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A Combined A-Train Perspective on Upper-Tropospheric Humidity and Radiative Heating

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ABSTRACT

There have been various studies in the past that have investigated upper tropospheric (UT) humidity structure in relation to clouds (e.g. *Soden (2004), GRL ; Comstock,et. al. (2004), GRL*). More recently global analyses of UT humidity in relation to clouds, using a combined A-Train humidity (AIRS only) and cloud products (Cloudsat and CALIPSO), have quantified the UT structure in relation to various cloud types (*e.g. Kahn, Liang (2008), ACP, Kahn, et.al. (2009), JGR*).

The A-Train provides upper troposphere (UT) water vapor (H_2O) retrievals from the Atmospheric Infrared Sounder (AIRS) and Microwave Limb Sounder (MLS). AIRS loses sensitivity at the elevated portions of the UT so we investigate the use of the AIRS and MLS averaging kernels (AK) to combine both H_2O profiles into a single product. Furthermore, we combine the AIRS/MLS H_2O data with CloudSat and CALIPSO cloud profiles to characterize the UTH in relation to different ice phase cloud types. We then quantify the radiative fluxes and heating along the A-Train and determine how these quantities jointly vary with the humidity and cloud fields.

METHODOLOGY

- Collocate AIRS v5 support product and MLS v2.2 data at the nearest neighbor points; data for entire year of 2008; data for only -40 to 40 latitude; use only clear-sky points over ocean.
- Using AIRS and MLS averaging kernels to determine where AIRS is most sensitive to H_2O.
- Collocate combined AIRS/MLS humidity profiles with CloudSat and CALIPSO cloud profiles (GEOPROF-LIDAR product; *Jay Mace*) from May, 2008 - February, 2009 (all available data which has 4-way co-registration).
- Cloudy and clear-sky are criteria determined by AIRS, CloudSat, and CALIPSO; land pixels are ignored.
- Lidar only Cirrus is forced to be clouds with bases 7km and above.
- Humidity fields partitioned by cloud types are chosen such that the cloud type of interest is the dominant type in the scene (more than 50% cloud fraction in AIRS FOV).
- Use parameterized water content and particle size with Fu-Liou radiative transfer model (*Fu and Liou, JAS, 1992*) to compute radiative fluxes and heating profiles (excludes pixels with deep convective clouds).

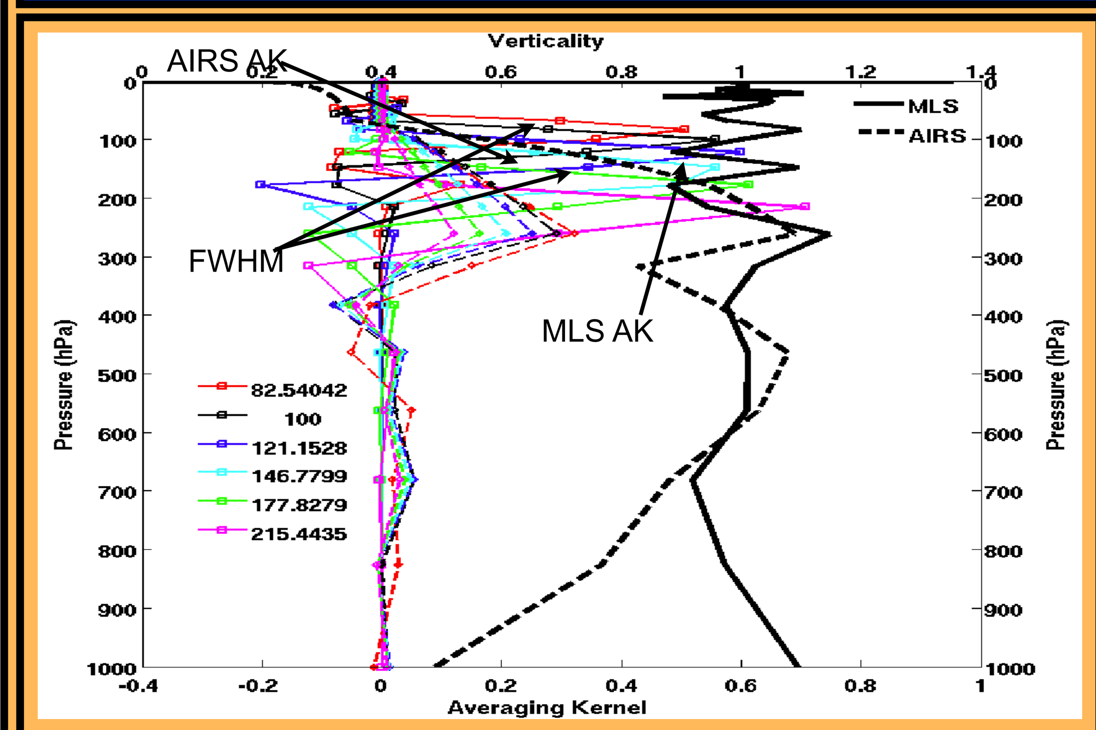

Figure 1: Sample AIRS and MLS averaging kernels (AK) and the verticality (sum of averaging kernels, *indicates how much information is received from the instrument radiances*) for 6 pressure levels; also shown is the FWHM definition.

