Using Aura MLS and CALIPSO Measurements to Constrain Simulations of Transport, Convective Injection, Cloud Formation, and Water Vapor in the Tropical Tropopause Layer

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Introduction

Our objective is to understand processes controlling tropical tropopause layer cloud formation and dehydration of air entering the stratosphere. By comparing simulated TTL water vapor and cloud fields with AURA MLS and CALIPSO measurements, we attempt to address the following science questions:

- How much does convective injection beyond the cold-point contribute to water vapor input to the stratosphere? Can convective injection during Boreal winter shortcut freeze-drying at the cold-point?
- How does relatively rapid ascent through the TTL indicated by the CO_2 clock affect simulated water vapor and cloud fields?
- Do simulations permitting high supersaturations (indicated by aircraft measurements) reproduce cloud distributions indicated by CALIPSO?

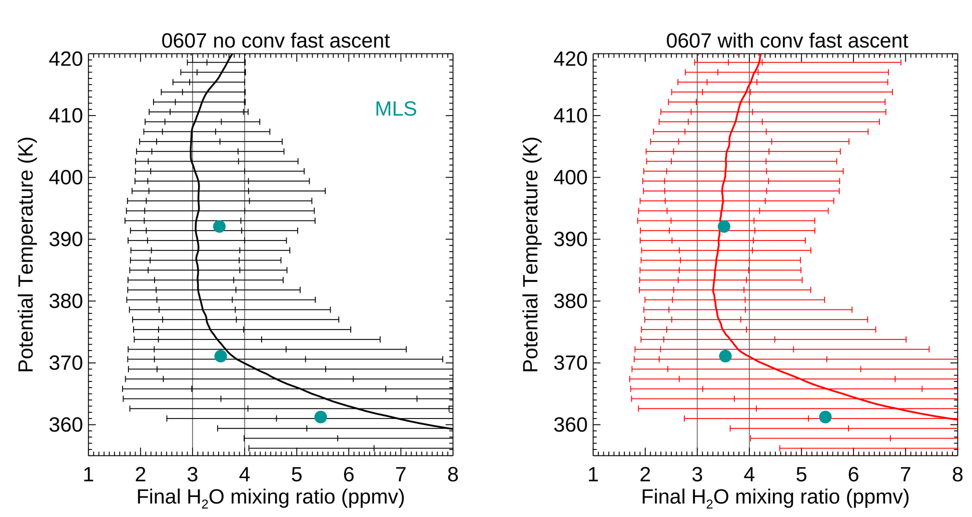
Model Description

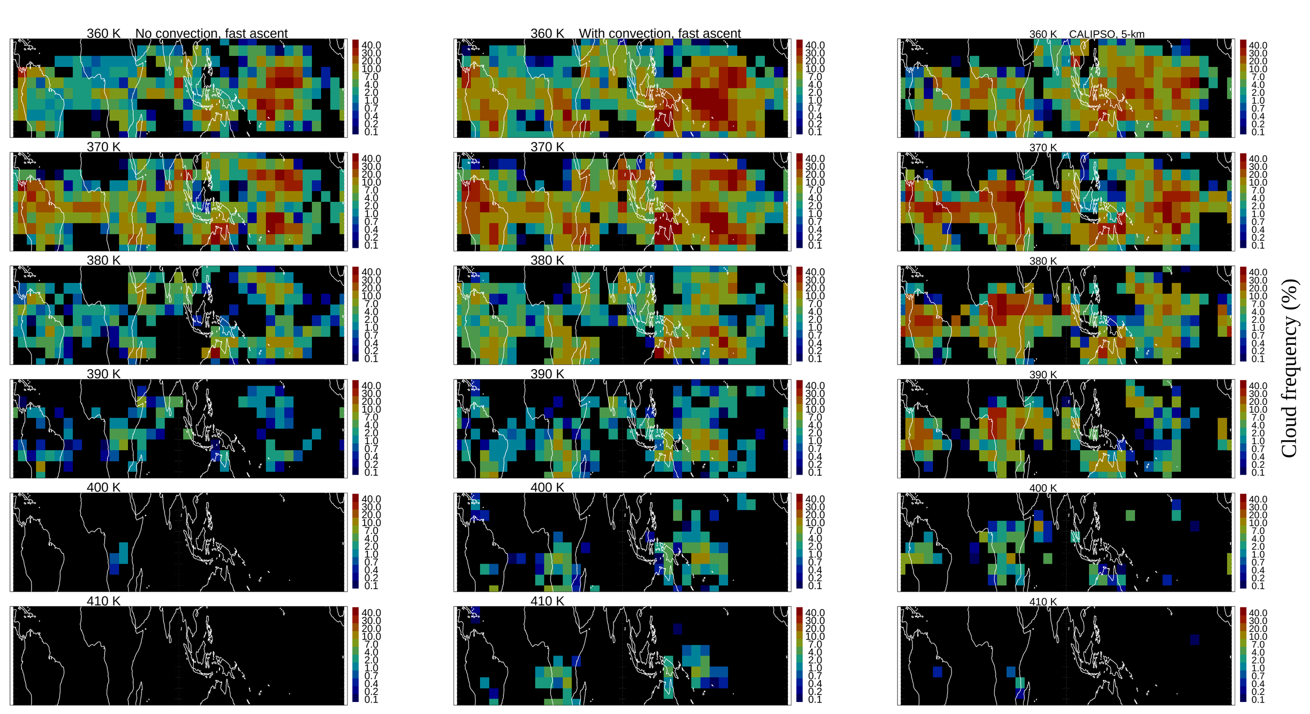
- 40 day diabatic back trajectories from a 5 by 5 grid of points using GEOS-4 analyses and GSFC trajectory model (Schoeberl and Sparling, 1995).
