Convective influence on the lower stratospheric water vapor in the boreal summer Asian monsoon region

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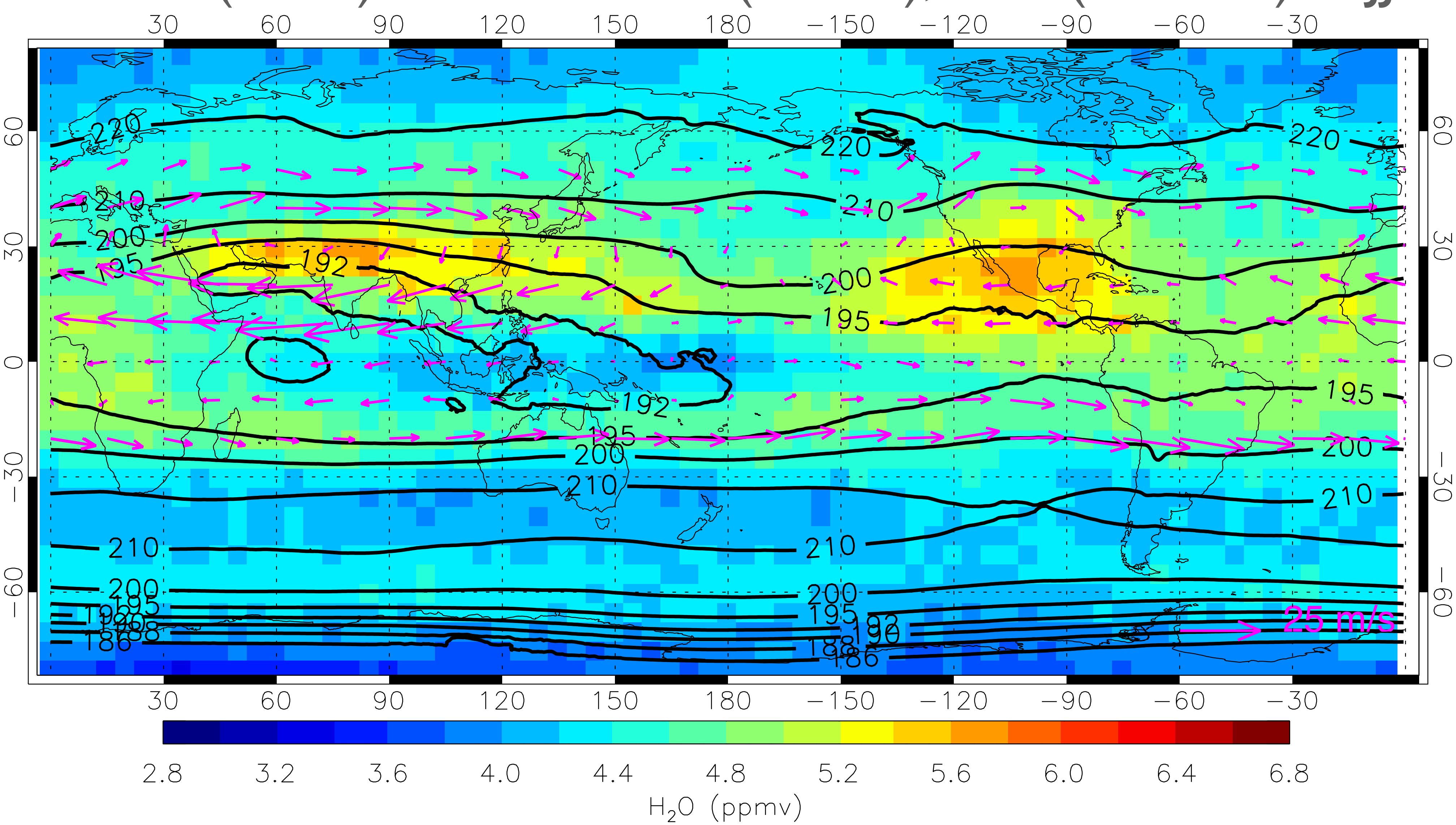
100 hPa H_2O (color) and UV winds (vector), CPT (contour) in JJA 2007



Questions

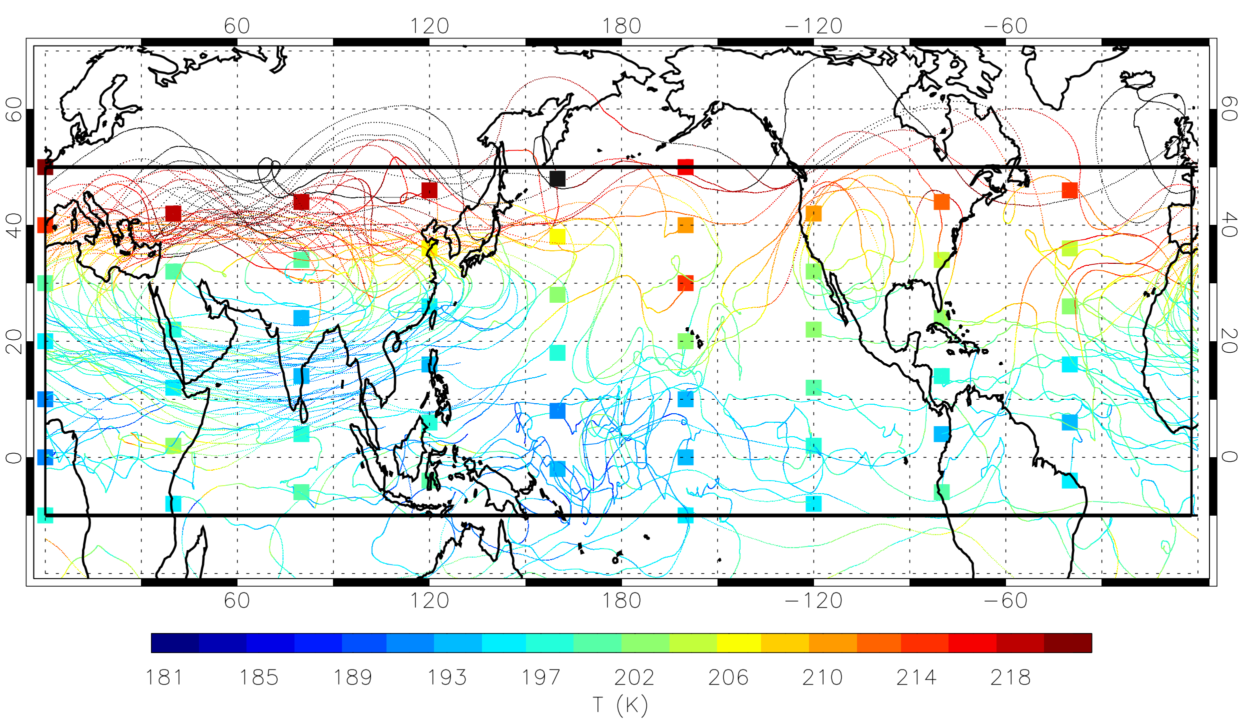
1. What is the impact of convection on the lower stratospheric humidity and clouds in the tropical tropopause layer (TTL)? Does it explain the abundance of moisture and clouds over the Asian monsoon region in boreal summer?
2. What is the role of convection over the Asian monsoon region and other deep convective systems?
3. Where do parcels encounter convection (and hydrated) on their journey to the Asian monsoon region? Where are they dehydrated by cloud formation?
4. How sensitive are the simulation results to the heating rates (observation-based vs. reanalysis)?

Method

(modified version of *Jensen and Pfister 2004*, *Bergman et al. 2012*, *Ueyama et al. 2014, 2015*)

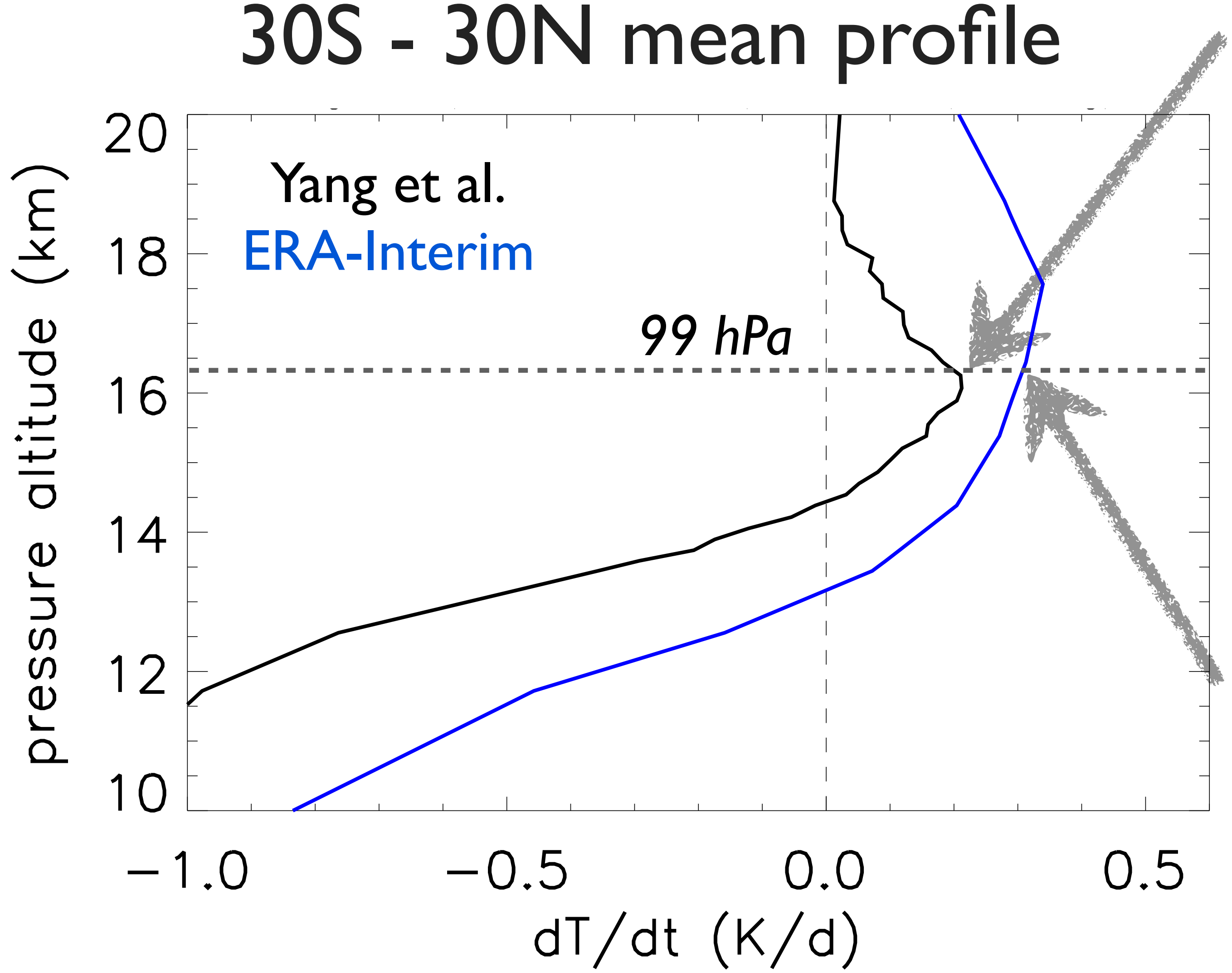
1. Calculate 60-day backward diabatic trajectories from every 2° lat x 2° lon grid points in the 10°S - 50°N domain at 379 K (~100 hPa) level at 3 Aug 2007 using ERA-Interim temperatures and winds with enhanced wave-driven variability in the TTL (Kim and Alexander 2013)

