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Relation between water entering the stratosphere and the residual circulation

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Stratospheric water ...

... is constrained by conditions in the TTL.

"Conditions" - Processes that control dehydration:

- Temperature,
- microphysical aspects,
- dynamics (meso- versus large-scale dynamics),
- transport.

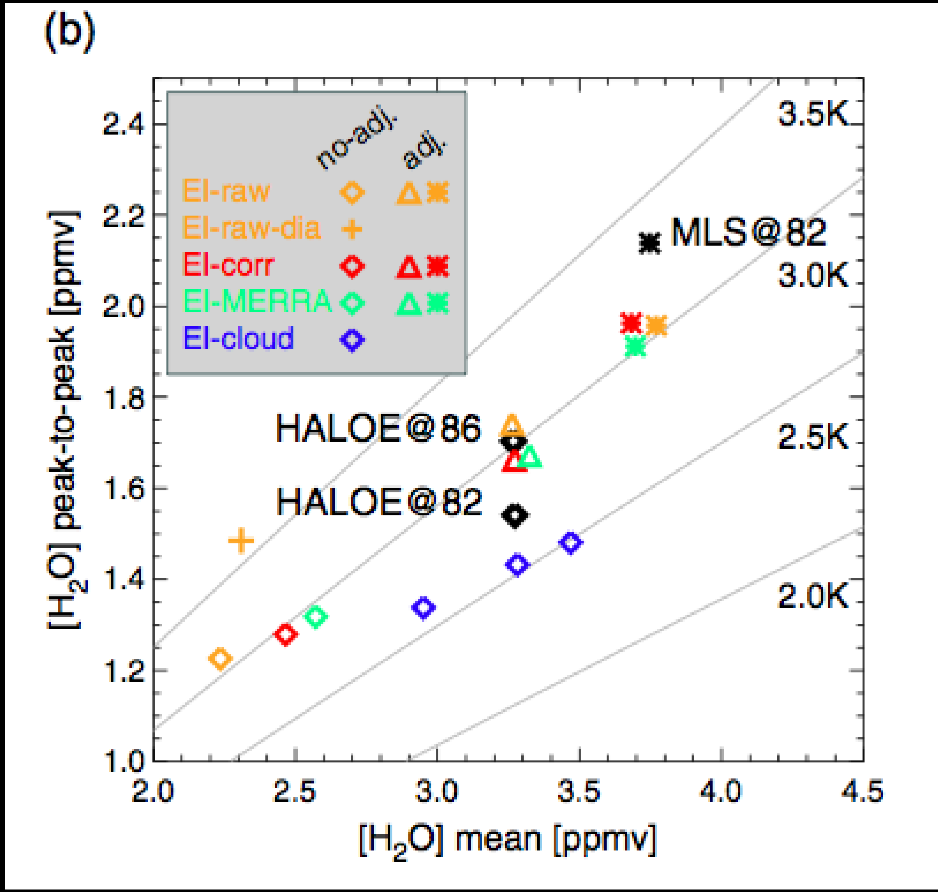
Except for polar vortex regions (and chemical source from CH_4), H_2O is a conserved tracer in the stratosphere.

-> The key quantity is the "entry mixing ratio".

Current understanding of entry mixing ratios

Mean annual cycle:

Mean and amplitude reasonably well reproduced (within observational uncertainty – order 10%).
"Lagrangian Dry Point" calculations give a dry bias (order 1ppmv).

