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1995 SUMMARY REPORT
SOUTHERN OXIDANTS STUDY: TECHNICAL SUPPORT FOR AIRBORNE MEASUREMENTS OF EDDY FLUXES WITH CHEMICAL AND METEOROLOGICAL VARIABLES

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ABSTRACT. The NOAA Twin Otter research aircraft was equipped with scientific instrumentation for participation in the 1995 Nashville/Middle Tennessee Ozone Study, a component of the Southern Oxidants Study. The program was designed to investigate the emissions, transport, and fate of tropospheric ozone and its precursors, furthering the scientific understanding of tropospheric ozone production and accumulation. The aircraft carried a suite of fast response sensors for determination of air-surface exchange (turbulent flux) processes, complemented by instruments for the measurement of photochemically active trace gases and meteorological variables. As an aid to users of the data set, this report introduces the program in general and elaborates on the airborne operations, the instrumentation used, and the data obtained by the NOAA flight program.

1. INTRODUCTION

The Southern Oxidants Study (SOS) was initiated to extend our knowledge of the formation, accumulation, fate, and effects of ozone (O_3) and other photochemical oxidants in the southeastern United States. In addition, the five-year multi-agency effort continues to focus on cultivating the intellectual and technological resources required to effectively evaluate new strategies for mitigation of the effects of photochemical oxidant accumulations in the South, as well as in the nation. While this report will serve to summarize the NOAA Air Resources Laboratory involvement in the SOS, a thorough background for the SOS can be found in The State of the Southern Oxidants Study: Policy-Relevant Findings In Ozone Pollution Research 1988-1994 [Chameides and Cowling, 1995].

In 1995, the SOS began the final year of its first five-year phase of research programs, involving cooperative agreements with federal, state, and industrial sponsors, by implementing an intensive field measurements and modeling program: the 1995 Nashville/Middle Tennessee Ozone Study. This campaign was primarily designed to examine sub-grid scale chemistry and meteorological processes especially with regard to interaction of rural/urban, urban/rural, power plant/urban, and power plant/rural plume exchanges. Additional aims of the program were to undertake a chemical and climatological comparison of SOS study areas, strengthen understanding of the function of biogenic emissions in accumulation of ozone in urban and rural regions of middle Tennessee, and test and improve both emissions-based and observations-based air quality models.

The Nashville and surrounding rural area is a natural laboratory for process-oriented studies. Distant from other urban areas, the location allows characterization of distinct regional, urban, and point source complexes. Large fossil-fuel power plants are located in or near the area of study surrounding Nashville, an area which continues to have difficulty meeting the national ozone standard. An investigation of sub-grid scale chemistry and meteorological processes by surface measurements alone would prove insufficient to extend our understanding of the mechanisms of photochemical ozone production and accumulation. The use of an aircraft, as a moving platform, is recognized as essential to a study where only time-resolved three-dimensional data will extend that knowledge. The 1995 Nashville/Middle Tennessee Ozone Study (NMTOS) provided a large-scale composite view of ozone chemistry and transport by accomplishing extensive aircraft measurements in concert with a vast ground-based monitoring/measurements network. The National Oceanic and Atmospheric Administration (NOAA) participated in the study, sponsoring a fully instrumented research aircraft for intermediate-range flux/flux divergence, chemistry and meteorological measurements. The airborne observations were managed and staffed by personnel of the NOAA Air Resources Laboratory (ARL), headquartered in Silver Spring, MD. The instrumented aircraft, with a flight crew of two pilots and three or four scientific observers, was deployed as a part of the coordinated, daily NMTOS flight activity. The ARL team flew 74.2 hours during 18 research flights, the first two of which completed airborne systems testing and pilot familiarization.

2. OBJECTIVES

The ARL airborne research program was planned to fully integrate with the large-scale NMTOS program as illustrated by the following objectives:

- Investigate the evolution and air-surface exchange dynamics in the Planetary Boundary Layer (PBL).
- Study flux /flux divergence in the mixed layer.
- Characterize the horizontal and vertical distribution of pollutant species in the urban (source) and subregional plumes, particularly obtaining accurate measurements of ozone and its precursors.
- Investigate the relationships among ozone and its precursors.
- Examine the relationships between surface and aloft trace gas concentrations.

3. DATA COLLECTION

3.1 Method of Collection

The airborne data collection platform was a model DHC-6, Twin Otter, built by The De Havilland Aircraft Co. of Canada. The Twin Otter is a high-wing, all-metal, unpressurized airplane with tricycle landing gear and a steerable nosewheel. Two wing-mounted turboprop engines drive three-blade, reversible pitch, full-feathering propellers. In a normal seating configuration it carries a flight crew of two and up to 20 passengers. Operations and services such as cargo transportation, air-ambulance, aerial survey and supply dropping demonstrate the versatility of this short-field takeoff and landing capable aircraft.

The aircraft was extensively modified in conversion to a useful scientific research platform. Structural alterations to the nose radome area permit mounting a unique research nose instrumented with the fast response sensors necessary for flux measurements. A power distribution system, which converts the 28 VDC available from the starter/generators to 3 KW at 110 VAC, was incorporated into the cabin to power research instruments and data systems. State variable sensor systems were installed appropriately on the exterior and interior of the fuselage. Fully engineered aluminum racks, mounted to the floor and bulkhead tracks, contained the trace gas sampling and analysis instrument systems. A forward-facing, window-mounted air inlet system was designed to provide a continuous air sample flow through the cabin to the analyzers and samplers. Excess sample air was ducted out of the cabin through a rearward window port along with pump and analyzer system exhausts. Sophisticated GPS systems completed the research package. A more thorough description of the instrumentation follows.

The base of airborne operations for the NOAA/ARL personnel and aircraft was leased space in a corporate hangar at the Nashville International Airport. Other aircraft participating in the program were similarly located at the Nashville International Airport. A command center for SOS operations, used for planning/coordination meetings, doubled as a computer center for the various participant groups and their data processing needs.

3.2 Flight Plans

Flight plans for the NOAA aircraft were tailored by the ARL scientists with the assistance of the pilot and co-pilot. Adherence to Federal Aviation Administration (FAA) rules of flight and the scientific objectives of the ARL effort for SOS were foremost in the design of each mission. The majority of observations were to center on the advected urban plume within the planetary boundary layer and lower free troposphere. Sampling tracks and vertical profiles, in general, were designed for altitudes below 3000 m and to take place under Visual Flight Rules (VFR) conditions, that is, clear of clouds. Conduct of flight tracks in support of flux/flux divergence at altitudes down to 100 m required FAA authority via a Certificate of Waiver or Authorization. Due to the dependence of the daily missions, and subsequently sampling tracks, on meteorology, the FAA waiver granted was general, allowing 160 m minimum altitude within 2 nm radius of downtown Nashville and 100 m minimum altitude within a 2 to 80 nm radius of downtown Nashville. The detailed flight tracks and altitudes for the ARL operations were selected to integrate fully with the daily SOS program and are presented in an expanded format in Appendix A: Daily Flight Operations.

3.3 Daily Ground Operations

Planning and coordinating the activities for a particular day commenced early in the morning a day in advance. The mentors, sponsors, and project scientists mapped a strategy for the missions of the next day premised by the forecast. They reviewed (debriefed) the flight activities of the previous day and further refined the plan for that day (which had been planned in detail during the meeting a day prior) supported by an update in local/regional weather conditions. Principal investigators (mission scientists), associated with each aircraft, provided flight plans for the following day to a project coordinator by mid-afternoon each day. The organized plans were then submitted to the FAA for approval and inclusion in scheduling. Meanwhile, the research flight for the day had commenced.

The start of flight operations was predicated on the scheduled take-off time of the aircraft. A late afternoon briefing of the aircraft operations personnel by the mission scientist assured a coordinated effort early the next morning and a research flight departure as scheduled. Preparation of the aircraft and research instrumentation for the flight(s) of the day normally consumed three hours of time. During this period preceding the scheduled take-off, a ground power unit was engaged to power all instruments for warmup and stabilization prior to calibrations. Meanwhile, supplies necessary for the flight were replenished, sensors were cleaned as necessary, and the data acquisition system and state variable sensors were placed in operation and checked. In addition, the ground and airborne GPS systems were powered and checked for proper data acquisition. As the calibrations were being completed, the flight crew received a final pre-flight briefing by the mission scientist and prepared for takeoff.

Immediately following the flight, a series of recovery activities began. After a short debriefing, ground operations personnel attended to the aircraft requirements, such as fuel and/or maintenance and hangaring. Ground-based computer systems began processing the research data acquired by the onboard computers. The canisters used for in-situ air sampling were sent for analysis, then cleaned, purged, and recycled into the sampling program. Additionally, necessary repairs or maintenance to the research instruments were accomplished.

4. INSTRUMENTATION

The instrumentation deployed on the aircraft are described in detail in the following four sections. Leading into the instrument (sensor) descriptions are Table 1, a list of all variables recorded aboard the Twin Otter, and Figure 1, line drawings showing the interior and exterior instrument/sensor locations.

Table 1. Data recorded aboard the NOAA Twin Otter for SOS 1995.

Measurement	Units	Accuracy
Time	HHMMSS	±0.5 second
GPS Time	ms	±2 μs
Temperature	°C	±0.25°C plus 0.5% of the temperature in °C.
Dew point	°C	±0.25°C at +50 °C; ±1.0 °C at -75 °C
Static Pressure	mb	<±0.30% FS
Dynamic Pressure	mb	±0.30% FS
Cabin Pressure	mb	±0.75% FS
Solar radiation	$W\ m^{-2}$	±5.0%
Radar Altimeter	ft	±5%
Net Radiometers (#1 & #2)	$W\ m^{-2}$	NA
Upward PAR	$\mu Es^{-1}m^{-2}$	±5%*
Downward PAR	$\mu Es^{-1}m^{-2}$	±5%*
Li-Cor CO_2	$\mu mol\ mol^{-1}$	±1 ppm at 350 ppm(<3ppm max); ±2 ppm at 1000 ppm (<6ppm max)
Li-Cor H_2O	$mmol\ mol^{-1}$	±1% of reading; at lower vapor pressure, <1% of reading
Surface Temperature	°C	±0.5 °C
TECO SO_2	ppb	~±15%
TECO O_3	ppb	~±5%
TECO CO	ppm	~±10%
TECO CO & SO2 Status Sig	mV	±5 mV
TECO NO_x	ppb	~±40% (NO_x) ,±15% (NO) ,±20% (NO_y)
NO_x Status	mV	±5 mV
NO_x Pressure	torr	±2 torr
NO_x Photocell Pressure	torr	±2 torr
Hydrocarbon Canister Flow	mV	±5 mV
Pressure Cone (also used for cabin pressure on later flights)	mb	<±0.30% FS
Dew Point Control Voltage	mV	±5 mV
Fast Delta X pressure	mb	±0.38% FS (-55°C to +71°C)

Fast Delta Y pressure	mb	±0.32% FS (-55°C to +71°C)
Fast Delta Z pressure	mb	±0.32% FS (-55°C to +71°C)
Fast MFP Static Pressure	mb	±0.14% FS (-20°C to +50°C)
IRGA CO_2 (#1 & #2)	mg m^{-3}	±300 μg m^{-3} (Noise Level - Not Accuracy)
IRGA H_2O (#1 & #2)	mg m^{-3}	±10 mg m^{-3} (Noise Level - Not Accuracy)
Fast Temperature	°C	±0.1% FS
Fast O_3 (#1 & #2)	ppb	NA
GPS TANS Latitude	deg	±100 m
GPS TANS Longitude	deg	±100 m
GPS TANS Altitude	m	±140 m
GPS TANS East-North-Up Velocities	m s^{-1}	±0.5 m s^{-1}
GPS TANS Position Time-of-Fix (TOF)	s	±0.5 s
GPS TANS Velocity TOF	s	±0.5 s
GPS TANS Euler Time-of-Solution (TOS)	s	±0.5 s
GPS TANS Roll	deg	±0.15 deg
GPS TANS Pitch	deg	±0.15 deg
GPS TANS Azimuth	deg	±0.08 deg
Novatel GPS Data Stream	NA	NA (see description in section 4.2.2)
!True Air Speed	m s^{-1}	±5%
!Wind direction	deg	±15%
!Wind speed	m s^{-1}	±15%

* for angles < 80° from normal incidence ! Calculated FS is full scale

The accuracies listed in Table 1 for temperature, dew point, pressure, and solar radiation are based on the manufacturer's specifications.

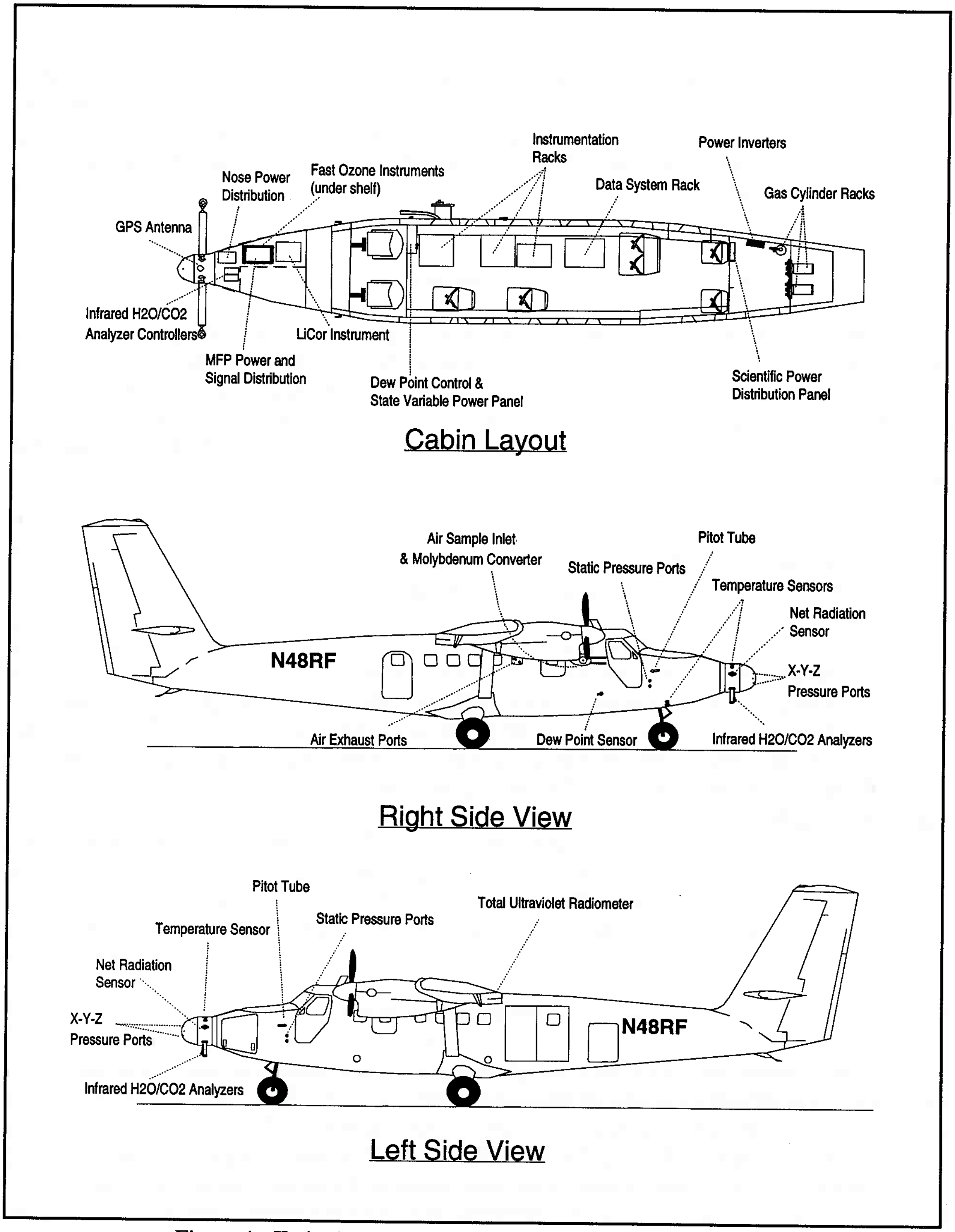


Figure 1. Twin Otter views with instrumentation placements.

4.1 State Variable Systems

The following subsections describe the instrumentation used to collect information on the basic state of the atmosphere during SOS 1995. Additionally, the data are of importance for corrections to data from other systems. When applicable, the description includes the principle of operation, specifications, and calibration information. The approximate mounting positions of the sensors are shown in Figure 1.

4.1.1 Total temperature sensor

The Rosemount Model 102AU1AF sensor is an hermetically sealed platinum resistance sensing element which provides a measurement of total air temperature. For stability and protection, the sealed element is surrounded by a gold-platinum-alloy radiation shield, which, in turn, is surrounded by a stainless steel shield. Through signal conditioning, the resistance is converted to a linear output voltage, which is proportional to total temperature according to the algorithm in Table 2.

