Clouds and Water Vapor in the Boreal Winter Tropical Tropopause Layer: Results from a trajectory based microphysical model and comparison with satellite observations

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- Motivation and some background
- Description of model approach
- Results
- Conclusions

Motivation

- TTL regulates input of water into the stratosphere, and thus the ozone budget
- Water in the TTL affects cloud distribution and global radiation budget
- Complex region because convective transport, radiatively driven vertical transport, horizontal temperature inhomogeneity on all scales (Kelvin waves to gravity waves) are all important.
- How are water vapor and cloud distributions in the TTL maintained?
- Specifically, what is the role of episodic convection on clouds and water in the TTL during Boreal Winter?
- Simulation of TTL water and clouds for Boreal Winter 2005-06.

Previous Work – Boreal Winter TTL water and clouds

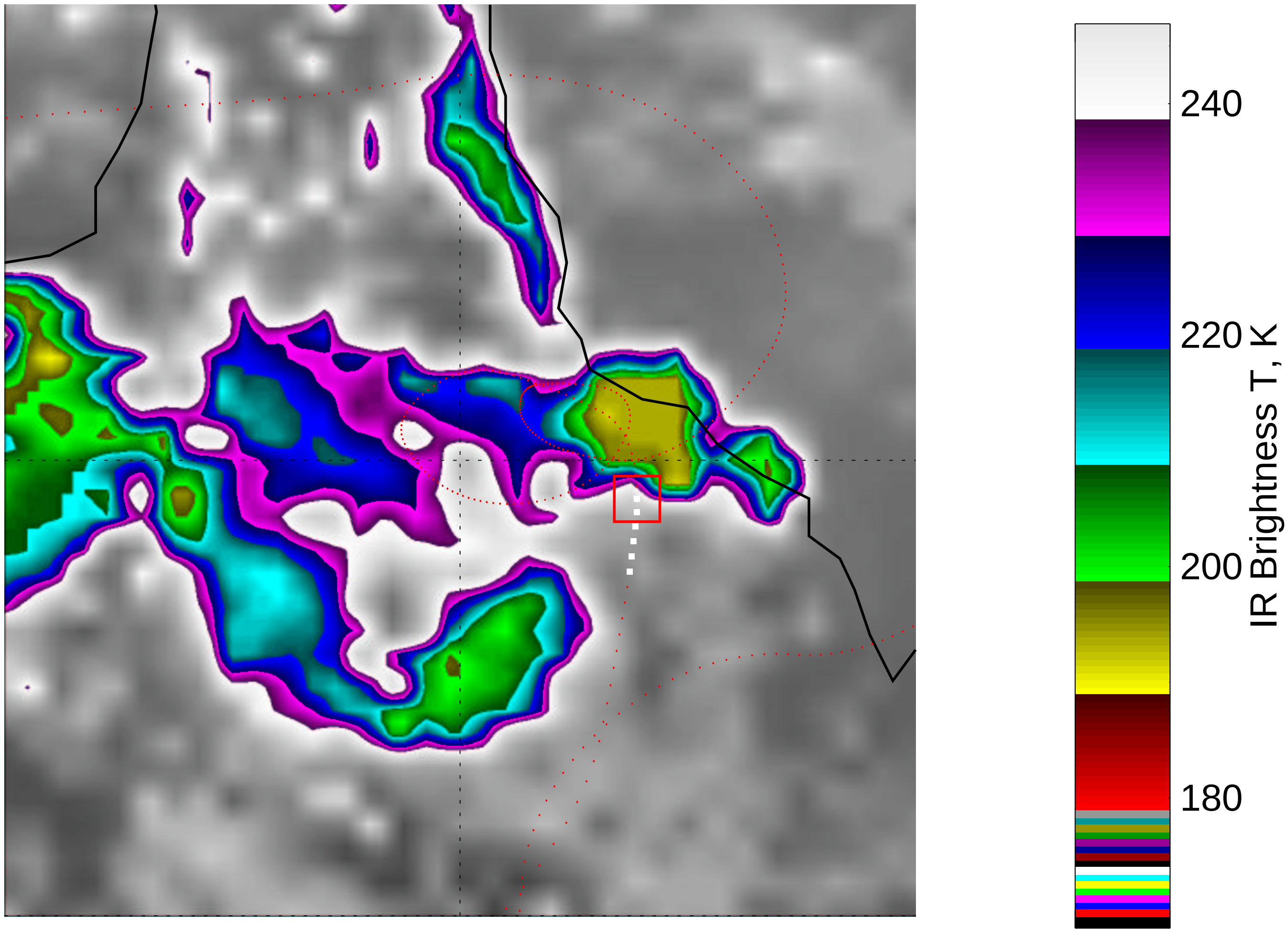
- Zonal asymmetry in TTL temperatures – cold regions over West Pacific (Newell)
- Large areas of subvisible cirrus clouds near tropical tropopause (e.g. Wang) in those cold regions
- Maintenance of observed water by horizontal flushing through cold regions and consequent dehydration (Holton and Gettelman, Gettelman et al, Fueglistaler and Haynes, Jensen and Pfister). No explicit inclusion of convection.
- Convection clearly gets into the TTL (Danielsen, Gettelman, Dessler)
- Measurements of isotopic water ratios imply convection (Kwang)
- Zonally asymmetric cold pools maintained by overall convection, either directly (Salby, Sherwood and Dessler) or indirectly (Randel)
- SVC observations downstream of convection (Massie, Pfister)

Model description and procedure

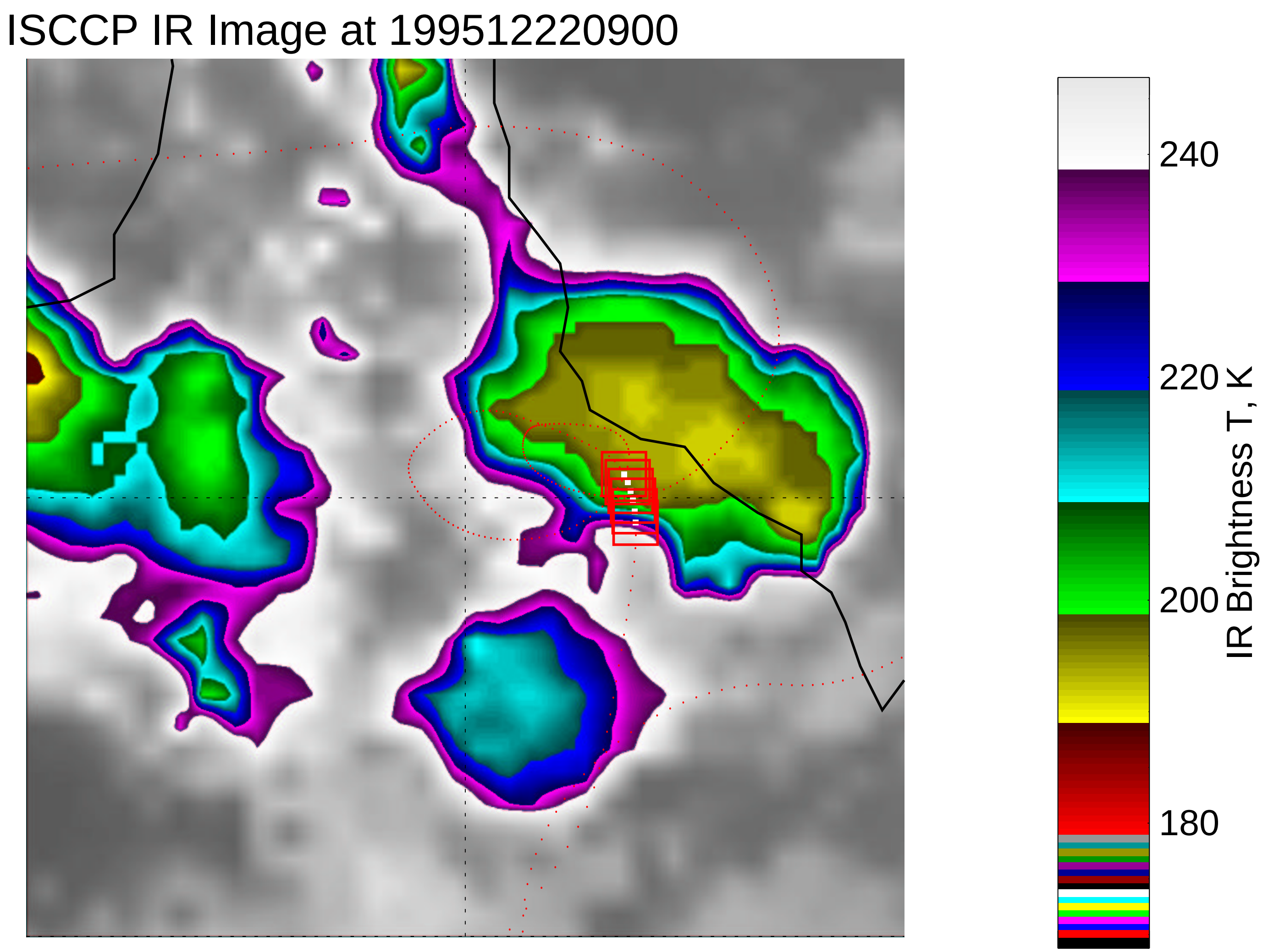
- Goal: Understand the role of episodic convection injection in regulating clouds and water in the TTL.
- Target: simulate water vapor in the TTL on a particular day in Boreal Winter 05-06 using a trajectory-based microphysical model and compare with satellite observations.
- Calculate large (648) set of back trajectories (diabatic and adiabatic) from a grid of points for 40 days using GSFC Assimilation analyses.
- Generate time-height "curtains" of temperatures along these trajectories. Temperatures modified based on a radiosonde correction that varies in latitude, longitude, and altitude.
- Introduce convection by running the trajectories through time and spatially varying global IR satellite imagery.
- Calculate cloud top altitude based on brightness temps in neighborhood of curtains (reduce temperatures by 5K to account for overestimate of Cloud temp by IR imagery – Sherwood et al)
- Perform time integration of 1-D (altitude) full microphysical model with "standard microphysics" and interactive (non-cloud) radiatively driven vertical velocity using input temperature curtains and an initial water vapor profile (Jensen and Pfister).

