Observations of TTL water vapor and cirrus properties during the Airborne Tropical Tropopause Experiment

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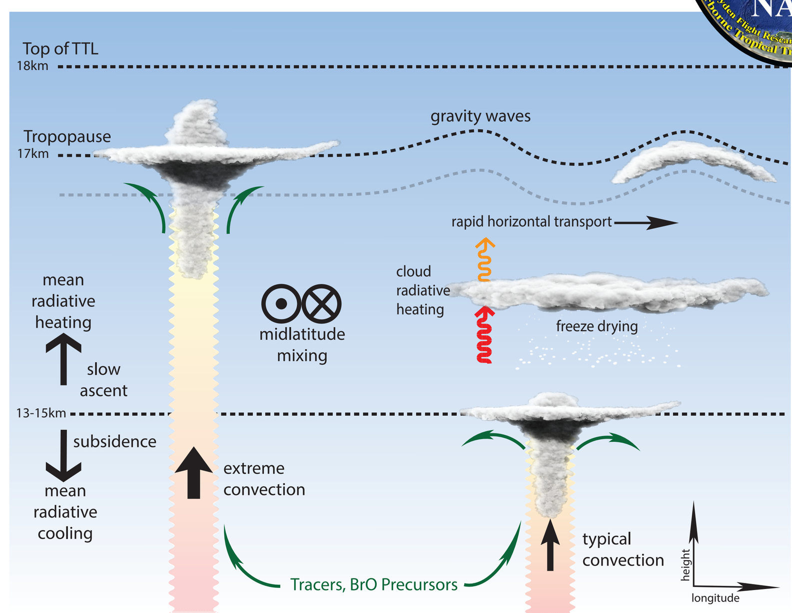
The Airborne Tropical Tropopause Experiment

The NASA Airborne Tropical Tropopause Experiment (ATTREX) is a five-year project using the NASA Global Hawk UAS to study transport and chemical processes in the Tropical Tropopause Layer (TTL) over the Pacific Ocean. The TTL, particularly over the western Pacific, is the principal gateway for air that is transported from the troposphere into the stratosphere.

The goals of the ATTREX mission include investigating:

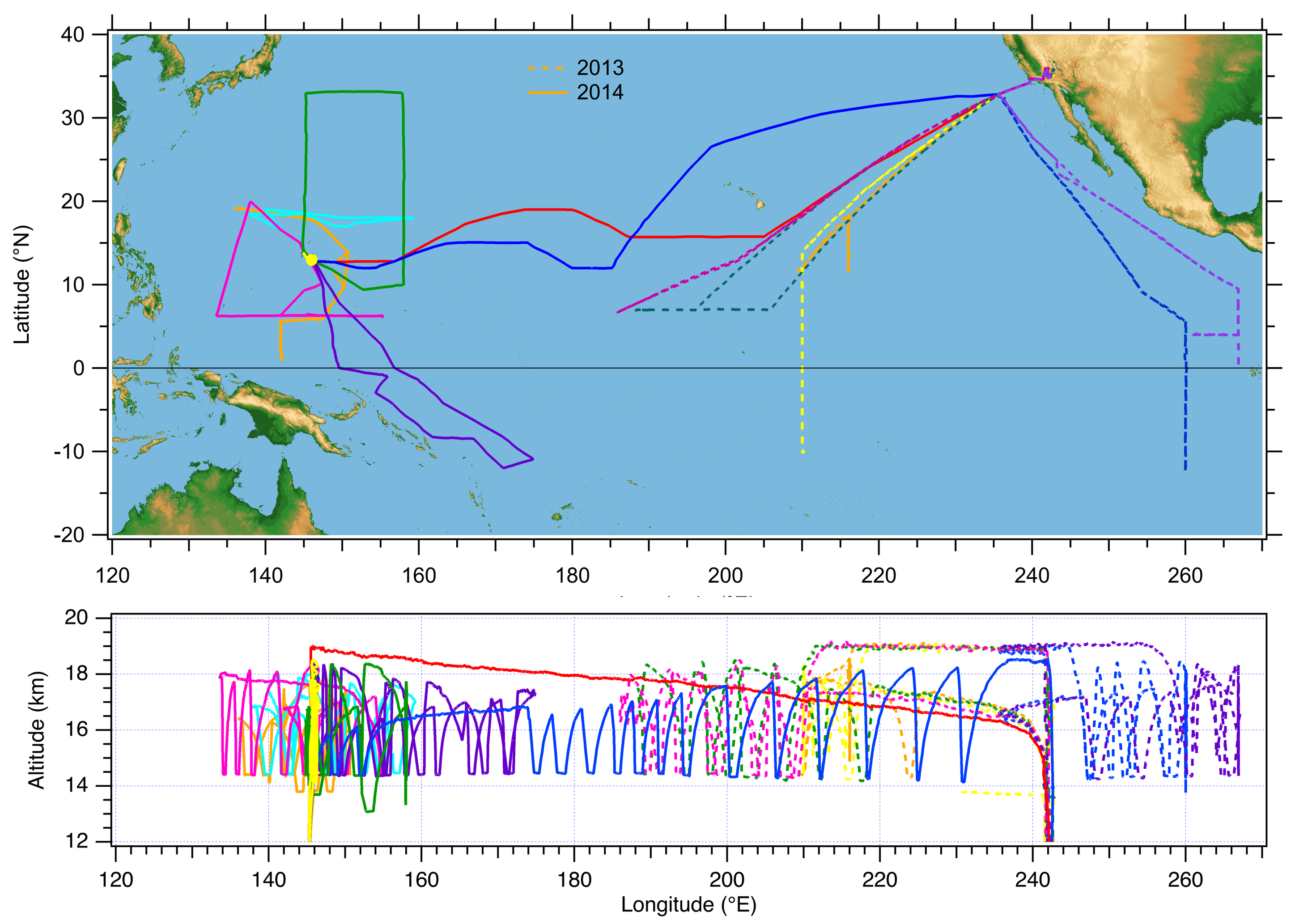
- The role of stratospheric water vapor in Earth's energy budget and climate
- Dehydration of tropospheric air entering the stratosphere
- The formation processes, microphysical properties, and climate impact of TTL cirrus



