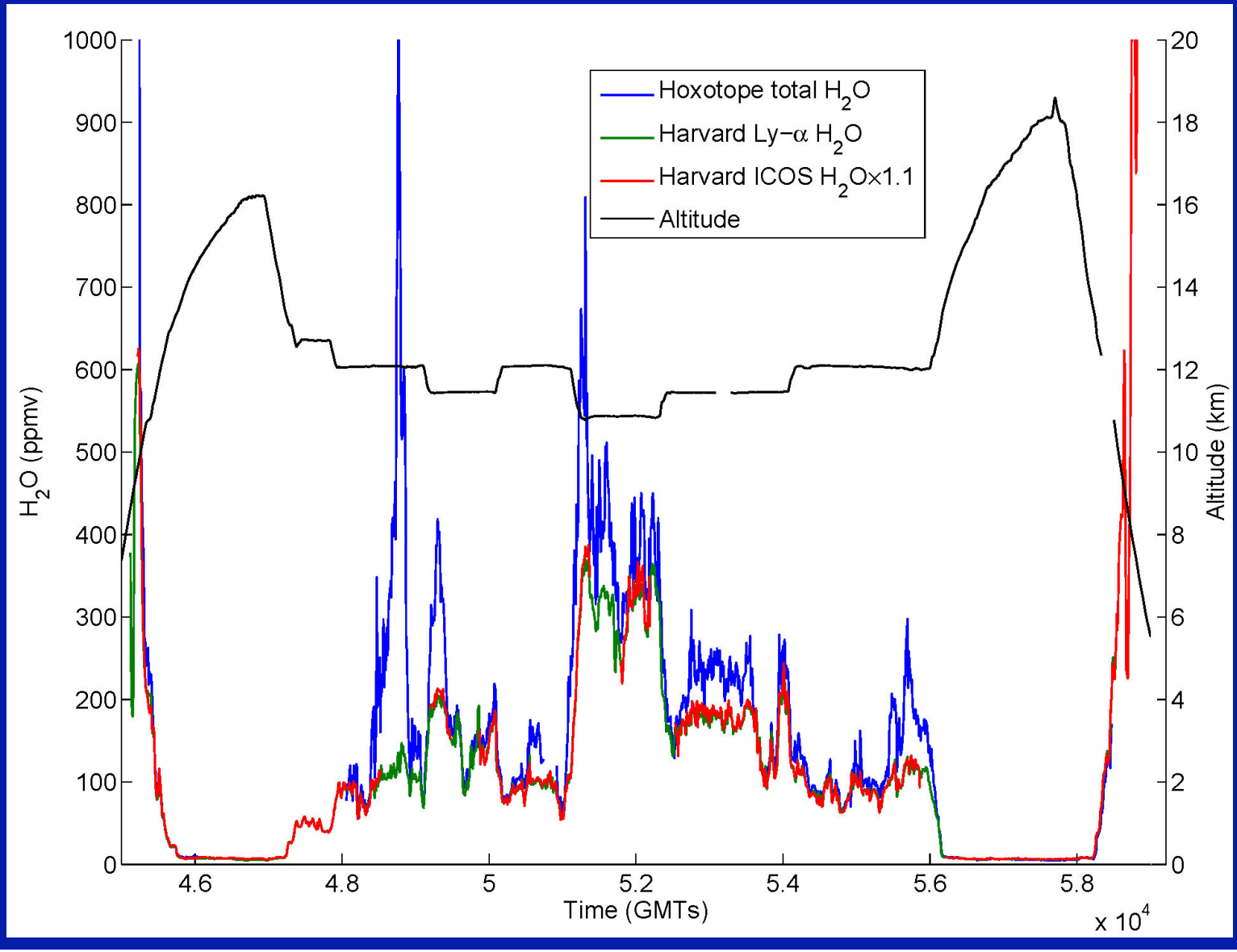

TC4 water isotope measurements summary
Hoxotope WB57
ICOS WB57
CIMS HDO
LaRC DLH H_2O DC−8
Rayleigh
Z (km)
δD (per mil)
20
18
16
14
12
10
8
6
4
2
0
−1000
−800
−600
−400
−200
0
200

Ice water isotopes

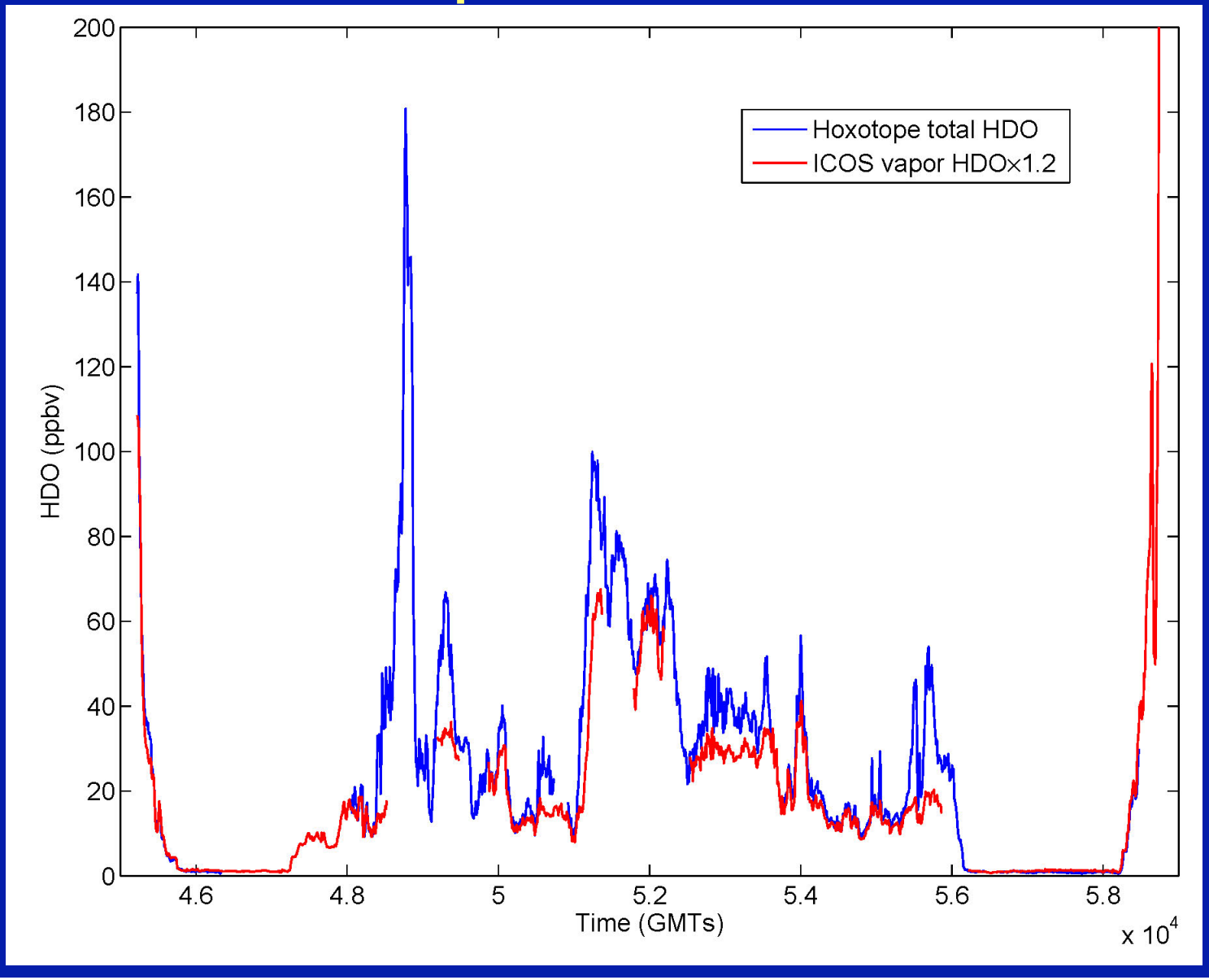
What is the source of water vapor in convective outflow in the base of the TTL?

