Vertical profile observations of water vapor deuterium excess in the lower troposphere

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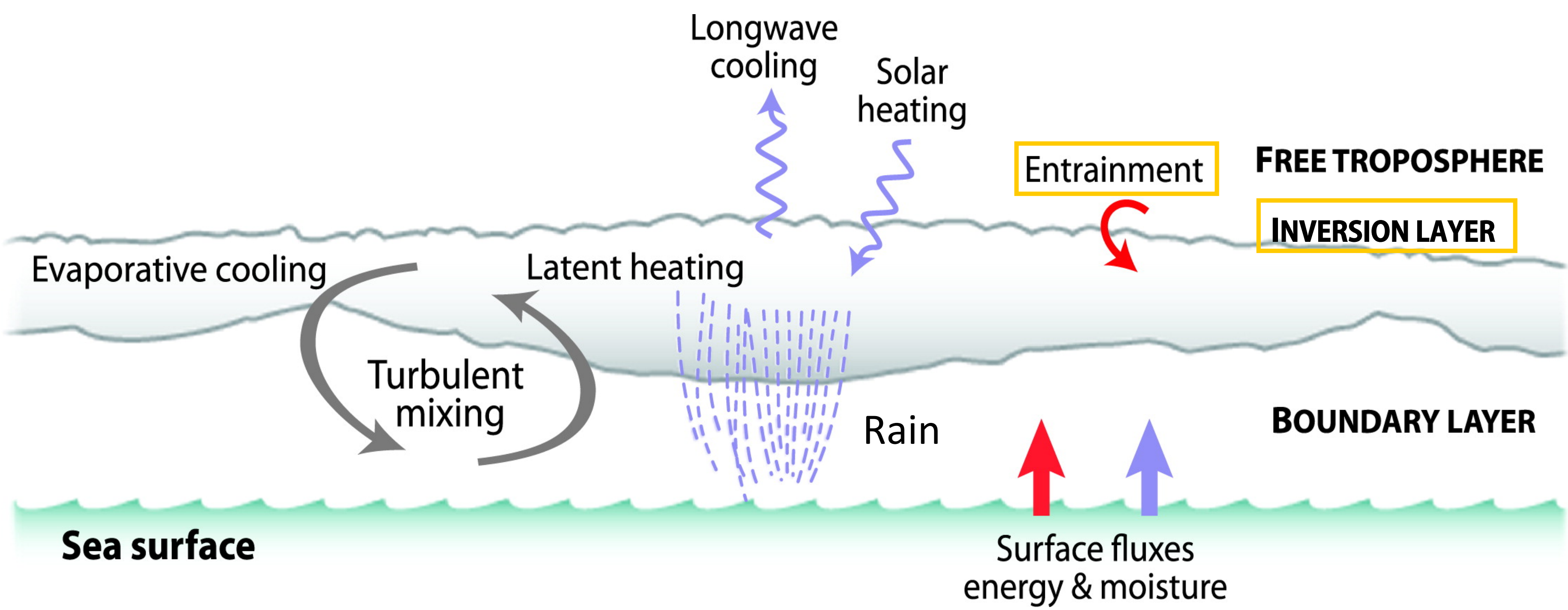
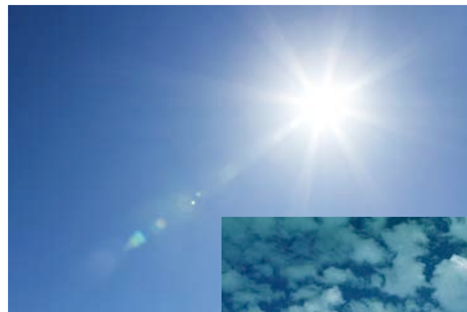
Boundary-layer processes are challenging to represent in models

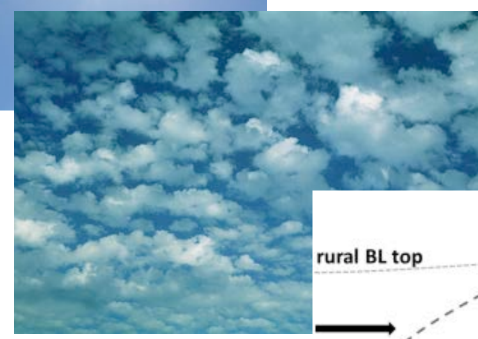


Water vapor stable isotopes can act as a record of air parcels' evaporation, condensation, and mixing history.

Wood, 2012

Isotopic fingerprints of moisture processes in the atmosphere in 3 case study days

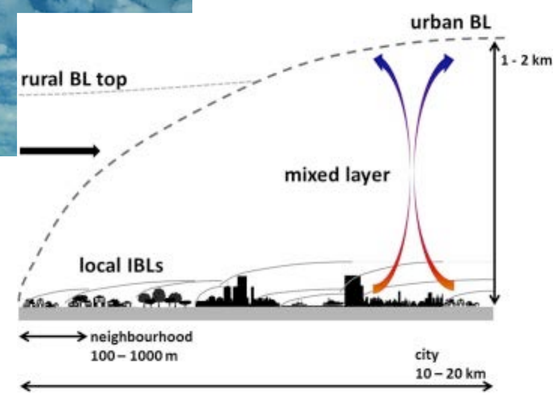




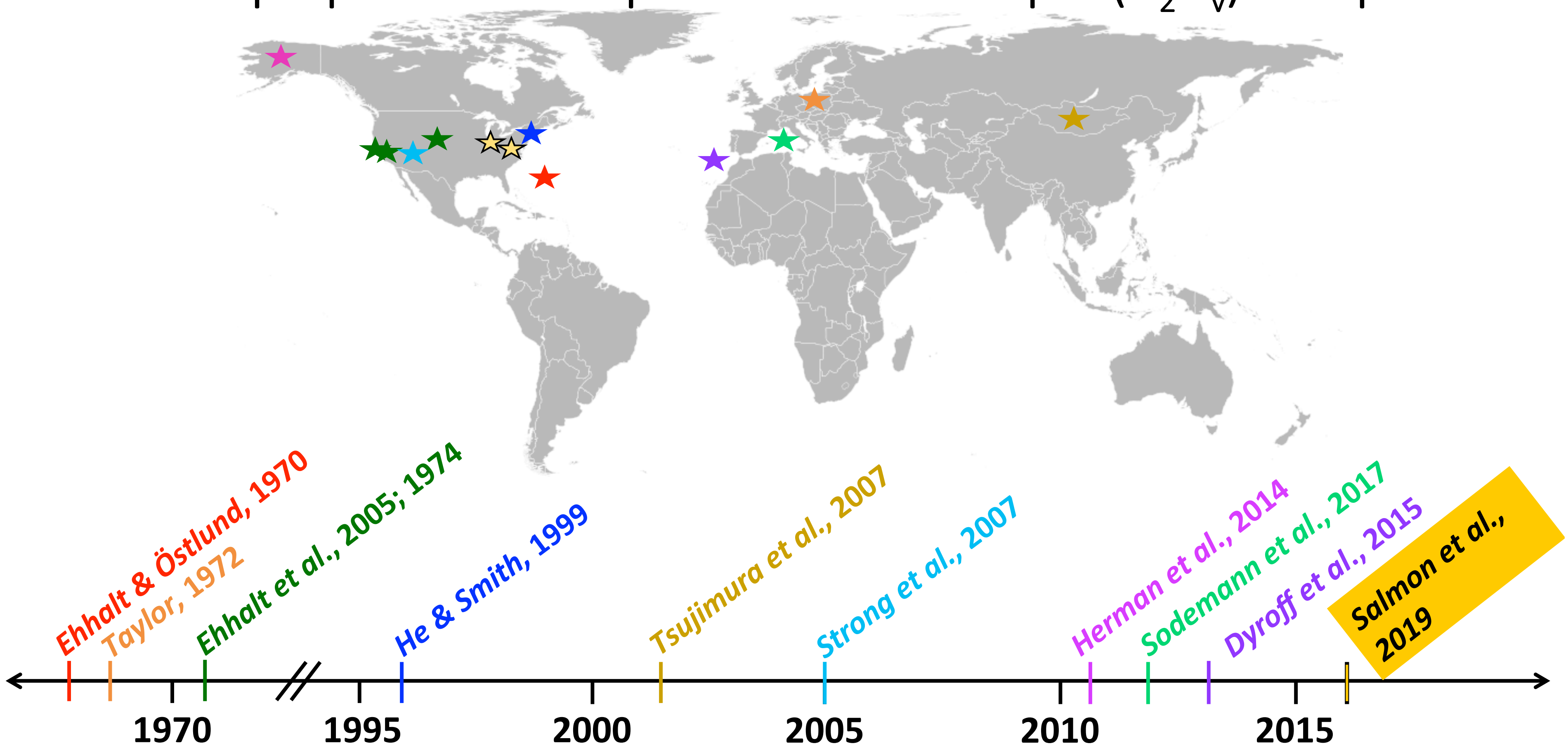
1. Clear, dry adiabatic day that Rayleigh rainout processes describes well. Preserved signature of earlier dehydration and FT-INV mixing.

