CSET RF11, near Hawaii

Ultra-clean layers and low albedo (“grey”) clouds in CSET

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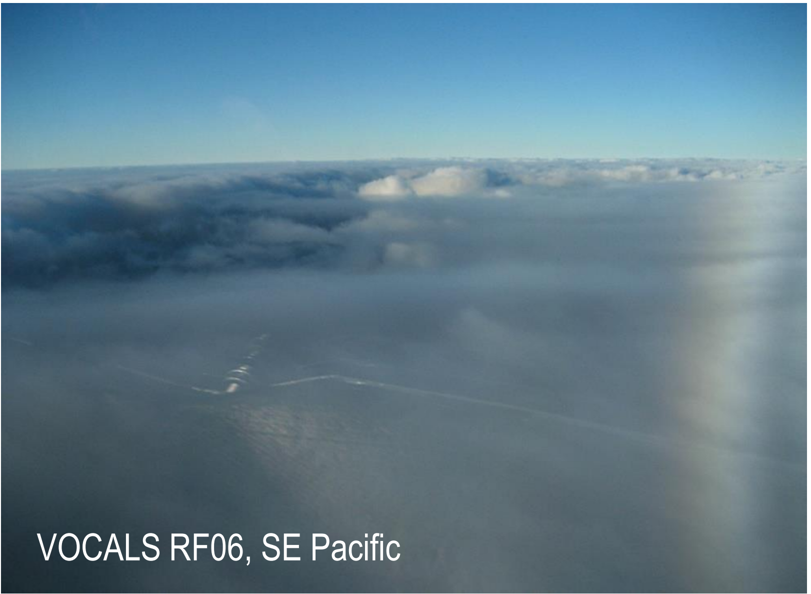
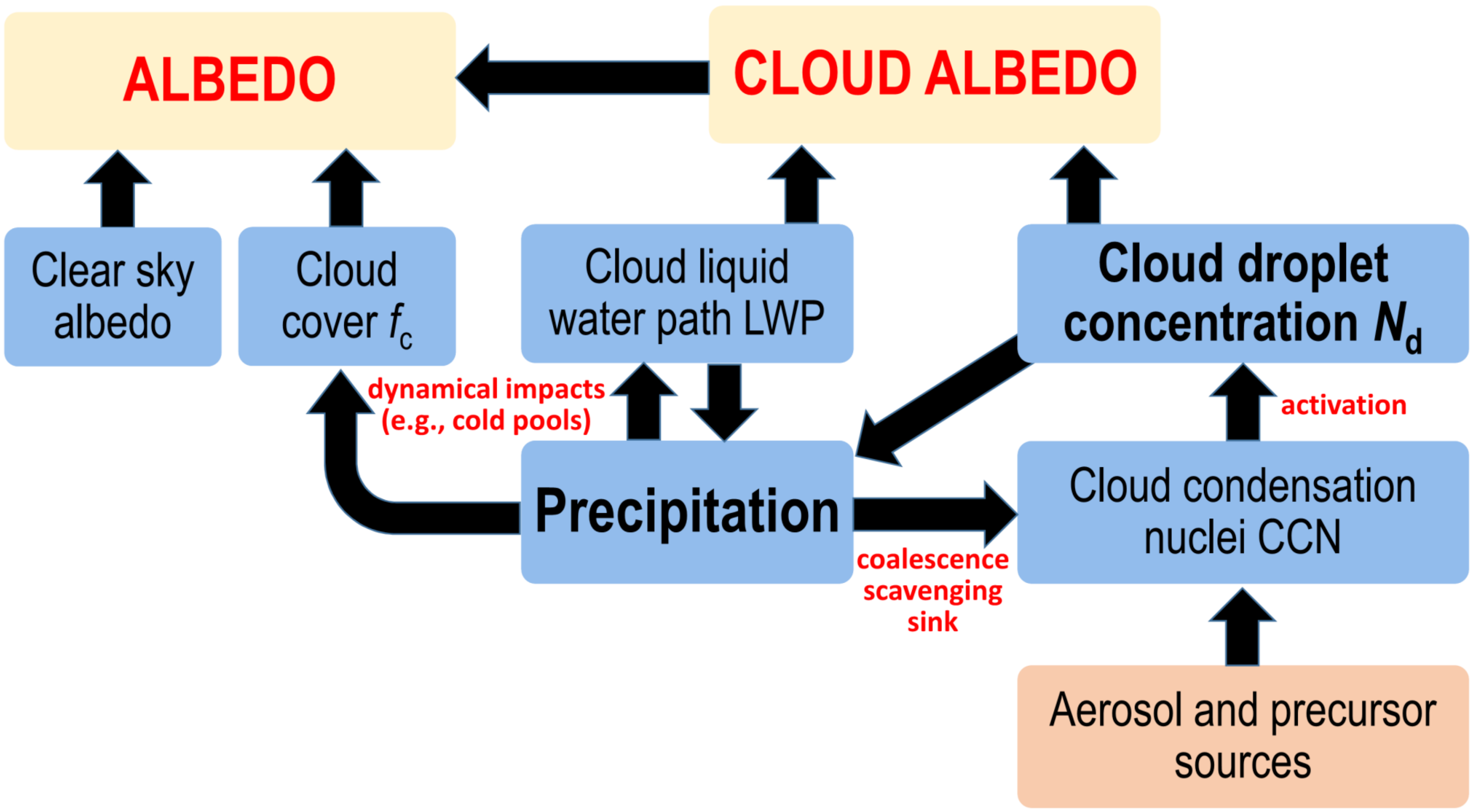
- Special thanks to EOL staff who worked to ensure a successful project



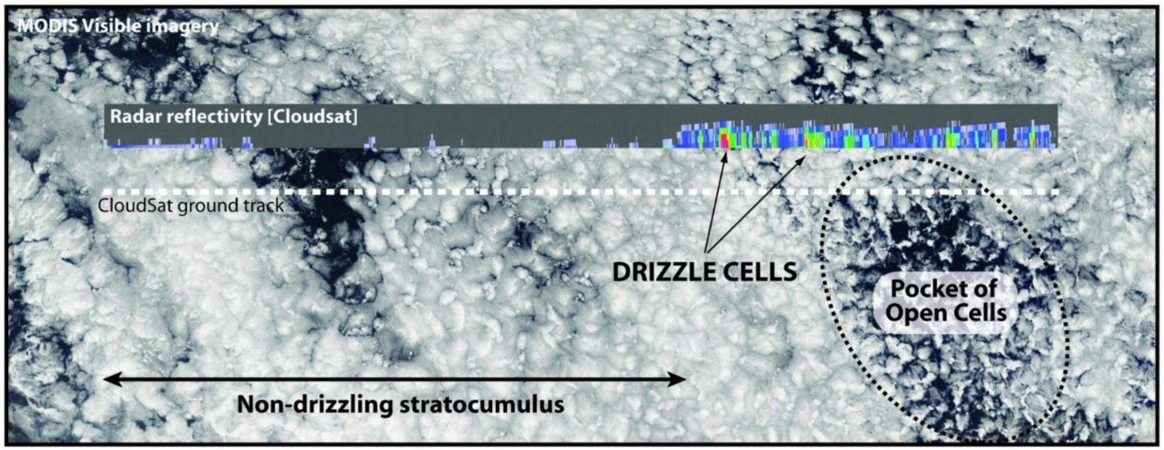
VOCALS RF06, SE Pacific

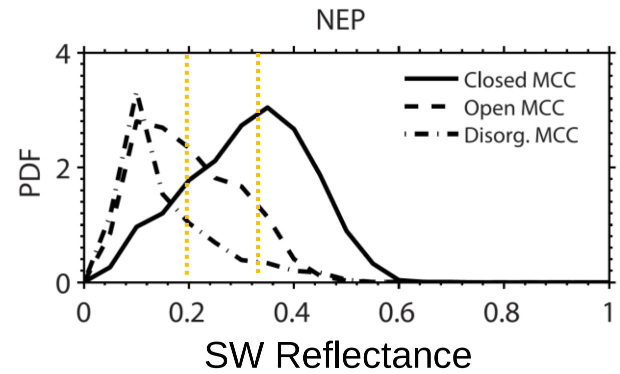
CSET RF11, near Hawaii

Pathways by which cloud droplet concentration and precipitation impact albedo



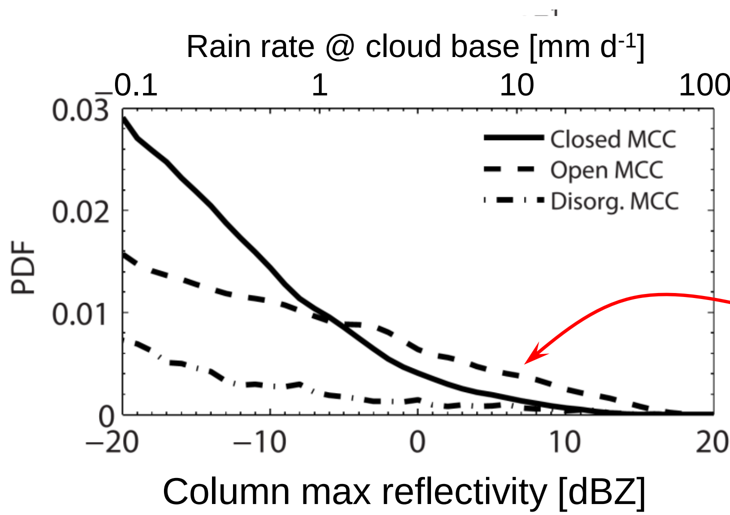
Intense drizzle associated with optically thin cloud layers





