SCOS97-NARSTO 1997 SOUTHERN CALIFORNIA OZONE STUDY AND AEROSOL STUDY

VOLUME IV: SUMMARY OF QUALITY ASSURANCE

FINAL REPORT
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PREPARED BY:

ERIC M. FUJITA
HANS MOOSMULLER
MARK GREEN
JOHN BOWEN
FRED ROGERS

DESERT RESEARCH INSTITUTE
P. O. BOX 60220
5625 FOX AVENUE
RENO, NV 89506

PREPARED FOR:

CALIFORNIA AIR RESOURCES BOARD
RESEARCH DIVISION
2020 L STREET
SACRAMENTO, CA 95814

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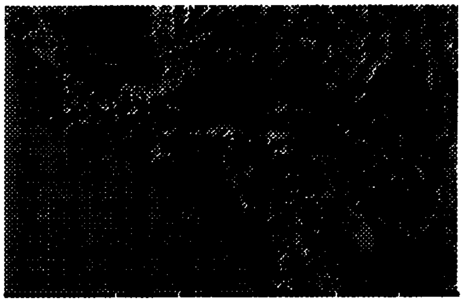

SCOS97-NARSTO
1997 Southern California Ozone Study and Aerosol Study

Volume IV: Summary of Quality Assurance

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Prepared by:

Eric M. Fujita, Hans Moosmuller, Mark Green, John Bowen, and Fred Rogers
Energy and Environmental Engineering Center
Desert Research Institute
P.O. Box 60220
5625 Fox Avenue
Reno, NV 89506

Leon Dolislager, Ash Lashgari, Nehzat Motallebi, Randy Pasek, and Jim Pederson
Research Division
California Air Resources Board
P.O. Box 2815
Sacramento, CA 95812

With extensive input from the SCOS97-NARSTO Technical Committee and Working Groups

SCOS97-NARSTO Technical Committee

Henry Hogo, South Coast Air Quality Management District
Don McNerny, Air Resources Board-Technical Support Division
Bart Croes, Air Resources Board-Research Division
Robert Ramirez, Air Quality Management District-Mojave Desert
Judith Lake, San Diego County Air Pollution Control
Doug Tubbs, Ventura County Air Pollution Control District
Carol Bohnenkamp, U.S. Environmental Protection Agency-Region 9
Jay Rosenthal, U.S. Navy

SCOS97-NARSTO Working Groups

Meteorology
Joe Cassmassi, South Coast Air Quality District
Leon Dolislager, Air Resources Board-Research Division
Jim Pederson, Air Resources Board-Research Division
Bruce Jackson, Air Resources Board-Technical Support

Air Quality
Dennis Mikel, Ventura County Air Pollution District
Ash Lashgari, Air Resources Board Research Division
Mahmood Hossain, San Diego County Air Control District
Steve Barbosa, South Coast Air Quality District

Emission Inventory
Dale Shimp (Chair), Air Resources Board Technical Support Division
Cheryl Taylor, Air Resources Board Technical Support Division

Study Personnel and Supporting Organization(s)

Personnel	Activity	Affiliation	Funding
Ozone			
Planning			
Eric Fujita	Field & QA	Desert Research Inst	ARB
Eric Fujita	QA Management	Desert Research Inst	Ventura CAPCD
Emission Inventory			
Debbie Niemeier	Traffic Counts	UC Davis	ARB
Roger Helvy	Shipping Traffic	U.S. Navy	U.S. Navy
Debbie Niemeier	Truck Activity	UC Davis	NREL
Tracer			
Russell N. Dietz	Tracer Release	Brookhaven National Lab	ARB Pacific Merchant SA Port of Long Beach Port of Los Angeles South Coast AQMD Steamship Association U.S. EPA
Supplemental Measurements of Ozone, Total Oxides of Nitrogen, and Meteorological Parameters at Ground Level			
Dennis Fitz	NO_Y	UC Riverside CE-CERT	ARB
Robert O'Brien	OH & O_2H	Portland State University	EPA
Daniel Grosjean	PAN-PPN	DGA	ARB
Jeffrey Shu	TDLAS	UC Riverside CE-CERT	ARB
Ernesto Tuazon	FTIR	UC Riverside CE-CERT	ARB
Janet Arey	Biogenics & PAH	UC Riverside	ARB
Bob Ramirez	NOY	Mojave Desert AQMD	U.S.M.C.
Dave Pankratz	Ozone & Met	Aerovironment	ARB
Mark Podrez	Ozone & Met	RTP	San Diego CAPCD
Radiation Measurements			
Dennis Fitz	Radiation Spectral, Broadband Continuous Aerosols	UC Riverside CE-CERT	ARB
William Carter	Actinometer Licor Spectral Photolysis	UC Riverside CE-CERT	ARB
James Gibson	UV Spectral	CSU-NREL	NREL
John Rives	Brewers Spectral	University of Georgia	EPA
Supplemental Speciated Hydrocarbon Measurements at Ground Level			
Dennis Fitz	VOC & Carbonyl	UC Riverside CE-CERT	ARB
Barbara Zielinska	VOC & Carbonyl	Desert Research Inst	ARB U.S. EPA
Sucha Parmar	VOC & Carbonyl	Atmospheric Analysis	U.S.M.C.
David A. Schorran	Halocarbons	Desert Research Inst	MDAQMD

Personnel	Activity	Affiliation	Funding
Ozone and Meteorological Measurements Aloft			
C. Russell Philbrick	Ozone Lidar	Penn State University	ARB, MDAQMD U.S. EPA, U.S.M.C.
Yanzeng Zhao	Ozone Lidar	NOAA	ARB, U.S. EPA
John Carroll	Cessna 182	UC Davis	ARB
Alex Barnett	Met Audits	Aerovironment	ARB, San Diego CAPCD South Coast AQMD
Robert Weber	Met Data Mgmt	NOAA	ARB
George Frederick	RWP-RASS (5)	Radian	ARB
William D. Neff	RWP-RASS (11), Sodars (3)	NOAA	U.S. EPA
Daniel Wolfe	RWP-RASS (2)	NOAA	U.S. EPA
Jerry A. Anderson	Aztec	Sonoma Tech	ARB
Dennis Fitz	Rawinsondes	UC Riverside CE-CERT	ARB
Ken Underwood	Sodar(3), Rawin	Aerovironment	U.S.M.C.
Roger Helvy	Rawinsondes	U.S. Navy	U.S. Navy
Dennis Mikel	Rawinsondes	Ventura CAPCD	Ventura CAPCD
Ken H. Underwood	Sodar	Aerovironment	San Diego CAPCD
John Collins	Ozonesondes	UC Riverside CE-CERT	ARB
Bill Brick	Rawinsondes	San Diego CAPCD	San Diego CAPCD
William Gibbs	Cessna 182	Gibbs Flite Center	San Diego CAPCD
William Gibbs	Navajo	Gibbs Flite Centere	San Diego CAPCD
Roger Helvy	Partnavia, Rawinsondes Ozonesondes, Met Audits Surface Sites	U.S. Navy	U.S. Navy
Dennis King	Met Audits	ARB	ARB
Ken Stround	RWP-RASS (2)	ARB	ARB
Kevin Durkee	RWP-RASS (2)	South Coast AQMD	South Coast AQMD
Kent Field	RWP-RASS (1)	Ventura CAPCD	Ventura CAPCD
Ms. Christy Crosiar	RWP-RASS (3)	U.S. Air Force	Vandenberg AFB
Ms. Jean Timmerman	RWP-RASS (2), Sodar (1)	San Diego CAPCD	San Diego CAPCD
Data Management & Analysis			
Bill Brick	Analysis & Mgmt	San Diego CAPCD	San Diego CAPCD
Paul Roberts	PAMS Analysis	Sonoma Tech	South Coast AQMD

Aerosols

Personnel	Activity	Affiliation	Funding
Supplemental Measurements at Ground Level			
Dennis Fitz	Nitrate & Sulfate	UC Riverside CE-CERT	ARB
Dennis Fitz	Ammonia	UC Riverside CE-CERT	ARB
Kim Prather	Time of Flight MS	UC Riverside	ARB, NREL
Glen Cass	Aerosol Comp	Cal Tech	CRC, NREL
Susan Hering	Real Time Aerosol	Aerosol Dynamics Inc	CRC, NREL
Susan Hering	Continuous Nitrate	Aerosol Dynamics Inc	EPRI
Delbert J. Eatough	Organic/Elem Carb	Brigham Young Univ	EPRI
Fred Rogers	Flow Audits	Desert Research Inst	EPRI
Petros Koutrakis	Fed Ref Method	Harvard School of PH	EPRI

Personnel	Activity	Affiliation	Funding
Petros Koutrakis	Nephelometers	Harvard School of PH	NREL
Measurements Aloft			
John Seinfeld	CIRPAS	Cal Tech	ARB

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1. INTRODUCTION

This document provides a summary of the results of external quality assurance audits that were conducted as part of the 1997 Southern California Air Quality Study – North American Research Strategy for Tropospheric Ozone (SCOS97-NARTSO). SCOS97-NARSTO was conducted in order to update and improve the existing aerometric and emission databases and model applications for representing urban-scale ozone episodes in southern California, and to quantify the contributions of ozone generated from emissions in one southern California air basin to federal and state ozone standard exceedances in neighboring air basins. The SCOS97-NARSTO Field Study Plan (Fujita et al., 1996) provided a conceptual model for the ozone episodes and transport scenarios of interest and specified the data requirements for data analysis and modeling. The SCOS97-NARSTO Quality Assurance Plan (Fujita et al., 1997) specified the systems and performance audits to be performed during the study. The QA plan identified the work elements to be performed, the technical approach for implementing each element, and schedules. It specified the measured quantities to be challenged during the audits, criteria for evaluation of audit findings, estimated precision and accuracy of audit standards, certification of audit standards, and approaches to problem resolution and verification of corrections. Pasek et al. (1998) provides a summary of the measurements that were actually made during the 1997 field study, and characterization of the intensive operational periods according to ozone transport scenarios.

Quality assurance for SCOS97-NARSTO was under the overall direction of Desert Research Institute. DRI coordinated a QA team consisting of staff from sponsoring agencies and other contractors that had the necessary expertise to carry out the QA activities in the QA plan. DRI and the QA team performed system and performance audits, reviewed and validated study data processing procedures and data, and estimated the uncertainties in the data. Data quality objectives were specified prior to the study in the QA plan (Fujita, et al., 1997) to ensure that all measured data meet the end-use requirements for air quality and meteorological model input and evaluation, data analyses, and monitoring the success of meeting data quality objectives. Precision and accuracy goals were also identified for measurement variables. Many methods and procedures employed in SCOS97-NARSTO are routinely measured variables for which expected precision and accuracy are known. Other measurements are experimental and target objectives that can only be estimated.

1.1 Quality Assurance Tasks, Organization And Responsibilities

The purpose of quality assurance is to provide a quantitative estimate of the uncertainty of the measurements through estimates of the precision, accuracy (or bias), and validity. In addition, QA ensures that the procedures and sampling methods used in the study are well documented and are capable of producing the data that meet the specifications of the study. The QA auditing program consists of two components: system audits and performance audits. System audits include review of operational and quality control procedures to assess whether they are adequate to assure valid data that meet the specified levels of accuracy and precision. After reviewing the procedures, the auditor examines all phases of the measurement or data processing activity to determine whether the procedures are being followed and the operating personnel are properly trained. Performance audits establish whether the predetermined specifications for accuracy are being achieved in practice. For measurements, the performance audit involves challenging the measurement/analysis system with a known standard sample that is traceable to a primary standard. Measurements that can be subject to sampling artifacts, such as carbonyl compounds, hydrocarbon speciation, and NOy, preclude simple performance audits. Intercomparison studies were used in these cases to assess the representativeness, accuracy, and precision of these measurements.

Quality assurance was under the overall direction of Desert Research Institute, the QA manager for SCOS97-NARSTO. DRI was responsible for developing a quality assurance plan in conjunction with field managers from sponsoring agencies, measurement contractors, and quality assurance personnel from the District and the California Air Resources Board. DRI conducted performance audits for measurement of carbonyl compounds and organized measurement comparisons for various VOC measurements and aloft air quality measurements. QA personnel from the ARB, South Coast Air Quality Management District, San Diego Air Pollution Control District conducted system and performance audits of surface air quality and meteorological measurements. Aerovironment Environmental Services, Inc. (AVES) reviewed candidate upper-air meteorological monitoring sites and performed system and performance audits of the network. The following is a summary of the quality assurance tasks/activities for SCOS97-NARSTO and responsibilities of the quality assurance team.

1.2 Surface Air Quality and Meteorological Measurements

The California Air Resources Board (ARB), South Coast Air Quality Management District (SCAQMD) and San Diego Air Pollution Control District (SDAPCD) quality assurance staff conduct regularly scheduled performance audits of all air quality monitoring stations. During the period between January and March 1997, the ARB audited 36 monitoring stations that are located in the SCOS97-NARSTO study area. During the April to June 1997, the ARB audited 37 other monitoring stations. Twelve additional monitoring stations in the SoCAB were audited by ARB during the study. These additional stations were selected on the basis of relative importance of the sites to the objectives of SCOS97. During this time, ARB also audited the five supplemental air monitoring sites operated by AeroVironment. ARB QA staff also audited the ozone and NOx analyzers onboard the four SCOS97 aircraft during early June 1997.

1.3 Upper-Air Meteorological Measurements

Upper-air meteorological measurement audits were performed by Aerovironment Environmental Services, Inc. They consisted of system audits at all measurement sites and performance audits at all sodar sites and some of the radar wind profiler/RASS sites. At least one site operated by each measurement group was included in the performance audits. The system audits primarily evaluated whether the instrument siting and setup was proper. The performance audits evaluated the data collected by the instruments against standards or other collocated instruments.

The radar wind profiler performance audits used sodars to check the lower gates of the RWP and rawinsondes to check the full RWP range. The sodars were checked against collocated rawinsonde data and with acoustic pulse transponders (APT). The APT produces a simulated wind profile made up of sounds with known frequencies that are timed to simulate the Doppler shifted echoes scattered by the atmosphere from various altitudes. The RASS performance audit used collocated rawinsonde data to compute virtual temperature for comparison to the RASS derived virtual temperature.

1.4 Aloft Air Quality Measurements

As part of SCOS97-NARSTO, the Air Resources Board and Desert Research Institute organized performance audits of aloft air quality measurements prior to the main study. This performance audit was conducted in the vicinity of El Monte Airport (EMA) with the airport serving as base. Aloft intercomparisons between the NOAA ozone lidar (located at EMA), CE-CERT ozonesondes and several instrumented aircraft were included in this audit. The ARB Quality Assurance staff conducted performance audits of the onboard air ozone and NO_X analyzers. In addition, the availability of upper air meteorological data is important to improve the comparison between different sample volumes. Data from the RWP/RASS system located at EMA were used for this purpose.

Three flight patterns for the participating aircraft were utilized for this performance audit:

- Spiral flight patterns were used for the intercomparison between aircraft themselves, and between aircraft, ozone lidar, and ozonesondes. This is the most generally useful flight pattern for intercomparison.
- Spiral flight patterns interspersed with orbits were used for the intercomparison between a single aircraft and the ozone lidar. The additional orbits made it possible to distinguish between horizontal and vertical gradients encountered by an aircraft flying a spiral pattern.
- Traverses were used for additional intercomparison between the different instrumented aircraft.

Section 4 provides the details of these intercomparisons. Conducting the audits before the main study made it possible to identify, address, and possibly correct potential performance problems prior to commencement of the main study period.

1.5 Volatile Organic Compound Measurements

The hydrocarbon performance audits consisted of two ambient samples. The protocol for this comparison and results are included in Appendix A. Participants included the California Air Resource Board (ARB), Atmospheric Analysis and Consulting, Inc. (AAC), Bay Area Air Quality Management District (BAAQMD), Biospheric Research Corporation (BRC), Desert Research Institute (DRI), U.S. Environmental Protection Agency (EPA), ManTech Environmental Technologies, Inc. (ManTech), San Diego Air Pollution Control District

(SDAPCD), South Coast Air Quality Management District (SCAQMD), and Ventura County Air Pollution Control District (VCAPCD). Participants supplied their own canisters. A DRI manifold sampling system (described in Appendix B) was used to collect up to twelve collocated samples at three sites. One set of canisters was collected in the morning in an area heavily influenced by on-road motor vehicles (at downtown Los Angeles). The second set was collected in the afternoon in a downwind ozone receptor area (Azusa). The third set represents upwind background, and was collected at Santa Monica Beach in the late afternoon after the marine layer had moved inland.

Performance audits for measurement of carbonyl compounds included sampling from a standard mixture of carbonyl compounds under field condition for both surface- and aircraft-based sampling and field measurement comparisons involving collocated sampling at Azusa during a non-IOP day with anticipated high levels of ozone. Participants included the San Diego Air Pollution Control District (SDAPCD), South Coast Air Quality Management District (SCAQMD), Ventura County Air Pollution Control District (VCAPCD), Atmospheric Analytical Consultants (AAC), and Atmospheric Assessment Associates (AtmAA). Appendix C describes the protocols for these comparisons.

Measurement comparisons were also conducted for measurement of halocarbons and biogenic hydrocarbons. Two canister samples that were collected at the Azusa sampling site during SCOS intensive operational periods were used in the intercomparisons of halocarbon measurements. In addition to speciated hydrocarbons, which were the primary reason for collection of these samples, Biospheric Research Corporation also analyzed the two samples for halogenated hydrocarbons. These samples were then be sent to DRI (Zielinska by laboratory GC-ECD), DRI (Schorran by on-site, semi-continuous GC-ECD) and Mantech, in round-robin fashion, for analysis of halogenated hydrocarbons. Semi-continuous measurements of halogenated hydrocarbons that are made at Azusa by Daniel Grosjean Associates, Inc (DGA). For the corresponding sampling period were also included in the comparison. Ambient sample collected by UC, Riverside in canisters and on absorbent tubes were used in a comparison of biogenic species. Canister samples were analyzed by BRC, DRI and ManTech. Protocols for the halocarbon and biogenic hydrocarbon measurement comparison are described in Appendix D and E, respectively.

1.6 Aerosol Measurements

DRI personnel conducted flow audits of the SCOS97 particle samplers. These audits included two MOUDI impactors, one EEA, one PM_{10} and three $PM_{2.5}$ samplers at each of three sites – Riverside, Los Angeles, and Azusa. In addition an optical particle counter was audited at two of the three sites.

1.7 Guide to Report

This introductory section has specified the goals and technical objectives of SCOS97-NARSTO quality assurance program. Results of audits and intercomparisons are summarized for surface air quality and meteorology, upper-air meteorology, upper-air air quality, volatile organic compound, and particulate measurements in Sections 2, 3, 4, 5, and 6, respectively.

2. SURFACE AIR QUALITY ANALYZERS AND METEOROLOGICAL MEASUREMENTS

In the SCOS97 study region, the Ventura County Air Pollution Control District (VCAPCD), South Coast Air Quality Management District (SCAQMD), Mohave Desert Air Quality Management District (MDAQMD), and San Diego Air Pollution Control District (SDAPCD) are responsible for determining compliance with state and federal air quality standards. Several agencies at the periphery of the study area (Santa Barbara Air Pollution Control District (SBAPCD), Imperial County Air Pollution Control District (ICAPCD), and the ARB) have similar responsibilities.

Three types of surface air quality monitoring stations are operated by the air pollution control districts. The National Air Monitoring Stations (NAMS) were established to ensure a long term national network for urban area-oriented ambient monitoring and to provide a systematic, consistent database for air quality comparisons and trend analysis. The State and Local Air Monitoring Stations (SLAMS) allow state and local governments to develop networks tailored to their immediate monitoring needs. Special purpose monitors (SPM) fulfill very specific or short-term monitoring goals. SPMs are typically used as source-oriented monitors rather than monitors which reflect the overall urban air quality. In California, photochemical assessment monitoring stations (PAMS) are required in Ventura County, and the South Coast, Southeast Desert and San Diego air basins. Each station measures speciated hydrocarbons and carbonyl compounds, ozone, oxides of nitrogen, and surface meteorological data. Additionally, each area must monitor upper air meteorology at one representative site. Data from all four types are submitted by state and local agencies to EPA's Aerometric Information Retrieval System (AIRS), which serves as the national repository for air quality, meteorological and emissions data. The operators of these routine measurement networks have in place quality assurance plans specific to their network. The ARB also provides regularly scheduled air quality audits of field sites and equipment.

2.1 Sampling Procedures

Operational procedures are contained in Standard Operating Procedures (SOP) of the various agencies and in the instrument manufacturers' manuals. All the Air Pollution Control Districts measure ozone and NO/NO_X with continuous analyzers. At present, most of the NO/NO_X analyzers are operated with an inline filter made of Teflon to remove particulate matter from the ambient air before the measurement is made. For the SCOS97 study, the Teflon filters were replaced by nylon filters (Membrana-Ghia Nylasorb) to remove nitric acid in addition to particulate matter.

AVES deployed continuous analyzers for the measurement of ozone and NO/NO_X concentrations at five supplemental sites. AVES developed a quality assurance project plan specific to measurements at these sites that include standard operating procedures (SOPs) to describe the quality assurance/quality control plans for the project. Nylon filters (Membrana-Ghia Nylasorb) were installed on the NO/NO_X analyzers and Teflon filters (Millipore LS 5.0 μm) were installed on the Ozone analyzers to remove particles. Filters were replaced once a week.

Specific instructions are contained in available QA Plans in the form of standard operating procedures and in the manufacturers' manuals. The Air Pollution Control Districts have routine calibration procedures that include multipoint calibrations of the ozone and NO/NO_X analyzers when instruments are installed or repaired. At the supplemental sites, multipoint calibrations of the continuous air quality analyzers for ozone and NO/NO_X were performed at the start and end of the study, following a zero and/or span adjustment necessitated by out-of-tolerance zero/span checks, and after instrument repair.

In addition to calibrations, routine site visits are made to each site by field technicians on a regular schedule at least once a week but usually daily. The technicians were trained to follow procedures setup by the APCD or by AVES. Automated zero/span checks are performed every night at most sites. Manual precision checks are made once a week at many sites. Site visits were made to ensure that all equipment were operating properly, to identify instrument problems and to give warning of developing problems.

Station checks are performed each site visit following the steps prescribed on station check forms. During each site visit, the site technician visually inspected the meteorological sensors, the ambient air sampling probe and inlet system, and the air sampling systems. All visits are documented. Copies of recorded data and documentation are returned at specified intervals, generally once a month, to the agency office for processing.

Quality control checks consist of periodic zero/span checks and precision checks. In both cases, test atmospheres are introduced to the analyzer operating in its normal sampling mode through a solenoid valve controlled by the site DAS. Test gases pass through all filters, scrubbers, conditioners, and other components used during normal sampling.

At many sites, each air quality analyzer is subjected to an automated zero/span check once a night. Test gases at zero and one span concentration are introduced to each analyzer. The span gas concentration is about 80% of the analyzer's nominal operating range. Zero/span data are used to determine if an analyzer needs adjustment and to evaluate validity of data. Zero/span data are accessed by telephone along with the ambient data and are reviewed daily. The following criteria are used in evaluating the data:

- Zero checks: Daily check should be within ±2% of full scale from the zero value established during calibration. If two consecutive zeros exceed ±2%, the instrument is removed from service, the problem corrected, and the instrument recalibrated and returned to operation. If the check exceeds ±3%, the instrument is immediately taken off line, given a "before" calibration, fixed, and given an "after" calibration. If the check exceeds ±5%, the instrument has serious problems and data is invalidated. The same action as the 3% criteria is done.
- Span checks: Daily check (about 80% of full scale) should be within ±10% of span value established during calibration. If two consecutive spans exceed ±10%, the instrument is removed from service, the problem corrected, and the instrument recalibrated and returned to operation. If the check exceeds ±15%, the instrument is immediately taken off line, given a "before" calibration, fixed, and given an "after"

calibration. If the check exceeds ±25%, the instrument has serious problems and data is invalidated. The same action as the 15% criteria is done.

At some sites, the technician performs a manual precision check once a week. For this, gas with concentration between 80 and 100 ppb is introduced to the analyzer. The response of the analyzer is entered on the log sheet. Precision checks are made before any instrument adjustments or recalibrations are done. Procedures for calibration, zero/span, and precision checks are summarized in the following sections.

2.1.1 Ozone

The Air Pollution Control Districts measure ambient ozone concentrations with instruments made by several different manufacturers. All analyzers employ the UV photometric technique to determine ozone concentration. All analyzers have been designated as EPA Equivalent Methods. The following analyzers were deployed in the networks:

Thermo Environmental Inc., model 49
Dasibi Environmental, model 1003
Advanced Pollution Instrumentation, Inc., model 400
Dasibi model 1003AH (at the supplemental sites)

The general methods for measurement for the different analyzers are similar. The analyzers consist of a sample chamber illuminated with a continuous ultraviolet (UV) lamp with frequency at 394 nm. The air sample is first introduced to the chamber after passing through a molybdenum oxide scrubber to catalytically convert ozone to oxygen. A sensing system measures the amount of radiation that passes through the chamber without ozone in it. Then the sample is introduced to the chamber with ambient ozone in it. The difference between the UV light passing through the chamber without ozone and with ozone is proportional to the amount of ambient ozone. Some analyzers also contain sensors to measure temperature and pressure in the sample chamber so that ozone readings can be referenced to ambient conditions. Other analyzers require the measurements to be referenced to fixed conditions as determined by the average absolute pressure and temperature in the analyzer sample chamber so that ozone concentrations are given at approximately ambient conditions.

The ozone calibration system includes a transfer standard and clean air system. Ozone-free air is generated by passing ambient air through a desiccant and activated charcoal and a desiccant. The ozone transfer standard has an internal ozone generator that supplies ozone to the instrument to be calibrated and its own measurement chamber.

First, ozone-free air from the dilution system is introduced to the instrument to obtain the zero level. Then, up to five concentrations of ozone are supplied to the analyzer ranging from 10% to 90% of the analyzer range with one near the span point of 450 ppb and one near the precision point of 100 ppb. The test gases are delivered to the analyzer's sample inlet via a Teflon tube to reduce losses of ozone. This tube contains a Teflon vent to allow excess flow escape and maintain the inlet at atmospheric pressure. Test gas passes through as much sample tubing as possible including any filter normally associated with the sampling process.

Readings from the calibrator display and primary site DAS are recorded on a calibration form and a least-squares linear regression between DAS and calibrator readings is computed. The regression for a valid calibration has a slope of 1.000±0.01, an intercept of 0.0±0.01, a regression coefficient of at least 0.999. Instruments exceeding these tolerances require further checking and possibly repair or replacement.

The ozone transfer standards are calibrated approximately once a quarter with a laboratory transfer standard. The laboratory standard is verified annually with the long-path UV Photometer at the California Air Resources Board in Sacramento, CA.

2.1.2 Oxides of Nitrogen

The Air Pollution Control Districts measure ambient NO/NO_X concentrations with instruments made by several different manufacturers. These analyzers measure the concentration of nitric oxide (NO) and total oxides of nitrogen (NO_X) by a chemiluminescence method and nitrogen dioxide (NO_2) by difference between NO_X and NO. Each analyzer has been designated as an EPA Reference Method. The following analyzers are deployed in the networks:

Thermo Environmental Inc., model 14B/D
Thermo Environmental Inc., model 42
Advanced Pollution Instrumentation, Inc., model 200A
TEI Model 42 NO/NO_X (at the supplemental sites)

When NO and ozone are mixed, a gas-phase reaction occurs that produces a characteristic luminescence with an intensity that is linearly proportional to the concentration of NO. A photomultiplier tube senses the luminescence generated by the reaction. Other oxides of nitrogen can also be measured by first reducing them to NO with a molybdenum converter heated to 325 °C and then measuring the result by chemiluminescence as NO_X. The analyzer switches between measuring NO and NO_X and electronically computes difference between NO_X and NO. The difference can in some cases be attributed to NO_2 as the other major constituent of NO_X. The instrument's converter can also convert other nitrogenous species, such as nitric acid and PAN, to NO. Nitric acid and nitrate particles can be removed from the sample by installing a nylon filter on the sample inlet.

The calibration standards consists of a dilution flow metering system, NO/NO_X-free dilution air (zero air) system, and a cylinder of compressed gas containing a known amount of NO. The manually operated dilution system contains one flow controller (mass or volumetric) to meter accurate amounts span gas, a second flow controller (mass or volumetric) to meter accurate amounts of dilution air, and a Teflon-lined or glass mixing chamber. The dilution air is generated by forcing ambient air through desiccant, Purafil, and activated charcoal. Purafil (potassium permanganate) oxidizes NO to NO_2 that is then removed by the charcoal. A cylinder of compressed gas provides a source of approximately 50 ppm NO in a balance of nitrogen. The dilution system also has a section that produces a known concentration of NO_2 by performing a gas phase titration (GPT) in which O_3 is mixed with NO to generate NO_2.

Zero and up to five upscale concentrations of NO are introduced to the instrument. The concentrations of NO range from 10% to 90% of the analyzer range with one near the span point of 450 ppb and one near the precision point of 100 ppb. Delivery to the analyzer is through as much sample line as possible including the switching solenoid valve and any inline filters.

Readings from the analyzer display and primary DAS for NO and NO_X are recorded and linear regressions of sampler versus calibrator NO and NO_X are computed. For linear operation of the analyzer, the computed regression coefficient should be at least 0.999.

The NO_2 channel response and the efficiency of the NO_X to NO converter are tested with NO_2 generated in the GPT section of the dilution system. These tests are done at 3 different NO_2 and NO_X concentrations while the NO concentration remains between 80 to 100 ppb. NO gas with concentrations for the three points are near 450, 300, and 150 ppb. The responses of the NO and NO_X channels to this NO are recorded and adjusted by the linear regression equations relating instrument response to calibration concentration. Ozone is mixed with the NO to generate NO_2 concentrations near 350, 200, and 50 ppb that are introduced to the instrument. The responses of NO and NO_X are recorded and corrected for the calibration results.

For each test, the response of the NO_2 channel is compared to the NO_2 concentration generated by the GPT as determined from

$$\text{GPT } NO_2 = \text{Orig NO} - \text{Rem NO}$$

where: Orig NO is adjusted response of NO channel before O_3 is mixed and
Rem NO is adjusted response of NO channel after O_3 is mixed.

The converter efficiency, Conv Eff, is determined in the following steps:

$$NO_X = \text{Orig } NO_X - \text{Rem } NO_X$$

$$\text{Conv } NO_2 = \text{GPT } NO_2 - \_NO_X$$

$$\text{Conv Eff} = 100 \times (\text{conv } NO_2)/(\text{GPT } NO_2)$$

where: Orig NO_X is adjusted response of NO_X channel before ozone is mixed and
Rem NO_X is adjusted response of NO_X channel after ozone is mixed.

An overall converter efficiency is calculated by averaging the efficiencies at the three levels. Converter efficiency less than 96% indicate that the converter material should be replaced.

2.1.3 Surface Meteorological Measurements

The audit standards that the AVES audit team used in the field were certified at the beginning of the audit program in accordance with the procedures recommended in the EPA monitoring guidelines (EPA, 1994a, 1994d). All instruments were certified by the AVES

Measurements Standards Laboratory, with the exception of the barometers that are certified by Temperature Standards, Inc. of Monrovia, California. The results of these certifications were documented and added to the existing certification history for each instrument. If the results of a certification showed that an instrument did not meet the EPA-recommended criteria (EPA, 1994a, 1994d), the instrument was repaired and recertified before it was allowed to be used again.

Performance audit procedures and criteria were those recommended in the U.S. EPA *Handbook for Air Pollution Measurement Systems*, Volume IV (EPA, 1994d). The audit standards used in the audits, audit standard accuracies and precision, as well as the audit criteria, are detailed in Table 2-1.

<u>Wind Speed</u>

Cup or propeller anemometers of several manufacturers and models measure wind speed. As the cup or propeller turns a pulse is generated by a magnetic or optical switch or a direct voltage is generated by a small electrical generator. The frequency of the pulses or the generated voltage is proportional to the wind speed. The manufacturers supply relations between wind speed and rotation rate for their sensors. The sensors using a propeller are generally combined with a moveable vane to align with the wind. The cups rotate about a vertical shaft have an omni-directional response to the wind. The following sensors are found in the study area:

Met One, model 010 and 014
Climatronics, model F460
R.M. Young, model Wind Monitor-AQ, Wind Monitor-RE
Bendix Aerovane

The supplemental sites used R.M. Young, model Wind Monitor-AQ and Wind Monitor-RE sensors.

The wind speed sensors are calibrated one to two times a year when routine maintenance is done on the sensors, such as replacement of bearing. Known rotation rates are applied to the sensors while monitoring the DAS reading. Variable or fixed rate motors are attached to the anemometer in place of propeller or cups and the sensor shaft is turned at known angular speeds. DAS wind speeds are compared to the values supplied by the manufacturer of the sensor for known rotation rates.

Bearings are checked before calibration to determine if they affected the wind speed data before replacement. Rotation of shaft is checked for smoothness of operation and starting torque is measured with a torque wheel. For the RM Young Wind Monitors, bearings are replaced if a sensor fails to respond to a 0.3 g-cm torque.

The wind speed audit began with the inspection of the wind speed cups or propeller(s) to ensure that they were intact. The cups were then removed to produce a zero point. Next, the R.M. Young selectable speed anemometer drive was connected to the sensor shaft to simulate wind speeds of approximately 10, 25 and 35 m/s. Actual values depended on the sensor model and were determined by multiplying the motor speed by a cup or propeller transfer coefficient supplied by the manufacturer. The data logger responses were entered into the AVES Audit Software Package (AVASP) and the difference between them and the audit input values were calculated. The calculated difference for each wind speed was then compared with the audit criteria (see Table 2-1).

The sensor bearings were then checked for excessive wear by manually turning the sensor shaft to determine whether there was any bearing drag. Next, the sensor was removed from the cross-arm and the R.M. Young torque was disk mounted on the sensor shaft. The starting torque was determined using the manufacturer-recommended procedures.

Anemometer Drive

Wind direction is measured with a vane to that aligns itself along the direction of the wind. The orientation of the vane relative to a fixed direction, generally true north, is measured by the voltage across a potentiometer and is proportional to the angle of the vane. The following sensors are found in the study area:

Met One, model 020 and 024
Climatronics, model F460
R.M. Young, model Wind Monitor-AQ, Wind Monitor-RE
Bendix Aerovane

The supplemental sites used R.M. Young, model Wind Monitor-AQ and Wind Monitor-RE sensors. The R.M. Young Model 18801 anemometer drive is certified quarterly. A photo tachometer is used to determine the actual rotational speed of the anemometer drive shaft for comparison with the rotational speed indicated by the anemometer drive display. Readings are made at six speeds evenly spaced through the entire operating range of the instrument.

Torque Disk

No certification required.

Wind Direction

Wind direction was measured with a vane to that aligns itself along the direction of the wind. The orientation of the vane relative to a fixed direction, generally true north, is measured by the voltage across a potentiometer and is proportional to the angle of the vane. The following sensors are found in the study area:

Met One, model 020 and 024
Climatronics, model F460
R.M. Young, model Wind Monitor-AQ, Wind Monitor-RE
Bendix Aerovane

The supplemental sites will use R.M. Young, model Wind Monitor-AQ and Wind Monitor-RE sensors. The wind direction sensors are calibrated one to two times a year using an angle calibrator. With the sensor in place on the calibrator and connected to the DAS, the vane is moved around the 360° circle in 10° increments. The DAS readings are compared to the calibrator angles. Sensors that have readings within ±2° of calibrator are used without correction. Sensors outside that limit are inspected for problems or used with an correction developed from the calibration.

The wind sensor cross-arm alignment relative to true north was checked using a tripod-mounted Brunton surveyor compass. The angle of declination was taken into account when performing this check. The wind direction vane was then pointed toward the four cardinal directions and the responses of the data logger were noted. The data logger responses were entered into the AVASP for comparison with the audit input values. The difference calculated for each input wind direction was compared with the criteria (see Table 2-1).

The sensor bearings were then checked for excessive wear, first by manually turning the sensor shaft to determine whether bearing drag was present and then by using an R.M. Young vane bearing torque gauge according to the manufacturer-recommended procedures.

Compass

No certification required.

Torque Disk

No certification required.

Ambient Temperature

Temperature at the sampling sites is measured with a thermistor, a platinum resistance thermometer, or a thermocouple. The thermistor and RTD are both resistance devices that respond proportionally to temperature with a voltage output that is proportional to temperature. The thermocouple develops a voltage proportional to temperature because of the proximity of dissimilar metals. A data acquisition system linearizes the voltage output for these sensors. The sensors are installed in radiation shields to reduce the effect of direct solar radiation. The shields are either mechanically aspirated with a small blower or naturally aspirated by air movement around the sensor. Vaisala model HMP35C temperature/relative humidity sensors were used at supplemental sites. The temperature sensor was a thermistor.

Temperature sensors that can be immersed in water are calibrated one to two times a year using water baths over the range of the sensor. Low temperature is obtained with an ice bath. Higher temperatures are reached by heating the bath with an immersion heater. A calibration thermometer with NIST-traceability should be used to measure the bath temperature. The error associated with this method is less than ±0.5 °C.

For temperature sensor than cannot be immersed in water, the calibration can be checked by placing an aspirated, NIST-traceable thermometer near the sensor and comparing the site sensor reading to the calibration thermometer. The side-by-side calibration check can have an error of about ±1 °C when done outdoors because of the effect of solar radiation. The mercury-in-glass thermometer was compared to AVES' NIST-traceable standard thermometer when it was purchased. The two thermometers were immersed in water baths of approximately zero, 10°, 20°, 30° and 40°C. Periodic comparisons with the standard thermometer are not required.

The temperature-sensing system was audited by immersing the system thermistor and an NIST-traceable mercury-in-glass thermometer in the same water bath and comparing the readings of the thermometer with the data logger and chart recorder outputs at approximately zero, 20° and 40° C. The comparisons were carried out using the AVASP . The difference calculated for each point was compared with the audit criteria (see Table 2-1).

Relative Humidity and Dew-point Temperature

The relative humidity or dew point is measured at some sites. Relative humidity is measured with capacitance or resistive devices having thin polymer films that change characteristics as water is absorbed. Dew point is measured with a chilled mirror sensor or LiCl dew cell with a heated wire-wound bobbin that absorbs water vapor and releases water vapor in proportion to the dew point. Vaisala model HMP35C temperature/relative humidity sensors were used at supplemental sites. The relative humidity sensor is a capacitive device.

When the psychrometer mercury-in-glass thermometers were purchased, they were compared to AVES' NIST-traceable standard thermometer. The two psychrometer thermometers and the standard thermometer were immersed in water baths of approximately zero, 10°, 20°, 30° and 40°C. Periodic comparisons with the standard thermometer are not required.

The calibration of the relative humidity/dew point sensor is checked by placing the sensor in chambers containing different saturated salt solutions. These solutions give relative humidities that depend on the salt and the temperature. The range of relative humidity for typical salts is about 12% for LiCl to 97% for K_2SO_4. This calibration is best done in a controlled environment and not outdoors.

The calibration can be checked in the field by placing a separate relative humidity sensor or an aspirated, psychrometer with NIST-traceable thermometers near the sensor. As with the temperature check, the psychrometer should be shaded from direct solar radiation while being exposed to the free-air. Simultaneous readings from the sensor and the wet- and dry-bulb thermometers of the psychrometer are recorded. The relative humidity is determined from psychrometric tables or a psychrometric slide rule.

The wet bulb thermometer's muslin wick of the motorized psychrometer was wetted with distilled water. The motorized psychrometer was then placed in close proximity to the relative humidity or dew-point sensor and allowed to run for at least five minutes or until the thermometer readings stabilized. Once the readings stabilized, the audit psychrometer wet and dry bulb temperatures, the audit barometric pressure and the station's relative humidity and ambient temperature or dew-point temperature were read simultaneously. These readings were entered into the AVASP where the audit relative humidity or dew-point temperature was calculated. If relative humidity was present, it was converted to an equivalent dew-point temperature for comparison with the calculated audit dew-point temperature. If dew-point temperature was measured directly, the station value was directly compared with the calculated audit value. The difference between the station equivalent or measured dew-point temperature and the calculated audit dew-point temperature was compared with the audit criteria (see Table 2-1).

Audit barometer (Ultimeter Model 3)

The audit barometer is compared yearly with a standard barometer by the AVES standards laboratory. The last certification was performed on May 2, 1997.

Solar Radiation Sensor

Solar radiation at most sampling sites is measured with LiCor model LI-200SZ pyranometers. This sensor consists of a silicon photodiode that responds to light over the range that includes visible spectrum. When calibrated and orientated properly, the sensor has an output that is proportional to the incoming solar radiation, both direct and diffuse. Some sites use Epply thermopile sensors that generate a voltage by differential heating of white and black materials.

The calibration of the solar radiation sensors is best done by returning the sensor to the manufacturer on an routine schedule. A secondary check of the sensor can be made with a side-by-side comparison between the site pyranometer and a similar pyranometer that is only used for comparison. This comparison sensor is placed as near to and with similar exposure as the site pyranometer for a several hour period. A comparison of the readings of the two pyranometers gives an indication of the operating characteristics of the site sensor.

2.2 Performance Audits of Air Quality Analyzers and Surface Meteorological Measurements

Table 2-2 presents a summary of the results of performance audits of surface air quality analyzers and meteorological measurements.

2.3 Evaluation of Surface Meteorological Networks in Southern California

A review was done of the expected quality of surface meteorological sites for categories of sites in the SCOS97 modeling domain in southern California. This involved obtaining listings of site locations, discussing the QA practices with the responsible person for each network, and obtaining documentation (if available) on audit procedures for each network. The networks described here include:

- RAWS (Remote Automatic Weather Stations) networks:
- Bureau of Land Management (BLM)
- United States Forest Service (USFS)
- California Department of Forestry (CDF)
- National Park Service (NPS)
- California Department of Water Resources CIMIS (California Irrigation management Information System) network

- Federal Aviation Administration and National Weather Service ASOS (Automated Surface Observation System) and AWOS (Automated Weather Observing System) networks

The purpose of the review was to determine which networks *may* have suitable data for input into the meteorological models. An additional goal was to identify stations located in data sparse areas that may help the modeling of certain features, such as slope flows. Even if a review of audit procedures indicates that the data may be appropriate for use, it is necessary to do a review of the data from any site that may be used. This review would involve screening for unrealistic or non-sensible values, generation of wind roses by time of day and comparison to local terrain features, screening for hourly changes (too great or non-changing values for many hours), visual inspection of time series plots, etc.

2.3.1 RAWS Networks

The main purpose for RAWS stations is for fire weather information. These sites are often located in remote areas and once per hour their data is sent to a satellite. The typical parameters measured include:

- 10-minute average wind speed and direction at 20 feet
- peak wind speed and associated direction
- precipitation in last one hour
- air temperature
- fuel temperature (temperature very close to ground)
- fuel moisture
- barometric pressure (at some sites)

The weather stations are made by Handar, mostly model 540, some model 550. Handar gives a starting threshold of 1.7 mph for wind speed, but the BLM does not put them out into the field unless starting threshold is <0.5 mph. There are 5 or 6 different air temperature and relative humidity sensors. Data from all sites is stored at the National Interagency Fire Center in Boise and the Western Regional Climate Center at the Desert Research Institute in Reno. The maintenance is done separately for each network and is described below.

Documented quality assurance protocols were requested, but were not made available for the RAWS networks. This apparent lack of formal quality assurance plans cannot help but raise concerns as to the overall validity of the data.

2.3.2 BLM

The BLM stations are maintained by the National Interagency Fire Center (NIFC) in Boise, Idaho. All stations are visited at least once per year, plus whenever a problem is detected. These are 3 teams that travel from site to site. The RH/air temperature sensors are recalibrated yearly; the wind speed/wind direction sensors every other year. Before the wind speed calibrations, the anemometer bearings are changed. A computer "watchdog" program continuously checks for problems (no information on what algorithms are used). Twice per week the watchdog reports are reviewed and if necessary, a team is sent to a site to check the weather station.

Site maintenance records are supposed to be kept continuously updated in a database that includes other station information (detailed location and some site characteristic information). When I accessed the database, the maintenance records did not appear to be up to date.

2.3.3 USFS

The USFS sites are serviced once per year usually by someone at the local forest; however the Angeles National Forest sites are maintained by the NIFC. The level of maintenance will likely vary from forest to forest; the USFS sites are not generally expected to be as well maintained as the BLM sites. The local forest employee responsible for the RAWS sites has access to the results of the watchdog program run at NIFC and *should* be regularly checking the program reports.

2.3.4 National Park Service

There is one employee at the National Interagency Fire Center that works for the National Park Service. She uses the watchdog program to check the NPS sites once per week and notifies the responsible person at the park unit if there is a problem. Each park with a RAWS site has one person responsible for the site. If they suspect a problem, the sensors are sent to the NIFC for maintenance. As the NPS employee at NIFC stated, the quality of the data depends on the ability and conscientiousness of the individual at each park, some are good, others not so good. She did think that most of the NPS sites in California had competent RAWS operators.

<u>California Dept. of Forestry (CDF)</u>

These sites are calibrated on a once-per-year basis. The calibration is done at the State of California Department of General Services by employees who have been trained by Handar (the RAWS manufacturer). These sites are typically on south facing slopes in open terrain. In the SCOS97 study area, the sites are concentrated in the Santa Ana Mountains and the mountains east of Santa Barbara.

<u>Ventura County Flood Control District</u>

These sites are similar to the RAWS. The weather station is also made by Handar and includes wind speed and wind direction at 12 feet, air temperature, RH, and precipitation. Maintenance is done on a yearly basis, or more often, as needed.

2.3.5 CIMIS Network

The purpose of the CIMIS network is to provide data for irrigation management. These sites are situated in flat, irrigated areas with grass mowed to a height of 3 inches. As such, temperature and humidity measurements may be applicable only to these narrowly defined conditions. The CIMIS network does have well defined siting criteria. Material for this section was taken from the California DWR web site (http://wwwdla.water.ca.gov/cimis/cimis/hq/stnoper.txt). The stations are all virtually identical according to DWR and operations and maintenance standardized. The sensors and their heights are:

Pyranometer (Solar Radiation)	2 meters
Soil Temperature Sensor	-15 cm
Air Temperature Sensor	1.5 meters
Humidity Sensor	1.5 meters
Anemometer (wind speed)	2 meters
Wind Vane (wind direction)	2 meters
Precipitation Gauge	1 meter

Every minute, a data logger takes a reading from each instrument. Each hour, hourly averages (or totals in the case of precipitation) are computed. After midnight, the CIMIS central computer obtains data for the previous day from each site via telephone lines. A quality control program is automatically run and flags are assigned to the data.

All DWR maintained CIMIS stations (all DWR stations and some non-DWR stations) are maintained according to standards developed by DWR (but not listed). Non-DWR maintained stations may or may not be maintained to the same standards). The maintenance standards call for a maintenance visit every 3-4 weeks in the warm season and every 5-6 weeks in the cooler portions of the year. The main purpose of the maintenance visit is to check the sensors for accuracy and/or operation and to clean or replace sensors as required. The maintenance is performed by DWR staff from the DWR district offices.

2.3.6 ASOS and AWOS Networks

The Automated Surface Observing Systems (ASOS) are automated weather stations being deployed at about 850 locations in the U.S. These sites are located at large and small airports and will replace and expand upon the National Weather Service (NWS) human-made observations with automated observations. ASOS is a joint program of the Federal Aviation Administration (FAA), NWS, and Department of Defense. Observations are taken every one-minute. The following weather elements are reported hourly or more often if conditions change significantly:

- Sky condition: cloud height and amount (clear broken, scattered, overcast) up to 12,000 feet

- Visibility (only up to 10 miles)
- Basic present weather: type and intensity for rain, snow, and freezing rain
- Obstructions to vision: fog, haze
- Pressure: sea-level and altimeter setting
- Ambient temperature, dew point temperature
- Wind direction, wind speed, and character (gusts, squalls)
- Precipitation accumulation
- Selected significant remarks including – variable cloud height, variable visibility, precipitation beginning/ending times, rapid pressure changes, pressure change tendency, wind shift, peak wind

ASOS hardware maintenance for NWS and FAA sites is done by NWS technicians. The ASOS Operations and Monitoring Center (AOMC) of the NWS in Silver Spring Maryland monitors the ASOS site 24 hours a day and dispatches technician to the sites as needed. Diagnostic programs (not specified as to what is evaluated) are run continuously. At 15 minutes after each hour, a list of sites with missing data is generated. Some problems can be remotely cleared, for other problems, technicians are sent to the site. If a sensor is found to be reporting erroneous data, the sensor is disabled to prevent dissemination of bad data.

The ASOS network is relatively new and some problems with sensors have been reported; these sensors are supposedly being improved. The AWOS sites and especially the non-Federal AWOS sites may not be as well maintained.

This information was taken from internet sites for the NWS and FAA. Specific information on QA such as calibration schedules, etc. was not given.

2.3.7 Recommendations

The lack of any written quality assurance plan for the various RAWS networks is somewhat bothersome. On the positive side most of the sites are calibrated on a yearly basis and for the BLM, USFS, and NPS sites programs are automatically run to evaluate the data quality. For the BLM sites, full time teams of experienced technicians maintain the sites. Visual inspection of spatial patterns in RAWS wind data for Project MOHAVE showed little relationship in space between RAWS derived wind vectors. This could be indicative or poor data quality or a site-specific nature of the measurements. It is recommended that RAWS sites be considered for use only in areas of otherwise sparse data, i.e. to fill in gaps. Before the data is used, the data should be thoroughly evaluated, as described in the Introduction. In addition, it would be recommended that a component of the evaluation should involve a site visit to see the setting of the sensors and to help evaluate the scale of representation of the station.

The CIMIS sites have better documented QA procedures and frequent site visits. The quality of this data is expected to be acceptable; however the scale of representation may be small, especially for temperature and relative humidity and the wind sensors are at a height of only 2 meters. As for all other networks, the data needs to be evaluated before using.

The ASOS sites are at airports across the country and support aviation safety. Because of this importance and the fact that the sites are maintained by National Weather Service technicians, it is expected that the data is generally of acceptable quality for SCOS97. However, the network is relatively new and apparently the bugs are still being worked out to some degree. The AWOS sites would be expected to be more variable in the data quality. Again, before use of any of the meteorological data, an evaluation of the data should be done.

Continuous surface-based measurements will be made daily throughout the study period, which begins June 15, 1997 and end on October 15, 1997. The study period monitoring network consists of existing surface air quality, surface meteorology, and upper-air meteorology monitoring sites, as well as new sites added specifically for this study. The continuous data are used to:

- Characterize or describe the spatial and temporal distribution of pollutant concentrations and meteorological parameters on days leading up to and during ozone episodes and for documenting the frequency of occurrence of different measures for comparison with prior and later years.
- Document the transport of pollutants and precursors between major source regions and non-attainment receptor areas, between the major source regions, and between offshore and onshore, during both episode and non-episode conditions.
- Provide initial and boundary conditions for air quality model initialization, and input data for data assimilation by prognostic meteorological models.
- Provide data within the modeling domain to evaluate the output of the models and to diagnose deviations of model assumptions from reality.

2.4 Acceptance Testing of NO_Y Analyzers

Early in the planning process, the Air Quality WG determined that the bulk of the NO_Y instruments in the study would be the new Thermo Environmental Instruments TECO 42CY [11]; external converters were additionally installed on TECO 42S trace level [4] and TECO 42 [3] model instruments. Of these, TECO 42CY instruments in the original single converter setting were installed on board UC Davis Cessna 182 and San Diego Navajo airplanes. The STI airplane had 2 TECO 42S in the single converter setting on board. San Nicolas Island and the Alpine stations also operated TECO 42CY instruments in the original setting. Two TECO 42 instruments were also operated in the original setting at Cajon and Calabasas. All other stations used the dual converter setting with a nylon filter pack to also measure nitric acid by the subtraction method. This method had previously been successfully used in the NARSTO studies in eastern United States. The nitrogen species measurements also included gas chromatography electron capture detection instruments [2] to measure peroxyacetyl and peroxypropionyl nitrates and perchloro ethylene at Simi Valley and Azusa stations. Other nitrogen species measurements included luminox method nitrogen dioxide and peroxy acteyl nitrate instruments at Cajon West and at Calabasas stations and the tunable diode laser at Azusa [NO_2 and HNO_3]. A detailed description of the acceptance testing for TECO 42CY instruments, as transmitted to study participants and conducted at CE-CERT Riverside facility before SCOS97-NARSTO began, is provided below.

To prevent nitric acid from being converted and reported as NO_2 and after discussions with representatives from the U.S. EPA, the Air Quality WG also suggested that nylon filters be used on nitrogen oxides instruments at selected sites in the Routine Network [Mojave Desert, South Coast, and South Central Coast air basins' non-NAMS-stations].

2.4.1 TECO 42CY Acceptance Testing

Prior to acceptance testing, the instrument was turned on, allowed to stabilize for 12 or more hours and then zero checked. A compressed gas source of ultra zero grade air that had been further purified by passing through a Purifil cartridge was used. To determine if the instruments operated within the specifications supplied by the manufacturer, the analyzer was subjected to EPA-developed test methods for linearity, zero drift, span drift, and detection limit (EPA, 1977, Federal Register, 1975).

Linearity Test

A multi-point calibration was performed using dilution calibrator supplied with zero air from an Aadco purification system and a certified NO in nitrogen compressed gas source. Five calibration points were used to cover the range from zero concentration to 80% of scale in even increments. A least squares regression was performed. Linearity was validated if all points were within 1% of the least squares regression line.

Zero Drift

The manufacturer specification of "negligible" zero drift was defined as the lower limit of detection at the 120 second averaging time, 50 pptV. The analyzer was allowed to sample a compressed zero air source for a 48 hour period. Hourly averages were obtained with a data logger. The difference in hourly average taken 24 hours apart were designated as zero drift and compared to the manufacturer specification for acceptance.

Span Drift

The analyzer was allowed to sample a known source of NO at 80% of full scale for a 48 hour period. Hourly averages were obtained with a data logger. The difference in hourly average taken 24 hours apart were designated as span drift and compared to the manufacturer specification of ± 1% of scale for acceptance.

Lower Detectable Limit

The lower detectable limit was defined as twice the noise and was determined from the zero drift evaluation. After this evaluation, the standard deviation of the twenty-four hours was calculated. This was defined as the instrument noise. The manufacturer specifications are 25pptV noise and a lower detectable limit of 50 pptV at the 120 second averaging time.

Interference Testing

A variety of oxidized nitrogenous species have been shown to be quantitatively converted to NO by the molybdenum catalysts typically used in chemi-luminescent oxides of nitrogen analyzers. These include NO_2, HNO_3, HONO, peroxy acetyl nitrate (PAN) (Winer et al., 1974). These species were therefore quantified when the analyzer inlet was routed through the converter; they were operationally defined as NO_Y. Other nitrogen oxides such as nitrous oxide, alkyl nitro compounds, and reduced nitrogen such as ammonia have shown very little conversion. The objective of these tests was to determine the converter efficiency for these nitrogenous species that are expected to contribute to NO_Y. The basic approach was to sample from a synthetic source of these species and determine the concentration of NO_Y measured with that expected. Since the amount expected could not be easily quantified directly for nitric acid, nitrous acid, PAN, or n-propyl nitrate directly, one or more approaches were used to determine concentrations of these gases:

- The concentration was measured with a NO_Y analyzer which had been calibrated with a certified NO source. A second converter, which had been shown to be effective (although the degree of effectiveness is not necessary) was then added in series to determine if any additional conversion occurs. If not, then the concentration could be determined by the response of the NO_Y analyzer.
- The concentration was measured with an NO_Y analyzer and the converter temperature incrementally raised until no further gain in response occurs. Complete conversion is assumed to have occurred.
- The responses of two or more NO_Y analyzers (or the same analyzer but different channels if a dual converter system was used) that had been evaluated as above gave the same response.

NO_Y analyzers were tested for efficiently converting various NO_Y species; an acceptable response was 90% of that expected or 90% converter efficiency. Gases evaluated for converter efficiency were:

NO_2 was generated by the gas phase titration with ozone using a commercial dilution calibration instrument equipped with an ozone generator and plumbed for performing gas phase work. Prior to dilution, NO in nitrogen was allowed to mix with air that had passed through an ultraviolet light-based ozone generator. NO_Y was sampled with the light off and then with the light adjusted to titrate approximately 80% of the NO. The change in response to the change in NO_2 concentration was therefore a measure of converter efficiency. The following gases were generated in the 30-50 ppbV range:

Nitric acid vapor was generated by flowing dry air past a permeation tube containing liquid nitric acid. The concentration was estimated by measuring the permeation and gas flow rates and verified as described above.

Nitrous acid was generated by the sublimation of ammonium nitrite (Vecera and Dasgupta, 1990). This has been demonstrated to be a clean and constant nitrous acid source.

Ammonium nitrite placed in a copper tube was held at constant temperature. A constant amount of dry nitrogen was passed through the tube and then diluted with zero air. The concentration was determined as described above.

A cylinder of PAN was prepared through generating PAN in solution by reaction of peracetic acid with nitric acid (Holdren and Spicer 1984) in a hydrocarbon solvent. The amount and purity in the solution was quantified by IR in a 0.25mm liquid cell. An aliquot of the solvent was injected into a 100 liter Teflon chamber and allowed to vaporize. The concentration was determined as described above.

N-propyl nitrate is known to be stable in compressed gas cylinders and is more difficult to reduce to NO than nitric acid (Hartsell, 1997). Diluting a compressed source of n-propyl nitrate may therefore provide a convenient and effective method of determining the efficiency of an NO_Y converter. A commercially prepared and analyzed source of n-propyl nitrate in nitrogen was diluted with zero air. The concentration of the source was verified as described above.

2.4.2 NO_Y QA Plan

The Air Quality WG also evaluated methods for nitrogen species measurements quality assurance. A summary of their consensus is provided in appendix F of this volume. Differences between NO_X and NO_Y instrument audits and suitability of audit methods for NO_Y instruments used in eastern United States were of concern to the Air Quality WG. Although, due to operational difficulties, it was not possible to contract an independent audit of the NO_Y network, such a course is recommended for operating any such network in the future. This independent audit should include a systems audit supervised by a mentor as is the practice with NARSTO studies in eastern United States. Each regional district and the CE-CERT provided personnel and resources to perform audits at stations outside their operations; audit groups also compared results at selected stations. A short discussion of the results are provided below.

Results of In-Kind Audits

CE-CERT, SCAQMD, MDAQMD, SDCAPCD, and VCAPCD conducted NO_Y in-kind audits at 12 sites, as well as the STI and the UC Davis airplanes. The results of these audits revealed that CE-CERT audit apparatus reported lower results than most others did. On average this discrepancy was –6%. Subsequently, it was determined that the NO gas cylinder checked at the end of the study was 6% lower than originally thought. Because it is not known when the loss of NO in this cylinder occurred, the data will not be corrected for this issue but the NO_Y data statement will carry this information to data users.

CE-CERT conducted ozone audits of UC Davis, STI, and U.S. Navy Point Mugu airplanes and obtained differences of 0% to 8%. The results of nylon filter modifications to the Routine Network are significant and interesting:

- Nylon filters differ in quality from batch to batch and at high nitric acid concentration and at high flow rates tend to fail in efficiently gathering nitric acid.
- This issue requires significant more careful management in nitric acid measurement by the difference method through the double converter setting.

- Teflon prefilter nylon filter packages plug up rapidly during high aerosol episodes.
- In the future, arrangement of a Teflon particle filter, a denuder, and a nylon filter sandwich for double converters has to be changed to incorporate a quartz filter impregnated with sodium chloride instead of a nylon filter.
- At certain stations [e.g., Simi Valley], routine measurements with and without the nylon filter are not fundamentally different. In areas where nitric acid and organic nitrates concentrations are low, use of nylon filters is unlikely to improve the measurement regime.

TECO 42CY In-Kind audits suggest:

- Daily zeroing is needed for proper operation of these instruments.
- For converter efficiency near 100%, converter temperatures must sometimes be significantly raised above factory settings.
- Converter efficiency tests of 100% may also be converting ammonia.
- Because n-propyl nitrate does not significantly differ in conversion efficiency tests characteristics than nitrogen oxides, its use does not offer any advantages.
- Single and double converter assemblies need to have their plumbing inside their outdoor box.

For PAN audits, CE-CERT injected known concentrations of peroxyacetyl nitrate into dark bags and rapidly took them to Cajon Pass, Calabasas, and Azusa sites. The results suggest that an order of magnitude difference exist between expected and measured concentrations. This is in essence a repeat of the experience of the 1990 San Joaquin Valley Air Quality Study (SJVAQS) audit program (Gertler, et. al). This issue was not satisfactorily resolved then and is unlikely to be resolved now. It is clear that the uncertainties in the PAN measurement programs are significant. PAN measurements are important to understanding the ozone and nitrate chemistry; it is also likely that measurement uncertainties are larger than that reported in literature (±25%)(Blanchard, et. al). LPA-4 and TECO 42 Modified NO_Y-NO comparison suggest that there is a high degree of correlation between these two data sets. This again is consistent with the 1990 SJVAQS audit program results.

The subtraction method nitric acid measurements at NARSTO stations in eastern United States have demonstrated remarkable consistency with the filter pack data (Mueller, 1998). This consistency was resolved through integrating the data from the subtraction method and comparing it to the data from the filter pack speciation. During SCOS97-NARSTO, it has been observed that the molybdenum converters inlet support assembly has sufficient amount of steel to allow absorption-desorption of nitric acid. This artifact has also been observed in the laboratory. Further environmental chamber testing will investigate this artifact. Data from IOP days when CE-CERT operated the TDLAS at Azusa were compared with the difference method nitric acid data. The comparison has revealed that due to the artifact, subtraction method peaks are smoothed and somewhat out of step with TDLAS peaks. Sometimes, TDLAS peaks are significantly higher than the subtraction method peaks. TDLAS can report values 30% higher than any other nitric acid measurement instrument (Tuazon, et. al). The diurnal behavior of both instruments is consistent with what was expected. The subtraction method still provides the best inexpensive and continuous measure of nitric acid.

TECO 42CY is a relatively new instrument, therefore no on-the-shelf inventory of instruments existed before SCOS97-NARSTO. Procurement delays and custom range modification for many instruments did not allow the full measure of acceptance testing, including evaluation in an environmental chamber, that is necessary for characterizing each instrument. Each of these instruments may respond to pressure and to temperature changes slightly differently than others and environmental chamber evaluation is the best way to determine the pressure and temperature corrections necessary for each instrument. Such corrections are necessary when these instruments are on board airplanes where significant pressure changes occur with changes in altitude and cabin temperature is significantly higher than the ambient temperature. For this and other reasons and at the conclusion of the study, further environmental chamber experiments on these instruments have been conducted.

Environmental Chamber Testing Protocol .

The goals of this study are:

- To characterize the performance of the analyzers as received from the field for NO, NOx, NO_Y, and nitric acid (NA). Towards this goal, the analyzers will not be re-calibrated. For each analyzer, the calibration factors last used in the field will be applied before data analysis.
- To characterize the performance of the analyzers for nitric acid (NA) after eliminating as much bias as possible. Towards this goal, the NO, NOx, NO_Y, NO_Y- channels of each analyzer will be corrected to reflect span and offset factors determined relative to the designated standard during the dark phase of the bag experiment. This will eliminate spurious NA caused by differences in the NO_Y and NO_Y- span and offset factors for a given analyzer, and will eliminate differences in NA caused by differences in span and offset factors among analyzers.

In fulfillment of the first goal, the species to be examined relative to the designated standard for each are as follows:

Species	Standard
NO	Teco42 in NO mode
NO_2	Teco42 NOx mode – Teco42 NO mode
NOx	Teco42 in NOx mode
NO_Y	Teco42 in NOx mode
NO_Y-	Tec42 NOx mode – TDLAS NA
NA	TDLAS NA

In fulfillment of the second goal, only NA versus TDLAS NA will be examined. For both goals, the specific objectives for each species are to determine:

1) the bias of each analyzer with respect to the designated standard

2) the single analyzer precision for each analyzer

3) precision among analyzers

Two types of bias will be calculated:

- the slope of linear regression of measured concentration vs. the designated standard,
- the offset of the linear regression of measured concentration vs. the designated standard,

Assuming reasonably constant variance with concentration, single analyzer precision will be calculated as the standard deviation of the residuals about the regression line. Among analyzers, precision will be calculated as a pooled estimate. For each 5 minute measurement observation, the standard deviation among the thirteen test analyzers will be calculated. These standard deviations will be pooled over concentration ranges to be determined after reviewing the relationship between variance and concentration.

NO_Y Instrument Preparation

All instruments will be used in exactly the same way as when they were removed from field operations. Denuders and filters to remove HNO_3 will not be renewed for the first run; they will be renewed later. Instruments that require significant repairs will not be included in the experiment as any repairs would be unlikely to capture the conditions obtained when instruments operated during SCOS97-NARSTO. Analyzers will be started up with the sample pump in the off position to verify proper operational parameters. Instruments will not be individually calibrated.

Tunable Diode Laser Absorption Spectrometer Preparation

The TDLAS will be operated in the NO_2 and HNO_3 mode. Data will be collected by the internal computer and stored as one-minute averages. Permeation tubes will be used to supply a steady state concentration of each gas for calibration purposes. The tubes output will be diluted with zero air to concentrations ranging from 10-50 ppbV. The concentrations will be determined with a NOx analyzer that is not a part of the comparison study. This analyzer will be calibrated by using a Columbia Scientific model 1700 gas dilution calibrator and by blending NO in nitrogen of certified concentration with ultra zero grade air.

Chamber Run Conditions

The chamber will be in the full surrogate mode of operation. This VOC surrogate consists of a mixture of eight species. Total NO_x will be less than 200 ppbV (target is 140 ppbV NO; 45 ppbV NO_2) so that all analyzers will remain within their operating range. The following VOC concentrations should give an ozone peak after 3-4 hours (units of ppmV):

N-C4:	0.327
N-C8:	0.088
ETHENE:	0.058
PROPENE:	0.048
T-2-BUTE:	0.046

TOLUENE: 0.083
M-XYLENE: 0.080
HCHO: 0.062

A minimum of three chamber runs will be performed, the first two with dry ultra zero air (one at less than 1% RH and one at approximately 20% RH)

Chamber Run Procedures

The chamber will be operated in the single-chamber mode (36 m^3) and filled with ultra zero air humidified if required to 20% RH (the first two runs will be performed dry). While still in the dark, NO_Y analyzer pumps will be turned on and readings manually logged from the display at 5-minute intervals. Data will be logged in the same instrument order throughout the experiment. Data will be logged for at least one half hour. NO will then be injected into the chamber (still in the dark) and data logged for one half hour. NO_2 will then be injected into the chamber (still in the dark) and data logged as for one half hour. The lights will then be turned on and data logged every five minutes for the following six hours.

