P2.37 Comparison of Aura MLS water vapor measurements with GFS and NAM analyses in the upper troposphere/lower stratosphere

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1. INTRODUCTION

Water vapor is crucial to the earth's heat balance, helping to maintain a mean surface temperature much higher than would otherwise be present. In addition to its direct role as a greenhouse gas, atmospheric water vapor plays an important indirect role in the determination of the weather and climate through the formation of clouds and precipitation.

Stratospheric water has two primary sources, oxidation of methane in the upper-stratosphere and transport from the troposphere. The global-scale upwelling of the classic Brewer-Dobson circulation in the tropics controls most of the flux from the troposphere. Much of the water vapor is frozen out as the air passes through the cold tropical tropopause (Newell and Gould-Stewart, 1981). The sources of enhanced water vapor from the troposphere are from convection associated with the intertropical convergence zone (ICTZ) just north of the equator and from the Asian and North American monsoons. Dunkerton (1995) concluded from rawinsonde data and European Center for Medium-Range Weather Forecast (ECMWF) analyses that the Asian and North American monsoons can transport significant mass into the lower stratosphere. Dethof et al. (1999) used contour advection to demonstrate that moisture can be transported into the lower extratropical stratosphere in the north and east sector of the Asian monsoon. Dynamically, the extra-tropical lower stratospheric water vapor budget is determined by several transport paths: mid-latitude cross-tropopause transport, transport across the subtropical jet between the mid-latitude lower stratosphere and the tropical upper troposphere, and slow descent from the upper stratosphere. The Brewer-Dobson circulation does not explain the positive trend in water vapor since tropical tropopause temperatures have exhibited a slight negative trend over the past two decades, implying that drier air is transported into the tropical stratosphere through this mechanism (Simmons et al., 1999). Increased extratropical troposphere to stratosphere transport of moisture remains as a likely cause. This uncertainty has significant impact on questions concerning climate change since the spatial and temporal water vapor changes cannot be predicted.

Climate change prediction is as strongly dependant on the background water vapor concentration as the assumed perturbation (Forster and Shine, 2002). Although some studies have been done on the water vapor in the upper troposphere and the lower stratosphere, few comparisons have been performed between satellite-derived values and analysis data sets. Water vapor mixing ratios from both global and regional model analyses will be compared with data from the Microwave Limb Sounder on the Aura satellite in the present study.

The purpose of this study is to determine how well the Global Forecasting System (GFS) and North American Mesoscale (NAM) analyses of water vapor compare with Aura MLS data in the upper troposphere and lower stratosphere. In addition, results from this study could be of value in diagnosing possible errors in both the GFS and NAM model initializations and may be of use in future studies of physical mechanisms for transportation of moistures between the upper troposphere and lower stratosphere. The results may support the need for assimilating satellite retrievals into models to improve forecasting ability.

2. DATA AND METHODOLOGY

We used data from two years, 2005 and 2006, and compared water vapor mixing ratios during four seasons, denoted in this study as winter [January and February 2005 (JF) and December 2005, January, and February 2006 (DJF)], spring [March, April, and May (MAM)], summer [June, July, and August (JJA)], and fall [September, October, and November (SON)]. To compute the water vapor volume mixing ratios, we used the temperature and relative humidity analysis data from the GFS model and the NAM model during the same time periods at levels 300mb, 250mb, 200mb, 150mb, 100mb, and 50mb. Water vapor volume mixing ratios were used in these comparisons in parts per million by volume (p.p.m.v).

The GFS incorporates codes including a medium range forecast model (MRF) and a global data assimilation system (GDAS). The GFS was developed experimentally during the late 1970s and implemented as the global forecast model at the National Meteorological Center (NMC, now the National Centers for Environment Prediction, NCEP) on 18 March 1981. Currently, the GFS is run four times per day (00UTC, 06UTC, 12UTC, and 18UTC) out to 384 hours and initial conditions are provided from the Spectral Statistical Interpolation (SSI) global data assimilation system (GDAS). GFS data interpolated to a 1 degree grid and initialized at both 00 and 12 UTC were used for the comparisons in the present study.

The NAM model used the Eta model for its time integrations during the January 2005 through June 20, 2006 portion of our study period. It then was replaced with the Weather Research and Forecasting

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model using the Nonhydrostatic Mesoscale Model dynamic core (WRF-NMM). The domain, horizontal resolution (12km) and output grid geometry did not change. By comparing three month summer (JJA) and three month fall (SON) seasons between 2005 and 2006, the differences due to the use of the two different models will be shown later.

