

An assessment of upper-troposphere and lower-stratosphere water vapor in GEOS5, MERRA, and ECMWF analysis and reanalyses using Aura MLS observations

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Jiang, J.H., et al., *JGR-Atmosphere*, in revision, 2015.

Why do we care?

1. H₂O amount

- Climate modeling community often use analysis/reanalysis data for model validations, thus evaluating/improving H₂O in the analysis/reanalysis product is critical.

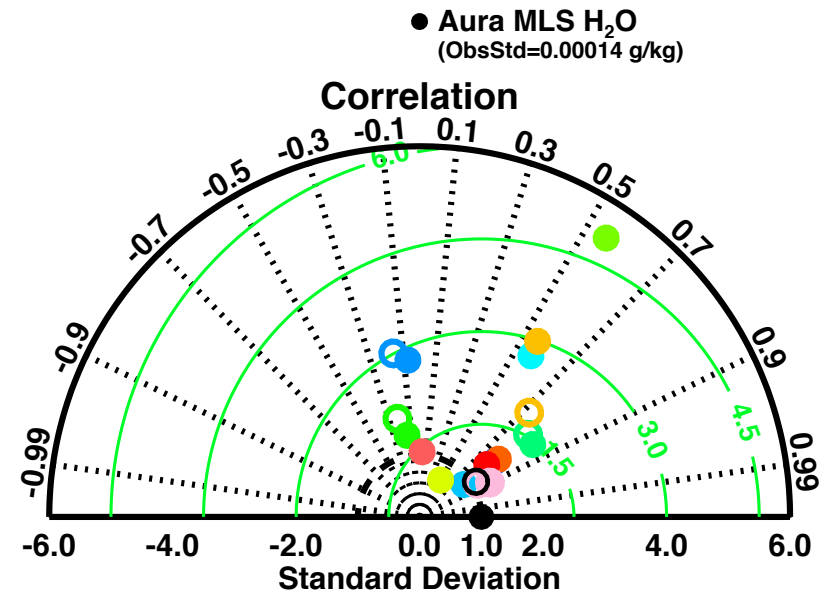
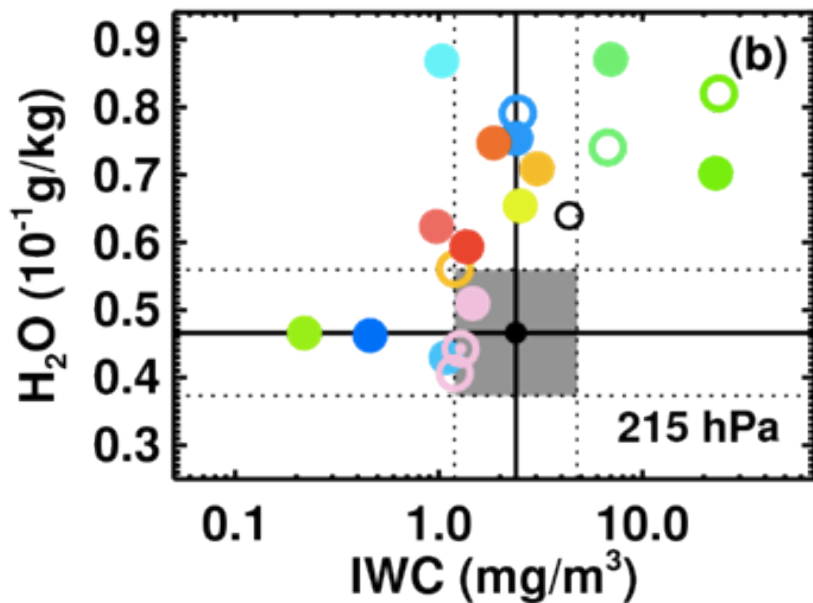
2. Transport from the troposphere (tropics) to the stratosphere (extra-tropics)

- Many UTLS transport studies rely on accurate simulations by analysis and reanalysis models.

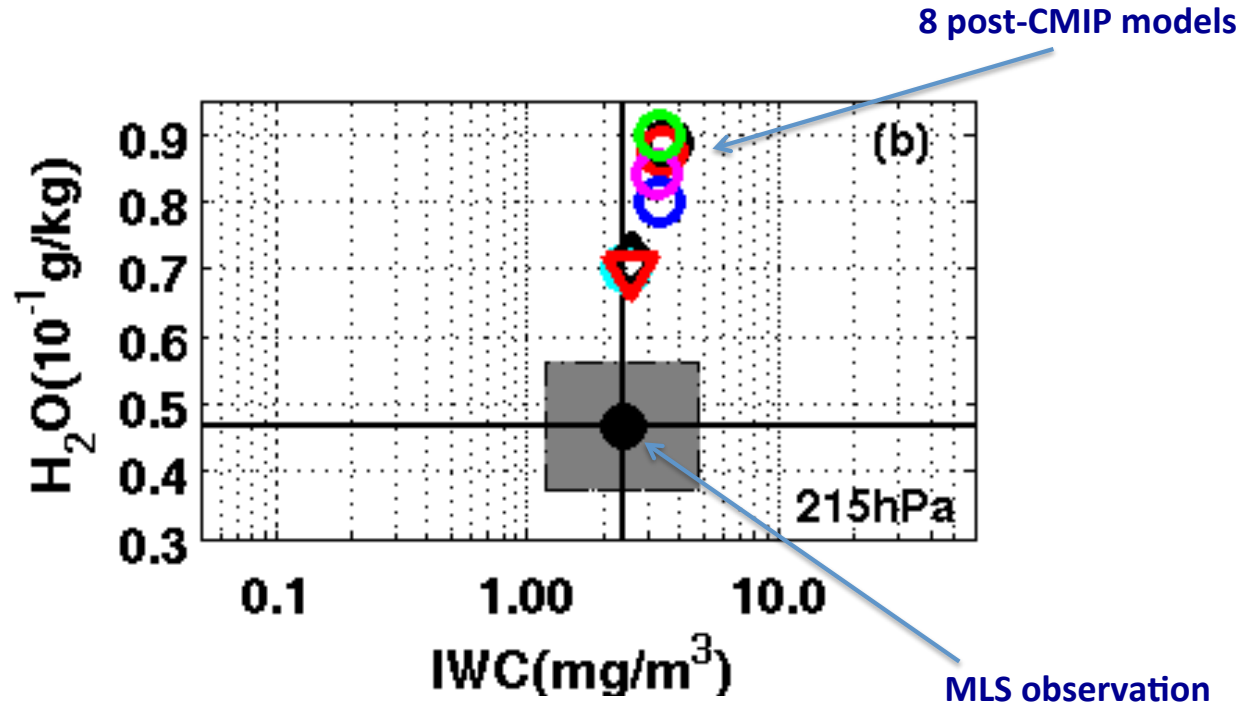
1. H₂O amount

The common errors of climate models are:

1. Too much H₂O in the upper troposphere (~200hPa);
2. Incorrect distribution of H₂O near the tropopause (~100hPa).



Examples from post-CMIP models

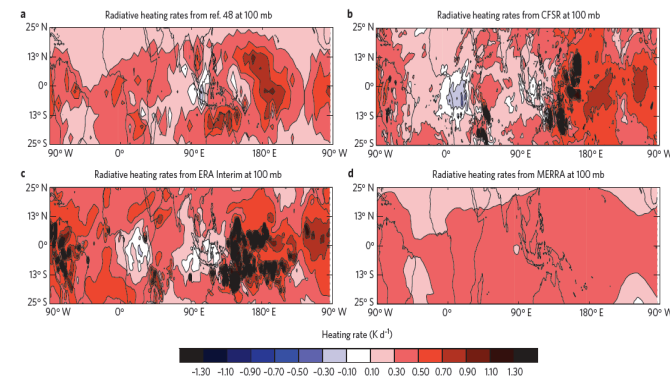
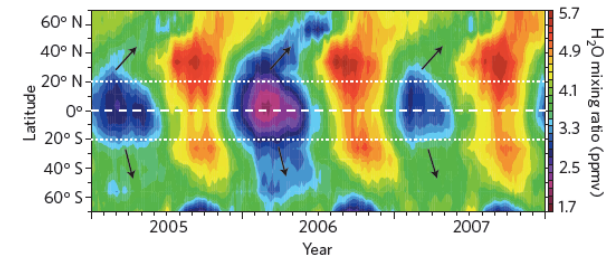
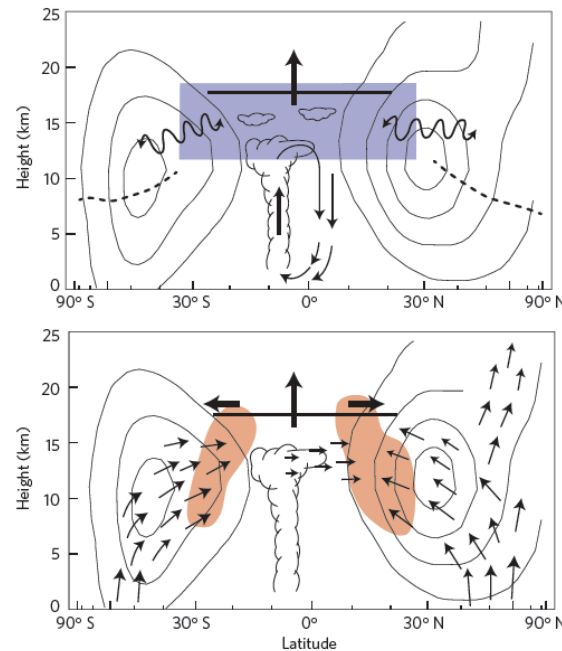


Recent post-CMIP5 models show significant improvement in simulating ice clouds, however, upper tropospheric H_2O remains poor.

2. Transport from the troposphere (tropics) to the stratosphere (extra-tropics)

- “Large differences in results from meteorological reanalysis systems suggest that models and data assimilation tools for the TTL need improvement.”
- “Ensuring the availability of long-term climate-quality data for the TTL are essential to constrain past and future global model simulations.”

Randel and Jensen (2013)



- “Heating rate calculations from current-generation meteorological analysis systems show large differences”

Objective: Using 10-year Aura MLS observations to quantitatively evaluate the H₂O amount and transport velocity produced by analysis/reanalysis products.

3-hourly H₂O data from analysis/reanalysis are interpolated onto the Aura MLS measurement locations in both space and time, i.e., only the data seen by MLS are averaged to construct daily or monthly means. The vertical interpolation of analysis data onto the MLS pressure grids is based on log-pressure and with the MLS vertical averaging kernels applied to match the vertical resolution of MLS observations.

Annual Mean (2005-2014)

