A42F-06 1715h

Multiply-Substituted Isotopologues of Atmospheric Gases

John M Eiler[1] (626-395-6942; eiler@gps.caltech.edu)

Edwin Schauble[1] (edwin@gps.caltech.edu)

Zhengrong Wang[1] (wzhr@gps.caltech.edu)

[1]California Institute of Technology, 1200 E. California Blvd., Pasadena, CA 91125

Stable isotope geochemistry is principally concerned with bulk isotopic compositions of natural materials (e.g., d13C). In atmospheric gases, these bulk compositions effectively depend only on abundances of molecules containing one rare isotope (e.g., 16O13C16O). However, the common di- and tri-atomic atmospheric gases also contain ca. 10-5 to 10-6 mole fraction of molecules containing two or more rare isotopes (e.g., 18O13C16O). These rare isotopologues are an untapped resource of constraints on physical chemistry and geochemical budgets. There are sparse data on the vapor pressures and chemical kinetics of multiply-substituted isotopologues, and the reduced partition functions of some were estimated by Urey (1947) and Bigeleisen and Mayer (1947). These studies demonstrate that these rare isotopologues have unique thermodynamic and kinetic properties, and thus that routine measurements of them could uniquely constrain geochemical problems. However, distributions of these rare isotopologues in nature are essentially unknown. We have developed a gas source mass spectrometer for analysis of doubly substituted isotopologues of N2, NO, CO, O2, CO2 and N2O at their naturally occurring abundances (in addition to the common and singly substituted isotopologues of these gases); associated sample preparation techniques and standardization protocols have been developed for CO2, N2O and are in progress for O2. Capabilities of this instrument vary with the abundances of the isotopologue of interest; external precision for the most abundant (e.g., 18O13C16O; 40 ppm of natural CO2) is typically $\pm$0.03 per mil, 1s, whereas that for more rare species (e.g., 18O12C18O; ca. 4 ppm of respective molecules) is typically $\pm$0.1 to 0.2 per mil, 1s. Accuracy based on comparisons to standards having the stochastic distribution of isotopes is similar to external precision. Interferences are the greatest analytical difficulty, with hydrocarbon fragments and recombination products being the most common and recalcitrant problem. The most extensive use of this instrument to-date has been to measure abundances of 18O13C16O in air and in experimental products. Preliminary results for 18O13C18O, 15N14N18O and 14N15N18O will also be reviewed, as will expected data for 18O18O and 17O18O if sufficiently complete. Near-surface air in southern California in mid-2003 is characterized by a 0.72 per mil enrichment in 18O13C16O relative to the abundance predicted for a stochastic (random) distribution of 18O and 13C among all CO2 isotopologues. This enrichment can be attributed to enhanced thermodynamic stability of 18O13C16O during air-sea and air-leaf water exchange which generates ca. 0.9 per mil enrichments modulated by anthropogenic emissions, fires and diffusive fractionations during photosynthesis all of which slightly (less than 0.1 per mil) reduce 18O13C16O mixing ratios. Variations in 18O13C16O in air with time and location will constrain the mean temperature of air-sea and air-leaf water exchange (and thereby add to the interpretation of d18O of CO2), and contributions from anthropogenic emissions and biomass burning. We will present data comparing southern California and Alaska during summer, 2003 as examples of these effects. Photolysis experiments on N2O demonstrate that photochemical reactions can generate large (up to tens of per mil) enrichments in multiply substituted isotopologues relative to their predicted stochastic abundance. Potential uses of such effects to constrain the physical budgets and physical chemistry of atmospheric gases will be discussed.

A42F-07 1730h

Modeling and measurements of oxygen isotope tracers of sulfate formation: Implications for the sulfur budget in the marine boundary layer

Becky Alexander[1] (617-495-5843; balexand@fas.harvard.edu); Joel Savarino[2] (jsavarino@lgge.obs.ujf-grenoble.fr); Charles C.W. Lee[3,5] (charles_ c_lee@urscorp.com); Rokjin Park[1] (rpark@fas.harvard.edu); Daniel J. Jacob[1] (djacob@fas.harvard.edu); Robert Yantosca[1] (bmy@io.harvard.edu); Mark H. Thiemens[3] (mthiemens@chem.ucsd.edu); Mian Chin[4] (chin@rondo.gsfc.nasa.gov)