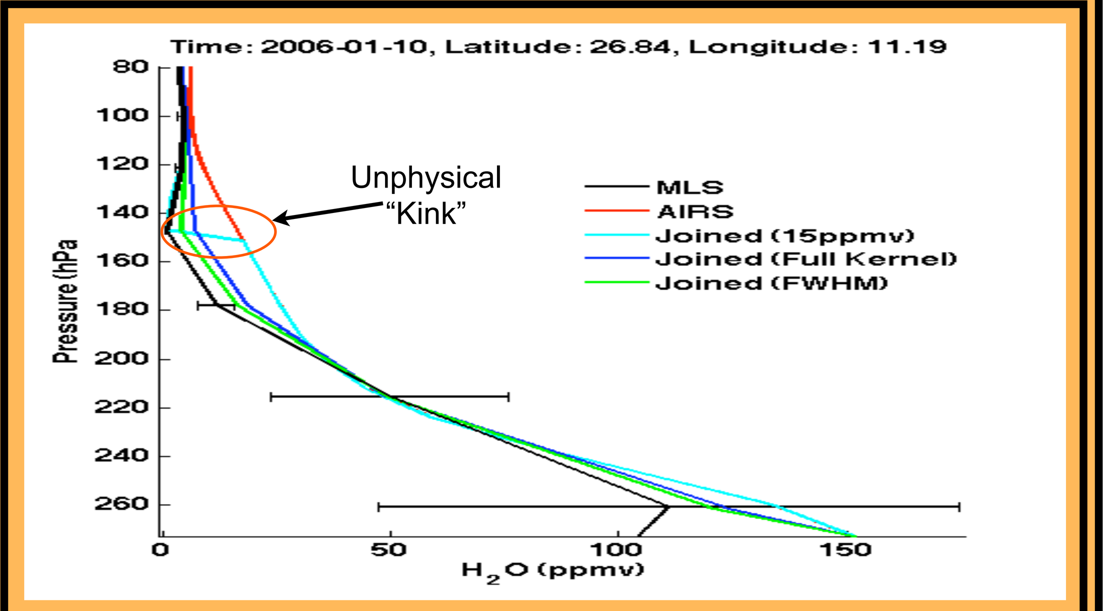

Figure 2: Shows the original AIRS and MLS H_2O profiles along with the 3 ways of splicing the H_2O profiles. Horizontal black bars are the MLS error bars.

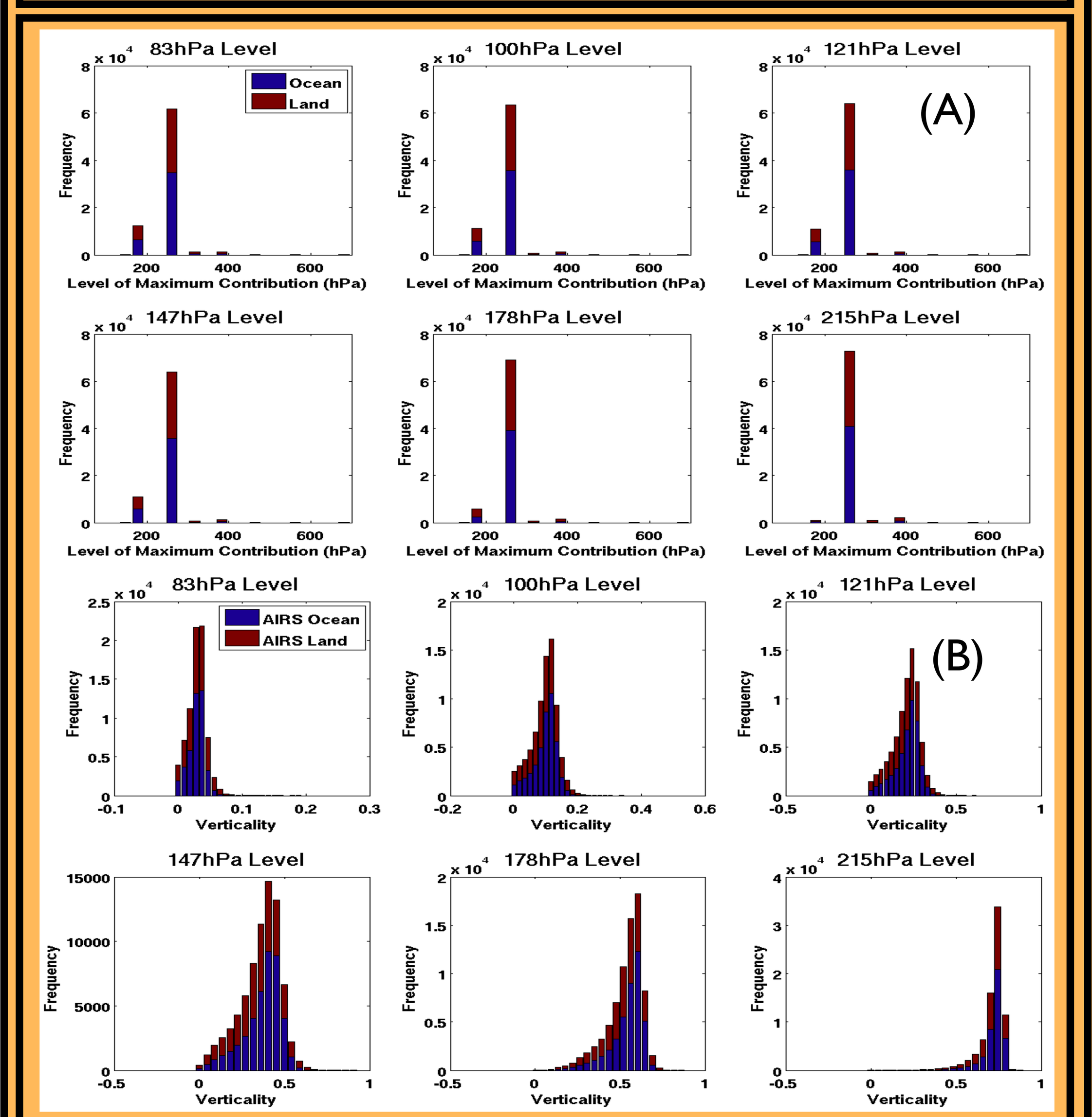

Figure 3: (A) Shows vertical distribution of where AIRS is "detecting" H_2O at each pressure level for land and ocean pixels. (B) Verticality distribution at each retrieval level.