Treatment of Convection in Model

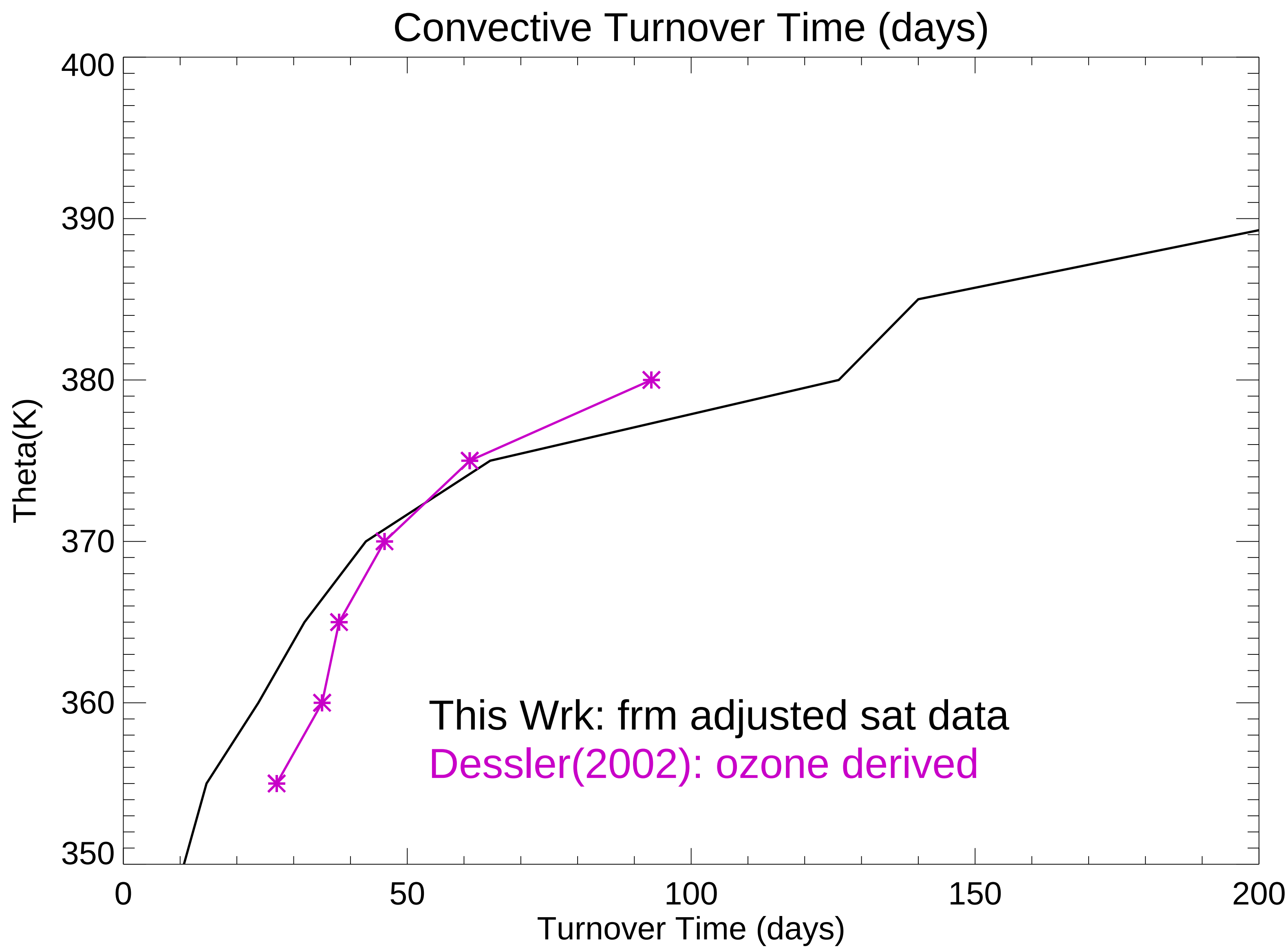
ISCCP IR Image at 199512220600



Treatment of Convection in Model



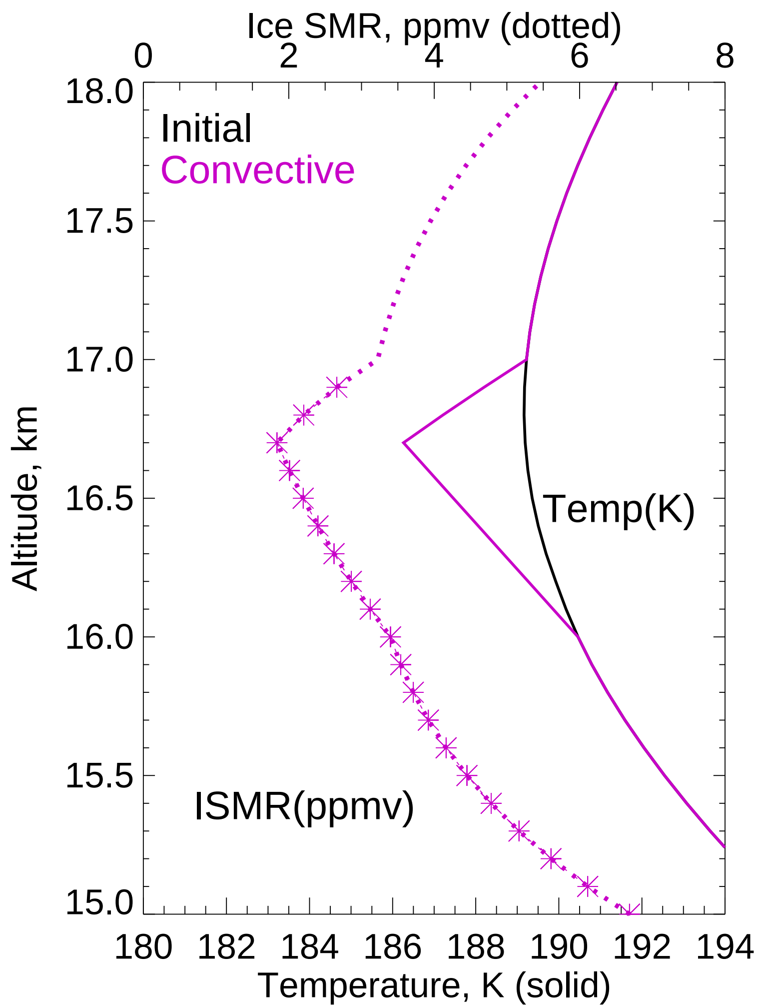
Convective Turnover Time



What does convection do to the variables (water, temperature)

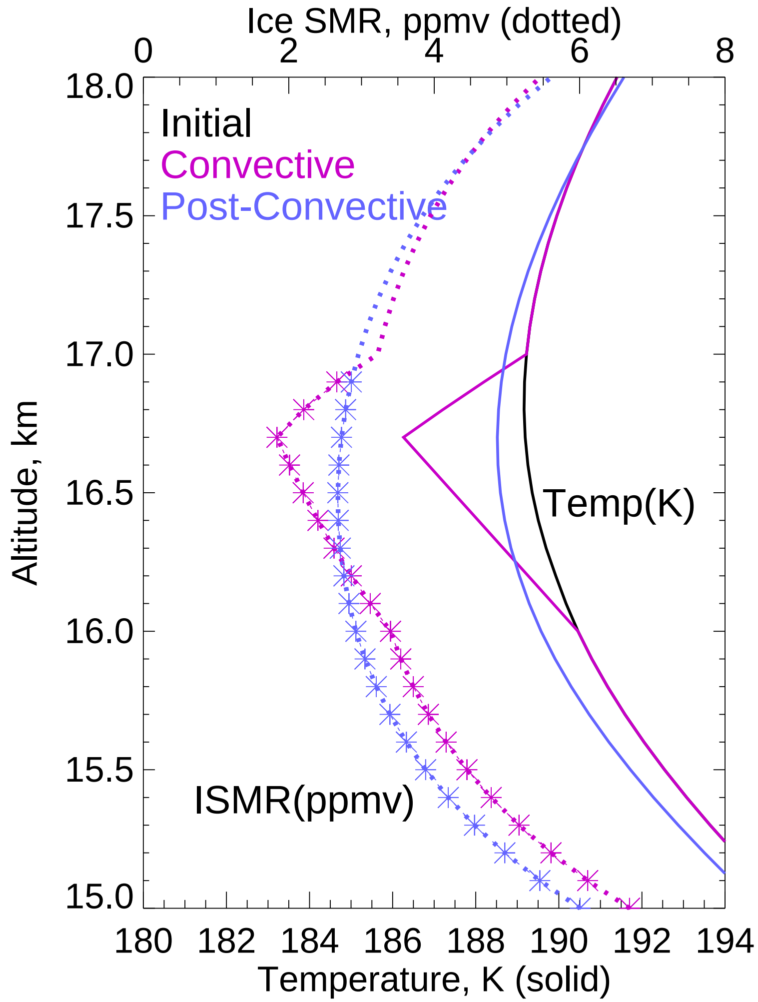
- If cloud top is below tropopause, saturate up to cloud top, leave temperature unchanged.
- If cloud top is above tropopause, convection overshoots and mixes, reducing temperature and leaving a saturated layer to cloud top.
  - Case a: Instant ice fallout – saturate to new cooler temperature profile.
  - Case b: 4 hour ice persistence – saturate to temperature profile 4 hours after convection.

