Clouds and Water Vapor in the TTL as simulated by a microphysical model

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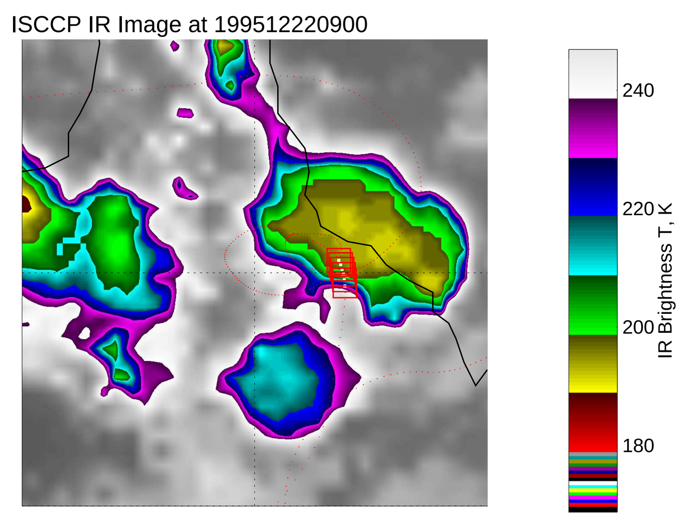
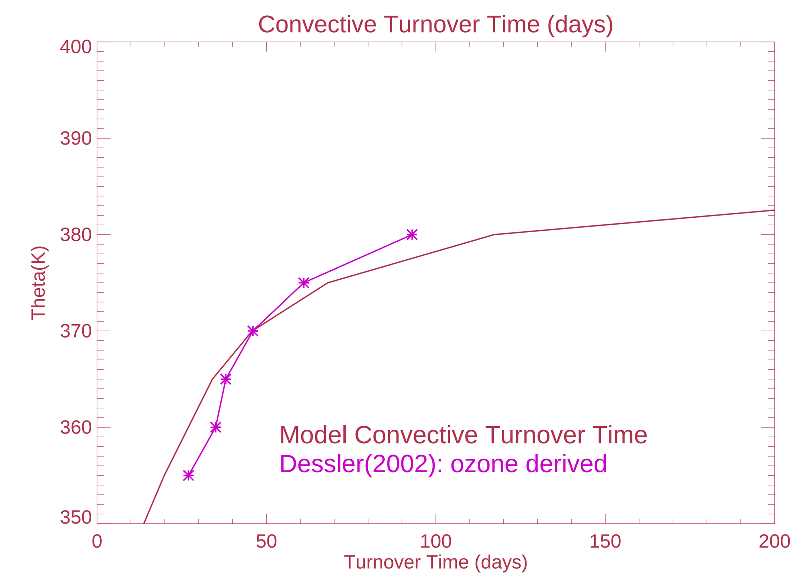
1. Introduction

- Clouds and water vapor in the tropical tropopause layer (TTL) are important for water vapor input into the stratosphere (ozone depletion increases with stratospheric water vapor) and the TTL's radiation budget (enhanced thin cirrus clouds will increase heating and are consistent with more upward motion).
- Current wisdom is that upper TTL water vapor is maintained by dehydration due to horizontal motion through cold regions as air undergoes a gradual radiative rise through the TTL (Fueglistaler et al, 2005; Bonazzola and Haynes, 2004; Holton and Gettelman 2001). Convection is important for CO to 360-370K in the boreal winter TTL (Schoeberl et al, 2006), higher for water and water isotopes (Dessler, 2002; Dessler et al, 2006), and in the boreal summer.
- The purpose of this work is to understand what governs the cloud and water vapor distributions in the TTL, with emphasis on the boreal summer. The approach is simulation using a trajectory-based microphysical model. We will: (1) describe the method and show some results from the boreal winter TTL; (2) show background and results for the boreal summer TTL; and (3) summarize and point to future directions.

