Improvements to UCATS for the Atmospheric Tomography (ATom) mission and recent results

Eric J. Hintsa[1,2], Fred L. Moore[1,2], Geoff S. Dutton[1,2], Brad D. Hall[1], Audra McClure-Begley[1,2], J. David Nance[1,2], Stephen Montzka[1], Carolina Siso[1,2], James W. Elkins[1], Chelsea Thompson[1,2], Jeff Peischl[1,2], Thomas Ryerson[1], Kathryn McKain[1,2], Colm Sweeney[1,2], Roisin Commane[3], Bruce Daube[3], Steve Wofsy[3], and Glenn Diskin[4]
[1]NOAA/ESRL, [2]University of Colorado/CIRES, [3]Harvard University, [4]NASA Langley Research Center

Introduction

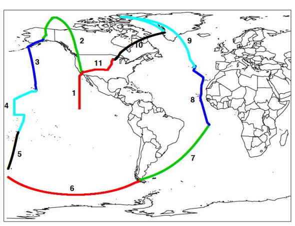
The NASA Atmospheric Tomography Mission (ATom) is designed to measure vertical cross sections of the atmosphere in different seasons, in order to better understand methane oxidation and ozone chemistry on regional to global scales and to challenge chemical transport models. For ATom, the NASA DC-8 aircraft has been outfitted with a large payload of instruments for reactive and trace gases, aerosols, radiation and meteorology, with flights from north to south over the Pacific, returning over the Atlantic. ATom is similar to the NSF HIPPO mission, but with a focus on chemistry and a correspondingly more complete chemical payload, a larger scope, and profiles over both the Atlantic and Pacific Oceans. For ATom, we made the following improvements to the UCATS (UAS Chromatograph for Atmospheric Trace Species) instrument: 1) an upgraded ozone instrument with greater sensitivity and the ability to avoid artifacts caused by rapid humidity changes; 2) a new water vapor instrument for high precision and accuracy measurements from the surface (2-4% humidity) to the stratosphere (~4 ppm); and 3) upgrades to the gas chromatograph (GC) in UCATS, including improved detector electronics.

We purchased a Model 211 ozone instrument (2B Technologies) with a longer cell, and installed it into UCATS by adding a new 3" section at the top. To avoid water vapor artifacts, we use Nafion moisture exchangers to maintain sample air samples at a high enough humidity such that the absorption cells never dry out. The Nafion tubes are mounted in a sealed box at the same pressure as the sample gas passing through them, to avoid damage to the tubes. A new tunable diode laser (TDL) instrument was built by Port City Instruments, using different infrared (IR) lines and different path lengths to cover the large range of water vapor concentrations. In ATom-1, the new ozone instrument was implemented along with faster electronics on the GC detectors, but benefits were not obvious because of much lower than anticipated pressures at our inlet over the wing. For ATom-2, the inlet was fixed, the new TDL added, and further improvements were made, with much better results. Recent data and a few intercomparisons are shown below, along with future work for ATom-3 and 4.

The ATom Mission

The goal of ATom is to map out the large scale distributions of greenhouse gases (particularly methane and tropospheric ozone), pollutants, oxidants, and aerosols, along with their source gases and reaction products. These data are being used to challenge and evaluate large-scale chemical transport models, and to improve our basic understanding of global atmospheric chemistry. For ATom, the NASA DC-8 aircraft measures vertical profiles of the atmosphere along roughly north-south transects over the Atlantic and Pacific Oceans from near the surface to about 12 km. Atom-1 took place in July-August 2016, and ATom-2 in January-February 2017. The remaining deployments will be in fall 2017 and spring 2018 to achieve coverage in each season. Integration and the start of each deployment are in Palmdale, CA. The DC-8 first flies north, stopping in Anchorage, AK, then south to Christchurch, NZ, across to Punta Arenas, Chile, north over the Atlantic to Greenland, then back across the Arctic to Palmdale. One circuit takes about a month, a dozen flights, and ten different locations, putting a high premium on stamina and instrument reliability.