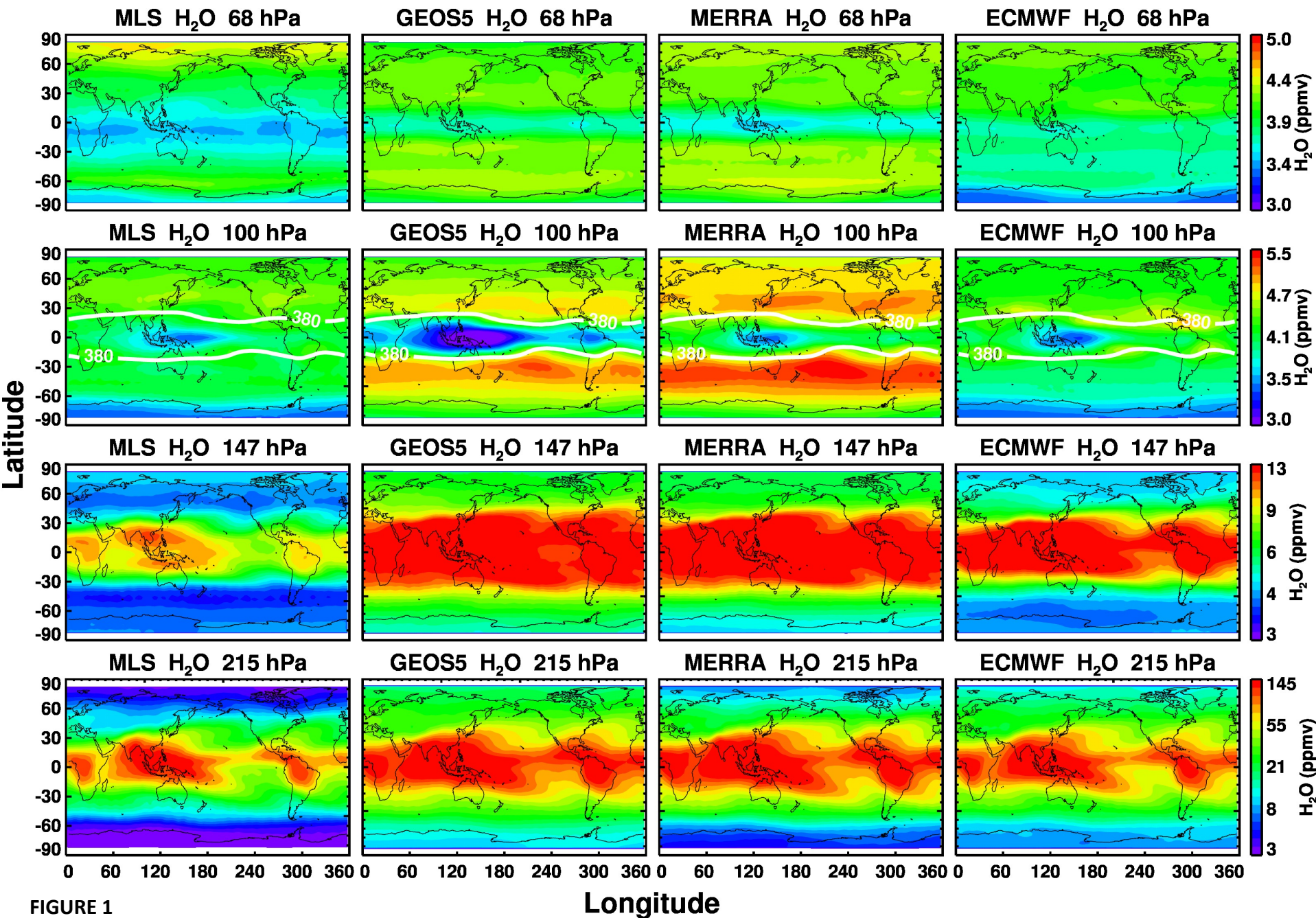
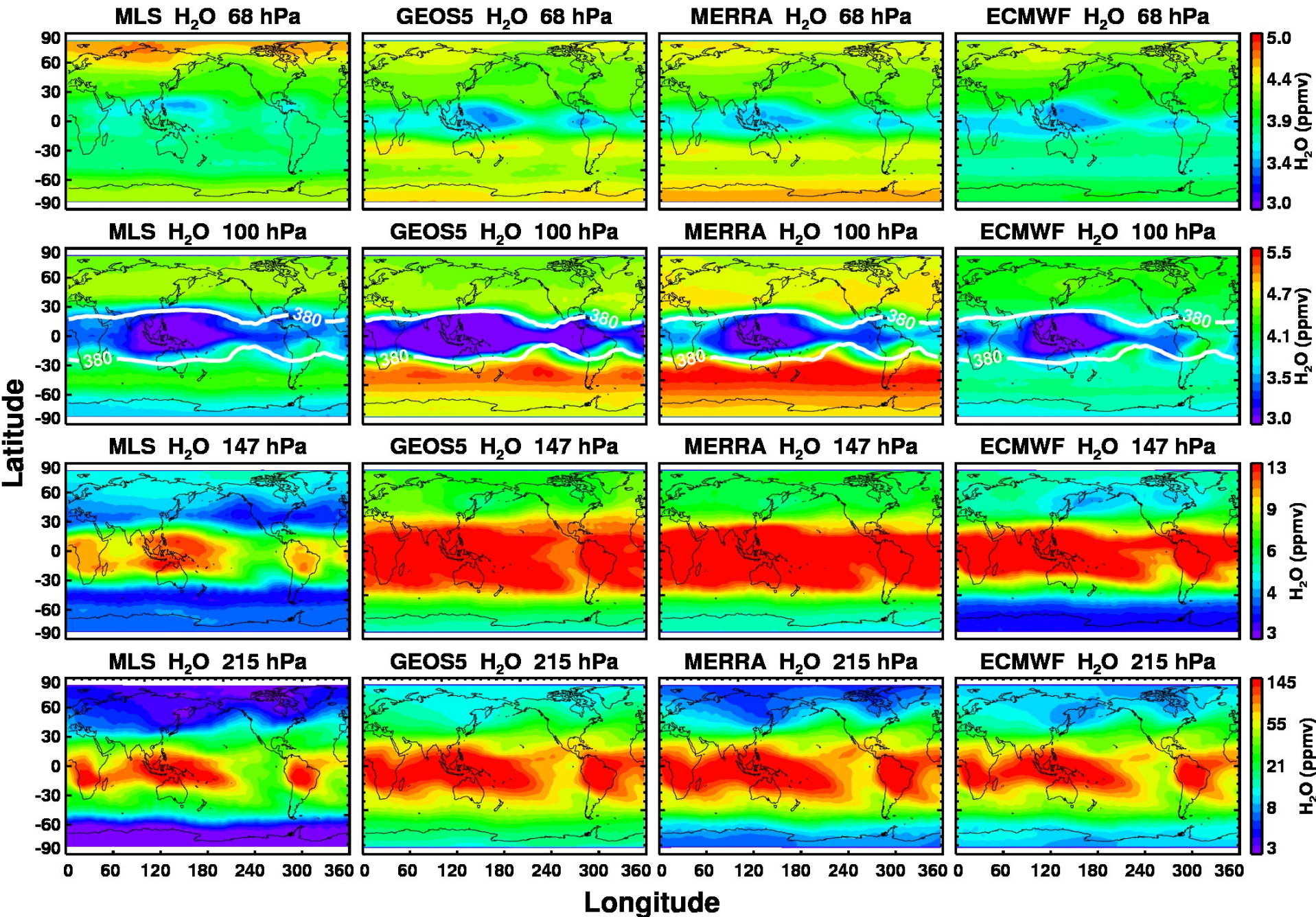
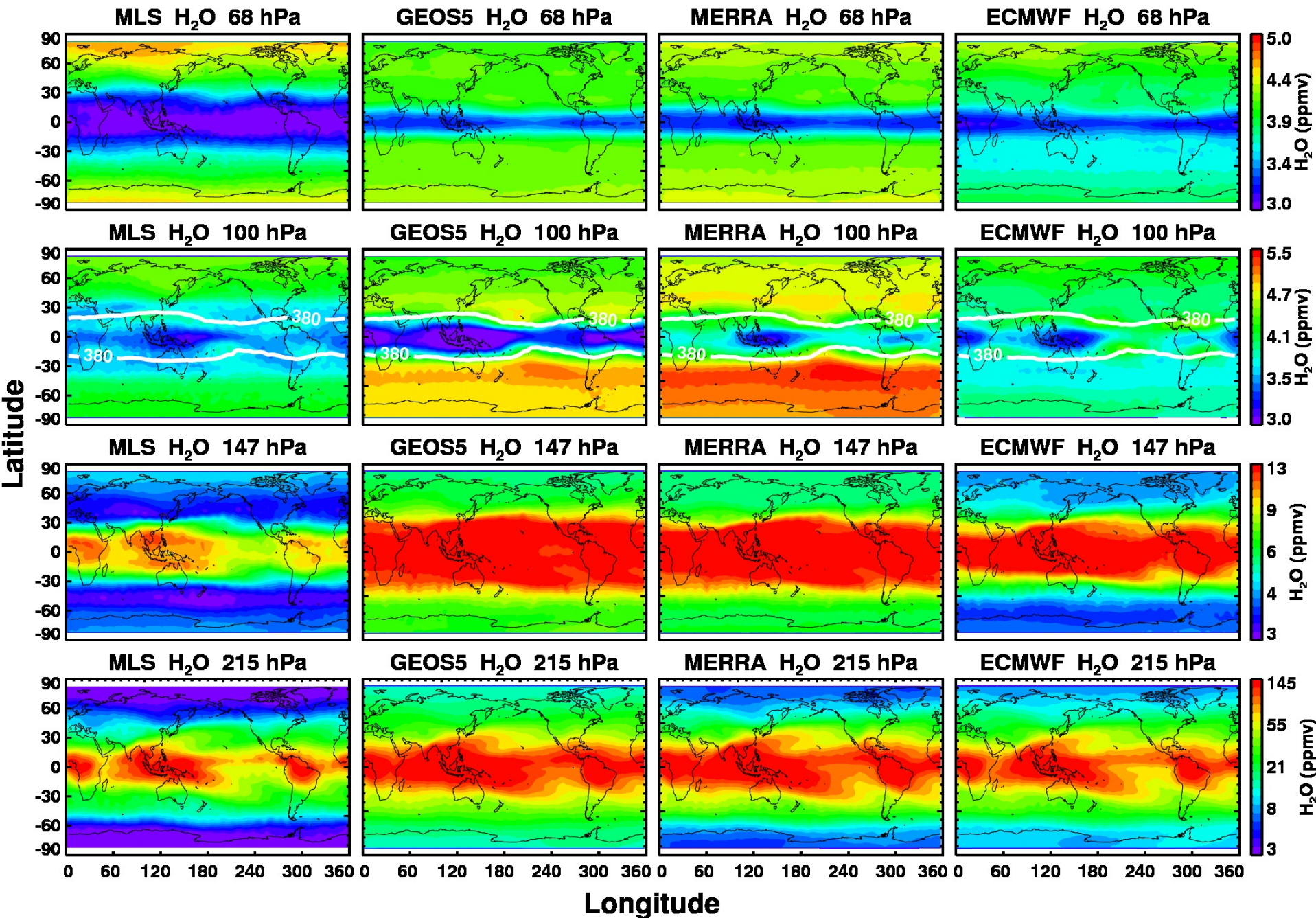


FIGURE 1

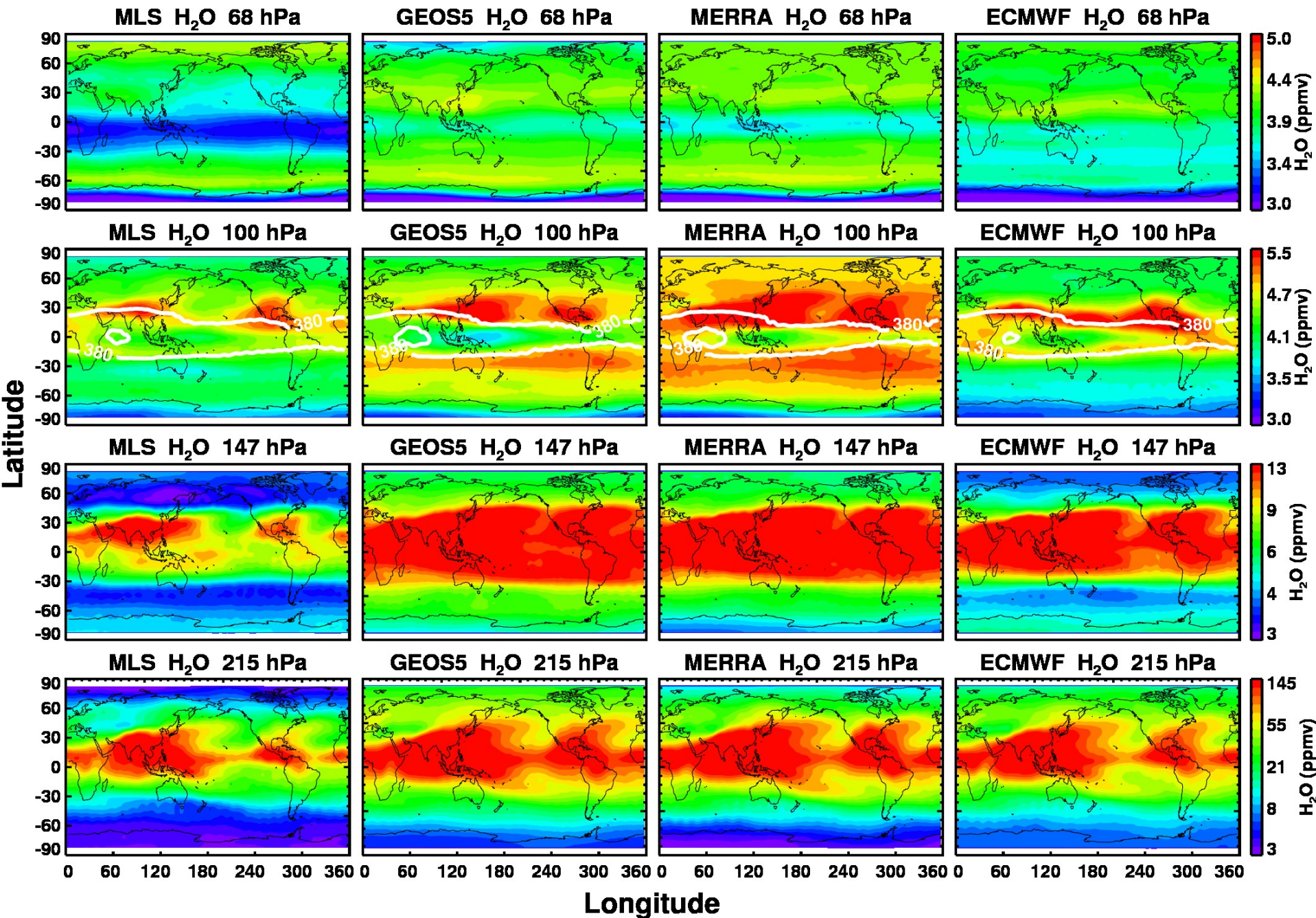
DJF (2004-2014)



