Impacts of microphysics, convection and waves on wintertime distributions of TTL water and clouds

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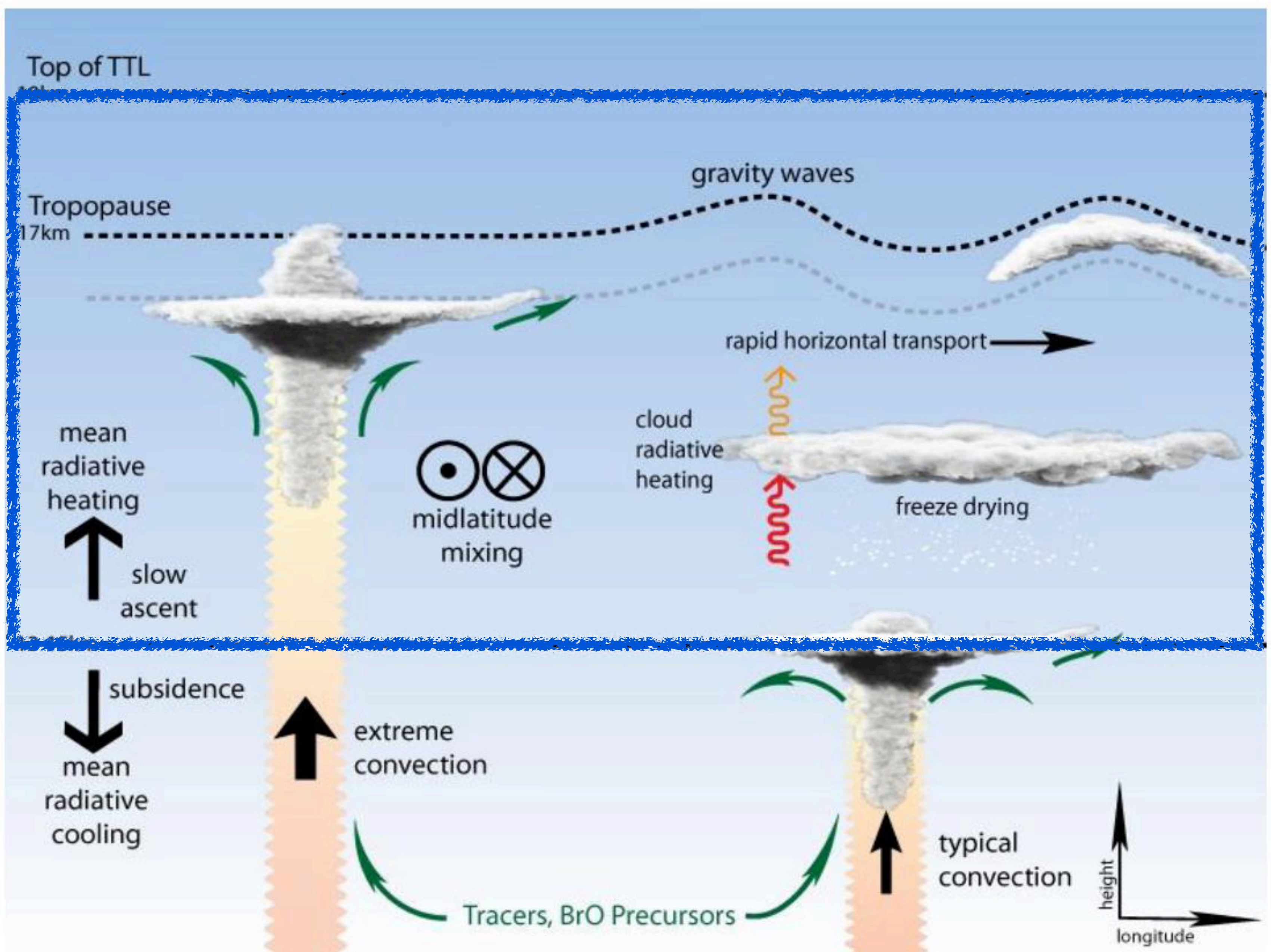
18 km
70 hPa
420 K

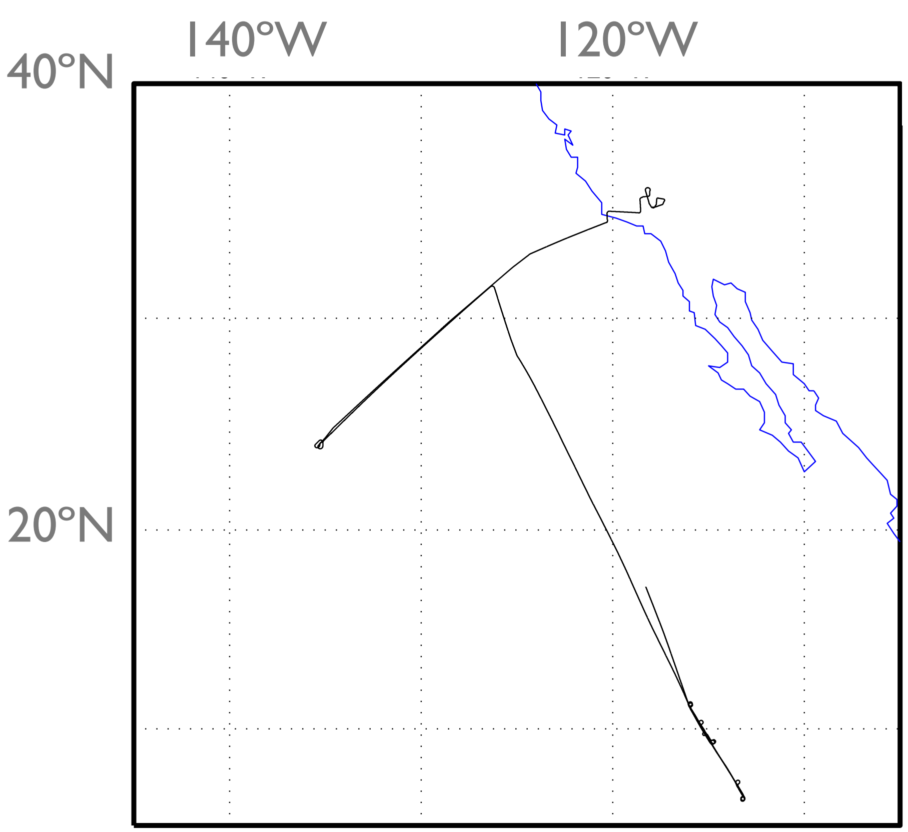


14 km
150 hPa
355 K

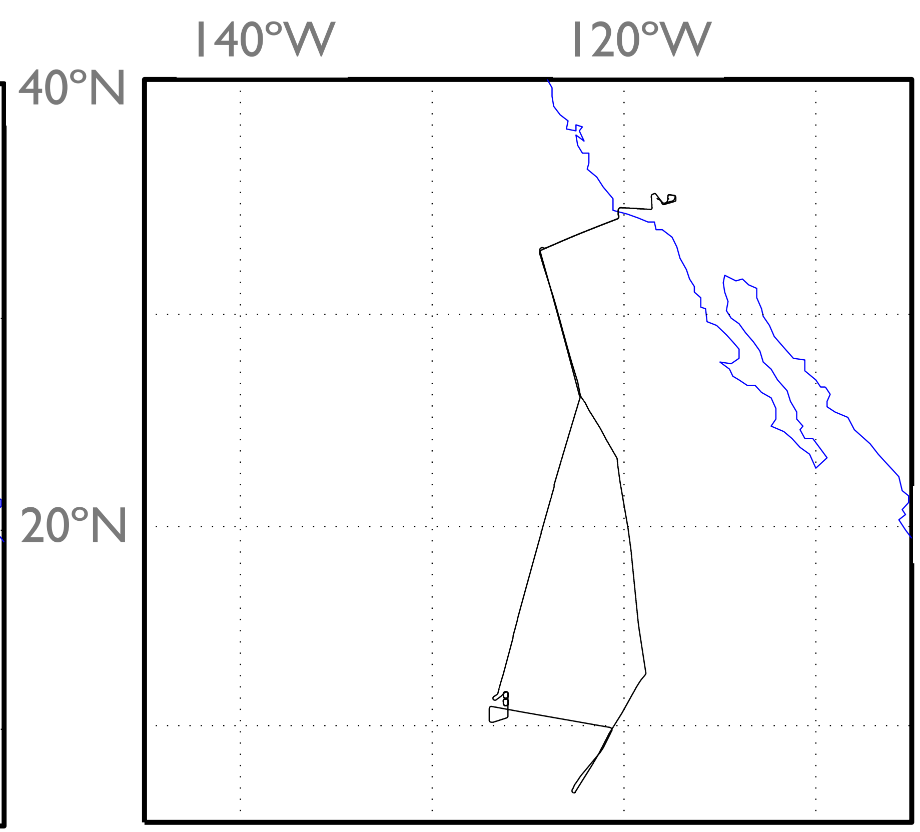
Tropical
Tropopause
Layer

ATTREX Fall 2011 Flight Tracks

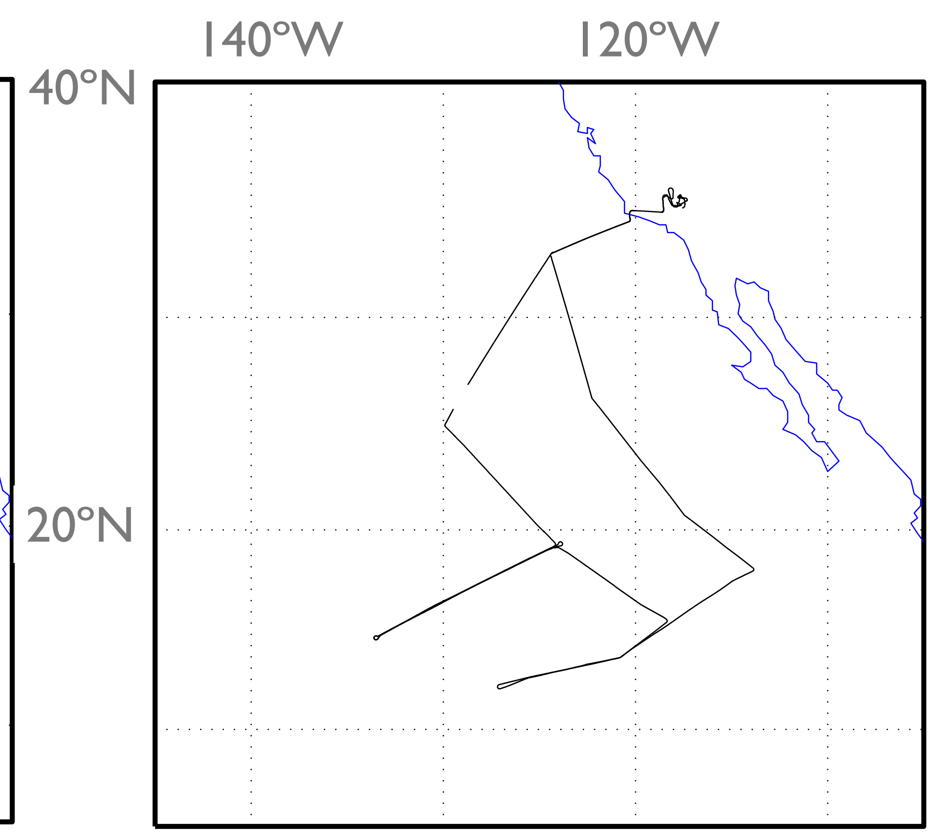
28-29 Oct



5-6 Nov

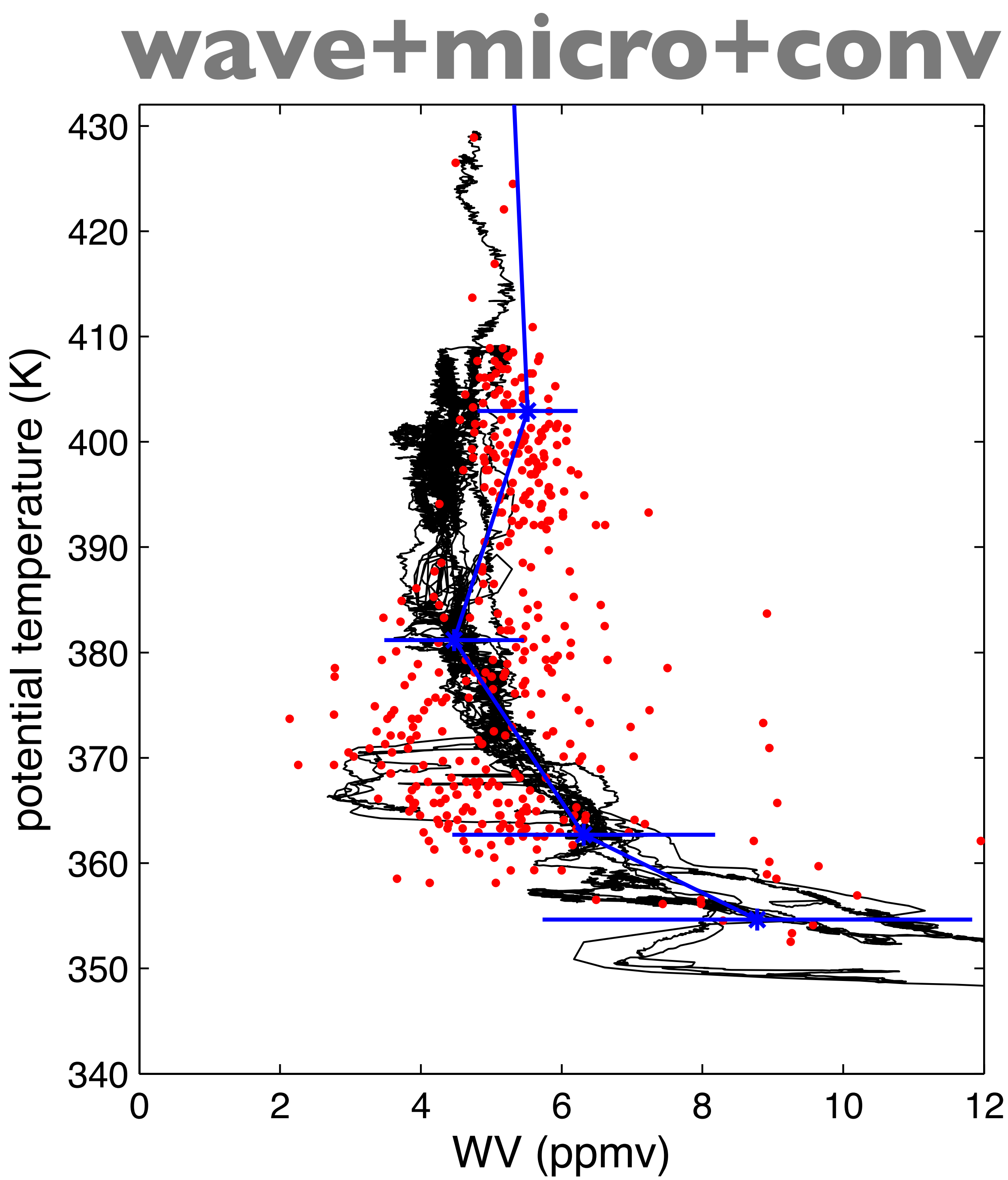


9-10 Nov



Vertical profile of H_2O

(5-6 Nov 2011)



aircraft (DLH)

MLS

model

- waves –0.5 ppmv
- microphysics +1 ppmv
- convection +1 - 5 ppmv

[*Ueyama et al. 2014*]

