Keeping Tahoe Blue through Atmospheric Assessment: Aircraft and Boat Measurements of Air Quality and Meteorology near and on Lake Tahoe

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DISCLAIMER

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ABSTRACT:

During the summer and fall of 2002, aircraft measurements of meteorological and air quality variables were obtained over the western Sierra Nevada and the Lake Tahoe Basin. During the winter of 2003, similar measurements were made close to the lake's surface using a small research vessel on the lake. Aircraft air quality sampling included real time monitoring of ozone, NO, NOy, and particulate concentrations plus grab samples of gaseous and particulate nitrogen species using annular denuder-filter pack (DFP) assemblies. Boat sampling was the same except that no ozone monitor was aboard. The primary objective of these field efforts was to document the concentrations of nitrogen-containing species as well as other pollutants in the air over and upwind of the lake, as these species can deposit into the lake and act as nutrients that accelerate eutrophication. This report describes the techniques used to acquire the data, assure their quality and summarizes the general conditions encountered. Descriptions of instrument calibrations and of the formats used for the QA/QC-ed data sets transferred to the ARB are also included.

Sampling was conducted on 20 days during the summer and fall with an aircraft and on 6 days during the winter with a boat. Two additional days were devoted to joint aircraft-boat sampling in the fall. Data recovery for the continuous real time measurements was nearly 100 percent. Analyses of the DFP samples from the aircraft also went well, although there were issues with blank levels for several chemical species. During our sampling days, the concentration of atmospheric N over Lake Tahoe ranged from 33 to 360 nmol-N m^{-3}-air, with an average value of 120 nmol-N m^{-3}-air. Gaseous ammonia was typically the dominant component, accounting for an average of 55% of total N, while particulate ammonium contributed an additional 10% of total N on average. Nitric acid/nitrate and organic nitrogen (gaseous and particulate) were also significant components that, on average, accounted for 20% and 14% of the total atmospheric N burden. In contrast, levels of nitrous acid and nitrite were generally insignificant.

A variety of weather conditions were encountered which clearly affect pollutant levels measured both in the Tahoe Basin and over the mountains to the west. On most days, late afternoon air quality was slightly to significantly worse to the west of the basin than in the basin. In the mornings, the variations among locations were more random. A preliminary analysis of our DFP measurements, in conjunction with meteorological data, suggests that nitrogen levels in the air above Lake Tahoe can be affected by a number of sources and factors including the regional "background" pollution level, in-basin emissions, local and distant forest fires, and pollution from the Central Valley.

EXECUTIVE SUMMARY

During the summer and fall of 2002 an instrumented general aviation aircraft, operated by UCD, flew prescribed routes over the western Sierra Nevada and Lake Tahoe making air pollution measurements. Additionally during the winter of 2003, a research boat operated on Lake Tahoe with a similar instrument package. The aircraft instrumentation included real time monitors for ozone, NO, NOy and particle concentrations (d > 0.3 and d > 3.0 micrometers), and annular denuder – filter pack (DFP) assemblies for collection of gaseous and particulate nitrogen-containing species. In addition, ambient temperature, humidity, pressure (altitude), GPS position and aircraft attitude were measured by a commercial meteorological sounding device (AIMMS-10) which also provided estimates of wind speed and direction. These data were recorded by an onboard, laptop-computer-based data acquisition system. The boat instrumentation was similar to the aircraft setup except that ozone concentrations and wind information were not collected.

Aircraft flight routes included data acquisition over the high country west of the Lake Tahoe Basin and DFP samples at 180 and 490 m above the lake surface. Morning and afternoon data were obtained on 20 days between July 10 and October 10, 2002, inclusive. Boat sampling routes were varied to assure that samples were collected only with the boat traveling into the apparent wind to avoid contaminating samples with exhaust from the boat's engine. Morning and afternoon boat samples were obtained on October 15 and 16, 2002 (in conjunction with simultaneous boat measurements), as well as on 6 days between January 24 and March 7, 2003, inclusive. The real time monitors worked well during all periods. Overall, the aircraft DFP system worked well although blank levels were high for some species. Because of this, concentrations of organic nitrogen (gaseous and particulate) should be considered qualitative and levels of particulate phosphorus (P) and potassium (K) are considered unreliable and therefore are not reported. In addition, we do not report DFP data for the 2003 boat data because of very high blank levels (in contrast to the 2002 sample, which had low accompanying blanks, whose values are reported).

The multiple deployments during both sampling seasons allowed measurements in a variety of weather conditions, providing information on how pollutant concentrations varied among these conditions. Flight paths that included sampling over the mountains west (and usually upwind) of the lake allowed comparison of conditions there with those in the Tahoe basin near the lake surface. During the morning hours, differences in concentrations between these "upwind sites" and the basin exhibit no clear pattern. In the late afternoon, concentrations at the upwind sites are usually higher than in the basin. During summer, pollutant concentrations west of the basin rim increase significantly during the course of most days; smaller increases during the day were observed within the Tahoe basin itself. Differences between the two "upwind" sites were generally small and somewhat random in the morning soundings. On most afternoons however,

the more westerly upwind site (Big Hill) was impacted more than the other upwind site (Loon lake), with both upwind sites being more polluted than the lake center on almost every day sampled.

The continuous data from both platforms show no systematic, basin wide, horizontal gradients of ozone, particles or NOy, although small zones (<1.5 km in width) of higher NOy and particle concentrations were occasionally encountered during sampling near population centers such as South Lake Tahoe and Tahoe City.

Over the lake at about 2380 m MSL in summer, the ranges of averaged measured constituents were: ozone 43 to 86 ppbv, NOy 2 to 6.5 ppbv, particulate N 0.9 to 54 nmol N m^{-3} and gas phase N 14 to 320 nmol N m^{-3}. The primary nitrogen species found was ammonia gas (which, on average, accounted for 55% of the total N) followed by nitric acid (~ 19% of the total N). Concentrations of total nitrogen varied widely from day to day, as did the relative contribution from individual N components. Averaging the ensemble of DFP samples, it appears that nitric acid decreases with height above the lake while there is no consistent gradient with gaseous ammonia. The boat DFP samples during winter indicate higher ensemble averaged particle, NO and NOy concentrations than were seen in summer at higher altitudes.

Based on a preliminary analysis of our data it appears that concentrations of nitrogen in the air above Lake Tahoe are affected by a number of sources, including in-basin emissions, local and distant forest fires, regional background pollution, and transport of pollutants from the Central Valley. In general the effort was successful but the problem with the high blank values needs to be resolved before the DFP techniques can be used to quantitatively measure phosphorus, potassium, and organic nitrogen.

INTRODUCTION

Lake Tahoe is a large alpine lake of exceptional clarity with an average surface altitude of 1900m MSL. It is located in a basin surrounded by mountains with peaks ranging between 2400m and 3050m MSL. Lake clarity has been decreasing due, in part, to increasing primary productivity fed by increased introduction of nitrogen and phosphorous to the lake. A significant source of these nutrients is believed to be atmospheric deposition of various forms of N and P from anthropogenic sources. This study is part of a comprehensive effort to understand the nutrient sources, input pathways and major impacts of these nutrients on the lake.

During the summer and fall of 2002, an instrumented general aviation aircraft operated by UCD flew prescribed routes over the western Sierra Nevada and Lake Tahoe basin making air pollution and meteorological measurements. Additionally, during the winter of 2003, a research boat operated on Lake Tahoe with a similar instrument package. The objective of the aircraft flights and boat measurements was to collect data pertinent to the evaluation of the near-ground meteorological conditions over the western Sierra Nevada and Lake Tahoe basin and to document selected pollutant concentrations over the lake. These data will be useful input for estimating deposition of air pollutants to the lake. The instrumentation, field procedures, data processing and other relevant details of this effort, plus some general observations about the data, are the subject of this report.

AIRCRAFT INSTRUMENTATION

A compact high-quality instrumentation system has been developed at UCD for installation on light aircraft. This instrumentation system, coupled with a self-contained, commercially purchased, meteorological sensing system was used on a Cessna 182 for this research project. The instrument package deployed for this study is listed in Table 1 and includes an Aircraft Integrated Meteorological Measurement Systems (AIMMS-10) unit that was attached approximately two-thirds of the way up the left hand strut of the aircraft. A 0.64 cm inner diameter Teflon tube that entered the cabin through the aircraft ventilation system provided ambient gas samples to the ozone analyzer. The Cessna 182 also utilized a 1 mm diameter metal tube, which pointed into the airflow, to feed air directly into a particle counter. This arrangement provided for isokinetic sampling at airspeeds of about 60 ms^{-1}. The particle sampling alarm triggered when the airspeed was greater than ~ 70 ms^{-1}or less than ~ 40 ms^{-1}. All of the sample intakes and the AIMMS-10 unit were located outside of the propeller slipstream and away from the engine exhaust system.

The intake for the oxides of nitrogen analyzer is a short length (< 10 cm) of 1.3 cm inner diameter Teflon tubing protruding outward, perpendicular to the right side cabin wall. The intake supplies two samples to the analyzer. One is an unaltered sample (NO) plumbed directly to the analyzer. The second (NO_y) enters a high temperature (> 300 ^{O}C) reactor located about 15 cm from the external sampling point, with the reactor outflow then plumbed to the analyzer. This inlet is within the propeller slipstream but is clear of the engine exhaust and beyond the aircraft surface boundary layer.

The AIMMS-10 unit provides airspeed, temperature, relative humidity, pressure (for deriving altitude), heading and Global Positioning System (GPS) location (for deriving winds). The primary meteorological, aircraft motion and position data from the AIMMS-10 system are of high quality and we found no inconsistencies or significant errors in these data. However, previous experience with the system has found that the wind data are not always reliable. The wind finding limitations of this instrument are described further in the "Data Reduction" section. The data from this unit, along with the output of the real-time analyzers, were recorded by a small personal computer. The data supplied by the AIMMS-10 unit are sampled at 16 Hz and output at 1 Hz. The data are recorded by the UCD logging system about every two seconds. Although recorded every two seconds, the ozone and nitrogen oxides monitors measure the sample gas over a longer period of time, and these data are essentially ten-second averages of the gas concentrations.

An annular denuder-filter pack system (DFP), shown in Figure 1, was used to collect gaseous and particulate nitrogen species. The inlet of the denuder system was located near the oxides of nitrogen analyzer inlet on the right side cabin window. This isokinetic Teflon inlet extended about 8 cm from the window facing forward into the relative wind. The inlet was connected, via a separating cyclone that removed particles greater than approximately 3.5 µm, to a pair of annular denuders (University Research Glass, Inc; hereafter URG), each with attached filter packs. Airflow through the system was provided by an engine-driven vacuum system. A valve system allowed the operator to select which of the two DFPs to use for sampling at two different altitudes.

BOAT INSTRUMENTATION

A UCD research boat was operated on Lake Tahoe for the purpose of taking samples with the denuder-filter pack system. The same instrument package used in the airplane was used on the boat with the exception of the AIMMS-10 device and the ozone analyzer. Temperature, relative humidity and GPS data were obtained using other measurement systems (see Table 1 footnote). The data logging system, particle counter and oxides of nitrogen analyzer were housed inside the boat cabin. The denuders, intakes for the NO/NO_y analyzer and particle counter, and the temperature and relative humidity probes were mounted on a platform attached to the boat's bow railing. This location was sufficiently high to prevent lake spray from contaminating the samples. To avoid contamination from the boat's exhaust, all sampling runs were made either into the wind or, if light winds, with the boat traveling fast enough to keep the exhaust from entering the sample inlets. (The boat exhaust stacks are located about two-thirds of the way from the bow to the stern.)