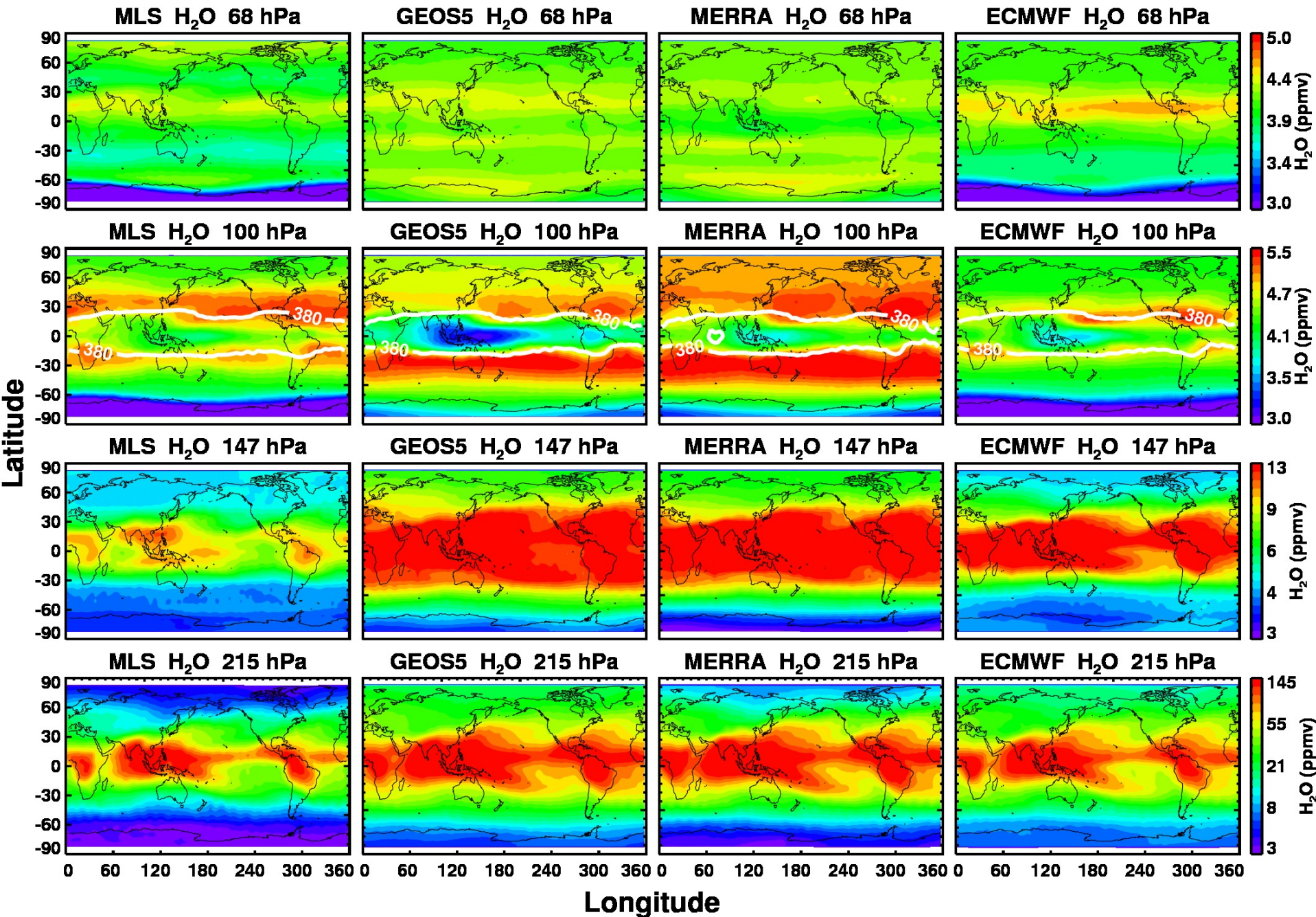
MAM (2005-2014)



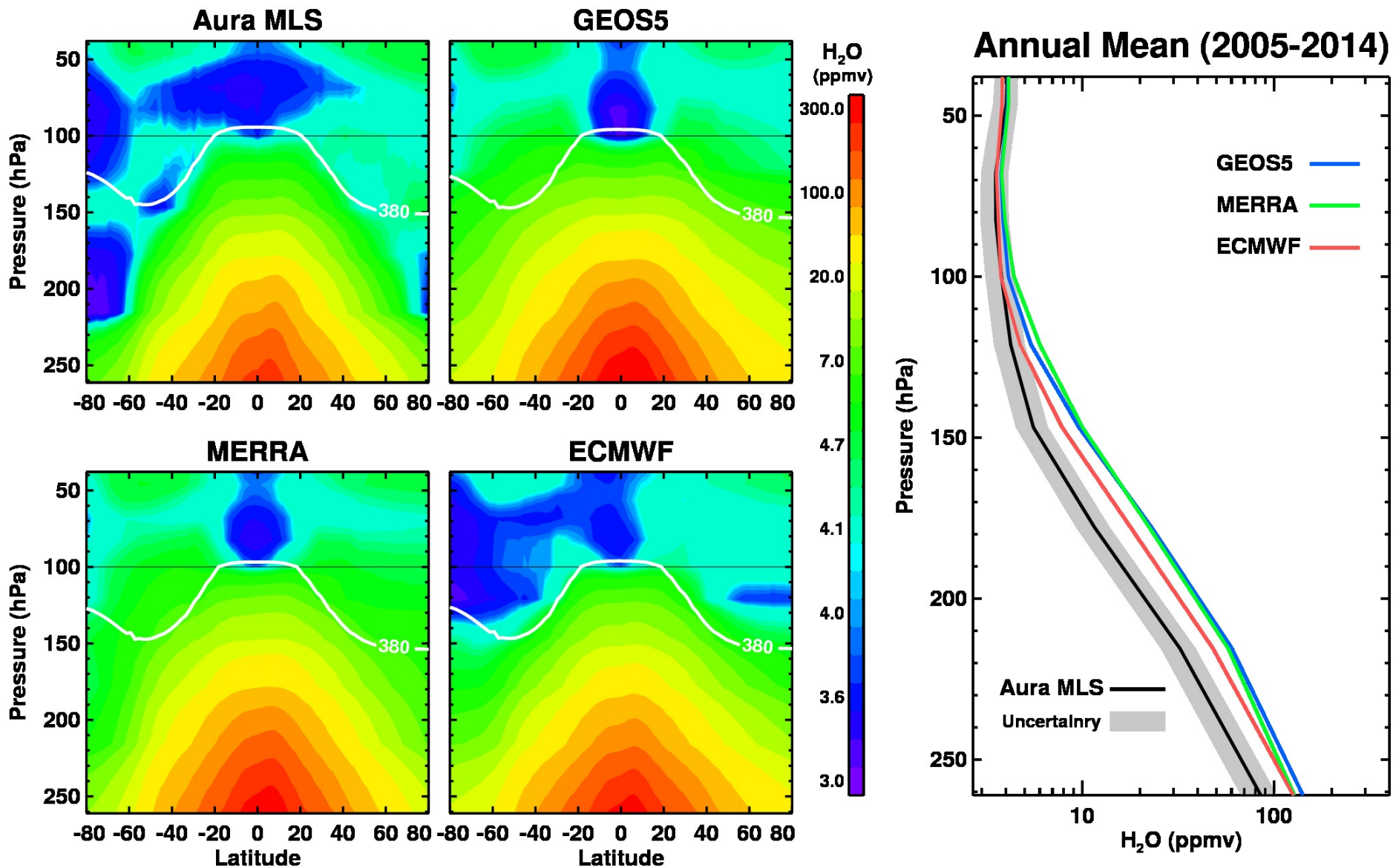
JJA (2005-2014)



SON (2005-2014)



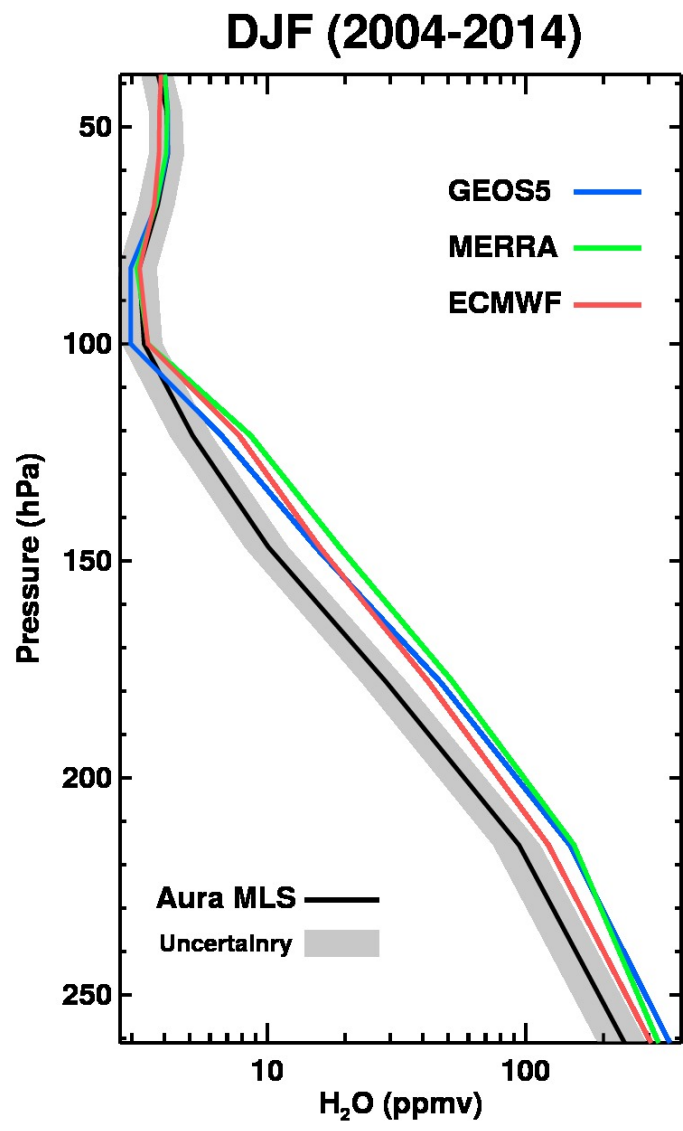
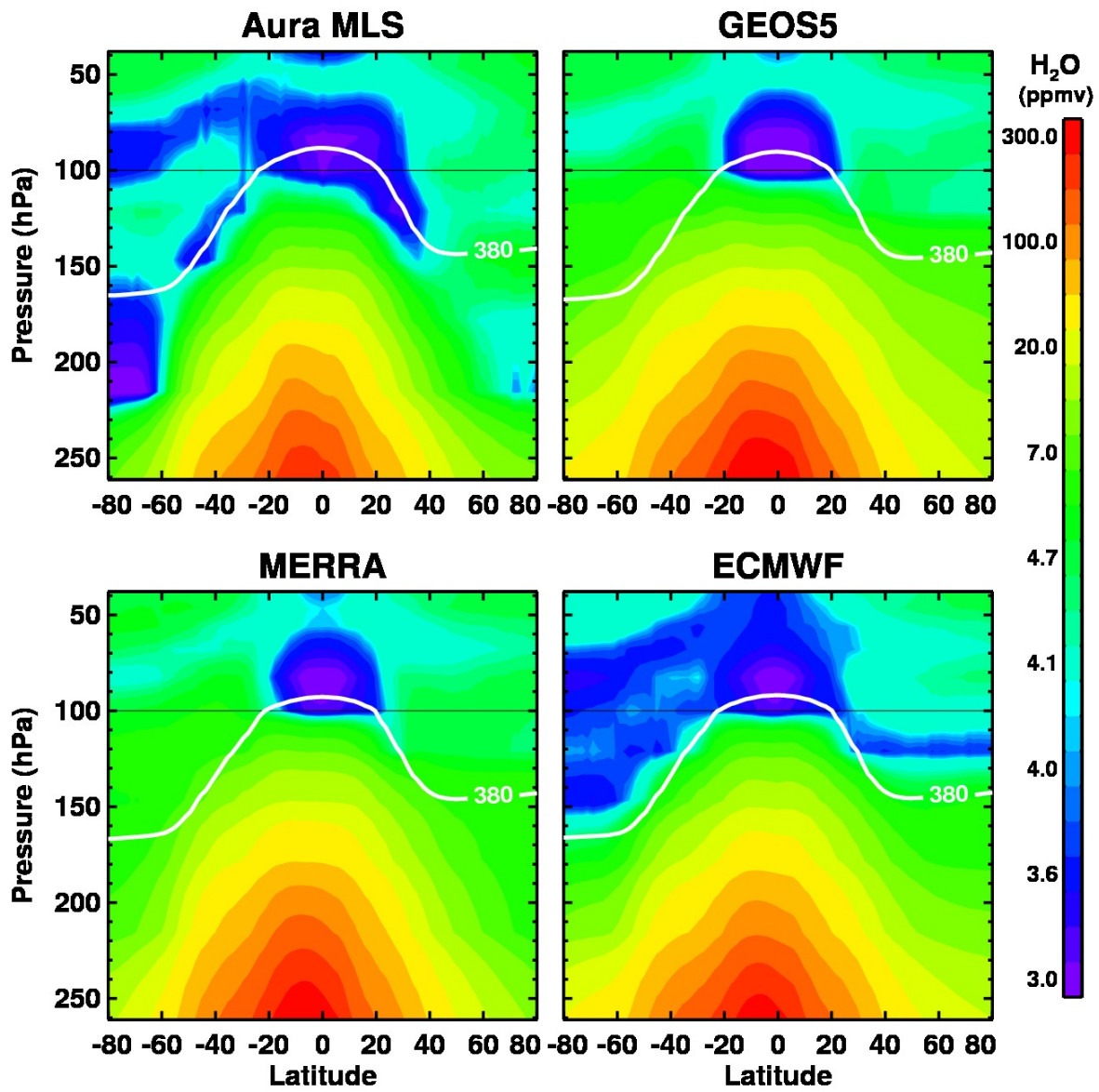
Global Mean