- Time-height curtains of T along trajectories. Temperatures adjusted for agreement with radiosondes.
- Include a synthetic spectrum of gravity, Rossby-Gravity, and Kelvin waves.
- Convective cloud top thetas from tracing curtains through 3-hourly satellite imagery, with satellite brightness temperatures adjusted to raise tops about 1 km.
- Set water vapor to the local ice smr up to the cloud top theta.
- Use 1-D (height) full microphysical model with vertical ascent derived either from clear-sky radiative heating ($\simeq$0.2 K/day) or CO_2 clock analysis ($\simeq$1 K/day) (Park et al., 2007).
- Use either “conventional” microphysics (1.6 saturation ratio for nucleation; standard ice smr values) or modified microphysics permitting large supersaturations.

Data Products

- AURA MLS v2.2 water vapor concentrations averaged over $\pm$10 deg latitude for 1–19 January, 2007. Pressure levels: 121, 100, and 83 hPa.
- CALIPSO Lidar Level 2 5-km Cloud Product. Cloud frequencies are calculated on a 5 x 5 degree lat/lon grid at 360, 370, 380, 390, 400, and 410 K potential temperature levels.
- For calculation of cloud frequencies from simulated cloud fields, the CALIPSO extinction threshold is assumed to be 0.02 km^{-1} (equivalent to an optical depth of 0.01 for a 500-m thick cloud.

