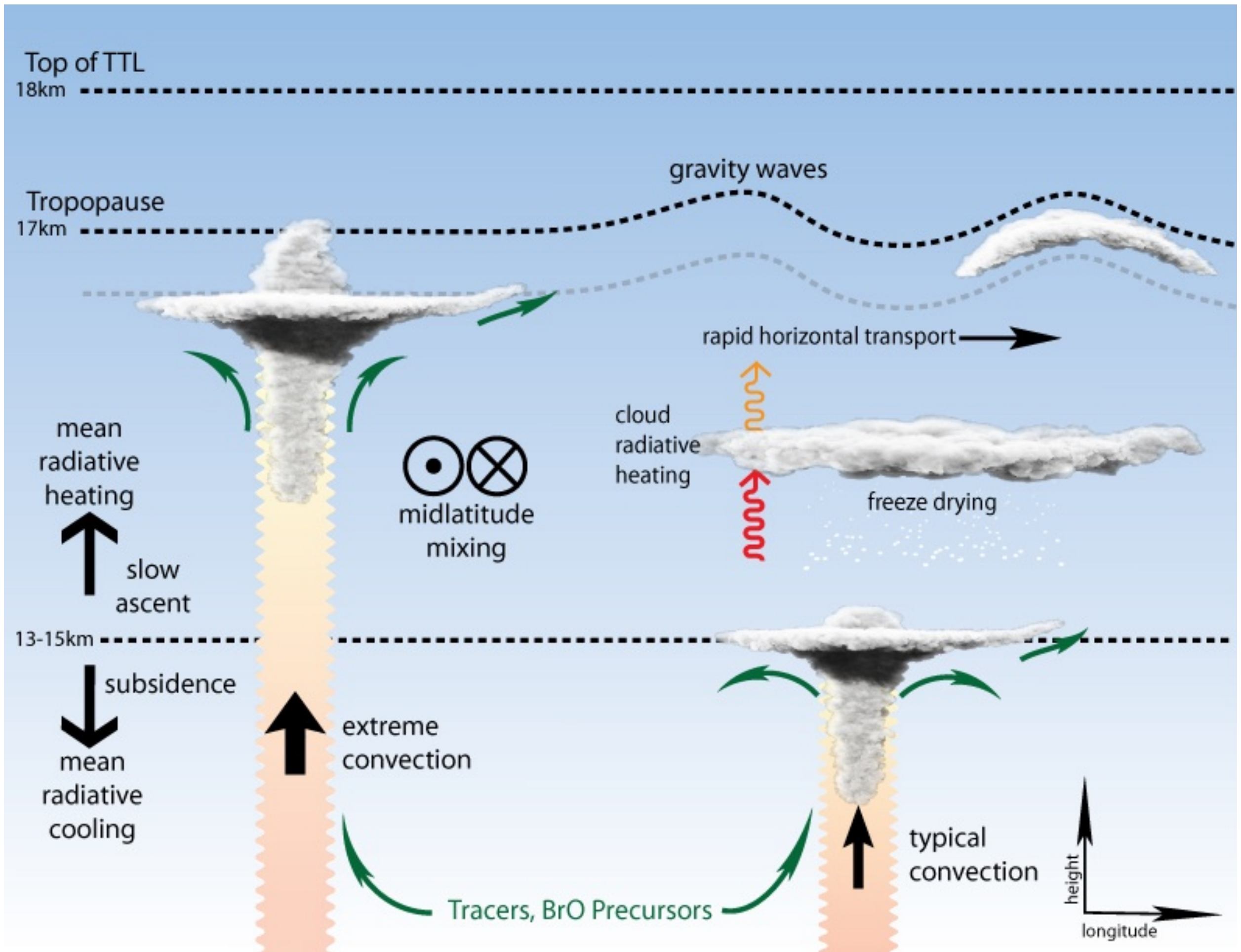
TTL dehydration efficiency evaluated using in-situ data and back trajectories

Troy Thornberry, Andrew Rollins, Paul Bui, Sarah Woods,
Leonard Pfister, Eric Jensen, and Ru-Shan Gao

Photo: NASA

ATTREX Science

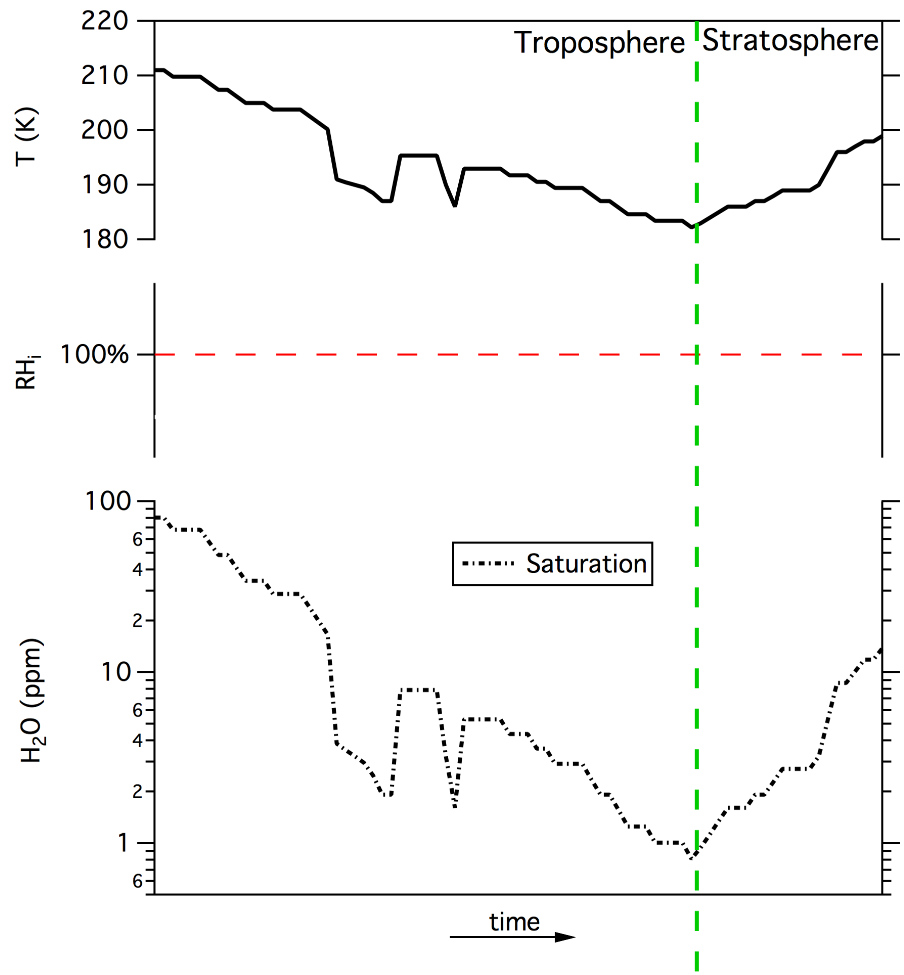


Processes occurring within the Tropical Tropopause Layer

- What processes control the humidity of air entering the stratosphere?
- What are the formation processes, microphysical properties, and climate impact of TTL cirrus, and how do these clouds regulate the humidity of air entering the stratosphere?

