Ozone and other trace gases in the Tropical Tropopause Layer (TTL) over the Pacific Ocean

Introduction

The distribution of ozone in the tropics is influenced by both chemistry and transport, and in turn affects the oxidation rate of a large number of organic species, including shorter-lived ozone depleting substances (ODSs) such as organic bromine compounds. The tropical tropopause layer (TTL; 14–18.5 km) over the western Pacific is one of the primary entry points of air from the troposphere into the stratosphere, yet in situ observations in this region have been relatively sparse. The NASA Airborne Tropical Tropopause Experiment (ATTREX) mission was designed to study trace gases, clouds, dehydration, and transport in the TTL over the Pacific Ocean, in order to better understand how water vapor and ozone-depleting gases reach the lower stratosphere or are removed in the TTL. Field campaigns were carried out on the NASA Global Hawk aircraft, with about 200 vertical profiles in the TTL over the central and eastern tropical Pacific (ATTREX-1 and 2), 2011 and 2013 and the western Pacific in January-March 2014 (ATTREX-3). During ATTREX-3, the Global Hawk was joined by the NSF/NCAR GV and B-44 aircraft for the CONTRAST and CAST missions, providing coverage of the stratosphere from the boundary layer to 19 km. Coincident balloon profiles of ozone and water vapor were also obtained from Guam during ATTREX-3.

Measurements and data quality

Measurements on the Global Hawk included water vapor and condensed water measured by the NOAA Chemical Sciences Division (CSD); long-lived trace species including N₂O, SF₆, and methane measured by the UCLA Chromatograph for Atmospheric Trace Species (UCATS); ozone measured by both CSD and UCATS; CO₂, methane, and CO measured by a Picarro instrument from Harvard University; a large suite of trace gases including bromine-containing compounds measured by a Whole Air Sampler from the University of Miami; remote sensing instruments for cloud particles, temperature profiles, and Br₂; and meteorological parameters. In ATTREX-1 and 2, both ozone instruments were on board; in ATTREX-3 the NOAA CSD instrument was not able to fly because of weight and balance considerations. Considerable effort was expended to ensure that the UCATS ozone data were of adequate quality for the science goals. This included adding a second ozone sensor from CSD, extensive calibrations and checks for offsets, tests of pressure sensors and other components, merging the data from the two 2B sensors, and intercomparisons with the CSD instrument in flight. With all effects accounted for, the two instruments agreed to within about 1% with an offset of about 5 ppb. Illustrative examples of data are shown below.

Ozone data from the Global Hawk, GV, and sonde launch from February 12-13, 2014, color-coded by altitude. These data are not collected in time or space, but occurred over an approximately one-day time period. The GV flight occurred on February 12, and the balloon launch was timed to coincide with the return of the Global Hawk on February 13. Despite a great deal of variability (caused by latitudinal gradients and tropospheric filaments), the data all show a consistent picture. Lowest ozone in the TTL was observed on the southernmost extent of the flight (dark colors).

ATTREX results

Ozone and water vapor are typically anti-correlated, with high water vapor and low ozone in the troposphere, and high ozone and lower water in the stratosphere. On February 26, 2013 over the central Pacific near 9°N, a more complicated pattern was observed, with ozone and water redisturbed by recent convection. There is evidence of layers of slightly enhanced ozone (e.g., at 5 km on January 13, 1987) but much less than what was frequently observed during CONTRAST in 2014. (Right) Ozone values in the free troposphere and TTL over Guam were actually lower than near the STEP Tropical study site at Darwin, Australia, where frequent and intense deep convection was observed.

Conclusions

• Low ozone (<20 ppb) can occur in the western tropical Pacific TTL, but it does not do so uniformly.
• The troposphere over the tropical western Pacific near Guam has changed dramatically since 1987. Or, meteorological conditions were much different during STEP tropical (future work)
• Intertropical gradients may reflect the influence of the ITCZ/SPCZ (inter tropical and South Pacific convergence zones), which form a barrier between the northern and southern hemispheres.

Acknowledgements

The ATTREX mission would not have been possible without the pilots, crew, and staff of the NASA/NOAA Global Hawk Program and the NASA Earth Science Project Office. Support was provided by the NASA Earth Venture program and from the Upper Atmospheric Research Program. We thank Andrew Weinheimer, Denise Montzka, and Lisa Kaiser for ozone data from CONTRAST, and Cameron Homer and Shawn Homolich for assistance with data analysis. STEP Tropical data were taken by Dan Murphy and David Fahey.