Twenty Five Years of Airborne Observations of Ozone-Depleting and Climate-Related Gases in the Upper Troposphere and Lower Stratosphere.

J. W. Elkins[1], F. L. Moore[1,2], E. J. Hintsa[1,2], G. S Dutton[1,2], J. D. Nance[1,2] D. F. Hurst[1,2], E. J. Dlugokencky[1], and B. D. Hall[1]

[1]NOAA/ESRL, Boulder, CO, United States; [2]Cooperative Institute for Research in Environmental Sciences, Boulder, CO, United States

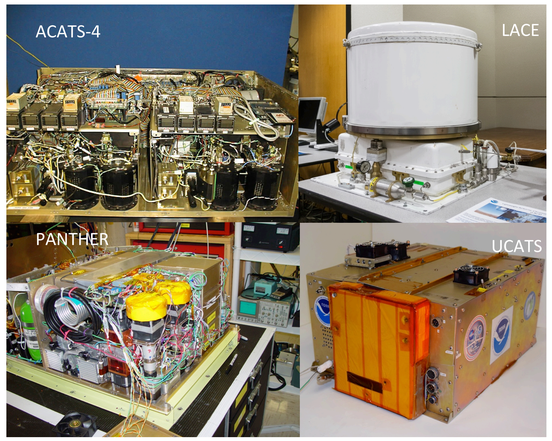

Figure 1 Airborne in situ gas chromatographs of NOAA.

1. Introduction: NOAA scientists started in situ airborne measurements of two strong ozone-depleting gases or chlorofluorocarbons, CFC-11 and CFC-113 in 1991 on the NASA ER2 aircraft with a two-channel gas chromatograph, *Airborne Chromatograph for Atmospheric Trace Species (ACATS & ACATS-2)*. This instrument was followed by ACATS-4; a balloon-borne GC version: *the Lightweight Chromatograph for Atmospheric Trace Species (LACE)*; *PAN and other Trace Hydro-halocarbon Experiment (PANTHER) for* shorter-lived gases mainly in the upper troposphere; and one Unmanned Aircraft Systems (UAS), called *UAS Chromatograph for Atmosphere Trace Species or UCATS (**Table 1**)*. These airborne measurements were to complement our ground-based flask and in situ measurements from the NOAA Halocarbon and other Trace Species Network (HATS) in ESRL/GMD. The airborne instruments are displayed above (***Figure 1***) and the airborne platforms that they flew on board below (***Figure 2***).

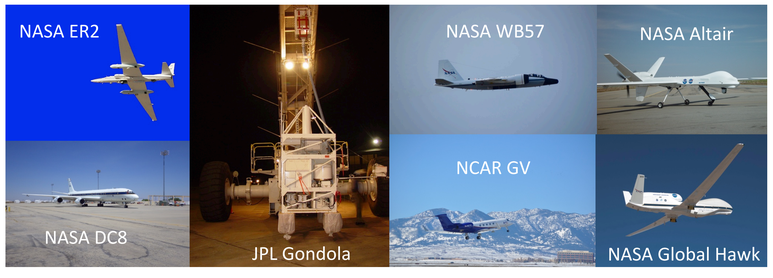

Figure 2 The various NASA and NSF platforms operating the NOAA GCs.

2. Experimental: The geographic coverage of the aircraft and balloon flights are above (***Figure 3***). The missions and platforms are indicated in the figure's legend. The early missions in the first half of the observation period focused on stratospheric ozone depletion in the lower stratosphere. The focus switched in the second half to issues in the troposphere involving air quality and greenhouse gases (GHGs)

Table 1 Details of each Airborne GC

Instrument	Channels	1st Mission	Gases
ACATS	1 GC-ECD	AASE2	CFC-11, -113
ACATS-2	2 GC-ECD	SPADE	CFC-11, -113, CH4, H2, CO
ACATS-4	4 GC-ECD	ASHOE/MAESA	CFC-11, -12, -113, halon-1211, N2O, SF6, CH3CCl3, CCl4, CH4, H2, CO
LACE	3 GC-ECD	OMS	CFC-11, -12, -113, halon-1211, N2O, SF6, CCl4, CH4, H2, CO
PANTHER	2 GC-MSD	SOLVE2	CFC-12, CH3Cl, CH3Br, CH3I, COS, HCFC-142b,-141b,-22, HFC-134a
	4 GC-ECD		CFC-11, -12, -113, halon-1211, N2O, SF6, CH4, H2, CO, PAN
UCATS	2 GC-ECD	NOAA DEMO	N2O, SF6, H2, CH4, CO
	2 O3 Photo		O3
	1 H2O TDL		H2O