Treatment of Convection in Model



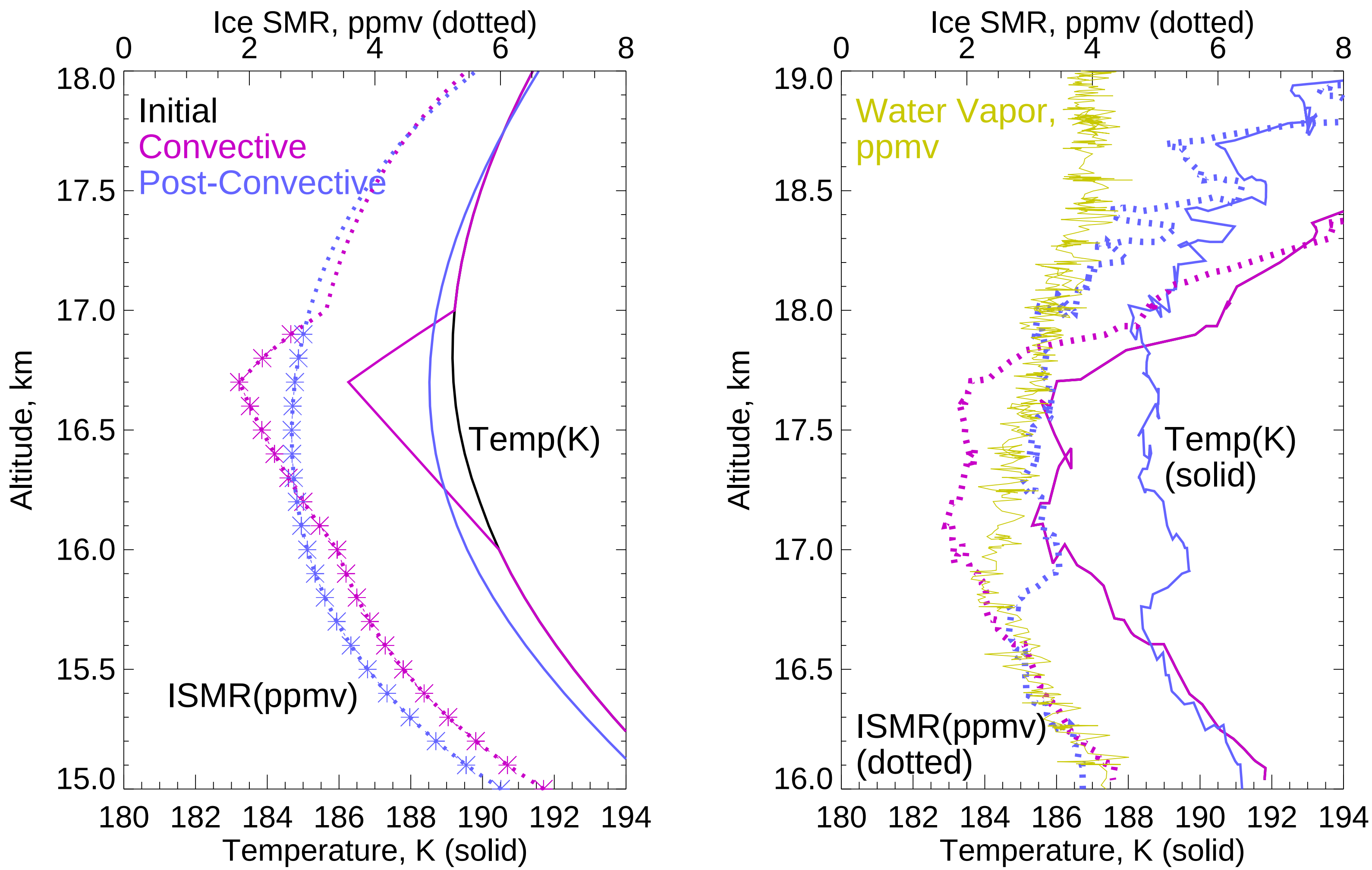
Model Profiles

Treatment of Convection in Model



Model Profiles

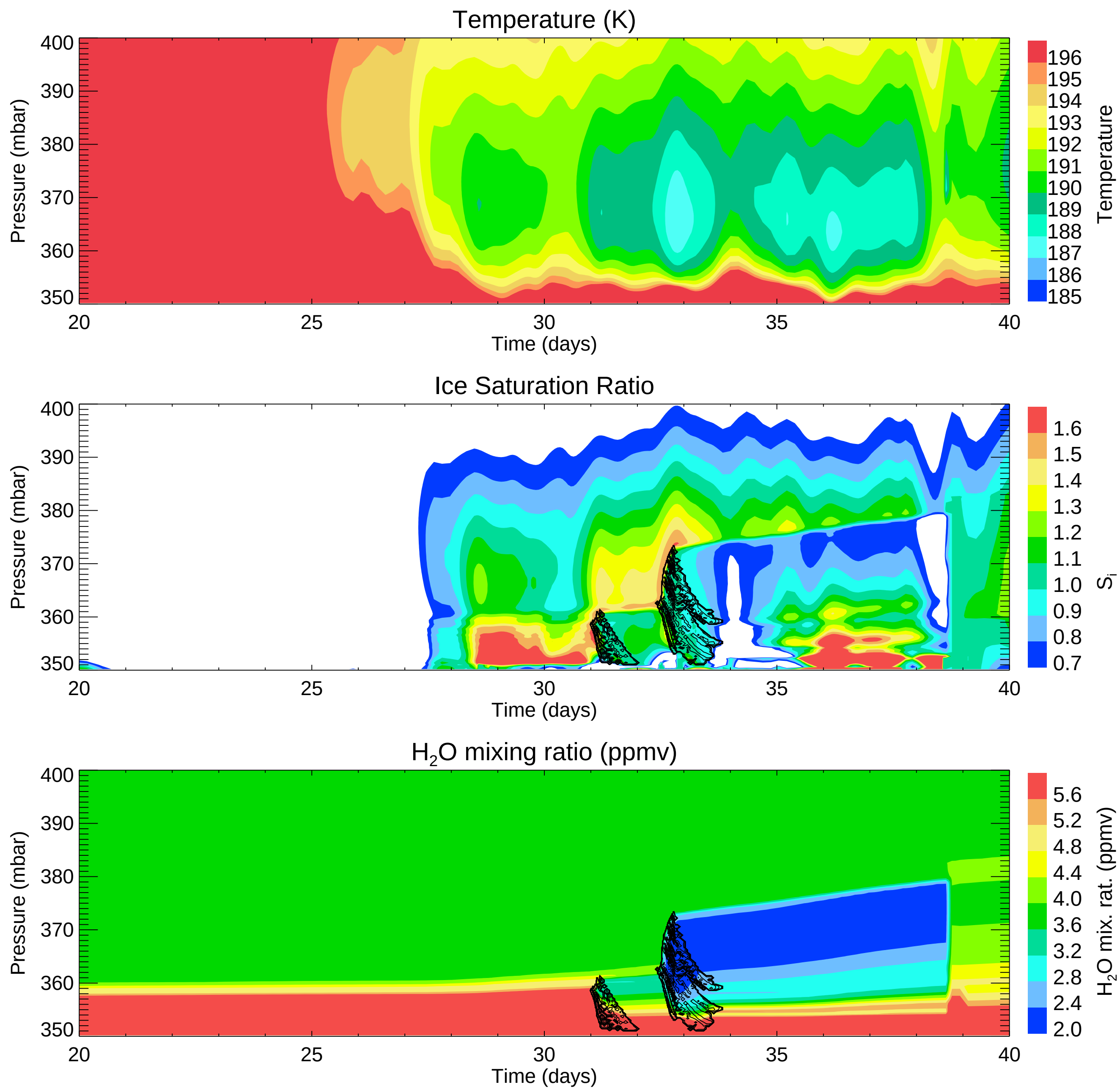
Treatment of Convection in Model



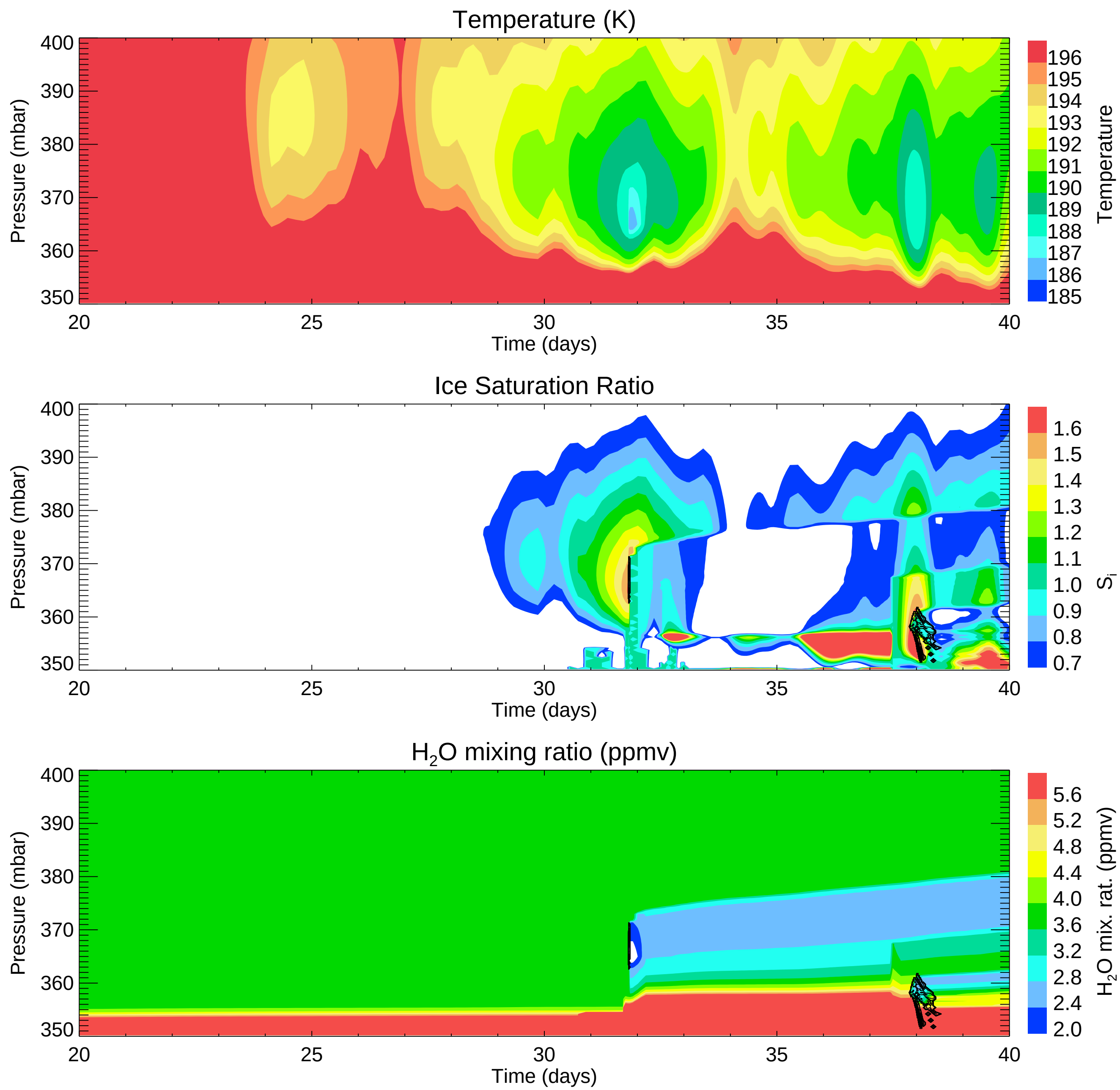