Primary deployments were:

- January - March 2013: Dryden Flight Research Center, California (Central and Eastern Pacific)
- Jan - Mar 2014: Andersen AFB, Guam (western Pacific)

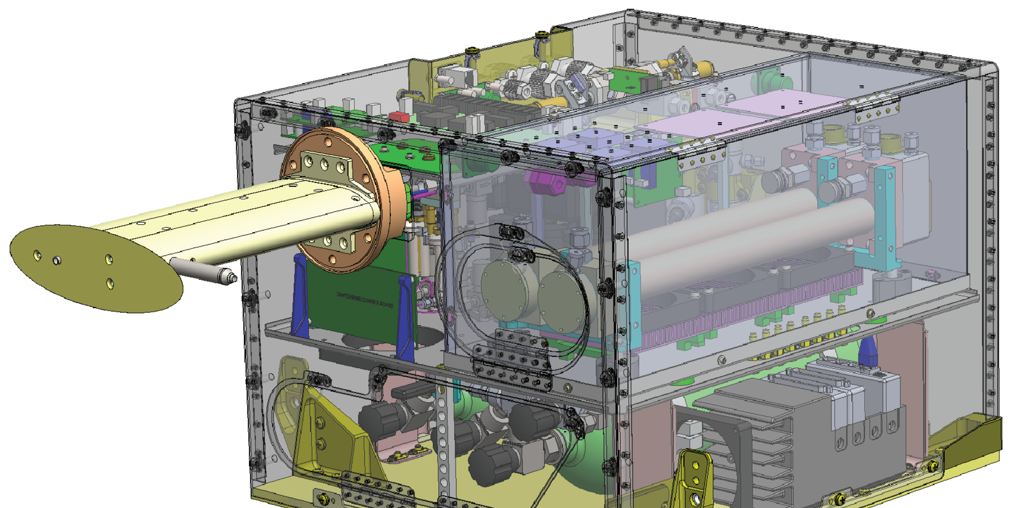
ATTREX achieved 184 hours sampling in the TTL, more than 34 hours in TTL cirrus



The NOAA Water Instrument

A two channel, TDL-based hygrometer for measuring water vapor and total (vapor + condensed) water in the TTL.