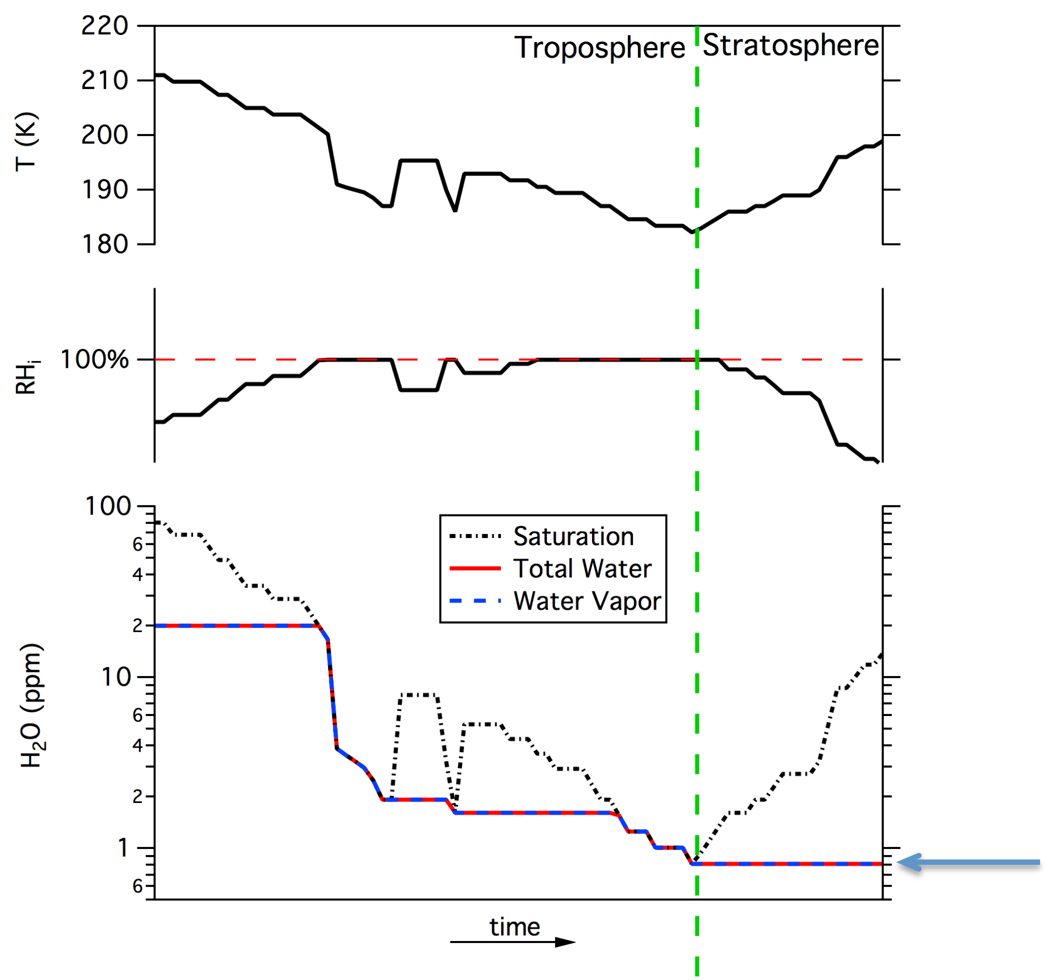
How efficient is dehydration in TTL?

Complete efficiency would imply that the stratospheric entry WV is equal to 100% RH_i at Lagrangian dry point (LDP = lowest saturation mixing ratio encountered on path to stratosphere).



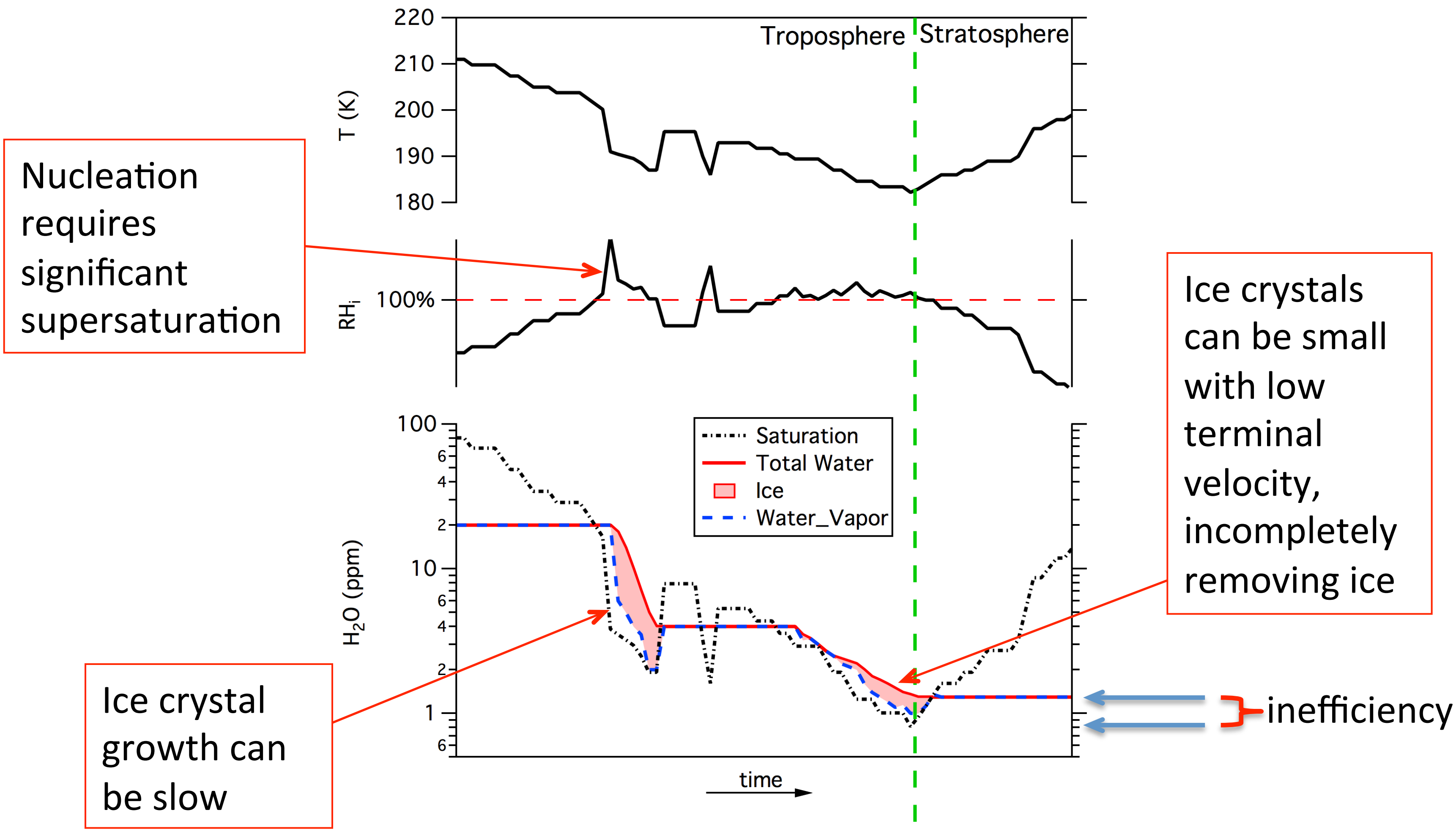
How efficient is dehydration in TTL?

Complete efficiency would imply that the stratospheric entry WV is equal to 100% RH_i at Lagrangian dry point (LDP = lowest saturation mixing ratio encountered on path to stratosphere).