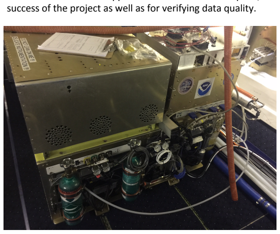
ATom–1 Flights



(left) Flight tracks for ATom-1 (July 29-August 23). All four deployments will follow the same basic circuit, with variations based on availability and condition of airfield facilities, weather patterns, etc. DC-8 flights can be ten hours or longer, depending on weight and fuel load, with each profile taking close to one hour. (below) The DC-8 landing in Thule, Greenland, February 19, 2017. Surface conditions ranged from tropical to sub-zero over the course of a few flights.

The UCATS instrument in ATom

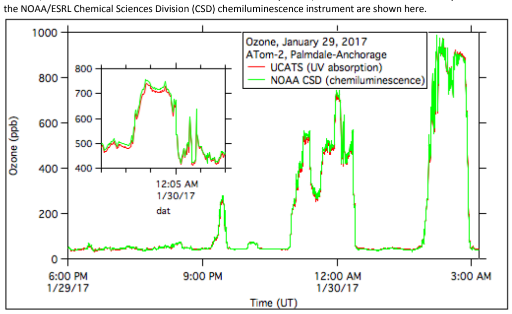
UCATS is a two-channel gas chromatograph (GC), packaged with small ozone and water vapor sensors for use on UAS, but it has also flown on piloted aircraft missions such as HIaper Pole-to-Pole Observations (HIPPO). One GC channel is configured to measure N_2O and SF_6, and the other measures molecular hydrogen (H_2), methane (CH_4), and CO. It is mounted on a DC-8 rack along with the PAN and other Trace Hydrohalocarbon ExpeRiment (PANTHER) and part of the Programmable Flask Package (PFP) system. In ATom-1, the Picarro instrument was also in this rack. PANTHER, UCATS, and the PFPs provide the only SF_6 (an important tracer of atmospheric age and transport, as well as a greenhouse gas) and H_2 data on ATom. UCATS also serves as a backup instrument for ozone, water, and N_2O. Particularly on a mission like ATom, with limited time and supplies for instrument field repairs, redundant measurements are crucial for the success of the project as well as for verifying data quality.

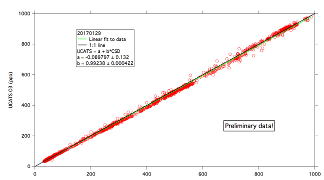


PANTHER (left) and UCATS (right) on the DC-8, looking aft. The new water and ozone instruments are in the 3" section added to the top of UCATS. The four gas lines from our inlet are visible in the upper right. They supply the PFPs, GCs and TDL water, ozone and PAN (peroxyacetyl nitrate), and for ATom-1, the Picarro instrument. In ATom-2, the ozone and PAN instruments had separate inlets and the Picarro moved up to a different rack.

Ozone

The new 2B Model 211 ozone instrument was repackaged into UCATS in the added top section. We replaced the NO-generating scrubber with a conventional MnO2 scrubber and Nafion moisture exchangers to keep the air flow humidified and avoid artifacts associated with rapidly changing humidity in the ozone cell. The instrument worked well in this configuration, but the data quality were compromised by unexpected low pressures from the inlet and cross-talk with the pump on the PAN system in ATom-1. For ATom-2, a shroud was used to boost the pressure at the inlet, and the PAN and ozone instrument inlet lines were separated, with much better results. Comparisons with the NOAA/ESRL Chemical Sciences Division (CSD) chemiluminescence instrument are shown here.

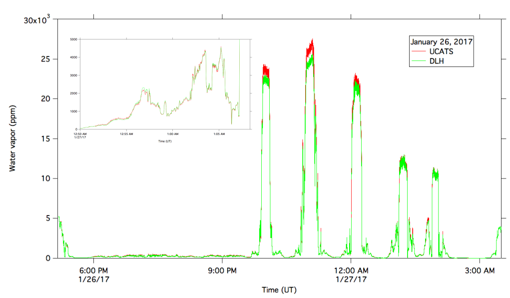


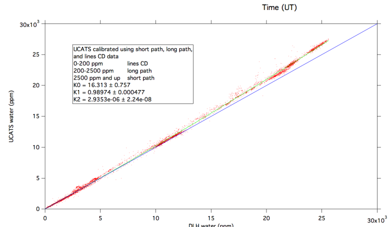


(top) Ozone time series for the ATom-2 Palmdale to Anchorage flight. The DC-8 reached the stratosphere with high ozone on the northern part of the flight. Both instruments agreed well, and were able to capture some of the fine structure on the profiles (inset). UCATS has 2-second time resolution; CSD is 1 second data. (left) Correlation plot for the two data sets, interpolated to a common time base, showing agreement to within 1% on this flight. Outliers are due to slight time differences with rapidly changing ozone.