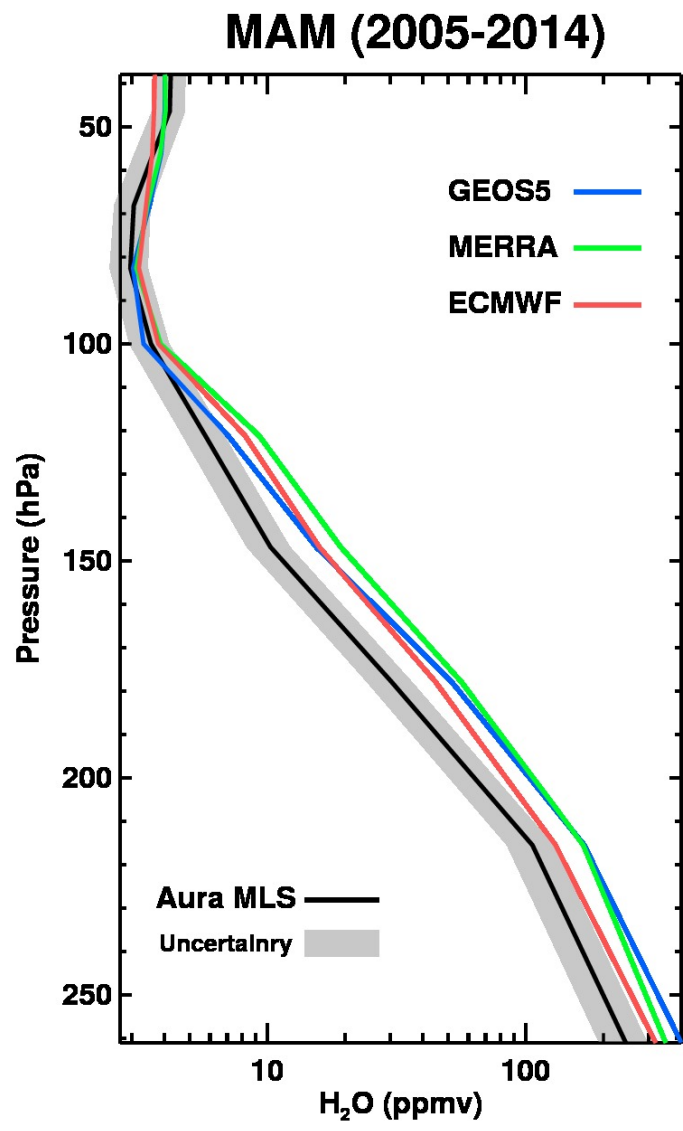
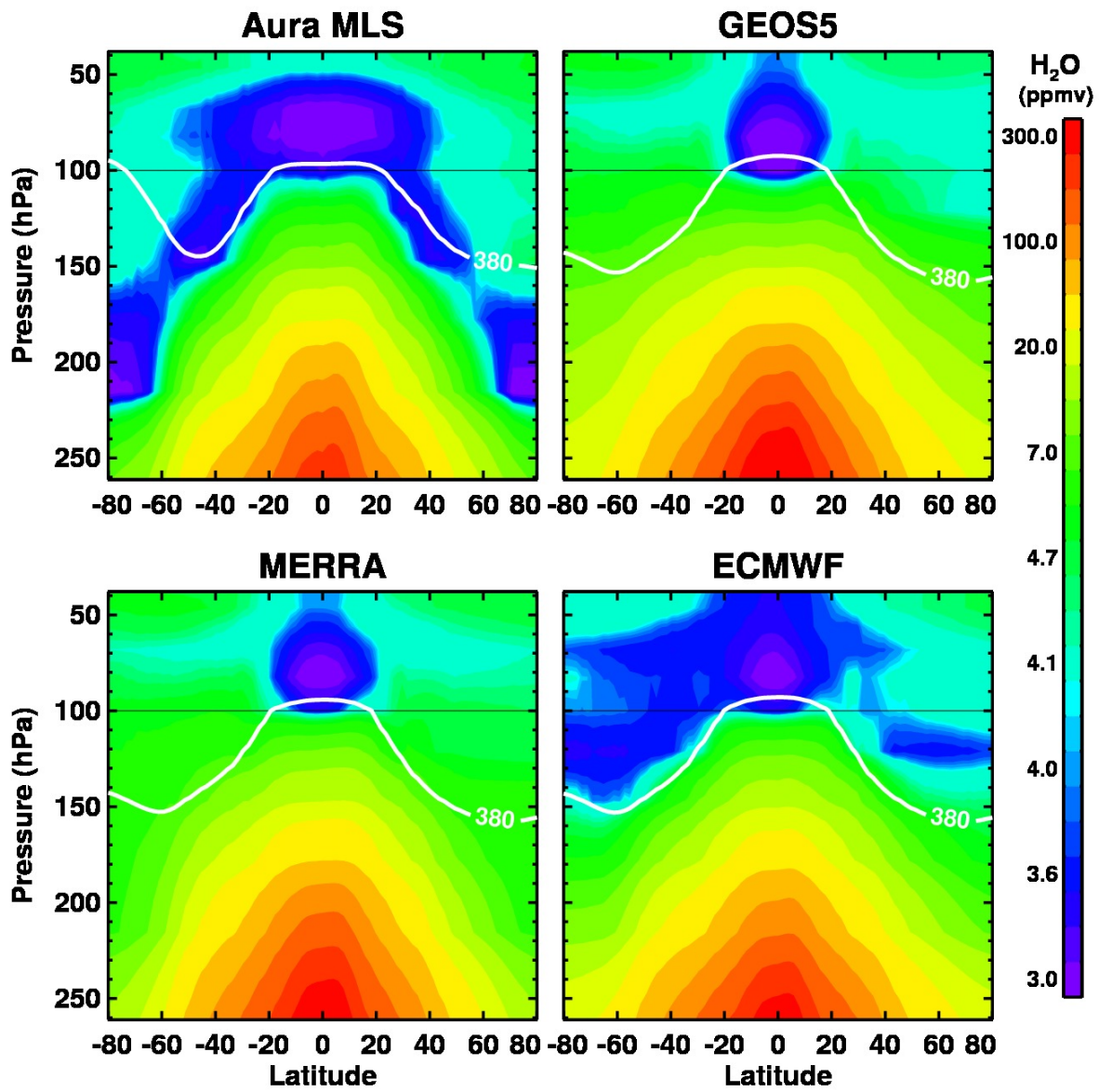
GEOS5 analysis and MERRA and ECMWF reanalyses over-estimated the H_2O by ~50% to 80% throughout upper troposphere.

FIGURE 2

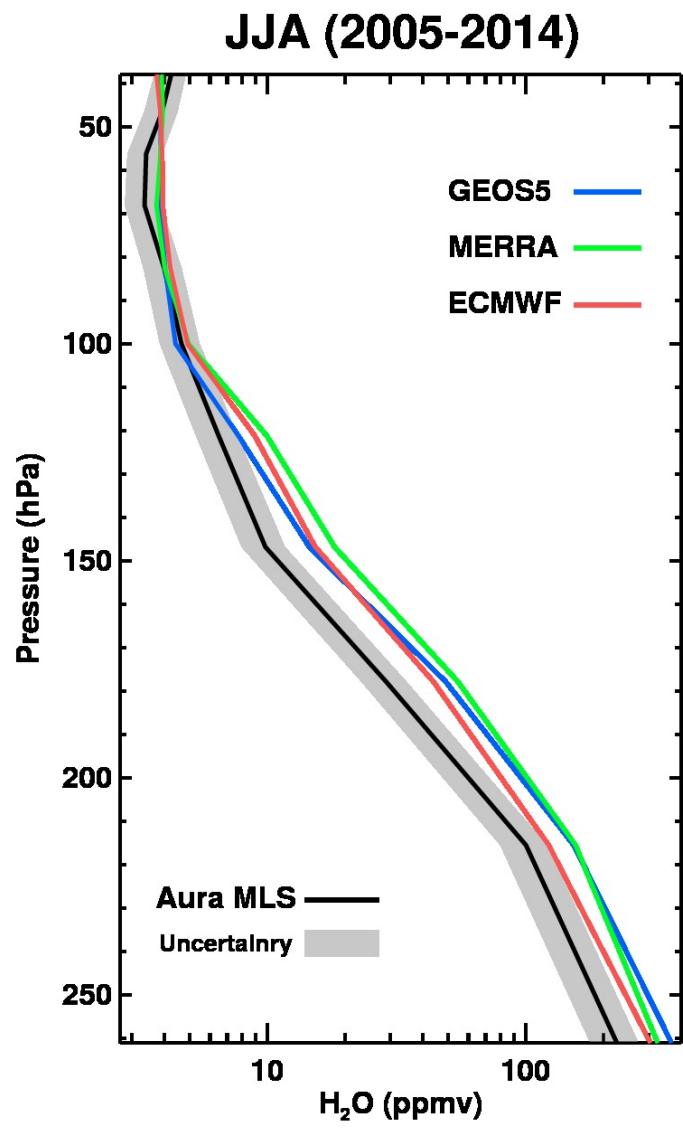
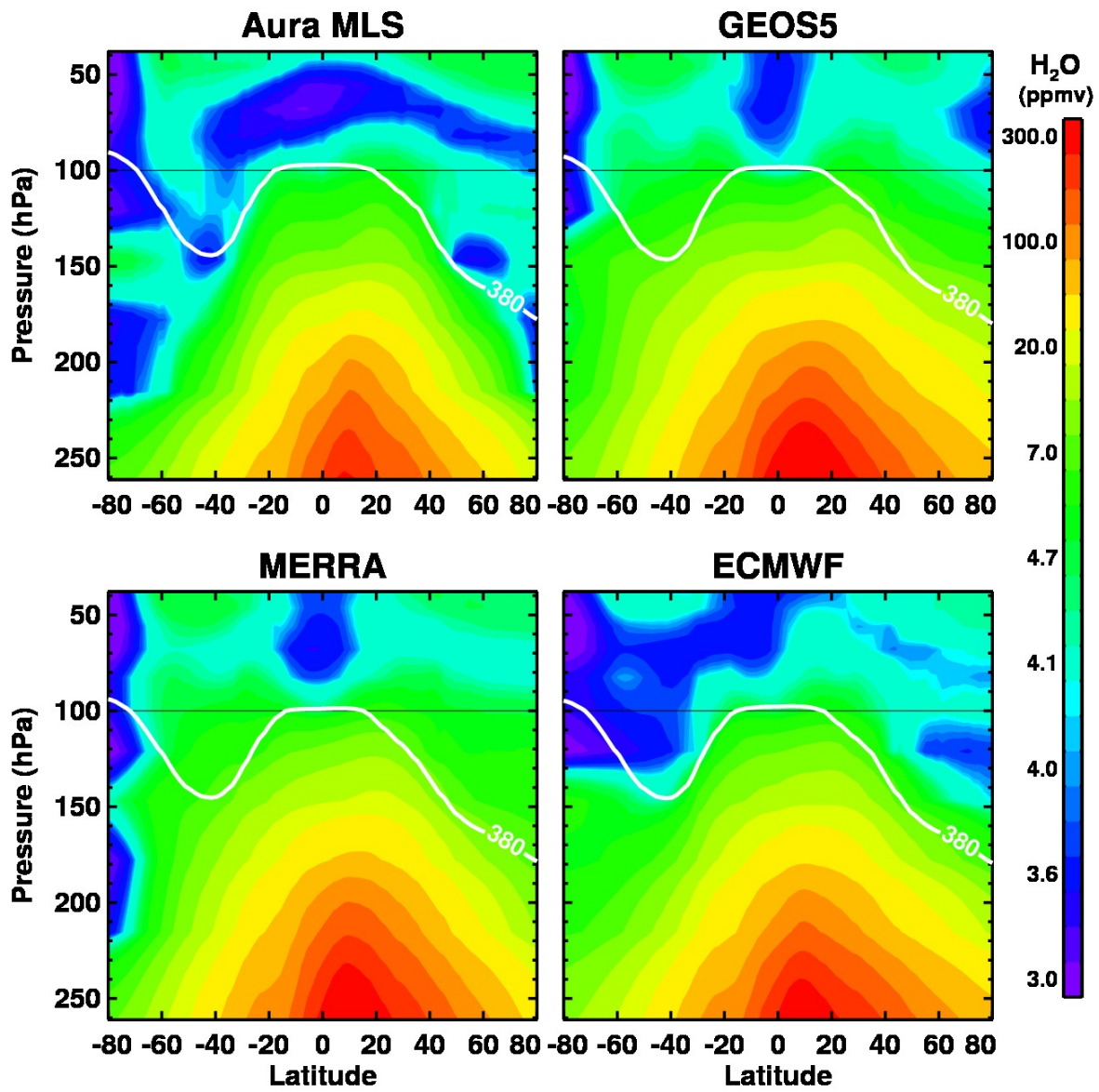
Tropical (15°S-15°N Mean)