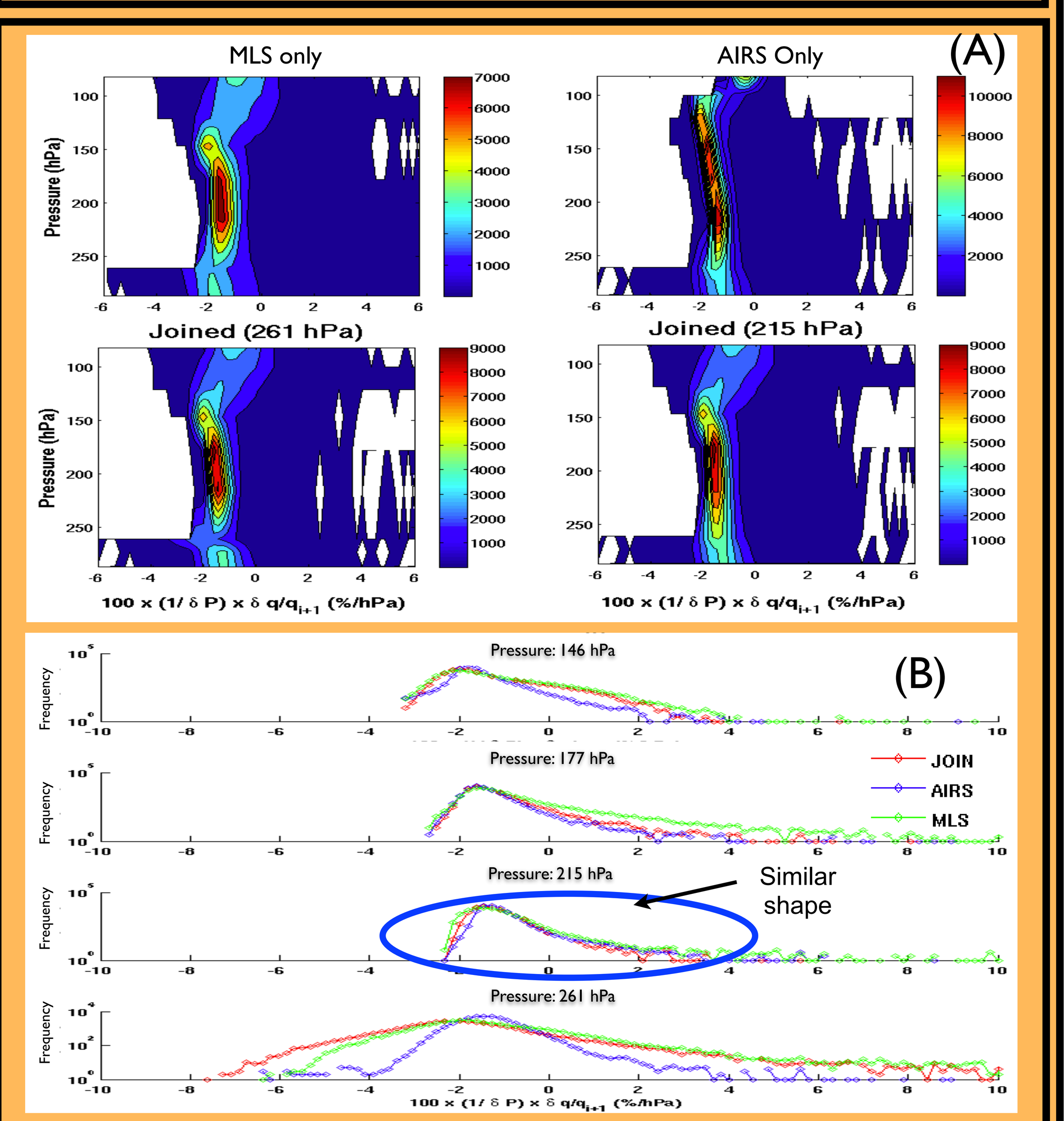

Figure 4: (A) percent change in H_2O (q) normalized by the change in pressure joint PDF's for AIRS, MLS, and joined H_2O profiles at 261 and 215 hPa. AIRS values show smooth transition throughout profiles while the MLS and Joined (261 hPa) profiles show "kinks" at 261 hPa. When AIRS and MLS are joined at 215 hPa discontinuity vanishes since the normalized percentage difference behaves similarly at 215 hPa for AIRS and MLS; see panel (B) - Joined profiles approach same behavior as MLS at higher levels; 261 hPa shows significant differences.