[1]Harvard University, 29 Oxford Street, Cambridge, MA 02138, United States

[2]CNRS/UJF Laboratoire de Glaciologie et Geophysique de l'Environment, 54 rue Moliere, BP 96, St. Martin d'Heres 38 402, France

[3]University of California, San Diego, 9500 Gilman Drive Mail code 0356, La Jolla, CA 92093, United States

[4]NASA Goddard Space Flight Center, Code 916, Greenbelt, MD 20771, United States

[5]URS Corporation, 911 Wilshire Boulevard, Los Angeles, CA 90017, United States

Measurements of the mass-independent fractionation (MIF) in the oxygen isotopes of sulfate provide information on the relative oxidation pathways of sulfate formation(Savarino et al. 2001). The oxidation pathway has important implications for the effect of sulfate aerosols on climate, because it regulates whether this process can form a new particle in the atmosphere (gas-phase oxidation by OH) or forms on an already existing particle (aqueous-phase oxidation by H_2O_2 and O_3). Both present and past measurements of the MIF of sulfate show that O_3 is an important aqueous-phase oxidant in the sulfur cycle with regional (Lee, 2001), climatic (Alexander et al., 2001) and anthropogenic (Alexander et al., in preparation) variations. However, most global climate models do not consider O_3 to be an important oxidant for sulfate formation, primarily due to the assumption that most aqueous-phase oxidation of SO_2 occurs in clouds with pH values at which H_2O_2 will be the dominant aqueous-phase oxidant. Oxidation on alkaline aerosols such as sea salt or mineral dust could provide this missing O_3 oxidation pathway, as has been previously suggested in the literature. We report measurements of the MIF of sulfate collected on aerosol filters from two INDOEX cruises that show large $\Delta^{17}O$ values in the ITCZ region of the Indian Ocean. These measurements are compared with results from the GEOS-CHEM model of atmospheric chemistry and climate. The $\Delta^{17}O$ values of sulfate in the GEOS-CHEM model are calculated off-line based on the relative sources of sulfate. In addition to gas-phase oxidation by OH and in-cloud oxidation by H_2O_2 and O_3, O_3 oxidation of S(IV) on alkaline sea salt aerosols has been implemented in the GEOS-CHEM model. Results from the model indicate that the large $\Delta^{17}O$ values of sulfate measured within the ITCZ can be explained by oxidation of S(IV) by O_3 on sea salt aerosols. This process can affect the predicted climate forcing of sulfate aerosols by perturbing the amount of sulfate formed through gas-phase oxidation, and also by affecting the lifetime of sulfate that forms on coarse aerosols. The implications of this change on the sulfur budget in the marine boundary layer will be discussed.

A42F-08 1745h

Seasonal Atmospheric Chemistry at Summit, Greenland Based on N and O Isotopes of Nitrate

Meredith G Hastings[1] (609-258-4124; mhasting@princeton.edu)

Eric J Steig[2] (206-685-3715; steig@ess.washington.edu)

Daniel M Sigman[1] (609-258-2194; sigman@princeton.edu)

Julia Jarvis[3] (206-543-6223; jjarvis@u.washington.edu)

[1]Princeton University, Department of Geosciences Guyot Hall, Princeton, NJ 08544, United States

[2]University of Washington, Quaternary Research Center Department of Earth and Space Sciences 19 Johnson Hall, Seattle, WA 98195, United States

[3]University of Washington, Department of Earth and Space Sciences Box 351310, Seattle, WA 98195, United States