<u>Specifications</u>

Range: +40° to -60°C

Time Constant: ~ 1.9 $\pm$ 0.6 sec (speed of flight dependent)

<u>Calibration</u>

Calibration in the field is not required. Intercomparison calibrations are performed using an additional temperature probe on the Boulder Atmospheric Observatory (BAO) tower. A calibration was performed on 24 April 1986. A tower flyby on 13 April 1990 showed that recalibration was not necessary. Daily check measurements of temperature and dew point were made with an aspirated pyschrometer. This was used as a basic check that the instruments were in working order, not as a calibration.

<u>Operational procedures</u>

The instrument was permanently installed low on the right side fuselage STA 54.4, and wired into the aircraft systems. When the scientific power was enabled on the aircraft, the sensor and signal conditioner were operational. Connection of the system output to the data acquisition system occurred before the field study. There are no operational considerations.

4.1.2 Dew point hygrometer

A continuous flow of air directed through the General Eastern Model 1011B dew point hygrometer sensing chamber contacts a thermoelectrically cooled mirrored surface. The presence of condensation is sensed optically and electronics maintain the condensate surface in vapor pressure equilibrium with the surrounding gas. When the dew on the mirrored surface is a constant thickness, in equilibrium with the partial pressure of the water vapor in the air sample, the rate of condensate equals the evaporation. At this point, the temperature of the mirror equals the dew point temperature.

The conditioned output voltage is proportional to the dew point temperature according to the algorithm in Table 2.

Specifications

Range: -75° to +50°C nominal

Time Response: 1°C sec^{-1} typical

Calibration

A standard calibration was performed on the instrument in March 1992. System balance checks were performed during the project to assure correctness of the instrument. Daily measurements of temperature and dew point were made with an aspirated pyschrometer. This was used as a basic check that the instruments were in working order, not as a calibration.

Operational procedures

The dew point hygrometer system, with sensor permanently mounted low on the aircraft right fuselage at STA 110, was powered and allowed a warm-up/stabilization of at least 30 min. prior to an operational ground check via the aspirated psychrometer. After takeoff, often while enroute to the research area, the dew point system was placed in the balance mode, allowing the control circuitry to electrically compensate for the optical effects of accumulated contamination on the optical surfaces. The function switch was then returned to dew point mode for sensing and data collection.

4.1.3 Static pressure transducer

The Rosemount Model 1201F2A14A1A Pressure Transducer consists of a precision capacitance pressure-sensing capsule with electronic signal conditioning. It senses the ambient air pressure through a static pressure port mounted on the skin of the aircraft cabin. Conversion from pounds per square inch absolute (psia) to millibars is through the algorithm given in Table 2.

Specifications

Range: 0 to 15 psia

Static Error: ± 0.10% FSP max.

Resolution: Continuous

Operating Accuracy: ±0.30% FSP

Calibration

None is required in the field. An audit of the instrument performance was conducted during the BAO tower flyby 13 April 1990; no adjustment was necessary. A calibration with reference to a dead weight piston gauge was performed June 1992. On June 23, 1995, an airborne test of the pressure system was conducted using a trailing cone and reference pressure transducer. A box pattern was flown at several altitudes and constant airspeed. Straight flight at constant airspeed "ramped" from 90 to 130 knots (indicated airspeed) was also performed. Data are being processed and analyzed to determine what correction factor, if any, would be employed for static pressure correction. A check of the transducer is made before each flight using an aneroid barometer which has a National Institute of Standards and Technology

(NIST) traceable calibration.

Operational procedures

The instrument, tubing and static port were permanently mounted on the aircraft fuselage and wired into the aircraft system. When the scientific power was enabled in the aircraft, the instrument was powered. The instrument output voltage was connected to the data acquisition system before the field study. There is no additional operation required.

4.1.4 Dynamic pressure transducer

The Rosemount Model 1221F2VL7B B is a precision capacitive pressure sensing module with electronic signal conditioning in a shielded housing designed for measurement of very low differential pressures in airborne environments. The sensing module is comprised of a diaphragm mounted between two fixed symmetrical and contoured capacitor plates. This very linear transducer measures the pressure differential between the static pressure port and the pitot tube (total pressure). The output is a voltage which is converted to millibars by the algorithm given in Table 2.

Specifications

Range: ±1 pound per square inch differential (psid)

Static Error Band: ± 0.12% FSP max.

Resolution: Continuous

Operating Accuracy: ±0.30% FSP

Response Time: 10ms max. at 1 atmosphere reference pressure

Calibration

Calibration in the field is not necessary. The latest calibration was performed by the manufacturer in May, 1995. The instrument was purchased new and installed for this program.

Operational procedures

The transducer was permanently installed and wired into the aircraft system such that when scientific power was energized the instrument was operating. The instrument output was tested and connected to the data acquisition system before the field study. There are no inflight operations.

4.1.5 Cabin pressure sensor

An Omega Engineering, Inc., Model PX142 solid state piezoresistive pressure transducer was utilized to provide data on pressure fluctuations in the cabin environment while in flight. A very small (0.10 in sq) silicone chip with integral precision resistors forms the sensing diaphragm. A change of pressure on the diaphragm causes it to flex and results in a change in the resistance values. The resistance changes yield an output voltage proportional to pressure. The hybrid integrated circuit device is compact, rugged, reliable, and inexpensive. Additionally, it provides integrated temperature compensation and requires no adjustment or recalibration.

Specifications

Range: 0-15 psia

Linearity: $\pm$ 0.50 %FSO typical

Repeatability and Hysteresis: $\pm$ 0.15 %FSO typical

Response Time: 1 ms max.

Calibration

None required.

Operational Procedures

The sensor was mounted in a remote location, within the data acquisition system rack, in the aircraft cabin. The device was operationally checked prior to flight by comparison to the static pressure system.

4.1.6 Total ultraviolet radiometer

The Eppley Laboratory, Inc., Model Total ultraviolet radiometer (TUVR) utilizes a selenium barrier-layer photoelectric cell protected by a quartz window. A narrow bandpass (interference) filter limits the spectral response to the desired wavelength interval. In addition, a teflon diffusing disk reduces the radiant flux to the photocell and ensures close compliance of the instrument response to the Lambert cosine law. The above components are housed in a weatherproofed brass tube. The microamp output current of the cell passes through a precision resistor, resulting in a measurable signal voltage.

Specifications

Spectral Response: 290-385 nm

Relative Output: 1.36 mV/mW cm^{-2}

Relative Linearity: $<\pm 2\%$ over normal operating range

Calibration

Calibration in the field is not required. Calibration by the manufacturer, prior to installation on the aircraft, was by exposure of the TUVR to a NIST standard spectral irradiance in March, 1995.

Operational Procedures

The instrument was mounted upward facing on the aircraft, above the cabin center, and well above the outer (black) surface of the fuselage. There is no power required to operate the TUVR; the output signal is simply connected to the data acquisition system. A daily inspection and a routine cleaning of the diffusing disk were accomplished.

4.1.7 Radar altimeter

Data from the aircraft radar altimeter, Sperry Instruments, Inc., Model RT220, were recorded for consideration during analyses of flux/flux divergence measurements. Flight tracks were flown at constant pressure altitude, as closely as possible, with the exception of low level 500 ft. AGL tracks, during which the flight crew depend on the radar altimeter. Due to the dependence on "height of measurement above vegetation", vertical turbulent flux explorations benefit from the radar altitude data. The range of the altimeter was 0 to 3000 ft.

4.2 Mobile Flux Platform (MFP) Systems

The MFP system is a group of instruments designed to collect data relevant to turbulent fluxes of key atmospheric constituents from a generic moving platform. Determining fluxes requires precise high frequency (10-100 Hz) measurement of the three dimensional wind vector and the atmospheric constituents of interest. In the case of the Twin Otter, the relative wind vector is determined by a pressure sphere anemometer integrated into the radome of the aircraft. Conversion from relative wind to absolute wind requires first expressing the relative wind vector in earth coordinates and then adding the velocity vector of the radome, which is already in earth coordinates, to the relative wind. Determination of aircraft attitude and velocity has traditionally been derived from inertial navigation systems, but in this more streamlined approach, they are determined by (GPS) techniques. The nose-mounted instruments required for the MFP system, shown in Figure 1, are described below.

4.2.1 Attitude Global Positioning System (GPS)

The Trimble TANS Vector GPS system uses four GPS antennas with their relative positions determined to sub-centimeter accuracy. System attitude is then determined to about three milliradian accuracy. Position and velocity accuracy is standard GPS accuracy (see Table 1). The TANS position and velocity data are not used for MFP calculations, but are used for calculating real-time horizontal winds on board the aircraft by the primary data system.

<u>Specifications</u>

Response: 4 Hz to 12 Hz

Accuracy: See text paragraph above

<u>Calibration</u>

The only calibration required is the initial determination of antenna positions.

<u>Operational Procedures</u>

The TANS Vector GPS system is set up to be powered whenever scientific power is on. Once powered, the system will acquire satellites, collect the necessary satellite information and begin computing position fixes. The installation data set is checked to ensure that it is valid. If valid, the system begins to process data to resolve the integer ambiguities between the antennas. The integers are then tracked by the system and attitude values are computed and output to the data acquisition system.

4.2.2 Position and velocity GPS system

The Novatel GPS Card 3951 system is an ISA-bus card, GPS antenna, and antenna cable. The system is capable of high speed (20 Hz) determinations of pseudo-ranges from GPS satellites. These data are corrected during post-mission processing with pseudo-ranges measured by a stationary ground station, taken in our case, with another Novatel 3951. Resulting "differentially corrected" accuracy is 1-5 m for position, and 2-3 cm s^{-1} for velocity. Post-processing is performed with C3NAV software, available from University Technologies International, Inc.

Specifications

Response: 20 Hz

Accuracy: See text paragraph above.

Calibration

No calibration is required.

Operational Procedures

Once the Data Acquisition System (DAS) has been powered, the Novatel GPS card will start acquiring pseudo-ranges. Pseudo-ranges are determined from as many as 12 GPS satellites simultaneously. The data are not recorded until the DAS software has been loaded and is running.

4.2.3 Fast response static pressure transducer

The Rosemount Model 1201F1B6A1A Pressure Transducer consists of a precision capacitance pressure-sensing capsule with electronic signal conditioning. The quartz diaphragm sensor material in the transducer provides stable, highly repeatable outputs with low hysteresis, continuous resolution, excellent linearity and outstanding over-pressure capability.

Specifications

Response: 66 Hz

Range: 600 to 1100 mb

Accuracy: ± 0.14% full scale (-20 °C to +50 °C).

Output: 0 to 5 volts

Calibration

Re-calibration in the field is not necessary. The factory calibration is

P(mb)= (volts*100.0) + 600

Operational procedures

The instrument, tubing and port are permanently mounted in the MFP nose cone and wired into the MFP power system. When the MFP power was enabled in the aircraft, the instrument was powered. The instrument output voltage was connected to the data acquisition system before the field study. There is no additional operation required.

4.2.4 Fast response delta Y and Z pressure transducers

The Rosemount Model 1221F2VL3A1A Pressure Transducers sense differential pressure with a precision capacitive sensing capsule and solid state signal conditioning electronics. The unique construction of the capacitor plates and interposed sensing diaphragm in the transducer provides stable, highly repeatable outputs with low hysteresis, continuous resolution, excellent linearity and outstanding over-pressure capability.

Specifications

Response: 100 Hz
Range: ± 17 mb
Accuracy: 0.32% full scale (-55 °C to +71 °C)
Output: ±5 volts

Calibration

Re-calibration in the field is not necessary. The factory calibration is

P(mb)= (volts*3.447)

Operational Procedures

The instruments, tubing and ports are permanently mounted in the MFP nose cone and wired into the MFP power system. When the MFP power was enabled in the aircraft, the instruments were powered. The instruments output voltages were connected to the data acquisition system before the field study. There is no additional operation required.

4.2.5 Fast response delta X pressure transducer

The Rosemount Model 1221F2VL17A1A Pressure Transducers sense differential pressure with a precision capacitive sensing capsule and solid state signal conditioning electronics. The unique construction of the capacitor plates and interposed sensing diaphragm in the transducer provides stable, highly repeatable outputs with low hysteresis, continuous resolution, excellent linearity and outstanding over-pressure capability.

Specifications

Response: 100 Hz
Range: ±52 mb
Accuracy: 0.38% full scale (-55 °C to +71 °C)
Output: ± 5 volts

Calibration

Re-calibration in the field is not necessary. The factory calibration is

P(mb)= (volts*10.34)

Operational Procedures

The instruments, tubing and ports are permanently mounted in the MFP nose cone and wired into the MFP power system. When the MFP power was enabled in the aircraft, the instruments were powered. The instruments output voltages were connected to the data acquisition system before the field study. There is no additional operation required.

4.2.6 Fast response H_2O/CO_2 gas analyzer

The fast response H_2O/CO_2 gas analyzers (IRGAs) are open-path infrared absorption spectrometers designed and constructed at the Atmospheric Turbulence and Diffusion Division (ATDD) of the Air Resources Laboratory (ARL). The output responds non-linearly to H_2O and CO_2 gas density. Specially designed vibration/isolation mounts are used to minimize vibration-induced signal noise.

Specifications

Output: ±12 V maximum
Response: 20 Hz
H_2O noise: 10 mg m^{-3}
CO_2 noise: 300 μg m^{-3}
H_2O range: Adjustable, nominally 0 to 40 mg m^{-3} for ± 5 V output
CO_2 range: Adjustable, nominally 200 to 500 μg m^{-3} for ± 5 V output
Power: 9 to 36 V, 3 A

Calibration

Laboratory H_2O calibrations are performed by using a cylinder of dry air and a water bubbler, a mixing system, and a chilled mirror hygrometer. Varying mixtures of dry and saturated air, corresponding to dew points ranging from -15 to +20 °C, are pumped into the calibration hood. Absolute humidity is calculated from the dew point, pressure, and temperature measurements. A second-order polynomial is fit to the H_2O voltage output of the IRGA vs. an absolute humidity curve. Due to the complexity and length of time required for this method of calibration, field calibrations are performed using the in-flight data of the on-board chilled mirror, temperature, and pressure to regress with the IRGA H_2O output.

In-lab CO_2 calibrations are performed by covering the instrument with a calibration hood, sealing the hood to the instrument base using vinyl (electrical) tape, and pumping standard calibration mixtures (i.e., Airco or Scott Specialty Gases) of CO_2 into the hood. Typically, concentrations of 330 and 370 ppm are used. The temperature and pressure of the calibration gas inside the hood must be measured to obtain gas density (mg m^{-3}) from the tank concentration (ppm). Ambient pressure may be used if the gas flowrate is low or zero. A large flow rate (2-4 liter min^{-1}) is used to purge the calibration hood (approximately 2 minutes or until a stable CO_2 output is reached), then reduced to <0.5 liter min^{-1} or zero and readings of gas temperature, pressure and CO_2 output are taken.

Field calibrations are performed daily using standard concentration tanks that have been verified with the lab standards. The portable calibration hood has a temperature sensor in the base, and a rubber sleeve that fits snugly over the instrument. Ambient pressure values are used in the calculations.

To convert ppm rating of calibration gasses to mg m^{-3}:

$$\rho = X * C * \frac{273.16}{T} * \frac{P}{1013.25}$$

where ρ = density of calibration gas(mg m^{-3})

X = CO_2 concentration rating of the calibration gas(ppm)
T = temperature of mixture inside calibration hood(K)
P = ambient pressure(mb)
C = 1.964 mg ppm^{-1}

To convert dew point (T_d) to mg m^{-3} of H_2O

$$\rho = \frac{(e * 100000)}{(461 * (T_a + 273.16))}$$

where ρ = density of calibration gas(g m^{-3})
T_a = ambient temperature in °C
e(mb) = vapor pressure = $6.108 * 10^{[(7.5 * Td)/(Td + 237)]}$
where Td = dew point temperature °C

Operational Procedures

The IRGA instruments were warmed up for a short period (5 min.) and calibrated before each flight (see calibration section). The IRGA instruments were left powered until after the flight.

4.2.7 Fast response temperature transducer

The VECO #31A401A fast response temperature sensor is a custom sensing element and electronics developed at ATDD mounted in a Rosemount fast response total temperature housing. The sensor is a micro-bead, with a time response of 0.1 s in still air.

Specifications

Response: 10 Hz minimum
Range: ±10 °C from ambient
Accuracy: 0.1% full scale
Output: ±5 volts

Calibration

Calibrations are accomplished using in-flight data from a slower response reference temperature sensor.

T (°C) = (Volts * -2.2) + 27.3

Operational Procedures

The instrument is permanently mounted in the MFP nose cone and wired into the MFP power system. When the MFP power was enabled in the aircraft, the instrument was powered. The instrument output voltage was connected to the data acquisition system before the field study. There is no additional operation required.

4.2.8 Fast response dual-channel ozone sensor

The fast response dual-channel ozone sensor is a custom, chemiluminescent, dry disk system (Coumarin solution) designed and constructed at ATDD. Sample air is drawn through the system, and the ozone in the air reacts with the Coumarin, producing light in proportion to the ozone concentration.

Specifications

Input: 11-16 V DC, 1.5 A maximum

Output: ± 12 V maximum (scalable to any lower range, positive only possible with offset adjustment)

Calibration

Calibrations are completed using in-flight data from a slower responding reference ozone sensor. Calibrations vary with flight conditions due to the sensitivity of the fast response ozone instrument; therefore, there exists a table of accurate sensitivities and offset values based on time of flight.