Data Analysis

Calibration (dark period) – The NO and NO_2 concentrations will be determined by the NO_x analyzer not used in the comparison study. For each of the three dark periods (zero air, NO, NO+NO_2), the output of all NO_Y analyzers will be multiplied by the latest calibration factor. The valves will first be compared to that of the dedicated chamber NO_x analyzer by calculating the average and standard deviation of all analyzers for the period. This will give an indication of the precision of the instruments. Zero offsets will be determined relative to the readings obtained on the dedicated NOx analyzer (1-2 ppbV is typical in the ultra zero air). New calibration factors for NO, NO_Y, and NO_Y-NA will be determined by the ratio of response to the dedicated analyzer. These will be compared with the factors determined from the final calibration as a percentage difference.

Comparison (irradiation period) – Data from each test analyzer will be corrected twice using the calibration factors determined in the previous step. A number of plots will then be made to compare the various instruments with both the old or the new calibration factors. The responses for NO, and NO_Y will be plotted against those from the dedicated NOx analyzer. NO_Y-NA will then be plotted against the dedicated analyzer NOx corrected for NA from the TDLAS. NA will be plotted directly against the NA from the TDLAS. The slopes of these plots will be used to compare the various NO_Y analyzers as a percentage difference.

The two airplane borne instruments will be subjected to additional testing:

A known concentration of nitrogen species [around 80% full scale] from a source outside the chamber is introduced into the chamber.

- Two or more hours time is allowed for stabilization of temperature.
- Temperature is raised or lowered depending on the temperature profile of choice.
- Two or more hours time is allowed for stabilization at each temperature.

- This process may be repeated.
- A recommended temperature profile is 25C, 35C, 45C, 40C, 30C, 20C.
- Correction factor at 30C is 1.

Pressure correction in TECO 42CY is unlikely to change from instrument to instrument and follows a hyperbolic algorithm [y=x/(a+bx)], where y is the calibration factor and x is reaction chamber pressure in mm of mercury (Kita, 1998). Both instrument pressure and temperature are recorded internally and should be down loaded after every flight to allow for calibration of NO_Y data aloft. Internal pressure is measured during the NO cycle. During boarding procedures, TECO 42CY is disconnected from the hangar power supply and reconnected to run on airplane power. In this process, the instrument may also experience a sharp change in internal pressure that may alter its calibration settings. These issues still require further investigation for final evaluation and resolution.

The environmental chamber evaluation will provide additional information for SCOS97-NARSTO nitrogen species measurements data qualification statements. Data qualification statements are part of the data quality and management practices of all NARSTO studies.

TABLE 2-1.
Tolerance Limits for Meteorological Audit Results.

Parameter	Accuracy Tolerance
Wind Speed	± 0.25 m/s, ws = 0 - 5 m/s * ± 5%, ws > 5 m/s
Wind Direction	± 5° *
Ambient Temperature	± 0.5°C **
Relative Humidity	± 1.5°C ***

* Audited by means of an artificial field, which implies simulation of the measured variable by artificial means.

** Audited by means of collocated sensors.

*** Equivalent dew-point temperature

Table 2-2
Audits of Surface Air Quality Analyzer and Meteorological Measurements

Site	Site Name	Operator	Type	Audit Results (% or Pass/Fail)										Date	Auditor
				O_3	NO_2	NO_y	HC	CO	SO_2	T	RH	WS	WD		
CHIM	Chino-Mira Loma-Union Pacific Auto Yard	CECERT	Aerosol			NA				NA	NA	NA	NA	10/20/97	AVES
AZSP	Azusa Aerosol-Hunt & Sons Plumbing	SCAQMD	Aerosol							--	--				
DIAM	Diamond Bar Right Side of Day Care Center	SCAQMD	Aerosol	--	--	NA		--		--	--	NA	NA	10/20/97	AVES
UCDC	Riverside-UC Ag Ops Children Health Site	SCAQMD	Aerosol	--	--	NA				--	--	--	--		
RIVC	Riverside-UC Campus Pierce Hall Lab	UCR	Aerosol							--	--	--	--		
RIPR	Riverside-UC Campus Pierce Hall-Roof	UCR	Aerosol	--	--					--	--	--	--		
CIRP	CIRPAS Pelican - El Monte AP	CALTECH	Aircraft							--	--	--	--		
SD-C	San Diego Cessna - Montgomery Field	SDAPCD	Aircraft	-2.7		NA	--			--	--	--	--	6/12/97	ARB
SD-C	San Diego Cessna M(Re-Audited)	SDAPCD	Aircraft	-1.6		--	--			--	--	--	--	7/18/97	SDAPCD
SD-N	San Diego Navajo - Montgomery Field	SDAPCD	Aircraft	-2.8	-4.4	NA	--			--	--	--	--	6/12/97	ARB
SD-N	San Diego Navajo M(Re-Audited)	SDAPCD	Aircraft	-1.6	6.5	--	--			--	--	--	--	10/18/97	SDAPCD
STIA	STI Aztec - Camarillo AP	STI	Aircraft	-5.1	-4.1	NA	--			--	--	--	--	6/9/97	ARB
STIA	STI Aztec - Camarillo AP(Re-Audited)	STI	Aircraft	NA	NA	NA	--			--	--	--	--	10/17/97	CECERT
UCDA	UCD Cessna - El Monte AP	UCD	Aircraft	-1.3	**Fail**	NA	--			--	--	--	--	6/10/97	ARB
UCDA	UCD Cessna - El Monte AP(Re-Audited)	UCD	Aircraft	--	4.6	NA	--			--	--	--	--	6/13/97	ARB
UCDA	UCD Cessna - El Monte AP(Re-Audited)	UCD	Aircraft	NA	NA	NA	--			--	--	--	--	10/16/97	CECERT
USNP	US Navy Partenavia - Oxnard AP	USN	Aircraft	-0.4						--	--			8/12/97	ARB
USNP	US Navy Partenavia - Oxnard A(Re-Audited)	USN	Aircraft	NA						--	--			10/17/97	CECERT
OJAF	Ojai Forest	UCR	Biogenic				--			--	--				
PINH	Pine Mountain - High Site	UCR	Biogenic				--			--	--				
PINL	Pine Mountain - Low Site	UCR	Biogenic				--			--	--				
BAKM	Bakersfield-Met	ARB	Met-Rawin							--	--	--	--		
NKX	Miramar Naval Air Station	NWS	Met-Rawin							--	--	--	--		
UCLA	UCLA-Met	UCLA	Met-Rawin							--	--	--	--		
CHLK	China Lake	USAF	Met-Rawin							--	--	--	--		
EDWD	Edwards AFB	USAF	Met-Rawin							--	--	--	--		
NVAS	Naval Air Station-North Island	USMC	Met-Rawin							--	--	--	--		
TUST	Tustin	USN	Met-Rawin							--	--	--	--		
EMAM	El Monte Airport	ARB	Met-RWP							--	--	--	--		
NAFB	Norton Air Force Base	ARB	Met-RWP							Pass		Pass	Pass	6/20/97	AVES

Table 2-2 (continued)
Audits of Surface Air Quality Analyzer and Meteorological Measurements

Site	Site Name	Operator	Type	Audit Results (% or Pass/Fail)										Date	Auditor
				O_3	NO_2	NO_y	HC	CO	SO_2	T	RH	WS	WD		
ALPM	Alpine-Met	NOAA	Met-RWP							Pass	Pass	Pass	F,Fixed	7/23/97	AVES
BRWN	Brown Field	NOAA	Met-RWP							Pass	--	Pass	F,Fixed	7/21/97	AVES
CARL	Carlsbad	NOAA	Met-RWP							Pass		NA	NA	7/25/97	AVES
CARL	Carlsbad **(Re-Audited)**	NOAA	Met-RWP							--	Pass	--	--	7/28/97	AVES
ECNT	El Centro	NOAA	Met-RWP							--	--	--	--		
GOLE	Goleta	NOAA	Met-RWP							--	--	--	--		
LOSM	Los Alamitos	NOAA	Met-RWP							Pass	Pass	Pass	F,Fixed	7/16/97	AVES
PALD	Palmdale	NOAA	Met-RWP							--		--	F,Fixed	10/23/97	USN
HUEN	Port Hueneme	NOAA	Met-RWP							NA		NA	Pass	6/30/97	AVES
SCLM	San Clemente Island	NOAA	Met-RWP							NA		NA	F,Fixed	7/3/97	AVES
CATM	Santa Catalina-Met-USC Research Station	NOAA	Met-RWP							NA		NA	F,Fixed	7/1/97	AVES
SVLM	Simi Valley Met - Madero Road Landfill*	NOAA	Met-RWP							F,Fixed	Pass	Pass	Pass	6/23/97	AVES
VNUY	Van Nuys Airport	NOAA	Met-RWP							Pass	**Fail**	--	F,Fixed	10/24/97	AVES
USCZ	USC-Hancock Fnd Bldg	NOAA	Met-RWP							Pass	Pass	--	F,Fixed	7/2/97	AVES
BARM	Barstow-Met	Radian	Met-RWP							Pass	Pass	Pass	Pass	6/22/97	AVES
HESO	Hesperia-Oak Hills Center	Radian	Met-RWP							NA		NA	Pass	6/18/97	ARB
RIHM	Riverside-H.J.Mills Water District	Radian	Met-RWP							NA		NA	Pass	6/17/97	AVES
TMCM	Temecula-East Municipal Water District	Radian	Met-RWP							Pass		Pass	Pass	6/21/97	AVES
THRM	Thermal Airport	Radian	Met-RWP							NA		NA	F,Fixed	9/23/97	AVES
LAXP	Los Angeles Airport	SCAQMD	Met-RWP							Pass	Pass	--	F,Fixed	7/11/97	AVES
ONTX	Ontario Airport	SCAQMD	Met-RWP							NA		NA	NA		AVES
PLMA	Point Loma	SDAPCD	Met-RWP											7/17/97	AVES
ESCM	Valley Center Met-Miller Pumping Station	SDAPCD	Met-RWP											7/19/97	AVES
VBG	Vandenberg Air Force Base	USAF	Met-RWP												
AZSM	Azusa-Met	NOAA	Met-SODAR							--	**Fail**	**Fail**	F,Fixed	7/13/97	AVES
CLAR	Santa Clarita Valley	NOAA	Met-SODAR							--		Pass	F,Fixed	7/12/97	AVES
WSPM	Warner Springs Met Site	SDAPCD	Met-SODAR	-0.5		NA				Pass	Pass	Pass	Pass	8/11/97	ARB
29PB	29 Palms-EAF	USN	Met-SODAR							--	--	--	--		
29PA	29 Palms-Sand Hill	USN	Met-SODAR							--	--	--	--		
CSUN	Cal State Northridge	CECERT	Ozonesonde	--											
ESCO	Valley Center (Escondido)	SDAPCD	Ozonesonde	--						--	--				
WILS	Mount Wilson	CECERT	Radiation	NA										8/8/97	ARB
RIRD	Riverside-CE-CERT-Roof Radiometry	CECERT	Radiation							--	--				
ARVN	ARVIN-20401 BEAR MTN BLVD	ARB	Routine	-4.6	2.4						--	--	--	1/29/97	ARB
BLFC	BAKERSFIELD-5558 CALIFORNIA ST	ARB	Routine	-4.7	5.1			2.2	--	Pass	**Fail**	Pass	Pass	6/17/97	ARB

Table 2-2 (continued)
Audits of Surface Air Quality Analyzer and Meteorological Measurements

Site	Site Name	Operator	Type	Audit Results (% or Pass/Fail)										Date	Auditor
				O_3	NO_2	NO_y	HC	CO	SO_2	T	RH	WS	WD		
CALE	CALEXICO-CALEXICO HIGH SCHOOL ETHEL ST	ARB	Routine	-4.5	-2.1			-2.2	-2.0	--	--	--	--	3/5/97	ARB
CALE	CALEXICO-CALEXICO HS ETHEL ST **(Re-Audited)**	ARB	Routine	-2.5	6.1			1.8	-1.1	Pass	Pass	Pass	Pass	7/28/97	ARB
TICS	Centro De Salud - Tijuana	ARB	Routine	NA	NA							--	--		ARB
EDSN	EDISON-JOHNSON FARM	ARB	Routine	-4.0	4.4					Pass		Pass	**Fail**	4/22/97	ARB
MRCP	MARICOPA	ARB	Routine	-4.5						--		--	--	4/21/97	ARB
MOJP	MOJAVE-923 POOLE ST	ARB	Routine	-5.1	0.6					**Fail**		Pass	Pass	6/16/97	ARB
THOS	OAK VIEW-5500 CASITAS PASS RD	ARB	Routine	-6.0	-5.7					Pass		Pass	Pass	2/24/97	ARB
OLDL	OILDALE-3311 MANOR ST	ARB	Routine	-3.6	-0.5				-7.9	**Fail**		Pass	Pass	4/29/97	ARB
PSRB	PASO ROBLES-235 SANTA FE AVE	ARB	Routine	0.0						**Fail**		--	--	4/25/97	ARB
SLOM	SAN LUIS OBISPO-1160 MARSH ST	ARB	Routine	0.0	-6.1		--	1.4		Pass		Pass	Fail	4/22/97	ARB
SBWC	SANTA BARBARA-3 W. CARRILLO	ARB	Routine	-0.2	-11.5			-0.4		Pass	Pass	Pass	Pass	4/17/97	ARB
SBWC	SANTA BARBARA-3 W. CARRILLO **(Re-Audited)**	ARB	Routine	-0.7	-5.3			0.1		Pass	Pass	Pass	Pass	8/13/97	ARB
SMSB	SANTA MARIA-500 S BROADWAY	ARB	Routine	-2.1	-9.0				-10.2	Pass		Pass	Pass	4/24/97	ARB
SHAF	SHAFTER/USDA	ARB	Routine	-4.7	-3.1					Pass		Pass	Pass	4/24/97	ARB
CPGB	CARPINTERIA-GOBERNADOR RD	CHVRON	Routine	--	--					--		--	--		
GAVE	GAVIOTA EAST-N OF CHEVRON PLANT	CHVRON	Routine	-1.6	--		--		--	Pass	Pass	Pass	Pass	5/6/97	ARB
GAVW	GAVIOTA WEST-NW OF CHEVRON PLANT	CHVRON	Routine	--	--		--		--	--		--	--		
UCSB	UCSB WEST CAMPUS-ARCO TANK	EXXON	Routine	--											
BMBY	BOMBAY BEACH	ICAPCD	Routine	--				--							
CLXC	CALEXICO-900 GRANT ST	ICAPCD	Routine	-7.9%	**-19.1**									3/6/97	ARB
EC9S	EL CENTRO-150 9TH ST	ICAPCD	Routine	-0.9				-0.3						2/26/97	ARB
INDO	INDIO-46-990 JACKSON ST	ICAPCD	Routine	**-19.3**								--	--	6/19/97	ARB
INDO	INDIO-46-990 JACKSON ST **(Re-Audited)**	ICAPCD	Routine	PA								--	--	12/4/97	ARB
NLNA	NILAND	ICAPCD	Routine	-0.2										3/3/97	ARB
WEST	WESTMORELAND-WEST 1ST STREET	ICAPCD	Routine	--											
BARS	BARSTOW-301 MOUNTAIN VIEW	MDAQMD	Routine	-1.4	-0.3	--		-0.9	--	--		Pass	Pass	2/5/97	ARB
BARS	BARSTOW-301 MOUNTAIN VIEW **(NO_Y Audit)**	MDAQMD	Routine	--	--	5		--	--	--		--	--	10/2/97	CECERT
HESP	HESPERIA-17288 OLIVE ST	MDAQMD	Routine	-1.6	-1.7			0.6	-1.5	Pass		Pass	Pass	2/4/97	ARB
LANC	LANCASTER-315 W. PONDERA	MDAQMD	Routine	-5.3	-7.2			0.1				--	--	1/29/97	ARB
LANC	LANCASTER-315 W. PONDERA **(Re-Audited)**	MDAQMD	Routine	PA	PA			PA				--	--	12/2/97	ARB
PHEL	PHELAN-BEEKLEY & PHELAN RDS	MDAQMD	Routine	-0.8	-1.6			--	8.9	Pass		Pass	Pass	2/6/97	ARB
TRNA	TRONA-83732 TRONA ROAD	MDAQMD	Routine	1.0	--				4.7	Pass		Pass	Pass	1/30/97	ARB
29PM	TWENTYNINE PALMS-6136 ADOBE DR	MDAQMD	Routine	-0.6	-3.7	NA		-2.7	-2.2	Pass	--	Pass	Pass	1/29/97	ARB
VICT	VICTORVILLE-14029 AMARGOSA RD	MDAQMD	Routine	2.5	-1.1			3.3	-1.9	Pass		Pass	**Fail**	1/28/97	ARB
JOSH	JOSHUA TREE NATIONAL MONUMENT	NPS	Routine	3.2						--	--	--	--	2/25/97	ARB

Table 2-2 (continued)
Audits of Surface Air Quality Analyzer and Meteorological Measurements

Site	Site Name	Operator	Type	Audit Results (% or Pass/Fail) O_3	NO_2	NO_y	HC	CO	SO_2	T	RH	WS	WD	Date	Auditor
ECSP	EL CAPITAN STATE PARK	SBAPCD	Routine	-1.8	1.0		--		-0.3	Pass	Pass	Pass	Pass	4/30/97	ARB
GLWF	GOLETA-380 W FAIRVIEW AVE	SBAPCD	Routine	-3.9	0.3			2.1	-0.2	Pass	Pass	Pass	Pass	4/29/97	ARB
LFC1	LAS FLORES CAYON # 1	SBAPCD	Routine	3.6	--		--	--	--	Pass		Pass	Pass	5/13/97	ARB
LFC2	LAS FLORES CAYON # 2	SBAPCD	Routine		--			--		--		--	--		
LFC3	LAS FLORES CAYON # 3	SBAPCD	Routine		-1.2				2.1	Pass		Pass	Pass	5/13/97	ARB
SYAP	SANTA YNEZ-AIRPORT RD	SBAPCD	Routine	-1.2						--		**Fail**	**Fail**	4/28/97	ARB
ANAH	ANAHIEM-1610 S HARBOR BLVD	SCAQMD	Routine	-5.1	-12.1			0.9		--	--	--	--	1/23/97	ARB
AZSA	AZUSA-803 N LOREN AVE	SCAQMD	Routine	-5.0	-6.6	NA	--	--	--	--	--	--	--	7/21/97	ARB
BANN	BANNING-135 N ALLESANDRO	SCAQMD	Routine	-2.4	-4.8	NA				--	--	--	--	5/28/97	ARB
BANN	BANNING-135 N ALLESANDRO **(Re-Audited)**	SCAQMD	Routine	0.9	NA							--	--	8/7/97	ARB
BANN	BANNING-135 N ALLESANDRO **(Re-Audited)**	SCAQMD	Routine	--	NA	1.3						--	--	9/18/97	ARB
BANN	BANNING-135 N ALLESANDRO **(Re-Audited)**	SCAQMD	Routine	PA	PA	PA						--	--	12/4/97	ARB
BRBK	BURBANK-228 W PALM AVE	SCAQMD	Routine	-2.6	1.9			--	--	--	--	--	--	7/21/97	ARB
CHIN	Children's Health Study Jurupa Valley HS	SCAQMD	Routine	-1.7	-5.2									5/29/97	ARB
CMMV	COSTA MESA-2850 MESA VERDE DR	SCAQMD	Routine	**-23.8**	-6.7			--	--			--	--	7/14/97	ARB
CMMV	COSTA MESA-2850 MV. **(Re-Audited)**	SCAQMD	Routine	**-17.6**	--			--	--			--	--	9/16/97	ARB
CMMV	COSTA MESA-2850 MV. **(Re-Audited)**	SCAQMD	Routine	PA	--			--	--			--	--	12/5/97	ARB
LGRE	CRESTLINE-LAKE GREGORY-LAKE DR	SCAQMD	Routine	-2.8							--	--	--	7/21/97	ARB
ELTR	EL TORO-23022 EL TORO RD	SCAQMD	Routine	-5.3				2.5				--	--	6/11/97	ARB
FONT	FONTANA-14360 ARROW BLVD	SCAQMD	Routine	-2	-4.5				0.0		--	--	--	6/4/97	ARB
GLDR	GLENDORA-840 LAUREL	SCAQMD	Routine	-5.9	-11.6							--	--	6/5/97	ARB
HAWH	HAWTHORNE-5234 W. 120TH ST	SCAQMD	Routine	-2.8	-1.3			3.7	-2.4	--	--	--	--	7/21/97	ARB
HEMT	HEMET - 880 STATE STREET	SCAQMD	Routine	--								--	--		
JOSL	JOSHUA TREE NATIONAL MONUMENT	SCAQMD	Routine	3.2						--	--	--	--	2/25/97	ARB
LHAB	LA HABRA-621 W. LAMBERT	SCAQMD	Routine	-6.4	-0.1			--				--	--	7/14/97	ARB
LKAR	LAKE ARROWHEAD	SCAQMD	Routine	-0.4	**-24.6**							--	--	6/17/97	ARB
LKAR	LAKE ARROWHEAD **(Re-Audited)**	SCAQMD	Routine	-0.5	NA							--	--	9/19/97	ARB
LAKR	LAKE ARROWHEAD **(Re-Audited)**	SCAQMD	Routine	--	PA							--	--	12/2/97	ARB
LELS	LAKE ELSINORE-506 W FLINT ST	SCAQMD	Routine	**-18.3**	**-23.1**							--	--	6/16/97	ARB
LELS	LAKE ELSINORE-506 W FLINT ST **(Re-Audited)**	SCAQMD	Routine	-13.9	-7.1							--	--	9/23/97	ARB
LELS	LAKE ELSINORE-506 W FLINT ST **(Re-Audited)**	SCAQMD	Routine	PA	--							--	--	12/3/97	ARB
LGRE	LAKE GREGORY	SCAQMD	Routine	--								--	--		
NLGB	LONG BEACH-3648 N LONG BEACH	SCAQMD	Routine	-6.7	-4.1			--	--	Pass	**Fail**	Pass	**Fail**	7/14/97	ARB
NLGB	LONG BEACH-3648 N LONG BEACH **(Re-Audited)**	SCAQMD	Routine	--	--			--	--	Pass	**Fail**	Pass	**Fail**	9/16/97	ARB
LANM	LOS ANGELES-1630 N MAIN ST	SCAQMD	Routine	-1.6	-9.9	NA	--	2.3	7.3	--	--	--	--	1/30/97	ARB

Table 2-2 (continued)
Audits of Surface Air Quality Analyzer and Meteorological Measurements

Site	Site Name	Operator	Type	Audit Results (% or Pass/Fail)										Date	Auditor
				O_3	NO_2	NO_y	HC	CO	SO_2	T	RH	WS	WD		
LYNW	LYNWOOD-11220 LONG BEACH BLVD	SCAQMD	Routine	-22.2	-8.1			-0.7	--			--	--	1/22/97	ARB
LYNW	LYNWOOD-11220 LB. BLVD **(Re-Audited)**	SCAQMD	Routine	-7.1	--			--	--			--	--	9/16/97	ARB
NORC	NORCO-NORCONIAN	SCAQMD	Routine	--								--	--		
PALM	PALM SPRINGS-FS 590 RACQUET CL	SCAQMD	Routine	-9.7	0.5			1.3				--	--	6/18/97	ARB
PDSW	PASADENA-752 S. WILSON AVE	SCAQMD	Routine	-2.2	-7.5			0.1		--		--	--	1/21/97	ARB
PERR	PERRIS-237.5 N "D" ST	SCAQMD	Routine	-8.7								--	--	6/6/97	ARB
PICO	PICO RIVERA-3713 SAN GABRIEL	SCAQMD	Routine	-3.3	-10.1		--	-1.2		--	--	--	--	7/28/97	ARB
POMA	POMONA-924 N. GAREY AVE	SCAQMD	Routine	-1.3	2.2			-2.1				--	--	6/3/97	ARB
RDLD	REDLANDS-500 N. DEARBORN	SCAQMD	Routine	-1.7								--	--	1/24/97	ARB
RSDA	RESEDA-18330 GAULT ST	SCAQMD	Routine	-5.8	-9.1			5.1		--	--	--	--	1/28/97	ARB
RIVM	RIVERSIDE-MAGNOLIA	SCAQMD	Routine					--							
RUBI	RIVERSIDE-RUBIDOUX	SCAQMD	Routine	--	--			--	--	--	--	--	--		
SANB	SAN BERNARDINO-24302 4TH ST	SCAQMD	Routine	0.3	-8.4			8.3		--	--	--	--	6/2/97	ARB
CLAR	SANTA CLARITA-SAN FERNANDO RD	SCAQMD	Routine	-8.6				-1.5				--	--	1/29/97	ARB
UCDC	UC RIVERSIDE-4919 CANYON CREST Ag Ops	SCAQMD	Routine	-3.3	--	NA				--	--			8/5/97	ARB
UCDC	UC RIVERSIDE-4919 CR. **(Re-Audited)**	SCAQMD	Routine	-10.9	--	NA				--	--			9/25/97	ARB
ULDS	UPLAND-1350 SAN BERNARDINO AVE	SCAQMD	Routine	-5.9	-4.4		--			--	--	--	--	5/29/97	ARB
VALA	W LOS ANGELES-VA HOSPITAL	SCAQMD	Routine	-5.0	0.1			4.9				--	--	1/1/97	ARB
ALPN	ALPINE-2300 VICTORIA DR	SDAPCD	Routine	6.5	1.8	NA	--			--	**Fail**	Pass	Pass	11/4/96	ARB
PEND	CAMP PENDELTON	SDAPCD	Routine	--	--										
CHVT	CHULA VISTA-80 E "J" ST **(NO_2 Audit)**	SDAPCD	Routine	--	5.5			--	--			--	--	8/13/97	SDAPCD
CHVT	CHULA VISTA-80 E "J" ST **(O_3 & SO_2 Audit)**	SDAPCD	Routine	12.4	--			--	2.9			--	--	8/14/97	SDAPCD
CHVT	CHULA VISTA-80 E "J" ST **(CO Audit)**	SDAPCD	Routine	--	--			3.8	--			--	--	8/19/97	SDAPCD
DMMC	DEL MAR-MIRACOSTA COLLEGE	SDAPCD	Routine	0.3								--	--	9/3/97	SDAPCD
ECAJ	EL CAJON-1155 REDWOOD AVE	SDAPCD	Routine	-4.9	-2.4		--	0.7		**Fail**	**Fail**	Pass	Pass	11/6/96	ARB
ESCO	ESCONDIDO-600 E. VALLEY PKWY **(NO_2 Audit)**	SDAPCD	Routine	--	-0.5			--		--		--	--	11/13/96	SDAPCD
ESCO	ESCONDIDO-600 E. VALLEY P. **(O_3 & CO Audit)**	SDAPCD	Routine	-0.2	--			4.9		--		--	--	11/14/96	SDAPCD
OCEA	OCEANSIDE-1701 MISSION AVE **(CO Audit)**	SDAPCD	Routine	--	--			8.3		--		--	--	3/10/97	SDAPCD
OCEA	OCEANSIDE-1701 MISSION AVE **(O_3 Audit)**	SDAPCD	Routine	-2.1	--			--		--		--	--	3/12/97	SDAPCD
OCEA	OCEANSIDE-1701 MISSION AVE **(NO_2 Audit)**	SDAPCD	Routine	--	5.2			--		--		--	--	3/13/97	SDAPCD
OTAY	OTAY-1100 PASEO INTL **(NO_2 Audit)**	SDAPCD	Routine	--	4.9			--	--	--		--	--	11/25/96	SDAPCD
OTAY	OTAY-1100 PASEO INTL **(O_3 Audit)**	SDAPCD	Routine	-1.3	--			--	--	--		--	--	11/26/96	SDAPCD
OTAY	OTAY-1100 PASEO INTL **(SO_2 & CO Audit)**	SDAPCD	Routine	--	--			2.2	-1.0	--		--	--	11/27/96	SDAPCD
SDUN	SAN DIEGO-1133 UNION ST	SDAPCD	Routine					2.7						9/18/97	SDAPCD
SD12	SAN DIEGO-330A 12TH AVE **(CO Audit)**	SDAPCD	Routine	--	--		--	3.9	--			--	--	4/14/97	SDAPCD

Table 2-2 (continued)
Audits of Surface Air Quality Analyzer and Meteorological Measurements

Site	Site Name	Operator	Type	Audit Results (% or Pass/Fail)										Date	Auditor
				O_3	NO_2	NO_y	HC	CO	SO_2	T	RH	WS	WD		
SD12	SAN DIEGO-330A 12TH AVE **(NO_2 Audit)**	SDAPCD	Routine	--	-2.5		--	--	--			--	--	4/16/97	SDAPCD
SD12	SAN DIEGO-330A 12TH AVE **(O_3 Audit)**	SDAPCD	Routine	-1.1	--		--	--	--			--	--	4/17/97	SDAPCD
SD12	SAN DIEGO-330A 12TH AVE **(SO_2 Audit)**	SDAPCD	Routine	--	--		--	--	0.1			--	--	4/21/97	SDAPCD
SDOV	SAN DIEGO-5555 OVERLAND AVE	SDAPCD	Routine	-5.6	-4.7		--	0.9		Pass	Pass	Pass	Pass	11/5/96	ARB
BKGS	BAKERSFIELD-1138 GOLDEN STATE	SJVUCD	Routine	-5.1	0.8			0.0		Pass	Pass	Pass	Pass	6/19/97	ARB
ATAS	ATASCADERO-6005 LEWIS AVE	SLOAPCD	Routine	0.6	-3.8					Pass		Pass	Pass	4/16/97	ARB
GCTY	GROVER CITY-9 LESAGE DR	SLOAPCD	Routine	4.6	4.2				0.9			Pass	Pass	4/23/97	ARB
MOBY	MORRO BAY-MORRO BAY BL & KERNR	SLOAPCD	Routine	-7.0					--			Pass	Pass	4/14/97	ARB
NPSW	NIPOMO-148 S WILSON ST	SLOAPCD	Routine	--	--				--	--		--	--		
GTCC	GAVIOTA-GTC C 1 MIIE E OF PLANT	TEXACO	Routine	-0.2	0.0		--		9.3	Pass	Pass	Pass	Pass	5/7/97	ARB
GTCB	NOJOQUI PASS-GTC B HWY 101	TEXACO	Routine	-3.2	1.4					Pass	Pass	Pass	Pass	5/6/97	ARB
ARGR	ARROYO GRANDE-RALCOA WAY	UNOCAL	Routine						-0.9			Pass	Pass	4/21/97	ARB
LPSH	LOMPOC-128 S 'H' ST	UNOCAL	Routine	3.1	**18.7**			0.2	3.6	Pass		Pass	Pass	5/1/97	ARB
LPSH	LOMPOC-128 S 'H' ST **(Re-Audited)**	UNOCAL	Routine	--	-4.6			--	--	--		--	--	9/15/97	ARB
LPHS	LOMPOC-HS&P FACILITY 500 M SW	UNOCAL	Routine	2.4	9.1		--		13.4	Pass		Pass	Pass	5/3/97	ARB
LOSP	LOS PADRES NF-PARADISE RD	UNOCAL	Routine	3.2	-4					Pass	Pass	Pass	Pass	5/13/97	ARB
NIPO	NIPOMO-1300 GUADALUPE RD	UNOCAL	Routine	-5.7					-8.4	Pass		Pass	Pass	4/15/97	ARB
SMBB	SANTA MARIA-BATTLES BETTERAVIA	UNOCAL	Routine							--					
VBWT	VANDENBERG AFB WATT RD	VBGAFB	Routine	--	--		--	--	--	--		--	--		
VBPP	VANDENBERG AFB-STS POWER PLANT	VBGAFB	Routine	-0.5	-5.9		--	0.1	--	Pass	Pass	Pass	Pass	8/5/97	ARB
ELRO	EL RIO-RIO MESA SCHOOL	VCAPCD	Routine	2.6	8.3		--	6.5	-0.6	--	--	Pass	Pass	2/25/97	ARB
EMMA	EMMA WOOD STATE BEACH	VCAPCD	Routine	2.0	0.9		--			--	--	Pass	Pass	2/27/97	ARB
OJAI	OJAI - OJAI AVENUE	VCAPCD	Routine	0.4	4.0					--	--	Pass	Pass	2/20/97	ARB
PRTG	PIRU-2SW, 2815 TELEGRAPH RD	VCAPCD	Routine	-0.4						Pass	--	--	--	2/18/97	ARB
SVAL	SIMI VALLEY-5400 COCHRAN ST	VCAPCD	Routine	-2.6	0.4	NA	--	1.3		--	--	Pass	Pass	2/26/97	ARB
TOMP	THOUSAND OAKS-9 2323 MOORPARK	VCAPCD	Routine	3.2	-0.9					--	--	Pass	Pass	2/19/97	ARB
MBLD	Mount Baldy Village	ARB	Supplemental	0.8	5.7			5.0		Pass	Pass	Pass	Pass	8/6/97	ARB
CAJB	Cajon Pass	AVES	Supplemental	-6.2	-1.8	NA				Pass	Pass	Pass	Pass	7/28/97	ARB
CALB	Calabasas	AVES	Supplemental	-2.1	**23.3**	NA				Pass	Pass	Pass	Pass	7/28/97	ARB
CALB	Calabasas **(Re-Audited)**	AVES	Supplemental	--	-3.5	NA								9/24/97	ARB
PVSP	Palos Verdes-San Pedro Hill	AVES	Supplemental	-2.3						Pass	Pass	Pass	Pass	7/28/97	ARB
CATA	Santa Catalina Airport	AVES	Supplemental	0.7						Pass	Pass	Pass	Pass	7/28/97	ARB
CATI	Santa Catalina Isthmus	AVES	Supplemental	1.8						Pass	Pass	Pass	Pass	7/28/97	ARB
ARCO	ARCO Plaza Tower	CECERT	Supplemental	-7.5										7/14/97	ARB
SNIC	San Nicolas Island NE Bldg 279	CECERT	Supplemental	--	--	NA				--	--				

Table 2-2 (continued)
Audits of Surface Air Quality Analyzer and Meteorological Measurements

Site	Site Name	Operator	Type	Audit Results (% or Pass/Fail) O_3	NO_2	NO_y	HC	CO	SO_2	T	RH	WS	WD	Date	Auditor
TEHP	Tehachapi Pass-Monolith	CECERT	Supplemental	**-16.4**[(1)]						--	--	--	--	8/4/97	ARB
TEHP	Tehachapi Pass-Monolith **(Re-Audited)**	CECERT	Supplemental	0.9										9/25/97	ARB
PTCL	Point Conception	CHVRON	Supplemental	0.1	1.8				--	Pass	Pass	Pass	Pass	5/15/97	ARB
CAJC	Cajon Pass-Cajon	MDAQMD	Supplemental	1.0	3.6				1.8	--		Pass	Pass	7/28/97	ARB
CAJC	Cajon Pass-Cajon **(Re-Audited)**	MDAQMD	Supplemental	--	3.6							Pass	Pass	9/22/97	ARB
EMAL	El Monte Airport - Lidar	NOAA	Supplemental	-2.7										6/10/97	ARB
HESL	Hesperia - Lidar	PennSt	Supplemental												
CERD	UC Riverside - CE-CERT	PSU	Supplemental	NA	--			--		--	--	--	--		CECERT
ROSA	Santa Rosa Island A	SBCAPCD	Supplemental	2.3										5/22/97	ARB
ROSB	Santa Rosa Island B	SBCAPCD	Supplemental							--					
TCCC	TEMECULA-COUNTY CENTER	SCAQMD	Supplemental	**-26.6**										9/17/97	ARB
TCCC	TEMECULA-COUNTY CENTER **(Re-Audited)**	SCAQMD	Supplemental	PA										12/4/97	ARB
BLKM	Black Mountain	SDAPCD	Supplemental	8.0						--				10/17/97	SDAPCD
SOLM	Mt. Soledad **(NO_2 Audit)**	SDAPCD	Supplemental	--	-3.8									8/27/97	SDAPCD
SOLM	Mt. Soledad **(O_3 Audit)**	SDAPCD	Supplemental	6.0	--									9/2/97	SDAPCD
REDM	Red Mountain	SDAPCD	Supplemental	-6.3						--				10/20/97	SDAPCD
CLEM	San Clemente Island	SDAPCD	Supplemental	5.0	1.0					--				11/4/97	SDAPCD
SMPK	San Marcos Peak	SDAPCD	Supplemental	-2.8		NA				--		Pass	**Fail**	3/10/97	ARB
VCEN	Valley Center-RTP site-public road dept.	SDAPCD	Supplemental	-1.1	--	--	--	--	--					9/17/97	SDAPCD
MEXT	CEBTIS-Mexicali	TRACER	Supplemental	0.0	-0.5			1.7	**-66.4**	Pass		Pass	Pass	3/13/97	ARB
MEXA	COBACH-Mexicali	TRACER	Supplemental	--	--			--	--	--		--	--		
MEXP	Colonia Progresso-Mexicali	TRACER	Supplemental	--	--			--	--	--		--	--		
MEXC	Conalep-Ejido Puebla-Mexicali	TRACER	Supplemental	--	--			--	--	--		--	--		
TITT	ITT-Tijuana	TRACER	Supplemental	-4.8	--			1.7	-1.2	--		--	--	3/17/97	ARB
TILM	La Mesa La Presa-Tijuana	TRACER	Supplemental	-10.8	-9.5			3.0	--	--		--	--	3/18/97	ARB
MEXB	New Border Crossing-Mexicali	TRACER	Supplemental	--	--			--	--	--		--	--		
TIPL	Playas de Tijuana	TRACER	Supplemental	-3.8	-3.0			0.0	-0.7	--		--	--	3/18/97	ARB
TIRP	Rosarito Playa (Beach)-Tijuana	TRACER	Supplemental	-6.0	-0.7			--	8.4	--				3/20/97	ARB
MEXI	Technical University-ITM-Mexicali	TRACER	Supplemental	-4.8	-0.9			7.4	-7.0	Pass		**Fail**	Pass	3/11/97	ARB
MEXU	UABC-Mexicali	TRACER	Supplemental	-3.0	-8.6			0.5	-0.2	Pass		Pass	Pass	3/12/97	ARB
LAGP	Laguna Peak	USN	Supplemental	-0.7										8/12/97	ARB
PMGU	Point Mugu	USN	Supplemental	-0.9										8/12/97	ARB

(1) After applying a 15% altitude correction, the results were less than 2% low. The ARB auditor later found the data to be acceptable after application of this factor.

Legend: Blank = not measured; "--" = not audited; F,Fixed = failed but fixed promptly; NA = audited but results not available; PA = planned audit

Wind Direction Summary at RWP & Sodar Sites

Site ID	Audit Date	Date Corrected	Audit Tests					
Field Ops			Sensor Orientation +	Sensor Height *	Sensor Exposure	Sensor Verticality	Starting Threshold	Misc.
BARM	6/22/97							
RIHM	6/17/97				(1)			
HESO	6/18/97				(2)			
THRM	6/19/97	6/19/97	5°			(3)		(4)
NAFB	6/20/97				(5)			(6)
TMCM	6/21/97				(7)			
SVLM	6/23/97							
HUEN	6/30/97						NP	
PALD	7/1/97	7/1/97	6°				NP	
USCZ	7/2/97			3 meters	(8)		NP	
SCLM	7/3/97	7/3/97 (10)				(9)	NP	(10)
VNUY	7/10/97		9°				NP	
LAXP	7/11/97	7/11/97	9°	23'				
CATM	7/11/97	7/11/97 (11)	6°				NP	(11)
CLAR	7/12/97	7/12/97	5°				NP	
AZSM	7/13/97		10°				NP	
LOSM	7/16/97		7°				NP	
PLMA	NM							
ESCM	NM							
BRWN	7/21/97		10°	3 meters			NP	
ALPM	7/23/97		10°				NP	
TUST	7/24/97		10°				NP	
CARL	7/25/97						NP	
EMAM	7/28/97		NP		(12)		NP	
WSPM	NM							
ONTX	NP							

Difference from true north if the difference exceeded the criteria of □ 5°.
Actual height of wind sensors if different from 10 meters.
NP = Not performed.
NM = Measurement not present.

1. The wind direction sensor was mounted on a building. The wake created by the building will influence the wind measurements.

2. The surface wind measurements will not be accurate when winds are from the southeast. The water tank will form an obstruction that exceeds the EPA siting criteria for distance from obstructions.

4. The wind vane was not balanced. The vane was balanced following the audit.
5. Trees to the south of the site presented an obstruction to the wind measurements.
6. The wind vane was bent.
7. The wind measurements were obstructed on the southwest by a building.
8. The meteorological sensor mast was mounted on a building. The wake created by the building will influence the wind measurements.
9. The wind sensor mast was found to be loose and leaning to one side. This was corrected during the audit.
10. The base of the meteorological tower is loose and could pivot. This will cause inaccuracies in the reported wind directions. The base should be secured.
11. The guy lines for the tower were loose allowing the tower base to pivot. This will cause inaccuracies in the reported wind directions. The base was secured during the audit.
12. The wind sensors were obstructed by the retaining wall, bushes, and trees on the east side of the site. The arc of unobstructed flow for these measurements was between 180 and 200°.

Wind Speed Summary

Site ID	Audit Date	Date Corrected	Audit Tests					
Field Ops			Performance Test +	Sensor Height *	Sensor Exposure	Sensor Verticality	Starting Threshold	Misc.
BTW	6/22/97	6/22/97	(1)					
RSD	6/17/97				(2)			
HPA	6/18/97				(3)			
TML	6/19/97	6/19/97				(4)		
NTN	6/20/97		NP		(5)		NP	
TCL	6/21/97	6/21/97	(6)		(7)			
SIM	6/23/97							
PHE	6/30/97							
PDE	7/1/97							
USC	7/2/97			3 meters	(8)			
SCE	7/3/97	7/3/97 (10)				(9)		(10)
VNS	7/10/97							
LAX	7/11/97			23'				
SCL	7/11/97	7/11/97 (11)						(11)
SCA	7/12/97							
AZS	7/13/97						0.6 m/s	
LAS	7/16/97							
PTL	NM							
VLC	NM							
BFD	7/21/97			3 meters				
APE	7/23/97							
TTN	7/24/97							
CBD	7/25/97							
EMT	7/28/97		NP		(12)		NP	
WSP	NM							
ONT	NP							

WS < 5 m/s; ± 0.25 m/s, WS ≥ 5 m/s: ± 5%.
Actual height of wind sensors if different from 10 meters.
NP = Not performed.
NM = Measurement not present.

1. The data logger was programmed with the wrong wind speed coefficients resulting in about a 4 to 5% error in reported speeds. The correct coefficients were entered following the audit. No further action is needed.
2. The wind direction sensor was mounted on a building. The wake created by the building will influence the wind measurements.
3. The surface wind measurements will not be accurate when winds are from the southeast. The water tank will form an obstruction that exceeds the EPA siting criteria for distance from obstructions.
4. The wind speed direction sensor was not vertical. This was corrected during the audit.

5. Trees to the south of the site presented an obstruction to the wind measurements.

6. The wind speed sensing system outputs differed from the corresponding audit inputs by more than the EPA-recommended criteria. The transfer coefficients that convert RPM to wind speed may not be correct. The operator should contact the manufacturer (Met One) for the proper coefficients and calibrate the system.

7. The wind measurements were obstructed on the southwest by a building.

8. The meteorological sensor mast was mounted on a building. The wake created by the building will influence the wind measurements.

9. The wind sensor mast was found to be loose and leaning to one side. This was corrected during the audit.

10. The base of the meteorological tower is loose and could pivot. This will cause inaccuracies in the reported wind directions. The base should be secured.

11. The guy lines for the tower were loose allowing the tower base to pivot. This will cause inaccuracies in the reported wind directions. The base was secured during the audit.

12. The wind sensors were obstructed by the retaining wall, bushes, and trees on the east side of the site. The arc of unobstructed flow for these measurements was between 180° and 200° .

Ambient Temperature Summary

Site ID	Audit Date	Date Corrected	Audit Tests			
Field Ops			Performance Test	Sensor Height *	Sensor Exposure	Misc.
BTW	6/22/97					
RSD	6/17/97		-1.3^{o}C		(1)	
HPA	6/18/97					
TML	6/19/97					
NTN	6/20/97					
TCL	6/21/97					
SIM	6/23/97		1.5^{o}C			
PHE	6/30/97					
PDE	7/1/97					
USC	7/2/97					
SCE	7/3/97					
VNS	7/10/97					
LAX	7/11/97					
SCL	7/11/97					
SCA	7/12/97				(2)	
AZS	7/13/97					
LAS	7/16/97					
PTL	NM					
VLC	NM					
BFD	7/21/97					
APE	7/23/97					
TTN	7/24/97					
CBD	7/25/97					
EMT	7/28/97				(3)	
WSP	NM					
ONT	NP					

Audit criteria = ± 1.0°C.
NP = Not performed.
NM = Measurement not present.

1. Due to the poor siting of the sensors, the surface data from this site should not be used for any purpose other than general QC checks of the profiler data.
2. The temperature and relative humidity sensors are not over representative terrain. Gravel and asphalt surfaces are nearby.
3. The temperature and relative humidity sensors were obstructed and/or influenced by the retaining wall, bushes, and trees on the east side of the site.

Relative Humidity Summary

Site ID	Audit Date	Date Corrected	Audit Tests			
Field Ops			Performance Test *	Sensor Height	Sensor Exposure	Misc.
BTW	6/22/97		-2.6°C			
RSD	6/17/97				(1)	
HPA	6/18/97		4.8°C			
TML	6/19/97		4.7°C			
NTN	6/20/97					
TCL	6/21/97		1.7°C			
SIM	6/23/97					
PHE	6/30/97					
PDE	7/1/97					
USC	7/2/97					
SCE	7/3/97					
VNS	7/10/97		-5.6°C			
LAX	7/11/97					
SCL	7/11/97					
SCA	7/12/97				(2)	
AZS	7/13/97		3.0°C			
LAS	7/16/97					
PTL	NM					
VLC	NM					
BFD	7/21/97					
APE	7/23/97					
TTN	7/24/97					
CBD	7/25/97					
EMT	7/28/97				(3)	
WSP	NM					
ONT	NP					

Audit criteria based on equivalent dew point temperature of ± 1.5°C.
NP = Not performed.
NM = Measurement not present.

1. Due to the poor siting of the sensors, the surface data from this site should not be used for any purpose other than general QC checks of the profiler data.
2. The temperature and relative humidity sensors were not over representative terrain. Gravel and asphalt surfaces are nearby.
3. The temperature and relative humidity sensors were obstructed and/or influenced by the retaining wall, bushes, and trees on the east side of the site.

3. UPPER AIR METEOROLOGY MEASUREMENTS

The SCOS97-NARSTO program included an aggressive campaign to collect meteorological data aloft to help understand the processes that lead to high ozone concentrations in the southern California region. In addition to rawinsondes and ozone sondes there were 30 upper-air monitoring stations that used remote sensing technology. This technology included 28 radar wind profilers (RWP), radio acoustic sounding systems (RASS), and 6 sodars. The RWP and RASS instrumentation included 449, 915, and 924 MHz commercial, and NOAA Environmental Technology Laboratory (ETL) profilers. Sodars included both commercial and ETL research instrumentation. Supplementing the upper-air measurements were surface (10-meter) measurements that provided both transport data as well as quality control information for the operations of the remote sensing instrumentation. This section describes the audit techniques and methods and presents the audit findings.

AeroVironment Environmental Services (AVES) under the sponsorship of ARB, SCAQMD, and SDCAPCD performed the lion's share of quality assurance of these meteorological measurements. Most of the following sections are taken from an AVES summary draft report.

The quality assurance program performed by AeroVironment Environmental Services for the stations in this network included system audits of most remote sensing instruments and associated surface collection systems. Performance audits were also performed on the surface sensors and a selected number of the remote profiling systems. Performance audits of the RWP included comparisons to a collocated mobile audit Doppler sodar and rawinsondes launched at the monitoring sites. RASS performance audits included comparisons to virtual temperature profiles from the launched rawinsondes. Sodar performance audits included comparisons to simulated Doppler shifted signals representing known wind speeds. The RWP/RASS sites selected for formal performance audits included at least one system operated by each of seven organizations -- ARB, NOAA, NOAA-ETL, Ventura County APCD, South Coast AQMD, San Diego County APCD, Radian/STI. South Coast and San Diego funded performance audits for each of their RWP/RASS

Of 28 RWP/RASS operated at 26 sites, 23 received system audits and 11 received performance audits from AVES. AVES conducted performance audits of RWP/RASS both with rawinsondes and with either a collocated project SODAR or with a portable audit SODAR. To supplement the performance audits provided by AVES, 24 additional rawinsonde releases were made at 12 sites by the ARB and the US Naval Weapons Center, Point Mugu. The additional performance audits or supplemental rawinsondes allowed comparisons with the RWP/RASS and with the SODAR at all but one site (Van Nuys). The US Navy released sondes at Port Hueneme, 9/18/97; University of Southern California, 9/26/97; Santa Catalina Island, 9/29/97; San Clemente Island, 9/29/97; and Palmdale,10/29/97; Goleta, 10/30/97. The ARB released sondes at Barstow, Hesperia, Riverside, Norton AFB, Thermal and Imperial Airport (near El Centro). The rawinsonde soundings have not yet been compared with the RWP/RASS data for these 12 sites.

Two additional RWP/RASS sites had access to project soundings for comparison. At Vandenberg AFB three RWP/RASS and a SODAR operated in near proximity; they can be checked against each other for consistency but were not otherwise audited. Likewise, the Tustin RWP/RASS was near a project rawinsonde site. Van Nuys was the only RWP/RASS site not audited or compared with collocated soundings. The airport did not grant site access.

Both systems and performance audits were conducted for the three SODAR installed by NOAA and the one SODAR installed by San Diego APCD. The existing SODAR at Vandenberg AFB was not audited but may be compared with nearby RWP-RASS and rawinsondes. The two SODAR installed later in the program at Twenty-nine Palms were not audited.

The objectives of the upper-air meteorological measurements audit program were to ensure that the established data quality objectives (DQOs) for these measurements were achieved. The approach taken was to first review the DQOs in the Quality Assurance Plan and the applicable standard operating procedures (SOPs) for these measurement systems to ensure that DQOs were adequate and realistic for the intended purpose and that the proposed procedures were appropriate in achieving those goals. The second part of the approach was to test the implementation of the procedures documented in the SOPs through system audits and performance audits of each measurement system. The system audits documented and commented on the extent to which the DQOs were met by the level of adherence to the applicable SOPs, and recommended changes in site operations, if needed, to achieving those goals. The performance audits compared the response of individual measurements to certified standards to determine any deviation from the project DQOs.

3.1 AUDIT EQUIPMENT

3.1.1 Radar Wind Profiler

The RWP was audited using a portable sodar, and rawinsondes. Each of the associated certifications is described below.

Portable Audit Sodar

A portable audit sodar was used to perform audits of the RWP systems. The sodar collected independent 15-minute average wind data that were compared to the collocated RWP. The sodar was an AeroVironment Model 2000 three-axis system. The AVES sodar is a self-contained, trailer-mounted unit developed for finer resolution remote measurements of wind speed and direction in the lower atmosphere. The certifications included both the initial checkout and acceptance of the system, and checks prior to each individual audits.

System Checkout and Acceptance

Prior to field deployment, the portable sodars' operation was verified against a known audit standard. The standard was an Acoustic Pulse Transponder (APT) capable of generating simulated Doppler shifted frequencies and known timing intervals.

To verify the system operation, the sodar was operated in the vertical velocity correcting mode. This was the same mode of operation as the RWP. At least three complete averaging intervals (15-minute) were run using the APT. Anticipated winds included horizontal components in the range of 5-10 m/s and a vertical component of about 0.5 m/s. An antenna rotation angle was used off of the normal north/south or east/west axes. Criteria for acceptable operation were horizontal and vertical components within ±0.2 m/s and vector resultant winds within ±0.5 m/s and ±5°. If the sodar data fell within this accuracy bound, then the sodar was considered suitable for use as an audit device.

To optimize the vertical range of the sodar and minimize the potential influence of reflective sources, the sodar was operated using a 20° zenith angle.

Sodar Operational Verification Prior to Each Audit

The orientation of the portable audit sodar was determined using a Brunton Pocket Transit Model F5007LM. The transit was tripod-mounted and could be read to an accuracy of approximately ±0.5°. This magnetic alignment was corrected to true north using the local magnetic declination. When possible, and cloud cover allowed, the orientation was verified using the solar azimuth angle and site latitude and longitude.

On-Site Sodar

At sites with existing collocated sodars, the sodars were audited to establish their validity as a transfer device to audit the collocated radar profilers. The procedures were divided into system audit procedures and performance audit procedures and are described below.

Rawinsonde System

For the audits of the RWP upper-range gates, VIZ Model W-9000 rawinsondes were released. Prior to release, the sondes' output was verified against the surface pressure and temperature readings of an audit device. Surface pressure was measured using a Peet Bros. Ultimeter Model 3. This barometer was certified by single-point comparisons to the AVES standard and their field barometers as well as periodic comparisons to airport pressure readings in the field. Temperature was measured using a Brooklyn Thermometers Model 76 mm mercury-in-glass thermometer. The Brooklyn Thermometers Model 76 mm mercury-in-glass thermometers were compared with the AVES NIST-certified standard thermometer.

3.1.2 RASS

The rawinsonde pressure, temperature and relative humidity data were used to calculate virtual temperature profiles for comparison with the RASS virtual temperature profiles.

3.1.3 SODARS

The sodars were audited using an acoustic pulse transponder (APT). The APT is a microcomputer-based system that is programmable for the number of pulses, pulse duration, pulse frequency, and timing delays. The system detects the transmit pulse from the sodar antenna and retransmits a preprogrammed pulse sequence. The pulse sequence consists of one or more sequential frequencies at specific timed intervals that represent known frequency offsets from the sodar system. The frequency offsets and timing of the pulses simulate wind speeds along each of the sodar component axes. The APT system consists of three modules that are described below.

Pulse transponder. The pulse transponder is placed near the sodar antenna and serves two purposes. First, it detects the transmit pulse from the sodar antenna; and second, it provides a speaker that transmits the audio audit frequency back into the sodar antenna. For the three-axis sodar, an individual transponder is placed in each of the three antennas and all components are verified at the same time.

System interface. The system interface provides the link between the pulse transponder and laptop computer. The interface converts the detected pulse into a digital signal that is transmitted to the laptop computer RS-232 port. In addition, the interface amplifies the audio frequencies generated by the computer that are sent to the transponder.

Laptop computer. The laptop computer detects the transmit pulse in the RS-232 port and initiates the pulse timing sequence. The computer software calculates the retransmission timing and frequency generation based on a preprogrammed configuration that is specific to the sodar being audited. The frequencies generated by the computer are transmitted to the system interface by means of an audio pickup. The system configuration, as well as a record of each retransmitted pulse, is recorded in a documentation file.

There are two variables that require verification in order to have confidence in the APT's ability to accurately simulate wind speeds. These variables include generation of known frequencies, and timing of the returned pulse or change in frequency.

The generation of known frequencies is verified using a Fluke Model 87 true RMS multimeter that measures the APT frequency. This multimeter is, in turn, certified against another traceable standard.

Two types of pulse timing checks are performed to check the timing in the computer software. The first checks the accuracy of the APT in timing the delay after pulse recognition. The second determines the accuracy of the retransmitted pulse length. Both of these timers are verified using a quartz clock.

3.2 SYSTEM AUDIT PROCEDURES

The purpose of the system audit is to assess consistency of measurements with the quality assurance plan and the applicable SOPs. A system audit form/checklist was used to ensure that the pertinent items of the audit were covered and to report the audit findings.

3.2.1 SODARS

The sodar system audit was divided into several tasks. A description of each task is provided below:

An evaluation of the site characteristics was performed. Passive and active noise sources were identified and noted to evaluate their impact on the sodar's ability to separate the return pulses from the background noise. Passive sources are objects that may reflect the pulse and contaminate the return spectra with what appears to be near-zero wind speeds. These sources include buildings, trees, nearby towers, etc. Active sources generate their own noise such as air conditioners, fans and industrial complexes. Low-level active white noise sources are not generally a problem except to reduce the maximum altitude. Active noise sources in the frequency spectrum of the sodar operations may affect the operations. General sound levels were measured using an integrating sound level meter and measuring levels, in dBA, in at least the four cardinal directions.

In addition to the evaluation of the total noise spectrum above, a system check was performed with the system "listening only"; i.e., without transmitting a pulse. The results of this check should produce no measured winds, or winds with very low reliability. If reliable winds are reported at any level, then there is probably an active noise source in the area that is generating frequencies in the operational region of the sodar.

Alignment checks were performed on the sodar systems. The orientation of the antenna array or individual component antennas will directly affect the accuracy of the calculated wind directions. The orientation of the respective antenna arrays were checked using a tripod-mounted Brunton Pocket Transit. The measured orientation was then compared to the software settings in the sodar. The criteria for acceptable orientation is ±2°. During the field audit, the compass alignment to magnetic north was compared against solar observations and the magnetic declination to verify the accuracy of the magnetic measurements.

The level of a phased sodar antenna array directly affects the calculations of the component speeds. The array level was checked using the inclinometer integral to the Brunton Pocket Transit. The criteria for acceptable level in any direction is ±1°.

3.2.2 Radar Profilers and RASS

Little guidance exists, regulatory or otherwise, for the quality assurance of remote sensing systems. For this program, *Draft Guidelines for the Quality Assurance and Management of PAMS Upper-Air Meteorological Data* (STI, 1995), which was prepared under funding from the EPA, was used as a starting point for the system and performance audit procedures. The procedures in the guidance are enhanced with experience of the auditor in previous quality assurance programs involving radar profiler and RASS instrumentation.

The system audit of the radar profiler inspected the antenna(s) and controller interface cables for proper connection, set up, and antenna level and alignment.

Antennas and enclosures or clutter fences were inspected for structural integrity. The orientation of the antennas were checked using a magnetic transit and tripod with the observed magnetic readings corrected to true directions using the local magnetic declination. The alignment of the array was checked using flags dropped from the antenna array that are visible from outside the clutter fence. The magnetic orientation measurements were also verified using solar azimuth measurements and latitude and longitude information provided by a geo positioning system (GPS). The level of the antennas was measured using a Pro SMARTLEVEL. Measurements were made in at least two directions on the bottom of the antenna array's support structure.

A vista diagram was prepared that documents the surroundings of the site. The diagram identified potential reflective sources for the radar signal, as well as potential active sources that could generate interference. The diagram also provided a description of the view in 30-degree increments around the antenna, including the elevation angle and estimated distance to potential sources.

A scan of frequencies around the central operating frequency of the radar was performed using an RF scanner. This method identifies potential sources of active radio frequency noise that can contaminate the wind and virtual temperature data.

The settings of the controller and data collection devices were checked and noted to ensure that the instrument was operating in the proper mode and that the data being collected were those specified by the SOPs. This included a check of all clocks for accuracy, verifying that they were within ±2 minutes of the standard. The site operator was interviewed to determine his/her knowledge of the system operation, maintenance and proficiency in the performance of quality control checks. Emphasis was placed on verifying that preventive maintenance procedures had been implemented and were adequate. The station logbooks were reviewed for completeness and content.

While no specific audit criteria exist for the orientation and level, we used values consistent with past audits and the EPA-funded document, *Draft Guidelines for the Quality Assurance and Management of PAMS Upper-Air Meteorological Data* (STI, 1995). For orientation we used a value of ±2°. For level we used ±0.5°. For siting, the recommendations of the EPA-funded document, *Draft Guidelines for the Quality Assurance and Management of PAMS Upper-Air Meteorological Data* (STI, 1995) were used to augment the recommendation that the radars be set up away from tall buildings, power lines and other obstructions that may be a potential source of interference. Ground clutter is the primary problem; therefore, locations on hilltops away from trees or other tall objects, are desirable.

3.2.3 Surface Meteorological Measurements Associated With RWP

The system audits of the surface meteorological sensing systems associated with the RWP and RASS consisted of an inspection of the site to assess proper siting of the instrument sensors, a review of the station check logs and other site documentation, as well as an interview with the site operator concerning his or her knowledge of the QAPP and applicable SOP sections.

Sensor siting criteria for meteorological sensors are specified in the EPA's *Quality Assurance Handbooks for Air Pollution Measurement Systems, Volume IV* (EPA, 1994d). On-site forms and site logs were reviewed to check that the documentation conformed to the specifications of the plan. The subjects that were addressed by the system audits were:

- Network design and siting
  - network size and design
  - sensor exposure
  - review of station
- Resources and facilities
  - instruments and methods
  - staff and facilities
  - standards and traceability
- Quality assurance and quality control
  - status of quality assurance program
  - audit participation
  - precision and accuracy checks

Additionally, once the system audits of all sites were completed, the auditor checked for possible differences in operation among the various sites.

3.3 Performance Audit Procedures

3.3.1 SODARS

The performance audits of the sodars were done by comparison with simulated winds from the APT. The audit criteria for the rawinsonde comparison was the same as for the RWP described in Section 3.4.2, with two flights performed per site. Sodar audit criteria are presented in Table 3.4-1.

Unlike conventional sensors where known wind speeds and directions can be input directly to the sensor through various rotational methods, the acoustic system relies on the measurement of time and frequency shift of the back-scattered acoustic pulse. The only means of truly providing a known input is through the introduction of fixed audio frequencies at known times. The frequency shift will correspond to a Doppler shift introduced by winds to or from an antenna. The timing of the simulated return will represent a known altitude based on the speed of sound.

These simulations of the Doppler shifted signal were performed with the APT described in Section 3.1.1. As in the evaluation of the portable sodar, at least three sampling intervals were evaluated using simulated wind speed and direction inputs. The audit criteria also followed the criteria set for the portable sodar.

As a final check of the sodar data, data collected during several days prior to the audit were reviewed to establish the internal consistency of the values. As this is a qualitative check, there were no fixed evaluation criteria. The goal was to evaluate the following:

- Data reliability or quality codes for consistency
- Measured vertical intensity values for detection of potential fixed echoes
- Vertical profile of the individual wind components for detection of potential fixed echoes and consistency
- Vertical profile of the calculated vector winds for internal consistency
- Methods used to create hourly values from sub-hourly intervals

3.3.2 RWP

Two sets of performance audit procedures were used that were specific to given sites. The profiling systems used at several sites were audited using a portable sodar. If the site was equipped with a collocated sodar, the profiling system was audited by first establishing the on-site sodar as an audit device and then using the sodar data collected to audit the RWP data. The performance audit procedures are described below.

The new EPA guidance for QA on radar profilers defines a series of system checks inherent to the profiler electronics. Unlike the sodar where instrumentation exists for simulation of winds by introduction of "Doppler shifted frequencies" no such instrumentation exists for the profiler or RASS systems. Thus, to audit the data gathered by these profilers, procedures similar to those used in acceptance testing were implemented. The acceptance test procedures included comparisons to another form of upper-air measurement. The comparisons were made to collocated sodars at each of the sites. For sites without existing collocated sodars, comparisons were made using a portable AeroVironment Model 2000. All comparisons were made over a minimum 24-hour period.

Performance audits with the portable sodar were performed by collocation with each of the radar profilers and collection of wind speed and wind direction data at 30-meter intervals up to 750 meters. Data were collected in 15-minute intervals, validated, and averaged in both time and vertical space to match the intervals on the radar profilers. Collocated data were collected over at least a 24-hour interval so as to include a variety of stability conditions. Prior to deploying the sodar to the field, its operation was verified using the Acoustic Pulse Transponder, as described above.

The wind data from the audit rawinsonde flights that were conducted midmorning and mid-afternoon at each site were used for comparison to the RWP data at altitudes above the maximum altitudes reached by the audit sodars.

Audit criteria for RWP (Table 3.4-2) is consistent with the *Draft PAMS Upper-air Guidance* document (STI, 1995). Overall systematic differences should be within ±1 m/s for wind speed and ±10° for wind direction. Comparabilities should be within ±2° m/s and ±30° for direction. If the observed differences exceed these criteria, it does not necessarily mean the RWP failed the audit. The reasons for the differences were fully explored before determination of a problem was established.

As a final part of the audit of the radar profilers, data from several days prior to the audit were reviewed for internal consistency. This type of review checked indicated flags for data reliability or quality codes for consistency, individual component intensity values to identify potential reflections, and the vertical profiles of the components and resultant values for internal consistency both in space and time. This was a subjective review which has proved useful in past audits as a "second set of eyes" reviewing the data.

3.3.3 RASS

The EPA-funded draft *PAMS Upper-air Guidance* document (STI, 1995) recommends that performance auditing of RASS consist of a comparison to independently collected virtual temperature (Tv) profiles. These profiles were collected using a rawinsonde system.

For this study, we launched two rawinsondes at each of the RASS sites to collect profile data from which the comparisons over several stability conditions were compared. Balloon-borne sondes collecting pressure, temperature and relative humidity were used to calculate the virtual temperature profiles (T*v*) for comparison to the RASS-derived T*v* values. The data collected from each launch were volume averaged to match the averaging intervals of the RASS. Audit criteria used for evaluation of the data were systematic differences of ±1.0°C and comparabilities of ±1.5°C. Experience gained in the LMOS, IMS-95 and NARSTO-Northeast studies showed these criteria are readily achievable. However, differences outside of this criteria do not mean the RASS system has failed. It indicates that the data need further analyses to determine the reasons for the differences.

As in the wind profiles, data from several days prior to the audit were reviewed. The review focused on the internal consistency of the data in both space and time and looked for the reasonableness of the Tv profiles.

3.4 AUDIT RESULTS SUMMARY

TABLE 3.4-1. Summary of audit observables and audit instrumentation – Sodars.

Instrument	Observable	Audit Device	Audit Device Traceability	Audit Device Precision	Accuracy	Audit Criteria (DQOs)	Comments
Sodar	Orientation	Brunton Pocket Transit model F5007LM	N/A	N/A	±1°	±2°	The accuracy of the orientation measurement is based on the ability to read the compass and avoid magnetic aberrations. When possible solar siting verifications will be obtained.
	Level	Pro SMARTLEVEL with inclinometer verification	N/A	0.2°	±0.2°	±0.5°	The SMARTLEVEL is calibrated according to factory recommendations over full operating range. The indicated accuracy and precision are conservative estimates. The manufacture claims ±0.1° accuracy.
	Wind Speed and Wind Direction	Acoustic Pulse Transponder	Fluke model 87 frequency meter for frequency. Quartz clock timing.	1 Hz 3 ms	±1 Hz ±3 ms	±0.2 m/s component speed. ±0.5 m/s speed. ±5° direction resultant vector. ± one range gate for altitude response.	The audit device precision and accuracy are expressed in simulated Doppler shift frequency and echo delay. The respective response in m/s and altitude depends on the operational parameters of the sodar audited. The audit criteria applies to both the portable sodar & the on-site sodars used to audit the radar profilers.
	Exposure	Brunton Pocket Transit model F5007LM and inclinometer	N/A	N/A	N/A	Minimize active & passive sources. below 20° in the beam directions.	The evaluation is subjective. More details are provided in the workplan.