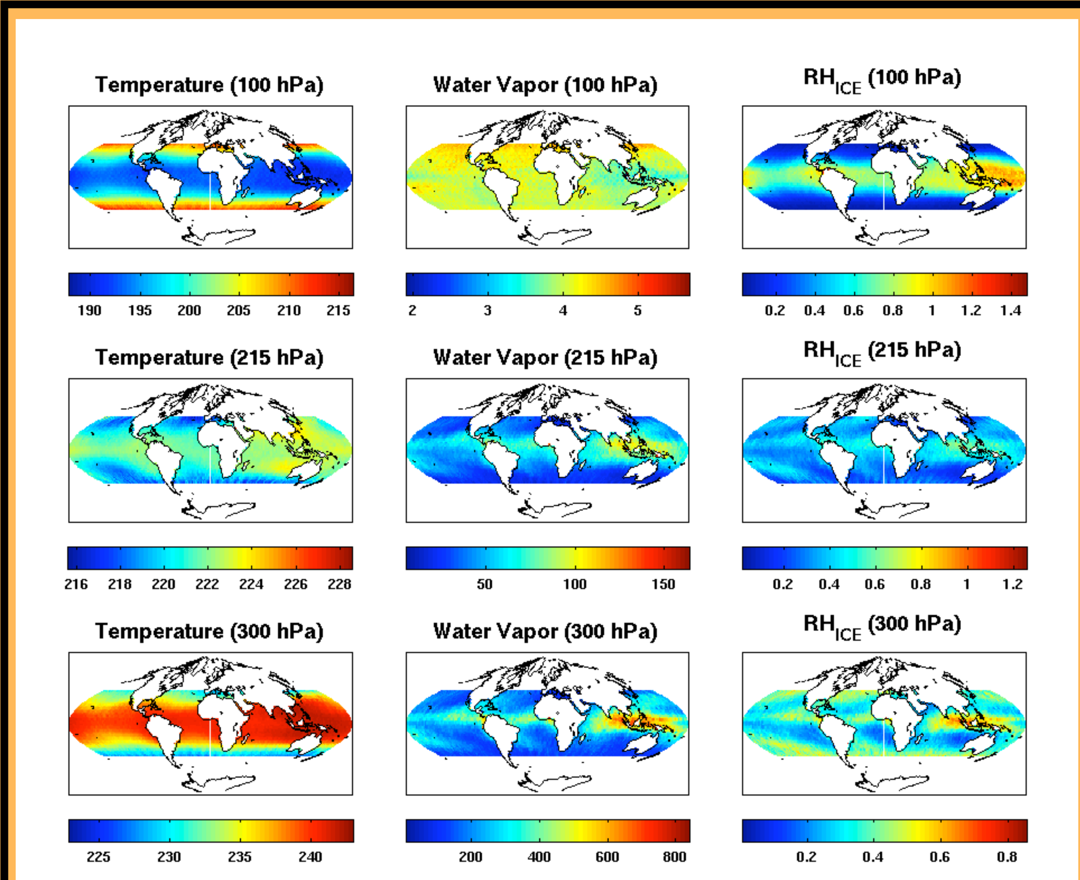

Figure 5: All-Sky 2008 climatology of temperature (K), H_2O (ppmv), and RH_{ICE} at 100, 215, and 300 hPa. Notable features is the persistent supersaturation at 100 hPa and the transition to the stratosphere in the higher latitudes between 215 to 100 hPa. Persistent high saturations at 100 hPa seems to be driven by temperature (see Figure 10).

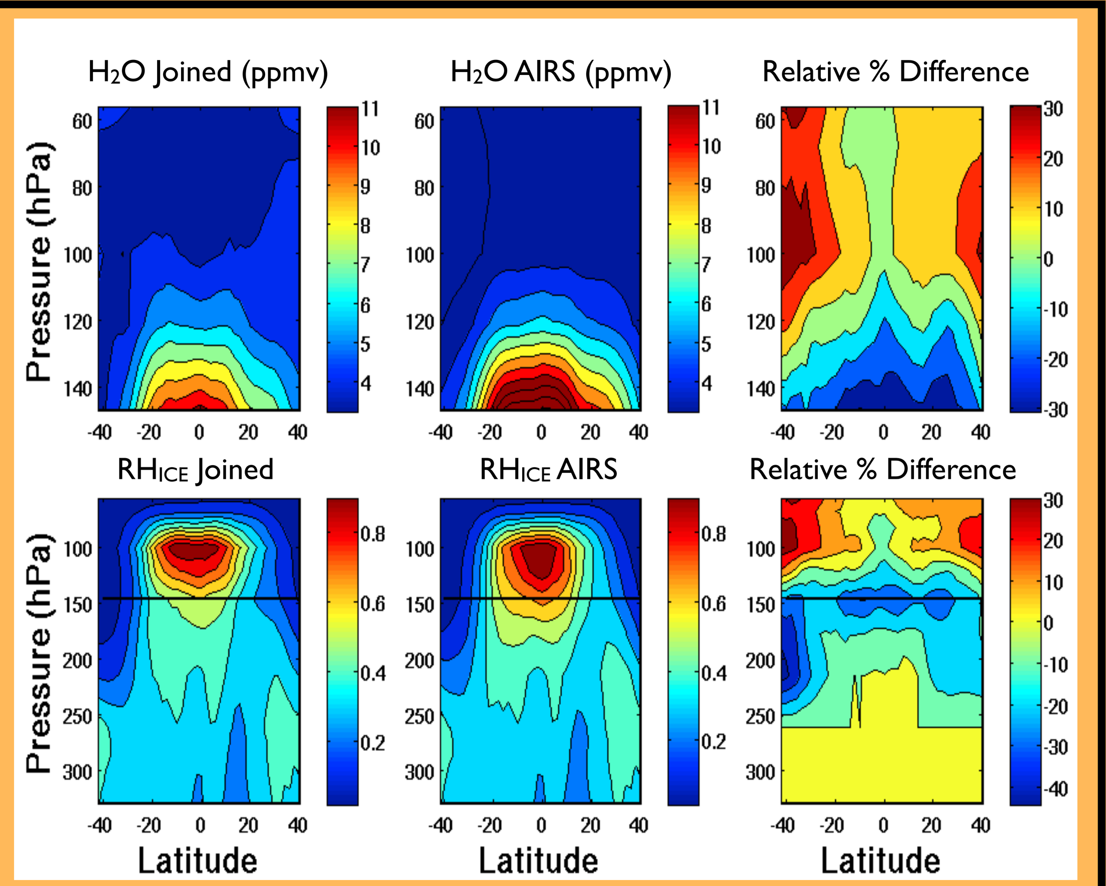

Figure 6: Top Row: H_2O vertical zonal mean ($150 \leq Long \leq 200$) for joined data and AIRS only; last column shows relative percent difference, 100x(JOINED-AIRS)/JOINED, between the two datasets. Bottom Row: Same as above but for RH_{ICE}; horizontal black line indicates pressure limits shown in the H_2O cross sections. H_2O and RH_{ICE} both show significant differences between 170 and 100 hPa, namely that AIRS is too moist in those regions.