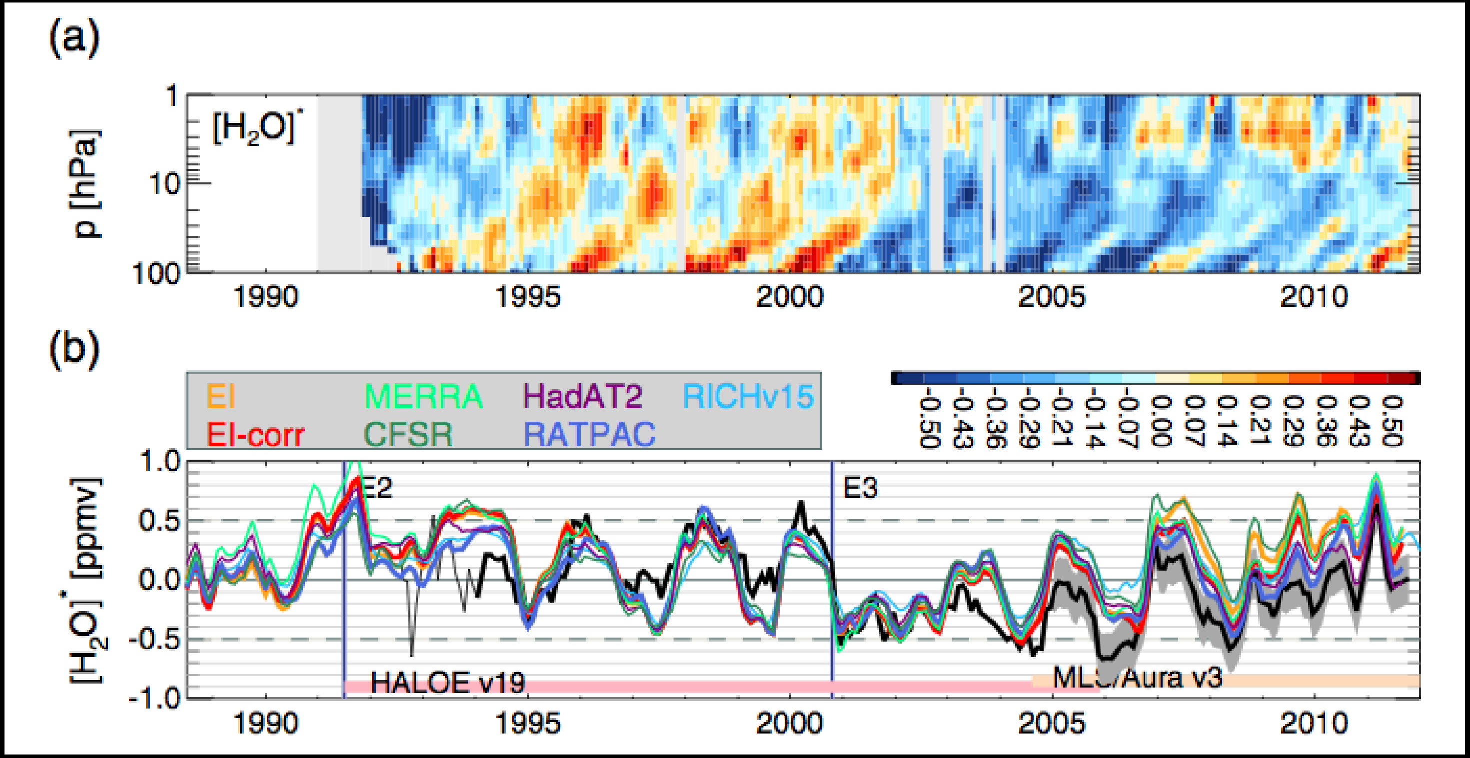


[Fueglistaler et al., 2013]

Current understanding of entry mixing ratios

Observations of H2O and H2O estimates based on LDP-concept, evaluated with trajectories based on ERA-Interim, and (almost!) all available temperature data sets.

-> Periods of systematic departures, but also observational uncertainties.

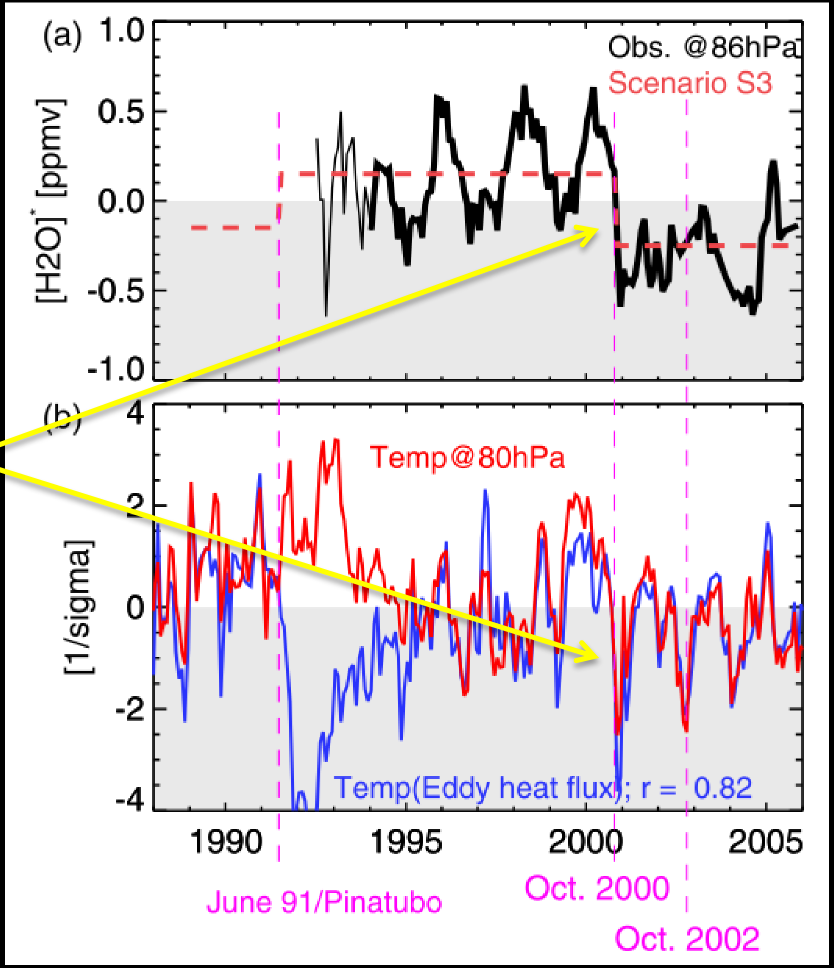


[Fueglistaler et al., 2013]

Mechanisms – the role of upwelling

In model calculations, most last dehydration occurs within the inner tropics.
-> Challenge to attribute "cause": B-D and QBO compete.