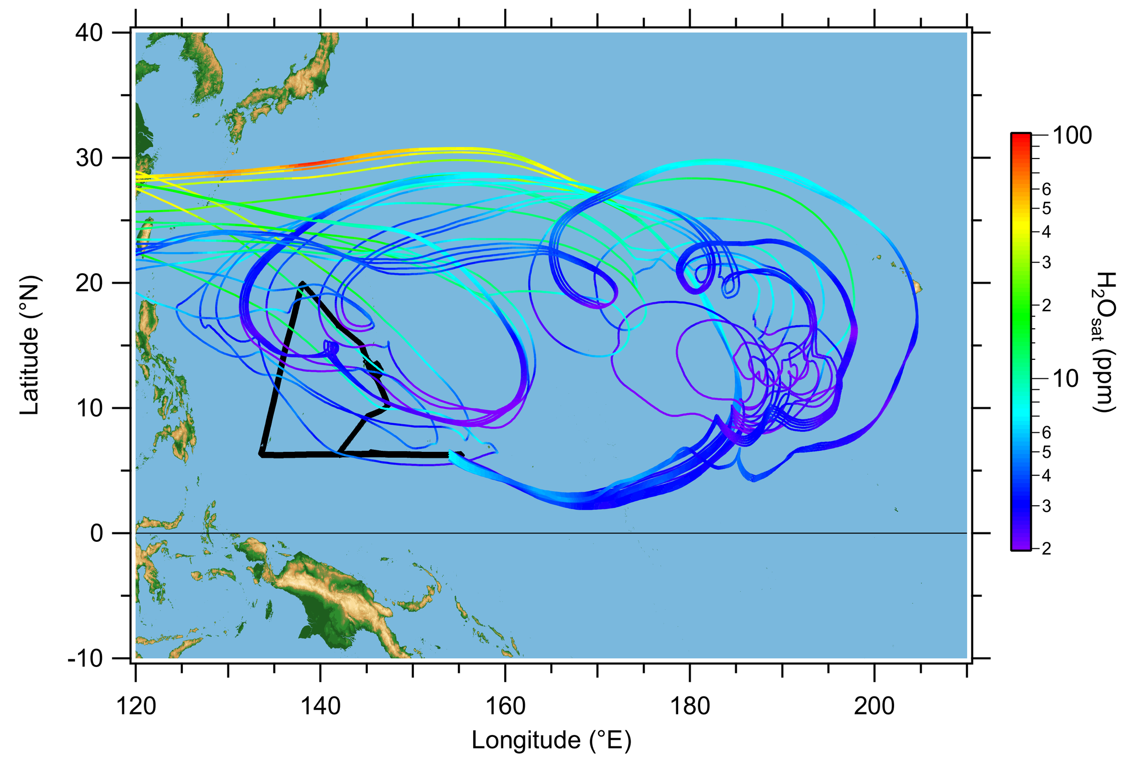
- Closed-path, single-reflection (path length = 78.6 cm) optical cells operated at constant T, P, and flow
- 2f detection in the wavelength range near 2.694 µm used to achieve high precision at low mixing ratios
- S/N (2σ, 1 s) @ 1 ppm = 4
- Scan across two H_2O lines with different strengths to produce large dynamic range (1 – 2500 ppm)
- Total instrument weight: 40 kg
- On-board calibration using catalytic oxidation of H_2/air to H_2O (*Rollins et al., 2011*)
- Overall H_2O vapor measurement uncertainty = 6% + 0.23 ppm
- Side-facing inlet for water vapor sampling
- Forward-facing inlet for sampling of vapor + condensed H_2O
- Subisokinetic flow results in sampling enhancement factor of 33 – 48 at Global Hawk flight conditions for particles larger than ~7 µm, which produces an IWC detection limit of < 3 µg/m³
- Size-dependent enhancement factor calculated using CFD-based parameterization described in *Eddy et al., Aerosol Sci., 2006*