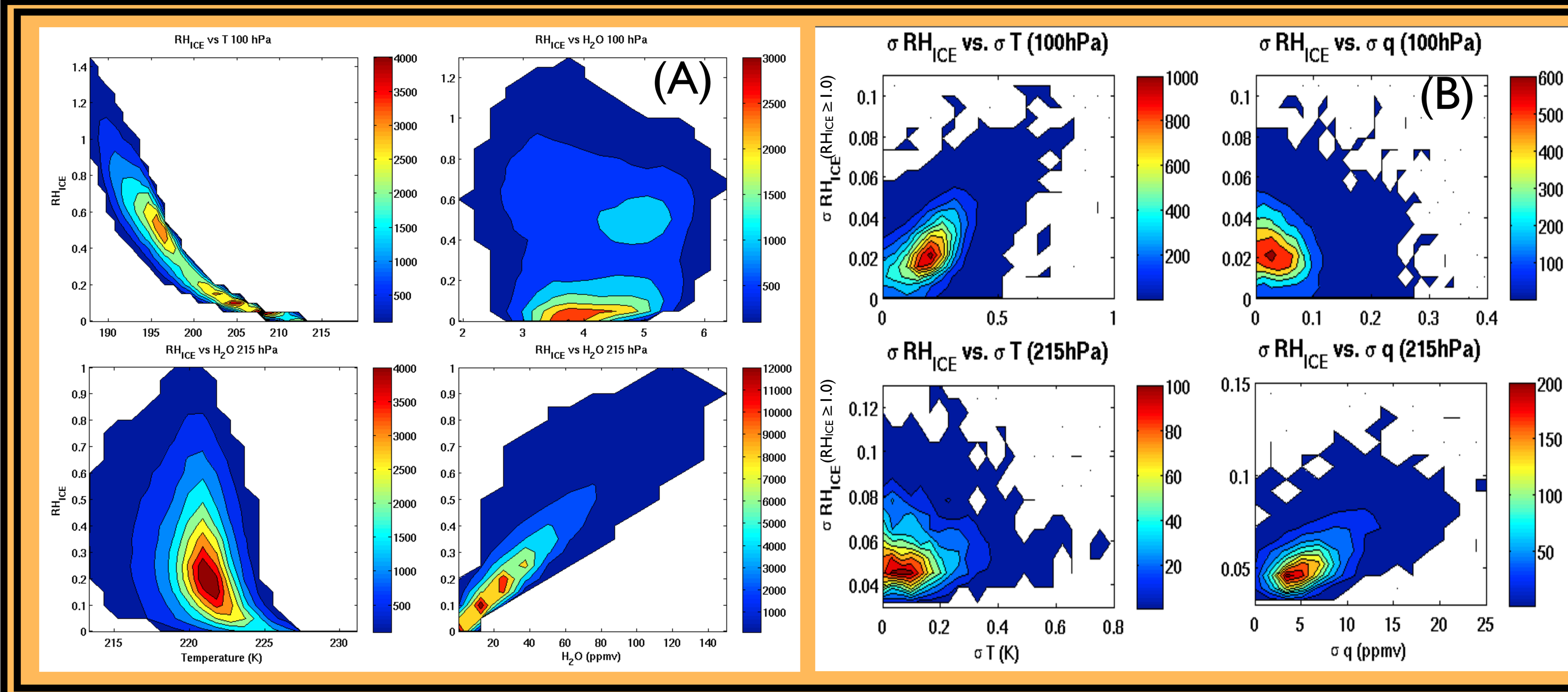

Figure 7: (A) All-sky relative humidity (ice) vs T and H_2O joint PDF's at 100 hPa and 215 hPa. Correlation between RH_{ICE} and T @100 hPa is strong but not w/H_2O, while RH_{Ice} @ 215 hPa is more strongly correlated with H_2O than T, (B) looking at supersaturation the temperature variance (σT) seems to partialy explain the variance in supersaturated RH (σRH_{ICE}) @100 hPa while σRH_{ICE} @+215 hPa seems to be tied the variance in H_2O (σH_2O) as oppose to σT; color scale is frequency of occurrence

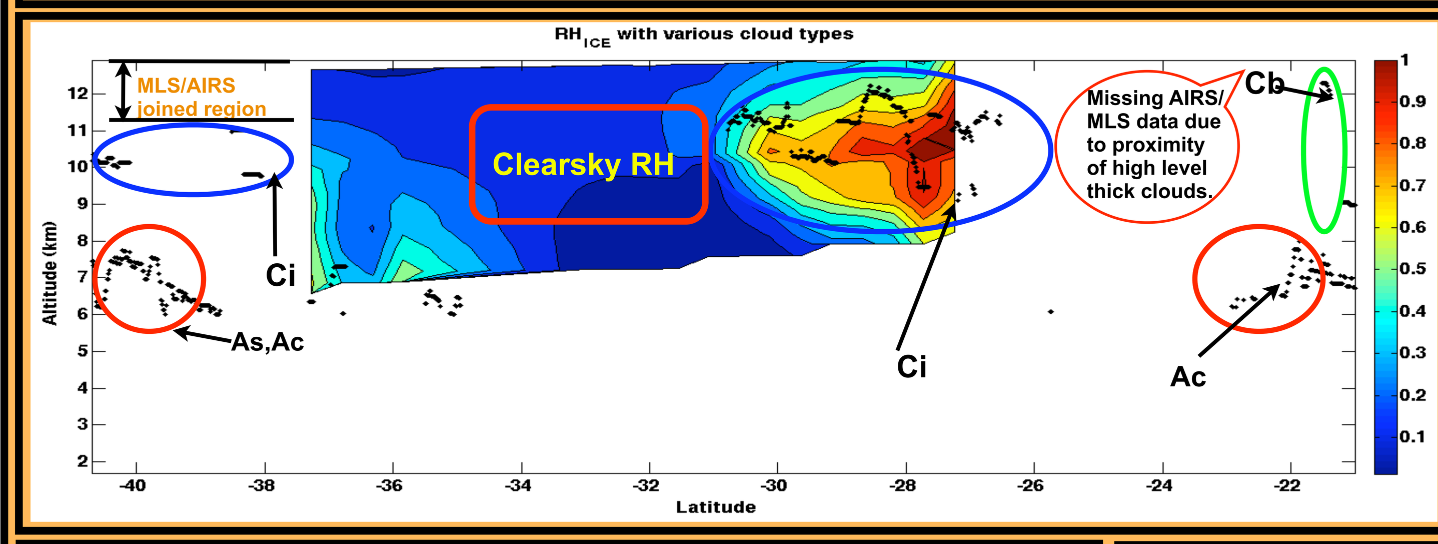

Figure 8: Transect of RH_{ICE} (color scale) with cloud tops of various cloud types plotted as black dots. Plot also show regions of clear-sky near clouds. Notice the heterogeneity of cloud types even in very small latitude bands. Also shown at the far top left is an indicator of where the AIRS/MLS joined profile data becomes important.