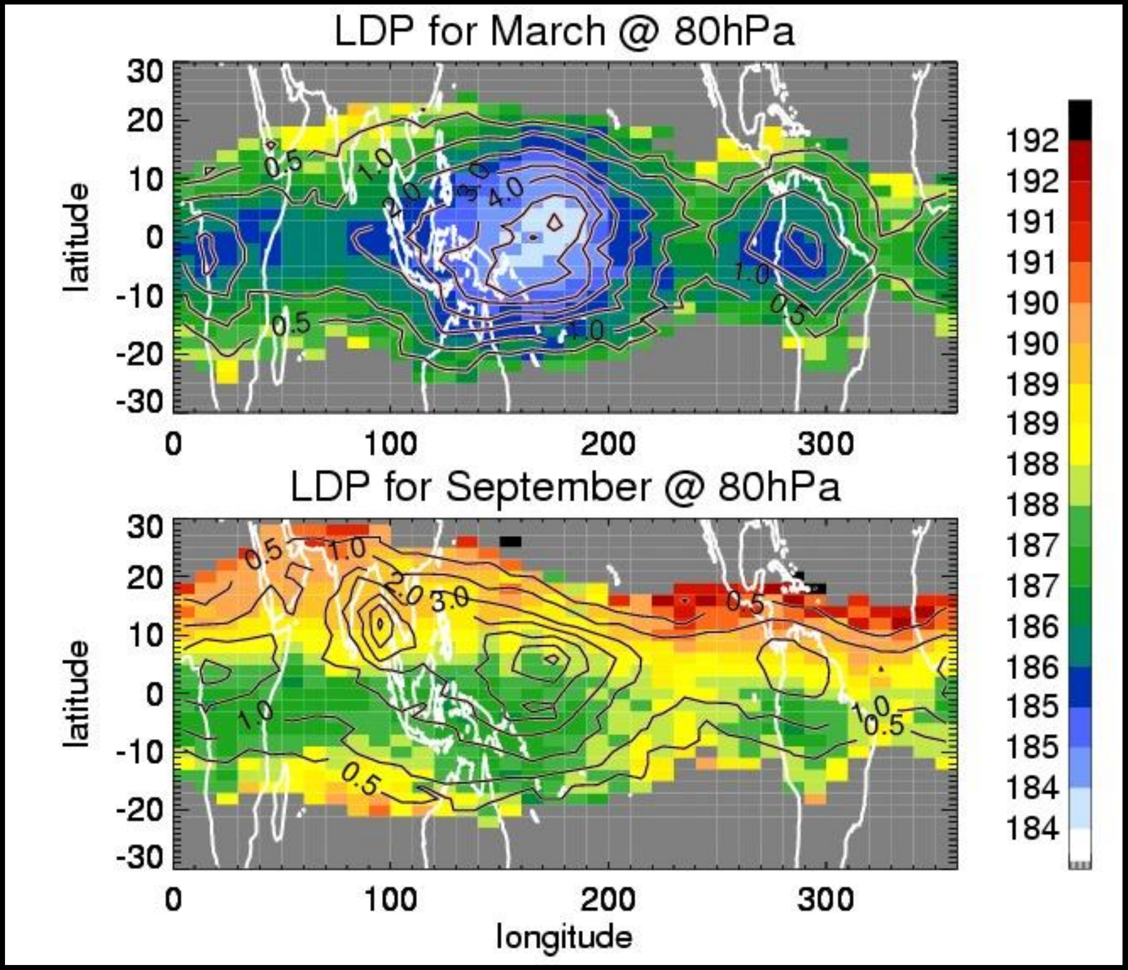
Fueglistaler [2012]: [v'T'] generally good proxy for tropical temperatures, indicates timing of drop related to SH dynamics, but fails to explain quantitatively the step-wise change in H2O.



Mechanistic connection between residual circulation and temperature:

$$\frac{T_{\mathrm{E}} - T}{\tau_{\mathrm{rad}}} = (N^2 H/R) \cdot w^* + \frac{\partial T}{\partial t}$$

The controlling regions – it's not 'average' temperature

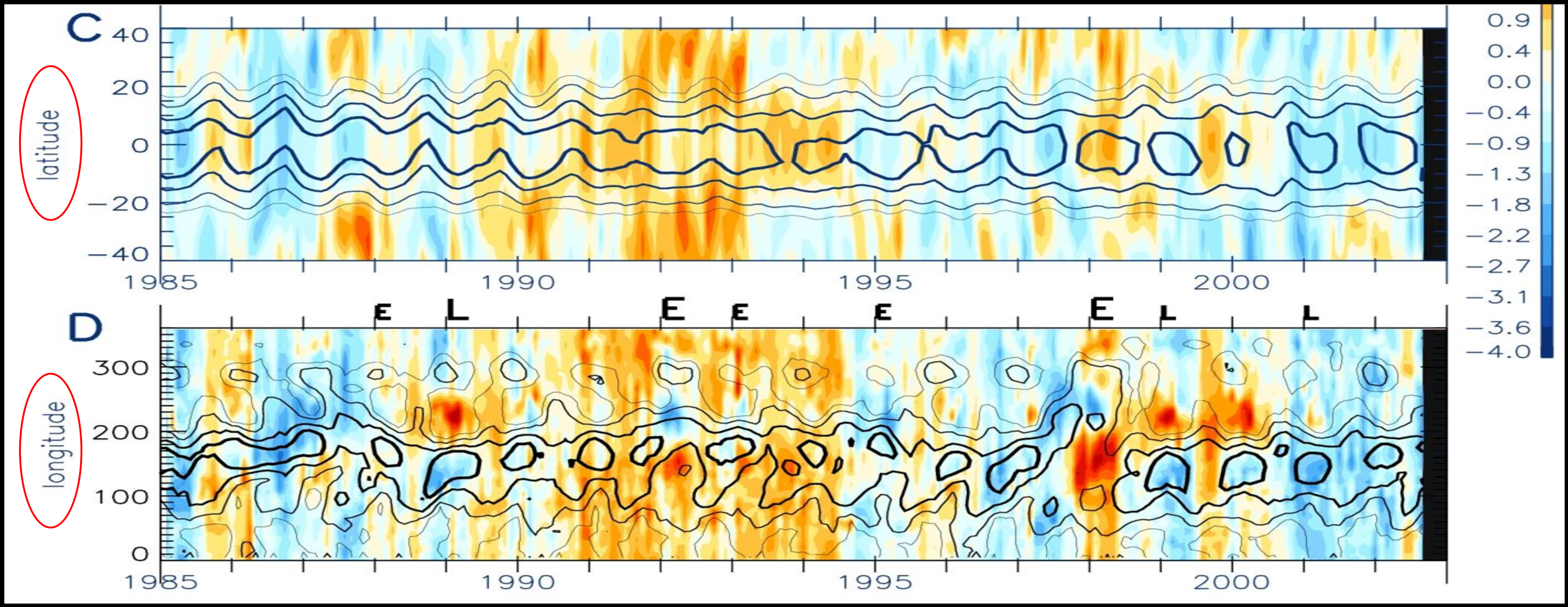


Use trajectories to determine the "Lagrangian Dry Point" (LDP).