Hoxotope total water isotopes and ICOS water vapor isotopes used to derive ice water isotope ratios

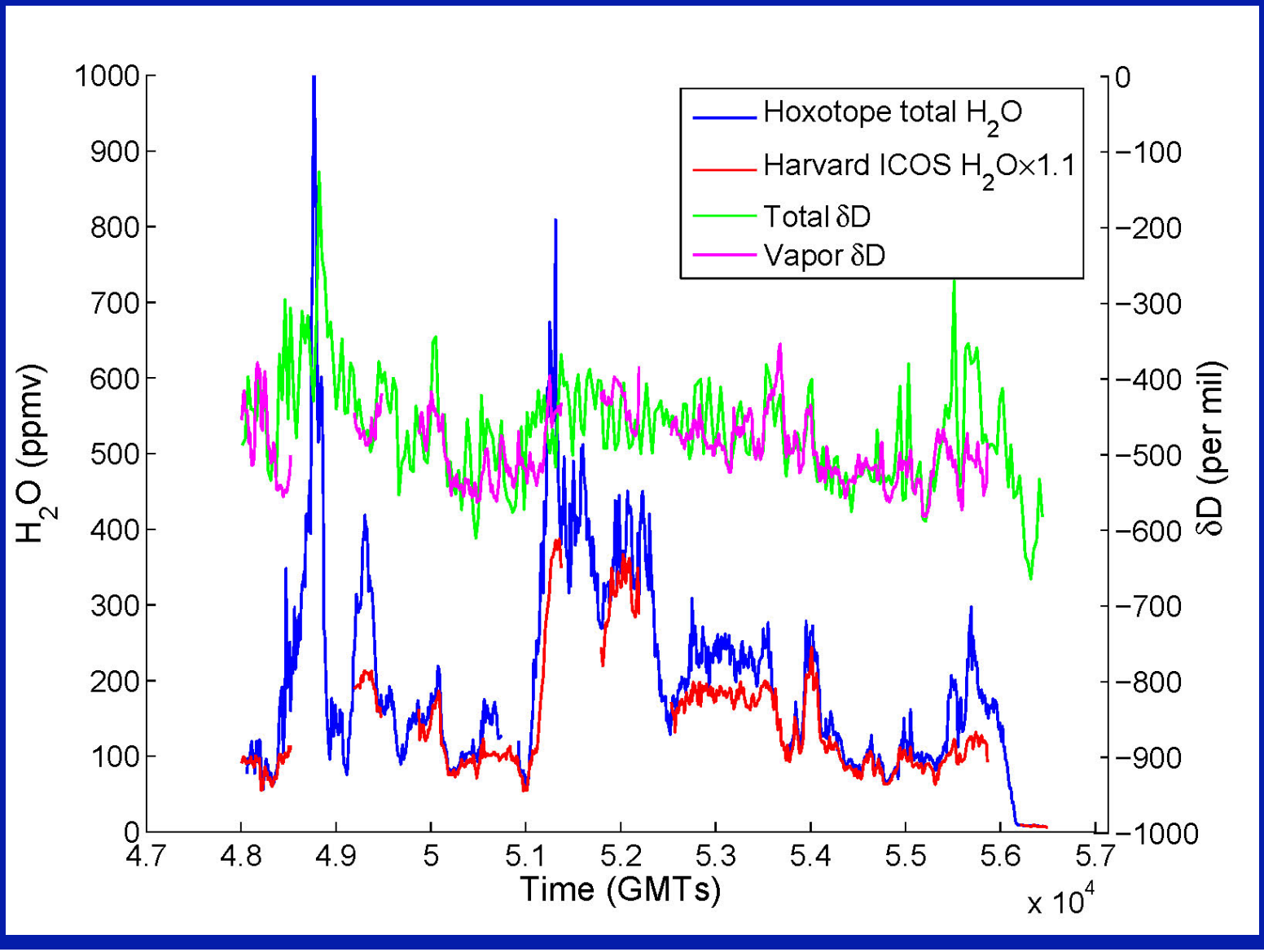
20070808 Pacific Convection
Total and vapor H_2O measurements