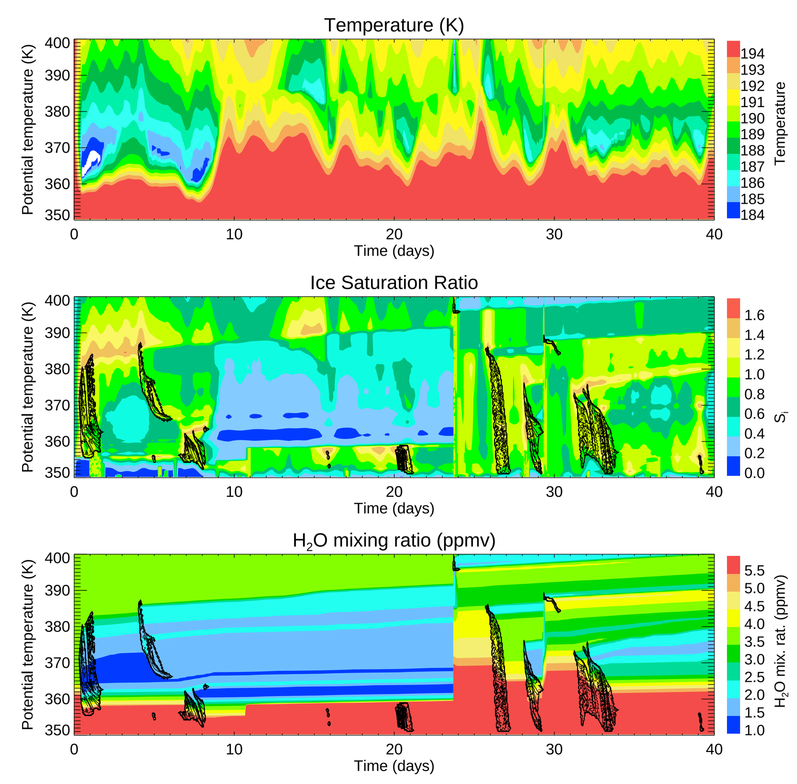
2. Procedure and and Boreal Winter results

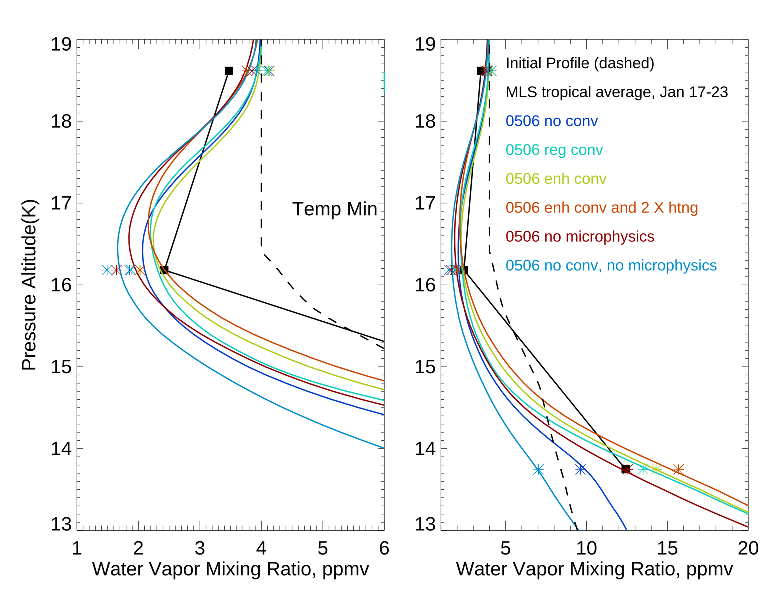
- 40 day diabatic back trajectories from a 5 by 5 grid of points using GEOS-4 analyses and the GSFC trajectory model (Schoeberl and Sparling, 1995).
- Generate time-height curtains of T along the trajectories and adjust temperatures to match time-average lat-lon-altitude radiosonde values.
- Evaluate convective cloud top thetas from tracing curtains through 3-hourly satellite imagery, adjusting satellite brightness temperatures to raise cloud tops about 1 km (Sherwood et al, 2004).
- Use "conventional" microphysics (1.6 saturation ratio for nucleation; standard ice smr values). Set water vapor to local ice smr up to cloud top theta. Figures below show the interaction of trajectories with convection (left) and the implied convective turnover time (red curve) compared with Dessler's (2002) ozone-based calculation (right).