Closed cells

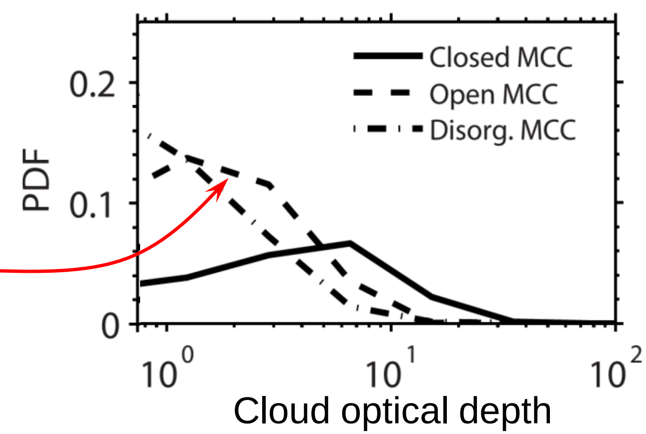
Almost twice as reflective



Open cells

More heavy drizzle

More optically thin cloud

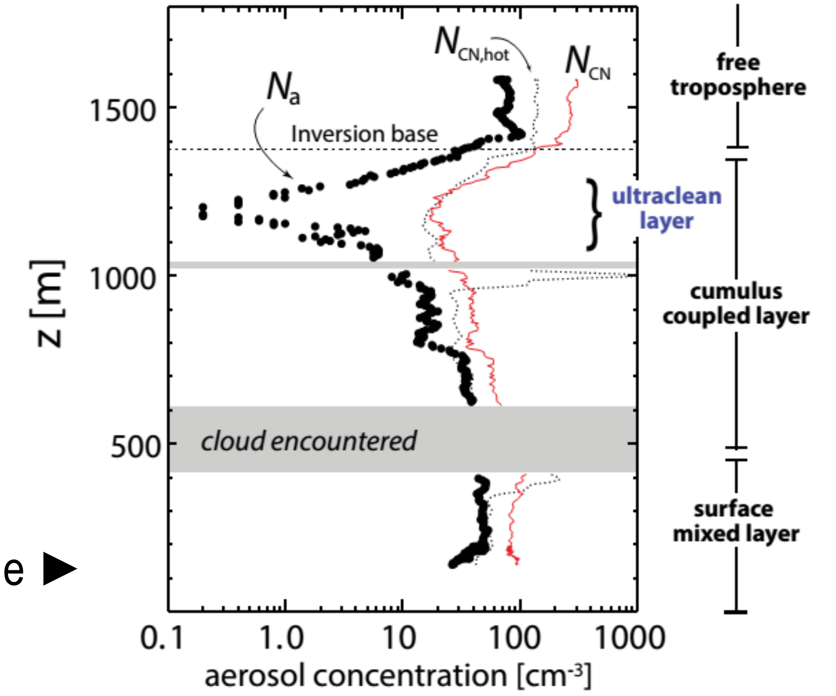


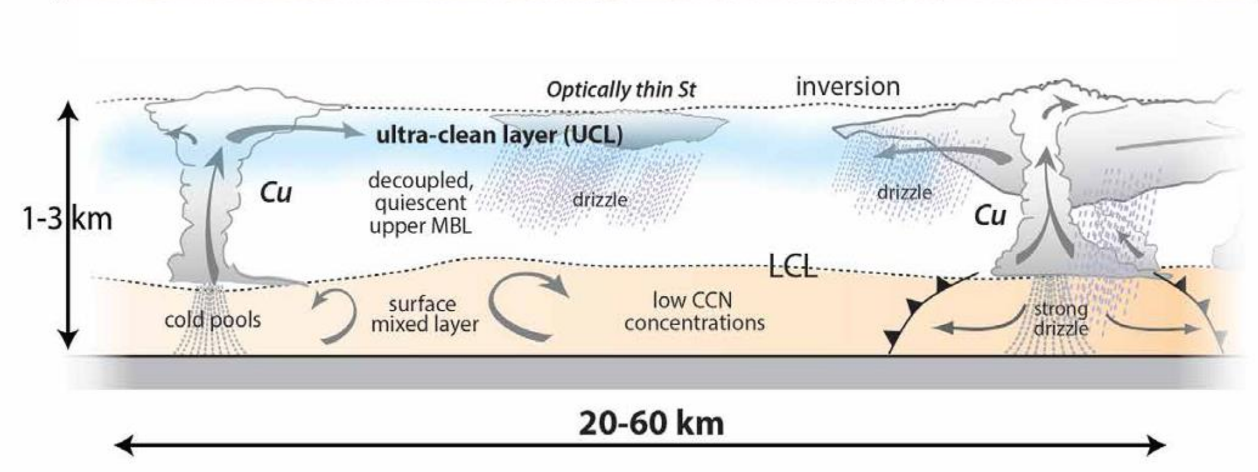
Muhlbauer et al. (*Atmos. Chem. Phys.*, 2014)

Ultra-clean layers and optically thin clouds

Strong depletions of N_d/CCN associated with optically thin "gray" clouds in all VOCALS open cell cases

VOCALS RF06 profile ►





Schematic figure of decoupled remote marine boundary layer

Gray layers and bright Cu

CSET RF04

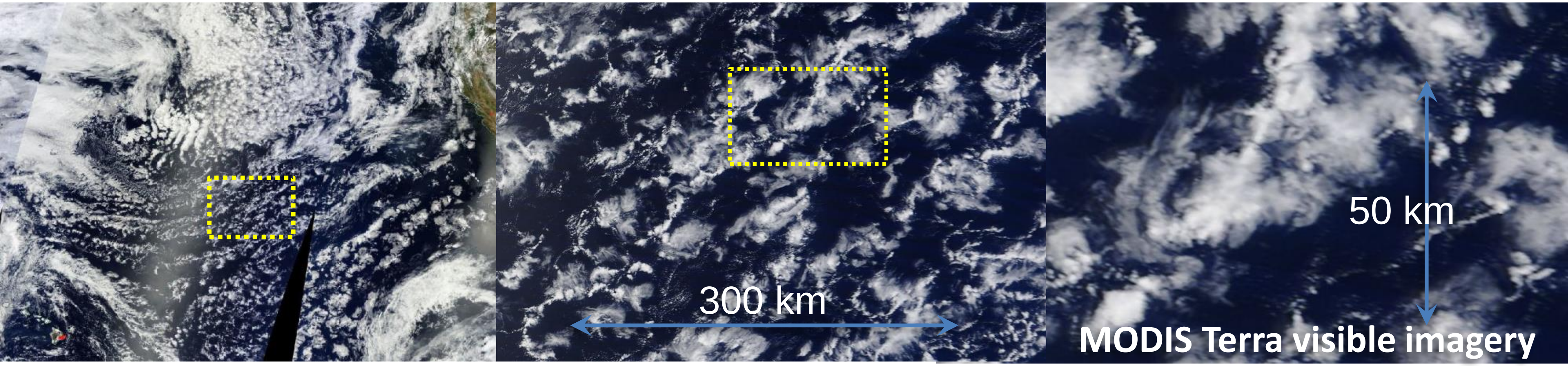
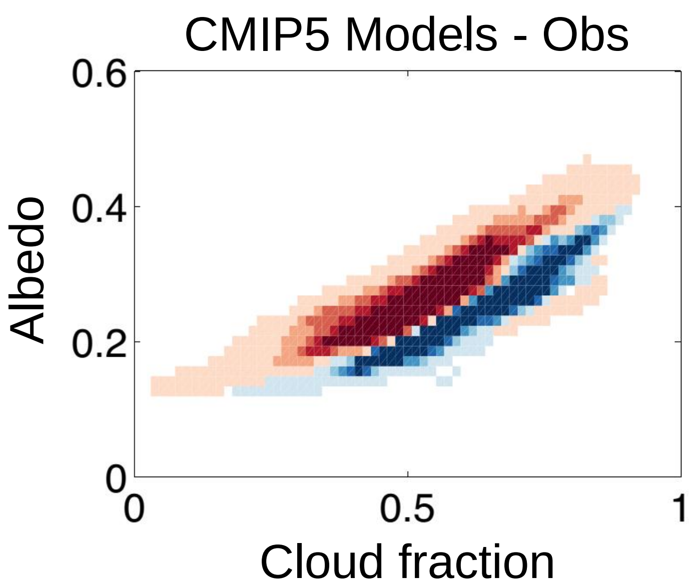
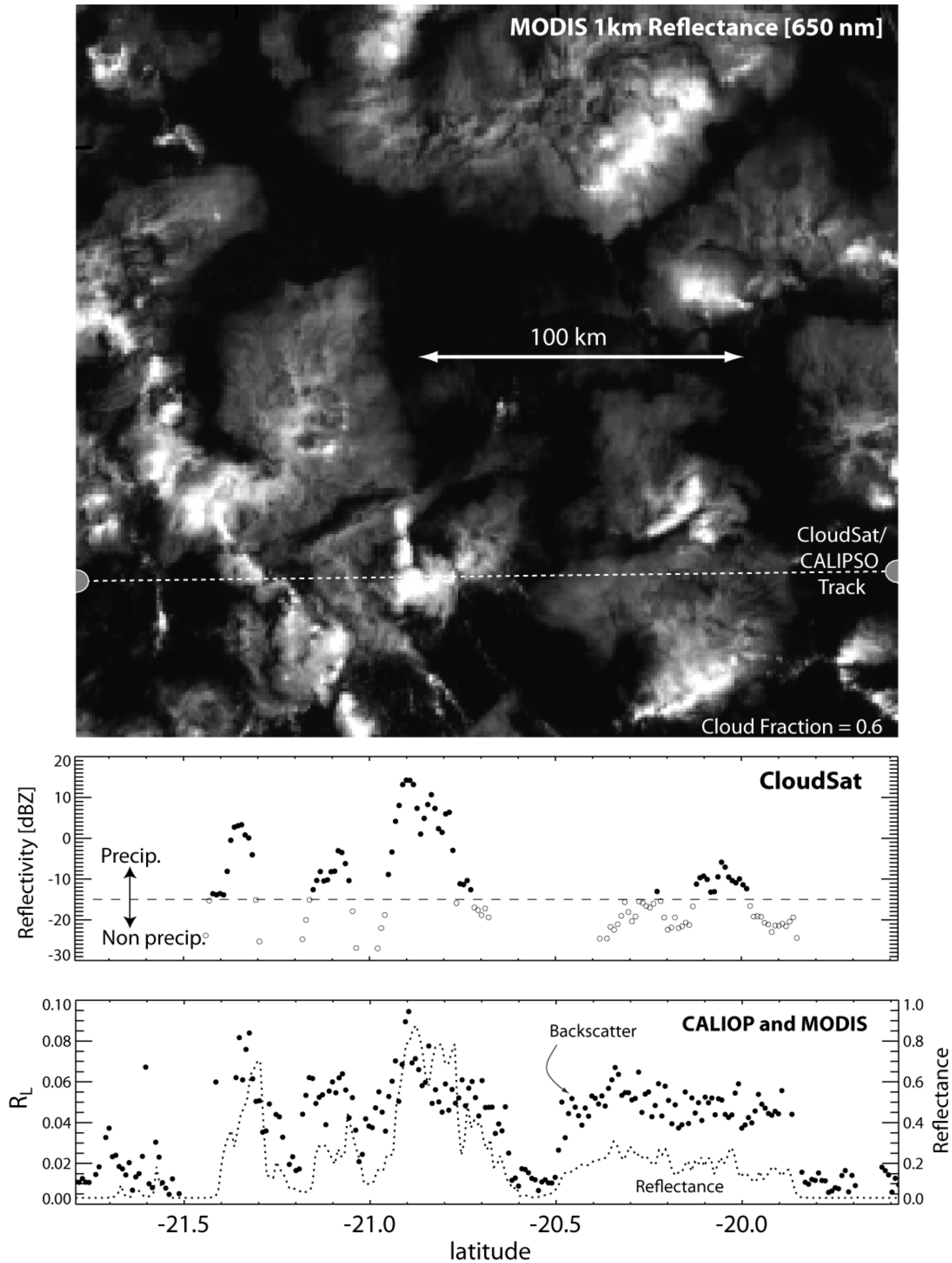