The Aura satellite was launched in July 2004 in a sun-synchronous polar orbit for a nominal mission of five years. The four Aura instruments are: the High Resolution Dynamics Limb Sounder (HIRDLS), measuring infrared emission profiles from high resolution atmospheric limb scans behind Aura, the Microwave Limb Sounder (MLS), obtaining limb emission profiles ahead of the satellite, the Ozone Monitoring Instrument (OMI), a nadir-viewing UV/VIS imaging spectrometer with high spatial resolution, and the Tropospheric Emission Spectrometer (TES), a Fourier Transform infrared spectrometer measuring in both the nadir and the limb mode behind Aura. In this study, water vapor mixing ratios were observed by the MLS in the upper troposphere and stratosphere, even in the presence of cirrus where observations by other techniques (infrared, visible, and ultraviolet) could be flawed. These measurements were especially valuable because of uncertainties in climate feedback mechanisms associated with upper tropospheric water vapor. MLS measurement locations for a 24 hour period include tangent points for individual limb scan with 200 km along track separation between adjacent limb scans and 7 km across track spacing. Thus, each satellite data point represented an area 200 km long and 7 km wide. Thus, water vapor mixing ratios in the model analyses were averaged over these same 200 x 7 km blocks for comparison with the Aura MLS data.

The primary tool for the comparisons of model analyses and MLS data will be conditional probability density functions (PDFs). The PDFs show the fraction of the observations that measure a given value. This powerful tool is ideal for use on large data sets and permits rapid and detailed information on the variability and bias of the data under a wide variety of atmospheric states and geophysical locations [e.g Sparling and Bacmeister, 2001]. The figures below show the PDFs of Aura MLS water vapor volume mixing ratios and the GFS and NAM analyses at levels 300mb, 250mb, 200mb, 150mb, 100mb, and 50mb. The GFS data covered the globe, and the comparisons for GFS data in four seasons are subset into five subregions defined as Tropics (TP) restricted by latitudes ranging from 20^0S to 20^0N, Northern Mid-latitude (NM) with latitudes from 20^0N to 60^0N, Northern Polar (NP) with latitudes from 60^0N to 90^0N, Southern Polar (SP) with latitudes from 90^0S to 60^0S, and Southern Mid-latitude (SM) with latitudes from 60^0S to 20^0S. The PDFs will be used to compare the global model analysis with the regional model analysis and both of these with satellite observations.

3. RESULTS

In subsequent discussions PDFs of the MLS mixing ratios will be compared with those from GFS model analyses over five global subregions and from NAM analyses over much of North America. Because of the large number of plots generated by such a comparison, a web site has been established at http://www.meteor.iastate.edu/~lvthien/ to complement the limited amount of plots discussed below.

3.1 GFS analyses and MLS observations

- *Tropics (20^0S-20^0N)*

The tropics have been known as an area with strong moistening and the deepest convection on the earth. The PDFs for this area were similar in shape in all four seasons of both 2005 and 2006. Results from summer 2005 are shown in Fig. 1a. In all seasons, the majority of GFS data points were moister than MLS at all levels. Differences in the datasets are most pronounced at 50 mb, where GFS values were often far higher than MLS values. Although the 2005 and 2006 results were generally similar, agreement between GFS and MLS values was better in 2006 than in 2005 at the 100 mb level (not shown). The peak of the PDFs at 100 mb during summer (Fig. 1a) and fall seasons is in better agreement (less of a moist bias in the GFS) than during winter and spring (not shown). In general, at all levels in all seasons, the GFS distribution is broader than that from MLS.

- *Northern mid-latitudes (20^0N-60^0N)*

In this region, the PDFs in all four seasons showed a moist bias in the GFS analyses at levels from 300mb to 200mb and at 50mb, with a distinct dry bias in the GFS analyses at 150 and 100 mb. This pattern of biases remains relatively the same in all four seasons, despite the fact the average tropopause height varies over seasons in this region. Results from summer 2006 are shown in Fig. 1b. The dry bias at 150 mb was a little less severe during the winter and spring of 2005 (not shown). At levels where the GFS has a moist bias, the distribution of mixing ratio values is broader than in the MLS measurements.

- *Northern pole (60^0N-90^0N)*

The number of MLS data points in the northern polar region was smaller than in the tropics and north and south mid-latitudes. However, the PDF curves for the GFS analyses and MLS data strongly resemble those valid for the northern mid-latitudes. Data from fall 2005 is shown in Fig. 2a. As in the northern midlatitudes, the pattern of biases does not seem to be affected much by the changing of seasons and average height of the tropopause.