a sample of the trajectories and their temperatures

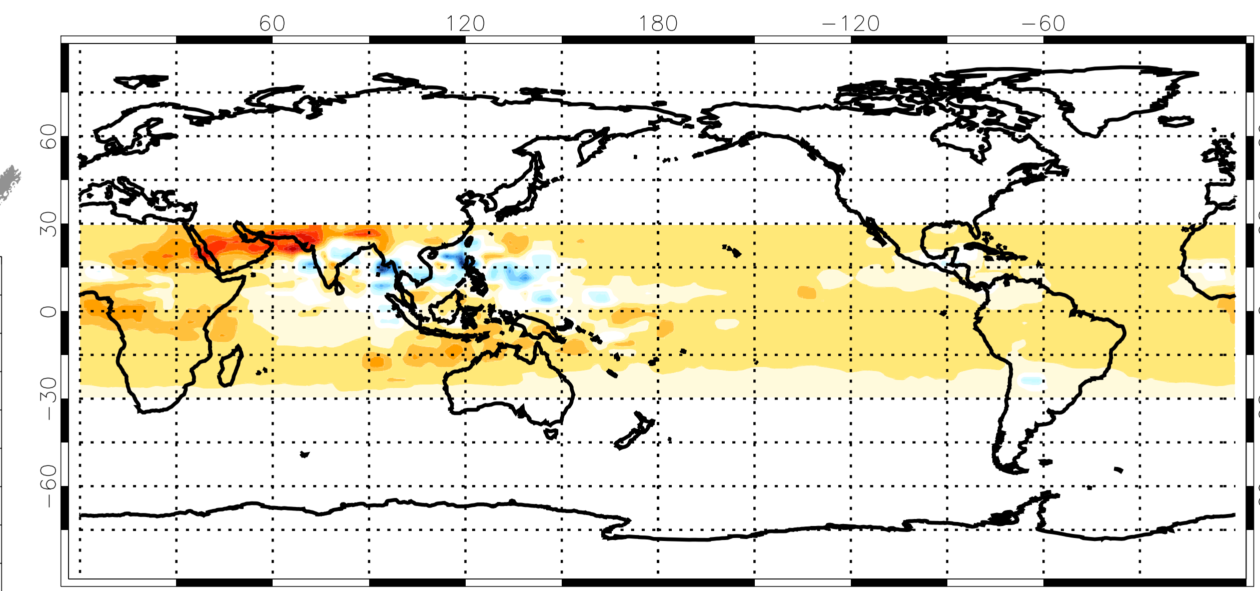


radiative heating rates

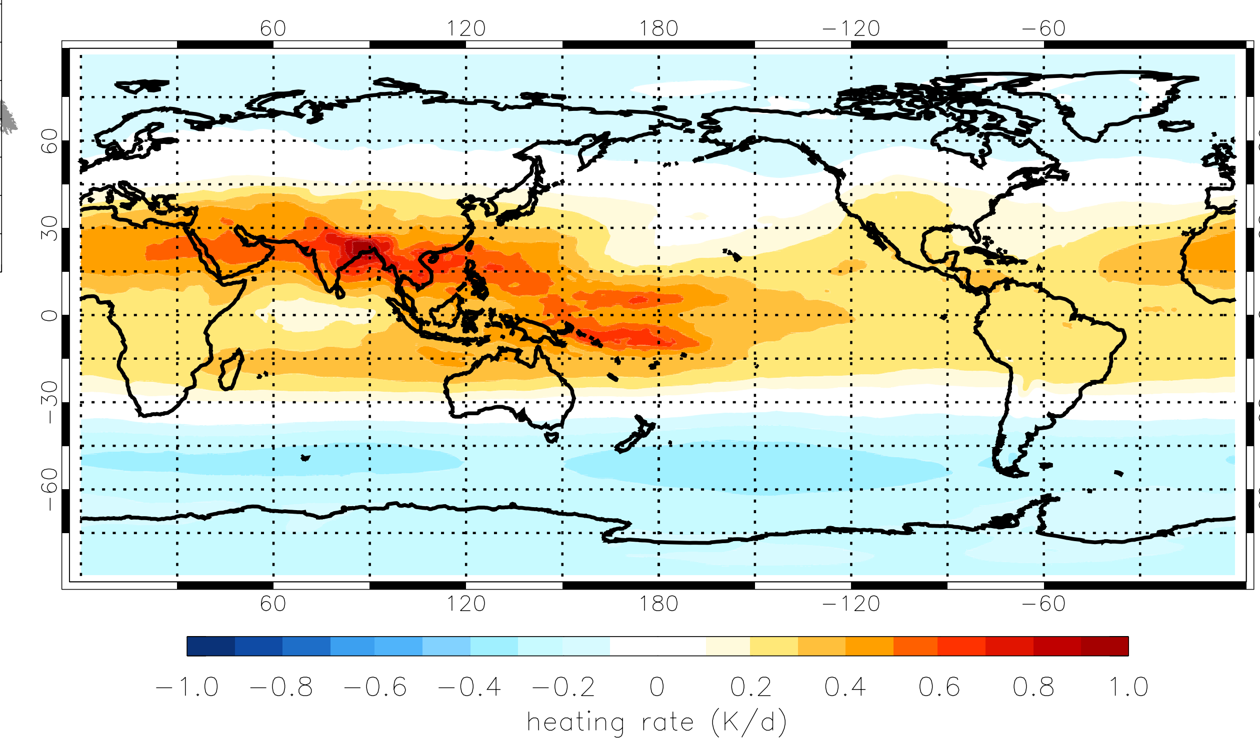
Jun-Jul-Aug 2007
30S - 30N mean profile



Yang et al. (2010), tropics only



ERA-Interim



Method

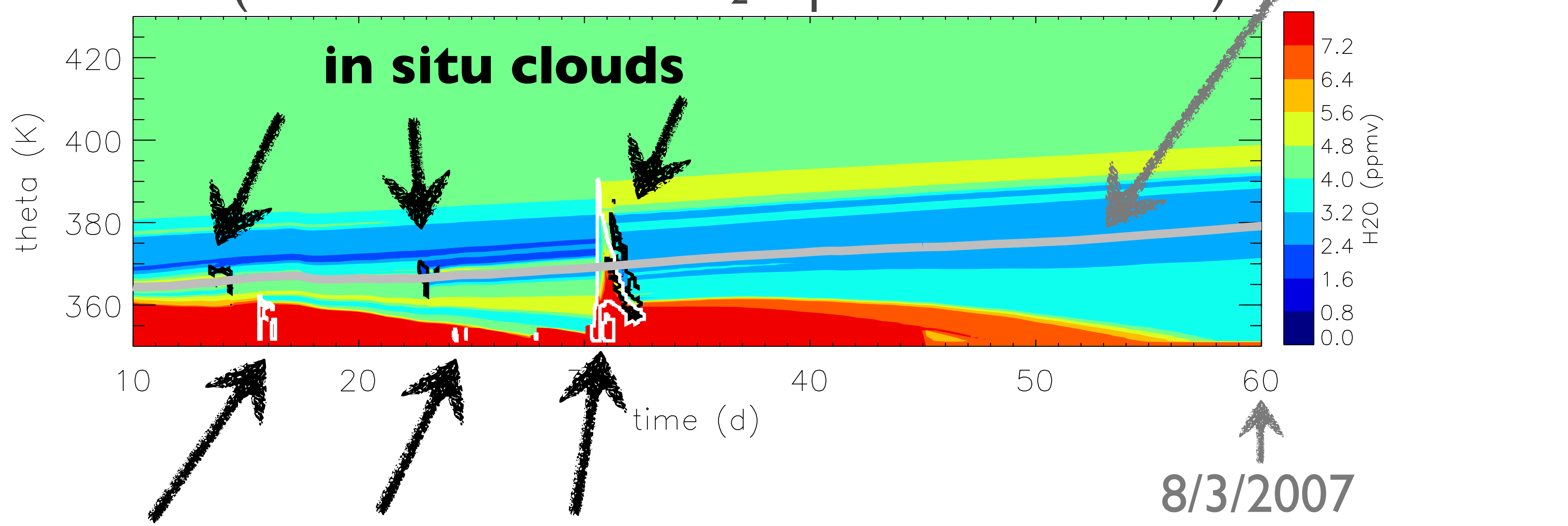
(modified version of *Jensen and Pfister 2004*, *Bergman et al. 2012*, *Ueyama et al. 2014, 2015*)

2. Use 1D (height) time-dependent microphysical model to simulate clouds along each parcel trajectory and calculate their time-integrated effects on H_2O mixing ratio

parcel trajectory

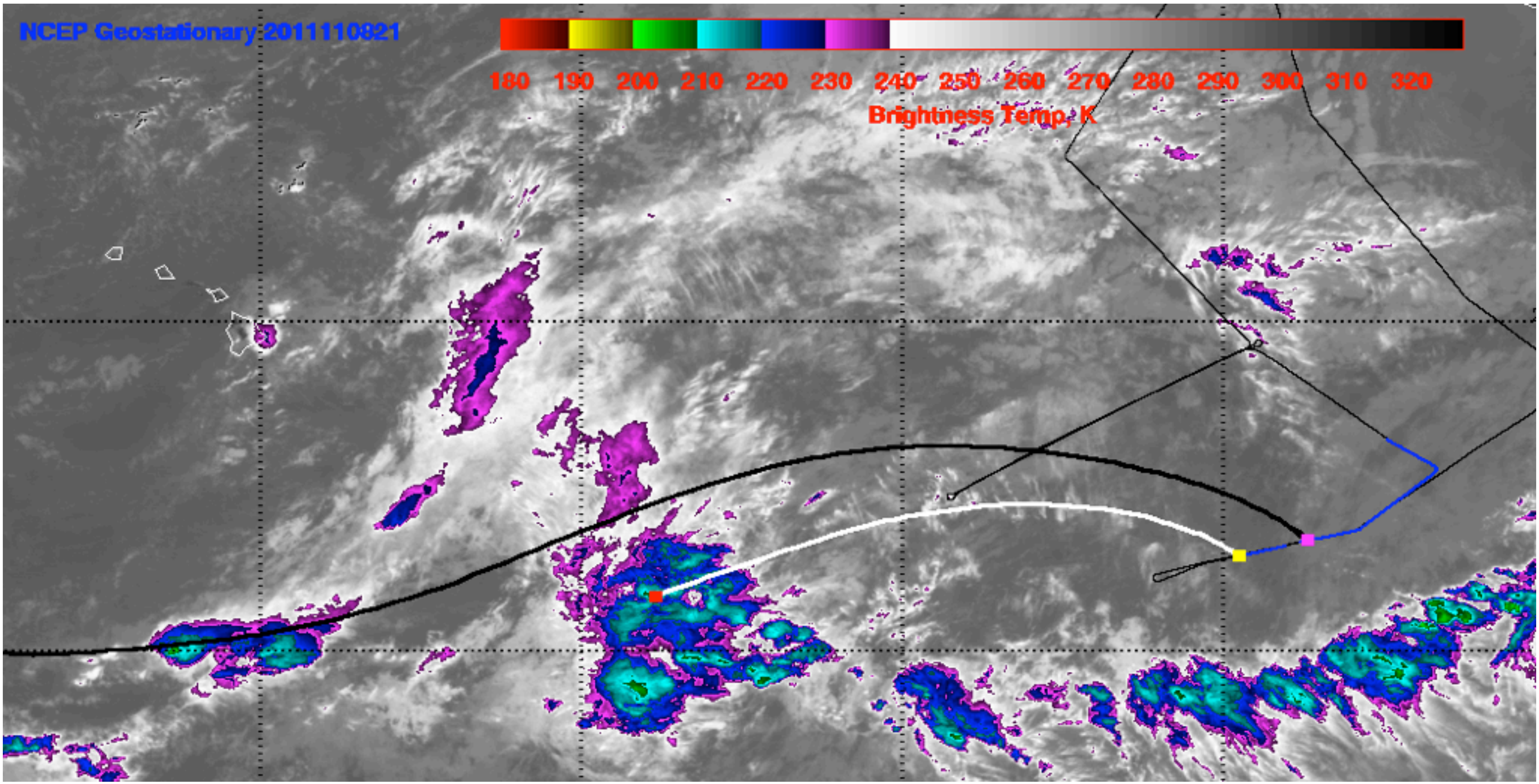
H_2O curtain

(initialized with MLS H_2O profile at time = 0)



convection (air is saturated up to the cloud top height and **anvil ice** is added)

Example:
tracing trajectories through geostationary satellite convective cloud-top height fields