- Figure below (left) shows a sample curtain trajectory evolution with convection. Black shows falling ice particles from in-situ cloud formation, sudden changes in water mixing ratio at 23 and 29 days are convective injection events.

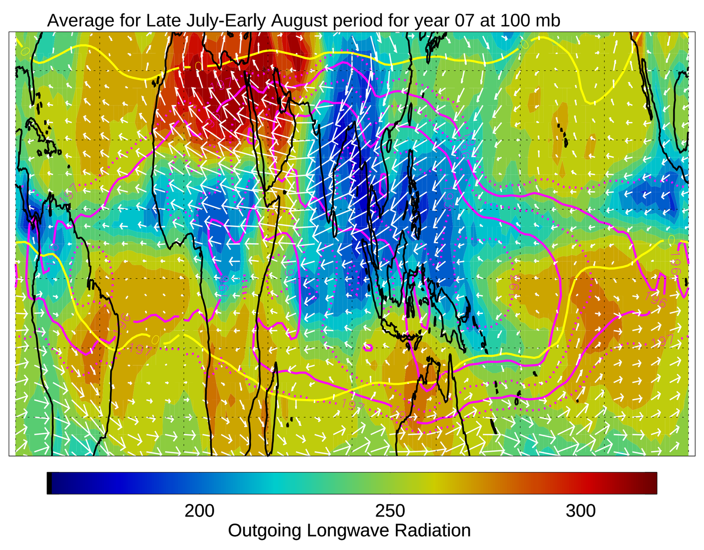


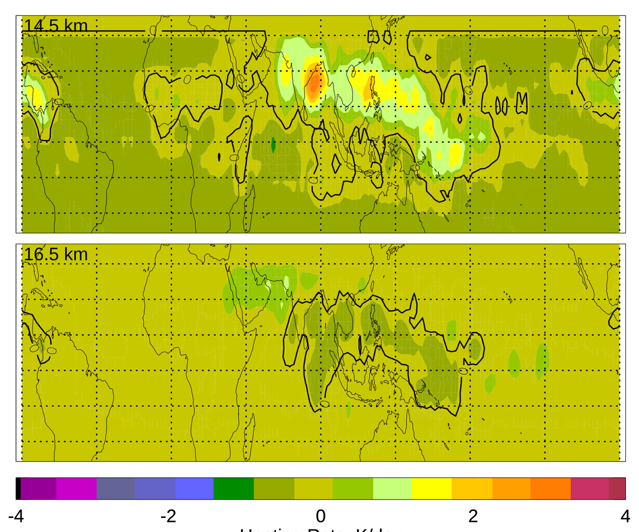


- Figure above (right) shows tropical (-10 to 10) average water vapor results for 2005-2006 boreal winter compared with MLS. Note that the best overall agreement is for standard heating rates (interactively calculated from T and water vapor), and inclusion of microphysics and convection. Calculations without these are too dry by over .5 ppmv.

3. Background for Boreal Summer

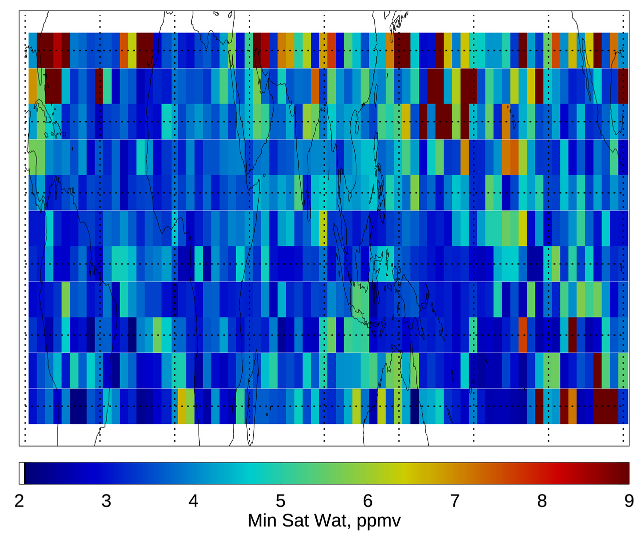
- Shown below left is the 100mb average plot for summer 07, the period we will look at with the model. A strong monsoon anticyclone is centered over Afghanistan (!), with convection to the southeast (low OLR). Much of the outflow from this passes through cold temperatures extending from the mid South Pacific to south-central India and Saudi Arabia. Other convection over the equatorial Americas and Africa occurs where TTL temperatures are warmer. Below right are the heating rates at 14.5 and 16.5 km used to drive the calculation (courtesy of Qiang Fu, UW); these are based on clear sky plus cloud forcing for 2006 CALIPSO and CLOUDSAT data. We used these fixed heating rates rather than interactively calculated heating rates. The results in the next section, however, ZERO OUT the negative heating rates.