TABLE 3.4-2. Summary of audit observables and audit instrumentation—Radar Profiler and RASS.

Instrument	Observable	Audit Device	Audit Device Traceability	Audit Device Precision	Accuracy	Audit Criteria (DQOs)	Comments
Radar Profiler	Orientation	Brunton Pocket Transit model F5007LM	N/A	N/A	±1°	±2°	The accuracy of the orientation measurement is based on the ability to read the compass and avoid magnetic aberrations. When possible, solar siting verifications were obtained.
	Level	Pro SMARTLEVEL with inclinometer verification	N/A	0.2°	±0.2°	±0.5°	The SMARTLEVEL is calibrated according to the factory recommendations over the full operating range. The indicated accuracy and precision are conservative estimates. The manufacture claims ±0.1° accuracy.
	Wind Speed and Wind Direction	AVES Model 2000 sodar	Sodar verification with Acoustic Pulse Transponder	0.1 m/s	±0.2 m/s	±1.0 m/s speed ±10° direction for collocated sites.	The audit device precision and accuracy refers to the response of the sodar to the Acoustic Pulse Transponder (APT) on a component-by-component basis. The audit criteria shown are based on the vector resultant comparisons. See sodar below for more on the APT.
	Exposure	Brunton Pocket Transit model F5007LM and inclinometer	N/A	N/A	N/A	Minimize active and passive sources. Passive sources below 20° in the beam directions.	The evaluation is subjective.
RASS	Virtual Temperature (Tv)	Rawin-Sonde	Brooklyn 76 mm mercury-in-glass thermometer for temp. Peet Bros. Ultimeter 3 for pressure	0.2° C 1 mb	±0.3°C ±4 mb	Tv ±1.0°C	The temperature precision and accuracy refer to the dry bulb thermistors. The devices used for traceability check the sondes before launch. Acceptable launch differences are ± 0.5°C and ±10 mb.

3.4.1 Systems Audits

Table 3.4-3. Systems Audit Results for Upper-Air Meteorology Measurements

Site ID	Site ID	Audit Date	Date Corrected	Audit Tests						
Field-Ops	SCOS97			RWP Antenna Level *	RWP Antenna Orientation+	RASS Source Level *	Sensor Exposure	Controller Set Ups	Range Gate Set Up	Misc.
BTW	BARM	6/22/97					(1)			
RSD	RIHM	6/17/97	6/17/97				(2)		(3)	
HPA	HESO	6/18/97	6/18/97, except (5)		-5°	1.3°		(4)	(5)	
TML	THRM	6/19/97	6/19/97, except (7)					(6)	(7)	
NTN	NAFB	6/20/97		0.9°			(8)		(9,10)	
TCL	TMCM	6/21/97								
SIM	SVLM	6/23/97						(11,12)		
PHE	HUEN	6/30/97	6/30/97 (13)			3.3°				(13)
PDE	PALD	7/1/97	7/1/97 (15)		5°	1.2°			(14)	(15)
USC	USCZ	7/2/97	7/2/97, except (16)		-19°	1.6°			(16)	
SCE	SCLM	7/3/97	7/3/97, except (17)		3°	2.1°			(17)	
VNS	VNUY	7/10/97	7/10/97, except (18)		6°	1.7°			(18)	
LAX	LAXP	7/11/97	7/11/97		-2°	0.9°				
SCL	CATM	7/11/97	7/11/97, except (21)		-4°	6.2° (19)		(20)	(21)	(22)
SCA	CLAR	7/12/97	7/12/97, except (23,24)			1.4°,0.6°	(23,24)			
AZS	AZSM	7/13/97			2.5°,4.5°		(25,26)			
LAS	LOSM	7/16/97	7/16/97, except (27)				(27,28)			
PTL	PTLP	7/17/97	7/19/97		-7°	3.8°	(29)		(30)	
VLC		7/19/97			3°	1.5°	(31)			
BFD	BRWN	7/21/97		0.5°,0.9°		1.4°			(32)	
APE	ALPM	7/23/97		-0.7°,-1.2°	4 °, 3 °	2.5 °, 2.3 °, 1.6 °, 1.5 °			(33)	
TTN	TUST	7/24/97		0.5 °, 0.5 °	0 °, -2 °	3.2°			(34)	
CBD	CARL	7/25/97			0 °,3 °	1.9 °			(35)	
EMT	EMAM	7/28/97			-5 °	1.5 °	(36)		(37)	(38)
WSP	WSPM									
ONT	ONTP									

* Audit criteria is ± 0.5°
\+ Audit Criteria is ± 2°

1. Highway 58 is a potential active noise source that appears to produce clutter.
2. Buildings around the site can produce reflections.

3. RASS set to 12 range gates. Changed to 20 range gates following the audit.
4. The RASS temperature range is from 2 to 36°C. The upper boundary should be increased to include temperatures that are normally expected in a desert environment.
5. The RASS height range was increased during the audit from 12 gates (780 m) to 20 gates (1280 m). Consideration should be given to raising it to 1560 meters.
6. The RASS temperature range is from 2 to 36°C. The upper boundary should be increased to include temperatures that are normally expected in a desert environment.
7. The RASS height range was increased during the audit from 12 gates (780 m) to 20 gates (1280 m). Consideration should be given to raising it to 1560 meters.
8. Power lines to the south may produce clutter when it is windy.
9. The RASS is set to collect data at 210-meter intervals starting at 285 meters up to 2185 meters. Collecting RASS in this mode can miss much of the surface stability structure.
10. The high mode winds are set to collect data at 210-meter intervals with a pulse length of 400 meters. Other participants are collecting the high modes winds at 100-meter intervals.
11. The RWP is set to collect 15-minute averages and the RASS makes a sounding every 15 minutes. Most RWP are set to collect hourly wind data.
12. The RWP is set to collect wind data in the low mode of operation only to a maximum altitude of 1988 meters. All other SCOS97 RWP are collecting wind data in the high mode as well as the low mode.
13. At the time of the audit there were two RASS sources not functioning. It was indicated they would be fixed after the audit.
14. The RASS is set for 100-meter spacing. Most of the RASS operating in SCOS97 are set to collect 60-meter data.
15. At the time of the audit, there were two RASS sources not functioning. It was indicated they would be fixed after the audit.
16. The RASS range gate spacing was 106 m instead of the recommended 60 m.
17. The RASS range gate spacing was 105 m instead of the recommended 60 m.
18. The RASS range gate spacing was 106 m instead of the recommended 60 m.
19. Three of the RASS dishes were out of level by 1.8 to 5.4°. In the worst antenna the transducer was out of level by 6.2°. The worst source was releveled.
20. The radar profiler time was 7 minutes slow. The time was corrected during the audit. The data logger time was within 1 minute.
21. The RASS range gate spacing was 106 m instead of the recommended 60 m.
22. One of the RASS transducers was not working. A loose connection was found and repaired.
23. There were several sources of noise. The most significant was background traffic that tends to decrease the altitude capabilities of the sodar. The antennas were aimed in the direction of two roads that produce significant amounts of noise. The second source of noise was the pumps that were internal to the adjacent building. While the building has been sound-proofed, a sampling of the frequency spectra generated by one of the internal pumps showed broad band active noise generation at frequencies between 1100 and 2000 Hz and again at about 2080, 2460 and 2700 Hz. There are three other pumps in the building in addition to a backup generator.
24. In the direction of the east beam was a building that could produce reflections in the range of about 40 to 100 meters. In the south beam were trees from which reflections could be heard. The data should be reviewed carefully to invalidate data that may be contaminated by these reflections.
25. There were a couple primary sources of noise. The most significant was traffic along the adjacent road. The second source of noise was the loud frequent gun shots from the nearby shooting range. These noise sources will limit the vertical range of the sodar.
26. The site is in a canyon with possible reflections from the canyon walls. During the audit, reflections could be heard from both of the transmit beams. This will contaminate the data and potentially bias the component wind values low.
27. There are several sources of noise that could affect the sodar operation. The most significant is an air conditioner on the adjacent trailer (about 5 meters from the sodar antenna). One sodar beam was toward the air conditioner. The broad band noise in the direction of the air conditioner averaged about 60 dBA, as opposed to 52 to 54 dBA in the other potential beam directions. A sampling of the spectral noise in the direction of the air conditioner showed active noise around the sodar operational frequency (the sodar frequency is 1889 Hz). Most significant was a band at about 1900 Hz. A quick review of the on-site data showed the sodar is seriously affected by the noise in the wind levels above about 250 to 300 meters. Aiming the beam away from the air conditioner may not help the problem because the interference is also seen in the

vertical beam. The noise from the air conditioner needs to be minimized in order to achieve reasonable data in the upper ranges of the sodar. Another possibility is to move the operating frequency to about 2400 Hz where the air conditioning frequency spectra was at a minimum. However, the best alternative is to separate the noise source from the sodar. Other active noise sources that could affect the sodar include broad band noise from the aircraft and helicopter operations at the airport and agricultural operations in the adjacent fields. These sources would tend to decrease the altitude capabilities of the sodar.

28. The RWP was just changed from 924 to 915 MHz to move away from interfering frequencies in the 924 MHz band.
29. The cliffs and hills to the north through east side of the site present potential reflective surfaces to the northeast beam. A review of the data showed ground clutter to approximately 500 meters in the northeast antenna data in the low mode of operation. The northeast antenna data in the high mode of operation did not show ground clutter, but the spectral peak for these range gates appeared smoothed and translated toward lower values.
30. The low mode winds are collected at 100-meter intervals instead of 60-meter intervals. The high mode winds are collected at 200-meter intervals instead of 100-meter intervals. The RASS virtual temperature data is collected at 100-meter intervals instead of 60-meter intervals.
31. The surrounding hills and embankments present a potential to interfere with the wind data. Clutter is present in the lowest two to three range gates. This potential will be investigated further when the audit, RWP and RASS data are compared.
32. The RASS range gate spacing was 106 m instead of the recommended 60 m.
33. The RASS range gate spacing was 106 m instead of the recommended 60 m.
34. The RASS range gate spacing was 106 m instead of the recommended 60 m.
35. The RASS range gate spacing was 105 m instead of the recommended 60 m.
36. The movement of the automobiles on Lower Azusa Road toward the north to northwest and the trees that line Lower Azusa Road toward the northwest present potential passive noise sources to the RWP measurements.
37. The RASS range gate spacing was 105 m instead of the recommended 60 m.
38. The RASS acoustic temperature and acoustic source ranges were set too low for the expected temperature ranges in the El Monte area. They were adjusted to more suitable ranges following the audit. No further actions are required.

3.4.2 Performance Audits

Table 3.4-4. Performance Audits - RWP Versus Audit Sodar

Site ID Field Ops	Site ID SCOS97	Audit Date	High Mode WS Average Diff./RMS (m/s)	High Mode WD Average Diff./RMS (deg)	Low Mode WS Average Diff./RMS (m/s)	Low Mode WD Average Diff./RMS (deg)
TCL	TMCM	6/21/97	0.6 / 1.4	-3 / 14	-1.7 / 4.8	-1 / 36
SIM	SVLM	6/23/97	(1)	(1)	0.8 / 2.6	-4 / 54
LAX	LAXP	7/11/97	-1.4 / 1.8	-8 / 48	-1.4 / 1.8	7 / 42
LAS	LOSM	7/16/97	(2)	(2)	(2)	(2)
PTL	PTLP	7/17/97	-0.8 / 1.1	-10 / 31	-1.5 / 2.1	-44 / 59 (3)
VLC		7/19/97	(2)	(2)	(2)	(2)
BFD	BRWN	7/21/97	(4)	(4)	-1.3 / 2.1	-3 / 38
APE	ALPM	7/23/97	(4)	(4)	-1.1 / 1.5	21/ 33
CBD	CARL	7/25/97	(4)	(4)	-1.5 / 2.2	1 / 67
EMT	EMAM	7/28/97	-4.8 / 7.7 (5)	60 / 106 (5)	-5.6 / 8.2 (5)	35 / 96 (5)
ONT	ONTP	10/23/97	-0.6 / 1.2	1 / 30	-0.4 / 0.9	-2 / 15

Audit criteria:
WS average difference: ± 1.0 m/s
WD Average Difference: ± 10 °
RASS Average Difference: ± 1.0 °

1. High mode winds were not measured at site.
2. Audit sodar data were not available.
3. The PTL low mode (60 meter) data was affected by ground clutter to about 500 meters in the northeast beam.
4. A) RWP high mode data not valid below 700 meters because of pulse coding.

   B) Final quality controlled RWP data were not available for the audit comparison. The audit comparison was made using preliminary data.

   C) The large average difference for the APE low mode wind direction could not be explained. Further, comparisons between the sodar and high mode winds (which are invalid) for all three NOAA sites audited (APE, BFD, and CBD) compared within the audit criteria, which is perplexing.
5. The audit sodar data were contaminated by noise.

Table 3.4-5. Performance Audits - RWP Versus Rawinsonde

Site ID Field Ops	Site ID SCOS	Audit Date	High Mode WS Average Diff./RMS (m/s)	High Mode WD Average Diff./RMS (deg)	Low Mode WS Average Diff./RMS (m/s)	Low Mode WD Average Diff./RMS (deg)	RASS Average Diff/Std. Dev. (°C)
TCL	TMCM	6/21/97	0.6 / 1.4	-3 / 14	(1)	(1)	0.6 / 0.4
SIM	SVLM	6/23/97	(2)	(2)	1.0 / 1.8	-1 / 49	1.2 / 1.2
LAX	LAXP	7/11/97	-2.4 / 4.0 (3)	-9 / 86 (3)	-3.2 / 4.7 (3)	21 / 58 (3)	0.0 / 1.2
LAS	LOSM	7/16/97	0.7 / 2.1	0 / 44	0.6 / 2.1	-6 / 65	0.4 / 1.5
PTL	PTLP	7/17/97	-0.6 / 1.3	0 / 12	-0.9 / 1.0	-3 / 25	0.6 / 1.0
VLC	ESCM	7/19/97	-0.6 / 1.6	4 / 37	-0.9 / 1.5	11 / 46	1.1 / 0.8
BFD	BRWN	7/21/97	-0.4 / 3.8 (4)	-5 / 19 (4)	0.8 / 1.9	-7 / 35	-0.4 / 0.8
APE	ALPM	7/23/97	-9.0 / 11.7 (4)	-17 / 34 (4)	-2.0 / 3.8	-10 / 38	-2.2 / 2.0
CBD	CARL	7/25/97	0.8 / 3.4 (4)	7 / 22 (4)	0.5 / 3.2	17 / 37	1.1 / 3.9
EMT	EMAM	7/28/97	-0.3 / 1.2	6 / 31	-0.4 / 1.5	0 / 23	0.5 / 0.4
ONT	ONTP	10/23/97	-1.6 / 2.6	2 / 39	-0.2 / 3.2	14 / 47	0.8 / 0.3

Audit criteria:

WS average difference: ± 1.0 m/s
WD Average Difference: ± 10 °
RASS Average Difference: ± 1.0 °

1. Rawinsonde data within the vertical range of the low mode data were not available for the comparisons.
2. High mode winds were not measured at site.
3. Large differences between the rawinsonde and RWP data are probably due to the distance between the rawinsonde launch site and the RWP location. The rawinsonde site was close to the east end of runway 25, and the RWP location was at the west end of the runways, a linear distance of more than five miles.
4. A) Results are from comparisons of data collected above 700 meters. RWP high mode data is not valid below 700 meters because of pulse coding.

   B) Final quality controlled RWP data were not available for the audit comparison. The audit comparisons were made using preliminary data.

Table 3.4-6. Performance Audit of Sodars

Site ID Field Ops	Site ID SCOS97	Audit Date	Audit Levels	SODAR - APT WS Average Diff./RMS (m/s)	SODAR - APT WD Average Diff./RMS (deg)
SCA	CLAR	7/12/97	1 (160 m)	1.79 (1)	1
			2 (367 m)	1.72 (1)	0
AZS	AZSM	7/13/97	1 (161 m)	-1.69 (2)	0
			2 (354 m)	-3.26 (2)	0
LAS	LOSM	7/16/97	1 (329 m)	0.11	3
			2 (657 m)	-0.01	1
WSP	WSPM	9/10/97	1 (327 m)	-0.99	-2
			2 (686 m)	-0.58	-2

Audit criteria:

WS average difference: ± 0.5 m/s
WD Average Difference: ± 5 °

1. Results of the Acoustic Pulse Transponder (APT) audit showed the sodar responded within criteria for the timing and altitude calculations. However, problems were found with the wind speed calculations. The calculation of the horizontal wind speed along the beam direction was found to differ from the audit input by up to 0.7 m/s. When combined into a resultant wind speed, this difference could be over 1 m/s. It is suspected the reason for the difference lies in sodar resolution in measuring the Doppler shift frequency of returned echoes. The current operational mode has a fairly broad bin range that translates into an effective resolution of component speeds of about 0.9 m/s. This provides a resultant resolution of about 1.2 m/s. Consideration should be given to using a finer resolution in the bin spacing for the calculation of the radial speeds.

   The second problem with the sodar was found in the calculation of the U and V wind components from the radial component speeds. Recognizing the identified resolution problem above (~0.9 m/s wind speed gates), the speeds along the radial directions were calculated correctly. However, errors were found in the calculation that takes the radial speeds and converts them to U and V components. In the tests performed, the errors resulted in U and V speeds that differed significantly from the audit speeds, but directions that were accurate. The calculation errors need to be corrected and affected data reprocessed from the radial values. Word was received from NOAA on July 14 that the U and V calculation algorithm was fixed and will be installed at both the Santa Clarita and Azusa sites on July 14.

   Given the zenith angle of the sodar at 20°, the horizontal components should be corrected for vertical velocity. Since vertical velocity is not measured with the sodar (it is only a two-axis sodar), there will be inaccuracies in the measured wind data even after the calculations and resolution are resolved with the problem stated above.

2. Similar to the Santa Clarita site above.

4. UPPER-AIR AIR QUALITY MEASUREMENTS

Aloft air quality measurements during SCOS97-NARSTO IOPs included ground-based lidar, instrumented aircraft and ozonesondes.

4.1 Specific Systems Used for Upper-Air Air Quality Measurements During SCOS97

4.1.1 NOAA ETL Ground Based Ozone Lidar

Differential Absorption Lidar (DIAL) has previously been used in a number of regional air quality studies to measure both spatial and temporal distribution of atmospheric pollutants. The pollutant of interest in most studies was ozone (O_3). Recent United States DIAL ozone measurement studies include the 1991 Lake Michigan Ozone Study (LMOS) (Uthe et al., 1992), the 1993 Coastal Oxidant Assessment for Southeast Texas (COAST) study (Moosmüller, 1994; Moosmüller et al., 1994), the 1993 Los Angeles Atmospheric Free Radical Study (Zhao et al., 1994) and the 1995 Southern Oxidant Study (SOS) (Alvarez II et al., 1997). Generally, DIAL systems have been operated in these studies on an exploratory basis without formal quality assurance procedures. However, to fully utilize DIAL capabilities for the respective study purposes, well established quality assurance procedures are necessary to provide quantitative estimates of precision, accuracy, and validity of the measurements and to optimize measurement and data analysis procedures. Therefore, every effort should be made to establish an effective DIAL quality assurance program for SCOS97. It is important that the QA team does not treat the DIAL system as a "black box" for measuring ozone concentrations, but has an in-depth understanding of the measurement and data analysis process, the DIAL hardware, and the potential problems involved. The specialized nature of ozone DIAL measurements precludes simple performance audits for these measurements. Intercomparison studies are typically used to assess the accuracy and precision of DIAL measurements.

In addition to the measurement of ozone concentration profiles ozone lidars can utilize their "off channel" to monitor aerosol backscatter structures. The resulting aerosol data are extremely valuable for the visualization of atmospheric layers, but are only semi-quantitative in nature due to limitations in lidar inversion techniques.

The Atmospheric Lidar Division of NOAA's Environmental Technology Laboratory in Boulder has developed a transportable ozone and aerosol lidar specifically for the measurement of ozone in the boundary layer and the lower free troposphere. This lidar has been employed in several field experiments:

- July 1993, Intercomparison Experiment in Davis, CA, sponsored by ARB (Zhao *et al.,* 1994)

- September 1993, LAFRS Experiment in Claremont, CA, sponsored by ARB (Zhao *et al.,* 1994)

□ August, 1995, Ozone Transport Experiment in Victorville, CA, sponsored by ARB

□ October–November 1995, Table Mountain Vertical Ozone Transport and Intercomparison Experiment in Boulder, CO, sponsored by NOAA.

This system is based on a solid state laser, the Nd:YAG laser with a fundamental wavelength of 1064 nm and a pulse repetition rate of up to 10 Hz. The third harmonic of this wavelength (i.e., 355 nm) with an operating pulse energy of 7–10 mJ is used for aerosol profiling with a range of about 9 km. The fourth harmonic of the fundamental (i.e., 266 nm) with an operating pulse energy of 20–30 mJ is used as "on-line" for the ozone measurement. The "off-line" for the ozone measurement is generated by Raman shifting the second harmonic (i.e., 532 nm) by the vibrational frequency of the deuterium molecule (i.e., 2987 cm-1) to 632.5 nm, and subsequent sum-frequency mixing of 532 nm and 632.5 nm, yielding an "off-line" at 289 nm. The Raman shifting takes place in a specially designed Raman cell, yielding a pulse energy of 1-2 mJ at 289 nm. This process utilizes the laser energy better than the more direct Raman shifting of the fourth harmonics (Ancellet et al., 1989; Zhao et al., 1994), while yielding the same wavelength.

The receiver section utilizes an 8"-diameter telescope to collect the backscattered light. Dichroic beamsplitters separate the light from the different laser lines for the detection by photomultiplier tubes. The signals are digitized by 12 bit A/D converters for subsequent analysis. The aerosol channel formerly had an 8-bit A/D converter that is being replaced by a 12-bit A/D converter.

Ozone measurements can be obtained for a range of up to 3 km under moderate to high surface ozone concentrations (< 150 ppb) while, for extremely high concentrations, a range of 2 km can still be achieved. The lower range limit is very good (□ 50 m) due to the use of an innovative technique for the compression of the lidar dynamic range (Zhao et al., 1992). The measurement direction of the lidar system can be scanned in one dimension from 30□ to 150□ yielding a two dimensional ozone measurement.

The data quality objectives for ozone measurements with the NOAA ozone lidar are □5 ppb for ranges up to 1.5 km and □10 ppb for ranges up to 3 km for moderate to high surface ozone concentration (< 150 ppb) under the assumption of 1 min temporal and 50 m spatial averaging. The lidar observation in a 2-dimensional vertical plane will take 11 min for a scan from 30□ to 150□ in 10□ steps, firing 100 laser shots at each angle with a pulse repetition rate of 2 Hz. If higher temporal resolution is desired the system can be operated with a pulse repetition rate of 10 Hz. Preliminary ozone data for visualization and for intercomparison with in situ sensors will be available in near real time. This ability will greatly facilitate an ozone lidar performance audit.

Successful use (i.e., meeting the quality objectives) of the NOAA ozone lidar in 2-dimensional scanning mode is contingent on improvements of the scanning system. Previous use of the system in scanning mode has yielded relatively poor quality data due to problems with thermal expansion of a scanning mirror and subsequent optical distortions. NOAA expects to have eliminated these problems and to have conducted system and performance tests prior to the system's deployment in SCOS97.

The NOAA ozone lidar will be transported to California in June 1997 and set up at the El Monte site. During SCOS97, the lidar will gather 350 hours of data, split up into seven intensive measurement periods to capture various types of ozone episodes. When an ozone episode of interest is expected to develop, NOAA staff will fly within 24 hours to the lidar site and begin to collect data.

4.1.2 UCD Airborne Instrumentation (UCD Cessna 182, Gibbs Cessna 182)

Instrumented aircraft will be used to measure the three-dimensional distribution of ozone, ozone precursors and meteorological variables. The aircraft will provide information at the boundaries of the modeling domain and will document the vertical gradients, the mixed layer depth, and nature of the polluted layers aloft. Four aircraft are included in the core program and additional aircraft may be available for short periods. The University of California, Davis Cessna 182 will be used to characterize processes resulting in ozone layer aloft in the SoCAB and ozone fluxes into the San Fernando Valley. It will also provide data to validate the ground-based lidar measurements by NOAA at the El Monte Airport. The Sonoma Technology Piper Aztec will provide boundary and initial conditions in the northern portion of the study domain and serve as back-up to the western boundary aircraft. It will also provide data to characterize ozone and NO_Y fluxes through Tehachapi, San Gorgino, and Cajon Passes and profiles in the eastern portion of the SoCAB. The Gibbs Flying Service Cessna 182 will provide initial condition in the southern portion of the modeling domain and provide data to determine the presence of pollutant transport between the SoCAB and the San Diego Air Basin. The EOPACE (Navajo) aircraft will provide boundary and initial conditions in the western (over-water) region of the modeling domain and provide data on any offshore movement of pollutants from the SoCAB.

4.1.3 UCD Airborne Instrumentation (UCD Cessna 182, Gibbs Cessna 182)

Air quality instrumentation provided by Dr. John J. Carroll of the University of California at Davis (UCD) will be utilized in two aircraft, UCD Cessna 182 and Gibbs Flying Service Cessna 182. The instrumentation has been used in the UCD C-182 for several years. It is being duplicated and installed onboard the Gibbs Flying Service Cessna 182. The air quality instrumentation onboard this aircraft will be maintained and calibrated by the San Diego Air Pollution Control District (SDAPCD). An overview of the UCD instrumentation complete with data quality objectives, i.e., accuracy, is given in Table 5-1.

The UCD aircraft will be used to investigate up to seven ozone episodes. During each episode of interest the aircraft will be based at the El Monte Airport (close vicinity to NOAA lidar) and will operate for three days. Each day, two to three flights consisting of up to seven vertical spirals (460 to 3,050 m MSL) will be conducted. The Gibbs Cessna will be based at Montgomery Field in San Diego. It will make two flights on IOP days consisting of up to five spirals.

System performance checks will be done daily and calibrations will be performed before and after each operational period. Each day's data will be screened as it is collected to check the performance of each component.

Table 4.1-1
UCD Instrumentation

Parameter Measured	Technique	Manufacturer	Time Response	Measurement Range	Accuracy
Pressure (Altitude)	Capacitive	Setra	1 s - 3 s	-30 m - 3700 m	□ 0.3 mB □ 3 m
Temperature	Platinum RTD	Omega	1 s - 3 s	-20□C - 50□C	□ 0.2□C
Relative Humidity	Capacitive	Qualimetrics	1 s - 3 s	10% - 98%	□ 3%
Air Speed	Thermal Anemometer	T.S.I.	1 s - 3 s	15 m/s - 75 m/s	□ 0.4 m/s
Heading	Electronic Compass	Precision Navigation	1 s - 3 s	0□ - 359□	□ 2□
Position	GPS	Garmin	10 s	Lat. - Long.	□ 15 m
Particle Concentration	Optical Counter	Climet	10 s	2 channels: d > 0.3 ∓m & d > 3 ∓m	□ 2%
NO, NO_2 Concentration	O_3 Titration Chemilumin.	Monitor Labs.	10 s - 15 s	0 ppmv - 20 ppmv	□ 0.5 ppbv
Ozone Concentration	UV Absorption	Dasibi 1008	10 s - 15 s	0 ppbv - 999 ppbv	□ 3 ppbv

4.1.4 STI Airborne Instrumentation (STI Piper Aztec)

Sonoma Technology, Inc. (STI) will use its instrumented twin-engine Piper Aztec aircraft for this study. The onboard instrumentation measures continuously ozone, NO, NO_y, b_{scat}, position, temperature, and dew point. There was an option to measure turbulence, and NO_y minus nitric acid and aerosol nitrate (NO_w). We measured NO_w during the study. The NO/NO_y, NO_w instruments are high-sensitivity instruments, capable of measuring background concentrations likely to be observed in the study area. An overview of the STI instrumentation complete with data quality objectives, i.e., accuracy is given in Table 5-2.

The STI aircraft will be based at Camarillo and about 38 flights (150 flight hours) will be conducted over 15 to 20 days during the study period. The aircraft will be available for two flights a day for up to four days in a row.

Instrument calibrations will be performed before and after each flight day. This makes it possible to immediately identify and correct problems and to know which data are affected. Some potential instrument problems are not identified by calibration. Therefore flight data will be reviewed in the field on a daily basis.

Table 4.1-2
STI Instrumentation

Parameter Measured	Technique	Manufacturer	Time Response	Measurement Range(s)	Accuracy[a] (Full Range)
NO/NO_y Concentration	Chemilumin.	Thermo Env. Model 42S	< 20 s	50 ppb, 100 ppb, 200 ppb	□ 10%
Ozone Concentration	Chemilumin.	Monitor Labs. 8410E	12 s	200 ppb, 500 ppb	□ 10%
b_{scat}	Integrating Nephelometer	MRI 1560 Series	1 s	100 Mm^{-1}, 1000 Mm^{-1}	□ 10%
Dew Point	Cooled Mirror	Cambridge Systems 137-C	0.5 s/□C	-50□C - 50□C	□ 10%
Altitude	Altitude Encoder	II-Morrow	1 s	0 m - 5000 m	□ 10%
Altitude (backup)	Pressure Transducer	Validyne P24	< 1 s	0 m - 5000 m	□ 10%
Temperature	Bead Thermistor/ Vortex Housing	YSI/MRI	5 s	-30□C - 50□C	□ 10%
Temperature (backup)	Platinum Resistance	Rosemont 102 AV/AF	1 s	-50□C - 50□C	□ 10%
Position	GPS	II-Morrow	< 1 s	Lat. - Long.	□ 50 m
Data Logger (includes time)	Dual Floppy Acquisition	STI 486 System	1 s	□ 9.99 VDC	□ 10%
NO/NO_w[b]	Chemilumin.	Thermo Env. Model 42S	< 20 s	50 ppb, 100 ppb, 200 ppb	□ 10%
SO_2[b]	Pulsed Fluorescence	Thermo Env. Model 43S	15 s	1 ppb, 5ppb, 50 ppb,200 ppb	□ 10%
CO[b]	Gas Filter Correlation	Thermo Env. Model 48S	< 20 s	1 ppm, 2 ppm, 5 ppm, 10 ppm	□ 10%

a For values between 10% and 90% of full scale

b Without modifying the aircraft for additional power, only one of these three instruments can be operated.

4.1.5 Navy EOPACE Airborne Instrumentation (Gibbs Piper Navajo)

The Navy EOPACE aircraft will be instrumented with an UV absorption instrument (Dasibi) for the measurement of ozone concentrations, four canisters for hydrocarbon sampling, three tedlar bags for carbonyl sampling and ancillary instrumentation for the measurement of temperature, relative humidity, and position. Position will be determined with a GPS instrument and a pressure (altitude) monitor. Further details and data quality objectives are currently not available.

4.1.6 Navy Partenavia

This aircraft's instrumentation will measure ozone by an UV absorption instrument (Dasibi) and ancillary instrumentation to measure temperature, relative humidity, and position. Position will be determined with a GPS instrument and a pressure (altitude) monitor. Further details and data quality objectives are currently not available.

4.1.7 Ancillary Instrumentation

Ancillary airborne instrumentation includes navigational instruments measuring quantities such as position, altitude, heading, and time, and instruments that determine additional atmospheric properties such as temperature, humidity, and aerosol characteristics. Some of the instruments used to measure these quantities on SCOS97 air quality aircraft are briefly described in the following.

4.1.8 Navigational Instruments

Position of the airborne platform in space and time is extremely important for the use and intercomparison of all other measured quantities. The Global Positioning System (GPS), a satellite system operated by the U.S. Department of Defense (DOD) provides radio signals from which GPS receivers can calculate 3-dimensional position and time at several different accuracy levels.

Civilian users worldwide use the Standard Positioning System (SPS) without charge or restrictions. Most receivers are capable of receiving and using the SPS signal. The DOD intentionally degrades the SPS accuracy by the use of Selective Availability (SA). The SPS predictable accuracies are: 100 m horizontal accuracy, 156 m vertical accuracy, and 340 ns time accuracy. These GPS accuracy figures are from the 1994 Federal Radio-navigation Plan. The figures are 95% accuracies, and express the value of two standard deviations of radial error from the actual antenna position to an ensemble of position estimates made under specified satellite elevation angle (five degrees) and Position Dilution of Precision PDOP (less than six) conditions. For horizontal accuracy figures 95% is the equivalent of 2drms (two-distance root-mean-squared), or twice the radial error standard deviation. For vertical and time errors 95% is the value of two-standard deviations of vertical error or time error. Receiver manufacturers may use other accuracy measures. Root-mean-square (RMS) error is the value of one standard deviation (68%) of the error in one, two or three dimensions. Circular Error Probable (CEP) is the value of the radius of a circle, centered at the actual position that contains 50% of the position estimates. Spherical Error Probable (SEP) is the spherical equivalent of CEP, that is the radius of a sphere, centered at the actual position, that contains

50% of the three dimension position estimates. As opposed to 2drms, drms, or RMS figures, CEP and SEP are not affected by large blunder errors making them an overly optimistic accuracy measure. Some receiver specification sheets list horizontal accuracy in RMS or CEP and without Selective Availability, making those receivers appear more accurate than those specified by more responsible vendors using more conservative error measures.

Authorized users with cryptographic equipment and keys and specially equipped receivers use the Precise Positioning System (PPS). U.S. and Allied military, certain U.S. Government agencies, and selected civilian users specifically approved by the U. S. Government, can use the PPS. The PPS predictable accuracies are: 22 m horizontal accuracy, 27.7 m vertical accuracy, and 100 ns time accuracy.

Differential GPS (DGPS) techniques improve the accuracy of GPS by correcting bias errors at one location with measured bias errors at a known position. A reference receiver, or base station, computes corrections for each satellite signal. Because individual pseudo-ranges must be corrected prior to the formation of a navigation solution, DGPS implementations require software in the reference receiver that can track all satellites in view and form individual pseudo-range corrections for each satellite. These corrections are passed to the remote, or rover receiver that must be capable of applying these individual pseudo-range corrections to each satellite used in the navigation solution. Applying a simple position correction from the reference receiver to the remote receiver has limited effect at useful ranges. This is so because both receivers would have to be using the same set of satellites in their navigation solutions and have identical Geometric Dilution of Precision (GDOP) terms (not possible at different locations) to be identically affected by bias errors. Differential corrections may be used in real-time or later, with post-processing techniques. Real-time corrections can be transmitted by radio link. The U. S. Coast Guard maintains a network of differential monitors and transmits DGPS corrections over radio beacons covering much of the U. S. coastline. DGPS corrections are often transmitted in a standard format specified by the Radio Technical Commission Marine (RTCM). Corrections can be recorded for post processing. Many public and private agencies record DGPS corrections for distribution by electronic means. Private DGPS services use leased FM sub-carrier broadcasts, satellite links, or private radio-beacons for real-time applications. To remove Selective Availability (and other bias errors), differential corrections should be computed at the reference station and applied at the remote receiver at an update rate that is less than the correlation time of SA. Suggested DGPS update rates are usually less than twenty seconds. DGPS removes common-mode errors, those errors common to both the reference and remote receivers (not multi-path or receiver noise). Errors are more often common-mode when receivers are close together (less than 100 km). Differential position accuracies of 1-10 meters are possible with DGPS.

An extensive overview of the GPS system and further references have been given by Dr. Peter H. Dana of the University of Texas at Austin and can be found on his web site at *http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html.*

The vertical accuracy of standard GPS (156 m for SPS) is marginal for lower tropospheric studies. Therefore, vertical position, i.e., altitude is often derived from pressure measurements. If the pressure-derived altitude measurement is corrected for atmospheric pressure changes before take-off and/or after landing an accuracy of ± 3 m can be obtained.

4.1.9 Temperature Measurement

Temperature can be measured via a diverse array of sensors. All of them infer temperature by sensing some change in a physical characteristic. Resistive temperature devices (RTDs and thermistors) are commonly used to measure air temperature in conjunction with a data acquisition system.

Resistive temperature devices capitalize on the fact that the electrical resistance of a material changes as its temperature changes. Two key types are the metallic devices (commonly referred to as RTDs), and thermistors. As their name indicates, RTDs rely on resistance change in a metal, with the resistance rising more or less linearly with temperature. Thermistors are based on resistance change in a ceramic semiconductor; the resistance drops nonlinearly with temperature rise.

A typical RTD consists of a fine platinum wire wrapped around a mandrel and covered with a protective coating. Usually, the mandrel and coating are glass or ceramic. The mean slope of the resistance versus temperature plot for the RTD is often referred to as the alpha value, alpha standing for the temperature coefficient. The slope of the curve for a given sensor depends somewhat on purity of the platinum in it. The most commonly used standard slope, pertaining to platinum of a particular purity and composition, has a value of 0.00385 (assuming that the resistance is measured in ohms and the temperature in degrees Celsius). A resistance versus temperature curve drawn with this slope is a so-called European curve, because RTDs of this composition were first used extensively on that continent. Complicating the picture, there is also another standard slope, pertaining to a slightly different platinum composition. Having a slightly higher alpha value of 0.00392, it follows what is known as the American curve. If the alpha value for a given RTD is not specified, it is usually 0.00385. However, it is prudent to make sure of this, especially if the temperatures to be measured are high.

The resistance-temperature relationship of a thermistor is negative and highly nonlinear. This poses a serious problem for engineers who must design their own circuitry. However, using thermistors in matched pairs, in such a way that the nonlinearities offset each other eases these difficulties. Furthermore, vendors offer panel meters and controllers that compensate internally for thermistors' lack of linearity. Thermistors are usually designated in accordance with their resistance at 25°C. The most common of these ratings is 2252 Ω; among the others are 5,000 Ω and 10,000 Ω. If not specified to the contrary, most instruments will accept the 2252 Ω type of thermistor.

4.1.10 Humidity Measurement

The humidity of air can be expressed as absolute humidity (either dew point or water concentration) or relative humidity. These quantities can easily be converted from one to the other if the atmospheric temperature is known. Two common methods of measuring atmospheric humidity are described in the following.

The dewpoint monitor determines absolute humidity from a fundamental measurement and therefore does not depend on empirical calibration factors. This instrument cools a small mirror to the point at which moisture condenses on the mirror surface and optically detects the first sign of condensation. The mirror temperature is measured accurately, often with an RTD resulting in a measurement of the dewpoint which is directly related to the absolute humidity.

The capacitive humidity sensor measures relative humidity via the change in capacity of a thin film polymer capacitor. The thin polymer film either absorbs or exudes water vapor as the relative humidity of the ambient air rises or drops. The dielectric properties of the polymer film depend on the amount of water contained in it: as the relative humidity changes, the dielectric properties of the film change and so the capacitance of the sensor changes. The electronics of the instrument measure the capacitance of the sensor and converts it into a humidity reading.

4.1.11 CE-CERT Ozonesondes

The objective of the ozonesonde program is to collect, validate and report vertical profiles of oxidant concentration, temperature, and humidity four times per day at each of six monitoring locations on 15 intensive operating period days, and to characterize these data with respect to precision and accuracy. The primary data quality objective for this project is 100% valid data capture for the resulting 360 oxidant profiles. To be considered valid, the profiles must meet specified tolerances for place and time of collection, for vertical extent and resolution, and for precision and accuracy.

The general locations of ozonesonde launch sites and the rationale for their location are as follows:

- Cal State Northridge: monitor ozone aloft in the San Fernando Valley that may contribute to transport through Thousand Oaks, Simi Valley, or Newhall.

- University of Southern California: monitor southern extent of recirculation from the San Gabriel Mountains or recirculation from the ocean.

- Anaheim: monitor transport into San Diego County, and monitor recirculation from the ocean.

- Upland/Pomona: monitor transport and re-circulation between the coastal plain and the low desert.

- Riverside: monitor ozone aloft in the low desert that may contribute to transport through the Banning Pass.

- Valley Center: monitor overland transport from SoCAB into San Diego County.

CE-CERT has established tentative data quality indicators (DQI) and goals for the ozonesonde instrumentation. Data quality indicators and goals for ozonesondes and the associated meteorological instruments are summarized in Tables 5-3 and 5-4, respectively.

The accuracy of the ozonesondes is mainly limited by the large interference bias of -10 ppb to +50 ppb. If the concentration range of interferents can be estimated it may be possible to reduce the interference bias.

Table 4.1-3: CE-CERT Ozonesonde, Data Quality Indicators and Goals

DQI	Goal
Precision	1-sigma < larger of 5 ppb or 10%
Calibration Bias	1-sigma < larger of 5 ppb or 10%
Interference Bias	-10 to + 50 ppb
Lower Quantifiable Limit	< 15 ppb
Response Time	> 80% of step change in 1 minute
Ascent Rate	< 3.0 m/s
Response Distance	> 80% in 180 meters
Time of Launch	+/- 3.0 hours from planned time
Location of Launch	+/- 100 meters from planned location
Duration of Flight	>3000 meters AGL

Table 4.1--4: CE-CERT Meteorological Instruments, Data Quality Indicators and Goals

Measurement	DQI	Goal
Temperature	Precision	□ 1 °C
Temperature	Calibration Bias	□ 3 °C
Temperature	Response Time	> 63% response in 20 s
Pressure	Precision	□ 2 mb
Pressure	Calibration Bias	□ 5 mb
Pressure	Response Time	> 63% response in 2 s
Relative Humidity	Precision	□ 5% RH
Relative Humidity	Calibration Bias	□ 10% RH
Relative Humidity	Response Time	> 63% response in 2 min

4.2 Ground Based Performance Audits

With the exception of the CIRPAS Pelican, all of the SCOS97-NARSTO aircraft were subjected to ground-based audits of their air quality instruments. These audits serve to verify whether the instruments themselves are operating properly; the ground-based audits do not confirm the performance of the monitoring system under the dynamics of flight operations where varying ram air-flow, temperature, pressures, etc. can influence the values measured. To evaluate the performance of the instruments under dynamic conditions, it is necessary to coordinate simultaneous measurements of the same air mass by two or more monitoring platforms and then to compare the data. These dynamic comparisons are discussed in Subsections 4.2 through 4.4.

Most of the aircraft air quality instruments were audited on two occasions. Staff of the CARB Quality Assurance Section audited the instruments at the beginning of the study and staff of the College of Engineering's Center for Environmental Research at the University of California, Riverside, audited the instruments of several aircraft at the end of the field study. Staff of the San Diego Air Pollution Control District also performed multi-point calibrations of the ozone instruments on the two San Diego aircraft. Details of the aircraft audits are presented in Table 4.1.

Table 4.2-1. SCOS97-NARSTO Aircraft Ground-Based Audits

AIRCRAFT	#	AUDIT RESULTS	AUDIT DATE	AUDITOR
FULL-TIME				
SD-Cessna	1	O_3 -2.7%	June 12	CARB
	2	O_3 -1.6% (multi-pt calibration)	July 18	SDAPCD
	3	O_3 & (multi-pt calibration)	October 15	SDAPCD
SD-Navajo	1	O_3 -2.8%; NO_2 -4.4%	June 12	CARB
	2	O_3 -1.6%	October 18	SDAPCD
	3	NO_2 +6.5%	October 19	SDAPCD
STI Aztec	1	O_3 -5.1%; NO_2 -4.1%	June 9	CARB
	2	O_3 -8%*; NO_2 0%*	October 17	CE-CERT
UCD Cessna	1	O_3 -1.3%; NO_2 failed	June 10	CARB
	2	NO_2 +4.6%	June 13	CARB
	3	O_3 -6%*; NO_2 +11%*	October 16	CE-CERT
PART-TIME				
CIRPAS Pelican		not audited		
USN Partnavia	1	O_3 -0.4%	August 12	CARB
	2	O_3 0%*	October 17	CE-CERT

& results within □ 10% but exact result not provided

unofficial results; official results will be provided in final report from contractor

All of the instruments passed the ground-based audits with the exception of the UCD Cessna's total reactive nitrogen analyzer at the beginning of the study. Corrective actions were taken and the analyzer passed a re-audit a few days later.

4.3 Aloft Intercomparisons: 11-June-97

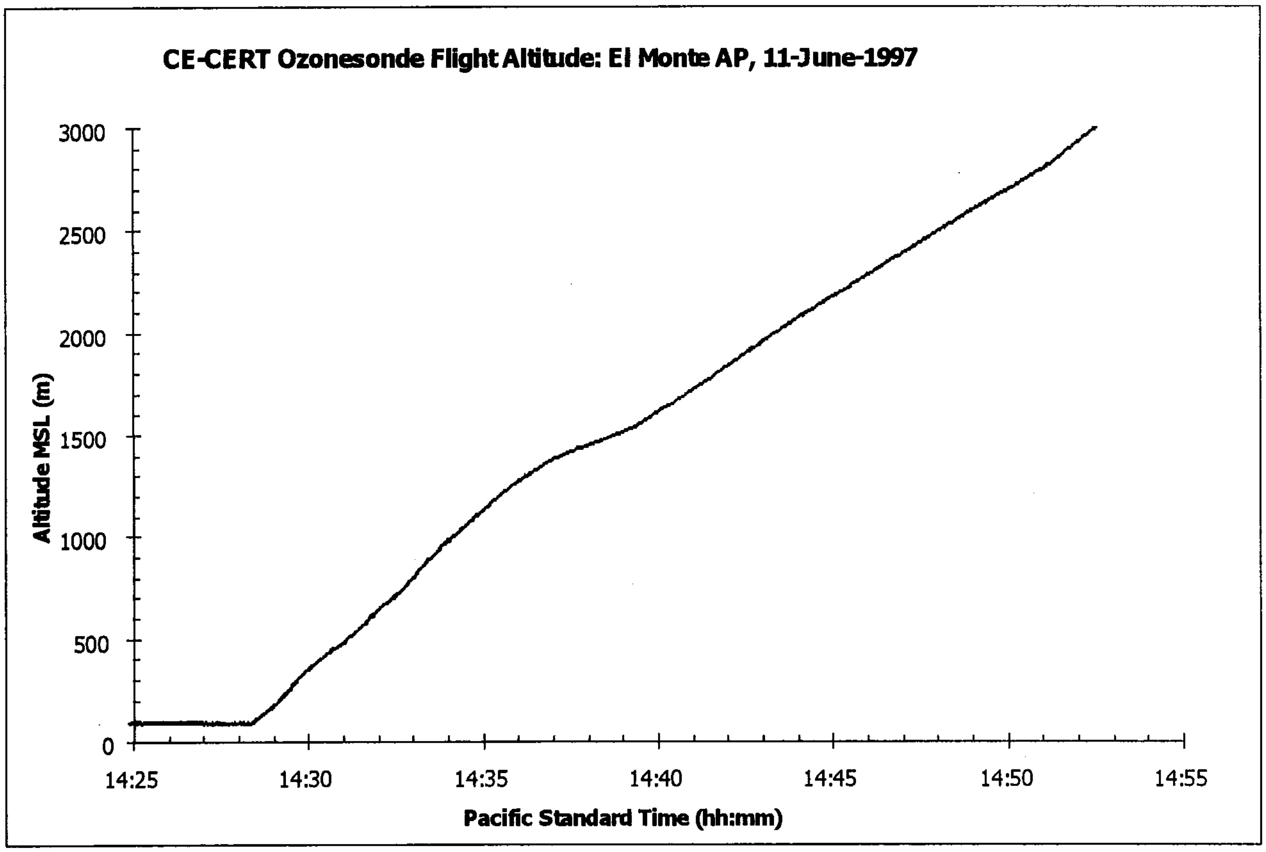
The lidar-ozone sonde-UCD Cessna ozone intercomparison took place at El Monte airport on June 11, 1997 in connection with a SCOS97 press conference. Pollution levels were quite low with a maximum ground level ozone concentration in the early afternoon just below 80 ppb. Two intercomparisons between the three instruments were planned, one in the early morning (7:00 - 9:30 PDT) and one in the early afternoon (13:00 - 15:30 PDT). The morning intercomparison was incomplete as the UCD aircraft did not receive FAA restricted category certification in time for the morning intercomparison. Lidar operation was hampered by low clouds, and an ozonesonde release took place around 08:30 PDT. Due to the lack of aircraft and lidar data, no data analysis was performed for the morning intercomparison. The afternoon intercomparison took place between 14:00 - 16:30 PDT under clear (blue sky) conditions. The intercomparison closely followed the protocol with the lidar measuring ozone concentrations in the zenith-pointing mode, the UCD Cessna flying spirals interspersed with orbit between ground level and 10,000', and an ozonesonde release at 15:30 PDT.

Data from the individual systems and intercomparisons are presented in the following for the afternoon data. None of the data are currently fully quality assured (middle April, 1998) and any observations and conclusions are therefore preliminary.

4.3.1 Ozone Data from Individual Systems

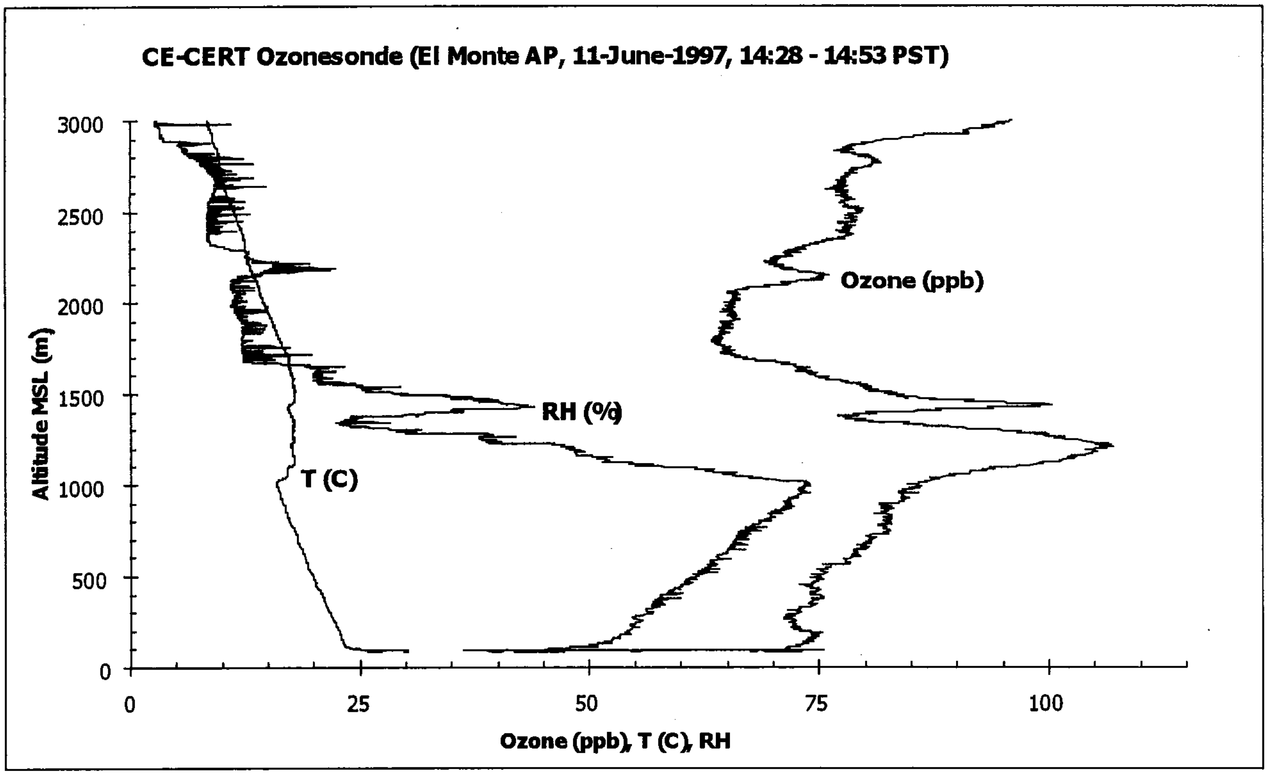
CE-CERT Ozonesonde

The afternoon ozonesonde was launched at □14:28 PST and reached an elevation of 3000 m msl at □14:53 PST. While ozonesonde data were recorded up to □6000 m msl, only data below □3000 m msl were used for the intercomparison. This is due to the lack of data from UCD and NOAA above □3000 m msl. Ozonesonde altitudes above ground level were calculated by CE-CERT from pressure data. For comparison purposes, the altitude has been converted to msl by adding the altitude of El Monte AP (90 m msl). The figure below shows the ozonesonde altitude as function of time.



Note that the vertical velocity component is relative constant with the exception of a slower ascent velocity around 1500 m msl..

Ozone, temperature, and relative humidity profiles for the intercomparison range are shown in the following figure. At the temperature inversion around 1100 m msl, the ozone concentration started increasing, while the relative humidity started decreasing drastically with altitude. The highest ozone mixing ratio in the displayed range of about 115 ppb was measured around 1200 m msl, just above the maximum in relative humidity of nearly 75% around 1000 m msl.



UCD Cessna 182

The UCD Cessna conducted one afternoon flight consisting of spirals and spirals interspersed with orbits between 13:00 and 15:25 PST. The flight plan was as follows :

1. Take off at El Monte AP
2. Spiral - Orbit to 10,000' msl (5 orbits each at □ 2,000', 4,000', 6,000', 8,000', and 10,000' msl)
3. Spiral to (near) ground level at El Monte AP
4. Spiral to 6000' msl
5. Spiral - Orbit to ground level at El Monte AP (5 orbits each at □ 6,000', 4,000', and 2,000' msl)

This flight plan was estimated to take about 2.5 hours. Orbit elevations were meant as approximate elevations and the actual elevations were to be chosen by the pilot to be in a homogeneous layer and not in an obvious boundary between atmospheric layers.

The actual flight took 2h and 25min closely following the plan. However, the assumption that the pilot could avoid orbiting at a sensitive altitude (e.g., near or in an inversion or stable layer) was not valid. The pilot had to inform the air traffic controller in advance of the intended altitudes for the orbits to assure that the controllers would keep other aircraft away. For example, he had to orbit at 1200 m msl (4000' msl), close to where both the sonde and the aircraft found the top of the inversion. At this altitude, variations of the inversion height together with strong vertical gradients in ozone concentrations can result in a large range of ozone concentrations encountered during an orbit.

UCD Ozone Data Overview

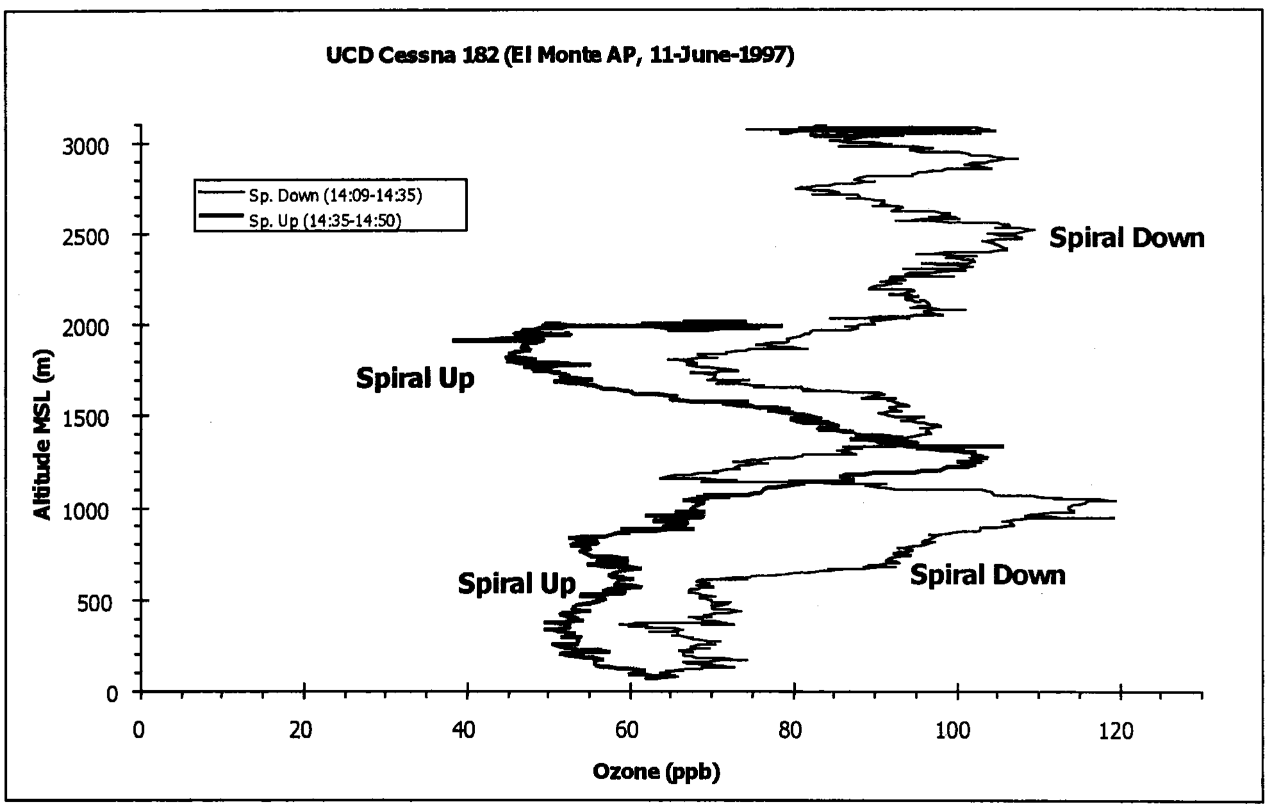
A table giving a statistical overview of the data recorded during this flight is shown below.

	Time PST	Temp. (□C)	RH (%)	Ozone (ppb)	Altitude MSL (m)
Min.	12:59	7.3	0.1	35.1	75.6
Max.	15:24	27.6	78.7	119.4	3092.4
Av.	14:12	16.6	26.9	71.7	1520.4
St. Dev.	0:41	3.9	27.3	15.4	822.6

In the following the different flight segments are discussed individually.

UCD Spiral Ozone Data

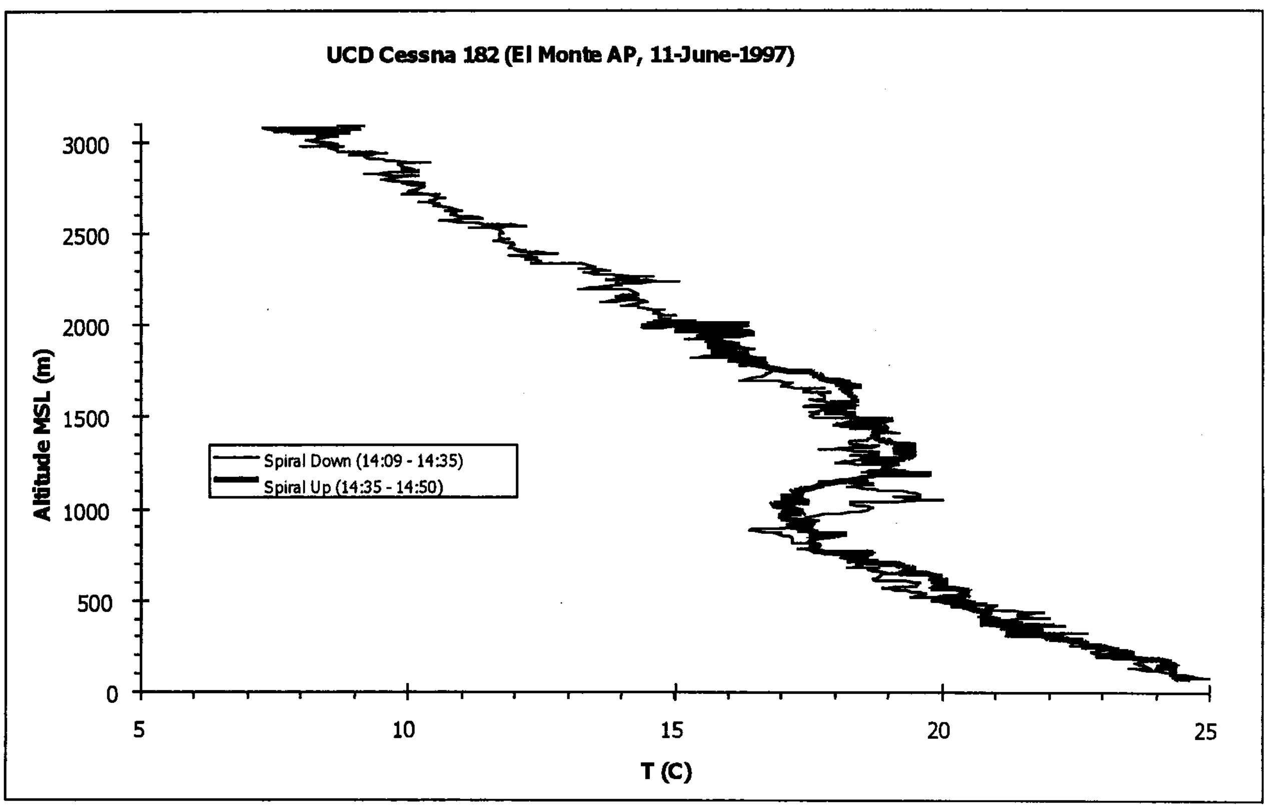
Two spirals were flown sequentially to test for possible differences between up-spiral and down-spiral measurements. First a down-spiral from □3000 m msl to ground level was flown between 14:09 and 14:35 PST, directly followed by an up-spiral from ground level to near 2000 m msl between 14:35 and 14:50 PST. The ozone measurements from these two spirals are shown in the graph below.



Immediately noticeable is the shift between the global maxima in the two ozone profiles. For the down-spiral the global maximum is 119 ppb at 1038 m msl, while for the up-spiral it is 106 ppb at 1333 m msl. In addition, it is not clear how to correlate the respective minima in ozone concentration above the global maxima.

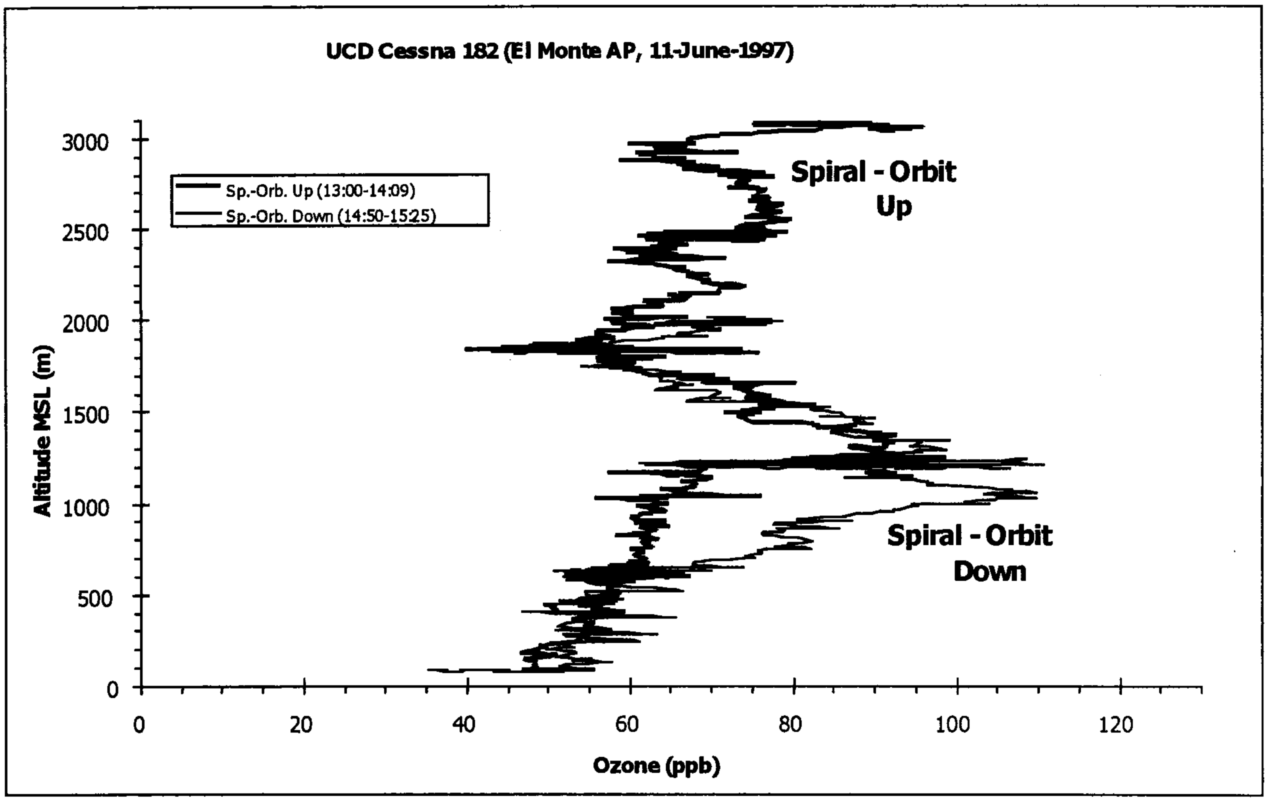
The shift between the global maxima cannot solely be explained by the nominal time delay of the ozone analyzer (i.e., 10 to 15 s). The elevation difference between the two maxima is nearly 300 m. At actual ascent and descent speeds of 2.8 m/s the time delay of the ozone analyzer would have to be more than three times larger than the nominal value (i.e., □53 s) to explain this shift. Other possible explanations include vertical shift of this layer in the time between the two spirals or strong horizontal inhomogeneities. Vertical shift of the layer seems not very likely as the down-spiral maximum was measured at 14:29 PST and the up-spiral maximum at 14:42 PST, only 13 minutes apart. The possibility of strong horizontal inhomogeneities will be further discussed in the section on the spiral-orbit flight pattern.

Temperature profiles recorded during ascending and descending spirals show that the inversion layer was found at a higher altitude during the ascending spiral. As the temperature measurement has virtually no time delay, it may be reasoned that the vertical structure of the atmosphere was different from spiral to spiral, probably due to horizontal variations in the inversion layer height. This fact leads to the conclusion that the different heights of the ozone maxima during ascending and descending spirals are partially due to the same phenomenon.