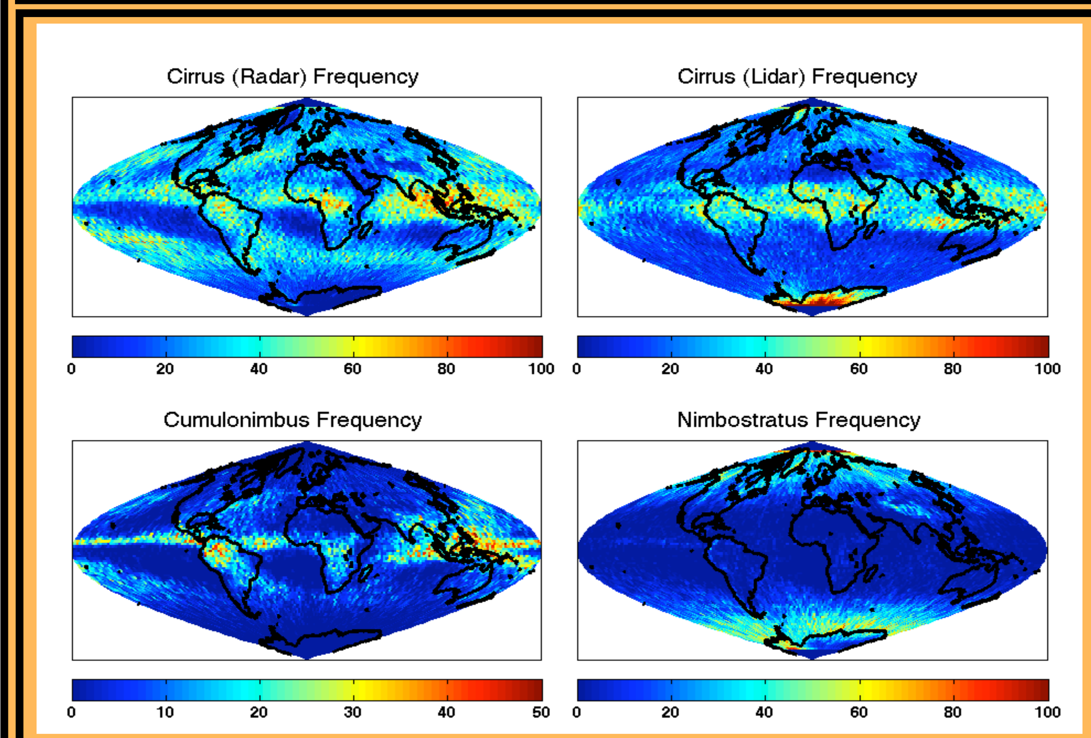

Figure 9: Frequency of occurrence for each cloud type.