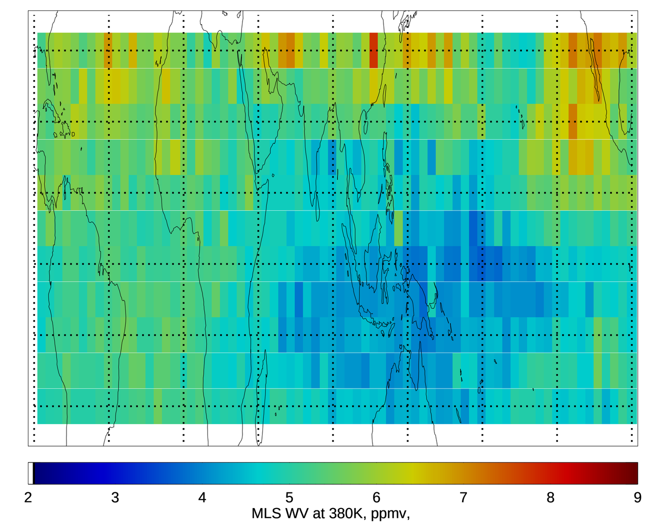




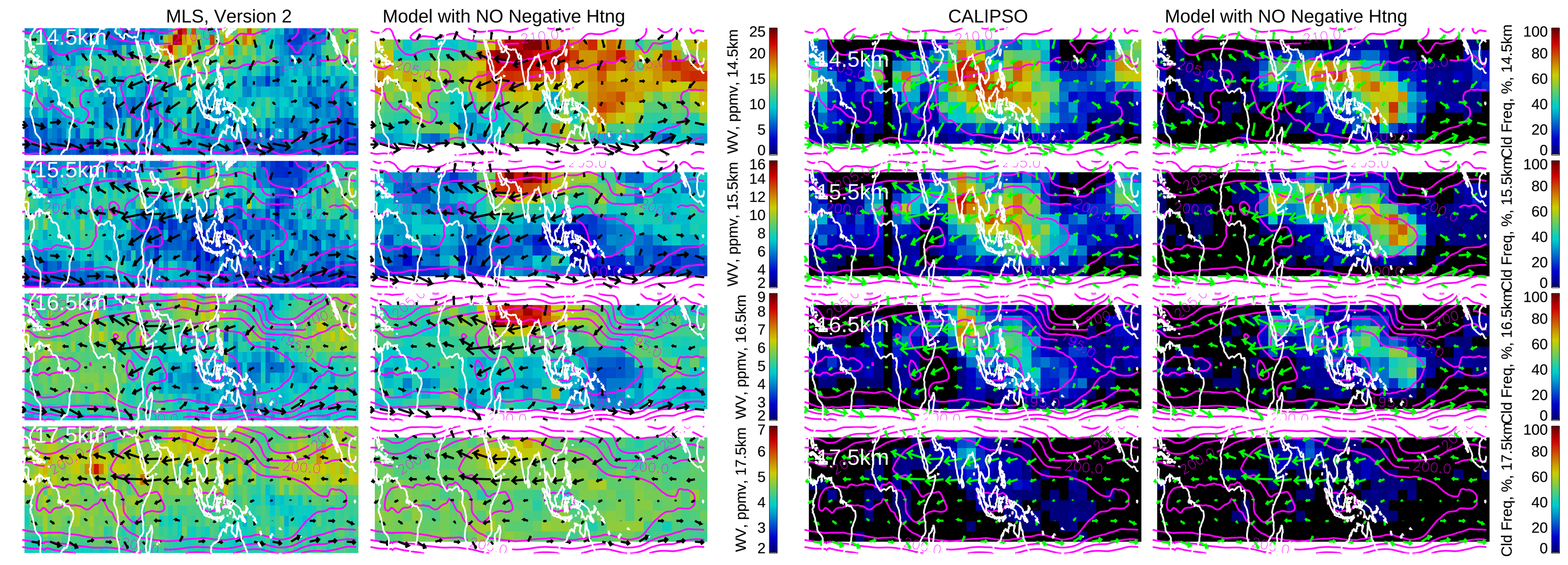
4. Results for Boreal Summer

- We compare the simple approach of taking the minimum SMR along the diabatic back trajectories initialized at 380K on August 6, 2007 (below left) to the MLS data at 380K (averaged for 5 days ending August 6 – below right). Consistent with what we got for the no microphysics-no convection boreal winter case (section 2), the results are too dry and the horizontal distribution is not captured.

