FINAL REPORT

PARTICIPATION AS MISSION SCIENTIST FOR THE SPADE II MISSION

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"Participation as Mission Scientist for the SPADE II Mission"

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Research Objectives

In a 1994 National Research Council report, "Atmospheric Effects of Stratospheric Aircraft: An Evaluation of NASA's Interim Assessment", the assessment panel's key issues for better determining the atmospheric effects of stratospheric aircraft, particularly on ozone, were presented. One of the three key issues is summarized in the statement:

- **"Uncertainties in the dispersion characteristics related to effluents in the lower stratosphere."**

A strategy for studying the transport of air through the stratosphere has evolved over the last ten years. It involves the measurements of long-lived trace chemicals that have different sources and sinks in the stratosphere and thus different lifetimes. By examining the distributions of these long-lived tracers and by comparing the mixing ratio of one tracer against another measured simultaneously, characteristics of transport between the troposphere and stratosphere and within the stratosphere can be determined. These observed characteristics then become benchmarks against which global stratospheric model calculations can be compared.

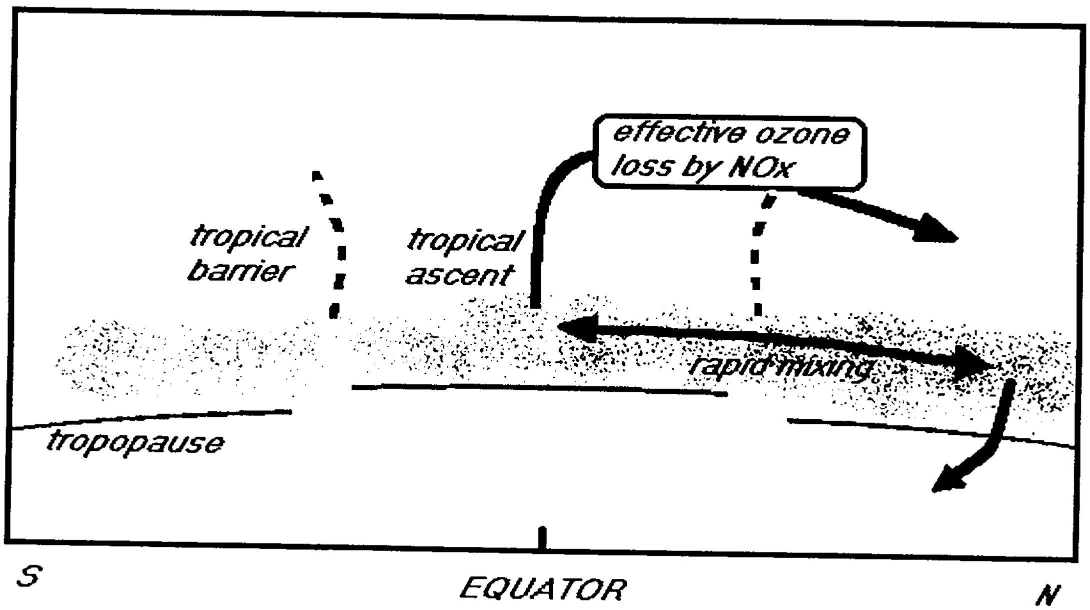
The NASA ER-2 aircraft has had the instrumentation to measure a suite of long-lived tracers since the SPADE mission in 1992-1993. ER-2 measurements have been made since then during the campaigns: ASHOE/MAESA (1994); STRAT (1995-1996); and POLARIS (1997). Unfortunately, the ER-2 can not probe the atmosphere above 20 km, a region of great interest for transport and chemistry. Space-borne instrumentation has also produced distributions of long-lived tracers, but the frequency, location, timing, and measurement precision was generally inadequate to provide the measurements required to determine the transport characteristics. Hence, another method for probing the middle stratosphere.

The information gap is filled by Observations from the Middle Stratosphere (OMS). OMS is a measurement strategy that uses instruments, carried aloft by large helium-filled balloons, to sample long-lived trace chemical distributions in the middle and lower stratosphere. In this strategy, existing balloon-borne remote sensing instrumentation would be used. However, to get the high precision and accuracy required, a new payload would have to be built that had in situ sampling instruments, similar to those on the ER-2.