2. Transition day from evaporating stratocumulus cloud layer to clear conditions. Deuterium-excess signal suggests droplet evaporation at the top of the inversion layer.

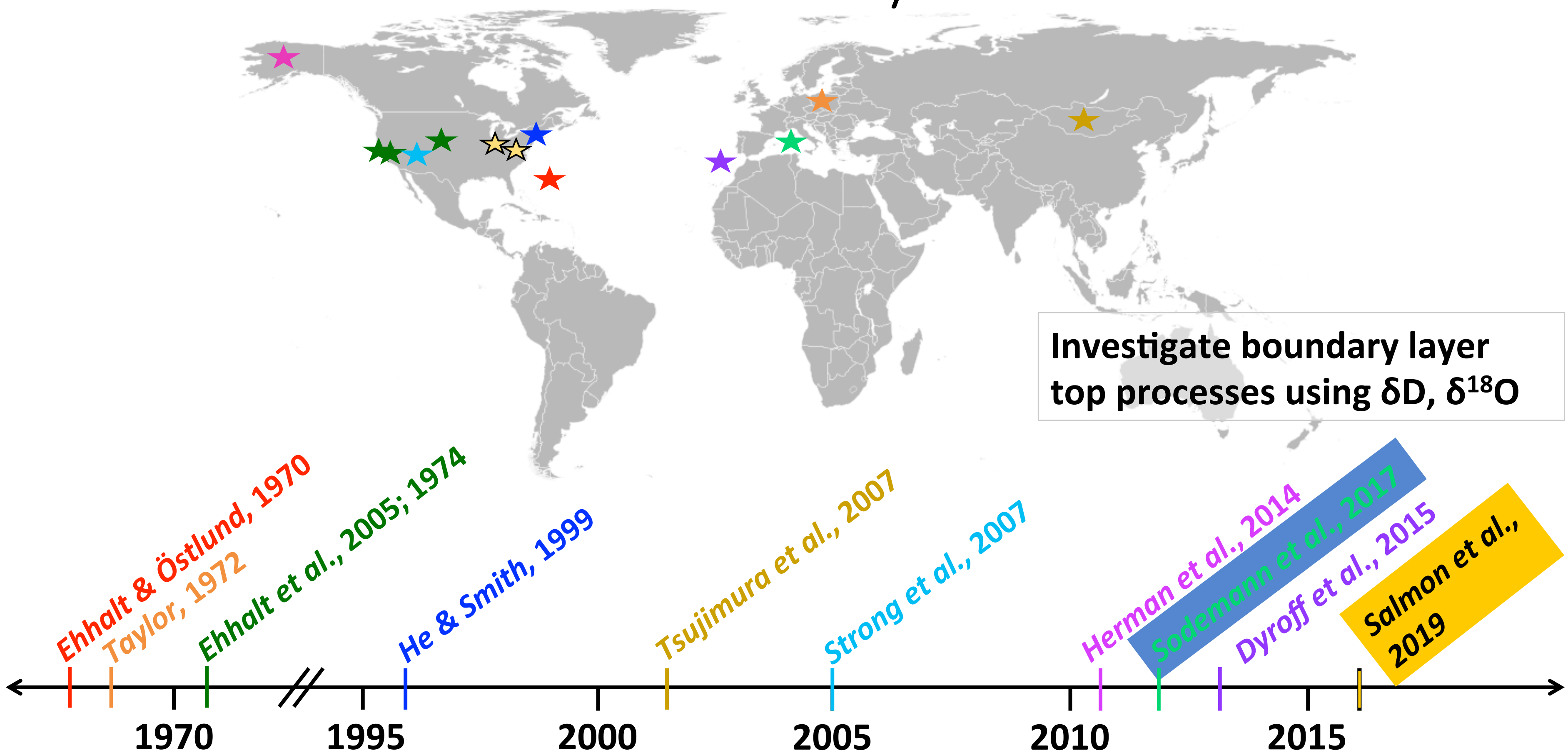
3. Complex boundary layer evolution and differences from upwind/downwind of urban area.