Color: LDP temperature;
Contours: LDP density.

-> Clear tendency for LDP to be preferentially at locations and times of local temperature minima.

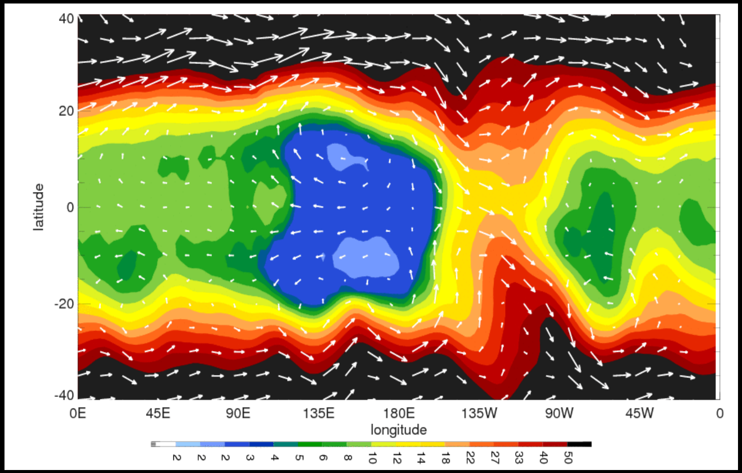
The LDP-distribution responds to temperature and circulation



[Fueglistaler and Haynes, 2005]

Color: "Eulerian" temperature anomalies.
Dark contour lines: LDP density.
-> The LDP distribution is highly variable, and responds strongly to changes in temperature structure.

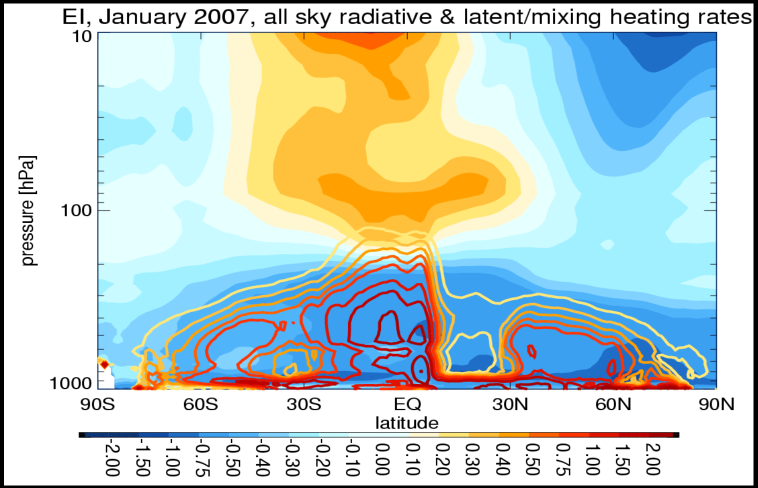
The "residence time" effect on $[H2O]_{entry}$



smr, log-scale, range: 2-50ppmv

Spatio-temporal variance in temperature field is important.
-> Efficiency of flow to sample cold regions is key.

Idealised experiments:
- modify diabatic heating for (offline trajectory calculation;
- modification based on zonal mean diabatic heating structure.



Corresponds to:
- Change in B-D strength (lower branch)
- Observational uncertainty in res. circulation
- Model-model differences in res. circulation

"Clausius-Clapeyron scaling"

The change in the residual circulation (upwelling) is associated with a radiative adjustment of temperature (recall TD-equation).

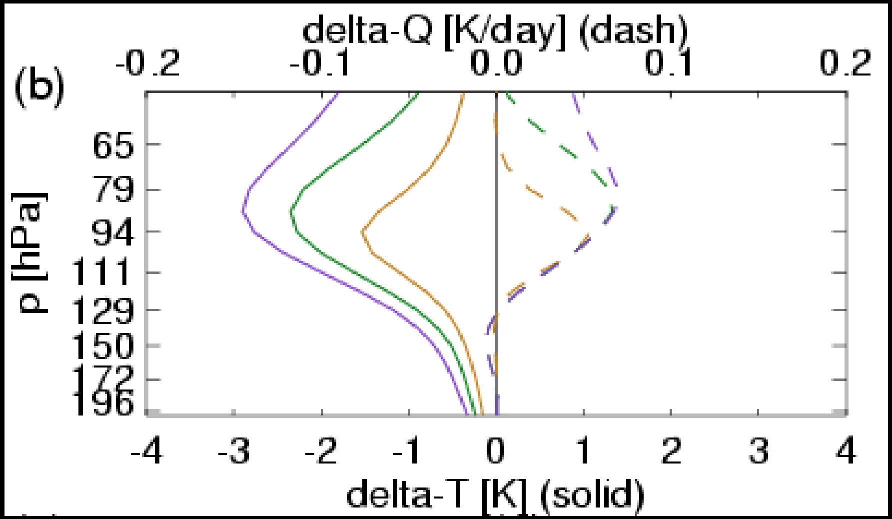
-> Relate the change in $[H2O]_{entry}$ due to the change in residence time to the temperature change at tropopause level due to the radiative adjustment.

