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Interactive comment

Interactive comment on "Enhanced Stratospheric Water Vapor over the Summertime Continental United States and the Role of Overshooting Convection" *by* Robert L. Herman et al.

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Authors' response to anonymous referee #1 on "Enhanced Stratospheric Water Vapor over the Summertime Continental United States and the Role of Overshooting Convection" by R. L. Herman et al., ACP-2016-1065

We would like to thank the referee #1 for detailed review, and for insightful and constructive comments (shown in quotations below). The individual points are addressed by the authors below:

Referee's Major Comment: "In my opinion this paper could easily stand alone if all Figures and in-depth discussions of Aura MLS stratospheric water vapor measurements

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were omitted. The vast majority of scientific conclusions can be made without the broader picture provided by the MLS data. The one significant contribution of MLS data to this paper is to show the low frequency of occurrence of anomalously high stratospheric water vapor mixing ratios over the North American monsoon region. However, this conclusion, based on MLS water vapor data, was already published by Schwartz et al. (2013, Geophy. Res. Lett.). There are also some difficulties translating between the aircraft and MLS results because of the presumably different mixing ratio thresholds used to identify "enhanced" water vapor for each. Intuitively the MLS threshold needs to be lower because of the much coarser vertical and horizontal resolution of MLS retrievals. See my comments below regarding this issue." "I will leave it up to the authors if they want to retain or omit the MLS data in their paper. I don't think its presence detracts from the main objectives of this paper, but I also think it doesn't contribute much to them."

Authors' Response: The Aura MLS stratospheric water vapor measurements place the aircraft field mission data into regional and decadal perspective. We have improved the text and figures (as described below) to tie MLS and the aircraft results together. MLS helps us address the question from Toon et al (2016): "Do deep convective cloud systems locally inject water vapor and other chemicals into the overworld stratosphere over the CONUS?"

We modified text in lines 116-117 (lines 135-136 in revised manuscript) for greater clarity: "Figure 1 adds the year 2013 including the SEAC4RS time period to the long-term Aura MLS 100-hPa time series from Schwartz et al. (2013)."

Also, in our revised paper we will demonstrate that both MLS water at 100 hPa and aircraft water are enhanced significantly above background. This point will be demonstrated in a clearer Figure 4 and histograms of both MLS and aircraft data.

Referee's Minor Comments: 1) Figure 1 and Caption. "'Each monthly histogram is normalized to unity over mixing Ratio' needs further explanation. I went back to the

Schwartz et al. (2013) paper for clarification and found the exact same statement. For me, to normalize each monthly histogram one would divide the population of each mixing ratio bin by the entire population or the population of the bin containing the mode or mean of the distribution. Assuming a somewhat Gaussian distribution, the normalization the mode or mean bin population would produce numbers near one and zero for the most and least populated bins (most and least probable in a PDF), respectively. This is how I interpret Figure 1 even though I don't understand "normalized to unity over mixing ratio" and the units on the color bar are ppmvËĘ-1. What am I missing here?"

Author's response to 1: We agree with the referee that this was not explained well in the Figure 1 caption. If the integral from 5 ppmv to 8 ppmv in a given month was 0.6, that would mean that 60% of observations fell in that range of mixing ratios. We have modified the Figure 1 caption: "Each monthly histogram is normalized over mixing ratio such that, if one integrates colors (ppmv-1) over a range of mixing ratio, the result is a dimensionless probability that is normalized to one when integrating over all colors for that month."

Figure 1 comment: "Also for Figure 1, the vertical lines are not "dashed" and the gray shading is too light, at least for my eyes."

Author's response to Figure 1: In the Figure 1 caption, we remove the word "dashed" and the gray shading is now darker (see accompanying Figure 1).

Figure 1. Time series of Aura MLS v4.2 100-hPa H2O over North America. The altitude is approximately 17 km. Each monthly histogram is normalized over mixing ratio such that, if one integrates colors (ppmv-1) over a range of mixing ratio, the result is a dimensionless probability that is normalized to one when integrating over all colors for that month. Thin vertical lines mark year boundaries, and gray-shaded areas denote July-August. Data are from the eastern CONUS through northern Mexico (see Figure 2 insert), a study box empirically chosen to enclose the highest outliers associated with

the North American Monsoon in the 10+ year MLS 100-hPa water vapor climatology (after Schwartz et al., 2013).