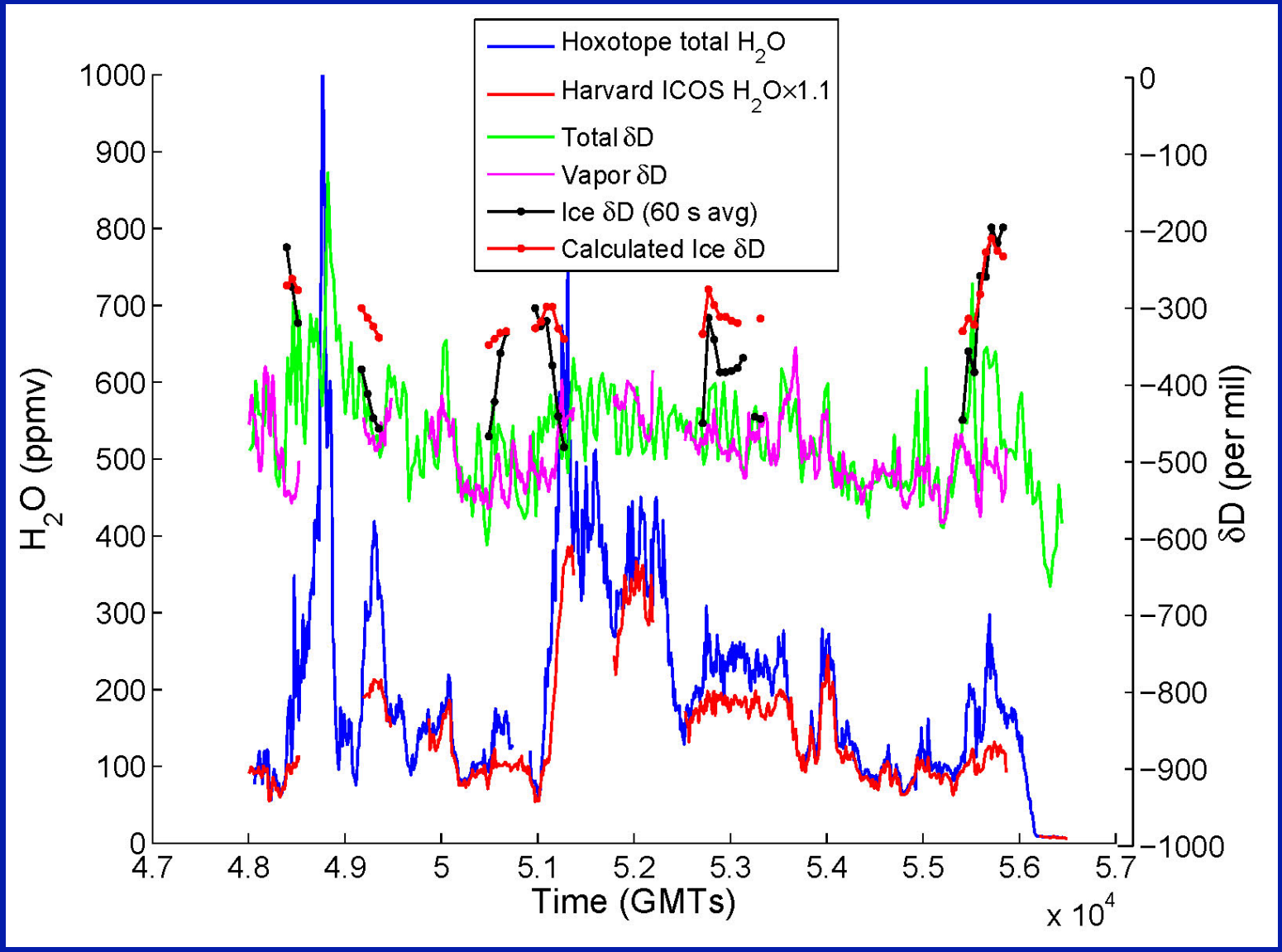
20070808 Pacific Convection
Total and vapor HDO measurements



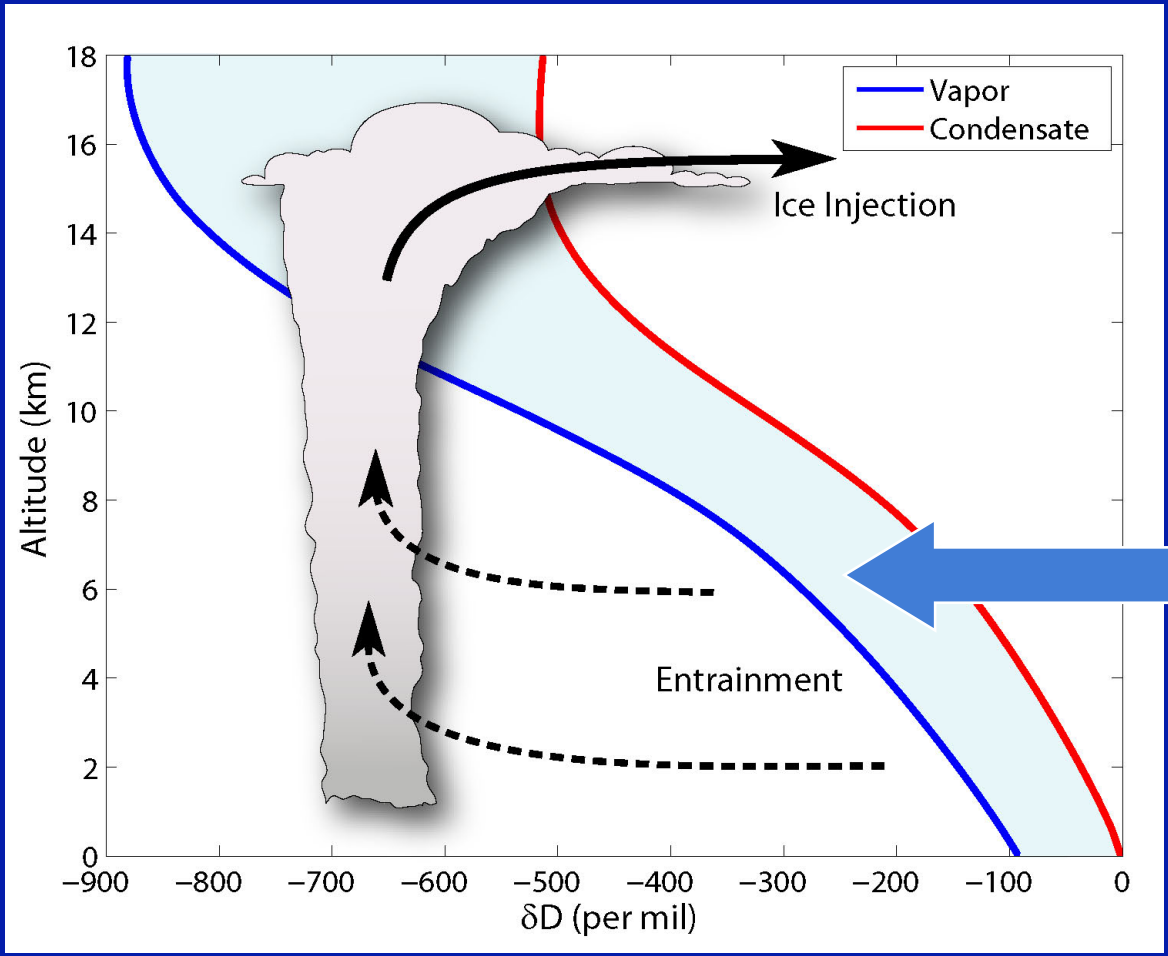
20070808 Pacific Convection
Total and vapor δD measurements