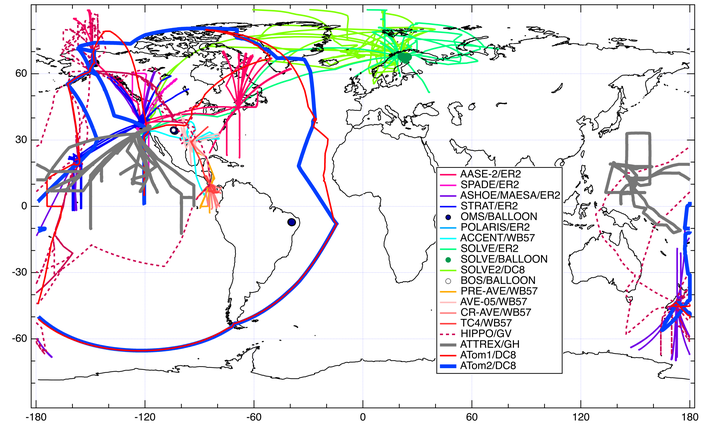

Figure 3 Flight tracks of aircraft (lines) and balloon sites (circles) of platforms with NOAA in situ gas chromatographs (excluding Cobra NA, Altair, and the NASA POSIDON mission).

with climate change. ***Table 2*** lists each major mission and describes its date(s) flown, the platform used, the NOAA GCs operated onboard, and the gases and types of gases measured.

3. Recent Results: An example of the vertical resolution in altitude of trace gases measured by UCATS on board the NASA Global Hawk on February 16, 2014 is shown in ***Figure 4,*** from the final phase of the Airborne Tropical TRopopause Experiment or ATTREX near Guam (grey thick line in ***Figure 3***). The focus of this study was the Tropical Tropopause Layer (TTL, shaded), which includes the tropopause in a region near Guam where convective activity is strong. All of the tropospheric source gases (SF_6, N_2O, CO, CH_4) drop off in mixing ratio levels once above the tropopause in the TTL, while O_3 levels increase in the stratosphere.

The cross sections of SF_6 mixing ratios during the Atmospheric Tomography Missions (ATom) in ***Figure 5*** shows that the sources are located in the northern hemisphere, NH (~95%), transported southward and upward, and that it is slowly destroyed in the mesosphere. The main purpose of ATom is study the influence of air quality on climate during the four seasons. The most interesting result so far for atmosphere SF_6 is the increased transport of NH high mixing ratio air into the southern hemisphere (SH) during August (circle), a result that we also observed in HIPPO. The GMD Carbon Cycle and Greenhouse Gases Group (CCGG) ground based, global-coverage network for SF_6 and a simple 2-box model shows that inter-hemispheric exchange time is fastest in August-September period (***Figure 6***), in reasonable agreement with several models (see B. Hall's GMAC Wednesday talk on SF_6).

Table 2 Details of Airborne Missions, where GMD Airborne GCs operated.

Mission	Dates	Platform	Instrument	Gases
AASE2	1991-1992	ER2	ACATS	CFC-11,-113
ASHOE/MAESA	1994	ER2	ACATS-4	CFCs, N2O, CH4, SF6
OMS	1996-1999	Balloon	LACE	CFCs, N2O, CH4, SF6
POLARIS	1997	ER2,Balloon	ACATS-4, LACE	CFCs, N2O, CH4, H2, SF6
SOLVE	1999-2000	ER2,Balloon	ACATS-4, LACE	CFCs, N2O, CH4, SF6
SOLVE2	2001-2002	DC8	PANTHER	CFCs, HCFCs, HFCs, GHGs
BOS	2002-2004	Balloon	LACE	CFCs, N2O, CH4, SF6
NOAA Demo	2005	Altair UAS	UCATS	CFCs, N2O
TC4	2007	WB57	PANTHER	CFCs, HCFCs, HFCs, GHGs
HIPPO	2009-2011	NCAR GV	PANTHER/UCATS	CFCs, HCFCs, HFCs, GHGs, O3, H2O
GloPac	2010-2011	Global Hawk	UCATS	N2O, SF6, CH4, O3, H2O
ATTREX	2012-2014	Global Hawk	UCATS	N2O, SF6, CH4, O3, H2O
ATOM	2016-2018	DC8	PANTHER/UCATS	CFCs, HCFCs, HFCs, GHGs, O3, H2O,PAN
POSIDON	2016	WB57	PANTHER	CFCs, HCFCs, HFCs, GHGs