O_3 (ppb) = (Volts * sensitivity) + offset,

where sensitivity and offset are time dependent

Operational Procedures

The ozone instruments were powered at the same time the aircraft was powered, then calibrated before each flight (see calibration section). The ozone instruments were left powered until after the flight.

4.2.9 Slow response H_2O/CO_2 gas analyzer

The Li-Cor model LI-6262 is a differential, non-dispersive, infrared (IR) gas analyzer. Measurements of CO_2 and H_2O are based on the difference in absorption of IR radiation passing through two gas-sampling cells. The reference cell is used for a gas of known CO_2 or H_2O concentration, and the sample cell is used for the gas of unknown concentration. IR radiation is transmitted through both cells, and the linearized output is based on the non-linear absorption of IR in the cells.

Specifications

H_2O:

Range: 0 - 75 mb or 40 °C dewpoint

Accuracy: 1% of reading; at lower vapor pressure, <1% of reading

Zero drift:: <0.5 mb in 24 hours from 10-40 °C

Span drift: <1% in 24 hours from 10-40 °C

CO_2:

Range: 0 - 3000 ppm

Accuracy: ± 1 ppm at 350 ppm (<3 ppm max); ±2 ppm at 1000 ppm (<6 ppm max)
Zero drift (over time): first hour - <5 ppm at 25 °C; after first hour - <1ppm at 25 °C
Zero drift (with temperature): 0.12 ppm $°C^{-1}$ typical, 0.45 ppm $°C^{-1}$ max
Span drift: typically < 1ppm in 24 hours at 25 °C and 350 ppm (absolute mode)

Calibration

Initially, there are factory linearizations over 0-1000 and 0-3000 ppm ranges using NIST-traceable standard gases. Daily in-field calibrations were performed by passing known CO_2 concentrations (high and low values) through the instrument. H_2O calibrations were not performed since the H_2O measurements were not to be used.

$$CO_2(\mu mol\ mol^{-1}) = (volts * 30) + 350$$
$$H_2O(mmol\ mol^{-1}) = (volts * 8) + 20$$

Operational Procedures

The LI-6262 instrument was powered upon application of ground power to the aircraft and calibrated before each flight (see calibration section). The LI-6262 instrument was left powered until after the flight.

4.2.10 Net radiometers

The REBS model Q*7 net radiometers use a differential thermopile to respond to the difference between incoming and outgoing total hemispherical solar radiation.

Specifications

Spectral response: 0.25 to 60 μm
Time constant: approx. 30 sec
Wind affect positive: up to 5.9% reduction at 7 m s^{-1}; negative: up to 1% reduction at 7 m s^{-1}

Calibration

The factory calibration for the radiometers was used in combination with the amplifier calibration.

$$Rn\ (W\ m^{-2}) = (volts * 180.33) + 1.08 \qquad (Net1).$$
$$Rn\ (W\ m^{-2}) = (volts * 180.9) + 1.27 \qquad (Net2).$$

Operational Procedures

The instruments are permanently mounted on booms attached to the MFP nose cone and wired into the MFP power system. When the MFP power was enabled in the aircraft, the instruments were powered. The instruments output voltages were connected to the data acquisition system before the field study. There is no additional operation required.

4.2.11 Quantum sensor

The Li-Cor model LI-190SB uses a silicon photodiode to measure solar radiation received from 180° field of view. This particular model of sensor measures photosynthetically active radiation (PAR) which is defined as radiation in the 400 to 700 nm waveband. PAR is the general radiation term which covers both photon and energy terms.

Specifications

Sensitivity: 5 mV per 1000 μEinsteins s^{-1} m^{-2}

Response: > 1000 Hz

Calibration

The factory calibration was used.

R (μEinsteins s^{-1} m^{-2}) = (volts * 200000) (PAR1)

R (μEinsteins s^{-1} m^{-2}) = (volts * 200000) (PAR2)

Operational Procedures

The instrument is permanently mounted in the MFP nose cone and wired into the MFP power system. When the MFP power was enabled in the aircraft, the instrument was powered. The instrument output voltage was connected to the data acquisition system before the field study. There is no additional operation required.

4.3 Standard Atmospheric Chemistry Instrumentation

An assembly of continuous trace gas analyzers and an non-methane hydrocarbons (NMHC) cylinder sampling system, all utilizing a single high-flow sample air inlet system, were mounted in the cabin of the research aircraft (Figure 1) and are described in the following sections.

4.3.1 Inlet system

A ram air inlet configuration employing a forward-facing inlet system was used to duct ambient air into the Twin Otter cabin for trace gas sampling. The inlet system consisted of a 90 cm length of 0.953 cm OD PFA Teflon tubing which protruded approximately 15 cm beyond the fuselage surface. This Teflon tubing was catheterized inside a reinforced-composite, forward facing inlet mounted on a composite blank covering the forward-most window on the starboard side of the aircraft, and the tubing terminated just aft of the co-pilot's door (see Figure 1). The tip of the inlet was 336 cm behind the tip of the extended nose of the Twin Otter, at STA 105. This position was judged to be most free of potential sources of contamination, and was forward of both the engine exhaust and the propeller line (STA 124.5). Protrusion 15 cm beyond the fuselage ensures the sampling of air uninfluenced by the skin of the aircraft.

The length of 0.953 cm OD tubing terminated a few cm inside the cabin, and was mated, with Teflon fittings (Galtek fittings, Fluoroware, Inc., Chaska, MN), to a longer section of 1.27 cm OD

PFA Teflon tubing which acted as the main sampling manifold. The overall length of the manifold as configured for SOS was approximately 213 cm. Sections of 0.635 cm OD PFA tubing branched at various points off the main manifold and acted as the inlet systems for the individual trace gas detectors. Each of these smaller inlets was filtered with 47 mm diameter PTFE Teflon filter membranes (see below). Air which remained unsampled by the individual detectors passed through the manifold system and was exhausted on a starboard-side window blank (STA 190).

The short 0.953 cm OD inlet tubing was changed on June 29 and July 14 to maintain the purity and cleanliness of the sampling path. Both the inlet tip and manifold exhaust port were capped at all times when the aircraft was not in flight. On flight SOS15, July 15, 1995, the air flow through the inlet was tested by injecting calibration gases (NO, CO, and SO_2) at a known flow rate through 0.318 cm OD Teflon tubing inserted into the tip of the main inlet. This test, in effect, constituted a standard addition for each instrument examined, and the measured instrument response was used, along with the calibration gas concentration and flow rate, to calculate the volume flow rate through the main manifold. Preliminary results suggest a manifold flow rate of approximately 60 liters per minute. In addition, the instrument response and lag times could be determined by comparing the timing of the calibration gas injection to the instrument rise and fall times.

4.3.2 Reactive nitrogen (NO, NOx, NOy)

Reactive nitrogen compounds were measured with a Thermo Environmental Instruments (Franklin, MA) Model 14 B/E chemiluminescence detector which had been modified for enhanced sensitivity [e.g. Delany et al., 1982; Dickerson et al., 1984]. The instrument uses a photomultiplier tube (PMT) to measure the light intensity resulting from the reaction of ozone, generated within the instrument from a small flow of compressed O_2, with NO contained in the ambient sample flow. Since the photons are emitted by excited NO_2^* in a broad band from 0.6 to over 3 microns (near infra-red and infra-red [IR]), electronic noise arising from thermally excited electrons in the PMT can seriously limit the detection of low levels of NO. For this reason, the PMT must be cooled; the 14B/E uses a Peltier junction to keep the PMT at approximately -30°C, depending upon ambient temperature. As discussed below, the lack of a climate control system in the Twin Otter led to a significant baseline drift in the detector, with an attendant degradation in performance.

Modifications performed on the instrument to enhance its sensitivity and response time are described in Delany et al.[1982] and Dickerson et al. [1984]. In addition to the modifications described in the above references, the manufacturer's ozonizer electrodes were replaced with a more sophisticated ozone generator using a ceramic dielectric (Eco-Physics, Durnten, Switzerland). The ozone production rate of the electrode assembly was determined to be 3.5% O_3 (v/v) in a flow of approximately 100 standard cubic centimeters per minute (sccm) O_2. Compressed oxygen (ultra-high purity grade, Air Products, Pittsburgh, PA), controlled at a flow rate of approximately 120 sccm with a Tylan Çorp. (Torrance, CA) mass flow controller (MFC) (S/N AA207391, 0-200 sccm), was used to maximize ozone production and hence sensitivity. A small O_2 cylinder carried aboard the Twin Otter was periodically recharged from a larger cylinder of O_2 between flights. The reaction chamber was equipped with two pressure gauges: a 0 to -30 psig gauge supplied by the manufacturer, and an Omega (Stamford, CT) series PX176 absolute pressure transducer. The 1-6 VDC output was recorded at 1 Hz by the Twin Otter's Data Acquisition System (DAS).

The ozone chemiluminescence technique is specific for nitric oxide; detection of higher oxides of nitrogen must be accomplished by first converting these species to NO. A 300W Xe arc lamp (Cermax LX-300, ILC Technology, Inc., Sunnyvale, CA) controlled by a switching power supply (PS300-SW1) was used to photolyze NO_2 to NO, and thus provide a measure of NOx [e.g., Kley and McFarland, 1980]. A beam splitter (Model HT-500-S, Corion Corp., Holliston, MA) oriented 45° to the both the lamp face and photolysis cell reflected the visible and near-UV radiation responsible for NO_2 photolysis into the 275 cm^3 pyrex vessel, through which the sample flow passed at approximately 1 standard liter per minute (slm) under reduced pressure (approximately 300 torr). The photolysis cell was equipped with an Omega series PX176 absolute pressure transducer. The 1-6 VDC output was recorded at 1 Hz by the DAS to allow calculation of residence time within the cell, assuming ambient temperature. A cell volume of 275 cm^3, typical cell pressures of approximately 300 torr, ambient temperatures of 30°C, and flow rate of 1 slm yield a residence time of approximately 6 s within the cell. Conversion efficiency of the photolysis cell was determined with a certified NO_2 permeation wafer (VICI Metronics, Santa Clara, CA; wafer certified at 48.7 ng NO_2/min at 30.0°C). The wafer was contained in a thermostated, insulated housing at 30.0°C and continually flushed with a 10 cm^3 min^{-1} flow of compressed N_2. Photolytic NO_2 conversion efficiencies were approximately 30%. An electrically actuated shutter assembly (Model 150-40, Bencher, Inc., Wood Dale, IL) allowed the lamp radiation to be blocked; passage of the sample flow through the non-illuminated photolysis cell allowed an alternative measure of NO.

It is important to note that the photolytic converter may respond to thermally and photolytically labile compounds such as PAN, HO_2NO_2, N_2O_5, and NO_3. However, the use of the beam splitter to shield the photolysis cell from the considerable IR output of the lamp maintained the photolysis cell near ambient temperature, avoiding the thermal decomposition of PAN and HO_2NO_2. In the polluted urban environment PAN and peroxynitric acid may be present at significant concentrations and may thus pose an artifact problem for the photolytic converter. Dinitrogen pentoxide (N_2O_5) and nitrate radical, NO_3, are both easily photolyzed by solar radiation, and are not present to an appreciable degree during the daytime. Further tests will be conducted in the future to characterize the response of the photolysis cell to potential interferences.

To reduce NOy species to NO, we used a heated molybdenum converter [Dickerson et al., 1984; Fehsenfeld et al., 1987] (NOy = NO + NO_2 + NO_3 + HONO + HNO_3 + HO_2NO_2 + 2*N_2O_5 + PAN + R-ONOx + fine p-NO_3^-.) The molybdenum converter used in SOS was essentially a commercial converter (Thermo Environmental Instruments Model 42S NO/NOx detector), in which the heated molybdenum is contained within a stainless steel housing equipped with a band heater. The inlet system exposed to ambient air was composed of a short (5 cm) length of Pyrex tubing to minimize surface adsorption of HNO_3 and similar "sticky" NO_y compounds. The mating of the Pyrex inlet and stainless converter housing was accomplished through a stainless Swagelok (Crawford Fitting Co., Solon, OH) fitting . The elevated temperatures of both the transition fitting and the stainless steel converter housing minimizes surface losses of HNO_3. Neither zero air flushes of the converter (see below) nor sharp transitions from polluted to clean air (e.g., upon entering the clean free troposphere (FT) from the more polluted planetary boundary layer (PBL)) produced significant response hysteresis.

The heated converter was housed in an insulated aluminum canister, approximately 12.7 cm in diameter and 43 cm in overall length. The converter housing protruded 20-25 cm through a streamlined faring above the surface of the composite window blank which contained the main sampling inlet. The tip of the Pyrex inlet protruded approximately 4 cm above the top of the cylinder, and thus approximately 28 cm above the fuselage surface. The inlet was positioned in a rear-facing configuration to avoid the sampling of coarse aerosols and cloud droplets. Thus, only fine particles were likely aspirated into the molybdenum converter and measured as NOy. The converter was heated to 350°C using a Newport Electronics (Santa Ana, CA) Model 81 PID controller (the manufacturer's temperature control circuit was removed). At a temperature of 350°C conversion of PAN, NO_2, and HNO_3 is virtually quantitative, while conversion of RONOx is roughly 90-100% efficient [e.g., Fehsenfeld et al., 1987; Nunnermacker, 1990]. Conversion of N_2O, HCN, CH_3CN, RNOx, and NH_3 at this temperature is insignificant [Winer et al., 1974; Dickerson et al., 1984; Fehsenfeld et al., 1987; Nunnermacker, 1990]. A 60μ sintered stainless steel filter (Model SS-4F-60, NUPRO Co., Willoughby, OH) was positioned immediately downstream of the converter to prevent any migration of molybdenum [see Fehsenfeld et al., 1987].

The inlet system, for measuring NO and NOx, tapped off the main manifold at a point just inside the cabin. A 24 cm length of 0.635 cm OD PFA Teflon tubing was used to direct the sample air to the instrument. The NO/NOx inlet system was filtered with 2-5μ pore size Zitex brand PTFE filters. This inlet filter was changed immediately before each flight. After July 10, 1995 a 5μ PTFE filter (Z50WP04750, Micron Separations, Inc., Westboro, MA) was used.

Once it entered the instrument proper, the sample flow could be routed through a variety of paths, or modes, by a series of Teflon solenoid valves (Galtek model 203-3414-415, Fluoroware, Inc., Chaska, MN) whose operation was controlled by a Chrontrol process timer (Model XTR4, Chrontrol Corp., San Diego, CA). Ambient air flow was routed either to a stainless steel prereactor, where nitric oxide (NO) reacts with O_3 out of sight of the photomultiplier tube to generate a chemical zero (background mode), directly to the reaction chamber (NO mode), or to the 275 cm^3 pyrex photolysis cell. Actuation of an additional solenoid valve allowed the sample flow to be first pulled through the heated molybdenum converter, which constituted a second, separate inlet system, for the measurement of NOy. An 8-bit D-A converter chip (Analog Devices, AD558) wired into the Chrontrol timer produced a unique analog voltage for each combination of valve configurations (mode). The 0-5 VDC analog signal was recorded at 2 Hz and filtered at 1 Hz intervals by the aircraft DAS. The instrument was typically cycled on each mode for 1-2 minutes, with an entire measurement cycle (BG, NO, NOx, NOy) lasting 4-8 minutes.

Due to the extreme variability of water vapor concentration in the troposphere, it is often desirable to expose the detector to a narrow range of humidities by continually adding a small (ca 100 sccm) flow of humidified compressed air to the inlet [e.g., Luke et al., 1992; Carroll et al., 1985;

Dickerson, 1985; Drummond et al., 1985]. Unfortunately, preparation time prior to SOS did not permit the design and implementation of such a system. The majority of the Twin Otter's flight time was spent in the humid PBL, however, so the absence of a humidity control system was not regarded as serious.

Operation

The NOx detector was typically turned on several hours prior to flight, to allow its Peltier cooler to thoroughly chill the PMT and provide a stable baseline prior to takeoff. A small flow of ultra-pure zero air (Scott-Marrin, Inc., Riverside, CA) was directed over the molybdenum converter at 350°C during instrument warmup, for approximately 2 hours prior to flight. In order to maintain high NOy converter efficiencies, the molybdenum converter was periodically "baked out" for 2 hours at 550°C, under a small flow of ultrapure N_2 (Scott Marrin, Inc.) on June 26 and 28, and July 6 and 14. The conversion efficiency of the molybdenum catalyst was determined immediately before and after the project, and at several times during SOS with the certified NO_2 permeation wafer described above.

Due to their rather large power draws, both the 28 VDC pump motor and the 300W Xe lamp for the photolysis cell were switched on only after engine start and power handoff. The instrument was continually flushed with ultrapure air and/or an NO calibration mixture during rollout, initial climbout, and landing, to prevent contamination in the polluted environment of the Nashville International Airport.

Calibration

The instrument was calibrated frequently during flight using a compressed gas mixture of NO in N_2 (Scott-Marrin, Inc). Reference of our NO standard against a National Institute of Standards and Technology (NIST) Standard Reference Material (SRM: 4.80 ± 0.09 ppmv NO/N_2 balance, SRM #48-12-D) at Brookhaven National Laboratory (BNL) on March 30, 1995 indicated a concentration of NO in the ARL standard to be 1.80 ± 0.06 ppmv.