20070808 Pacific Convection
Ice δD measurements

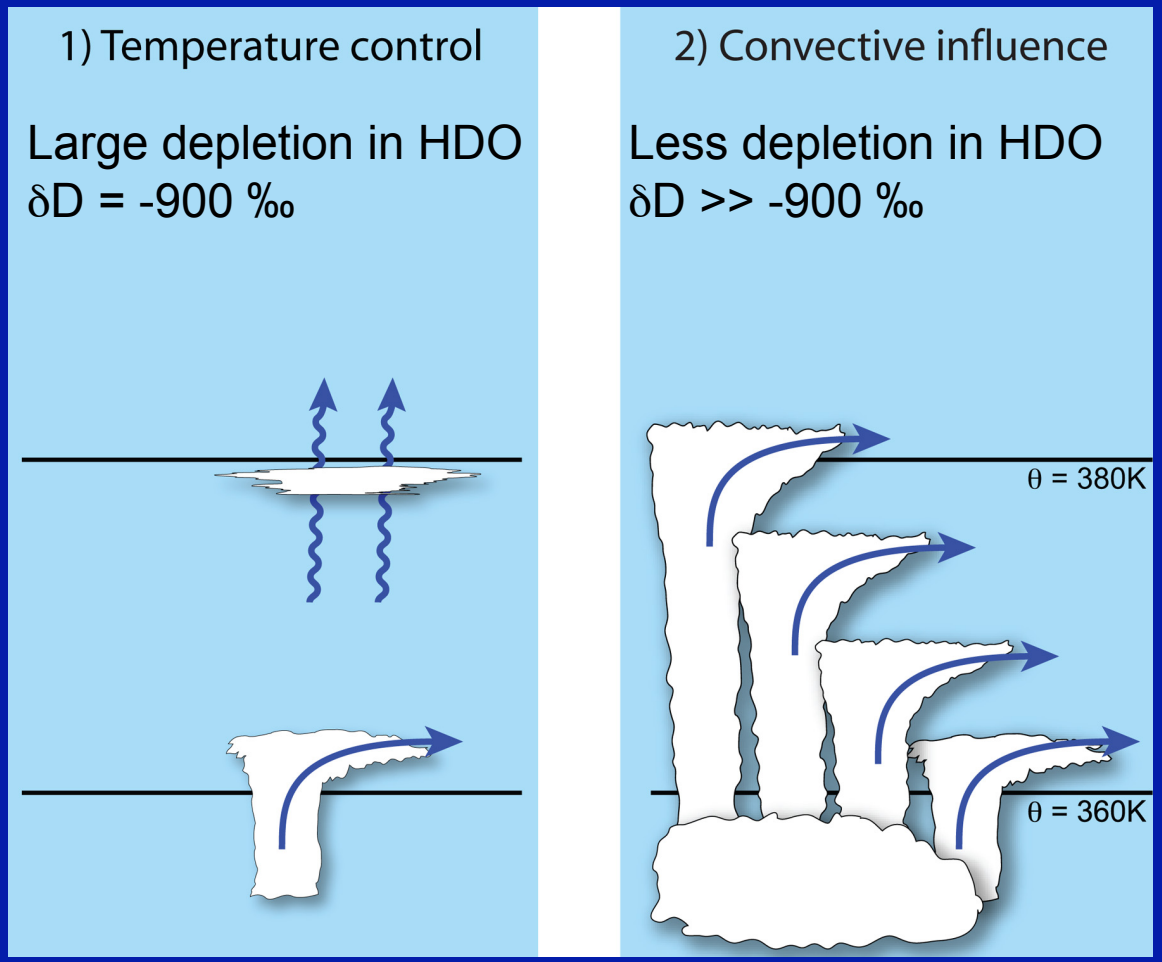


Ice water isotope ratio summary



Condensed phased water isotope measurements indicate entrainment from 6 – 8 km

TTL convection and water isotopologues

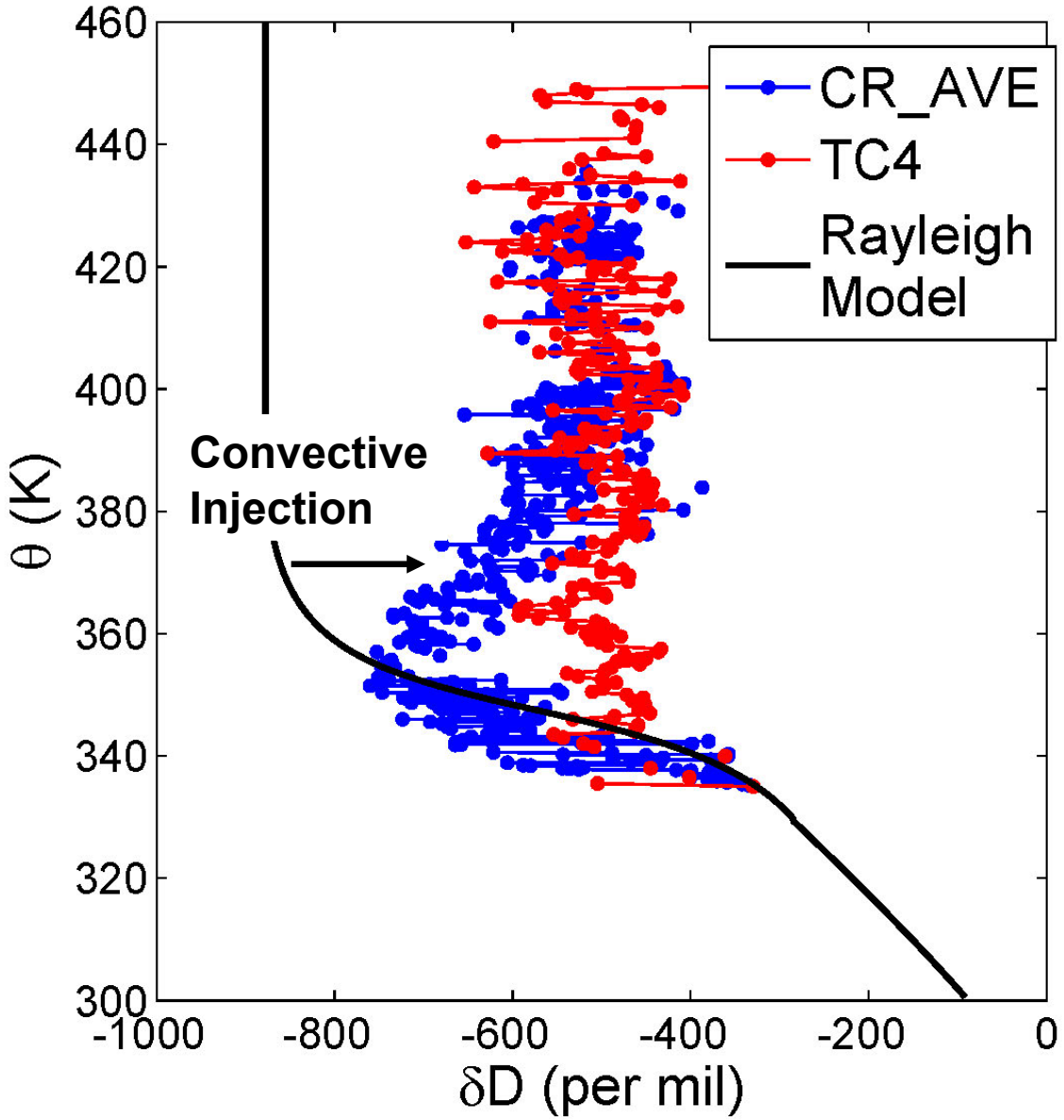


In situ profiles of δD indicate convective input

We expect δD to follow the Rayleigh curve in an atmosphere where H_2O is removed with increasing altitude

Departure from the Rayleigh curve indicates rehydration by the evaporation of ice

How much ice evaporates?