Model Profiles

STEP 1987, 870123

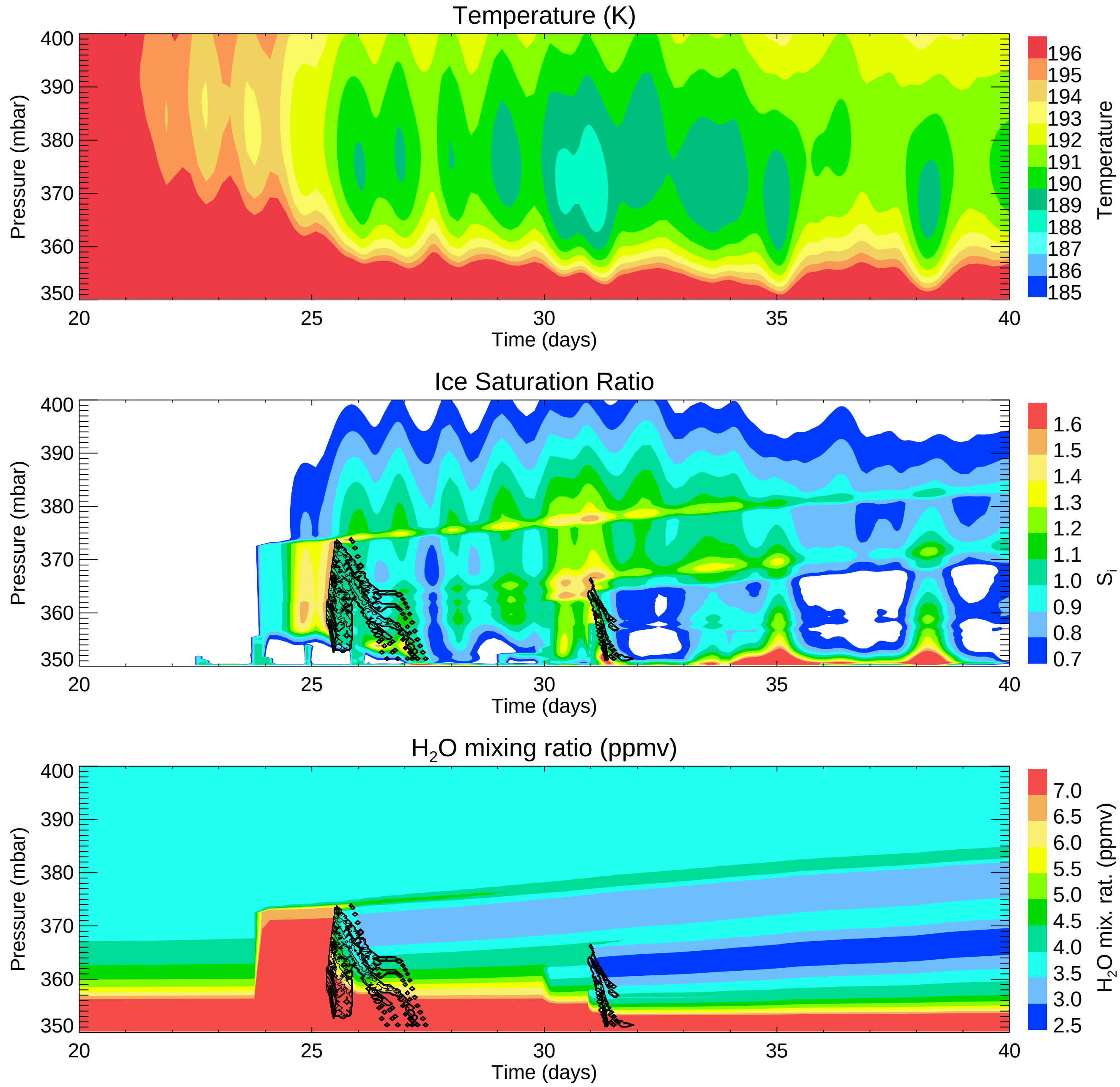
Sample hydration case



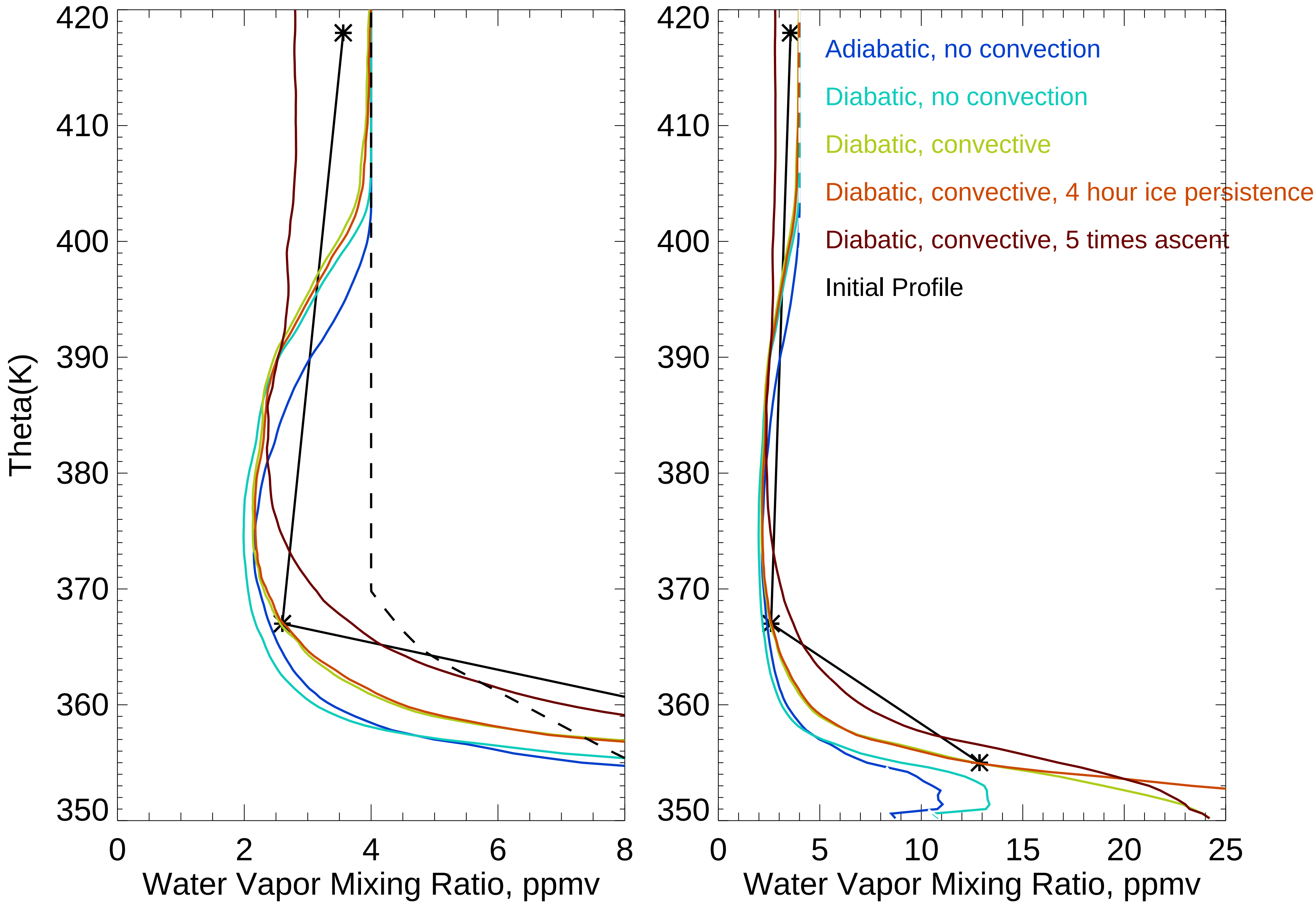
Sample dehydration case



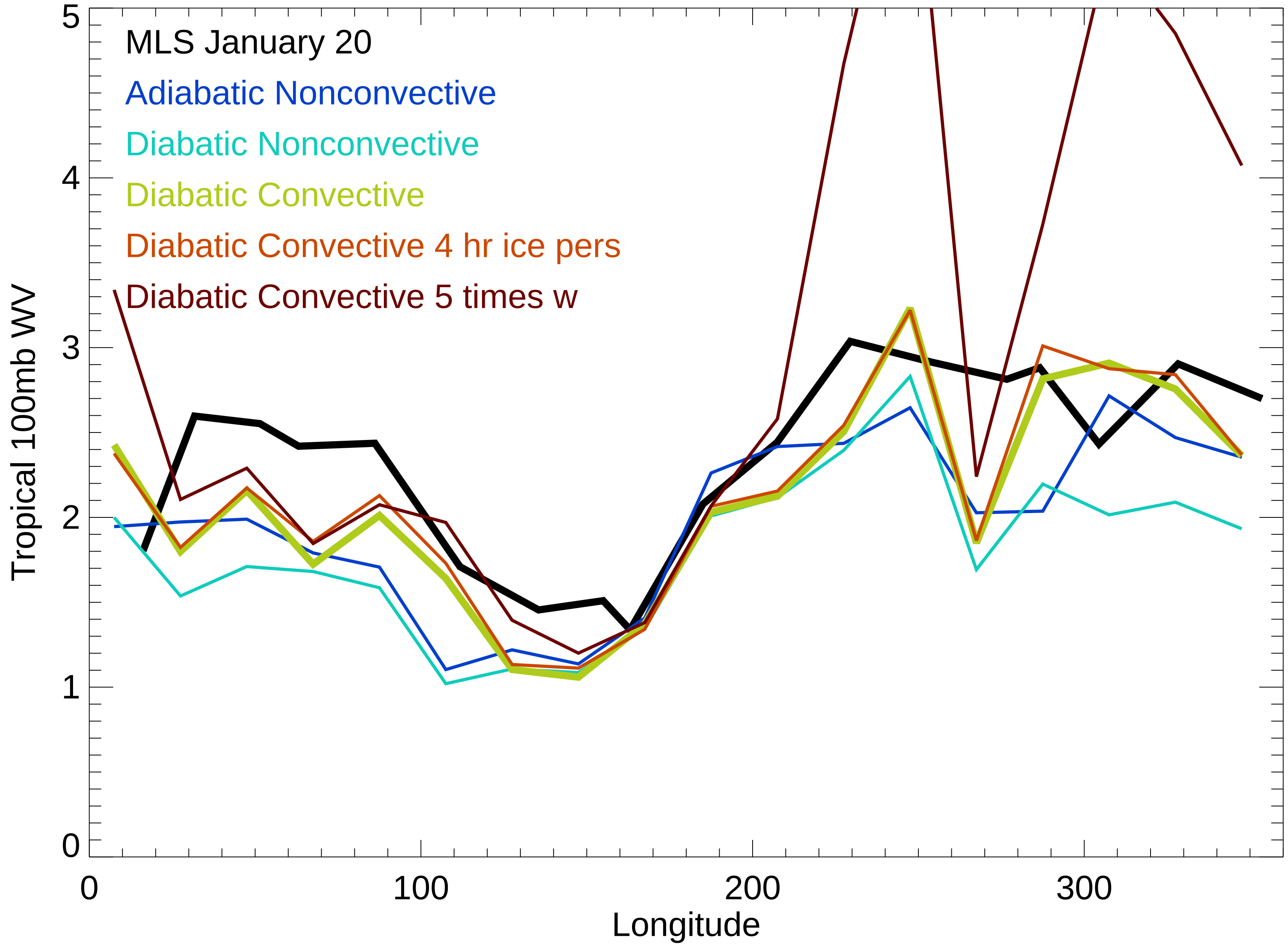
Sample hydration with subsequent nonconvective dehydration