2) "The paper uses three vertical coordinates and doesn't tie them together very well. The introduction focuses on potential temperatures, everything pertaining to Figures 1-4 is discussed and shown in pressure coordinates, then Figures 5-7 are presented in altitude coordinates. Are the profiles in Figures 4-7 entirely in the lowermost stratosphere or do they extend into the overworld (or upper troposphere for that matter)? Profiles in Figures 4 extend from 150 to 50 hPa but in Figure 5a (same profiles) span 15.5 to 18.5 km. Are the axis ranges of these two Figures the same in terms of vertical span? I understand the need to discuss stratospheric layers in terms of potential temperature (introduction), but why can't everything else be presented uniformly using either pressure or altitude coordinates (or both together)? It would make the discussion and Figures much more intelligible."

Author's response to 2: To be consistent with previous literature on OT, the vertical coordinate of choice is altitude. We will change Figure 4 vertical coordinates to Altitude (left axis) and approximate Potential Temperature (right axis). Figures 1, 2 and 3 use the standard MLS 100-hPa product but we will modify each caption to 100 hPa (approximately 17 km altitude). The profiles in figures 4-7 are mostly overworld stratosphere, with some lowermost stratosphere at the bottom of the profile (no upper tropospheric data are shown). This will be made clear by the revised figure 4: altitudes 14.5 to 20 km and potential temperature from 365 K to 480 K.

Figure 4. Map and profiles of aircraft and satellite water vapor on 8 August 2013 over California (number 1 shown in dark blue) and Texas (number 2 shown in green). (a) Map of ER-2 aircraft flight track (solid colored trace) and nearly coincident Aura MLS geolocations (asterisks and lines). (b) ER-2 aircraft pressure profiles (solid colored trace) color-coded by dives and MLS times (horizontal lines). (c) Vertical profiles of water vapor from JLH Mark2 (dots), in situ with MLS averaging kernel (asterisks and lines), and MLS (circles and lines)

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3) [1] “Though the phrase ‘enhanced water vapor’ appears in the paper’s title and is used frequently throughout the paper, it is never defined for the aircraft measurements. [2] Presumably there is a mixing ratio threshold used to identify air parcels with enhanced water vapor? The abstract may indirectly imply, likely incorrectly, that “enhanced” mixing ratios measured from aircraft are those >10 ppmv. [3] Adding to the mystery are the blue markers in panels (a) of Figures 5-7 that represent the “enhanced H2O region” but range well below 5 ppmv. What exactly is the threshold for “enhanced” water vapor measured from the aircraft? Why are there mixing ratios <5 ppmv in regions of enhanced water vapor? This is quite confusing and requires some important clarification in the paper.”

Author’s response to 3: We agree with the referee that ‘enhanced water vapor’ should be presented more clearly. [1] A definition, added to the paper at line 84 (new lines 91-92 in revised manuscript), is: “Here we define ‘enhanced water vapor’ as a mixing ratio that is greater than two standard deviations above the mean in situ measurement.” This is the threshold for ‘enhanced water vapor’ as measured from the aircraft. [2] In the revised paper, we will present a statistical analysis of the aircraft data, showing the value of mean plus 2 sigma, the threshold for enhanced water, that varies with pressure (new figure in preparation). In the overworld stratosphere, water vapor mixing ratios > 10 ppmv are very rare and thus “enhanced.” [3] The referee is correct that panels (a) of Figures 5-7 are confusing. We will modify panels (a) so that enhanced water vapor is shown in a different color. We consider only the extreme elevated mixing ratios (mean + 2 sigma) to be “enhanced” water vapor.

4) [1] “Is it appropriate to try to combine information from MLS and aircraft-based detections of ‘enhanced’ water vapor in this paper when their thresholds are probably very different? Figure 3 shows only 13 instances where MLS retrievals at 100 hPa during Jul-Aug 2013 exceeded 8 ppmv. [2] Is this the threshold for MLS-detected “enhanced” water vapor? [3] Given the greatly different vertical and horizontal resolution of the MLS and aircraft measurements, how can the MLS findings be integrated with the

aircraft-based results that follow? I don't think they can. [4] What does a MLS retrieval of 8 ppmv with a 3-km averaging kernel width translate to for the in situ aircraft measurements? [5] Figures 1-3 contribute to only one conclusion drawn in this paper: that MLS retrievals at 100 hPa over the NAM region during Jul-Aug rarely exceed 8 ppmv. In my opinion that is a secondary (and already published) conclusion compared to the dominant conclusion of this paper that enhanced stratospheric water vapor measured over the NAM region during Jul-Aug 2013 can be traced back to convection-induced overshooting cloud tops."