Research Goal

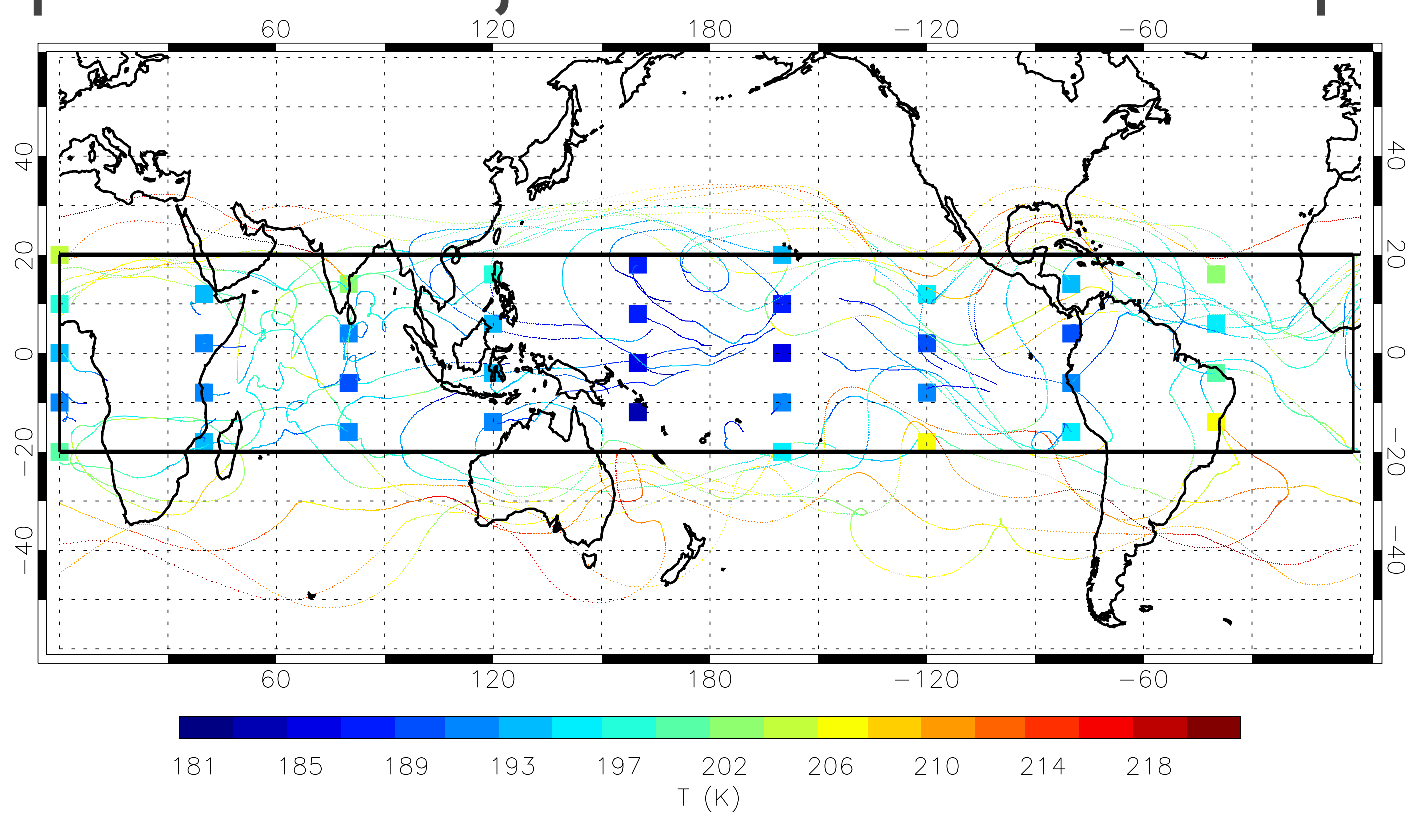
To apply our case study method to a global TTL study to improve understanding of processes (microphysics, convection, waves) that control TTL H_2O and cirrus cloud formation

Method

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

1. Calculate 60-day backward diabatic trajectories from every 2° lat x 2° lon grid points in the tropics (20°S - 20°N) at 371 K (~100 hPa) level ending at 1 Feb 2007 using ERA-Interim temperatures and winds

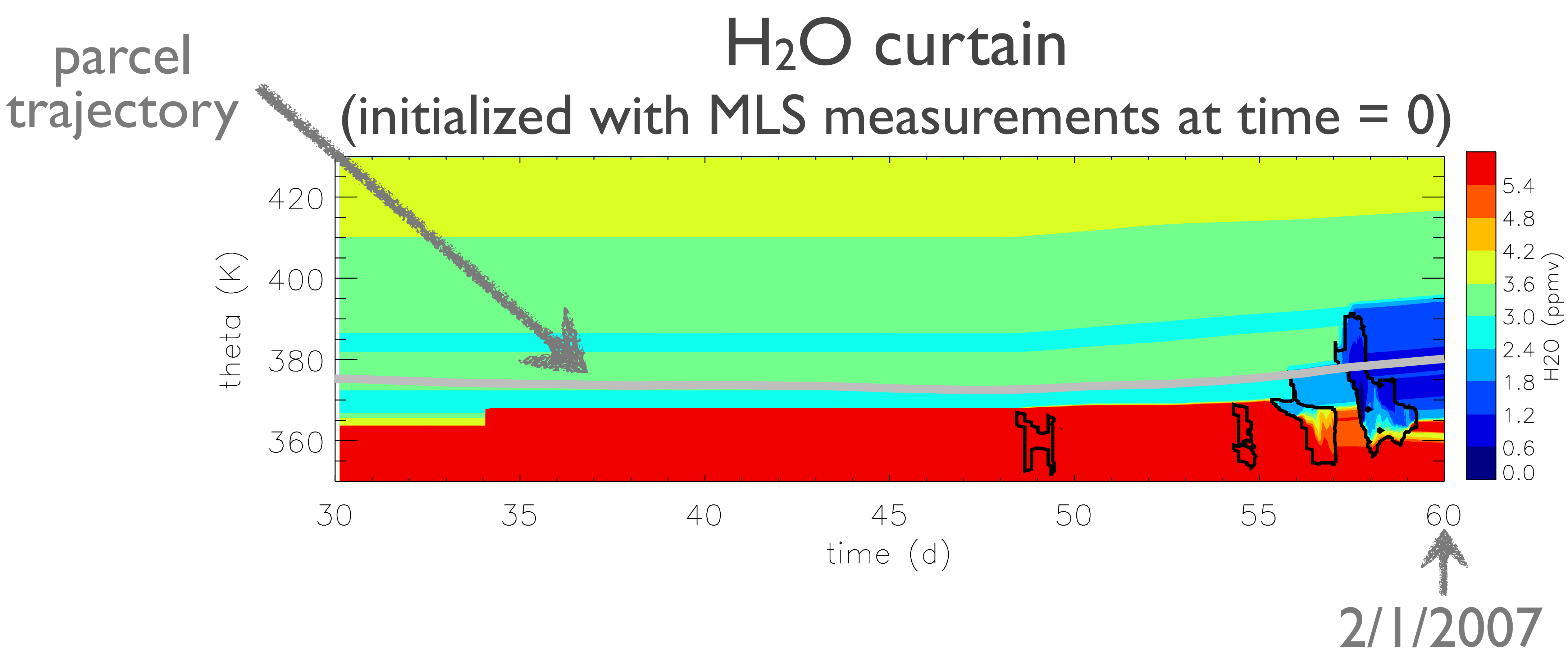
a sample of the trajectories and their temperatures



Method

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

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



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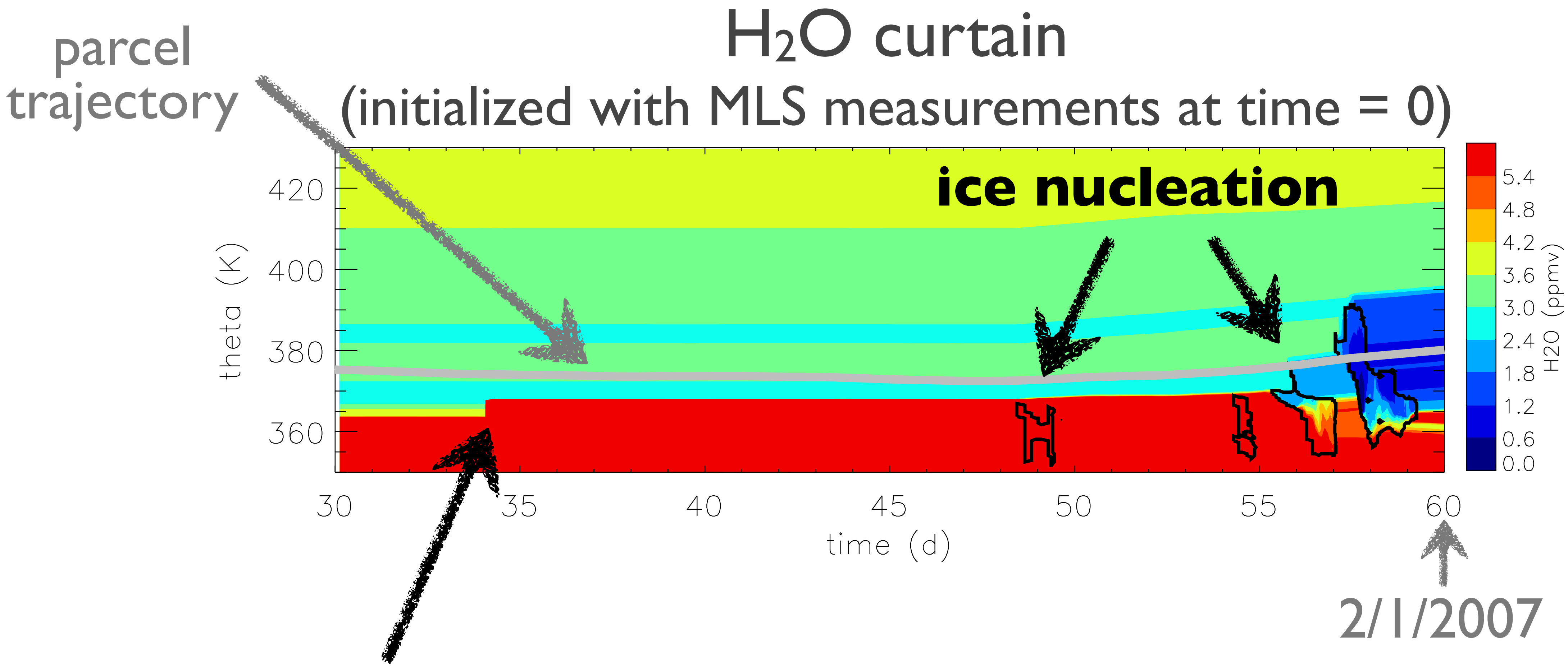
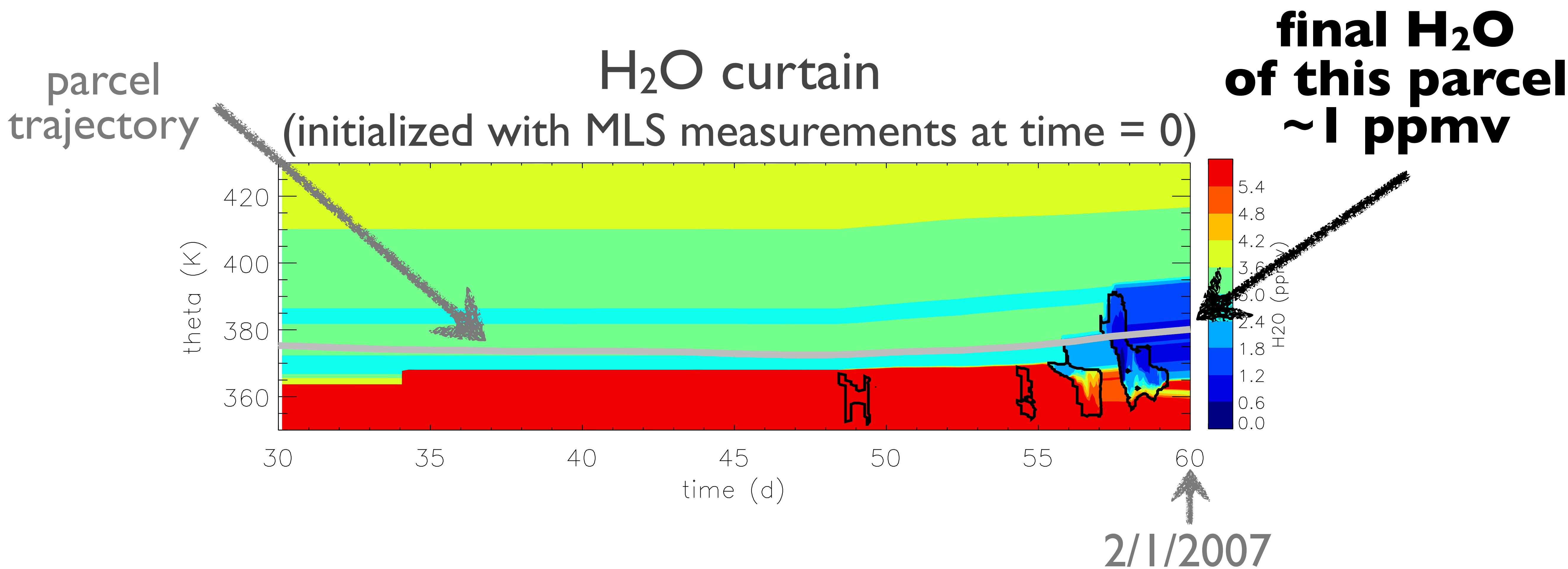


convection (air is saturated up to the cloud top height)

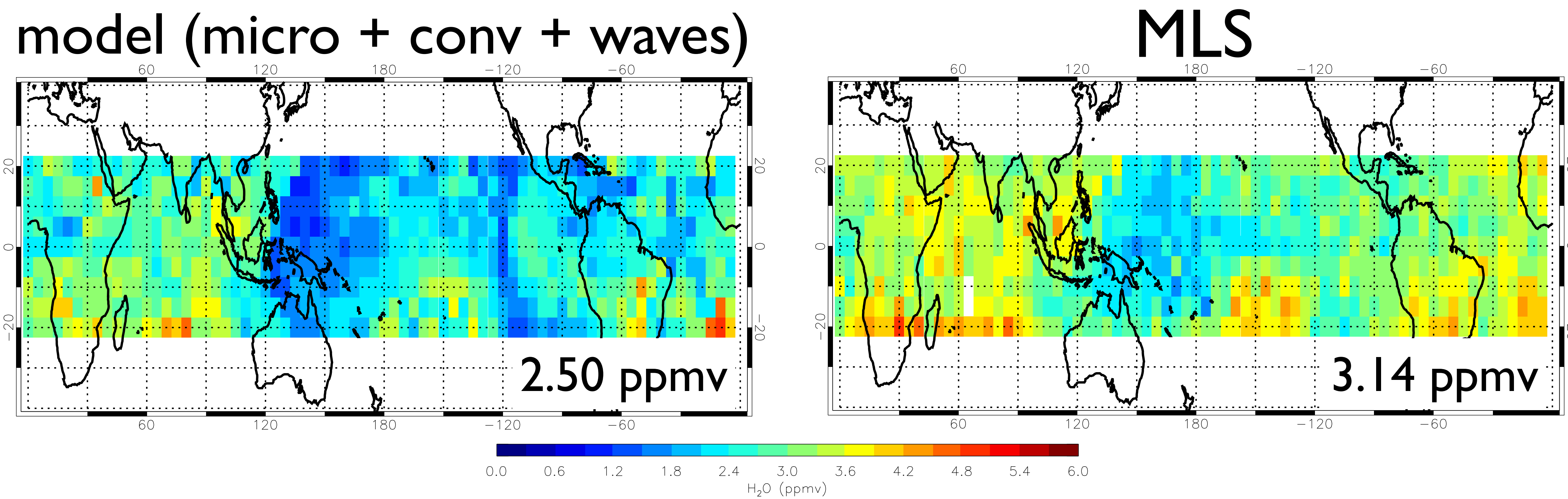
Method

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

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



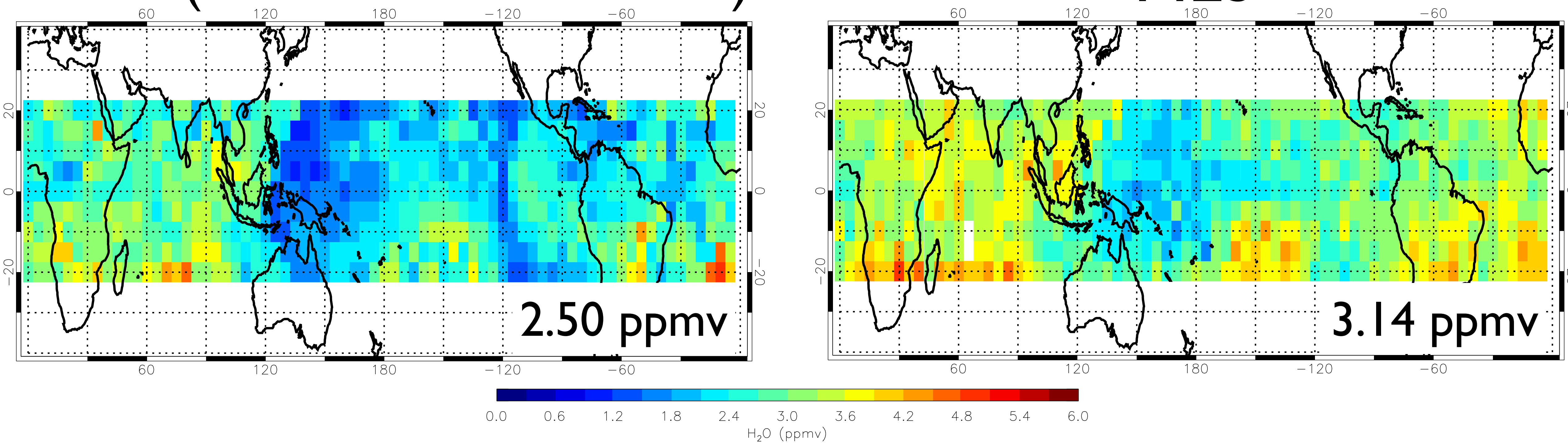
100 hPa H_2O



- reasonable agreement with MLS
  (r = 0.62, *RMSE* = 0.50 ppmv)