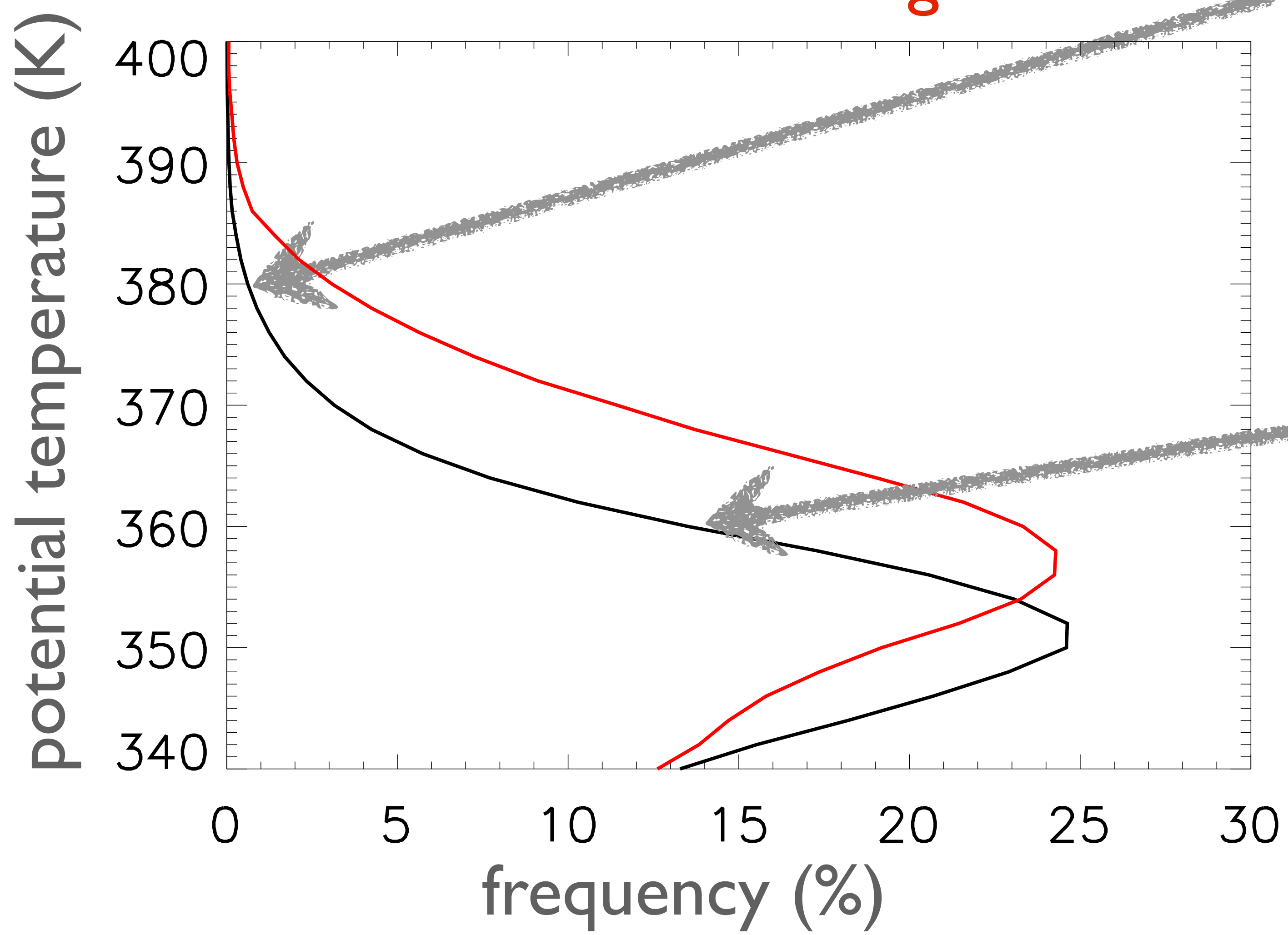


Convective cloud top distribution

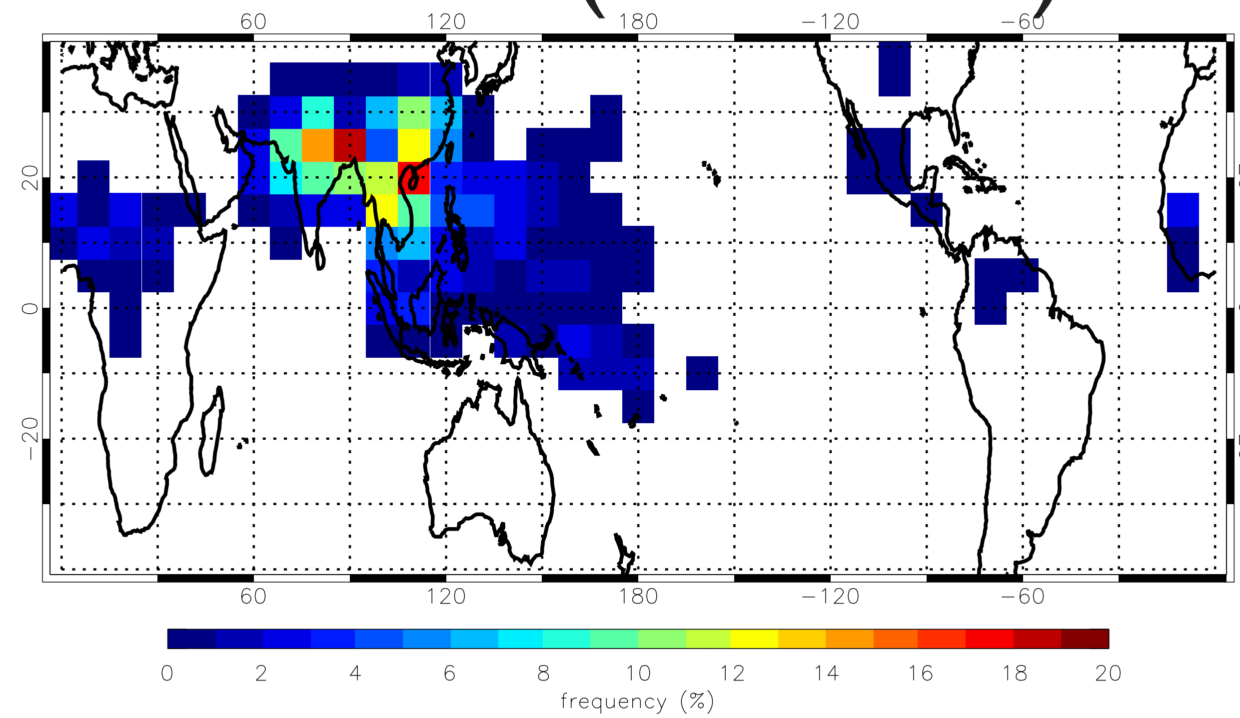
Jun-Jul-Aug 2007 mean profile

10S - 40N mean

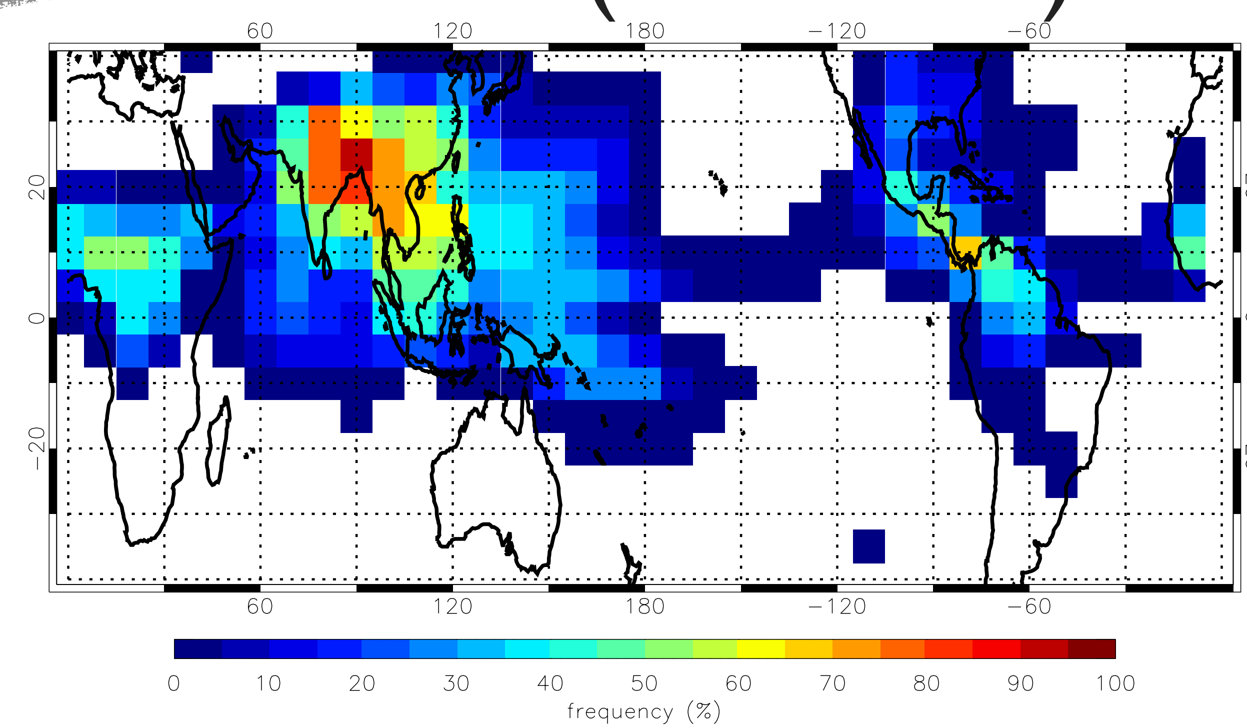
Asian monsoon region



>380 K (~100 hPa)



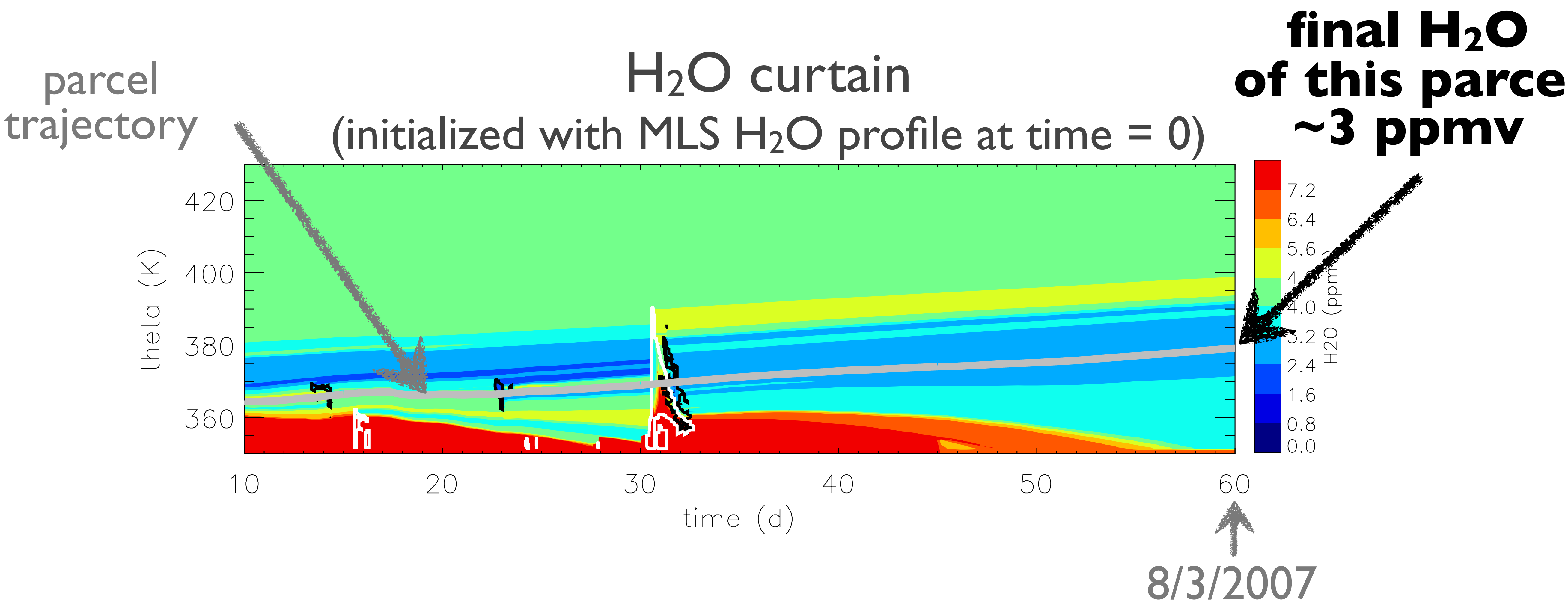
>360 K (~130 hPa)