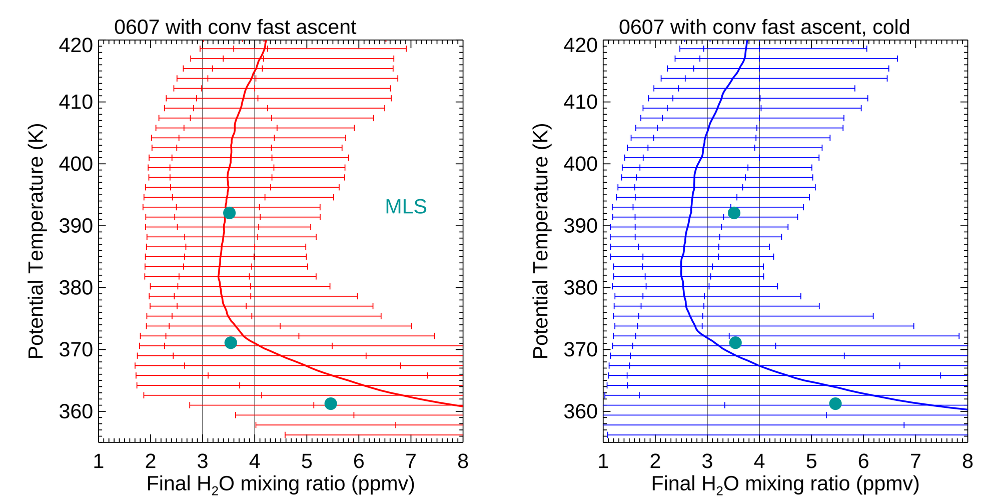
Results: 1. Influence of Convection





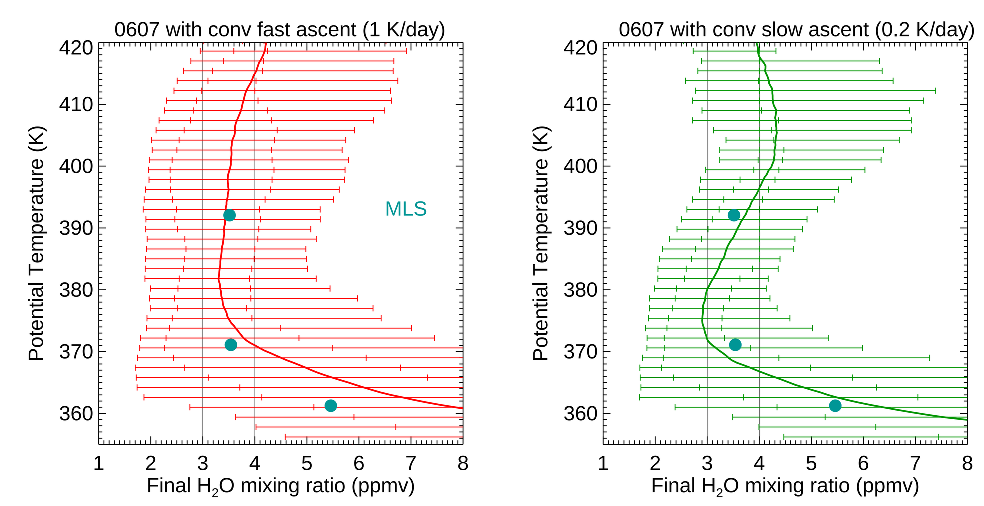
- Convective injection injection increases mean H_2O concentration at upper levels by as much as about 0.7 ppmv, as well as increasing H_2O variability at upper levels.
- Convection slightly improves agreement with MLS H_2O at 83 hPa.
- Convection greatly increases H_2O variability at upper levels.
- Without convection, there are essentially no clouds at or above 400 K.
- The simulated cloud frequencies with convection have too few clouds over central Africa and too many clouds at 410 K.