Photo: Bruce Albrecht

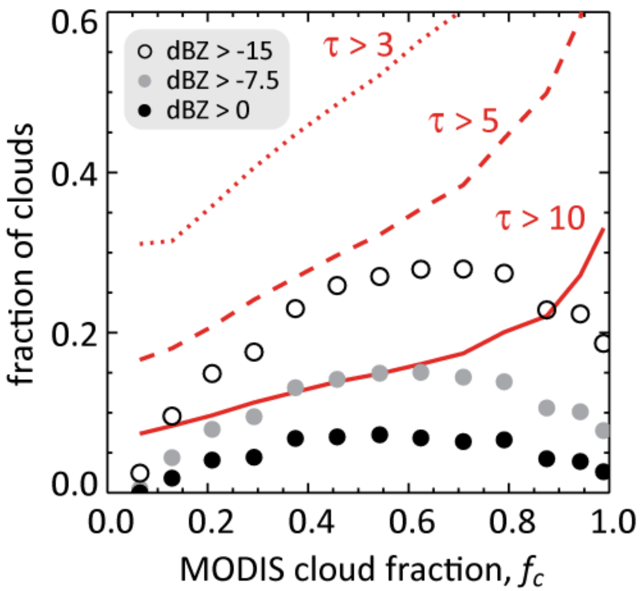
A-Train example of gray clouds



“Too few, too bright” pathology from Bender et al. (2016), Nam et al. (2012)

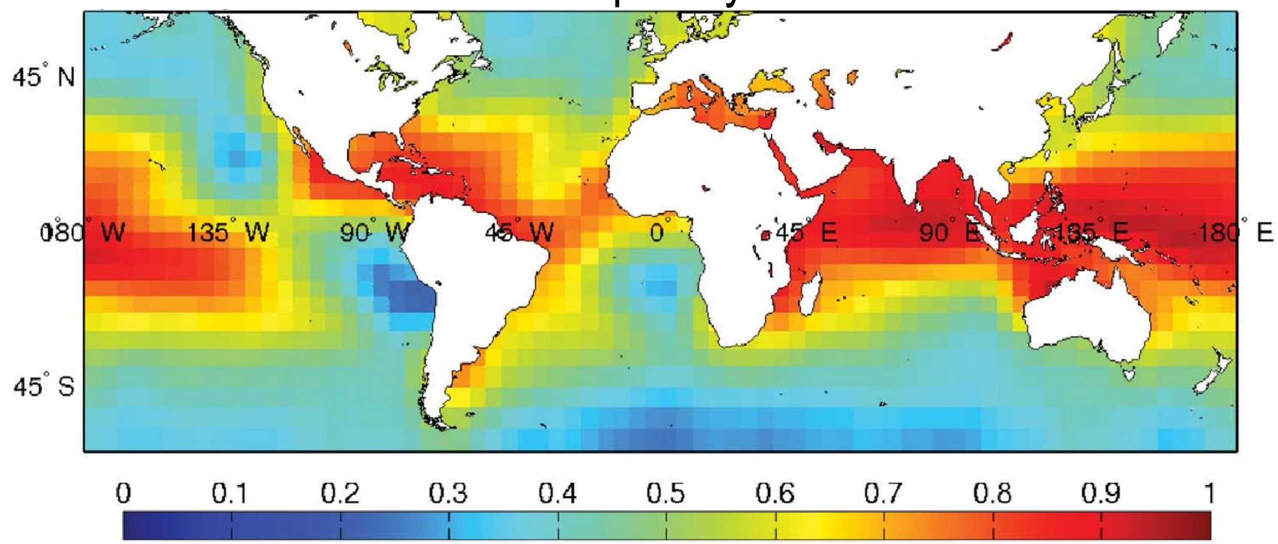


Prevalence of optically thin clouds in trade PBL



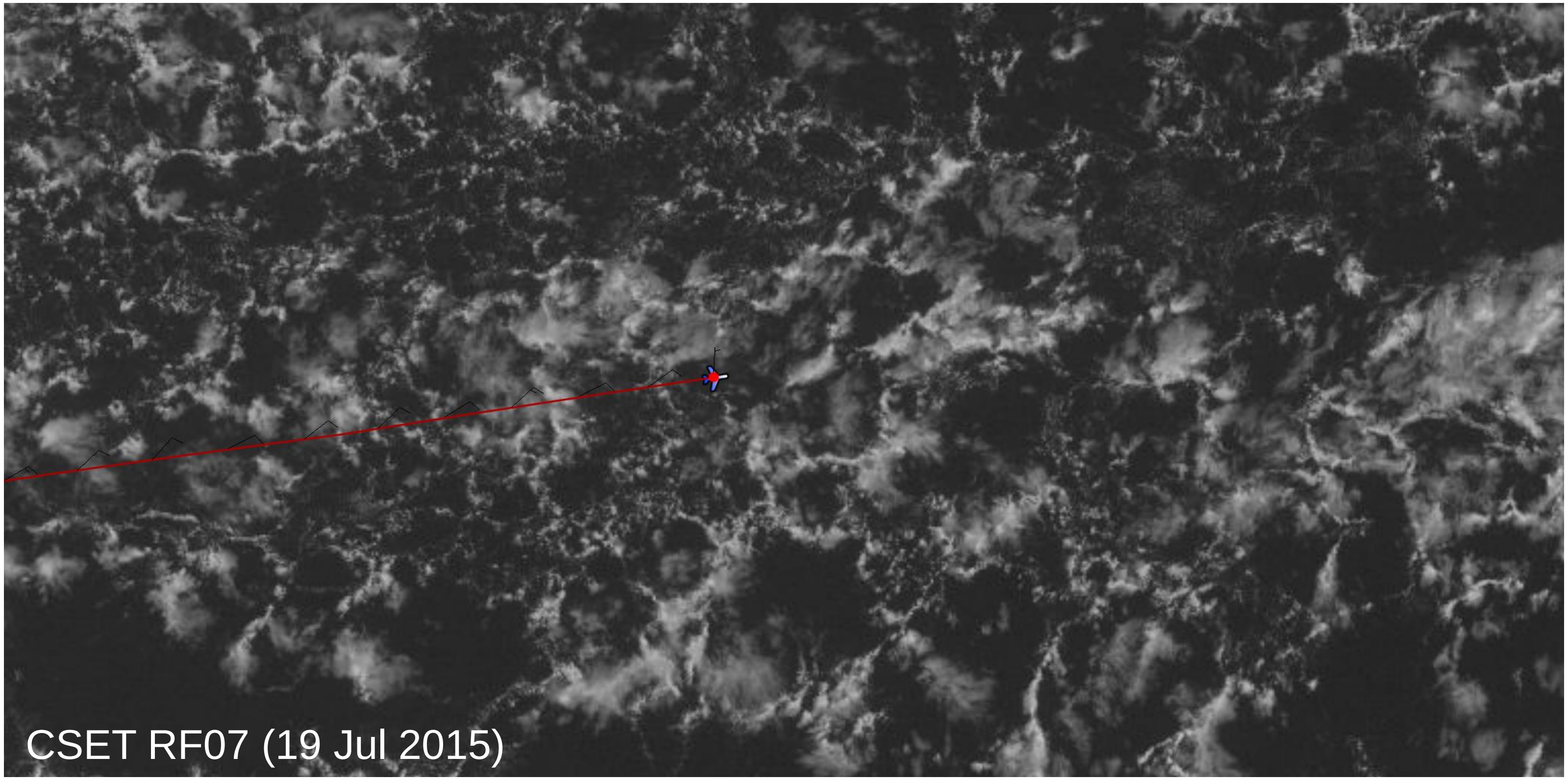
◄ MODIS perspective
In regions with 50% low cloud (e.g., Hawaii), 50% of clouds have optical thickness $\tau<3$