Nitric acid (HNO_3), or nitrate (NO_3^-) is the major sink for reactive nitrogen oxides (NO_x) in the atmosphere. Ice core records of NO_3^- could provide information about past reactive nitrogen chemistry and oxidative capacity of the atmosphere. However, processes that take place in the surface snow (e.g., evaporation, photolysis) can affect the final NO_3^- concentrations that are archived in the ice cores, making it difficult to interpret past changes in atmospheric chemistry or climate. The isotopic composition of NO_3^- in surface snow provides an additional constraint on the effect of post-depositional processing in the upper meter of snowpack on the NO_3^- content measured in glacial ice cores. Furthermore, the isotopes of NO_3^- in ice cores have the potential to allow for reconstruction of sources of NO_x and aspects of atmospheric chemistry in the past. Snow pit samples (sampled every 3 cm to 1 m) collected at Summit, Greenland during August 2001 show seasonal variation in N and O isotopes of NO_3^-. $\delta^{15}N$ of NO_3^- in the upper meter of snow ranges from -15 to +16 per mil (vs. atmospheric N_2), with higher values found in summertime snow. The $\delta^{15}N$ of snowpack NO_3^- falls in the range reported for NO_3^- in precipitation from other parts of the world. $\delta^{18}O$ of NO_3^- in the snowpack ranges from 65 to 80 per mil (vs. VSMOW), similar to high values observed for rainwater and aerosol NO_3^-. In contrast to the $\delta^{15}N$, the $\delta^{18}O$ of NO_3^- is lower in summertime snow than in wintertime. Preliminary analyses also show diurnal variation in the isotopes of NO_3^- during summer, with depletion of ^{15}N and ^{18}O at "night" followed by enrichment during the "day." The similar behavior of the N and O isotopes is suggestive of a simple physical mechanism for the diurnal change, such as photolysis or evaporation. The seasonal $\delta^{15}N$ and $\delta^{18}O$, however, vary in opposite directions suggesting that these processes are not the dominant mechanism determining the seasonal signals. Our hypothesis is that isotope ratios preserved in the snow are determined by seasonal changes in atmospheric chemistry rather than post-depositional processes. To first order, we can explain the variation in $\delta^{18}O$ of NO_3^- as a switch in the reactions that produce HNO_3 from NO_x from predominantly homogeneous reactions in the summer ("day chemistry" influenced by OH) to predominantly heterogeneous reactions in the winter ("night chemistry" more influenced by ozone). Given our current information, the seasonal change in $\delta^{15}N$ of NO_3^- may be determined by seasonal changes in chemistry (i.e., ozone concentrations and its effect on the fraction of NO_x as NO_2), the source of NO_x, or both.

A42G MCC: 3016 Thursday 1600h

Results From the SOLVE II/VINTERSOL Mission II *(joint with C)*

Presiding: **M R Schoeberl,** NASA Goddard Space Flight Center**; L R Poole,** NASA Langley Research Center

A42G-01 1605h INVITED

An Overview of the Second SAGE III Ozone Loss and Validation Experiment (SOLVE-II)

Paul A Newman (301-614-5985; paul.a.newman@nasa.gov)

NASA GSFC, Code 916 Building 33, Room E320, Greenbelt, MD 20771, United States

The SOLVE II Field mission was a field campaign designed to investigate polar ozone loss, polar stratospheric clouds, processes that lead to ozone loss, the dynamics of the polar stratosphere, and to acquire correlative data needed to validate satellite measurements of the polar stratosphere. The campaign was closely coordinated with VINTERSOL-EUPLEX campaigns. This combined international campaign was staged over the course of the winter of 2002-2003. SOLVE-II measurements were made from the NASA DC-8 aircraft, ozonesondes and other balloon payloads, ground-based instruments, and satellites. In particular SOLVE-II was designed to validate the Meteor-3M/Stratospheric Aerosol and Gas Experiment (SAGE) III satellite mission. We will review the overall objectives of the combined campaigns, discuss some of the broad observations of the winter of 2002-2003, and highlight the major findings of this campaign.

A42G-02 1625h INVITED

Arctic Stratospheric Ozone Loss in Winter 2002/2003 as Observed During the European VINTERSOL Campaign

Fred Stroh[1] (+49-2461-614307; f.stroh@fz-juelich.de)

. VINTERSOL Core Group (+32-2295-8815; geogios.amanatidis@cec.eu.int)

[1]Forschungszentrum Juelich GmbH, Leo Brandt Str., Juelich, NRW 52425, Germany

The first phase of the European Validation of International Satellites and Ozone Loss (VINTERSOL) program was focussed on stratospheric ozone loss and related processes and satellite validation in the 2002/2003 Arctic winter. Over the winter several measurement campaigns employing balloons, ozone sondes, aircraft, and satellite data focussed on PSC formation, halogen activation, and ozone loss processes. The talk will give an overview of the activities carried out and will highlight the major results on the formation of NAT particles, chlorine activation and partitioning, and ozone loss processes.