Lower troposphere vertical profiles of water vapor (H_2O_v) isotopes

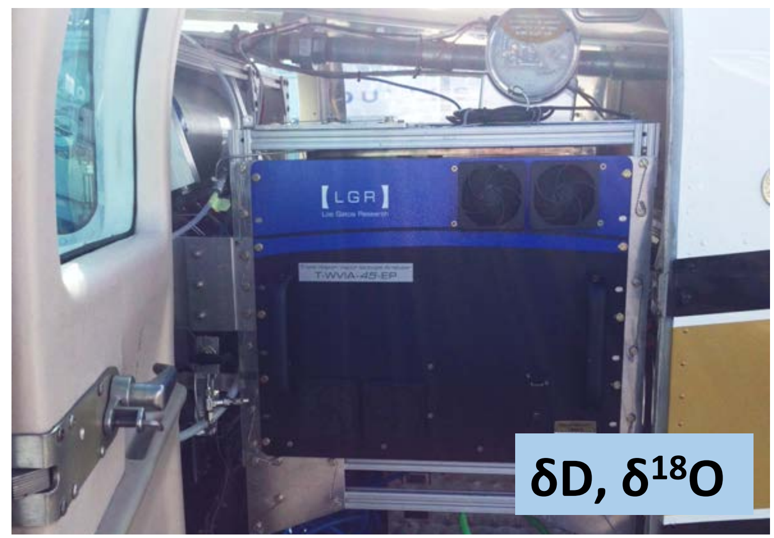


Few have observed δD and $\delta^{18}O$ to study deuterium excess

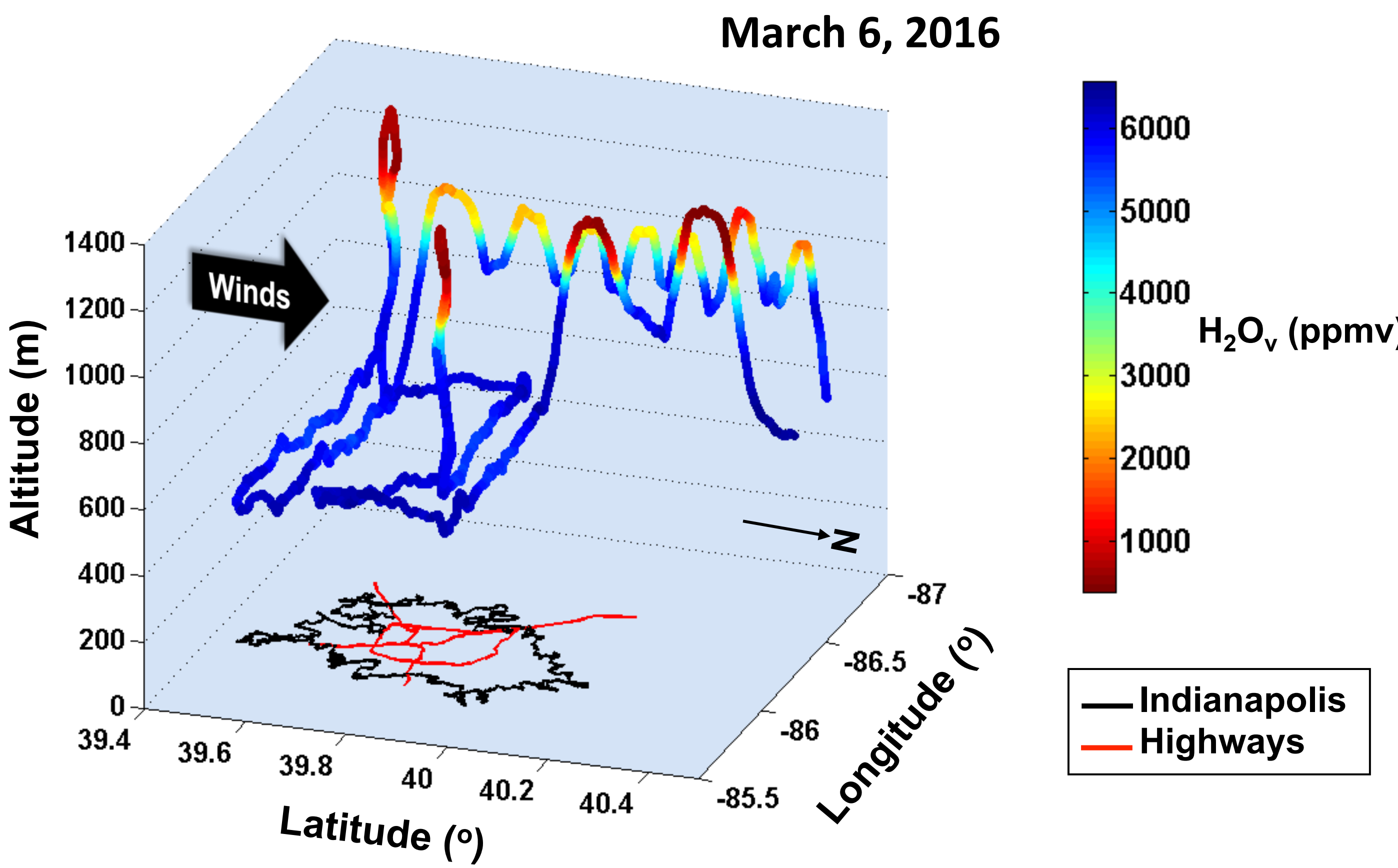


H_2O_v isotope flights in Washington, D.C. and Indianapolis

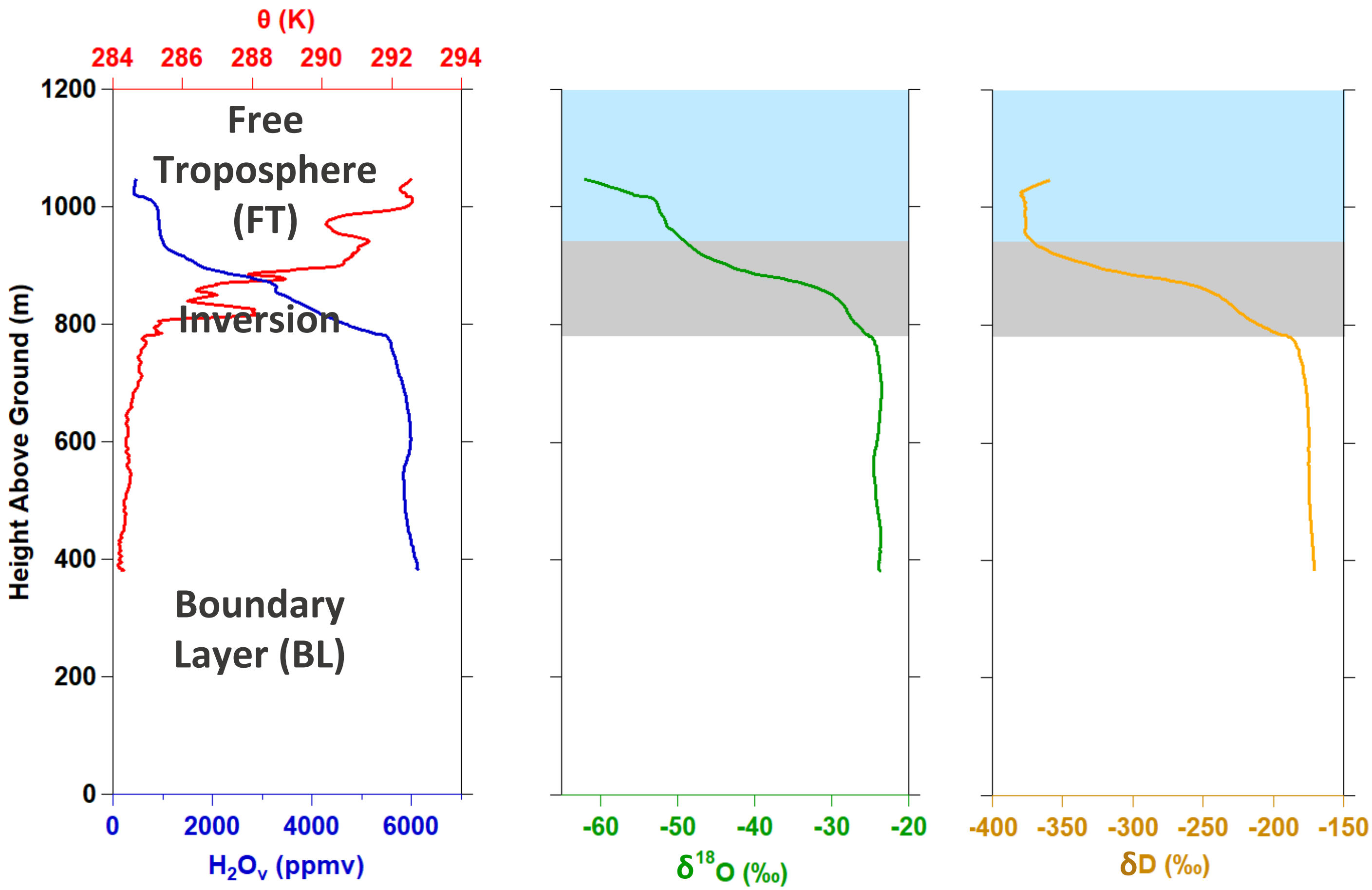
Airborne Laboratory for Atmospheric Research (ALAR)



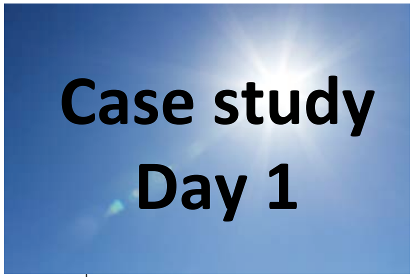
Goal: Investigate boundary-layer processes using H_2O_v isotopes