CALIBRATIONS AND QUALITY CONTROL

Periodic calibration of the ozone and nitrogen oxides analyzers was performed as shown in Tables 2 and 3, respectively. (These tables show the results of the calibrations. For details of each calibration see Appendix A.) A Dasibi 1008 PC transfer standard was used to calibrate the ozone analyzer. For calibrating the nitrogen oxides analyzer, a calibrator, which provides precise mixing of pure air with known concentrations of NO, was used. This calibrator is very stable and was itself calibrated on 1/4/00 at the College of Engineering-Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside. Full calibrations of the gas analyzers were performed periodically during the sampling program. Calibration factors from the full ozone and nitrogen oxides calibrations were applied to the data during post-flight processing. The ozone analyzer is set to record ozone concentrations 9 ppbv higher than actual to better identify the instrument zero, as any negative values reported by the analyzer would not be recorded in the data acquisition system unless an offset is used (Dasibi, 1990, Section 6.6.4). This offset was corrected during data processing and the final data set represents actual ambient values.

It has been noted in previous reports (Carroll and Dixon, 1999) that the NO_y concentrations recorded by the analyzers are dependent on the temperature and pressure in the reaction chamber. To determine the effect(s) of flying the instruments at altitudes higher than sea level, tests of the pressure dependency of the nitrogen oxides analyzers were performed in the past. This was done by filling a Tedlar bag with a known concentration of NO, as supplied by the calibrator, and then flying from the surface upward about 2000 meters and back while sampling the NO in the bag. It was found that the Cessna 182's analyzer showed increasing concentration values of NO and NO_y with altitude. Pressure correction factors computed from these test flights are applied to the data during the post-flight processing.

Calibration of the wind derivation feature of the AIMMS-10 device is completed by flying multiple box patterns in calm air or steady winds. The derived heading and airspeed corrections can then be applied to the data. Subsequent calibrations can detect any major deviations which are noted or applied. These calibration flights were made as a separate flight or at the beginning of a Tahoe flight. Separate calibration and instrument test flights are shown along with the routine sampling flights in Table 4.

Extracts from the DFP denuders and filter packs were analyzed using ion chromatography as described in a later section. During each set of analyses the ion chromatograph was calibrated using gravimetrically prepared standards of each ion, which were in turn compared with commercially prepared calibration check standards.

AIRCRAFT AND BOAT OPERATIONS AND DATA ACQUISITION

The aircraft and boat operations were conducted following standard operating procedures developed to minimize data loss and enhance safety during operations.

At the start of each flight period for the airplane, the sampling instruments were turned on and warmed up for about 45 minutes prior to departure. This assured that the ozone and nitrogen oxides analyzers were stable before sampling began. During this time the aircraft was prepared for flight. The denuder sampling tubes were assembled and installed in the aircraft during this preparation time. Pertinent information describing the upcoming flight was noted on a cassette tape.

Immediately before the aircraft took off, the sampling instruments were again checked and data recording was begun. The operator would note the time, file number, location and elevation of the departure airport on the cassette. During the flight, data were recorded in files of 20 to 50 minutes in length. These files automatically sequenced, thus freeing the pilot-operator to concentrate on flying. However, when practical, the pilot-operator would note on the audiotape the time, file number, location, altitude and other information at the beginning and end of each file or at other times deemed necessary. This information helped with the later processing of the data. Additionally, notes on turbulence, wind direction and speed, and the denuder sampling system were recorded.

Raw air quality data from the Cessna 182 were recorded in electronic files named according to the convention C-mm-dd-nn.RAW, where “mm” is the month, “dd” is the day and “nn” is the file number. These files have the format shown in Table 5A. Additionally, the AIMMS-10 data were downloaded to files named Rmmddttt.DAT where “mm” and “dd” are the same as in the .RAW files and “ttt” is the Pacific Standard Time (PST) (in hours and minutes) divided by ten.

Boat sampling operations were conducted on Lake Tahoe from 10/15/2002 to 3/7/2003. The samples taken on 10/15 and 10/16/2002 were denuder-filter pack samples only. Beginning on

January 24, 2003, NO, NO_y, particles, temperature, relative humidity, and GPS position were added to the boat operations. For these operations, the oxides of nitrogen analyzer was warmed up while the boat was being readied at the dock. After departing and clearing the harbor, the data logging system was started and then the denuder sampling began. Boat runs were initially about one hour in length. Later, the time was extended to two hours in order to increase the sample loading on the DFPs. The exact route of the boat cruise was often determined by the wind speed and direction so as to reduce the possibility of sample contamination from the boat exhaust.

The file naming format is the same as for the original (.RAW) aircraft data files. Since fewer variables were recorded, the file format is different and is shown in Table 5B. Table 6 summarizes the boat sampling operations.

DENUDER-FILTER PACK SAMPLE COLLECTION PROCEDURES

Working in the field with the denuder system required careful assembly and disassembly procedures to minimize any contamination of the denuders. Laboratory gloves were worn at all times during the handling of denuders. The assembly and disassembly of the system was always done in the most protected environment available. When working from the aircraft hangar or the trunk of the car, assembly was performed inside a plastic Tupperware container whenever possible. The denuders, caps, and other parts were kept in sealed plastic bags when being stored. Denuder caps from different denuders were kept in separate bags to avoid any potential cross-contamination. The period of time between the removal of a denuder cap and its coupling to another DFP component was kept to a minimum. This was especially important for the citric acid denuders (used to collect gaseous ammonia) which are most easily contaminated due to the relative abundance of ammonia in ambient air. The citric acid denuders were uncapped only when they could be immediately attached to the denuder train, with the minimum amount of open air exposure. Exposed denuder sections were capped, sealed in plastic bags and stored in a dry-ice containing cooler until analysis was performed at the UCD laboratory.

Field blanks of the denuder system were collected during each sampling episode. The denuder inlet coupling is designed to hold two separate DFP samples. When the field blank was installed in the airplane or boat, the opening for the second denuder sample was capped to prevent contamination. In addition, a plastic membrane sealed the intake nozzle. The vacuum hose was attached to the filter of the field blank, but the pump was not turned on. For the boat trips, a field blank was often left in the sampling setup for the entire run, but without drawing air through that denuder.

Airplane:

On Day 1 of a sampling period, the denuders were assembled in the UCD laboratory shortly before being placed in the airplane while it was being readied for flight at the UCD airport. After landing in Truckee, the airplane was refueled and parked in a hangar. Inside the hangar, the field blank was assembled and switched with the exposed denuders in the plane. The exposed denuders were disassembled and immediately stored in the cooler. The field blank was kept in the plane, in the closed hangar, for about one hour. In preparation for the afternoon flight, unexposed denuder sections were assembled in the hangar and the field blank was disassembled and placed in the cooler. Upon completion of the afternoon flight with denuder sampling, the plane returned directly to the hangar for disassembly and storage of the exposed denuder. (On flights before July 19, the plane was refueled prior to returning to the hangar for removal of the denuder.)

On Day 2 of monitoring activity, the assembly, installation, removal and disassembly of the denuders proceeded as on Day 1 with the following exception: the morning denuders and the field blank were assembled in the hotel room on a wooden table, instead of in the hangar, just prior to their transportation to the airport and installation in the plane. Also, for the flights before July 19, the afternoon denuder was removed from the plane and disassembled in Davis instead of Truckee. In all cases on Day 2, the exposed denuders and used field blanks in the cooler were transported by car to the UCD laboratory for analysis. During a sampling period, the containers holding both the prepared and exposed denuders were kept in either the hangar or the hotel room in order to be protected from direct sunlight and the potentially high temperatures in the trunk of the car.

Boat:

The boat denuder sampling differed from the airplane denuder sampling due to the absence of laboratory, hangar or hotel assembly options. In all cases, the denuders were assembled in the trunk of the car. However, temperatures tended to be much colder than during the summer sampling events. Morning denuders were assembled in the car trunk inside the plastic container. They were placed on the boat and deployed within about 20 minutes. Upon returning to shore after the morning run, the field blank was assembled in the trunk and placed on the boat. The morning denuders were disassembled in the trunk and placed in the cooler. Due to time constraints between runs, the field blank only remained on the docked boat for about 15 minutes. After this time, the afternoon denuders were assembled in the trunk. These denuders then replaced the field blank, which was disassembled in the trunk and placed in the cooler. In addition to this field blank, a second field blank was left on the boat attached to the sampling system during most sampling runs, but without drawing air through this part of the system. At the end of the afternoon runs, the boat was refueled before returning to its dock. Upon docking, the denuders were disassembled in the car trunk and placed in the cooler. Shortly after, the samples were transported back to the lab in Davis.

DENUDER-FILTER PACK PREPARATION & POST-SAMPLING PROCESSING

Each DFP contained two denuders in series followed by a filter pack containing two filters. The first (upstream) denuder collected gaseous nitric and nitrous acids (HNO_3 and HNO_2, respectively), while the second collected gaseous ammonia (NH_3). The upstream denuder was coated with 1% K_2CO_3 in a 50:50 mixture of methanol and water. The second (ammonia collecting) denuder in each set was coated with 1% citric acid in methanol. Denuders were prepared by adding 10 ml of the coating solution to the denuder, shaking gently, pouring out the excess solution, and drying with purified air. To minimize contamination, denuders were prepared within 36 hours of the start of sampling.

The filter pack of each DFP contained a Teflon filter (Zefluor, 2 μm pore size) to collect fine particles (< 3.5 μm approximately), followed by a Nylon filter (Nylasorb, 1 μm) to collect any HNO_3 that volatilized from particles on the upstream Teflon filter. All filters were 47 mm diameter and were pre-cleaned by repeatedly shaking in Milli-Q water followed by rinsing with copious amounts of Milli-Q. After preparation, denuders and filter packs were capped and kept in sealed plastic bags until immediately prior to deployment on the aircraft or boat.

As soon as possible after each flight, the DFP components were brought to the laboratory and extracted. Denuders were extracted with 6.0 ml of purified water (Milli-Q), while filters were extracted by shaking (3 hours at ~ 4 °C) in high density polyethylene bottles containing Milli-Q. For the Teflon filters, one half was wetted with 100 μl ethanol and extracted with 4.0 ml Milli-Q water (for inorganic N and P analyses), while the other half (for organic N and P analyses) used the same procedure without ethanol (because ethanol would interfere with the organic analyses). Nylon filters were extracted with 8.0 ml of Milli-Q. Filter extracts were not filtered since they contained no discernable particles.

Concentrations of NH_4^+, NO_3^-, NO_2^-, K^+, SO_4^{2-} and PO_4^{3-} were analyzed using a Dionex DX-120 ion chromatograph with conductivity detection. Organic nitrogen (ON) was determined as the difference in inorganic N concentrations in a given sample before and after adjustment to pH ≈ 3 and illumination with 254 nm light (to convert ON to inorganic forms) (Zhang et al., 2003). Since Teflon filter extracts were not filtered, reported concentrations of particulate ON include both water-soluble species and some portion of the less soluble species.