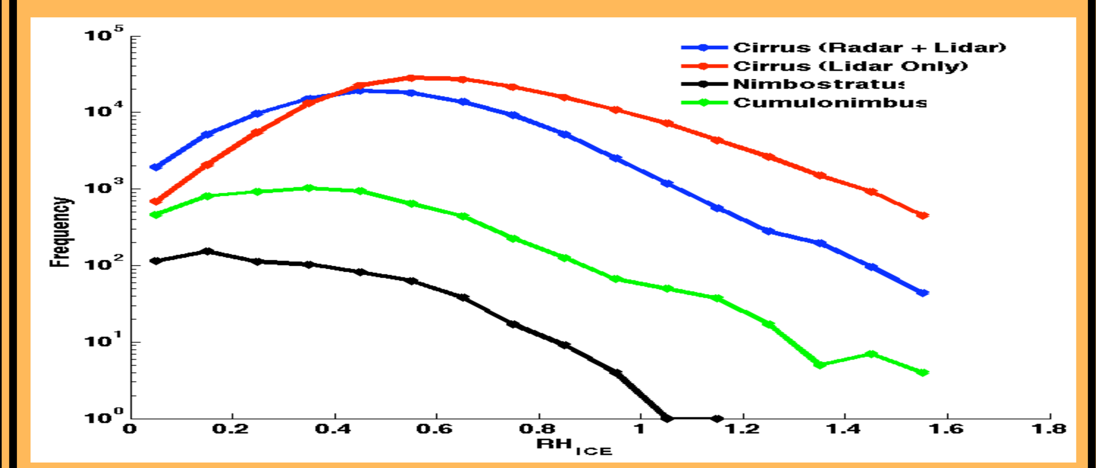

Figure 10. All-sky relative humidity (ice) PDFs with listed clouds in scene

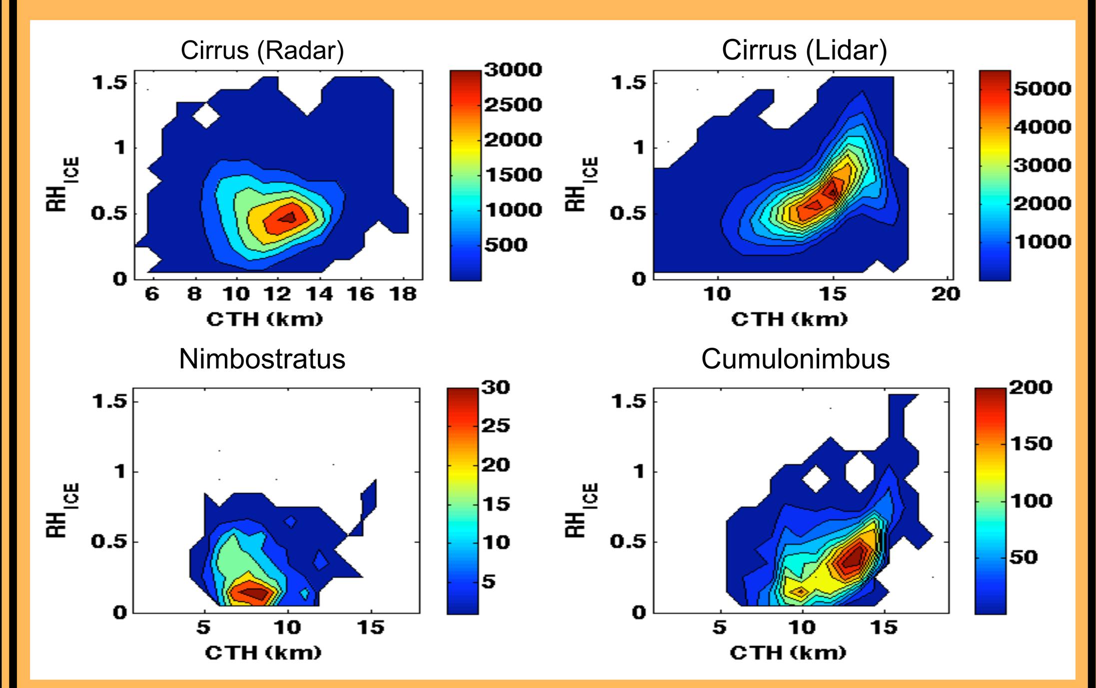

Figure 11: Relative Humidity (RH_{ICE}) vs CTH joint PDF's for each cloud type; color scale is frequency of occurrence. Strong relationship between high RH and high cloud tops seems to be determined by the σT (see Figure 7).

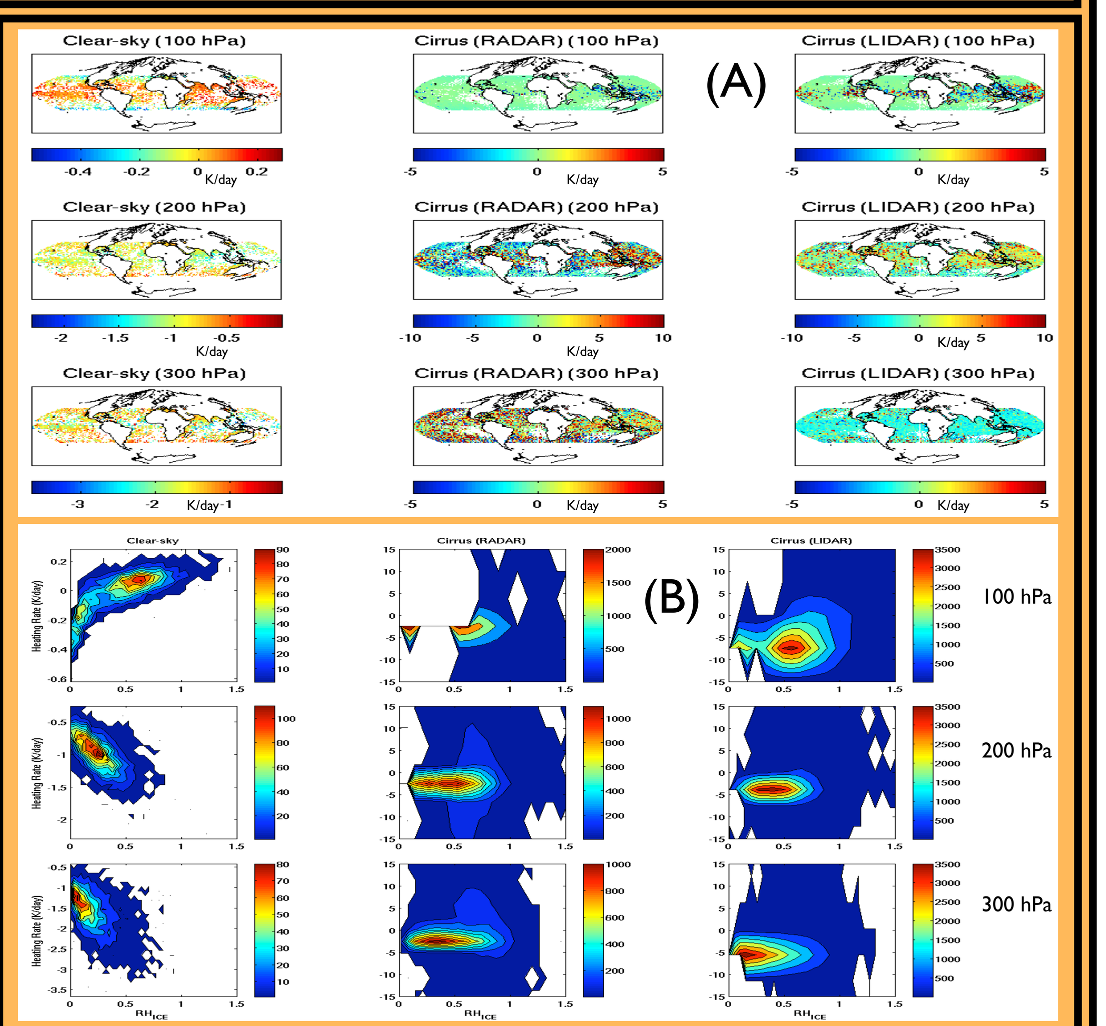

Figure 12: (A) Global maps of IR heating rates (K/day) for clear-sky, cirrus (RADAR), and cirrus (LIDAR) scenes @ 100, 200 and 300 hPa. Clear-sky heating rates are positive at 100 hPa a region of persistent supersaturation. @ 100 hPA large heating rates are seen over Pacific. (B) Heating rates show strong relationship with RH_{ICE} *only for clear-sky scenes,* although the different clouds have noticeable differences in their distributions.