Greenhouse Gases (GHGs) include CH_4, N_2O, SF_6, and COS measured by PANTHER.

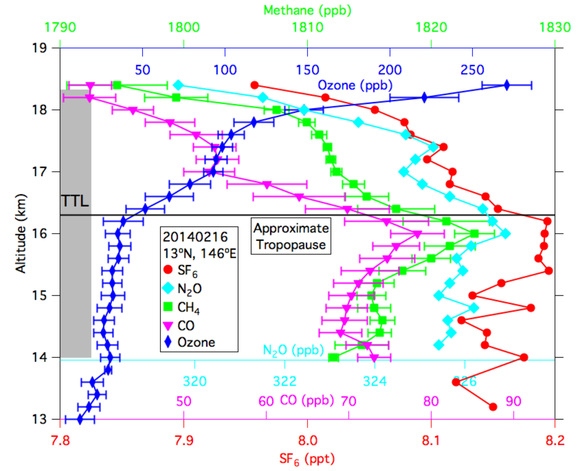

Figure 4 Vertical profiles of trace gases measured from UCATS in ATTREX.

4. Summary: Our airborne measurements help us understand transport on trace gases measured by our ground network, mixing processes, calculate atmospheric lifetimes of gases destroyed in the stratosphere, and examine the vertical distribution and trends of trace gases in the upper troposphere and lower stratosphere.

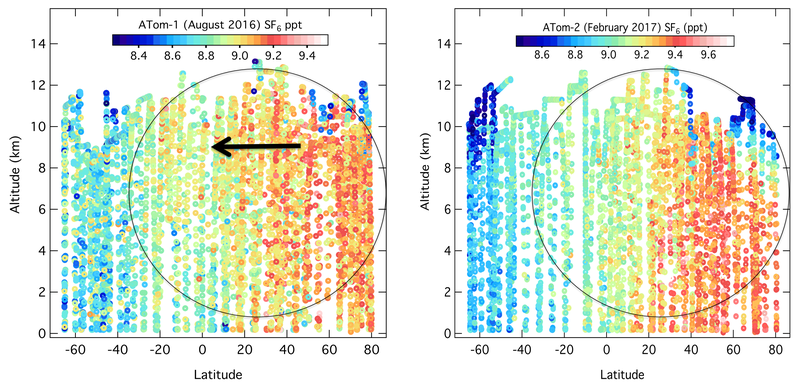

Figure 5 Latitudinal cross sections of SF_6 from two airborne GCs during ATom-1 and -2.

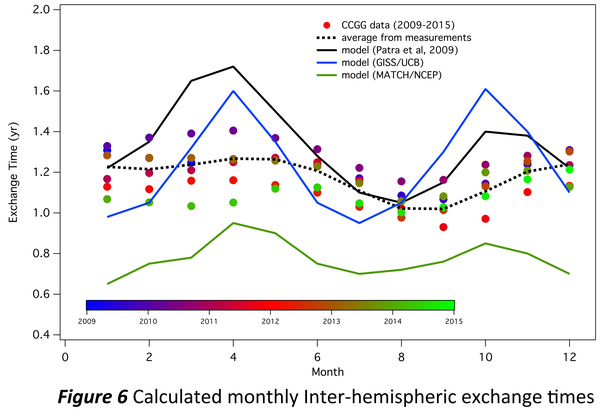

Figure 6 Calculated monthly Inter-hemispheric exchange times From CCGG measurements of SF_6. (doesn't include trop-strat exchange).