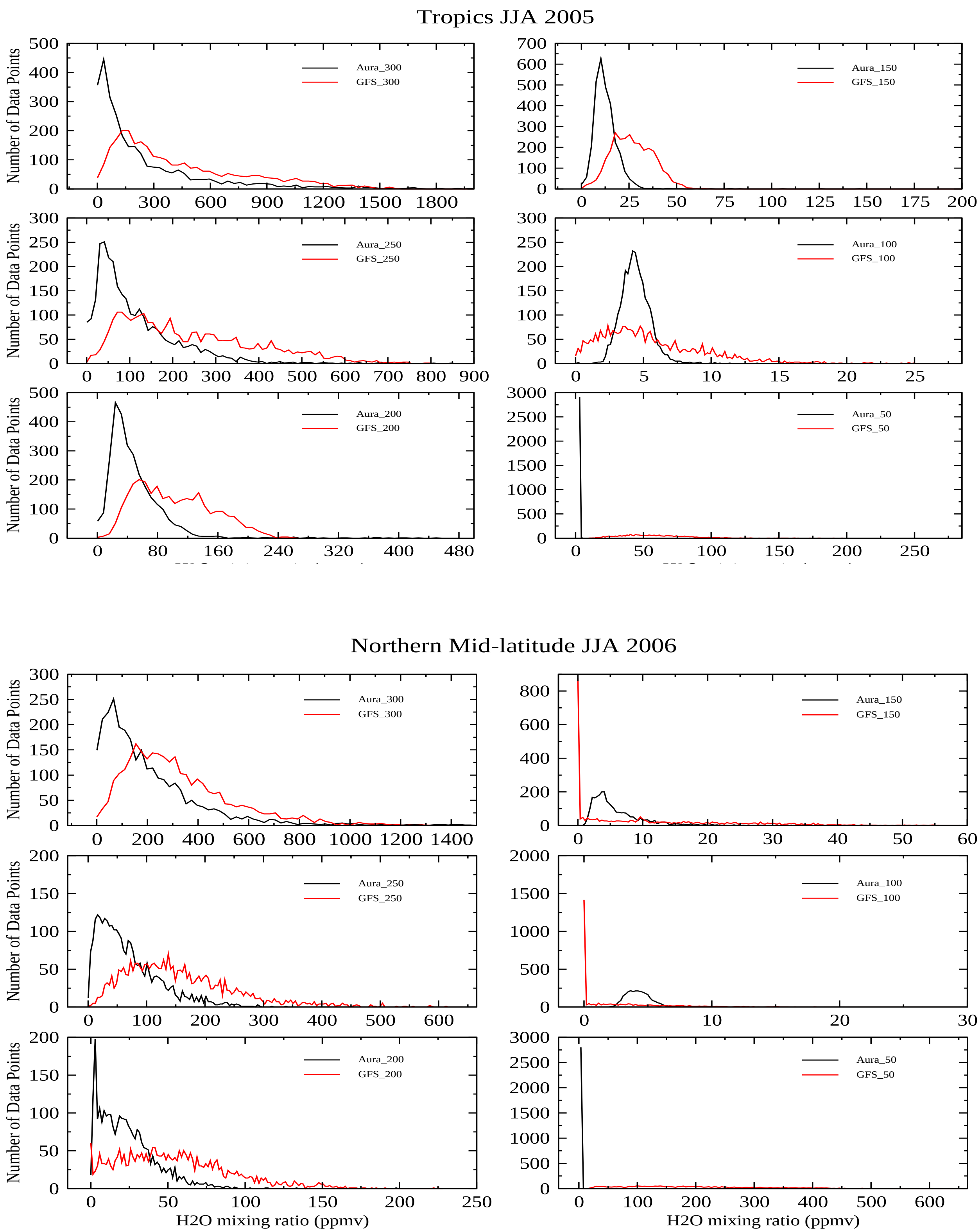


Figure 1. PDFs comparing GFS model analysis with Aura MLS water vapor volume mixing ratios at 300mb, 250mb, 200mb, 150mb, 100mb, and 50mb: (a) in tropics for summer 2005. (b) in northern midlatitudes for summer 2006