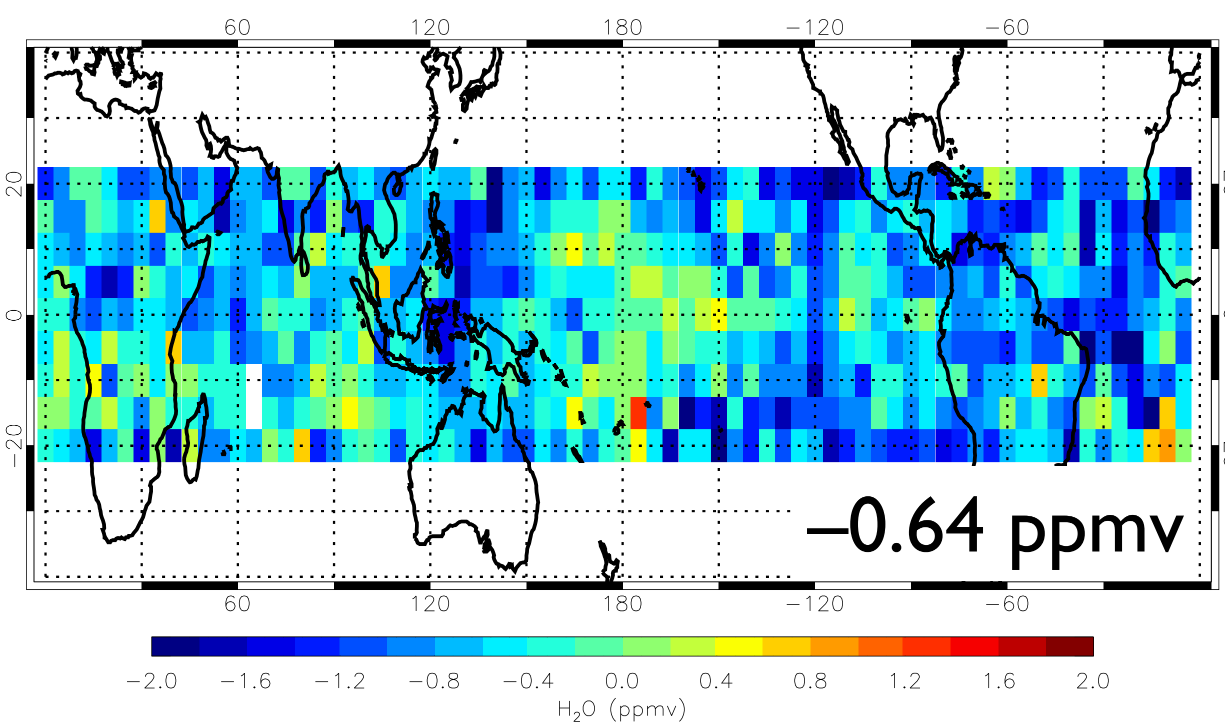
100 hPa H_2O

model (micro + conv + waves) MLS

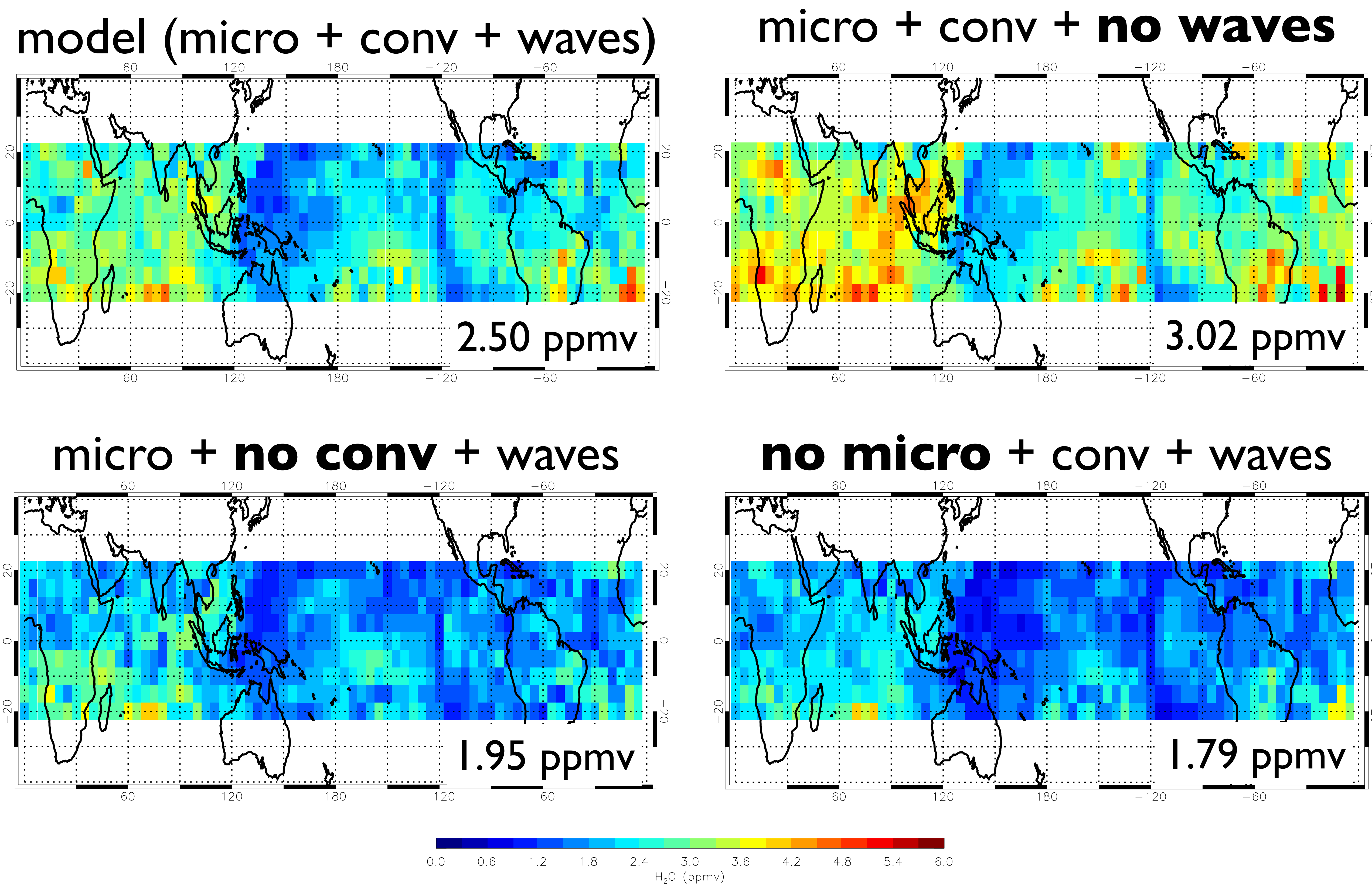


- reasonable agreement with MLS
  (r = 0.62, $RMSE$ = 0.50 ppmv)
- –20% model dry bias
  - *T too cold?* **X**
  - *too little convective influence?* **X**
  - *missing convective injection of ice?* **X**
  - *too many ice nuclei?* **X**
  - *lack of vertical mixing?*
  - *heating rate variability?*

model – MLS



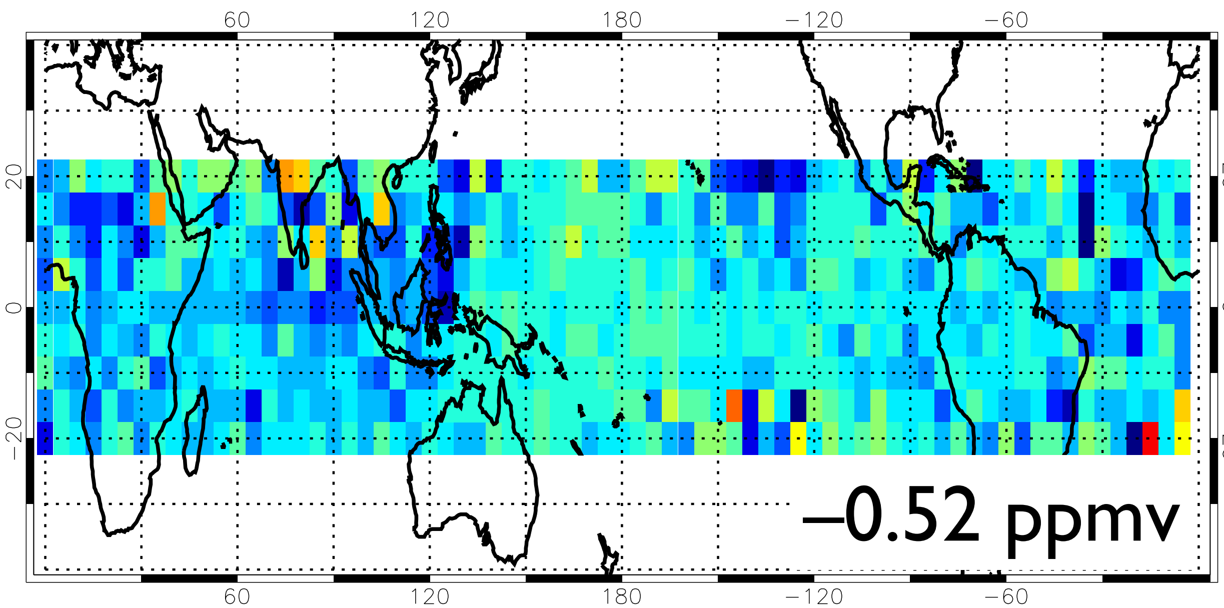
100 hPa H_2O


model (micro + conv + waves)
2.50 ppmv
micro + conv + no waves
3.02 ppmv
micro + no conv + waves
1.95 ppmv
no micro + conv + waves
1.79 ppmv
60 120 180 −120 −60
20 0 −20
0.0 0.6 1.2 1.8 2.4 3.0 3.6 4.2 4.8 5.4 6.0
H2O (ppmv)

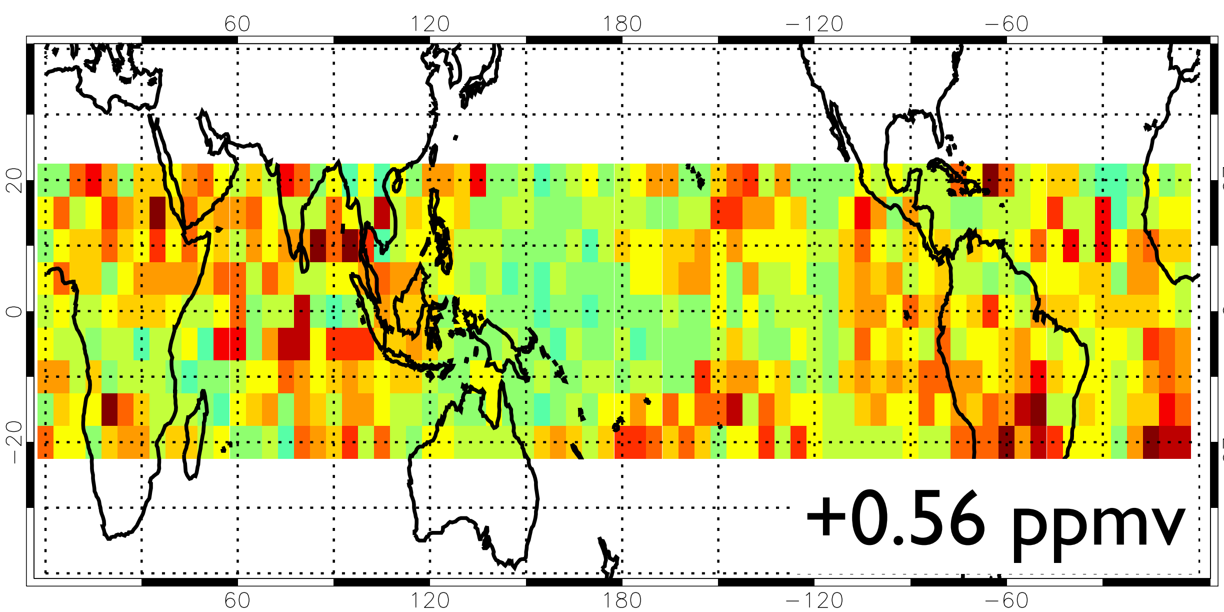
Impact on 100 hPa H_2O

- dehydration pattern by waves resembles CPT difference pattern
- convection moistens everywhere, except over cold T region in western Pacific
- moistening by microphysics due to supersaturation and ice sublimation