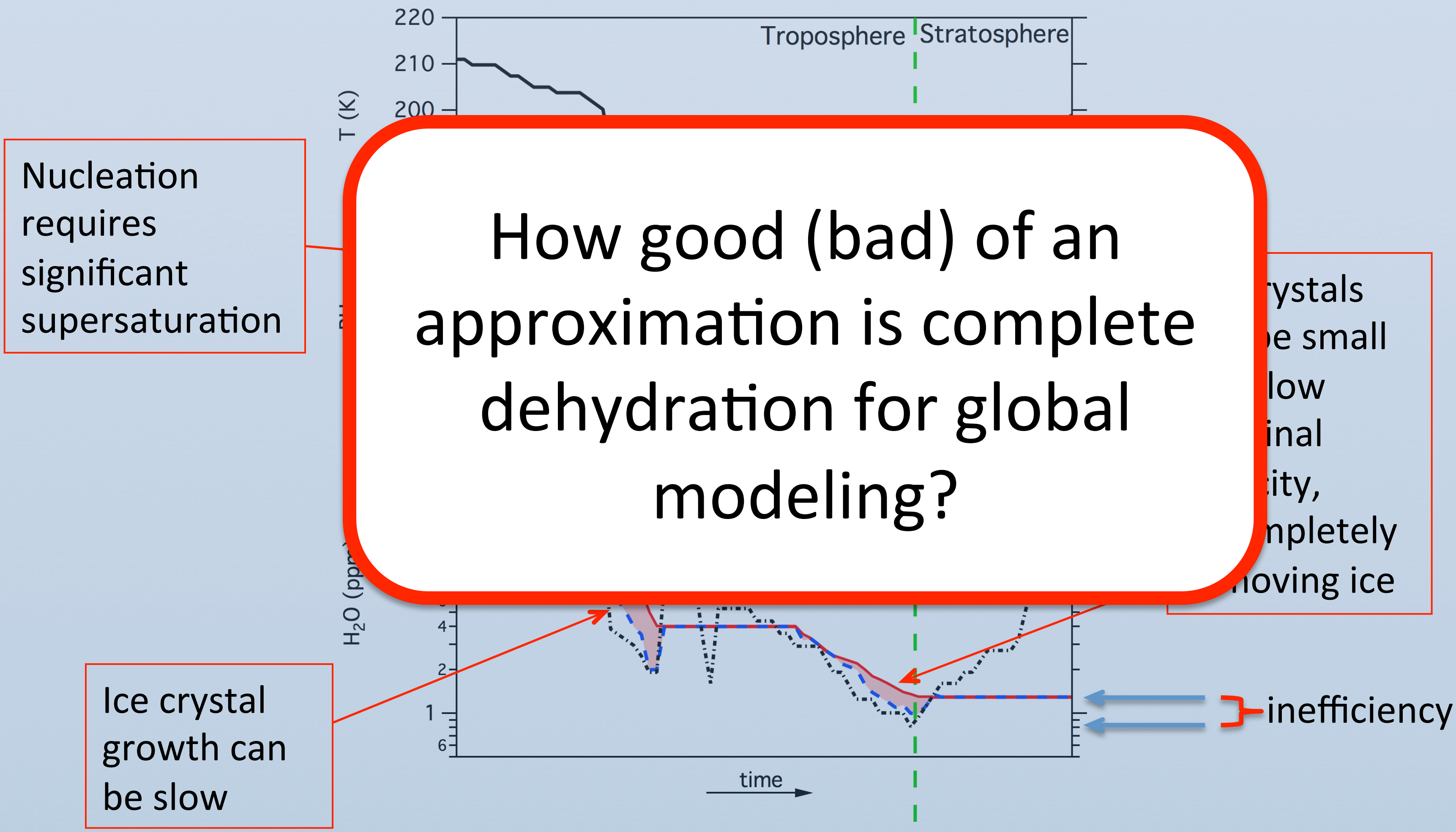
How efficient is dehydration in TTL?

Complete efficiency would imply that the stratospheric entry WV is equal to 100% RH_i at Lagrangian dry point (LDP = lowest saturation mixing ratio encountered on path to stratosphere).



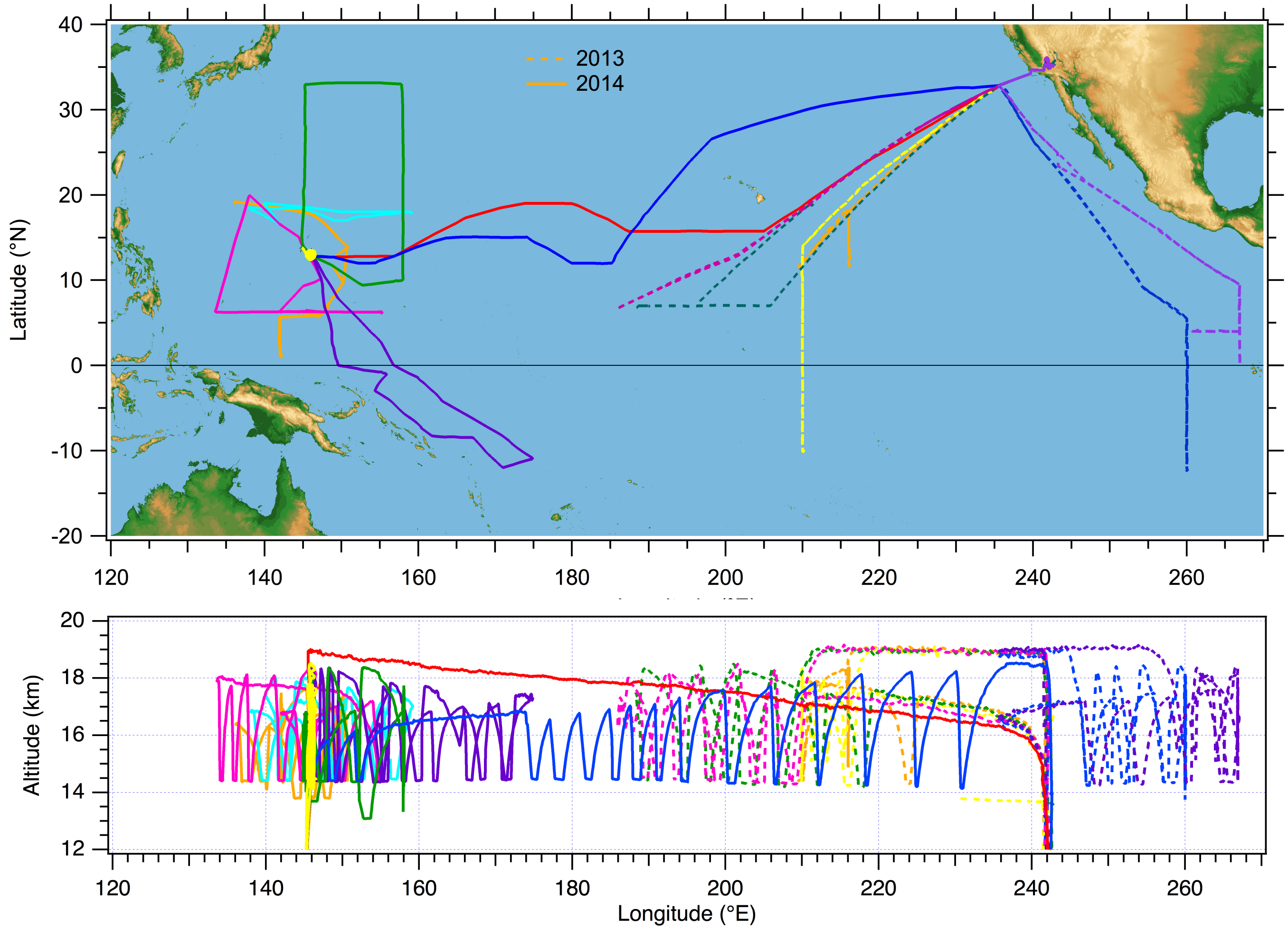
How efficient is dehydration in TTL?

Complete efficiency would imply that the stratospheric entry WV is equal to 100% RH_i at Lagrangian dry point (LDP = lowest saturation mixing ratio encountered on path to stratosphere).