Conceptual model

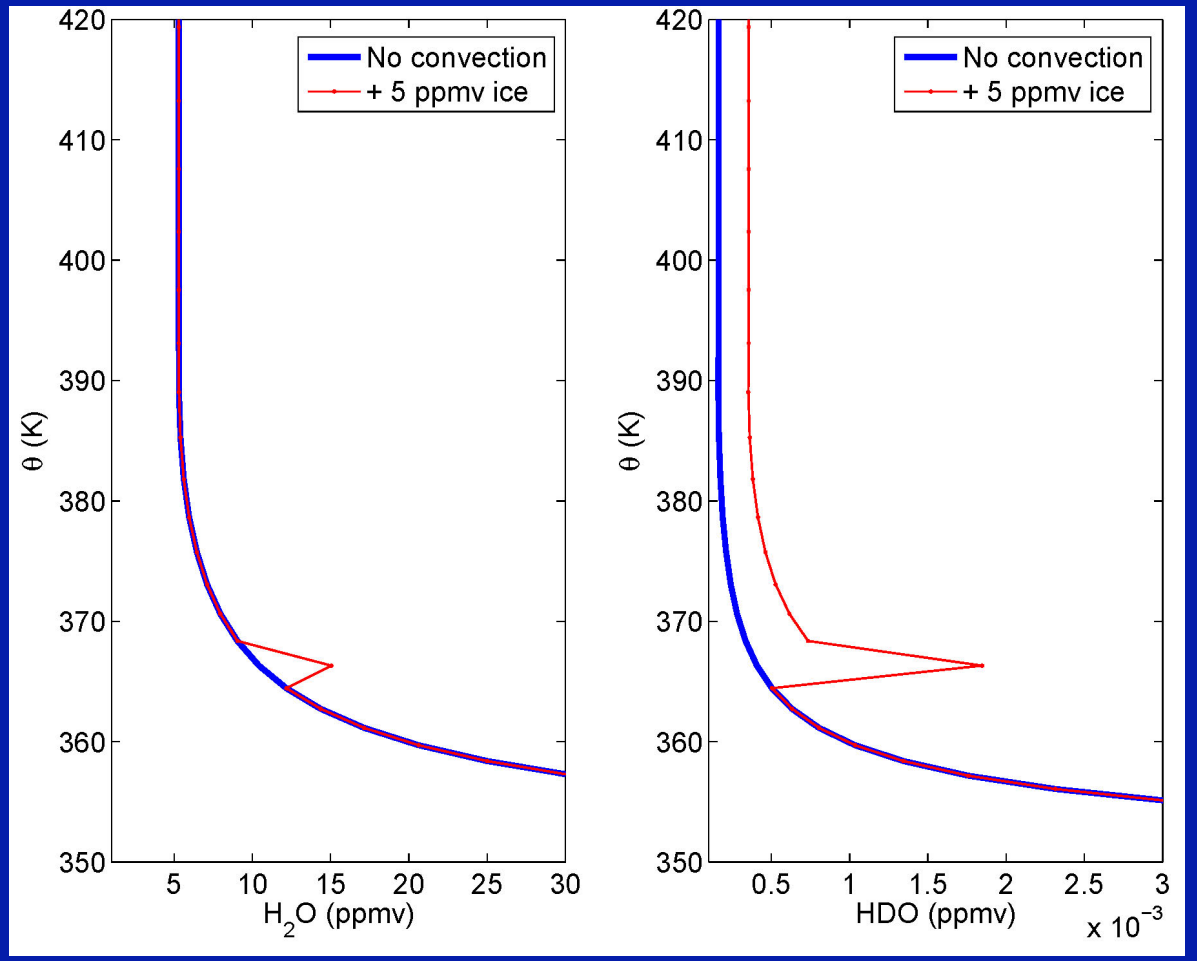
Consider an airmass rising in the TTL, slowly dries as T drops.

Inject isotopically heavy water (eg. ice)

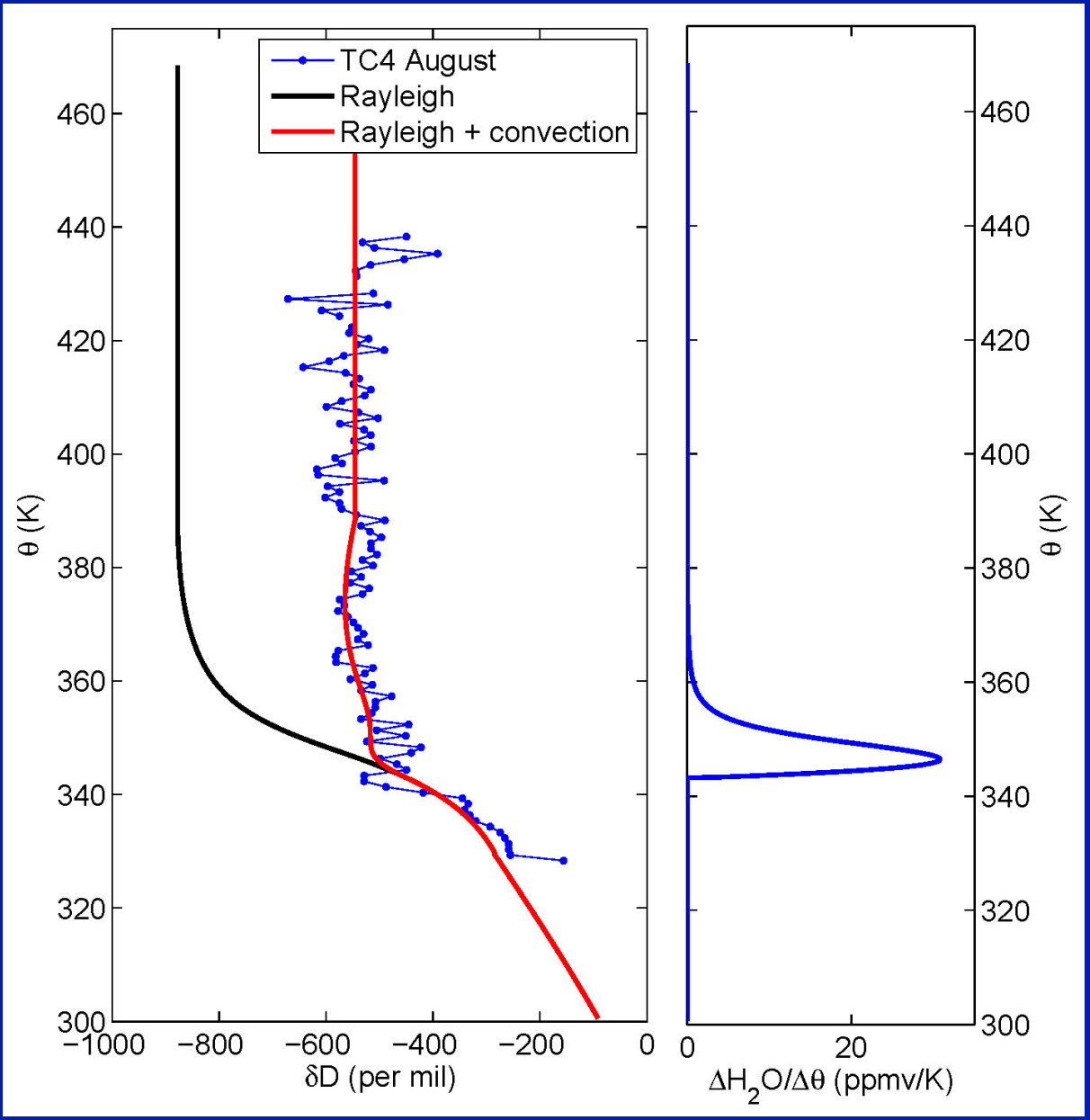
Assume that T fluctuates enough to support ice evaporation but H_2O and HDO are still defined by ice saturation (ie T_{min}).