Method

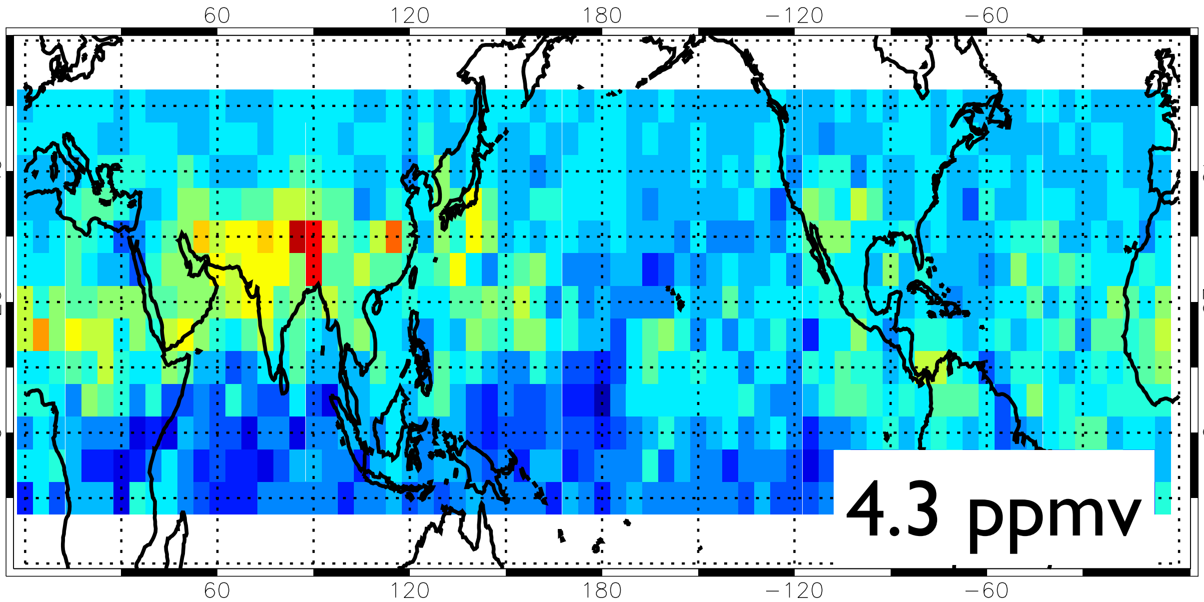
(modified version of *Jensen and Pfister 2004*, *Bergman et al. 2012*, *Ueyama et al. 2014, 2015*)

3. Compare the simulated H_2O mixing ratios on the final day of the trajectories (MLS averaging kernel applied) with corresponding MLS measurements at 100 hPa

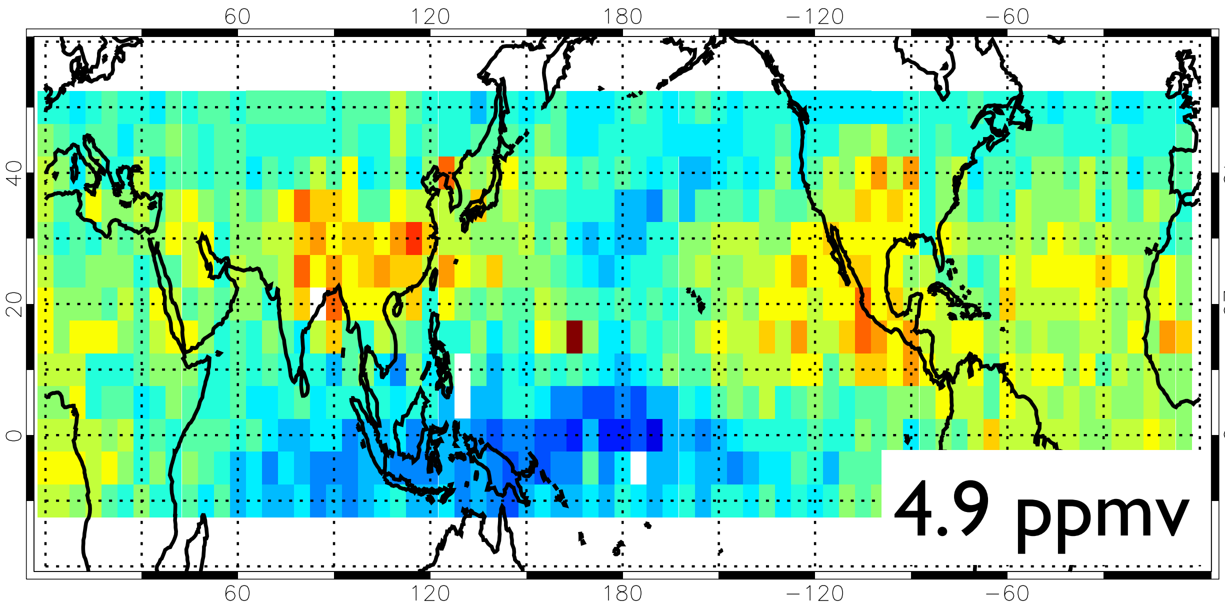


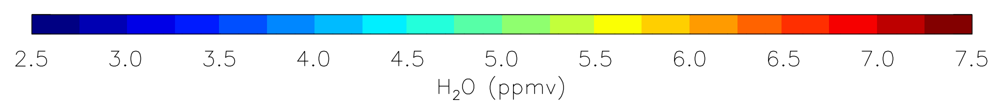
100 hPa H_2O

model



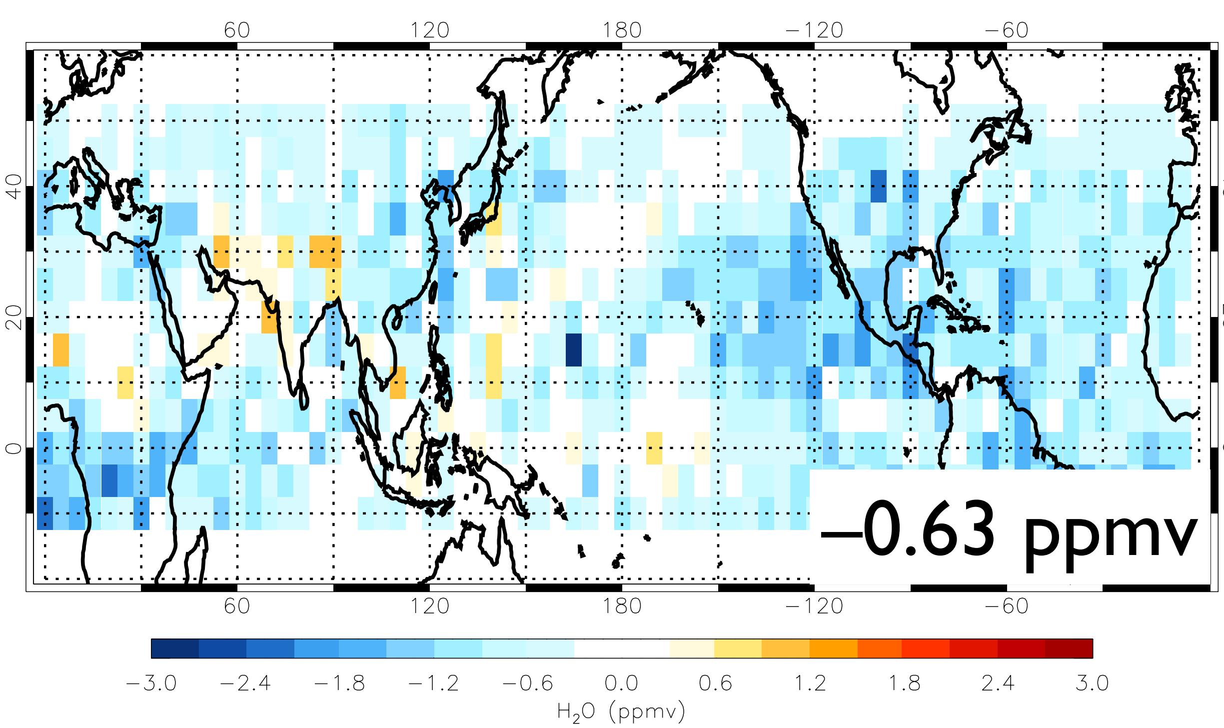
MLS





- model is too dry compared to MLS (mean difference –0.63 ppmv), particularly over the N American monsoon region
  - ➔ role of mixing?
- western sector of the Asian monsoon anticyclone is wetter than the eastern sector in the model, opposite of MLS observations