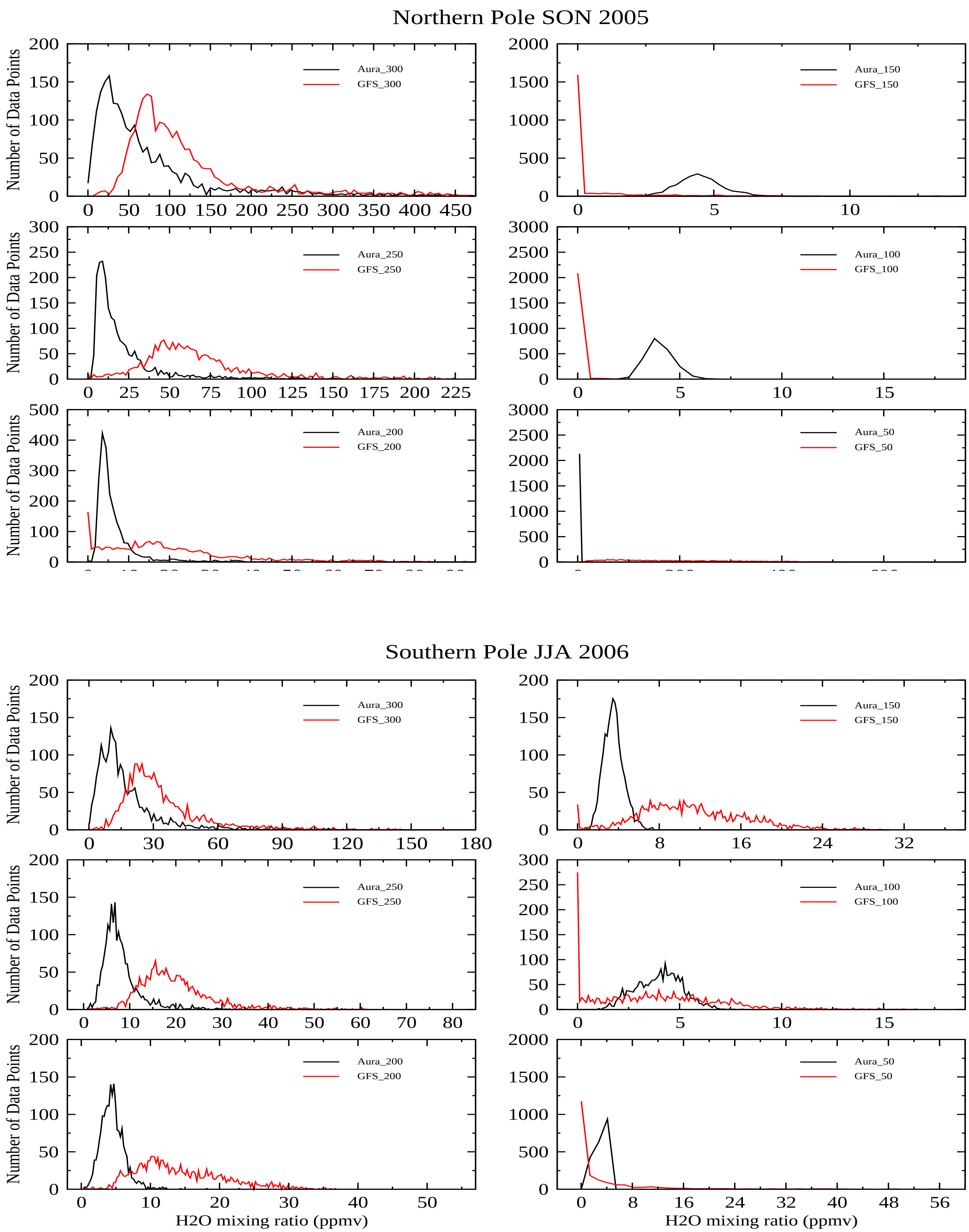


Figure 2. PDFs comparing GFS model analysis with Aura MLS water vapor volume mixing ratios at 300mb, 250mb, 200mb, 150mb, 100mb, and 50mb: (a) in northern pole region for spring 2005. (b) in southern pole region for summer 2006

- *Southern pole (60^0S-90^0S)*

In general, PDFs for the southern polar region were similar to what was found in the northern polar region (Fig. 2b is an example for summer 2006) with the exception that a moist bias was present at 150 mb in the GFS data instead of a dry bias. This reversal of biases was true at all time periods except winter and spring of 2005 when a dry bias was present at 150 mb, as was the case in the northern polar region.

- *Southern mid-latitudes (20^0S-60^0S)*

The shapes of the PDFs for MLS data and GFS analyses for the southern midlatitudes were similar to those for the northern mid-latitudes at all seasons and levels (not shown).

3.2 NAM analyses and MLS observations

The NAM is a regional model with horizontal resolutions higher than the GFS. Since NAM covers most of North America and most of the MLS data points missed the NAM domain (longitudes from 133.459^0W to 63.9548^0W and latitudes from 12.19^0N to 59.5132^0N) at all times except 18UTC, this study used the NAM analyses at 18 UTC to compare with the MLS data at the same time.