Author's response to 4: To respond to the referee's comments, we will add information to the paper about comparing MLS and aircraft-based detections. This subject did not receive adequate description in the submitted manuscript, and is addressed below. 1) Rodgers and Connor (2003) mathematically described how to rigorously compare satellite remotely-sensed data with a different dataset (e.g., a high-resolution in situ dataset). Following from this article, the MLS data may be compared to the aircraft data once the MLS averaging kernel (observation operator) is applied to the in situ data. 2) The threshold for MLS-detected 'enhanced water vapor' is set at 8 ppmv, same as Schwartz et al. (2013), to exclude the larger population of measurements at 6 to 8 ppmv water vapor that may have other sources. 3) By using the MLS averaging kernel, we can address both the satellite data and the aircraft in situ data. 4) Figure 4 shows that an MLS retrieval of 7 ppmv with a 3-km averaging kernel width translates to 11 ppmv for in situ aircraft measurements. 5) Each summer has different meteorology, and we wish to use a decade of MLS measurements to place 2013 in context. There are three major results from the MLS figures that we want to retain in the paper, that summer 2013 had fewer extreme events than the previous three years (Figure 1), summer 2013 was drier on average than the previous nine summers, 2004-2012 (Figure 2), and the estimated frequency of H2O > 8ppmv was 0.9 percent (see below). The author wishes to keep the MLS figures in the paper to demonstrate these points. Please note that Schwartz et al. (2013, Geophys. Res. Lett.) did not show data from the year 2013.

Referee's Editorial Comments:

Line 58: "please give the lowermost stratosphere a rough lower limit (in potential temperature) otherwise this implies it extends down to the surface. "Commonly" suggests these mechanisms are highly probably pathways for tropospheric water vapor to reach the stratosphere, which they are not." Author's response: We have modified the underlined text at line 58: "In contrast to water entry into the overworld stratosphere, water transport from the troposphere to the lowermost stratosphere (350 K < < 380 K over summer CONUS) may occur through several different pathways. Poleward of the subtropical jet, water may be transported into the lowermost stratosphere through isentropic troposphere-stratosphere exchange (Holton et al., 1995) or through convective overshoot of the local tropopause (Dessler et al., 2007; Hanisco et al., 2007). Isentropic transport from the tropics is the dominant pathway for water into the lowermost stratosphere, with evidence from the seasonal cycle of water (e.g., Flury et al., 2013)."

Flury, T., Wu, D. L., and Read, W. G.: Variability in the speed of the Brewer-Dobson circulation as observed by Aura/MLS, Atmos. Chem. Phys., 13, 4563–4575, www.atmos-chem-phys.net/13/4563/2013/, doi:10.5194/acp-13-4563-2013, 2013.

Descent of middle stratospheric air into the lowermost stratosphere plays a smaller role than isentropic transport, as evidenced by relatively high water mixing ratios and low ozone mixing ratios of the lowermost stratosphere.

Line 62: "Please make it clear that ice (not elevated water) is transported into the stratosphere where it sublimates and produces "enhanced" water vapor mixing ratios. Author's response: we have modified the underlined text at line 62: "Case studies have reported extreme events in which ice is transported to the overworld stratosphere and subsequently sublimates, but the amount of ice that is irreversibly injected into the stratosphere is poorly known."

Line 63: "Here and elsewhere "stratospheric overworld" (defined in Line 45) has now become the "overworld stratosphere"." Author's response: Consistent with other publi-

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cations, we will change the wording in line 45 and elsewhere from “stratospheric overworld” to “overworld stratosphere.”

Line 66: “Ice does not “bypass” the cold trap, it is unaffected by it.” Author’s response: The referee is correct, we have modified the underlined text at line 66: “Ice injected directly into the stratosphere is unaffected by the cold trap in the vicinity of the tropopause (Ravishankara, 2012).”

Line 67: “Suggested paragraph break before “Paraphrasing”.” Author’s response: We inserted a paragraph break in line 67 with a new topic sentence: “The subject of this paper is the role of convective overshooting tops in enhancing stratospheric water.”

Line 81: “are limited by their horizontal and vertical resolution in detecting fine-scale three-dimensional variations in water vapor ...” Author’s response: the reviewer has a good suggestion. We will change this sentence to: “are limited by their horizontal and vertical resolution in detecting fine-scale three-dimensional variations in water vapor ...”

Line 101: “ ‘Instruments on the NASA ER-2’ – which instruments and what was measured that allows you to conclude that ‘the aircraft intercepted convectively-influenced air’?” Author’s response: Only the hygrometers onboard the aircraft measured a tropospheric signature (e.g., enhanced water vapor). Other tracers did not show a tropospheric signature because lofted ice transported a disproportionate amount of H2O relative to gas-phase tracers. We have modified the text at line 101 to: “Enhanced water vapor measured in situ by both the JLH Mark2 instrument and the Harvard Water Vapor instrument (J. B. Smith, pers. comm.) on the NASA ER-2 aircraft indicated that the aircraft intercepted convectively-influenced air.”