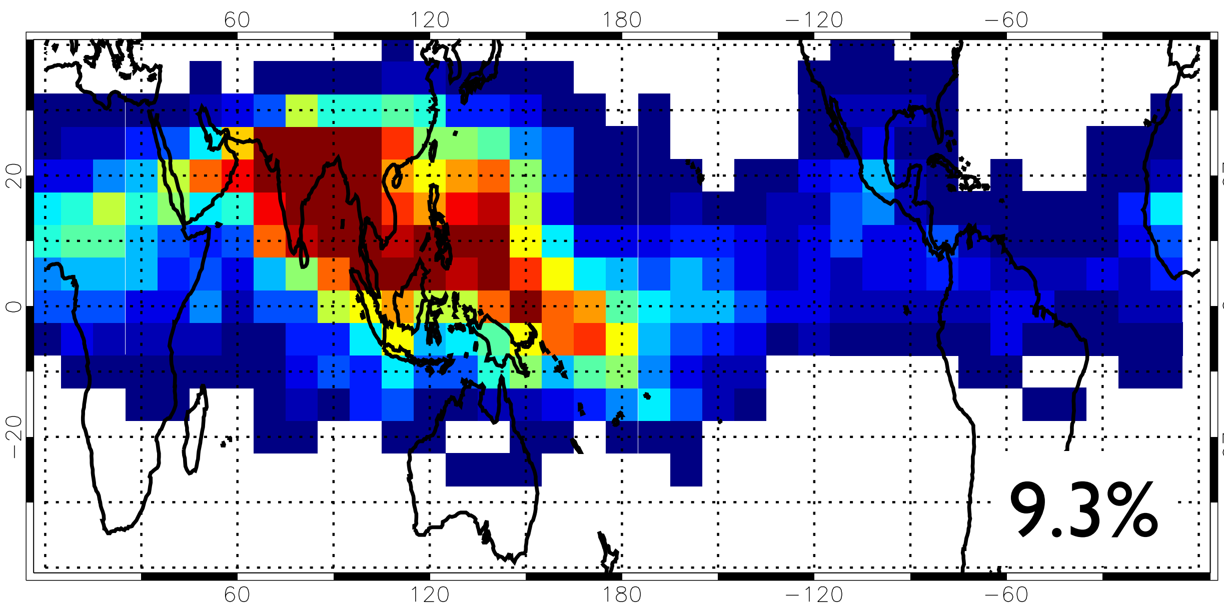
model – MLS



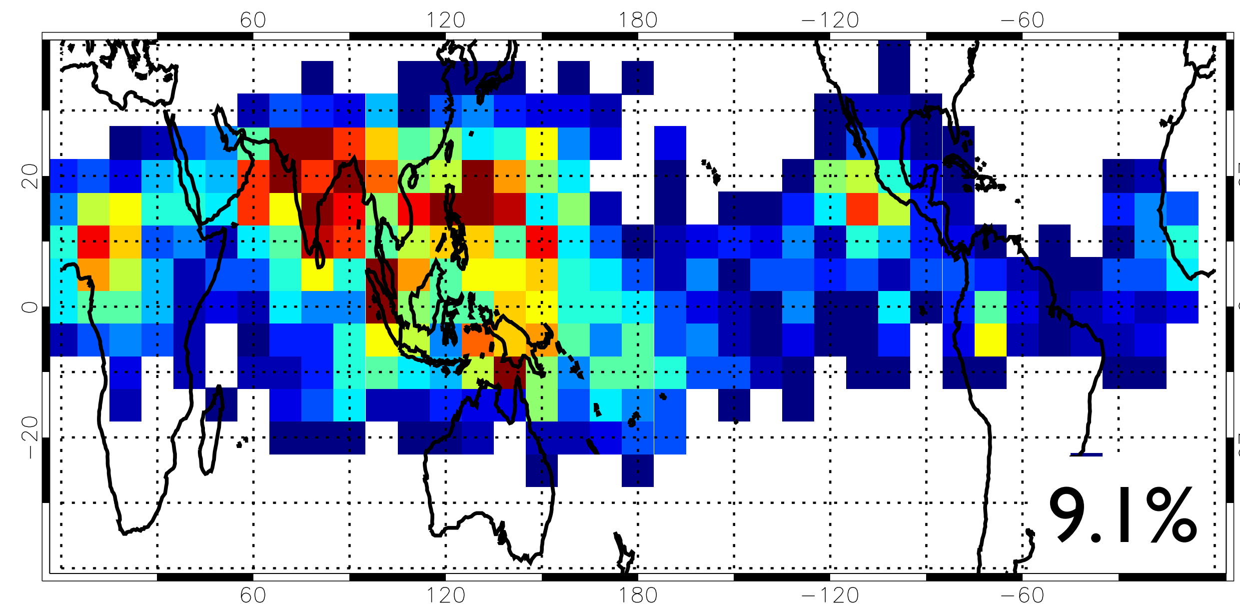
Cloud occurrence frequency

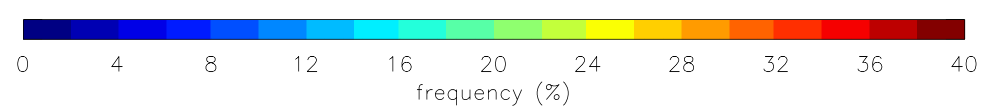
15 – 17 km, 4 Jul - 3 Aug 2007

model



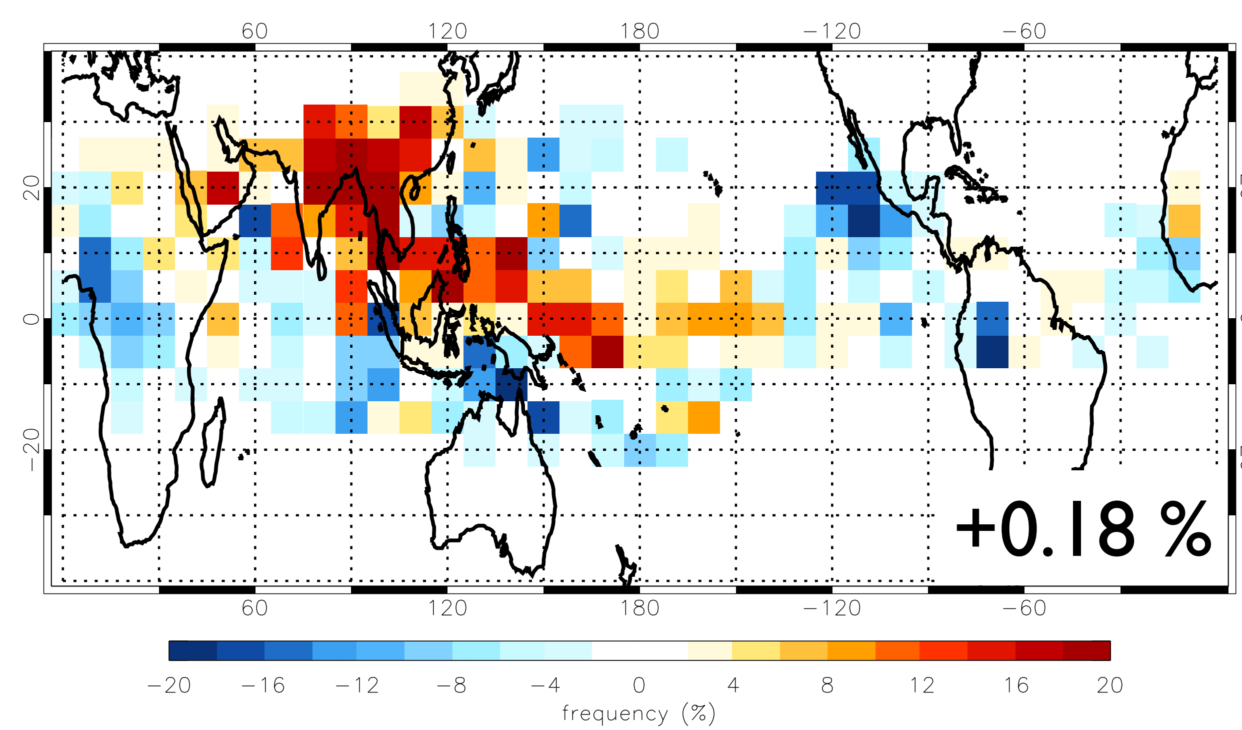
CALIPSO



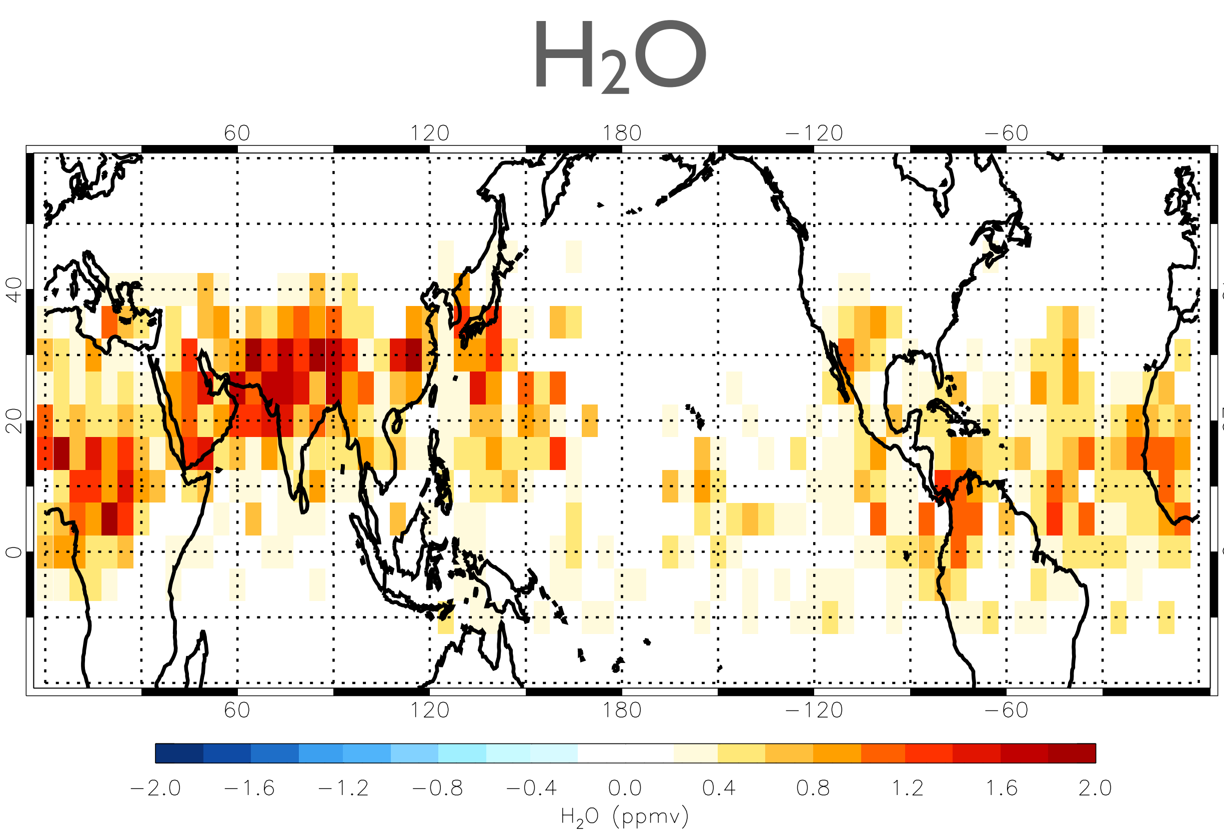


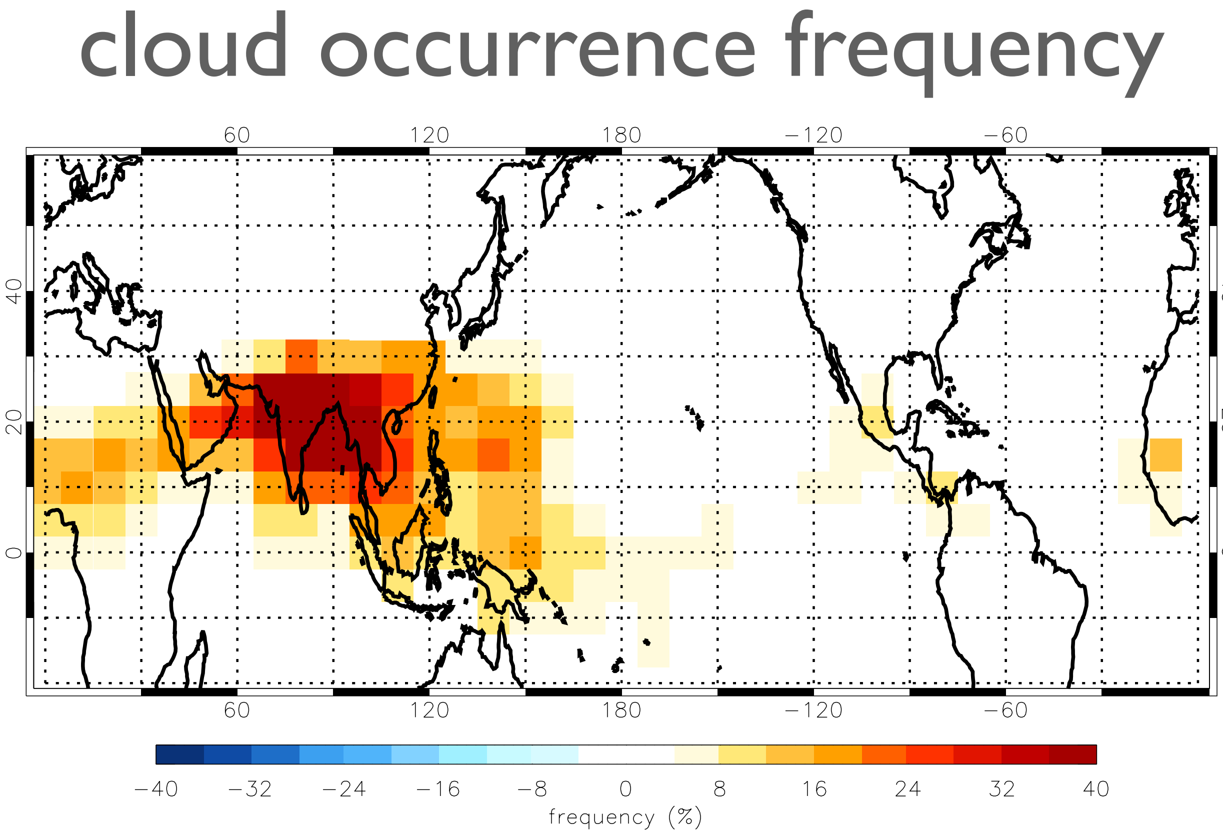
- reasonably good agreement with CALIPSO (r = 0.84, $RMSE$ = 7.1%) but the model overestimates cloud occurrence over the Asian monsoon region
  - ➔ discrepancy may be due to CALIPSO sampling issues and uncertainty in cloud top heights

model – CALIPSO



Impact of convection



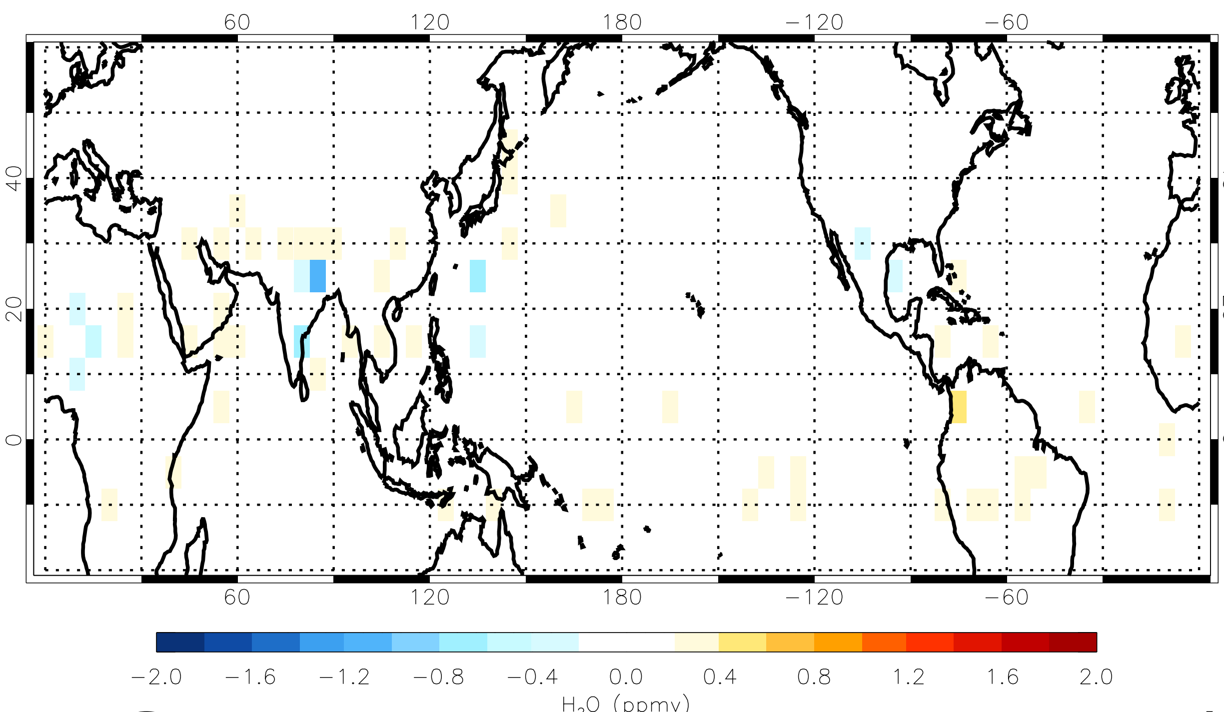


➤ Convection moistens the 100hPa level by ~0.3 ppmv (~7% of 10S-50N mean H_2O) and increases cloud occurrence in the TTL by ~6% (~60% of 20S-30N mean frequency)