If $[H2O]_{entry}$ scales as expected from the vapor pressure change due to the (zonal mean) radiative temperature adjustment, we say it scales like "CC".

(Equivalent to "constant relative humidity" in troposphere – but relative humidity in stratosphere is not relevant; only in the "regulating" region.)

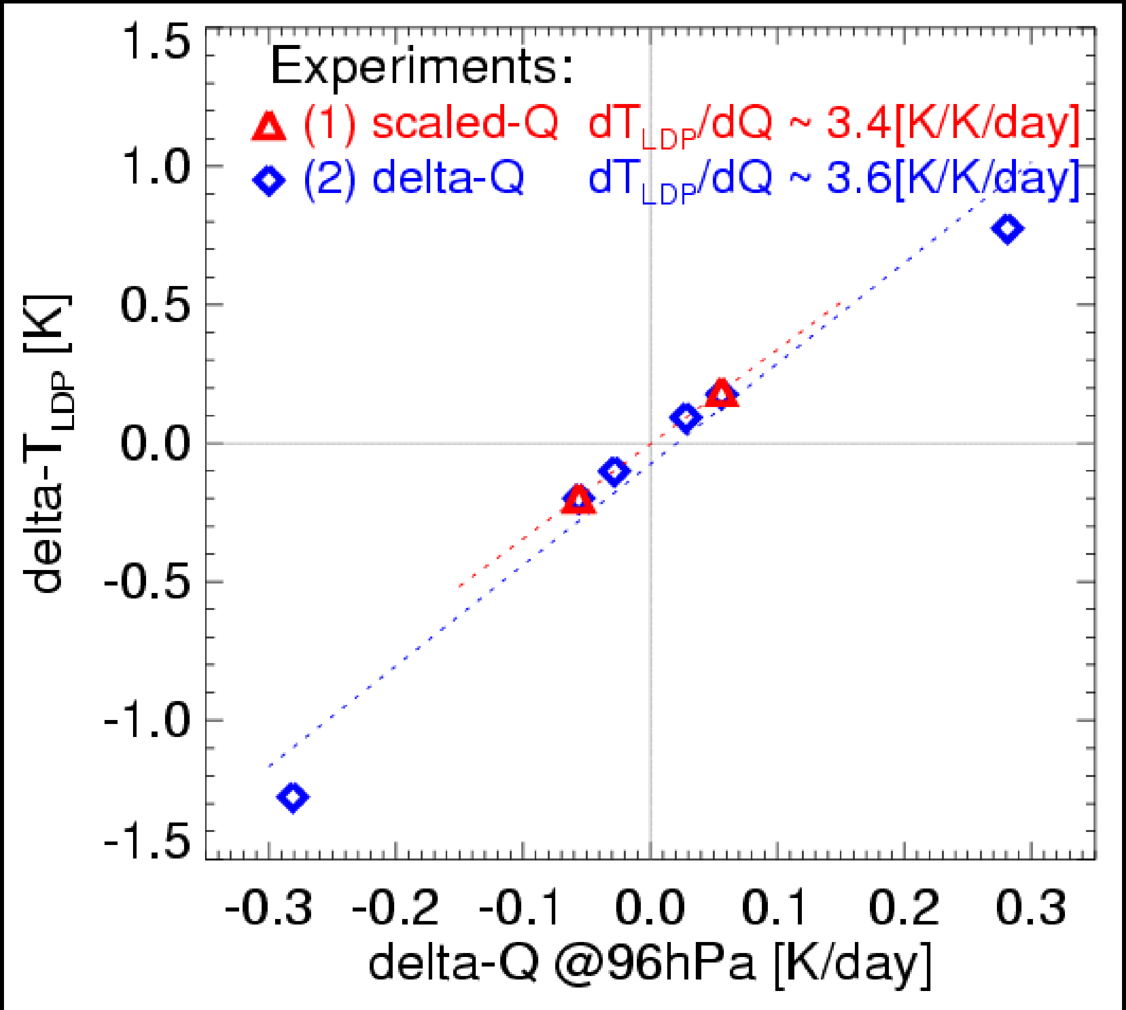
The radiative response to a change in upwelling

The radiative perturbation (dashed line) ...



... gives a response in temperature (solid lines) that depends on the vertical length scale. As a rule of thumb, a 10% change in rad. heating corresponds to order 1K temperature change at tropopause levels.