The overall OMS science objectives is to define atmospheric transport processes important for the stratospheric dispersion of HSCT effluents as a first step toward reducing uncertainties in predicting HSCT effluent effects. Two questions are:

- Will effluents be carried higher into the stratosphere by entering the tropics and rising?
- Where in the stratosphere will the effluent stay and for how long?

A rough view of the transport of interest to the AESA program is shown in the schematic.



In 1994, I was asked to be the project scientist overseeing the development and deployment of a new payload that contained in situ sampling instruments (called OMS *in situ*). We began work in earnest on the design of the payload and the operational goals at a workshop in Washington DC in January 1995. The operational objectives that we defined were:

- Measurement of a select group of long-lived tracers from 30 km to the troposphere, at high, middle, and tropical latitudes, to define mixing, tropical ascent, and the mean age-of-air, a surrogate for HSCT effluents.

Long-lived tracers with different tropospheric trends, seasonal cycles, and destruction rates and methods act as "clocks" of atmospheric motion.

Scatter plots of two long-lived tracers are different in the tropics and middle latitudes. These differences are used to examine mixing between the tropics, midlatitudes, and high latitudes.

- Frequent simultaneous sampling of the same air mass by in-situ balloons, remote-sensing balloons, satellites, and the ER-2 to develop a large, cohesive observational data base that will be used to test assessment models.

Intercomparisons give confidence in different measurement techniques.

These operational objectives were met during the course of the next three years.

OMS in situ payload

The payload for OMS *in situ* consists of instruments to measure long-lived gases that trace atmospheric motions. This payload consists of instruments to measure CO_2, CFC-11, SF_6, CH_4, N_2O, H_2O, O_3, pressure, and temperature: chemical species with a wide variety of trends, lifetimes, and seasonal variations. The principal investigators and their organizations are: CO_2 (Boering and Wofsy, Harvard University); N_2O and CH_4, (Webster, JPL); N_2O and CH_4 (Loewenstein, Ames Research Center); CFC-11, CFC-113, SF_6, (Elkins, NOAA CMDL); O_3, P, and T (Margitan, JPL); H_2O (Oltmans, NOAA CMDL). The redundancy in the N_2O measurement is required because both of these instruments were new and the N_2O measurement is so important to the mission. All of these instruments are based on earlier designs or have been tested on aircraft. They were placed on a balloon gondola that is being constructed at JPL by James Riccio and his colleagues.

Other remote sensing payload already existed. A listing of the payloads and their measurement capabilities is given below.

Balloon-borne instruments:

- OMS *in-situ* payload instruments
  high accuracy, high precision, subkilometer altitude resolution
  - JPL ALIAS II (N_2O, CH_4)
  - NASA ARC Argus (N_2O, CH_4)
  - Harvard University CO_2 (CO_2)
  - NOAA CMDL LACE (CFC-11, SF_6, CFC-12, CFC-113)
  - JPL Ozone (O_3, P, and T)
  - NOAA CMDL Water vapor (H_2O, P, and T)

- JPL Mark IV solar infrared absorption
  good accuracy, good precision, 2 km altitude resolution
  - measures: H_2O, CH_4, N_2O, CFC-11, CFC-12, SF_6, O_3, CO_2, CO, NO, NO_2, HNO_3, HCl, HF, CF_4, and many more

- Harvard FIRS-2 far-infrared spectrometer
  good accuracy, good precision, 2 km altitude resolution
  - measures: O_3, N_2O, HNO_3, NO_2, N_2O_5, H2O, OH, HO_2, HCl, and more

- U.of Denver CAESR infrared thermal emission
  good accuracy, good precision, medium altitude resolution

- measures: O_3, HNO_3, CH_4, CFC-11, CFC-12, N_2O_5, aerosol

- JPL SLS submillimeter limb sounder
  good accuracy, good precision, medium altitude resolution
  - measures: O_3, N_2O, HNO_3, HO_2, ClO, HCl

A history of recent balloon flights:

To meet the operational objectives, a number of flights were planned in a short time interval. All flight operations were conducted by the National Scientific Balloon Facility, in Palestine, Texas. We worked closely with them to optimize the probability of achieving the operational objectives, and hence the scientific goals.

A total of 7 OMS *in situ* flights and 4 remote sensing payload flights were conducted from June 1996 to May 1997. This feat is truly remarkable and probably unprecedented for a payload of the complexity of the OMS *in situ* payload. A listing of the flights and how they met the operational objectives is given below.