Line 107: “ ‘measures daily global atmospheric profiles’ sounds like one gigantic profile is measured each day. How about ‘measures ∼3500 profiles around the globe each day of atmospheric species ...’ ” Author’s response: The reviewer has a good suggestion, we will change this sentence to “measures ∼3500 profiles each day of water vapor and other atmospheric species (Livesey et al., 2016).”

Livesey, N. J., Read, W. G., Wagner, P. A., Froidevaux, L., Lambert, A., Manney, G. L., Millan Valle, L. F., Pumphrey, H. C., Santee, M. L., Schwartz, M. J., Wang, S., Fuller, R. A., Jarnot, R. F., Knosp, B. W., and Martinez, E.: Earth Observing System (EOS) Aura Microwave Limb Sounder (MLS) Version 4.2x Level 2 data quality and description document, Tech. Rep. JPL D-33509 Rev. B, Version 4.2x-2.0, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, available online at: http://mls.jpl.nasa.gov/data/datadocs.php (last access: May 9, 2016), 2016.

Line 118: “Aren’t ‘the decadal histogram’ and ‘the previous multi-year MLS record’ the same thing in Figure 2? Don’t you want to compare and contrast the histogram of 2013 with the histogram of 10-year mean values? Figure 2 would be a great place to visually show (as a vertical line) the threshold for ‘enhanced’ MLS water vapor.” Author’s response: Yes, the referee is correct, the ‘decadal histogram’ and the ‘previous multi-year MLS record’ are the same. The purpose of Figure 2 is to compare the histogram of July-August 2013 with the histogram of 9-summer mean values (also July-August). We have reworded this sentence in line 118 to: “Figure 2 shows that the July-August 2013 CONUS lower stratosphere was drier than the previous nine-summer MLS record (2004 to 2012).”

We have also added a vertical line to Figure 2 for the threshold for ‘enhanced’ MLS water vapor (8 ppmv). See attached Figure 2.

Figure 2. Distribution of Aura MLS v4.2 100-hPa H2O over CONUS (blue shaded box in insert), corresponding to approximately 17 km. The two histograms for July-August 2013 (blue asterisks and trace) and the previous nine-summer MLS record, July-August 2004 through 2012 (red circles and trace) indicates that 2013 was drier than average. The 8-ppmv threshold for “enhanced” water vapor is shown by the thick black line.

Line 120: “You have the histograms so why say ‘rare’ when you can be quantitative?” Author’s response: We have added a sentence at line 126 stating: “From the MLS histogram, the frequency of 100-hPa H2O > 8ppmv was 0.9% of the observations in July-August 2013 in the blue shaded box." We also modified the sentence at line 263 in the final paragraph: "The fraction of Aura MLS observations in the same time period with H2O greater than 8 ppmv is only 0.9%."

Line 122: "At least 3 of the white circles in Figure 3 are near the west coast of Mexico, not Central America." Author's response: We have changed the line 122 text to "water greater than 8 ppmv was measured only nine times over North America (in the blue shaded box), three times near the west coast of Mexico, and once over the Caribbean Sea."

Line 146: "What is the spatial resolution (horizontal and vertical) of the convective storm information used to link 'enhanced' water vapor to overshooting tops? Later (Line 503) you say that the OT data are 'high resolution' but the spatial resolution is never described." Author's response: The horizontal spatial resolution of the OT product is dependent on the underlying satellite imagery resolution, i.e., the size of the GOES IR pixel at any given spot.Âă The size goes as you move further away from the subsatellite point.Âă At subsatellite the pixel size is 4 km.Âă At the junction between GOES East and GOES West, the pixel size is about 7 km in Montana, probably 6+ km in Mexico.

When the referee asks about the spatial resolution in the vertical dimension of the convective storm information, perhaps a more relevant question is: what is the accuracy of the OT altitude? This has been addressed in Griffin et al. (JAMC, 2016), who report that 75% of OT height retrievals are within 0.5 km of CloudSat OT height.

We have added text to line 140: "For a description of the method, the reader is directed to Bedka et al. (2010). The horizontal spatial resolution of the OT product is dependent on the underlying satellite imagery resolution, i.e., the size of the GOES IR pixel, which is 7 km or less over the CONUS."

And text to line 146: "Griffin et al. (2016) finds that 75% of OT height retrievals are within 0.5 km of CloudSat OT height, so we conservatively estimate the accuracy of the OT altitude to 0.5 km."