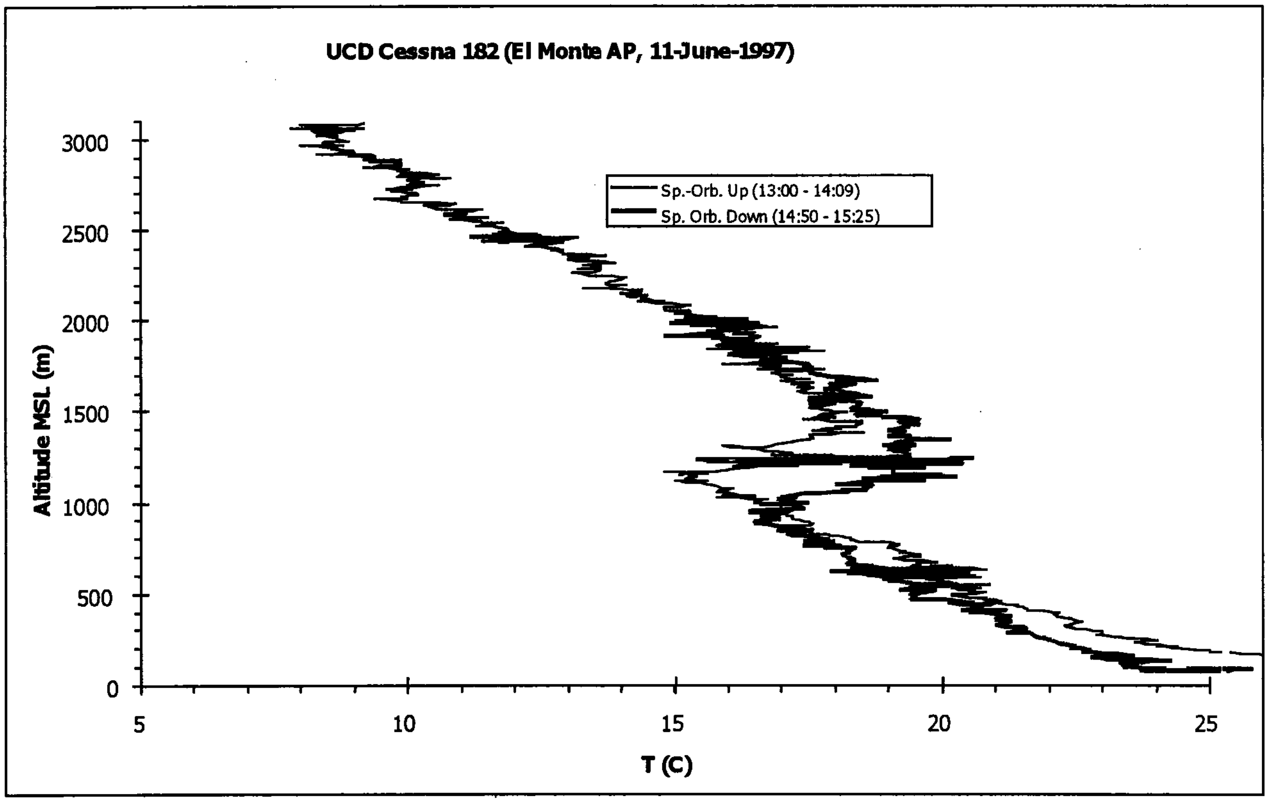


UCD Spiral-Orbit Ozone Data

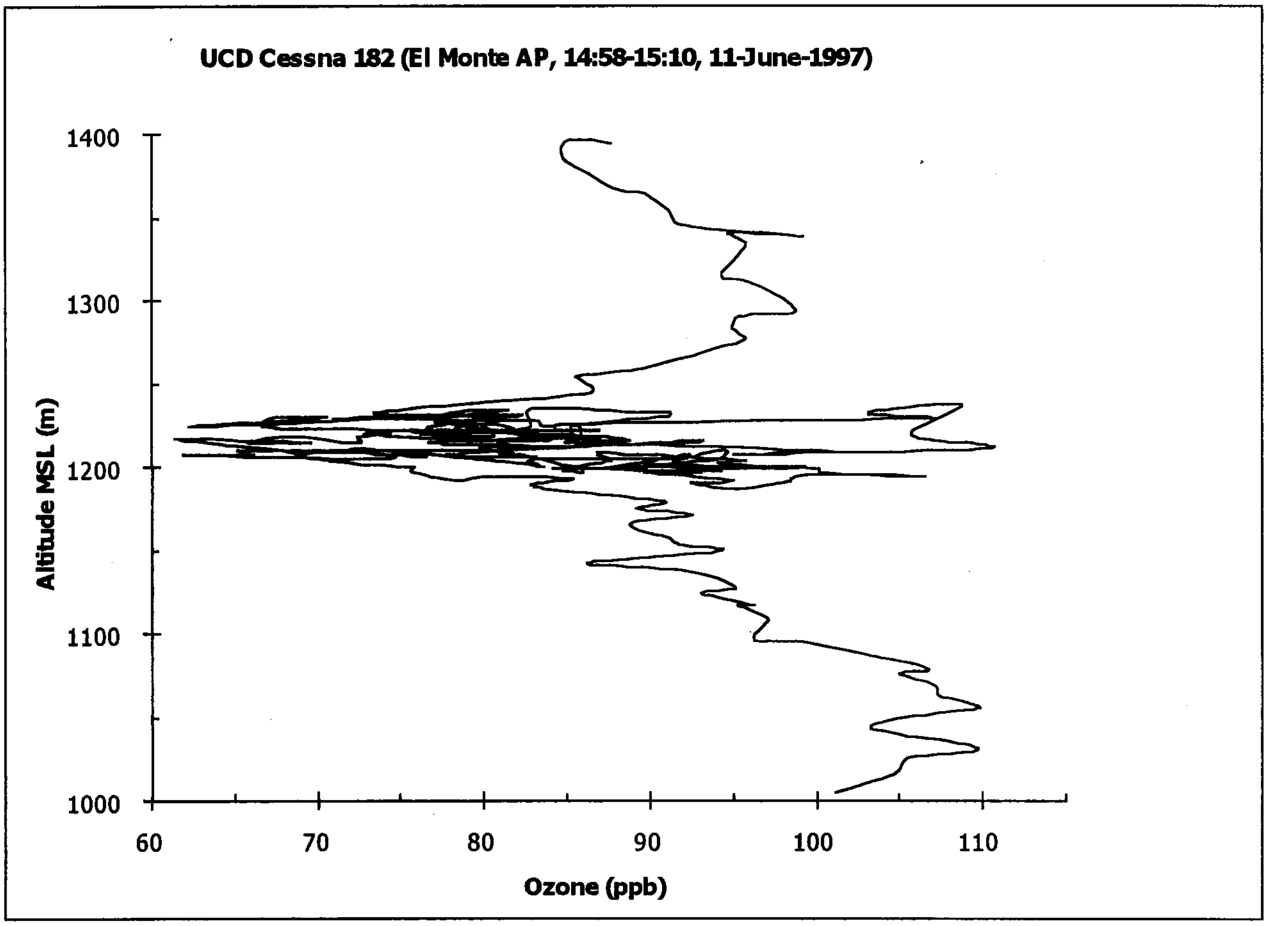
Two spirals interspersed with orbits were flown. One was a spiral-orbit ascending from ground level to about 3100 m msl with orbits at about 510 m msl, 1200 m msl, 1850 m msl, 2450 m msl, and 3100 m msl. The other was spiral-orbit descending from about 2000 m msl to ground level with orbits at about 2000 m msl, 1200 m msl, and 600 m msl. Measured ozone concentrations as function of elevation are shown for these two spiral-orbits patterns in the graph below.



Generally good agreement between the ozone concentrations measured during the two spiral-orbit flight segments can be found above about 1300 m msl, i.e., above the inversion layer. Below the inversion layer large differences between ascending and descending ozone measurements exist. Again, part of these differences is probably due to the different inversion height encountered during ascent and descent as can be seen in the following graph of temperature.



Somewhat surprising is the large range of ozone concentrations during some of the orbits, possibly indicating large horizontal inhomogeneities in ozone concentration. To further investigate this suspicion, a closer look at one of the orbits, the orbit at □1200 m msl of the descending spiral orbit has been taken. The figure below shows the detail of this orbit.



One notices that the elevation of the UCD Cessna 182 was kept to within better than 50 m during the orbit and the large range of ozone concentrations during the orbit (i.e., 60 - 110 ppb) seems indeed to be due to a horizontal inhomogeneity. This also sheds further light on the discussion of the ozone concentrations taken during the spiral flight patterns.

NOAA Lidar Ozone Data

The NOAA ozone lidar uses three transmitter beams to reduce the dynamic range of the received signal. During the afternoon intercomparison the lidar was operating at different times with only beam 1 (range □ to 500 m agl), only beam 3 (range □ to 2000 m agl, but probably invalid below 700 m agl), and all 3 beams (range □ to 1500 m agl). Most data files result from zenith pointing operation with the data file at 15:51:48 PST being the only exception. It was "tailored" from a scanning file. Times used to identify data files are the starting times with averaging times for each profile between 5 and 10 minutes.

The lead scientist for the NOAA ozone lidar, Dr. Yanzeng Zhao had noticed alignment problems with the lidar system on June 11, 1997. To keep confusion to a minimum, her statement is quoted verbatim:

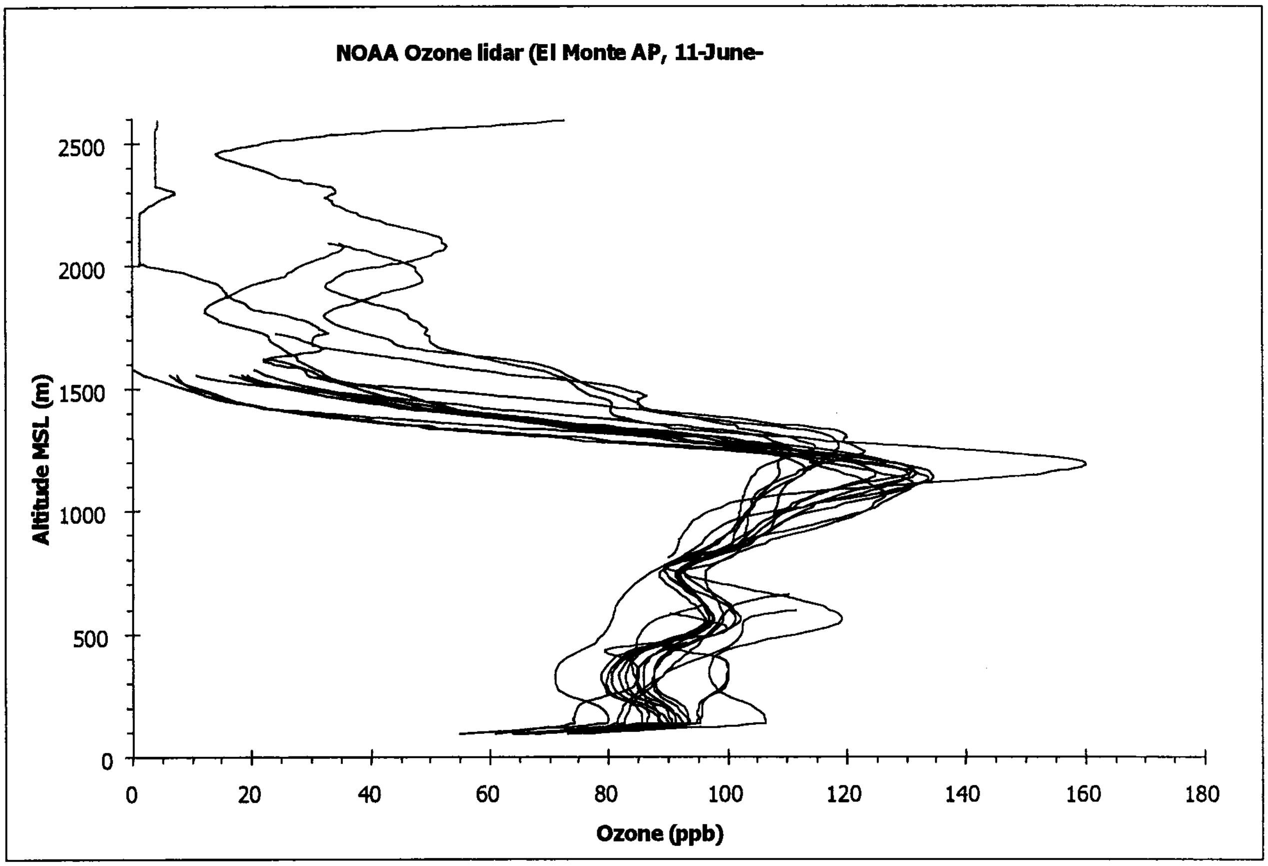
"2. Because the crew had hoped to let the beams having closer full overlap ranges, the beams were re-aligned. However, this was a little overdone, which made the

signals at 266 and 289 nm end at a much shorter range than before, and the dynamic range is too large with a 3-beam configuration. The fluorescence kicks in at the end of signals. So even with a routine to remove the fluorescence, the signal to noise ratio is still too low and the remaining fluorescence at 266 nm tends to cause the ozone mixing ratio low. Thus with 3-beam configuration we cannot reach beyond 1.5 km. Fluorescence also limits the beam1-only files to about 500 m. Beam3-only files can reach to about 2000 m, but the near-range (below ~700 m) results are not supposed to be used.

3. We are going to fix the above problems before the first day of next IOP by applying a ND filter (as we did in Victorville experiment) to the first beam, and re-aligning the beams. This will give us a much smaller dynamic range of the signals and improve the far range SNR a lot. We also will buy two new PMT's to replace the old ones (6-8 weeks delivery). Hopefully the fluorescence will be much lower. The scanning data look good in terms of showing horizontally stratified structures."

In addition, these data have not yet been corrected for signal induced pulses (SIP). This is a distortion of the photomultiplier (detector) signal, which can occur for signals with a large dynamic range. Correction procedures are currently being developed by NOAA scientist and may be applied at a later time to the June 11 lidar data.

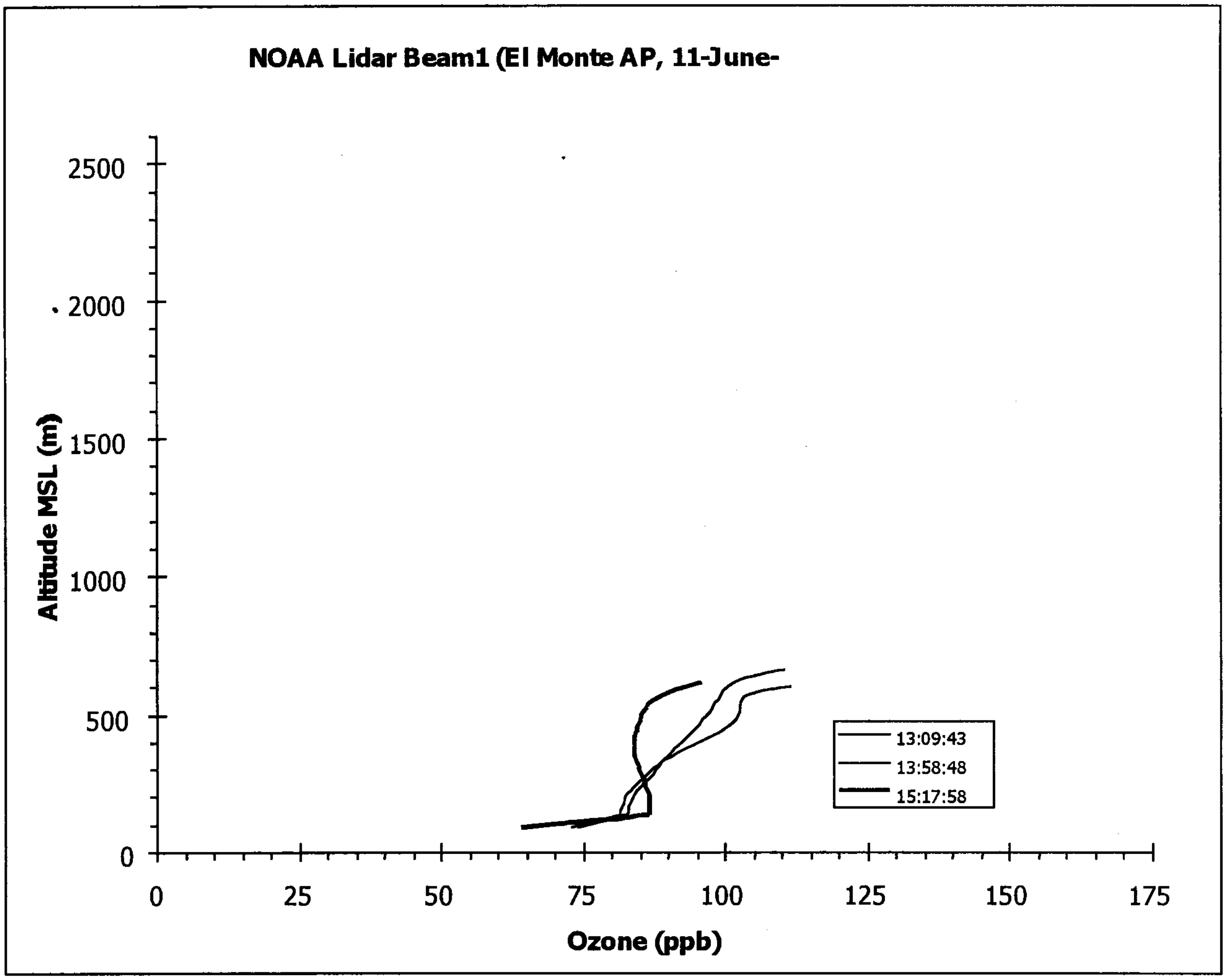
An overview over all 17 profiles acquired in the afternoon of 11-June-97 is shown below.



Generally the global maximum of the ozone concentration is around 1200 m msl, with a rapid drop-off toward higher elevation. However, the display of 17 profiles together is somewhat confusing. In the following the profiles for the different transmitter configurations are displayed separately.

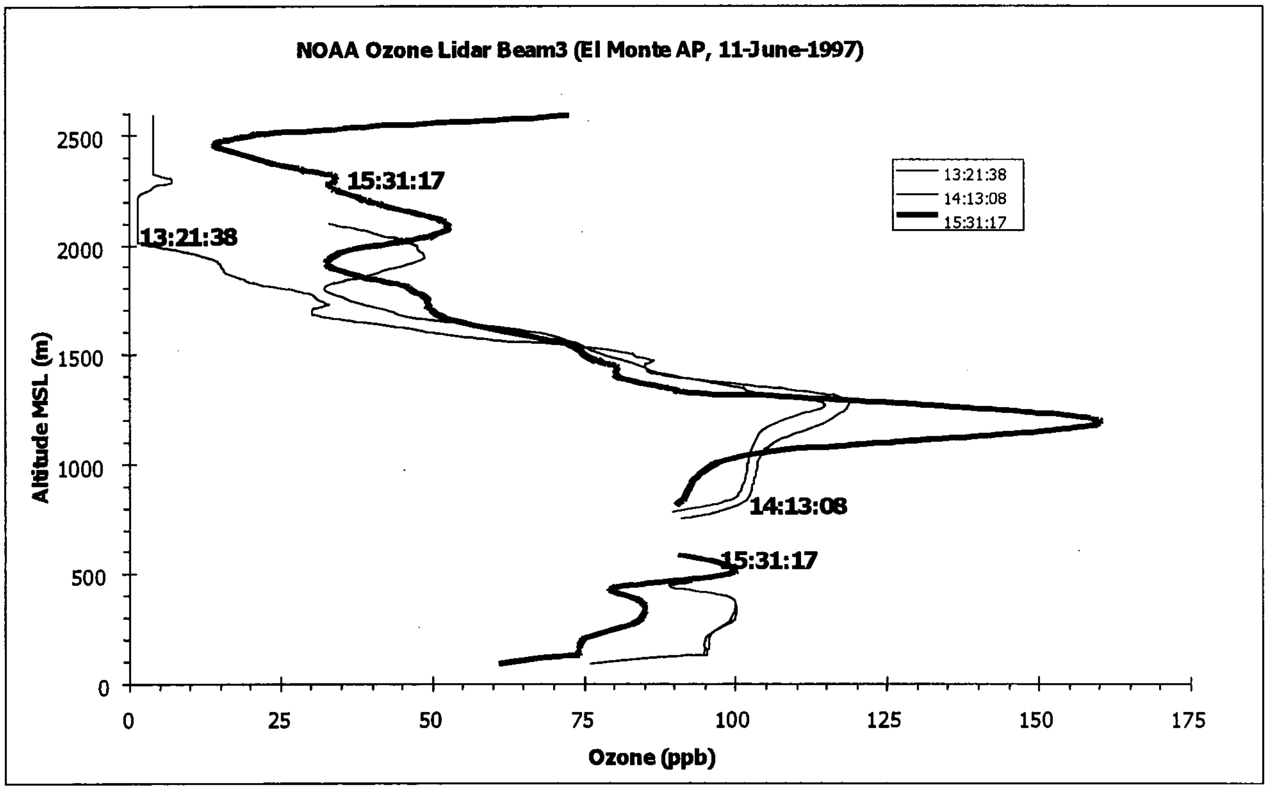
NOAA Lidar Ozone Data Acquired with Beam 1

These are the data acquired only with beam1, resulting in valid data only for the near field below roughly 700 m msl. The two profiles at 13:10 and 13:59 PST are in close agreement while the profile from the later time (15:18) shows qualitatively different features.



NOAA Lidar Ozone Data Acquired with Beam 3

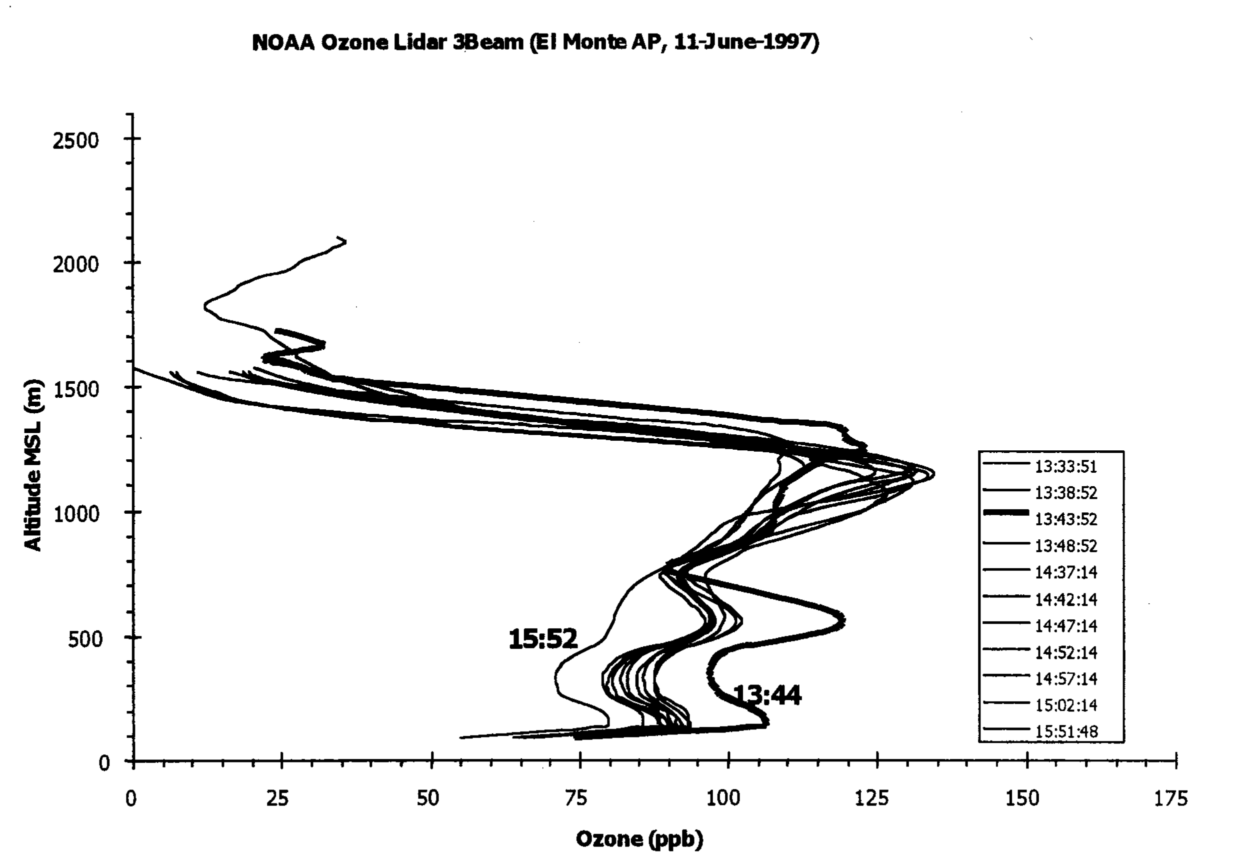
Lidar data acquired with beam 3 only are for the measurement in the far field with data below 700 m agl being suspect. The data above about 2100 m msl have also been labeled as suspect. The two earlier profiles (i.e., 13:22 and 14:13) show good agreement below about 1700 m msl. The later measurement (15:31) shows a substantially (□45 ppb) larger maximum ozone concentration. Above the elevation of the maximum it shows features comparable to the 14:13 measurement. At low elevations (< 500 m msl) it shows the lowest concentrations possibly due to the decrease of ozone concentrations during the afternoon. NOAA, it should be noted, calculated the 15:31 PST profile from scanning data.



NOAA Lidar Ozone Data Acquired with 3 Beams

NOAA lidar data acquired in the 3 beam configuration should in principle cover the whole range, nominally from ground level to about 3100 m msl. During this intercomparison, however, the valid data range from ground level to about 1600 m msl. Ozone data above 1500 m msl are suspect.

All 3 beam data show a similar vertical ozone structure. Data from 13:44 PST show substantially higher and data from 15:52 PST substantially lower ozone concentrations below about 800 m msl. The value of the maximum ozone concentration at about 1200 m msl varies from about 105 ppb (13:49 PST) to about 135 ppb (15:52 PST). The drastic drop-off of the ozone concentrations toward near 0 ppb at about 1600 m msl might be an artifact.



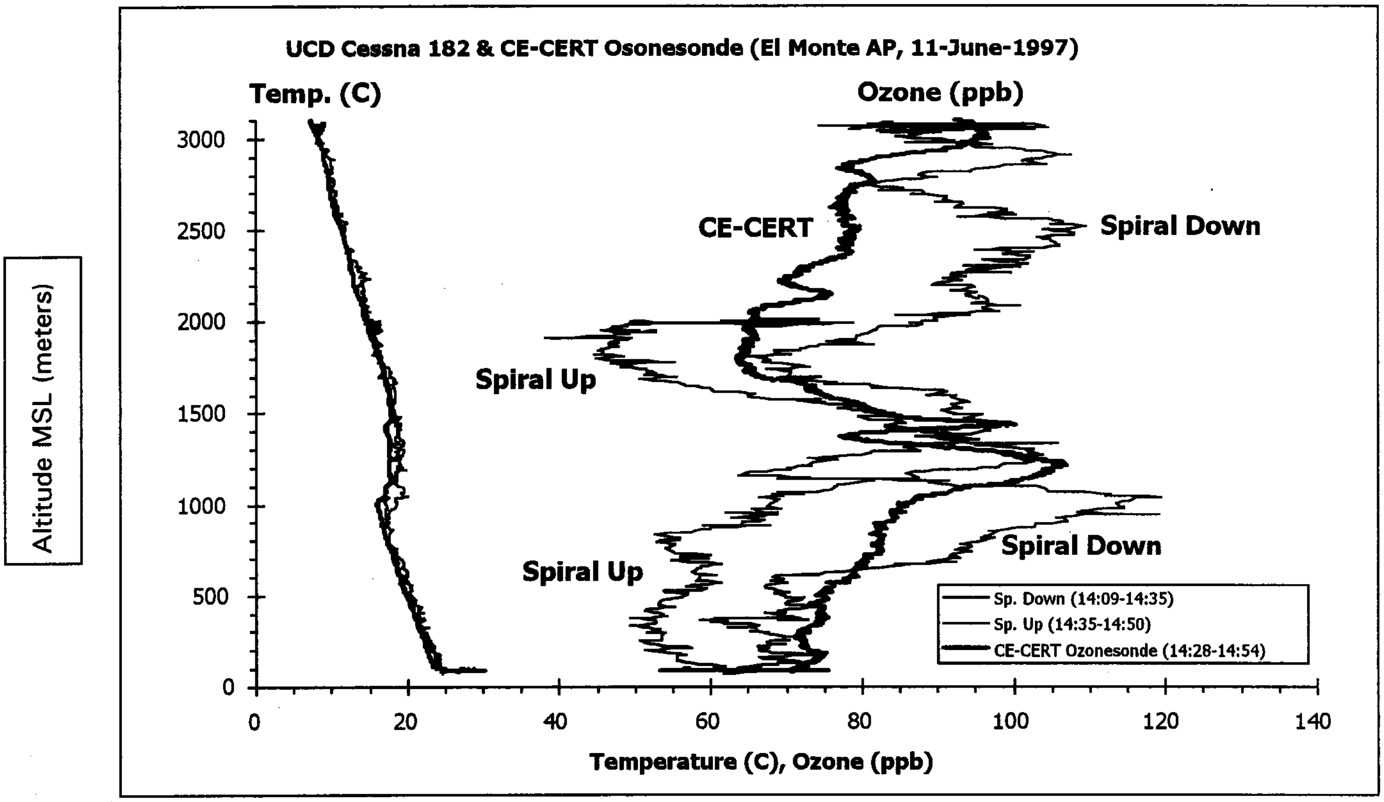
4.3.2 Ozone Data Intercomparison

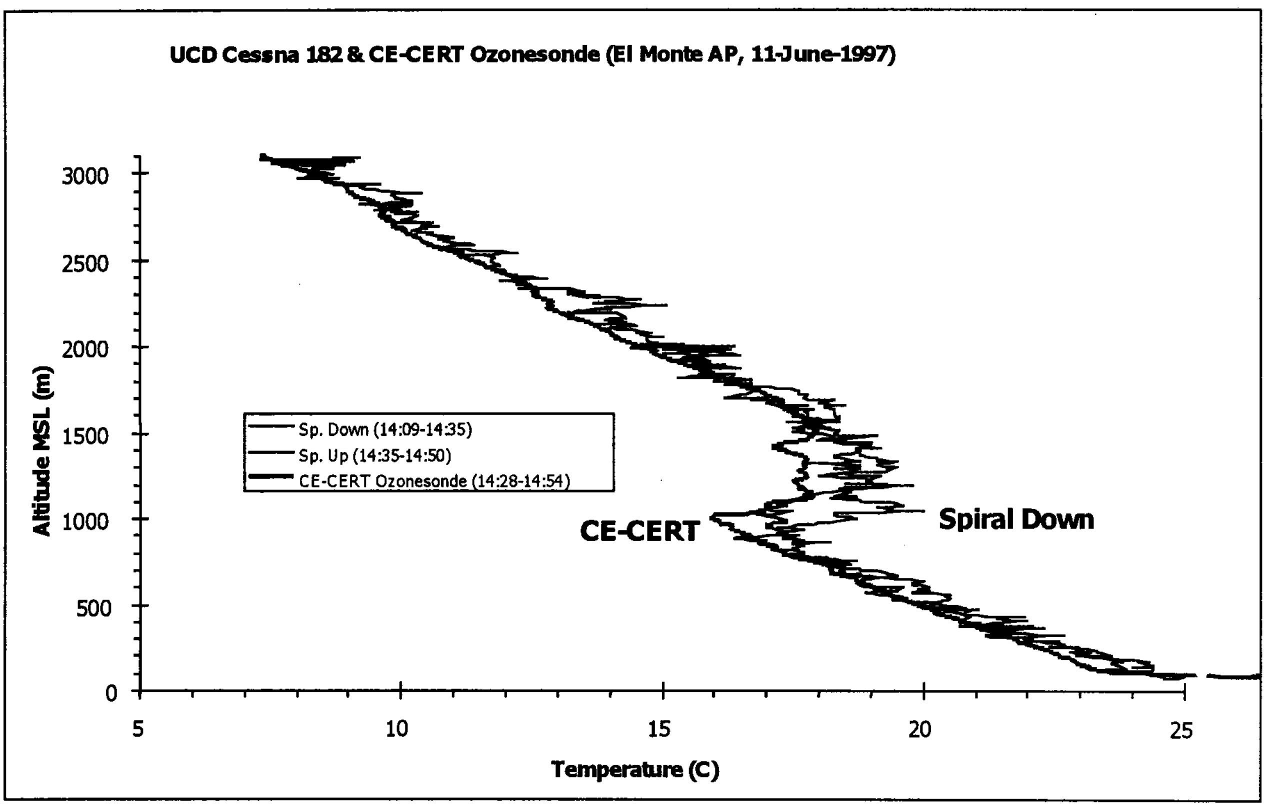
<u>UCD Cessna 182 versus CE-CERT Ozonesonde</u>

UCD Cessna data are compared with CE-CERT ozonesonde data in two graphs, one for the spirals, and one for the spiral-orbits. Both comparisons are based on altitude above mean sea level (msl). These elevations were directly given by UCD for the aircraft data. CE-CERT ozonesonde data were listed as function of elevations above ground level (agl). They were converted to msl by adding the elevation of the El Monte airport (90 m msl). A more direct comparison could be based on the directly recorded pressure values.

Spirals

The two UCD spirals are well suited for intercomparison with the ozonesonde as the ozonesonde was released at 14:28 PST, just (7 min) before the UCD ascending spiral. Ascending somewhat faster than the UCD Cessna, the ozone sonde reached an elevation of □3000 m msl at 14:54 PST. The location of the ozonesonde ozone maximum is between the elevation determined by the two UCD spirals. An ozone peak just above the elevation of the maximum ozone value can be seen both in the ozonesonde and UCD descending spiral but not in the UCD ascending spiral. Temperature values are shown in more detail in the following graph.

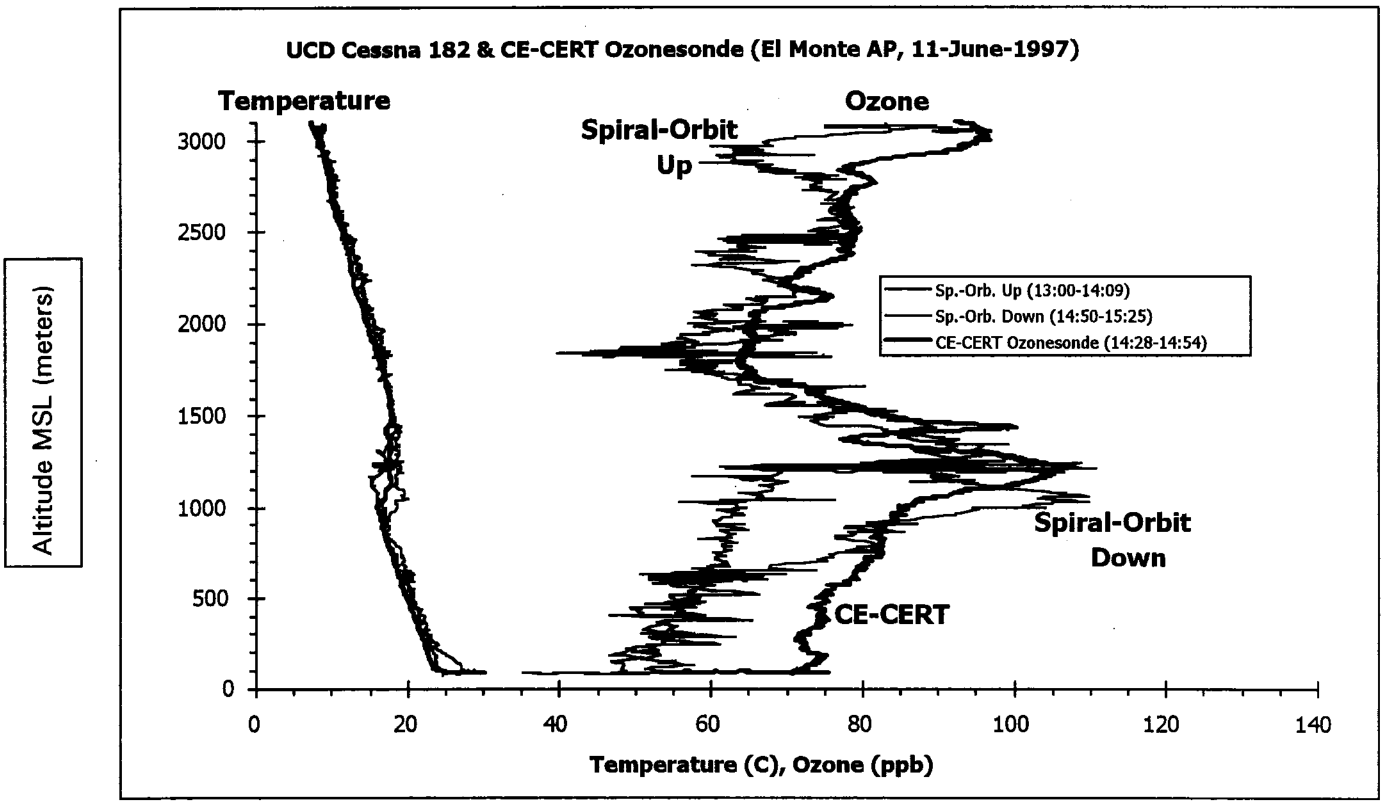

UCD Cessna 182 & CE-CERT Osonesonde (El Monte AP, 11-June-1997)
Temp. (C)
Ozone (ppb)
Altitude MSL (meters)
3000
2500
2000
1500
1000
500
0
CE-CERT
Spiral Down
Spiral Up
Spiral Up
Spiral Down
Sp. Down (14:09-14:35)
Sp. Up (14:35-14:50)
CE-CERT Ozonesonde (14:28-14:54)
0
20
40
60
80
100
120
140
Temperature (C), Ozone (ppb)


UCD Cessna 182 & CE-CERT Ozonesonde (El Monte AP, 11-June-1997)
Altitude MSL (m)
3000
2500
2000
1500
1000
500
0
Sp. Down (14:09-14:35)
Sp. Up (14:35-14:50)
CE-CERT Ozonesonde (14:28-14:54)
CE-CERT
Spiral Down
5
10
15
20
25
Temperature (C)

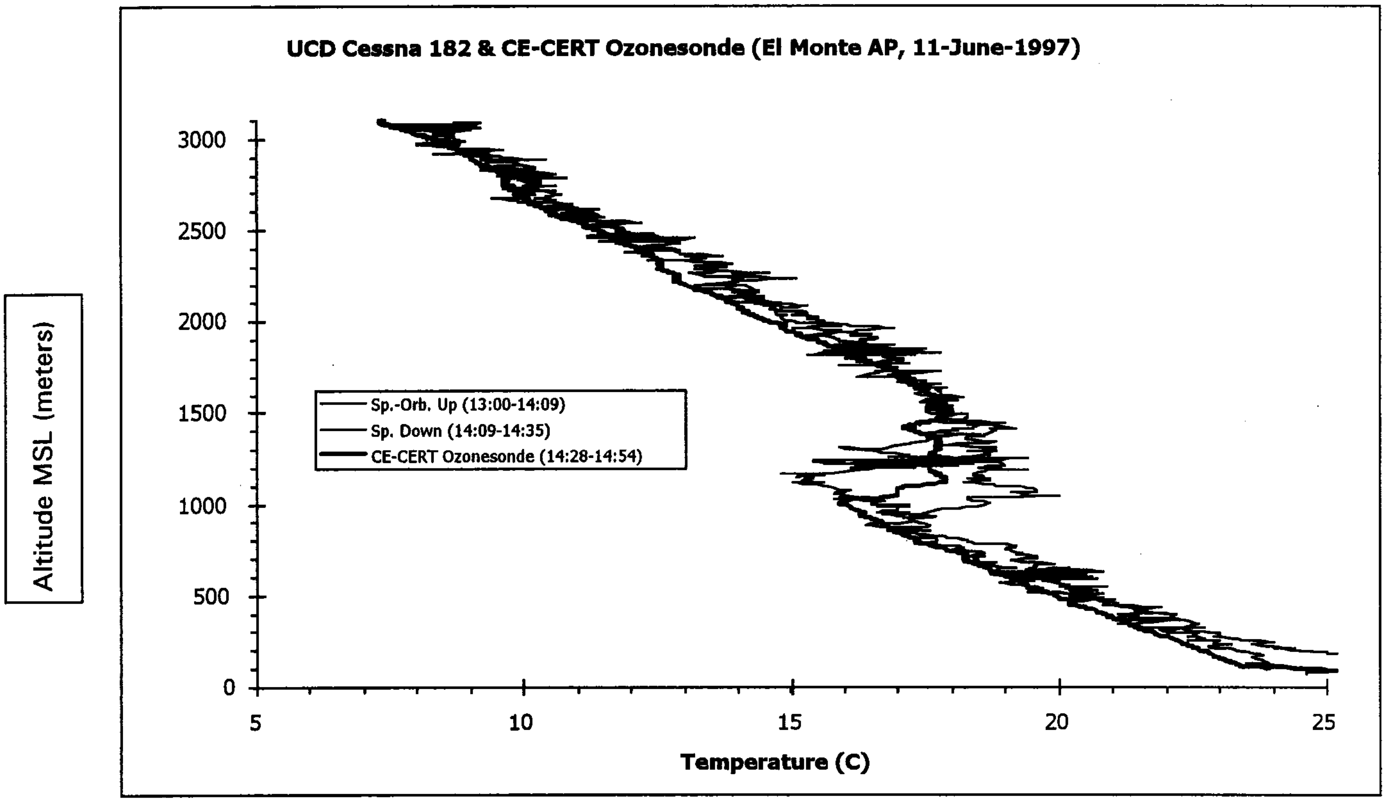
Similar to the ozone maxima, the height at which the CE-CERT ozonesonde located the inversion layer is between the heights determined by UCD up and down spirals. This indicates that part of the difference in ozone profiles is due to the different inversion heights encountered, which are probably due to the horizontal variation in inversion height.

Spiral-Orbits

The initial UCD ascending spiral-orbit began about 1.5 hours before the ozonesonde release and ended at about 3000 m msl about 45 min before the ozonesonde reached this elevation. The descending spiral-orbit was started near 2100 m msl just before the ozonesonde reached 3000 m msl. It reached ground level nearly an hour after the ozonesonde release. Ozonesonde ozone concentrations again tend to be higher than the corresponding UCD measurements at low elevation and comparable at high elevations.

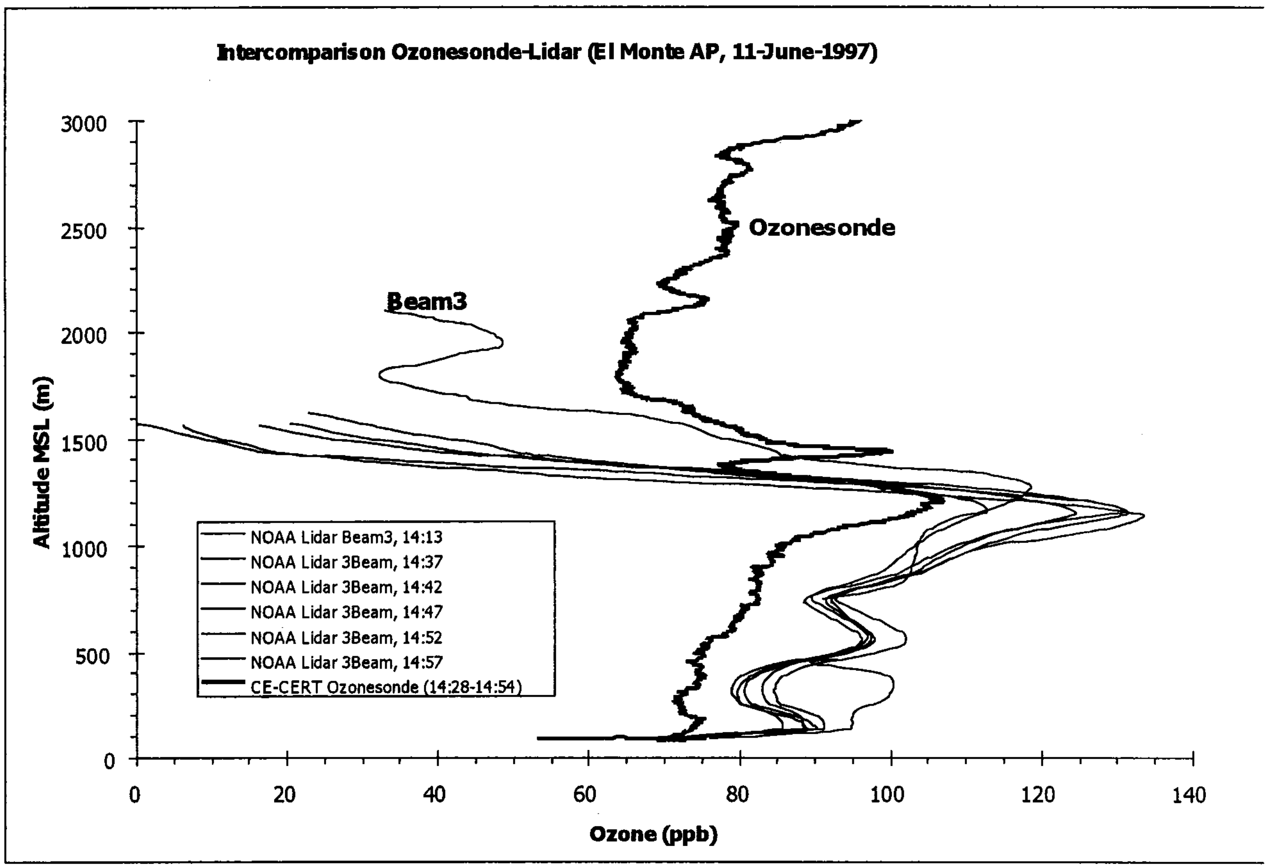


Once again the CE-CERT ozonesonde finds the inversion layer at an intermediate altitude when compared to measurements during the UCD ascending and descending spiral orbits as can be seen in the following graph of temperature measurements.



<u>CE-CERT Ozone sonde versus NOAA Lidar</u>

The CE-CERT ozonesonde ozone profile is compared with all NOAA lidar ozone profiles taken during the ascend of the ozonesonde. With the exception of the lidar profile at 14:13 PST, which was taken with beam 3 only, all other lidar profiles were taken in the 3-beam configuration. Ozonesonde ozone data are lower than lidar data at elevations below about 1300 m msl. The maximum ozonesonde ozone concentration is about 10-30 ppb lower than that measured by the lidar. The ozonesonde data do not show the drastic drop off towards 1600 m msl, which figures prominently in the lidar data. The local peak in the ozonesonde ozone concentration at an elevation of about 1500 m msl does not exist in the lidar data, though the beam3 (14:13) lidar data show a hint of this feature.

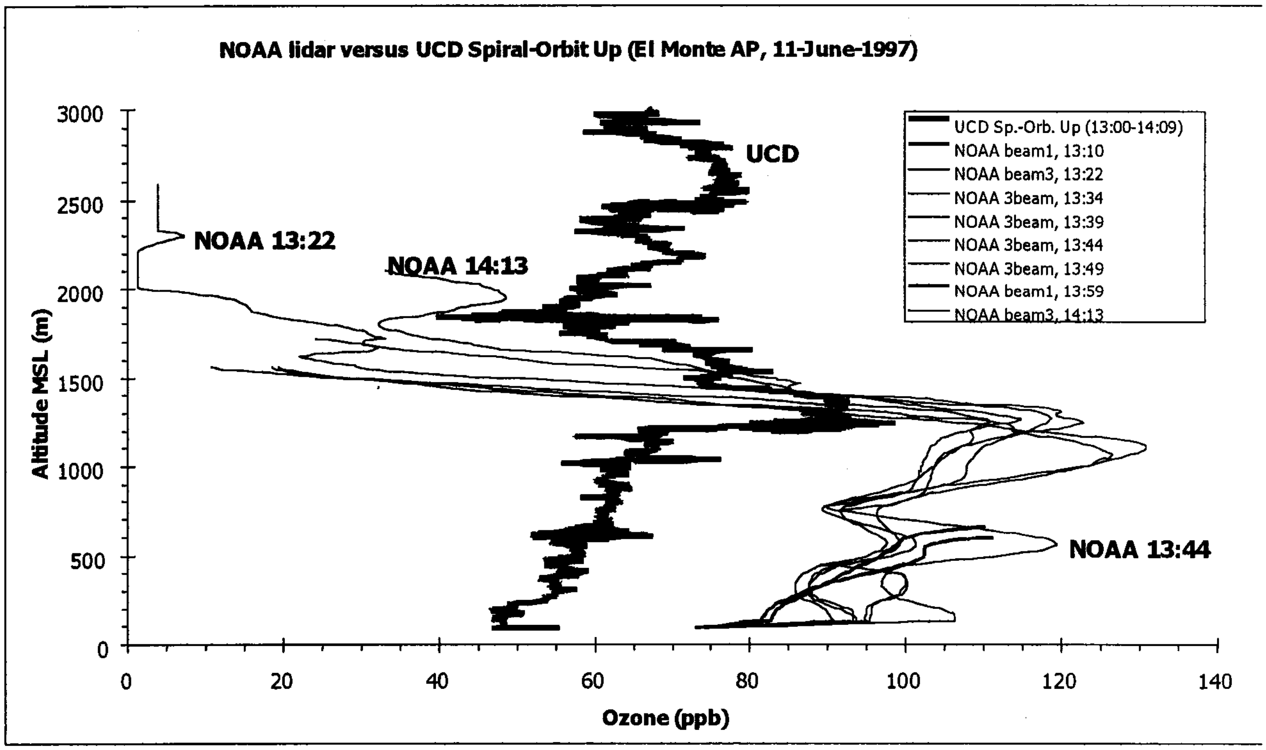


UCD Cessna 182 versus NOAA Lidar

UCD ozone data are compared with NOAA lidar ozone data separately for each of the four components of the UCD flight plan. Lidar ozone profiles for times comparable to the flight time of the respective flight component are shown.

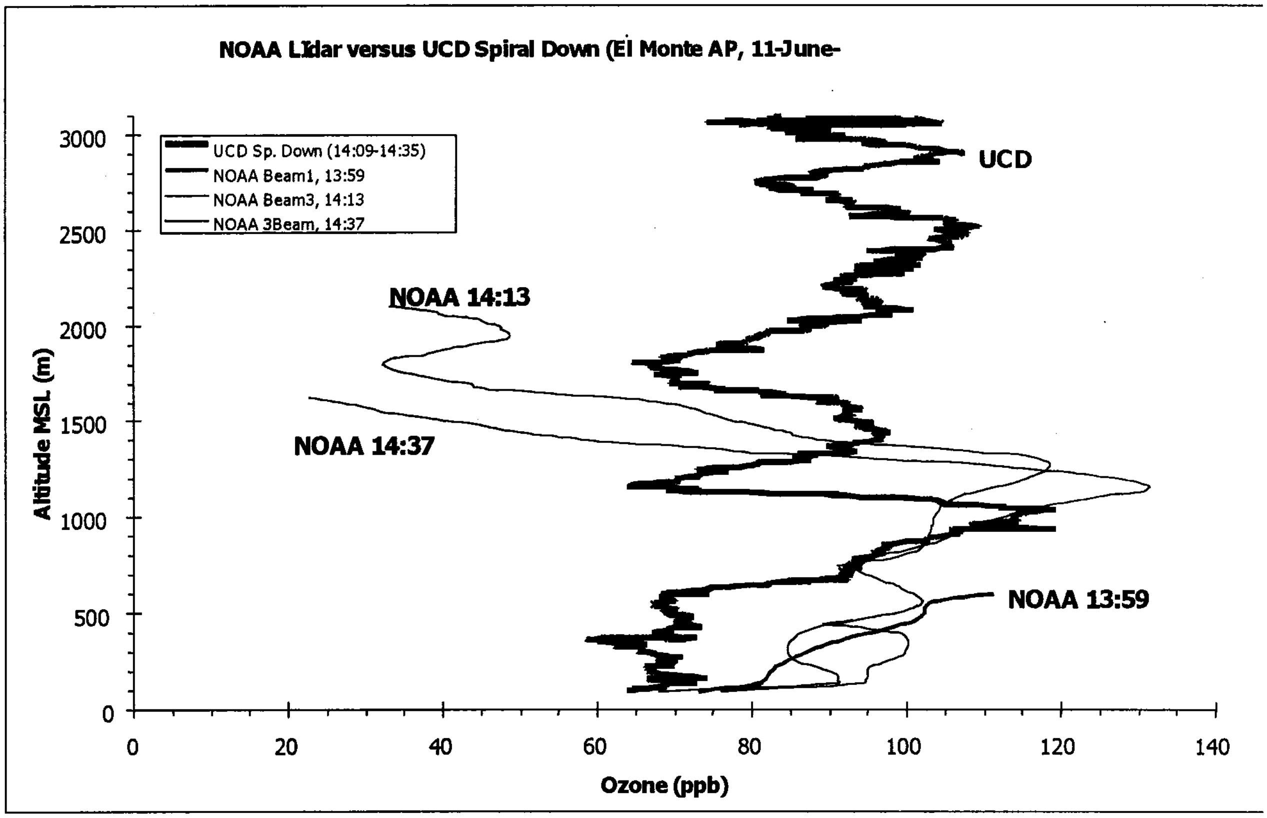
Ascending Spiral-Orbit (13:00-14:09)

Lidar measured ozone concentrations are substantially higher than UCD determined concentrations below and at the elevation of the ozone maximum at about 1200 m msl. Above this elevation the lidar determined concentrations quickly fall below the UCD concentrations. The UCD profile shows no evidence of the drastic drop-off towards 0 ppb, which is prominent in the 3 beam lidar profiles above about 1500 m msl. This feature in the lidar data may be an artifact of the low signal-to-noise ratio encountered towards the far end of the lidar measurement range.



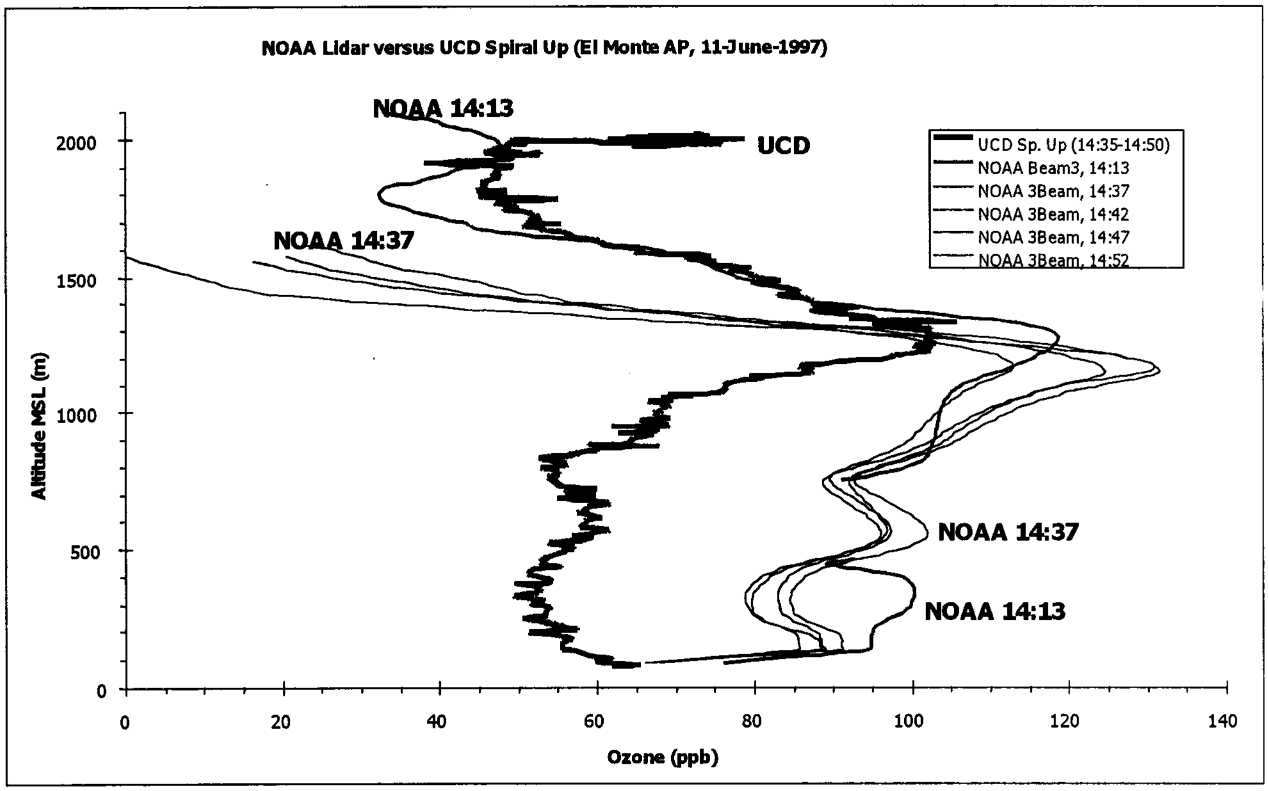
Descending Spiral (14:09-14:35)

Lidar determined ozone concentrations are significantly higher at elevations below about 600 m msl, then comparable for a few hundred meters. The ozone maximum as determined by lidar is located at a higher elevation than that determined by UCD, and is followed by a drastic drop off above which is not reflected in the UCD data.



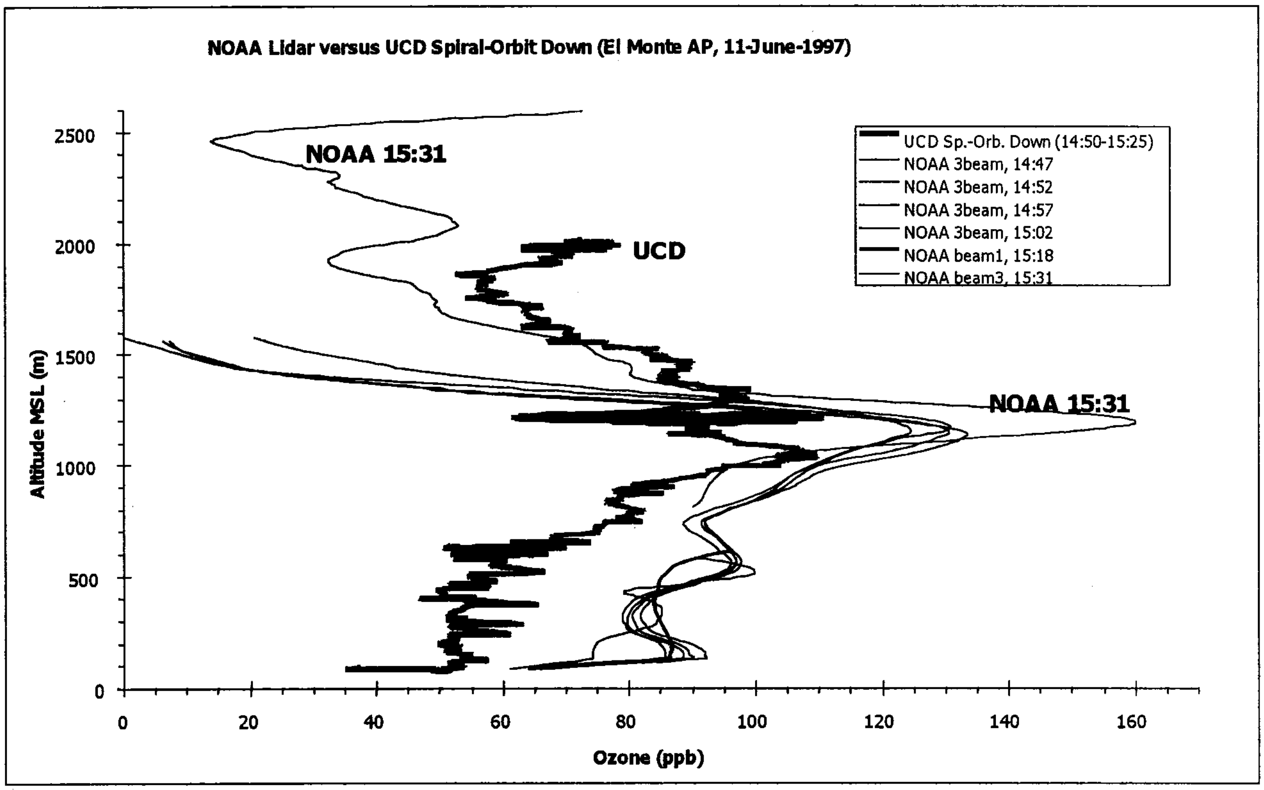
Ascending Spiral (14:35-14:50)

Again the NOAA lidar measures significantly higher ozone concentrations below and at the ozone maximum at about 1200 m msl. The structure of the ozone data below this elevation is quite similar for UCD and (especially 3 beam) lidar data. Above the maximum, the beam 3 lidar data show good agreement with the UCD data while the 3 beam lidar data are dominated by a more rapid drop of ozone concentrations towards higher altitude.



Descending Spiral-Orbit (14:50-15:25)

Again the NOAA lidar measures significantly higher ozone concentrations below and at the ozone maximum at about 1200 m msl. The structure of the ozone data below this elevation is similar for UCD and lidar data. Above the maximum, the beam 3 lidar data show some agreement with the UCD data while the 3 beam lidar data are dominated by a rapid drop of ozone concentrations towards higher altitude.



4.4 Aloft Intercomparisons: 08-July-97

The second SCOS97 aloft air quality intercomparison took place at El Monte airport on July 8, 1997. This intercomparison included the measurement of vertical profiles by the NOAA ozone lidar and a CE-CERT ozonesonde at El Monte Airport (ground elevation = 90 m msl). In addition the UCD Cessna and the STI Aztec aircraft flew spirals at El Monte Airport and Cable Airport (ground elevation = 439 m msl) and traverses between these two locations.

Only the STI data are currently fully quality assured (middle April, 1998) and many observations and conclusions are therefore preliminary.

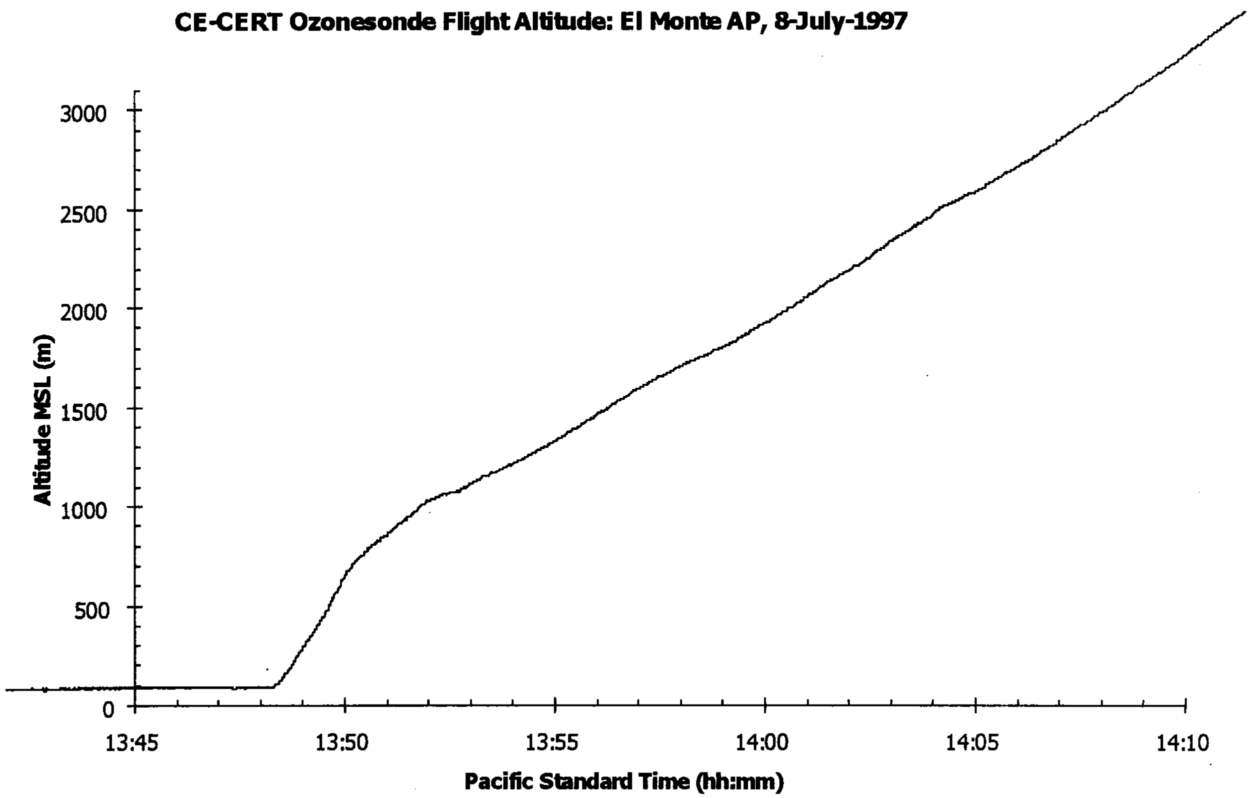
4.4.1 Data from Individual Systems

CE-CERT Ozonesonde

The ozonesonde was launched at □13:48 PST and reached an elevation of 3000 m msl at □14:08 PST. While ozonesonde data were recorded up to □6000 m, only data below □3000 m msl were used for the intercomparison. This is due to the lack of data from UCD, STI, and NOAA above □3000 m msl.

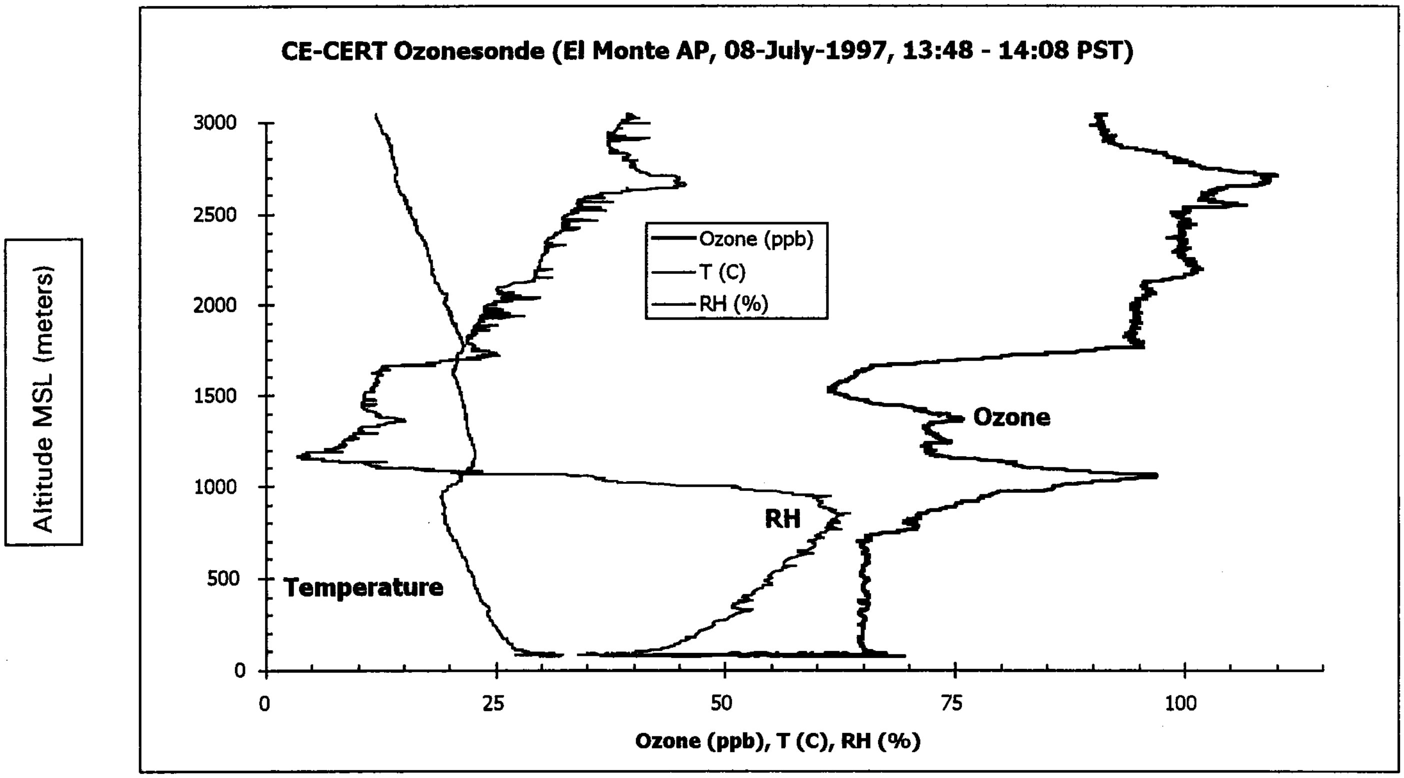
The ozonesonde release was timed to coincide with the ascending (up) spiral of STI and UCD aircraft above El Monte AP. These spirals are labeled transect #7 for both aircraft.