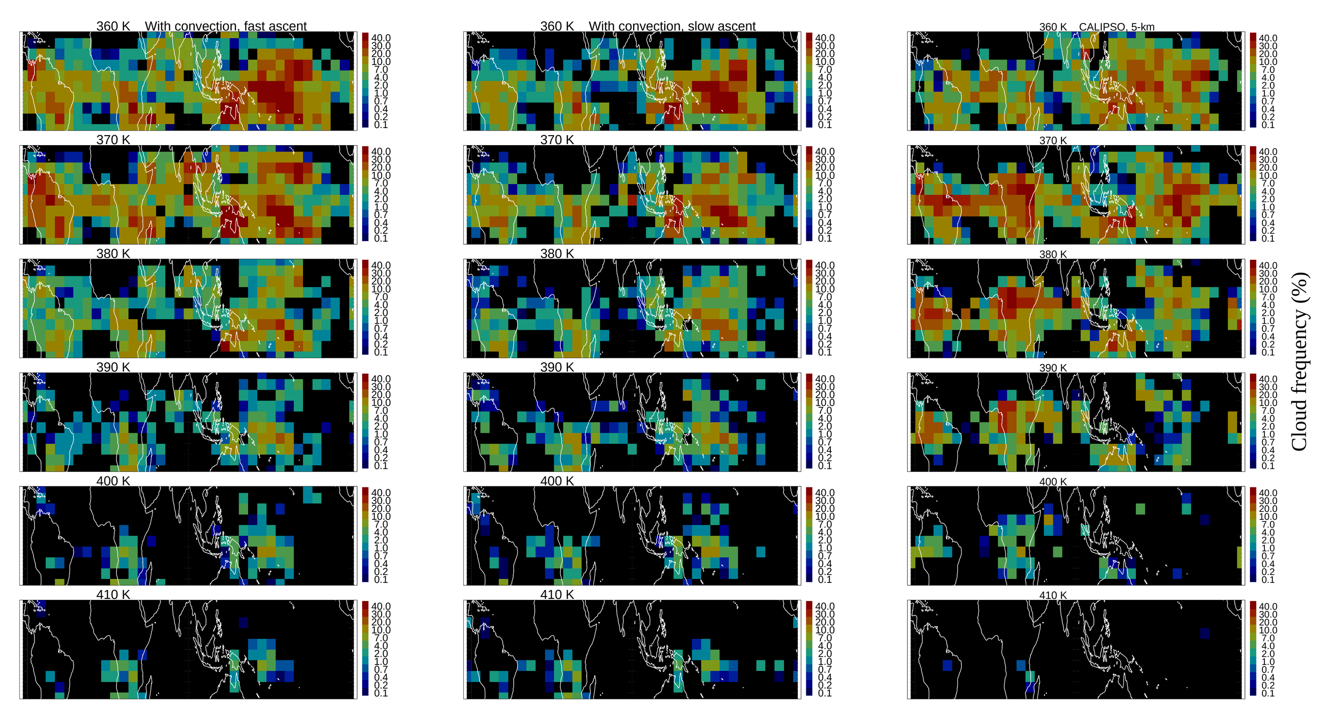
Results: 1.5 Can Convection Short-Circuit the Cold Trap Control of Stratospheric Water Vapor?



- In a simulation with TTL temperatures below 195 K decreased by as much as 5 K (temperature dependent), the upper TTL is considerably drier.
- However, convection does affect H_2O up to top of TTL, and enhanced convection beyond the cold point would increase stratospheric entry H_2O.

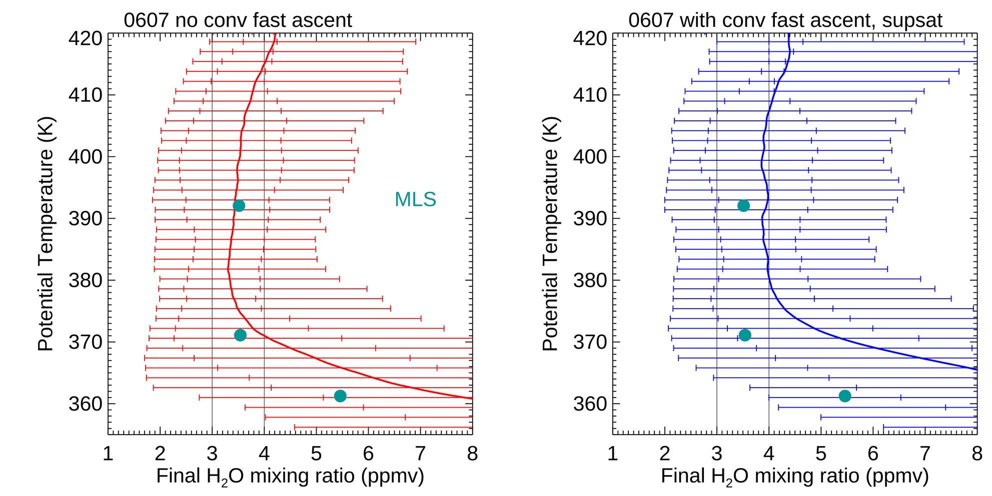
Results: 2. Influence of TTL Ascent Rate