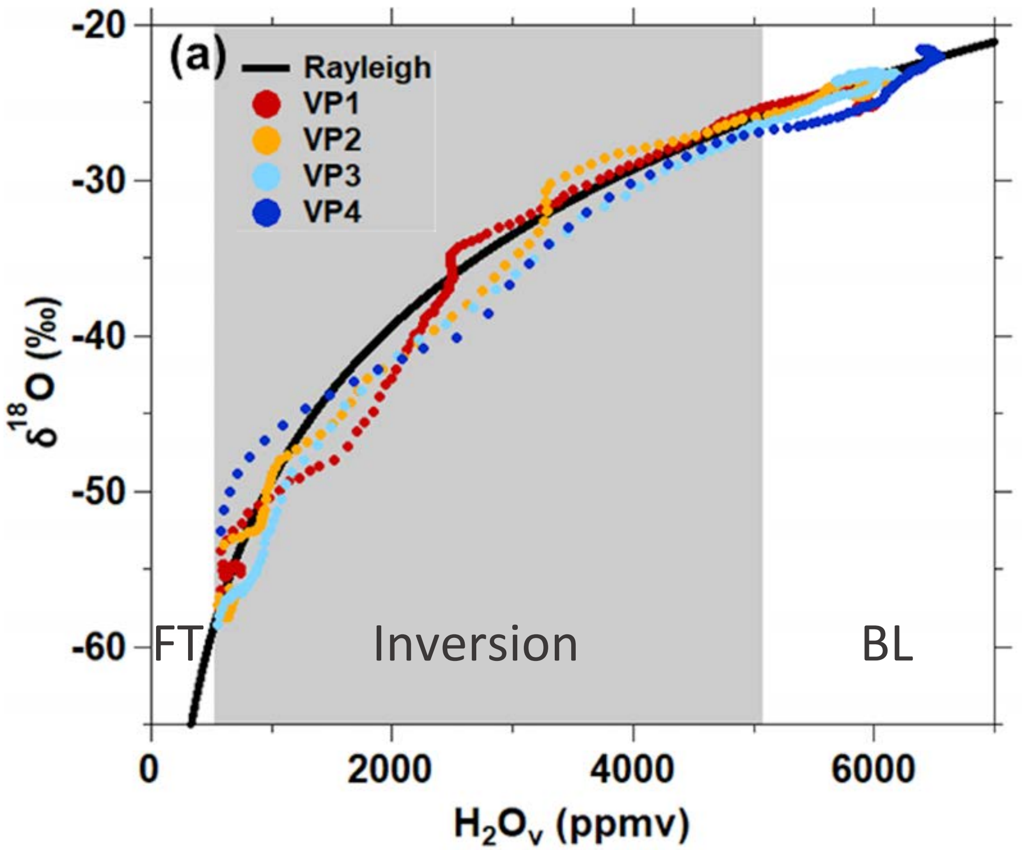


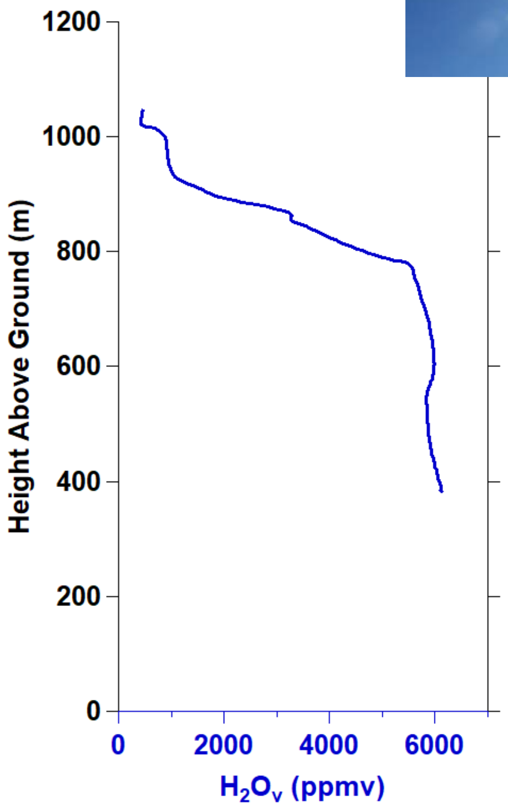
Vertical profiles show expected dehydration and decrease in $\delta^{18}O$, δD



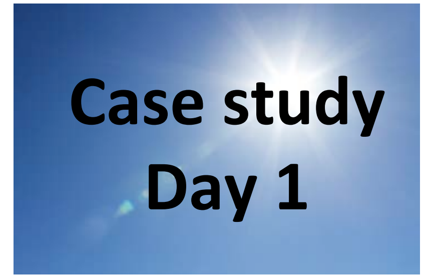
Rayleigh distillation describes clear day



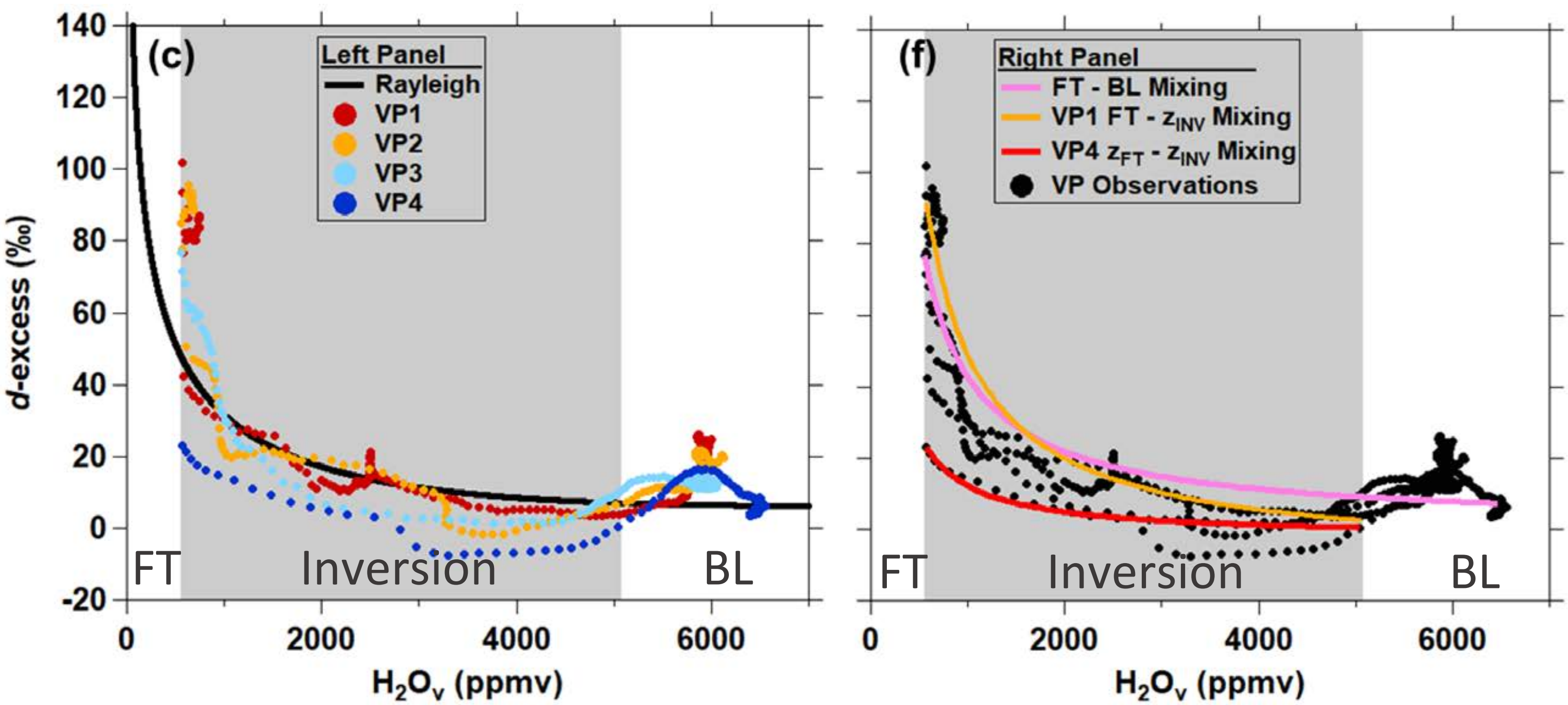




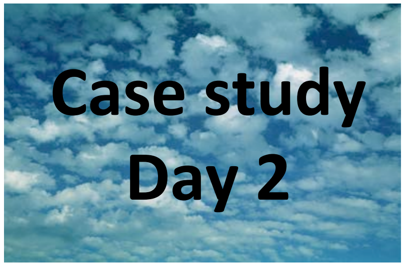
Deuterium excess indicates some mixing influence at the top of the inversion layer