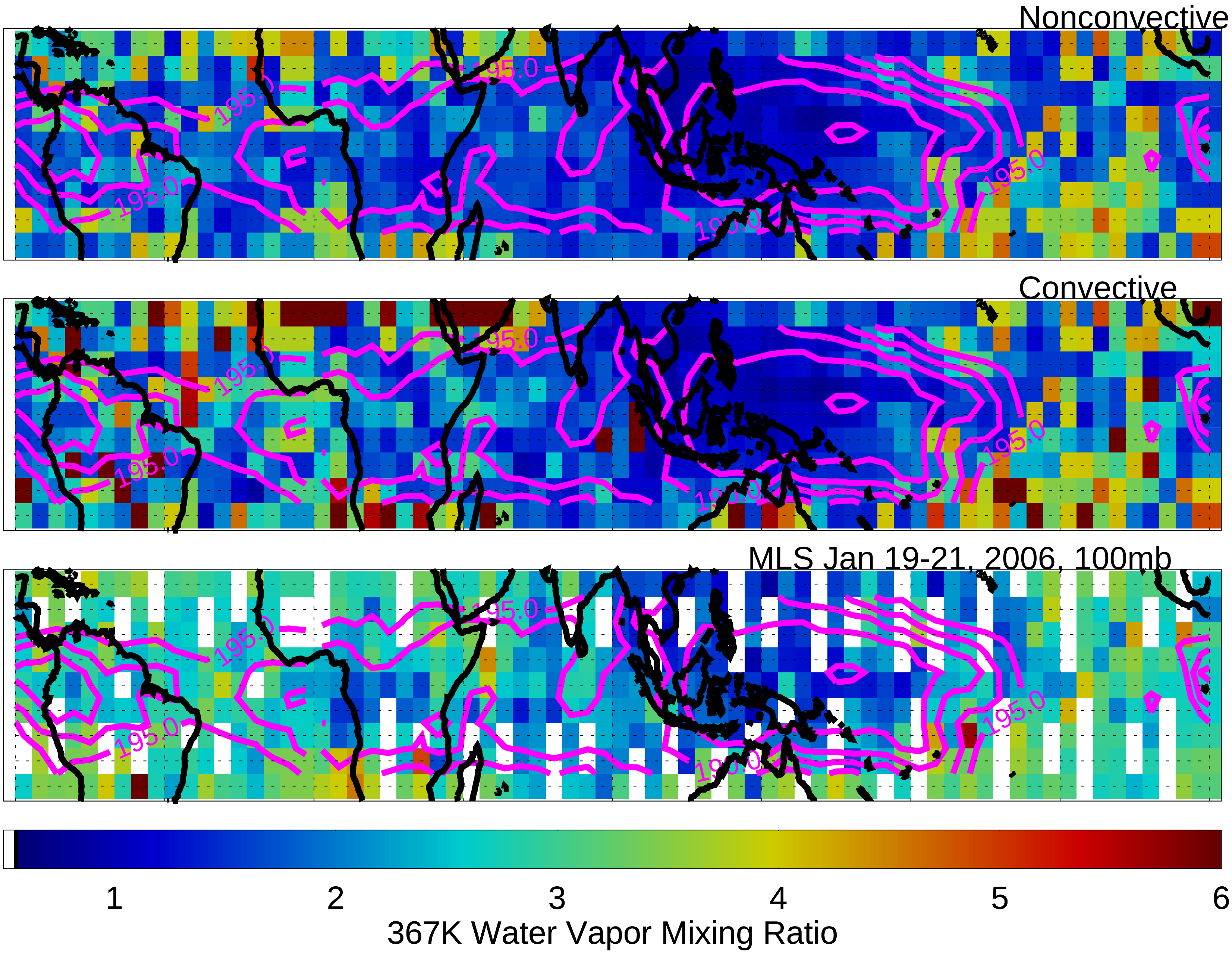
Overall effect on water vapor distribution (-20 to 20 degrees)



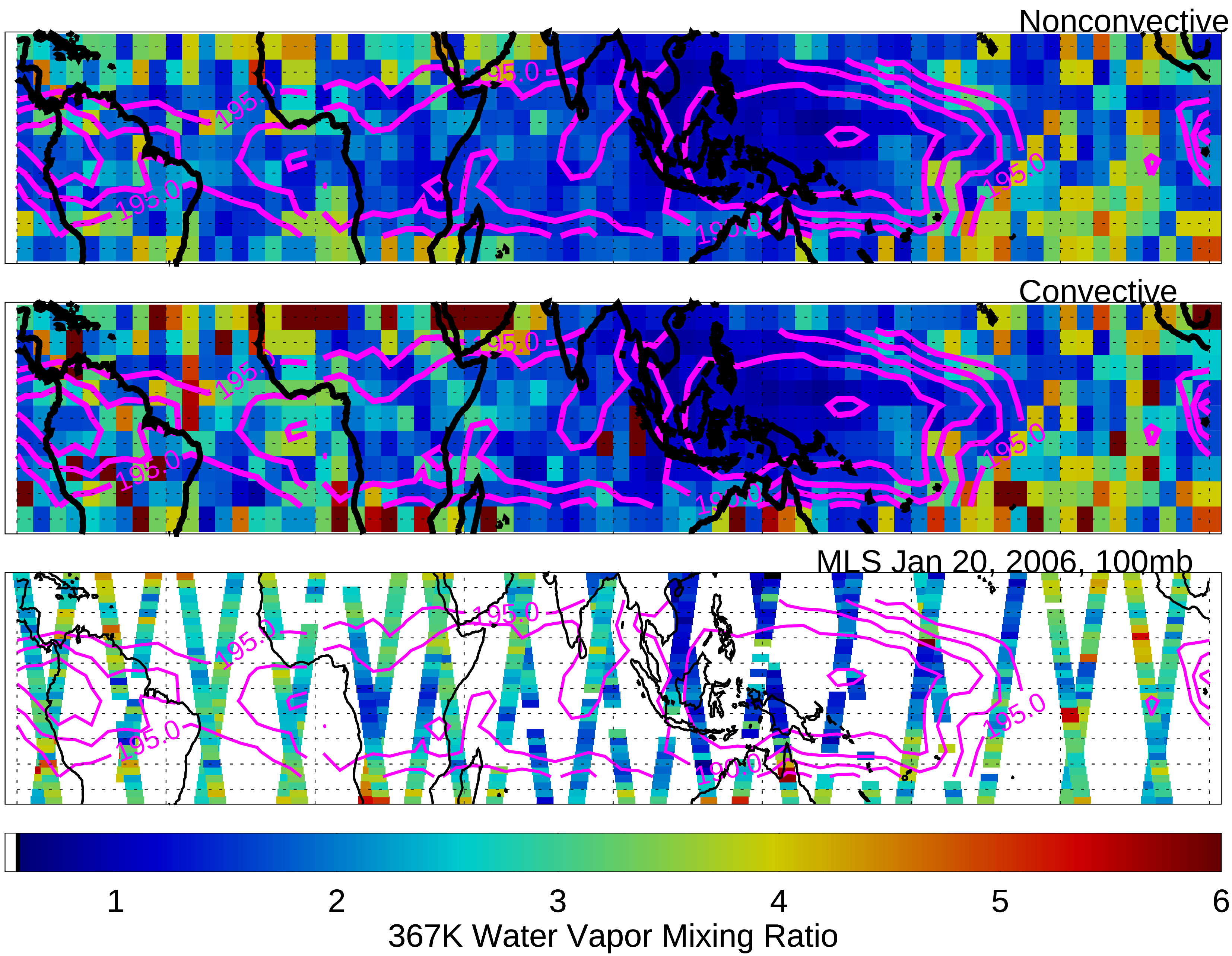
Longitudinal Distribution in the -10 to 10 degree region