Line 156: "What was the time step interval for back trajectory calculations?" Author's response: We added the following text to line 155: ". . ., and the trajectory time step interval was one hour."

Line 158: "How were these tolerances chosen? Do they have any relationship to the spatial resolution (horizontal and vertical) of the convective storm information?" Author's response: We added the following text to the end of the paragraph (line 159): "These tolerances were chosen primarily due to the resolution of the NCEP meteorology used to run the trajectories (1 deg x 1 deg) and also based on personal communication with Leonard Pfister."

Line 164: You already wrote about initializations (Line 153). This statement is again repeated in Line 180. Author's response: At line 164, we have replaced "For each of these ER-2 flights, seven-day back trajectory analyses are initialized at locations and times of enhanced water vapor along the ER-2 flight track. These analyses are combined with overshooting cloud top data from the SEAC4RS OT data product." With "For each of these ER-2 flights, the back trajectories are presented along with the intersection of coincident OT." We also deleted the sentence at line 180, and moved the rest of the paragraph to after "Analysis of the 8 August 2013 case is shown in Figure 5."

Line 169: It would be beneficial to include the lats/lons of these sites. Author's response: we have modified the text to: "Palmdale, California (34.6 N, 118.1 W), to Ellington Field, Houston, Texas (29.6 N, 95.2 W)."

Line 173: Same comment as for Line 58. Author's response: we have changed the text to: "(350 K < < 380 K)"

Line 182: This information is already in the Figure Captions. Author's response: these sentences are needed to help explain the plots. We slightly modified the text to: "Anal-

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ysis of the 8 August 2013 case is shown in Figure 5. For clarity only some example trajectories (a subset of our analysis) are shown. These are displayed as thin blue traces in panels (b) and (c). The initial water vapor mixing ratios of the example trajectories are shown as red squares in panels (a). The intersections of the example trajectories with coincident OT are shown as red squares in panels (b) and (c). All overshooting convective tops within +/-3 hours of the red squares are shown by green symbols in panels (b) and (c)."

Line 184: In Figures 5-7, panels (b) and (c), the green markers show "near coincidences" (within the tolerances listed in Line 158) between back trajectories and OTs, while red squares show "coincidences". What are the criteria for "coincidences"? Author's response: We thank the referee for catching this typo. The description in the original text doesn't quite match what's on the figure.Âă The red symbols are where there were coincidences for the specific example trajectories plotted in light blue.Âă The green symbols show all overshooting convective locations within +/- 3 hours of the red points, not related to where any of the trajectories went (see modified text above for line 182).Âă

We changed the text in Figure captions 5, 6 and 7 to remove "nearly coincident" since the only coincidence for green markers is in time. That doesn't really qualify as nearly coincident. The reason to show all the green symbols is to give an indication of how robust the coincidences are. For instance, the mass of green points north of Texas on Aug. 8 indicates there were a lot of overshoots there and the coincidences should be robust for the trajectories that went through that region.ÂăThe two coincidences in Arizona are among only a small cluster of overshoots and so this is not as robust a coincidence.

The criteria for coincidence (red markers) is, as described in Section 3.2: "+/-0.25 degrees latitude and longitude, +/-3 hours, +/-0.5 km in altitude."

Line 191: In Figure 5b there are many green markers in western Mexico, so why is this location not listed? Author's response: As described above (line 184), green markers are not coincident. Only the red markers are coincident in space and time, so we only describe the locations of the red markers.

Line 198: In Figure 5d there are many red markers depicting transit times >6 days, but here you claim domination by transit times of "two to five days". Author's response: in line 198, we changed "two to five days earlier than" to "within seven days prior to".

Line 205: TX, OK and AR are in the "South Central" U.S. Author's response: in line 205 we have replaced "Central" with "South Central".

Line 216: Define MCC as mesoscale convective complex Author's response: in line 216 we have replaced "MCC" with "mesoscale convective complex".

Line 227: Earlier you stated that back trajectories were initialized for every measurement of enhanced water vapor. Now, "Example" infers that this was done only for a subset. Did "all" (Line 228) of the back trajectories connect to OTs? Really? All? Author's response: The referee has an excellent point here. Not all of the back trajectories connect to OTs, although a majority do. This will be made more quantitative in the revision. The trajectories (initialized for every measurement of enhanced water vapor) are a way to show that the enhanced water comes from OT over CONUS. We will delete the old text "Example air parcel back-trajectories were initialized at the locations and time of enhanced water. All of the back-trajectories connect these air parcels to convective OT one to seven days prior to aircraft intercept." And add the following: "Back trajectories initialized on the flight track where enhanced water vapor was measured connect the sampled air parcels to convective OT within seven days prior to the flight."