The preferred calibration method was that of standard addition, in which a small, controlled flow of calibration gas is added to the inlet and thus subjected to the identical sampling matrix experienced by the analyte. This calibration technique thus provides an accurate measure of instrument response under normal operating conditions. However, the background ambient NO, NOx, or NOy concentrations, to which the calibration gas is added, must be relatively invariant in order for the incremental detector response to be accurately quantified. The calibration gas flow was controlled by a Tylan mass flow controller (MFC) (S/N AW9409023, 0-10 sccm), and was typically diluted into a sample flow rate of approximately 1 slm (sample flow was controlled by a Tylan MFC, S/N AA107929, 0-2 slm). Standard addition concentrations of approximately 1.8 to 18 ppbv (parts per 10^9 by volume) were achieved. Matrix replacement (zero-air dilution) calibrations were also routinely performed, by diluting the output of the calibration MFC with a larger flow of zero air (controlled with a Tylan MFC, S/N AA9001201, 0-5 slm). Calibration mixtures of approximately 4-5 ppbv were generated. An MKS (Andover, MA) model 247C MFC readout was used to control the calibration and dilution MFCs, as well as those regulating the sample and oxygen flows into the

NO detector.

The Tylan MFC used to control NO cal gas flow was dedicated to this purpose, and was exposed only to NO calibration gas. Calibration gas flow was initiated and passed through the MFC upon aircraft power up, 2-3 hours prior to takeoff, to ensure adequate equilibration inside the MFC. All calibration gases were added at the detector inlet, upstream of the Teflon filter, to calibrate through the entire sampling system and therefore account for systematic errors induced by irreversible sample losses.

Miscellaneous

The NO detector has three e-folding signal time constants: 0.25, 2, and 20 seconds. For the Southern Oxidants Study, the instrument was operated with a 2-s time response; its analog output signal was sampled at 1 Hz and averaged over 5-s intervals for data processing.

The variation of the NO detector response with pressure was evaluated before and during SOS, on two test flights of the Twin Otter. A constant-concentration NO/zero air calibration mixture was delivered to the instrument during initial test flights in Tampa, FL, as the aircraft ascended from 0-10,000 ft above mean sea level (MSL). This test was repeated June 21 in Nashville (at the start of SOS), at altitudes of 0-5,000 ft MSL. Ambient data collected during SOS were corrected for variations in ambient pressure.

Post-project analysis of the NO detector signal suggests that the lack of a climate control system in the Twin Otter adversely affected the baseline stability of the instrument. Even with a 4-8 minute cycle time, baseline drift was often quite severe, and limited the accuracy with which low NO, NOx, and NOy concentrations may be calculated.

4.3.3 Carbon monoxide

A non-dispersive infrared, gas filter correlation (NDIR/GFC) spectrometer was used to measure carbon monoxide during SOS. The detector, a Thermo Environmental Instruments, Inc. Model 48S, was factory modified for enhanced sensitivity. The instrument measures CO from the absorption of 4.67 micron radiation by a fundamental vibration-rotation band of CO. A heated wire glow bar is used to generate IR and visible radiation. The non-dispersive instrument uses no monochromator to isolate the appropriate wavelengths responsible for CO absorption. Instead, a gas filter chopper wheel, composed of two semicircular shells containing N_2 and a low-pressure mixture of CO, respectively, spins in front of the heated source. When the N_2-filled filter is positioned in front of the source, the IR radiation passes unimpeded into the optical cell, where it is attenuated by ambient CO in the sample flow. When the low pressure CO filter is in front of the source, the IR radiation is absorbed in the wheel, with no further attenuation by CO in the optical cell. The revolution of the gas filter thus produces a modulated signal whose magnitude is proportional to CO concentration.

The signal is corrected for temperature and pressure by internal transducers and a microprocessor to yield a 0-10 VDC output which is proportional to the CO mixing ratio. Some residual pressure dependence of the signal remains, however, and this dependence was determined through extensive in-flight calibrations prior to and during SOS. During SOS the instrument was typically run with a full scale voltage equivalent to 2 ppmv or 2000 ppbv. An updated EEPROM obtained from the manufacturer was used to provide 1 second signal updates, with a running time constant of 10-20 s; the 0-95% rise time of the signal was determined to be approximately 50s. The detection limit of the instrument is approximately 60 ppbv (S:N = 1 at $\pm 2\sigma$ noise) with a 10s time constant; the accuracy of the technique at levels well above the detection limit is approximately ± 10%.

In addition to the factory adjustments to enhance sensitivity (primarily through the use of hand selected, low-noise optical components), modifications were made to the instrument to minimize water vapor interference and baseline drift. Water vapor efficiently absorbs IR radiation and poses an interference to the NDIR technique [Dickerson and Delany, 1988]. For SOS this residual interference was reduced by continually drying the sample airstream prior to detection, using a Nafion dryer membrane (Model PD-625-24AFS, Perma Pure Inc., Toms River, NJ). A flow (ca 1000 cm_3/min) of dry sheath air was generated from a cylinder of compressed ultrapure air (Scott-Marrin, Inc.) and was regulated with an encapsulated porous metal flow restrictor (Mott Metallurgical Corporation, Farmington, CT). Water vapor in the ambient air flow is absorbed by the Nafion tubing and diffuses through the membrane walls, to be carried away in the sheath air flow. Carbon monoxide passes, without loss, through the Nafion dryer and into the detector. Ultimate dew points obtained with the 61 cm Nafion dryer used in SOS were not measured prior to the project.

Baseline drift in the TECO 48S was minimized by regulating the temperature of the optical bench with a high quality temperature controller (Newport Electronics, Model 81 PID controller), and by insulating the bench with a 0.635 cm thick layer of closed-cell foam. The PID temperature controller replaces the factory heater control circuit on the 48S. Temperature-induced baseline drift is not eliminated by this approach, however, and must be carefully monitored during operation, especially when the instrument is subjected to rapid and large changes in ambient temperature on an aircraft sampling platform.

The baseline of the ARL TECO 48S was monitored by oxidizing CO to CO_2 on hot (200°C) Pd/alumina (3.2 mm pellets, catalog number 20,574-5, Aldrich Chemicals, Milwaukee, WI) to generate a chemical zero. The palladium catalyst was contained in a short length of 1.27 cm OD stainless steel tubing housed in an insulated aluminum box and mounted inside the 48S instrument box. The catalyst temperature was regulated with a Newport Electronics Model 81 PID controller and heater. Conversion efficiency of the catalyst was measured before, during, and after the SOS project by frequent span checks and instrument calibrations, and was always found to exceed 99%. A series of internal 3-way valves supplied by the manufacturer were actuated by grounding contact closure terminals on the rear of the instrument, using a Micromaster WP6200 (Minarik Electric Co., Los Angeles, CA) programmable controller. An applied voltage was also modulated by the action of the contact closure, and was recorded by the DAS to provide an indication of instrument mode (zero or measure). The instrument was typically zeroed for 2-3 minutes out of every 6-10 minutes.

4.3.4 Sulfur dioxide

Sulfur dioxide (SO_2) was measured aboard the Twin Otter with a Thermo Environmental Instruments (Franklin, MA) Model 43S pulsed fluorescence (PF) detector. The PF technique is a continuous-flow method based upon the detection of ultraviolet/visible radiation emitted by SO_2 which has been electronically excited at 190-230 nm with a pulsed xenon flash lamp and a series of reflective interference filters. While SO_2 absorbs UV/VIS radiation primarily in three wavelength bands, the strong absorption at 190-230 nm is less susceptible to quenching by O_2, N_2, etc., and is thus selected as the excitation wavelength range of choice [Okabe et al., 1973]. The fluorescent radiation is emitted in a broad band continuum from ca 240-420 nm, with an emission peak at approximately 320 nm [Okabe et al., 1973]. A bandpass filter is used to isolate the emitted radiation and transmit it to a PMT oriented orthogonally to the propagated excitation radiation. The fluorescent intensity is linearly proportional to SO_2 concentration at relatively low levels [Okabe et al., 1973; Thermo Environmental Instruments, 1992].

The TECO 43S detector uses digital timing circuitry to control both the lamp flash pulse (50 msec pulses at a 10 Hz repetition rate) and the gated sampling window of the PMT, which is delayed by 30 μs from the start of the flash trigger to allow the electrical noise associated with the flash to decay. Such a gated detection scheme minimizes baseline drift and dark current noise associated with the PMT. Because the electronically excited SO_2^* emits high-energy blue photons, cooling the PMT is not necessary. Further advantages of a pulsed detection scheme include increased lamp life and lower power consumption; higher optical intensity and better signal-to-noise ratio; and long term lamp stability. A photodiode is used to monitor the intensity of flash lamp pulses, and is configured in a feedback circuit to the lamp power supply to keep lamp intensity constant [Thermo Environmental Instruments, 1992].

In order to act as an interference to the PF method, a compound must absorb and fluoresce at the appropriate wavelength ranges. Some compounds which act as interferant to the PF method include NO, CS_2 (rejection ratios of approximately 35 and 20, respectively), and ethylene. Unless otherwise corrected for, hydrocarbons may pose a significant interference. Aromatic hydrocarbons, which tend to be highly fluorescent, are of particular concern. Detailed data are not available on the exact response of many hydrocarbon compounds. However, the TECO 43S is equipped with a "kicker" membrane, which is permeable to hydrocarbons but not to SO_2. Permeation of interfering hydrocarbons is in response to an applied (negative) differential pressure. The ARL PF detector has also been fitted with a 250 cm^3 PFA Teflon canister, filled with activated charcoal, in order to further reduce hydrocarbon partial pressures on the low-pressure side of the membrane (thus increasing removal efficiency).

Frequently zeroing the instrument during flight allows for the correction of baseline drift and offset arising from thermal, electrical, and chemical interferant effects. A carbonate-impregnated paper filter [Leahy et al., 1995] was used to remove SO_2 quantitatively, while preserving the overall sampling matrix of the ambient air. The instrument is operated in one of two modes (measure mode, where the sample airstream passes unperturbed into the detector, and zero mode, where the sample flow first passes through the carbonate filter). Interfering species such as nitric oxide, carbon disulfide, and non-methane hydrocarbons pass unimpeded through such a filter and into the detector during zeroing intervals, and their effects may thus be subtracted out. The SO_2 concentration is then determined as the *difference* between these signals. A Teflon 3-way solenoid valve (Galtek model 203-3414-415) was used to control instrument mode, and was actuated by grounding contact closure terminals on the rear of the instrument, using the Micromaster controller described above. An applied voltage was also modulated by the action of the contact closure, and was monitored by the DAS to provide a recorded indication of instrument mode (zero or measure) for the detector. The instrument was typically zeroed for 2-3 minutes out of every 6-10 minutes.

The SO_2 detector shared a common inlet with the CO analyzer, and the intake of both instruments were filtered with a single 47 mm diameter, 2μ PTFE Teflon filter membrane. This inlet filter was changed prior to each flight.

Additional modifications were made to the 43S PF detector prior to SOS. The 20.0 KΩ resistor #1217 on the input board of the instrument was replaced with a 2.2 KΩ resistor to reduce instrument response time. Instrument response time was also reduced by replacing the capillary sample flow restrictor with a mass flow controller (S/N 50312365, 0-5 slm, Edwards High Vacuum International, Wilmington, MA), and by increasing the sample flow rate to approximately 1.75 slm. A second hydrocarbon kicker was installed to ensure efficient hydrocarbon removal, and a larger Teflon diaphragm sample pump (Model N010ST2I, KNF Neuberger, Inc., Trenton, NJ) was installed to maintain an adequate pressure drop across the kickers at larger sample flow rates.

<u>Operation</u>

The CO and SO_2 detectors were typically switched on at least 2-3 hours prior to flight, to ensure proper warm-up of the electronics. After approximately 1 hour the detectors were calibrated with a CO/zero air (or SO_2/zero air) mixture at several concentrations (see below). Both the CO and SO_2 detectors have been fitted with a separate power switch to control the sampler pump, and their pumps were switched off after calibration to avoid intake and aspiration of polluted air at the Nashville airport. The sample pumps were switched on, and the detector signals acquired, after initial climbout. The outputs of the detectors were sampled at 2 Hz and filtered at 1 Hz intervals by the DAS. Finally, instrument status and performance specifications were recorded by periodic inquiry of the detectors' diagnostic functions.

<u>Calibrations</u>

A separate calibration system was dedicated to the CO and SO_2 detectors, and consisted of an MKS type 247C MFC readout; the Micromaster WP6200 programmable controller to select instrument modes (described above); three mass flow controllers (Tylan AA511048, zero air/dilution flow 0-5 slm; Datametrics S/N 1099, 0-10 sccm, for SO_2 cal gas flow; and Tylan S/N AA404196, 0-100 sccm, for CO cal gas flow); and a mixing volume. All calibration gases were added at the detector inlets, upstream of the Teflon prefilters, to calibrate through the entire sampling system and account for any systematic sampling errors.

The CO and SO_2 detectors were calibrated before each flight by diluting a controlled flow of calibration gas with a larger flow of ultra-pure zero air. Multi-point calibrations were conducted on both instruments prior to every flight (at the 0.5-10.0 ppbv level for SO_2 and at the 50-500 ppbv level for CO). Both the CO and SO_2 calibration gases were supplied with an ultrapure air balance by Scott-Marrin, Inc. The CO concentration was certified to 9.81 ± 0.20 ppm (referenced to NIST SRM 2612), and the SO_2 concentration was rated at 1.878 ± 0.094 ppmv (referenced to a NIST volumetric standard).

The variation of signal response of the CO and SO_2 detectors as a function of pressure was evaluated before and during SOS. The detectors were placed into the altitude chamber at BNL and were exposed to a constant-concentration of the appropriate calibration gas as the chamber was exposed to simulated altitudes of 0-10,000 ft MSL. In addition, both instruments were calibrated with invariant calibration gas mixtures during the test flight period of the Twin Otter in Tampa, FL, as the aircraft ascended from 0-10,000 ft MSL. This test was repeated for the SO_2 detector on June 21 in Nashville (at the start of SOS), at altitudes of 0-5,000 ft MSL. Finally, both detectors underwent multipoint calibrations at altitudes of 500 ft above ground level (AGL), and at 1000, 2000, 4,000, and 6,000 ft MSL, on a flight around Nashville on June 23, 1995, at the start of SOS. Data collected during these tests were used to correct the ambient signal response for variations in pressure/flight altitude.

4.3.5 Ozone

Ozone was measured by a Thermo Environmental Instruments Model 49 ultraviolet absorption photometer. This instrument measures O_3 through its absorption of the 254 nm radiation produced by a mercury vapor lamp. The instrument consists of a single source lamp, two ozone absorption cells, two separate flow paths, and two detector systems. Sample air flows continually through both absorption cells; one flow path allows ambient air to be drawn directly into the first absorption cell (where O_3 absorbs a fraction of the incident radiation, I_o, to generate a signal I), while the second path carries the sample air through an ozone-destroying catalyst upstream of the second cell, to generate a reference signal (I_o). The ratio (I/I_o) is proportional to the ozone number concentration through the Beer-Lambert relation. The model 49 detector is unique in that it employs a series of solenoid valves to automatically switch the two flow paths, so that for each measurement cycle Cell A and Cell B will each be treated as both reference and sample cell. Calculating the ozone concentration using the average of the two determinations accurately corrects for fluctuations in source lamp intensity. The detector is capable of measuring O_3 with a precision of ± 2 ppbv and a 0-95% response time of 30 seconds. The instrument produces an output signal proportional to the mixing ratio of ozone, using internal temperature and pressure transducers.

The ozone detector sampled ambient air through a short section of 0.635 cm OD PFA tubing which tapped off the main manifold described above. The inlet was filtered with a 2μ, 47 mm diameter PTFE filter housed in a PFA Teflon holder. This filter was changed prior to each flight.

Preventive maintenance was performed on the ozone detector prior to SOS. The preventive maintenance routine included checking the instrument for leaks; thoroughly cleaning the absorption cells, and windows and mirrors of the optical bench; and calibrating the temperature and pressure transducers. After SOS, the accuracy of the pressure correction scheme was determined by exposing the instrument to a constant concentration of O_3 in the BNL altitude chamber and varying the ambient pressure in the chamber. Detector output varied by no more than ± 1.5% (± 1σ) over the altitude range of 0-10,000 ft MSL. The pressure transducer was even able to accurately correct the signal output for large, rapid changes in ambient pressure. In addition, the instrument was calibrated against a NIST Standard Reference Photometer (SRP), and agreed with the SRP to within ± 1% over an ozone concentration range of 0 to 500 ppbv.

Operation

The TECO 49 served as a reference O_3 standard for the fast-response sensor, located in the forward baggage compartment, used to derive ozone fluxes. Therefore, the UV absorption detector was typically turned on at aircraft power-up, approximately 2-3 hours before takeoff. A range of ozone concentrations was generated in zero air using a custom built ozone generator, consisting of a pump and mercury pen ray lamp. The instruments were calibrated at 3-5 concentrations prior to each flight, and remained powered up until takeoff.