- *Summer seasons (JJA) in 2005 and 2006*

The PDFs showed that the NAM analyses are most consistent with the MLS data at 300mb in both 2005 and 2006, and reasonably consistent also at 150mb and 100mb in 2005. The most probable data points at 300mb were mainly concentrated at values around 150ppmv. At levels 150mb and 100mb, the peaks of PDFs of NAM and MLS are closer in 2005 than in 2006. In particular, both NAM and MLS reproduced the same shapes of a two peak PDF structure at 150mb in 2005. At other levels, the shapes of the PDFs of NAM and MLS were also similar. Most of the NAM data points were at values larger than MLS data at all levels (Fig. 3), indicating a moist bias in the NAM analyses, similar to the bias found for GFS. Comparing the shapes of PDFs for MLS and GFS in the Northern Midlatitude (NM) region in summer 2005 and 2006, the PDFs for NAM and MLS are to be closer, especially at levels such as 300mb, 250mb, 200mb, and 150mb. Both NAM and GFS analyses were moister than MLS at levels 300mb, 250mb, 200mb and 50 mb,. Unlike the GFS analyses, NAM mixing ratios continued to be higher than MLS values at 150 and 100 mb, and the dry bias present in the GFS for midlatitudes was not present.

- *Fall seasons (SON) in 2005 and 2006*

A comparison of the fall season is important because the NAM changed from using the Eta model to using the WRF model on June 20, 2006, and a fall comparison thus allows one to see what impact the change in model may have had in representation of mixing ratios at these high levels. The shapes of the NAM PDFs in both 2005 and 2006 generally resembled the shapes of the MLS PDFs at levels from 300mb to 100mb (Fig. 4). However, at higher levels from 200mb to 50mb the peaks of the NAM PDFs in 2005 are more consistent with those from the MLS PDFs than in 2006. Figure 5 allows for a more direct comparison of the NAM and GFS analyses during these two fall seasons, with GFS data analyzed over the smaller NAM domain. Compared to the GFS, the NAM PDFs agree better with MLS PDFs at all levels over this domain. Also, although GFS PDFs for 2005 and 2006 stayed basically the same, NAM PDFs changed between these two years, being more consistent with MLS PDFs in 2005 than in 2006 at levels from 200mb to 50mb (Fig. 5).

4. SUMMARY AND FUTURE WORK

We have presented the first comparisons between Aura MLS satellite based water vapor measurements and GFS and NAM analyses in the upper troposphere and the lower stratosphere. Considering geographical regions, the GFS analyses generally agreed better with satellite observations in the tropics and both northern mid-latitudes and southern mid-latitudes than in both the northern and southern poles with regard to the overall amount of water vapor volume mixing ratio and to all seasonal distributions. It is likely that the model analyses suffer from significantly less assimilation data in Polar Regions.

NAM water vapor analyses were overall more consistent with MLS measurements at all levels than GFS analyses. In particular, the NAM water vapor analyses in two seasons, summer (JJA) and fall (SON) 2005, seem to be in better agreement with the MLS data than the same two seasons in 2006. The poorer performance may be related to the change in the NAM from using the Eta to using the WRF model in June 2006. Also in the fall seasons of both 2005 and 2006, the NAM analyses agreed better with the MLS data than in the summer seasons. One question not answered here is whether these differences have affected the accuracy of NAM forecasts during these seasons?

Overall, a moist bias was found in the NAM analyses in all four seasons at all six levels evaluated, and in the GFS analyses for the tropics. In other regions, the moist bias was present in all four seasons at 300mb, 250mb, 200mb, and 50mb, with a dry bias at 150mb and 100mb. The PDFs also showed that NAM analyses were more consistent with the MLS estimates than GFS analyses at all levels from 300mb to 50mb.

Comparisons between GFS and NAM analyses and Aura MLS satellite data not only help diagnose possible errors in the model initializations but may also allow improved accuracy in weather and climate forecasts through a better dynamical understanding of the upper troposphere/lower stratosphere. Future research will continue to use Aura data to investigate possible physical mechanisms for transportation of water vapor in the upper troposphere/lower stratosphere by monsoon convection and the interactions between these physical processes.