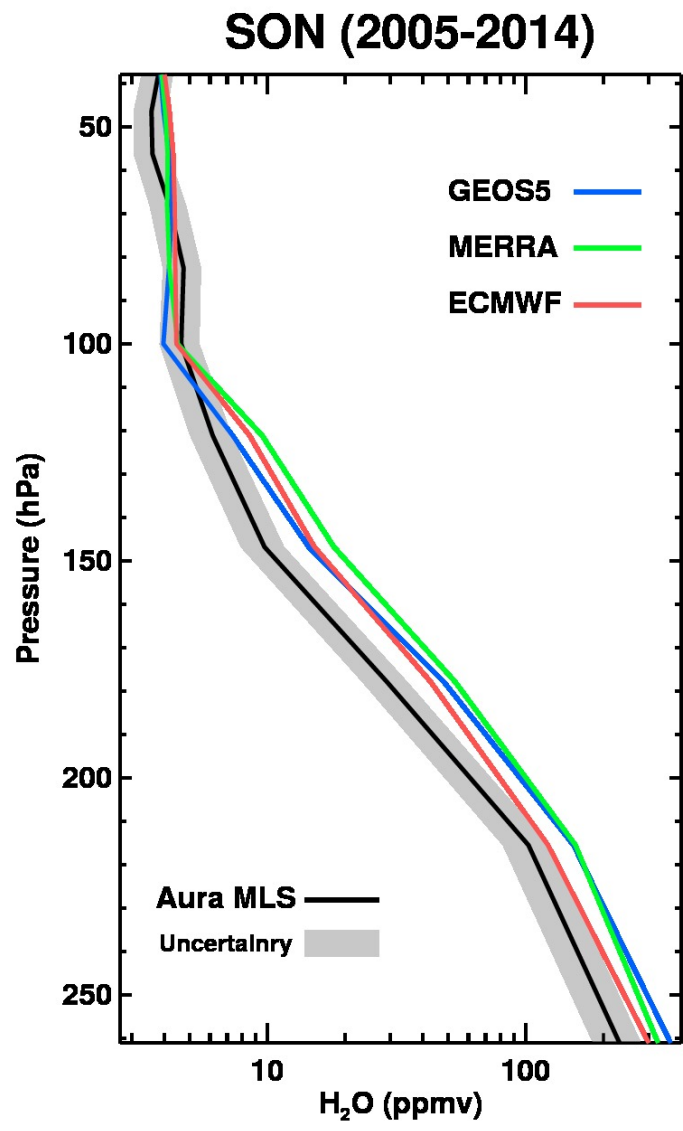
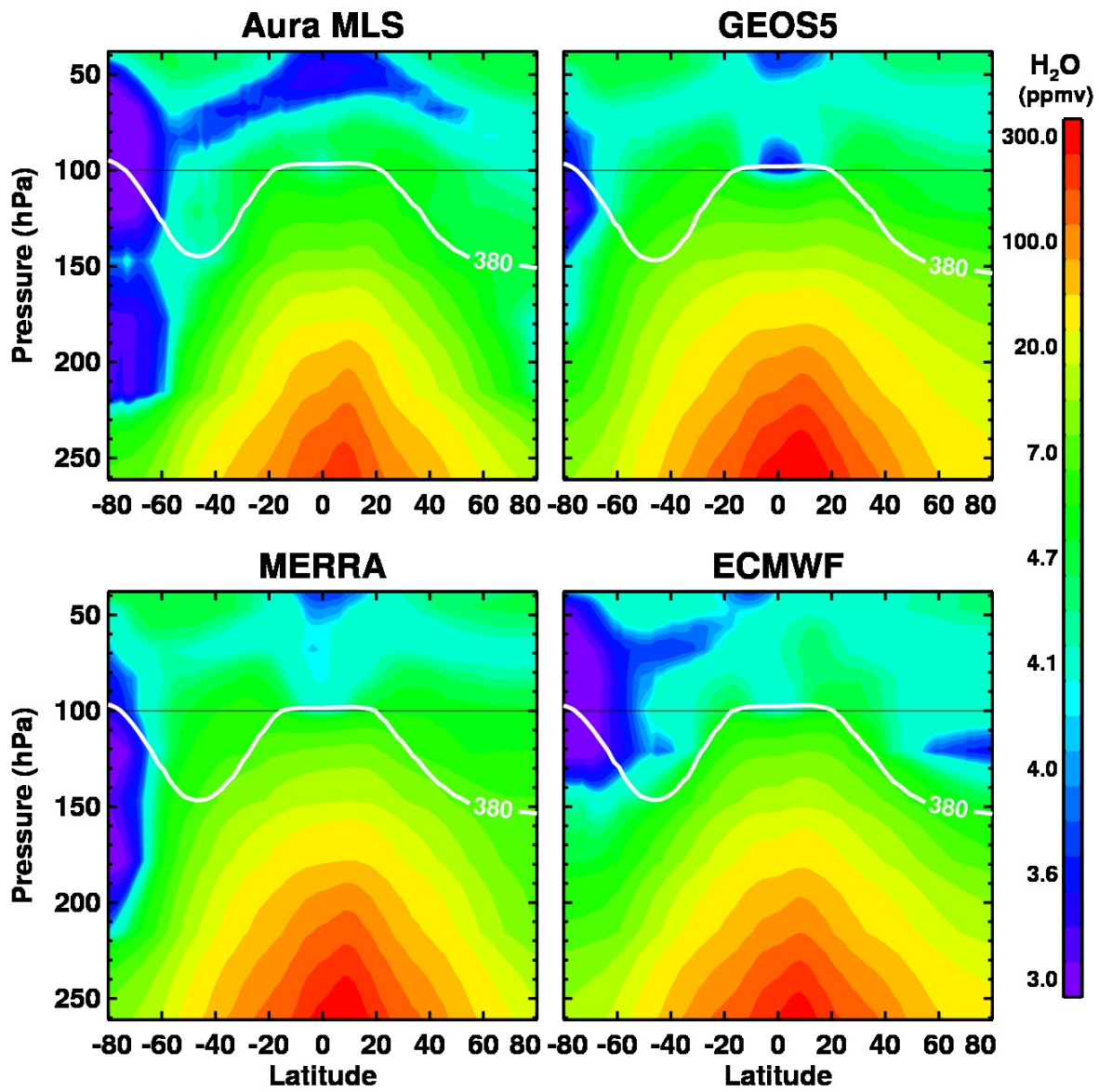
Tropical (15°S-15°N Mean)



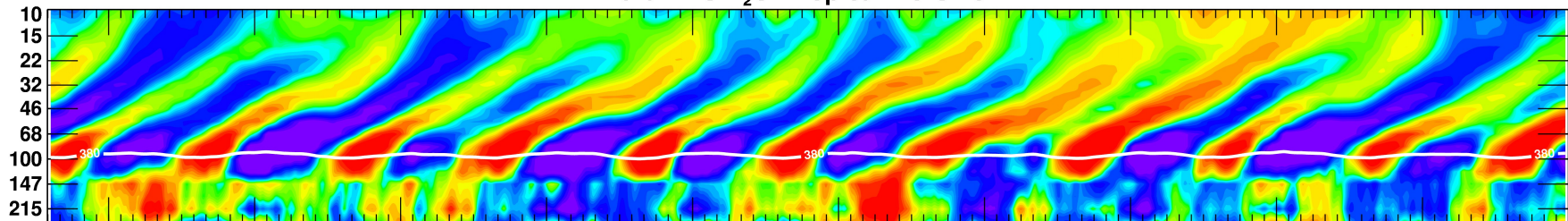
Tropical (15°S-15°N Mean)



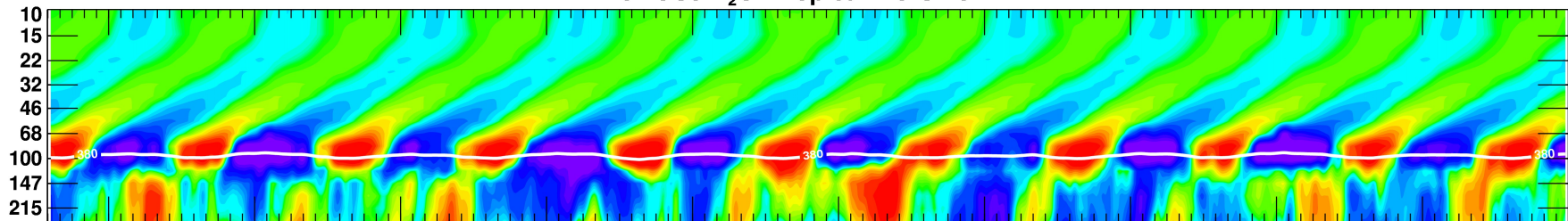
Tropical (15°S-15°N Mean)