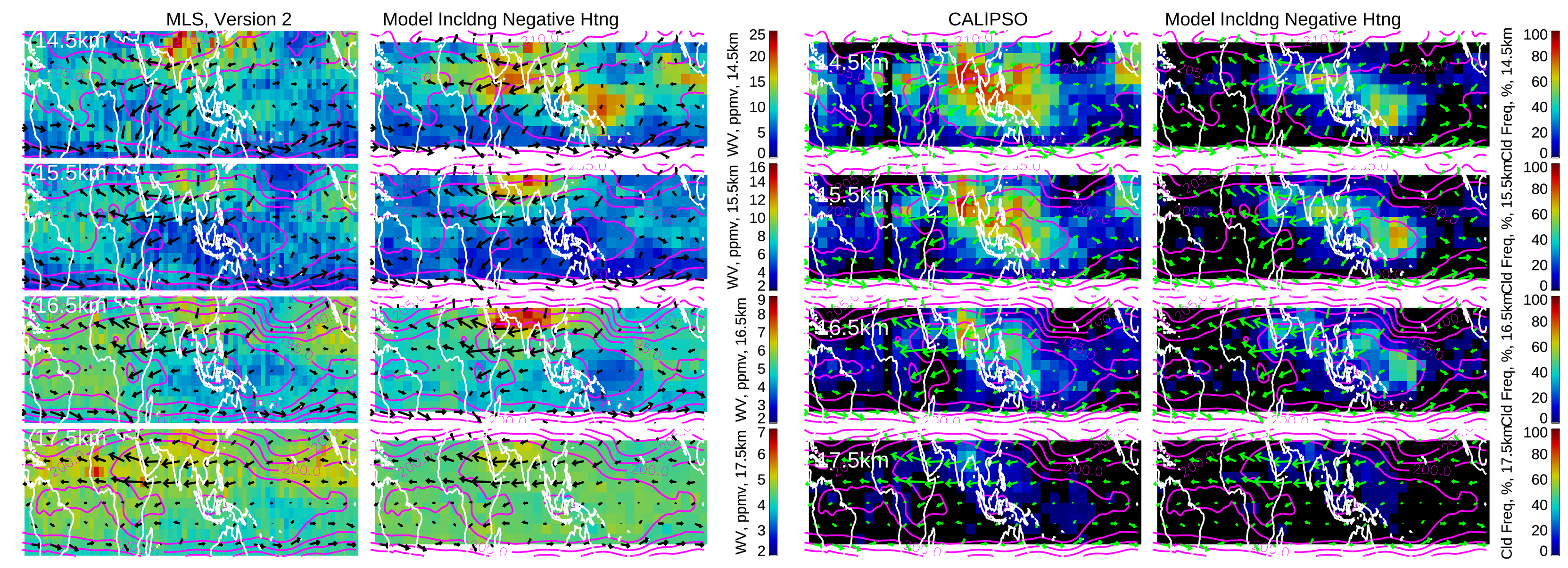




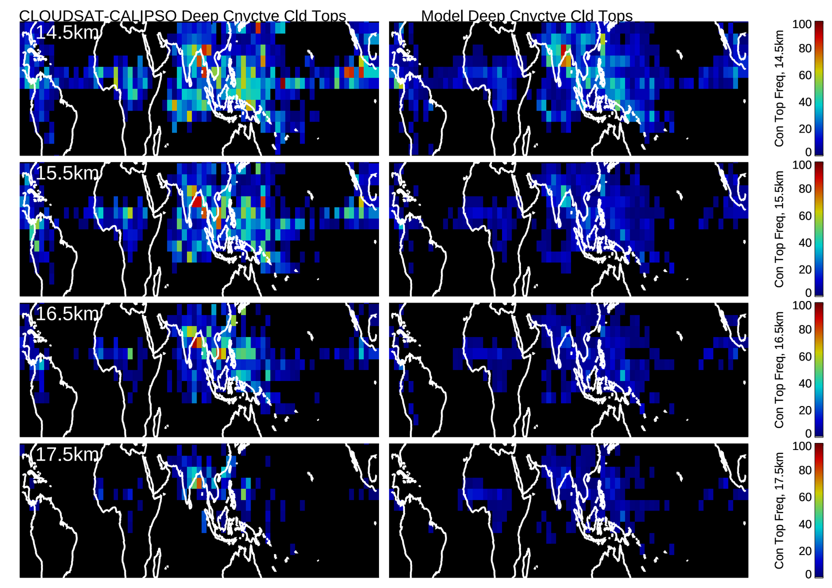
- The model is initialized with a melding of NCEP water (to 200mb) and MLS water above, evalauted in the week of June 27, 2007. We transition gradually to global horizontal MLS averages between 14.5 and 17.5 km.
- The figure below left shows MLS and model water at 4 levels for a calculation with convection, but with all negative heating rates set to 0. (The nonconvective calculation is not shown because there is little difference.) (1) The lowest level (14.5 km) is too wet in the model, and upward advection of the vertical water vapor gradient rather than convection is responsible. (2) The model captures the western Pacific and south Indian ocean dry regions at the two middle levels. (3) At the two middle levels, the simulation is good except for excessive model water in the center of the monsoon anticyclone. (4) The weak average heating rates and 40 day integration time are probably responsible for the largely featureless model calculation at the highest level. (5) The moist regions at the two top levels in the MLS data (convection?) over West Africa and the Northern Tropical Eastern Pacific are not modeled.



- Cloud frequencies (right, above) are well-captured by the model, except for insufficient cloud outside the monsoon region and at the top level. This could be due to the absence of waves in the simulation.
- The figure below left shows water for a simulation where negative heating rates are NOT set to zero. The water simulation is improved in every respect, especially at the lowest levels, though the Asian monsoon region is still too wet. Not surprisingly, the cloud simulation is not as good (less ascent means less upward advection of the water vapor gradient into cold regions).



- Our convective injection matches Dessler's results (section 2). Comparison with CLOUDSAT-CALIPSO deep convective cloud top distributions in 1 km layers (below) shows, however, that our model has a lower incidence, up to a factor of three too low averaged over the tropics.



4. Summary and Future Plans

- Boreal winter simulations agree well with MLS water. Convection/microphysics add .7 ppmv to TTL water.
- Boreal summer simulations show a strong dependence on the input heating rates (ascent/descent), but less dependence on including convection. The "no microphysics" calculation is far too dry.
- Water and cloud distributions are reasonable, but too wet in the Asian monsoon anticyclone and not cloudy enough.
- Future plan 1: Include waves (Jensen and Pfister, 2004) – this should increase clouds/remove water.
- Future plan 2: Modfiy convective scheme to match CLOUDSAT-CALIPSO distributions and magnitudes.