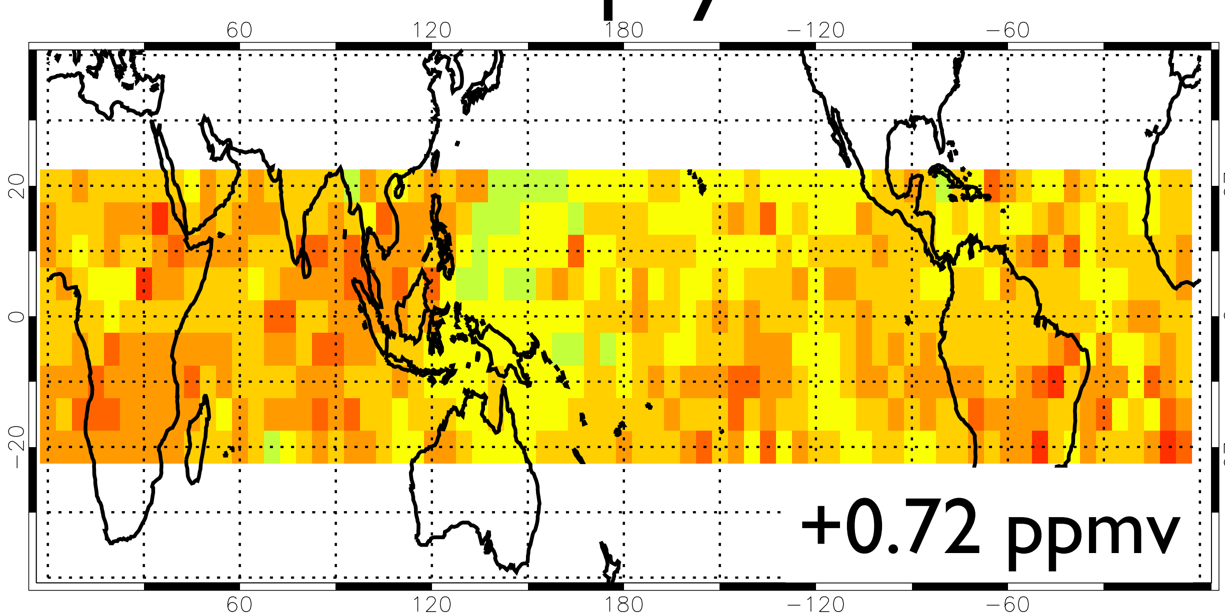
waves

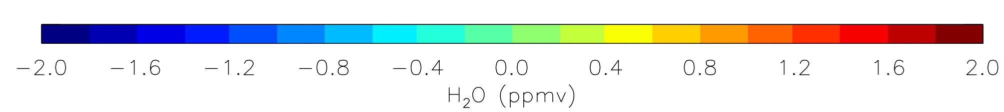


convection



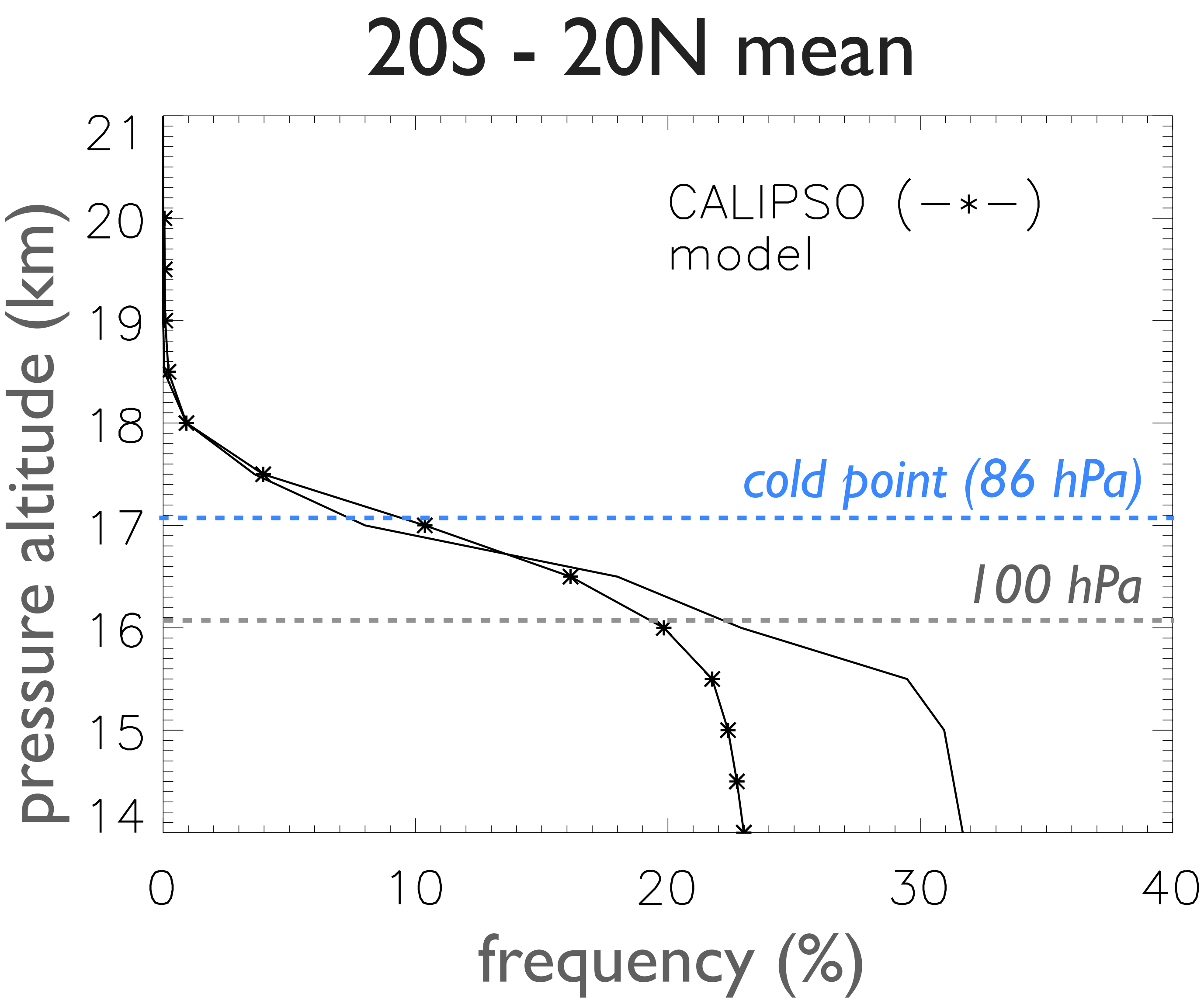
microphysics





Cloud occurrence frequency

Jan 2007



➤ Model produces ~10% more clouds than CALIPSO below ~100 hPa; excellent agreement in mid-upper TTL

Cloud occurrence frequency

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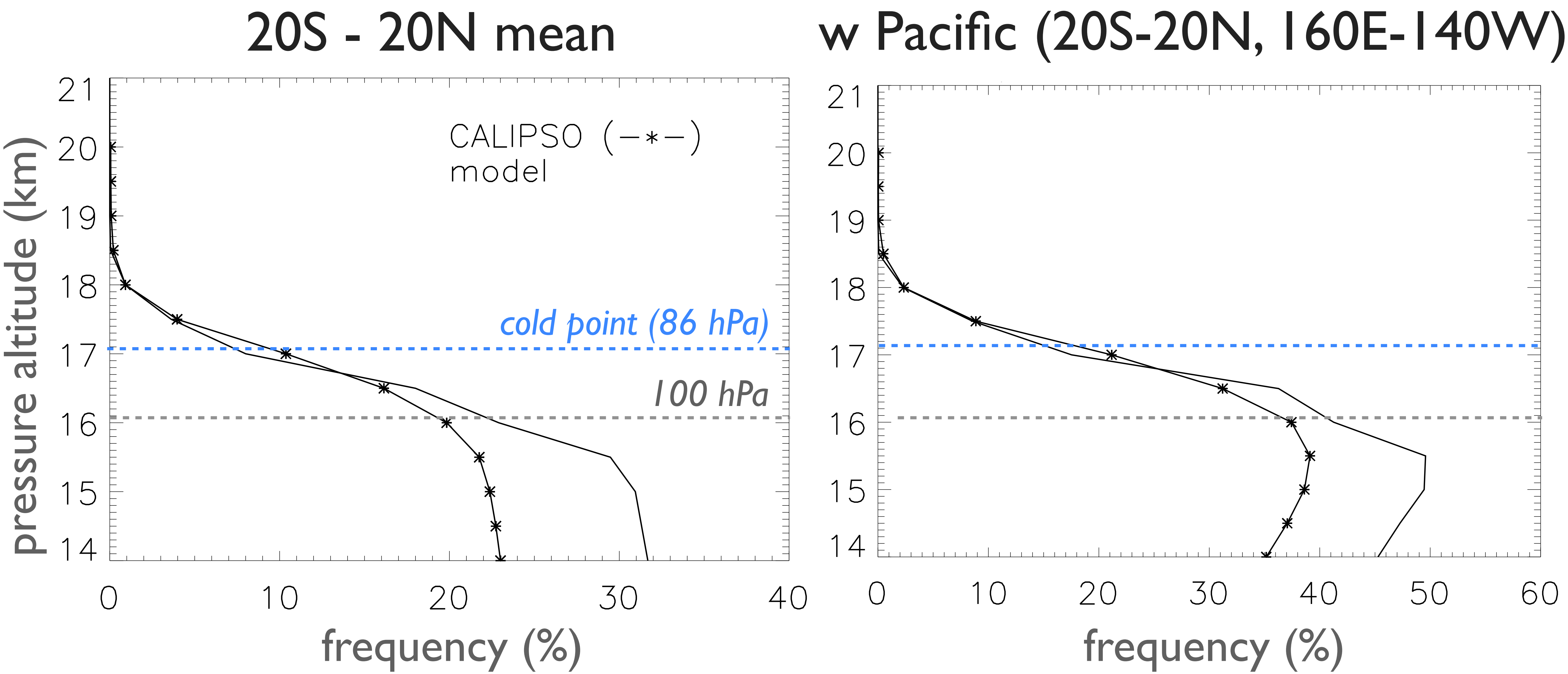

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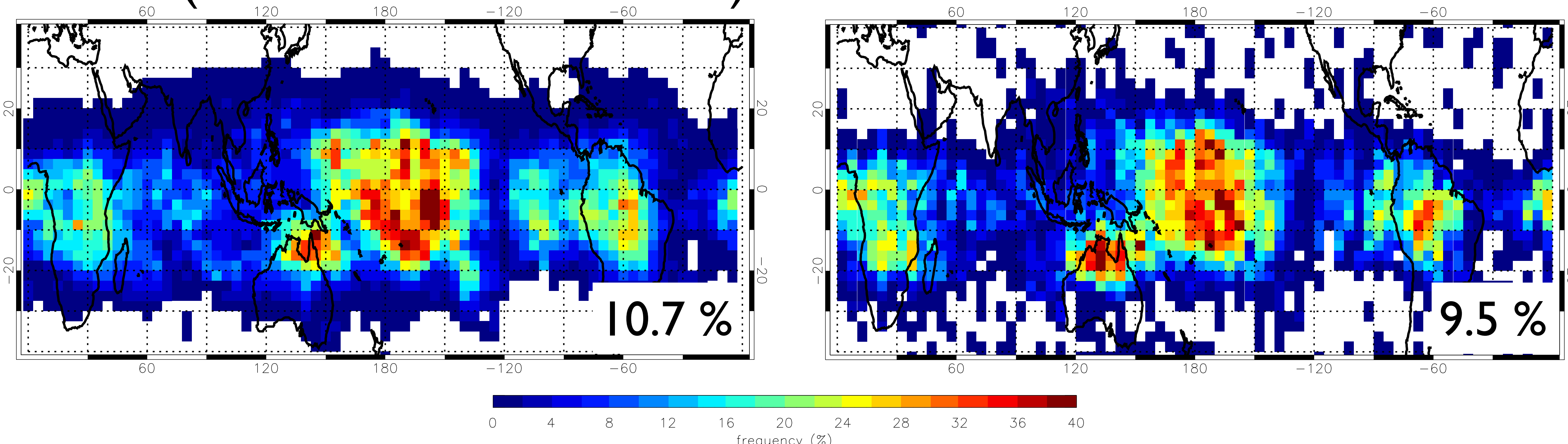
Cloud occurrence frequency

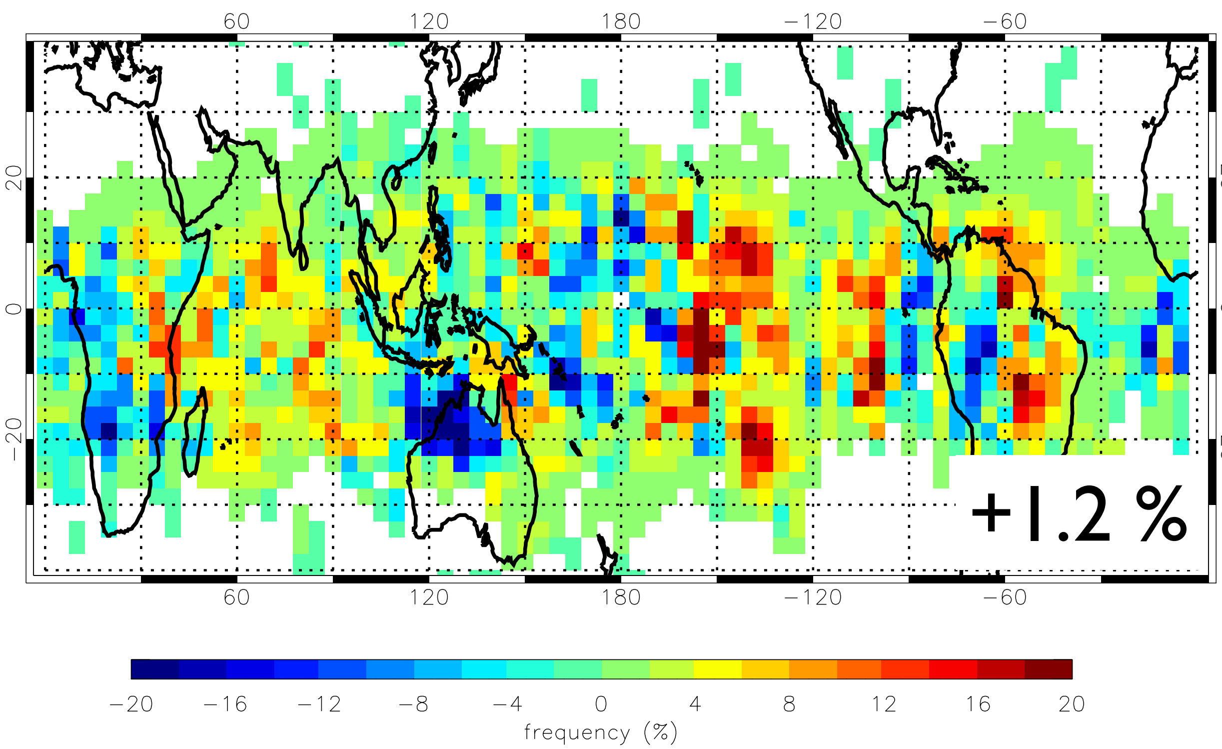
16 – 18 km, Jan 2007

model (micro + conv + waves) CALIPSO

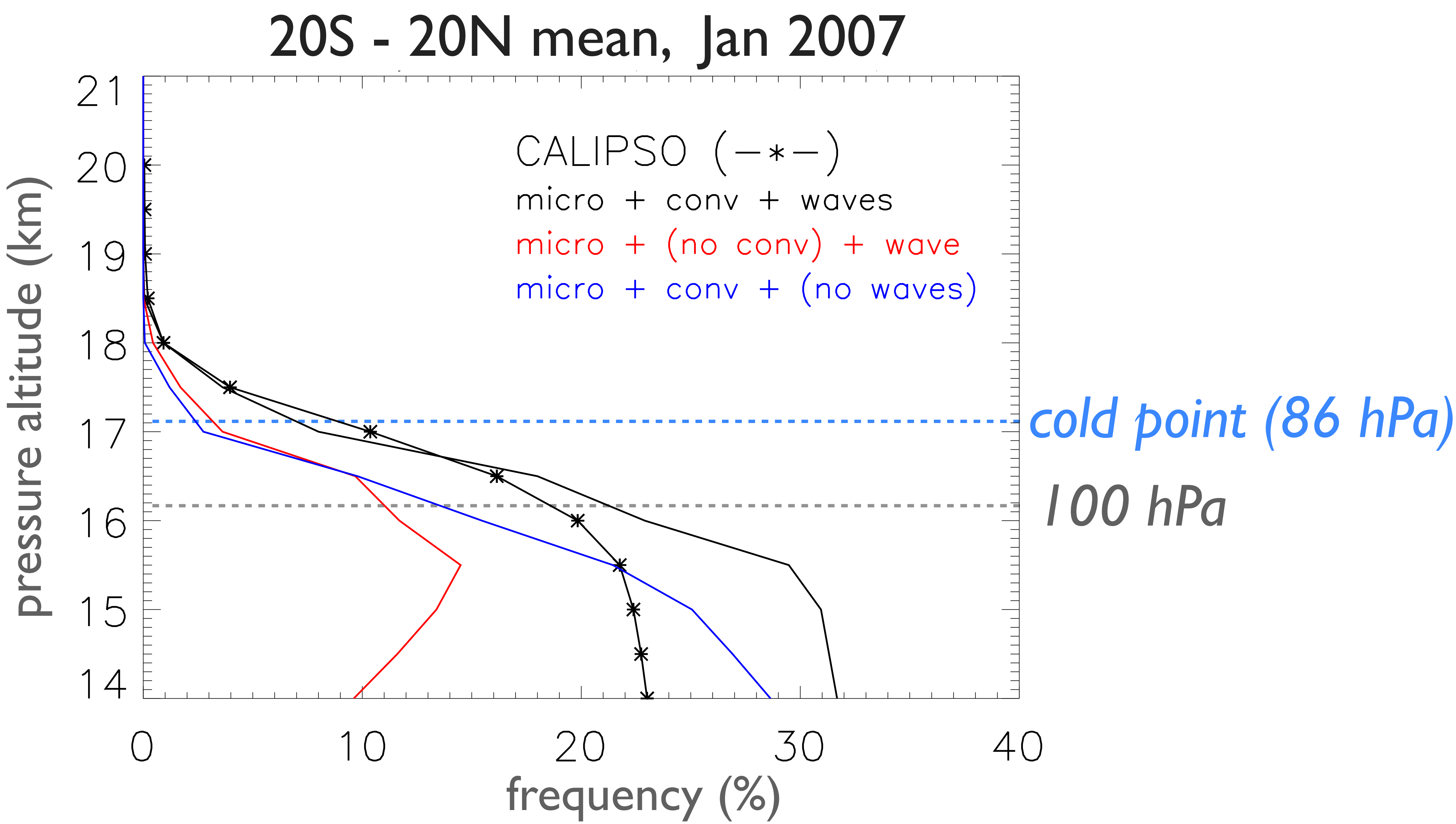


- excellent agreement with CALIPSO (r = 0.79, $RMSE$ = 5.7%)
- ~10% cloud occurrence (20S-20N mean)
- discrepancy may be due to CALIPSO sampling issues and uncertainty in cloud top heights