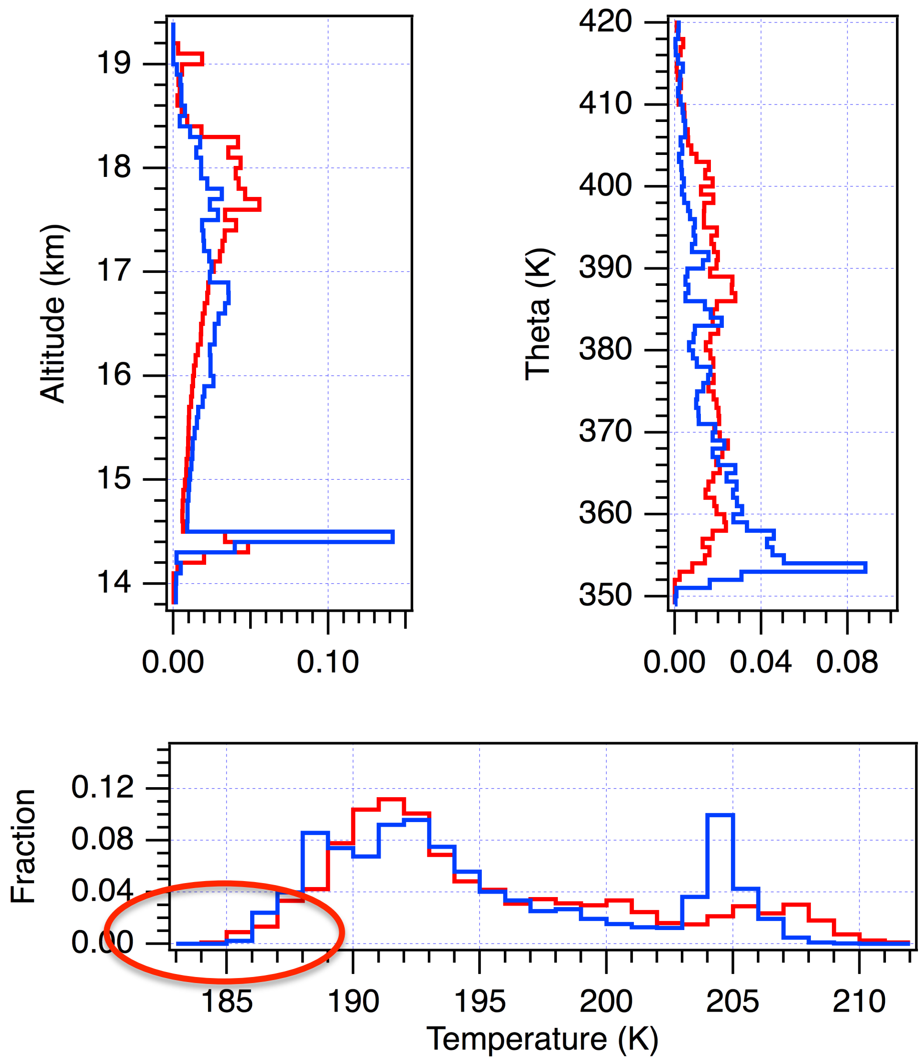
ATTREX Deployments 2013 & 2014

Photos courtesy of D. Fratello



- Use data to statistically understand/parameterize dehydration efficiency

ATTREX Sampling Histograms



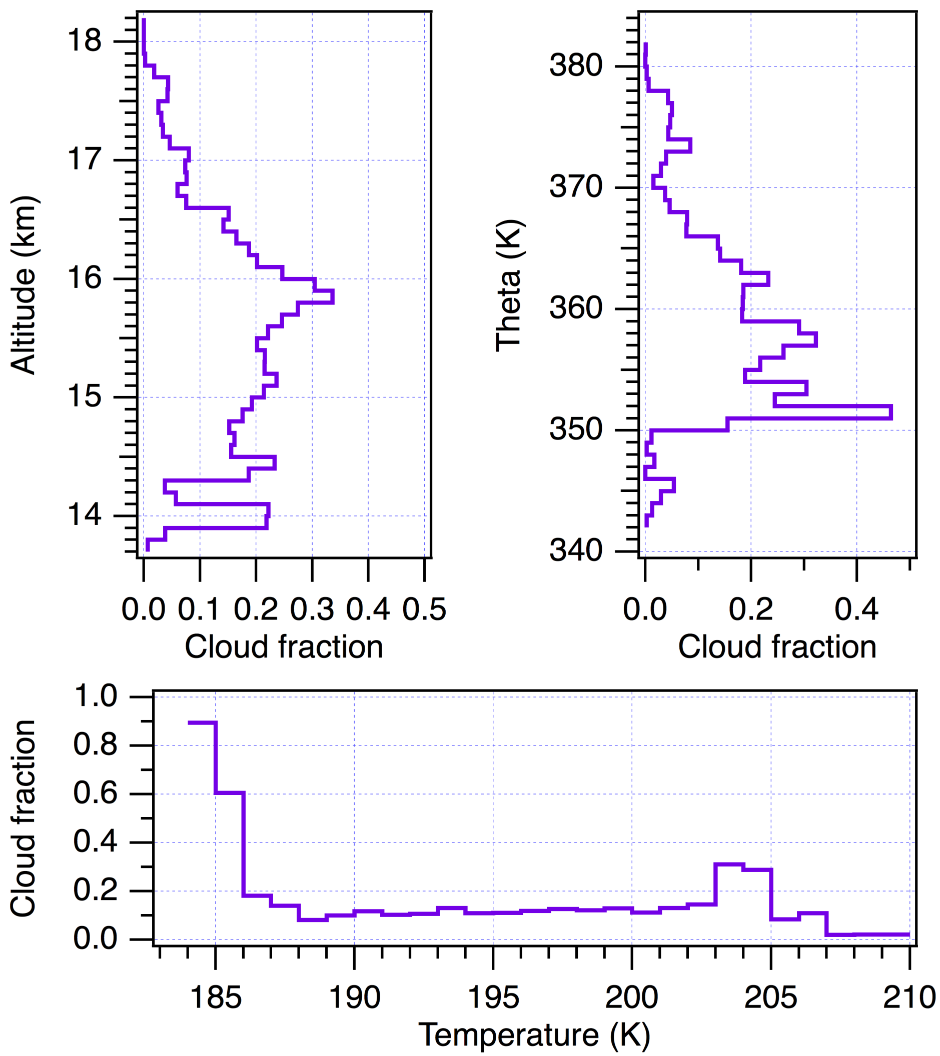
Comparison of 2013 and 2014 from GH sampling perspective

2013: > 74 hours in the TTL
2014: > 108 hours in the TTL

Combined > 34 hours sampling TTL cirrus (mostly in 2014)