Atmospheric concentrations of gaseous NH_3 were calculated based on the amount of NH_4^+ collected on the citric acid denuder. Concentrations of gaseous HNO_2 and HNO_3 were calculated based on the amounts of NO_2^- and NO_3^-, respectively, collected on the K_2CO_3 denuder. Since a portion of NO_2^- might have been converted to NO_3^- on this denuder during sampling (e.g., by reaction with ozone), reported values of HNO_2 might be underestimated and HNO_3 overestimated. Concentrations of gaseous ON were calculated as the sum of the corresponding species on both denuders. Because the denuder coatings used here likely had low collection efficiencies for neutral or weakly acidic/basic gasses, reported concentrations of gaseous ON might be underestimated. Atmospheric concentrations of fine particulate species were calculated based on the concentrations on the Teflon filters. Concentrations of N on the downstream Nylon filters were not significantly different from field blank values, or were below detection limits, indicating no apparent evaporation of particulate nitrate. Thus results from the nylon filters are not discussed further in this report. For all gaseous and particulate species, the reported concentrations are the calculated sample value minus the corresponding average blank value for that species. Because of differences in handling, airplane and boat samples were treated separately, with separate sets of corresponding airplane and boat field blanks (and separate corresponding averages).

FLIGHT PATTERNS

The aircraft flights were designed to look at various meteorological conditions in the Tahoe basin but included information over the western Sierra Nevada. A typical sampling episode consisted of two days. The standard flight routes for the sampling initially consisted of two flights per day but were increased to three flights after July 19 in order to characterize the conditions in the late afternoon over the crest of the Sierra. After this date the flight patterns were finalized in consultation with ARB personnel. The typical flight paths within and around the Tahoe Basin are shown in Figure 2 and were as described below.

Day 1:
The first flight would depart Davis around 7:45 PST[1] and fly over Sacramento, approximately along Highway 50, at 915 m above Mean Sea Level (MSL). Nearing Cameron Park, a slow (100 m/min) climb would be initiated and the heading would be directly toward Big Hill. This climb rate would allow the sampling to continue at about 450 m above ground level (AGL) while flying up the Sierra slope. At Big Hill the climb rate would be increased and a box pattern sounding would be flown over this location. A traverse to Loon Lake at 3,660 m MSL would commence after the Big Hill sounding. At Loon Lake, a descending sounding would be flown before climbing up to 3,350 m MSL en route to Lake Tahoe. A third sounding was flown over the middle of the Lake. Subsequent to these soundings, two constant-altitude circuits of the lake were made at 2,380 m and 2,070 m MSL (i.e., 490 m and 180 m above the lake surface). During

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[1]All times in this report are in PST and 24-hour format, unless otherwise stated.

these circuits, the denuder sampling system was run for about 35 minutes on each denuder. In between these two circuits, a transect was made including a descent from 2,380 m MSL over the south shore of the lake to the surface of the Tahoe Valley Airport (TVL, el. 2017m MSL) and then a climb southbound toward Echo Summit before returning to the lake shore. To conclude the flight, an ascending sounding over the middle of the lake to 2,900 m MSL was made prior to returning to the Truckee airport around 11:00 PST.

Flight number two departed Truckee airport around 13:00 PST with a climb to 3,350 m MSL at Lake Center. A sounding to the surface was made, similar to the third sounding in the first flight, and the remainder of the flight proceeded as did the first flight with the collection of two denuder samples and a traverse via TVL. Landing occurred around 15:30 PST.

Flight number three departed Truckee at 17:00 PST and returned at 18:30 PST (16:00 PST to 17:30 PST after 9/4/02). The flight proceeded to 3,350 m MSL over the middle of Lake Tahoe, followed by a descending sounding to the surface. After a traverse at 150 m to 305 m AGL to Loon Lake, an ascending sounding was made to 3,660 m MSL. The flight continued to Big Hill at this altitude before descending toward the surface. Then a return to Truckee was made at 2,900 m MSL.

Day 2:
This day began with an 8:00 PST departure from Truckee to Big Hill while climbing up to 3,660 m MSL. A descending sounding was made at Big Hill followed by a traverse to Loon Lake at 150 m to 305 m AGL. After climbing to 3,660 m MSL over Loon Lake and then traversing to the middle of Lake Tahoe, the flight proceeded as on Day 1 with two denuder-filter pack samples collected over the lake and a traverse to TVL.

Flight number two was identical to the second flight conducted on Day 1.

Flight number three was flown along the same path as the third flight on Day 1 until the sounding at Big Hill. After the descent, a southwesterly course was flown toward Davis at about 305 m AGL until reaching 915 m MSL. Over Sacramento, a descent was initiated followed by a landing at Davis.

Exceptions:
The above flight patterns describe the planned, and generally flown, flight itinerary. Small variations were made according to sampling conditions and can be seen in the data. For example, on days when the top of a sounding still had the aircraft sampling in hazy conditions, continued ascent for a hundred meters or so would usually allow the flight to clear the boundary layer and sample ‘clean air.’ Larger deviations from the flight plans, due to adverse weather or other

problems are noted in the flight logs and summarized in Table 4.

Before July 20, the two flights per day were similar to the above mentioned first two flights with the following exceptions: No soundings were made at Big Hill. The first flight up from Davis made its first sounding at Loon Lake. The second flight of the day began with a sounding at Loon Lake in addition to the sounding over the middle of the lake. On Day 2, after finishing the denuder samples and ascending to 2,900 m MSL over the lake, no further soundings were made. Instead, a slow descent over the western Sierra was made while returning to Davis.

The sampling on October 15 and 16, 2002 was made in connection with a boat-deployed denuder system, so the flight plans varied significantly on these two days. The main part of the first two flights on each day consisted of flying over the boat at an altitude of 2,070 m MSL while the boat tracked outbound (easterly or northeasterly, depending on wind and wave conditions) from Tahoe City. While over the boat, both the plane and boat ran the denuder sampling systems for about 50 minutes. The first flight of each day also included soundings at mid-lake, Big Hill and Loon Lake. A sounding at the middle of the lake and a traverse via TVL were included in each of the second flights of the day. The third flight on both days was the same as the standard flight plans.

DATA REDUCTION

The aircraft audio tapes were transcribed into text files for each flight and hard copies were printed. These files contain the time, altitude and file number for each pertinent comment during a flight as well as other relevant comments. Interactive programs were used for data reduction and processing. During data processing using these programs, the instrument calibration factors are applied to the data. Additionally, any missing data or known errors in the data are marked as invalid.

The AIMMS-10 instrument's wind speed and direction information require careful examination to retrieve valid data during the data reduction phase. First, the wind data are valid only during straight flight. While the system automatically stops updating the wind direction and speed data whenever it detects a turn, use of the system has shown that speed and direction information often are still erroneous several seconds after the completion of a turn.

Secondly, the wind computation method magnifies any aircraft heading or airspeed errors. The wind-finding technique of the system computes the difference between the apparent motion of the aircraft with respect to the ground (based on its true airspeed and true heading) and the actual motion as determined from the GPS data. Since the typical wind speeds (< 10 ms^{-1}) are much smaller than the airspeed (~ 50 ms^{-1}), small errors in either the measured airspeed or in the measured aircraft heading can introduce large errors in the wind calculation. Two figures demonstrate this. Figure 3 shows the errors in wind direction and speed as a function of angle between the heading and the wind direction introduced with a small (2 degree) error in the reported aircraft heading. Figure 4 shows that the magnitude of the wind direction error is greatest with light winds and decreases with increasing wind speed. The error in wind speed is relatively small, being less than about 1.2 times the air speed error. Note that these errors also depend on the ratio of the wind speed to the air speed. Further discussion of this error analysis can be found in Carroll and Dixon, 2002. While the directional errors can be large when wind speeds are low, the variability of the real wind direction is also large when winds are light. Hence the AIMMS-10 wind data when the winds are light show a similar condition of light and variable winds. As wind speeds increase, the real wind directions become more uniform as do the AIMMS-10 winds. As long as these limitations of the method are recognized, the wind data can be used to understand the general wind conditions for a particular sounding.

During the data processing, the above limitations have been considered. The final reported data set flags any suspicious wind speed and direction data as invalid. Final data are in files of the name C-mm-dd-nn.CWT for the both the airplane and the boat where "mm" is the month, "dd" is the day and "nn" is the file number. The file format is shown in Table 7A for the airplane and 7B for the boat. These continuous, real time data have been delivered to the ARB on CD-ROM in CWT files along with a program for viewing the data in either text or graphical form for each platform. The DFP data are contained in a spreadsheet similar to Table 9. This CD-ROM contains the sequential files as named above for viewing. Additionally, subdirectories contain the data for specific locations or times (e.g. denuders, Lake Center). The files in these subdirectories use the same naming format as above except that the "C" is replaced with a designator for the operation being conducted (e.g. Big Hill = BH, lower altitude denuder sample = Lo), and the data in each file roughly corresponds to the original file of the same number.

Summaries of the average aircraft conditions during denuder sampling are shown in Table 8. Table 8A shows the averages for the denuder sampling made at the higher altitude over the lake (~ 2,380 m MSL) and Table 8B shows the averages for the lower altitude sampling (~ 2,070 m MSL). Table 8C lists the average vertical gradients between the two altitudes as well the average wind observed at 2380m MSL. The averaged 2003 boat data are listed in Table 10.

RESULTS

To meet the objectives of this project, we dedicated 27 days of field operations to the Lake Tahoe area. Standard aircraft sampling was conducted during nine, two-day periods and one,

one-day period in July to October 2002. Aircraft-boat inter-comparison samples were taken on two days in October 2002. Sampling from the research vessel occurred on six days during January to March 2003. While some problems were encountered (see Table 4), we experienced a high data recovery rate and relatively few instances of lost continuous (real time) data. A total of 96 denuder-filter samples were obtained. Of these, 82 were aircraft, in-basin samples, 10 were winter boat samples and 4 were aircraft-boat comparison samples. Analyses of the aircraft denuder-filter samples were also successful except for the period July 17 through September 5 when the filter (particle) samples were plagued by high blank values, which (apparently randomly) ranged up to hundreds of times greater than the typical levels. Because the blank results suggest that some fraction of the filters were contaminated of this problem we consider the particulate samples unusable during this period. However this is of minor significance for the N budget since, on average, particulate N only accounted for ~ 20% of the total N collected in the other aircraft samples. Inexplicably high constituent levels plagued both the filter and denuder blanks from the 2003 boat sampling, although not for the 2002 boat samples. As a result, we do not report concentrations of gaseous or particulate N (or other DFP species) from the 2003 boat samples. In addition, due to high filter blank levels of phosphorus and potassium throughout the sampling campaign, these elements are not reported for either the aircraft or boat samples. (During a previous, shorter campaign in the summer of 2001 we found that P levels were typically 2 – 3 nmol P m^{-3} above the lake, as described in Zhang et al., 2002.)

Sampling was conducted under different meteorological conditions, allowing some insight into which conditions lead to high atmospheric concentrations of measured pollutants in the Tahoe Basin. By design, the measurements reported here are daytime only: morning periods to evaluate conditions prior to development of local and regional upslope flow, and mid-afternoon when these flows are expected to be well developed. The late afternoon flight to the west of the basin is intended to evaluate the influx of pollutants from the Central Valley that would occur if strong upslope flow developed over the western slopes during the day.

Aircraft Data:

Table 8 lists the averaged conditions measured by the real-time samplers during the periods of denuder-filter sampling over the lake: 8A is for the higher altitude samples (490 m above the lake) and 8B is for the lower altitude samples (180 m above the lake). These data were used to compute the vertical gradients between 180 and 490 m listed in Table 8C. Also listed in Table 8C are estimates of the wind using the AIMMS wind data for the higher altitude transects. The vertical gradients show general agreement with what one would expect – higher during the more stable times of day and with light winds - but there are some exceptions (e.g., the afternoon of August 6).