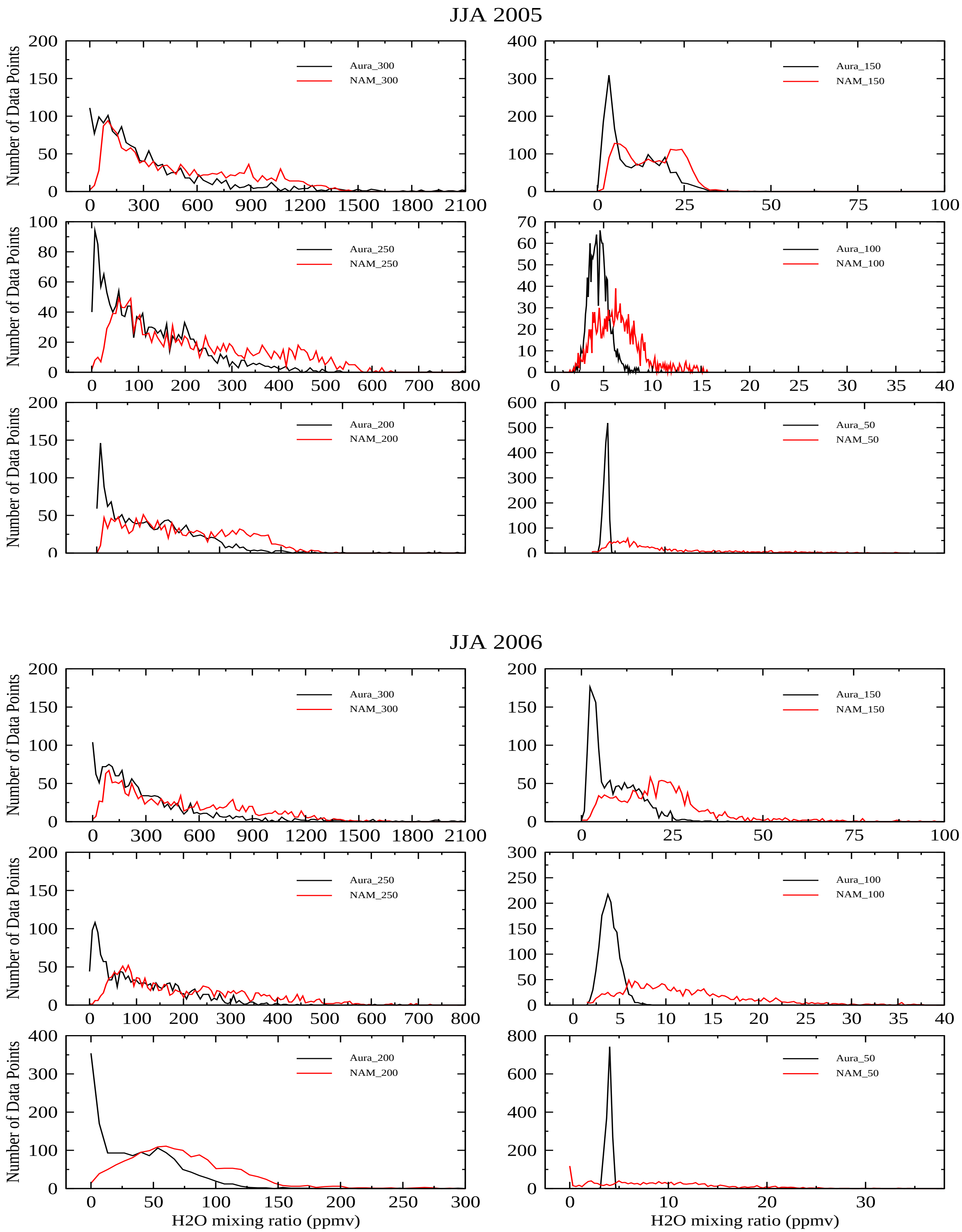


Figure 3. PDFs comparing NAM model analysis with Aura MLS water vapor volume mixing ratios at 300mb, 250mb, 200mb, 150mb, 100mb, and 50mb in north America for summer season June, July and August: (a) in 2005 and (b) in 2006.