model – CALIPSO



Cloud occurrence frequency

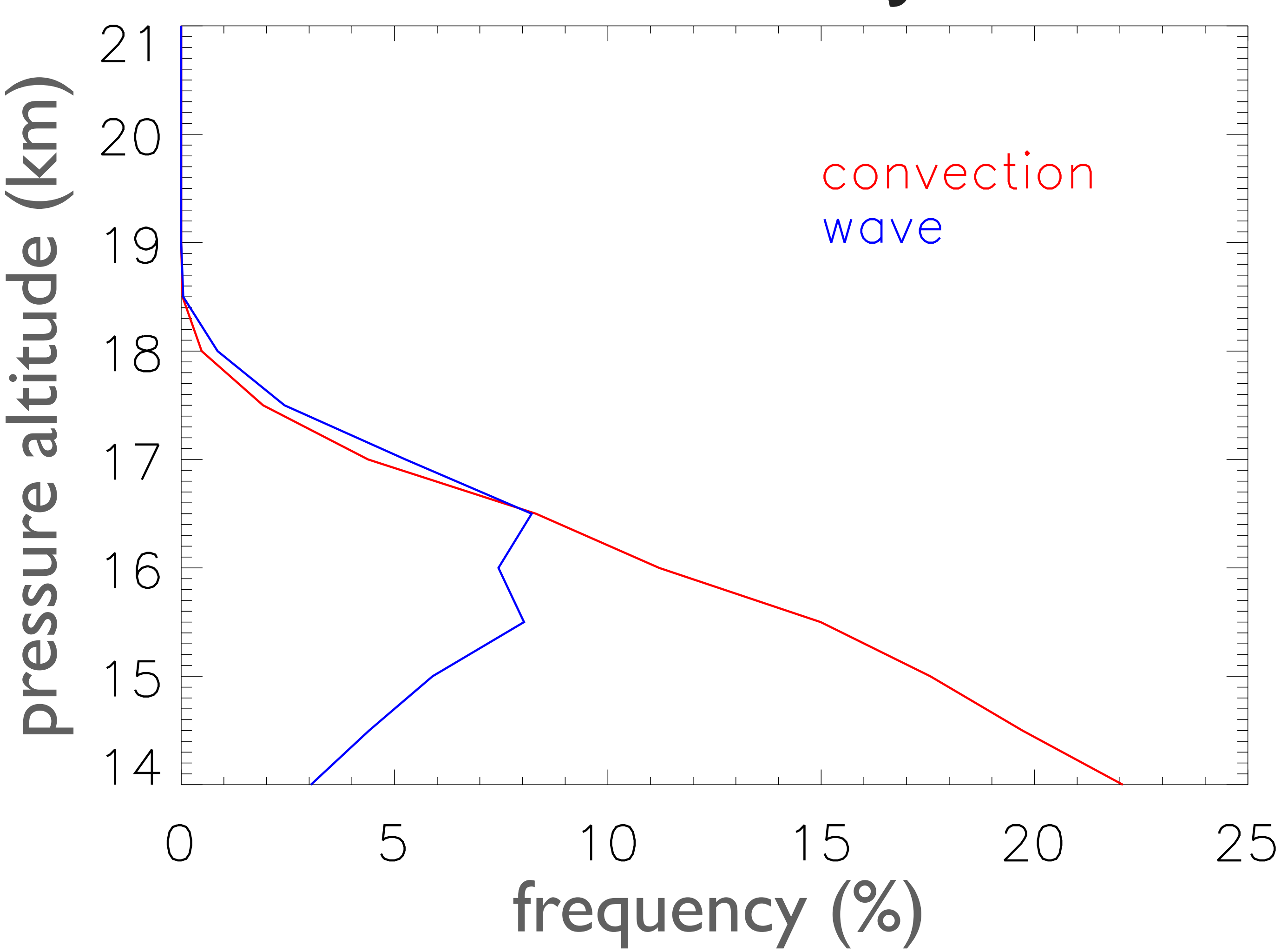


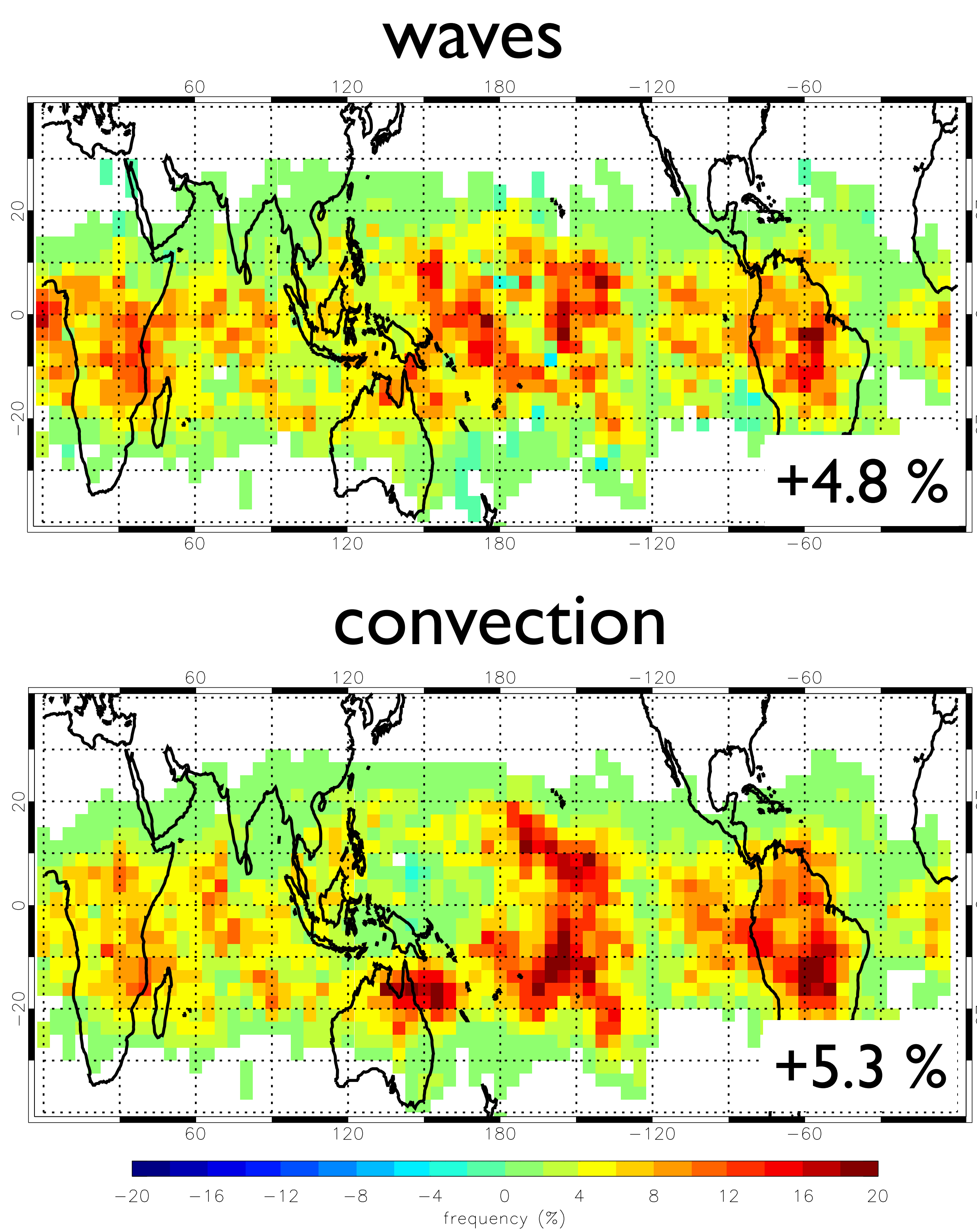
➤ Convection and waves both increase cloud occurrence throughout the TTL

Impact on cloud occurrence

16 - 18 km

20S - 20N mean, Jan 2007





- enhancement by convection dominates in the lower TTL (10-20%)
- waves and convection increase cloud occurrence by ~5% in 16-18 km layer

Summary

- Simulation of wintertime TTL (100 hPa) H_2O with microphysics, convection and waves improves agreement with MLS, but is still 20% too dry
  - role of mixing? temporal variability of heating rates?

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  - waves –0.5 ppmv
  - convection +0.6 ppmv
  - microphysics +0.7 ppmv

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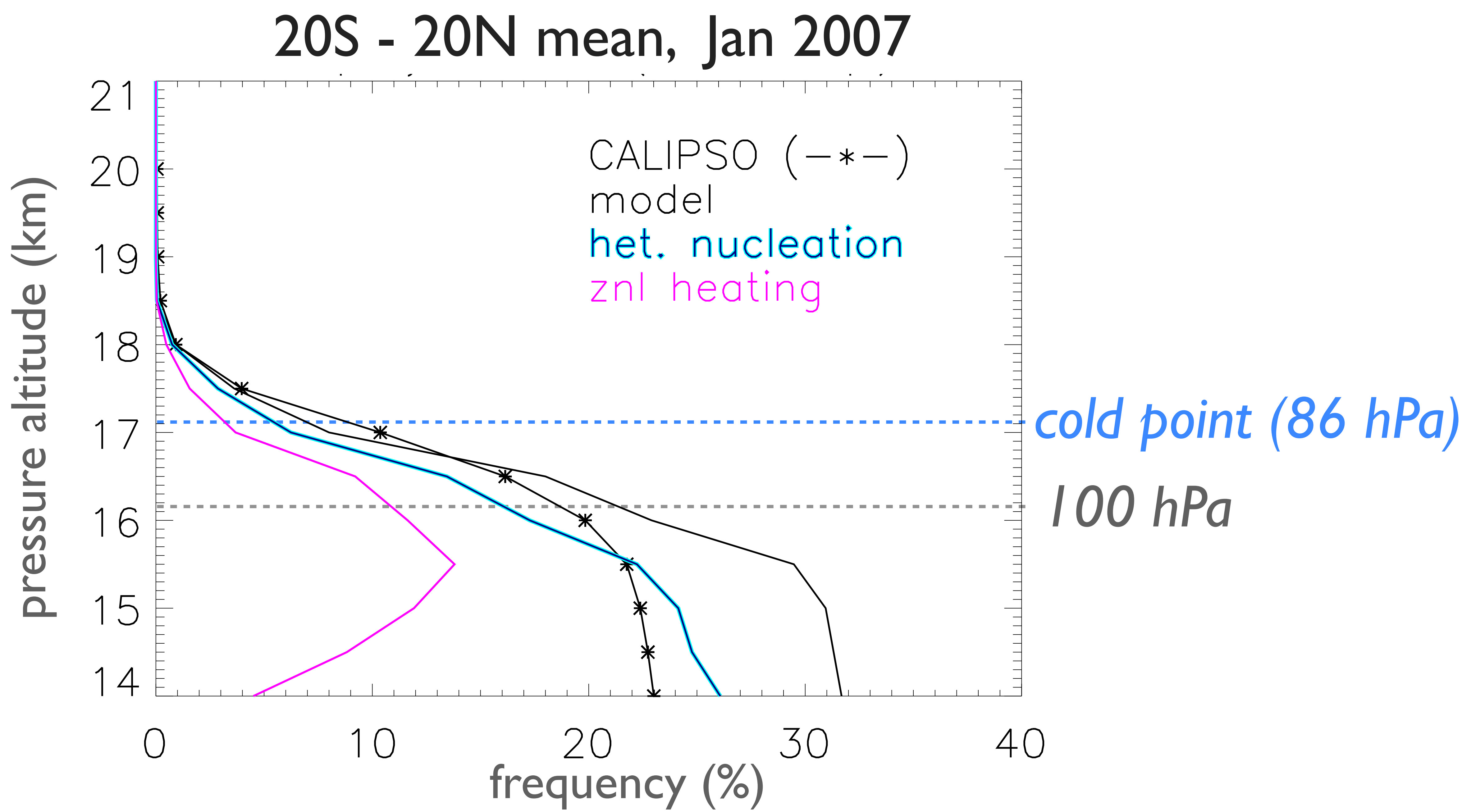
- The model overestimates cloud occurrence by 10% in the lower TTL where convection enhances tropical mean frequencies by up to 20%

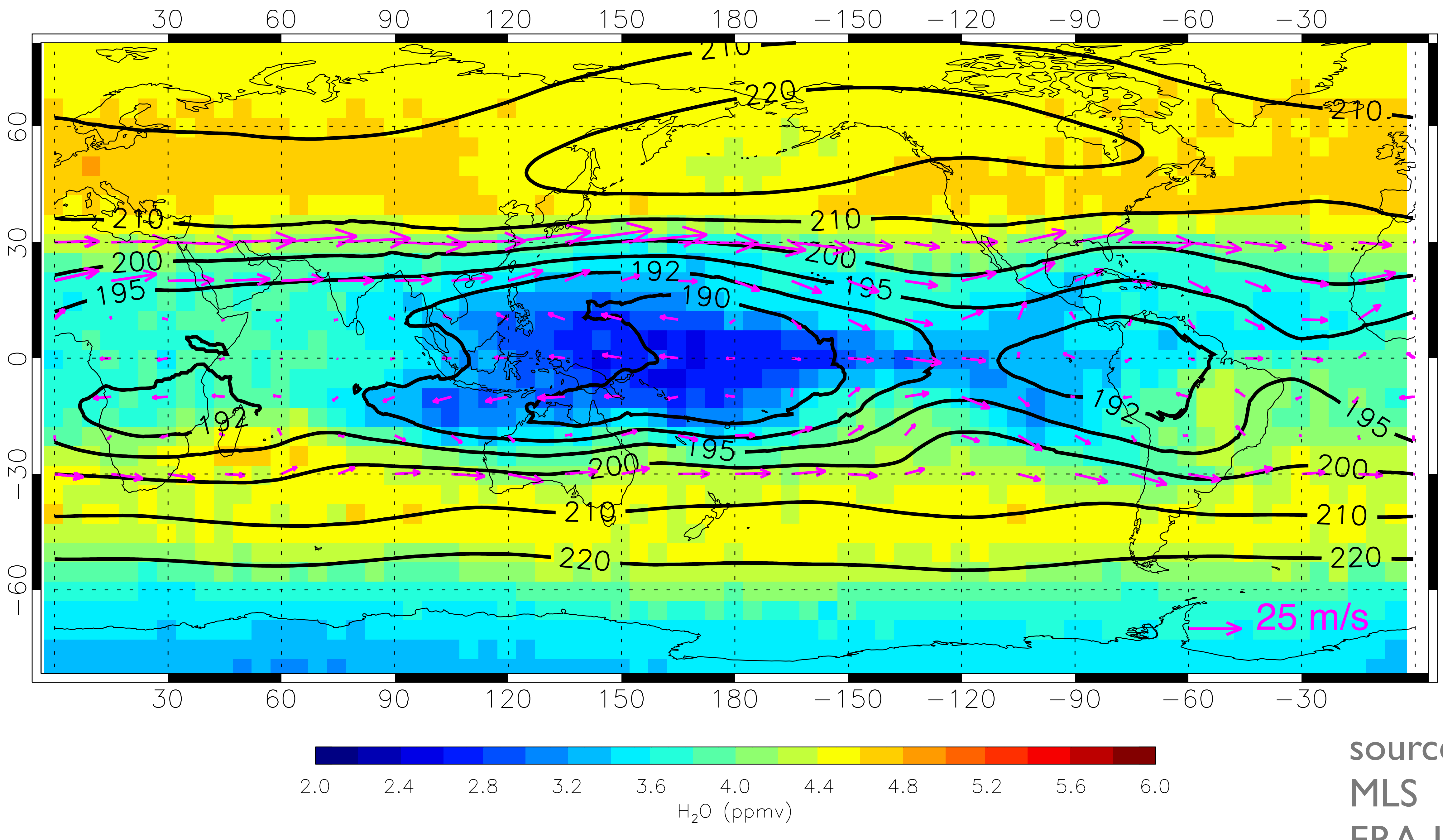
extra slides

Cloud occurrence frequency



➤ Model produces ~10% more clouds than CALIPSO below ~100 hPa; excellent agreement in mid-upper TTL

