Observational Evidence for Incomplete Dehydration in the Tropical Tropopause Layer

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The Tropical Tropopause Layer (TTL), especially above the western Pacific, is the primary gateway for entry of air into the stratosphere from the troposphere. Dehydration of stratosphere-bound air parcels by deposition of water vapor to ice particles in the TTL is therefore a key process controlling the humidity of the stratospheric overworld. Strong correlations between large-scale stratospheric humidity and TTL temperatures on intra-annual and interannual timescales have demonstrated that this mechanism is largely correct. What remains uncertain is how efficiently air is dehydrated on its passage through the TTL and therefore the absolute value of water vapor entering the stratosphere. In the absence of appropriate particles to act as nuclei for ice crystal formation, relative humidity with respect to ice (RHi) exceeding 160% at TTL temperatures is required for clouds to form and remove water from the gas phase. If ice crystal concentrations are low (~100 / liter or less), the time for thermodynamic gas-particle equilibrium to be achieved can be on the order of hours following the formation of ice crystals. It is also possible that ice crystals, once formed, may evaporate before they are removed from the TTL by sedimentation. These mechanisms suggest the likelihood that air parcels with RHi exceeding 100% may frequently pass the through the cold point and enter the stratosphere.

Here we present measurements made from the NASA Global Hawk Unmanned Aircraft System during the Airborne Tropical TRopopause EXperiment (ATTREX) of relative humidity, ice water content, and ice crystal concentrations in the central and eastern Pacific TTL in winter 2013 (ATTREX-2) and in the western Pacific TTL in winter 2014 (ATTREX-3). This dataset provides unprecedented high-quality observations of the key parameters required to test theoretical descriptions of dehydration in the TTL. During ATTREX, the cirrus clouds encountered most frequently had low ice crystal concentrations. While those clouds encountered with high ice crystal concentrations exhibited RHi very close to 100%, the more common thin clouds exhibited higher average and more variable RHi. A number of observations show supersaturated air or air with residual ice crystals at the potential temperature of the cold-point tropopause. ATTREX achieved a significant number of flight hours sampling air in this key region of the atmosphere. These observations provide evidence that suggest that the average entry value of water into the stratosphere is somewhat supersaturated due to incomplete dehydration to 100% RHi at the cold point.

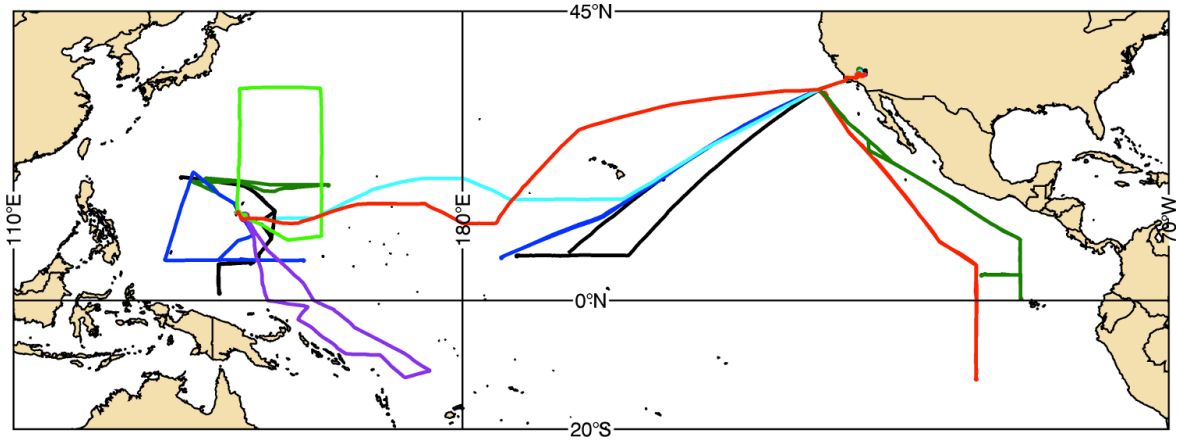

Figure 1. Flight tracks showing the regions covered by the ATTREX-2 and ATTREX-3 missions.