H_2O abundance is not changed:
$H_2O = H2O_{sat}(T,P)$

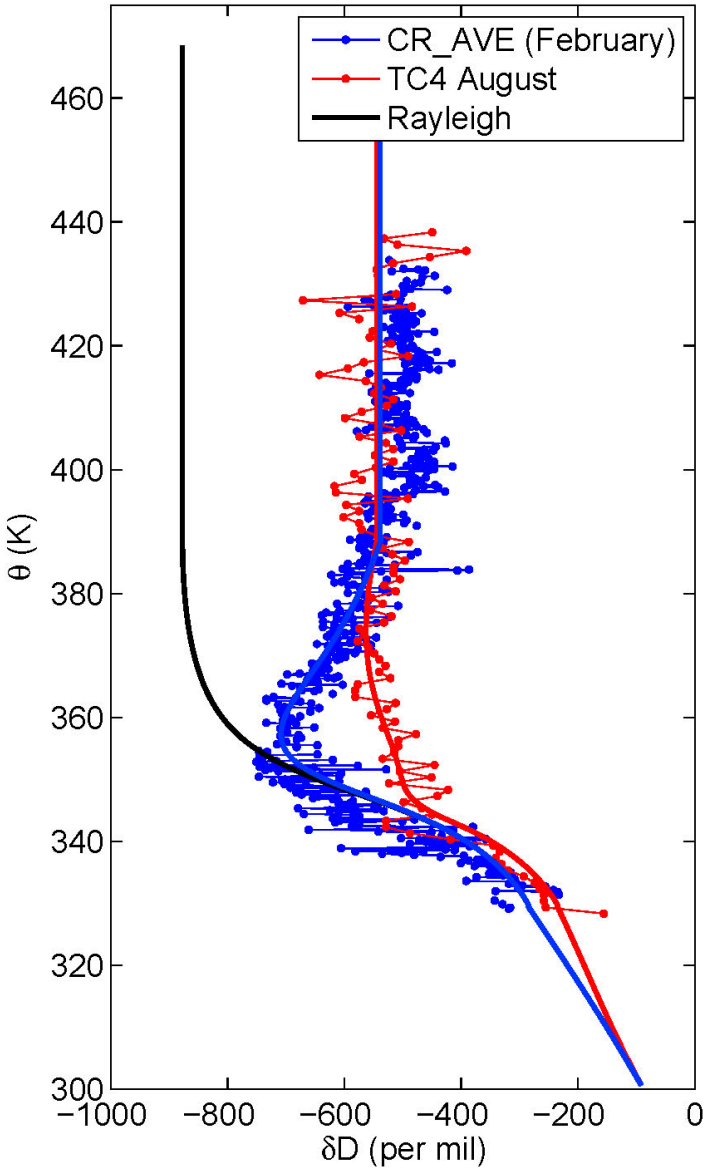
HDO abundance is changed:
$HDO = H2O_{sat}(HDO/H_2O, T)$