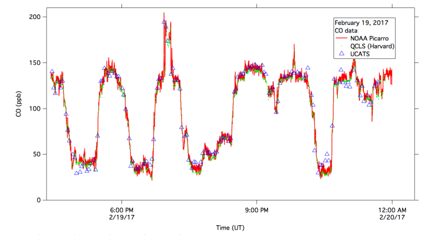
Water vapor

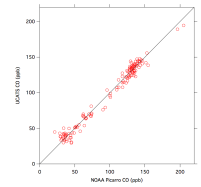
The new TDL instrument uses absorption of IR radiation from a laser near 2.57 um by water vapor over different closely spaced lines and two optical paths – 5.14 cm (short) and 280.0 cm (long). Water mixing ratio is calculated from both direct absorption and second harmonic (2f) modulation (for the long path only). The different path lengths, lines, and detection schemes allow coverage of the entire range of atmospheric water vapor with good to excellent signal to noise. The data rate is about 1 Hz and the data are transmitted to the main UCATS computer by a serial line. A set of preliminary laboratory calibrations have been performed using prepared water standards (0-800 ppm) and an MBW chilled mirror instrument (which covers the whole range of water vapor, but can only operate at atmospheric pressure). This has allowed us to assess data quality for the ATom-2 flights and prepare preliminary data files for archiving. More extensive pressure dependence and other calibration studies will be performed before final data are released. Water vapor is also being measured by the Diode Laser Hygrometer (DLH), an external path IR instrument with a path length from the DC-8 fuselage to a reflector on the wing.





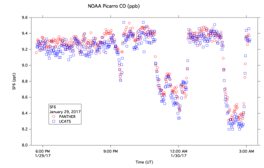
(top) Time series of water vapor for the flight from Palmdale to the tropics and back in ATom-2. Both instruments capture most of the variability in the atmosphere. (left) The correlation plot between DLH and UCATS shows deviations up to 10% at high mixing ratios. Though these are preliminary data, more calibrations are needed for UCATS water vapor.



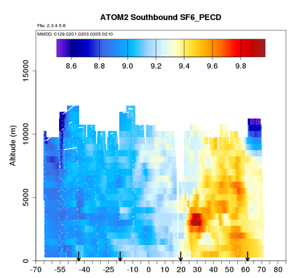


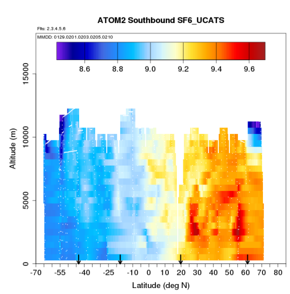
UCATS GC data

In ATom-1, UCATS GC data were affected by electrical noise, which was fixed for ATom-2. The flight of February 19, 2017 from Thule, Greenland, to Anchorage, passed through some extremely polluted air in the Arctic. Discrepancies between CO data from the three instruments (above) are largely masked by the large variations as the DC-8 went from the polluted lower troposphere to the lower stratosphere.



SF_6 data can be used to determine age of air since it was last in contact with the surface, and to diagnose atmospheric transport. The time series of SF_6 (left) shows high values near the surface at high northern latitudes and much lower amounts in the stratosphere. Because of the 70-second data rate for both PANTHER and UCATS, there are very few coincident points, but the agreement in ATom-2 time series plots was very good.





Curtain plots of SF_6 data for PANTHER (top) and UCATS (bottom), for the winter 2017 transect from Alaska to southeast of New Zealand over the Pacific and Southern Oceans. Slight differences in the plots are mainly due to differences in the color bar. More complete analysis of transport patterns will need to wait for complete and final data from both instruments and the PFPs. For now, the results have been roughly consistent with HIPPO data over the Pacific. The curtain plots were kindly prepared by Britt Stephens, NCAR, from merged ATom data.

Tasks for the future

- Complete calibration of TDL water, including pressure dependence.
- ATom-3 and 4 deployments and archival of all data.
- Further exploration of improvements in signal to noise for UCATS N_2O and SF_6.
- Actual science - atmospheric transport from SF_6 and other tracers, the hydrogen budget, and ozone chemistry.