It should be noted that the model 49 had not been equipped with a separate pump switch prior to SOS, and so continually sampled ambient air on the ground until flight time. Any potential contamination due to unburned hydrocarbons emitted by passing aircraft was determined by chemically zeroing the instrument with a hopcalite-filled PFA Teflon canister permanently mounted in the detector housing. On only one occasion was significant contamination evident, and it diminished to background levels by flight time. In flight, the baseline of the ozone detector was periodically monitored using the hopcalite zeroing volume. In addition, instrument status and performance specifications were recorded by periodic inquiry of the detector's diagnostic functions.

4.4 Aircraft Data Acquisition System

The Science Engineering Associates (SEA) Model M200 Data Acquisition System is based on the IBM AT computer system architecture, which provides a standardized, low-cost hardware platform. The system employs a table-driven software package written in the C language. The user-modifiable text tables control all functions of acquisition, computation, display, and storage. The tables can be modified by most word-processing programs, so the user has the ability to configure the system easily for each new research program or application.

An acquisition table is used to define the data elements to be acquired. Once acquired the data are then passed through a formula table. Many prewritten formulas are available for averaging, finding maximums, minimums, etc.. A formula table allows the user to type formulas, in Reverse

Polish Notation (RPN), for scaling the data. Once the data are scaled by the formula table they may be displayed by the DAS using instructions from several different display tables. Some of the available displays are aircraft position plots (with capability to have a base map behind the plot), X-Y plots, time series plots, text displays, particle image displays, etc.. These displays may have range, color, and scaling changes made in-flight.

Specifications

Computer: Intel 80486 CPU, 50 MHZ
Screen: Dual standard VGA monitors and Dual Flat Panel displays, 4 displays total.
Analog to Digital: 64 differential input channels (expandable to 256), 16-bit A/D acquisition rates from 0 to 6000 Hz.
Storage medium: 1.1 Gigabyte DAT4540 small computer systems interface tape drive.
IRIG-B Timecode interface (reads GPS time from TANS Vector GPS).
TANS Vector GPS interface.
Novatel GPS PC card.

Calibration

The A/D converter is audited annually using a calibrated millivolt standard, National Institute of Standards and Technology (NIST) traceable.

5. DATA PROCESSING

Data were recorded inflight on 1.1 Gigabyte Digital Audio Tape(DAT) cartridges. After flight, the data were transferred to a PC for processing. A program, incorporating the equations in Table 2, was used to process one-second-averaged files in engineering units (pre-program values were used initially, then updated as field calibrations were performed). Headers defining the variable were added to each column and the files were saved in ASCII format.

Table 2. Measurements and algorithms used for data reduction

Measurement	Algorithm
Time	Read directly from onboard computer. The system time is set before flight by the IRIG-B interface, which obtains real time from the TANS Vector GPS.
True air speed	$(2C_pT_f\,[((P+P_d)/P)^{R/mCp}-1])^{0.5}$ where $C_p = 1005$ J kg^{-1} K^{-1} (Specific heat of dry air at constant pressure) T_f = Free air Temperature

P = Static pressure
P_d = Dynamic pressure
$R/mC_p = 0.28562$

Temperature (°C) TAS> — (volts*20.0)-60.0 NOTE: Free air temperature is calculated using

$$Free\ Air\ Temperature(K) = \frac{((Temperature + 273.16) - Offset)}{(((\frac{(SPres + DPres)}{Spres})^{c} - 1) * Alpha1) + 1}$$

Where:

SPres is the Static Pressure
DPres is the Dynamic Pressure
$c = R/mC_p = 0.28562$
Alpha1 = 1.0

and *Offset* = 0.0

Dew point (°C)	volts * 10
Static press (mb)	[(volts * 2.996401) - 0.00913] * 68.95
Dynamic press (mb)	(volts / 10.0) * 68.95
Cabin pressure (mb)	(volts * 217.2572) - 201.026
Total UV Radiometer [TUVR] (W m^{-2})	(volts * 7.33999) * 100.9314
Radar Altitude (ft)	$[(volts)^3 * 0.2206] - [(volts)^2 * 5.4962] + [(volts) * 96.2962] - 147.0087$
Pressure Cone (mb)	(volts * 96.1587) + 563.0335
Latitude	Read directly from TANS Vector GPS
Longitude	Read directly from TANS Vector GPS
Azimuth	Read directly from TANS Vector GPS

Pressure Altitude

$$1.4545 * 10^5 * (\frac{Spres}{1013.25})^{0.1903}$$

Where: *Spres* is the static pressure from above.

Wind direction — arctan(V/U)(180/π) simplified equation

Wind speed — $(U^2 + V^2)^{0.5}$ simplified equation

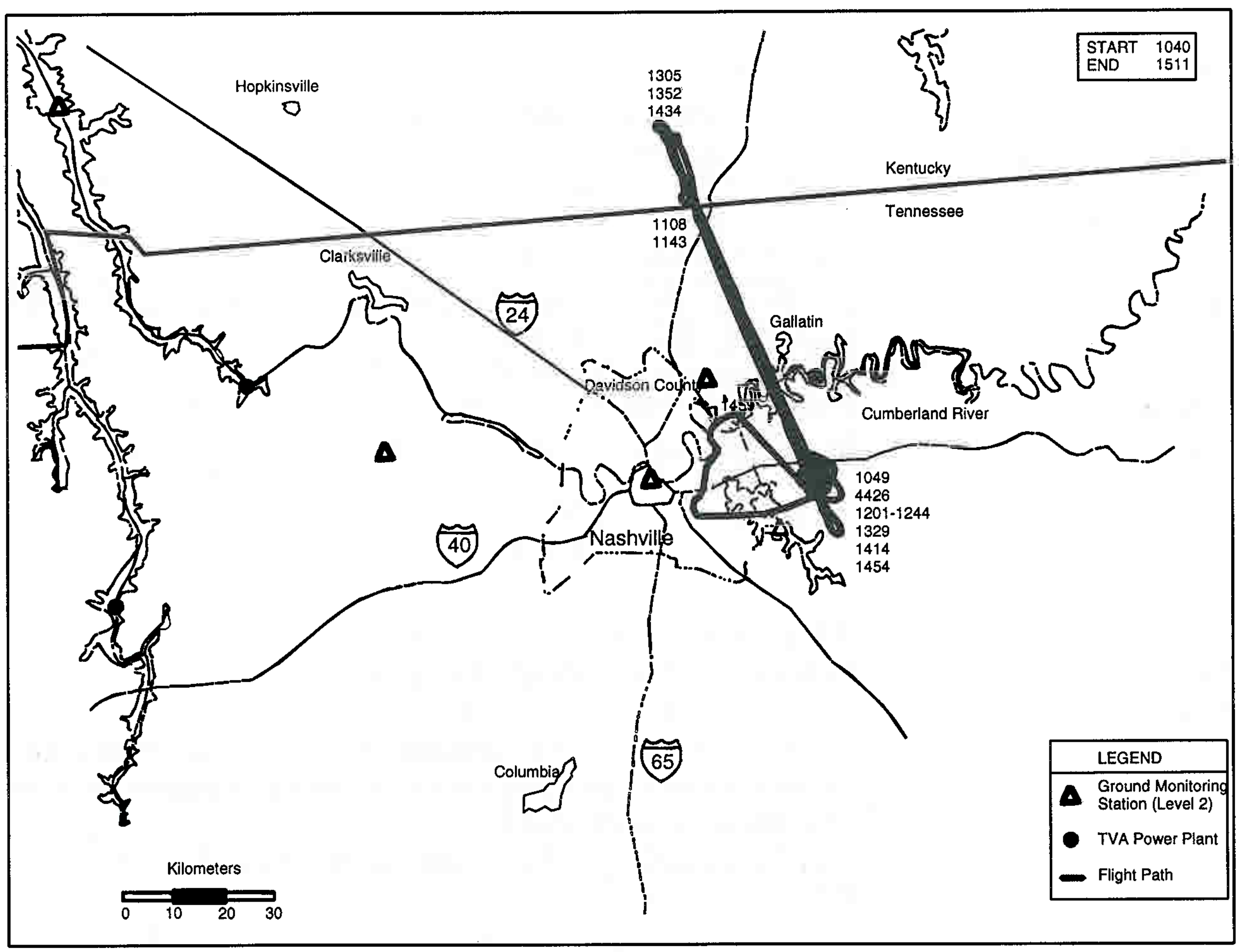
where U is the horizontal (longitude) component of the difference between actual aircraft position and a position calculated using the Azimuth and True Airspeed.

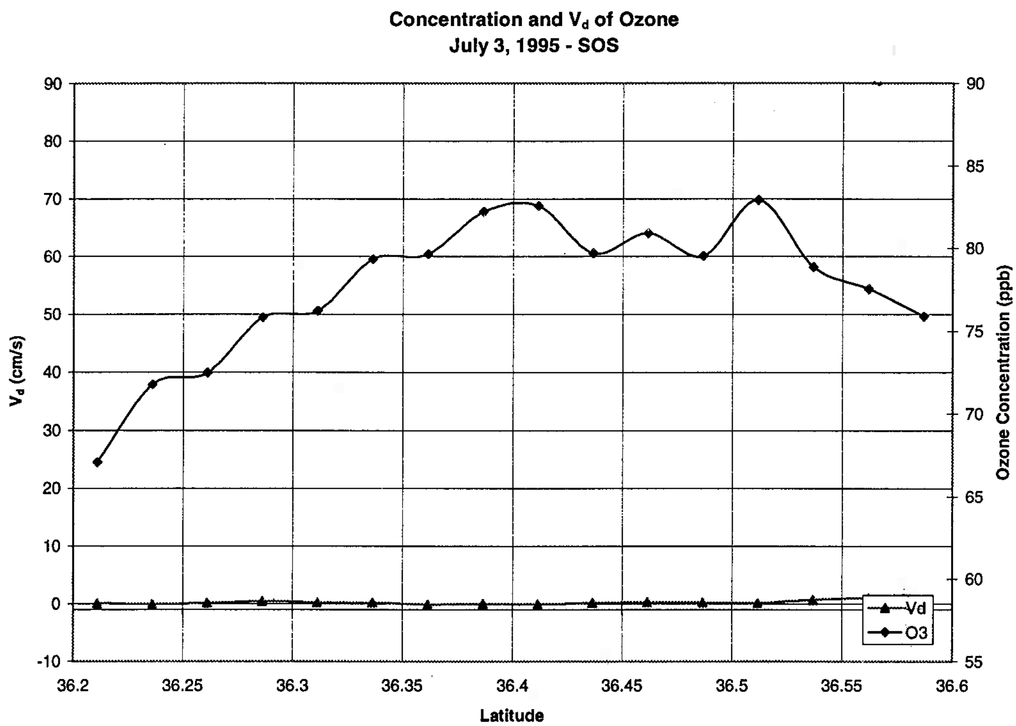
V is the vertical (latitude) component of the calculation described above.

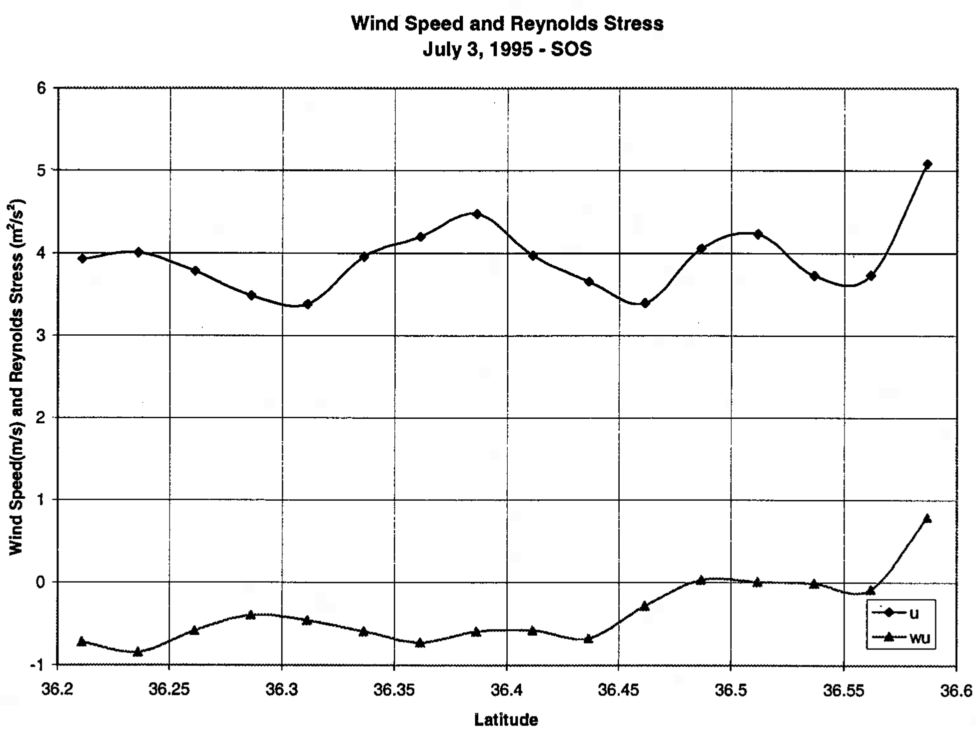
After the field study, final values for the zero offsets, intercepts, and scaling factors were determined and entered into the processing program and data were reprocessed using those final values. These processed files were examined to assure that the calibration equations were properly applied, that spans and zeroes gave the correct values, and that anomalies could be accounted for. Data for each flight were plotted for this purpose. Records of calibrations, instrument status reports, and log books were used to determine time periods when verifiable errors or problems occurred. If correction of an error or problem was possible, the data file was reprocessed with the correction applied. The data were then replotted to confirm that the proper corrections had been applied. The original data files are maintained separately.

Mobile flux data and gas analyzer data were processed by the respective investigator responsible for the instrumentation. Examples of the output data for July 3, 1995 follow.

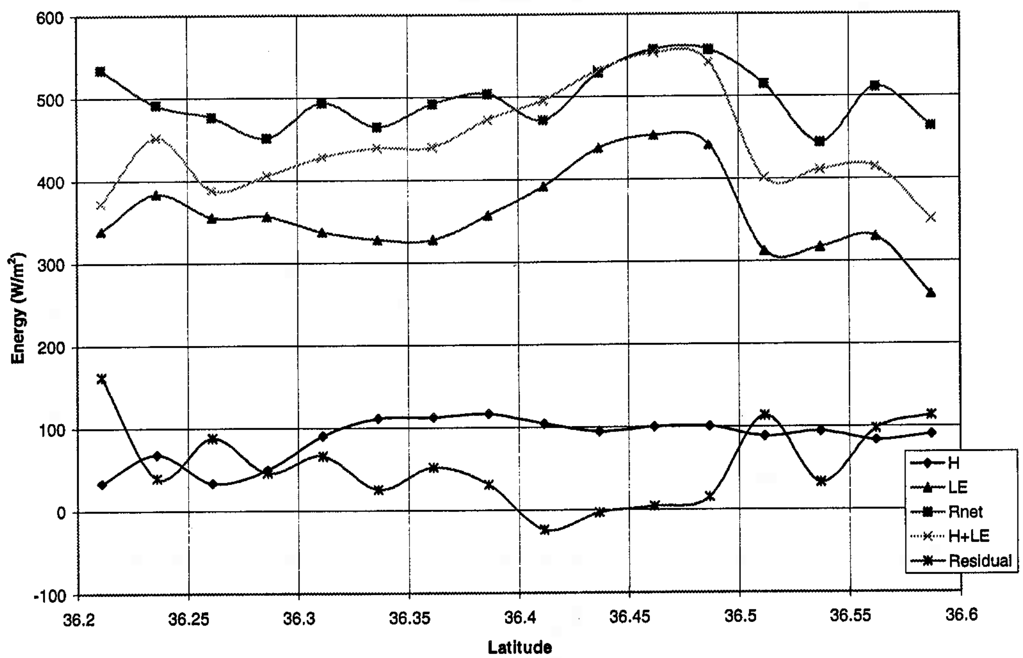
EXAMPLE FLIGHT TRACK
NOAA TWIN OTTER July 3, 1995