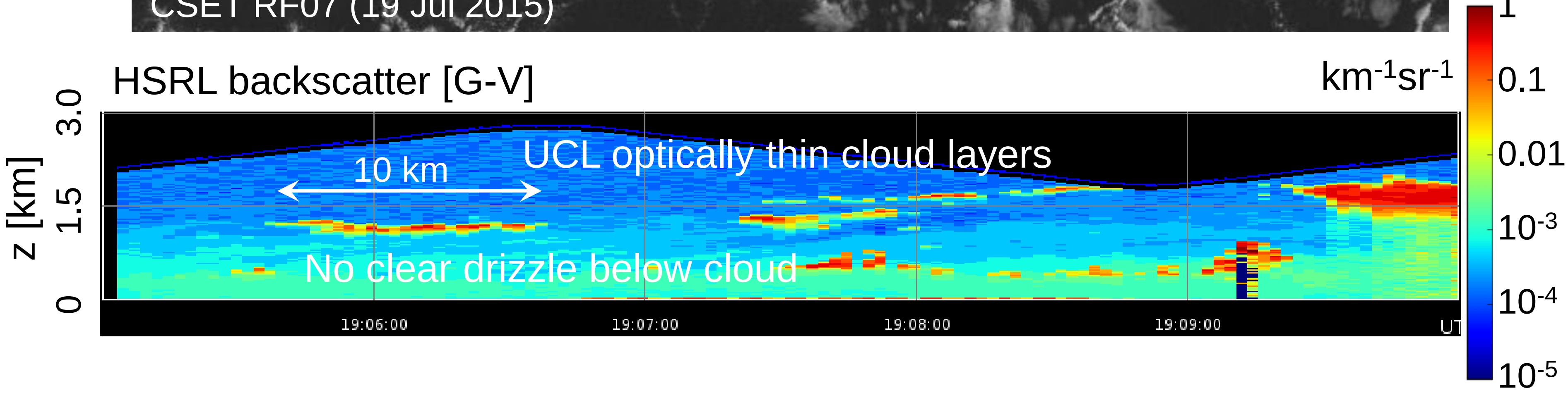
Optically thin fraction of low cloud



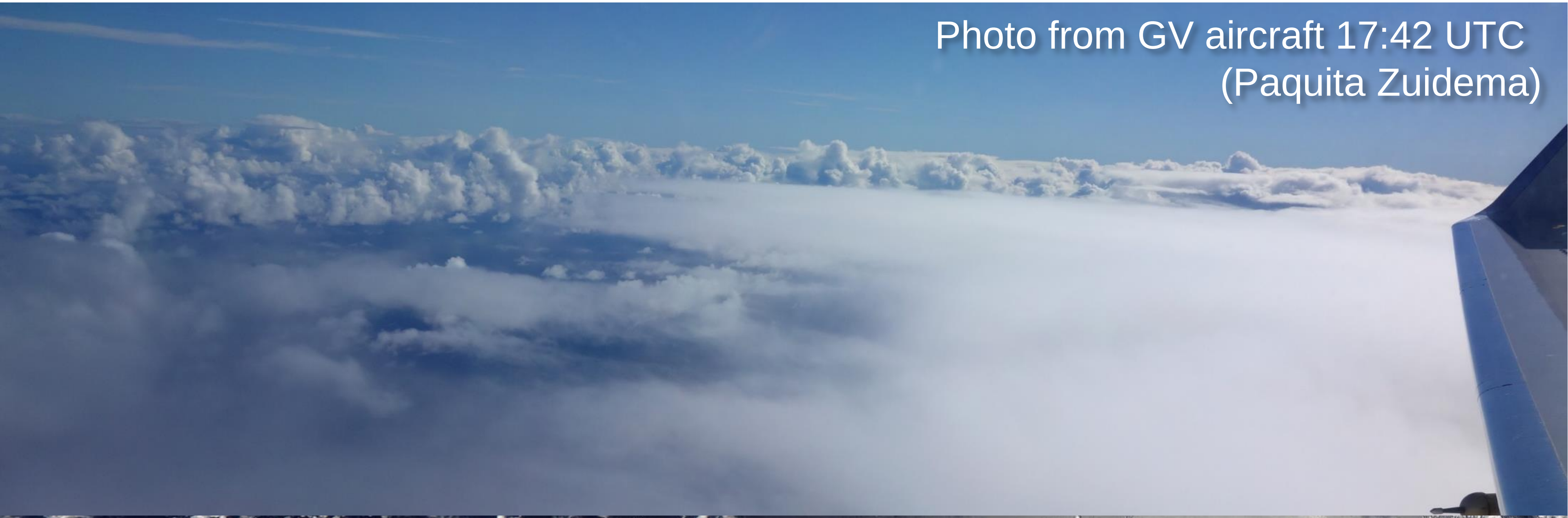
CALIOP lidar perspective ►
In regions with 50% low cloud (e.g., Hawaii), the surface can be detected through >50% of low clouds [Leahy et al. 2012]