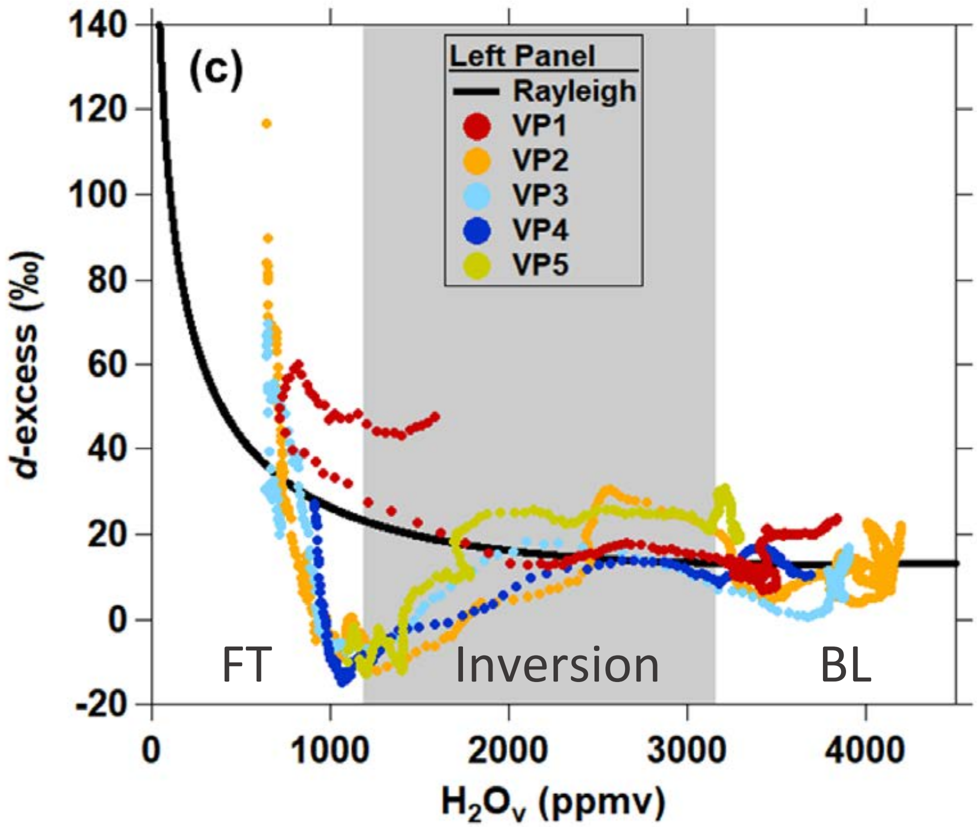


d-excess = δD - 8×δ^{18}O



Rayleigh distillation does not match on cloudy day

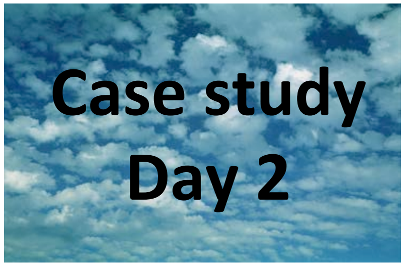


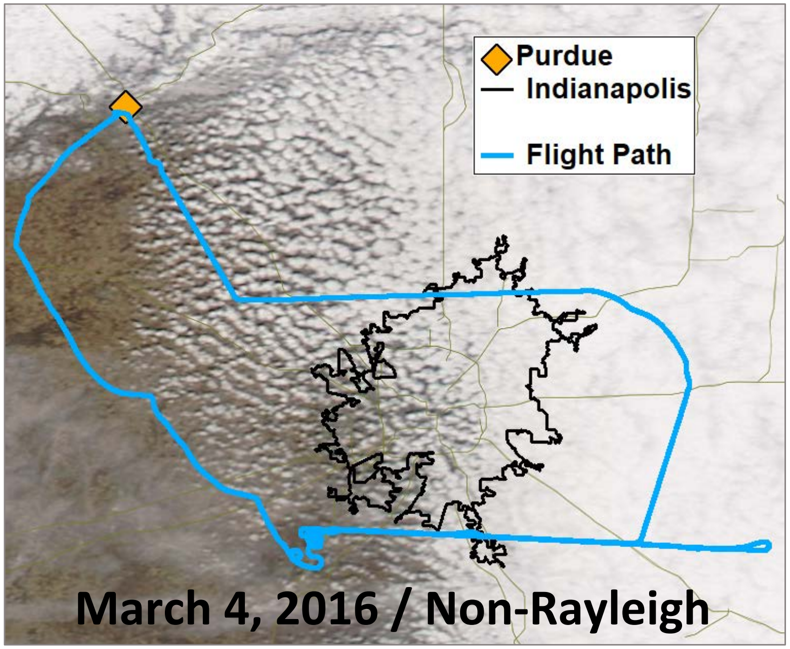


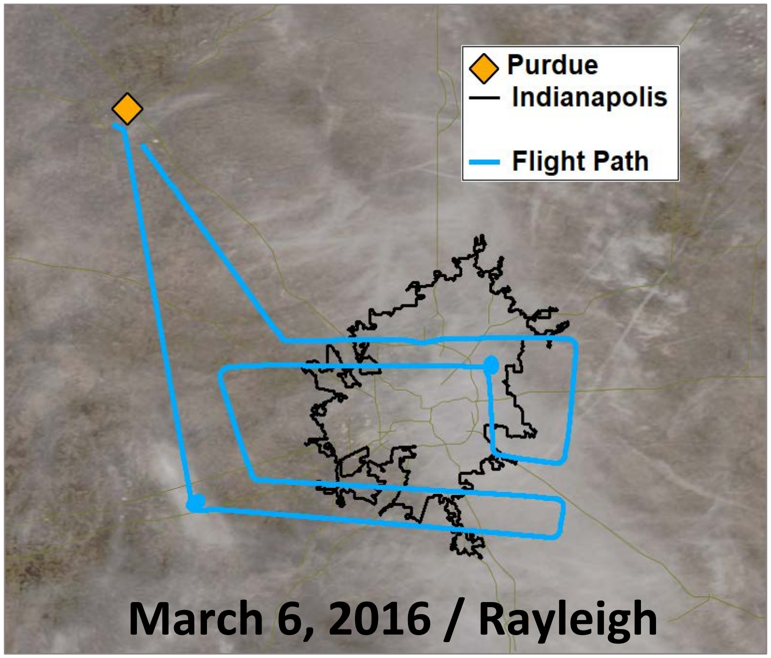
<u>*d*-excess anomalies</u>

1. Min. at inversion top
2. Local max. within inversion

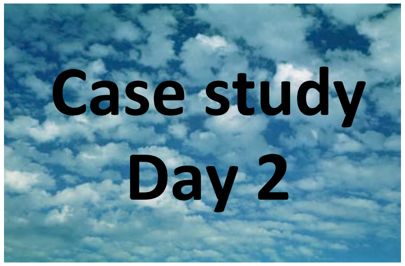
Stratocumulus clouds were observed that day