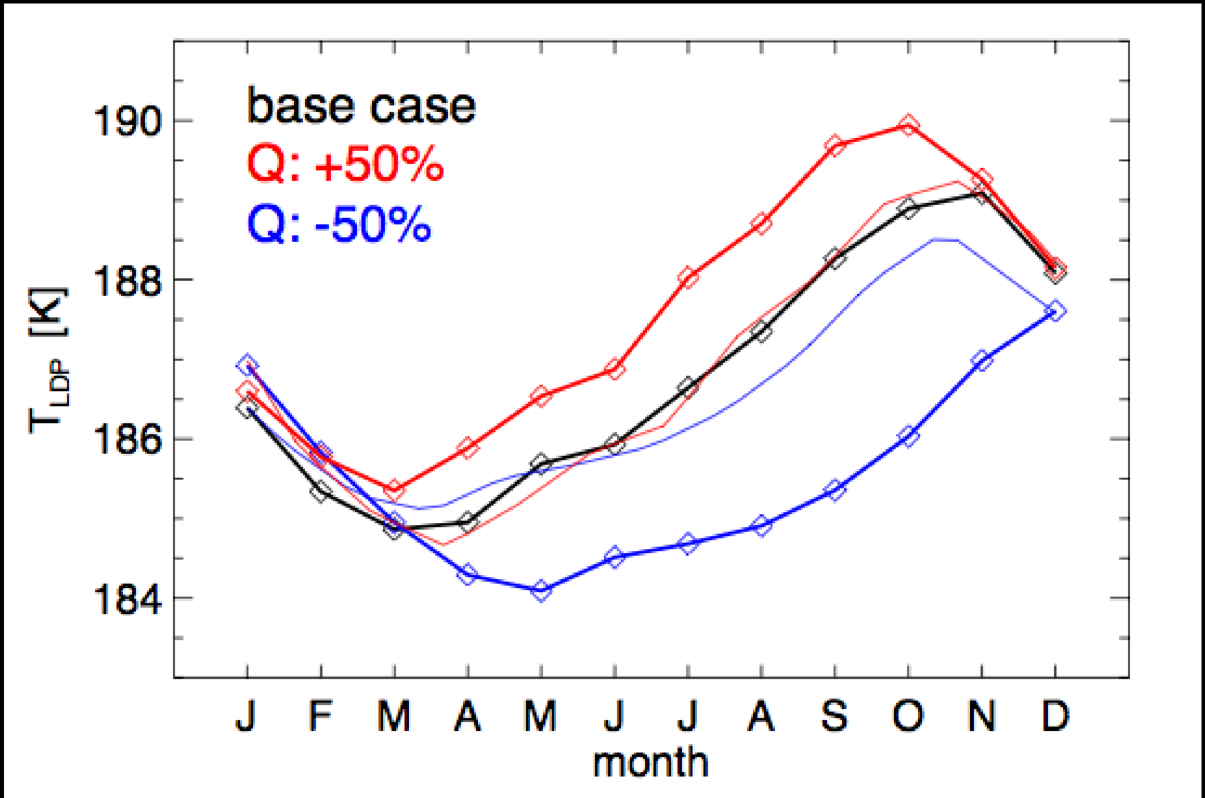
The residence time effect



The residence time effect:
The stronger upwelling (the longer residence time), the less efficient sampling and the moister $[H2O]_{entry}$.

-> Negative feedback to radiative effect.
But: About 1OM smaller than rad. effect.

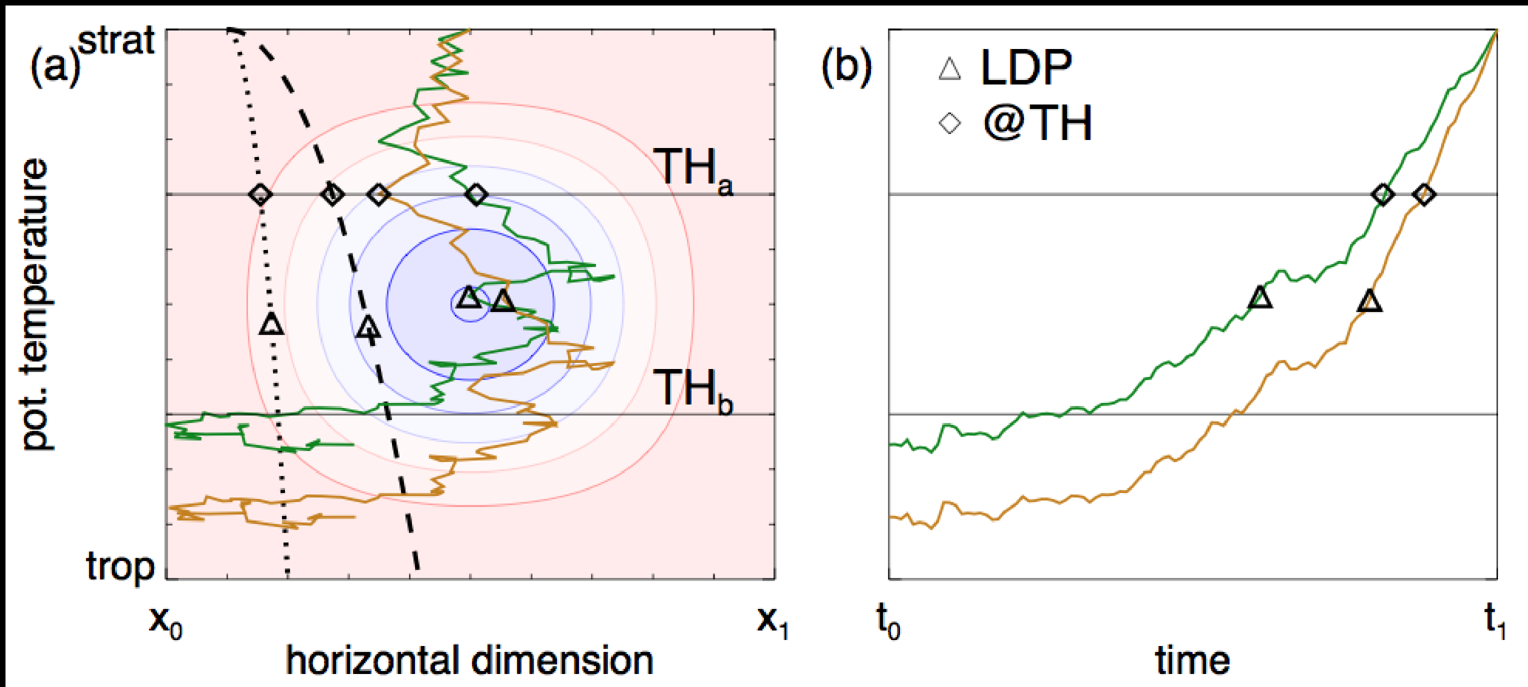
The seasonality of the residence time effect



Numerical experiments show phase shift (simple effect from change in velocity), change in amplitude (effect from widening/narrowing of "averaging kernel").