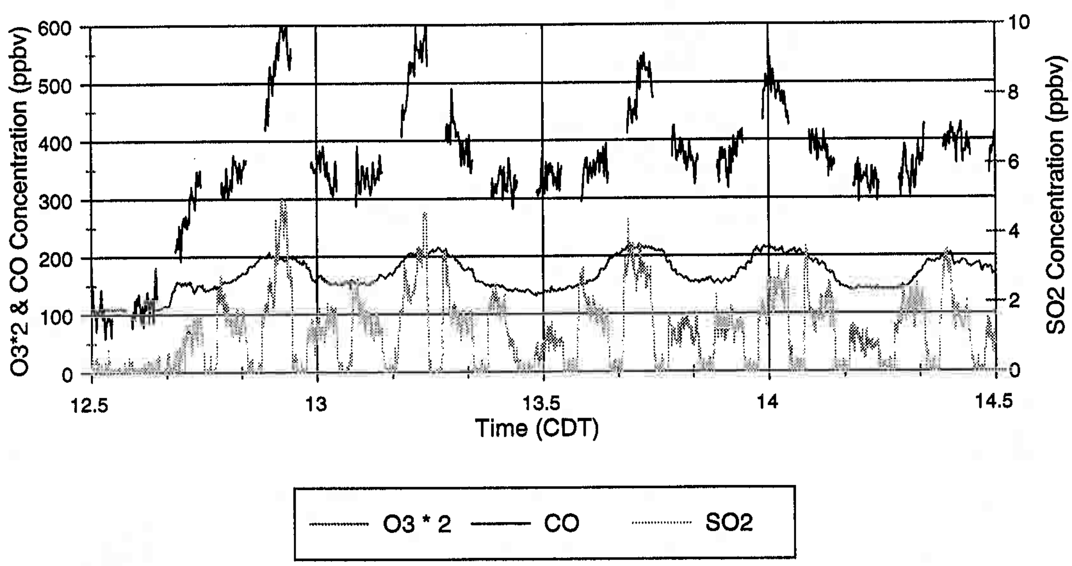

Concentration and V_d of Ozone
July 3, 1995 - SOS
V_d (cm/s)
Ozone Concentration (ppb)
Latitude
Vd
O3

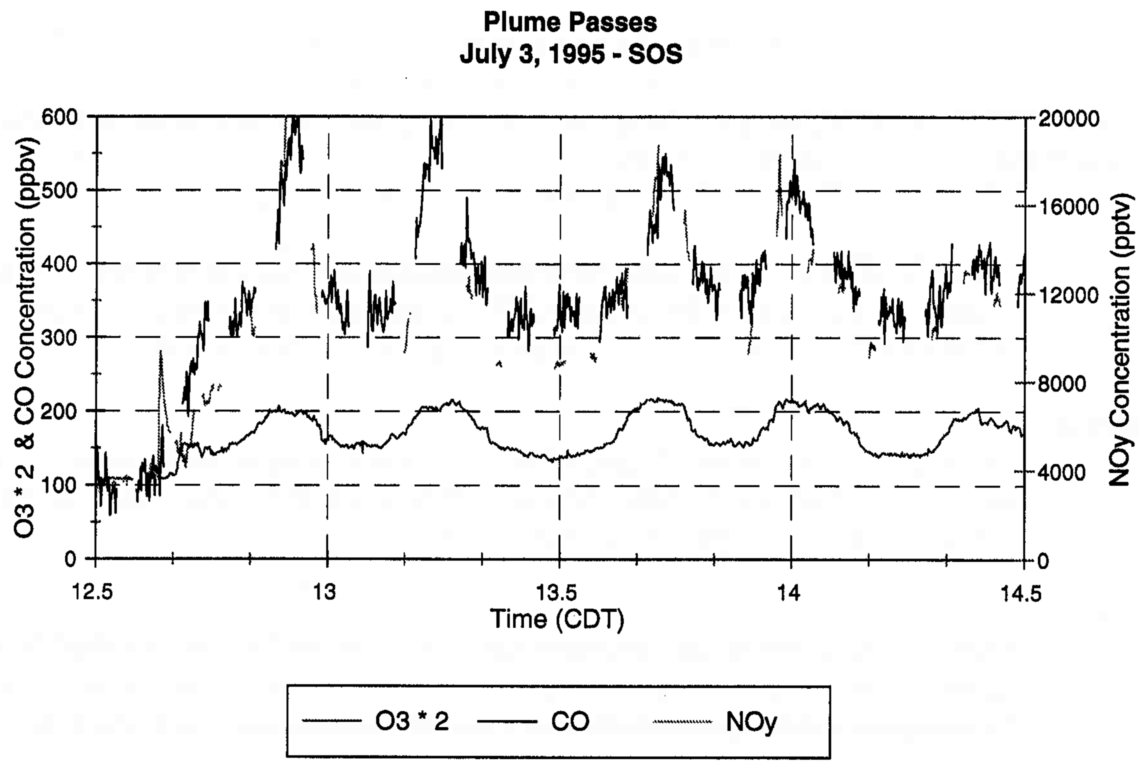

Wind Speed and Reynolds Stress
July 3, 1995 - SOS
Wind Speed(m/s) and Reynolds Stress (m^2/s^2)
Latitude
u
wu

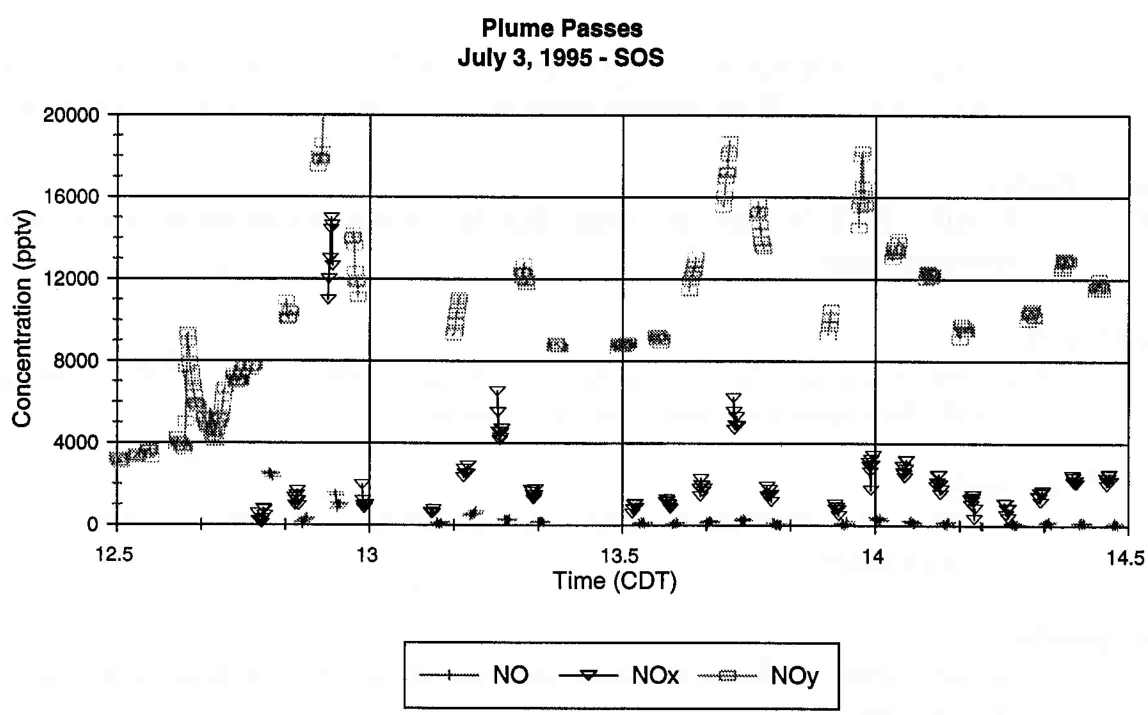
Energy Fluxes
July 3, 1995 - SOS



Plume Passes
July 3, 1995 - SOS




Plume Passes
July 3, 1995 - SOS
O3 * 2 & CO Concentration (ppbv)
NOy Concentration (pptv)
600
500
400
300
200
100
0
20000
16000
12000
8000
4000
0
12.5
13
13.5
14
14.5
Time (CDT)
O3 * 2
CO
NOy


Plume Passes
July 3, 1995 - SOS
Concentration (pptv)
20000
16000
12000
8000
4000
0
12.5
13
13.5
14
14.5
Time (CDT)
NO
NOx
NOy

6. DATA QUALITY

In addition to the calibration procedures, the following quality control checks are routinely performed on the NOAA aircraft instrumentation:

Time

The computer time is set using GPS time and checked with WWV, the National Institute of Standards and Technology (NIST) broadcast time and frequency standard, before each flight. GPS Time is also recorded from the IRIG-B interface.

Temperature

On the ground, before each flight, values are checked using a psychrometer and/or data from the National Weather Service (NWS), Federal Aviation Administration (FAA), or the FAA Flight Service Station (FSS).

Dew point

System balance checks are performed periodically in the field as described in the standard operating procedure for this instrument. On the ground before each flight, the dew-point values are checked using a psychrometer and/or NWS, FAA, or FSS information.

Static pressure

On the ground before each flight, data are checked by an aneroid barometer and NWS, FAA, or FSS information to ensure that correct data are being recorded.

Dynamic pressure

A daily check is made to ensure that the device is functional and in proper operating range.

Cabin pressure

Before each flight, the cabin pressure reading is taken with the cabin door open and checked against the static pressure reading.

Total UV Radiometer

A daily check is made to ensure that the device is functional and in proper operating range.

Radar Altitude

A daily check is made to ensure that the device is functional and in proper operating range.

Latitude, Longitude

The latitude and longitude determined onboard during a flight are compared with the known latitude and longitude of landmarks.

Azimuth

The azimuth is checked on the ramp when possible.

True air speed, wind direction, wind speed, pressure altitude

Computed values.

7. DATA AVAILABILITY

The data, in any units requested and averaged over any specified time period greater than 1.0 seconds, are available in standard ASCII format on any of the following four media:

3½ inch floppies, MS DOS formatted: 720 kbytes or 1.44 Mbytes
5¼ inch floppies, MS DOS formatted: 360 kbytes or 1.2 Mbytes

A listing will accompany the data files that describes the parameters in each column and the units in which the data are reported. Also, an information file is included that provides any pertinent information regarding the data. It is planned that the data become available for anonymous FTP.

Contact Stan Wilkison for information on data and availability at:

Stan Wilkison
R/E/ARX1
325 Broadway
Boulder, CO 80303
e-mail: swilk@srrb.noaa.gov

8. ACKNOWLEDGMENTS

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APPENDIX A: Daily Flight Operations

Following the Flight Program Summary are the flight operations for each day, in abbreviated form, directly from the onboard scientific observer's notebook. The reader/user should be cautious of the approximate and general nature of these "notes". (While most of the statements in the notes are valid, not all of them can be verified. Each section also includes a table of information on the non-methane hydrocarbons (NMHC) cans sampled on the flight.

Table A. Flight program summary

Date	Flight	Type of flight	Duration (hr)
June 14-16		Ferry from Tampa, FL	4.7
June 21	SOS1	Chemistry tests, shakedown	3.0
June 23	SOS2	Chem tests (multipoint cals), trailing cone pressure cal.	2.7
June 25	SOS3	Flux/flux divergence and profiling	3.0
June 27	SOS4	Urban plume experiment, Gallatin power plant	4.5
June 28	SOS5	Urban plume experiment, Nashville	4.8
June 29	SOS6	Flux/flux divergence, Intercomparison (IC) with TVA helicopter	4.3
July 2	SOS7	Regional connectivity (overflight of gnd sites)	4.8
July 3	SOS8	Flux/flux divergence	4.7
July 7	SOS9	PBL evolution	4.8
July 8	SOS10	PBL evolution	4.8
July 10	SOS11	Flux/flux divergence, IC with TVA helicopter	4.5
July 11	SOS12	Flux/flux divergence	4.4
July 12	SOS13	PBL evolution (with BNL aircraft)	4.6
July 14	SOS14	Urban plume experiment (ladder pattern over city)	4.4
July 15	SOS15	Regional flight to Adairsville and Walker Branch	4.6
July 15	SOS16	Regional flight to Adairsville and Walker Branch	1.5
July 18	SOS17	Flux/flux divergence	5.0
July 19	SOS18	PBL evolution	4.7
July 21		Ferry to Tampa, FL	4.7

Notes: All flight times listed are local time (LT), equivalent to CDT.
All altitudes are Mean Sea Level (MSL) unless noted as Above Ground Level (AGL)
Nashville International Airport elevation is 182.6 m (599 ft. MSL) and the airport identifier code is BNA.

June 21-SOS1

Type of Flight: Test/shakedown/survey flight. Plan calls for 15 minute level legs at 0.5, 1, 2, 3.5, 5 Kft, ~20 miles E of Nashville

Takeoff from BNA at 0958. Climb to 1500 ft, proceed to NE of BNA to survey potential location of flux transects. Gentle turn to the W, descend to 500 ft AGL at ~1017. Turn east at ~1033, ascend to 2000 ft. At ~1049, reverse heading (?) and ascend to 3500 ft. Turn at ~1108, reversing course, ascend to 5000 ft. Turn west (toward city), descend to 4500 ft at ~1120, then descend to 1500 ft. Flying near Gallatin power plant at ~1146? Due north of Nashville at 1153. Return to BNA, land at 1231.

All systems except for dynamic pressure functioning properly.(possible TANS problems). Note: NO/NOx/NOy on ambient measure. CO on ambient measure (cabin air), SO_2 fed a constant calibration concentration of SO_2 in ultrapure air, O_3 on ambient measure. No NMHC cans aboard yet. NOTE: no zero air flow to Nafion dryer on CO detector, so instrument will suffer from water vapor interference!!

June 23-SOS2

Type of Flight: Calibration and testing; wind boxes, trailing cone pressure test, instrumentation pressure response, multipoint calibration. Plan calls for 20 min boxes (5 min per side) at 0.5, 1, 2, 4, and 6 Kft. CO, SO_2 multipoint cal gas/zero air calibrations. NOx/NOy CE test with perm tube (not successful)

Takeoff from BNA at 0844. Climb to 6000 ft, fly direct to Cedars of Lebanon area, level off at 6000 ft ~0900. Begin box pattern at 0900, fly westward on first box side. Turn south at 0908, E at 0914, N at 0919. Start descent to 4000 ft at 0924, repeat box pattern until ~0950. Descend to 2000 ft at 0954, repeat box pattern until ~1018, descend to 1500 ft, continue with box pattern at 1500 ft until ~1040. Possible Air speed variations 1040-1043. Low pass over Lebanon air field for ground photos of Twin Otter at ~1047. Climb to ~4000 ft at 1047, level off at 1050. Speed variations at this altitude from 1052-1055. Descend at 1056 to 3000 ft, return to BNA. Landing at 1110.

All systems except for dynamic pressure functioning properly, calibrations conducted as stated above. No NMHC cans installed yet.

June 25-SOS3

Type of Flight: Flux/Flux Divergence

Takeoff from BNA at 1030. Fly N-S transects approximately 12 miles east of BNA (50 km legs). Most legs were flown at 500 ft AGL. Twin Otter encountered rain and clouds at the south end of the transects. Weather to the north was clearer. Haze and continuous clouds (above flight level) were prevalent for much of the flight. Weather began clearing to the north, later into the flight. Flight spiraled up to 7500 ft at the north end of the transect. Returned to BNA at 4000 ft. Landed at ~1300. Flight was cut short due to clouds/rain/building thunderstorms over BNA. All systems except for dynamic pressure functioning properly.

June 27-SOS4

Type of Flight: Urban Plume experiment (boxes, transects), encounter with Gallatin power plant plume

Takeoff from BNA at 1115. Vector to the NE, toward New Hendersonville, at 1500 ft. At New Hen. turn to the SW, flying along the northern edge of Nashville at 1500 ft. At the NW corner of the city, turned to the SE (still at 1500 ft). At midpoint of flight leg, spiral up to 9000 ft at approximately 36°05.65' N, 86°50.91' W, from 1134-1200 hours. Then spiral down to 1500 ft and continue SE. Turn NE and fly along southern edge of Nashville at 1500 ft. Proceed to eastern edge of city, turn to the NW and fly orthogonal to the mean wind at 1500 ft, 3000 ft, and 4000 ft, 13 miles NE of BNA at closest approach. Repeat legs at 4000 ft, 2500 ft, 1500 ft, still orthogonal to wind, 5 miles NE of BNA at closest point. At the end of the 1500 ft leg, head NE to Gallatin PP at 500 ft AGL. Sample briefly downwind of Gallatin. Spiral up to 4000 ft and return to BNA. Land 1530.

Status report: All systems including newly installed dynamic pressure sensor functioning properly.

Can Summary

		Pressure			
Can#	Time	Start	End	Alt	Comments
A1	113600-113800	-4	27	500	Most A canisters (1-6) were filled
A2	114000-114100	0	25	2000-2600	during a climbing spiral west of
A3	114300-114400	0	20	3300-3735	Nashville
A4	114500-114600	-10	20	4000-4300	
A5	114700-114800	-5	20	5100-5400	
A6	115600-115800	0	25	9037-9064	Free trop -above clouds
A7	123800-123820	-10	20	960	East of Nashville
B1	124900-125000	-10	25	2986	
B2	132200-132300	0	20	3929-3946	
B3	134600-134800	-10	24	3945	
B4	140700-140900	-10	25	2460	
B5	141900-142000	-10	25	959	
B6	Mistakenly opened instead of B7; sample was upwind of Gallatin power plant				
B7	Missed plume				

June 28-SOS5

Type of Flight: Urban Plume experiment (boxes/transects)

Takeoff from BNA at 1048. Fly NE to New Hendersonville at 1500 ft. Turn NW and fly at 1500 ft to 36°34.20'N, 86°48.00'W, arriving at 1111 hrs. Turn to SW and fly at 1500 ft to 36°09.00'N, 86°58.20'W, then turn SE at 1125. Fly SE, upwind of Nashville at 1500 ft. Spiral ascent from 500 ft AGL to ~9000 ft, 1131-1222 hrs. Filled NMHC cans on (brief) level portions of the climb, at

~500 ft AGL, 2000 ft, 4000 ft, 6000 ft, and 9000 ft. After spiral, continue ESE track, turn to NE at 36.08°N, 86.4°W, at 1235 (1500 ft). Begin series of cross wind urban plume passes, ~13 miles from BNA at closest point of approach. Passes were conducted at 500 ft AGL, 1500 ft, 2500 ft, 4000 ft. Move closer to BNA at 4000 ft at 1424 LT. Make cross wind passes ~5 miles from BNA at closest point of approach. Legs flown at 4000 ft and 2500 ft. Finish leg at 2500 ft and land at 1508. NMHC cans were collected at 1500 ft, 2500 ft and 4000 ft on farthest downwind passes (~13 miles from BNA) and at 4000 ft and 2500 ft on closest passes (5 miles from BNA). All systems seemed to function well and 10 NMHC cans were collected.