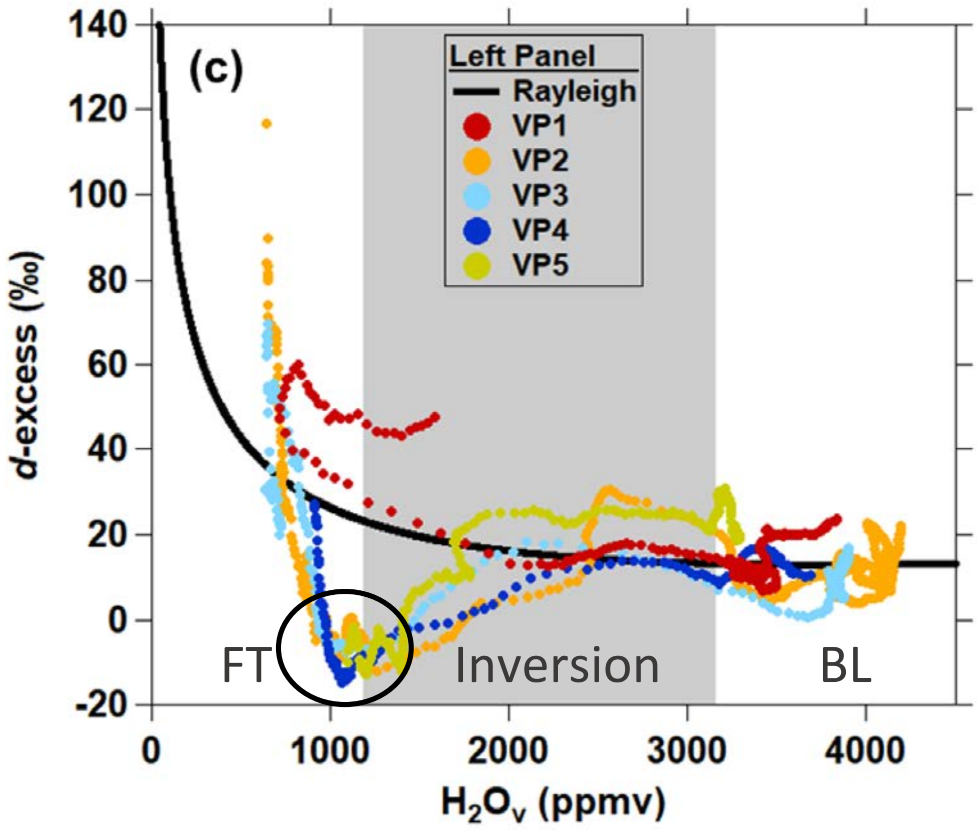




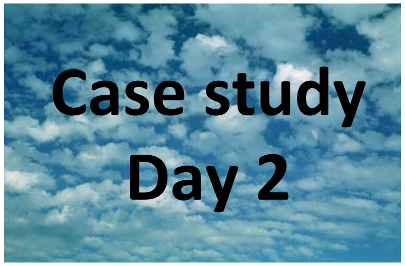


Potential causes of deuterium-excess anomalies

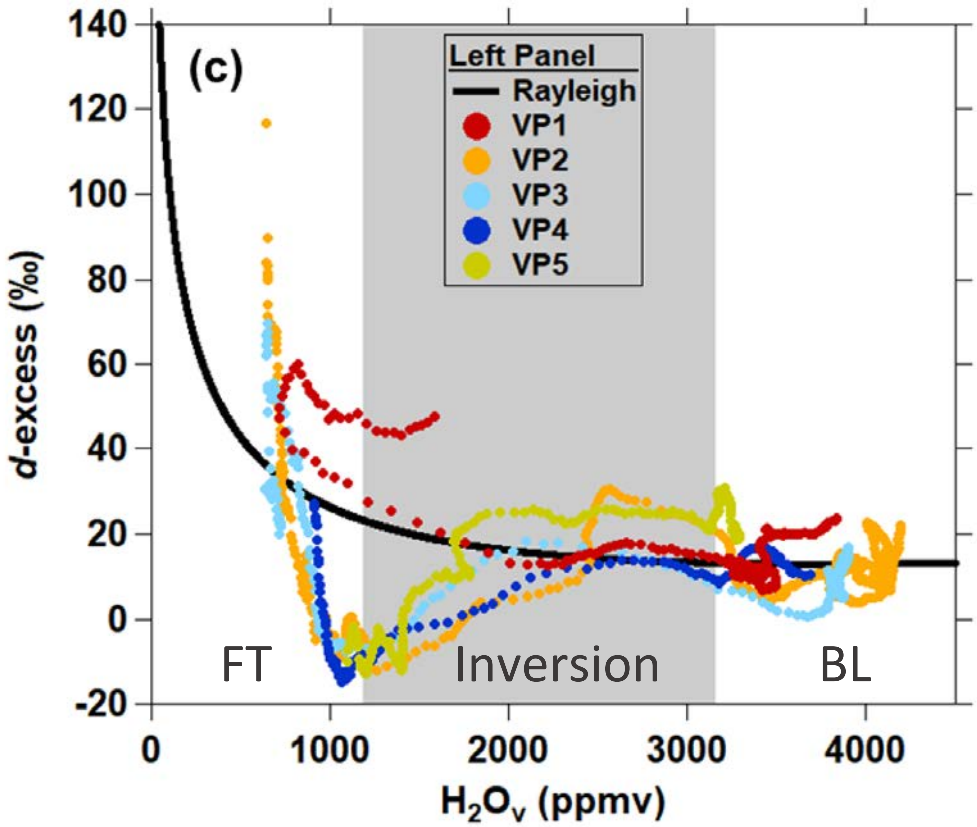




- Ice supersaturation
- Vertical mixing
- Cloud/rain droplet evaporation



Ice super-saturation is unlikely on that day



- Ice super-saturation
- Vertical mixing
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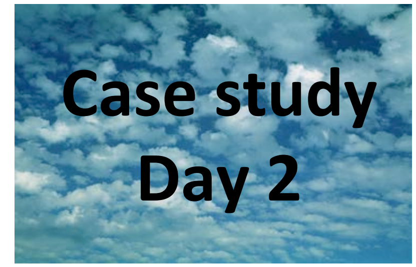
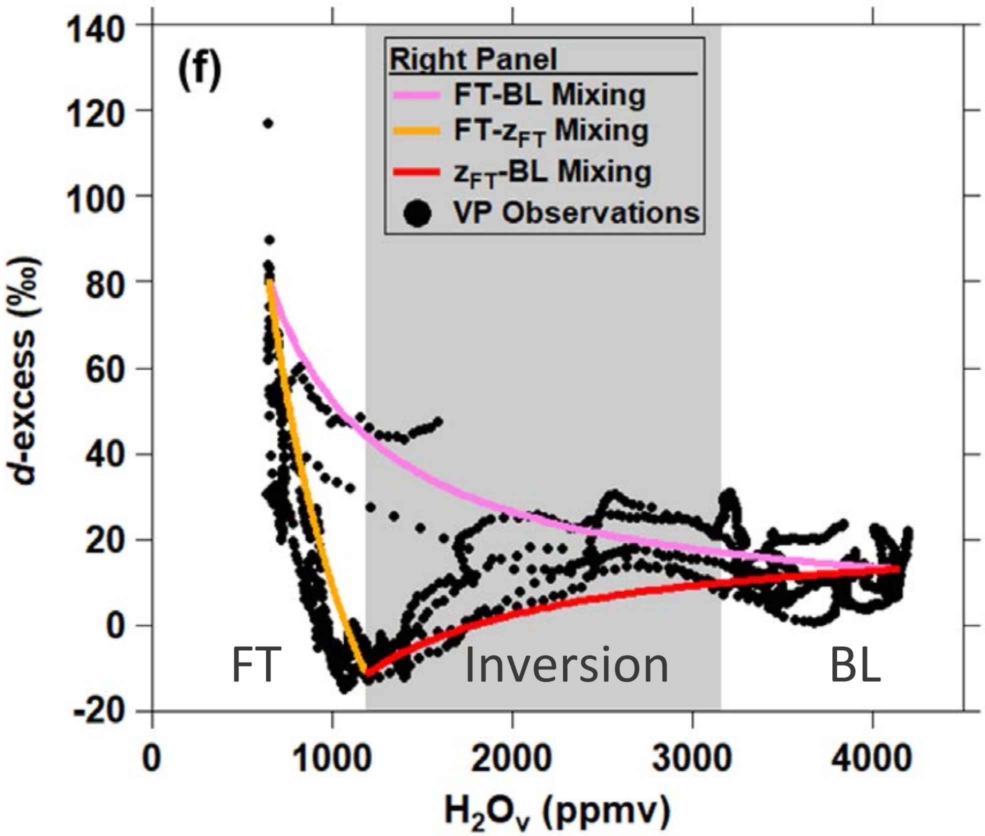
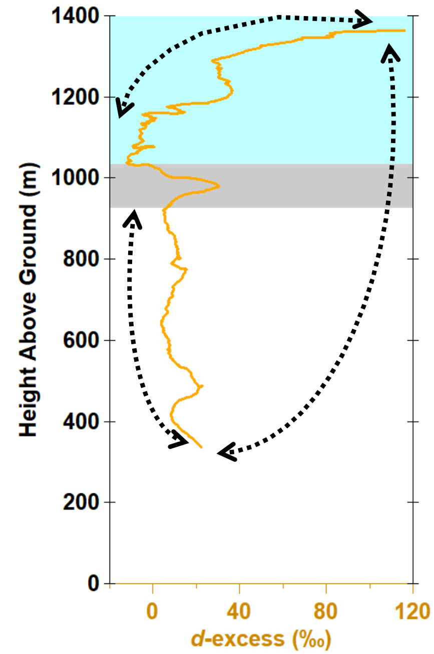
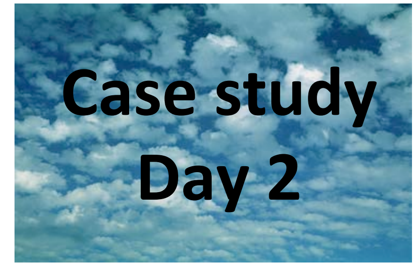
Vertical mixing may occur, but doesn't explain how the negative deuterium-excess anomaly formed