Line 230: Figure 7b shows there were influences from storm systems in South Central Canada as well. Author's response: We have added to line 231: "and South Central Canada."

Line 235: "leaving behind" should be "producing" Author's response: we have changed the text at line 235 to: "... producing water vapor mixing ratios elevated up to 15 ppmv above background levels."

Line 238: "propel water" gives the wrong impression while "loft ice" is more accurate. Author's response: we have changed "propel water" to "loft ice".

Line 239: "the enriched delta-D isotopic signature" needs a bit more explanation, including a mention of the isotope itself, HDO. Author's response: We modified the text as follows at line 239: "Further evidence of ice is provided by water isotopologues. Evaporation and condensation are fractionating processes for isotopologues, especially HDO relative to H2O (e.g., Craig, 1961; Dansgaard, 1964). Condensation preferentially concentrates the heavier HDO isotopologue, so lofted ice is relatively enriched in HDO/H2O compared to gas phase (e.g., Webster and Heymsfield, 2003, and references therein). Ice sublimation is supported by the enriched HDO/H2O isotopic signature observed by the ACE satellite over summertime North America (Randel et al., 2010)."

New references: Craig, H.: Isotopic Variations in Meteoric Waters, Science, 133, 1702-3, doi: 10.1126/science.133.3465.1702, 1961. Dansgaard, W.: Stable isotopes in precipitation, Tellus, 16, 436-68, 1964.

Line 246: "The water is almost certainly injected in the ice phase" needs support. I suggest you combined this paragraph with all or some of the previous paragraph that provides such support. Author's response: we have merged this paragraph with the previous paragraph.

Line 252: "from a long (200 km) path through the atmosphere" also needs to include information about the vertical resolution. The qualitative statement "may be enhanced even more" is the basis for my argument that the MLS and aircraft results cannot be meaningfully integrated together in this paper. Author's response: The revised Figure 4 (see above) demonstrates that we can compare satellite and in situ measurements and, furthermore, map the aircraft to MLS resolution through averaging kernels. We will describe Figure 4 better in the text.

Line 254: what percent of the 10 years of MLS observations show enhanced water? Author's response: we have modified the sentence at line 264 (for better flow): "The fraction of Aura MLS observations at 100 hPa with H2O greater than 8 ppmv is only 0.9% for July-August 2013. Schwartz et al. (2013) reports that, for the nine-year record 2004-2012, July and August had 1.4% and 3.2% of observations exceed 8 ppmv, respectively."

Line 261: Which "monsoon region"? Author's response: Randel et al. (2015) addresses the North American Monsoon (NAM) region. We have changed the text in line 261 to: "NAM region."

Figure 2: Caption: "ten year mean for 2004 through 2013." Author's response: We decided to compare 2013 with the previous nine-summer record, 2004 through 2012. Figure 2 has been updated, and the caption changed to: "Distribution of Aura MLS v4.2 100-hPa H2O over CONUS (blue shaded box in insert), corresponding to approximately 17 km. The two histograms for July-August 2013 (blue asterisks and trace) and the previous nine-summer MLS record, July-August 2004 through 2012 (red circles and trace) indicates that 2013 was drier than average. The 8-ppmv threshold for "enhanced" water vapor is shown by the thick black line."

Figure 3: Caption: "Average Aura MLS 100-hPa" Author's response: we will change the caption to "Two-month mean map of Aura MLS v4.2 100-hPa..."

Figure 4: "[1] Colored markers are not "retrievals" from the aircraft, they are the actual aircraft measurements. [2] Why do multiple aircraft profiles produce only one profile convolved with the MLS averaging kernels? [3] Without strongly magnifying this Figure I can't tell the difference between the MLS profiles and the convolved aircraft profile. [4] I suggest omitting the convolved aircraft profile in each panel. It does shows that the averaging kernels smooth the aircraft profiles, but isn't that exactly what one would expect anyway? [5] Also, the black asterisks showing MLS retrieval locations on flight