Optically thin layer clouds in open cells





Gray clouds in ultra-clean layers (UCLs) RF07

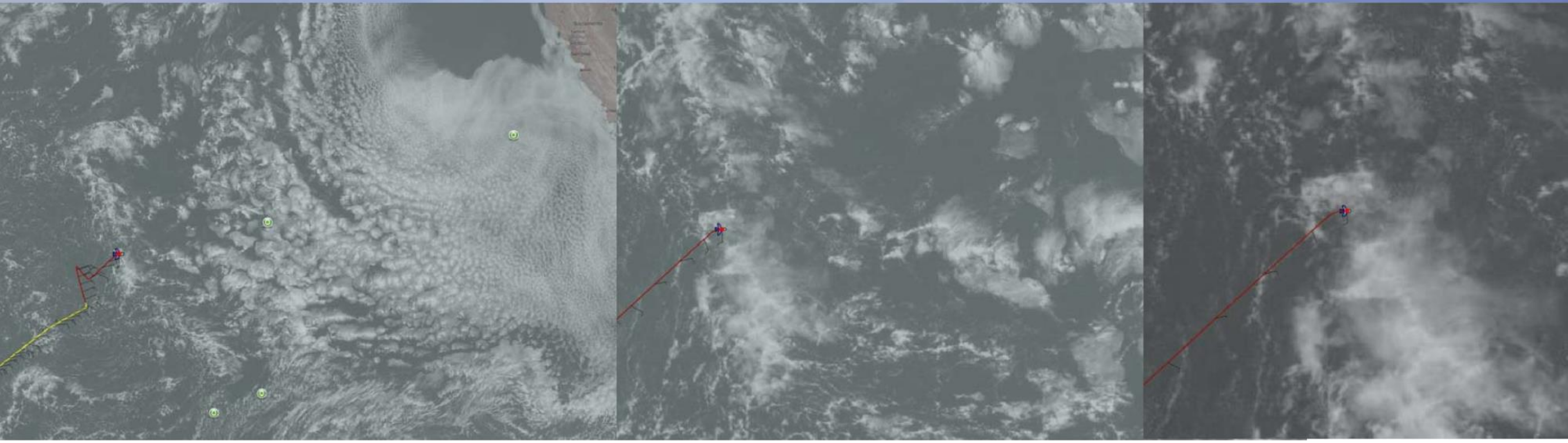


Cold pools seen in sunglint

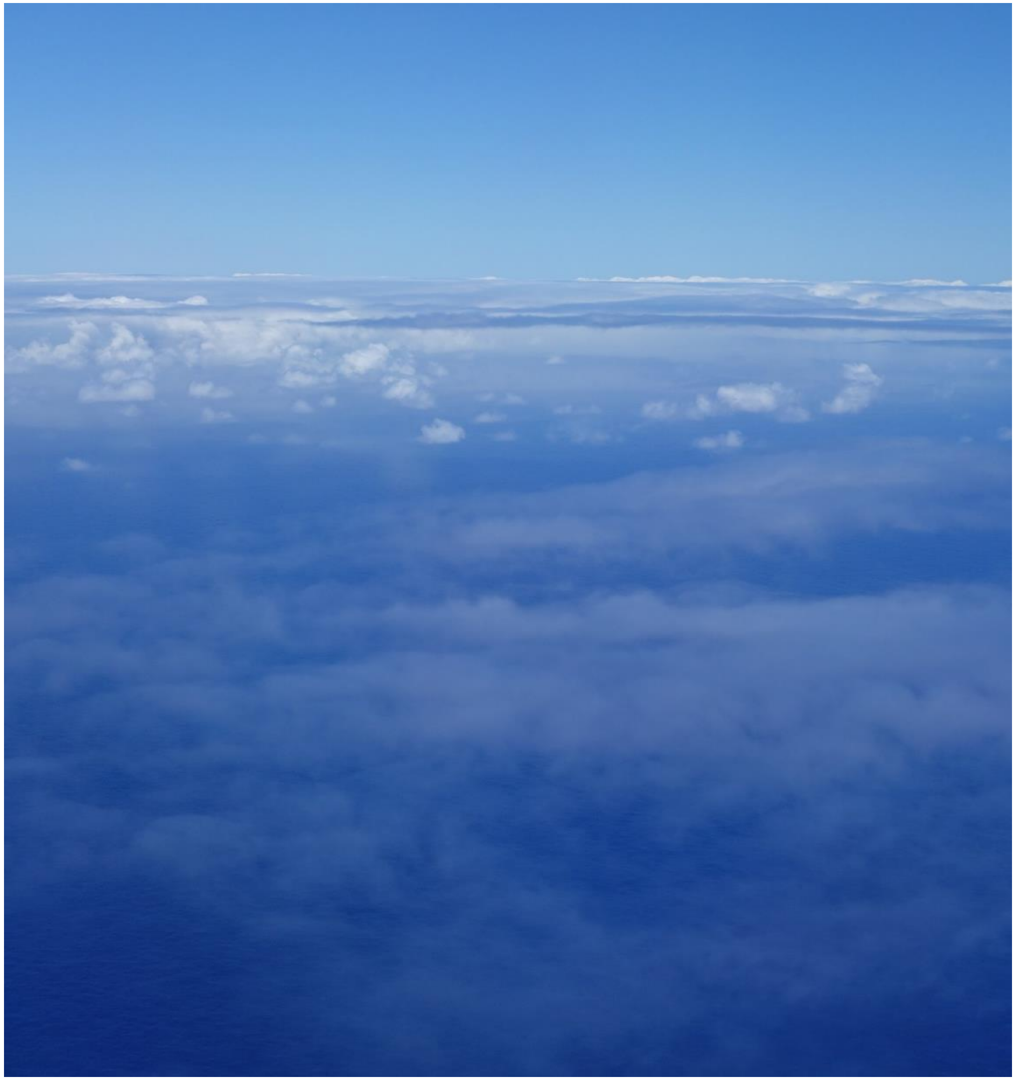
Gray layers and bright Cu RF04

Laminar gray clouds

RF11



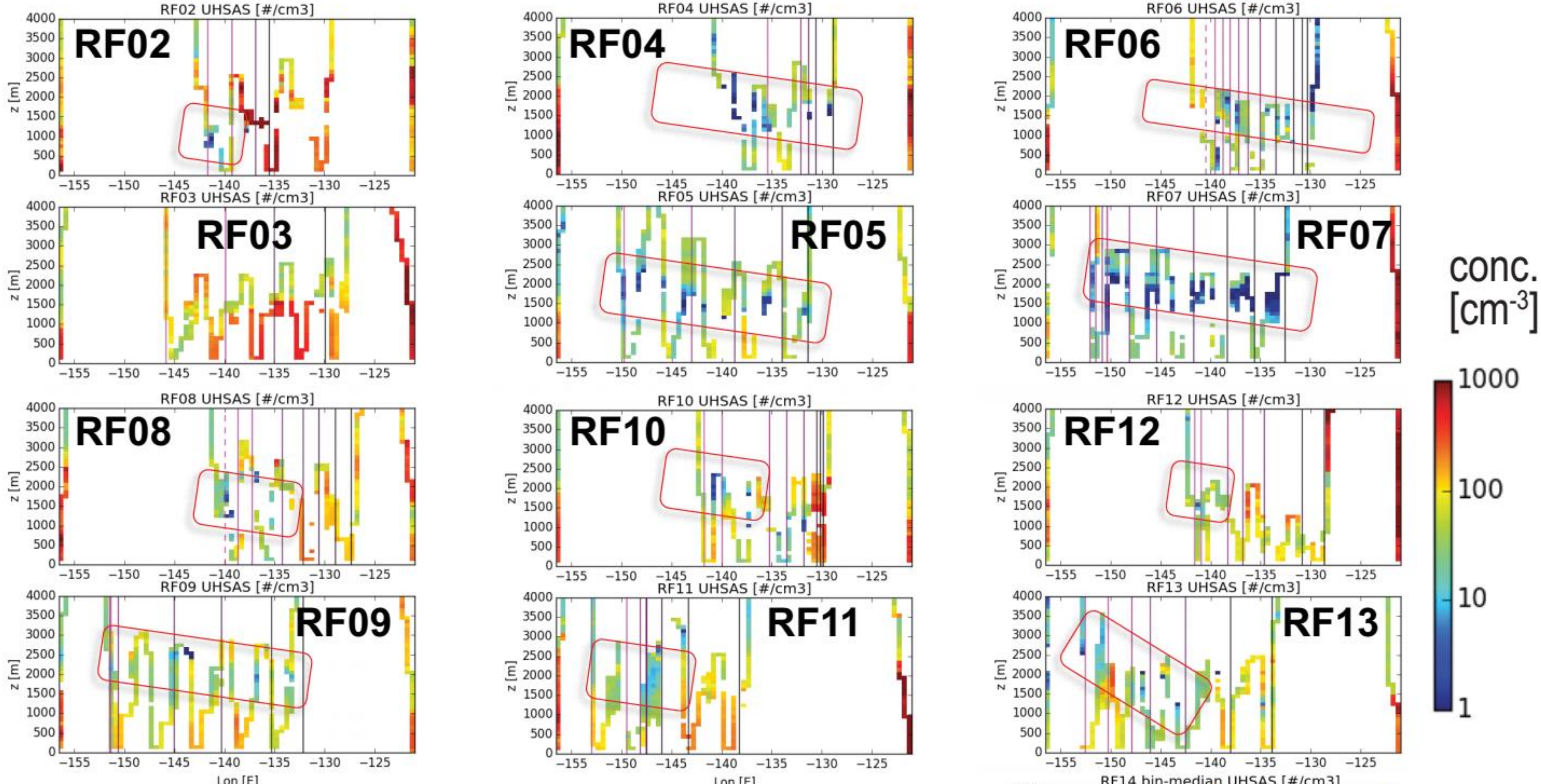
View angle dependence of perceived gray cloud morphology



RF07

Photo: Paquita Zuidema


Near-nadir view. Not so laminar
RF11



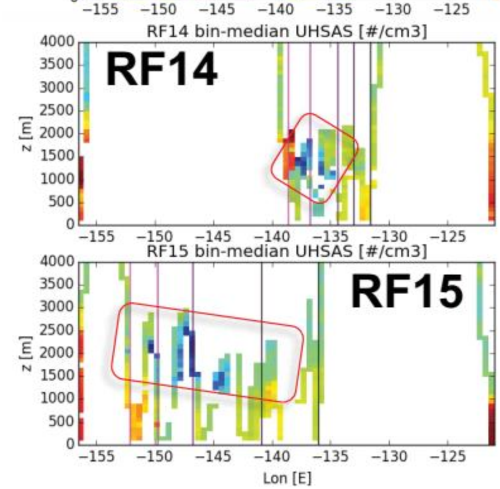


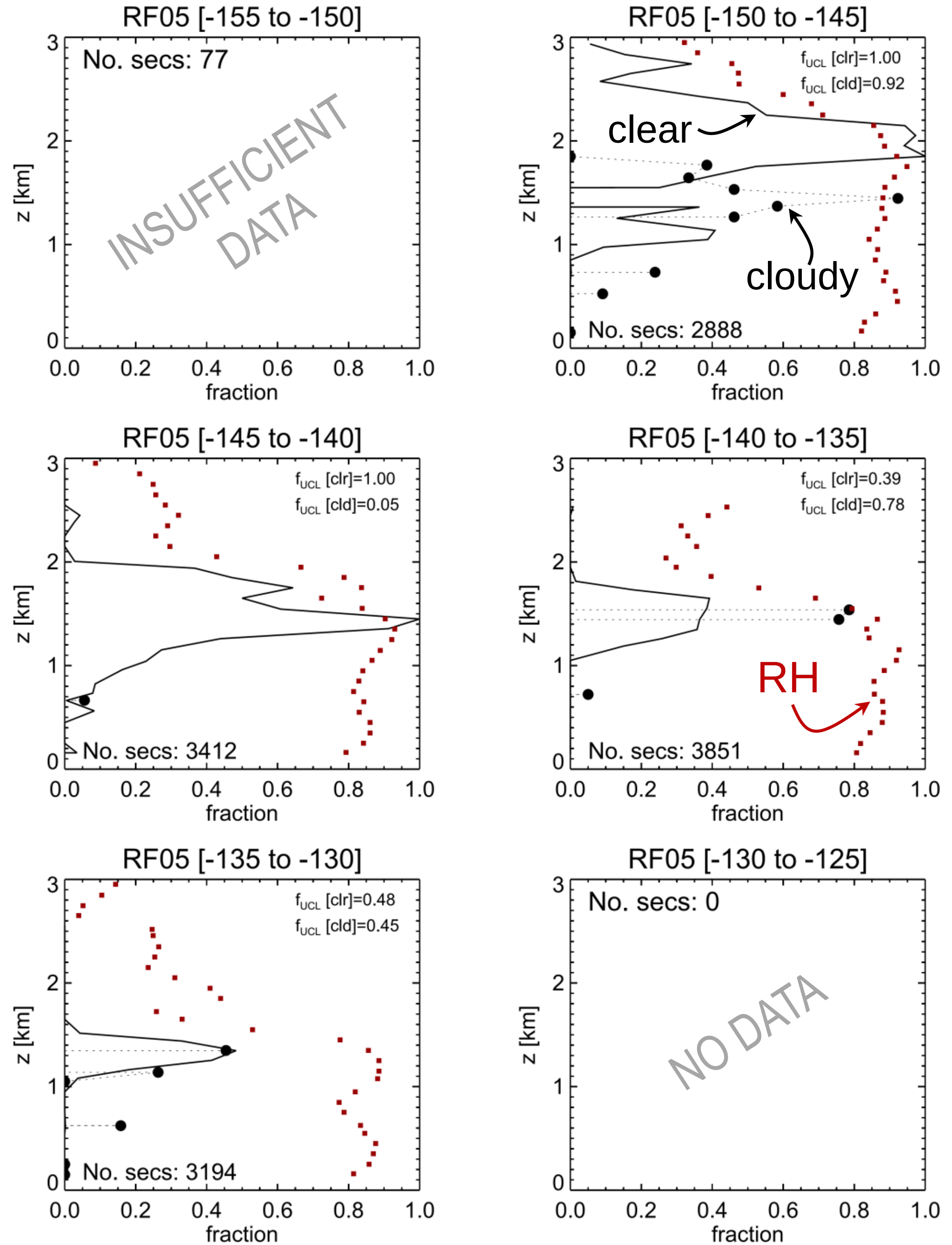
Figure 5: Very low aerosol concentrations often occur in the upper MBL demonstrating near-ubiquity of UCLs over the subtropical NE Pacific Ocean. Figure shows longitude-height cross sections from CSET flights showing concentration of aerosol particles larger than 0.1 μm (UHSAS) from all clear-air samples.

What is an Ultra-Clean Layer?

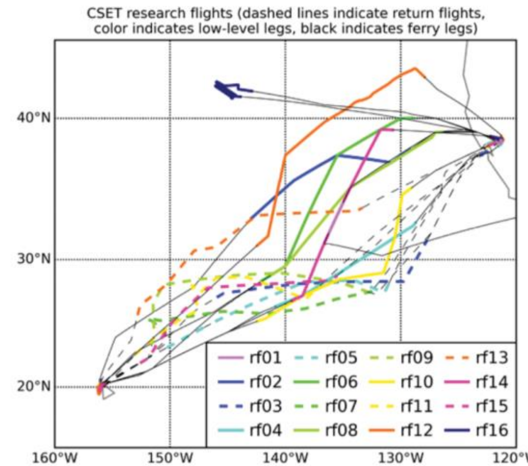
- A horizontally-extensive layer that can contain either clear air, cloud, or both cloudy/clear air with very low concentrations N_a of accumulation mode aerosol particles (diameters > 0.1 μm), or very low cloud droplet concentrations N_d (when the layer is cloudy)
- Here, we define a UCL as having:
  - $N_a < 10$ cm^{-3} [CLEAR SAMPLES]
  - $N_d < 10$ cm^{-3} [CLOUDY SAMPLES, $q_{L,CDP} > 0.01$ g m^{-3}, RH > 0.95]

UCL coverage

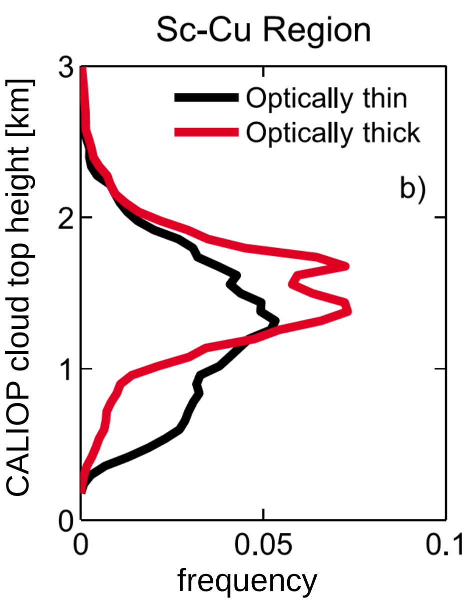
- UCL coverage determined separately for clear and cloudy samples.
- Aggregate data flight-by-flight into 5º longitude boxes and 100 m altitude bins
- Level with maximum UCL frequency sets coverage on any given day.
- Average daily coverage to give overall UCL coverage for all flights/longitude boxes