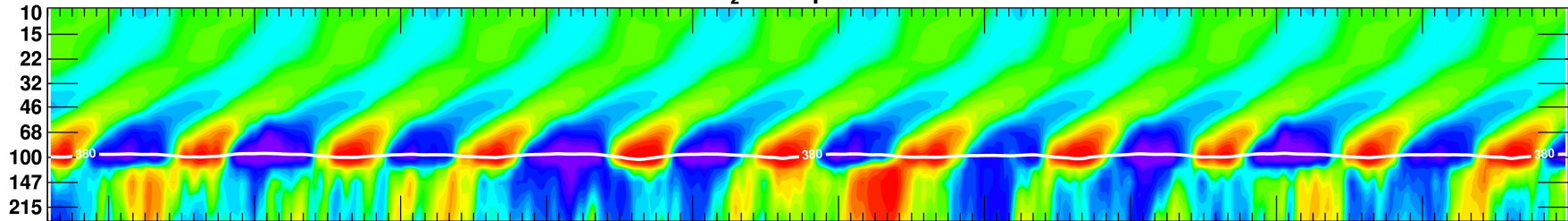
Aura MLS H₂O Tropical: 15°S-15°N



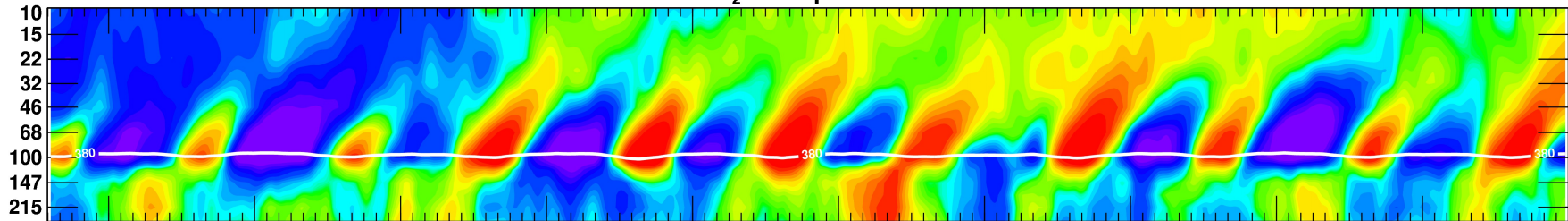
GEOS5 H₂O Tropical: 15°S-15°N



MERRA H₂O Tropical: 15°S-15°N



ECMWF H₂O Tropical: 15°S-15°N



Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct

2005 2006 2007 2008 2009 2010 2011 2012 2013 2014

FIGURE 3a

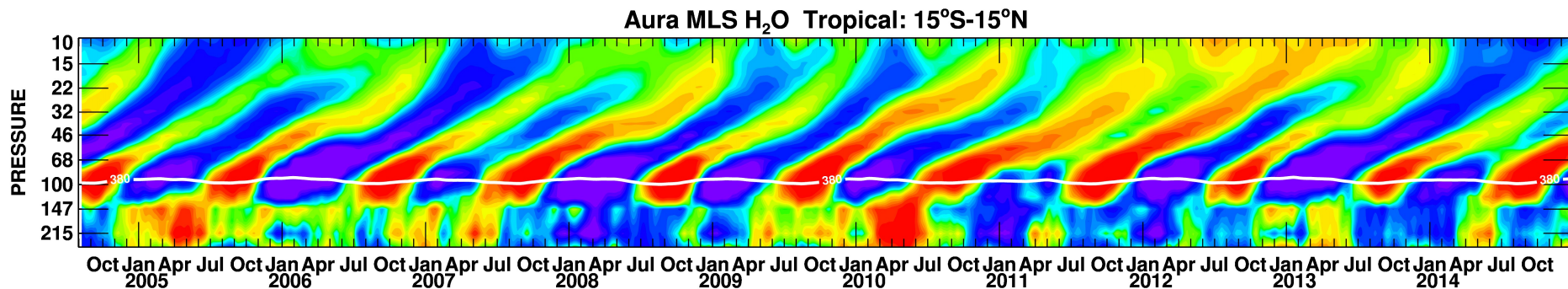
Vertical Transport Velocity Estimate

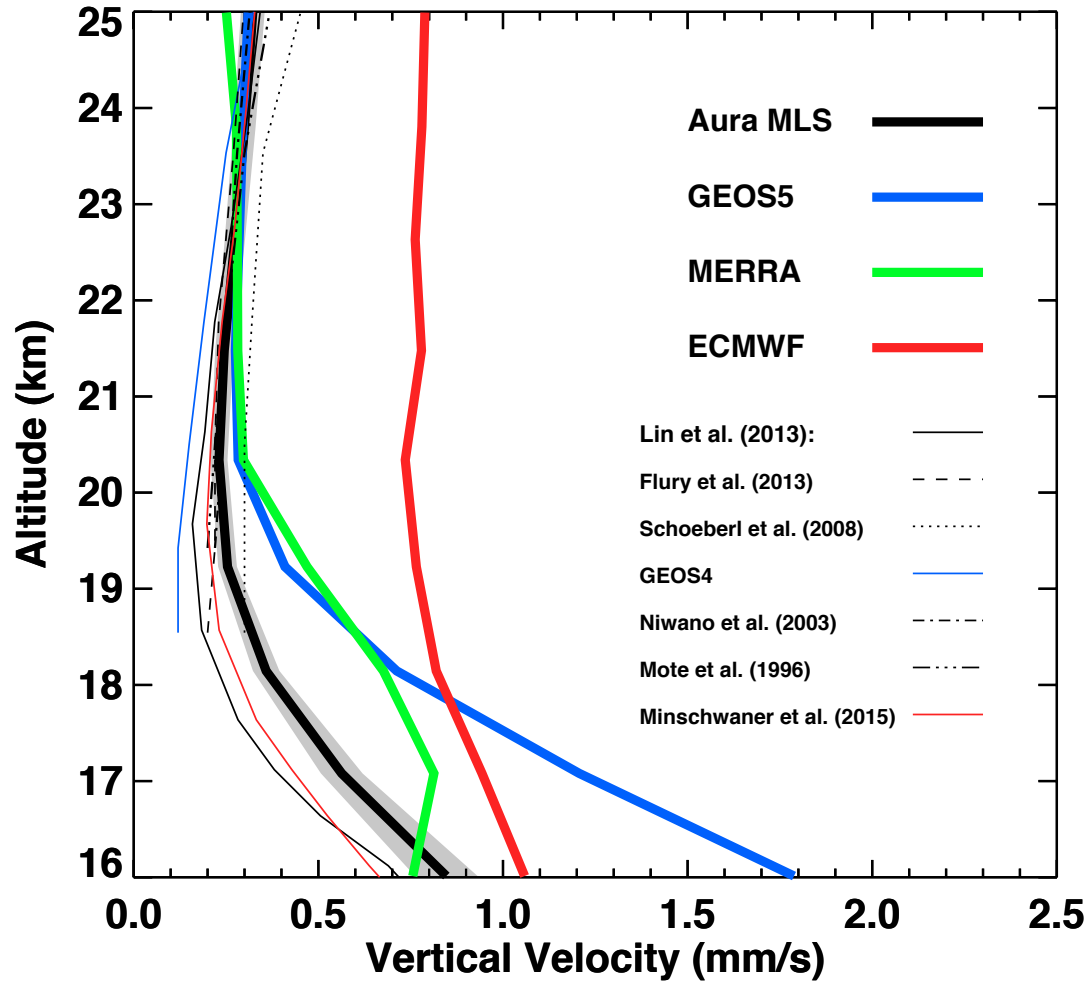
1. Compute the cross correlation between the H₂O time series at two consecutive pressure levels.
2. The time lag that yields the maximal cross correlation is the time for the water vapor to travel from one level to the next one.
3. The estimated vertical transport velocity is the ratio of the difference between the altitudes of two pressure levels and the time lag.

$$t_{lag}(z_1, z_2) = \arg \max_{\tau} \langle q(t, z_1) q(t + \tau, z_2) \rangle$$

$$v_z = (z_2 - z_1) / t_{lag}(z_1, z_2)$$

The uncertainty of the estimated v_z mainly comes from the estimations of time lag and the altitudes of pressure levels using geopotential heights.





H₂O transport across the tropical (15°S-15°N) tropopause (16-19 km) simulated by GEOS5, MERRA and ECMWF are faster by about 103%, 34% and 77% respectively, compared to MLS observations; In the lower stratosphere (20-25km); ECMWF simulated mean vertical transport is 180% faster than the MLS estimate, while GEOS5 and MERRA have vertical transport velocities similar to the MLS value.