Can Summary

Can#	Time	Pressure Start	End	Alt	Comments
C1	112900-113000	-10	20	971	Spiral-E of city
C2	113400-113500	-10	20	1887	Spiral-E of city
C3	114100-114200	-10	20	3927	Spiral-E of city
C4	114900-115000	-10	20	5862	Spiral-E of city
C5	120000-120100	4	20	8951	Spiral-E of city (FT)
C6	131200-131300	-10	20	1401	13 miles from BNA
C7	134200-134300	-10	20	2435	36°19.30'N, 86°41.51'W; 13 miles
D1	141500-141600	0	20	3936	36°15.01'N, 86°34.90'W; 13 miles
D2	144000-144100	-10	20	3930	36°16.21'N, 86°41.41'W; 5 miles out
D3	144700-144800	-10	20	2361	36°17.28'N, 86°44.92'W; 5 miles out

June 29-SOS6

Type of Flight: Flux/Flux Divergence, Intercomparison with TVA helicopter

Takeoff from BNA at 1302 LT. Proceed to NW waypoint for intercomparison leg with TVA helicopter at 1500 ft. Pass TVA at ~1311 LT. At 1323, climb to 3000 ft and reverse heading for second intercomparison leg. Passed TVA at 134845 LT. Filled 2 NMHC cans at this level. Finish intercomparison, spiral up over NW waypoint to ~8000 ft. Descend to 3000 ft, reverse heading to SE. Fly a level leg at 3000 ft to 1434 LT. At SE waypoint descend to 2500 ft, reverse heading to NW. Finish 2500 ft leg at 1454 LT, drop to 1500 ft and reverse heading to the SE. Finish 1500 ft leg at ~1525, drop to 500 ft AGL and do 4 passes on reverse headings (low level flux runs). Land BNA at 1703. All systems, with the exception of a few minor glitches in the TANS system, worked well. A total of 4 NMHC grab cans were collected: 2 on the I/C leg with the TVA helicopter, a third at 1500 ft (1500 LT) at 36°25.09'N, 86°31.27'W. A fourth can was collected at 500 ft AGL at 1528 LT, at 36° 14.99 N, 86°28.68 min W.

Can Summary

Can#	Time	Pressure Start	End	Alt	Comments
D4	132900-133044	-10	25	2836	I/C with TVA -in plume
D5	133400-133522	-10	25	2868	I/C with TVA -out of plume
D6	150040-150140	-10	25	1427	36°25.09'N, 86°31.27'W
D7	152800-152900	-10	25	1133	36°14.99'N, 86°28.68'W

July 2-SOS7
Type of Flight: Regional Connectivity (overflights/profiles over ground sites)

Takeoff 1315, proceed NE to just upwind of Gallatin power plant at 1500 ft. Turn to the west and fly to Dickson ground site. Collect one NMHC can along this transect. Spiral over Dickson from 500 ft AGL to 7500 ft MSL. Collect (3) cans over Dickson at 500, 1000, 2000 ft AGL. Finish spiral back to 1500 ft MSL at 1420. Proceed SE to approximately 35°40.00'N, 86°40.00'W. Turn N at this waypoint (1445) and head to Youth, Inc. ground site at 1500 ft. Contacted edge of urban plume at this waypoint. Collected a total of (3) cans at 1500 ft; duplicate can sample outside of plume, third can in urban plume after S waypoint. Once over Youth, Inc., spiral from 500 ft AGL to 7500 ft MSL and back to 500 ft AGL from 1457 to 1546 (at top of spiral at 1523). Collect (3) NMHC cans over Youth, Inc. at 500, 1000, 2000 ft AGL. Proceed to S waypoint of standard flux run (36°06.00' N, 86° 38.00' W) at 500 ft AGL, then do three low-level flux transects between S point and N point (36°40.00'N, 86° 40.00'W) at 300 ft AGL. Collect one NMHC can at 300 ft AGL. After final flux run, fly to New Hendersonville ground site and spiral from 500 ft AGL to 7500 ft MSL. Collect (3) NMHC cans over New Hendersonville, at 500, 1000, 2000 ft AGL. Return to BNA, land at 1750.

The TANS vector system went out at 1315. TANS data is sporadic throughout the flight. Fast winds could not be calculated during this flight. Dew point sensor not powered until ~1358.

Can Summary

Can#	Time	Pressure Start	End	Alt	Comments
E1	133500-133542	-20	20	1461	36°17.22,86°58.11
E2	134900-134940	-10	20	1156	36°13.87,87°22.70; Spiral -Dickson
E3	135000-135100	-10	20	1469	36°15.01,87°21.59; Spiral -Dickson
E4	135440-135530	-20	20	2625	36°14.24,87°21.68; Spiral -Dickson
E5	144500-144610	-20	20	1334	35°49.96,86°38.36
E6	144500-144610	-20	20	1334	35°49.96,86°38.36
E7	144900-144958	-10	20	1351	35°51.36,86°35.69; Spiral -Youth, Inc.
F1	145730-??????	-15	20	982	35°51.36'N, 86°35.69'W; Spiral -Youth, Inc.
F2	150040-150140	-15	25	1401	35°51.36'N, 86°35.69'W; Spiral -Youth, Inc.
F3	150600-150646	-15	20	2393	35°51.36'N, 86°35.69'W; Spiral -Youth,

					Inc.
F4	163200-163242	-10	20	849	36°23.52'N, 86°31.75'W; Flux transect
F5	165020-165108	-10	20	976	36°19.23'N, 86°38.00'W; Spiral- N. Hendersonville
F6	165600-165629	-10	20	1504	36°19.95'N, 86°38.02'W; Spiral- N. Hendersonville
F7	165940-170022	-10	20	2517	36°20.32'N, 86°38.56'W; Spiral- N. Hendersonville

July 3-SOS8

Type of Flight: Flux/Flux Divergence

Takeoff 1045, proceed SE to southern waypoint of our normal flux path. At S waypoint (approximately 36°06.00'N, 86°24.00'W) descend to 300 ft AGL and proceed on heading of 335 to northern waypoint of flux run (approximately 36°38.00' N, 86°38.00' W). Fly reverse headings between the two points for a total of 4 runs at 300 ft AGL. At southern waypoint, spiral up to 7500 ft MSL. PBL top at approximately 5000 ft. At top of spiral (7500 ft) from 1218 to 1237 LT. Drop to 4000 ft and fly near top of PBL to northern waypoint (reached N point at 1303); descend to 2500 ft and fly to southern waypoint (reached at ~1322 LT); descend to 1500 ft and fly to N point (reached at 1348). Reverse course and drop to 300 ft AGL, fly to S waypoint (reached at 1412); reverse course and fly north at 300 ft AGL (reached N point at 1430 LT). Reverse course and climb to 2500 ft, flying SE to S waypoint (reached at 1452). Return to BNA, land at ~1500.

NMHC grab cans:

Filled (2 ea.) 6.0 L cans (6 minute fill time); both at southern end of flux run, outside of urban plume, at altitudes of 300 ft AGL and 4000 ft MSL.

Filled (7ea.) 0.8 L cans during flight:

Can Summary

		Pressure			
Can#	Time	Start	End	Alt	Comments
105	112800-113400	-20	25	811	36°12.17'N, 86°27.61'W; Flux transect
067	124800-125400	-20	22	3898	36°14.28'N, 86°27.86'W; Flux transect
A1	130940-131020	-10	20	2507	36°37.06'N, 86°36.83'W; Outside plume, end of flux run
A2	131300-131340	-13	20	2498	36°31.07'N, 86°34.89'W; In urban plume, heading SE
A3	134320-134400	-10	20	1414	36°31.12'N, 86°34.94'W, In urban plume, heading NW
A4	134830-134928	-12	10	1457	36°41.51'N, 86°38.85'W; Outside plume, N end of flux run. LOW PRESSURE!
A5	135245-135320	-12	20	951	36°45.33'N, 86°39.82'W; Outside plume, N end of flux
A6	140030-140110	-12	20	1156	36°31.10'N, 86°34.80'W; In urban plume,

					heading SE
A7	142532-142640(??)	-10	20	1105	36°41.36'N, 86°34.98'W; Outside plume, end of flux run

July 7-SOS9

Type of Flight: Sub-regional (boundary layer evolution)

Takeoff from BNA at 0908 LT. Proceed to waypoint 1 (36°11.00'N, 86°20.00'W) at 500 ft AGL. Turn and head SW on a transect at 500 ft AGL to waypoint 2 (36°49.00'N, 86°45.00'W). Pass over Youth, Inc. ground site at 500 ft AGL at ~0923. Locate southern edge of urban plume at ~35°52.00'N, 86°41.00'W. Once at waypoint 2, reverse course while maintaining 500 ft AGL. On second pass over Youth, Inc., spiral up to 5500 ft. Climb from ~0945-1000. Head to waypoint 1 at 5500 ft, descend to 3000 ft over waypoint 1 and fly SW to waypoint 2. Boundary layer higher to south end of track, lower toward north end. At waypoint 2 reverse course and descend to 2000 ft (~1030), fly to waypoint 1. Overshot point 1 by ~6 miles, reverse course, climb to 4000 ft then to 5000 ft, finally to 6000 ft to clear PBL. Once over waypoint 2, drop to 4000 ft and fly NE to waypoint 1. At waypoint 1 reverse course and descend to 2000 ft (~1130), fly to the SW. Over waypoint 2, climb to 6500 ft (spiral, 1146-1150) and reverse course to the NE. Over waypoint 1, descend to 4000 ft (~1205-1210), reverse course to point 2. At ~1221 over waypoint 2, drop to 2000 ft and reverse course to NE, reverse course over waypoint 1 and fly to Youth, Inc. site at 2000 ft. Over Youth, Inc., descend to 500 ft AGL then spiral up to 6400 ft (spiral ~1255-1321). Return to BNA, land at 1336. All systems working

Can Summary

Can#	Time	Pressure Start	End	Alt	Comments
C1	092430-092520	-15	??	777	36°03.09'N, 86°22.50'W; Over Youth, Inc.
C2	101518-101600	-10	22	2769	36°04.03'N, 86°29.22'W; Over Youth, Inc.
C3	102800-102855	-10	??	1782	35°50.85'N, 86°45.91'W; Out of urban plume
C4	103650-103800	-10	27	1792	36°02.90'N, 86°30.70'W; Over Youth, Inc.
C5	105720-105818	-12	22	5842	36°03.72'N, 86°30.66'W; Over Youth, Inc. in FT
C6	110900-110950	-20	20	3806	35°51.40'N, 86°45.76'W; Urban, past N side of plume
C7	111738-111830	-10	20	3746	36°03.64'N, 86°29.41'W; Over Youth, Inc.
B1	112800-112841	-20	20	1750	36°14.06'N, 86°15.89'W
B2	113530-113630	-20	25	1741	36°03.54'N, 86°30.15'W; Over Youth, Inc.
B3	115730-115833	-12	20	6400	36°03.52'N, 86°29.72'W; Over Youth, Inc.
B4	125330-125410	-15	20	795	36°03.48'N, 86°30.97'W; Ascending spiral over Youth, Inc.
B5	125930-130012	-15	22	1303	36°03.33'N, 86°30.80'W; Ascending spiral over Youth, Inc.

B6	130430-130515	-10	20	2500	36°04.21'N, 86°30.11'W; Ascending spiral over Youth, Inc.
B7	131130-131225	-10	20	3314	36°03.46'N, 86°30.58'W; Ascending spiral over Youth, Inc.

July 8-SOS10

Type of Flight: Boundary layer evolution study (sub-regional). Essentially a repeat of flight track of July 7-SOS9.

Takeoff from BNA at 0801 hrs., climb to 4000 ft toward NE waypoint (36°11.00'N, 86°20.00'W), ultimately climbing to 6200 ft. Descended to 500 ft AGL over NE waypoint, turn to fly SW toward waypoint 2. Flying SW on a transect at 500 ft AGL to waypoint 2 (36°49.00'N, 86°45.00'W). At ~0840, over waypoint 2, reversed course and ascended to 2700 ft to fly to point 1. At ~0900, reverse course over point 1 and climb to 3300 ft. Maintain altitude of 3300 ft and continue reverse heading transects until ~1132. Repeatedly encountered distinct and merging transported power plant plumes over the Youth, Inc. site during this flight. Encountered mixed layer rising above us (3300 ft) at ~1034. Gliding descent over Youth, Inc. ground site; begin descent at SW waypoint, flying NE, to arrive 500 ft AGL over ground site at ~1143. Spiral ascent over ground site from 1145-1158, ultimately reaching an altitude of 7200 ft. Remain at this altitude (circling) until ~1217, then descend and return to BNA, landing at 1229.

All systems working this flight; collected 14 NMHC can samples, many stacked vertically over the Youth, Inc. ground site.

<u>Can Summary</u>

		Pressure			
Can#	Start Time	Start	End	Alt	Comments
A1	083145-083320	-10	20	889	36°03.39'N, 86°31.15'W; can opened but pump not on -pump then started. Over Youth, Inc. ground site
A2	085200-085300	-10	25	2621	36°03.44'N, 86°30.30'W; Over Youth, Inc.
A3	085800-085900	-15	25	2702	36°11.14'N, 86°14.45'W; N end of track
A4	090525-090620	-10	24	3116	36°03.56'N, 86°36.35'W; Over Youth, Inc.
A5	091500-091620	-15	20	3191	35°50.13'N, 86°47.23'W; S end of track
A6	092600-092700	-10	20	3152	36°03.53'N, 86°30.03'W; Over Youth, Inc.
A7	093152-093233	-10	20	3085	36°11.80'N, 86°19.26'W; N end of track
D1	095900-100030	-10	29	3146	36°02.63'N, 86°31.37'W; Over Youth, Inc.
D2	101250-101340	-10	20	3146	36°03.27'N, 86°30.59'W; Over Youth, Inc.
D3	103237-103350	-10	25	3141	36°03.29'N, 86°30.30'W; Over Youth, Inc.
D4	104430-104548	-12	27	3155	start 36°05.09'N, 86°28.38'W; end 36°03.35'N, 86°30.60'W
D5	110500-100600	-10	24	3154	36°03.02'N, 86°30.40'W; Over Youth, Inc.
D6	112200-112300	-10	23	3163	36°04.30'N, 86°29.42'W; Over Youth, Inc.

D7	114420-114520	-10	25	934	36°03.71'N, 86°31.09'W; Begin spiral over Youth, Inc.

July 10-SOS11

Type of Flight: Flux/flux divergence; intercomparison (I/C) with TVA helicopter at 1500 ft, 3000 ft.

Takeoff from BNA at 1107 LT. Proceed to I/C waypoint 2 (36°06.00'N, 86°24.00'W) at 1500 ft. Descend to 300 ft AGL and fly four (4) transects between waypoints 2 and 1 (36°37.80'N, 86°37.80'W). Spiral up to 8500 ft, then rendezvous with TVA helicopter at 1500 ft (over waypoint 2) and fly NW to waypoint 1. Repeat transect with helicopter at 3000 ft. Finished flight with 4 flux runs between waypoints 1 and 2 at 300 ft AGL. Land BNA at 1515. Some problems with TANS and fast winds calculations this flight. CO detector pump failed at ~1415, 1 hour before landing ...problem (loose contact) fixed on ground after flight.

Can Summary

Can#	Start End	Pressure Start	Pressure End	Altitude	Comments
E1		-10	20	Ground	Zero air thru pump
E2		-10	20	Ground	Z. air directly into manifold
E3	114110-114145	-15	22	800	no GPS
E4	115725-115800	-10	20	825	
E5	120230-120313	-10	23	1000	
E6	130500-130600	-10	20	1425	
E7	134524-134600	-10	20	2975	
F1	140220-140300	-12	20	1150	
F2	141830-141910	-10	15	850	
F3	143700-143746	-12	20	1000	
F4	144600-144650	-12	20	950	
F5	145340-145445	-12	20	800	Duplicate cans
F6	145340-145445	-12	20	800	Duplicate cans
F7	150120-150154	-10	20	1200	

July 11-SOS12

Type of Flight: Flux/flux divergence

Takeoff from BNA at 1100. Proceed to waypoint 1 (36°37.80'N, 86°37.80'W) at 1500 ft. Descend to 300 ft AGL and fly flux transects to waypoint 2 (36°06.00' N, 86°24.00'W). Repeat transects for a total of 3 runs at 300 ft AGL. Spiral ascent over Youth, Inc. ground site from 300 ft AGL to 6000 ft. Reverse track to fly from waypoint 2 to waypoint 1 at 4500 ft, waypoint 1 to waypoint 2 at 3800 ft, waypoint 2 to waypoint 1 at 2000 ft, two transects between waypoint 1 and 2 at 300 ft AGL, waypoint 1 to waypoint 2 at 2000 ft, waypoint 2 to waypoint 2 at 3800 ft, waypoint 1 to waypoint

2 at 4800 ft. Return to BNA, land at 1526.