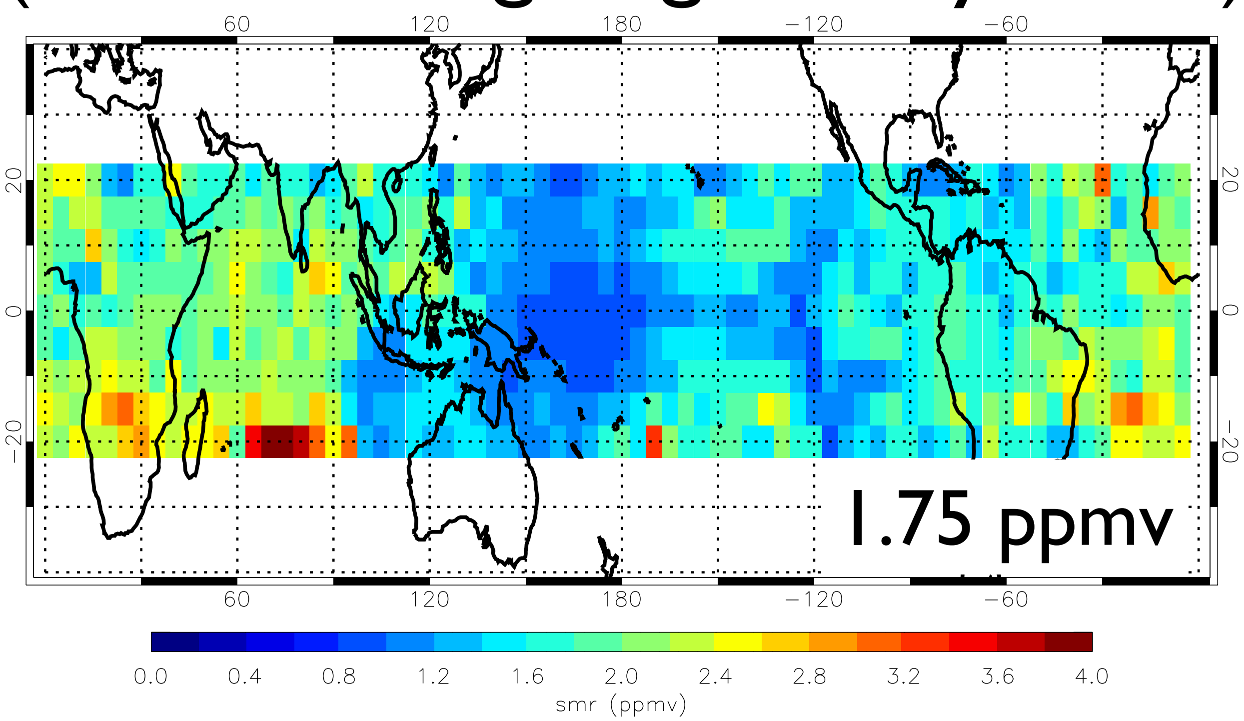
H_2O (color), T (contours) at 100 hPa
Dec-Jan-Feb 2006-07



source:
MLS
ERA-Interim

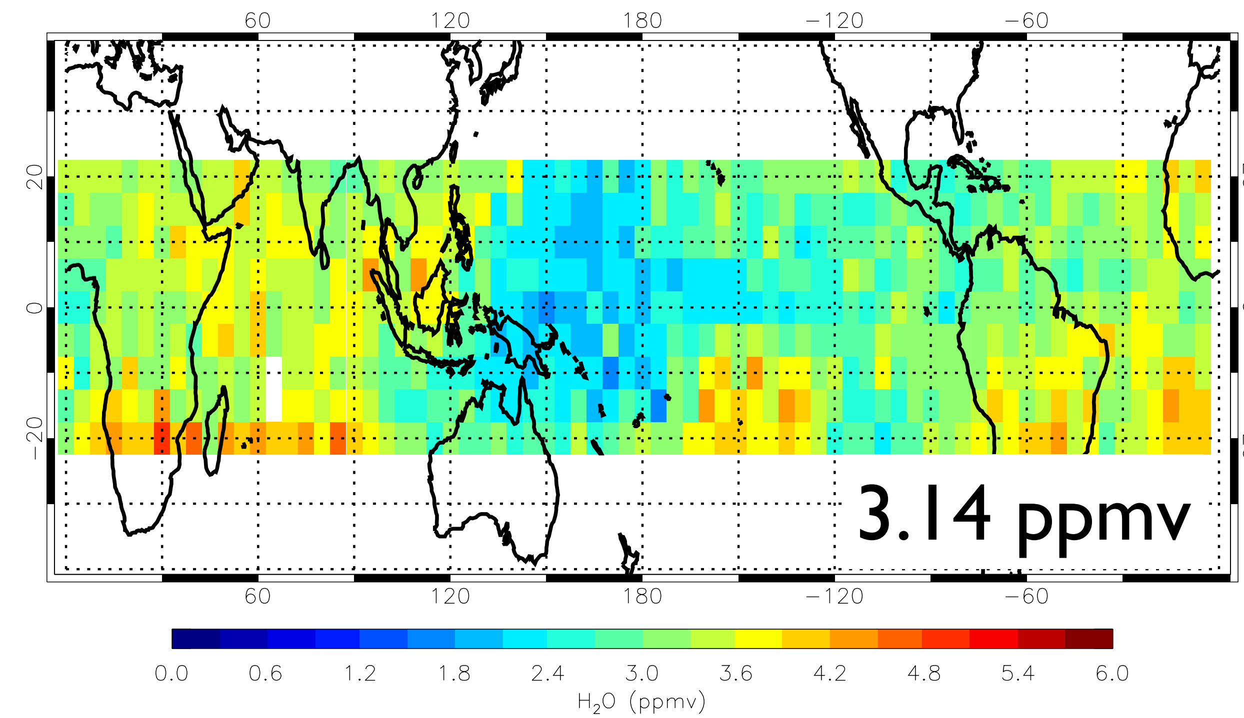
100 hPa H_2O
(1 Feb 2007)

min saturation mixing ratio
(based on Lagrangian Dry Point)



(0 - 4 ppmv)

MLS

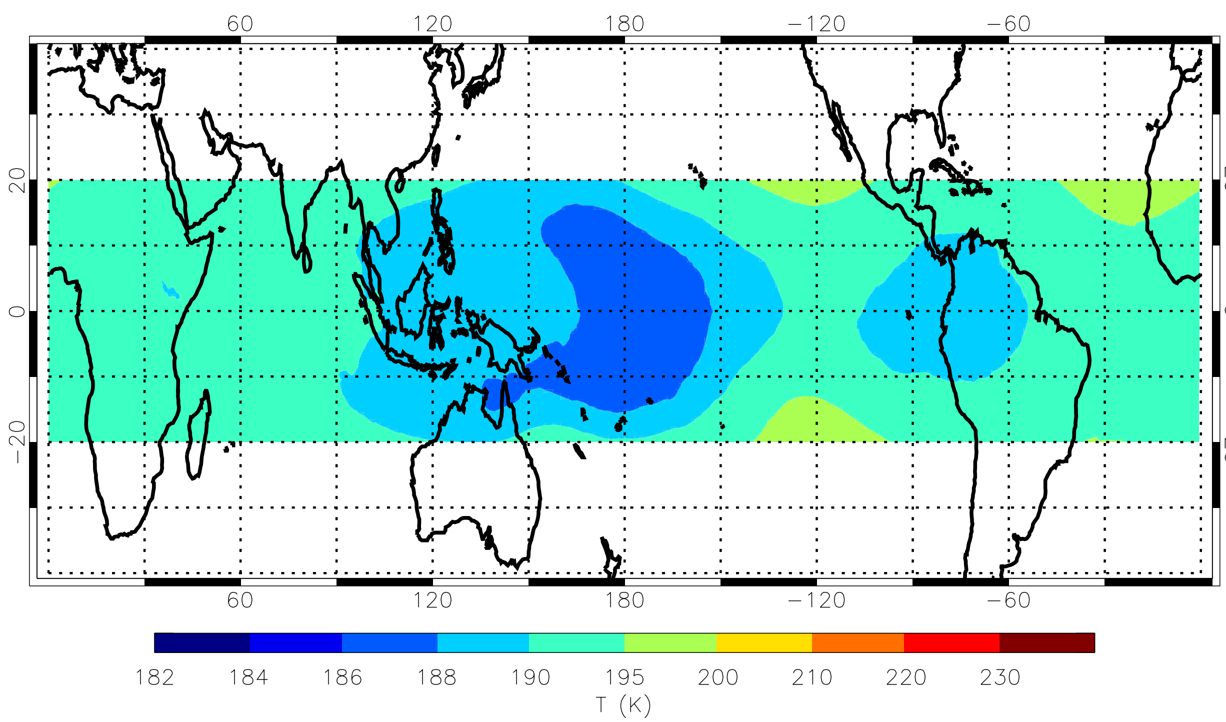


(0 - 6 ppmv)

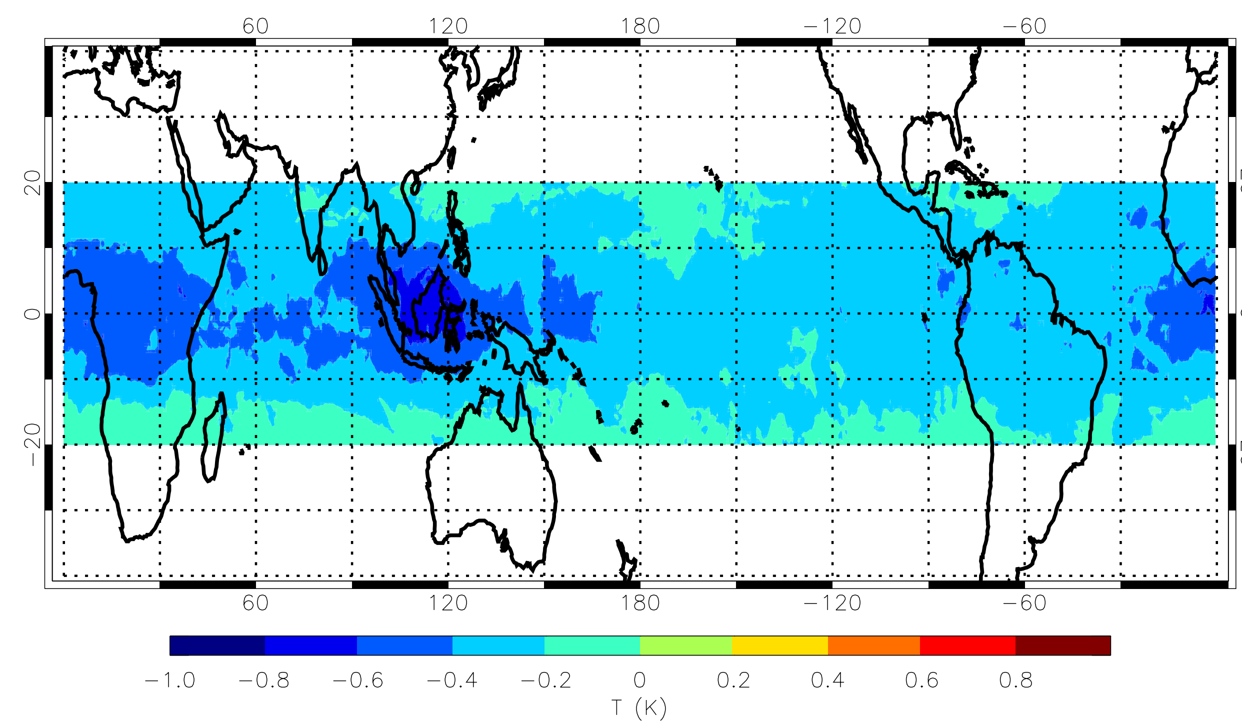
➤ LDP of the trajectories (no cloud simulation) underestimates TTL humidity by ~45%

ERA-Interim data (DJF 2006-07) with *Kim and Alexander 2013* wave scheme

cold point temperature (CPT) with waves



CPT difference (waves – no waves)

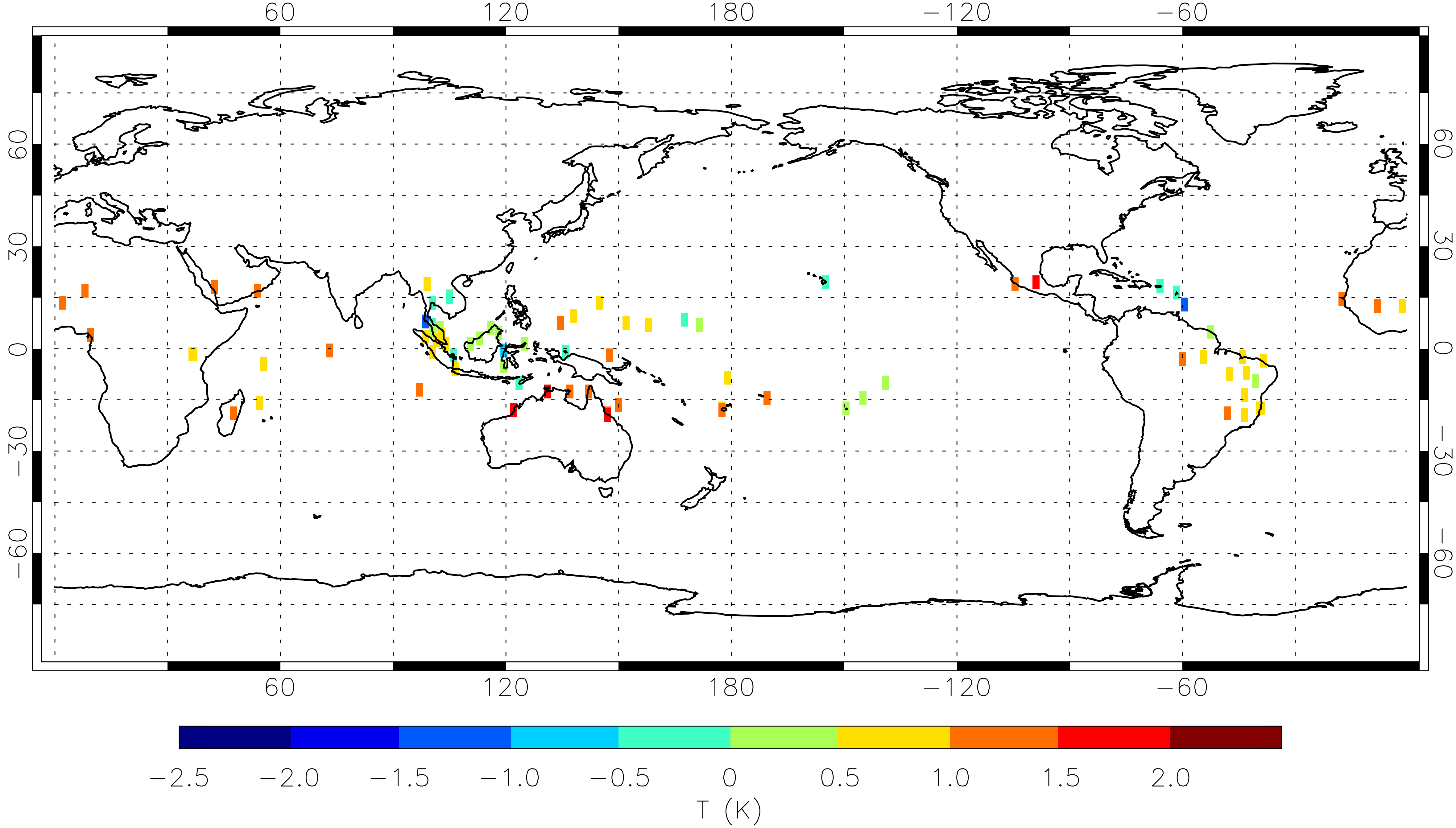


➤ Waves decrease CPT everywhere in the tropics (min –0.8 K over Indonesia)

