Water vapor in the Tropical Tropopause Layer over the Eastern Tropical Pacific during the wintertime

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INTRODUCTION

- Water vapor plays a critical role in the radiative balance of the upper troposphere (UT) and lower stratosphere (LS) and in stratospheric ozone chemistry. Therefore, understanding the mechanisms that control its distribution in the UT/LS is necessary to accurately forecast changes in the climate system.
- The dominant location for Troposphere-to-Stratosphere Transport (TST) occurs in the Tropical Tropopause Layer (TTL), a region in the tropics bounded from below by the level of neutral buoyancy (340-350 K) and from above by the cold point tropopause (380-390 K).
- The entry value of water vapor into the tropical stratosphere has been suggested to be controlled by: (i) tropopause temperatures, (ii) horizontal transport through TTL regions colder than the local tropopause, (iii) convective overshoot, (iv) convective air mixed-in with TTL air, and/or (v) cloud microphysics.

OBJECTIVES

- Compare aircraft and satellite-based measurements of water vapor in the TTL during two wintertime aircraft campaigns over the Eastern Tropical Pacific (ETP): Pre-AVE in January 2004 and CR-AVE in January 2006.
- Explore the interannual variability of water vapor in the TTL.
- Test the hypothesis that transport through cold pool regions (i.e., Lagrangian cold point) is the dominant mechanism in regulating the moisture content of the TTL over the ETP.

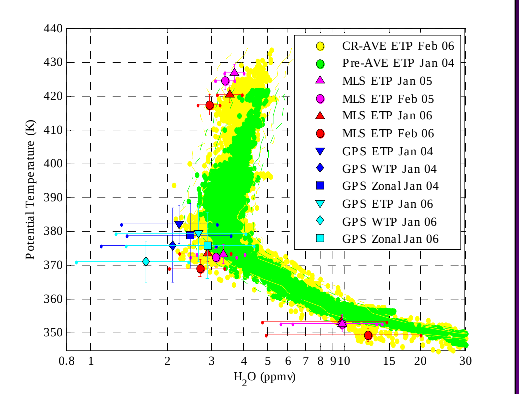

Figure 3. Vertical profile of water vapor over the ETP obtained from the Harvard hygrometer flown on the WB-57, MLS monthly averages over the ETP, and GPS-based minSMR from individual profiles monthly averaged over different regions (ETP, WTP, and zonal). Dashed lines represent +/- 20% departure from the mean water vapor profile from each aircraft campaign (green for Pre-AVE, yellow for CR-AVE) and dotted lines represent the +/- 30% departure. The interannual variability in the satellite-borne measurements is larger than in the aircraft measurements.

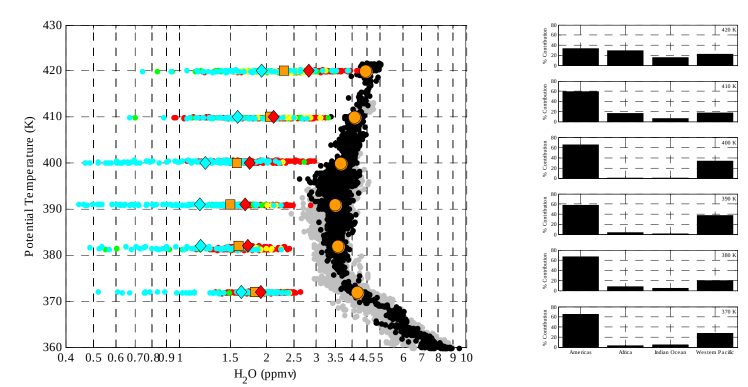

Figure 4. (Left) Comparison of the in-situ measurements of water vapor on January 30, 2004 to minSMR derived from trajectory calculations of parcels located along and in the vicinity of the flight path (actual spatial coverage is shown on the left column of Figure 5). The gray points are the measurements obtained during the rest of the Pre-AVE flights (January, 27 and 29) and the black points are the measurements obtained on the flight analyzed (January, 30). Results from trajectories are color-coded according to the geographical location where they attained the minSMR shown. Large symbols represent averages over given regions, namely cyan diamond for the WTP, red diamond for the ETP, orange squares for all regions, and orange circles for the aircraft measurements over the ETP.
(Right) Percent contribution of four different regions where parcels sampled over the ETP had their minSMR set. Each altitude represents the final potential temperature surface over the ETP on the flight day.