track maps are difficult to distinguish from black map lines. Perhaps larger gray symbols "x" or "+" would stand out more? [6] And the "line" mentioned in the caption, is this the horizontal line in each "Flight Altitude" (should be "Pressure") vs UTC hour panel indicating the time range of measurements shown in the profiles? [7] This Figure would be an ideal place to visually show (as a vertical line in each profile panel) the threshold for aircraft "enhanced" water vapor." Author's response on Figure 4: These are great points by the referee. 1) We will change the figure 4 caption from "water vapor retrievals from aircraft (color), aircraft with MLS averaging kernel (asterisk and lines)" to "JLH Mark2 in situ water vapor data (dots), in situ with MLS averaging kernel (asterisks and lines), . . ." 2) In each Figure 4 panel, the pair of aircraft profiles (descending and ascending) are combined to produce one profile convolved with the MLS averaging kernels. 3) Figure 4 has been redone (see above). 4) We wish to keep the convolved aircraft profile to demonstrate that 7 ppmv MLS corresponds to approximately 11 ppmv in situ aircraft data. 5) Figure 4 MLS symbols are now in color (see above). 6) The Pressure vs UTC hour panel is now altitude vs time, properly labeled "Altitude", with new caption "MLS times (horizontal lines)". 7) We will add text to describe the threshold for aircraft "enhanced" water mixing ratios (still in work).

Figure 5: These comments apply to each of Figures 5-7: In panels (a), the captions claim the blue markers denote "enhanced water measurements" (which range below 5 ppmv) while in the panel (a) legends the blue markers are said to represent the "Enhanced H2O region", which must be something quite different from "enhanced water vapor" measurements. This distinction needs to be clarified in the paper by defining exactly what is meant by the terms "enhanced water measurements" and "enhanced H2O region". Author's response: The referee has a good point, we will remake the Figures 5-7 to clearly delineate the enhanced water mixing ratios (still in work).

Interactive comment on Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-1065, 2016.

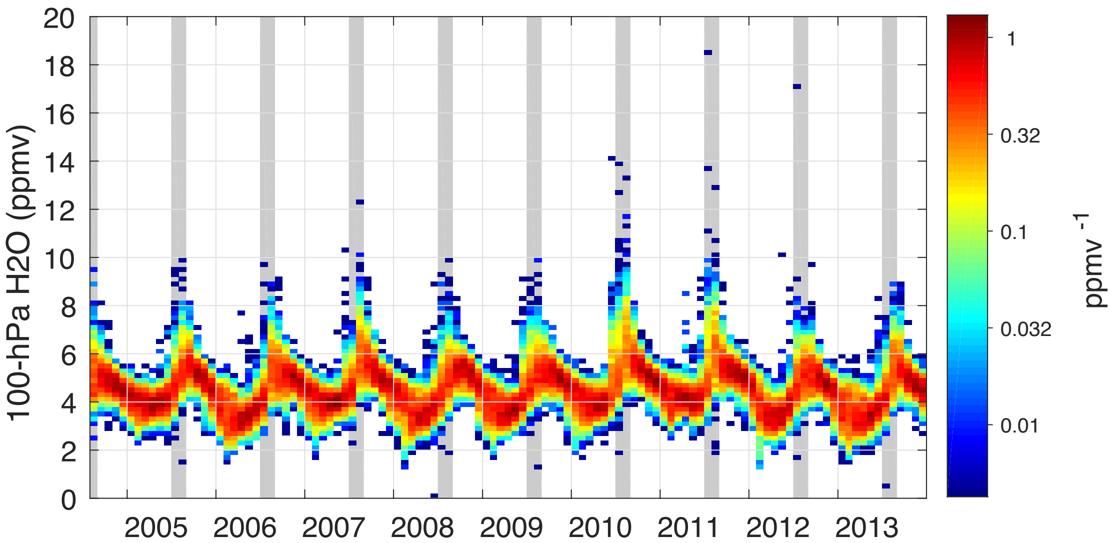

Fig. 1. Figure 1. Time series of Aura MLS v4.2 100-hPa H2O over North America - see text for full caption.