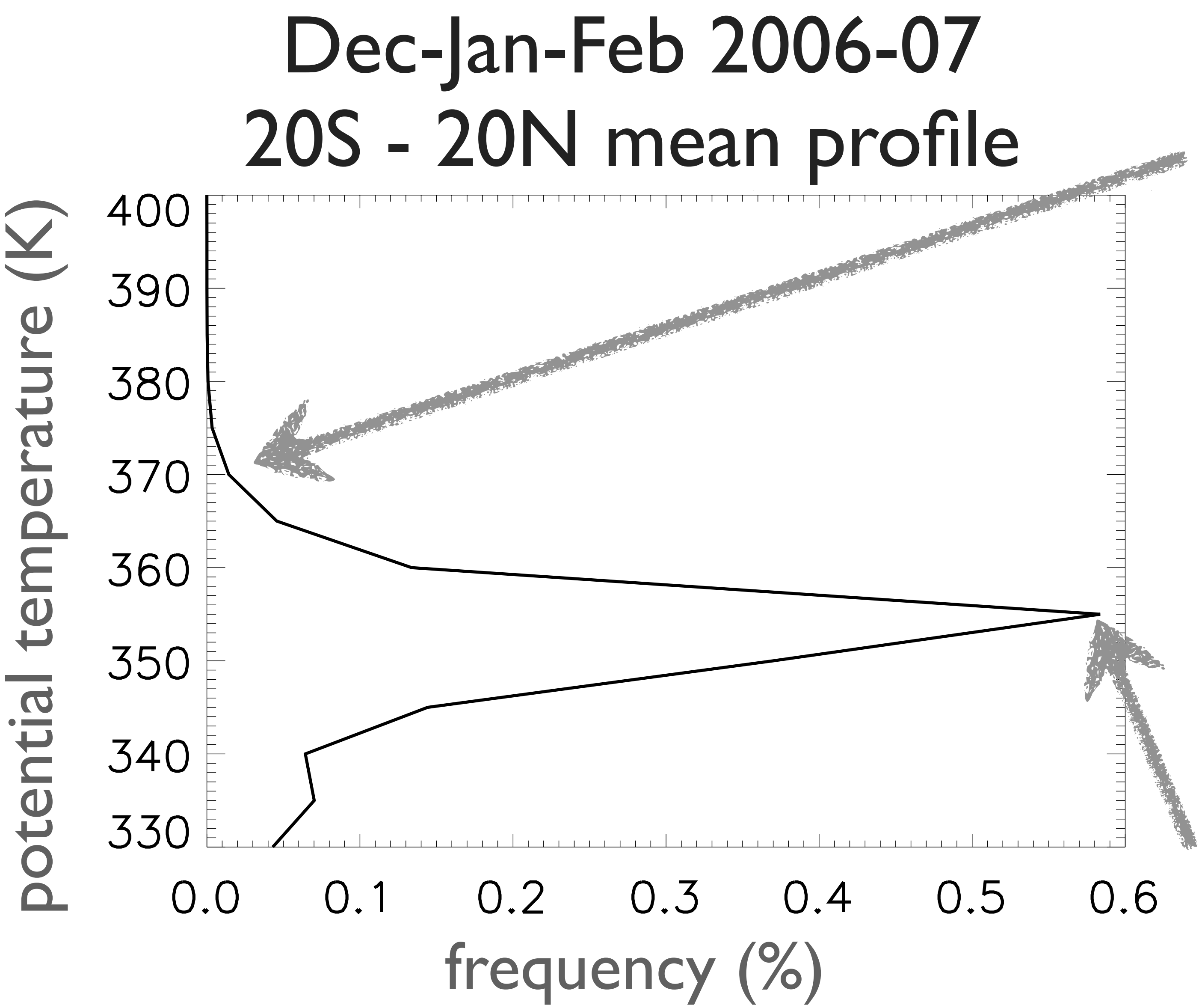
CPT difference

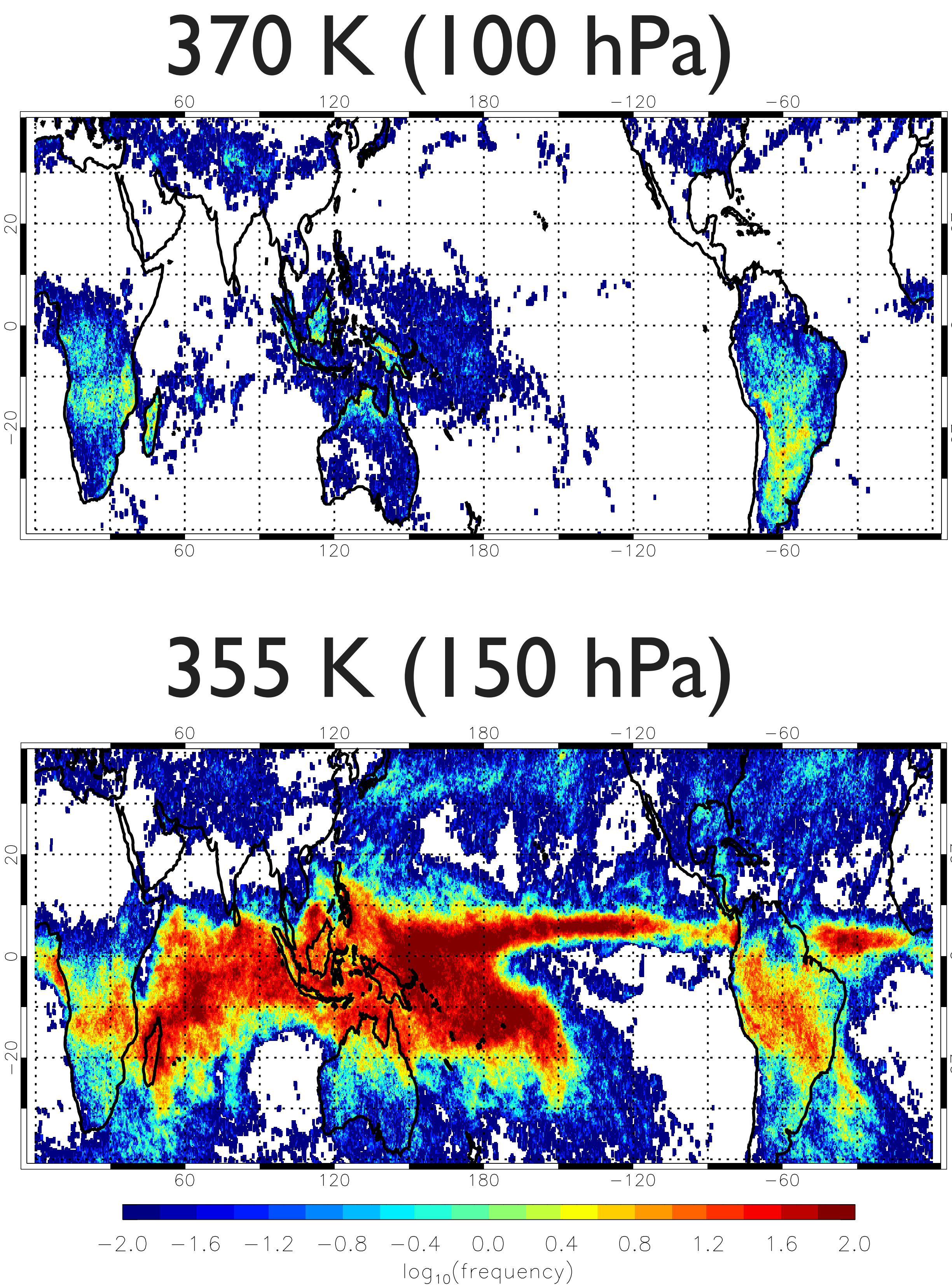
(Dec-Jan-Feb 2006-07)

mean difference (ERA – radiosonde) = +0.34 K



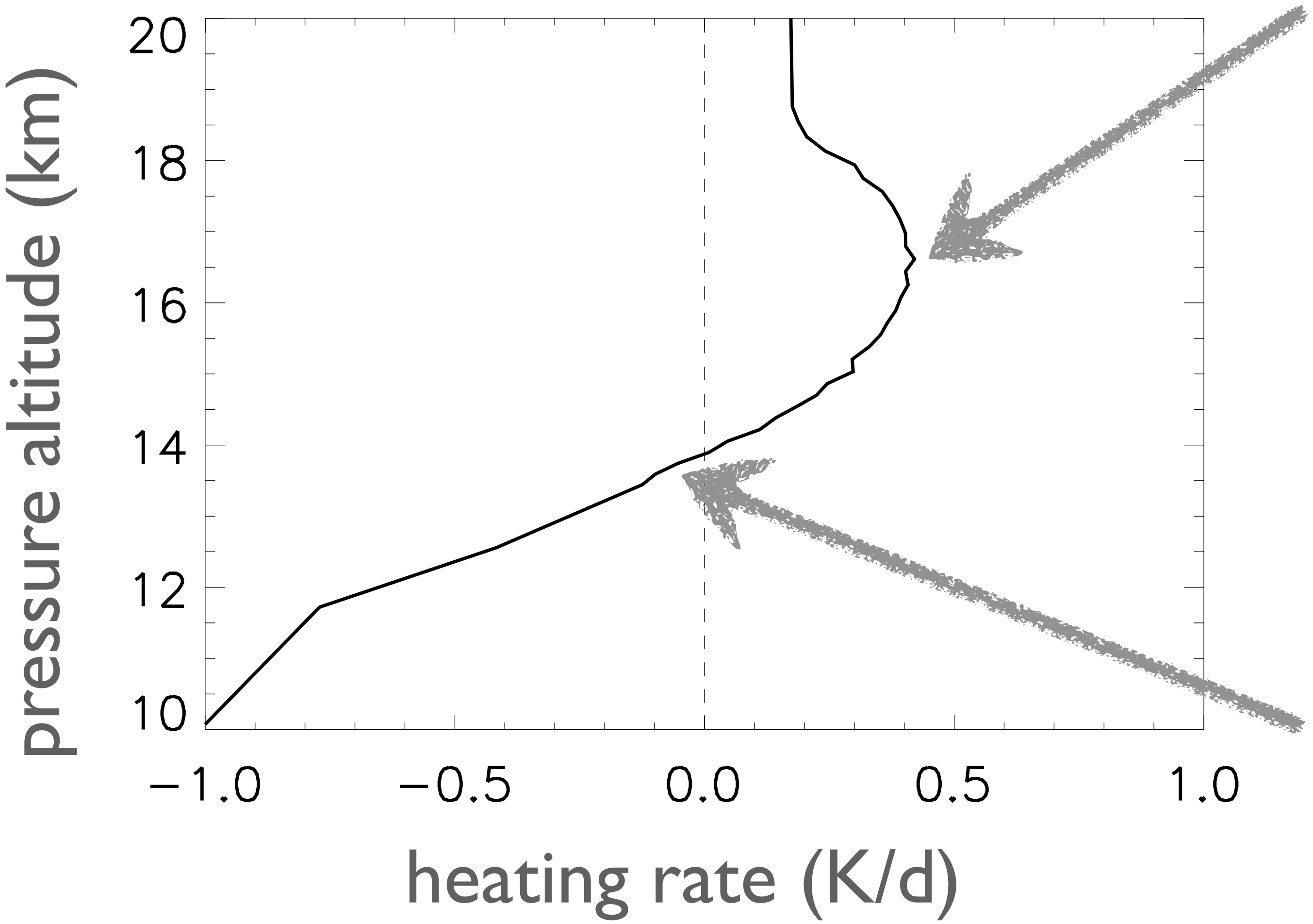
Convective cloud top distribution



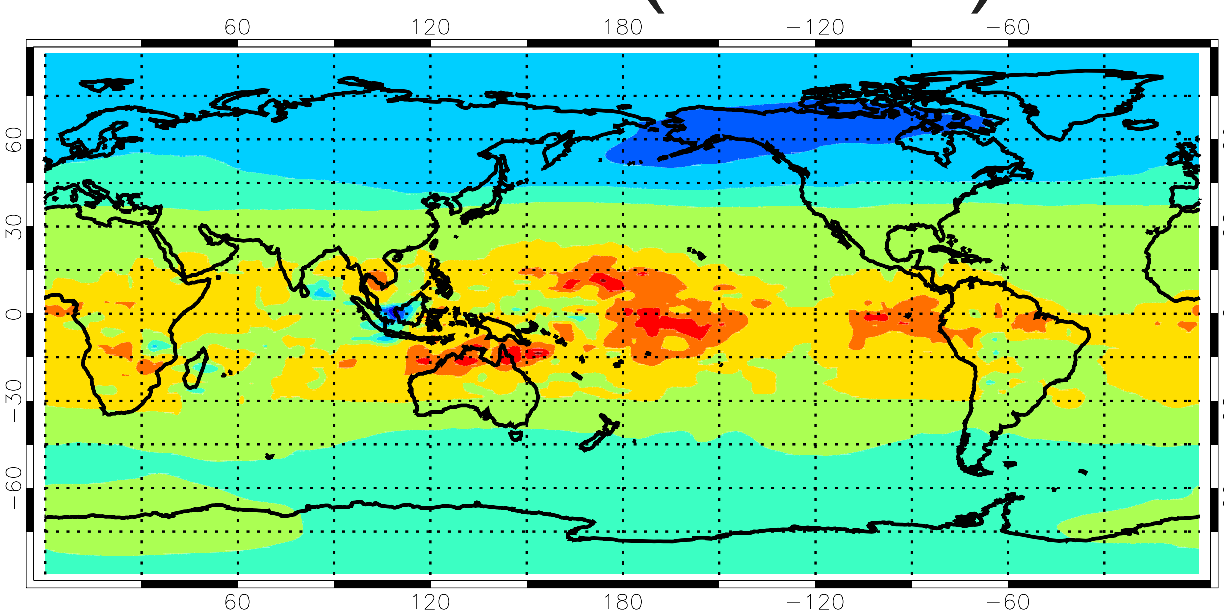


Yang et al. (2010) + MERRA heating rates

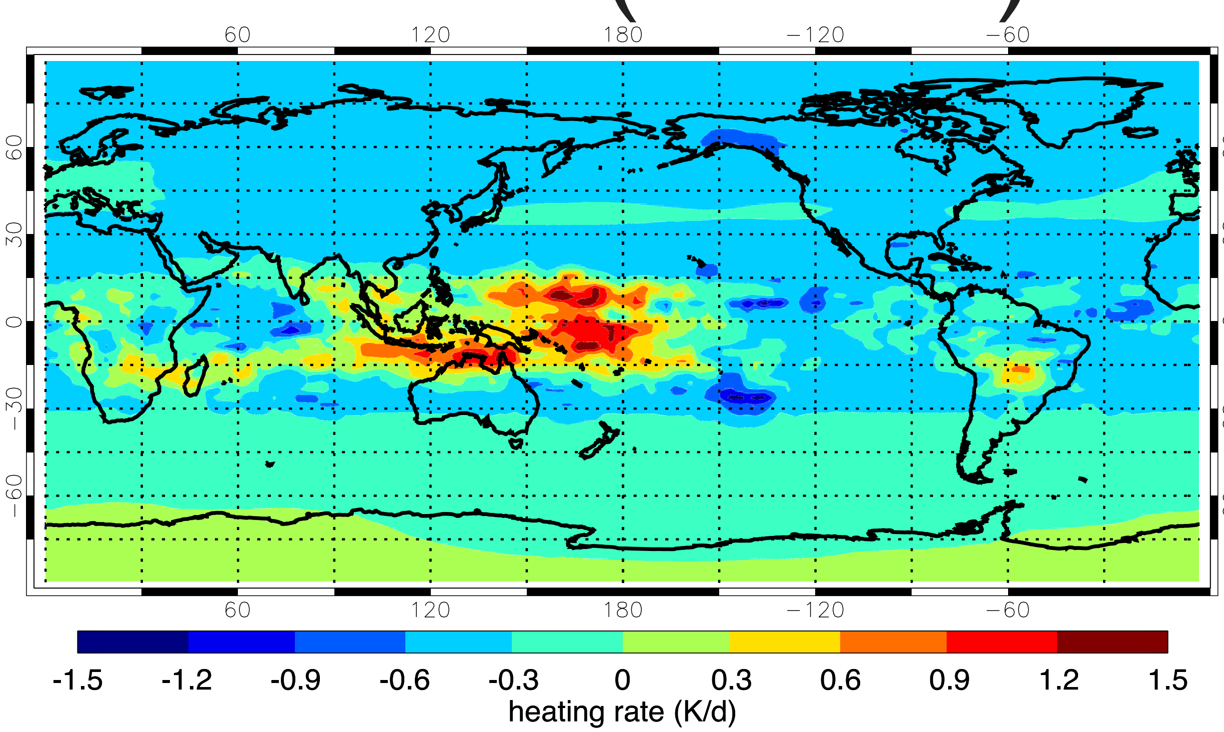
Dec-Jan-Feb 2006-07
20S - 20N mean profile