A

A42G-03 1645h INVITED

An Overview of SAGE III Validation Activities during the SOLVE-2/VINTERSOL Campaigns

Charles Trepte ((757) 864-5836; Charles.R.Trepte@nasa.gov)

NASA Langley Research Center, Mail Stop 475 Radiation and Aerosols Branch, Hampton, VA 23691, United States

A major goal of the SAGE III Ozone Loss and Validation Experiment (SOLVE) II and the Validation of International Satellites and Study of Ozone Loss (VINTERSOL) field experiments is to support validation studies for a new generation of satellite experiments that had been recently placed in orbit. The Stratospheric Aerosol and Gas Experiment (SAGE) III instrument was launched in December 2001 on board a Russian Meteor 3M satellite to provide information on the behavior of ozone, aerosols, water vapor and other trace species at high and mid latitudes in the upper troposphere and stratosphere. The instrument supports an advanced design from its predecessor with added spectral coverage and resolution and greater dynamic range that allows for observations during solar and lunar occultations as well as measurements of scattered light along the limb. During the SOLVE-2/VINTERSOL campaigns, a comprehensive set of correlative measurements was obtained from a network of ground-based instruments and the launch small balloon payloads from high latitude sites, the launch of several large balloon payloads and multiple rockets from Esrange, Sweden and flights of the NASA DC-8, the DLR Falcon, and the M55 Geophysica aircraft based from Kiruna, Sweden. These measurements provide an opportunity to assess biases between instrument techniques and to help interpret satellite observations in a variety of meteorological settings. This presentation will highlight comparison findings for the SAGE III satellite experiment from the array of observations collected during the SOLVE-2/VINTERSOL campaigns.

A42G-04 1700h

POAM III Observations During the SOLVE2/VINTERSOL Winter: PSCs, Denitrification, and Ozone Loss

Richard M Bevilacqua[1] (202-767-0768; bevilacqua@nrl.navy.mil); Karl Hoppel[1] (202-767-1320; karl.hoppel@nrl.navy.mil); Michael Fromm[2] (202-404-1389; fromm@nrl.navy.mil); Cora Randall[3] (cora.randall@lasp.colorado.edu); Jerry Lumpe[2] (lumpe@cpi.com); Jerome Alfred[2] (alfred@cpi.com)

[1]Naval Research Laboratory, Code 7220, Washington, DC 20375

[2]Computational Physics Inc., 8001 Braddock Road, Springfield, VA 22151

[3]Laboratory for Amospheric and Space Physics, University of Colorado, Boulder, CO 80309

The POAM III satellite instrument was fully operational during the SOLVE2/VINTERSOL campaign (2002/3 northern hemisphere winter), and sampled the vortex core, the vortex edge, and outside the vortex throughout this winter. In this paper we present an overview of POAM observations and analysis obtained during the SOLVE2/VINTERSOL winter. PSCs were observed quite frequently in the early part of the winter (through December). In fact, in the first half of December the PSC occurrence frequency was larger in the 2002/3 winter than that observed in any other POAM measurement year (POAM II: 1993/94-1995/96, and POAM III: 1998/99-2002/03). After a warming, which occurred in mid-January, PSCs were observed only episodically for the remainder of the winter, and the last POAM PSC observation was made on 21 March. From an analysis of PSC occurrence frequency as a function of UKMO temperature, we infer that the intense PSC activity in December resulted in extensive denitrification of the polar vortex by the beginning of January. Furthermore, the analysis suggests that when PSCs were again observed in early February (after the mid-January warming) the vortex remained denitrified. Significant ozone loss was observed in the early part of the winter, particularly between early December and late January. Vortex average ozone mixing ratios in the lower stratosphere in late January were lower by nearly 1 ppmv than those observed in any other POAM measurement year. Finally, we present estimates of ozone chemical loss determined using POAM data and the vortex average descent method.