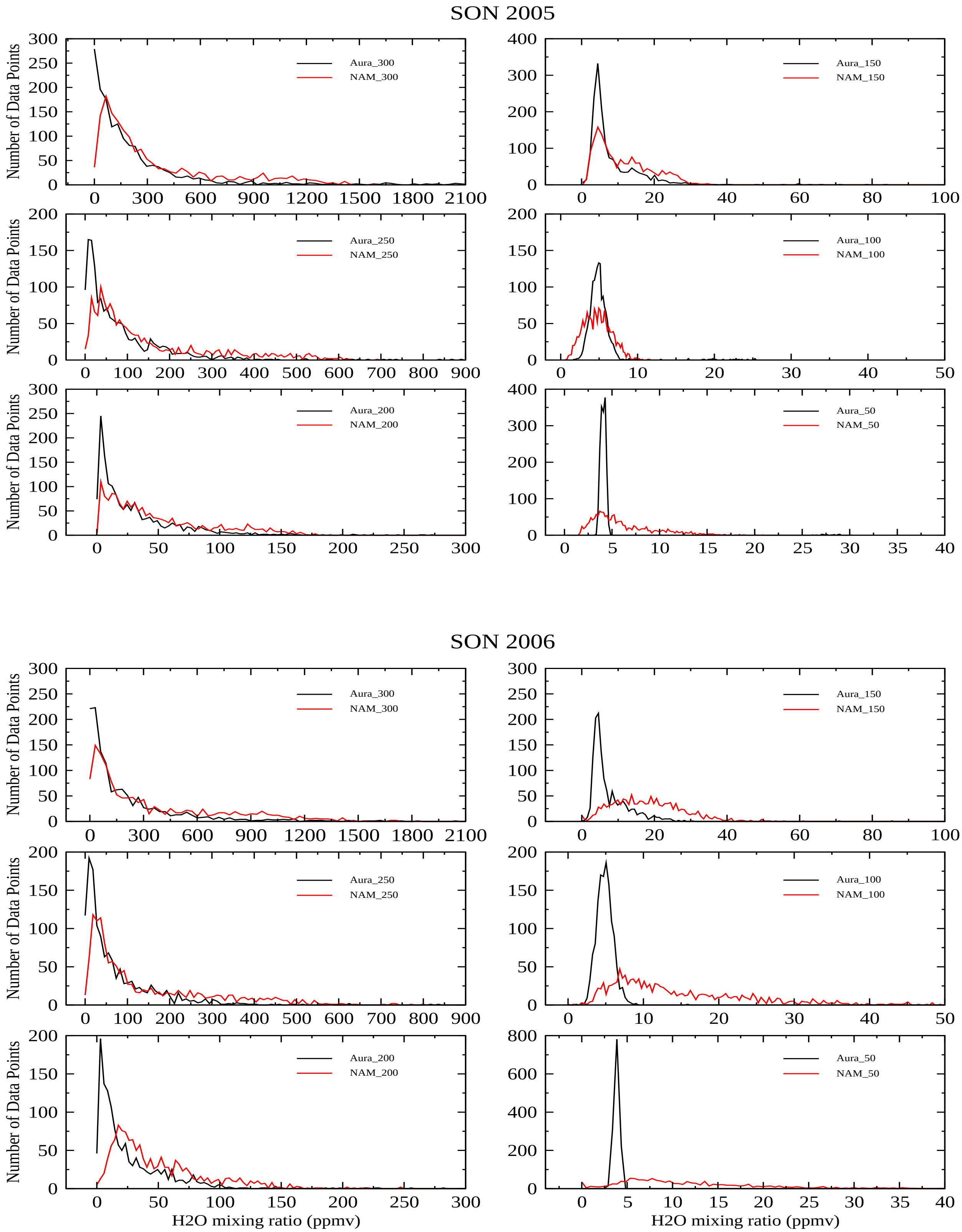
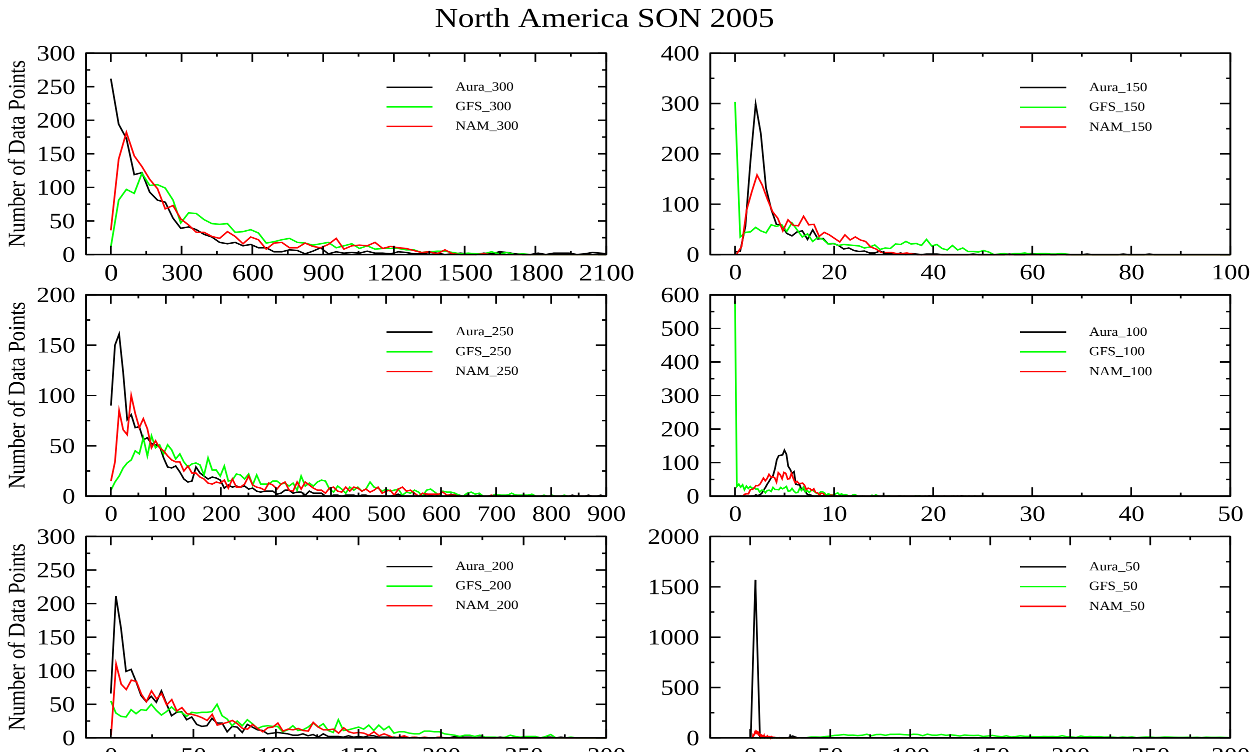