16.2 km (99 hPa)

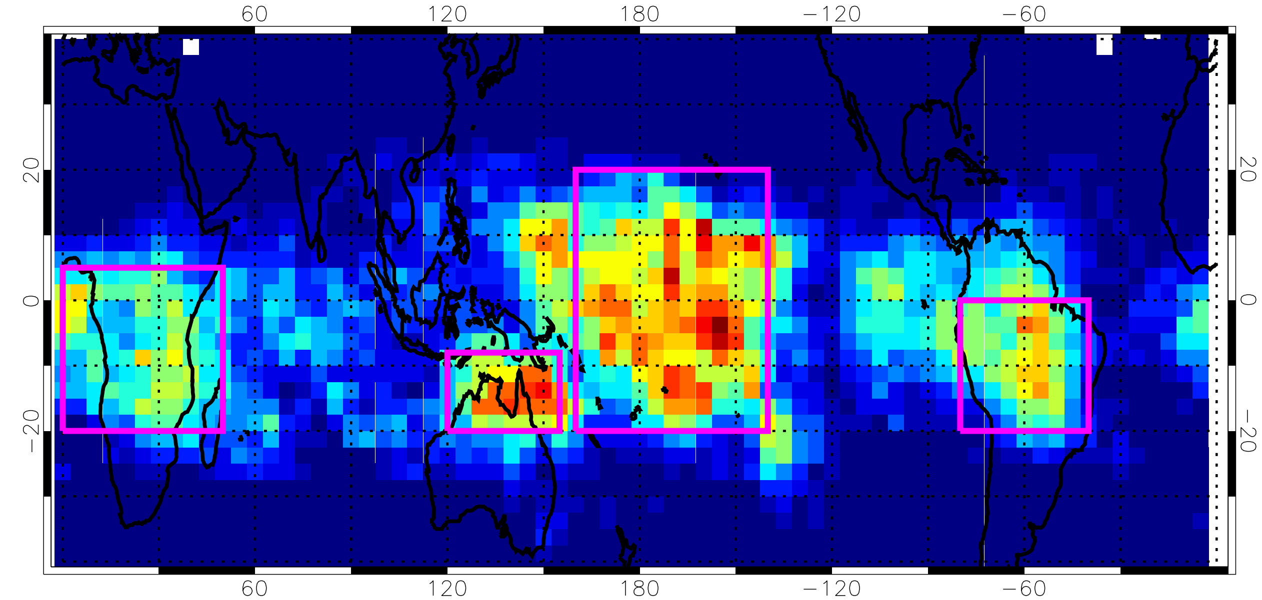


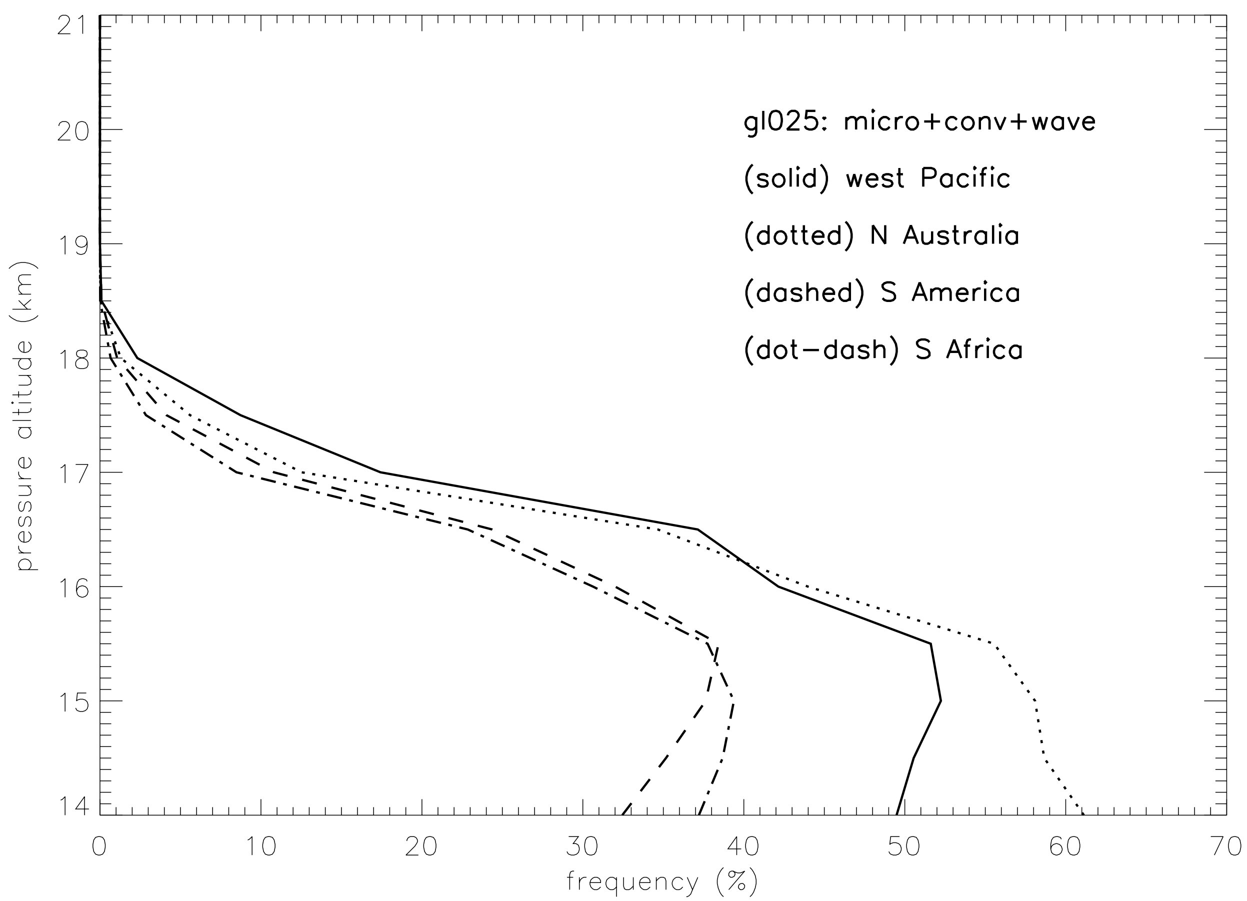
13.5 km (150 hPa)

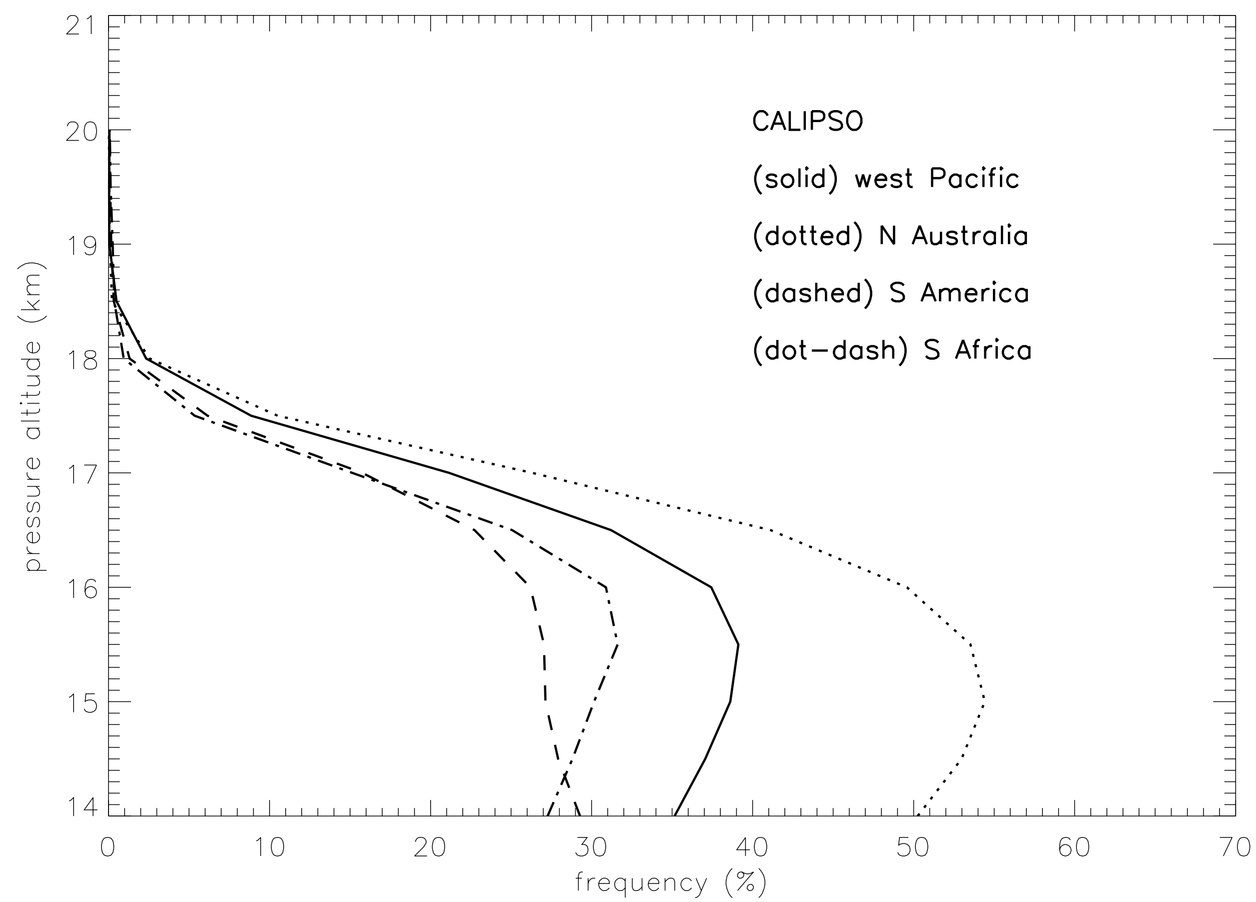


cloud occurrence frequency

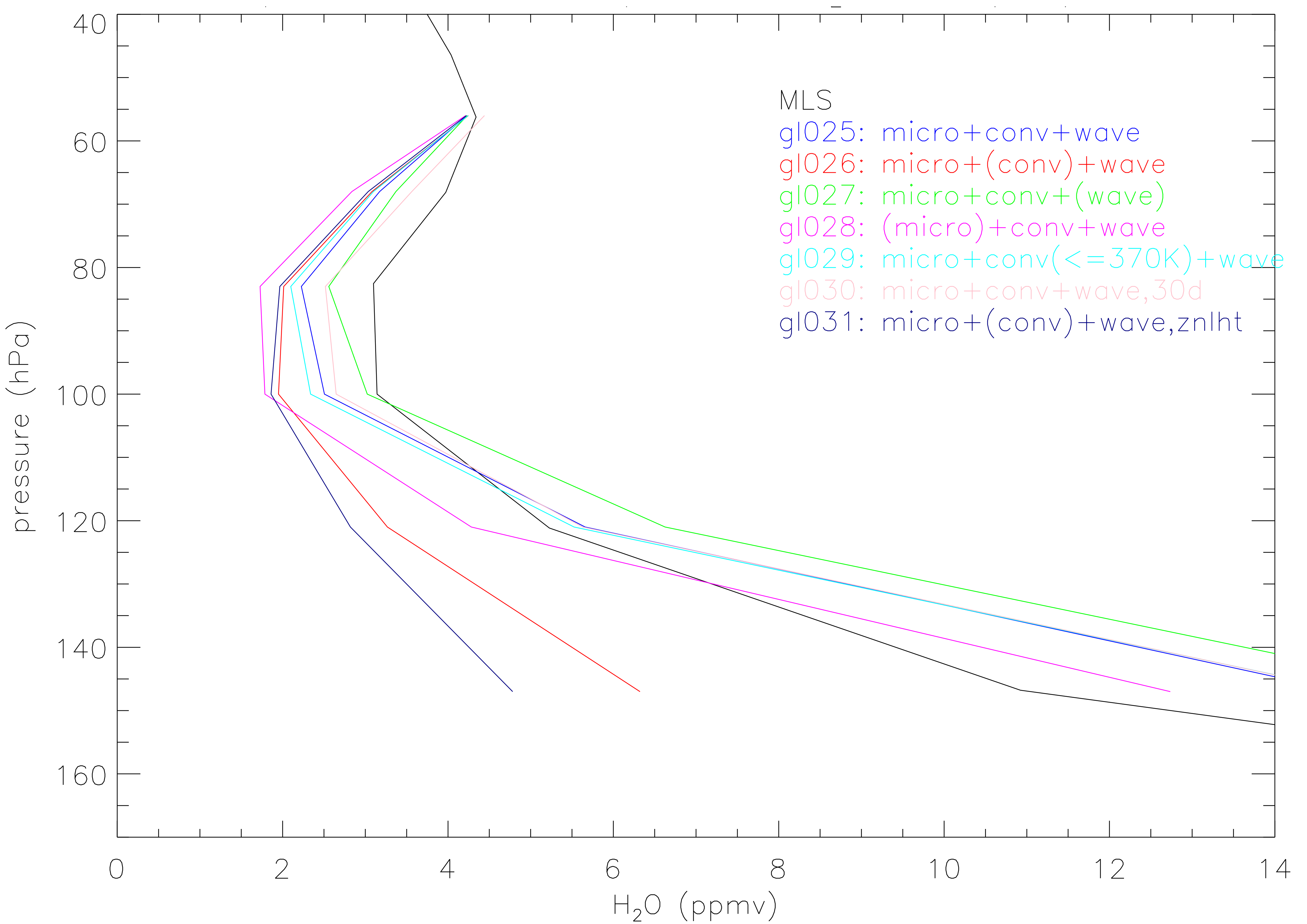
(20S-20N, Jan 2007, regional means)







vertical profile of tropical (20S-20N) mean H_2O



Sensitivity test results

simulation types	100 hPa H_2O difference (ppmv)	comments
reduced aerosols (heterogeneous nucleation)	–0.09	fewer ice crystals grow faster and fall out
convection parameters	+/– 0.1	(within uncertainty of CloudSat and CALIPSO measurements)
high clouds (top >370K)	+0.17	dehydrate over western Pacific
30-d trajectories	+0.14	some parcels have not gone through the cold point in 30-d
large-scale upwelling (zonally-asymm heating rates)	+0.09	weaker ascent in wet regions vs. less time spent in dry regions