A42G-05 1715h

Large-Scale Ozone Variations in the Arctic During SOLVE-2 and Comparisons of Remote and In Situ Ozone Profile Measurements

Edward V. Browell[1] (757-864-1273; Edward.V.Browell@nasa.gov); Marta A. Fenn[1] (m.a.fenn@larc.nasa.gov); William B. Grant[1] (w.b.grant@larc.nasa.gov); Melody A. Avery[1] (m.a.avery@larc.nasa.gov); Roland Neuber[3] (neuber@awi-potsdam.de); Thomas J. McGee[2] (mcgee@aeolus.gsfc.nasa.gov); Charles R. Trepte[1] (c.r.trepte@larc.nasa.gov); Carolyn F. Butler[1] (c.f.butler@larc.nasa.gov); Susan A. Kooi[1] (s.a.kooi@larc.nasa.gov); Anthony Notari[1] (a.notari@larc.nasa.gov); Johnathan W. Hair[1] (j.w.hair@larc.nasa.gov); Leslie R. Lait[2] (lrlait@ertel.gsfc.nasa.gov)

[1]NASA Langley Research Center, Mail Stop 401A, Hampton, VA 23681, United States

[2]NASA Goddard Space Flight Center, Code-916, Greenbelt, MD 20771, United States

[3]Alfred Wegener Institute, Forschungsstelle Potsdam Telegrafenberg A43, Potsdam D-14473, Germany

Ozone cross sections were obtained from near the surface to above 30 km along the ground track of the NASA DC-8 on long-range flights across the Arctic during the 2003 SAGE-III (Stratospheric Aerosol and Gas Experiment) Ozone Loss and Validation Experiment (SOLVE-2). Extensive regions of lower than expected ozone were found inside the polar vortex below about 22 km at the start of the mission (January 9, 2003), and by the end of mission (February 12, 2003) ozone had decreased to less than 2.0 ppm in localized regions inside the vortex at about 19 km. These regions of particularly low ozone were associated with air masses that had seen extended periods of sunlight. Extensive structure was observed in the ozone field near the edge of the vortex on many flights, and on occasion, large filaments of extra-vortex air were observed inside the vortex. When the vortex divided into two separate vortices, the ozone field reflected the separation with extra-vortex air in between. The nadir ozone data showed strong evidence of downward transport in vicinity of jet streams, and these intrusions were observed to extend down to below 4 km in some cases. Directly under the vortex, large-scale descent of stratospheric air produced ozone levels exceeding 100 ppbv down to 5 km. This is the first time the entire ozone cross section was obtained during an airborne field experiment, and it will provide important new information on atmospheric dynamics and ozone chemistry in the Arctic. This experiment also provided a unique opportunity to compare ozone measurements from several different remote and in situ instruments. Ozone profiles were measured above and below the DC-8 with the airborne UV Differential Absorption Lidar (DIAL) system, and the Airborne Raman Ozone, Temperature, and Aerosol Lidar (AROTAL) measured ozone profiles above the aircraft. In situ ozone measurements were made at the DC-8 flight level, and ground-based lidar and ozonesonde measurements were made from Ny-Ålesund. Coincident SAGE-III and DC-8 ozone measurements were obtained as the primary objective of SOLVE-2. Good agreement was found between in situ and nadir DIAL measurements; DIAL, AROTAL, and SAGE-III measurements; Ny-Ålesund lidar, ozonesondes, DIAL, and AROTAL. Examples of all these different types of ozone intercomparisons will be presented.

A42G-06 1730h

Arctic Chemical Ozone Loss Deduced from POAM III Using Chemical Transport Models

Cynthia Shaw Singleton[1] (303-735-5093; shaw@lasp.colorado.edu); Cora E. Randall[1] (randall@lasp.colorado.edu); Martyn Chipperfield[2] (martyn@env.leeds.ac.uk); Stewart Davies[2] (stewart@env.leeds.ac.uk); Doug Kinnison[3] (dkin@ucar.edu); Franck Lefevre[4] (franck.lefevre@aero.jussieu.fr); Richard Bevilacqua[5] (bevilacqua@nrl.navy.mil); Karl Hoppel[5] (karl.hoppel@nrl.navy.mil)

[1]Laboratory for Atmospheric and Space Physics, UCB 392 University of Colorado, Boulder, CO 80309-0392, United States

[2]School of the Environment, University of Leeds, Leeds LS2 9JT, United Kingdom

[3]National Center for Atmospheric Research, Mesa Lab P.O. Box 3000, Boulder, CO 80307-3000, United States

[4]Service d'Aeronomie, Universite Pierre et Marie Curie 4 place Jussieu,BP 102 75252, Paris Cedex 05, France