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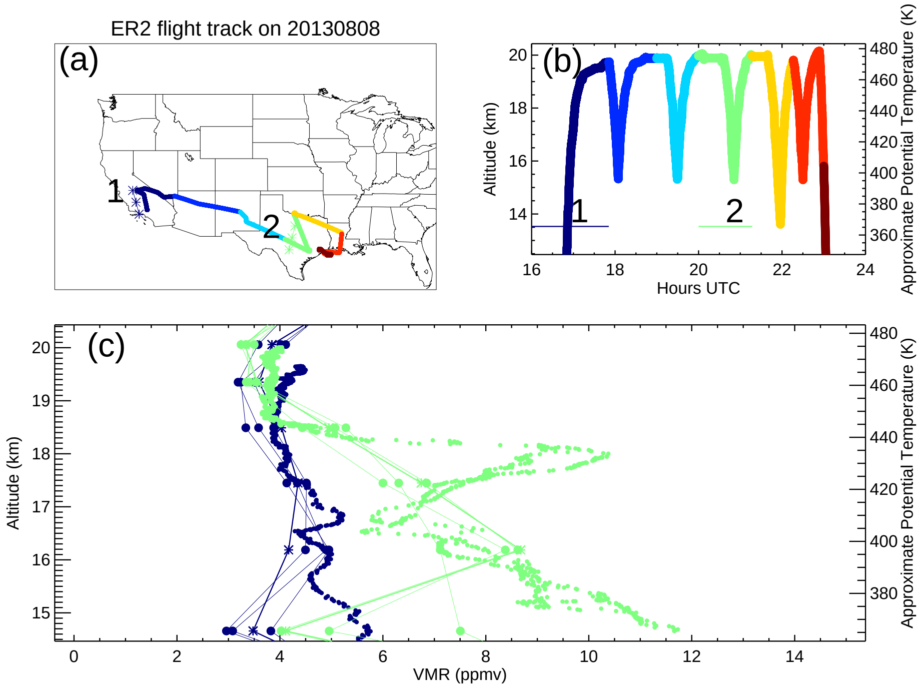

Fig. 2. Figure 4. (a) Map of ER-2 track and MLS geolocations. (b) Pressure profile of ER-2 aircraft. (c) comparison of JLH Mark2 H2O with MLS - see text for full caption.See text for full caption.

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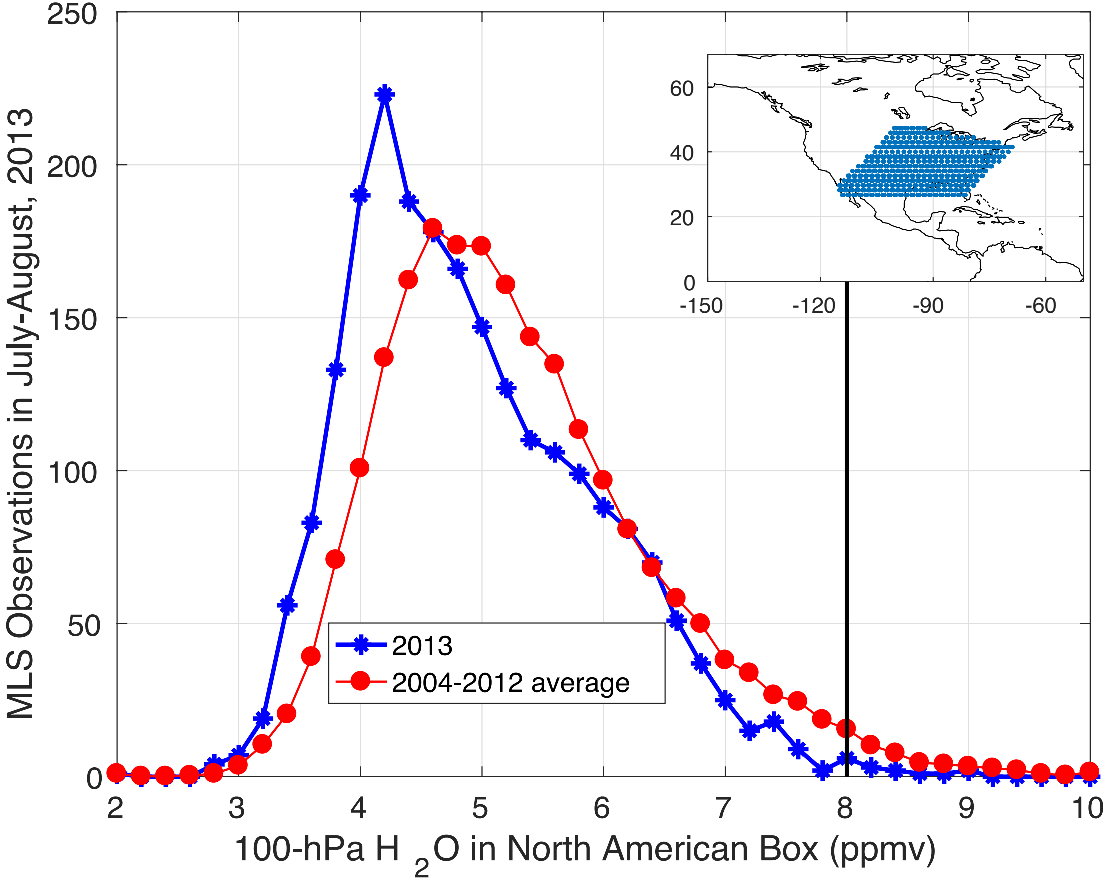

Fig. 3. Figure 2. Histogram of MLS H2O - see text for full caption.