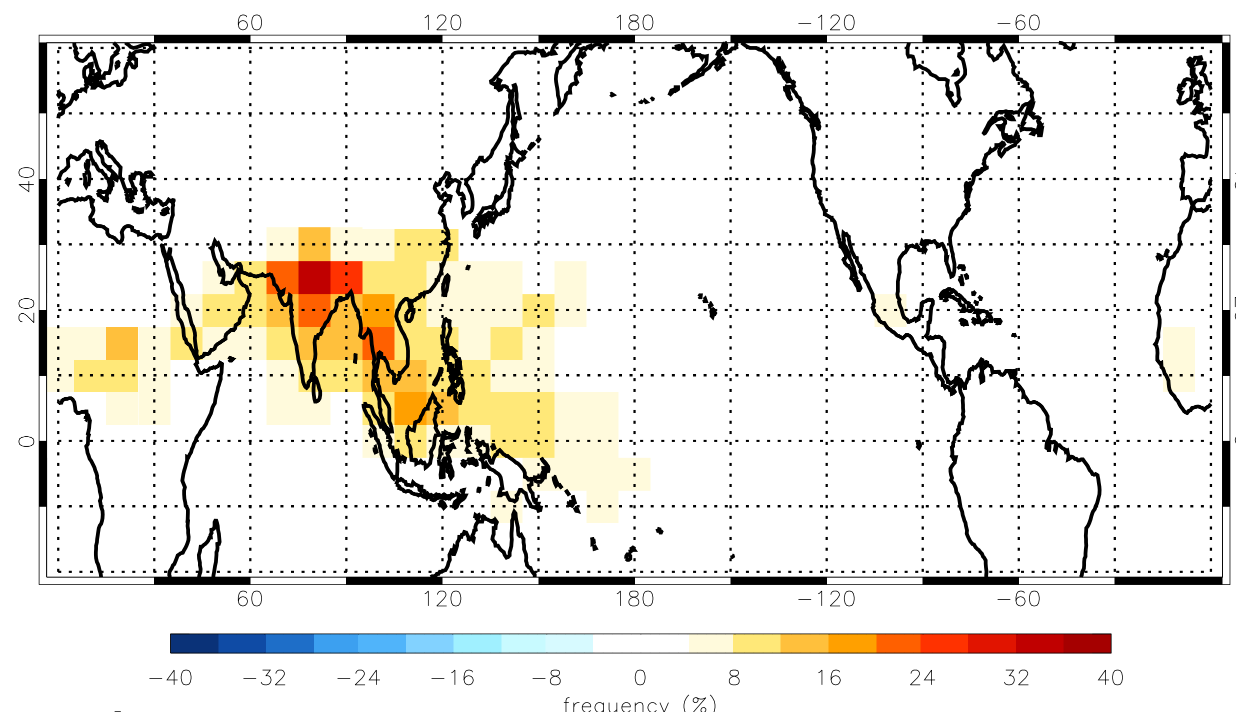
➤ Convection increases water and clouds over the Asian monsoon region by ~17% and ~80%, respectively

Impact of anvil ice

H_2O



cloud occurrence frequency

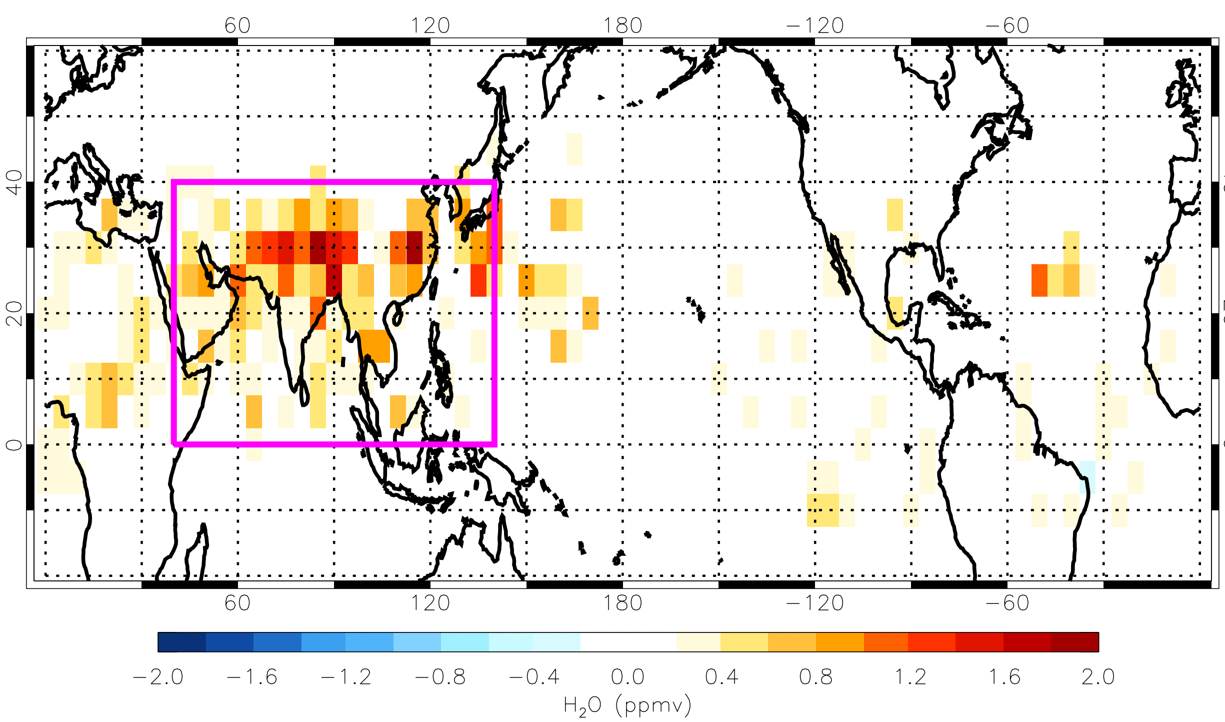


➤ Convectively-detrained (anvil) ice increases TTL cloud occurrence frequency by ~3%, accounting for half of the total convective impact; remaining half is due to the impact of convective saturation

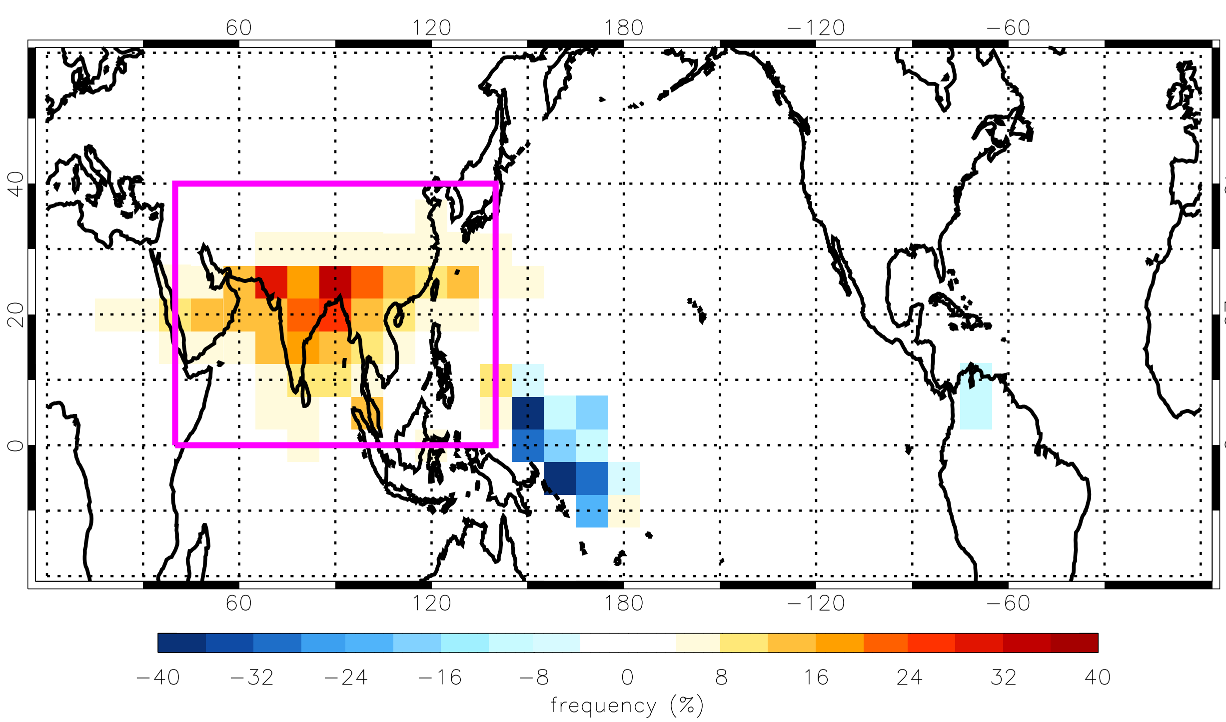
➤ Anvil ice has a negligible impact on 100 hPa H_2O presumably because most of the detrained ice sediments out of the TTL relatively quickly

Impact of Asian monsoon convection

H_2O



cloud occurrence frequency



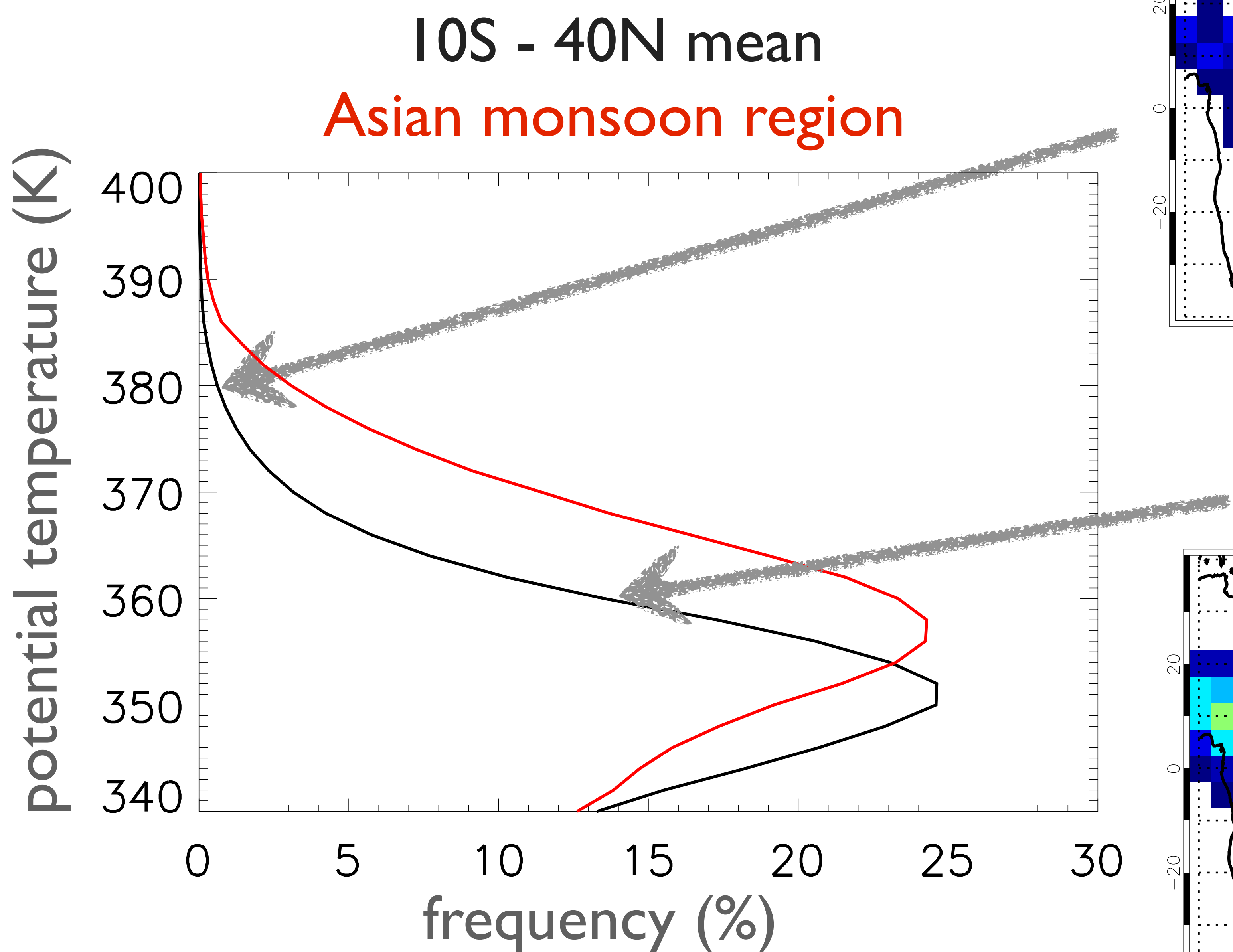
Asian monsoon convection (magenta box)...