Dehydration in the TTL

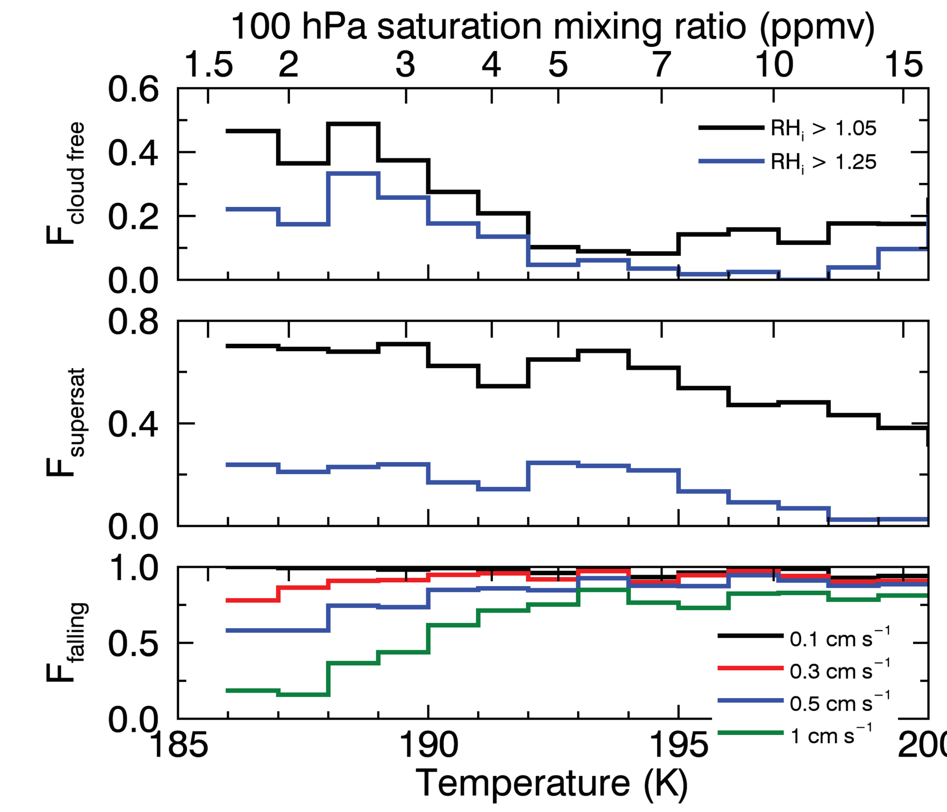
Reduction of the H_2O mixing ratio to the minimum saturation mixing ratio with respect to ice encountered during an air parcel's trajectory is assumed in many large-scale models. This assumption does not account for a number of possible inefficiencies in the TTL microphysical dehydration processes and leads to a dry bias in the value of H_2O entering the stratosphere. These inefficiencies include:

- Supersaturation with respect to ice required to nucleate cloud ice crystals
- Competition between the time required for the growing ice crystals to take up the excess humidity and temperature changes in the air parcel
- Competition between sedimentation of ice crystals (removal) and sublimation of ice crystals as air parcel temperature varies



Approach to evaluating the potential model bias in stratospheric H_2O entry value

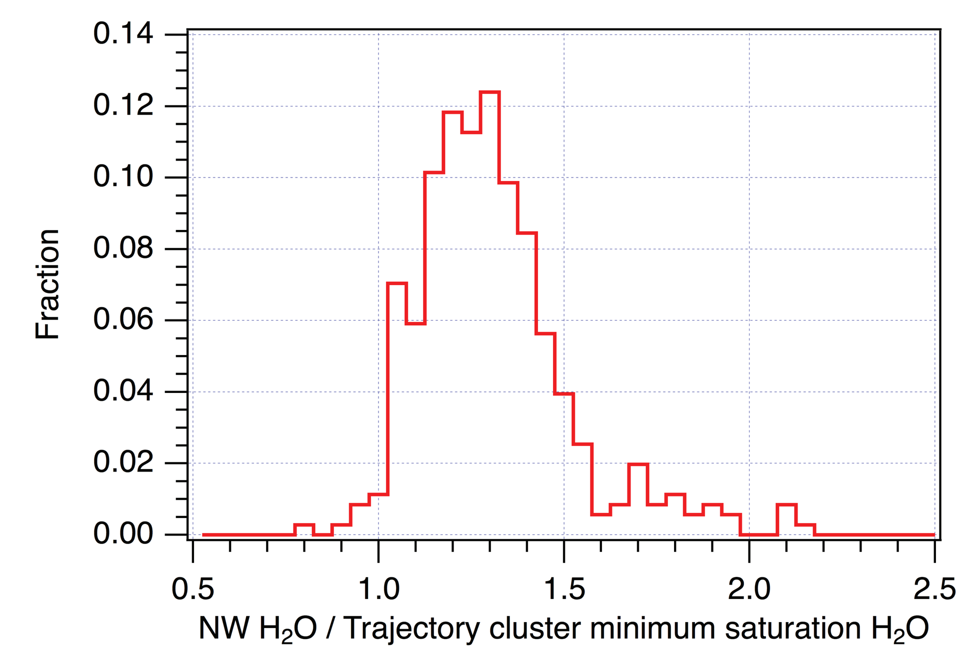
- 40-day diabatic back trajectories using ERA-interim and climatological heating from *Yang et al. (2008)*
- Use cloud field to determine final convective influence
- Determine minimum H_2O_{sat} between final convective influence and the flight track for potential temperature 375 – 390 K, above the highest observed clouds but prior to significant H_2O production from CH_4 oxidation
- Cluster of 25 trajectories launched around each point and average minimum H_2O_{sat} calculated