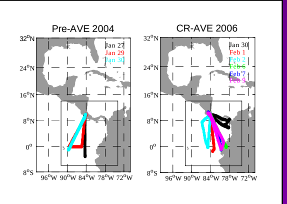

Figure 1. Geographical coverage of flights during the Pre-AVE 2004 and CR-AVE 2006 campaigns where in situ measurements of water vapor, pressure, and temperature were collected. The black box represents the area used to obtained MLS data representative of the Eastern Tropical Pacific.

METHODOLOGY

1. Measurements intercomparison

- Water vapor measurements are obtained from the Harvard University Ly-α hygrometer and the NOAA Pressure and Temperature Instrument that flew aboard NASA's WB-57F out of San Jose, Costa Rica during the Pre-AVE campaign in January 2004 and the CR-AVE campaign in January-February 2006.
- 100-mb monthly averages of Aura-MLS Water Vapor and Temperature are calculated using both ascending and descending nodes for January and February 2006.
- GPS Radio Occultations obtained from the CHAMP satellite are used to calculate the minimum Saturation Mixing Ratio (minSMR) in individual profiles.
- Regions in the measurement intercomparison section are defined as follows: ETP is 6ºS - 14ºN, 92ºW - 74ºW, Western Tropical Pacific (WTP) is 10ºS - 10ºN, 140ºE - 160ºW, and the Zonal average is 10ºS - 10ºN.

2. Trajectory analysis

- 60-day backward trajectory calculations for January 2004 are performed using the Lagranto Model (Wernli and Davies, *Q. J. R. Meteorol. Soc.*, 1997) and ECMWF Operational Analysis with 60 vertical levels, T511 spectral resolution, and 3-hr wind and temperature fields interpolated to 1ºx1º grids.
- Air parcels are initially positioned every 0.5º between 6ºS - 10ºN, 91ºW - 77ºW and every 10 K between the 370 K and 420 K isentropes. Each air parcel is followed for 60 days back in time. All trajectories are initialized at 18Z on the following flight days: 27, 29, and 30 January 2004. We use the results from the flight on January, 30 as representative of the campaign.
- SMR is calculated along each trajectory, and the location, magnitude, and timing of the *minimum* value is recorded.
- Regions in the trajectory analysis section are defined based on longitudes only as follows: Americas (red) is 100ºW – 30ºW, Africa (green) is 30ºW – 50ºE, Indian Ocean (yellow) is 50ºE – 100ºE, and Western Pacific (cyan) is 100ºE – 160ºW.

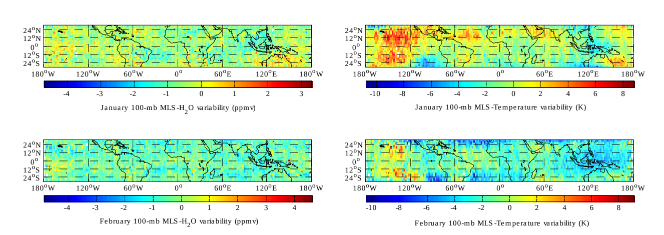

Figure 2. Comparison of 100-mb MLS-H_2O (left column) and MLS-Temperature (right column) during the wintertime. Values are the differences between 2006 and 2005. Warmer and colder conditions are observed over the Central Pacific and Western Pacific, respectively, during both months in 2006 without the corresponding magnitude change in water.