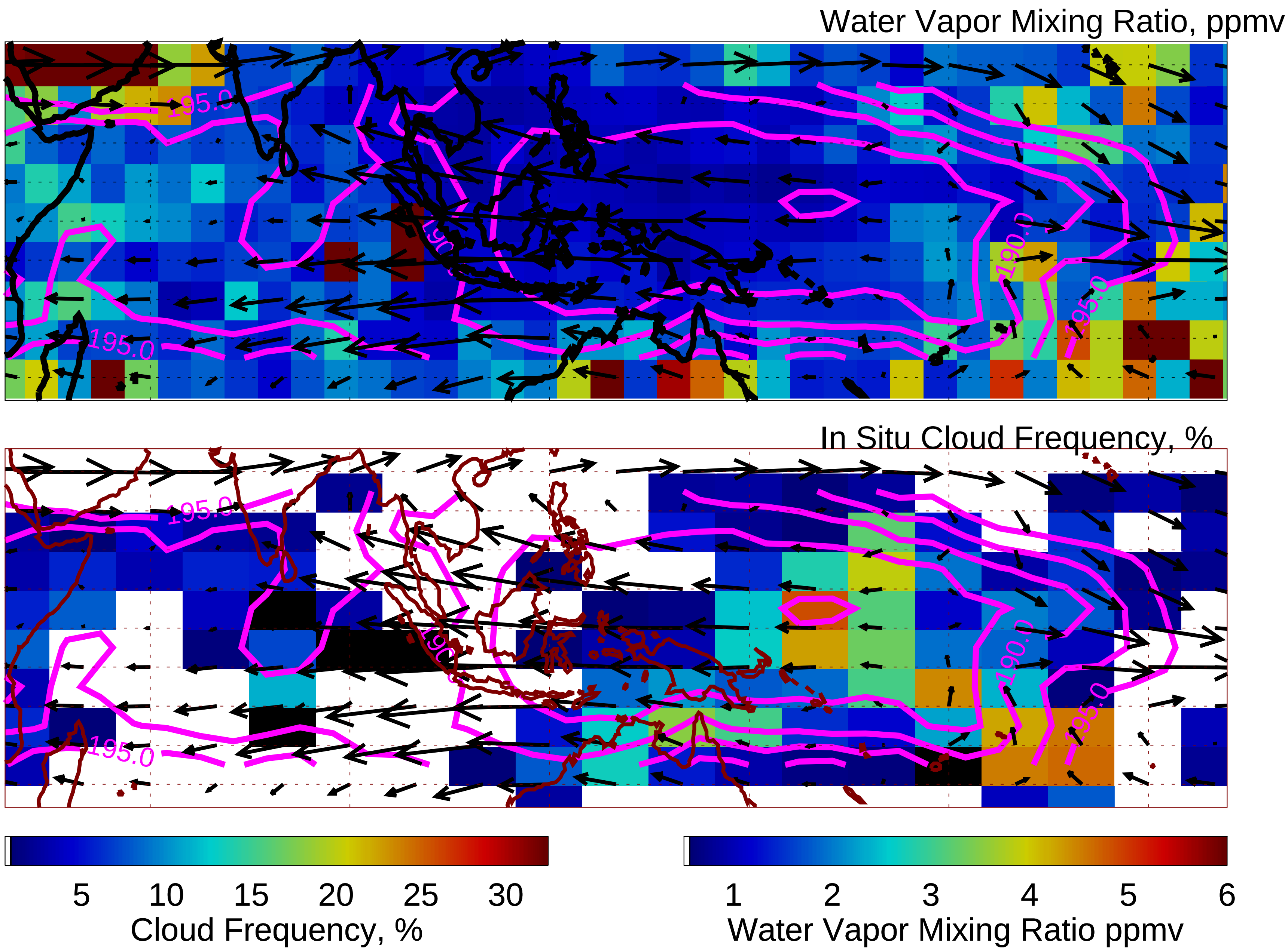
Water Distribution at 367K compared with 3 MLS days



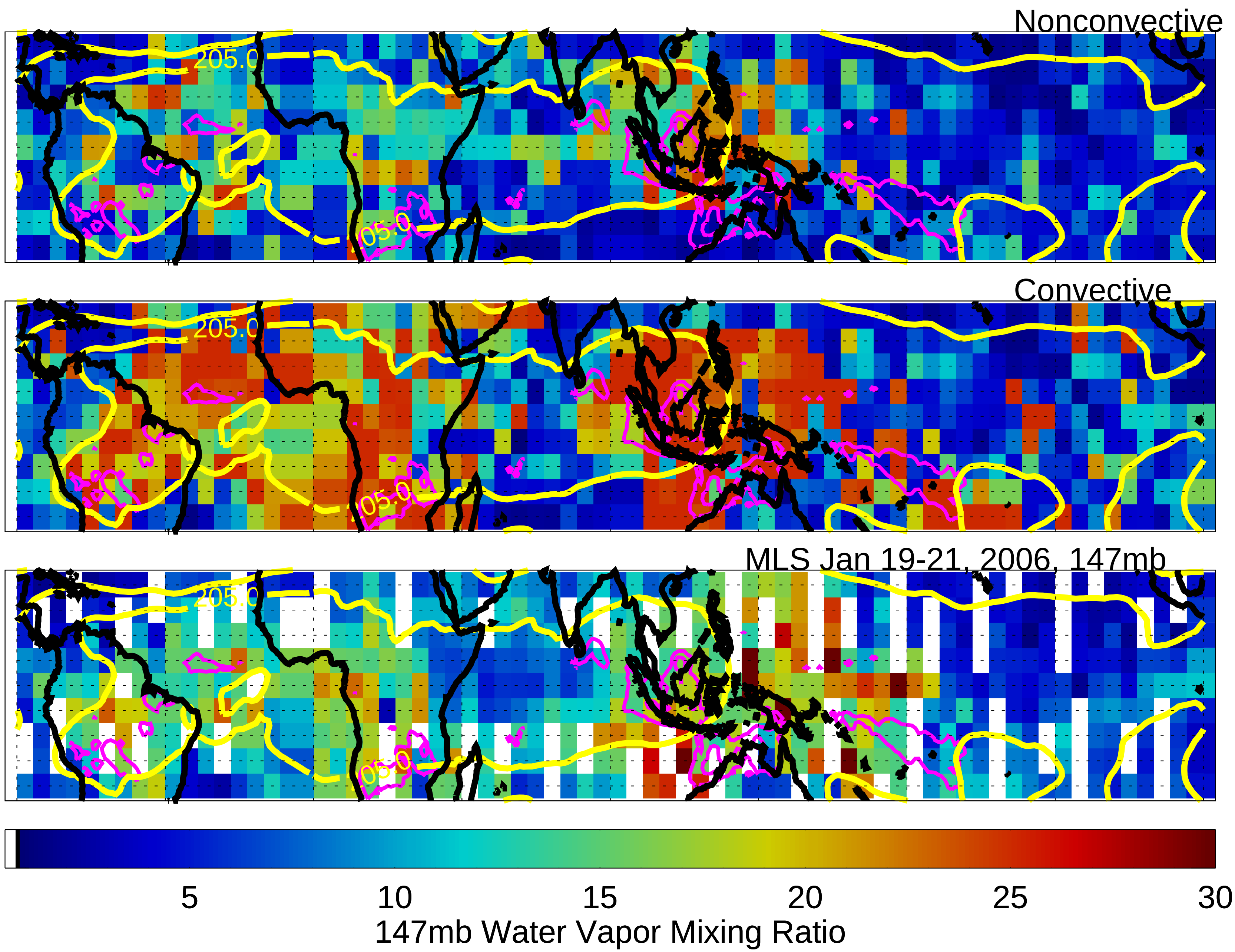
Water Distribution at 367K compared with Jan 20 MLS