Limited sampling in either year at temperatures < 186 K

ATTREX cloud sampling

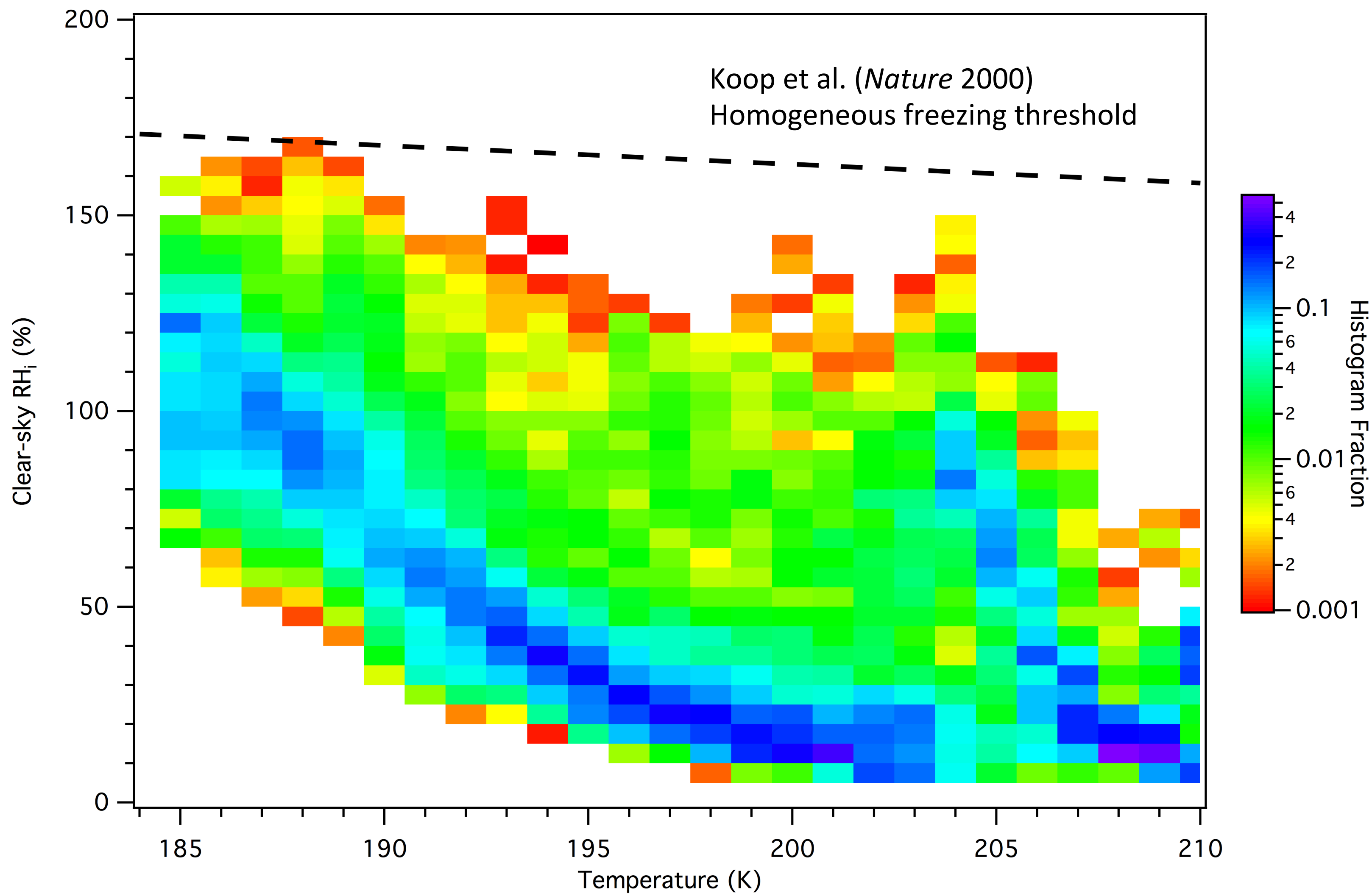


Define cloud using both cloud probe and NW IWC measures

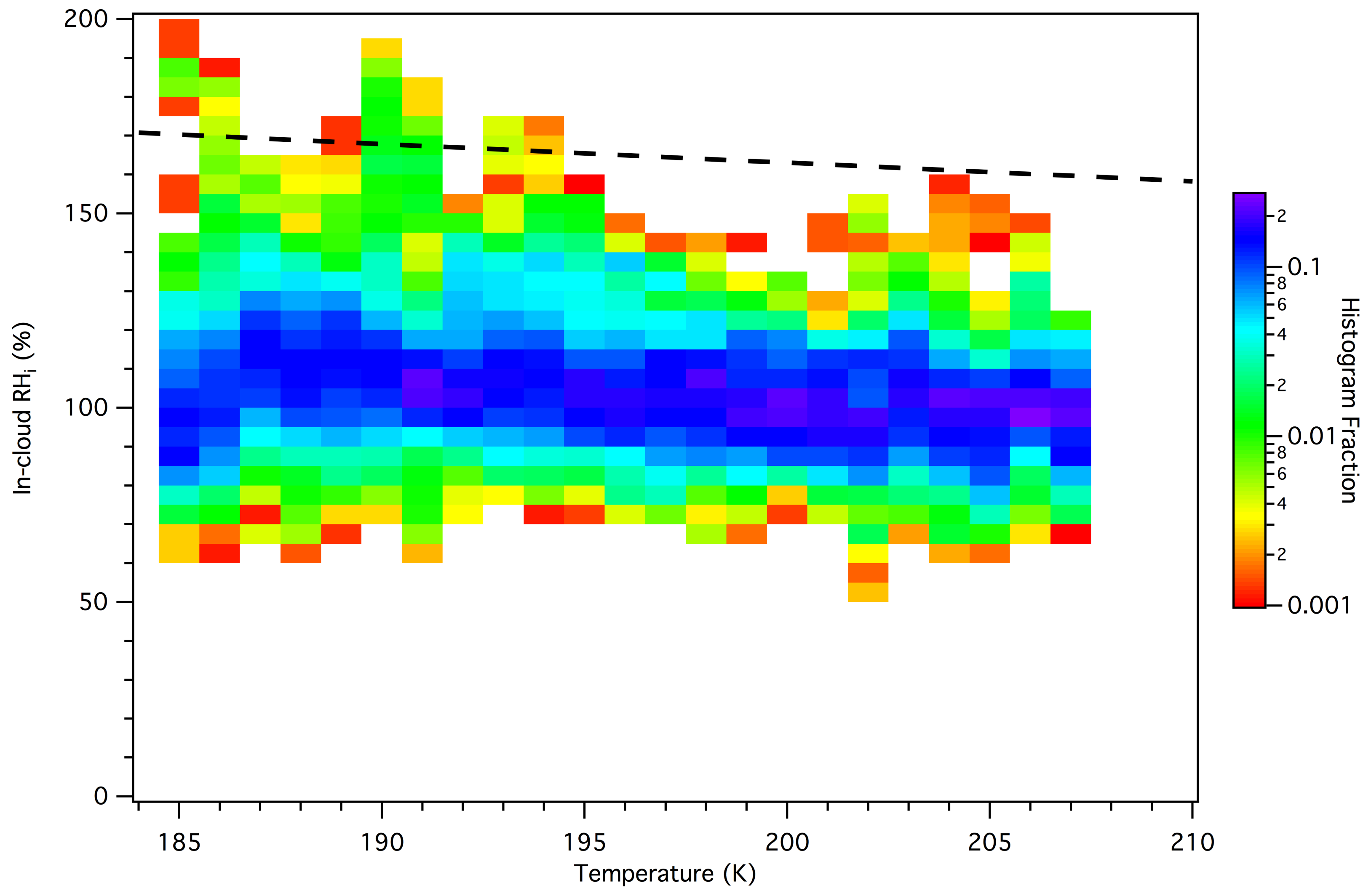
Sampled cloud fractions similar to satellite climatology (CALIOP)