The ozonesonde altitude above ground level (agl) has been calculated by CE-CERT from pressure data. For comparison purposes, the altitude has been converted to msl by adding the altitude of El Monte AP (90 m). The figure below shows the ozonesonde altitude as function of time.



Note that the vertical velocity component is relative constant to about 800 m msl, then slows down considerably and remains roughly constant for the rest of the ascent shown above.

Ozone, temperature, and relative humidity profiles for the intercomparison range are shown in the following figure. Temperature inversions were encountered around 1100 m msl and 1700 m msl. During the first, more pronounced temperature inversion, an ozone maximum (□ 100 ppb) and a drastic drop-off in relative humidity were observed. The second temperature inversion coincided with minimum in the ozone concentration (□ 60 ppb) and a sharp increase in relative humidity. The highest ozone concentration in the displayed range of about 110 ppb is measured around 2700 m msl.



UCD and STI Aircraft

The UCD Cessna and STI Aztec intercomparison flight took place between 12:52 and 13:51 PST incorporating spirals at El Monte AP and Cable AP and traverses between the two airports. The UCD aircraft followed slightly behind the STI aircraft on the traverses and about a minute behind on the spirals. The initial ascents from El Monte AP for UCD and STI aircraft were flown on somewhat different paths due to different interpretations of noise abatement procedures that are in effect at El Monte airport. During the flight several checks of recorded time took place between the aircraft and their data have been adjusted to a common time.

The balloon launch was also well synchronized as described by Mr. Jerry Anderson (STI):

"The balloon launch was a thing of beauty. They launched as we started the upward spiral. At almost every turn of the spiral we had visual contact with John (UCD) *and the balloon."*

UCD Cessna 182

The UCD Cessna conducted one early afternoon flight consisting of spirals and traverses between 12:52 and 14:28 PST. The flight included the following transects:

1. Take off from El Monte AP and ascent to □ 1000 m msl

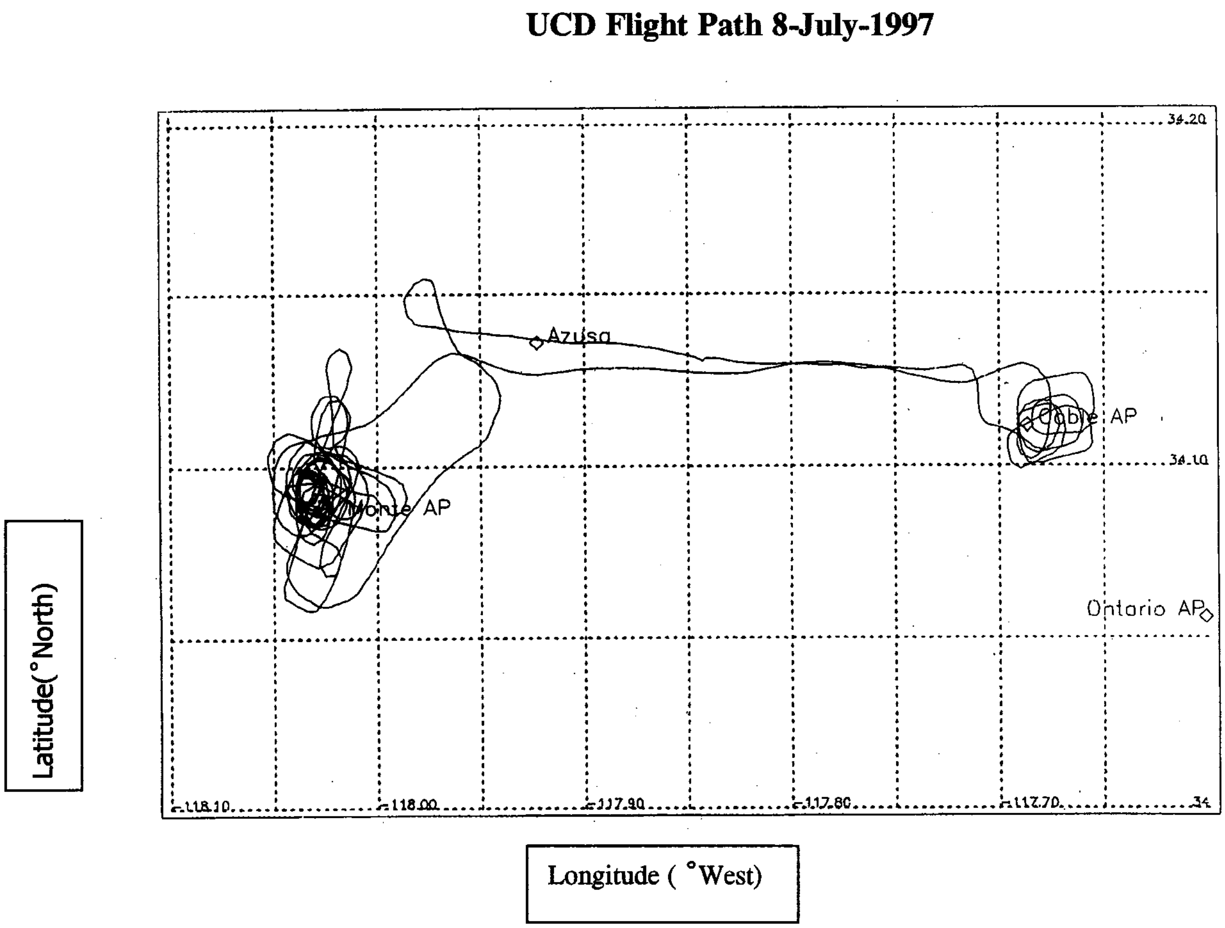
2. Traverse from El Monte AP to Cable AP at □ 1000 m msl

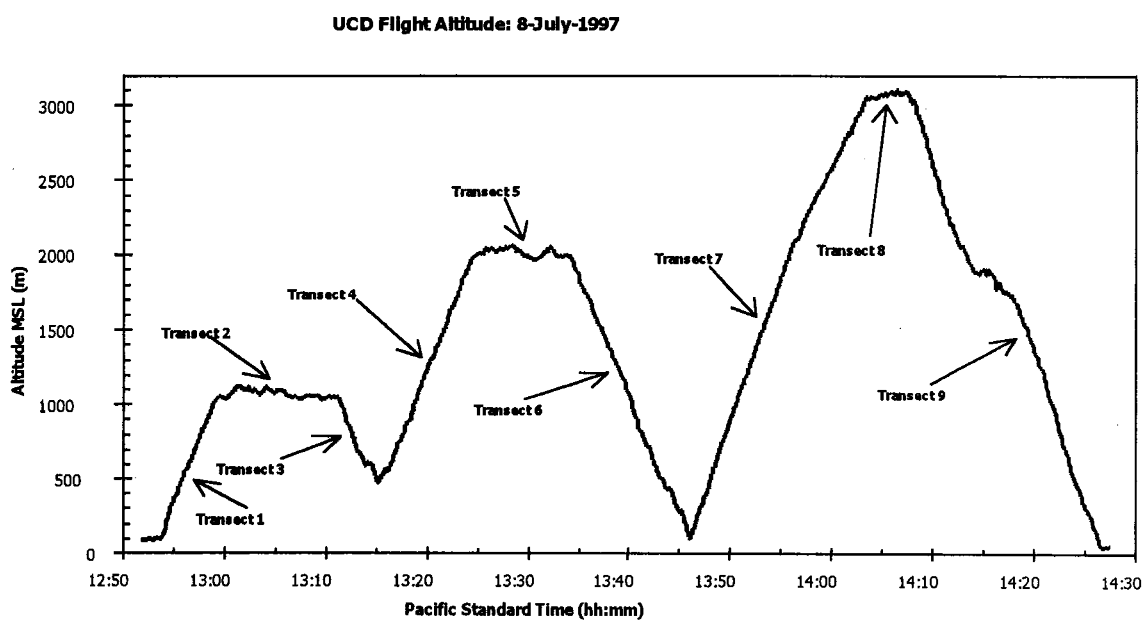
3. Down spiral to (near) ground level above Cable AP
4. Up spiral to □ 2000 m msl above Cable AP
5. Traverse from Cable AP to El Monte AP at □ 2000 m msl
6. Down spiral to (near) ground level above El Monte AP
7. Up spiral to □ 3000 m msl above El Monte AP
8. Orbit at □ 3000 m msl above El Monte AP
9. Down spiral to ground level and land at El Monte AP

It should be noted that prior to the initial departure from El Monte the ozone monitor pump was inadvertently turned off. This was noticed at about 13:09 PST and the pump was turned on. Therefore, no ozone data are available before 13:09 PST, i.e. for transect #1 and most of transect #2. The initial ozone data in transect #2 might also be somewhat suspect.

The following page show an overview of the UCD flight path followed by graphs of the flight path and of some of the data for each transect.

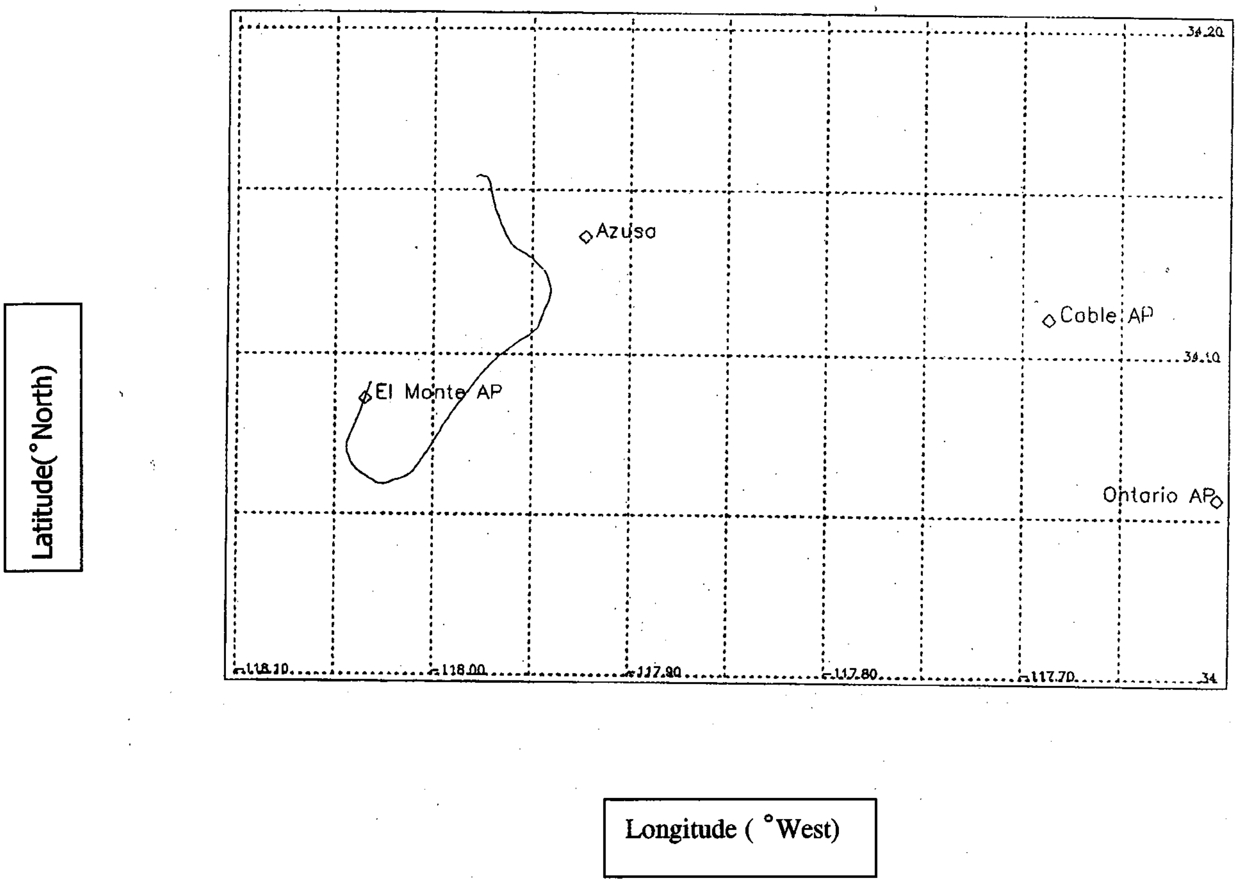
UCD Flight Path Overview

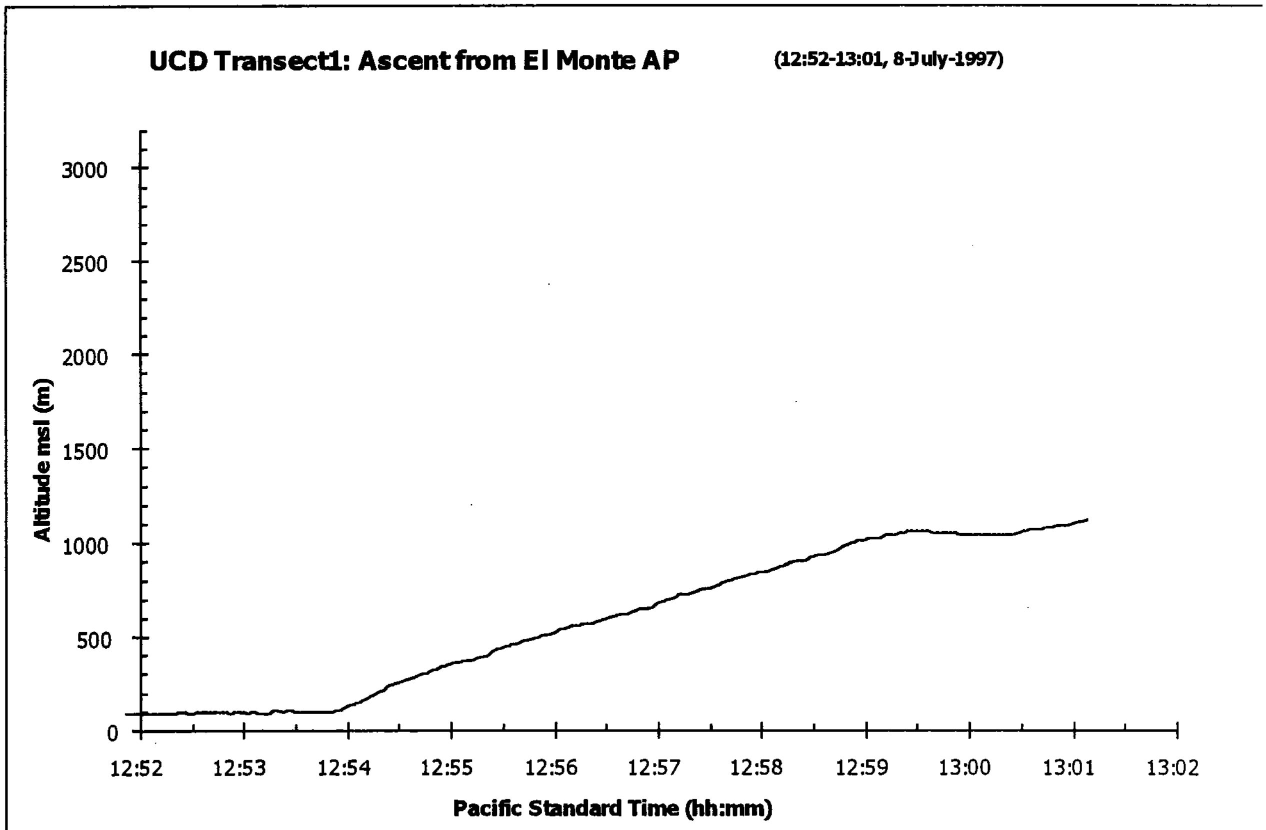


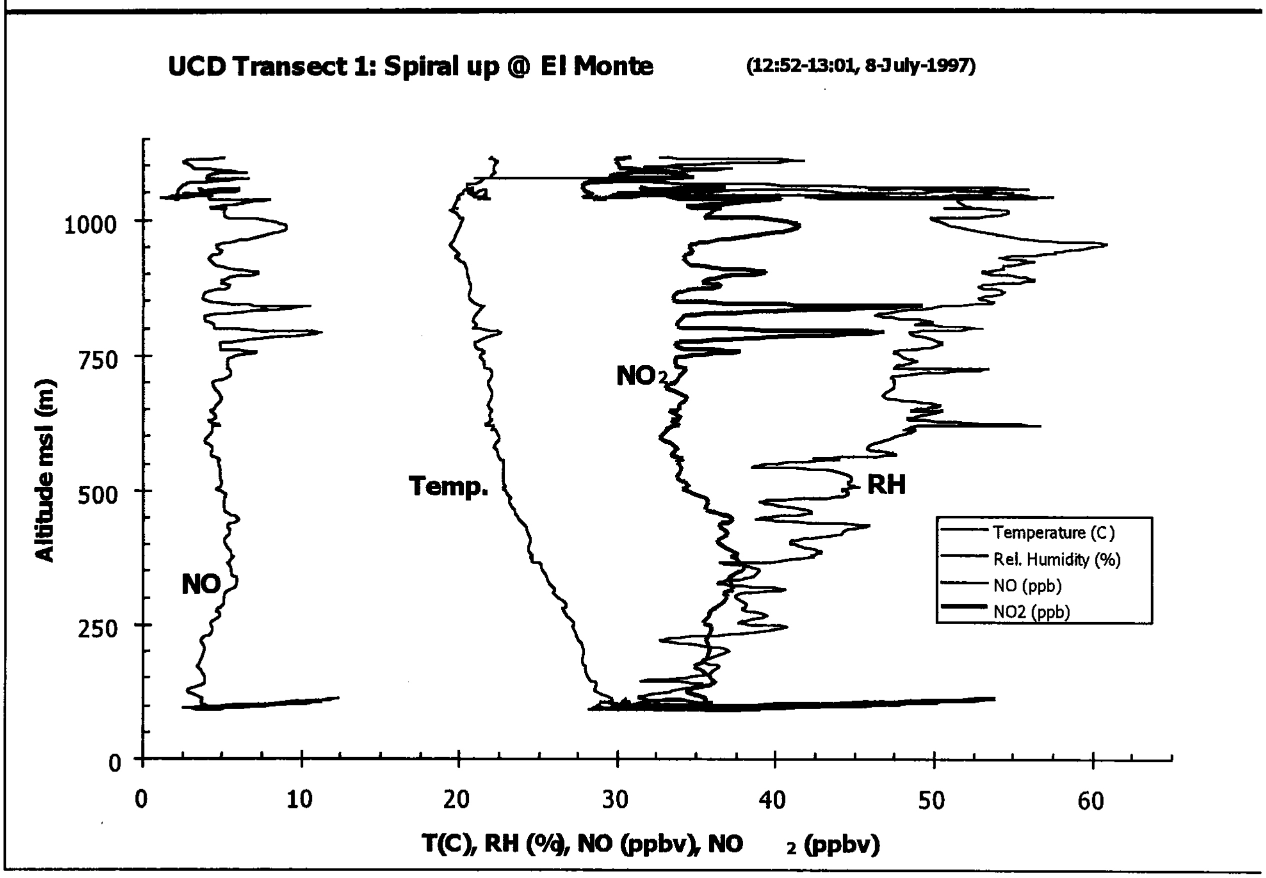


UCD Flight Path and Data for Individual Transects

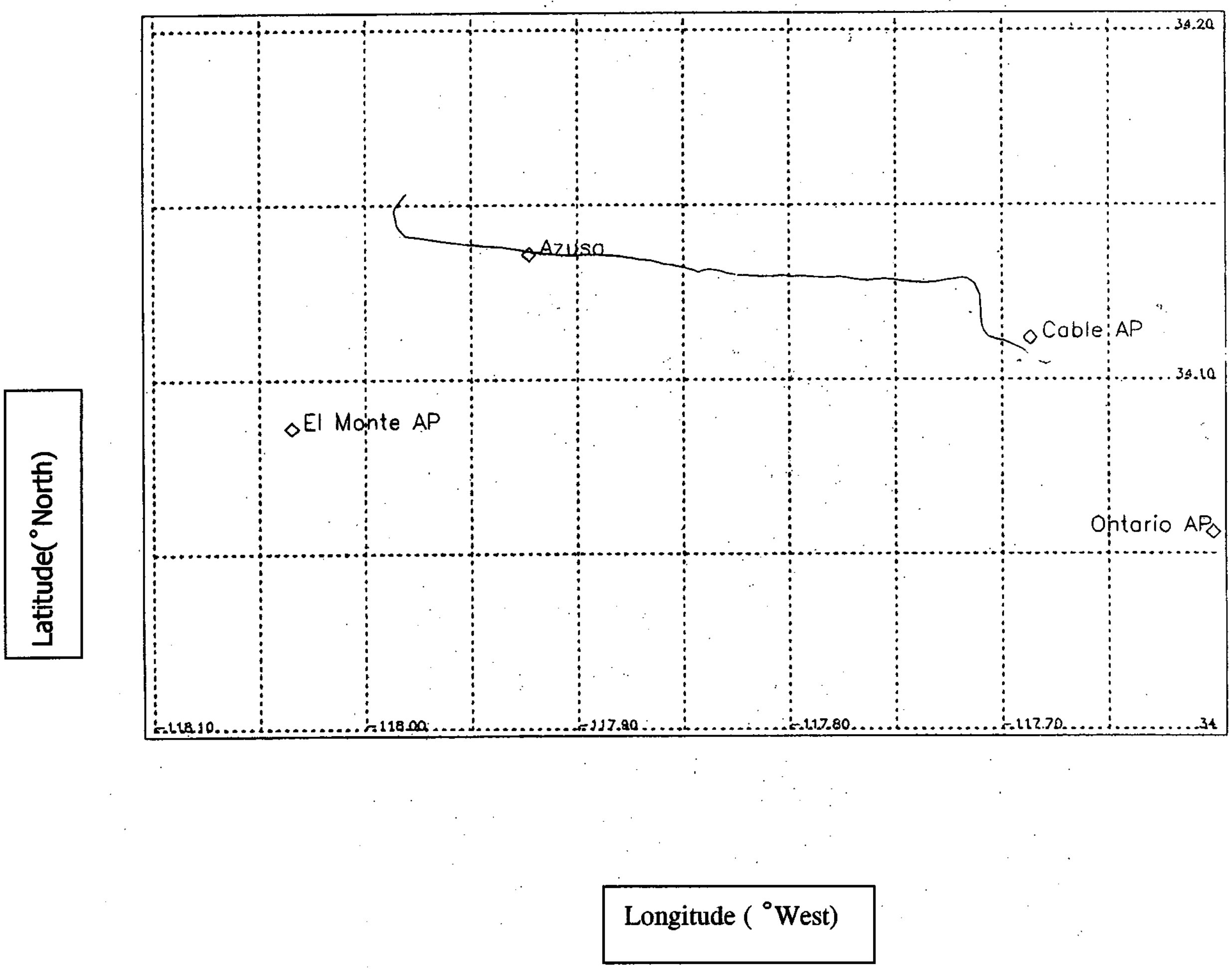
UCD Flight Path Transect 1: Ascent to □ 1000 m msl above El Monte AP

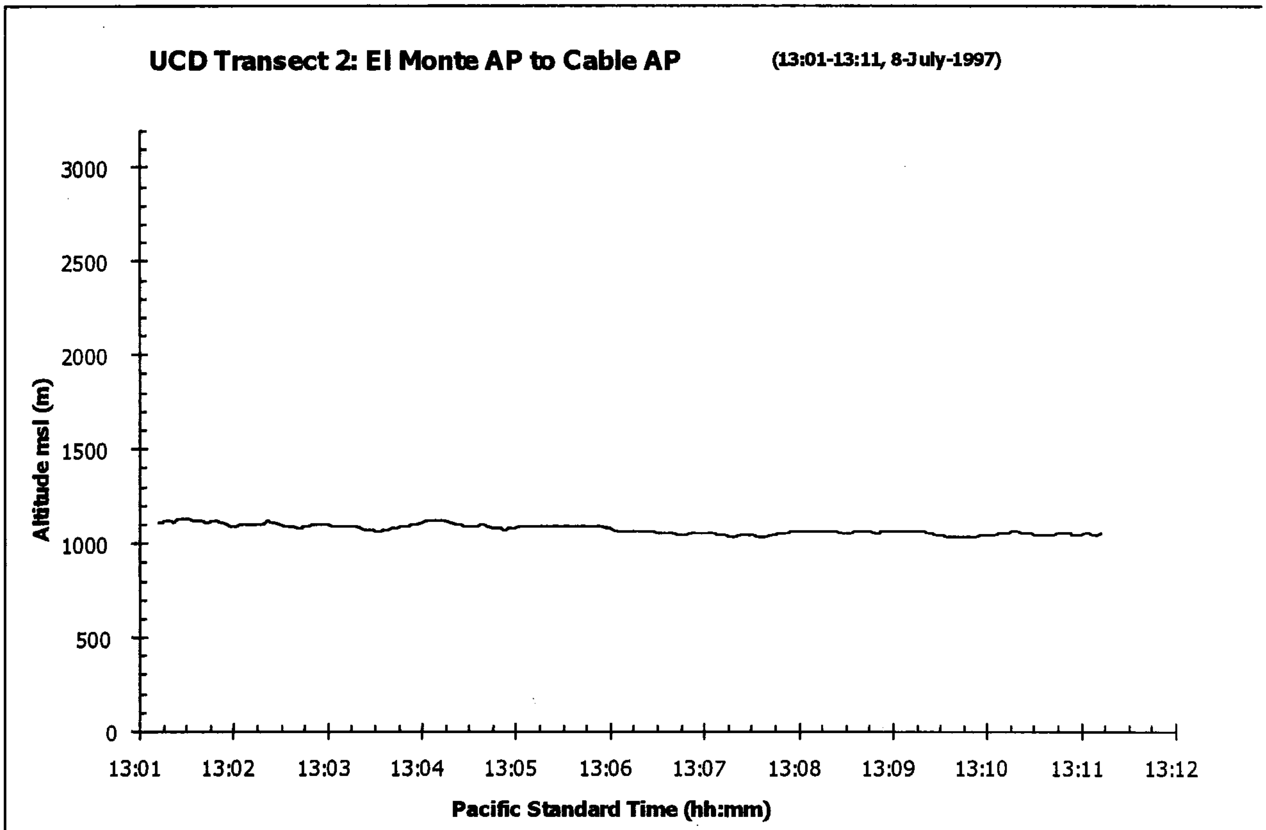



UCD Transect1: Ascent from El Monte AP
(12:52-13:01, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
12:52
12:53
12:54
12:55
12:56
12:57
12:58
12:59
13:00
13:01
13:02
Pacific Standard Time (hh:mm)

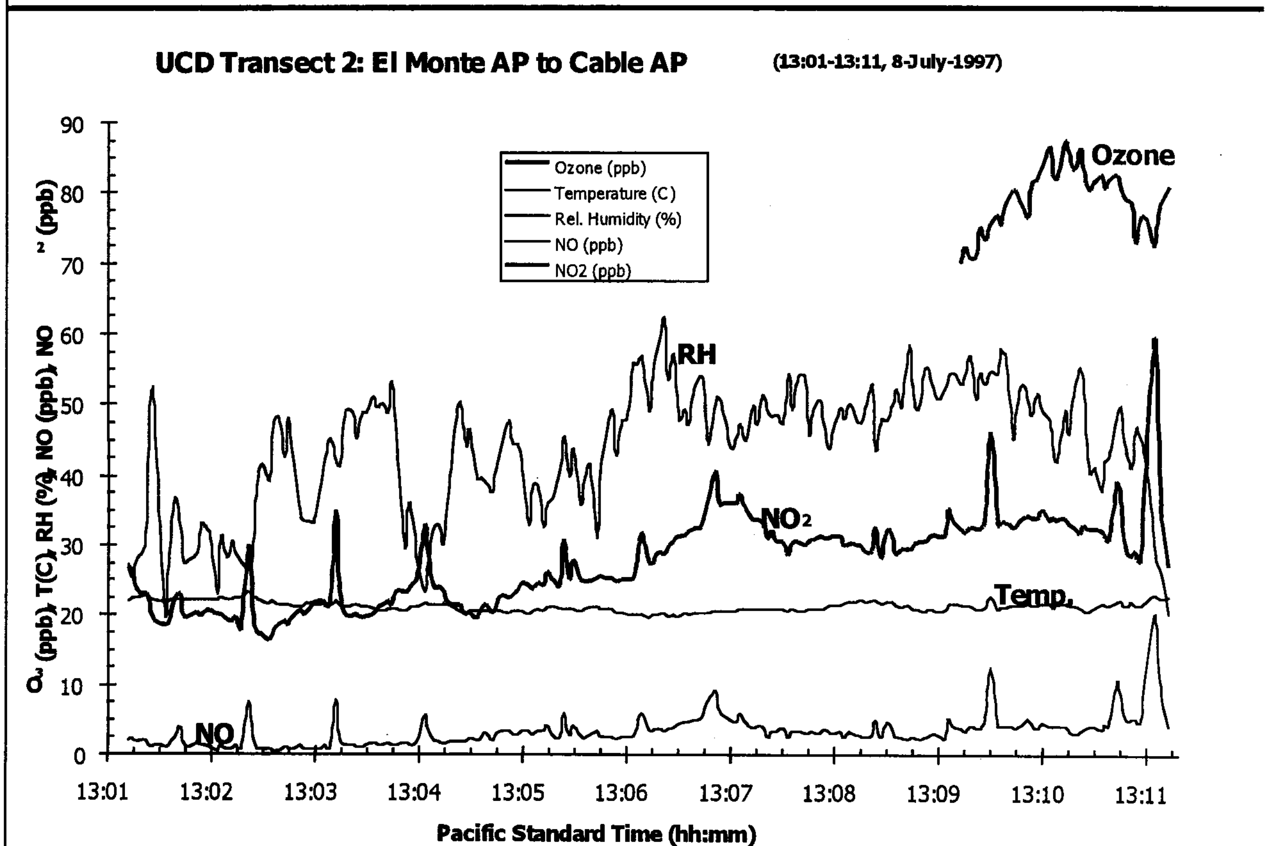

UCD Transect 1: Spiral up @ El Monte
(12:52-13:01, 8-July-1997)
Altitude msl (m)
1000
750
500
250
0
NO
Temp.
NO2
RH
Temperature (C)
Rel. Humidity (%)
NO (ppb)
NO2 (ppb)
0
10
20
30
40
50
60
T(C), RH (%), NO (ppbv), NO 2 (ppbv)

UCD Flight Path Transect 2: Traverse from El Monte to Cable at □ 1000 m msl



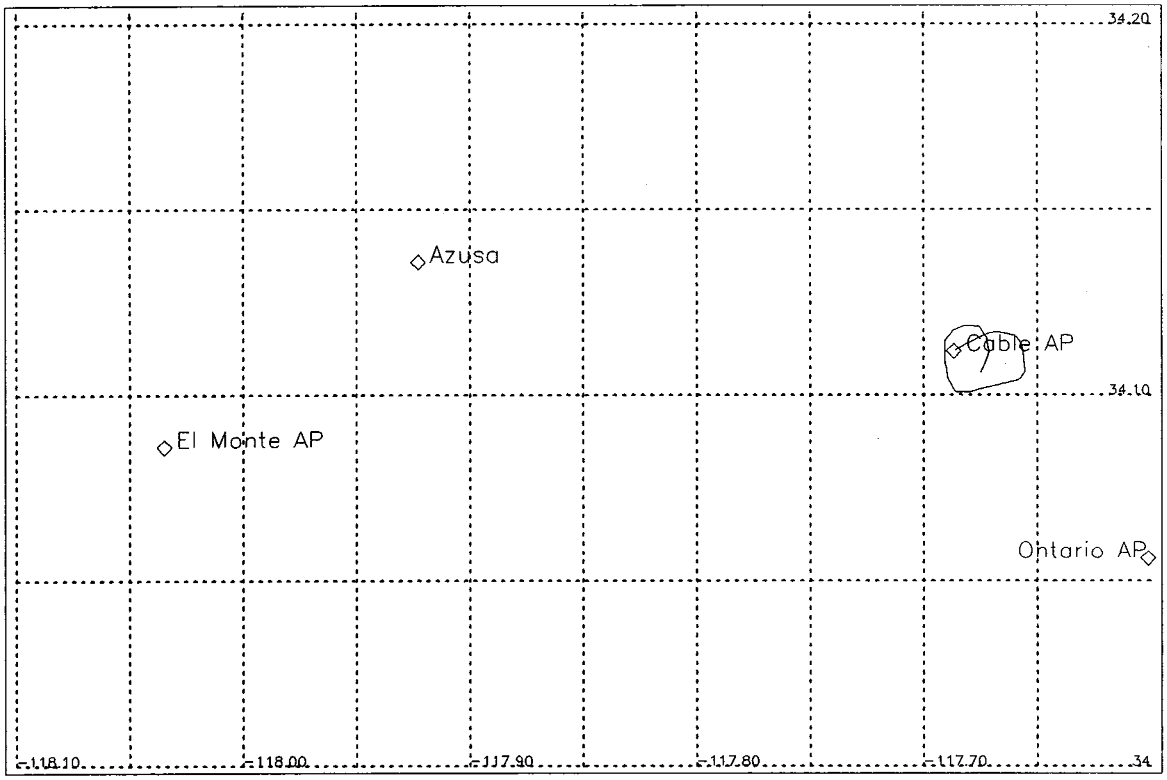


UCD Transect 2: El Monte AP to Cable AP
(13:01-13:11, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
13:01
13:02
13:03
13:04
13:05
13:06
13:07
13:08
13:09
13:10
13:11
13:12
Pacific Standard Time (hh:mm)

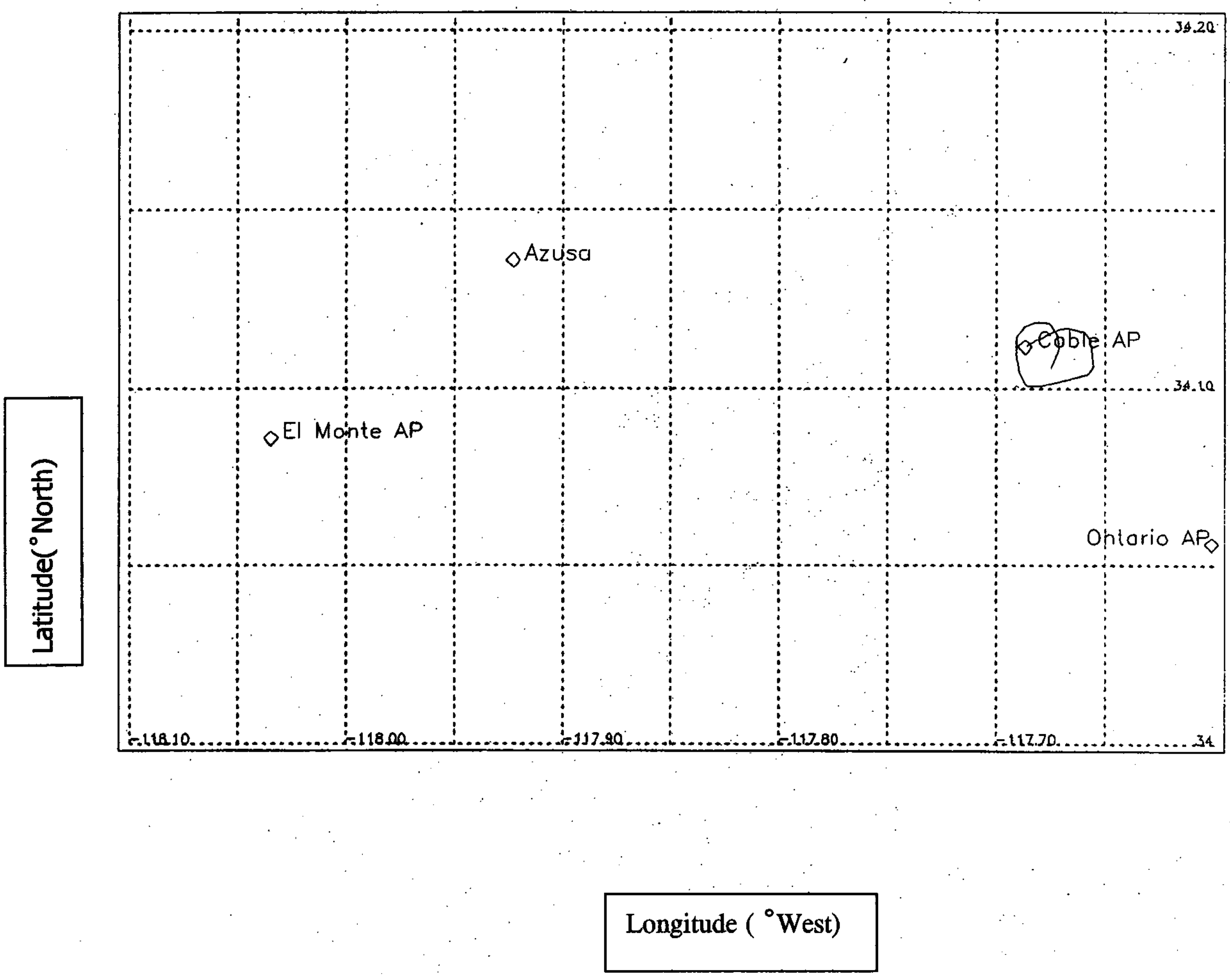


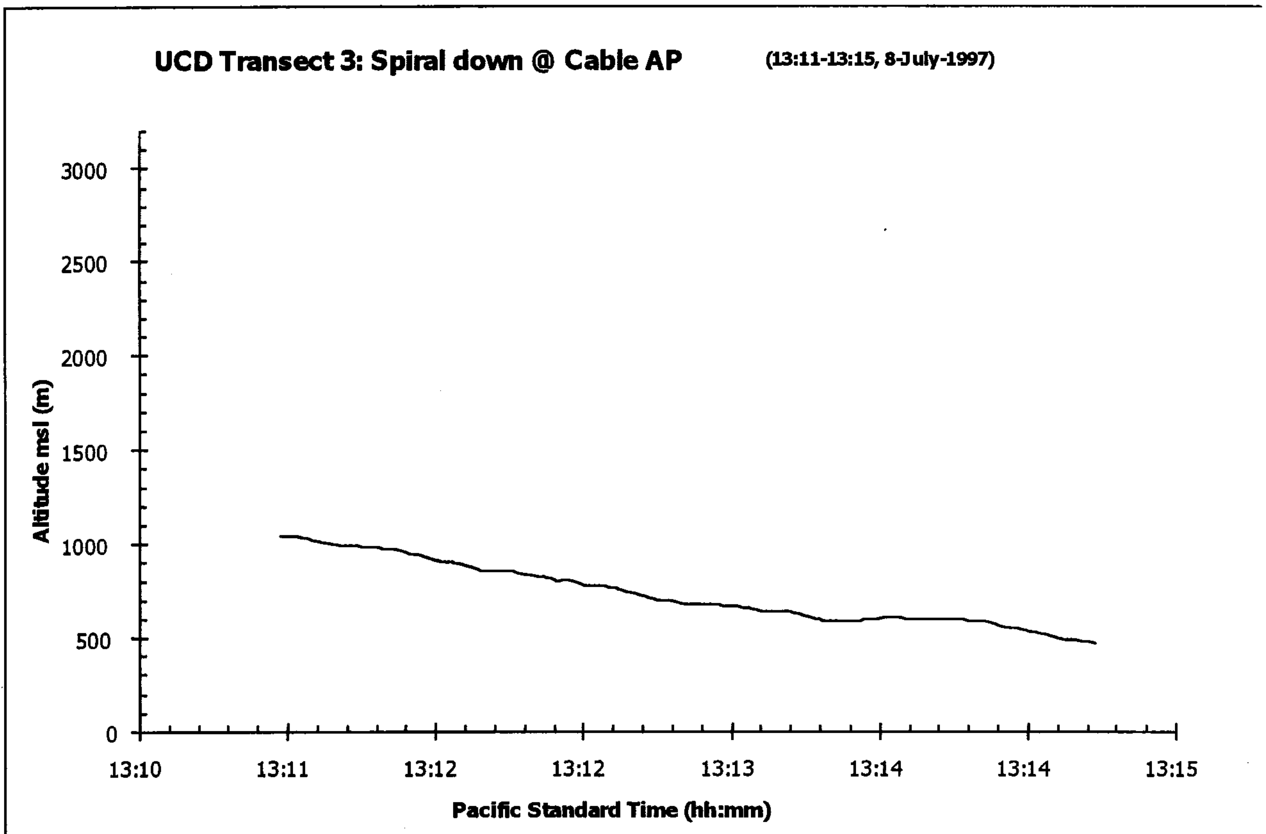
UCD Transect 2: El Monte AP to Cable AP
(13:01-13:11, 8-July-1997)
Ozone (ppb)
Temperature (C)
Rel. Humidity (%)
NO (ppb)
NO2 (ppb)
Ozone
RH
NO2
Temp.
NO
90
80
70
60
50
40
30
20
10
0
13:01
13:02
13:03
13:04
13:05
13:06
13:07
13:08
13:09
13:10
13:11
Pacific Standard Time (hh:mm)

UCD Flight Path Transect 3: Down spiral to (near) ground level above Cable AP

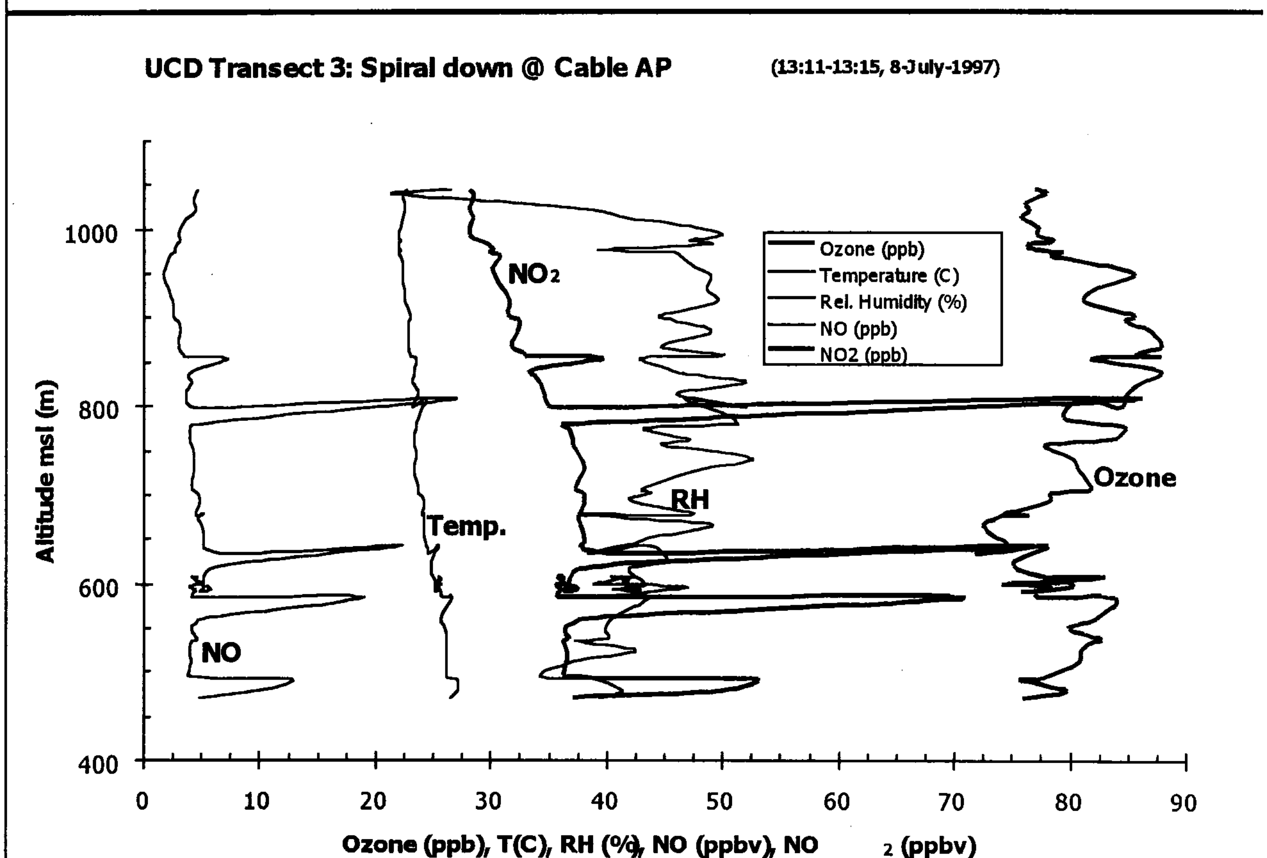


UCD Flight Path Transect 3: Down spiral to (near) ground level above Cable AP



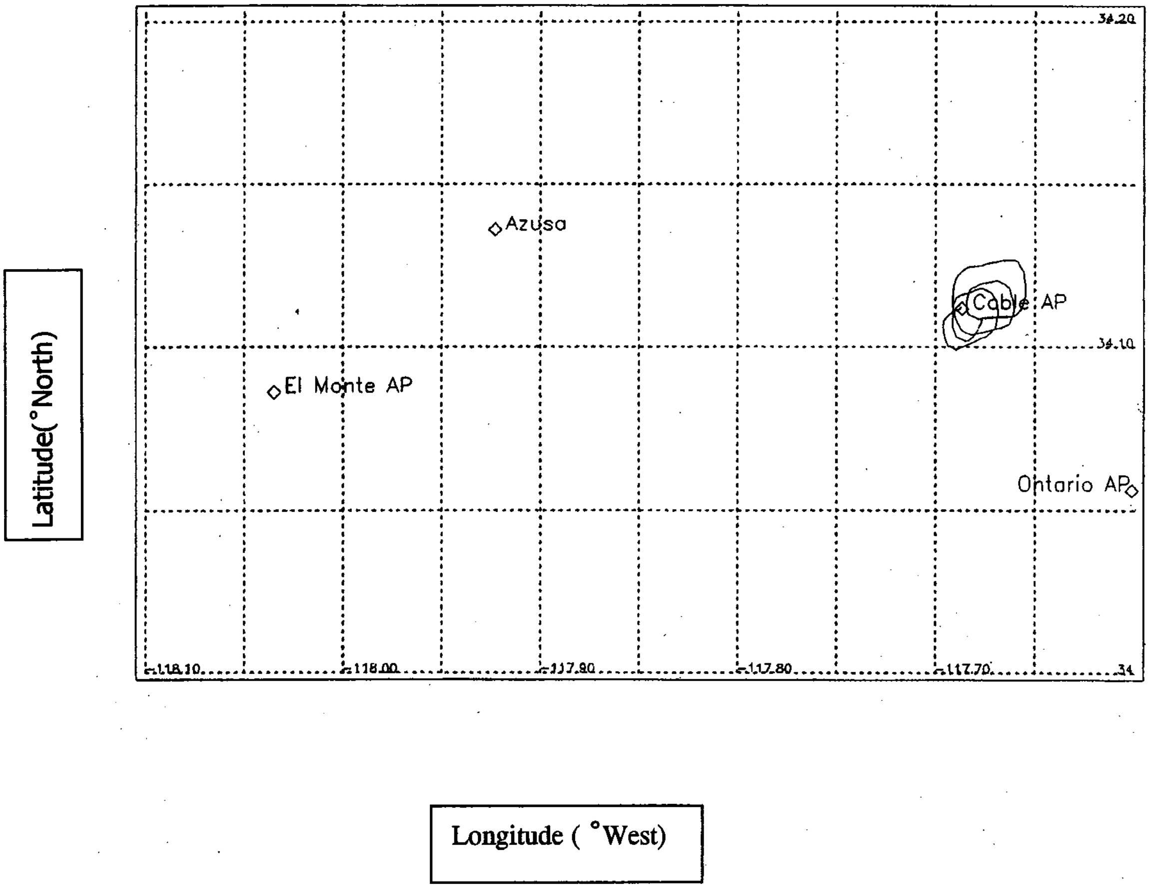


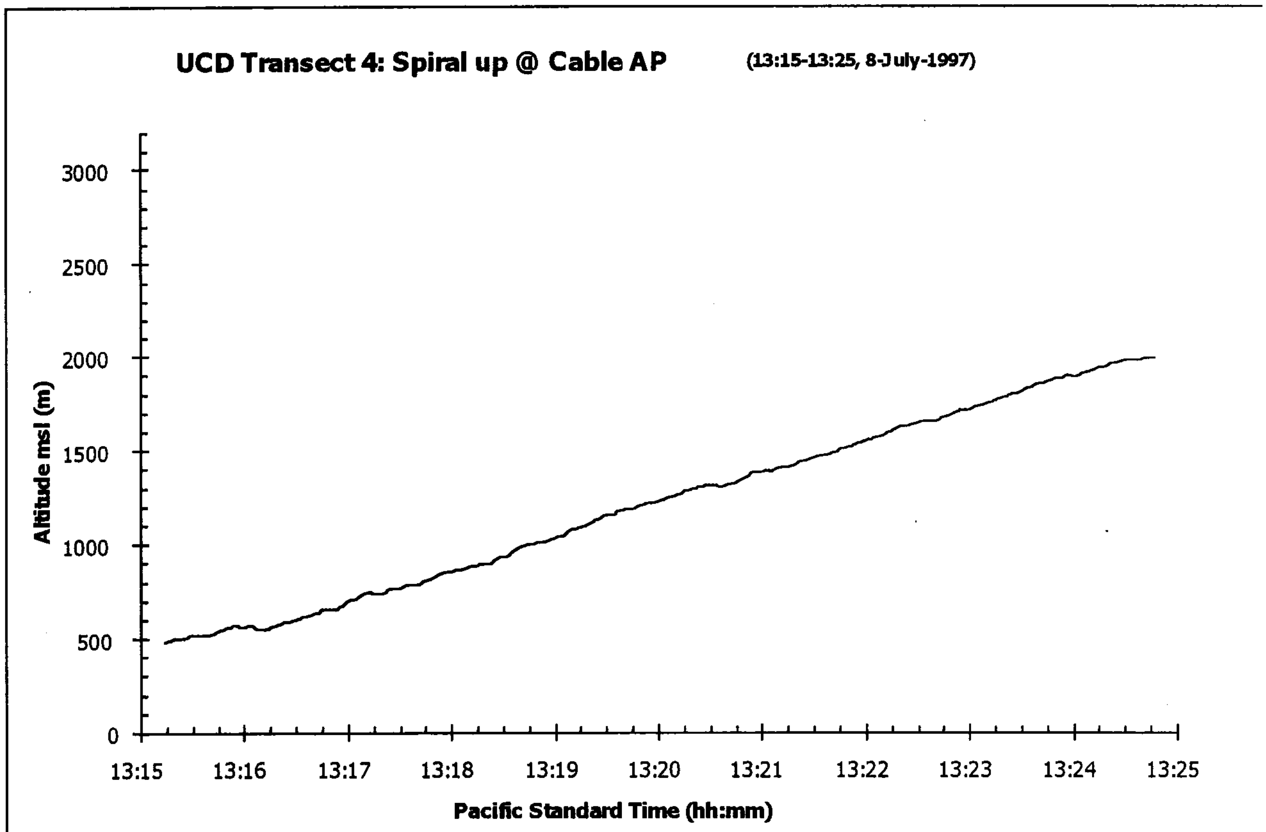
UCD Transect 3: Spiral down @ Cable AP
(13:11-13:15, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
13:10
13:11
13:12
13:12
13:13
13:14
13:14
13:15
Pacific Standard Time (hh:mm)



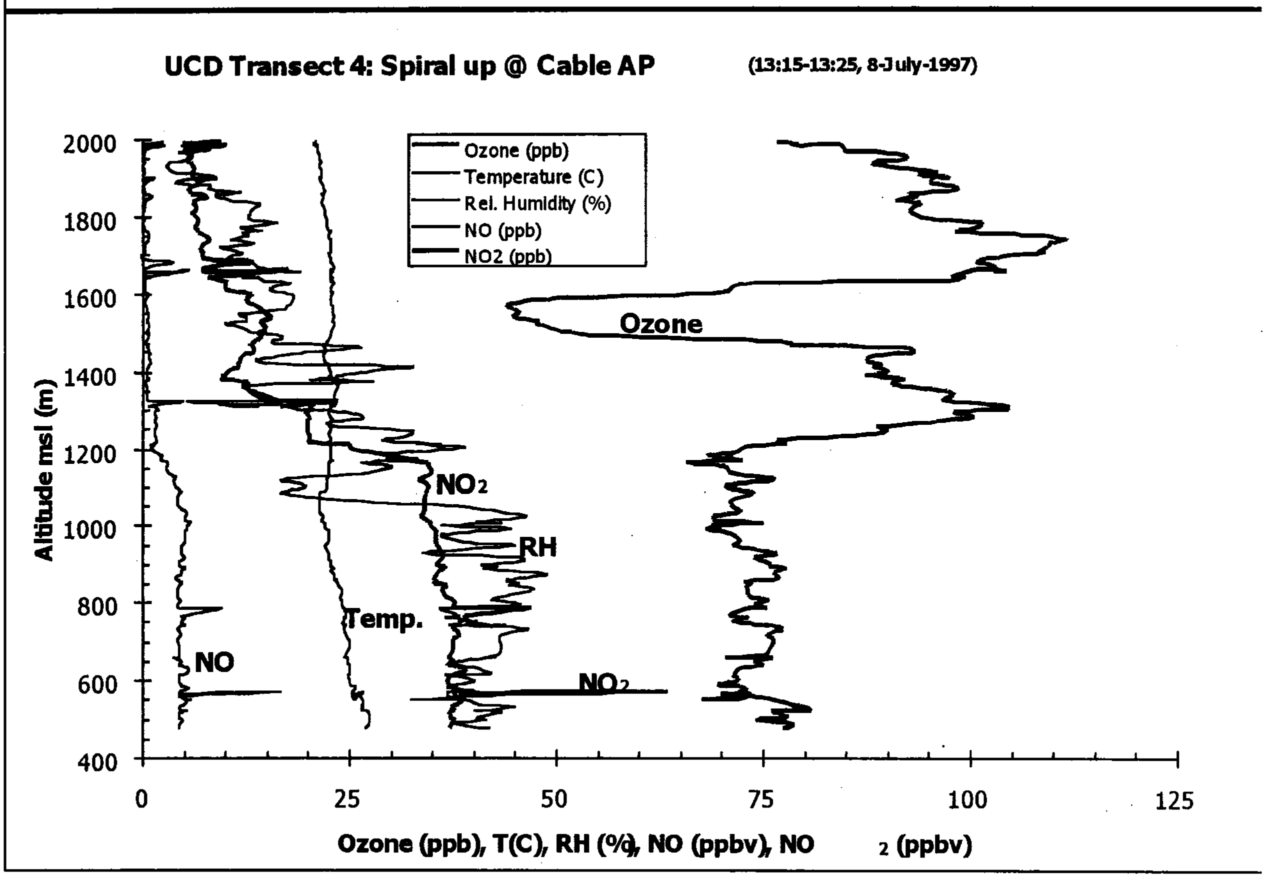
UCD Transect 3: Spiral down @ Cable AP
(13:11-13:15, 8-July-1997)
Ozone (ppb)
Temperature (C)
Rel. Humidity (%)
NO (ppb)
NO2 (ppb)
NO2
RH
Ozone
Temp.
NO
Altitude msl (m)
1000
800
600
400
0
10
20
30
40
50
60
70
80
90
Ozone (ppb), T(C), RH (%), NO (ppbv), NO 2 (ppbv)

UCD Flight Path Transect 4: Up spiral to 2000 m msl above Cable AP



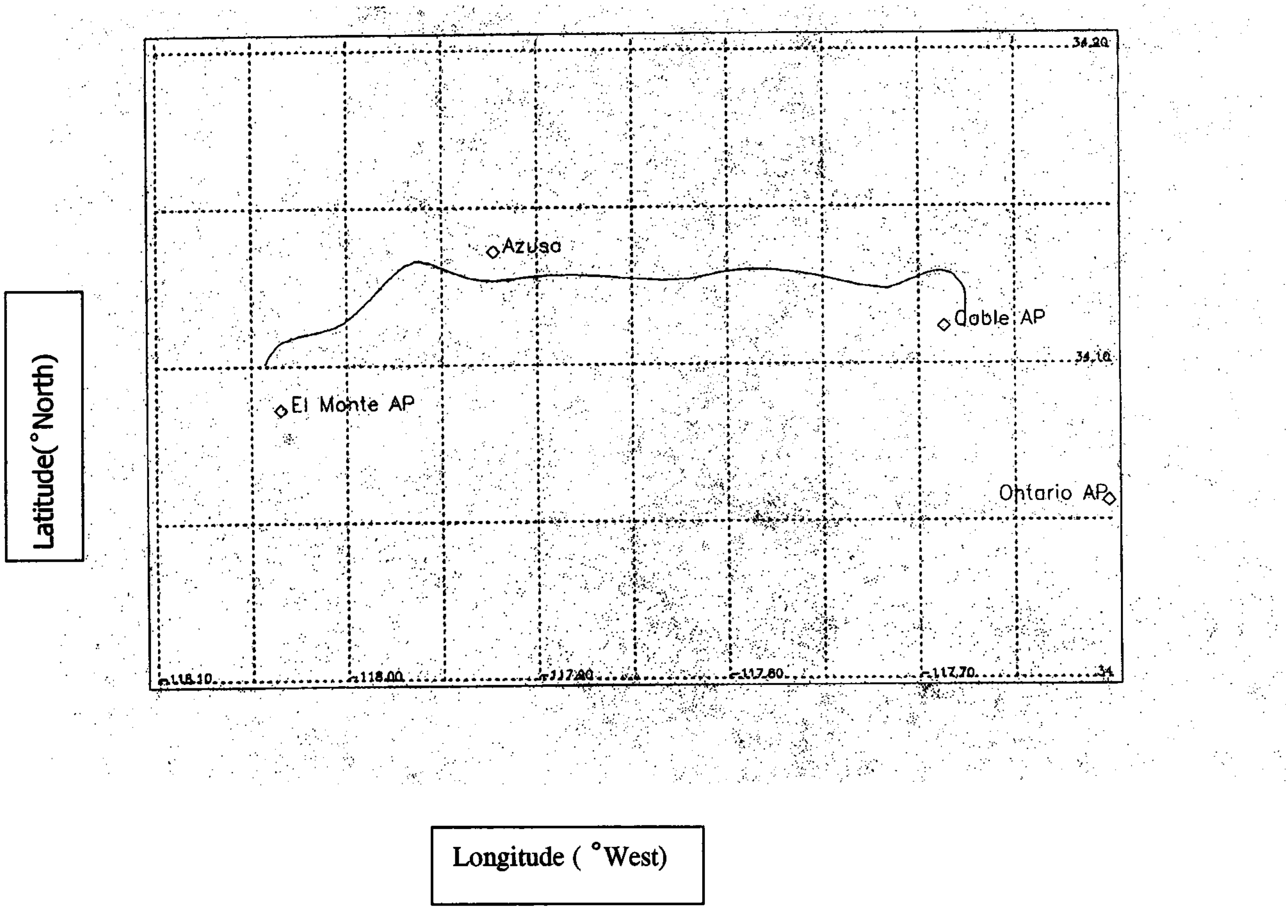


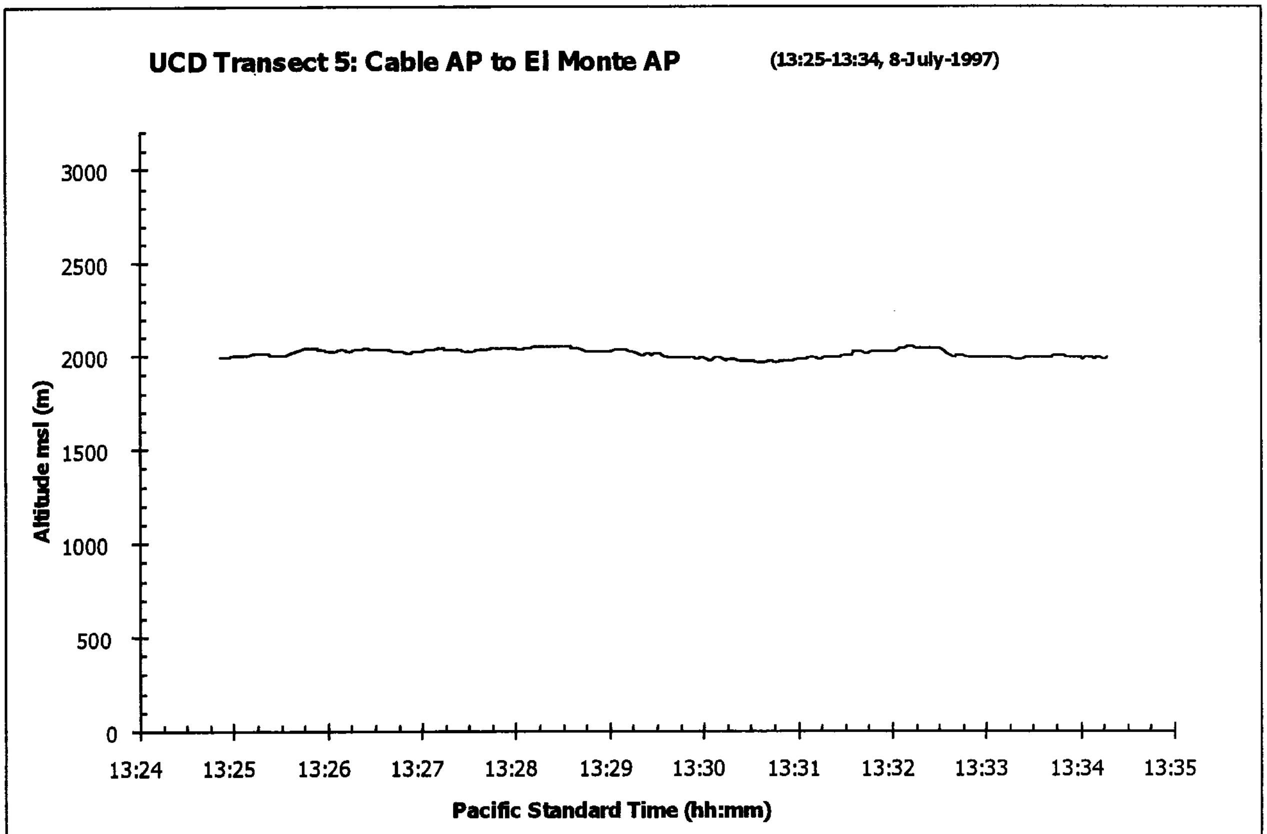
UCD Transect 4: Spiral up @ Cable AP
(13:15-13:25, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
13:15
13:16
13:17
13:18
13:19
13:20
13:21
13:22
13:23
13:24
13:25
Pacific Standard Time (hh:mm)

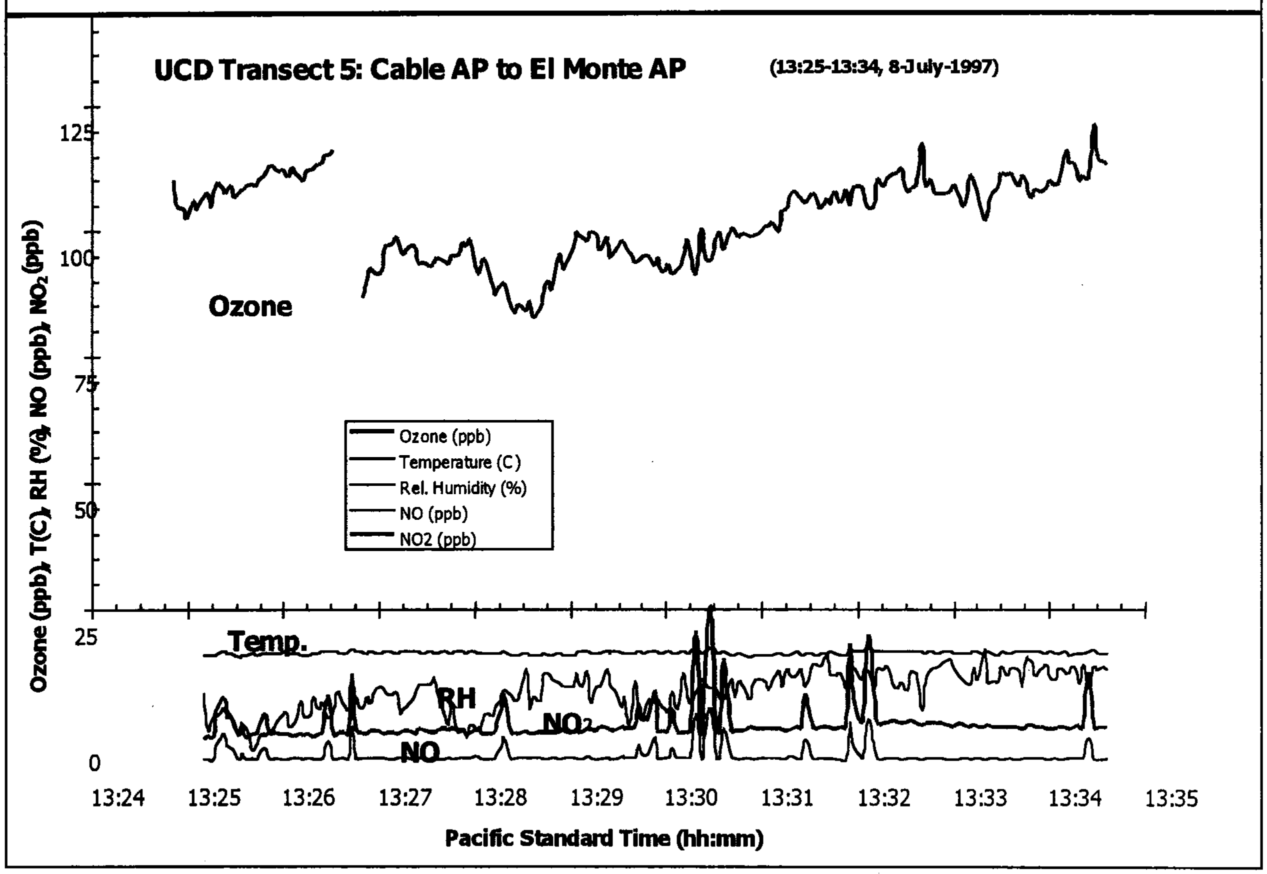


UCD Transect 4: Spiral up @ Cable AP
(13:15-13:25, 8-July-1997)
Ozone (ppb)
Temperature (C)
Rel. Humidity (%)
NO (ppb)
NO2 (ppb)
Ozone
NO2
RH
Temp.
NO
NO2
Altitude msl (m)
2000
1800
1600
1400
1200
1000
800
600
400
0
25
50
75
100
125
Ozone (ppb), T(C), RH (%), NO (ppbv), NO 2 (ppbv)