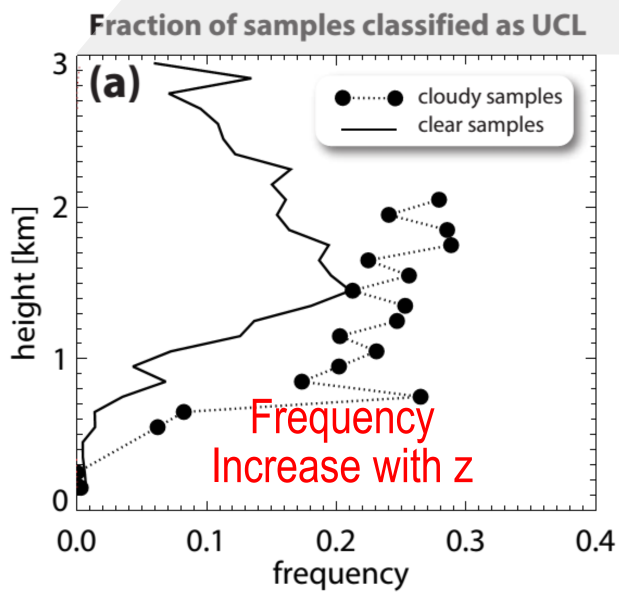


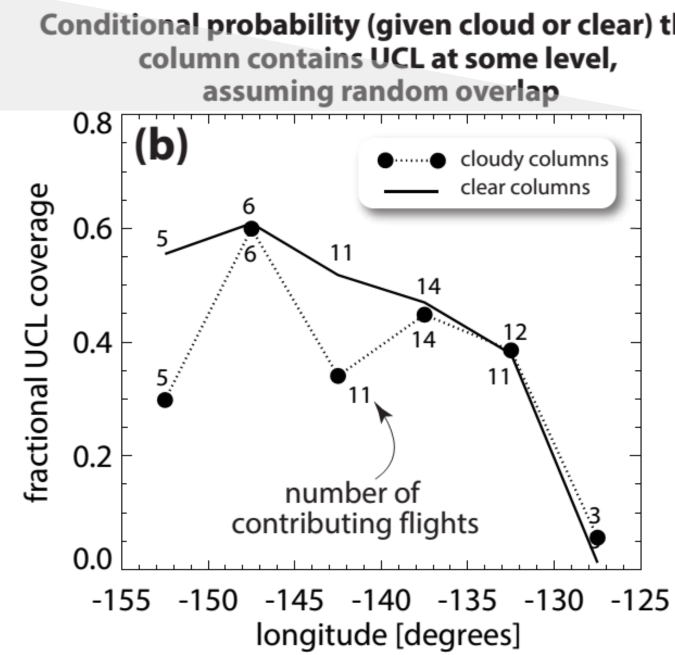
Ultra-clean layers (UCLs) are common over NE Pacific



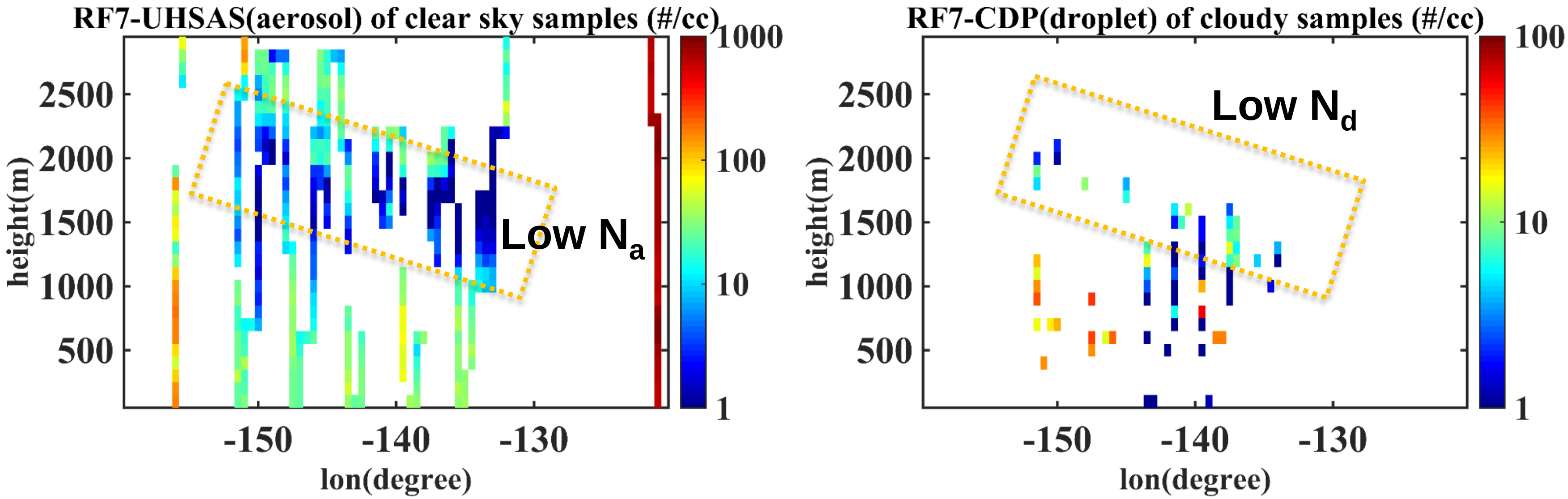
Cloud System Evolution in the Trades (CSET) project,
NCAR G-V, Jul-Aug 2015





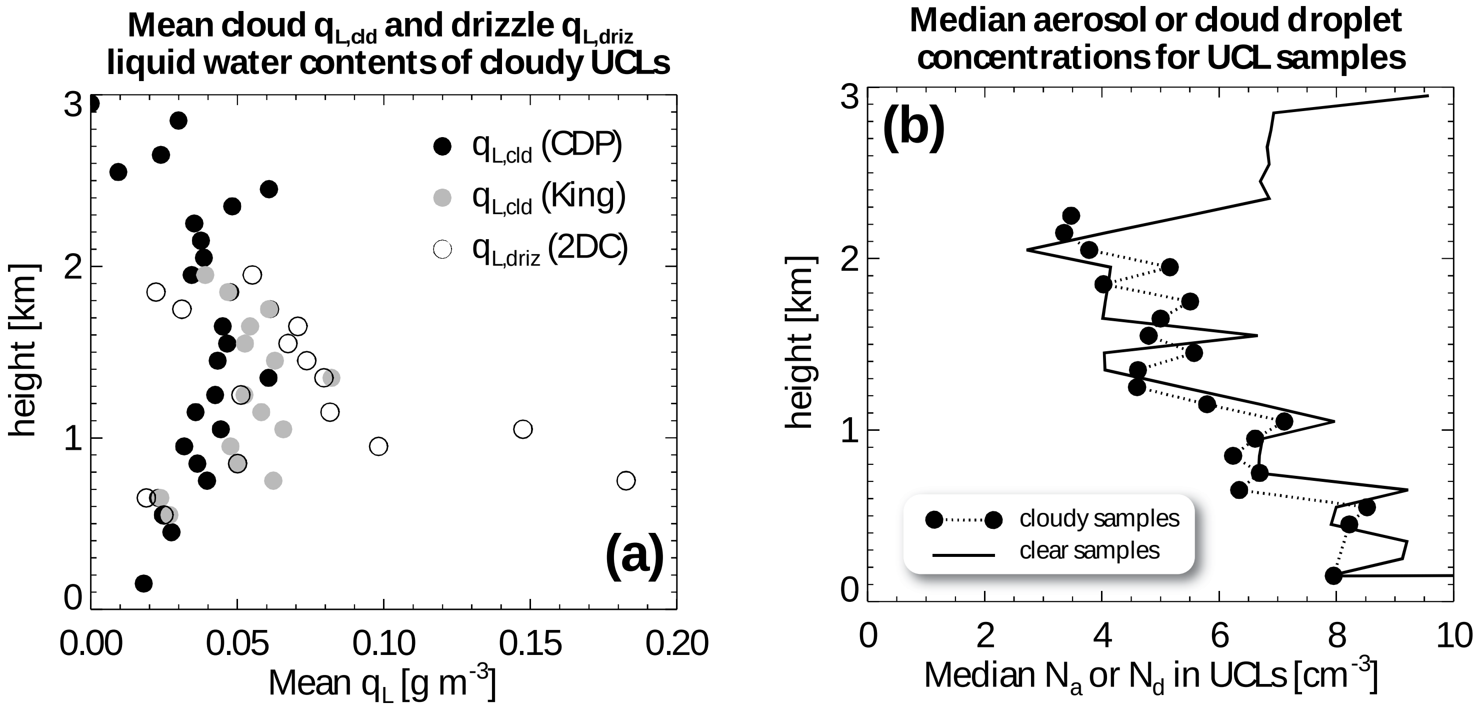


UCLs defined as samples with N_d (cloudy) or N_a (clear) < 10 cm^{-3}



- Clear and cloudy UCLs tend to occur near the top of the PBL, with higher concentrations below.

Liquid water contents and particle concentrations in UCLs

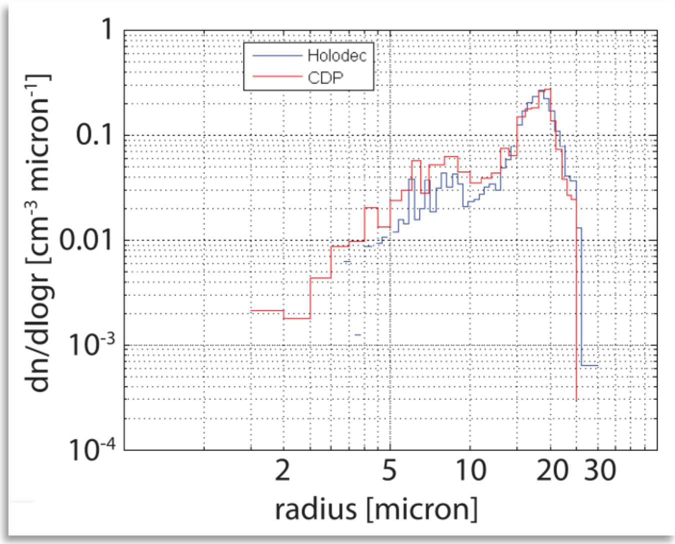


(a) Mean liquid water contents in UCLs partitioned into condensate in cloud droplets (r<20 mm) and drizzle drops (r>20 mm). Cloud liquid water contents are shown for two different measurements (CDP and King hotwire probe); (b) Median concentrations of cloud droplets (for cloudy UCL samples) and accumulation mode aerosols (for clear UCL samples).