[5]Naval Research Laboratory, Code 7220, Washington, DC 20375, United States

Inferring ozone loss from satellite data requires that ozone variations due to dynamical perturbations be taken into account. Currently several techniques to accomplish this exist; however, many only consider vertical descent of ozone. In order to account for ozone variations due to both vertical descent and horizontal mixing, we use a three-dimensional chemical transport model (CTM). In the work presented here, results from three CTMs, SLIMCAT, REPROBUS, and MOZART3, were used to infer chemical ozone loss from observations from the Polar Ozone and Aerosol Measurement (POAM) III instrument inside the vortex during the 1999/2000 and 2002/2003 Arctic Winters. In order to deduce the dynamical change of ozone each CTM was run in a passive mode, in which ozone was treated as a dynamical tracer, from early December until the middle of March. We have estimated chemical ozone loss by subtracting the model passive ozone, evaluated at the time and location of the POAM observations, from the POAM measurements themselves. This technique relies on the accurate initialization of the CTM and a realistic description of vertical/horizontal transport. Therefore, it is important to understand the sensitivity of ozone loss inferences to model uncertainties, which vary depending on the meteorological conditions. Advantages/disadvantages of this technique will be discussed as well as comparisons with different ozone loss techniques.

A42G-07 1745h

Aerosol Optical Depth Measurements by Airborne Sun Photometer in SOLVE II: Comparison to SAGE III and POAM III Measurements

P. Russell[1] (Philip.B.Russell@nasa.gov); J. Livingston[2] (jlivingston@mail.arc.nasa.gov); B. Schmid[3] (bschmid@mail.arc.nasa.gov); J. Eilers[1] (jeilers@mail.arc.nasa.gov); R. Kolyer[1] (rkolyer@MAIL.ARC.NASA.GOV); J. Redemann[3] (jredemann@mail.arc.nasa.gov); J-H. Yee[4] (Sam.Yee@jhuapl.edu); C. Trepte[5] (c.r.trepte@larc.nasa.gov); L. Thomason[5] (l.w.thomason@larc.nasa.gov); J. Zawodny[5] (j.m.zawodny@larc.nasa.gov); W. Chu[5] (w.p.chu@larc.nasa.gov); M. Pitts[5] (m.c.pitts@larc.nasa.gov); J. Lumpe[6] (lumpe@cpi.com); C. Randall[7] (cora.randall@lasp.colorado.edu); R. Bevilacqua[8] (bevilacqua@nrl.navy.mil)

[1]NASA Ames Research Center, MS 245-5, Moffett Field, CA 94035-1000, United States

[2]SRI International, 333 Ravenswood Avenue, Menlo Park, CA 94025, United States

[3]Bay Area Environmental Research Institute, 560 Third St. West, Sonoma, CA 95476, United States

[4]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 21218, United States

[5]NASA Langley Research Center, MS 475, Hampton, VA 23681-2199, United States

[6]Computational Physics, 8001 Braddock Road, Springfield, VA 22151, United States

[7]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309, United States

[8]Naval Research Laboratory, 4555 Overlook Avenue, S.W., Washington, DC 20375, United States

The 14-channel NASA Ames Airborne Tracking Sunphotometer (AATS-14) made measurements during the sunlit segments of eight science flights on the NASA DC-8 during the Second SAGE III Ozone Loss and Validation Experiment (SOLVE II). These included six flights out of Kiruna, Sweden, one out of NASA Dryden Flight Research Center (DFRC), and the Kiruna-DFRC return transit flight. Aerosol optical depth (AOD) spectra, columnar ozone and columnar water vapor have been derived from the AATS-14 measurements. This paper focuses on AATS-14 AOD data. In particular, we compare AATS-14 AOD spectra with temporally and spatially near-coincident measurements by the Stratospheric Aerosol and Gas Experiment III (SAGE III) and the Polar Ozone and Aerosol Measurement III (POAM III) satellite sensors. We examine the effect on retrieved AOD of uncertainties in relative optical airmass (the ratio of AOD along the instrument-to-sun slant path to that along the vertical path) at large solar zenith angles. Airmass uncertainties result from uncertainties in requisite assumed vertical profiles of aerosol extinction due to inhomogeneity along the viewing path or simply to lack of available data. We also compare AATS-14 slant path solar transmission measurements with coincident measurements acquired from the DC-8 by the NASA Langley Research Center Gas and Aerosol Measurement Sensor (GAMS).

URL: http://geo.arc.nasa.gov/sgg/AATS-website/