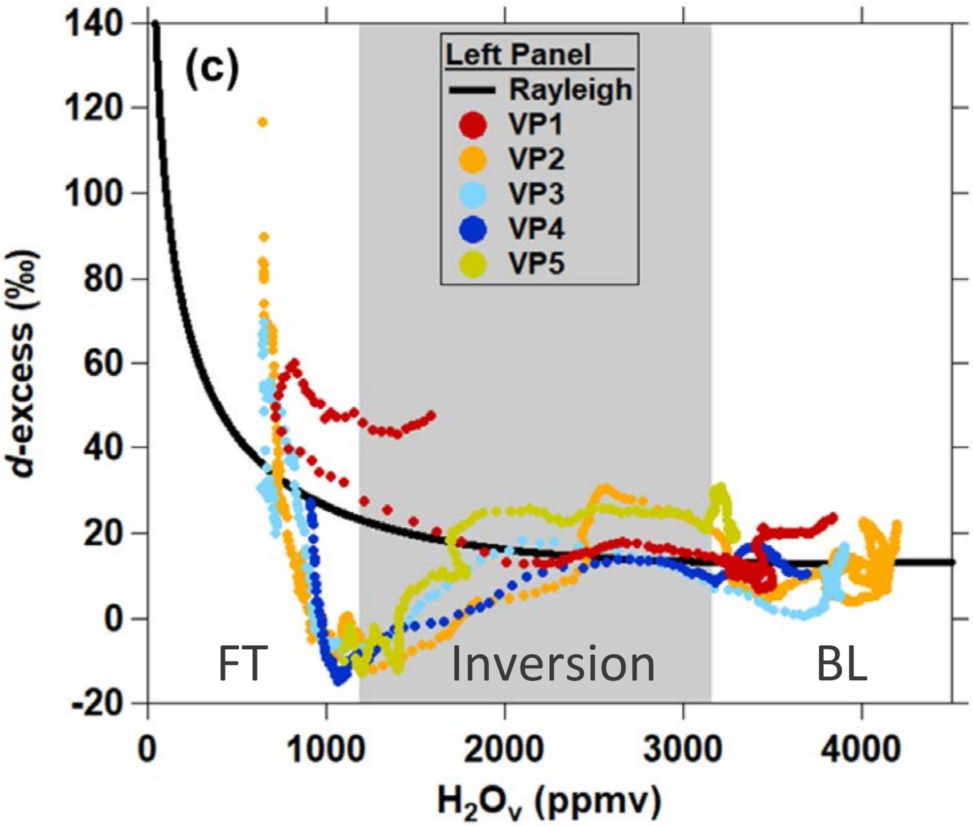






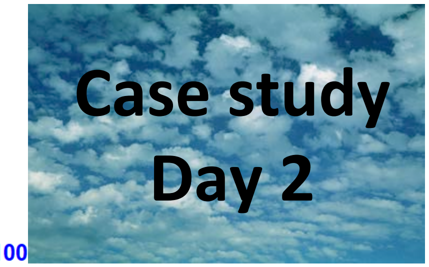
Cloud or rain droplet evaporation may produce negative deuterium excess in the inversion top

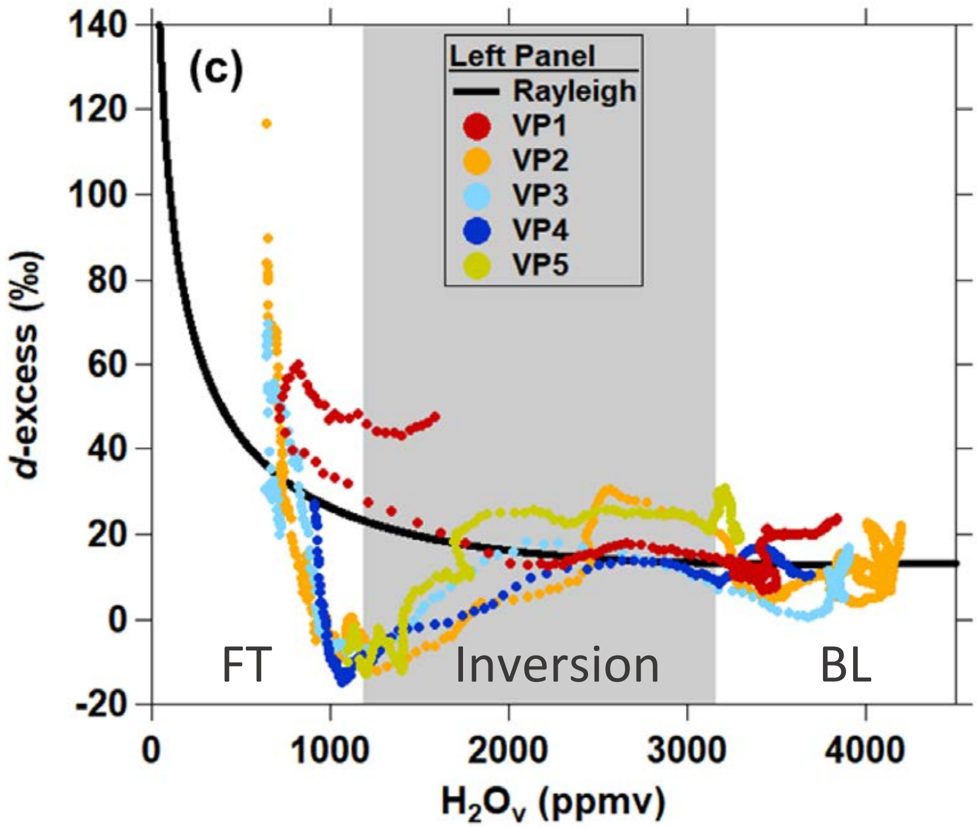


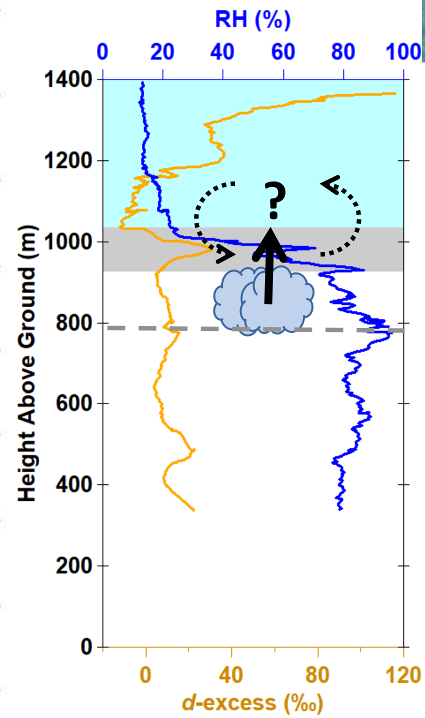


- ~~Ice super-saturation~~
- ~~Vertical mixing~~
- Cloud/rain droplet evaporation

Cloud or rain droplet evaporation may produce negative deuterium excess in the inversion top