Particularly high cloud fraction observed at lowest sampled temperatures

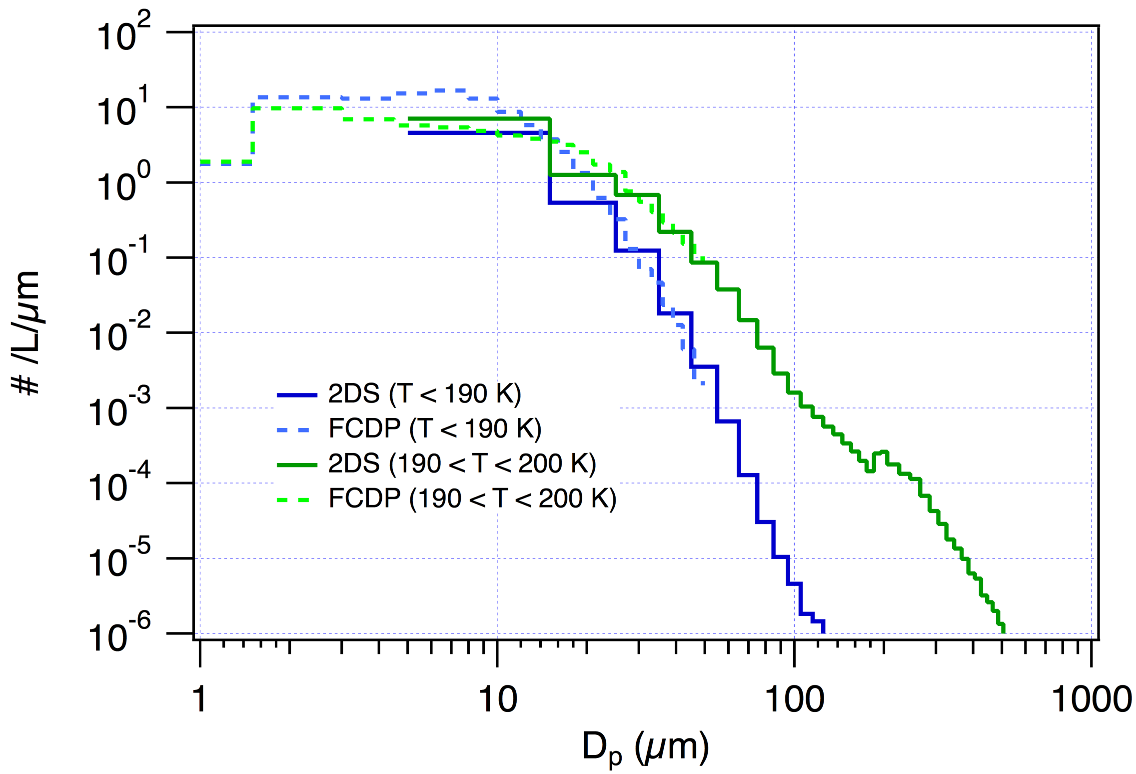
Clear-sky RH_{ice} vs T

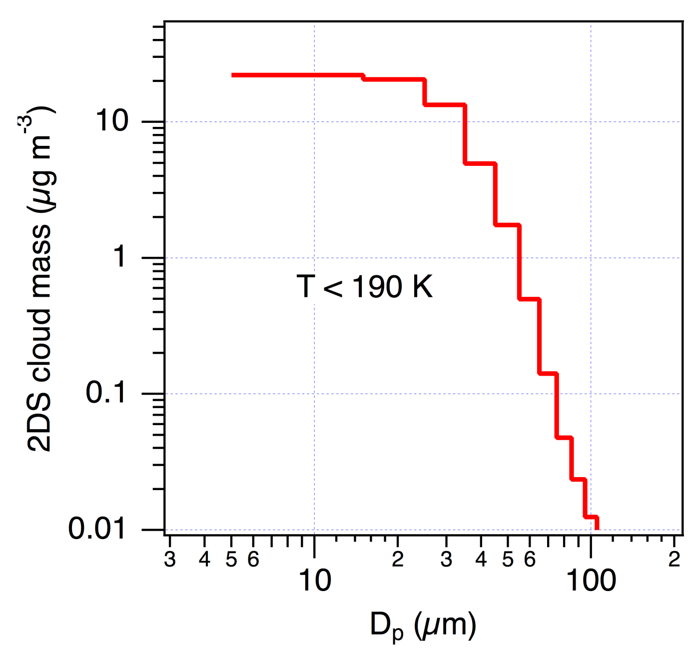


In-cloud RH vs T



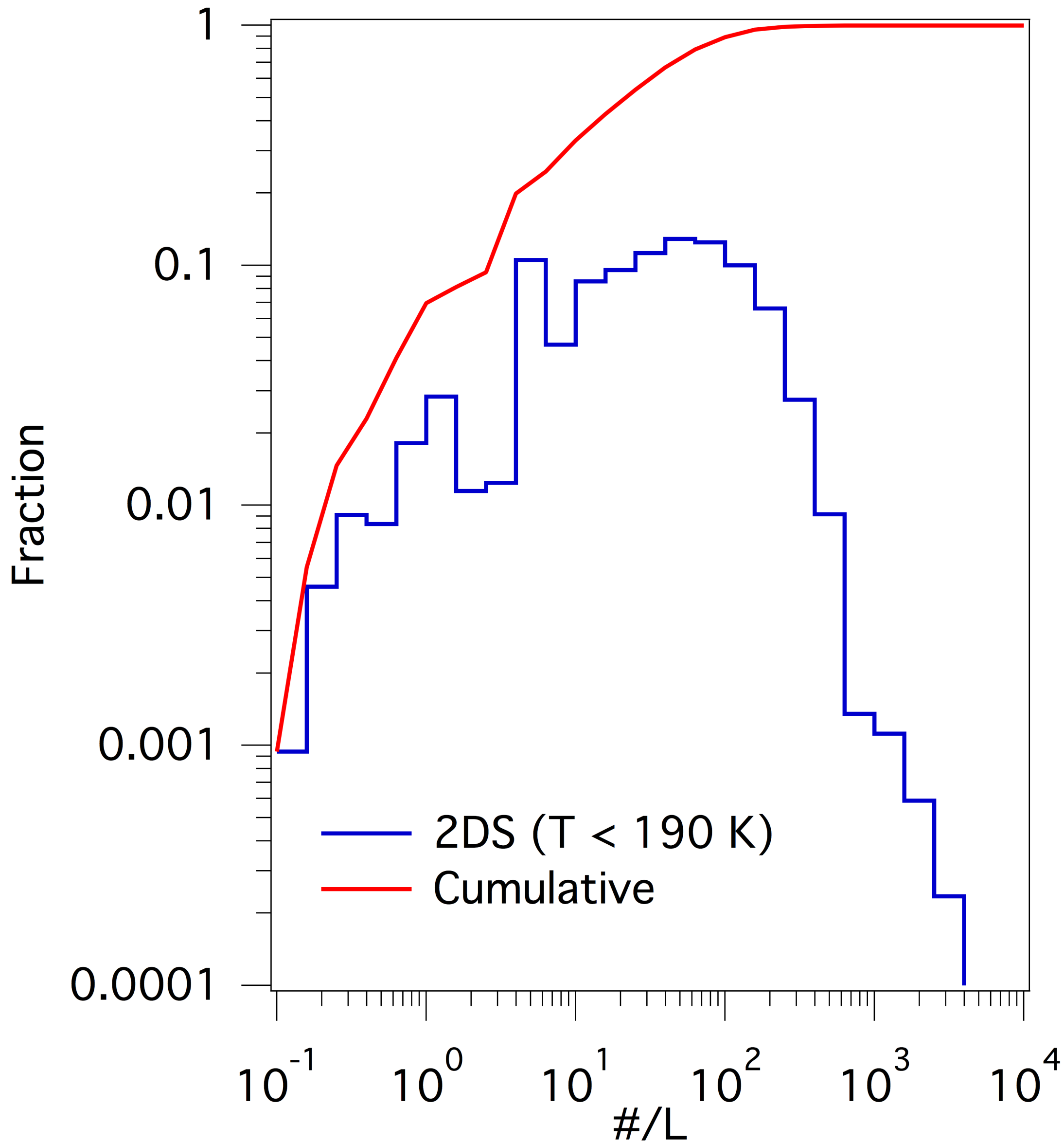
Cirrus Cloud Particle Size Distributions





- Dominant fraction of TTL cirrus particles < 15 μm
- Distribution smaller at lower temperature
- Mass also concentrated in small sizes (< 35 μm)
  - ➢ Implications for dehydration