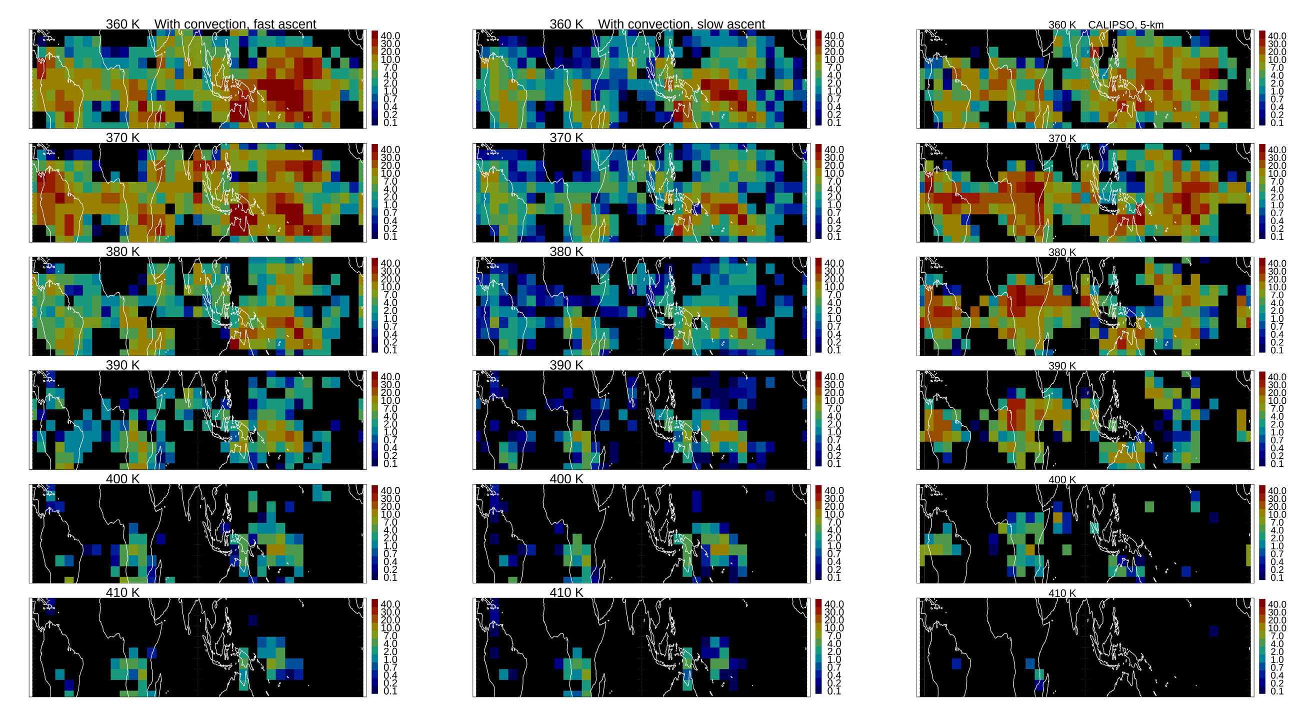




- Decreasing the TTL ascent rate to values indicated by clear-sky radiative transfer calculations results in considerably drier air near the cold point (around 375 K) because there is less transport of moist air from below and air spends more time in the coldest altitude range.
- In the slow ascent rate simulation, parcels passing through the cold point do not make it past about 390 K in the 40-day simulation. Thus H_2O values above this level should be ignored.
- Changing the ascent rate has surprisingly little effect on TTL cloud frequencies.

Results: 3. Influence of High Supersaturation





- Permitting supersaturation (RHI up to 200% before cloud formation) increases water vapor substantially and gives H_2O values in excess of MLS but in better agreement with aircraft measurements.
- Allowing supersaturation decreases cloud frequency, degrading agreement with CALIPSO below 400 K.

Summary

- Simulations of TTL transport, water vapor, and cloud formation do a reasonable job of reproducing MLS water vapor concentrations and the magnitude of CALIPSO cloud frequencies.
- There are differences in the regional distributions and height distributions of clouds between the simulations and the observations.
- Injection of water by very deep convection, followed by subsequent cooling downstream, is responsible for all of the all of the cloud formation at or above 400 K. transfer calculations results in considerably drier air near the cold point (around 375 K) because there is less transport of moist air from below and air spends more time in the coldest altitude range.
- Decreasing the TTL temperature will dry air entering the stratosphere despite convective injection above the cold point.
- Decreasing the TTL ascent rate from fast values indicated by the CO_2 clock to slow values indicated by clear-sky radiative heating dries out air near the cold point.
- Permitting high supersaturations to build up increases TTL humidity (as expected) and also decreases cloud frequencies.