➤ moistens the 100hPa level by ~0.1 ppmv, accounting for ~40% of the total convective impact on 100hPa H_2O

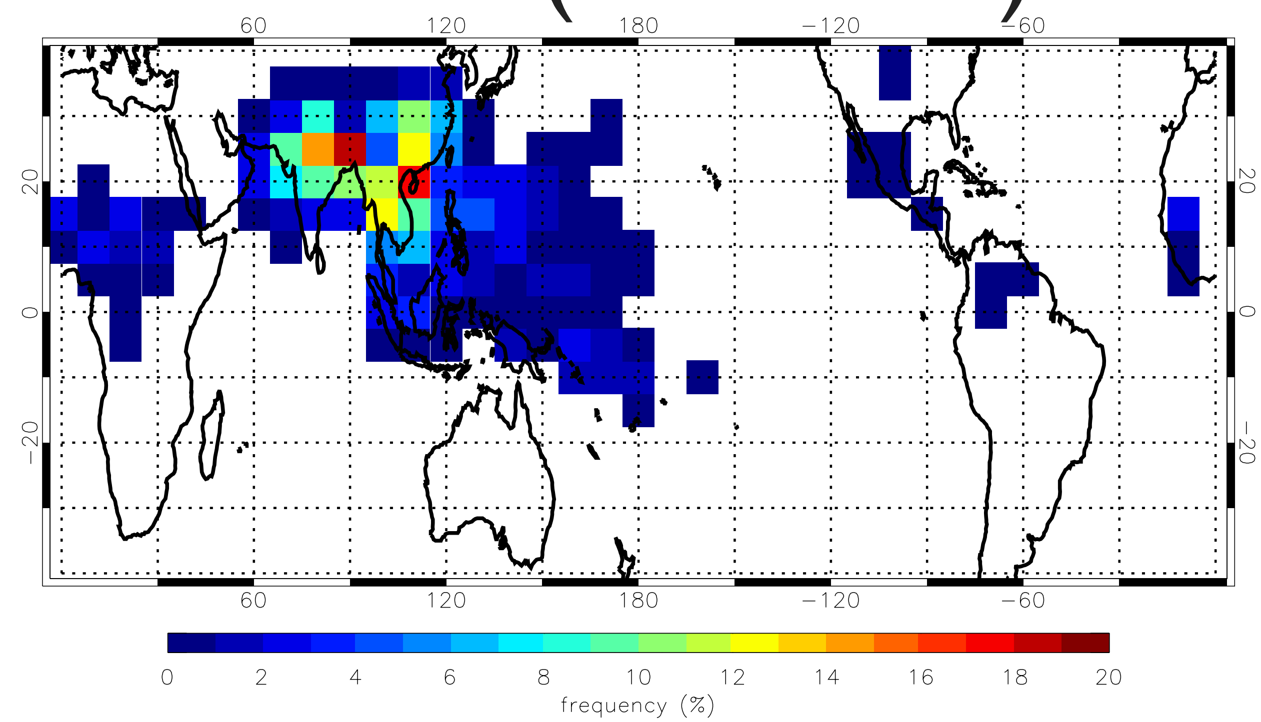
➤ increases clouds over the Asian monsoon region by ~40% and decreases them over the western tropical Pacific by ~50%

Convective cloud top distribution

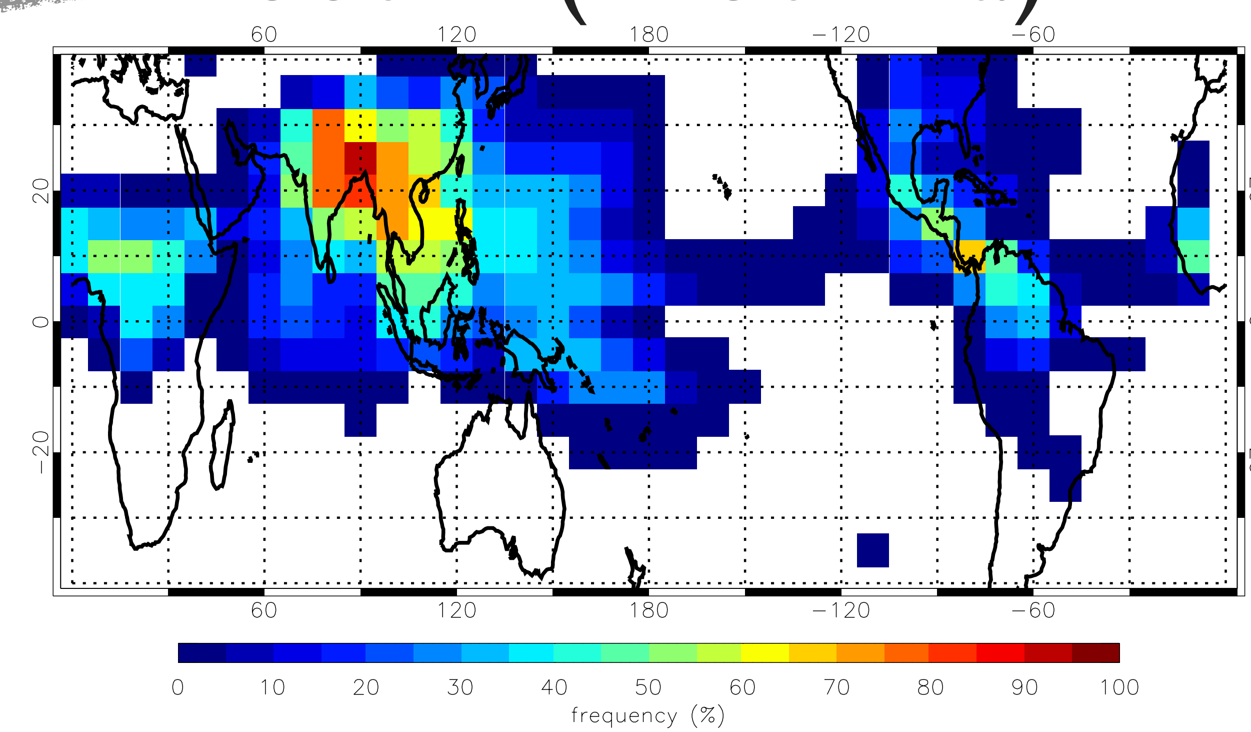
Jun-Jul-Aug 2007 mean profile



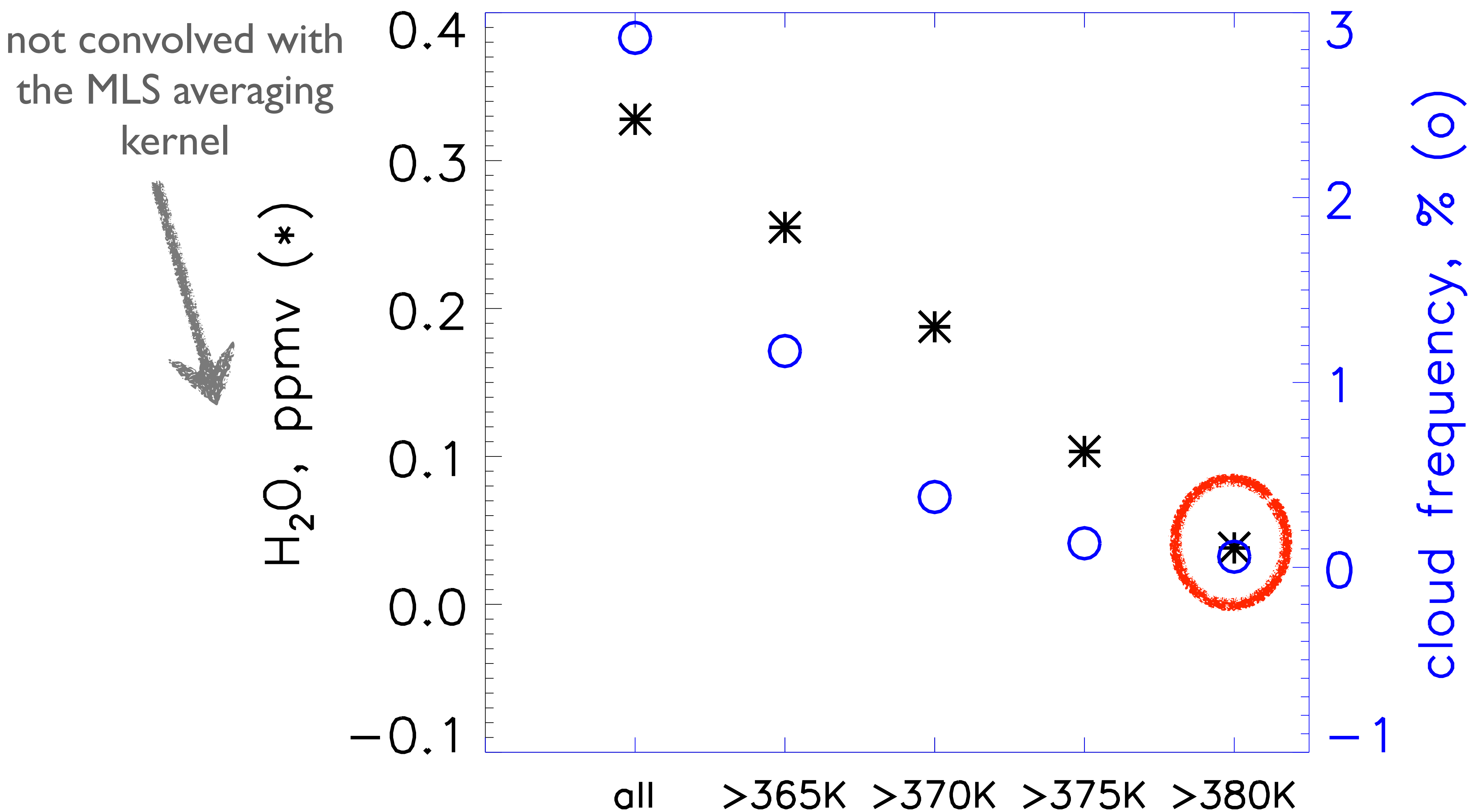
380 K (~100 hPa)



360 K (~130 hPa)



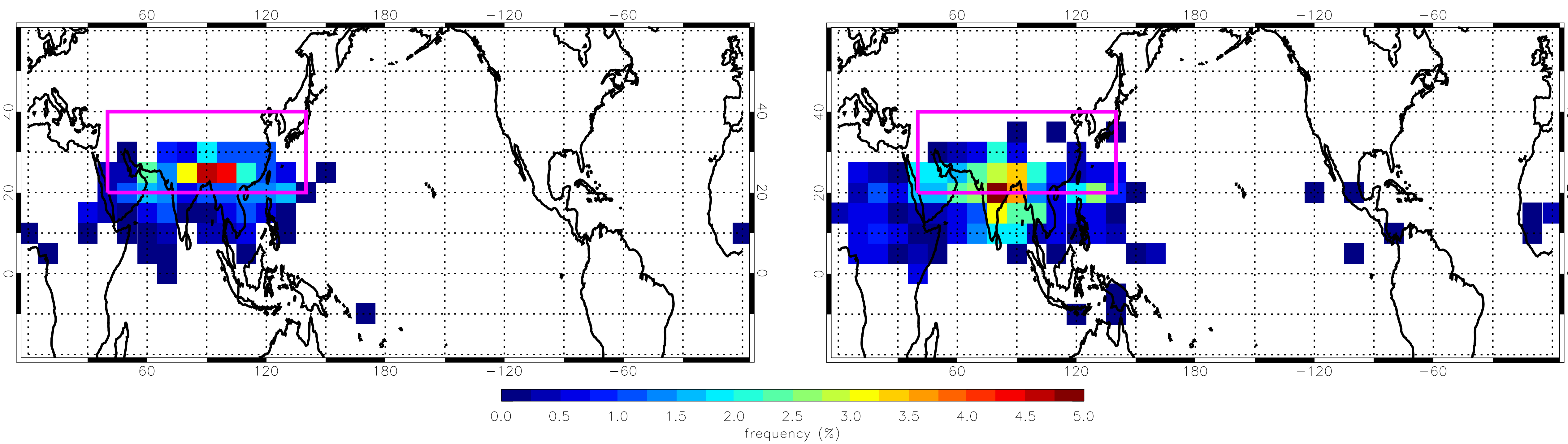
Impact of convection of varying heights



Deep convective systems with cloud tops >380K (≲100 hPa) account for ~10% and ~2% of the total convective impact on the 100 hPa H_2O and TTL cloud occurrence, respectively.