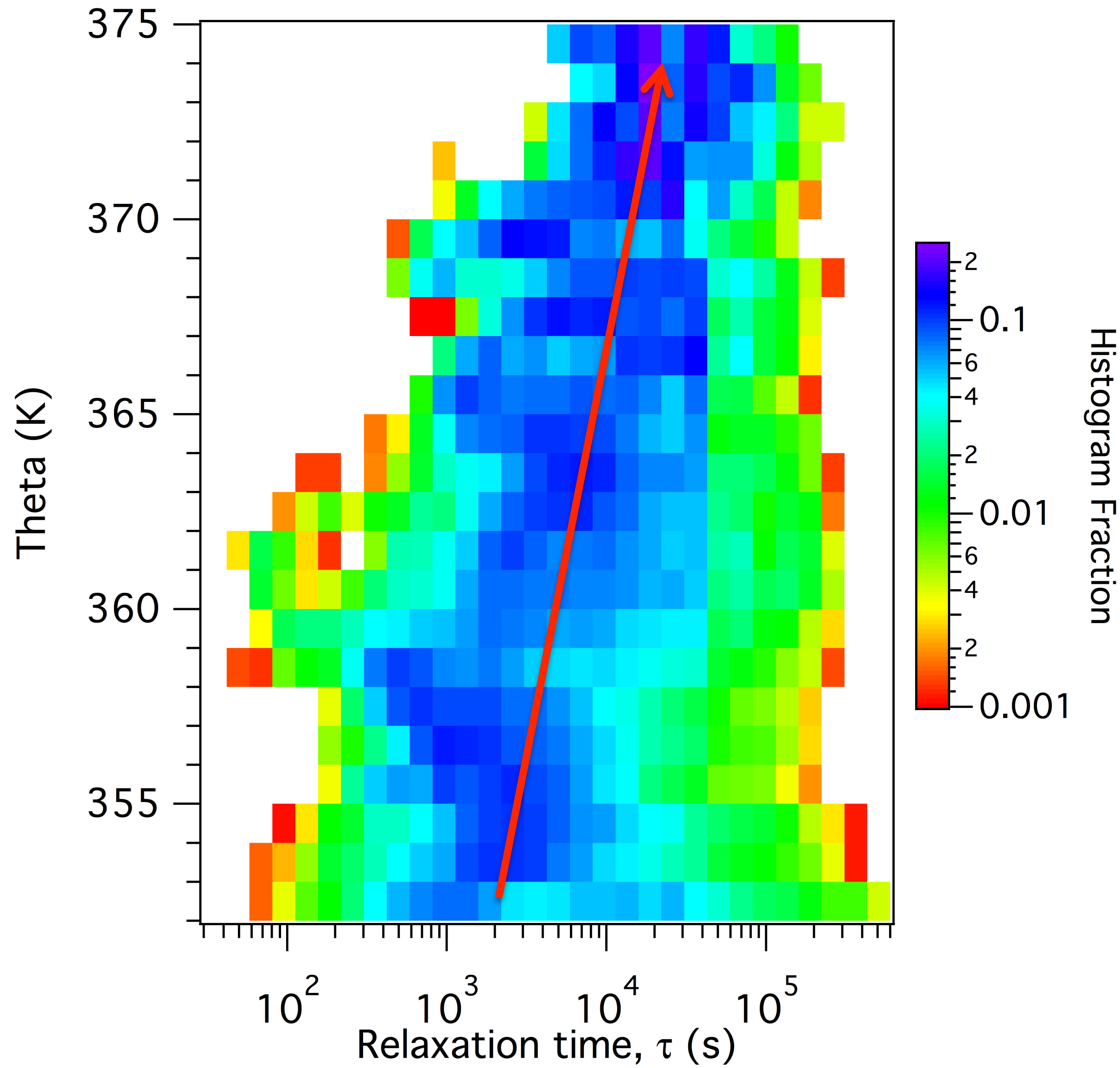
Cirrus Particle Concentrations



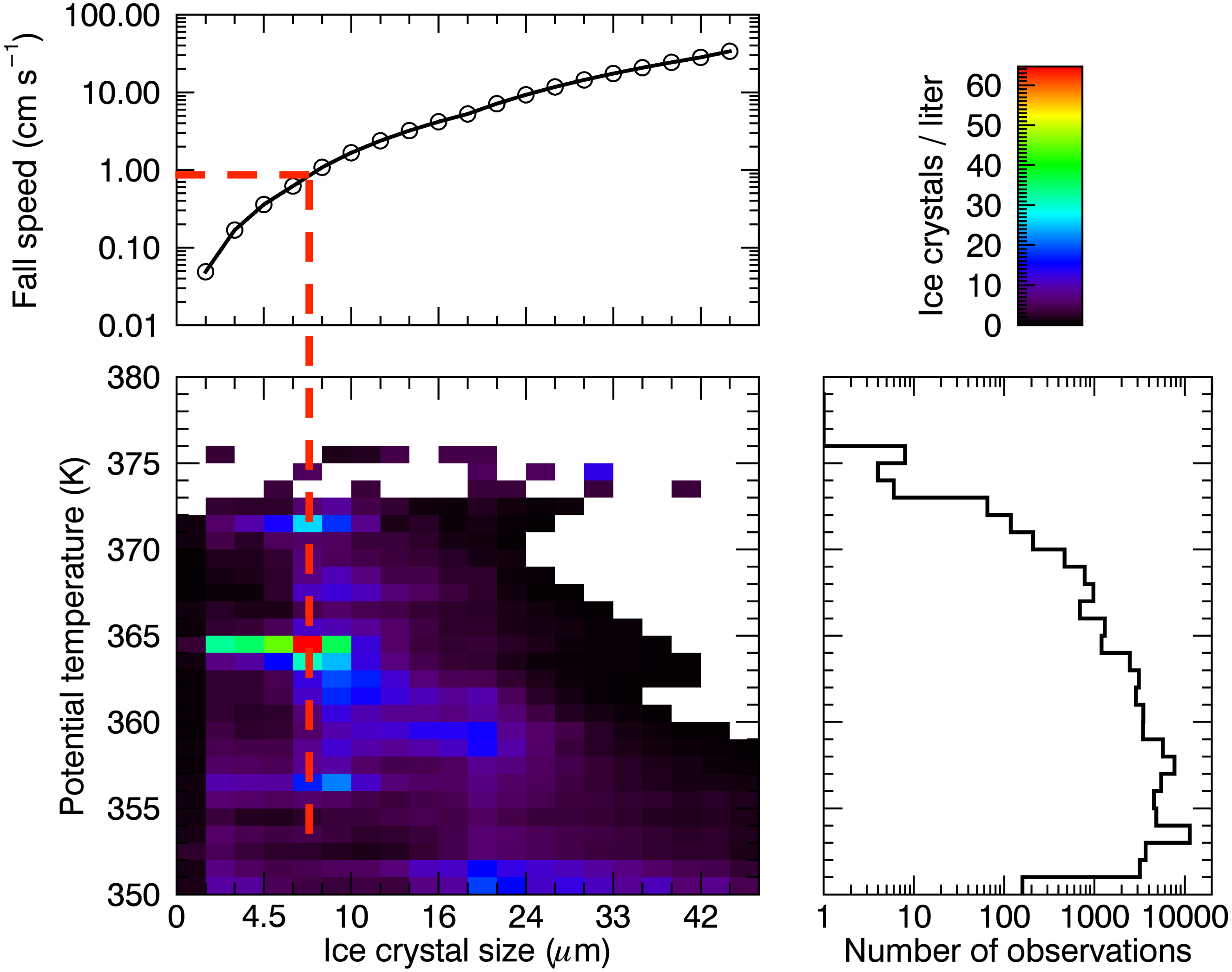
- 90% of cirrus observations have $N < 100\ L^{-1}$
- Less than 0.05% have $N > 1000\ L^{-1}$

Supersaturation Quenching Time

- τ proportional to $1 / \Sigma N_i \cdot r_i$
- calculated using formulation of *Korolev and Mazin, J. Atmos. Sci., 2003*



How efficiently is ice removed?



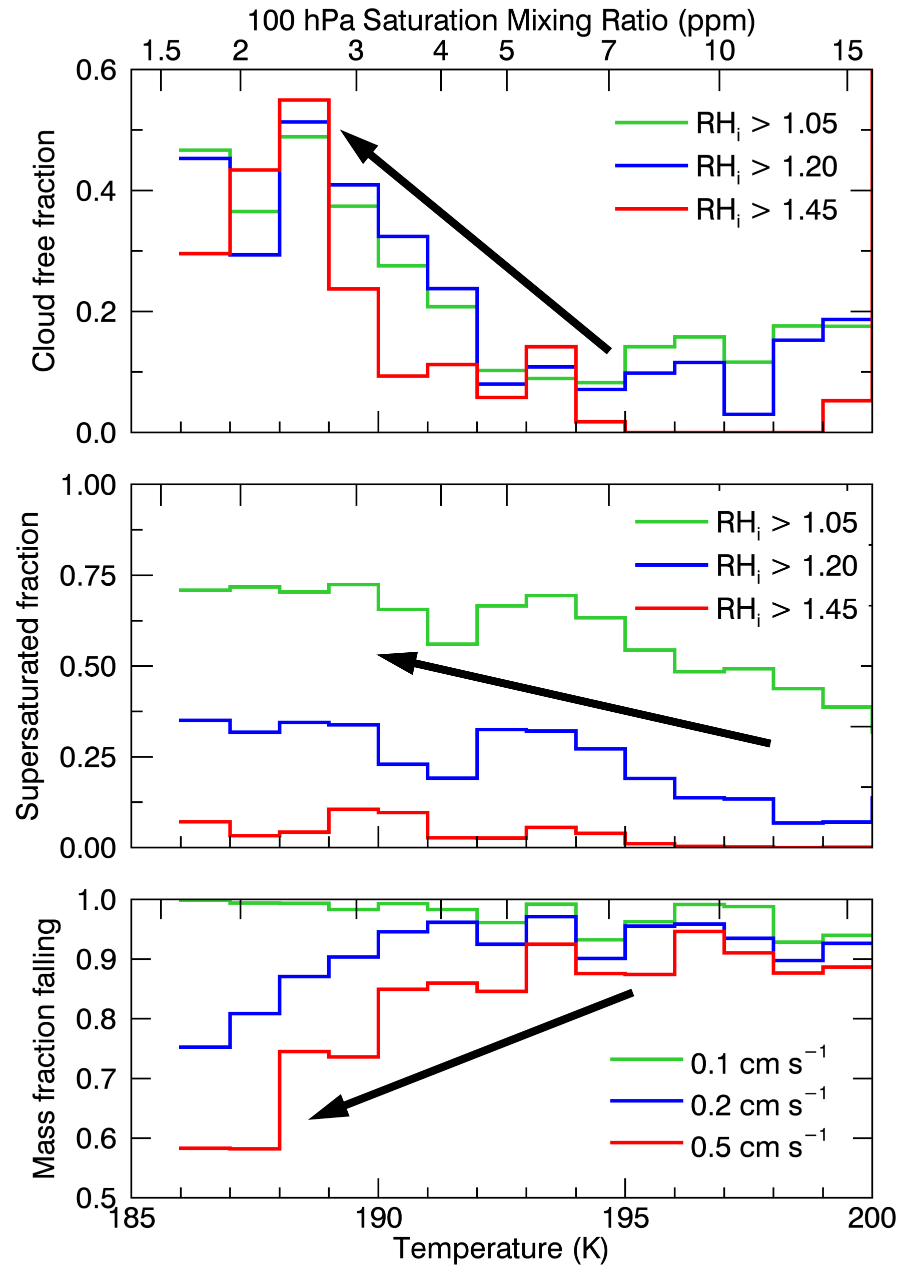
Inefficiency of Dehydration in the TTL

- Significant supersaturations observed inside and outside of clouds, in agreement with our expectations. Supersaturated frequencies increase with decreasing T.