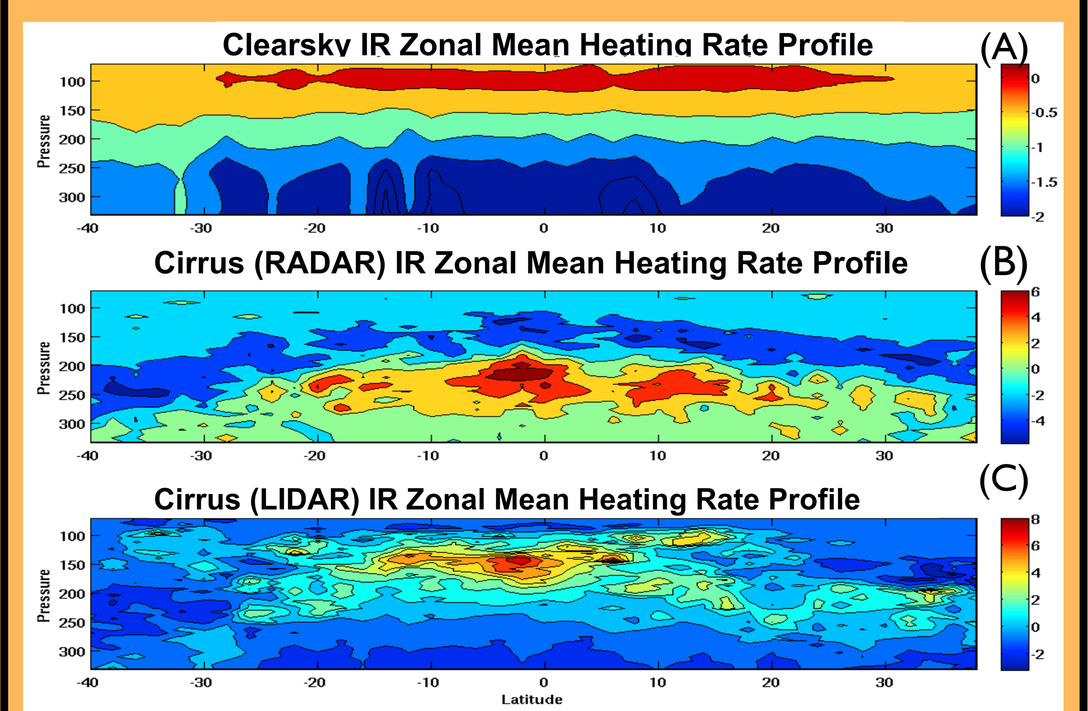

Figure 13: Zonal mean IR heating profiles ($120 \leq Long \leq 200$) for (A) Clear-sky scenes, (B) scenes with Cirrus detected by CloudSat, and (C) scenes with cirrus detected by CALIPSO. Clear-sky shows consistent radiative cooling in the lower parts of the UT but @ 100 hPA there is a large mode of slight heating. Figures 5 and 6 show that this region is persistently supersaturated. In (B) we see that there is significant cooling aloft but between 170 to 300 hPa, location of most cirrus clouds (between 9-13 km) we see large heating modes, but in (C) we see the heating occurs between 100 hPa and 170 hPa (13-17km) where more optically thin cirrus reside (see Figure 11).

Summary

- ★ AIRS and MLS seem to have good agreement at around 215 hPa (see gradient test results in Figure 4) but above that the AIRS AK's indicate it loses sensitivity to H_2O.
- ★ Combining the AIRS & MLS H_2O profiles using their averaging kernels we create the first global remote sensing dataset of H_2O throughout the entire troposphere and stratosphere.
- ★ Using AIRS data alone can lead to a moist bias in the tropical UT with AIRS data being up to ~30%, in water vapor and RH_{ICE}, more moist than the joined dataset. This, again, is due to AIRS losing sensitivity in parts of the UT leading to retrievals pulling in H_2O information from lower parts of the atmosphere.
- ✤ RH_{ICE} strongly correlates with T at 100 hPa but at 215 hPa the relationship is stronger with H_2O. When looking at supersaturation the we see that the σT drives the σRH_{ICE} at 100 hPa while σH_2O drives σRH_{ICE} at 215hPa. This could explain the strong relationship between high CTH and high RH_{ICE}.
- ✤ CloudSat and CALIPSO clouds show consistent horizontal spatial patterns as well as vertical distribution.
- ✤ AIRS and MLS see dryer RH_{ICE} for the deep convective clouds. This may be because AIRS and MLS are averaging in air from the dry downdraft regions of these systems due to the coarser instrument resolution in the UT.
- ✤ AIRS and MLS do not sample regions with deep convective clouds well as compared to regions of cirrus removed from convection.
- ✦ Clear-sky radiative heating doesn't contribute much to the budget in the UT but at 100 hPa there is a small positive heating contribution which corresponds to a region of high supersaturation. It has been shown that small positive radiative contributions in ice-supersaturated regions in the TTL can lead to changes in moisture transport (*Fusina, et.al, JGR, 2007*)
- ✦ Cirrus (RADAR) contributes to heating heating between 9-13km while cirrus (LIDAR) contributes to heating between 13-17km consistent with the cloud distributions shown in Figure 11. Heating rates for both clouds types tend to be stronger in the southern hemisphere over the warm pool region.
- ✦ Heating rates are for both cloudy cases exhibit very little statistical relationship but shows strong correlation with clear-sky RH_{ICE}, however different clouds show differences between their PDF's.

Future Analyses

- ✦ Collocate AIRS/MLS for the entire mission; the same for AIRS and CloudSat and CALIPSO.
- ✦ Integrate IWC, De, and τ from the A-Train retrievals; use these values in RTM calculations as oppose to parameterizations.
- ✦ Composite all fields with ECMWF wind fields.
- ✦ Currently we look at cloud on a pixel by pixel basis; need to better partition clouds by cloud systems and quantify humidity fields based on these systems.
- ✦ Use delta-4 stream RTM model to retrieve De and τ from AIRS radiances and clouds (*Yue, et.al. JAS, 2007*)
- ✦ Better characterize the AIRS/MLS sampling abilities through different atmospheric conditions; although we have done some of this in this work, we want to better quantify when AIRS and MLS can provide high quality humidity fields.
- ✦ Explore using ice microphysical and radiative retrievals from MODIS.
- ✦ Run back-trajectories starting from CALIPSO and CloudSat clouds to explore mechanisms of UT/LS moistening and dehydration. Explore TTL dehydration by thin cirrus.

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