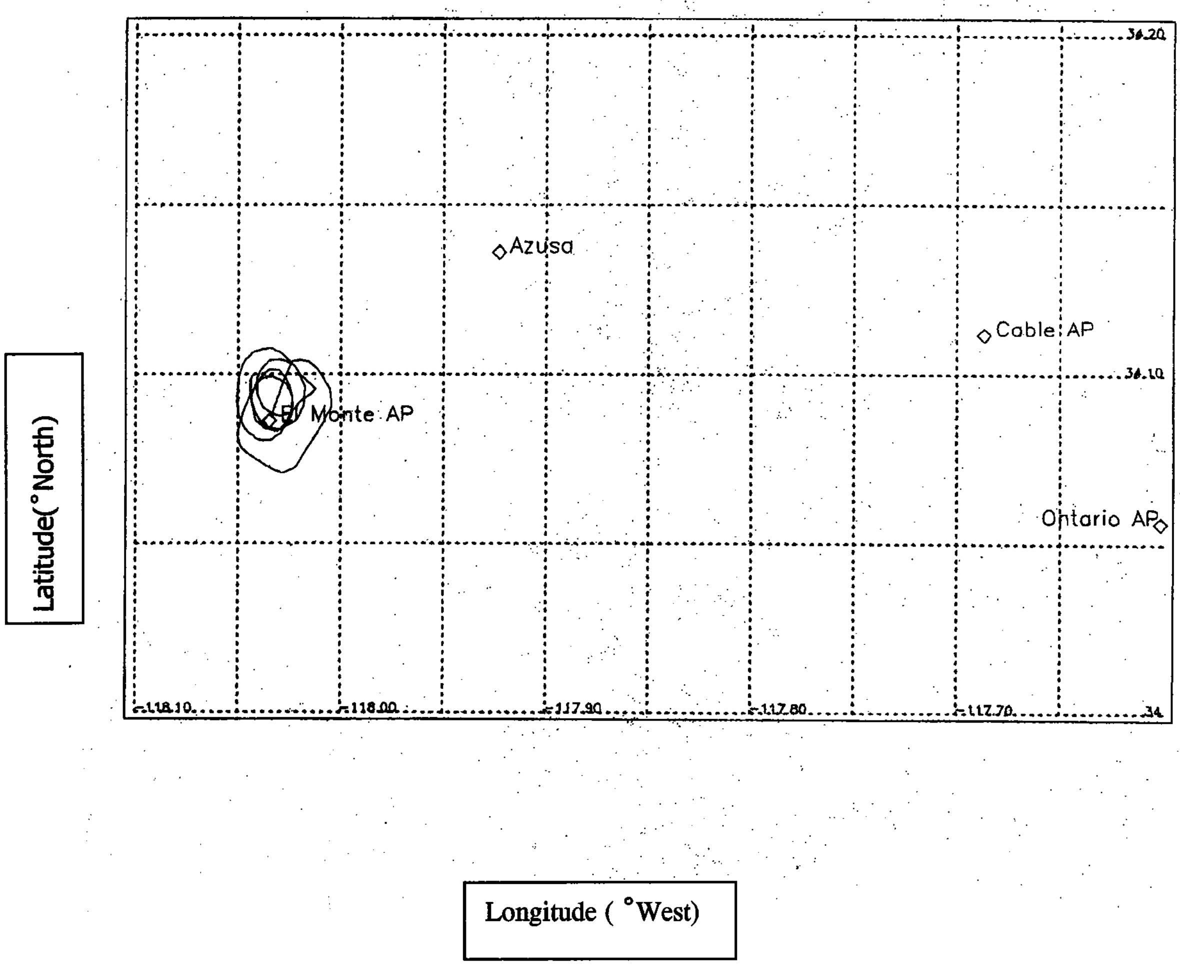
UCD Flight Path Transect 5: Traverse from Cable to El Monte at □ 2000 m msl

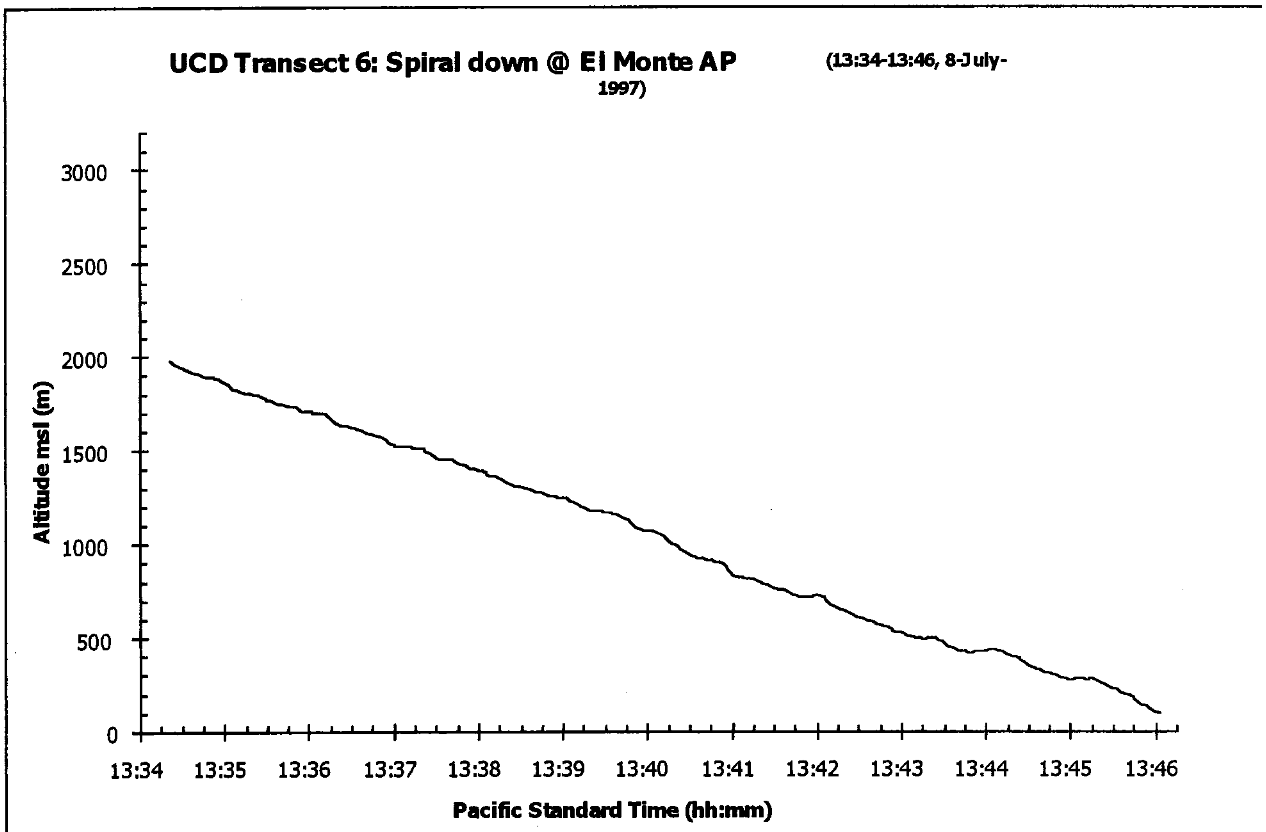


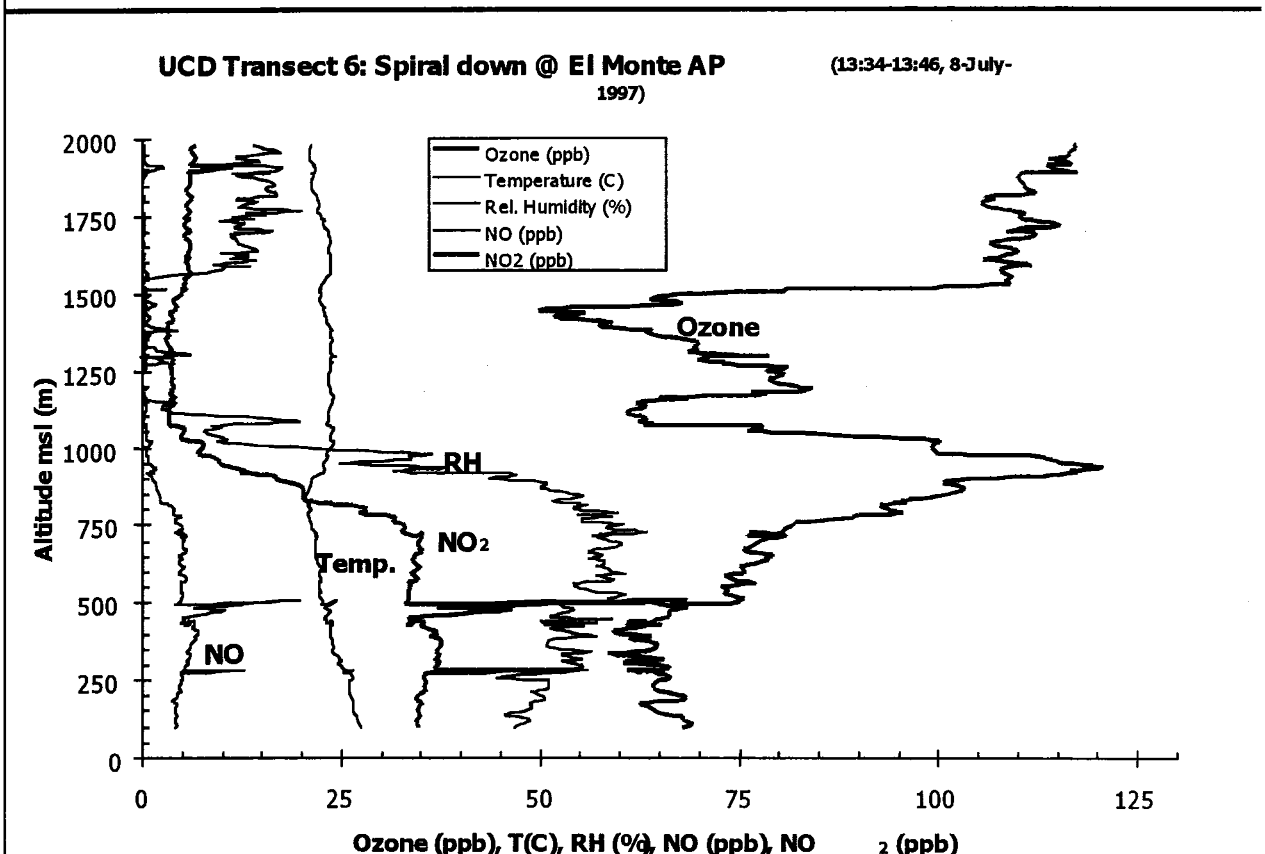

UCD Transect 5: Cable AP to El Monte AP
(13:25-13:34, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
13:24
13:25
13:26
13:27
13:28
13:29
13:30
13:31
13:32
13:33
13:34
13:35
Pacific Standard Time (hh:mm)


UCD Transect 5: Cable AP to El Monte AP
(13:25-13:34, 8-July-1997)
Ozone (ppb), T(C), RH (%), NO (ppb), NO2 (ppb)
125
100
75
50
25
0
Ozone
Ozone (ppb)
Temperature (C)
Rel. Humidity (%)
NO (ppb)
NO2 (ppb)
Temp.
RH
NO2
NO
13:24
13:25
13:26
13:27
13:28
13:29
13:30
13:31
13:32
13:33
13:34
13:35
Pacific Standard Time (hh:mm)

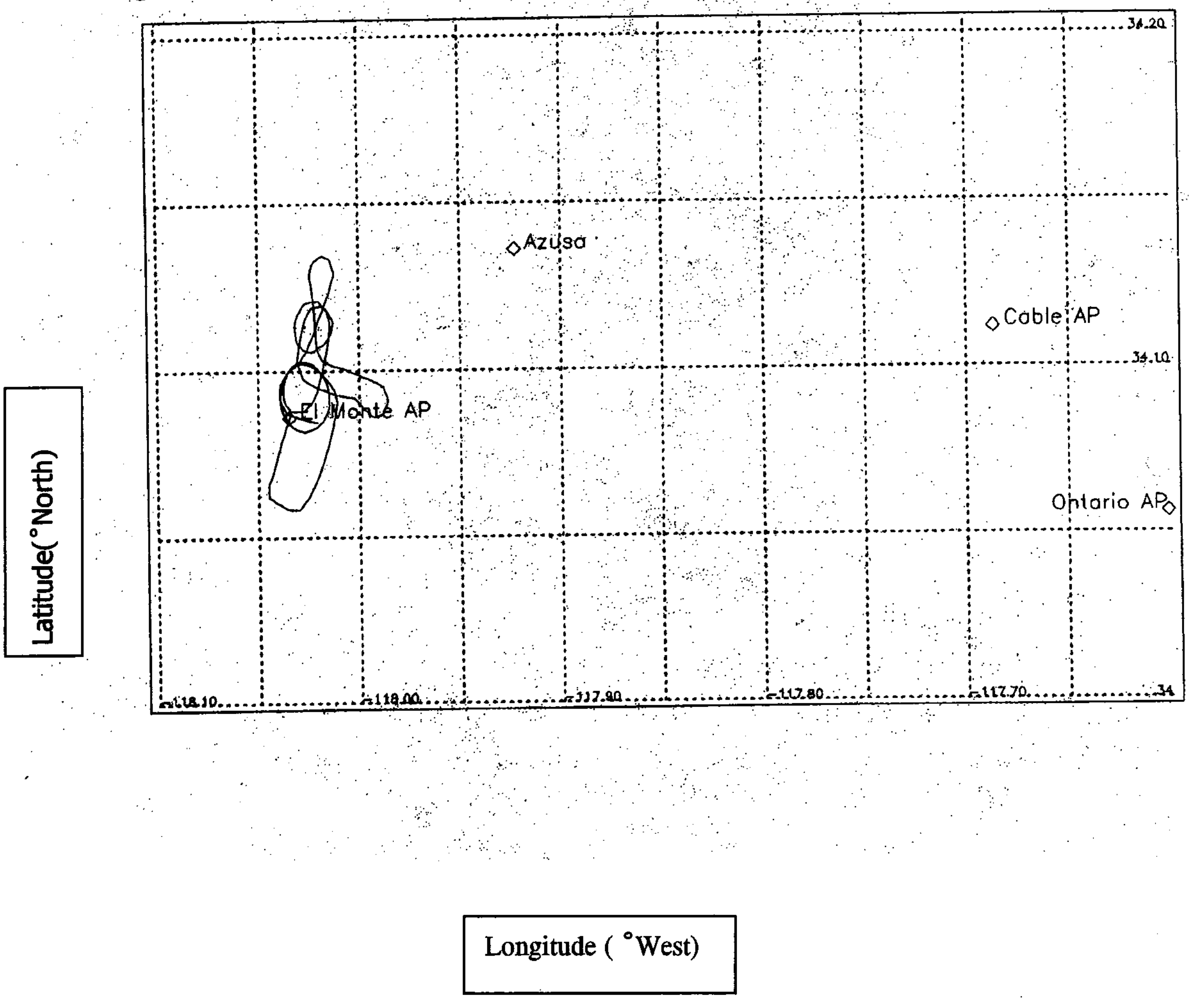
UCD Flight Path Transect 6: Down spiral to (near) ground level at El Monte AP

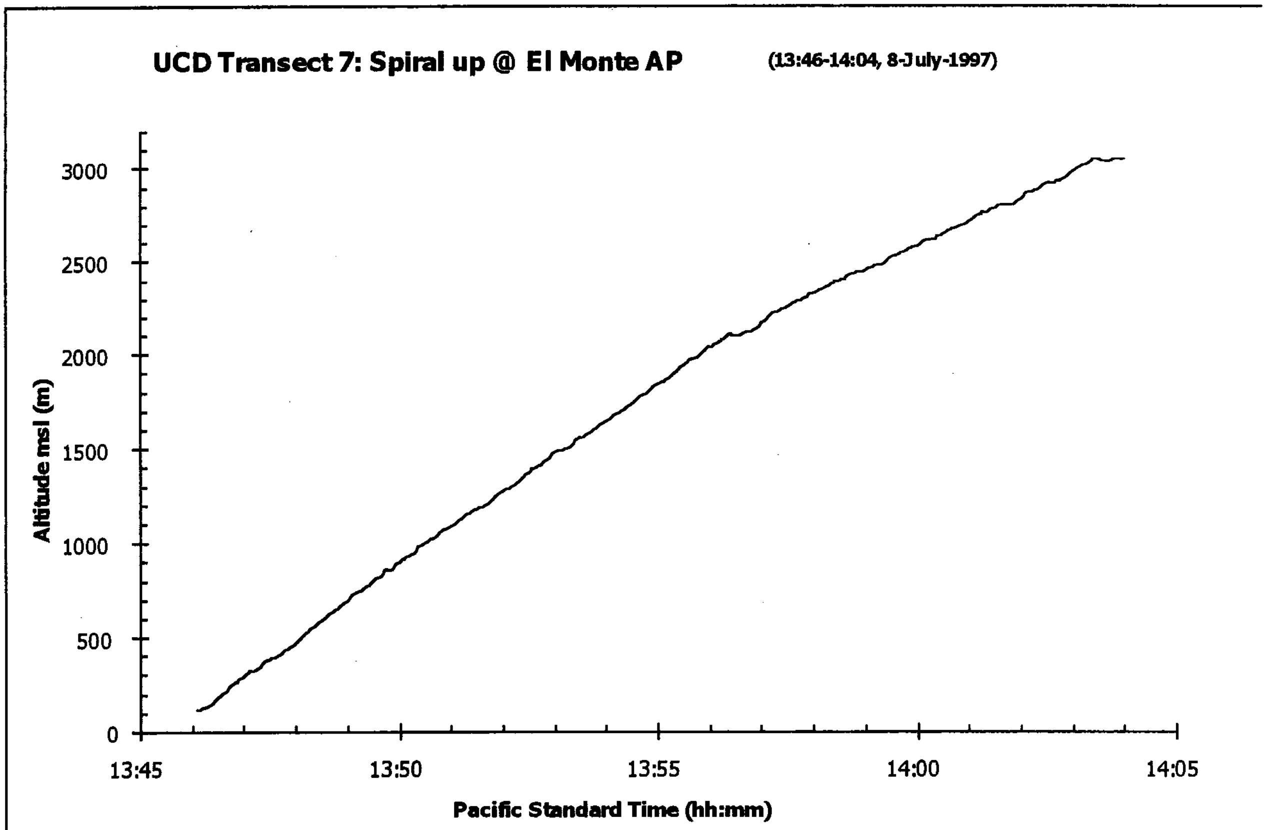



UCD Transect 6: Spiral down @ El Monte AP (13:34-13:46, 8-July-1997)
Altitude msl (m)
0
500
1000
1500
2000
2500
3000
13:34
13:35
13:36
13:37
13:38
13:39
13:40
13:41
13:42
13:43
13:44
13:45
13:46
Pacific Standard Time (hh:mm)

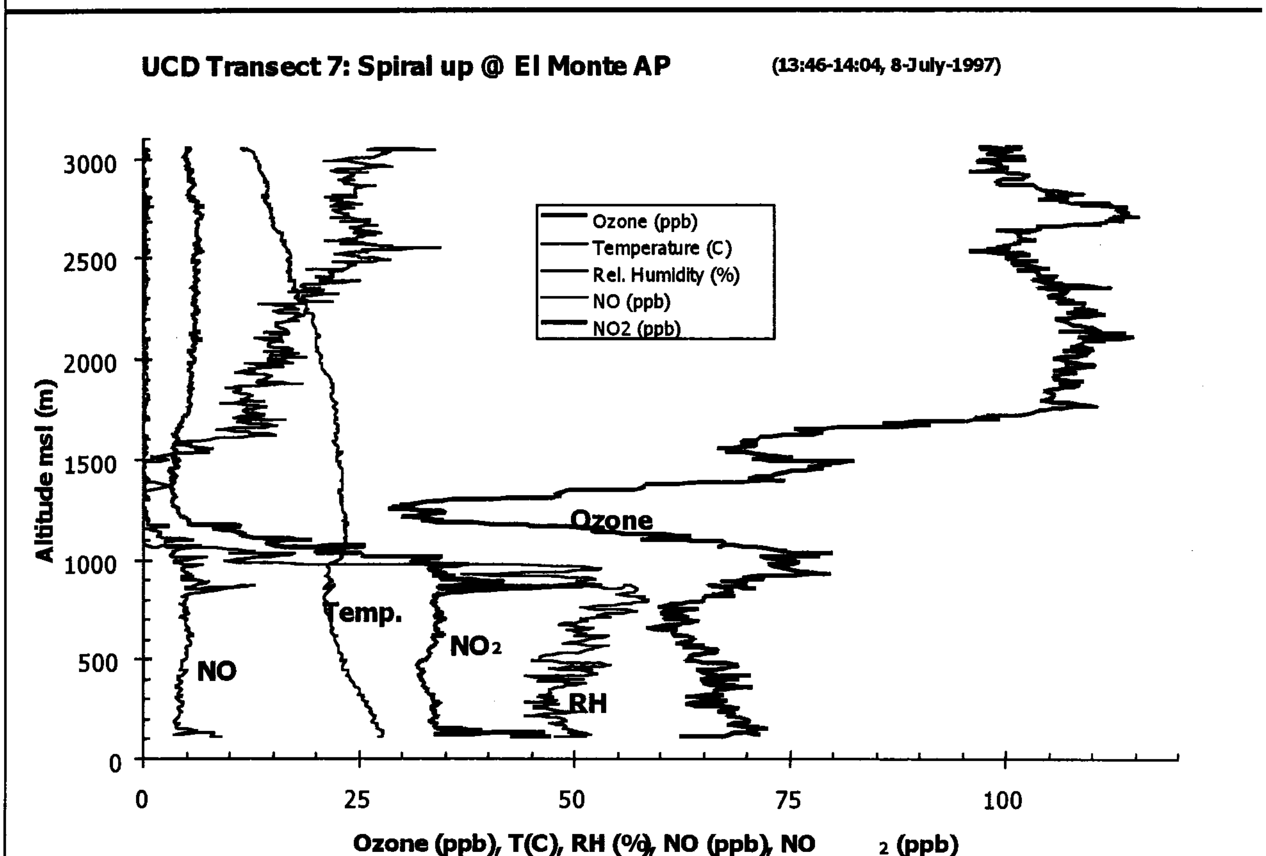

UCD Transect 6: Spiral down @ El Monte AP (13:34-13:46, 8-July-1997)
Ozone (ppb)
Temperature (C)
Rel. Humidity (%)
NO (ppb)
NO2 (ppb)
Ozone
RH
NO2
Temp.
NO
Altitude msl (m)
0
250
500
750
1000
1250
1500
1750
2000
0
25
50
75
100
125
Ozone (ppb), T(C), RH (%), NO (ppb), NO2 (ppb)

UCD Flight Path Transect 7: Up spiral to 3000 m msl above El Monte AP



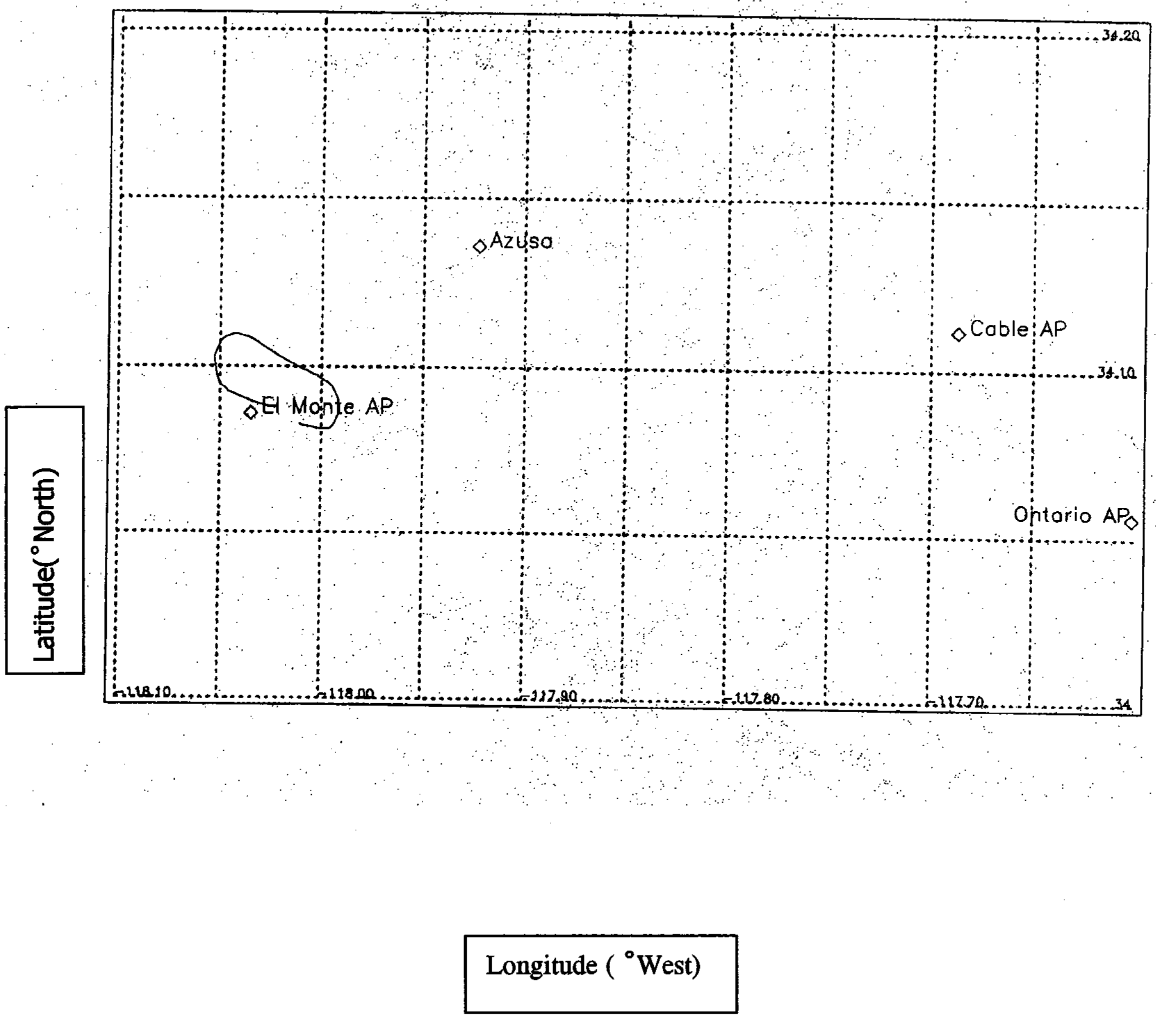


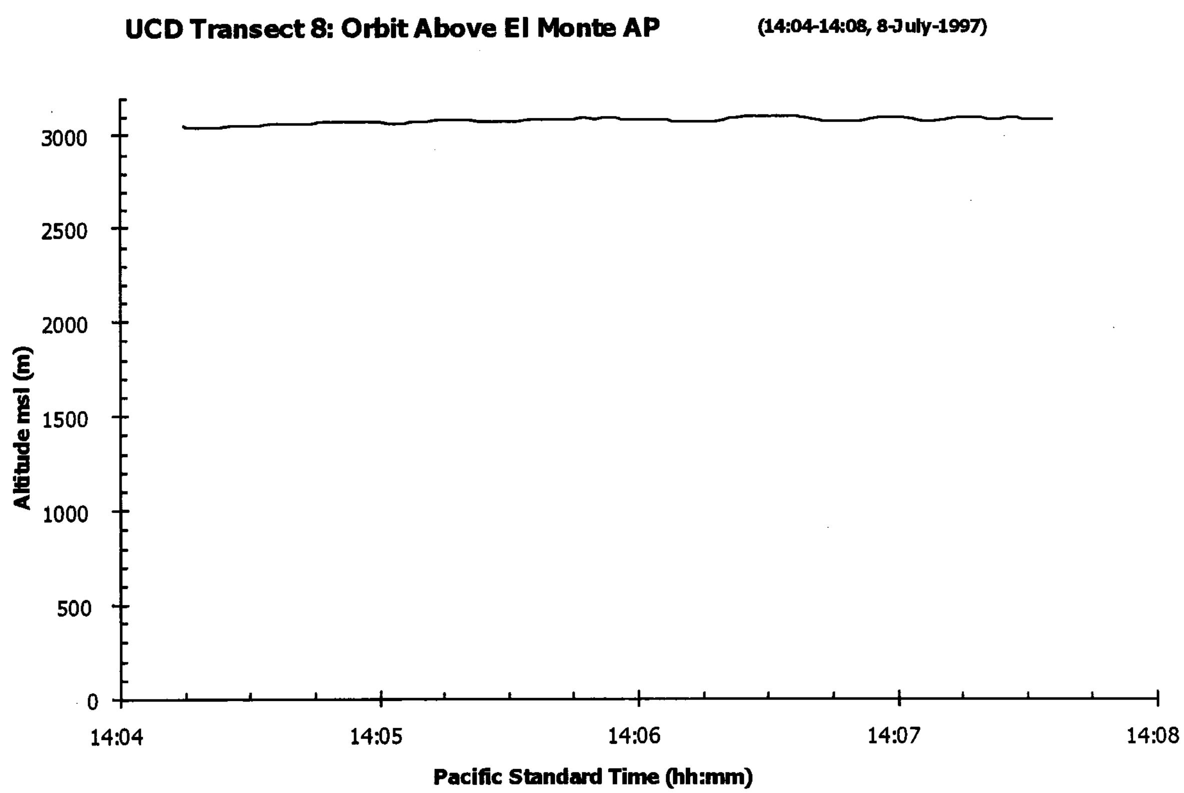
UCD Transect 7: Spiral up @ El Monte AP
(13:46-14:04, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
13:45
13:50
13:55
14:00
14:05
Pacific Standard Time (hh:mm)



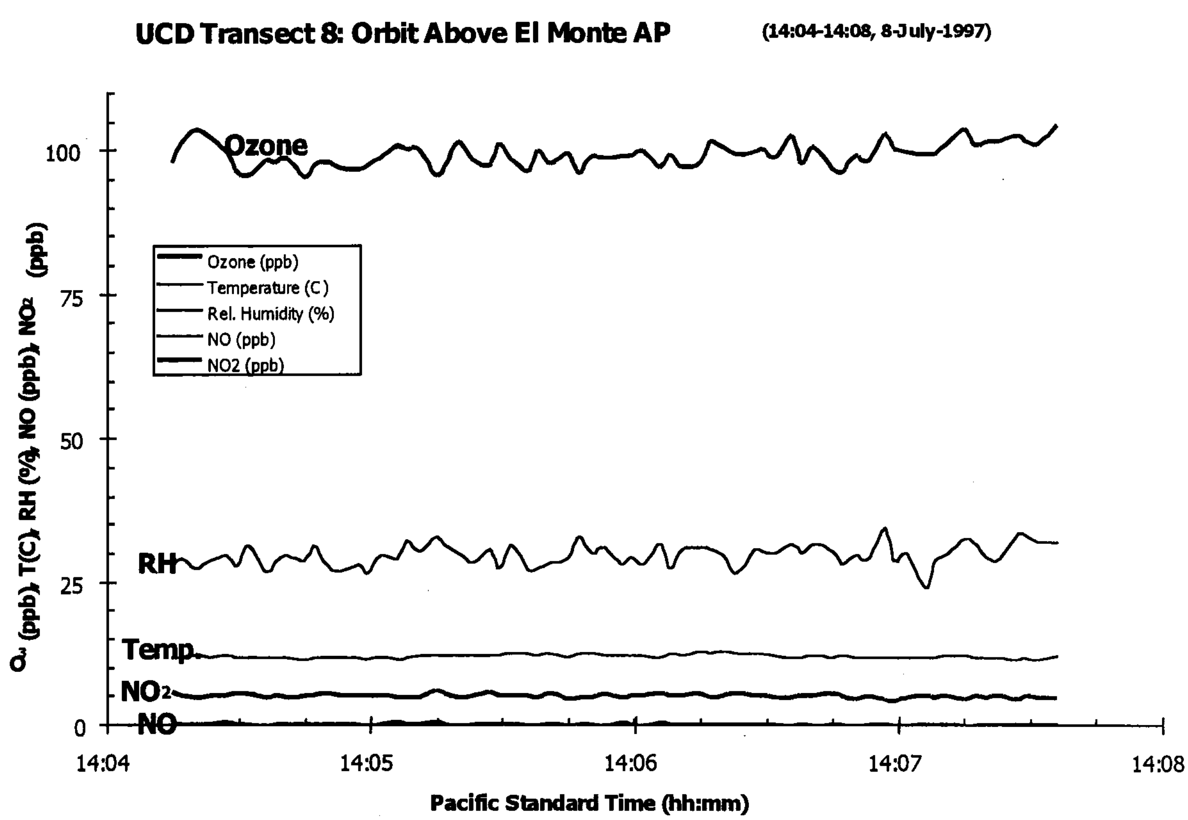
UCD Transect 7: Spiral up @ El Monte AP
(13:46-14:04, 8-July-1997)
Ozone (ppb)
Temperature (C)
Rel. Humidity (%)
NO (ppb)
NO2 (ppb)
Ozone
Temp.
NO2
NO
RH
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
0
25
50
75
100
Ozone (ppb), T(C), RH (%), NO (ppb), NO 2 (ppb)

UCD Flight Path Transect 8: Orbit at □ 3000 m msl above El Monte AP



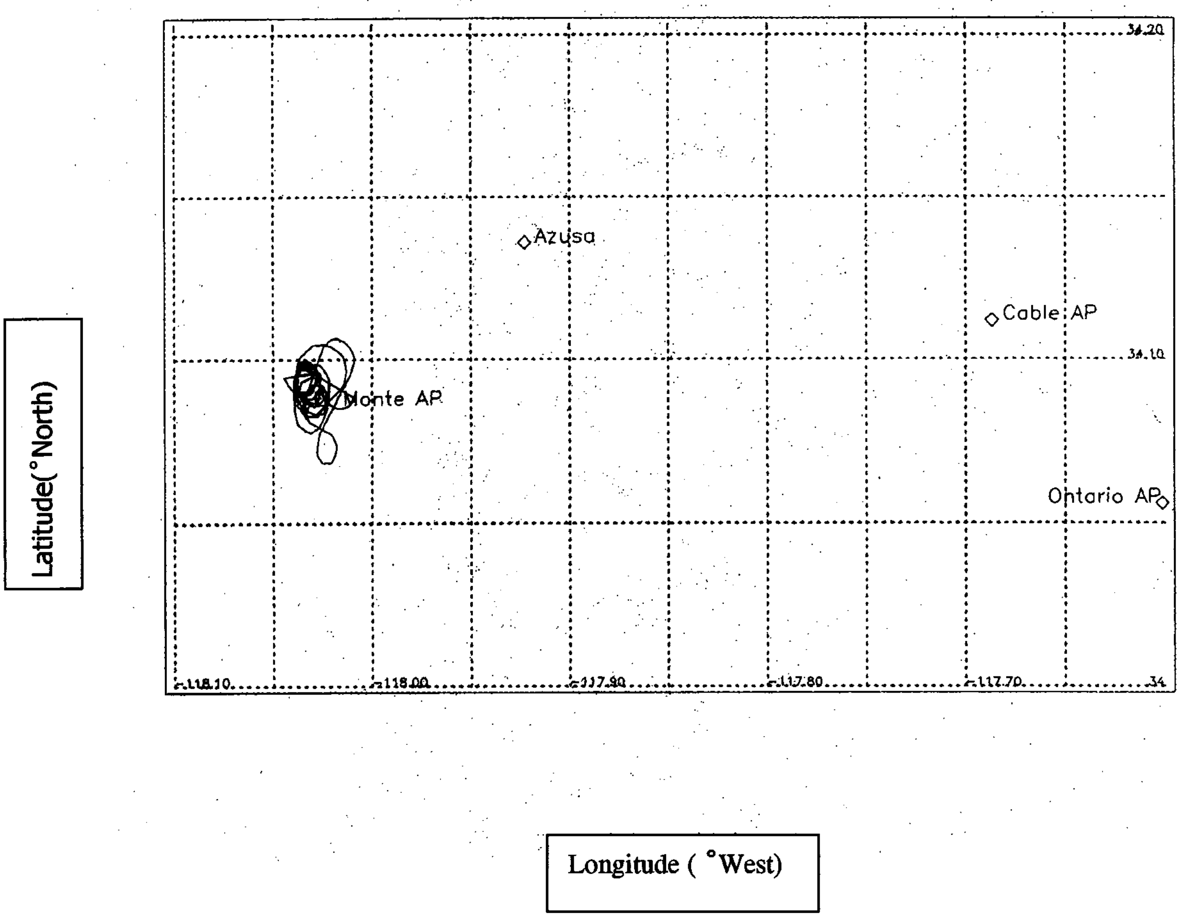


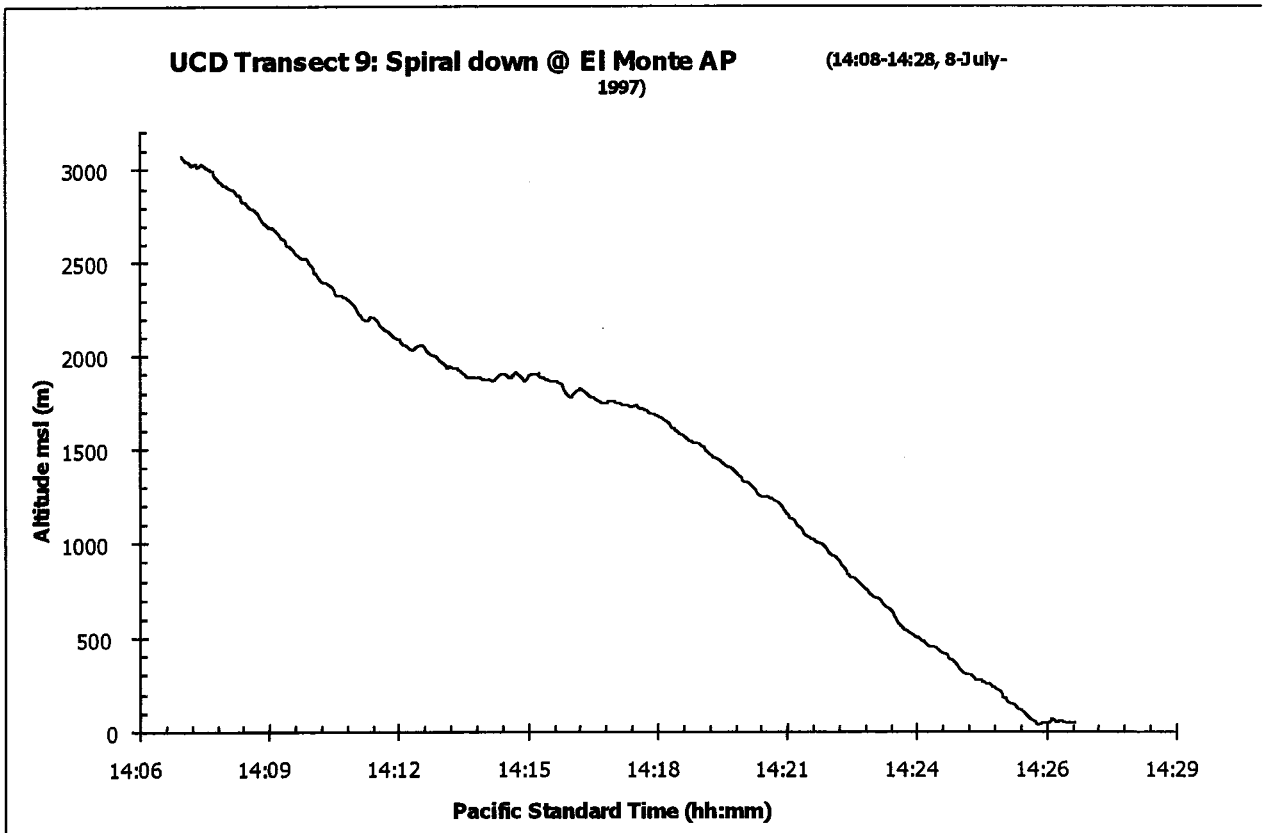
UCD Transect 8: Orbit Above El Monte AP
(14:04-14:08, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
14:04
14:05
14:06
14:07
14:08
Pacific Standard Time (hh:mm)

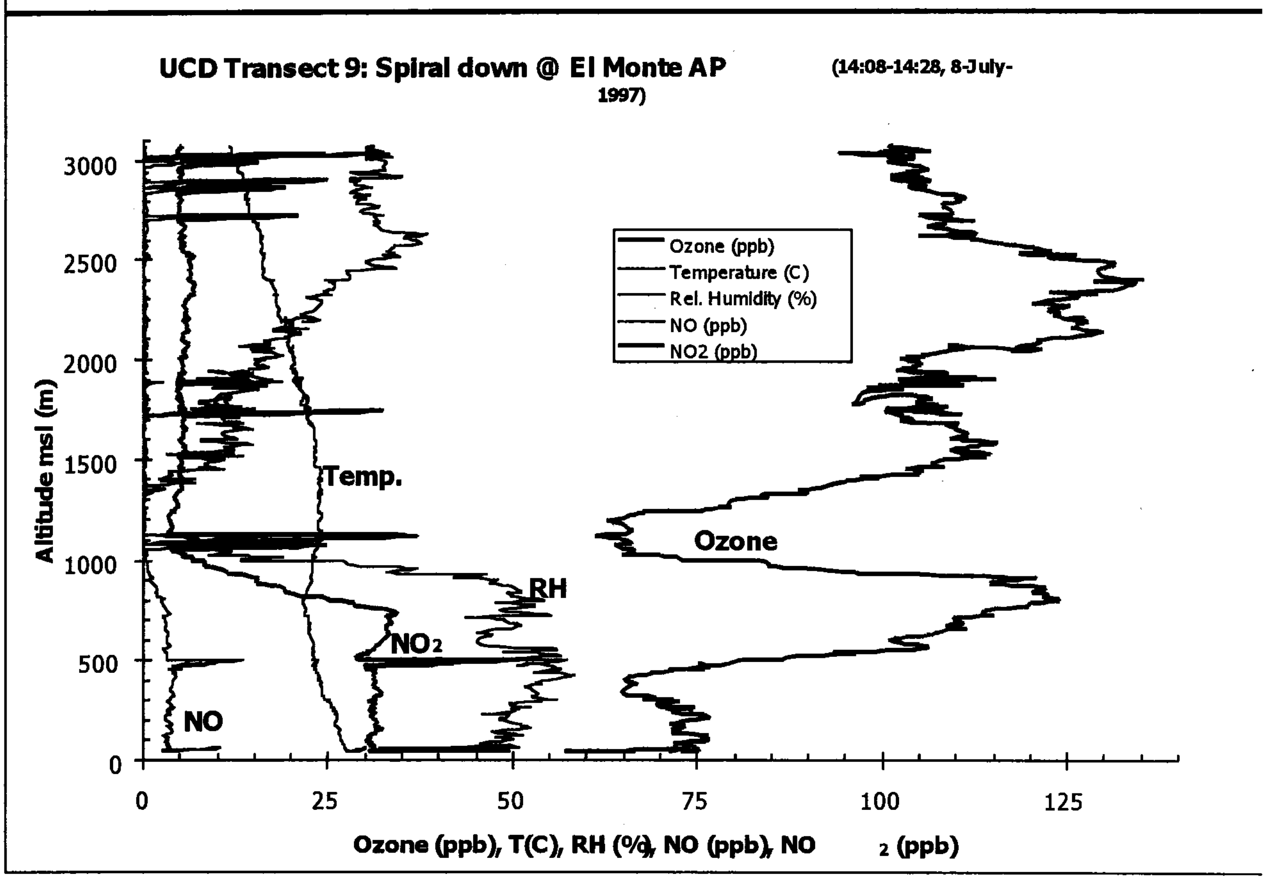


UCD Transect 8: Orbit Above El Monte AP
(14:04-14:08, 8-July-1997)
O3 (ppb), T(C), RH (%), NO (ppb), NO2 (ppb)
100
75
50
25
0
Ozone
RH
Temp.
NO2
NO
Ozone (ppb)
Temperature (C)
Rel. Humidity (%)
NO (ppb)
NO2 (ppb)
14:04
14:05
14:06
14:07
14:08
Pacific Standard Time (hh:mm)

UCD Flight Path Transect 9: Down spiral to ground level at El Monte AP



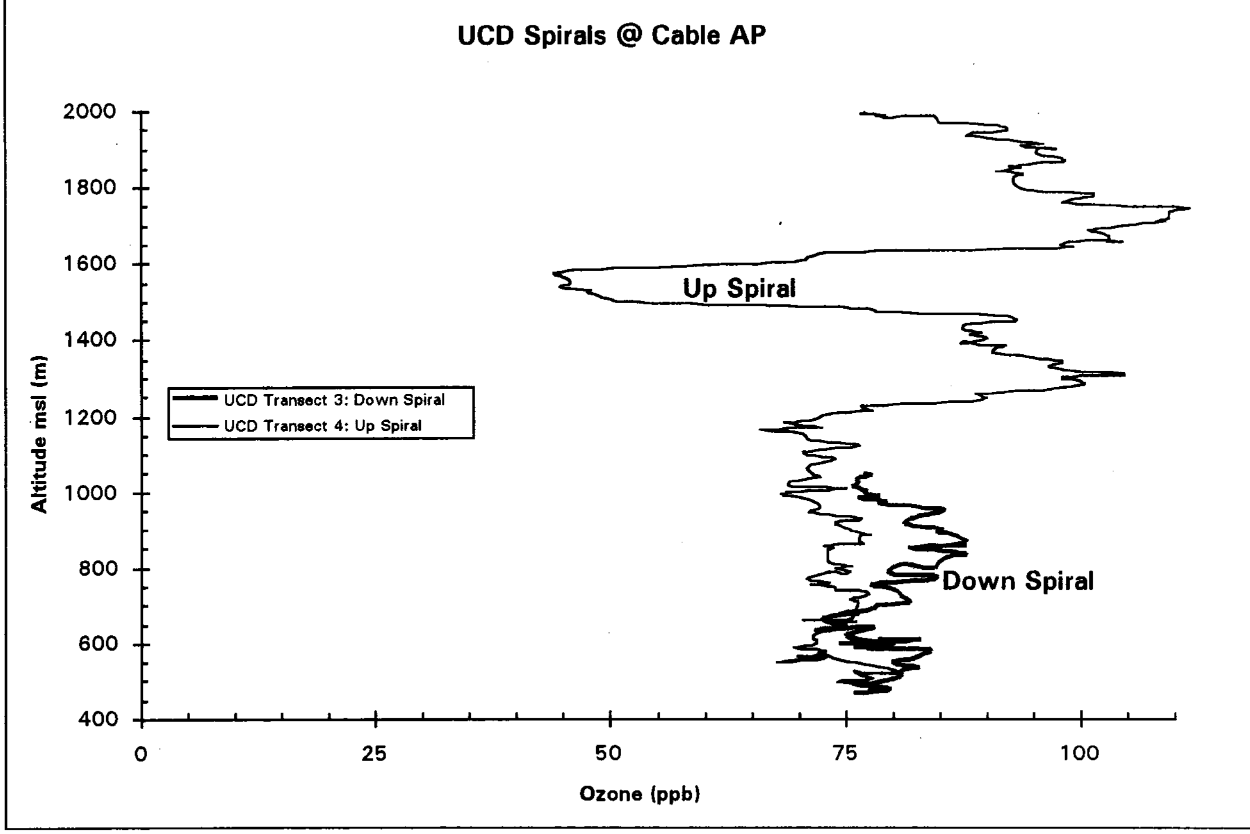

UCD Transect 9: Spiral down @ El Monte AP
(14:08-14:28, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
14:06
14:09
14:12
14:15
14:18
14:21
14:24
14:26
14:29
Pacific Standard Time (hh:mm)


UCD Transect 9: Spiral down @ El Monte AP
(14:08-14:28, 8-July-1997)
Ozone (ppb)
Temperature (C)
Rel. Humidity (%)
NO (ppb)
NO2 (ppb)
Temp.
Ozone
RH
NO2
NO
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
0
25
50
75
100
125
Ozone (ppb), T(C), RH (%), NO (ppb), NO 2 (ppb)

UCD Spiral Down - Spiral Up Comparisons

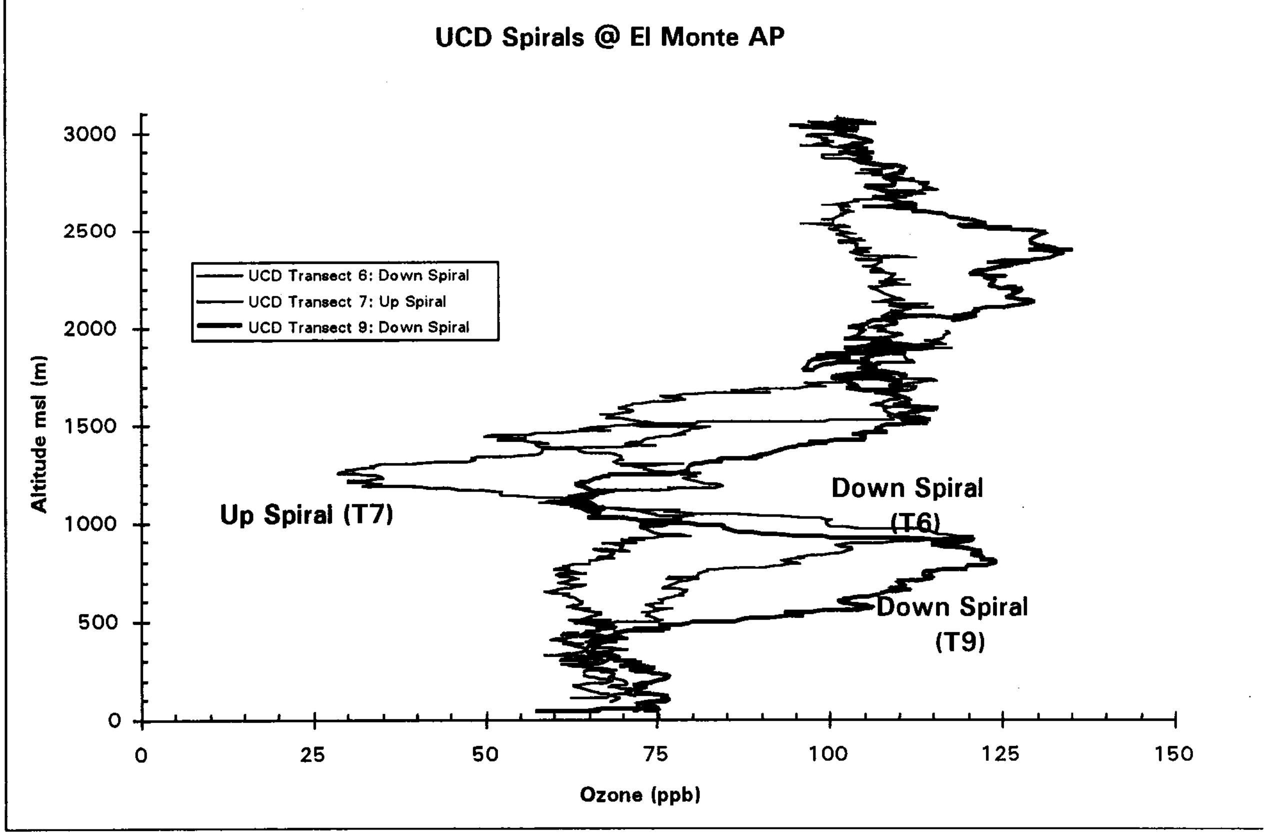
Comparisons between data acquired during successive ascending and descending spirals can be useful as internal check on measurement accuracy and/or atmospheric homogeneity in time and horizontal space. Unfortunately it is generally not trivial to distinguish between the two.

Spiral Up - Spiral Down Comparison at Cable AP

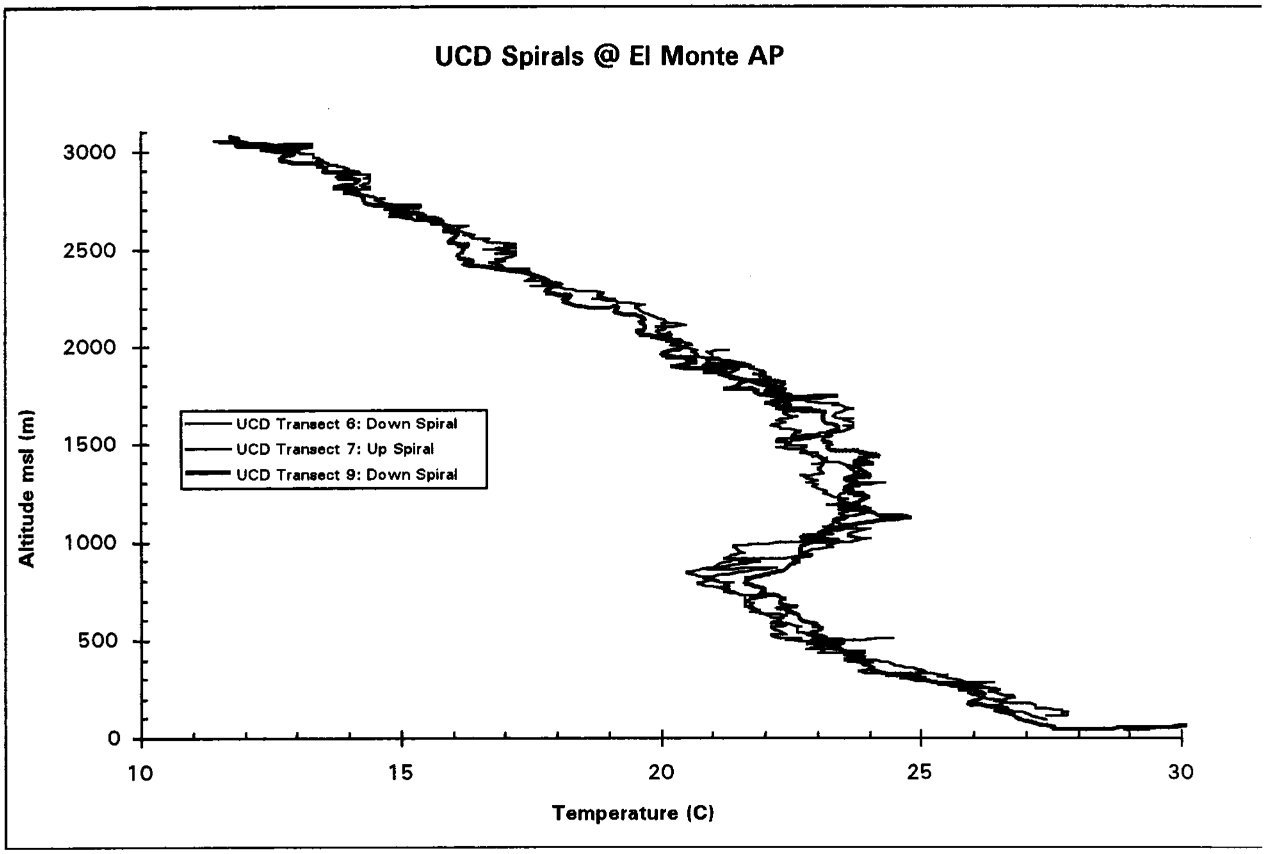


There is not much structure in the region covered by both spirals and the agreement between ascending and descending ozone measurements is reasonable (i.e. within 15 ppb) with the ascending spiral showing lower ozone concentrations. Lower ozone concentrations during the ascending spiral at Cable AP were also measured during the near simultaneous STI spirals.

Spiral Up - Spiral Down Comparison at El Monte AP



These consecutive spirals show strong vertical structure and large differences (up to 60 ppb) between the individual measurements. Generally the two sets of descending spiral ozone data seem to agree closer with each other than with the ascending spiral ozone data. In addition, features in the ascending spiral data seem to be elevated relative to the descending spiral data. This might hint towards a delay (hysteresis) in the ozone measurement process. However, the generally different structure of the individual profiles, if not caused by systematic instrument errors might indicate horizontal inhomogeneities such as changes in the height of atmospheric layers. To further investigate this possibility with UCD data, temperature data for these three consecutive spirals are shown in the following figure. The temperature sensor is much faster than the ozone instrument, therefore hysteresis is not a concern for the temperature profiles.



The temperature profiles show sizable differences (1□C) in particular near the lower and upper boundary of the inversion layer around 1000 m msl where the ascending spiral indicates a thinner inversion layer. Additional strong differences can be found near the weak inversion layer at about 2400 m msl, which is visible in the ascending spiral data but not in the descending spiral data. Generally, the differences in measured ozone concentrations seem to be correlated with the differences in temperature profiles which indicates that differences in the height and structure of atmospheric layers contributed to the differences in ozone profiles.

STI Aztec

The STI Aztec conducted one early afternoon flight consisting of spirals and traverses between 12:53 and 14:15 PST. The flight included the following transects:

1. Take off from El Monte AP and ascent to □ 1000 m msl
2. Traverse from El Monte AP to Cable AP at □ 1000 m msl
3. Down spiral to (near) ground level above Cable AP
4. Up spiral to □ 2000 m msl above Cable AP
5. Traverse from Cable AP to El Monte AP at □ 2000 m msl
6. Down spiral to (near) ground level above El Monte AP
7. Up spiral to □ 1500 m msl above El Monte AP
8. Traverse from El Monte AP to Camarillo AP at □ 1500 m msl
9. Land at Camarillo AP

Transects 8 and 9 are not of much interest for this intercomparison and will not be analyzed in the following.

STI humidity data are given as dew point temperature (T_{dew}) in contrast to UCD and CE-CERT, which report relative humidity (RH). For comparison purposes, DRI has converted the STI data to RH, with RH being defined as the ratio of ambient water vapor pressure (e_{amb}) to saturation pressure (e_s) at the ambient temperature T. Using the Magnus equation (Magnus, 1844), RH can be calculated as

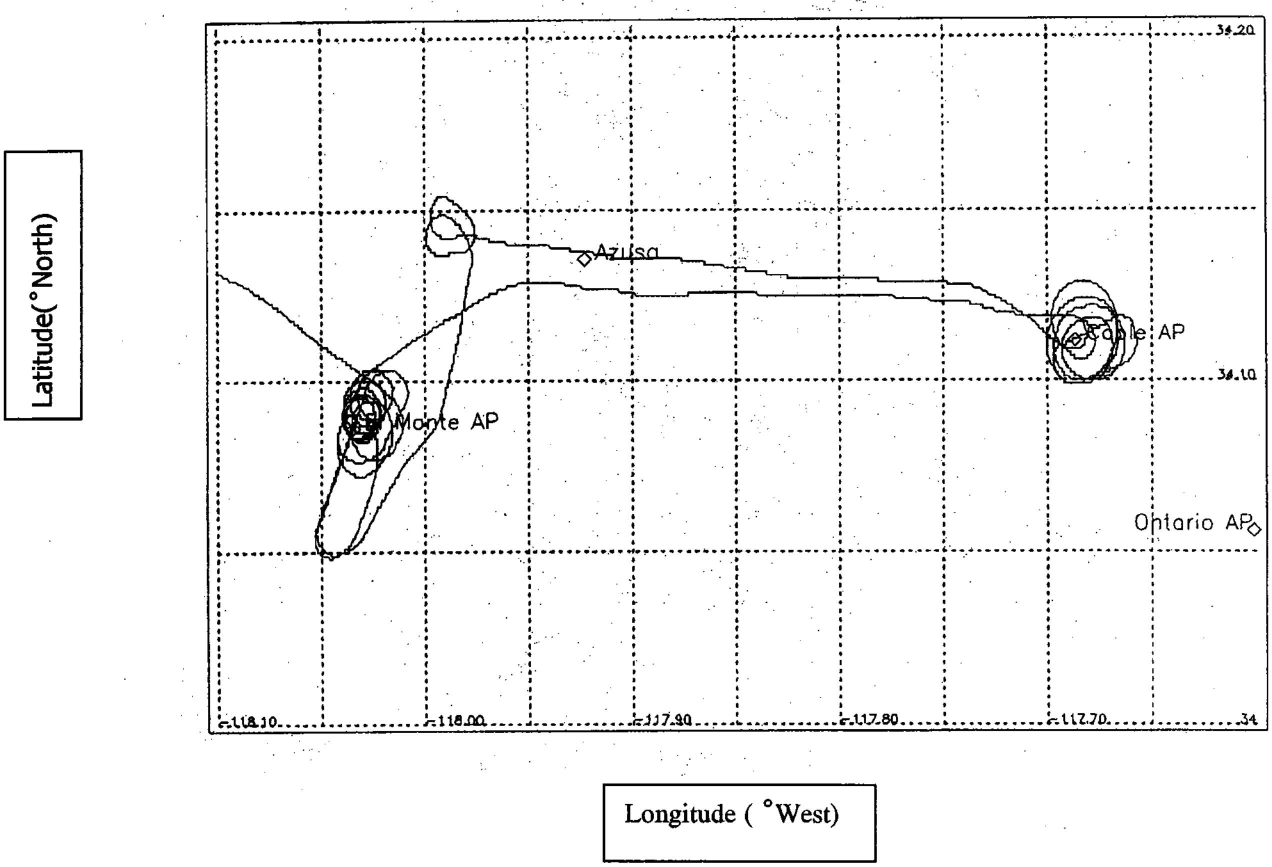
$$RH = \frac{e_{amb}}{e_s(T)} = \frac{e_s(T_{dew})}{e_s(T)} = \exp\left[b\left(\frac{T_{dew}}{T_{dew} + c} - \frac{T}{T + c} \right) \right],$$

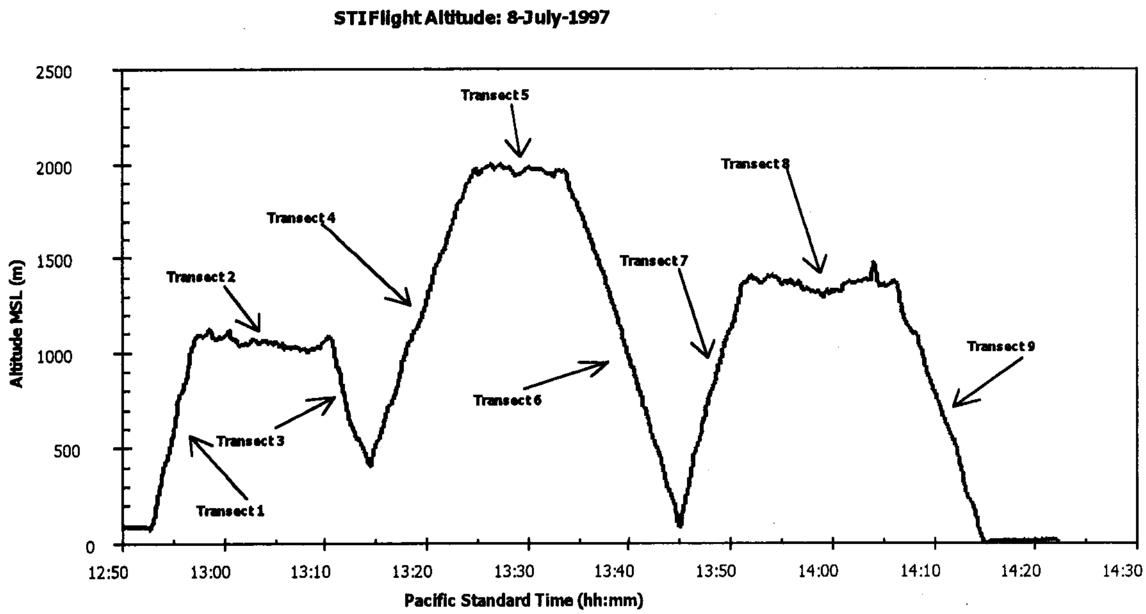
where b = 17.502 and c = 240.97 for vapor pressures in mB and temperatures in °C (Buck, 1981).

The following graph shows an overview of the STI flight path followed by graphs of the flight path and of some of the data for each transect.