Concentrations of fine particulate N (and sulfate) from the filter samples are listed in Table 9A while levels of gaseous nitrogen species from the denuder samples are in Table 9B. Note that for the gas phase, concentrations are presented in two ways, nanomoles of N per cubic meter of air (nmol N m^{-3}) and ppbv N.

Using data from the higher altitude sample as the basis for comparison, as well as logged pilot observations, we can categorize the winds during our sampling days. Weak wind conditions (speeds < 2 ms^{-1}) were encountered during the periods July 10 - 11, September 11 - 12 and September 21 - 22. Strong winds (speeds > 12 ms^{-1}) were seen during September 4 - 5 and October 10. Monsoonal conditions (winds aloft from SE or SSE with high humidity and cumulus cloud development) occurred July 17-18. Other periods had the more typical light winds in the morning and moderate SW to WSW winds in the afternoon.

Based on the higher altitude transect averages, the extreme values of selected variables are:

Highest:

– Wind speed:	> 13 ms^{-1}	September 4-5, October 10
– Ozone:	~ 86 ppbv	July 31, August 1 and October 10
– NOy:	4.5 - 6.5 ppbv	October 10
– Haze:		July 31 and August 1
(Forest fire influences: July 10-11 and July 31-Aug. 1)		
– Particulate N:	48 - 54 nmol N m^{-3} (0.67 - 0.76 μg N m^{-3})	July 11, September 11, October 10 and 15
– Gas phase N:	210 - 320 nmol N m^{-3} (6.5 - 10 ppbv N)	July 10, August 28, October 10
– Air temperature:	> 27 ^{O}C	July 10 - 11
– Stability:	10 - 13 ^{O}C/km	July 10 -11 and September 21-22.

(Vertical potential temperature gradient = [T(490 m AGL)-T(180 m AGL)]/0.310 km)

Lowest:

– Wind speed:	< 1.5 ms^{-1}	July 11, September 12
– Ozone:	43 - 48 ppbv	September 5 and 17
– NOy:	~ 2 ppbv	September 17 and October 9
– Haze:		September 16-17, 22, and October 9
– Particulate N:	0.9 – 2.2 nmol N m^{-3} (0.01 – 0.031 μg N m^{-3})	September 21 – 22
– Gas phase N:	14 - 21 nmol N m^{-3} (0.42 – 0.65 ppbv N)	September 16 and 25
– Air temperature	< 8 ^{O}C	September 16
– Stability:	< -0.6 ^{O}C/km	August 6, September 17, October 10

(Vertical potential temperature gradient = = [T(490 m AGL)-T(180 m AGL)]/0.310 km)

Measurements of "haze", i.e., particle concentrations (PC1 and PC2), generally track well with the ozone and NOy data. These particulate concentrations might also help identify non-photochemical sources of particles such as regional and local smoke plumes.

To examine temporal and spatial gradients among the three primary vertical sounding sites (Big Hill, Loon Lake and Lake Center), pollutant data were averaged for the lower part of the soundings at each site, i.e. below 2600m MSL. The differences between the morning and late afternoon near ground concentrations of ozone, NOy and particles (d > 0.3 micrometers) are plotted versus date in Figures 6A-6C. Each plot shows the "% Difference" between the AM and PM samples on the 18 days for which paired AM and PM data are available at each location. This "% Difference" was calculated as [(Cpm-Cam)/(0.5*(Cpm+Cam)] * 100%, where "Cpm" and "Cam" are the concentrations of a given pollutant in the afternoon and morning, respectively. For Big Hill (Figure 6A) and Loon Lake (Figure 6B), afternoon concentrations of ozone and NOy are nearly always higher than morning values, and the same is generally true for particles. The exception is the October 9-10 period during which NOy and particle concentrations increased significantly during the day on the 9th and decreased somewhat on the 10th. A similar, but not exactly the same, pattern is seen for the Lake Center (Figure 6C) but the magnitudes of the fluctuations are smaller. As described later (in the DFP "episodes" section), DFP and meteorological data indicate that on October 10 a flush of pollutants from the Central Valley was transported to the Sierra-Nevada and Lake Tahoe.

Figures 7A-7C show the spatial differences in the near ground averaged data for the morning soundings plotted versus date. With the exception of the particle concentrations on September 25 (when a slash fire or control burn was emitting smoke about 6 km west of Loon Lake), the morning pollutant differences between Big Hill and Loon Lake are generally relatively small and are as likely to be positive as negative (Figure 7A). The differences between these western sites and the Lake Center are larger but also both positive and negative in the morning (Figures 7B and 7C). Note that on October 9, the morning particle and NOy concentrations were much higher over the lake than at the sites to the west, and conversely on October 10. Figures 8A-8C show the differences in pollutant levels at the three different locations for the afternoon soundings. On most days, Big Hill was more impacted than Loon Lake (Figure 8A), while both western sites (Big Hill and Loon Lake) were nearly always more impacted than the Lake Center (Figures 8B and 8C). In part we believe that this is because the eastward transport of polluted valley air is generally limited because the near ground wind reverses from a daytime valley wind to an evening mountain wind (as is regularly seen at stations like Blue Canyon in the late afternoon). Hence during conditions of weak synoptic forcing when Central Valley air quality degrades, this flow reversal limits the impact of these elevated pollutant loads on the Tahoe Basin. However, it is also possible that the pollutant levels at Lake Center are generally lower than those at Big Hill and Loon Lake because of dilution during transport into the Tahoe Basin.

The average concentrations of NOy and ozone measured during the DFP sampling periods over the lake are shown in Figure 9A for the higher altitude segments. Also plotted are the extreme (maximum and minimum) values of NOy during the DFP exposure periods. Note that here the morning and afternoon data are plotted on the same graph, giving two data points per day. The NOy data were highly variable, with local maxima that were several times the generally low mean value. Given the high maxima and low mean NOy concentrations, it is clear that the high NOy values encountered were of limited spatial extent. Examination of the time plots of individual runs showed most of these to be narrow plumes of high NOy concentrations near areas of high vehicular traffic, such as near Tahoe City or South Lake Tahoe. The ozone data at 2380 m MSL (Figure 9B) show a larger variation in mean values between days than did NOy, but generally lower variability in the maxima and minima compared to NOy. Another difference between the ozone and NOy data is that the ozone maxima and minima are more symmetric about the mean. Data for NOy and ozone at the lower DFP sampling altitude (2070 m MSL; Figures 9C and 9D, respectively) are very similar to the corresponding data from higher altitude discussed above. As mentioned earlier, vertical gradients in NOy and O_3 between these upper and lower DFP sampling altitudes are listed in Table 8C.

Blank-corrected nitrogen concentrations measured on the DFP filters and denuders are tabulated, along with statistical summaries, in Tables 9A (particulate data) and 9B (gaseous data). The corresponding blank levels of each N species in the DFP assemblies are given in Tables 9C (particulate) and 9D (gaseous). As shown at the ends of these latter two tables, the mean sample/blank ratios were quite good (2.5 – 3.7) for the dominant N species (i.e., NH_3, HNO_3, NH_4^+, and NO_3^-). Sample/blank ratios for the less abundant N species (nitrite, nitrous acid and organic nitrogen) were significantly smaller, a result of lower concentrations in the samples (especially for NO_2^- and HNO_2) and higher blank levels caused by the more complicated analyses for gaseous and particulate ON. Therefore, we consider concentrations of these less abundant species to be qualitative, although some of the higher ON values are probably more accurate than this. Because blanks were handled and analyzed in the same way as samples, the blank statistics can be used to estimate the uncertainties associated with the sample values. Assuming that the samples have standard deviations similar to those of the field blank averages, we estimate that standard deviations for gaseous NH_3, HNO_3, and organic nitrogen in the aircraft samples are 12.7, 4.9, and 15.2 nmol N m^{-3}, respectively. Similarly, for aircraft particulate ammonium, nitrate, and organic nitrogen we estimate standard deviations of 2.4, 0.7, and 14.3 nmol m^{-3}, respectively. Because concentrations of HNO_2(g) and NO_2^-(p) were very low and variable, we are unable to estimate meaningful standard deviations for these species. It should be noted that these standard deviations are an estimate of the uncertainty associated with our sampling and analysis and do not reflect the (much larger) inter-sample variability in actual N concentrations in the air above Lake Tahoe.

Figure 10 graphically shows the data listed in Tables 9A and 9B, i.e., the speciated gaseous and particulate N concentrations measured using the denuder-filter pack equipment. Two points are clear from this figure: (1) concentrations of atmospheric nitrogen above the lake are quite variable (with total N concentrations ranging from 30 to 360 nmol N m^{-3}), illustrating the complexity of air quality in the Tahoe basin and (2) gaseous species, especially ammonia, account for most of the N above the lake. This latter point is illustrated more clearly in Figure 11, which shows the N distribution for the 2002 campaign as well as results from a smaller, but otherwise similar, sampling campaign carried out in the summer of 2001. Note that the average total N (TN) concentrations in these two summers are very similar: 124 ± 76 nmol N m^{-3} in 2002 and 140 ± 33 in 2001. Furthermore, the N speciations in the two campaigns are nearly identical: approximately 65% NH_3 and NH_4^+, 20% HNO_3 and NO_3^-, 14% organic N, and 1% HNO_2.

As shown in Figure 12 (top panel), the denuder-filter data show frequent vertical gradients in gaseous HNO_3. Excluding one outlier, in 31 out of 38 cases (i.e., flights), the HNO_3 concentration at 180 m above the lake (2070 m MSL) is greater than that at 490 m above the lake (2380 m MSL). This vertical gradient is most pronounced during the morning flights, where the higher altitude HNO_3 concentration was greater than the lower value in 90% (18 out of 20) of the flights. The average (± 1 σ) concentration ratio (2070 m value / 2380 m value) for all 38 flights is 0.76 ± 0.32; the corresponding morning value is 0.63 ± 0.32, while the afternoon value is 0.90 ± 0.25. These results suggests that there is a significant, lower altitude, likely in-basin, contribution to total HNO_3 from local sources such as the oxidation of NOx emitted from vehicles or biomass combustion. In the case of gaseous ammonia, which dominates the N budget at the altitudes sampled here, the data show, overall, no vertical gradient (Figure 12, bottom panel). Excluding one outlier, 21 out of 38 flights (55%) had higher NH_3(g) levels at 2380 m compared to at 2070 m, with an average ratio (2380 m value / 2070 m value) of 1.26 ± 1.15. In contrast to nitric acid, the morning and afternoon values of this ratio were similar (1.10 ± 0.90 and 1.43 ± 1.38, respectively). However, if we consider only the flights with above-average NH_3 concentrations (i.e., those where the average ammonia concentration at the two altitudes is greater than the mean value for all flights) there is some evidence of a vertical gradient. In this subset of the data 11 of 16 samples (69%) had a ratio greater than 1 and the overall average ratio (2380 m value / 2070 m value) was greater than unity but not statistically significant (1.64 ± 1.38). The morning and afternoon ratios in these higher concentration samples were 1.27 ± 0.87 and 2.00 ± 1.74, respectively. These data hint that there might be significant out-of-basin sources of ammonia (e.g., from Central Valley agriculture) but more work needs to be done to examine this.