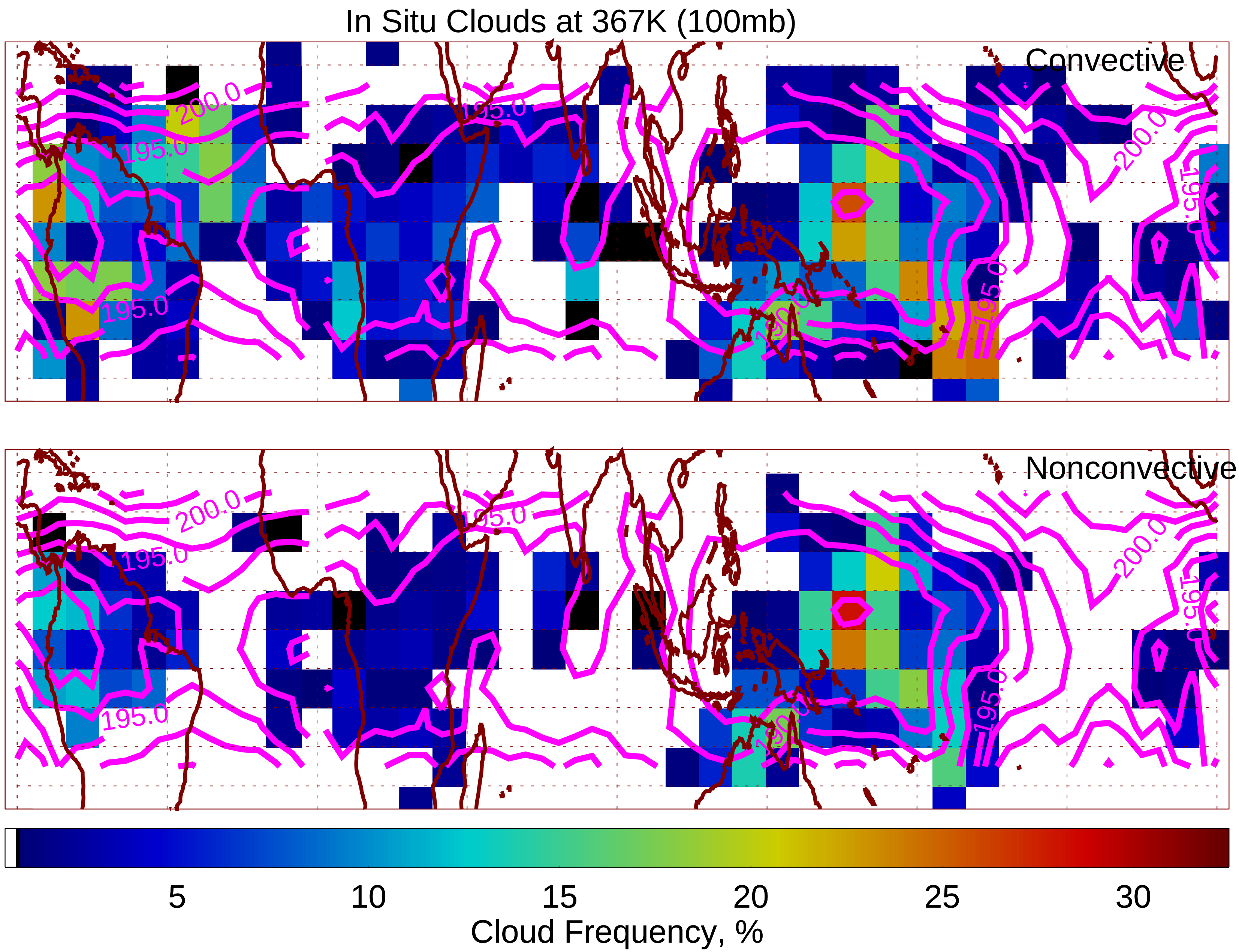
Dehydration over the Cold Pool



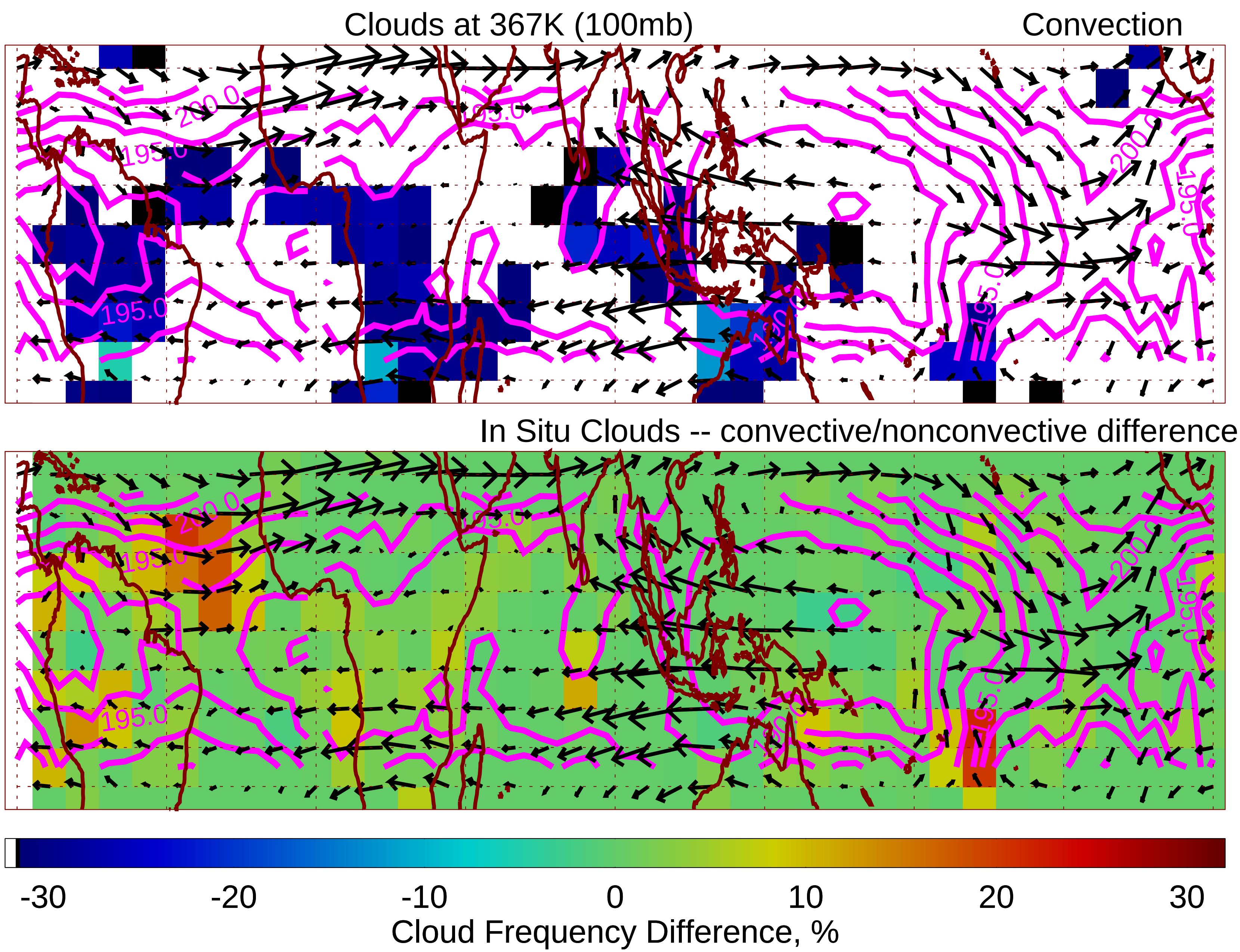
Water Distribution at 146mb compared with 3 MLS days