FIGURE 5

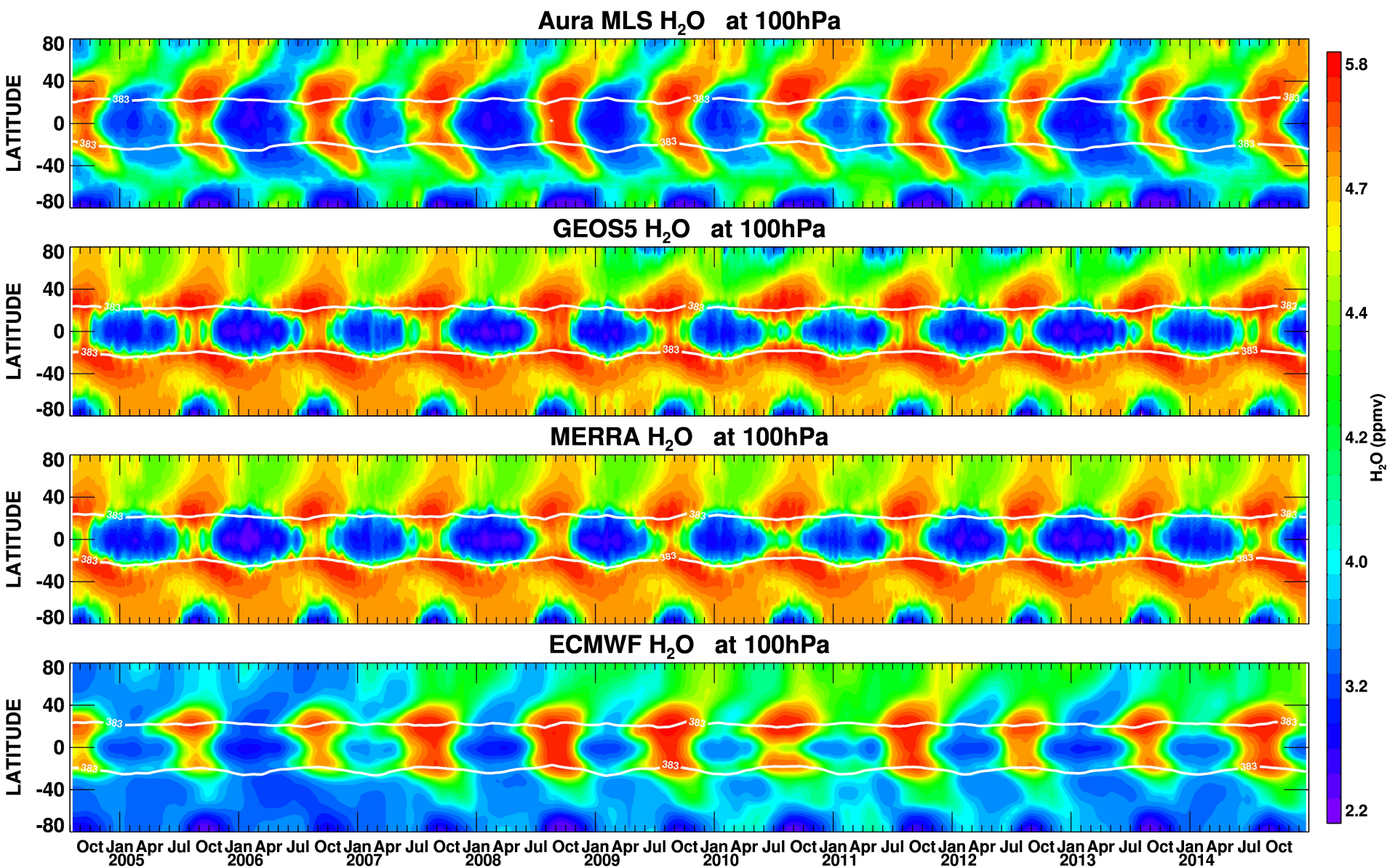


FIGURE 4

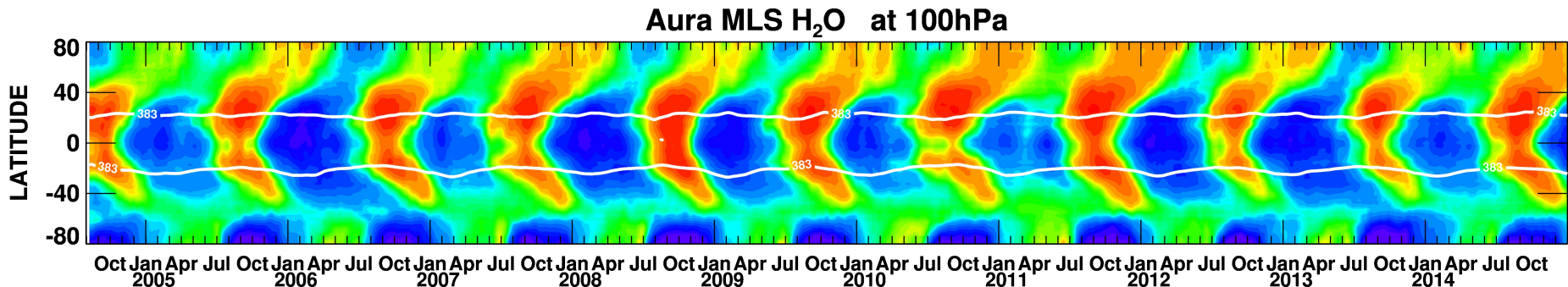
Horizontal Transport Velocity Estimate

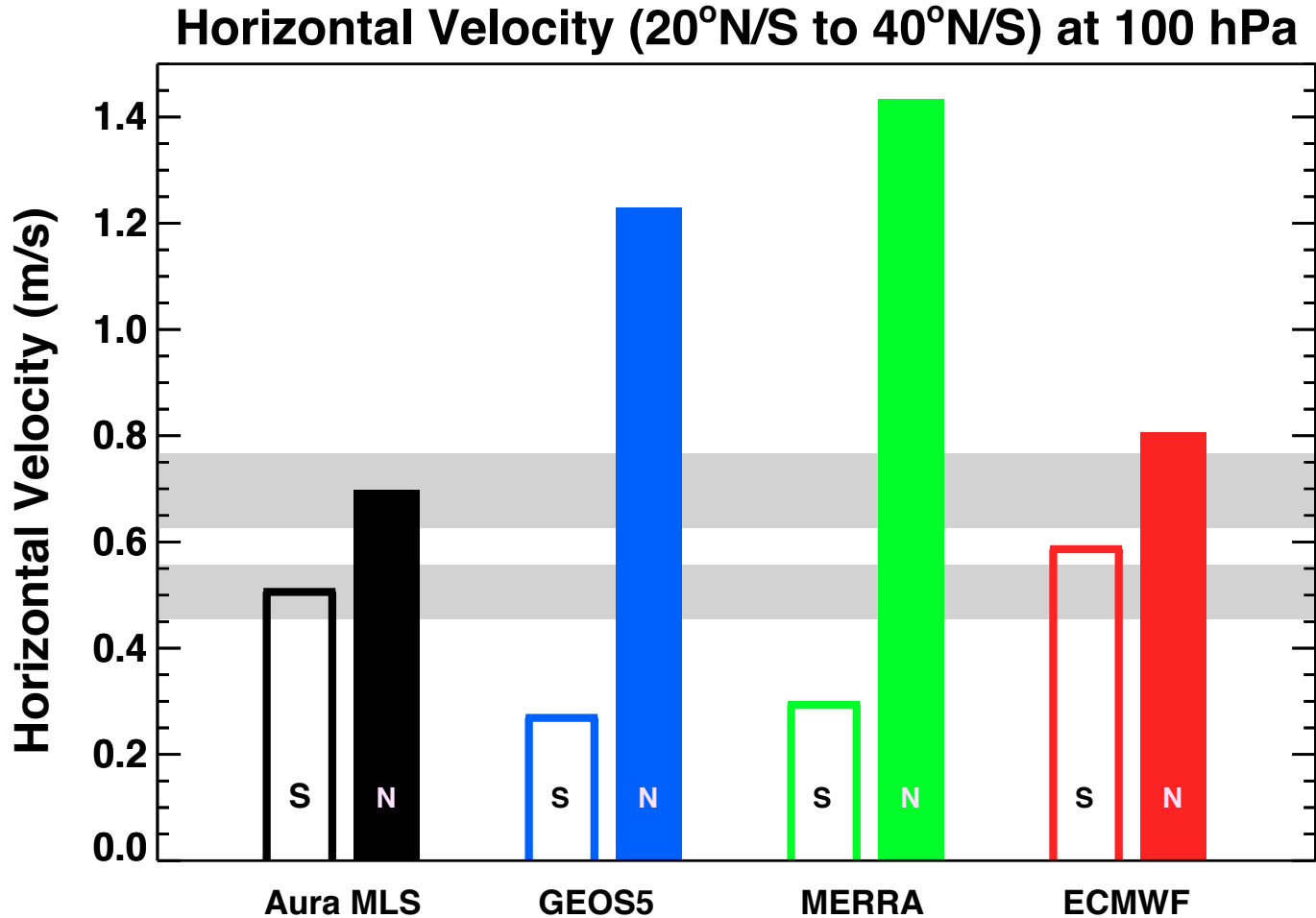
1. Compute the cross correlation between the H₂O time series at two neighbor latitude bands.
2. The time lag that yields the maximal cross correlation is the time for the water vapor to travel from one latitude to the next one.
3. The estimated horizontal transport velocity is the ratio of the distance between the two latitudes and the time lag.

$$t_{lag}(lat_1, lat_2) = \arg \max_{\tau} \langle q(t, lat_1) q(t + \tau, lat_2) \rangle$$

$$v = (Lat_2 - Lat_1) / t_{lag}(Lat_1, Lat_2)$$

The uncertainty of the estimated v comes from the estimations of time lag and the distances of latitudes.





H₂O horizontal transport across the tropopause is faster into the northern hemisphere (NH) than into the southern hemisphere (SH); In NH, the simulated 100hPa H₂O horizontal transport velocities are 76%, 106%, and 16% faster than the MLS observed value for GEOS5, MERRA, and ECMWF respectively; In SH, these simulated horizontal transport velocities are slower by 47% and 42% for GEOS5 and MERRA, but faster by 16% for ECMWF, compared to MLS observations.

FIGURE 7

Summary

1. **GEOS5 analysis and MERRA and ECMWF reanalyses over-estimate the H₂O by up to ~ 80% throughout upper troposphere.**
2. **The simulated H₂O_s also show substantial differences in vertical and horizontal transports across the tropopause into the lower stratosphere, comparing to MLS observations.**
 - **Vertical:** H₂O transport across the tropical tropopause (16-19 km) simulated by GEOS5, MERRA and ECMWF are faster by ~103%, 34% and 77% respectively, compared to MLS observations; In the lower stratosphere (20-25km); ECMWF simulated mean vertical transport is 180% faster than the MLS estimate, while GEOS5 and MERRA have vertical transport velocities similar to the MLS value.
 - **Horizontal:** At 100 hPa, MLS observation and simulations by GEOS5, MERRA, ECMWF show H₂O horizontal transport across the tropopause is faster into the northern hemisphere (NH) than into the southern hemisphere (SH);
 - In NH, the simulated 100hPa H₂O horizontal transport velocities are 76%, 106%, and 16% faster than the MLS observed value for GEOS5, MERRA, and ECMWF respectively;
 - In SH, these simulated horizontal transport velocities are slower by 47% and 42% for GEOS5 and MERRA, but faster by 16% for ECMWF, compared to MLS observations.

Backup slides

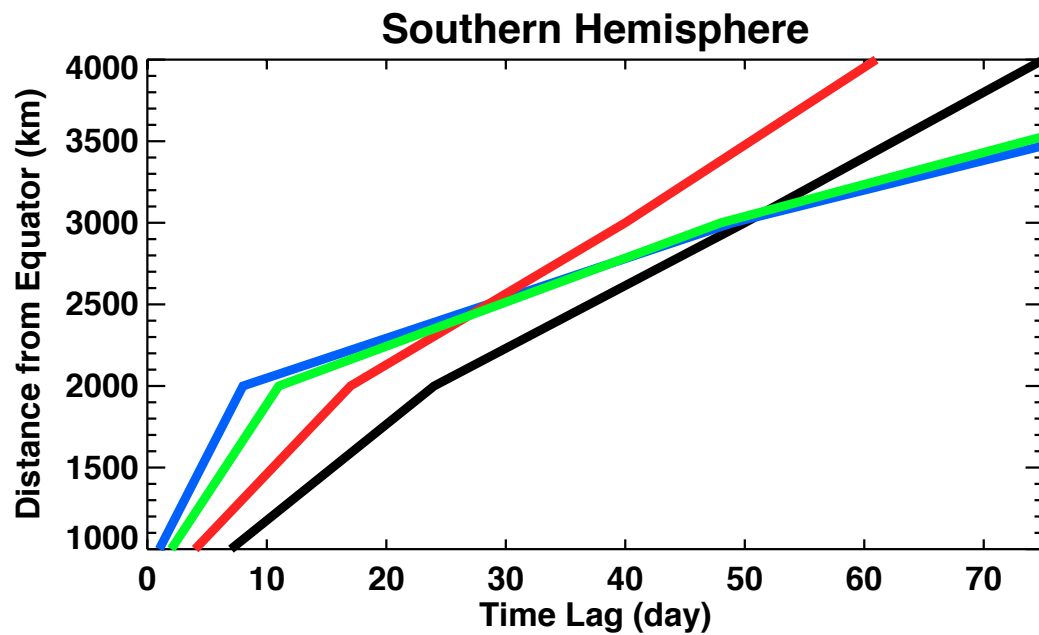
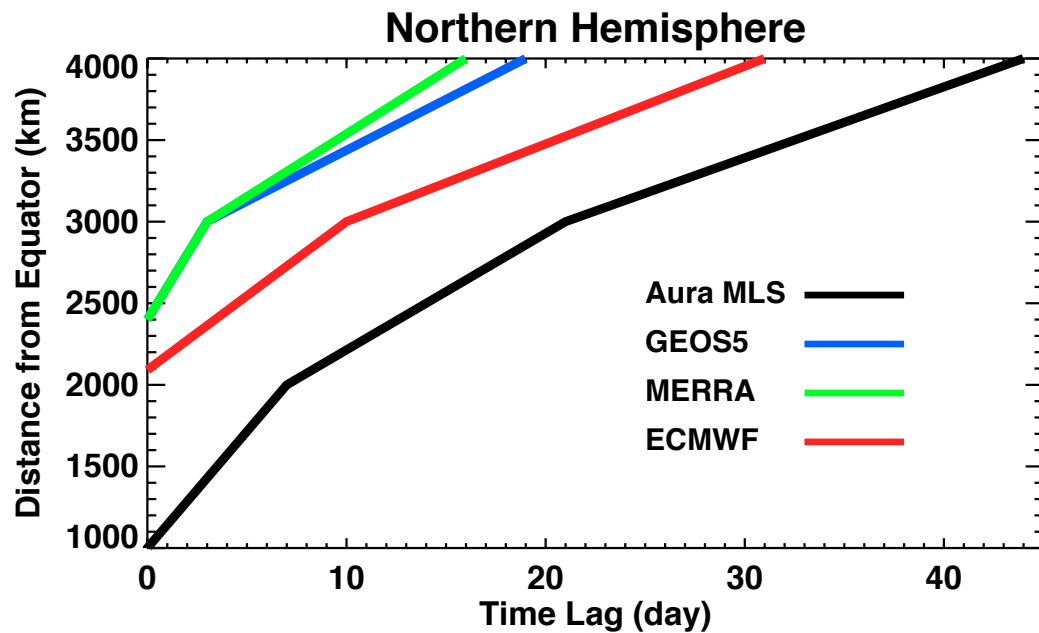


FIGURE 6

Tracking the changes for the GEOS5-AGCM development

e0179: a version of the GEOS5 AGCM that was used in the MERRA Data Assimilation System.

e0178: identical to e0179 except the rate of re-evaporation of precipitation (liquid & ice) was increased by a factor of 2.

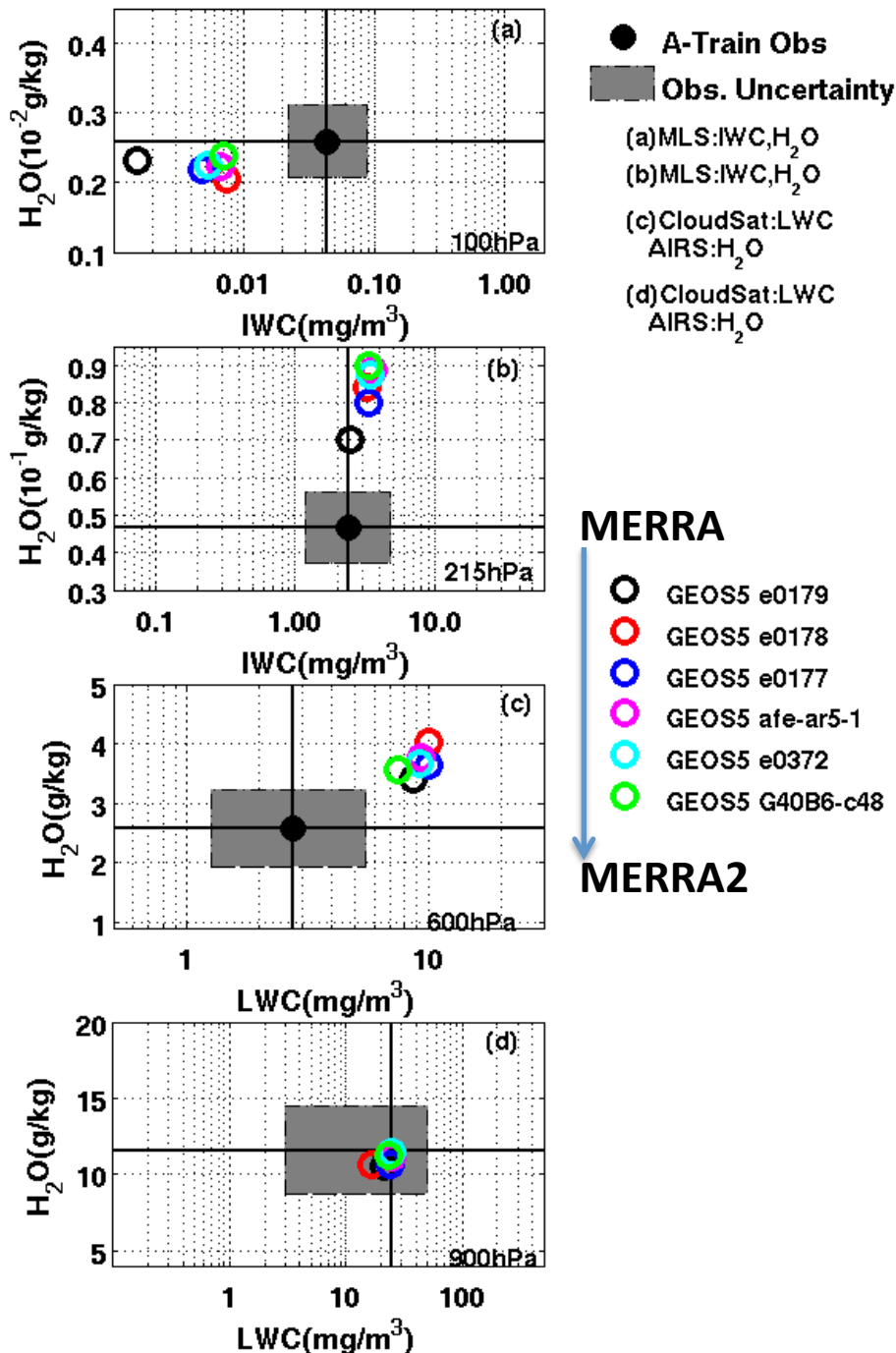
e0177: added to e0178 a change in the specified vertical profile of the width of PDF for subgrid scale water (vapor + condensate). Near the surface this change resulted in a decrease in the PDF width, and above the boundary layer the new PDF is wider.

afe-ar5-1: added to e0177 changes in the turbulence parameterization, which included an increase in near-surface turbulent diffusion, and replace the turbulent surface layer parameterization stability functions with ones that increase the fluxes under stable and cold conditions.