STI Flight Path Overview

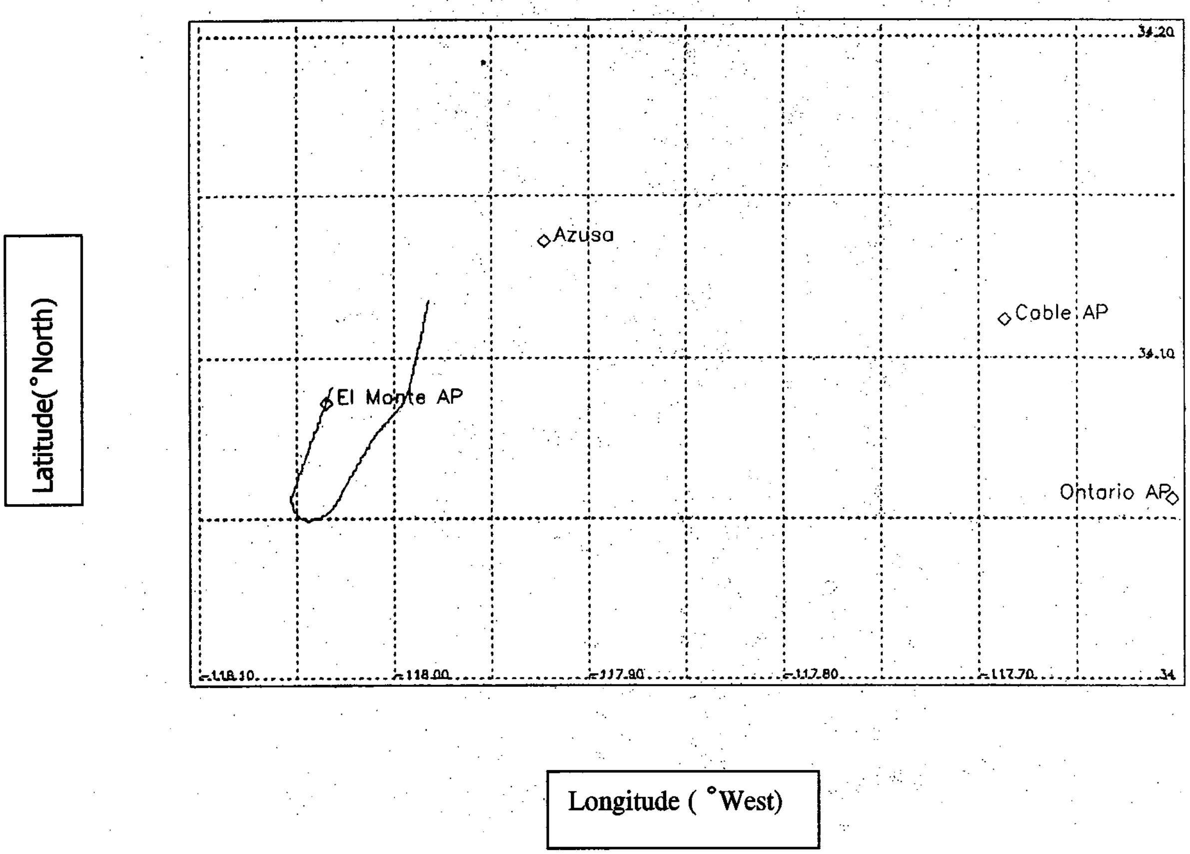
STI Flight Path 8-July-1997: All Transects

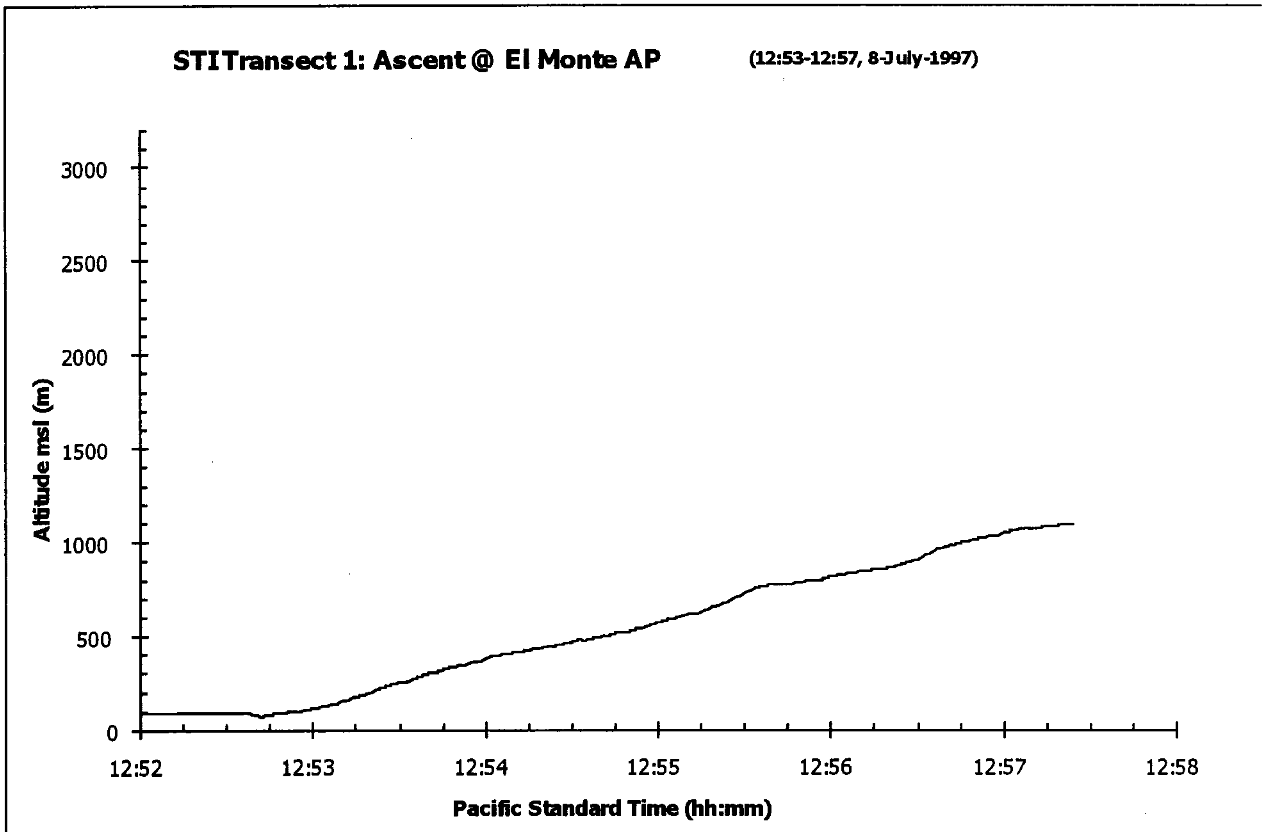


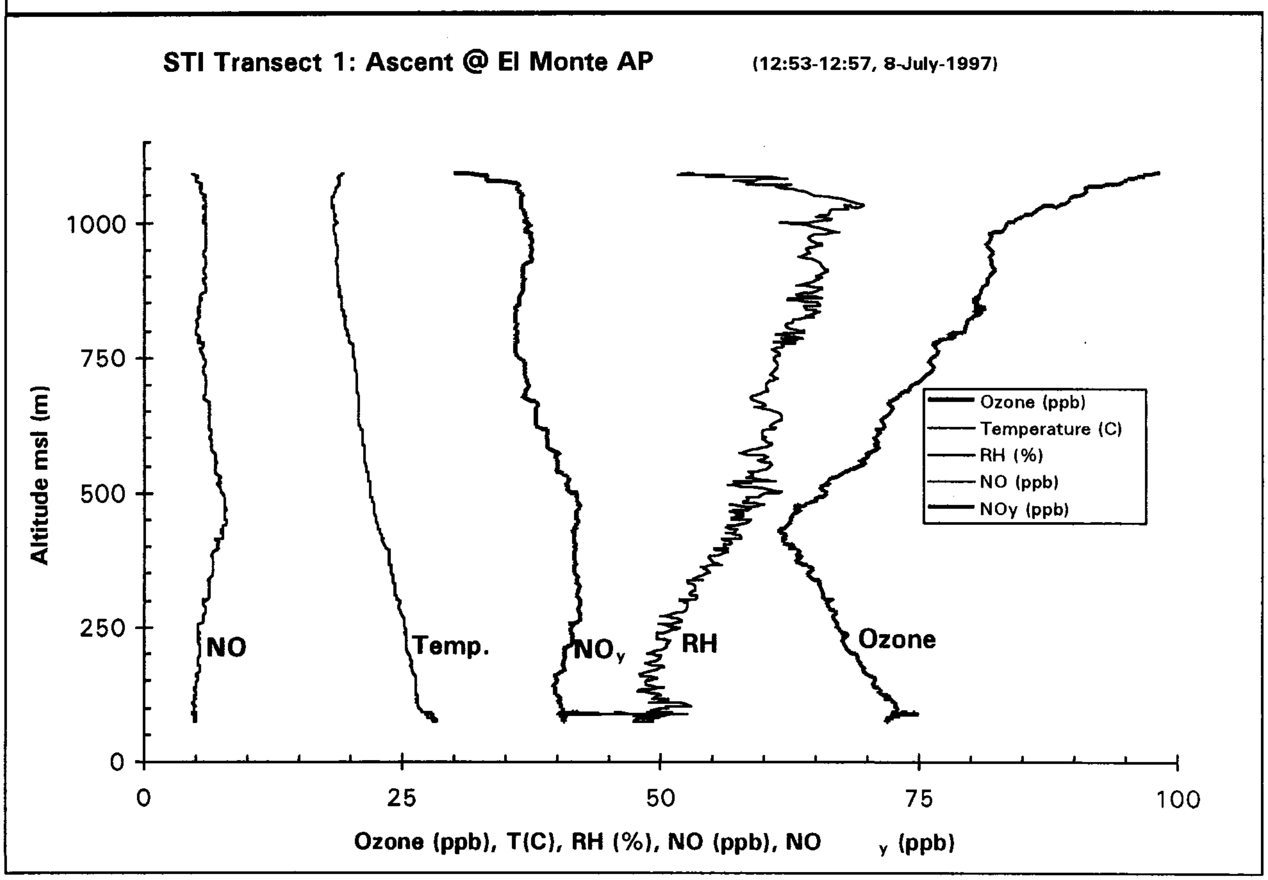

STI Flight Altitude: 8-July-1997
Altitude MSL (m)
2500
2000
1500
1000
500
0
Transect 1
Transect 2
Transect 3
Transect 4
Transect 5
Transect 6
Transect 7
Transect 8
Transect 9
12:50
13:00
13:10
13:20
13:30
13:40
13:50
14:00
14:10
14:20
14:30
Pacific Standard Time (hh:mm)

STI Flight Path and Data for Individual Transects

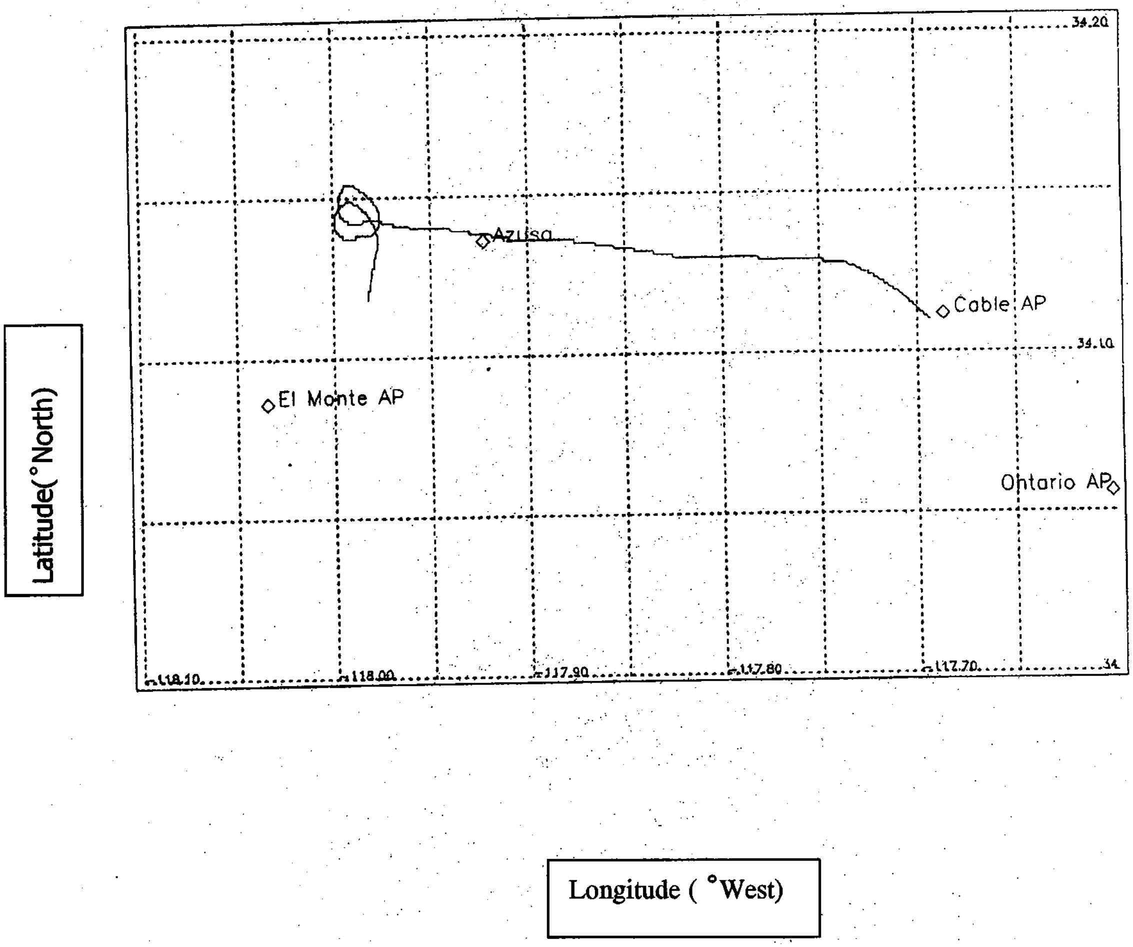
STI Flight Path Transect 1: Ascent to □ 1000 m msl from El Monte AP

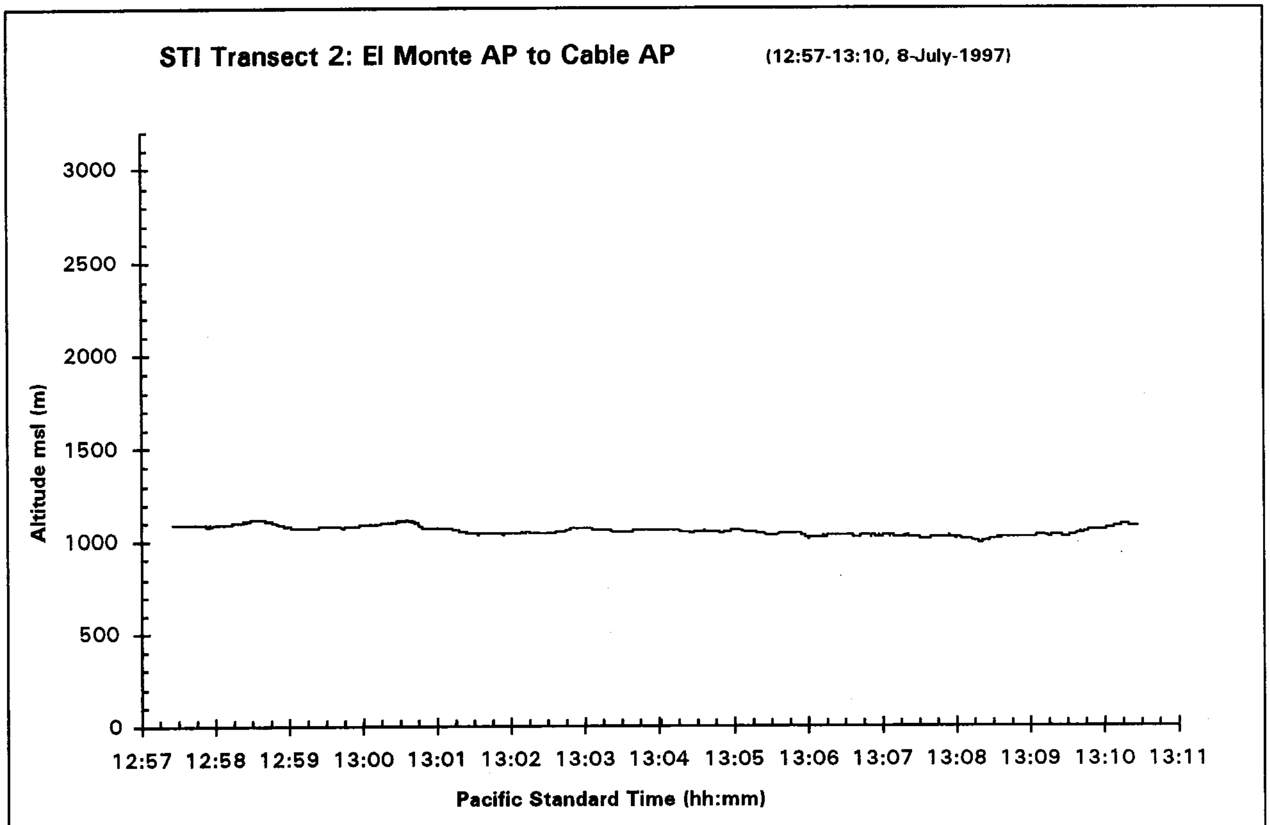


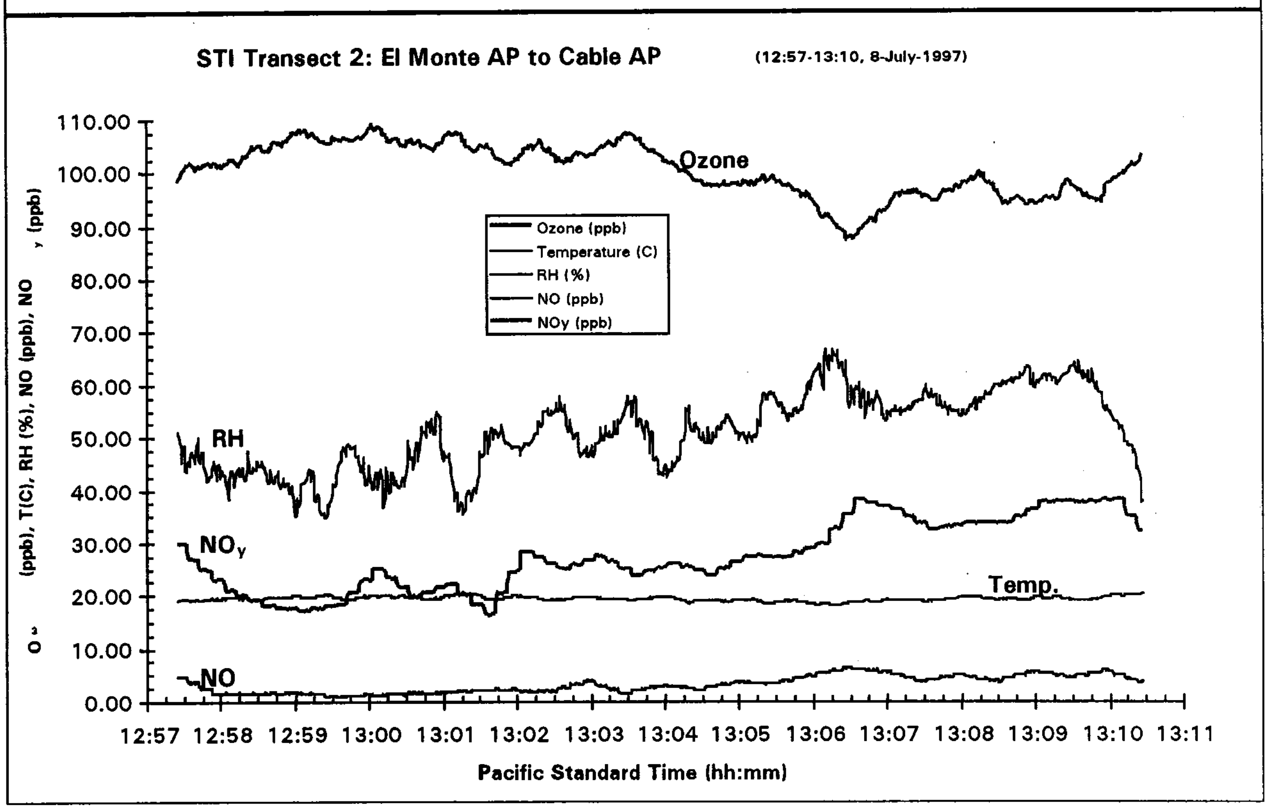

STITransect 1: Ascent @ El Monte AP
(12:53-12:57, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
12:52
12:53
12:54
12:55
12:56
12:57
12:58
Pacific Standard Time (hh:mm)


STI Transect 1: Ascent @ El Monte AP
(12:53-12:57, 8-July-1997)
Altitude msl (m)
1000
750
500
250
0
0
25
50
75
100
Ozone (ppb), T(C), RH (%), NO (ppb), NOy (ppb)
Ozone (ppb)
Temperature (C)
RH (%)
NO (ppb)
NOy (ppb)
NO
Temp.
NOy
RH
Ozone

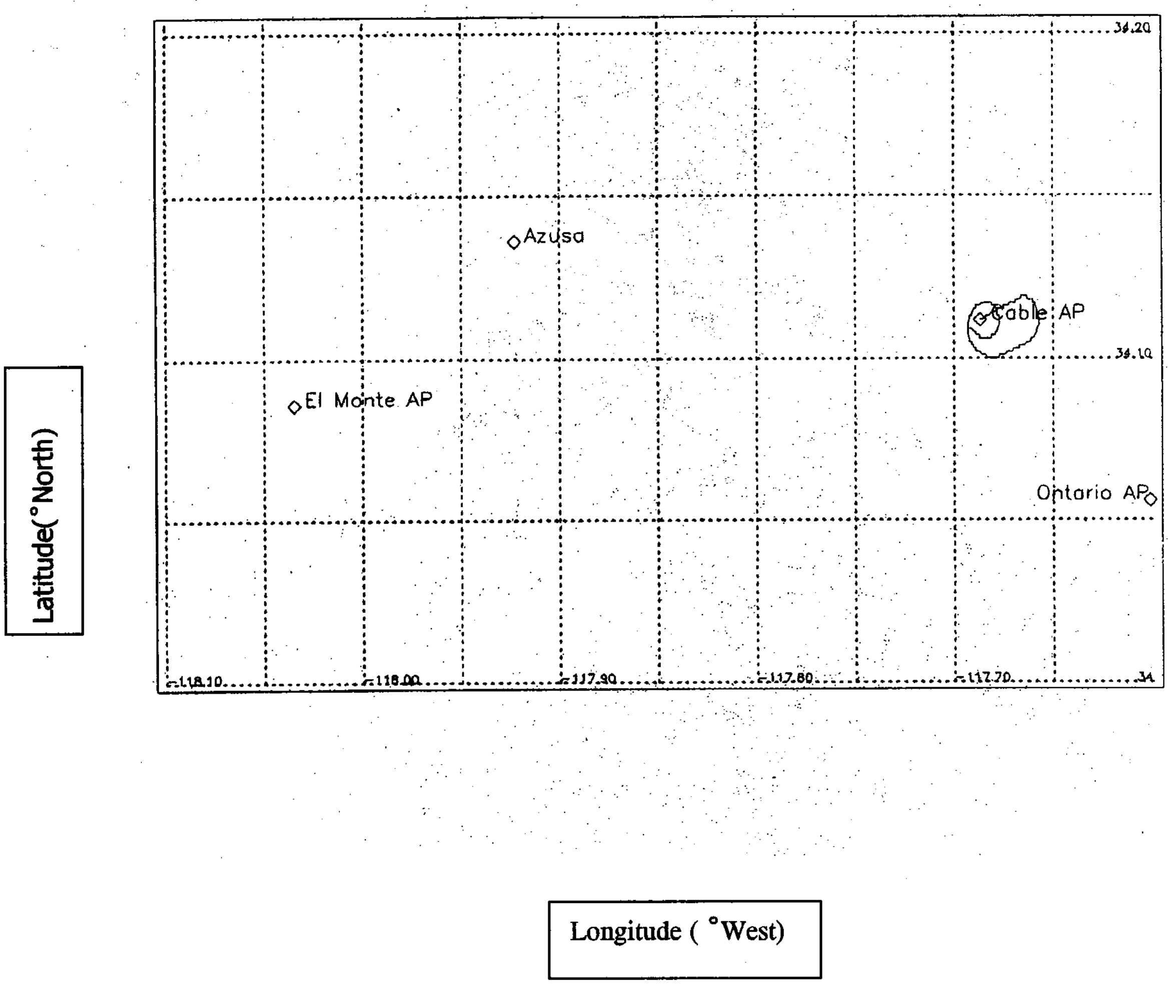
STI Flight Path Transect 2: Traverse from El Monte to Cable at ~~ 1000 m msl

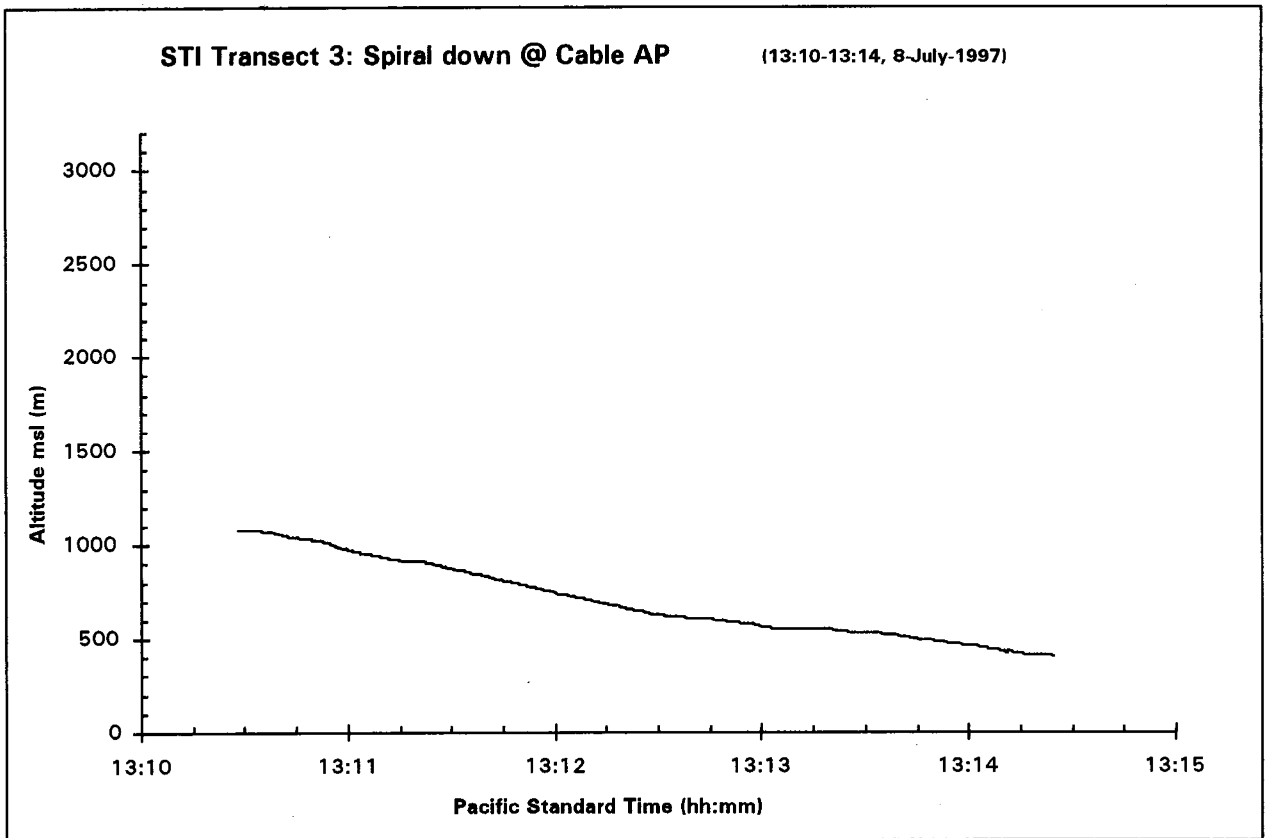


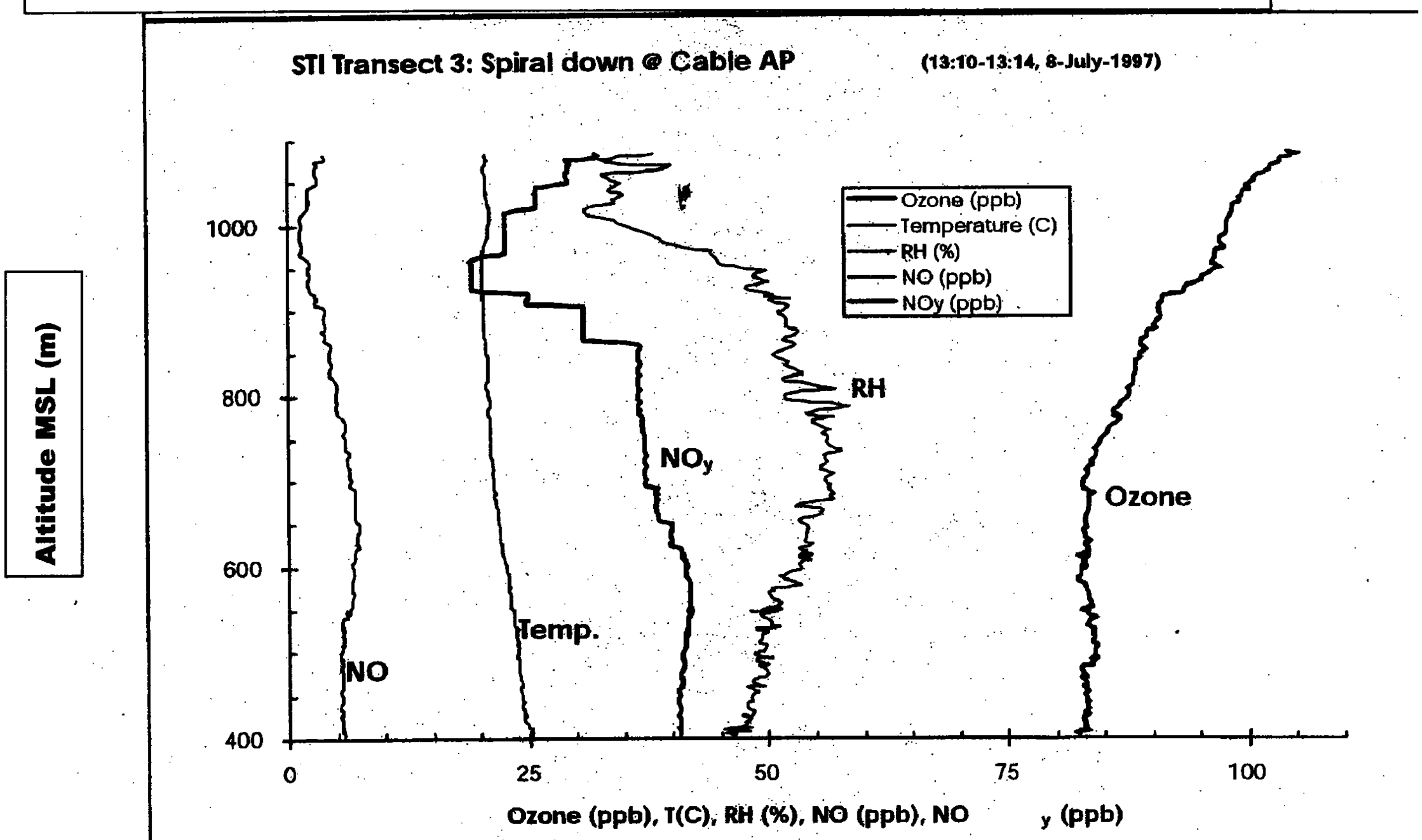

STI Transect 2: El Monte AP to Cable AP
(12:57-13:10, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
12:57 12:58 12:59 13:00 13:01 13:02 13:03 13:04 13:05 13:06 13:07 13:08 13:09 13:10 13:11
Pacific Standard Time (hh:mm)


STI Transect 2: El Monte AP to Cable AP
(12:57-13:10, 8-July-1997)
O3 (ppb), T(C), RH (%), NO (ppb), NOy (ppb)
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Ozone
Ozone (ppb)
Temperature (C)
RH (%)
NO (ppb)
NOy (ppb)
RH
NOy
Temp.
NO
12:57 12:58 12:59 13:00 13:01 13:02 13:03 13:04 13:05 13:06 13:07 13:08 13:09 13:10 13:11
Pacific Standard Time (hh:mm)

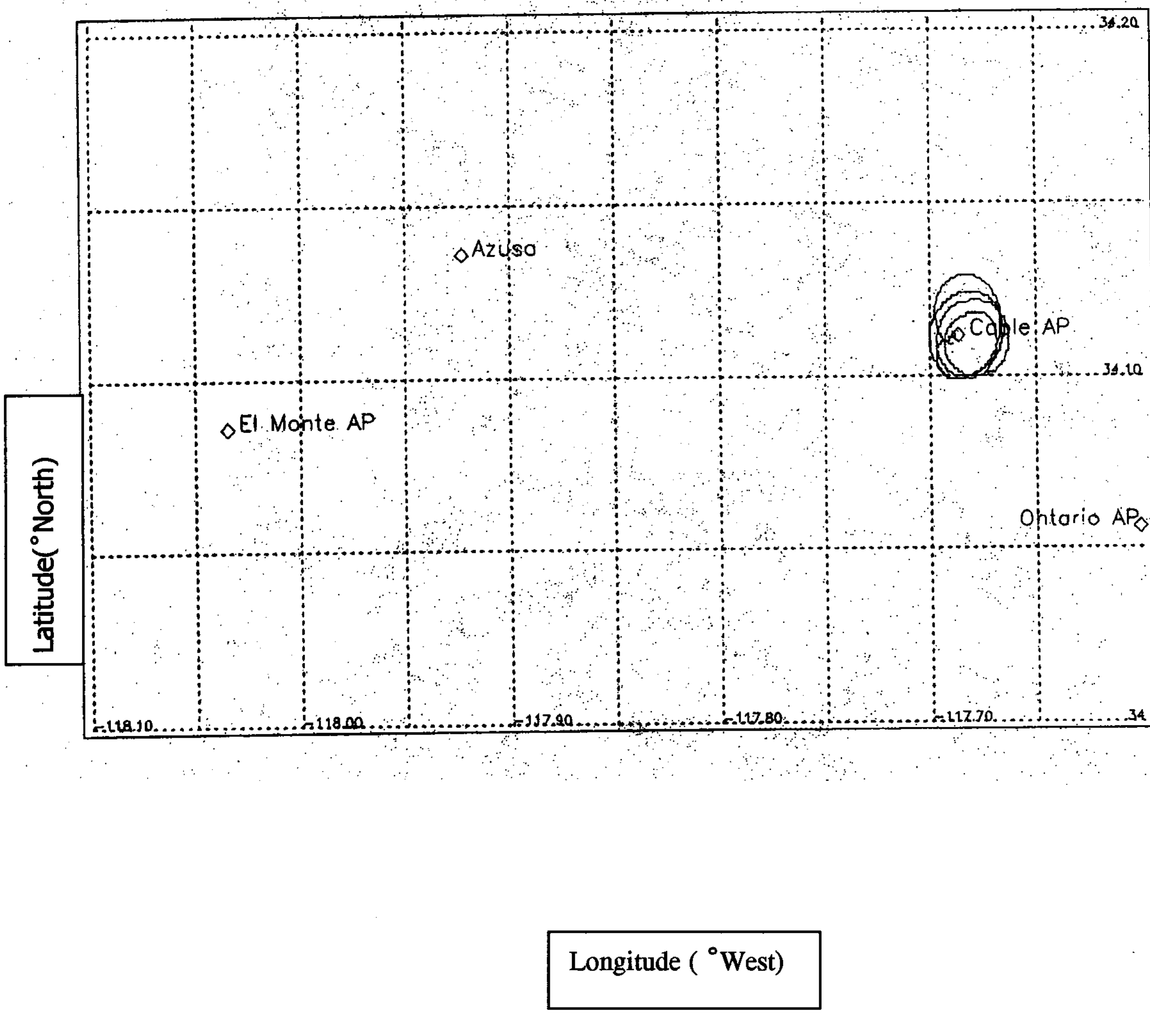
STI Flight Path Transect 3: Down spiral to (near) ground level above Cable AP

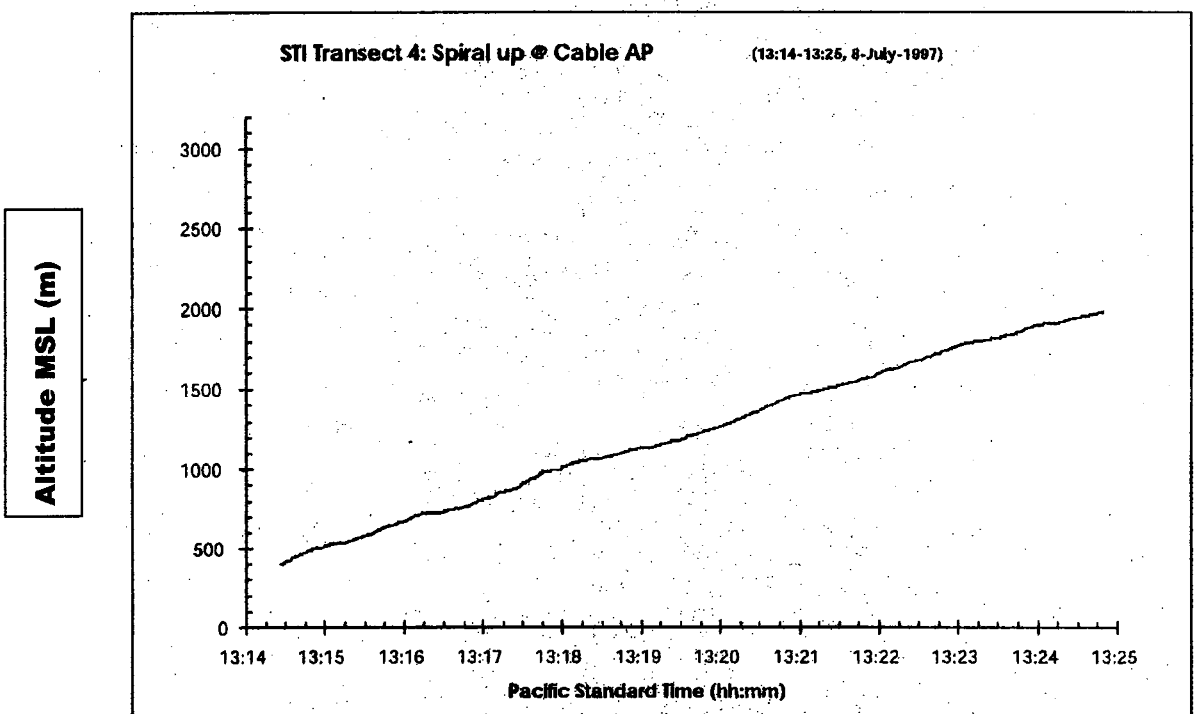


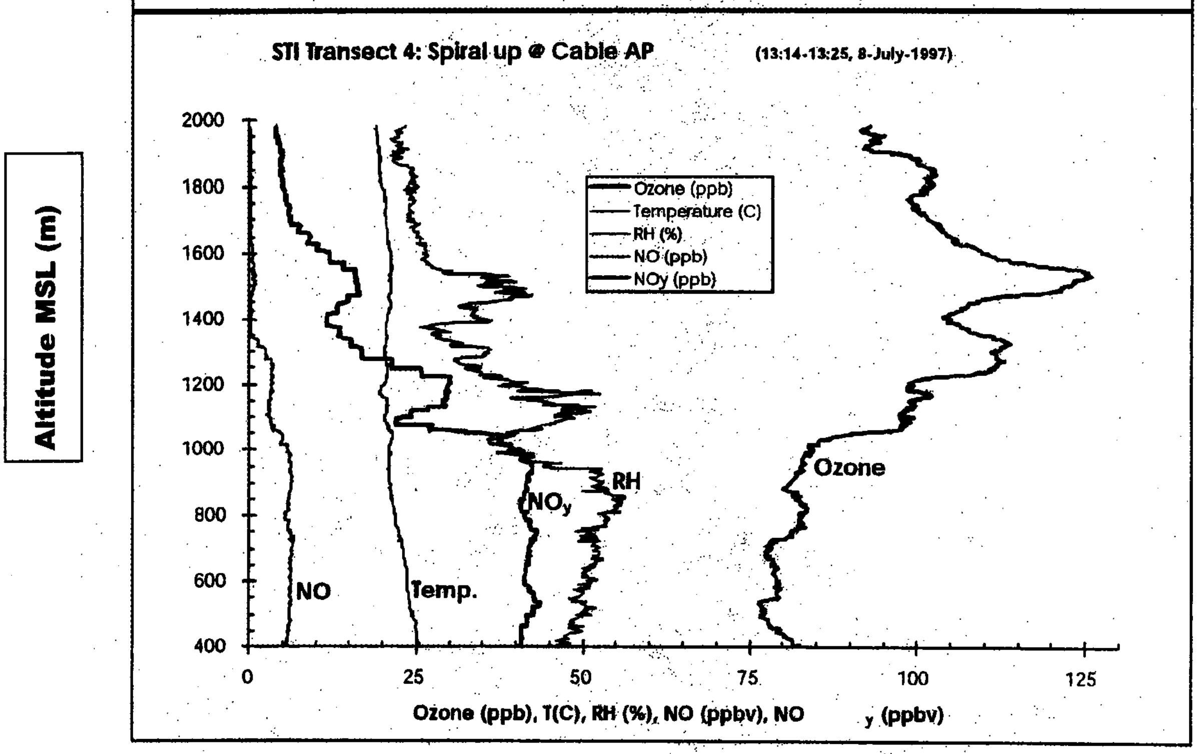

STI Transect 3: Spiral down @ Cable AP
(13:10-13:14, 8-July-1997)
Altitude msl (m)
3000
2500
2000
1500
1000
500
0
13:10
13:11
13:12
13:13
13:14
13:15
Pacific Standard Time (hh:mm)


STI Transect 3: Spiral down @ Cable AP
(13:10-13:14, 8-July-1997)
Altitude MSL (m)
1000
800
600
400
0
25
50
75
100
Ozone (ppb)
Temperature (C)
RH (%)
NO (ppb)
NOy (ppb)
RH
NOy
Ozone
Temp.
NO
Ozone (ppb), T(C), RH (%), NO (ppb), NOy (ppb)

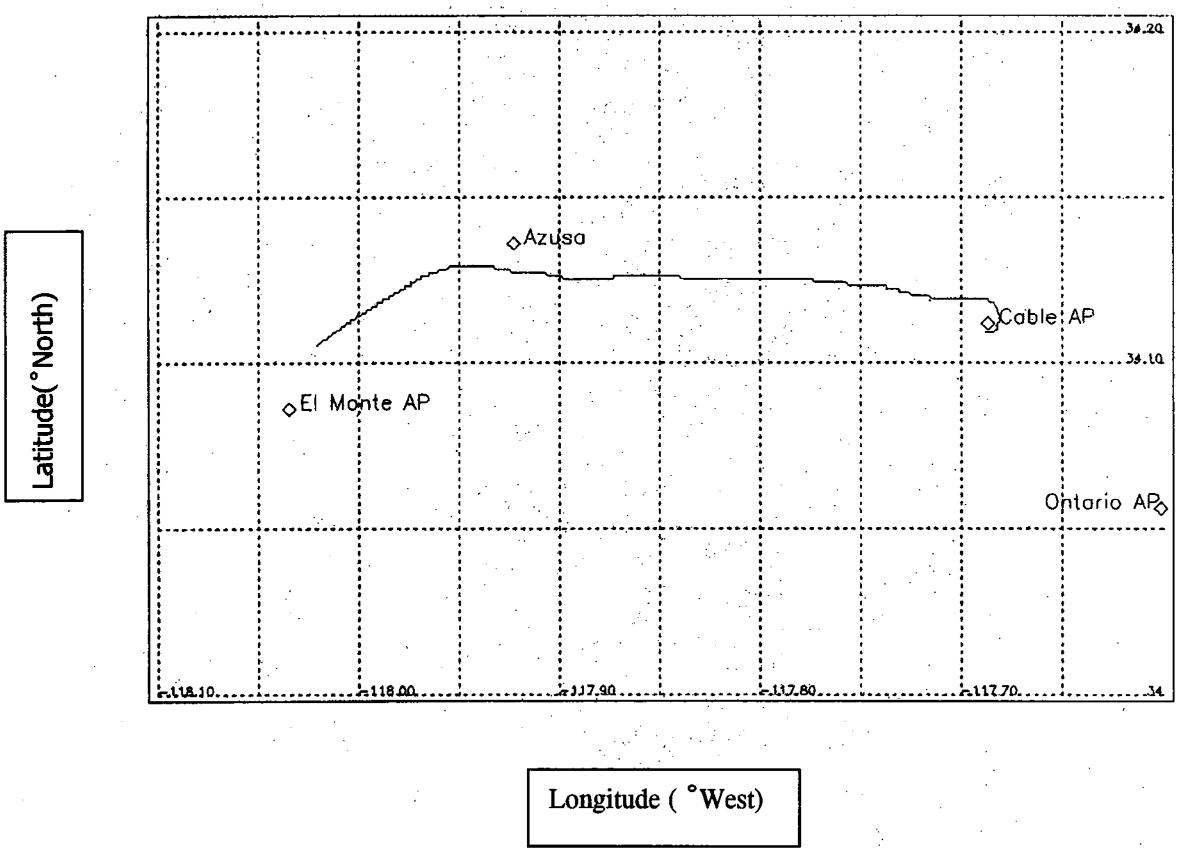
STI Flight Path Transect 4: Up spiral to □ 2000 m msl above Cable AP

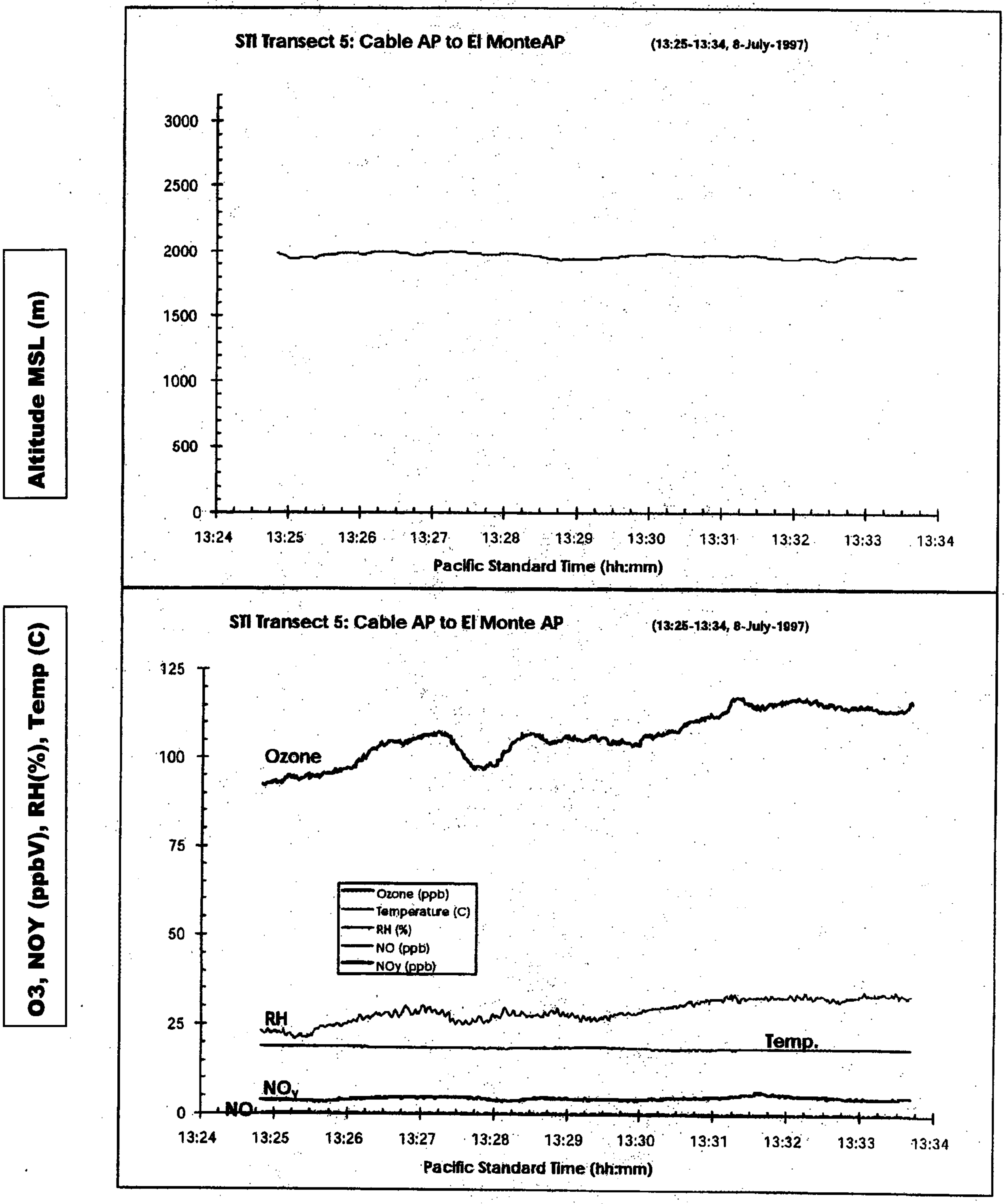



Altitude MSL (m)
STI Transect 4: Spiral up @ Cable AP
(13:14-13:25, 8-July-1997)
3000
2500
2000
1500
1000
500
0
13:14
13:15
13:16
13:17
13:18
13:19
13:20
13:21
13:22
13:23
13:24
13:25
Pacific Standard Time (hh:mm)

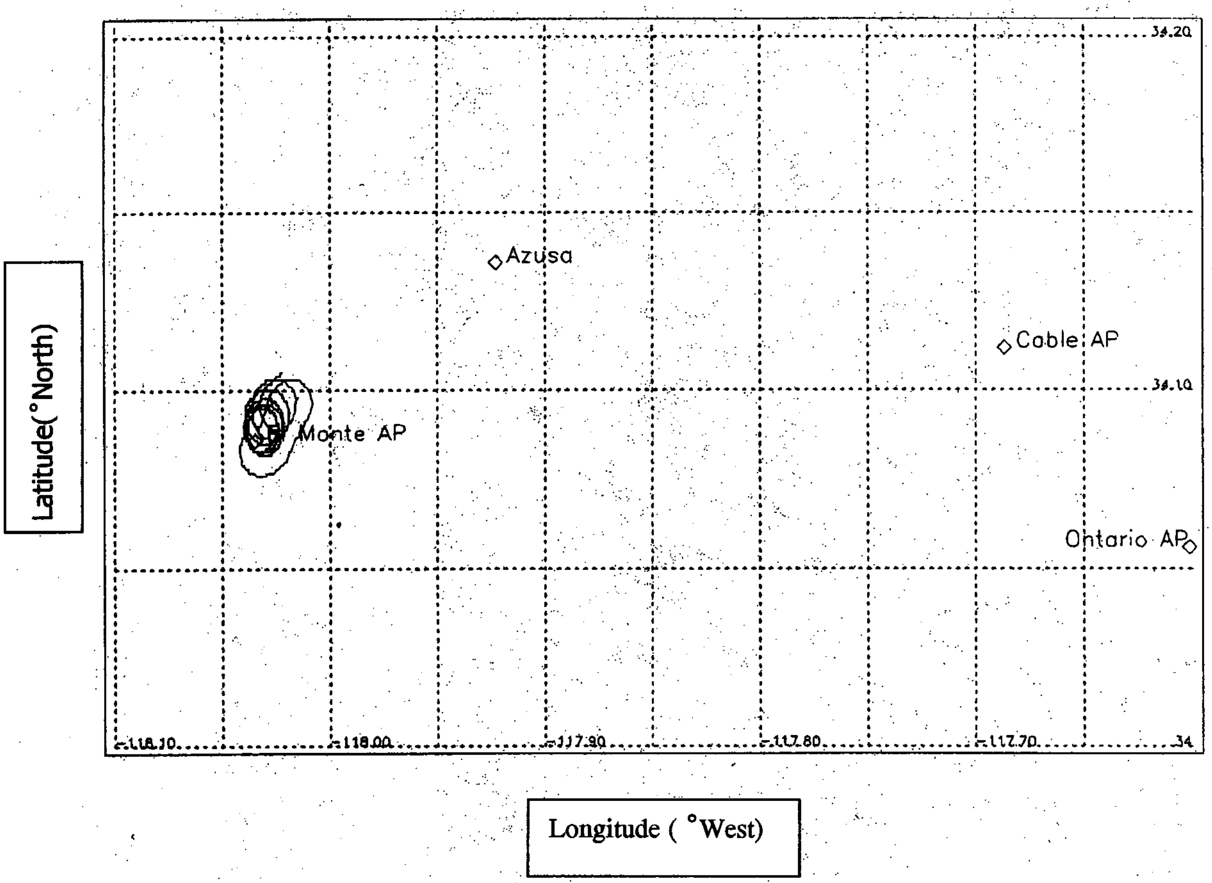

Altitude MSL (m)
STI Transect 4: Spiral up @ Cable AP
(13:14-13:25, 8-July-1997)
Ozone (ppb)
Temperature (C)
RH (%)
NO (ppb)
NOy (ppb)
2000
1800
1600
1400
1200
1000
800
600
400
NO
Temp.
NOy
RH
Ozone
0
25
50
75
100
125
Ozone (ppb), T(C), RH (%), NO (ppbv), NOy (ppbv)

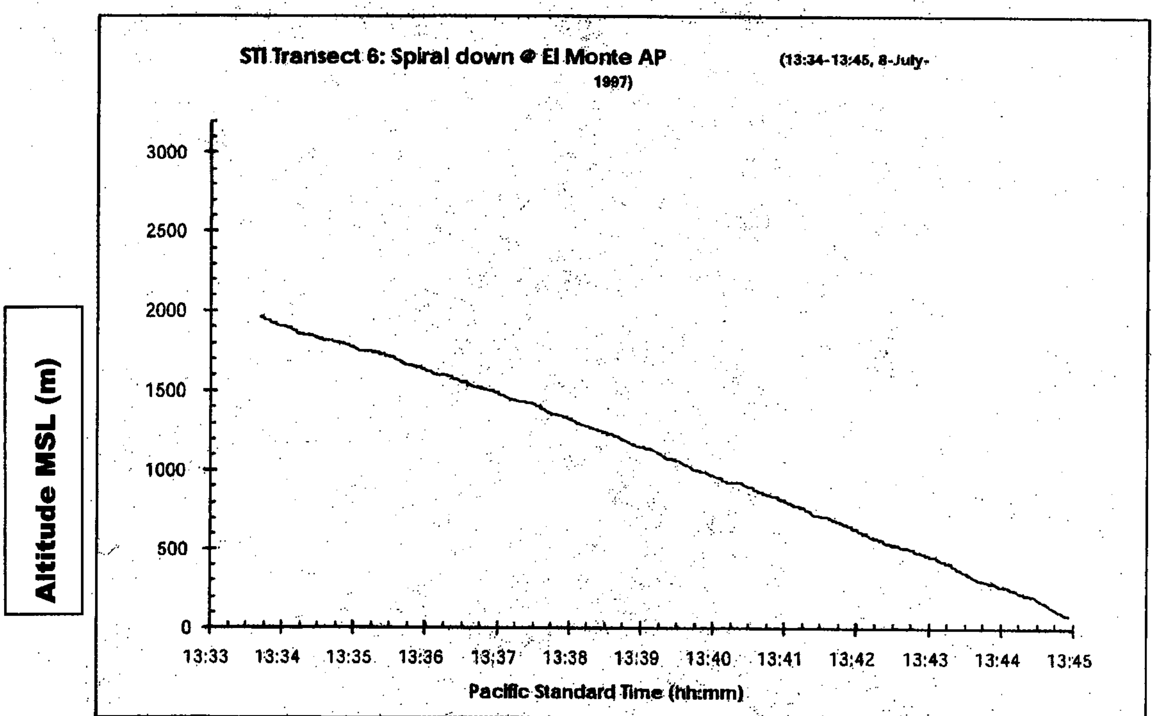
STI Flight Path Transect 5: Traverse from Cable to El Monte at □ 2000 m msl



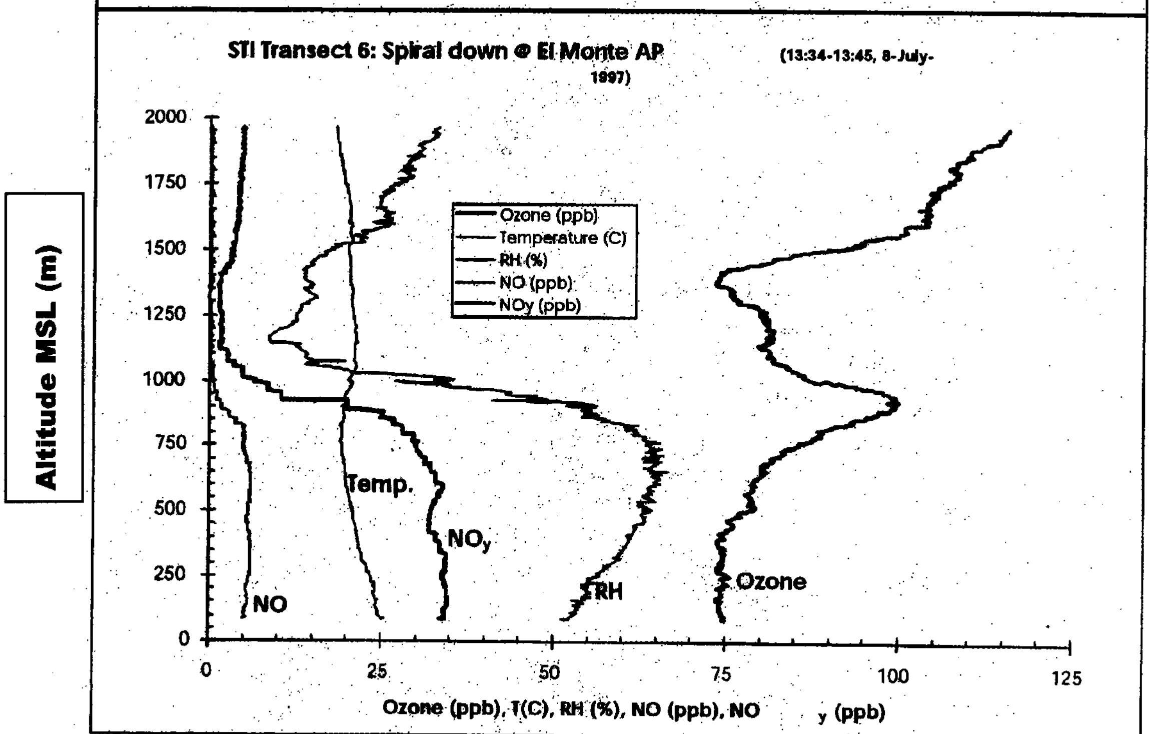

Altitude MSL (m)
STI Transect 5: Cable AP to El MonteAP
(13:25-13:34, 8-July-1997)
3000
2500
2000
1500
1000
500
0
13:24
13:25
13:26
13:27
13:28
13:29
13:30
13:31
13:32
13:33
13:34
Pacific Standard Time (hh:mm)
O3, NOY (ppbV), RH(%), Temp (C)
STI Transect 5: Cable AP to El Monte AP
(13:25-13:34, 8-July-1997)
125
100
75
50
25
0
Ozone
Ozone (ppb)
Temperature (C)
RH (%)
NO (ppb)
NOy (ppb)
RH
Temp.
NOy
NO
13:24
13:25
13:26
13:27
13:28
13:29
13:30
13:31
13:32
13:33
13:34
Pacific Standard Time (hh:mm)

STI Flight Path Transect 6: Down spiral to (near) ground level at El Monte AP



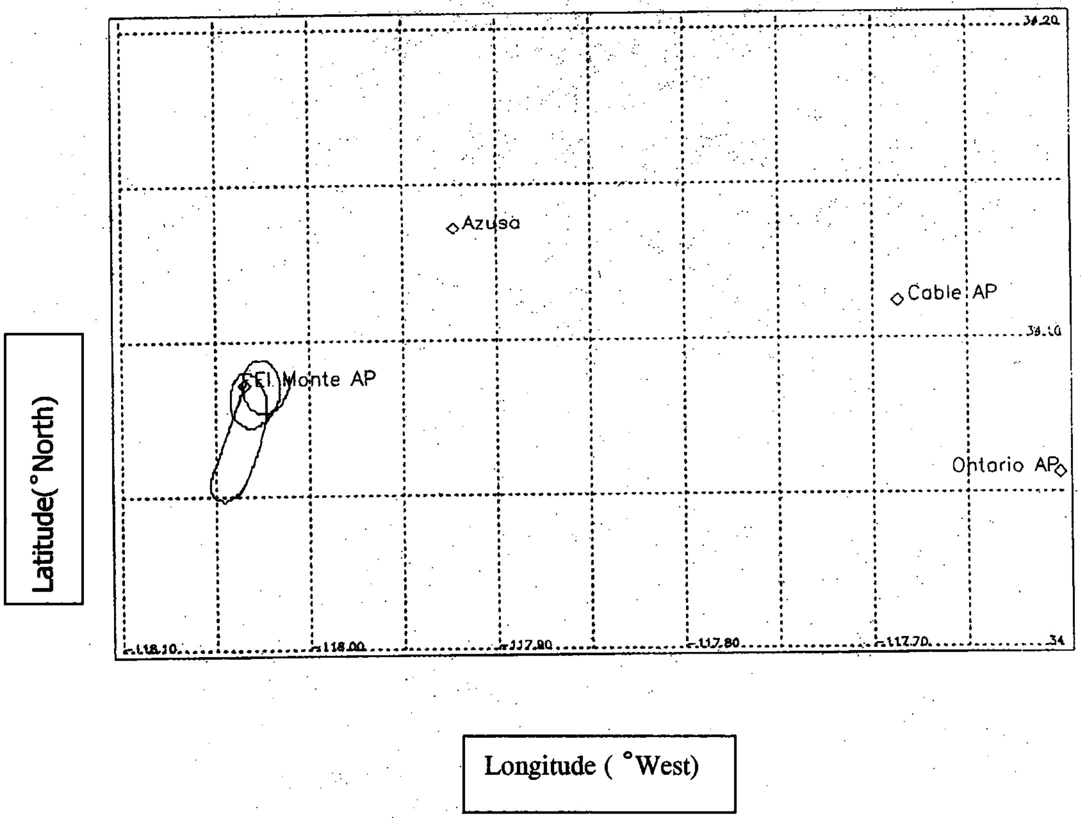


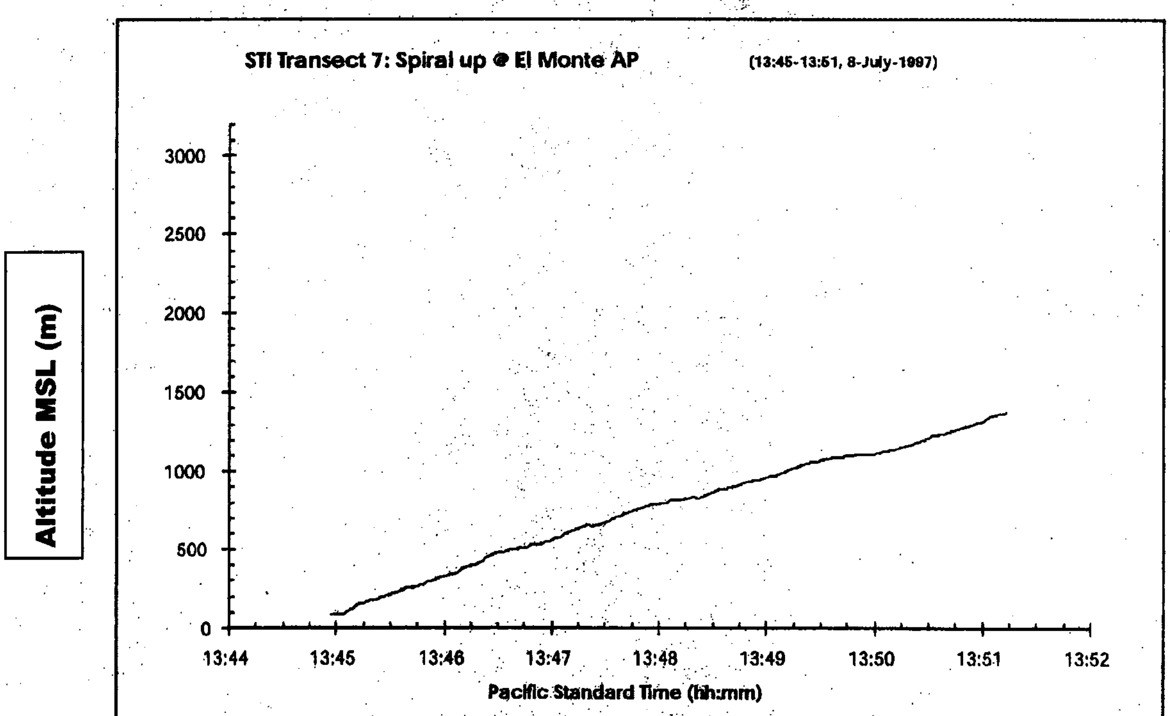
STI Transect 6: Spiral down @ El Monte AP
(13:34-13:45, 8-July-1997)
Altitude MSL (m)
3000
2500
2000
1500
1000
500
0
13:33
13:34
13:35
13:36
13:37
13:38
13:39
13:40
13:41
13:42
13:43
13:44
13:45
Pacific Standard Time (hh:mm)

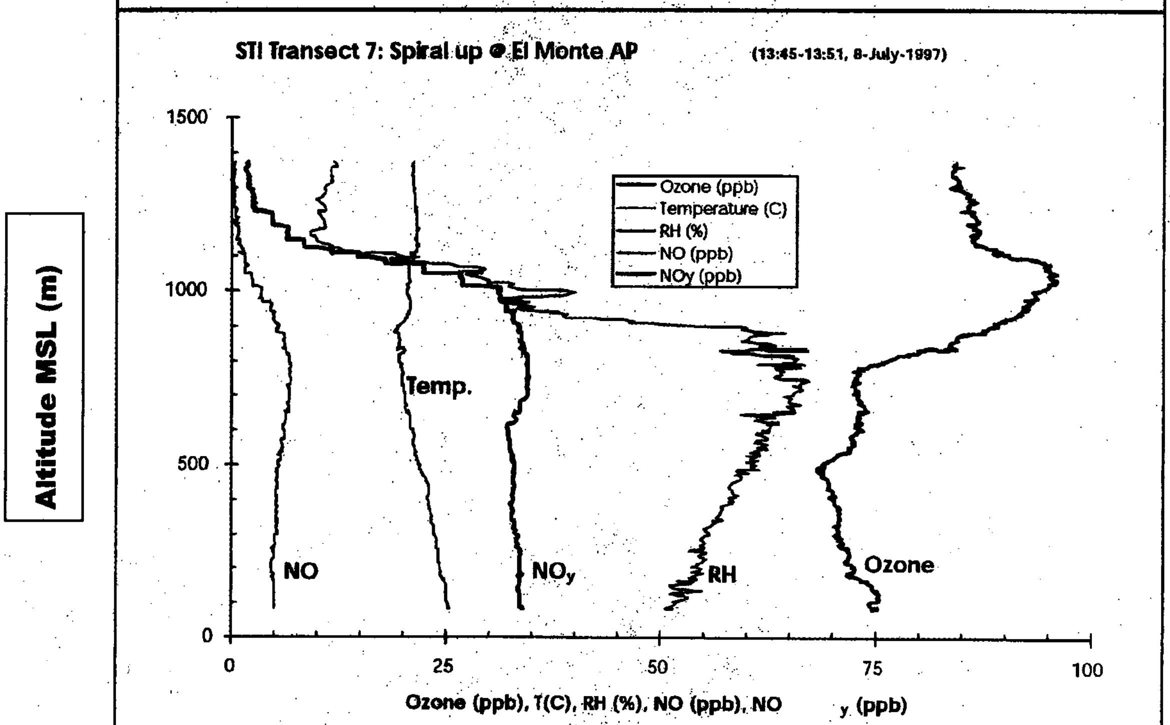


STI Transect 6: Spiral down @ El Monte AP
(13:34-13:45, 8-July-1997)
Altitude MSL (m)
2000
1750
1500
1250
1000
750
500
250
0
Ozone (ppb)
Temperature (C)
RH (%)
NO (ppb)
NOy (ppb)
Temp.
NOy
RH
Ozone
NO
0
25
50
75
100
125
Ozone (ppb), T(C), RH (%), NO (ppb), NOy (ppb)

STI Flight Path Transect 7: Up spiral to 1500 m msl above El Monte AP



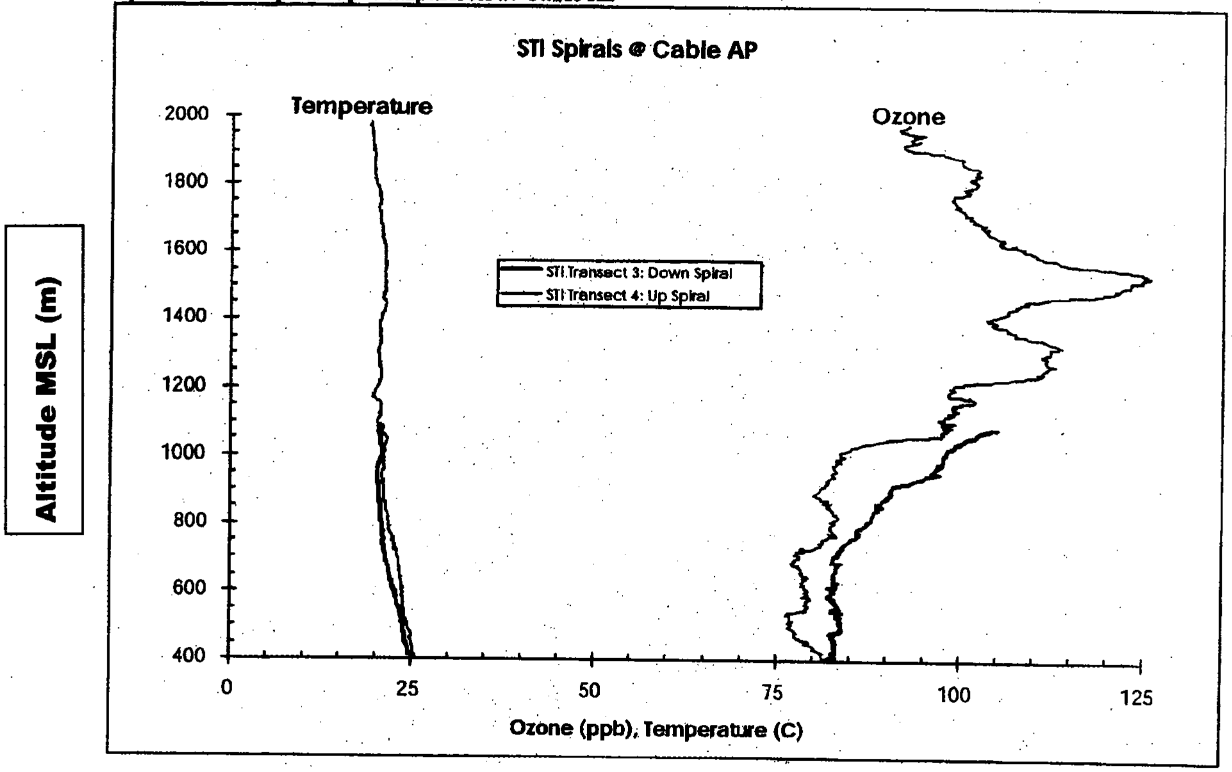

STI Transect 7: Spiral up @ El Monte AP
(13:45-13:51, 8-July-1997)
Altitude MSL (m)
3000
2500
2000
1500
1000
500
0
13:44
13:45
13:46
13:47
13:48
13:49
13:50
13:51
13:52
Pacific Standard Time (hh:mm)


STI Transect 7: Spiral up @ El Monte AP
(13:45-13:51, 8-July-1997)
Altitude MSL (m)
1500
1000
500
0
Ozone (ppb)
Temperature (C)
RH (%)
NO (ppb)
NOy (ppb)
Temp.
NO
NOy
RH
Ozone
0
25
50
75
100
Ozone (ppb), T(C), RH (%), NO (ppb), NOy (ppb)

STI Spiral Down - Spiral Up Comparison

Ascending - descending spiral data comparisons were made for STI spirals both at Cable and El Monte Airport and are shown in the following two sections.