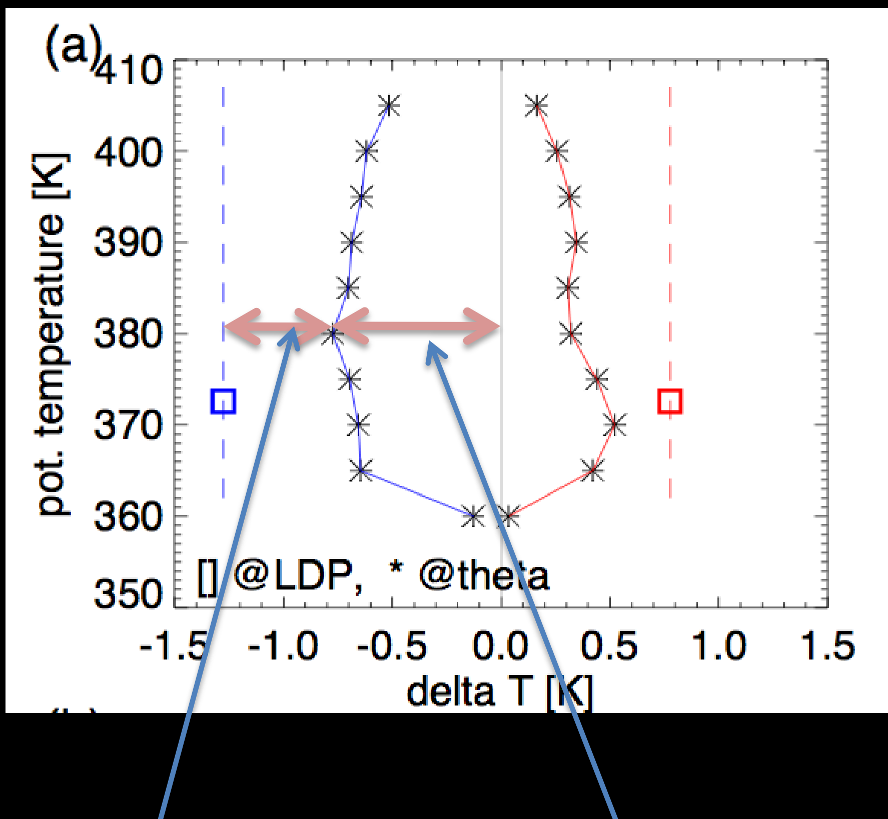
"Residence time effect" similar in all seasons.

Disentangling 2 aspects of the "residence time effect"



Schematic of idealised pathways through temperature field (filled contours).
Black dotted/dashed: Systematic relation between path and temperature.
Green/brown: Random path.
Triangle: Lagrangian Dry Point.
Diamond: Position/temperature at intersection with specific pot. temperature.

"Random walk" versus "systematic Temp <-> flow relation"



Evaluation of Lagrangian Dry Point (squares) temperature change in response to changing upwelling by +/- 10%, and ditto for temperature at intersection with specific pot. temperature. (Each datapoint based on about 300'000 trajectories.)

Both systematic & random effect are important for the residence time effect in the TTL.

random walk

systematic T <-> flow relation

Summary

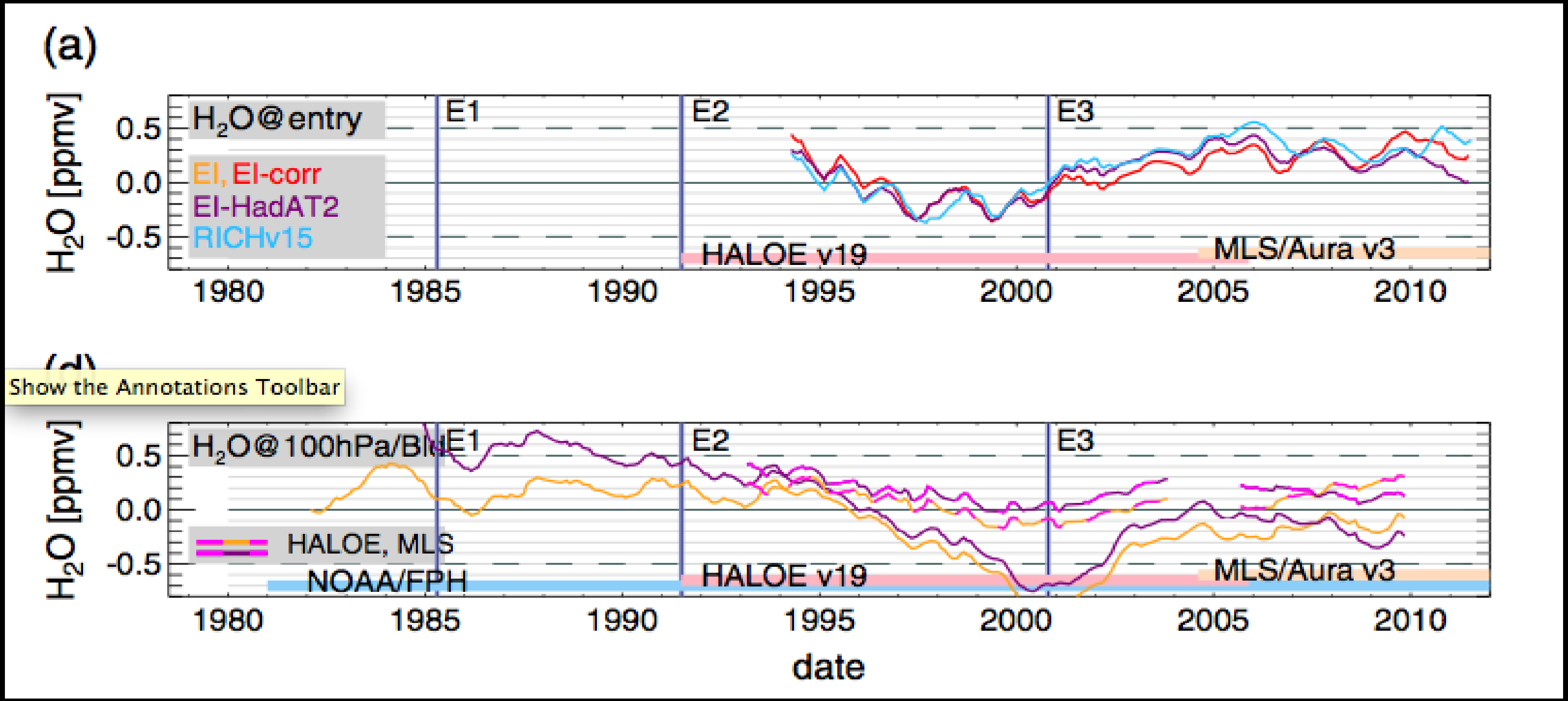
(i) $[H2O]_{entry}$ based on transport and perfect dehydration gives a dry bias.
-> No need for a "drying mechanism", but for a moistening process.
(ii) Periods of systematic departure between model and "observed" H2O identified. (See Fueglistaler et al. 2013 for details).