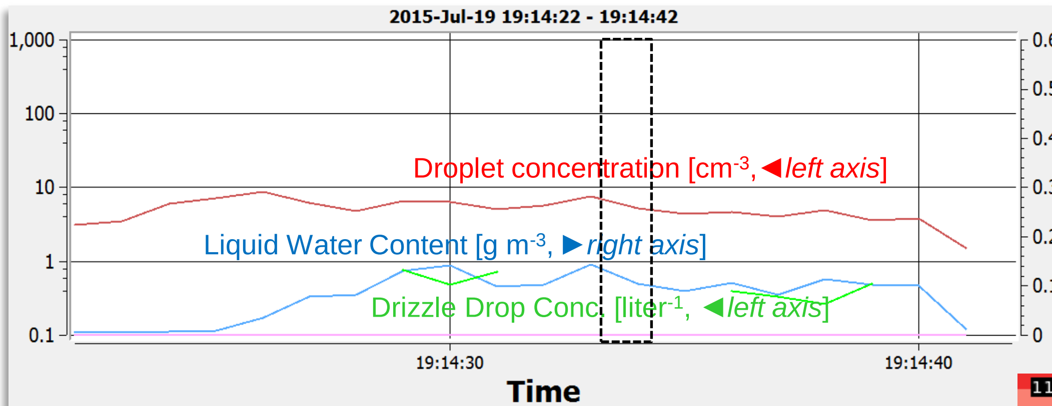
UCL Gray Cloud Microphysics

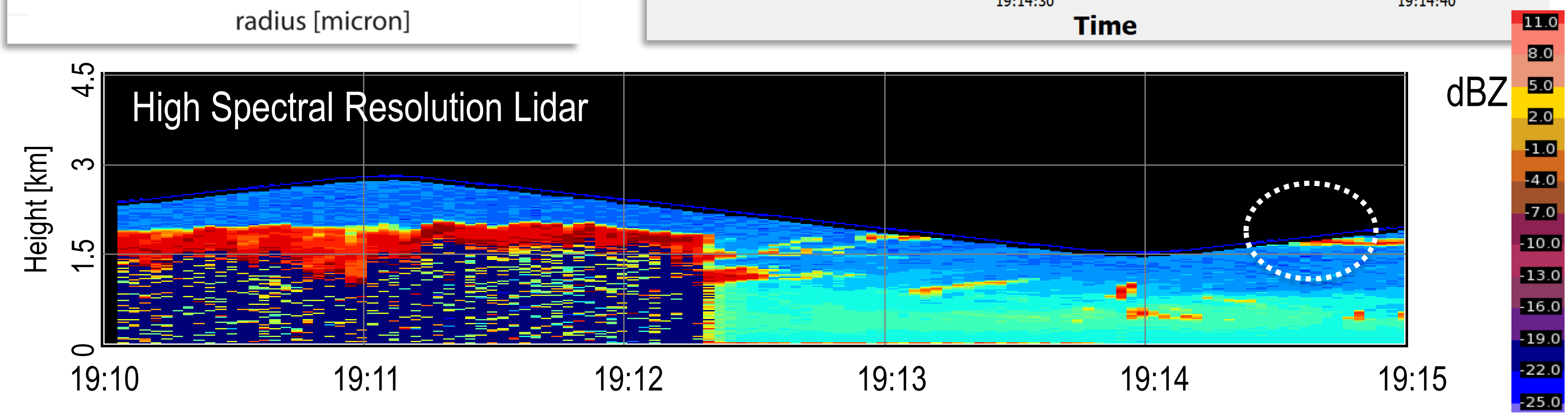
Droplet size distribution

RF07 - July 19th

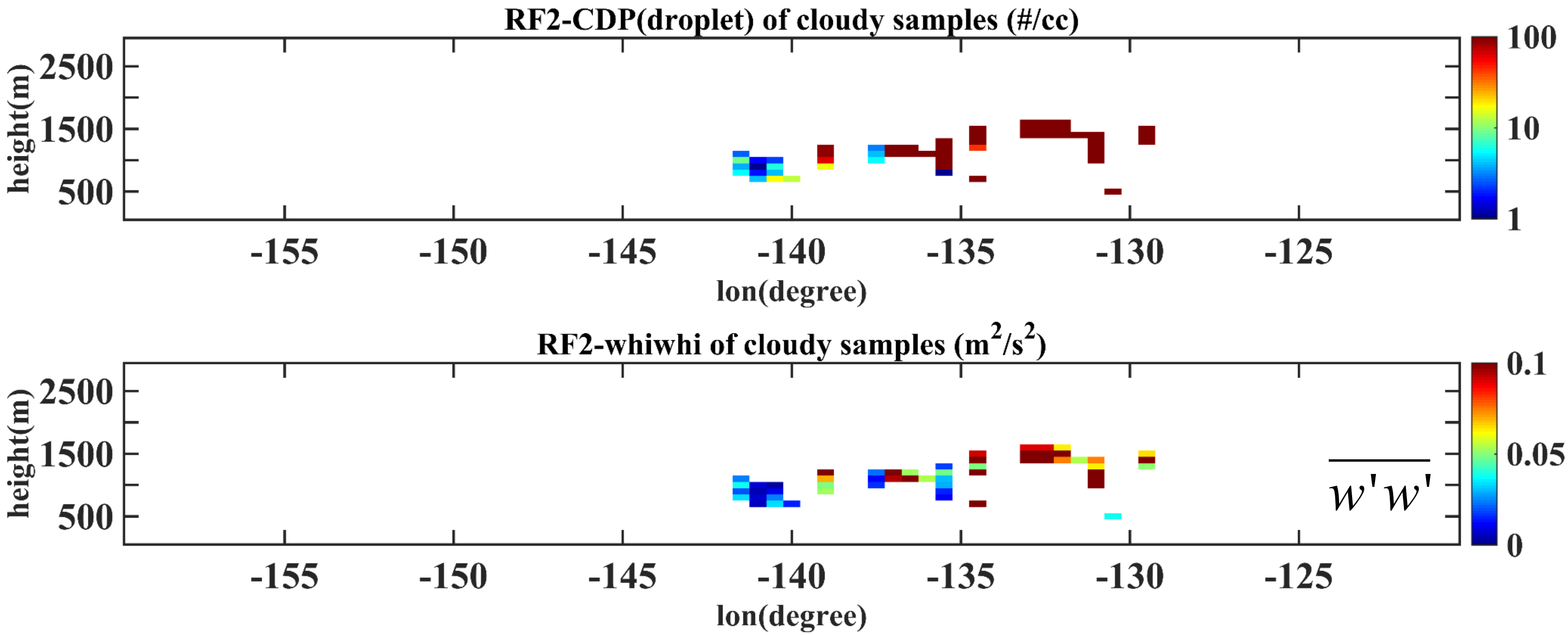


Concentrations and condensate





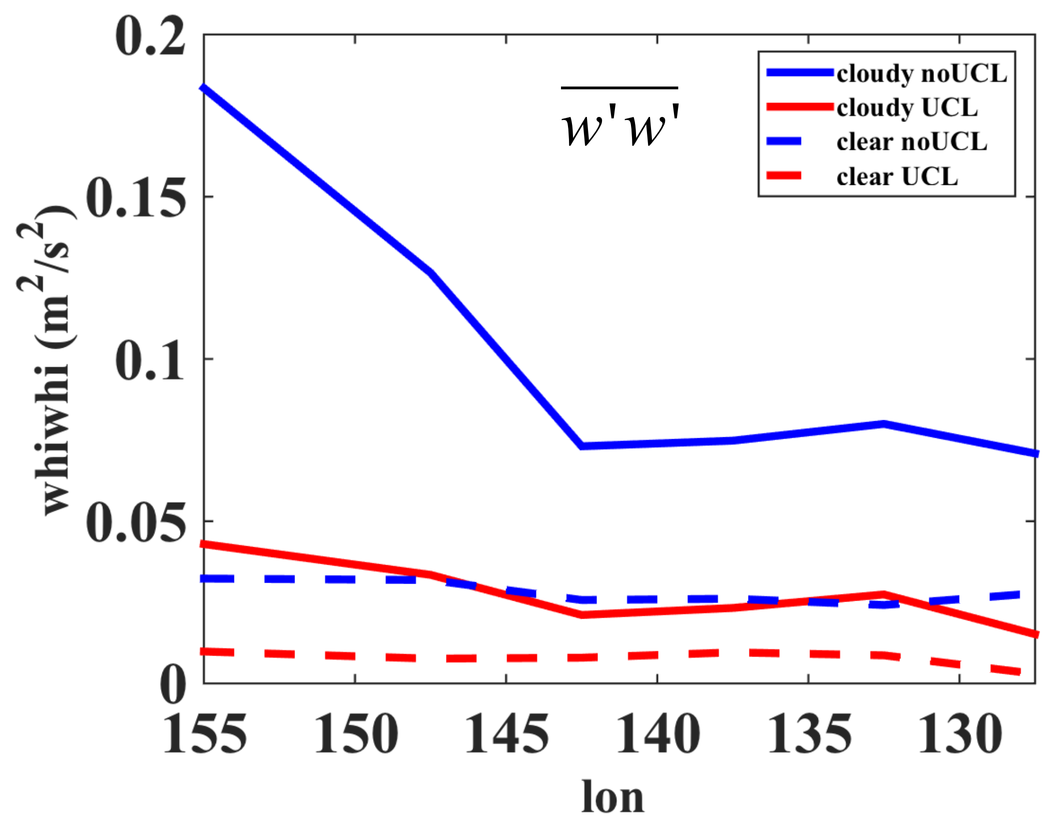
UCL clouds and vertical turbulent motions



- Example from RF02 shows positive correlation between Nd and vertical wind variance (using Chris Bretherton's derived *whi2* variable)
- UCL clouds associated with low values of *whi2*

UCL clouds and vertical turbulent motions

- Statistical analysis from all CSET flights
- UCL clouds have much lower turbulence than non-UCL clouds
- Clear UCLs also much less turbulent than non-clear UCLs? Consistent with UCLs tending to occur in the upper PBL away from surface-driven mixing