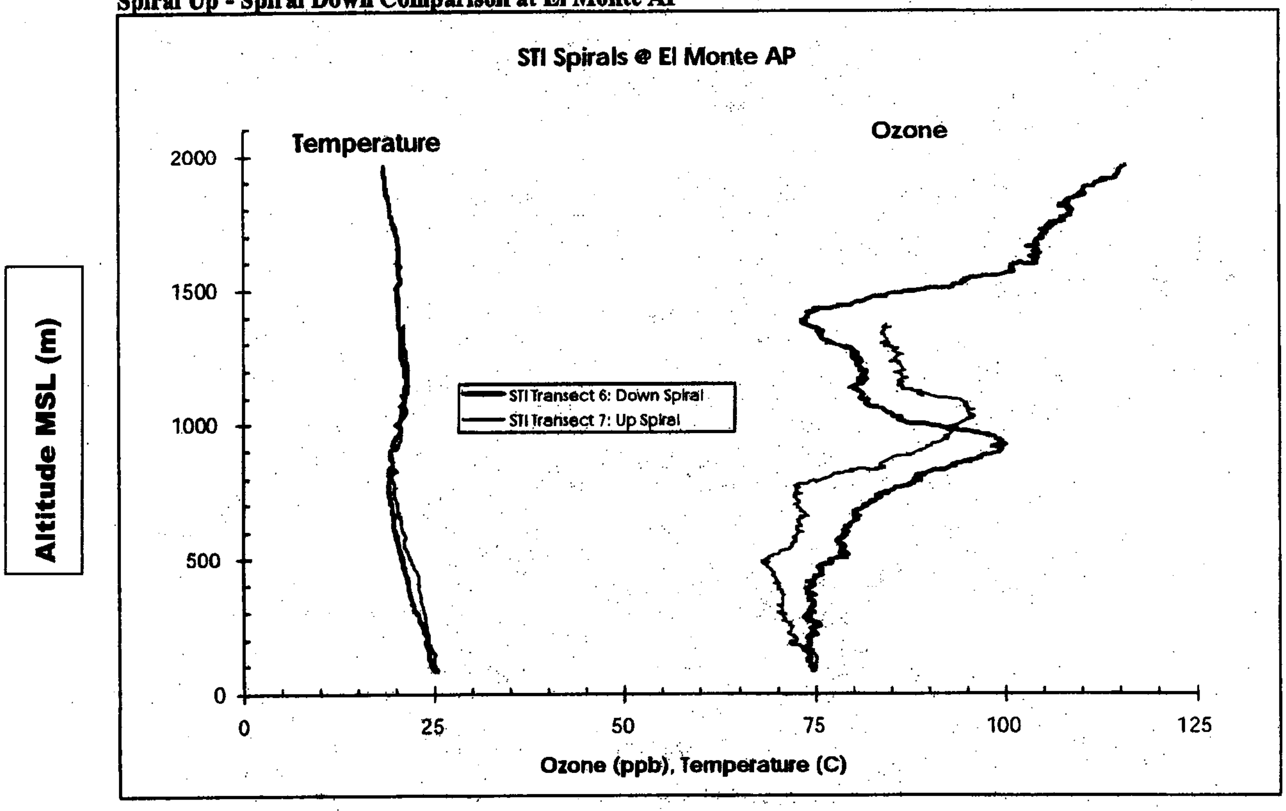
Spiral Down - Spiral Up Comparison at Cable AP



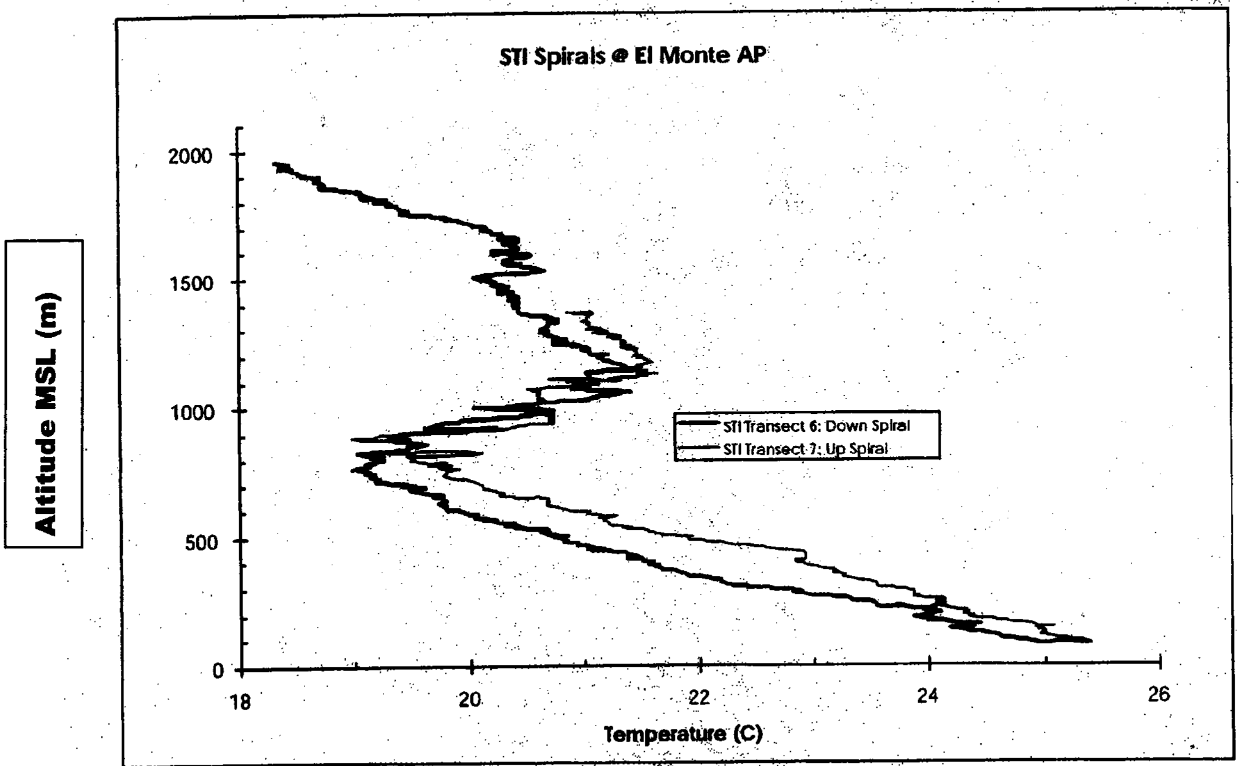
*Relative Humidity not shown

The agreement between ascending and descending ozone measurements is reasonable (i.e., within 15 ppb) with the ascending spiral showing more structure and lower ozone concentrations. Lower ozone concentrations during the ascending spiral at Cable AP were also measured during the nearly simultaneous UCD spirals.

Spiral Up - Spiral Down Comparison at El Monte AP

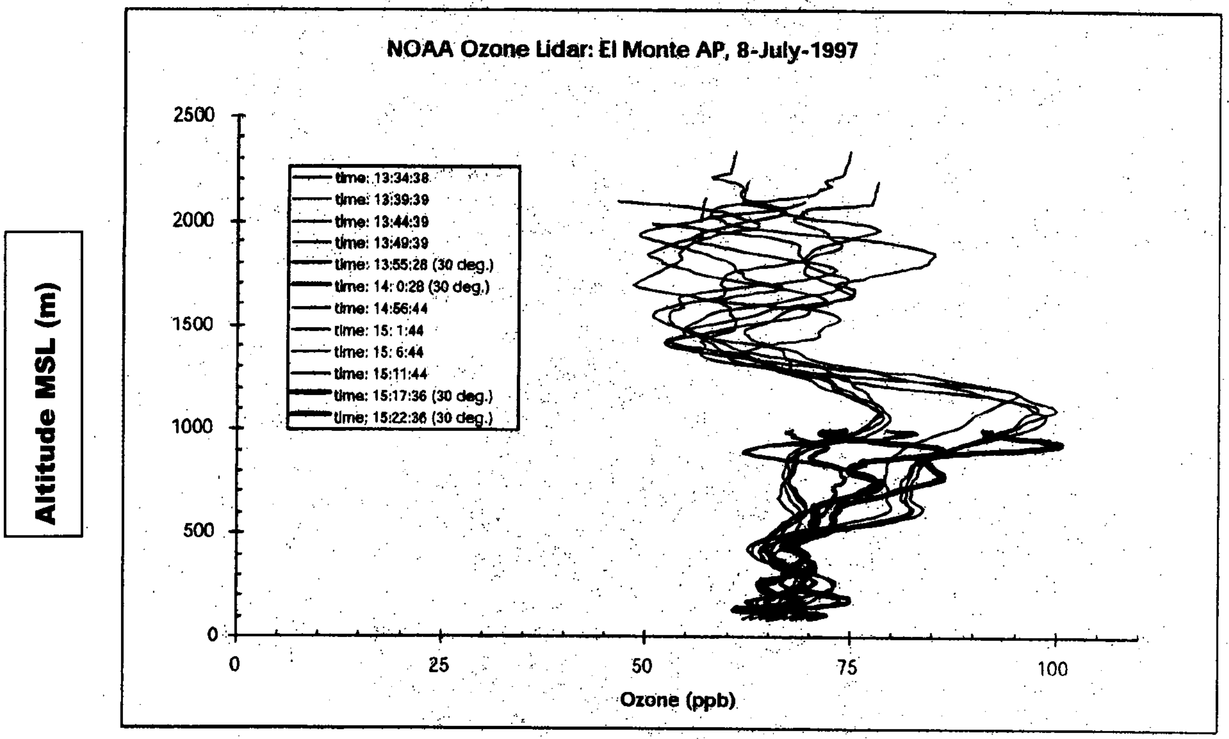


The qualitative structures shown for ascending and descending spirals are quite similar. However, the ascending spiral's main feature, the peak around 1100 m msl is at higher altitude than the peak of the descending spiral and ozone concentrations are generally lower. The peak shift could possibly be due to a measurement delay. Differences below 400 m can also be due to the significantly different STI flight paths during descent and ascent at El Monte due to noise abatement rules. Interestingly, the temperature data for these two spirals show a hysteresis effect very similar to the ozone data. This indicates that the differences between the ozone data measured for the two spirals are partly caused by atmospheric differences.



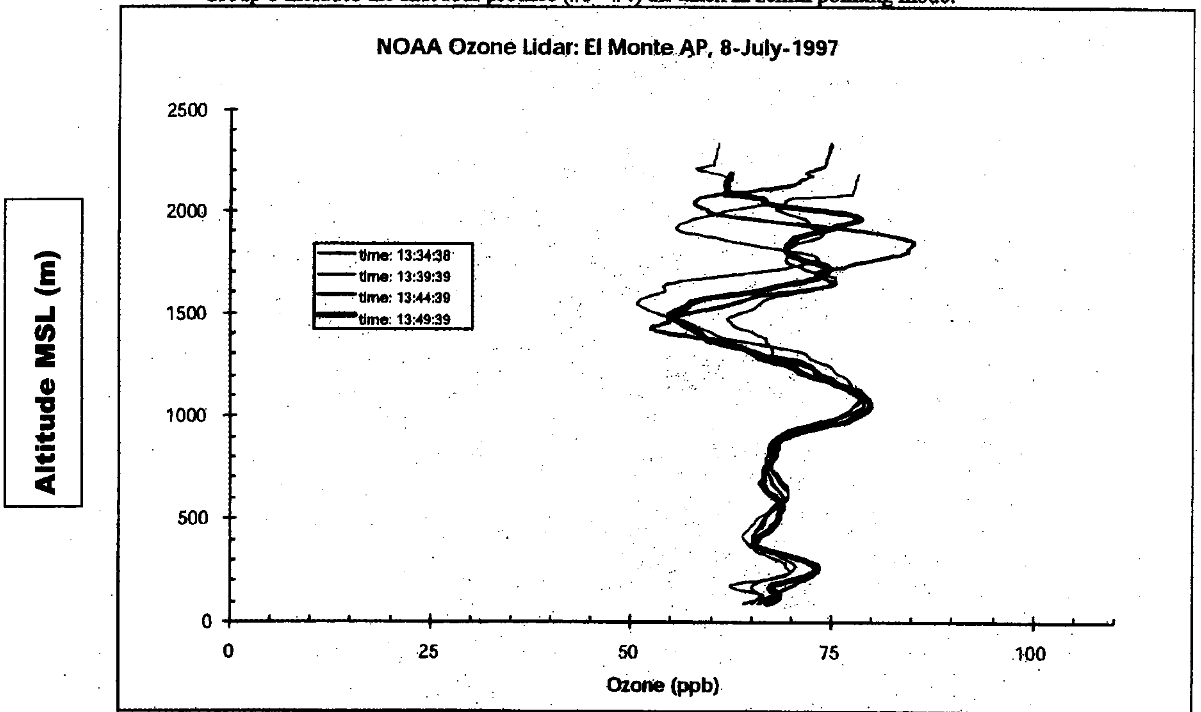
NOAA Lidar Ozone Data

An overview of all 12 ozone profiles acquired with the lidar during the afternoon of 8-July-97 is shown below. Four profiles, #7 through #10, had an approximately 100 ppb maximum ozone concentration around 1100 m msl, all with starting times between 14:56 and 15:12 PST. None of the other profiles measured before or after show this distinct feature, with the possible exception of the last two profiles taken in 30° slant mode. It should be noticed that both the two profiles #5 and #6 directly before and profiles #11 and 12 were acquired in 30° slant mode while profiles #7 through 10 were acquired in zenith pointing mode.

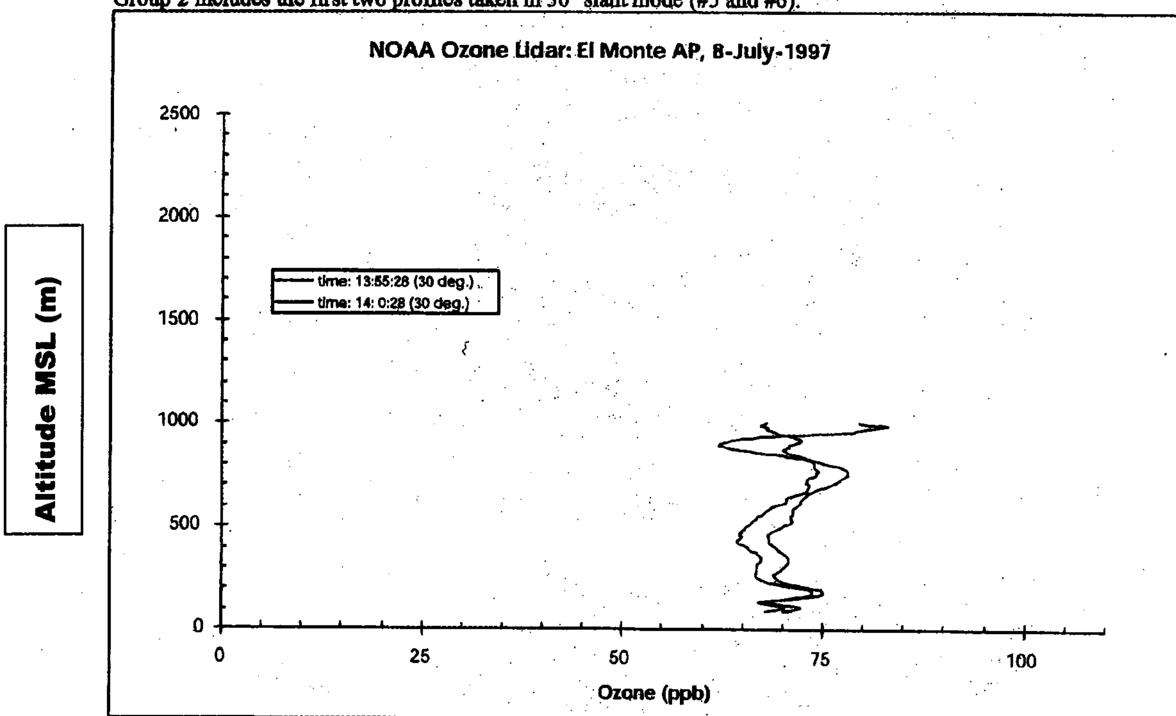


The display of 12 profiles together is somewhat confusing. In the following, the profiles have been separated into four groups.

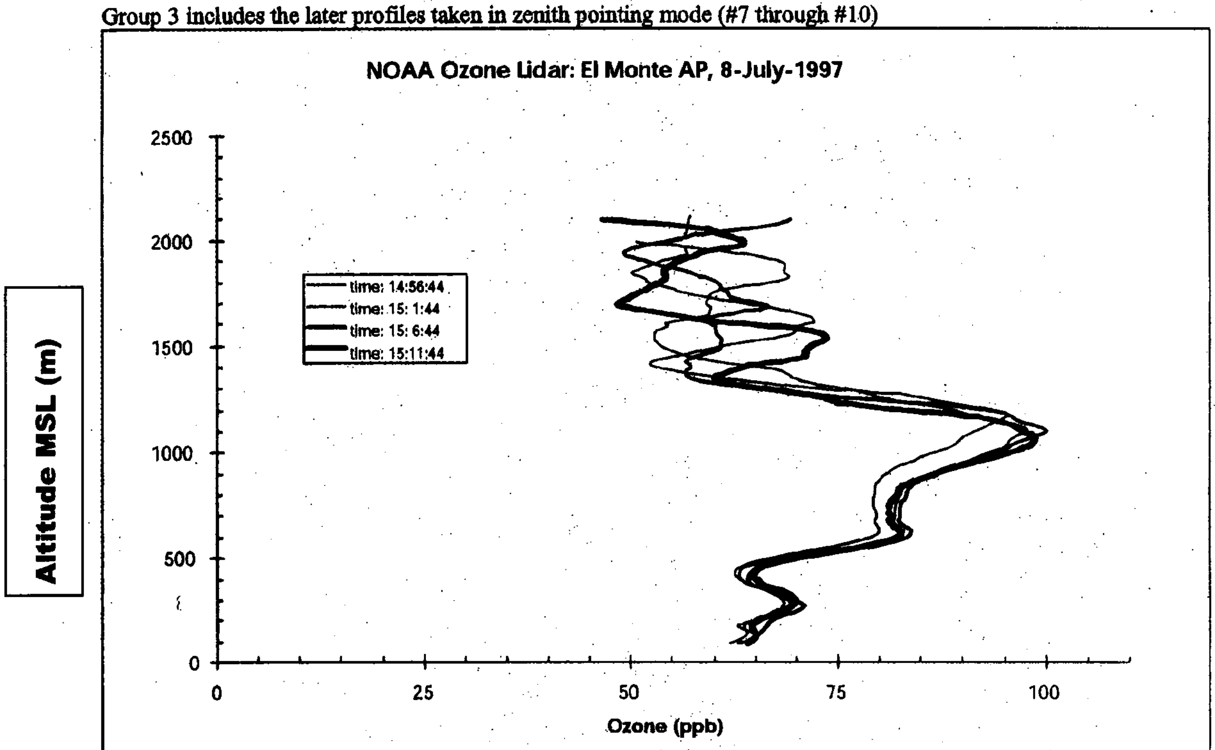
Group 1 includes the first four profiles (#1 - #4) all taken in zenith pointing mode.



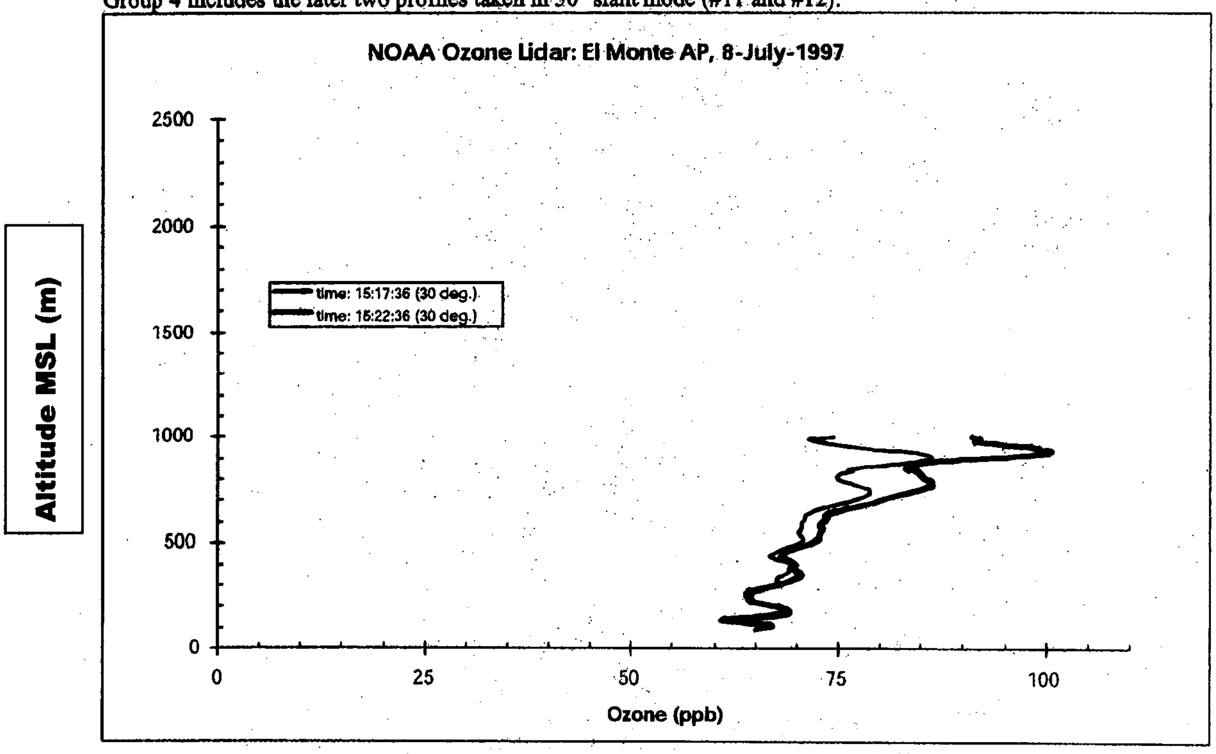
Group 2 includes the first two profiles taken in 30° slant mode (#5 and #6).



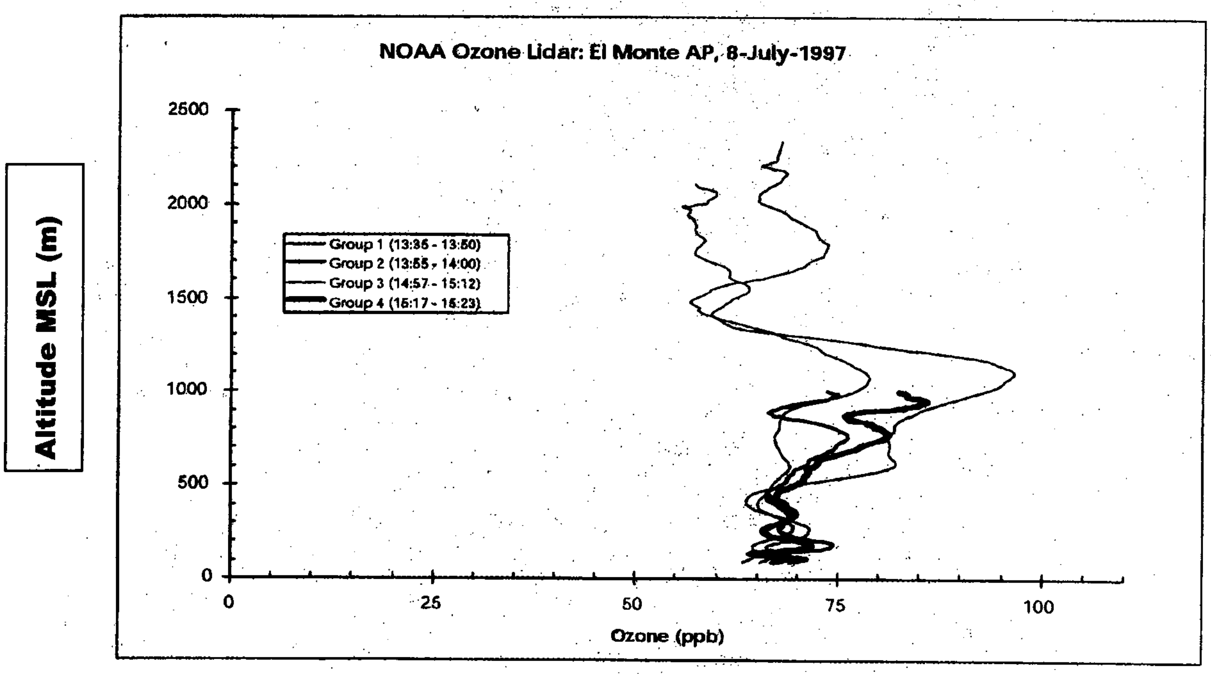
Group 3 includes the later profiles taken in zenith pointing mode (#7 through #10)



Group 4 includes the later two profiles taken in 30° slant mode (#11 and #12).



The profiles in each group show fairly good qualitative agreement among each other, which deteriorates somewhat towards the far end of the lidar range. In any case, the agreement within each group is far better than between the averages of the groups as shown in the following graph.



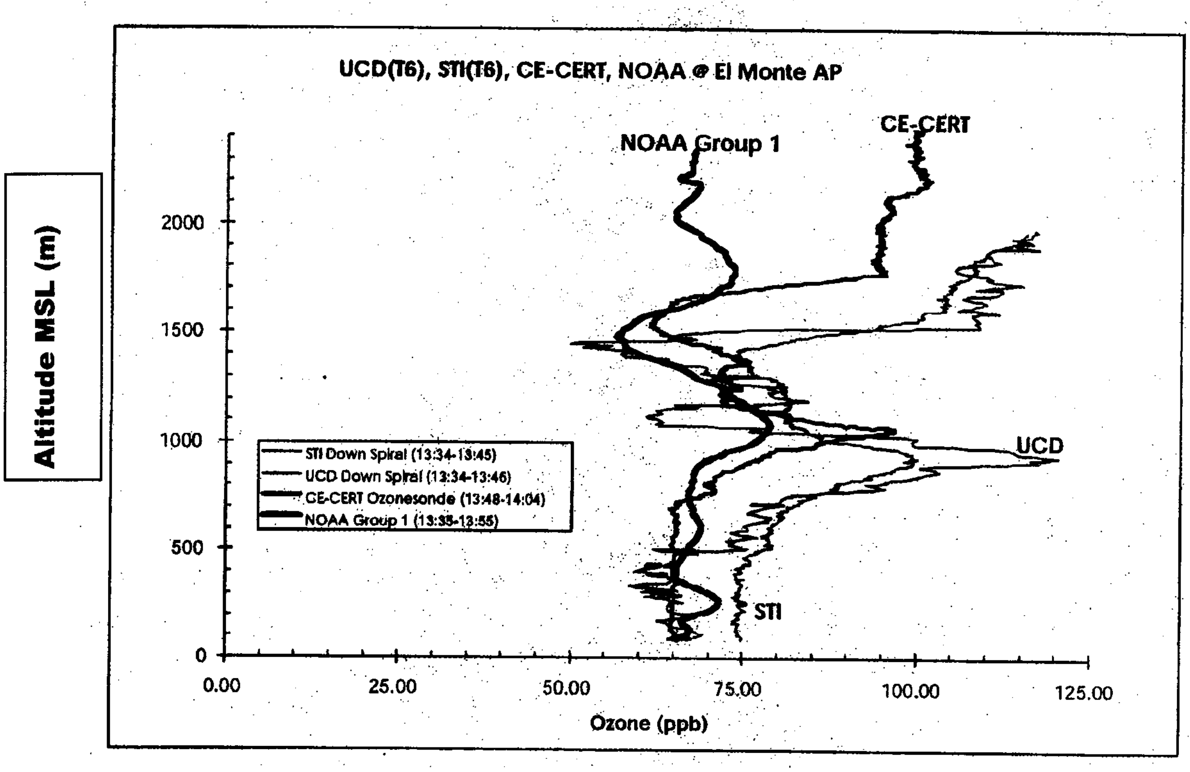
From these considerations it seems that the measured NOAA lidar ozone profiles might not only depend on true atmospheric ozone profiles but might also be influenced by operation mode and history. Although this conclusion may be true, more demonstration is needed (e.g., comparison with aircraft data). These groups represent significantly different times and probably profiles as even the aircraft indicated short-term changes in profiles. Data Inter-comparison.

4.4.2 Data Inter-Comparison

The data inter-comparison between the different platforms is focused on the most interesting part of the study, i.e., STI and UCD transects 6 and 7 which are descending and ascending spirals above El Monte Airport. The two aircraft flew these spirals about one minute apart with the NOAA ozone lidar operating simultaneously and a CE-CERT ozone sonde release at the start of ascending transect 7.

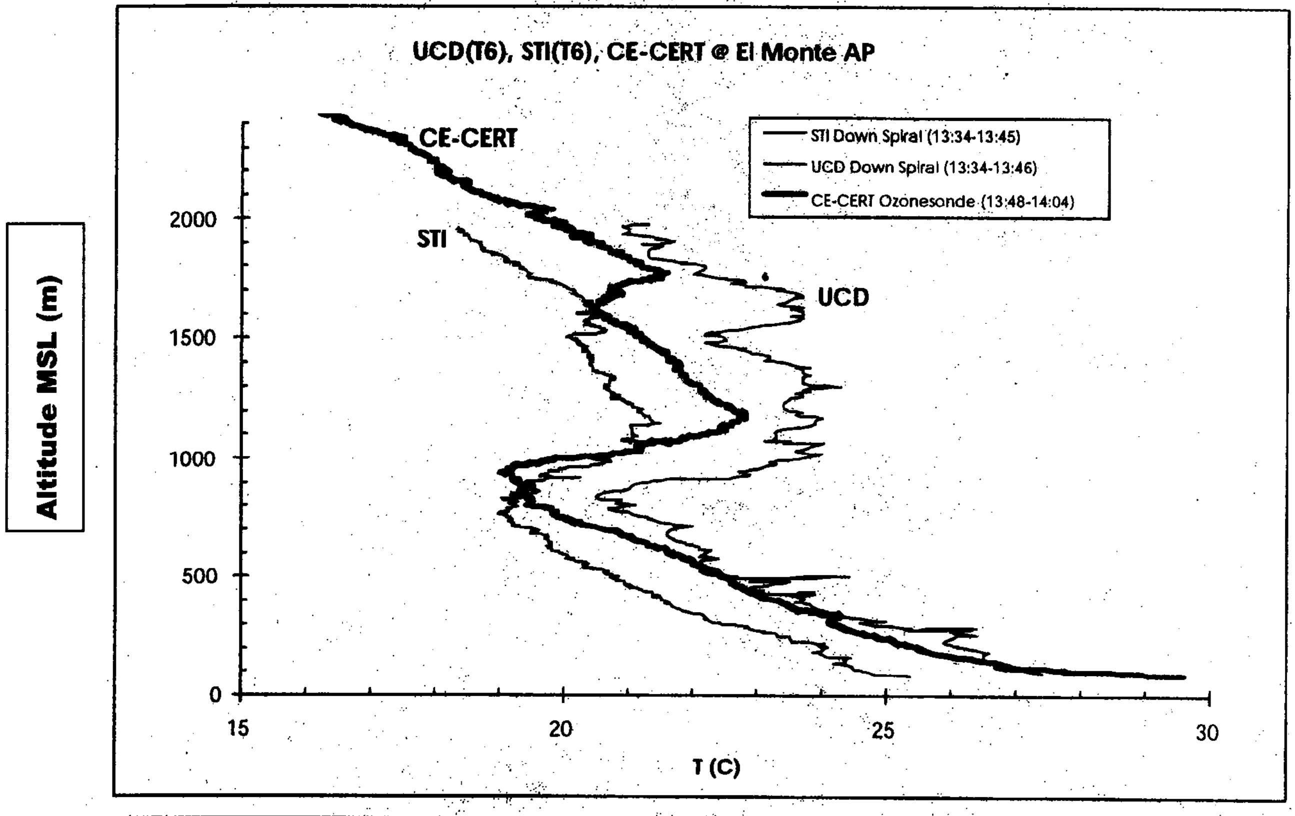
UCD Transect 6, STI Transect 6, CE-CERT Ozonesonde, NOAA

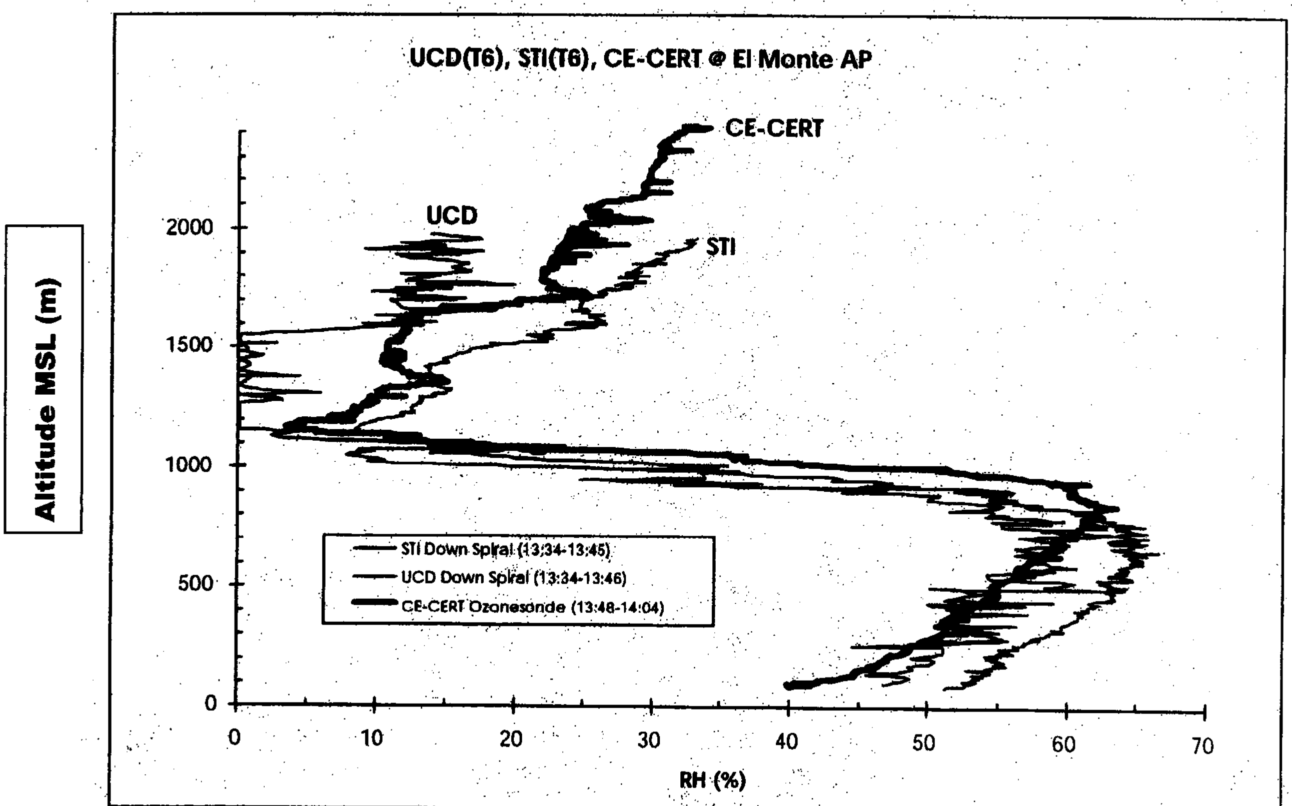
The first graph shows a comparison of descending spiral ozone data (transect 6) for UCD and STI with NOAA lidar data averaged over 20 min and the CE-CERT ozonesonde ozone data.



The lower part of the ozone profiles (90 - 500 m msl) shows excellent agreement between UCD, CE-CERT, and NOAA data and good agreement with STI ozone data which are about 10 ppb higher. The first peak around 1000 m msl occurs at the same altitude for UCD and STI data and somewhat higher for CE-CERT and NOAA data. This shift could partly be due to instrument delays as STI and UCD are descending and CE-CERT is ascending. The following minimum around 1100 m msl is most pronounced for UCD data, far less pronounced for CE-CERT data, barely noticeable for STI data, and does not show up at all in NOAA data. The vertical relationship between the different profiles for this minor minimum and the other higher altitude features are qualitatively the same as for the first (i.e., 1000 m msl) maximum. The following major minimum can be interpreted in the same way. However, the final strong rise in ozone concentrations around 1500 m msl to above 100 ppb, as registered by STI, UCD, and CE-CERT does not show up in the NOAA data which remain around 60 ppb. A possible explanation for this could be the lower signal to noise ratio in the far range of the NOAA lidar.

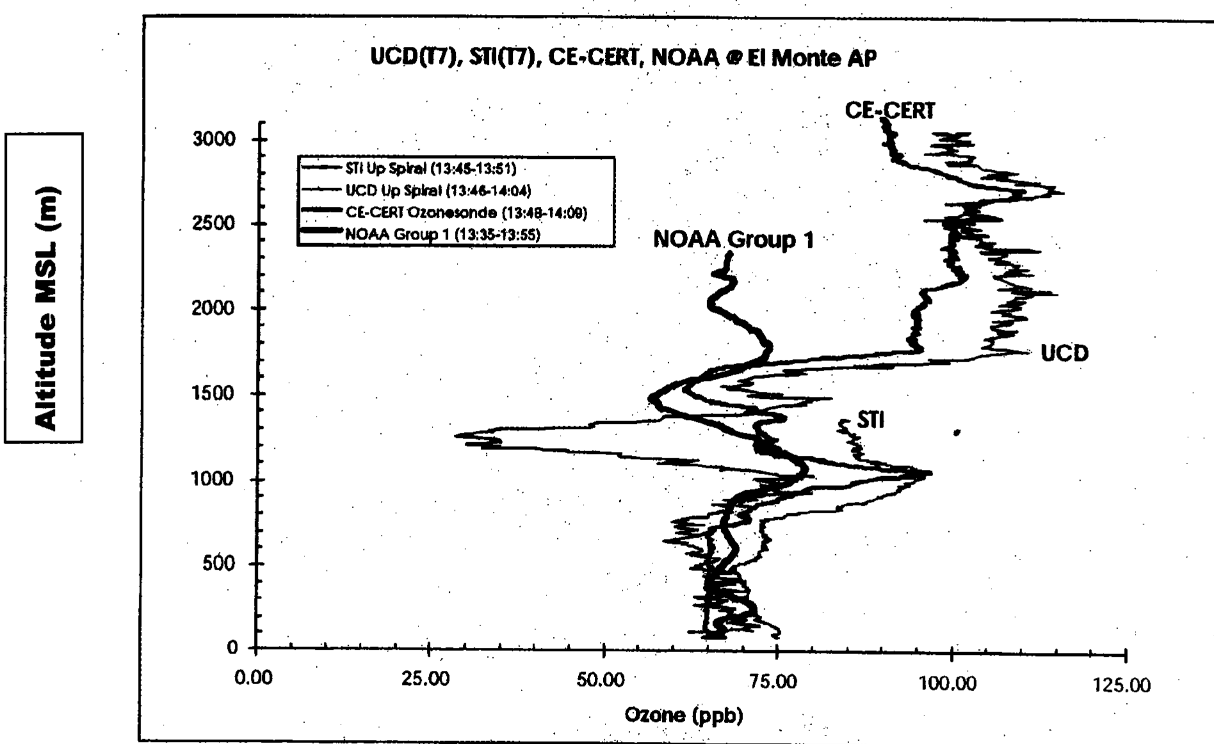
The following temperature and relative humidity profiles confirm the fact that the CE-CERT ozonesonde registered atmospheric features at a higher altitude than either STI or UCD on their descending spirals. This may be partly due to horizontal variations in inversion height. Discrepancies between the low RH values (< 10%) are not unusual as the capacitance devices like the one UCD uses have poor performance at very low (<10%) and very high (>90%) humidities.


UCD(T6), STI(T6), CE-CERT @ El Monte AP
STI Down Spiral (13:34-13:45)
UCD Down Spiral (13:34-13:46)
CE-CERT Ozonesonde (13:48-14:04)
CE-CERT
STI
UCD
Altitude MSL (m)
0
500
1000
1500
2000
15
20
25
30
T (C)

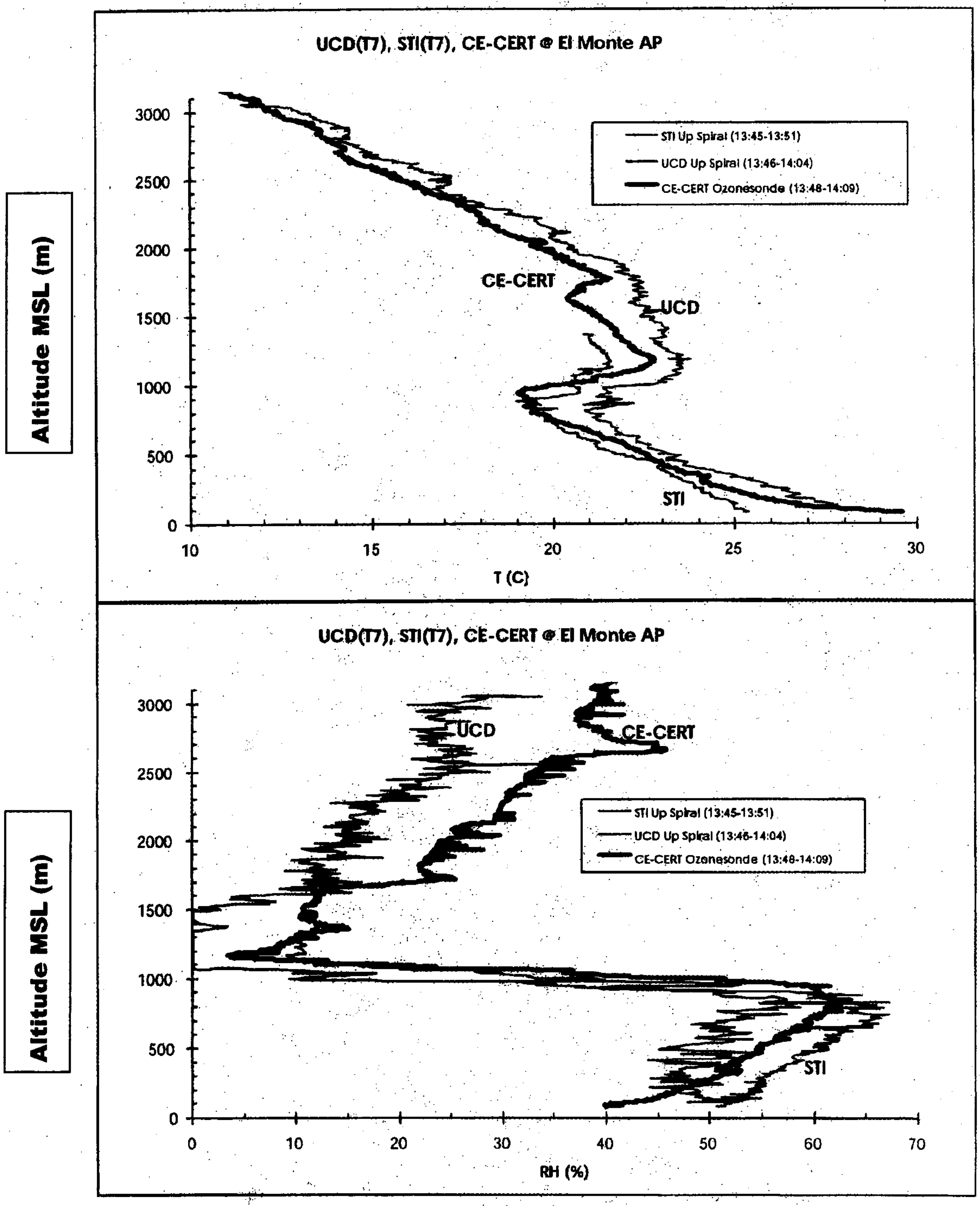

UCD(T6), STI(T6), CE-CERT @ El Monte AP
CE-CERT
UCD
STI
STI Down Spiral (13:34-13:45)
UCD Down Spiral (13:34-13:46)
CE-CERT Ozonesonde (13:48-14:04)
Altitude MSL (m)
0
500
1000
1500
2000
0
10
20
30
40
50
60
70
RH (%)

UCD Transect 7, STI Transect 7, CE-CERT Ozone sonde, NOAA

The following UCD and STI ascending spirals are compared with the simultaneous ozone sonde profile and the NOAA (group 1) lidar profile. Lidar and ozone sonde profiles are the same as used for transect 6. Most of the general comparison is similar to that of transect 6. However, UCD values for the ozone peak around 1000 m are now lower than for all other systems and the minimum around 1200 m msl which is minor or nonexistent in the other data dominates the UCD data with a drop below an ozone concentration of 30 ppb. Locations of the ozone peak around 1000 m msl are now quite comparable between the different systems with STI and UCD ascending. UCD and CE-CERT measured ozone concentrations around 100 ppb above 1700 m msl. STI did not spiral to that altitude and the NOAA profile indicated only 65-70 ppb of ozone above 1700 meters msl.

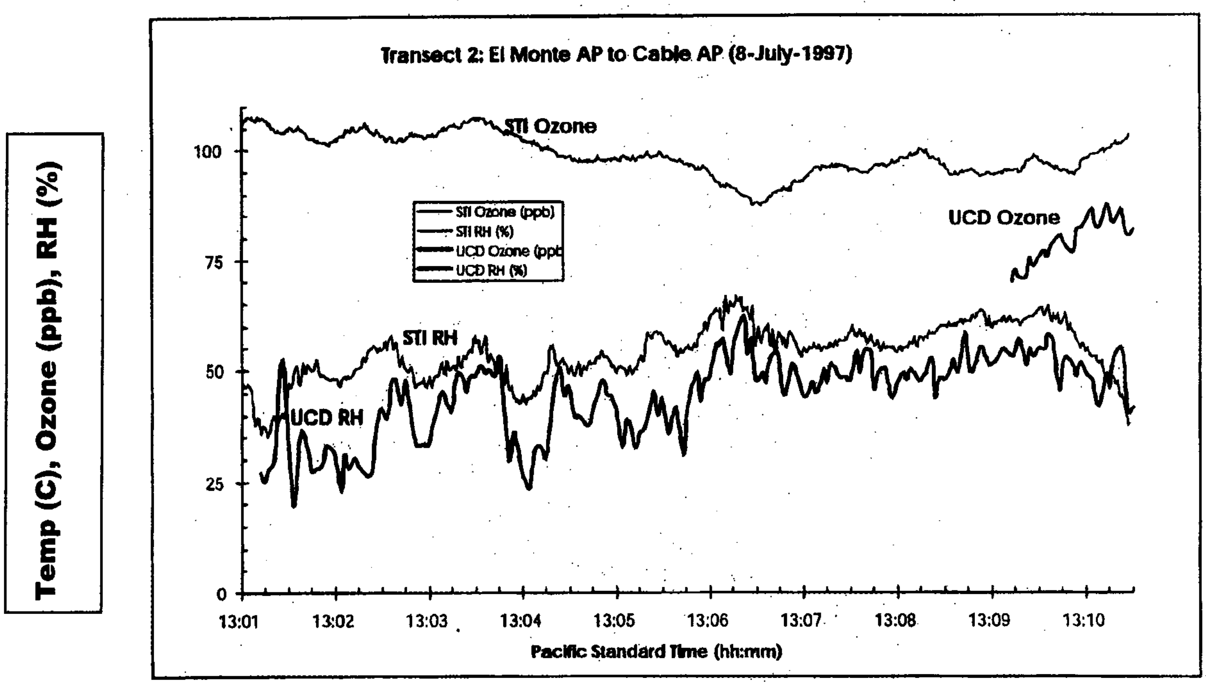


Temperature and humidity profiles have similar features below about 1300 m msl. Above this altitude, the CE-CERT data show a temperature inversion around 1700 m msl with a corresponding feature in the humidity profile. These features do not appear in the UCD data, and STI data are not available at this altitude for transect 7.

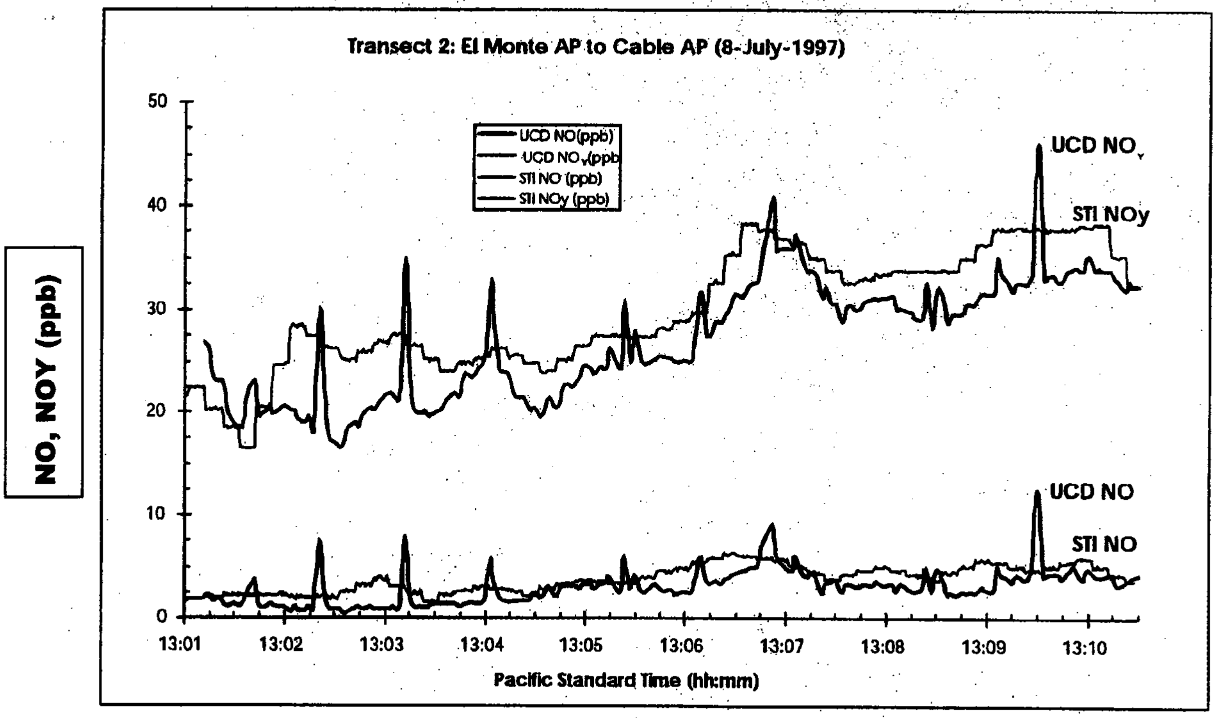

UCD(T7), STI(T7), CE-CERT @ El Monte AP
Altitude MSL (m)
3000
2500
2000
1500
1000
500
0
10
15
20
25
30
T (C)
STI Up Spiral (13:45-13:51)
UCD Up Spiral (13:46-14:04)
CE-CERT Ozonesonde (13:48-14:09)
CE-CERT
UCD
STI
UCD(T7), STI(T7), CE-CERT @ El Monte AP
Altitude MSL (m)
0
10
20
30
40
50
60
70
RH (%)
UCD
CE-CERT
STI

UCD Transect 2 and STI Transect 2: El Monte AP to Cable AP

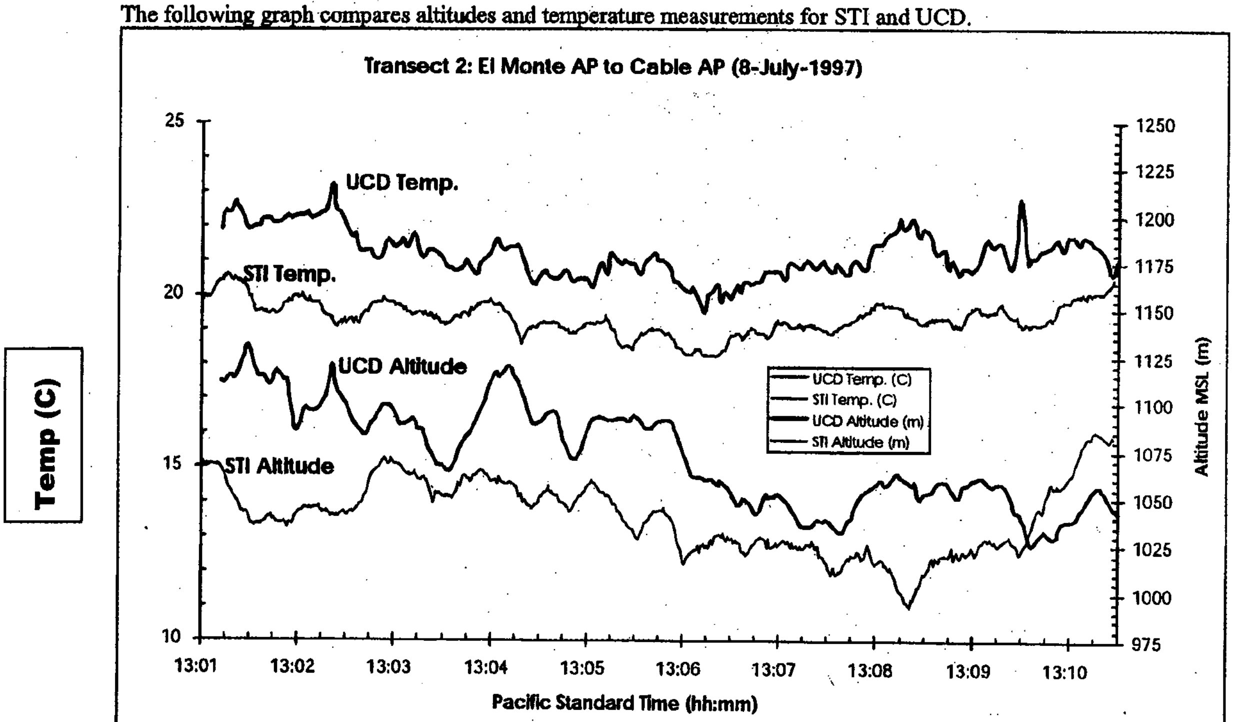
During the traverse from El Monte AP to Cable AP, UCD and STI aircraft flew close to each other but UCD may have lagged a little, at around 1100 m msl, yielding an opportunity for data inter-comparison under conditions where less gradients are expected compared to spirals. During transect 2, UCD measured ozone concentrations only at the very end of the transect as the ozone monitor pump was inadvertently turned off during most of the transect. For the existing ozone data, UCD measured ozone concentrations lower by 10 to 20 ppb than the STI values. UCD relative humidities were also somewhat lower (□ 10%) and showed more short term variability than the corresponding STI RH data. However, slower changes in RH have very similar structure for both UCD and STI data.



Measurements of nitrogen oxides shown in the following graph are very similar between UCD and STI. However, UCD measurements show a number of sharp spikes with a one-to-one correspondence between NO and NO_Y spikes neither of that appear in the STI data. These differences could be due to different time resolution of STI and UCD instruments. However, such spikes did not appear in other measured quantities (see also transect 5).



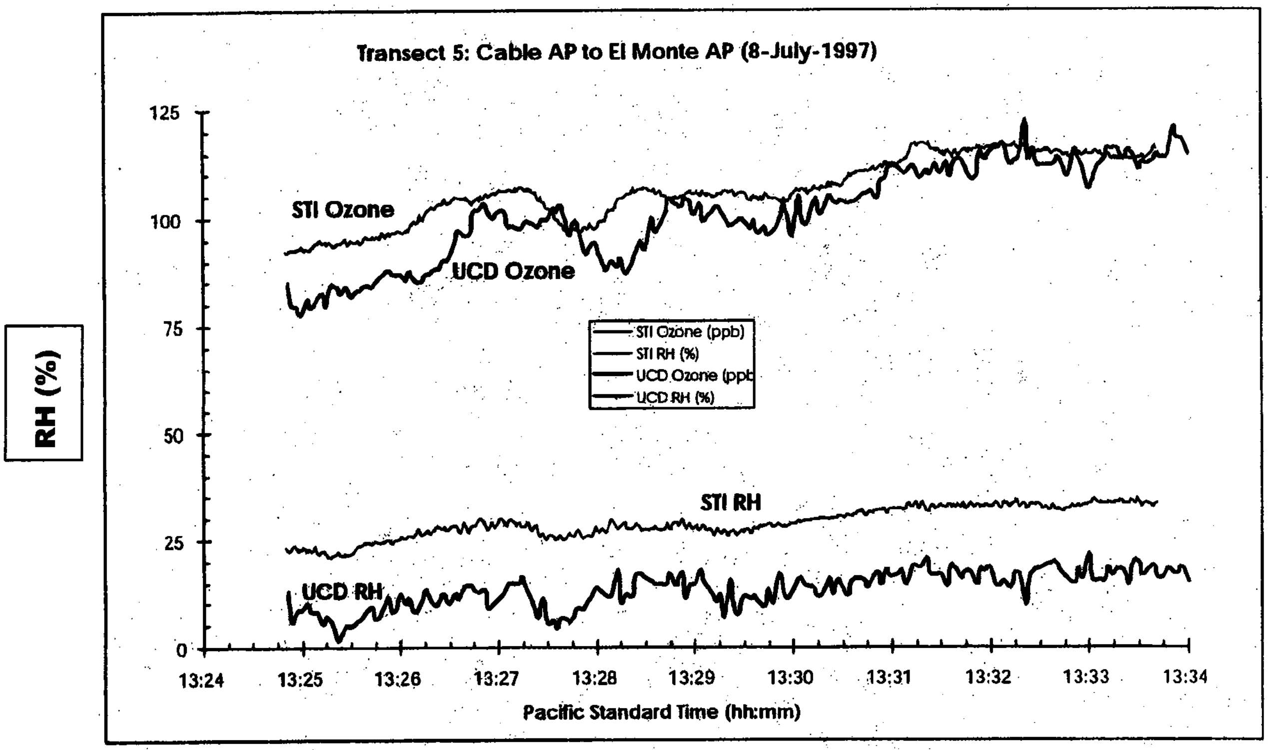
The following graph compares altitudes and temperature measurements for STI and UCD.



Recorded altitudes show generally less than 50 m difference between UCD and STI, with UCD altitudes being slightly higher. The two temperature profiles are very similar with an offset of about 2°C between UCD and STI temperatures.

UCD Transect 5 and STI Transect 5: Cable AP to El Monte AP

During the return flight from Cable AP to El Monte AP the altitude was around 2000 m msl, substantially higher than during transect 2. Ozone measurement compared very well with maximum differences around 15 ppb, similar features, and STI generally measuring slightly higher values. Relative humidity measurements also compared quite well, with STI recording higher values than UCD (by about 15 %).



Measurement of nitrogen oxides are substantially lower during this transect compared to transect 2. While the measurement baseline compares quite well between UCD and STI, the spikes in the UCD measurements were much more pronounced than during transect 2. Part of this is due to the lower ambient concentrations which make spikes of equal absolute magnitude look larger. It is highly questionable if these spikes reflect rapid changes in ambient concentrations. As no other data show comparable spikes, the possibility of measurement artifacts should be considered.

There is no page 4-88.

4.5 Other Aloft Inter-comparisons

Although the June 11 and July 8 intercomparisons featured the full suite of monitoring platforms, all of the aircraft and lidars were not able to participate. Thus, additional intercomparisons of air quality aloft measurements were made during SCOS97-NARSTO to enable evaluations of the comparability of data from almost all of the monitoring systems (only the CIRPAS Pelican did not participate in a formal inter-comparison because their ozone instrument did not function no ozone data were collected by the Pelican). The purpose of the intercomparisons was to identify and accurately quantify biases within (e.g., hysteresis in aircraft measurements) and between platforms. The University of California (Davis) Cessna 182 generally served as a common link in the intercomparisons. The intercomparisons were scheduled so as not to interfere with activities during IOPs. Consequently, ozone concentrations during the intercomparisons usually were not as high as the sponsors desired. Table 4.4 summarizes the formal (planned) intercomparisons that occurred during SCOS97-NARSTO.

Table 4.5-1. SCOS97-NARSTO Intercomparisons of Air Quality Aloft Measurements

Platforms	Date	Location/Conditions
UCD Cessna, NOAA lidar, CE-CERT ozonesonde	June 11	El Monte AP ozone concentrations decreasing
UCD Cessna, STI Aztec, NOAA lidar, CE-CERT ozonesonde	July 8	El Monte & Cable APs ozone concentrations moderate
UCD Cessna, SD-Cessna, SD-Navajo	August 24	El Monte & Cable APs ozone concentrations low
UCD Cessna, PSU lidar	September 18-19	Hesperia ozone concentrations low
STI Aztec, USN Partnavia	September 30	Ventura County ozone concentrations low

Additional opportunities for intercomparison of the monitoring platforms occurred during IOPs. Because the NOAA lidar and UCD Cessna were based at the El Monte AP and because the STI Aztec generally made one spiral per IOP day at the El Monte AP, opportunities exist for comparing the lidar ozone measurements with those from the two aircraft. In addition, potential opportunities exist for comparing the air quality measurements from the aircraft; these comparisons however, are dependent upon the timing of the aircraft spirals each performed above the El Monte AP. Because both of the San Diego aircraft (Cessna and Navajo) flew out of Montgomery Field at about the same time in the morning, comparisons of the air quality data from these two platforms may also be possible.

4.6 Evaluation of Ozonesondes Responses

Staff at UCR, CE-CERT, evaluated the performance of an ozonesonde (EN-SCI model 2Z ECC) in their laboratory to a variety of environmental factors. These test evaluations yielded the following results:

1. Zero and span (100 ppb) stability: Less than 2 ppb drift in three hours.
2. PAN interference: Approximately 50% at 100 ppb PAN.
3. Reproducibility (new KI solutions each day for 7 days): Zero and span response changes of less than 1 ppb at zero and 5 ppb at 100 ppb span.
4. Response time: The sonde was subjected to step changes of 0-100 ppb and step changes between 100 and 200 ppb. The 1/e value was approximately 20 seconds. The only potential problem was equilibration to zero air from any significant amount of ozone; for the response to go from a few ppb to zero could require more than 30 minutes. This is not a problem, however, because ambient ozone concentrations seldom, if ever, drop to zero ppb. CE-CERT staff will evaluate algorithms to remove the influence of the response time to step changes in concentration.
5. Multiple reuses and long term span stability: Multiple tests with the same sonde at a test concentration of 210 ppb showed negligible drift (within the ±1 ppb noise).
6. Humidity dependence: The sonde response did not change within the ± 1 ppb noise of the instrument when the relative humidity was changed from 0 to 80% (0 and 100 ppb ozone input).
7. Performed a six-point span check of the ozonesonde; a linear regression correlation coefficient of 0.998 was obtained.
8. NO_2 dependence: No ozone response was observed to 50 ppb input of NO_2.
9. Pressure dependence (test performed on a different ozonesonde): The ozone sensitivity increased by a few percent more than the compensation for pressure correction alone.

In general, the laboratory performance of the ozonesonde far exceeded expectations. In addition to the pre-study evaluation tests, CE-CERT staff also performed zero and span checks on every sonde used during the field study. These data will be used to evaluate precision and accuracy during the field program.