- **June 1996, Ft. Sumner, New Mexico.**
  - OMS *in situ* engineering test flight - first flight
  - Test new instruments and gondola.
- **September 1996, Ft. Sumner, New Mexico.**
  - OMS *in situ* first midlatitude flight - transport.
  - ER-2 flight to New Mexico. Intercomparison.
  - Mark IV flight 1 week later. Intercomparison.
- **February 1997, Juazeiro do Norte, Brazil.**
  - OMS *in situ* first tropical flight -transport.
  - Tropical observations of unprecedented quality.
- **April - May 1997, Fairbanks, Alaska. (ADEOS).**
  - ADEOS intercomparison - photochemistry and transport.
  - Mark IV, FIRS-2, SLS, CAESR, O_3. Aerosol.
  - ER-2 POLARIS flights. Intercomparison.
  - Two launches 8 days apart.
- **June - July 1997, Fairbanks, Alaska.**
  - OMS *in situ* high latitude - transport.
  - ER-2 POLARIS flights. Intercomparison.
  - Mark IV - photochemistry, transport, & intercomparison.
- **November 1997, Juazeiro do Norte, Brazil.**
  - OMS *in situ* second and third tropical flights.
  - Later time, different stratospheric conditions
- **May, 1998, Ft. Sumner, New Mexico**
  - OMS *in situ* midlatitude flight
  - Observations of the highest quality ever obtained

OMS results that impact the assessment of stratospheric ozone loss from HSCTs.

The scientific results from these flights has had the anticipated impact on the understanding of stratospheric transport. The key findings are summarized below.

- OMS tracer-tracer relationships are distinctly different in the tropics, midlatitudes, and high latitudes, as also seen from the ER-2 and from space (ATMOS).

  These observations confirm the utility of tracer-tracer relationships for defining stratospheric transport and for testing transport in the HSR assessment models.

- OMS tracer-tracer relationships confirm ASHOE/MAESA and STRAT ER-2 observations that lower-stratospheric quasi-horizontal mixing is rapid just above the tropopause and 30% of tropical air came from the midlatitude lower stratosphere.

  Thus HSCT effluents could get into the lower tropical stratosphere in greater amounts than currently calculated.

- Ascent rates, entrainment rates, and mean age of the air in the tropical stratosphere (18 - 30 km) are being determined from OMS measurements of CO_2, SF_6, N_2O, and CH_4. The mean age of tropical stratospheric age is 2-4 years. Above 25 km, mixing with midlatitude air appears to be substantial.

  Thus HSCT effluents will ascend to at least 25 km where they will mix out into middle latitudes.

- The mean age of air in the summertime polar stratosphere is 5-6 years. Mixing is slow in the stagnant air, as seen by the presence of polar filaments.

  Thus HSCT effluents could remain longer in stratospheric regions where they are effective in destroying ozone.

How do assessment models compare to OMS, STRAT, and ATMOS observations?

Overall, the assessment models do not match the observed:

- mixing into the tropical lower stratosphere;
- lifetime (probably mixing) in the tropical stratosphere above 25 km;
- stratospheric mean age-of-air at high latitudes.

The goal was to have these results available to impact the 1998 assessment of the impact of stratospheric aircraft on stratospheric ozone and climate. This goal was accomplished. Numerous publications from OMS *in situ* and remote sensing payloads as well as the results are essential components that support the findings of the assessment. This assessment – Assessment of the Effects of High-Speed Aircraft in the Stratosphere: 1998 – is currently in press.

Publications resulting from this effort and those of the OMS investigators

Several publications are in preparation and will be submitted this year. Two that are already submitted are:

Andrews, A. E., K. A. Boering, B. C. Daube, S. C. Wofsy, E. J. Hinsta, E. M. Weinstock, and T. P. Bui, Empirical age spectra for the lower tropical stratosphere from *in situ* observations of CO_2: Implications for stratospheric transport, *J. Geophys. Res.*, submitted, 1999.

Jost, H., M. Loewenstein, L. Pfister, J. J. Margitan, A. Y. Chang, R. J. Salawitch, and H. A. Michelsen, Filaments in the tropical middle stratosphere: Origin and age estimation, *Geophys. Res. Lett.*, accepted, 1998.