Final (de)hydration location frequency
of parcels in the Asian Monsoon region

final hydration (convection) final dehydration (cloud)

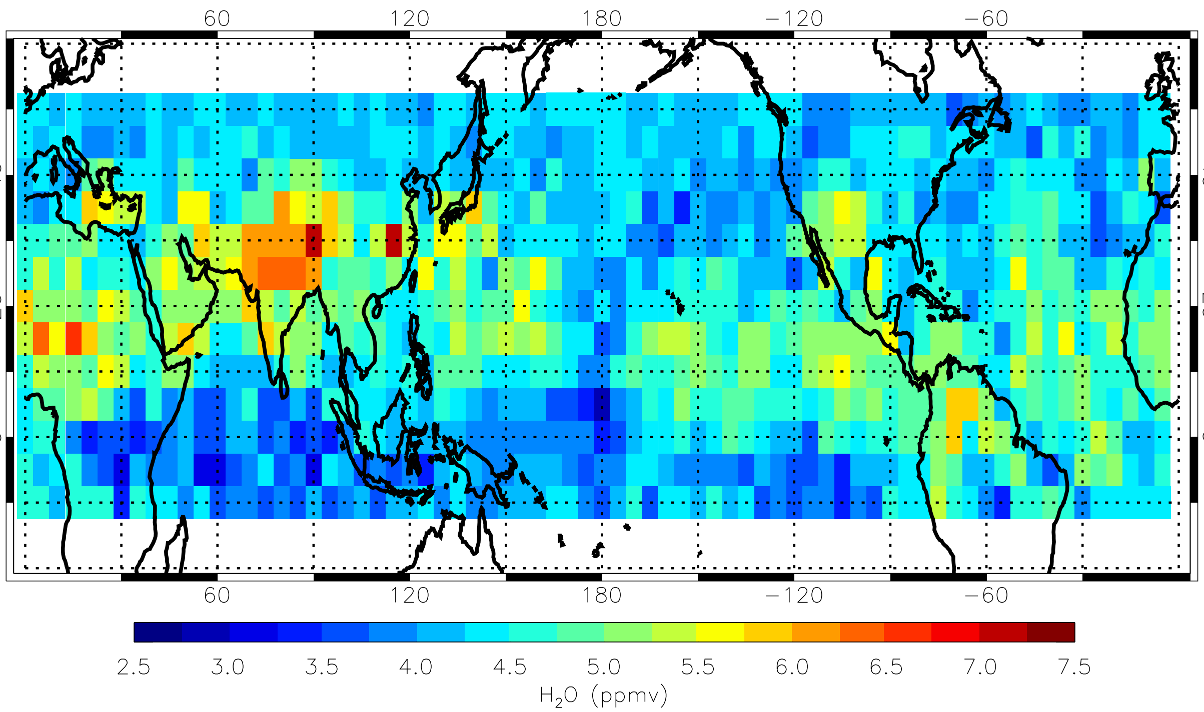


Majority (~80%) of the parcels are dehydrated ~10 days *after* encounter with convection.

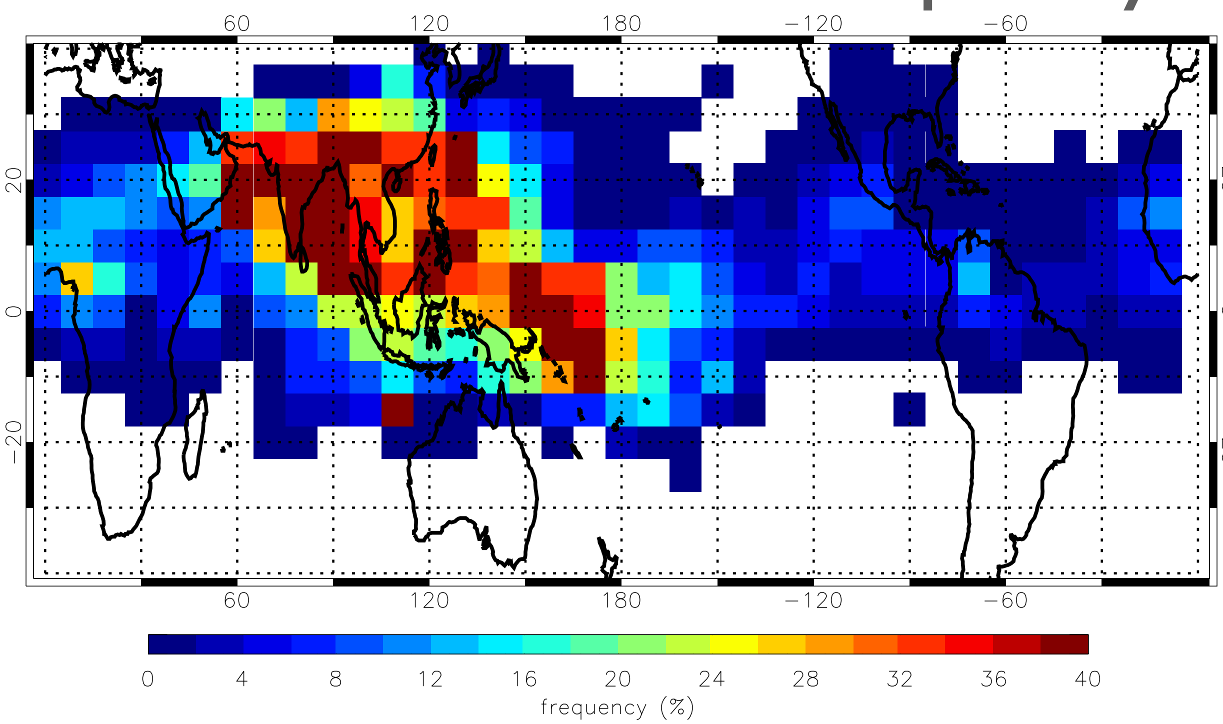
Parcels are convectively hydrated over northern India and south slope of the Tibetan Plateau ➔ transported by the anticyclonic circulation ➔ dehydrated by cloud formation over the cold temperature regions to the south of the anticyclone

simulation with 6-hrly ERA-Interim heating rates

H_2O

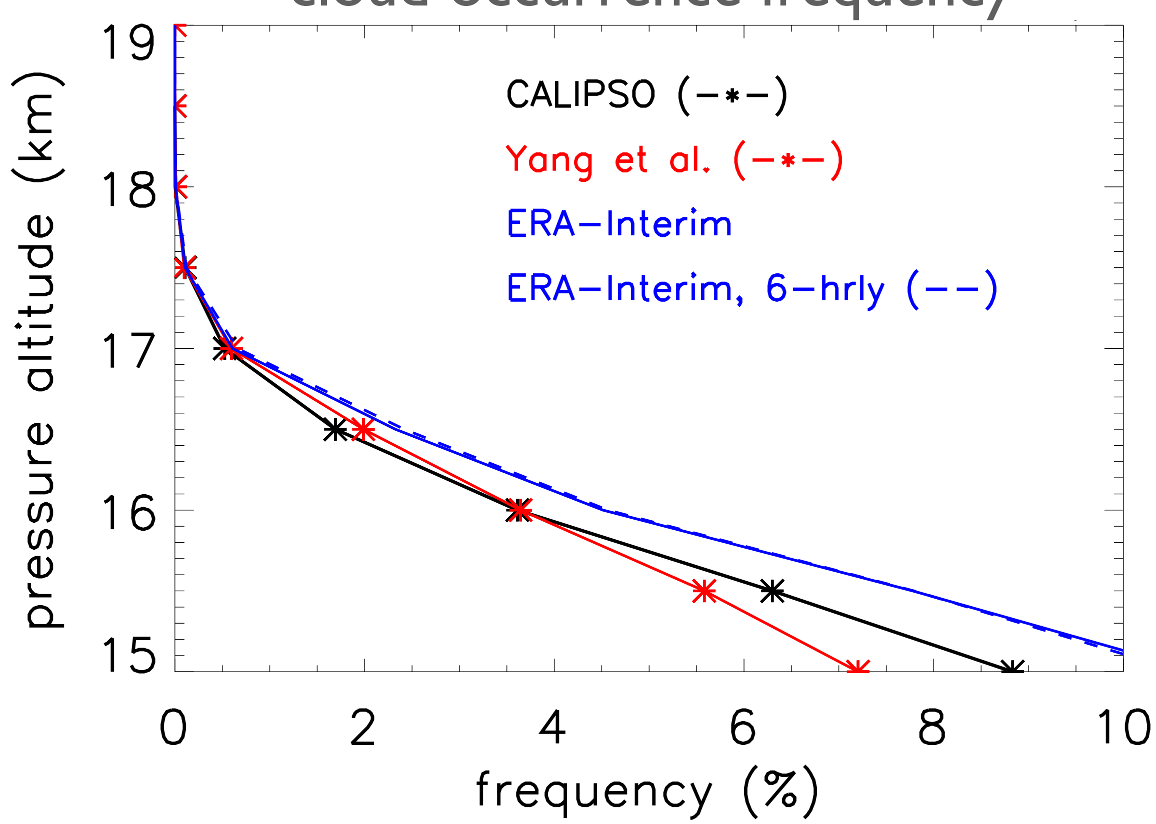


cloud occurrence frequency



- using seasonal mean ERA-I heating rates moistens the 100hPa level by ~0.2 ppmv while adding temporal variability decreases it by <0.1 ppmv
  ➔ model is still ~10% too dry compared to MLS
- TTL cloud occurrence frequencies are ~45% too high compared to CALIPSO

tropical mean profile of
cloud occurrence frequency



Summary

1. Convection moistens the 100 hPa level by ~0.3 ppmv (~7% of the 10S-50N domain average on 3 Aug 2007) and increases the TTL (15-17km) cloud occurrence frequency by ~6% (~60% of the 20S-30N domain average during 4 Jul - 3 Aug 2007)
    - Convection increases H_2O and clouds over the Asian monsoon region by ~17% and ~80%, respectively
    - Approximately half of the cloud occurrence increase is due to convectively-detrained (anvil) ice; the other half is the effect of convective saturation
    - ~40% of the total convective impact on H_2O is due to convection over the Asian monsoon region; ~10% is due to deep convective cloud tops >380 K (<100 hPa)
2. Convection over the Asian monsoon increases cloud occurrence over the Asian monsoon region while decreasing it over the western tropical Pacific
3. Majority of the parcels in the Asian monsoon regions are convectively hydrated over northern India and the south slope of the Tibetan Plateau, transported by the anticyclonic circulation, and then dehydrated ~10 days later over the cold temperature region to the south of the anticyclone
4. Using ERA-Interim heating rates instead of the observation-based Yang et al. (2010) data reduces the model dry bias by a few percent, but overestimates TTL cloud occurrence frequency by ~45%.

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Processes and linkages in the upper troposphere and lower stratosphere: observations and models

contact: Rei Ueyama (rei.ueyama@nasa.gov), Bill Randel