- Ice settling efficiency decreases significantly below IWC ~ 3 ppm, T ~ 190 – 195 K.

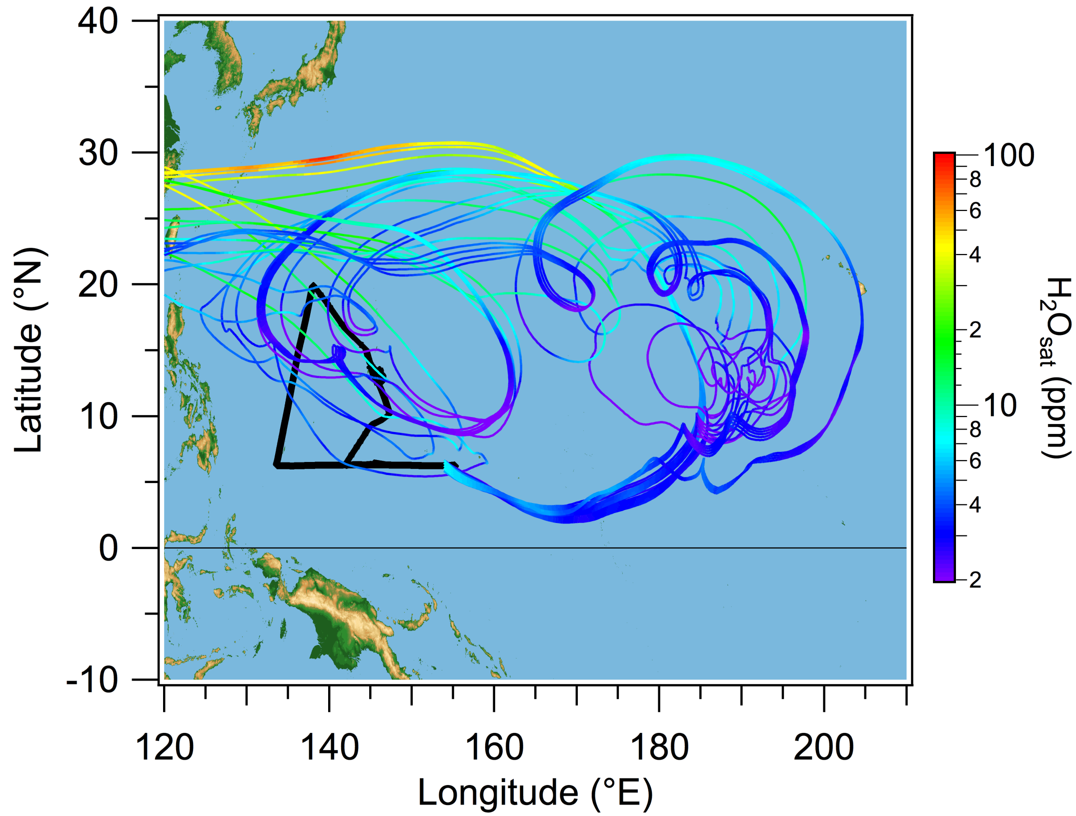
- All three mechanisms suggest that dehydration will be less efficient as temperatures decrease below ~ 195 K.

- More measurements < 185K needed.

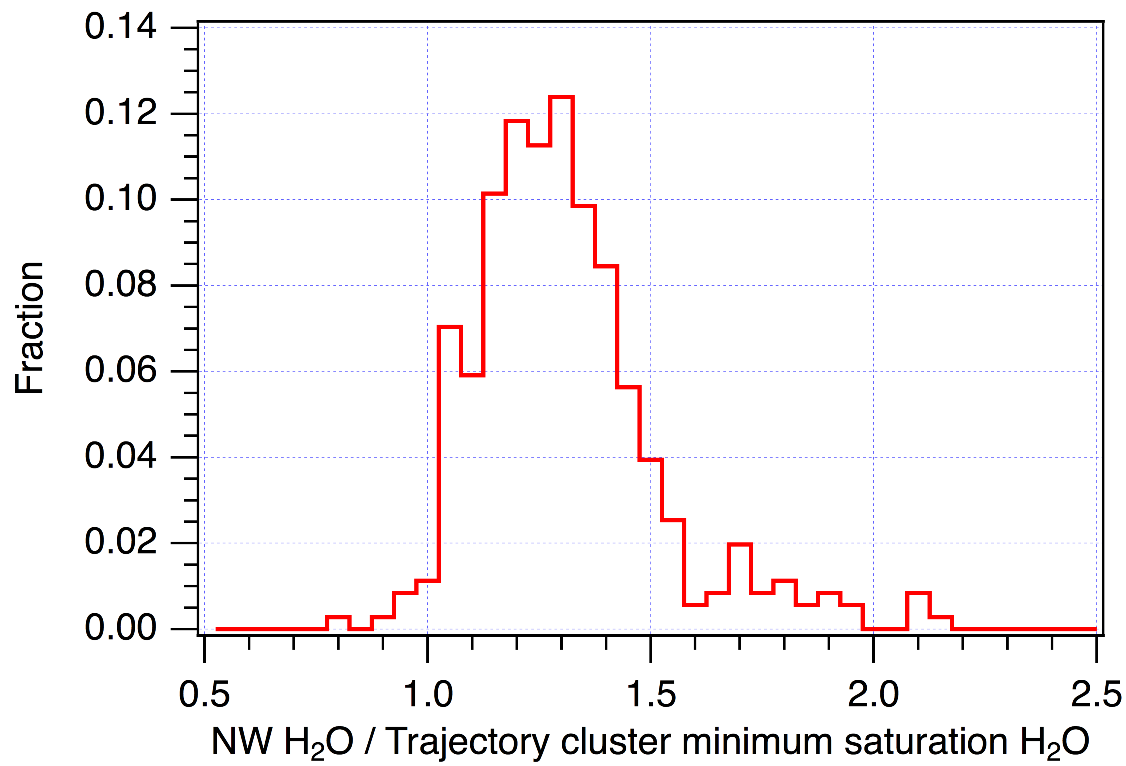


Back Trajectory Analysis

- Run back trajectories from various points along the flight track
- Compare the value of the minimum saturation mixing ratio along the trajectories to measured H_2O in the TTL at potential temperatures just above highest observed clouds
- 40-day diabatic back trajectories using ERA-interim and climatological heating from *Yang et al., JGR, 2010*
- Use cloud field to determine final convective influence
- Determine minimum saturation H_2O between final convective influence and flight track for $375\ K < \Theta < 390\ K$
- Cluster of 25 trajectories launched around each point and average minimum H_2O_{sat} calculated



Inferred Dehydration Efficiency



- Measured H_2O in the LMS consistently higher than the minimum saturation H_2O along trajectory
- Mean value of ratio indicates 30% dry bias by assuming dehydration to minimum H_2O_{sat}
- Dry bias will be higher when wave-induced cooling included in trajectories (*Kim and Alexander, GRL, 2013*)

Conclusions

- ATTREX made use of the capabilities of the NASA Global Hawk platform to acquire a substantial amount of high-quality water vapor and cirrus cloud data in the Pacific TTL
- ATTREX cloud sampling statistics in the western Pacific consistent with satellite observations
- Significant supersaturation observed in clear air
- Low ice crystal numbers and small size result in slow quenching of supersaturation
- Particle mass concentrated at small crystal sizes could limit dehydration due to slow sedimentation
- Dehydration inferred from the minimum saturation mixing ratio along back trajectory produces a dry bias of ~30% relative to the measured H_2O mixing ratios in the LS
  - This is similar to the 40-50% dry bias found by *Liu et al. (JGR, 2010)* comparing reanalysis-based Lagrangian trajectories to MLS observations
  - The inefficiency we infer will be larger than 30% when small-scale wave effects are considered in the trajectory analysis


Acknowledgements
The NOAA Water instrument team: Laurel Watts, Steve Ciciora and Richard McLaughlin
The ATTREX Science Team
The Global Hawk ground and flight crews
Questions?
Photo courtesy of R. Rafael Mendez Peña and Diego Beltran)