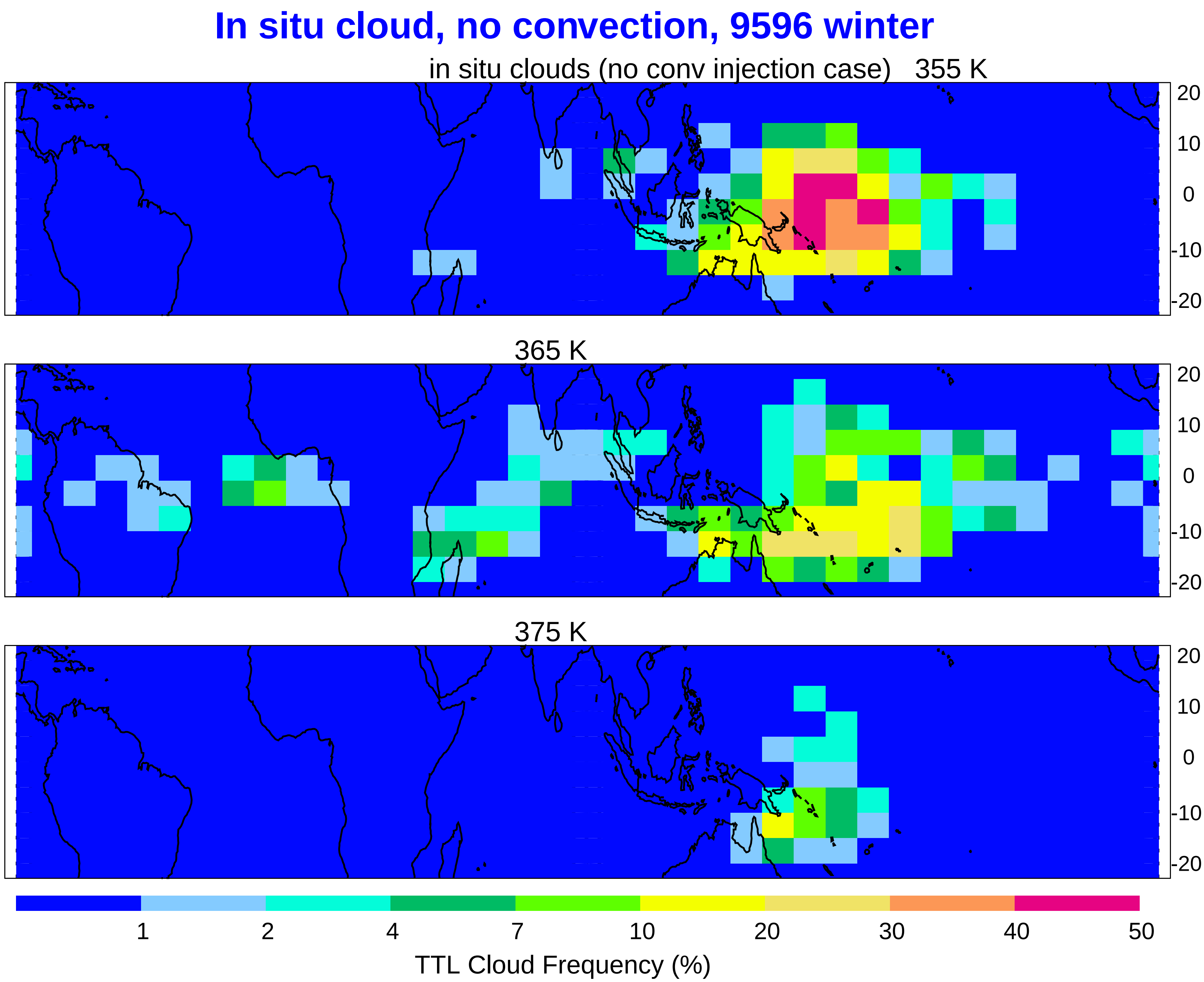


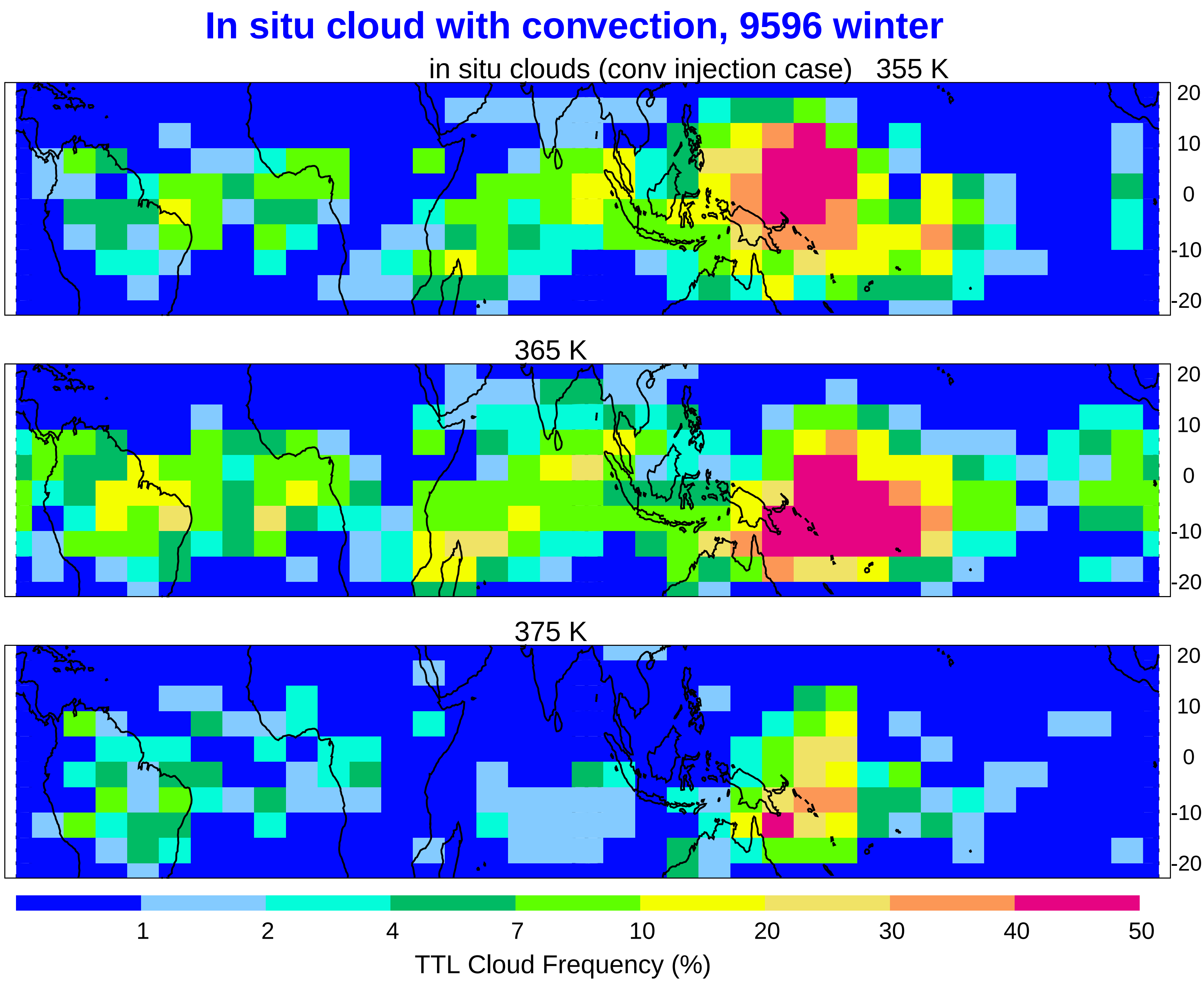
Cloud Distribution in January at 367K



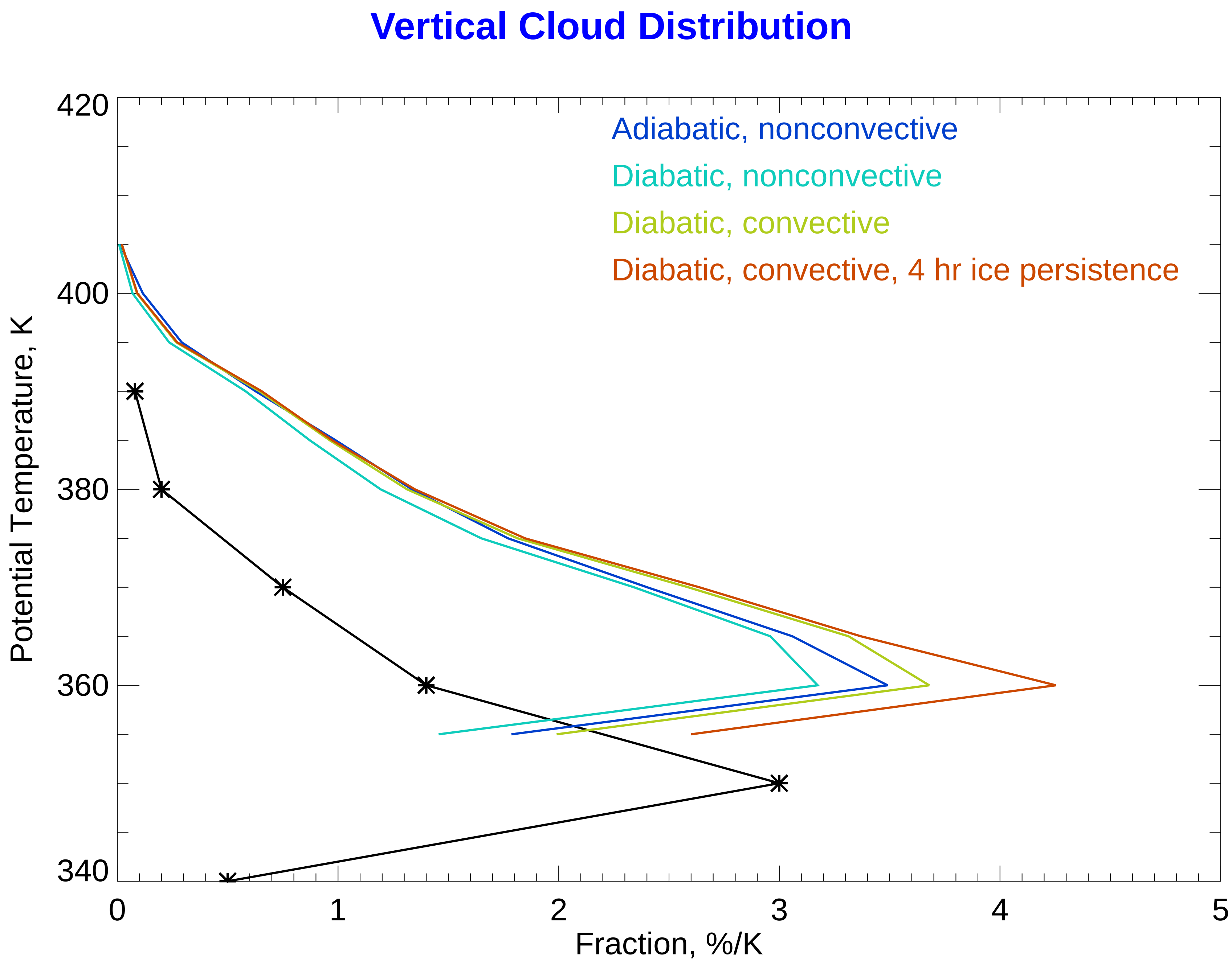
Convective Cloud, and Differences in January at 367K




In situ cloud, no convection, 9596 winter
in situ clouds (no conv injection case)   355 K
365 K
375 K
20
10
0
-10
-20
1
2
4
7
10
20
30
40
50
TTL Cloud Frequency (%)

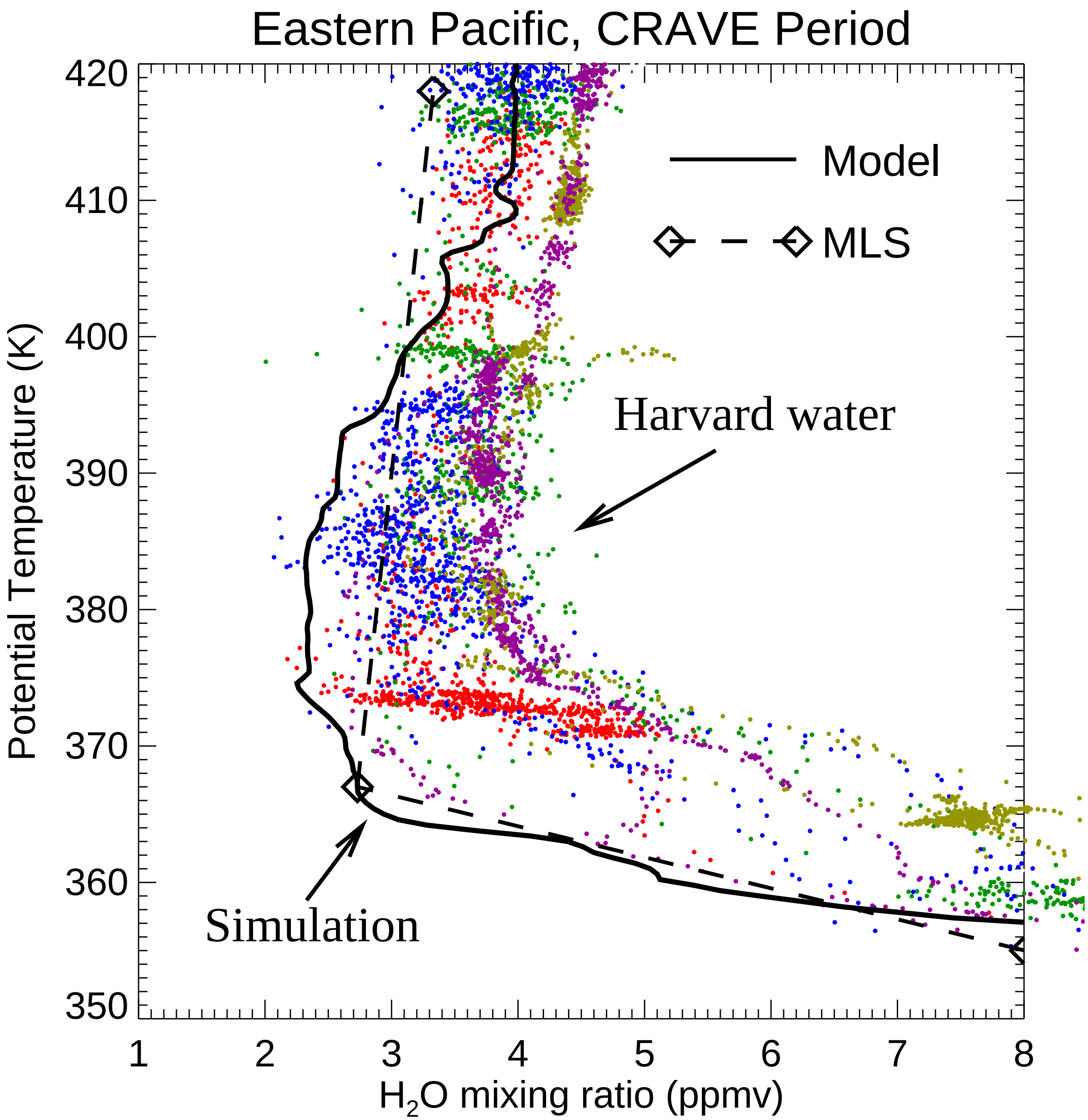


In situ cloud with convection, 9596 winter
in situ clouds (conv injection case) 355 K
20
10
0
-10
-20
365 K
375 K
1
2
4
7
10
20
30
40
50
TTL Cloud Frequency (%)



Vertical Cloud Distribution
Adiabatic, nonconvective
Diabatic, nonconvective
Diabatic, convective
Diabatic, convective, 4 hr ice persistence
420
400
380
360
340
Potential Temperature, K
0
1
2
3
4
5
Fraction, %/K

Comparison with Aircraft Measurements in CRAVE



Conclusions

- Very reasonable agreement with MLS measurements in both vertical and horizontal water distributions (model is somewhat dry). Inclusion of convection improves agreement.

- Diabatic trajectories give drier results than adiabatic – because of the concentration of parcel time in the cold pool

- Convection hydrates significantly at lower levels, less at upper levels. Minimal dehydration at highest levels

- 4 hour ice persistence vs instant ice fallout makes minimal difference on the average.

- Major pool of dehydrated air is downstream of the coldest air and the highest cloud frequencies.

- Enhanced vertical velocity is the major perturber of water vapor in these simulations at tropopause altitudes.

- In situ formed clouds are enhanced by 20% or so in the convective case.

- Enhancements are near regions of convection and downstream of convection. Enhancements are notable at edges of cold temperature regions (hydration of warm regions by convection with air moving to colder regions).

- Effect of convection is much larger in 9596, because in situ clouds in the non-convective case are much more limited in that year

- Reasonable quantitative agreement with ICESAT GLAS measurements, with caveat about different time and IWC threshold issues.

- “Standard” microphysics cannot explain the aircraft measurements, even if convection is included. Only way is if we up the vertical velocity a lot(?).