Measured H_2O in the LMS consistently higher than the minimum H_2O_{sat} along trajectory

Dehydration inferred from the minimum saturation mixing ratio 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.* (2010) comparing reanalysis-based Lagrangian trajectories to MLS observations
- The inefficiency is probably larger than 30% when small-scale wave effects on temperature are included in the trajectory analysis (e.g. *Kim and Alexander, 2013*)



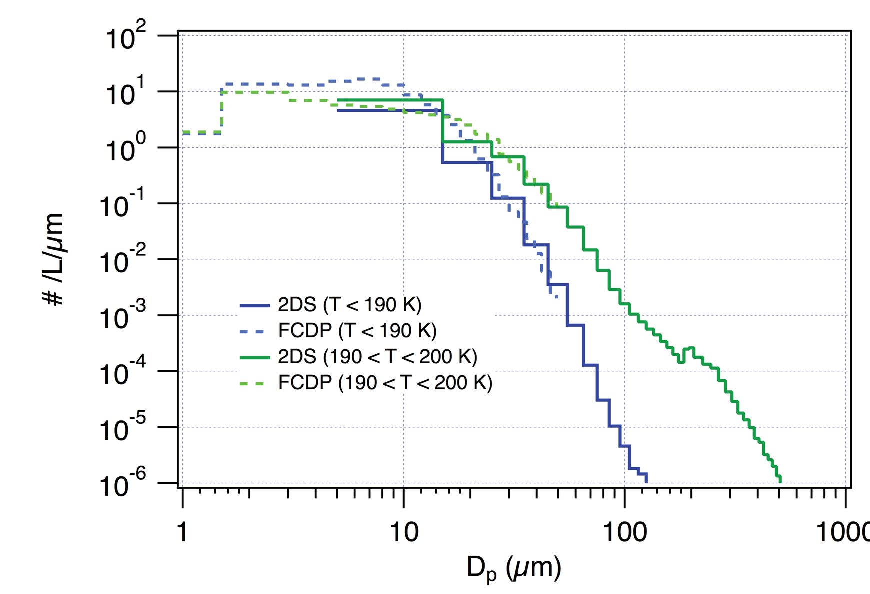
TTL cirrus ice water content (IWC) vs extinction (σ)