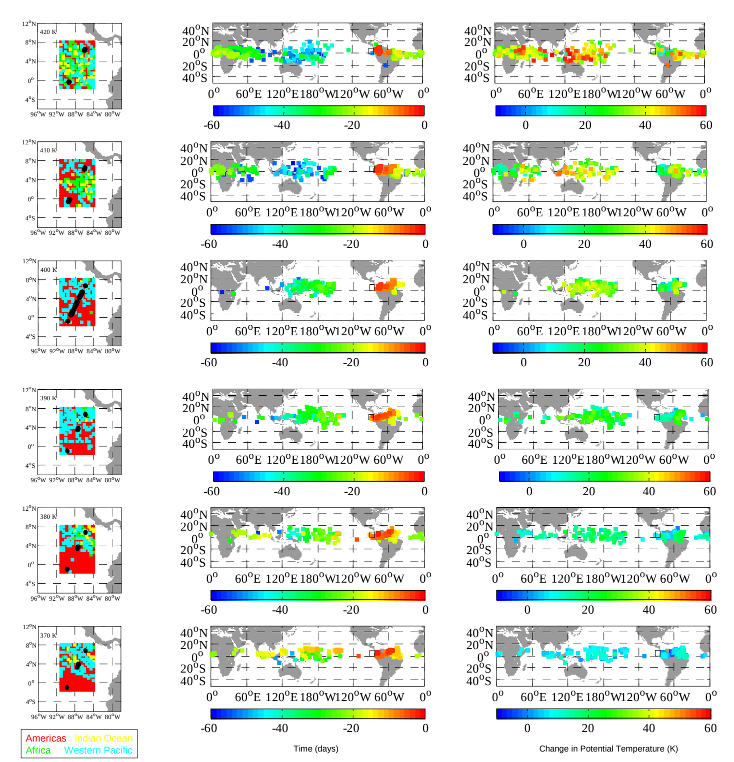

Figure 5. Characteristics of the minSMR attained by the air parcels along and in the vicinity of the flight path on January 30, 2004. Left column shows the initial location of the air parcels color-coded by the region where they attained their minSMR along their trajectory, and the location of the aircraft (black circles) at each altitude analyzed. Middle column shows the location where the minSMRs were attained color-coded by the number of days when those conditions were experienced since January 30. Right column is the same as the middle, but the color-coding represents the change in potential temperature experienced between the minSMR and January 30. The more positive this difference is, the further the parcel ascended from the altitude of the minSMR to the final altitude (i.e., altitude on January 30). The black box in middle- and right-column plots represents the area of the initial location of the parcels. Each row corresponds to a different altitude from 420 K (top) to 370 K (bottom).

RESULTS

- Warmer conditions over the Central Pacific and Atlantic, and colder conditions over the Western Pacific are observed during both January and February 2006 based on MLS-Temperatures, as shown in Figure 2. The magnitude of the temperature difference, however, is not matched in water vapor.
- Smaller interannual variability of water vapor is observed in the aircraft data set compared to both satellite and GPS-derived minSMR over the ETP, as shown in Figure 3. MLS water is 20-30% lower than the aircraft, but with larger regional and interannual variability. While minSMR derived from GPS are largely variable within each geographical region shown in the plot, we find the minSMR over the ETP and the average tropics to be in better agreement with the aircraft measurements compared to the Western Pacific.
- Backward trajectory analysis show the Lagrangian minSMRs to be on average 50% drier than the aircraft measurements at all altitudes, as seen in Figure 4. In terms of regional differences, minSMRs from the WTP were 56 to 67% drier and minSMRs from the ETP were 36-54% drier than the aircraft measurements.
- The distribution of the location of the minSMR shows that more than 55% of the air around the flight path attained its minSMR over northern South America (except at 420 K). Less than 40% of the air parcels attained their minSMR over the WTP.
- Properties of the minSMRs are illustrated in Figure 5. The majority of the air parcels attained their minSMR over the Americas less than 20 days prior to the aircraft sampling and the potential temperature of the minSMR was within 20 K for parcels whose terminal potential temperatures were 400 K or less on January 30. The next significant group attained their minSMR over the WTP on average a month prior to the aircraft sampling and at potential temperatures between 365 and 370 K for all parcels whose potential temperatures were less than 400 K on January 30.
- The aircraft measurements and the Lagrangian minSMRs show consistent vertical shapes over the ETP. This result suggests that the dominant mechanism controlling water vapor acts in a synoptic scale and it is captured by ECMWF. However, systematic differences in the magnitude of water vapor at all latitudes exist. Since a 50% uncertainty in SMR implies ~2.5 K uncertainty in temperature, some, but not all, of the disagreement could be explained by cold temperature biases in the ECMWF Operational analysis.
- Other possible explanations for the quantitative disagreement include: sub-grid processes such as convection and mixing not captured properly in the operational analysis, inefficiency of cold pool regions to dehydrate the air to SMR (kinetic effect), and slower sedimentation rates of ice formed in the cold pool regions compared to horizontal transport allowing for subsequent evaporation of ice outside the cold pools.
- Assuming the winters of 2004 and 2006 are thermodynamically similar, the 100-mb MLS measurements shown in Figure 3 are 20-30% higher than the minSMRs at the same altitude shown in Figure 4.

ACKNOWLEDGEMENTS

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