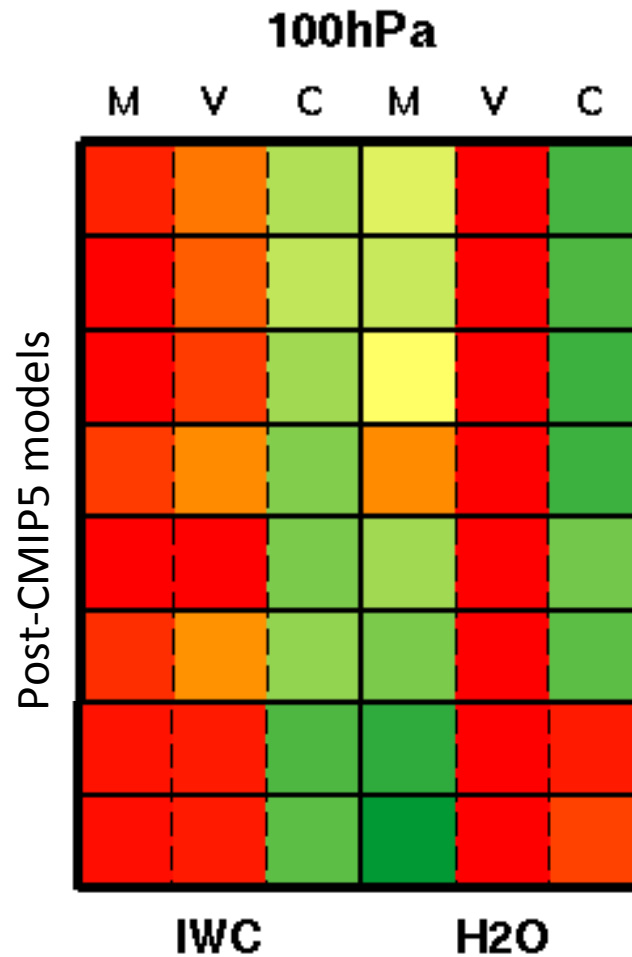
e0372: added to afe-ar5-1 a change in ocean surface roughness parameterization. The roughness was increased in the medium (>5 m/sec) wind speed range based on new observations, and was decreased in the high wind speed range (>25 m/sec) based on theoretical arguments and laboratory results.

G40B6-c48 added to e0372 changes in the cryosphere parameterizations. A new glacier model was added which includes snow layers on top of the glacier, and the sea ice albedo was modified to include a seasonal cycle. This is essentially the version of the GEOS-5 AGCM that was used as part of the MERRA2 Data Assimilation System.

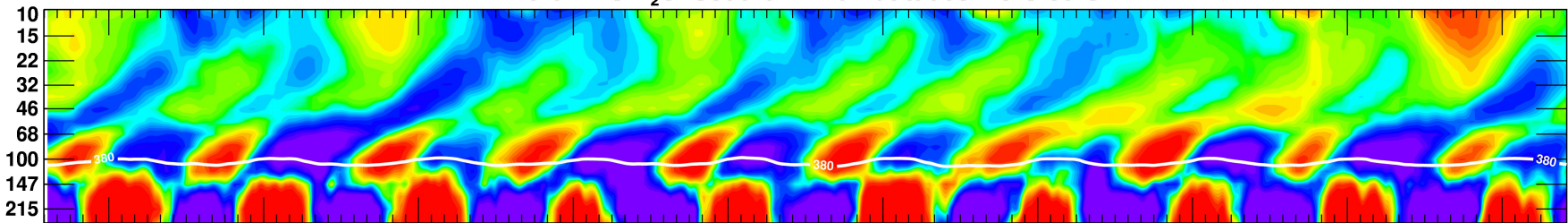
Molod et al. (2012)



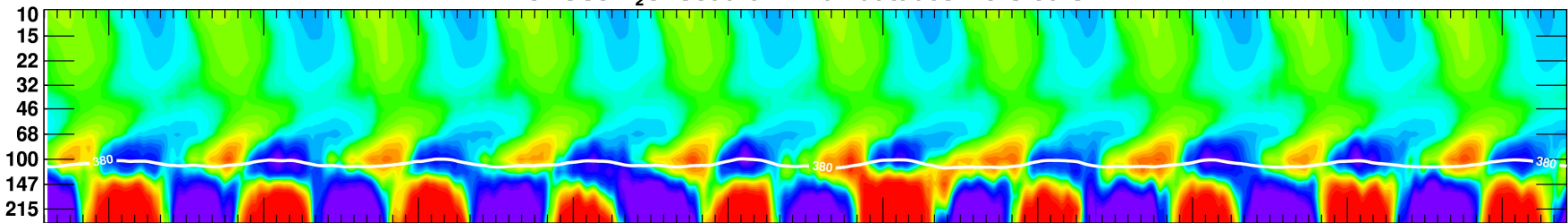
UTLS water simulation can not be simply improved by tuning convective parameterizations without correctly simulate physical processes of UTLS transport (vertical and horizontal).



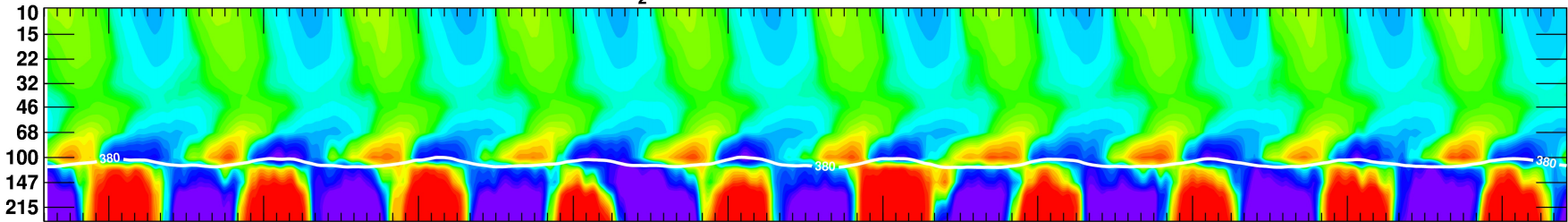
Aura MLS H₂O Southern Mid-Latitudes: 15°S-30°S



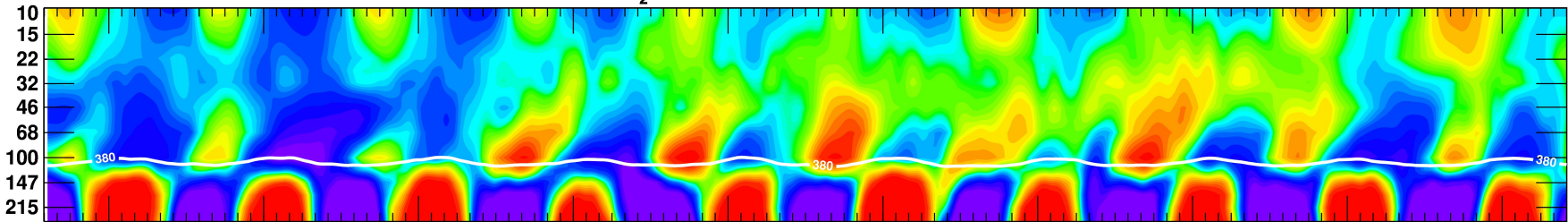
GEOS5 H₂O Southern Mid-Latitudes: 15°S-30°S



MERRA H₂O Southern Mid-Latitudes: 15°S-30°S



ECMWF H₂O Southern Mid-Latitudes: 15°S-30°S

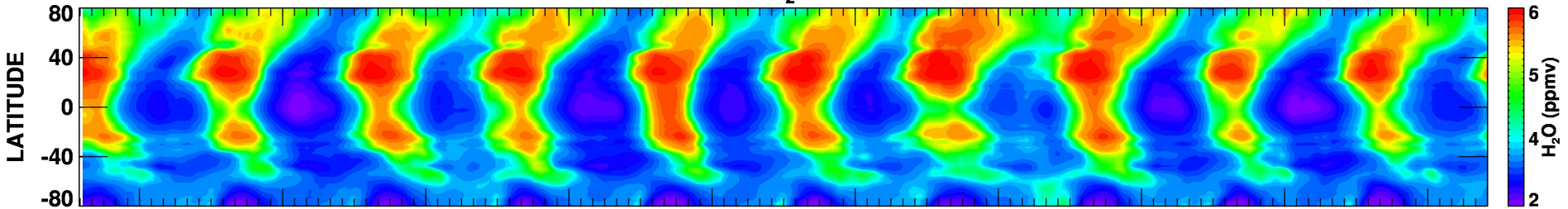


H₂O Anomaly%

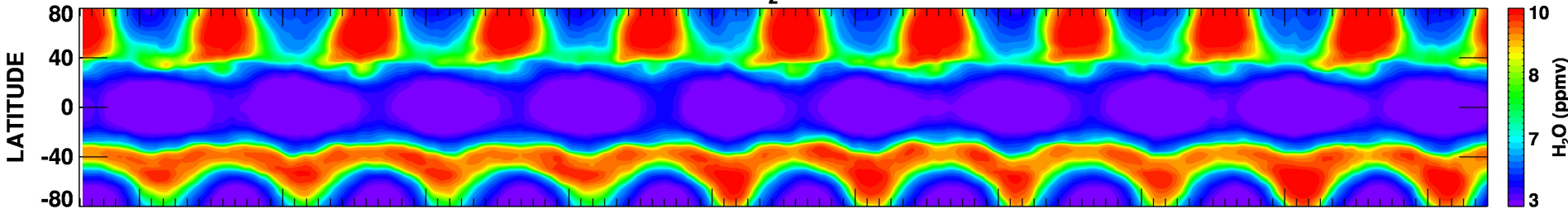
20
12
6
3
1
0
-1
-3
-6
-12
-20

Oct 2005 Jan Apr Jul Oct 2006 Jan Apr Jul Oct 2007 Jan Apr Jul Oct 2008 Jan Apr Jul Oct 2009 Jan Apr Jul Oct 2010 Jan Apr Jul Oct 2011 Jan Apr Jul Oct 2012 Jan Apr Jul Oct 2013 Jan Apr Jul Oct 2014

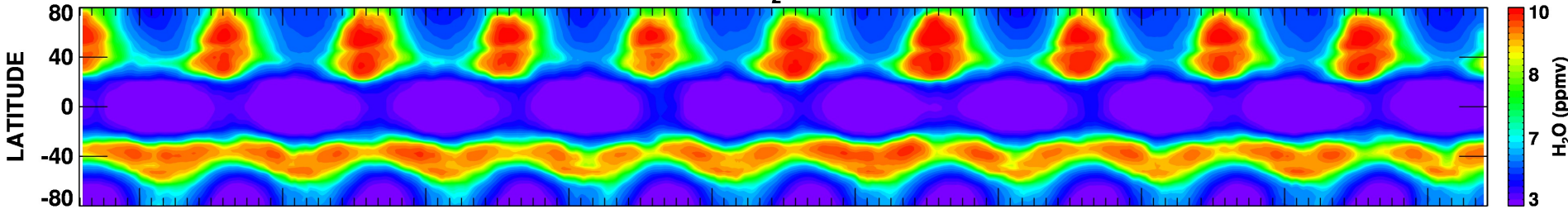
Aura MLS H₂O at 380K



GEOS5 H₂O at 380K



MERRA H₂O at 380K



ECMWF H₂O at 380K