Investigation of three episodes:

As described earlier, Figure 10 shows that concentrations of N above Lake Tahoe can be highly variable from day to day, and even in some cases from the morning to afternoon on the same day. To explore the factors responsible for air quality above the lake, we examined the DFP data, along with meteorological and other information, for three of the "episodes", i.e., consecutive 2-day sampling periods, during our campaign.

The first episode consists of our first two days of sampling, July 10 and 11. Concentrations of N on 10 July were among the highest measured (Figure 10), with an average total N of 290 ± 71 nmol N m^{-3}, while the average on 11 July was approximately one-half as large (150 ± 46 nmol N m^{-3}). On both days ammonia/ammonium was the dominant species, accounting for an average of 83% and 74% of TN, respectively, during the first and second days of the episode. Temperatures were very high on both days, ranging from 24 – 30 °C as measured by the airplane during the DFP sampling. NOAA HYSPLIT 4-day backward air trajectories, in conjunction with surface and 850 mbar weather charts, suggest that there was a regional pollution event from 08 – 10 July and that at Tahoe this was diluted with flow from the north and northeast on 11 July. Furthermore, the pilot observed a small fire burning within the Tahoe basin, south-southeast of the lake; this could have also contributed significantly to the N concentrations above the lake during this regional pollution episode.

The second episode we examined occurred on 11 and 12 September. As shown in Figure 10, pollutant levels on these days were moderate: total N increased from an average of 116 (± 9) nmol N m^{-3} on the 11^{th} to 160 (± 40) nmol N m^{-3} on the 12^{th}. More striking was the large shift in N speciation, where the organic nitrogen contribution approximately doubled, from an average of 19% on the first day to 43% on the second day. HYSPLIT back-trajectories indicate that the air on these two days was from southern and southwest Oregon, with a stronger influence from the latter on the 12^{th}. This is the same region where the massive Biscuit fire was burning at the time. This Oregon fire, which burned from 13 July to 09 November and was contained on 05 September, burned approximately 500,000 acres of forest in southwest Oregon. Our previous results (Zhang et al., 2002) suggested that organic nitrogen can be a tracer for aged forest fire emissions. These past results are consistent with this 2002 episode, especially on the second day, where it appears that emissions from the Biscuit fire contributed to N concentrations in the air above Lake Tahoe. It is likely that this Oregon fire (or other forest fires) also added to the atmospheric nitrogen burden above the lake during some of the episodes in July and August that have spikes in organic N (Figure 10). Indeed, on four days during this period the pilots observed smoke in the area (Table 4).

The final episode we examined occurred on 09 and 10 October (Figure 10). Over these two days there was a dramatic increase in total N concentration, from an average TN of 54 ± 17 nmol N m^{-3} on 09 October to 230 ± 17 nmol N m^{-3} on the 10^{th}. This quadrupling of N levels was accompanied by a large shift in N speciation to become ammonia-dominated. On the first day of the episode, NH_3/NH_4^+ and HNO_3/NO_3^- accounted for an average of 47% and 42% of TN, respectively, while on the second day these species contributed 70% and 20%, respectively. Back-trajectories and local wind records (from the Coast Guard pier in Tahoe City) both suggest that the second day of this episode represented a "flush" of polluted air from the Central Valley to the Tahoe area. This interpretation is also consistent with CARB ozone data from three relevant sites (Folsom/Natoma (F/N), Cool, and South Lake Tahoe (SLT)). The CARB data show that on 08 – 09 October there were midday peaks in ozone at F/N and Cool of ~ 80 – 90 ppbv, while midday ozone at SLT on these days peaked at ~ 50 ppbv. Starting during the evening of 09 October and running through 10 October (i.e., during the flush), the levels of ozone at F/N and Cool decreased while the concentration at South Lake Tahoe increased. By the afternoon of 10 October, ozone at SLT (~ 65 ppbv) was greater than that at Folsom or Cool (~ 40 – 50 ppbv). By the morning of the next day, however, O_3 levels at all three locations were very low (~ 10 – 20 ppbv), indicating that the Central Valley pollution had been pushed out of the Tahoe basin.

2002 Boat data:

On 15 and 16 October we simultaneously collected DFP samples on the aircraft (at 2070 m) and from a boat in the lake (with inlets at approximately 2 m above lake level). DFP blanks for these boat samples were similar to those collected during our aircraft sampling, unlike the 2003 boat blanks (described below), which were significantly higher. Because of this similarity, the 2002 boat blanks were included with the 2002 aircraft blanks (e.g., in Tables 9C and 9D). Since the boat was not instrumented with the other (real-time) analyzers present in the plane, we can only compare DFP results between the two platforms.

As shown in Figure 10, levels of total N in the simultaneous airplane and boat samples were nearly identical for three of the four pairs of samples taken. In the one exception (morning of 16 October), the TN level on the boat (180 nmol N m^{-3}-air) was more than twice the level measured by airplane (67 nmol N m^{-3}-air). There is no clear pattern in the nitrogen speciation on these two days. On October 15 the speciation is highly variable, with different species dominating in different samples, while on the 16^{th} gaseous ammonia is dominant in all four samples (accounting for ~ 50 – 80% of TN) while HNO_3 contributes ~ 10 – 40% of TN. Because of the similarity between these boat data and the simultaneous aircraft data, we have included the four 2002 boat samples with all valid aircraft data (e.g., in Figure 10, Tables 9A – 9D, and in the statistical summary of the data).

2003 Boat data:

Real-time analyzers for NO, NOy and particles were run on the research boat (with inlets at a height of approximately 2 meters above the lake surface) on six sampling days during January – March of 2003. A summary of the data is presented in Table 10. Several problems occurred during these deployments. Prior to March, the GPS receiver was unable to obtain fixes so no position data are in the data stream for the January and February runs. Beginning on the afternoon of February 5, the counts for particles greater then 3 micrometers in diameter (PC2) were no longer available; the total count of particles > 0.3 micrometers (PC1) appears unaffected. The weather differed considerable among the various days, especially with respect to the wind speed and direction, forcing different sampling routes to be followed so that the sampled air flow was predominantly from in front of the bow. Also, unlike the 40 - 60 minute exposure times for the aircraft samples, after the first samples we increased sampling periods on the boat to between 100 and 120 minutes to improve the mass loading on the DFP samplers. Despite this, most of the 2003 boat trips had high DFP blank levels relative to the samples. Therefore, we do not have confidence in the 2003 boat DFP results and do not report them here.

The route and weather conditions for each sample are summarized below. Times given are those when the DFP sampling system was activated.

1/24: Broken to overcast with cloud base ~ 1500m (5000') AGL, calm winds with a glassy lake surface. Route: afternoon (14:04 – 15:00 PST) from the Tahoe City Marina eastward to a point about 1 mile south of State Line Point, then southward about 4 miles, then return to Tahoe City Marina.

1/26: Winds calm with fog (visibility ~ ½ mile), improving and clearing by 1230 PST. Weak north wind developed by noon, hazy all quadrants and low clouds along the west shore. Routes: Morning (10:56 – 11:57 PST) Sample 1: traveled due east from about ½ mile off Tahoe City Marina to 1 mile west of Sand Harbor; Afternoon (12:24 – 13:25 PST) Sample 2: Traveled westward from about 1 mile off Cave Rock to Sugar Pine Point.

1/27: Early morning rain ending before 0800 PST. Cloudy with scattered showers, light SW wind. Route: (9:20 – 11:06 PST) eastward from point ~ 1 mile off shore from the Tahoe City Marina to about 2 mile west of Sand Harbor, then southwestward to Sugar Pine Point.

2/ 05: Morning, (11:27 - 13:20 PST) Sample 1: Clear to partly cloudy. Winds initially from east at 10 knots, calm around noon then ESE 10 to 15 knots after 1230 PST. Route: southward from Tahoe City for 3 miles, then NE to Carnelian Bay, then SE toward Glenbrook, then north along the eastern shore toward Incline Village, and return to Tahoe City.
Afternoon, (14:42 – 16:23 PST) Sample 2: Initially calm wind and glassy lake

surface. Light NNE breeze after 1530 PST. Route: Tahoe City to Cave Rock and return.

3/03: Scattered clouds, moderate SSW wind, scattered white caps on the lake surface all day. Light snow shower encountered 15:30 PST. Routes: Morning (10:52 – 12:51 PST) Sample 1: South from Tahoe City to Meeks Bay and return. Afternoon (13:40 – 15:40 PST) Sample 2: Southward from Tahoe City 3 miles then east 5 miles then very slowly WSW toward Meeks Bay.

3/07: Clear sky but hazy. Wind SW 10 to 15 knots, water choppy with many whitecaps all day. Routes: Morning (10:34 – 12:41 PST) Sample 1: Tahoe City southward to Sugar Pine Point, stop sample, traverse 5 mile NNE and restart sampling heading SSW return to Sugar Pine Point. Afternoon (13:51 – 15:47 PST) Sample 2: Tahoe City traveled very slowly southward to Sugar Pine Point.

SUMMARY AND CONCLUSIONS:

A total of 28 days were sampled during the course of this project: 20 days of aircraft sampling in the Lake Tahoe area during the summer of 2002, two days of combined aircraft and boat sampling during October 2002, and six days of boat sampling during the winter of 2003. Aircraft operations went well: there was only one mechanical problem with the aircraft during the operational period. The continuous (real-time) data had nearly 100% recovery and are of high quality for both the aircraft and boat operations. The denuder-filter samples gave good results for the major N components (ammonia/ammonium and nitric acid/nitrate), but only qualitative results for the less abundant species (nitrous acid/nitrite and organic nitrogen). Furthermore, because of high blank levels on filters, we do not report N particle data during the period of 07 July – 05 September or levels of P or K for any of the sampling. (Preliminary data on phosphorus concentrations from the 2001 campaign are described in Zhang et al., 2002.) Finally, while the four boat DFP samples collected during October 15-16, 2002 were valid (low blank levels), the 10 samples collected during 2003 had high accompanying blank levels and are therefore not reported here.

Over the lake during summer, the ranges of averaged measured constituents were: ozone 43 to 86 ppbv, NOy 2 to 6.5 ppbv, particulate N 0.9 to 54 nmol N m^{-3} and gas phase N 14 to 320 nmol N m^{-3}. Gaseous ammonia typically dominated the N budget (accounting for an average of 55% of total N) followed by nitric acid (~ 19% of the total N).

The multiple deployments allowed measurements in a variety of weather conditions and thus provided information on how pollutant concentrations varied among those conditions. Flight paths that included sampling over the mountains west (and usually upwind) of the lake allowed comparison of conditions there with those in the Tahoe basin near the lake surface. During the morning hours, differences in concentrations between these “upwind sites” and the basin showed no clear pattern. In the late afternoon, concentrations at the upwind sites were usually higher than in the basin. This is probably because during periods of weak synoptic scale wind flow the low level wind reverses from up slope to down slope in the late afternoon, limiting transport of highly polluted air into the Tahoe basin. In contrast, during periods of strong synoptic scale wind flow, pollutants from the Central Valley are clearly transported to the Tahoe basin, as seen during the 9 – 10 October episode.