(iii) Cloud processes (inefficient dehydration) can "fill the gap" (order 1ppmv).
(iv) Transport time scale plays also a role – the "residence time effect".
(v) A 10% change in residence time corresponds to ~ 0.1ppmv change in $[H2O]_{entry}$.
-> Smaller than cloud effects, but perhaps of relevance for trends, where it causes a departure from CC-scaling (about 10% less).

Atmospheric humidity can change even when all cloud microphysical aspects remain constant.

Thank you!

Can we recover observations? - The residual

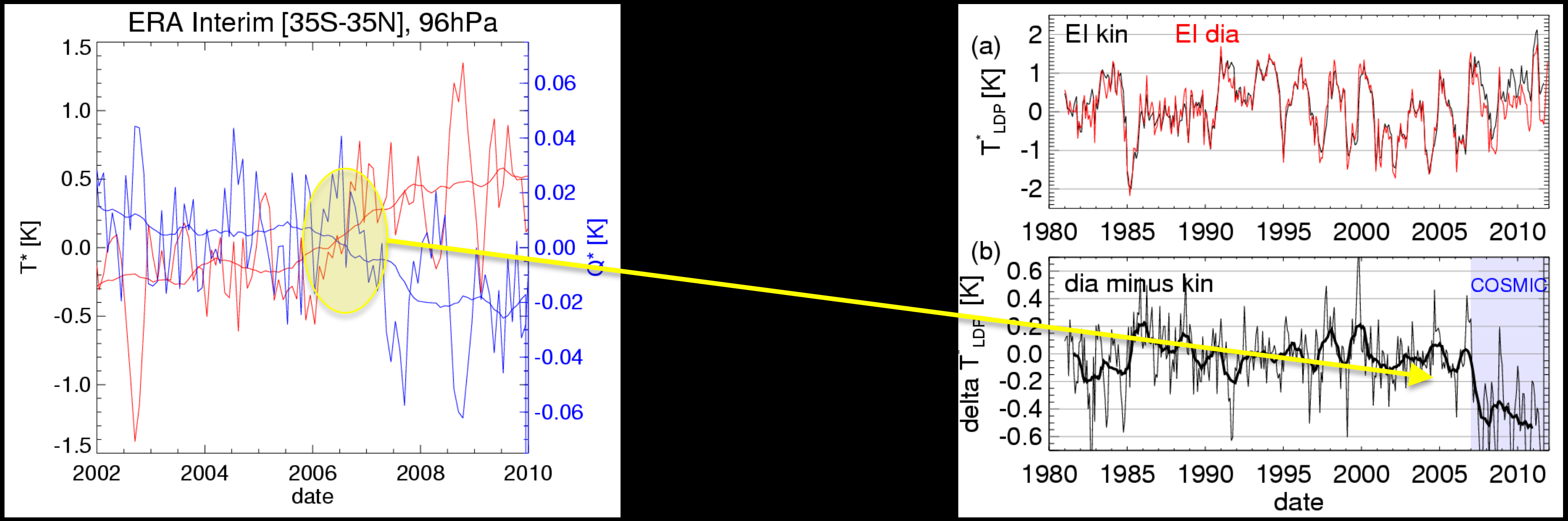


The problem is not "solved" – there remain systematic residuals.

- T measurement?
- Circulation in reanalyses?
- H2O measurement?
- "Interesting science" (i.e. process in reality different than in idealised model)?

Experiment 3: Impact on modeled stratospheric water

Diabatic trajectory estimate of H_2O gets drier relative to that of kinematic trajectories (which does not have a change in residence time).



[Fueglistaler et al., 2013]

The temperature drift is about +0.5K, the transport-timescale related decrease in T_{LDP} is about -0.5K -> fortuitous cancellation! (I.e. in diabatic calculation the temperature drift due to COSMIC is not visible!)