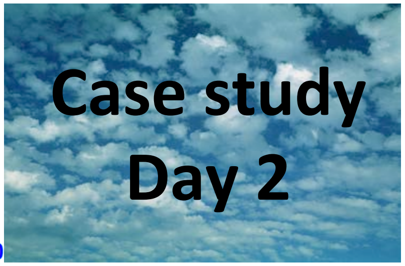


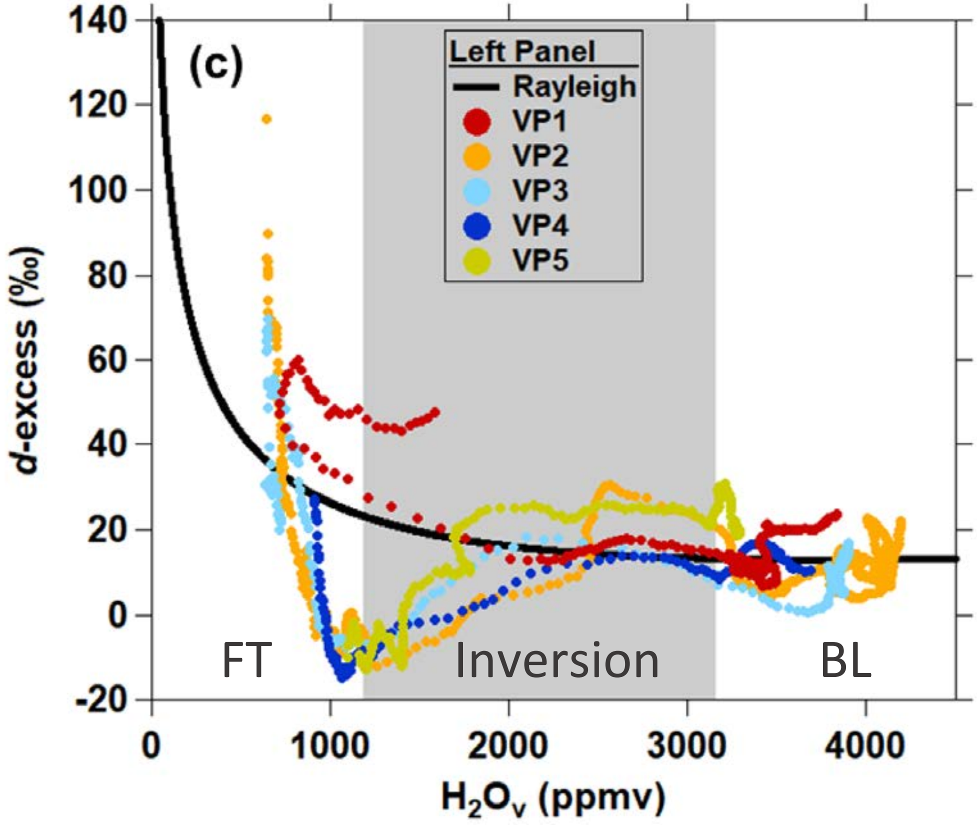


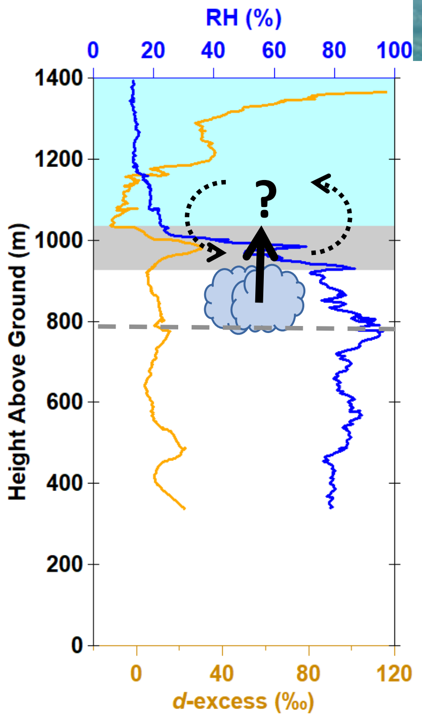
The trick is to have a droplet start evaporating in the region of higher deuterium excess (lower inversion) and finish evaporating in the region of low deuterium excess (top of the inversion).

Example: sub-cloud evaporation of falling raindrops.

Cloud or rain droplet evaporation may produce negative deuterium-excess in the inversion top





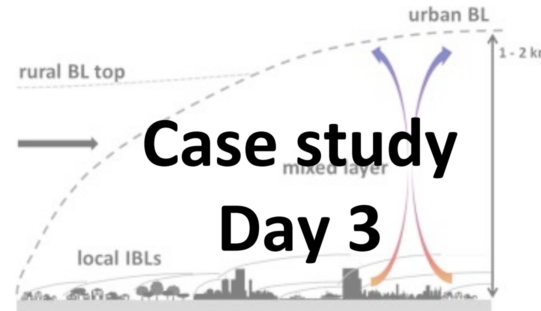


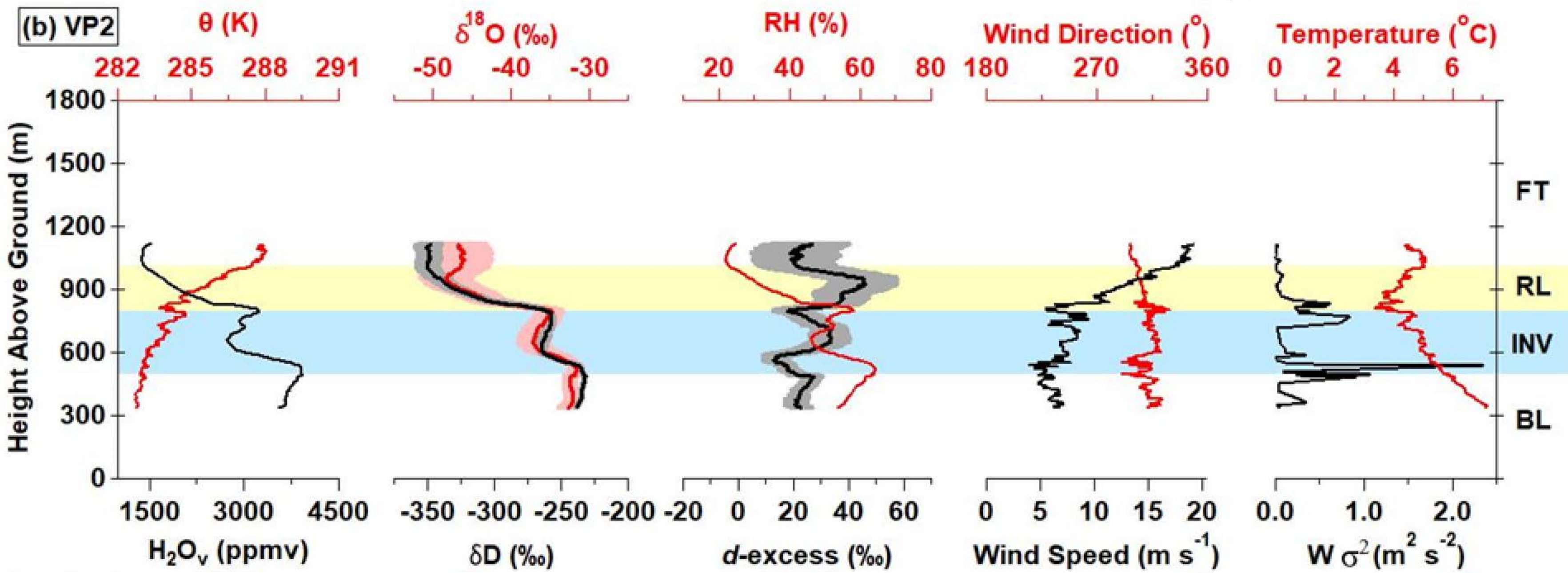
In this case: a bit of a puzzle how that would work at the top of the inversion with cloud or small rain drops but entrainment may play a role.

Sodemann et al., 2017 also observed a low deuterium-excess signal near the boundary layer top in a marine environment.

Complex boundary layer development when a new boundary layer grows into a residual layer from the previous day

Case study Day 3





Deuterium excess provides a record of Rayleigh, mixing, and evaporation which could help improve model representations of inversion layer processes

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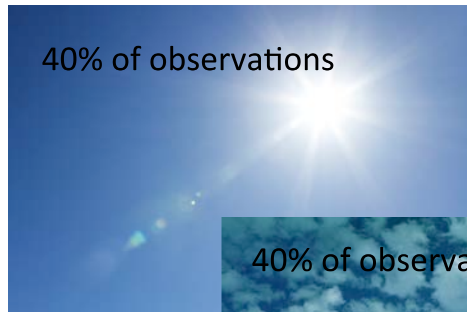
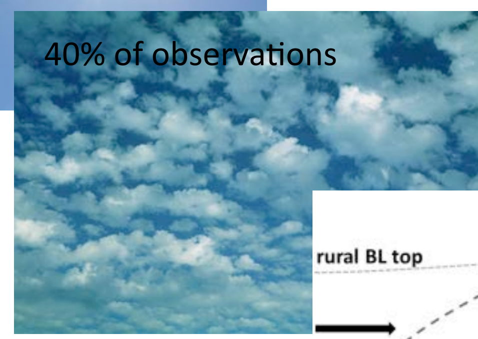


Data available in the Yale vapor isotope repository.

lwelp@purdue.edu @WelpLisa



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