The continuous data show no systematic, basin scale horizontal gradients of ozone, particles or NOy although small zones (< 1.5 km in width) of higher NOy and particle concentrations were occasionally encountered in the vicinity of the high vehicle traffic areas and major population centers such as South Lake Tahoe and Tahoe City. This suggests that local sources are not the major source of the pollutants measured over the middle of the lake. However, the vertical gradient observed in nitric acid, where levels at 2070 m were typically greater than at 2380 m, does suggest a significant, lower altitude, in-basin source of HNO_3, such as the oxidation of locally emitted NOx. In the case of ammonia, there is no clear vertical gradient, although in the higher concentration samples there is a bias towards higher concentrations at the higher sampling altitude.

In winter during boat sampling ensemble-averaged concentrations of particles, NO and NOy were higher than those seen in summer. One possible reason for this is that the lower mixing depths and lack of photochemical activity yield higher NOx concentrations just over the lake surface in winter. However, given the small number of boat samples taken, more work needs to be done in this area to characterize the air just above the lake surface.

Overall, this project successfully characterized the typical conditions of atmospheric N above the lake as well as the variability in these levels. Our results have also shown that ammonia/ammonium typically dominate the N budget above the lake, while nitric acid/nitrate and organic nitrogen are generally both important as well. Follow-up work is needed in order to model the transport of these (and other pollutants) from our sampling altitudes to the lake surface. Our results have also shown that air quality above Lake Tahoe is affected by many sources, and that the relative importance of these sources can vary rapidly. Based on our work, these sources include: (1) regional, large-scale, polluted air, (2) in-basin emissions, (3) the Central Valley, and (4) local and distant forest fires. The relative importance of these sources, especially on an annual average basis, is currently unclear.

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TABLE 1
UCD Instrumentation System

Variable	Sensor	Manufacturer	Useful Range	Accuracy
Pressure (Altitude)	AIMMS-10 Pitot-static and yaw probe	Aventech Research Inc.	- 150 to 8,400 meters MSL	0.3 mb (3 meters)
Temperature	AIMMS-10 Platinum RTD	Aventech Research Inc.	- 30 to 50 ^oC	~ 0.2 ^oC
Relative Humidity	AIMMS 10 Solid-state polymer	Aventech Research Inc.	0 to 100%	~ 2%
Airspeed	AIMMS-10 Pitot-static and yaw probe	Aventech Research Inc.	30 to 125 ms^{-1}	~ 1 ms^{-1}
Heading	AIMMS-10	Aventech Research Inc.	0 to 360 ^{o}	~ 2 ^{o}
Wind speed Wind direction	AIMMS-10	Aventech Research Inc.	0 - 50 ms^{-1} 0 - 360 degrees	Depends on wind speed.
Position	AIMMS-10 Global Positioning System (GPS)	Aventech Research Inc.	~ 90 ^{o} Latitude ~ 180 ^{o} Longitude	Position = 100 m (15 m with Selective Availability) Velocity = 0.2 ms^{-1}
Particle Concentration	Optical counter	Climet Model CI-3100-0112	Count for: PC1 (d > 0.3 μm) PC2 (d > 3.0 μm)	~ 2% of count
Ozone Concentration	U. V. absorption	Dasibi Model 1008 AH	0 to 999 ppbv	~ 3 ppbv
Nitrogen Oxides (NO,NO_y) Concentration	Gas-phase chemiluminescence	Thermo Environmental Instruments, Inc. Model 42C	0 to 200 ppbv	0.5 ppbv or 1% of reading. Linearity is ~ 1% of full scale.
Mass Flow	Heated Thermistor	Sierra Inc.	0-100 standard liters per minute (slpm)	~ 1%
Pressure[2]	Capacitive	Setra 270	600 to 1100 mb	~ 0.3 mb
Temperature[2]	Platinum RTD	Omega Engineers	- 20 to 50 ^oC	~ 0.5 ^oC
Relative Humidity[2]	Capacitive	Met One 083C	0 to 100%	~ 3% between 20 and 85%
Position[2]	Global Positioning System (GPS)	Garmin 10-05 Board Set	~ 90 ^{o} Latitude ~ 180 ^{o} Longitude	Position < 100 m

[2]These instruments were used only during boat sampling in 2003 in lieu of the AIMMS-10.

TABLE 2 Ozone Analyzer Calibrations		
Date	Slope	Intercept
09/25/01	1.013	0.7
06/20/02	1.009	0.9
07/09/02	0.990	0.6
07/29/02	0.981	2.2
08/19/02	1.012	0.5
09/13/02	1.002	1.0
09/24/02	1.014	0.5
10/22/02	0.994	1.3
07/15/03	1.027	0.1
Average	1.005	0.9
Standard Deviation	0.014	0.6

TABLE 3 Nitrogen Oxides Analyzer Calibrations			
Date	NO_y Slope	NO_y Intercept	Converter Efficiency (%)
09/25/01	0.958	-0.2	101.3
06/20/02	1.041	0.9	102.9
07/09/02	1.024	1.6	102.2
07/29/02	1.044	1.6	101.6
08/19/02	1.014	1.4	102.2
09/13/02	1.027	1.4	101.0
09/24/02	1.007	1.1	100.8
10/22/02	1.013	1.2	101.3
Average	1.016	1.1	101.7
Standard Deviation	0.027	0.6	0.7
01/23/03[3]	1.152	2.6	101.5
07/15/03	1.115	1.8	102.8

[3] Note: These calibrations were performed in our laboratory following removal of analyzer, converter and plumbing from the aircraft and removal of the calibrate gases and calibration system from the hanger. The calibration change is typical of the systems' responses to such changes and reinstallation. Hence, we separated these data from those obtained from the in situ aircraft calibrations.

TABLE 4
Overviews of 2002 Flights of UCD C182

Date	Purpose of Flight	Flt #	File #s	[4]Weather Characterization	Notes, Problems and Corrections made.
1/23	Test	1	11,12	Strong north wind.	AIMMS test.
7/02	Test	1	11,12		Denuder and instrument test.
7/05	Test	1	11		Instrument test.
7/10	Tahoe am	1	11-13	Record heat in Sacramento Valley and mountains. Light and variable winds at Tahoe and Truckee. Fire 40 miles SSE of lake. Light haze layers in the Tahoe basin.	Mass flow recording problems.
7/10	Tahoe pm	2	21-24		Mass flow recording problem. AIMMS battery problem.
7/11	Tahoe am	1	11-13		Mass flow recording problems.
7/11	Tahoe pm	2	21-23		Mass flow recording problems for first denuder sample.
7/17	Tahoe am	1	11-13	Monsoonal conditions. Winds aloft from SSE. Humid. Gradual build ups of Cu to CBs by 18:00. Fire 40 SSE of lake.	Mass flow recording problems.
7/17	Tahoe pm	2	21,22		Mass flow recording problems.
7/18	Tahoe am	1	11-13	Monsoonal conditions more unstable. AM flight OK. PM flight cancelled. CBs, hail, lightning, heavy rain Truckee area.	Mass flow recording problems.
7/18	Tahoe pm	2			Flight cancelled due to weather (thunderstorms).
7/19	Tahoe Rtn	1	11	Drier conditions this morning.	Sounding at Loon Lake and return to Davis. Blank denuder.
7/30	Test	1	11		AIMMS and denuder test.
7/31	Tahoe am	1	11-14	Very smoky with low visibility. Good afternoon winds from west and/or SW.	
7/31	Tahoe pm1	2	21-23		
7/31	Tahoe pm2	3	31,32		
8/1	Tahoe am	1	11-14		
8/1	Tahoe pm1	2	21,22		
8/1	Tahoe pm2	3	31,32		
8/2	Wind Box	1	11		AIMMS test.
8/5	Tahoe am	1	11-13	Conditions hazy but clearer in Tahoe basin. Smoky over Sierra slop. Strong SW-W winds both days. Very choppy, moderate turbulence.	
8/5	Tahoe pm1	2	21,22		
8/5	Tahoe pm2	3	31,32		
8/6	Tahoe am	1	11-13		
8/6	Tahoe pm1	2	21,22		
8/6	Tahoe pm2	3	31-33		
8/28	Tahoe am	1	11-14	Moderate haze. Warm. AM easterly winds at lake, PM westerlies. High late day ozone over Loon Lake and Big Hill.	
8/28	Tahoe pm1	2	21,22		
8/28	Tahoe pm2	3	31,32		
8/29					The Tahoe sampling flights on this day were cancelled due to the power inverter failure.
9/4	Tahoe am	1	11-14	Very windy from SW. Very turbulent.	
9/4	Tahoe pm1	2	21,22		
9/4	Tahoe pm2	3	31,32		
9/5	Tahoe am	1	11-13	Very windy and turbulent again. Flights over lake stayed in NE part of lake due to turbulence. Skipped Tahoe Valley airport in	
9/5	Tahoe pm1	2	21,22		

9/5	Tahoe pm2	3	31,32	afternoon flight.	
9/11	Tahoe am	1	11-14	Winds aloft are W to SW. PM winds at lake are W.	AM flight delayed one hour due to mechanical problem.
9/11	Tahoe pm1	2	21,22		
9/11	Tahoe pm2	3	31,32		
9/12	Tahoe am	1	11-13	Hazy over W Sierra slope.	
9/12	Tahoe pm1	2	21,22		
9/12	Tahoe pm2	3	31,32		
9/16	Tahoe am	1	11-13	Light winds, smooth air, good visibilities except in shallow moist polluted layer in SAC valley during AM.	
9/16	Tahoe pm1	2	21,22		
9/16	Tahoe pm2	3	31,32		
9/17	Tahoe am	1	11-13	Stronger W to WNW winds. Moderate choppy turbulence. Scattered fracto-Cu ~3,660 m and scattered cirrus.	
9/17	Tahoe pm1	2	21,22		
9/17	Tahoe pm2	3	31,32		
9/20	Test	1	11		AIMMS wind box.
9/21	Tahoe am	1	11-13	Light winds. Hazy with hot temperatures in Sacramento Valley and at Tahoe.	
9/21	Tahoe pm1	2	21,22		
9/21	Tahoe pm2	3	31,32		
9/22	Tahoe am	1	11-13		
9/22	Tahoe pm1	2	21,22		
9/22	Tahoe pm2	3	31,32		
9/25	Tahoe am	1	11-13	Hazy all around. Fire to W of Loon Lake.	
9/25	Tahoe pm1	2	21,22		
9/25	Tahoe pm2	3	31,32		
9/26	Tahoe am	1	11		Aborted flight after soundings at Loon Lake and Big Hill due to mechanical problem. No denuder samples taken.
9/26	Tahoe Rtn	2	21		Returned to Davis due to mechanical problem.
10/9	Tahoe am	1	11-13	Morning winds aloft are light from W.	
10/9	Tahoe pm1	2	21,22	Afternoon winds W at 10 to 20 knots.	
10/9	Tahoe pm2	3	31,32	High cirrus throughout day.	
10/10	Tahoe am	1	11-13	Morning winds aloft WSW 25-35 knots. High cirrus plus some altoCu and standing lenticulars. Turbulent over Lake. PM strong W winds. Hazy over lake. Lenticulars. Turbulent. Good Sacramento Valley clean out day.	
10/10	Tahoe pm1	2	21,22		
10/10	Tahoe pm2	3	31,32		
10/15	Tahoe boat am	1	11-13	Winds aloft SE-NE at 10-15 knots throughout episode. Some altocumulus with virga. Surface winds also easterly.	Over boat flight. One aircraft denuder.
10/15	Tahoe boat pm	2	21,22		Over boat flight. One aircraft denuder.
10/15	Tahoe pm2	3	31,32		
10/16	Tahoe boat am	1	11-13		Over boat flight. One aircraft denuder.
10/16	Tahoe boat pm	2	21,22		Over boat flight. One aircraft denuder.
10/16	Tahoe pm2	3	31,32		
10/18	Test	1	11		AIMMS wind box.