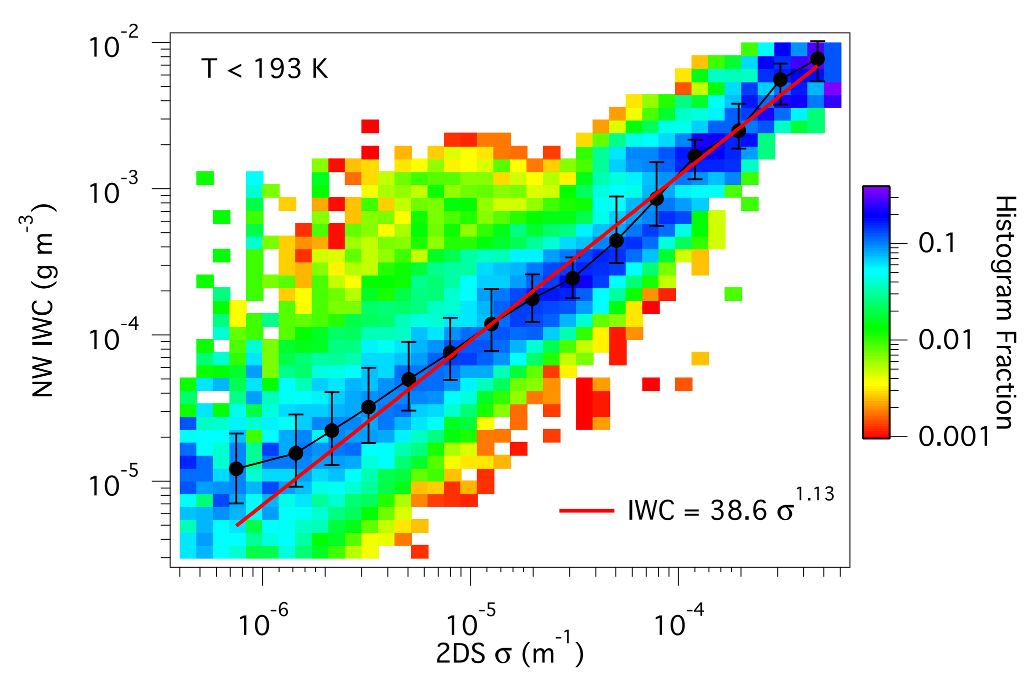
The IWC – σ relationship is used to relate satellite observations of clouds to the cloud IWC, an important parameter in global climate models which directly affects the cirrus net radiative forcing

ATTREX cirrus cloud observations

- In the temperature ranges < 190 K and 190 – 200 K, the dominant fraction of the size distribution resides in D_p < 15 µm, although a shift toward larger sizes with increasing temperature is observed
- Ice crystal mass is also concentrated in small sizes (D_p < 35 µm) at these temperatures, which has implications for dehydration (see above)
- 90% of cirrus observations have N < 100/L, less than 0.05% have N > 1000/L
  - — will shift to slightly higher number with inclusion of FCDP small particles

Are the low values of N relative to what would be expected from homogeneous nucleation evidence for importance of wave-moderated homogeneous nucleation (*Spichtinger and Krämer, 2013*) or heterogeneous nucleation in TTL cirrus?

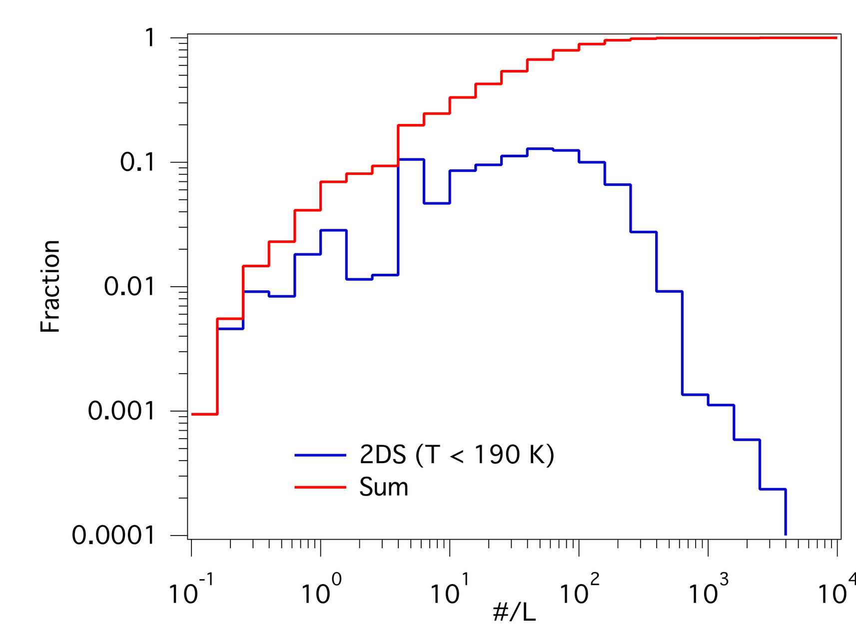




The IWC – σ relationship in TTL cirrus

- Power law fit to median values yields reasonably consistent relationship
- Deviation at small values possibly due to a larger contribution from small particles
- Derived parameterization falls in between previous estimates (e.g. *Heymsfield et al., 2005; Heymsfield et al., 2014*)

The extensive ATTREX data set can be used to provide a robust IWC – σ parameterization for radiatively important TTL cirrus clouds



Acknowledgments

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