Figure 4. PDFs comparing NAM model analysis with Aura MLS water vapor volume mixing ratios at 300mb, 250mb, 200mb, 150mb, 100mb, and 50mb in North America for the fall season September, October and November: (a) in 2005 and (b) in 2006.



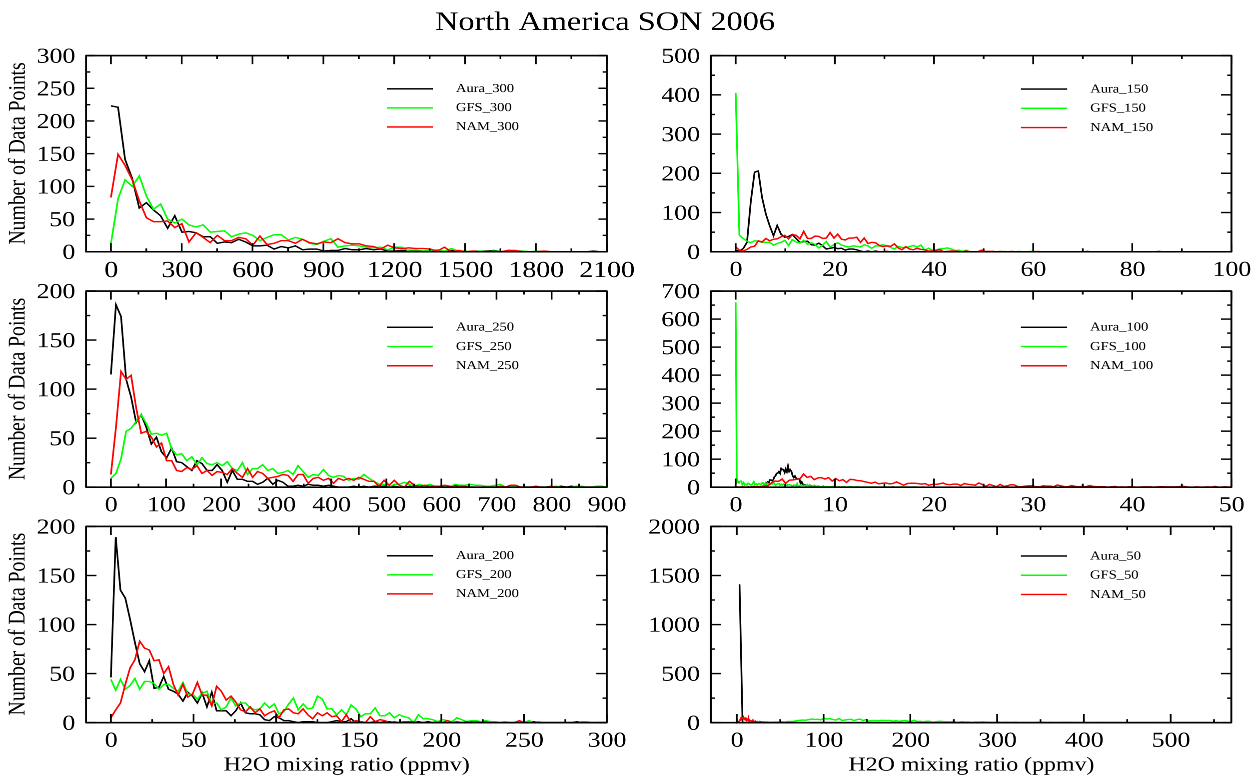


Figure 5. PDFs comparing NAM and GFS model analyses with Aura MLS water vapor volume mixing ratios at 300mb, 250mb, 200mb, 150mb, 100mb, and 50mb in North America for the fall season September, October and November: (a) in 2005 and (b) in 2006.

5. ACKNOWLEDGEMENTS

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