TABLE 5A Aircraft Data File Variable List for C-mm-dd-nn.RAW		
Header Variables Aircraft Type, Date, Time, File Number		
INDEX	VARIABLE	UNITS
1	Time	seconds[5]
2	Temperature	^{o}C
3	Relative Humidity	%
4	Pressure	mb
5	v wind component	ms^{-1}
6	u wind component	ms^{-1}
7	NO	ppbv
8	NO_y	ppbv
9	Ozone	ppbv
10	Particles d > 0.3 µm (PC1)	N $x10^6/m^3$
11	Particles d > 3.0 µm (PC2)	N $x10^4/m^3$
12	Event Marker	—
13	Latitude	degrees North
14	Longitude	degrees West[6]
15	Airspeed	ms^{-1}
16	Heading	degrees (magnetic)
17	Mass Flow	standard liters per minute
18	Aircraft Roll	degrees[7]
19	Aircraft Pitch	degrees
20	Navigation Code	—
21	AIMMS-10 Battery Voltage	volts

[5]Seconds past midnight (PST).

[6]West longitude is shown by positive values.

[7]Positive values are banks to the right. Negative values are banks to the left.

TABLE 5B Boat Data File Variable List for C-mm-dd-nn.RAW		
Header Variables Data Description, Date, Time		
INDEX	VARIABLE	UNITS
1	Time	seconds[8]
2	Relative Humidity	%
3	Pressure	mb
4	Temperature	^{o}C
5	NO	ppbv
6	NO_y	ppbv
7	Particles d > 0.3 µm (PC1)	N x10^6/m^3
8	Particles d > 3.0 µm (PC2)	N x10^4/m^3
9	Mass Flow	standard liters per minute
10	Event Marker	—
11	Latitude	degrees North[9]
12	Longitude	degrees West[5, 10]

[8]Seconds past midnight (PST).

[9]Of the form DDDMM.MMMM where DD = degrees, MM = minutes.

[10]West longitude is shown by positive values.

TABLE 6
Overview of 2002-2003 Boat Operations

Date	Period	File #s	Route[11]	Weather Characterization	Notes, Problems and Corrections Made.
10/15/02	am	n/a	TC E to buoys	Winds aloft SE-NE at 10-15 knots throughout episode. Some altocumulus with virga. Surface winds also easterly.	With aircraft. One boat denuder.
10/15/02	pm	n/a	TC NE to mid LT		With aircraft. One boat denuder.
10/16/02	am	n/a	TC NE toward CAL		With aircraft. One boat denuder.
10/16/02	pm	n/a	TC NE toward CAL		With aircraft. One boat denuder.
1/24/03	pm	11-14	TC east to between 1st and 2nd buoys and return.	Broken to overcast skies with glassy, calm lake.	Data logging system problems. No GPS data.
1/26/03	noon	11-13	D1 = TC east to Stateline buoy. D2 = CR to MB.	Calm with fog, initially. Later weak NNE breeze. South side sample, light N winds. Haze all quads.	No GPS data. 2 denuder samples.
1/27/03	am	11,12	TC east toward buoys then SW into wind.	Light SW wind and light rain showers increasing to SW wind with white caps forming	No GPS data. 1 denuder sample.
2/5/03	noon	11-15	TC east, SE, N then W.	11:30 = East wind ~10 knots. 11:52 = wind calm. 12:30 = ESE winds ~15.	One denuder sample.
2/5/03	pm	21,22	TC to CR and rtn.	Calm wind, glassy water with swells.	One denuder sample.
3/3/03	am	11,12,14	TC to MB and return	Moderate SSW wind. Scattered clouds.	One denuder sample.
3/3/03	pm	21,22	TC to MB, very slow boat speed	SSW wind. Few white caps. Ptly cloudy. Light snow shower near end.	One denuder sample.

[11] Location abbreviations are: CAL = Calneva, CR = Cave Rock, MB = Meeks Bay, TC = Tahoe City.

3/7/03	am	12,13	TC to Homewood.	Clear, a bit hazy. Wind strong from SW.	One denuder sample.
3/7/03	pm	21,22	TC to Homewood.	SW at 10-15.	One denuder sample.

TABLE 7A Aircraft Data File Variable List for C-mm-dd-nn.CWT		
Header Variables Aircraft Type, Month-Day-Year, File Number, Scan Number		
INDEX	VARIABLE	UNITS
1	Time	hours:minutes:seconds
2	Temperature	^{o}C
3	Relative Humidity	%
4	Pressure	mb
5	Altitude	meters MSL
6	Altitude	feet MSL
7	v wind component	ms^{-1}
8	u wind component	ms^{-1}
9	NO	ppbv
10	NO_y	ppbv
11	Ozone	ppbv
12	Particles d > 0.3 µm (PC1)	N $x10^6/m^3$
13	Particles d > 3.0 µm (PC2)	N $x10^4/m^3$
14	Event Marker	—
15	Latitude	degrees North
16	Longitude	degrees West[12]
17	Airspeed	ms^{-1}
18	Heading	degrees (magnetic)
19	Mass Flow	standard liters per minute
20	Aircraft Roll	degrees[13]
21	Aircraft Pitch	degrees
22	Navigation Code	—
23	AIMMS-10 Battery Voltage	volts

[12]West longitude is shown by positive values in the Cessna 182.

[13]Positive values are banks to the right. Negative values are banks to the left.

TABLE 7B
Boat Data File Variable List for C-mm-dd-nn.CWT

Header Variables
Data Description, Date, File Number, Number or Records

INDEX	VARIABLE	UNITS
1	Time	hours:minutes:seconds
2	Temperature	^{o}C
3	Relative Humidity	%
4	Pressure	mb
5	NO	ppbv
6	NO_y	ppbv
7	Particles d > 0.3 µm (PC1)	N $x10^6/m^3$
8	Particles d > 3.0 µm (PC2)	N $x10^4/m^3$
9	Mass Flow	standard liters per minute
10	Event Marker	—
11	Latitude	degrees North
12	Longitude	degrees West[14]

[14]West longitude is given as positive values.

TABLE 8A
Average Conditions During Denuder Sampling above Lake Tahoe at ~ 2,380 m MSL (~ 490 m above lake level)

Date	Start Time (PST)	End Time (PST)	Temp. (^{o}C)	RH (%)	Altitude (m)	Pressure (mb)	NO (ppbv)	NO_y (ppbv)	Ozone (ppbv)	PC1 (# x10^6/m^3)	PC2 (# x10^4/m^3)	Mass Flow (slpm)
7/10/02	09:19:49	09:53:52	24.8	12.6	2373.1	767.1	1.1	2.5	64.6	5.8	2.9	-99.9
7/10/02	13:44:45	14:08:28	27.2	10.3	2385.4	766.0	1.1	2.2	52.8	7.7	3.3	-99.9
7/11/02	09:22:55	09:54:16	24.2	16.1	2367.9	766.5	1.2	3.1	57.9	14.1	6.3	-99.9
7/11/02	13:25:08	14:01:15	27.2	12.0	2383.6	764.1	1.2	3.2	72.3	12.6	3.9	-99.9
7/17/02	09:02:48	09:39:18	16.9	37.3	2355.2	764.4	1.2	3.2	59.4	14.0	3.9	-99.9
7/17/02	13:34:56	14:06:13	17.3	40.5	2393.8	763.2	1.2	3.3	59.1	12.6	3.7	-99.9
7/18/02	08:42:46	09:16:01	14.7	55.8	2372.4	767.3	1.2	3.7	65.6	18.1	4.2	-99.9
7/31/02	09:04:53	09:43:47	18.6	23.1	2372.2	765.8	1.0	2.6	86.0	33.0	3.4	25.1
7/31/02	13:38:41	14:16:18	21.0	26.7	2376.9	765.4	1.0	3.1	83.7	40.5	4.2	31.8
8/1/02	08:53:13	09:59:24	17.9	35.8	2392.2	764.4	1.0	3.6	85.8	42.3	5.5	22.2
8/1/02	13:49:54	14:23:51	20.4	32.6	2393.9	762.4	1.1	3.4	81.9	39.2	4.0	29.7
8/5/02	09:06:01	09:40:58	10.5	32.5	2355.3	756.4	1.0	2.2	58.2	25.3	4.7	27.2
8/5/02	13:39:42	14:14:17	11.8	37.3	2434.5	757.0	1.0	2.9	61.7	32.3	8.1	28.9
8/6/02	08:55:06	09:31:08	10.7	35.6	2383.3	762.4	1.0	2.9	67.2	25.9	5.0	30.4
8/6/02	13:24:58	13:58:58	12.8	32.7	2385.6	762.5	1.0	3.1	73.7	32.3	8.7	27.7
8/28/02	09:27:16	10:00:29	13.7	35.6	2358.9	761.1	1.0	3.2	66.6	19.5	3.2	29.3
8/28/02	13:58:43	14:28:02	17.6	24.7	2388.4	760.0	1.0	3.0	75.6	24.5	4.0	28.1
9/4/02	09:04:32	09:37:06	12.5	43.2	2354.0	760.2	1.0	2.6	57.5	7.5	2.8	27.7
9/4/02	14:05:50	14:39:48	13.0	50.4	2391.4	762.8	1.1	3.0	54.9	11.6	4.4	30.0
9/5/02	09:11:30	09:45:38	11.0	45.3	2365.8	762.0	1.1	2.3	48.1	9.5	4.4	31.4
9/5/02	13:47:30	14:21:31	11.8	41.8	2376.7	762.8	1.0	2.3	48.9	10.9	6.6	29.3
9/11/02	09:54:55	10:29:40	15.6	17.3	2368.0	762.7	1.1	3.0	72.2	8.0	2.9	29.6
9/11/02	14:00:06	14:34:47	17.3	16.9	2387.3	761.6	1.1	3.4	75.8	9.4	3.1	29.7
9/12/02	09:02:56	09:38:27	14.7	25.0	2373.5	764.7	1.1	3.5	75.6	11.9	3.6	30.5
9/12/02	13:40:59	14:15:10	18.2	16.3	2387.3	762.8	1.0	3.2	71.3	11.3	3.9	27.7
9/16/02	09:10:53	09:43:54	7.9	27.2	2363.6	762.3	1.0	2.2	63.5	5.1	2.6	28.0
9/16/02	13:49:04	14:24:00	12.5	21.8	2384.4	761.1	1.0	2.4	67.0	6.2	3.1	29.3