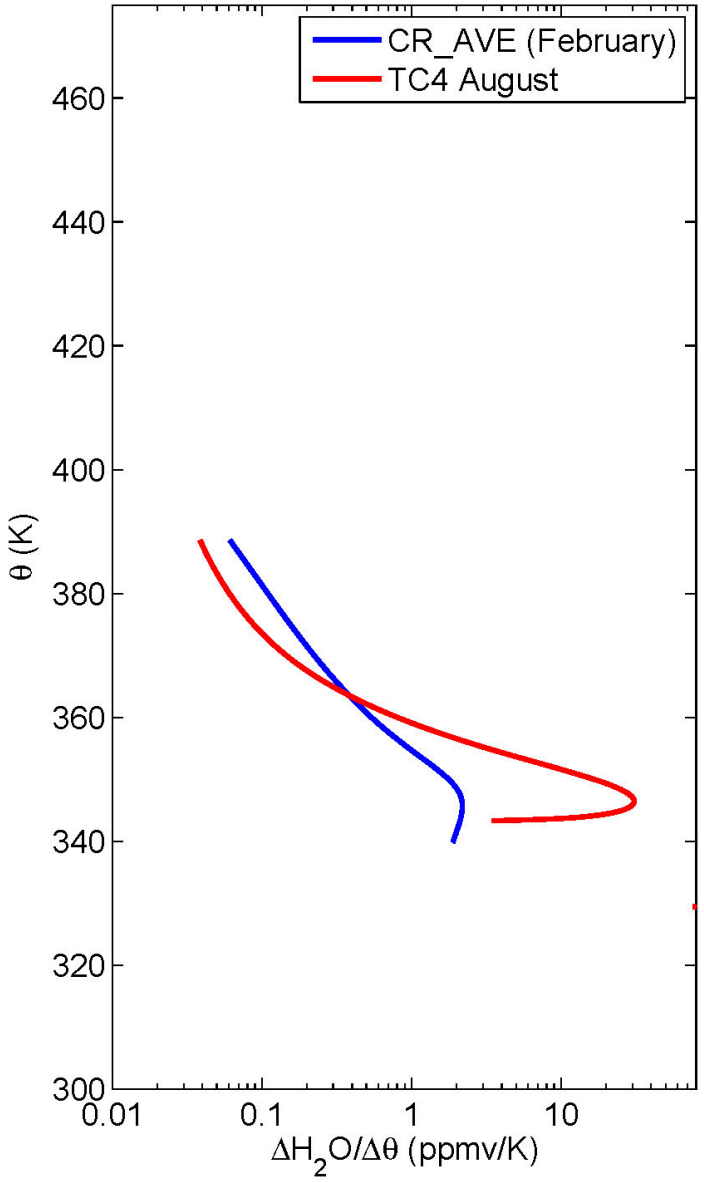


Modeled convective influence

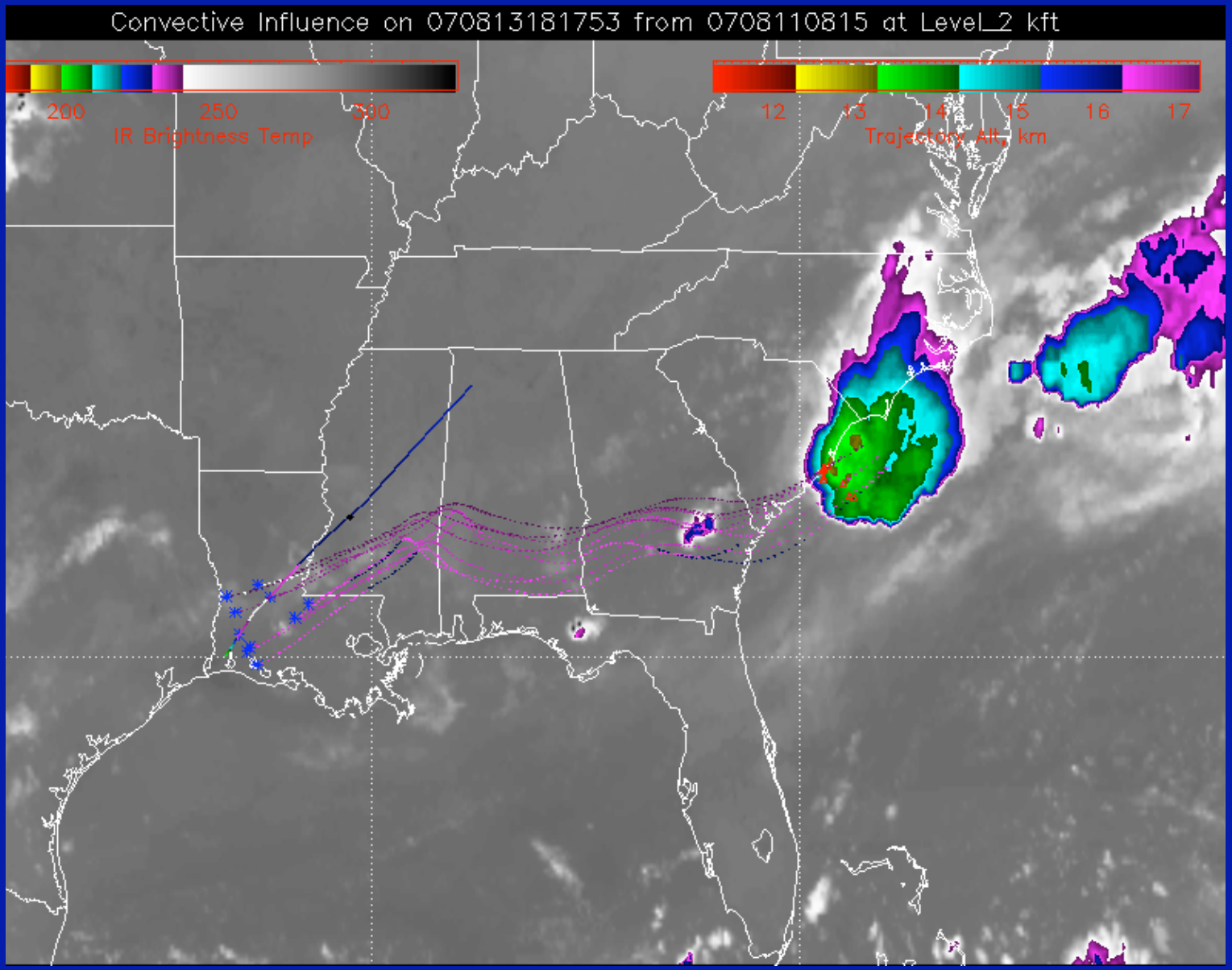


TTL seasonal comparison





Extra Tropical Convection



Lenny Pfister

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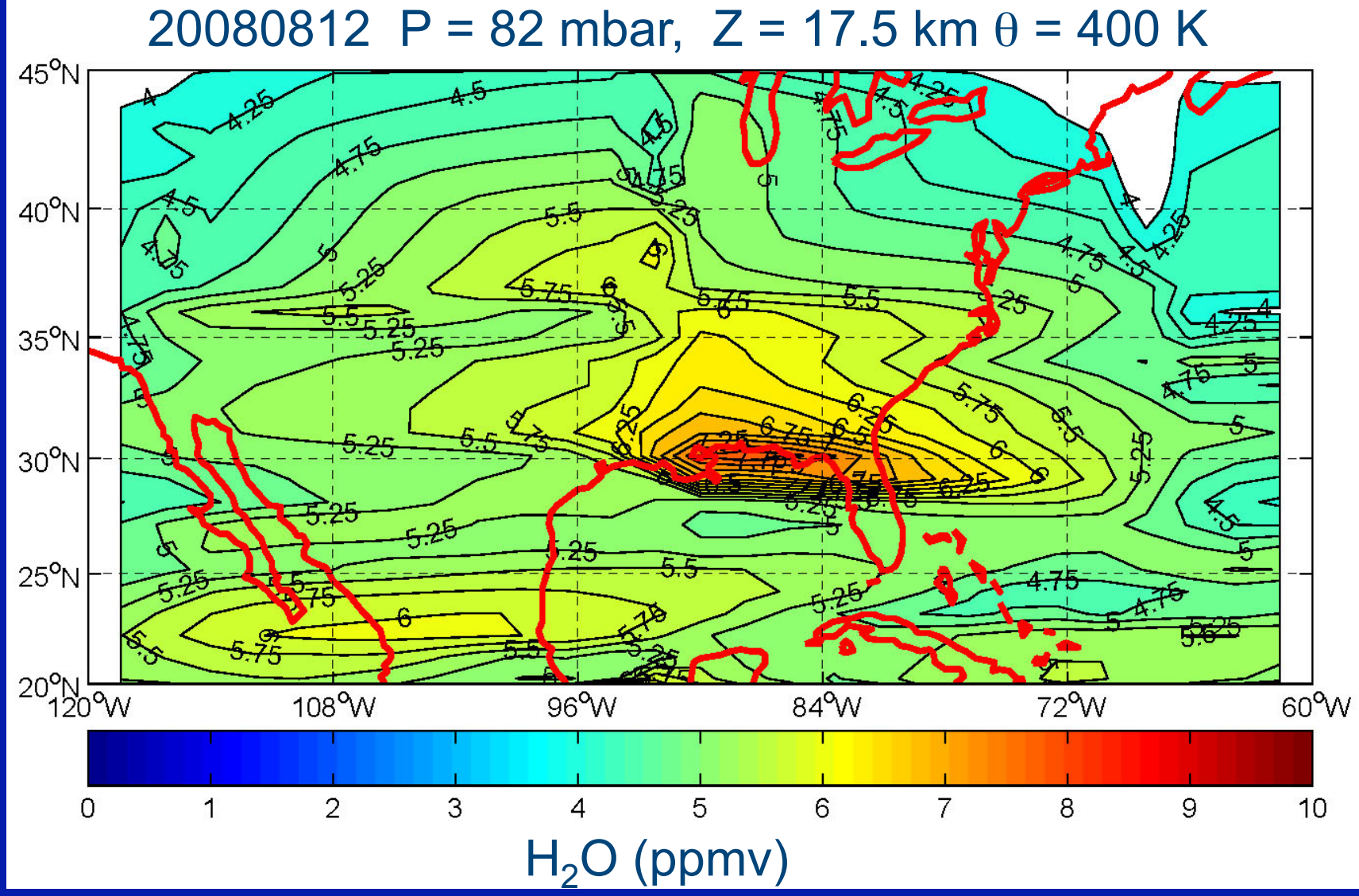
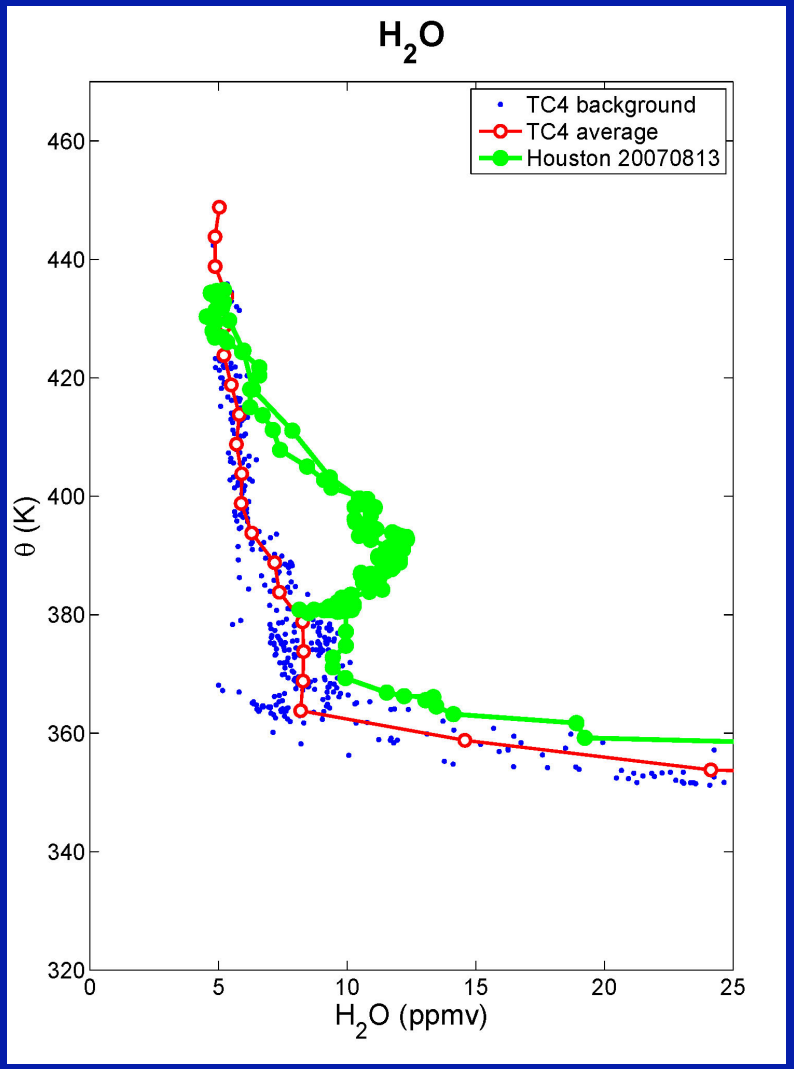
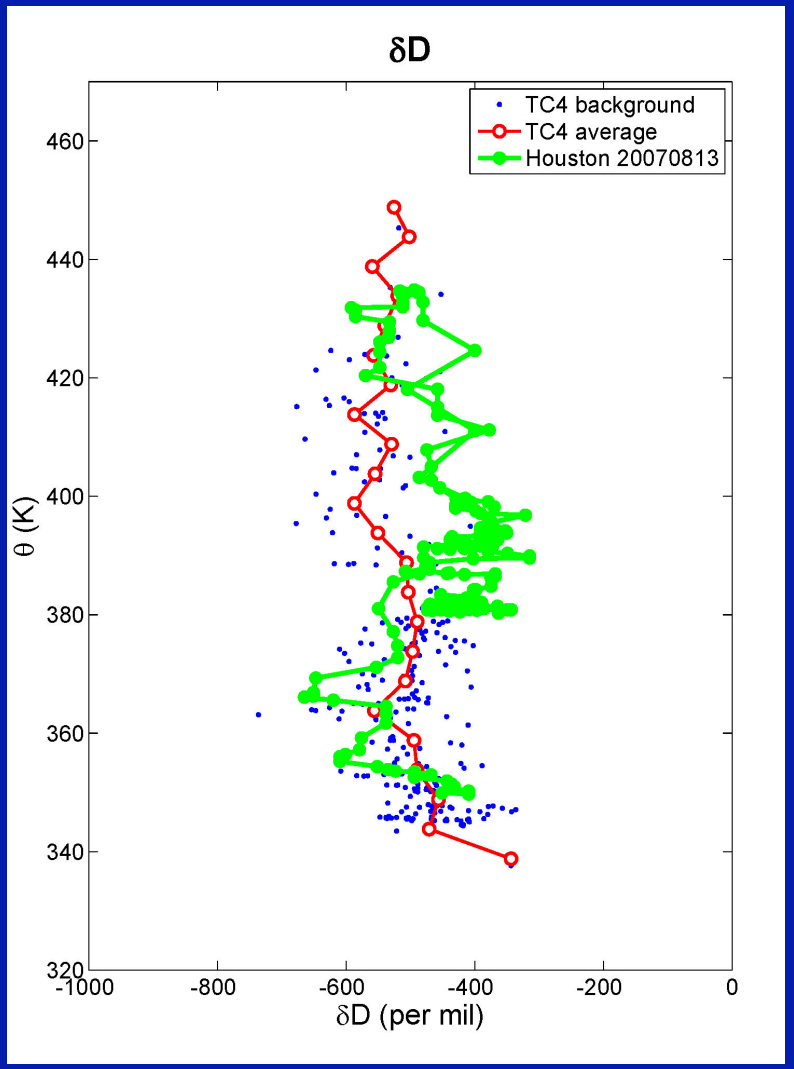

20080812 P = 82 mbar, Z = 17.5 km θ = 400 K
45°N
40°N
35°N
30°N
25°N
20°N
120°W
108°W
96°W
84°W
72°W
60°W
0
1
2
3
4
5
6
7
8
9
10
H2O (ppmv)

Extra tropical H_2O and δD





We continue to see the influence of deep convection on mid-latitude and tropical stratospheric water vapor.

Summary

H_2O and H_2O isotopes observations indicate:

- Ice lofting significantly perturbs the water isotope ratio via path 3.
- H_2O abundance is not significantly perturbed by deep convection in the TTL by path 3, but HDO is.
- Convective influence on stratospheric water isotopes by path 2 is small and yet to be determined in the tropics.
- Pathway 1 is significant and frequently observed, but not yet quantified.