All systems working on this flight; however, fast response CO2 (IRGAs), fast O3, and LICOR were not calibrated before the flight. A total of 14 NMHC cans were collected.

Can Summary

Can#	Time	Pressure Start	End	Alt	Comments
B1	113640-113730	-17	24	692	36°22.53'N, 86°31.05'W
B2	115430-115510	-10	22	750	36°23.92'N, 86°32.02'W
B3	120200-120240	-15	22	890	36°38.10'N, 86°37.70'W, N end of track
B4	121130-121210	-12	22	730	36°23.44'N, 86°31.73'W, middle of track
B5	122240-122325	-15	22	801	36°03.84'N, 86°30.95'W, Spiral-Youth,Inc.
B6	122900-122950	-12	20	1393	36°03.37'N, 86°30.98'W, Spiral-Youth,Inc.
B7	123340-123420	-15	22	2408	36°03.22'N, 86°30.96'W, Spiral-Youth,Inc.
C1	124520-124600	0	20	5910	36°04.02'N, 86°40.90'W; Open valve
C2	130930-131010	-15	20	3667	36°37.71'N, 86°37.29'W, N end of track
C3	131640-131725	-12	20	3662	36°23.21'N, 86°31.76'W, middle of track
C4	132430-132520	-12	22	3723	36°07.77'N, 86°25.60'W, S end of track
C5	132620-133715	-10	22	1847	36°22.59'N, 86°31.58'W
C6	134420-134500	-12	22	1417	36°38.72'N, 86°38.64'W
C7	135445-135520	-12	20	785	36°22.04'N, 86°31.27'W

July 12-SOS13

Type of Flight: Sub-regional (boundary layer evolution), intercomparison (I/C) within a few miles of DOE aircraft, G1.

Takeoff from BNA at 0700. Proceed at 4000 ft to waypoint 1 (36°16.00'N, 87°07.00'W), spiral descent to ~800 ft AGL and fly SW to waypoint 2 (36°02.00'N, 87°40.00'W). Reverse track at waypoint 2 and fly to waypoint 1 at 800 ft AGL. Repeat transect 2 more times at 800 ft AGL. At 0830 ascend to 5000 ft and fly transects between waypoints 1 and 2 until 1000. Repeat transects at 4000 ft, 2500 ft, 1500 ft, 500 ft AGL, then spiral ascent over waypoint 1 to 6000 ft. Return to BNA and land at 1130.

All systems working, but LICOR and fast response O3 not calibrated prior to flight.

14 NMHC grab cans collected. 1 set of duplicate cans, 12 others

Can Summary

Can#	Time	Pressure Start	End	Alt	Comments
A1	074330-074410	-15	20	1287	36°00.71'N, 87°40.79'W, W end of track
A2	075230-075315	??	23	1326	36°09.32'N, 87°22.59'W, middle of track

A3	080020-080100	-10	22	1348	36°15.64'N, 87°05.76'W, E end of track
A4	081200-081240	-10	22	1362	36°07.26'N, 87°27.89"W
A5	091550-091640	-11	23	4882	36°08.91'N, 87°23.96'W, W end of track
A6	102250-102335	-10	22	2299	36°03.04'N, 87°37.17'W, E end of track
A7	102920-103000	-12	20	2356	36°09.48'N, 87°22.65'W, Middle of track
D1	103730-103815	-10	22	1555	36°15.84'N, 87°05.58'W, W end of track, One cap on manifold missing
D2	104750-104830	-15	22	1394	36°07.87'N, 87°27.12'W, 2 min past middle of track
D3	105330-105410	-5	20	1299	36°02.27'N, 87°39.75'W, E end of track
D4	105600-105640	-12	22	1039	36°02.99'N, 87°37.15'W
D5	110215-110330	-10	20	1187	36°04.79'N, 87°32.62'W, Middle of track
D6	Same as D5				Duplicate of D5
D7	110920-111000	-10	20	982	36°15.91'N, 87°07.01'W, E end of track

July 14-SOS14

Type of Flight: Urban Plume (ladder pattern over city)

Takeoff 1302 from BNA; proceed to waypoint 1(36°16N, 86°35'W), northeast of the city , and fly waypoints 1-8 at 1500 ft. Cross city from SE corner to NW corner of ladder pattern (waypoint 8 to waypoint 2) at 1500 ft and spiral up to 2500 ft. Fly from waypoint 2(36°16'N, 86°54'W) to 1(36°16N, 86°35'W) to 4(36°11'N, 86°35'W) to 3(36°11'N, 86°54'W) to 6(36°05'N, 86°54'W) to 5(36°05'N, 86°35'W) to 8(36°01'N, 86°35'W) to 7(36°01'N, 86°54'W). Fly across city from SW to NE at 2500 ft to waypoint 1. Spiral up to 4000 ft and fly waypoints 1-8 (same order, same pattern as that flown at 1500 ft). After waypoint 8, proceed to Youth, Inc. site at 4000 ft at 1600 hrs. Spiral to 9000 ft over Youth, Inc. ground site, then spiral down to 500 ft AGL. Land at BNA at 1709. Note: we had to alter/delay flight path many times while over the city due to air traffic, especially at 1500 ft. Later in the flight, clouds and precip near final leg at 4000 ft, waypoint 7-8, and during spiral over ground site, also forced deviations from original flight plan. We observed wide variations in pollutant concentrations on the spiral ascent over the Youth, Inc. site (as we caught bits and pieces of convection) and remarkably uniform concentrations a few minutes later during the descending spiral over the same site. Interesting case study.

All systems working. 14 NMHC grab cans collected.

Can Summary

		Pressure			
Can#	Time	Start	End	Alt	Comments
C1	131350-131430	-15	20	1284	36°16.76'N, 86°46.00'W
C2	132630-132710	-12	20	1284	36°10.85'N, 86°44.00'W
C3	135230-135315	??	22	1404	36°00.94'N, 86°43.02'W
C4	140118-140205	-10	20	1370	36°07.61'N, 86°42.55'W
C5	141630-141715	-12	23	2350	36°15.80'N, 86°43.55'W

C6	142615-142703	-10	22	2424	36°11.00'N, 86°45.23'W
C7	155000-155135	-10	20	3871	35°56.44'N, 86°43.57'W, Out of sequence
E1	144550-144633	-15	20	2369	36°01.11'N, 86°45.10'W
E2	150700-150745	-15	20	2396	36°08.06'N, 86°44.81'W
E3	152230-152330	-10	23	3863	36°15.86'N, 86°48.60'W
E4	153055-153155	-10	22	3959	36°10.80'N, 86°43.17'W
E5	164130-164215	0?	22	2500	36°04.08'N, 86°30.60'W; can evacuated?
E6	164430-164510	0?	23	1370	36°03.60'N, 86°31.05'W; can evacuated?
E7	164700-164740	-10	20	923	36°03.45'N, 86°30.26'W

July 15-SOS15/SOS16

Type of Flight: Regional (flight to Adairsville, KY and Oak Ridge, TN)

Takeoff from BNA at 1013. Fly to waypoint A at 36°08.25'N, 86°26.00'W at 500 ft AGL, then turn NNW to fly to waypoint B at 36°38.00'N, 86°37.50'W. Turn west, fly to waypoint C (36°39.66'N, 87°01.93'W), the site of the EPA/NOAA flux tower and chemistry experiment near Adairsville, KY. Overfly this site on E-W headings at 500 ft AGL, from ~1045-1110 LT. After overflight, proceed to waypoint B then to waypoint D at 36°00.00' N, 86°25.00'W at 500 ft AGL. Fly at 500 ft AGL due east along 36th parallel to the Walker Branch watershed near ATDD lab in Oak Ridge, TN. We had to dodge some clouds and precipitation along the way. At the Walker Branch site, make approximately 6 low level flux transects over the ATDD ground-based flux tower. Spiral up over this site (collecting NMHC can samples) to ~6500 ft. Time of spiral ~1315-1340 CDT (note Oak Ridge on EDT). Proceed to Cove Mountain, TN, Level II chemistry ground site while descending from 6500-3000 ft MSL (?). Spiral over Cove Mountain site from 500 ft over the ridge top to 6500 ft. Time of spiral ~1349-1408 CDT. Land and refuel in Knoxville. Takeoff 1518 CDT and fly at 500 ft AGL back to Nashville dodging some (at times) intense clouds and precip. Land BNA at 1630 CDT. Collected NMHC cans along track A-B (1030 CDT), near waypoint C (1047 CDT), midway between waypoints D-E (1200 CDT), over the Walker Branch site (spiral, 1316-1326 CDT), over the Cove Mtn. site (spiral, 1353-1400 CDT), and finally along track E-D on return home.

All systems working, except TECO 49 O3...there is a 30 minute period where detector exhibited strange behavior...detector OK, but data no good. Detector turned off 1245-1315. A total of 14 NMHC cans this flight. CO detector pump stopped near end of flight? Tom W. and Winston L. conducted inlet tests for dilution factors (main manifold) and instrument lag times.

Can Summary

Can#	Time	Pressure Start	End	Alt	Comments
B1	102845-102925	-10	20	864	36°22.85'N, 86°31.72'W
B2	104725-104815	-15	22	1000	36°39.03'N, 87°01.12'W
B3	120340-120425	-12	23	2152	35°58.72'N, 85°18.32'W
B4	131340-131420	-10	22	1601	35°57.61'N, 84°16.81'W
B5	131620-131700	-12	20	1922	35°57.42'N, 84°16.78'W

B6	132050-132145	-12	24	2816	35°58.15'N, 84°17.73'W
B7	132520-132625	-10	24	3911	35°57.26'N, 84°17.35'W
F1	135350-135445	-12	22	4291	35°41.56'N, 83°36.02'W, Over Cove Mtn.
F2	135820-135910	-15	20	4548	35°42.43'N, 83°37.20'W, Over Cove Mtn.
F3	140100-140150	-12	22	5082	35°41.42'N, 83°35.87'W, Over Cove Mtn.
F4	154020-154112	-10	24	2360	35°58.18'N, 84°43.72'W
F5	155210-155300	-10	24	2224	35°58.48'N, 84°59.59'W
F6	155615-155700	-10	20	1765	35°58.79'N, 85°10.82'W
F7	160725-160810	-10	24	1401	36°07.24'N, 85°44.49'W

July 18-SOS17
Type of Flight: Flux/Flux Divergence

Takeoff from BNA at 1101. Proceed to waypoint 1 (36°37.80'N, 86°37.80'W), western waypoint (flight plan called for E-W transects along 36° latitude line). Spiral ascent to 8300 ft to find top of mixed layer, 1106-1116. Remain at altitude until 1126, then spiral descend to 300 ft AGL at 500 ft per minute. Note layer of elevated SO_2 at ~3300 ft. Arrive at 300 ft AGL at 1140. Turn to east, fly to eastern waypoint (arrive at ~1154), then reverse course and fly to western waypoint (still at 300 ft AGL), arriving at 1209. Reverse course to fly east, arriving at east waypoint at 1222. Overflew Smyrna airport at 1220. Noted center of urban plume (~36°00.00'N, 86°56.00'W). Fly to western waypoint, arriving there at 1237. Turn to head east, climb from 300 ft AGL to 2000 ft MSL. Arrive eastern waypoint (2000 ft), then reverse course at this altitude and fly west, arriving at W waypoint at ~1306. Climb to 4000 ft, reverse course, fly to east. Arrive E waypoint at 1322. Climb to 5500 ft, reverse course, fly west 1325-1340. Descend over W waypoint at 1340, fly east, arrive at E waypoint (4000 ft) at 1354, descend to 3000 ft and fly west. Arrive W waypoint at 1408; reverse course, descend to 2000 ft, fly east, arrive at E waypoint at 1423. Spiral descent over E waypoint at 1423, to 300 ft AGL. Arrive W waypoint at 1437, turn to east, arrive E waypoint 1451. Proceed to 36°00.00'N, 86°40.00'W, spiral up to 7500 ft. Sampling cloud updraft at this waypoint (heterogeneous concentrations). Punch through cloud tops at 7500 ft at ~1515. Ramp speed tests at 7500 ft, ~1525. Spiral descent over same point at 1534. Return to BNA. Land BNA at 1541. Generally cleaner air this flight, with higher NOx to NOy ratios, low NOy at eastern waypoint, but high SO_2 there (power plant?). All systems working. Briefly sucked in polluted airport air into NOx detector prior to takeoff; no lasting effects. Consistent 2-3 ppbv difference between 2 cells of ozone detector. Noted that NOx detector output was a bit noisier on this flight (due to pump oil contamination?).

Can Summary

Can#	Time	Pressure Start	End	Alt	Comments
E1	115500-115545	-15	20	840	36°00.02'N, 86°48.91'W, east end of track
E2	120320-120500	-20	25	823	36°00.00'N, 86°47.37'W, middle of track
E3	Duplicate of E2				
E4	120930-121020	-12	24	1000	35°59.28'N, 87°01.76'W, W end of track

E5	121700-121745	-12	22	858	36°00.29'N, 86°43.27'W, middle of track
E6	122300-122400	-12	25	920	35°59.42'N, 86°29.14'W, E end of track
E7	123100-123150	-10	24	1038	36°00.15'N, 86°45.88'W, middle of track
C1	123730-123815	-15	20	1759	35°59.43'N, 87°01.53'W, climbing, W end
C2	124520-124600	-10	20	1901	36°00.05'N, 86°44.21'W, middle of track
C3	125345-125435	-12	24	1894	35°59.13'N, 86°30.44'W, E end of track
C4	130025-130115	-15	23	1880	36°00.12'N, 86°46.46'W, middle of track
C5	131010-131100	-10	23	3958	36°00.05'N, 86°59.28'W, higher at W end
C6	131540-131630	-11	23	4002	36°00.09'N, 86°44.12'W, middle of track
C7	132140-132210	-10	17	4380	36°00.13'N, 86°28.30'W, E end of track

July 19-SOS18

Type of Flight: Boundary layer evolution

Takeoff from BNA at 0806, climb to 6000 ft. Proceed to waypoint 1 (36°13.00'N, 87°05.00'W) and spiral descent to 500 ft AGL. Ascend to 1000 ft AGL and fly SE to waypoint 2 (35°51.00'N, 86°49.00'W). Fly transects between waypoints 1 and 2 at 500 ft AGL (0841-0856), 1000 ft AGL (0857-0912), 2500 ft MSL (6 passes: 0915-0928, 0930-0942, 0944-0958, 1000-1014, 1016-1030, 1032-1046). At waypoint 2, spiral ascent to 7000 ft (1045-1053), then fly NW to waypoint 1 at 5500 ft. Over waypoint 1, descend to 4000 ft at 1115, reverse course and fly SE to waypoint 2 (1120-1134). Reverse course and descend to 3000 ft (1136-1150). Over waypoint 1, spiral ascent through top of PBL, 7500 ft, then descend to 500 ft AGL (1150-1202) (complete profile). Spiral up to 2000 ft and fly SE to waypoint 2 (1202-1216). Overfly waypoint 2 and head to BNA, land at 1234.

All systems working this flight. Terrain along flight track was wooded, hilly, and undeveloped near waypoint 1, flatter and much more developed (fewer trees, more roads, houses, businesses) near waypoint 2. Consequently turbulent evolution of the mixed layer was higher in elevation) and more pronounced to the south, lower to the north. Flying at 2500 ft, for example, put the aircraft well within the surface layer near waypoint 2, but above it near waypoint 1.

Can Summary

		Pressure			
Can#	Time	Start	End	Alt	Comments
A1	084240-084320	-15	23	1200	35°50.99'N, 86°46.10'W, SE end of track
A2	084815-084900	-15	23	1012	35°59.97'N, 86°33.85'W, middle of track
A3	085900-085945	-12	22	1471	36°11.92'N, 87°03.84'W, NW end of track
A4	090615-090700	-12	23	1474	35°59.81'N, 86°53.21'W, middle of track
A5	091200-091230	-12	20	1466	35°50.65'N, 86°44.98'W, SE end of track
A6	093600-093650	-12	22	2384	36°00.01'N, 86°53.82'W, middle of track
A7	111020-111110	-10	20	4881	36°00.94'N, 86°54.83'W, middle of track
D1	Can compromised -sample no good				
D2	112800-113010	-18	25	3855	36°59.76'N, 86°53.52'W, Lat/Lon correct?
D3	Duplicate of D2				

D4	113610-113700	-10	22	2876	35°51.89'N, 86°46.88'W, SE end of track
D5	114200-114300	-10	24	2872	36°02.19'N, 86°55.61'W, past middle of track
D6	Can compromised -sample no good				
D7	121840-121925	-11	22	1890	36°00.09'N, 86°53.35'W, middle of track