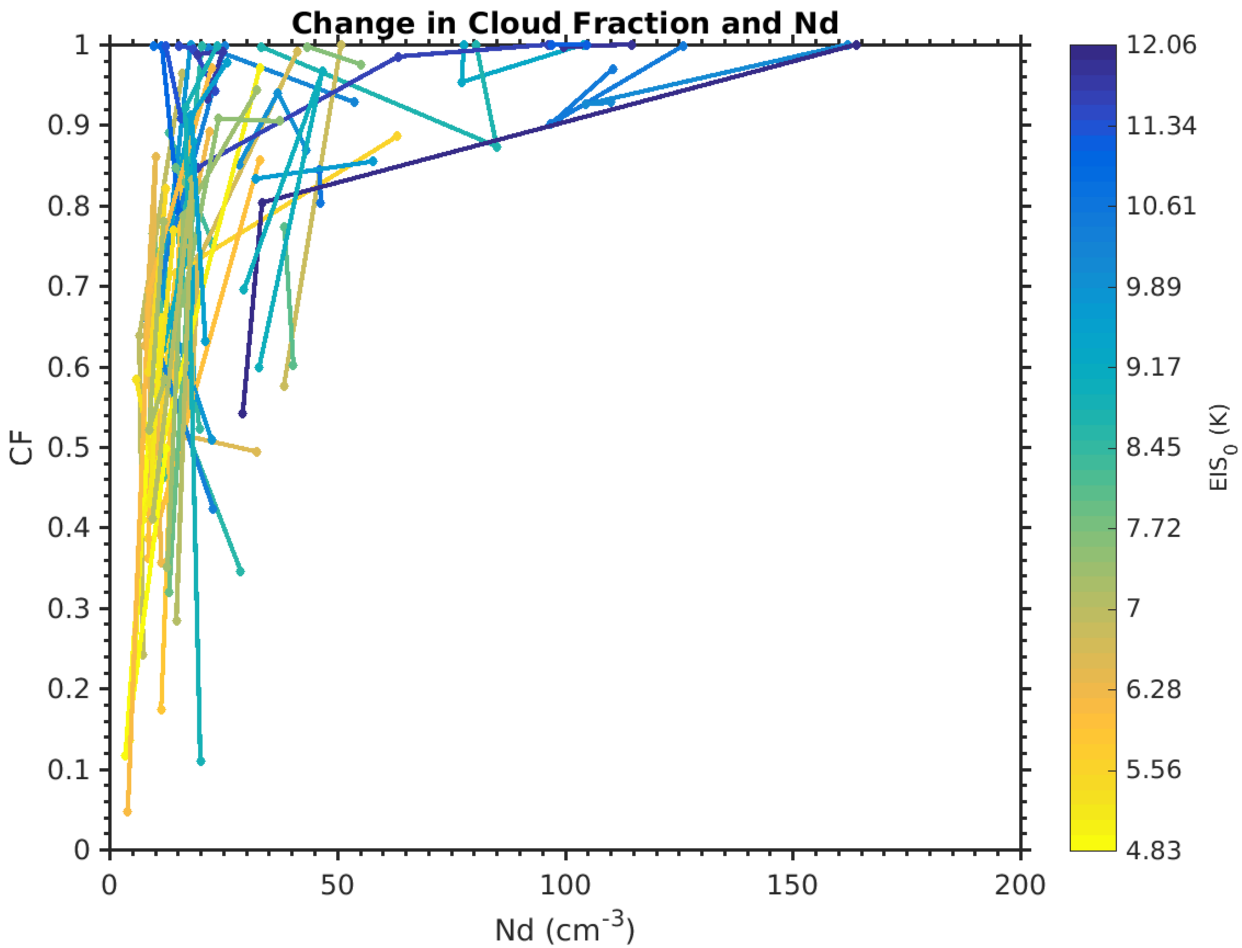


Hypothesis for UCL-gray cloud formation

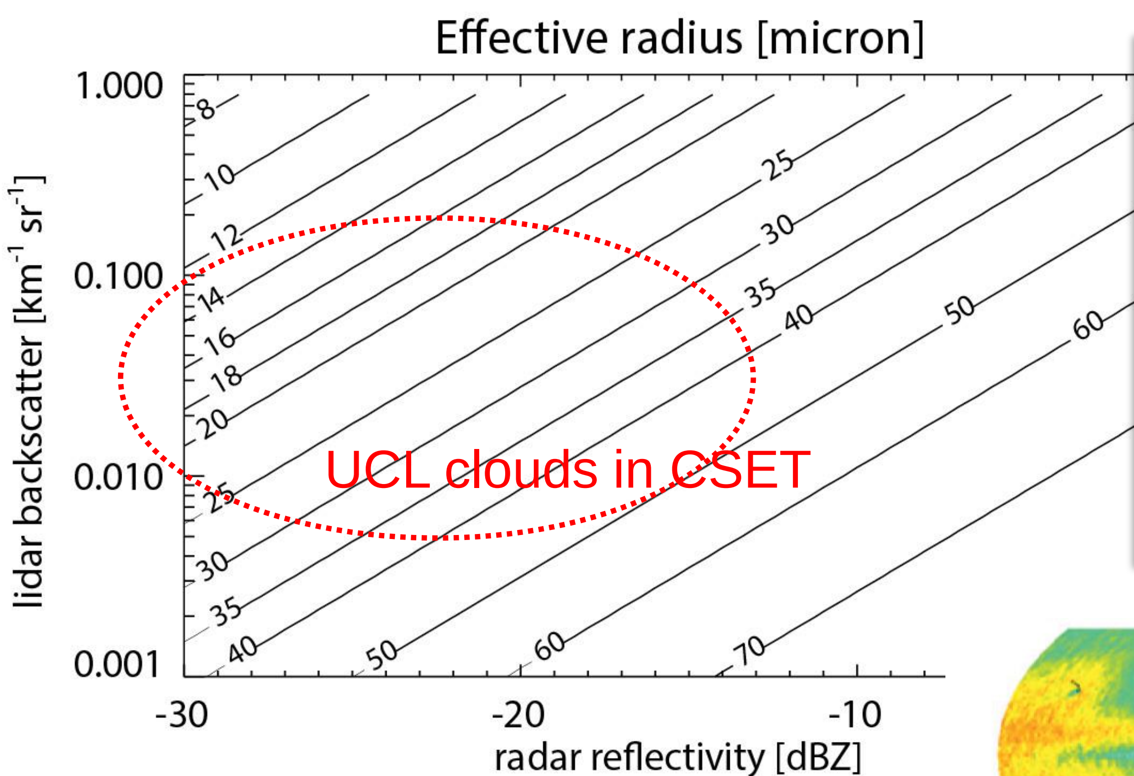
- Active trade Cu towers driven by surface and latent heating loft condensate into the upper PBL, but the strong trade inversion quickly decelerates the rising column, which must therefore spread by continuity of mass.
- Turbulence in the spreading Cu “anvils” dissipates, resulting in relatively long in-cloud residence times, and an opportunity for cloud microphysical processes to act to broaden drop size distribution and deplete droplets.
- Upon evaporation of UCL clouds, few accumulation mode particles are returned to the clear sky, leaving horizontally-extensive layers strongly depleted in aerosol.
- The long overturning timescale (~12 hr) for the upper trade PBL means that numerous Cu events can result in UCLs extending many hundreds of km

GOES: evolution of cloud fraction and retrieved N_d along CSET Lagrangian trajectories

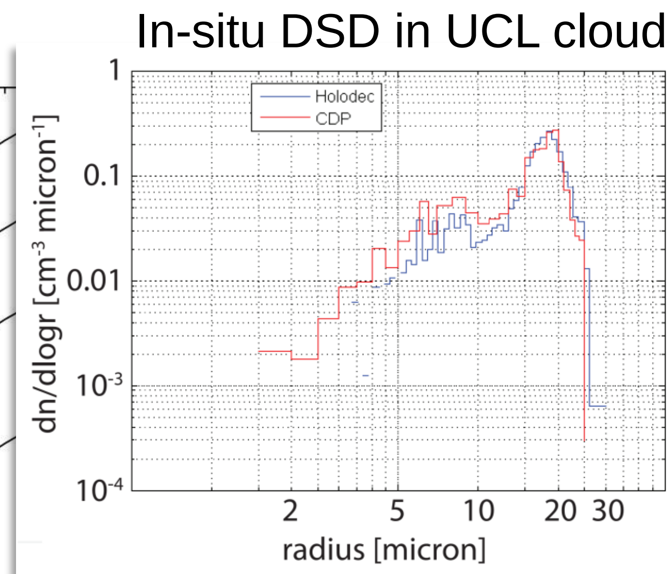
- During CSET, only trajectories starting with extensive cloud cover (CF > 0.8) had $N_d > 40\ cm^{-3}$
- Transition to lower CF along Lagrangian trajectories was associated with N_d values < $40\ cm^{-3}$
- Is the formation of low N_d (UCLs) a requirement of Sc to Cu transition?

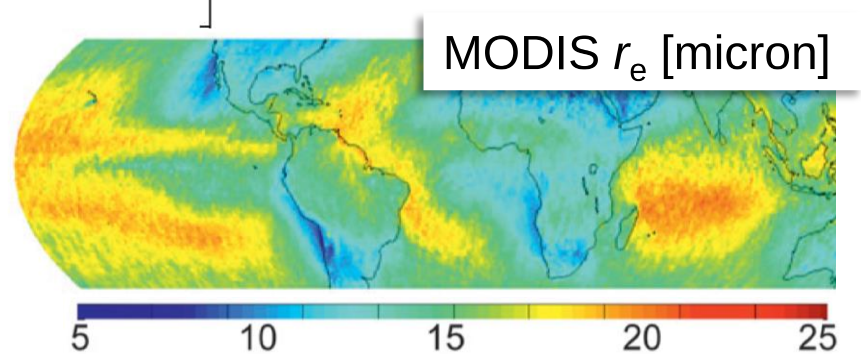


Potential for retrieval of droplet size in UCL clouds with radar-lidar



O'Connor et al. (2005) radar-lidar method to estimate effective radius





Maddux et al (2010)

Next steps

- Complete UCL analysis of CSET in situ data
  - Further examination of cloud and aerosol size distributions
  - Examination of thermodynamic PBL structure associated with cloudy and clear UCLs
  - Turbulence analysis
- Remote sensing investigation of UCL clouds
  - How to characterize gray clouds using CSET remote sensing (radar, lidar, radiometry) and satellites?
  - Evaluate how well satellites measure N_d in UCL clouds

Acknowledgements

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