9/17/02	09:00:23	09:34:31	10.3	51.7	2368.2	761.7	1.0	2.0	43.4	5.6	2.6	28.1
9/17/02	13:44:17	14:19:13	11.7	40.2	2391.4	759.8	1.0	2.1	56.6	8.2	3.6	30.1
9/21/02	09:08:11	09:42:39	16.1	25.9	2364.2	765.4	0.9	3.4	72.3	10.1	4.3	31.1
9/21/02	13:46:55	14:22:22	18.9	18.3	2400.6	763.1	1.0	2.5	66.6	9.1	4.2	26.6
9/22/02	09:04:53	09:40:15	17.3	18.2	2365.0	768.1	1.0	2.7	59.5	5.6	3.0	28.1
9/22/02	13:42:54	14:17:49	19.6	16.1	2383.3	766.4	1.0	2.6	63.8	9.2	4.0	30.1
9/25/02	09:02:45	09:36:51	15.2	10.6	2366.7	762.5	1.0	2.2	58.6	23.0	2.7	26.2
9/25/02	13:56:15	14:31:06	17.7	14.2	2392.5	760.5	1.0	2.6	63.7	15.6	3.9	28.4
10/9/02	09:13:01	09:46:34	12.5	22.7	2367.7	763.9	1.0	2.2	61.3	5.6	2.8	29.7
10/9/02	13:49:27	14:27:07	15.0	18.7	2385.6	762.0	1.0	2.1	61.8	6.3	3.0	29.9
10/10/02	09:08:30	09:47:34	10.7	36.1	2368.5	760.5	1.0	4.5	77.5	21.9	5.9	27.4
10/10/02	13:53:22	14:31:16	10.4	39.6	2393.5	758.6	1.0	6.6	86.2	25.3	8.8	29.4

TABLE 8B

Average Conditions During Denuder Sampling above Lake Tahoe at ~ 2,070 m MSL (~180 m above lake level)

Date	Start Time (PST)	End Time (PST)	Temp. (^oC)	RH (%)	Altitude (m)	Pressure (mb)	NO (ppbv)	NO_y (ppbv)	Ozone (ppbv)	PC1 (# x$10^6/m^3$)	PC2 (# x$10^4/m^3$)	Mass Flow (slpm)
7/10/02	10:03:13	10:37:01	24.5	20.1	2084.7	797.6	1.0	3.3	66.3	8.8	2.8	-99.9
7/10/02	14:28:00	14:38:51	30.0	9.4	2095.6	794.5	1.0	2.0	54.5	8.4	3.2	-99.9
7/11/02	10:03:30	10:34:27	24.0	25.5	2063.7	796.3	1.2	3.7	61.3	21.2	6.0	-99.9
7/11/02	14:11:58	14:45:20	29.6	11.5	2080.6	792.7	1.1	4.9	71.2	13.0	4.1	33.4
7/17/02	09:50:07	10:24:01	19.7	33.5	2056.6	794.9	1.2	3.2	57.5	14.0	4.1	-99.9
7/17/02	14:16:47	14:47:50	19.4	35.7	2087.8	791.5	1.2	3.4	57.0	11.2	3.4	-99.9
7/18/02	09:25:59	10:00:04	17.0	53.0	2031.1	799.9	1.0	3.5	61.1	18.4	3.9	-99.9
7/31/02	09:54:37	10:30:28	19.9	28.2	2073.1	795.0	1.0	2.9	82.0	33.4	3.6	29.0
7/31/02	14:26:29	15:01:32	23.8	26.5	2071.0	794.1	1.0	3.2	82.4	41.6	4.5	29.5
8/1/02	10:09:33	10:44:33	20.0	29.8	2090.5	793.5	1.0	3.4	87.5	42.0	5.4	30.2
8/1/02	14:34:11	15:08:11	23.1	30.2	2071.3	792.1	1.1	3.7	82.6	39.9	4.3	29.4
8/5/02	09:22:39	10:26:37	13.3	27.9	2098.5	781.5	1.0	2.2	56.2	24.1	4.8	23.5
8/5/02	14:24:40	14:59:32	14.5	36.4	2078.4	785.2	1.0	3.2	64.1	37.1	7.9	31.2
8/6/02	09:43:38	10:19:31	14.1	29.9	2080.0	791.0	1.0	2.9	68.2	29.9	8.1	30.3
8/6/02	14:09:11	14:45:11	15.8	27.3	2067.9	791.9	1.0	3.0	69.9	28.8	8.6	23.2
8/28/02	10:02:59	10:35:01	16.5	33.5	2098.4	788.7	1.0	3.4	66.9	20.2	4.0	33.6
8/28/02	14:38:17	15:12:14	20.5	22.1	2071.2	789.4	1.0	3.0	75.3	26.0	4.7	31.2
9/4/02	09:46:17	10:19:25	15.3	37.9	2075.6	788.8	1.0	2.7	58.7	8.2	3.1	26.2
9/4/02	14:51:15	15:25:13	16.1	44.3	2100.4	791.1	1.1	2.9	53.1	12.0	4.9	27.2
9/5/02	09:56:27	10:30:24	14.1	39.5	2075.7	790.7	1.0	2.1	46.9	9.9	5.3	28.5
9/5/02	14:24:05	14:58:05	14.5	38.0	2062.9	791.2	1.0	2.2	47.2	10.7	6.6	29.3
9/11/02	10:40:51	11:15:48	17.6	18.5	2078.4	791.8	1.1	3.1	75.3	9.0	3.1	29.7
9/11/02	14:44:40	15:18:29	20.3	14.7	2070.3	790.6	1.0	3.4	76.0	9.9	3.6	33.6
9/12/02	09:48:50	10:23:51	16.2	25.9	2059.1	794.1	0.9	3.3	80.1	12.8	4.0	30.7
9/12/02	14:25:35	14:59:40	21.2	13.8	2083.1	792.2	0.9	3.0	70.2	11.0	3.7	28.9
9/16/02	09:53:44	10:28:02	10.8	28.5	2077.6	791.1	1.0	2.5	64.0	5.8	2.7	26.2
9/16/02	14:33:07	15:08:04	15.5	21.2	2072.4	789.4	1.0	2.2	64.4	6.1	3.1	30.2

9/17/02	09:43:55	10:17:52	13.8	43.1	2075.5	790.6	0.9	2.0	42.2	5.5	2.5	26.8
9/17/02	14:28:37	15:03:32	14.2	37.8	2080.8	788.2	0.9	2.5	60.0	9.1	4.0	30.0
9/21/02	09:52:36	10:27:32	16.3	34.2	2064.3	796.4	0.8	4.4	90.1	14.5	5.2	30.8
9/21/02	14:32:42	15:06:42	22.0	15.7	2071.3	793.5	1.0	2.6	61.4	9.2	4.3	27.4
9/22/02	09:49:32	10:23:33	17.8	21.4	2073.6	798.2	1.0	3.0	64.0	7.8	3.2	28.2
9/22/02	14:26:23	15:01:21	22.6	13.9	2076.6	795.2	1.0	2.8	63.5	9.1	4.2	29.7
9/25/02	09:47:51	10:22:50	17.2	10.6	2075.9	791.7	1.0	2.0	56.1	19.8	2.8	29.8
9/25/02	14:41:26	15:15:24	20.8	13.0	2072.0	790.8	0.9	2.3	63.4	15.1	4.1	30.3
10/9/02	09:57:49	10:33:59	14.1	30.8	2056.5	794.6	1.2	4.4	67.2	9.9	3.6	29.8
10/9/02	14:36:17	15:14:25	18.0	18.3	2077.3	791.0	1.0	2.4	65.0	9.6	3.5	30.9
10/10/02	09:56:25	10:35:18	13.8	33.6	2080.2	788.5	0.9	5.0	81.0	27.0	7.5	31.1
10/10/02	14:39:17	15:15:11	12.9	36.0	2107.5	786.5	0.8	6.5	84.1	25.4	10.3	29.3
10/15/02	07:56:06	08:49:58	11.6	25.4	2063.4	792.7	1.1	3.5	54.3	12.0	5.5	28.9
10/15/02	13:22:05	14:07:59	15.3	14.8	2086.0	789.9	1.1	3.7	61.8	11.8	5.4	30.5
10/16/02	09:00:03	09:50:00	12.6	10.5	2086.9	791.0	1.1	2.6	55.6	7.4	4.0	30.1
10/16/02	13:50:04	14:40:02	14.8	10.5	2077.6	789.4	1.4	4.1	58.2	8.1	4.5	27.3

TABLE 8C: Gradients[15] and Average Winds at 2380 m MSL														
Date	High Start Time	Low Start Time	Temp.	Potential Temp.	RH	NO	NO_y	O_3	PC1	PC2	Ave v	Ave u	Ave Speed	Resultant dir.
			°C/km	°C/km	%/km	ppbv/km	ppbv/km	ppbv/km	unit/km	unit/km	m/s	m/s	m/s	degrees
07-10-02	09:19:49	10:03:13	1.0	13.5	-26.0	0.3	-2.8	-5.9	-10.4	0.3	-4.8	3.7	6.0	128
07-10-02	13:44:45	14:28:00	-9.7	1.3	3.1	0.3	0.7	-5.9	-2.4	0.3	4.0	1.6	4.3	248
07-11-02	09:22:55	10:03:30	0.7	12.2	-30.9	0.0	-2.0	-11.2	-23.3	1.0	-3.1	1.9	3.6	122
07-11-02	13:25:08	14:11:58	-7.9	2.7	1.7	0.3	-5.6	3.6	-1.3	-0.7	-0.3	1.1	1.1	166
07-17-02	09:02:48	9:50:07	-9.4	1.7	12.7	0.0	0.0	6.4	0.0	-0.7	0.9	3.3	3.4	196
07-17-02	13:34:56	14:16:47	-6.9	3.3	15.7	0.0	-0.3	6.9	4.6	1.0	0.4	1.4	1.5	197
07-18-02	08:42:46	9:25:59	-6.7	3.6	8.2	0.6	0.6	13.2	-0.9	0.9	1.4	2.5	2.9	210
07-31-02	09:04:53	9:54:37	-4.3	6.6	-17.1	0.0	-1.0	13.4	-1.3	-0.7	1.6	4.8	5.1	198
07-31-02	13:38:41	14:26:29	-9.2	1.1	0.7	0.0	-0.3	4.2	-3.6	-1.0	4.0	2.9	4.9	234
08-01-02	08:53:13	10:09:33	-7.0	3.6	19.9	0.0	0.7	-5.6	1.0	0.3	1.8	2.1	2.8	220
08-01-02	13:49:54	14:34:11	-8.4	1.7	7.4	0.0	-0.9	-2.2	-2.2	-0.9	6.1	3.1	6.8	243
08-05-02	09:06:01	9:22:39	-10.9	-0.6	17.9	0.0	0.0	7.8	4.7	-0.4	---	---	---	---
08-05-02	13:39:42	14:24:40	-7.6	0.9	2.5	0.0	-0.8	-6.7	-13.5	0.6	---	---	---	---
08-06-02	08:55:06	9:43:38	-11.2	-1.4	18.8	0.0	0.0	-3.3	-13.2	-10.2	2.6	7.7	8.1	199
08-06-02	13:24:58	14:09:11	-9.4	0.4	17.0	0.0	0.3	12.0	11.0	0.3	4.9	5.1	7.1	224
08-28-02	09:27:16	10:02:59	-10.7	0.6	8.1	0.0	-0.8	-1.2	-2.7	-3.1	-4.4	2.6	5.1	121
08-28-02	13:58:43	14:38:17	-9.1	0.9	8.2	0.0	0.0	0.9	-4.7	-2.2	2.8	1.7	3.3	239
09-04-02	09:04:32	9:46:17	-10.1	0.9	19.0	0.0	-0.4	-4.3	-2.5	-1.1	5.5	13.2	14.3	203
09-04-02	14:05:50	14:51:15	-10.7	-0.4	21.0	0.0	0.3	6.2	-1.4	-1.7	4.7	9.1	10.2	207
09-05-02	09:11:30	9:56:27	-10.7	-0.3	20.0	0.3	0.7	4.1	-1.4	-3.1	5.3	10.3	11.6	208
09-05-02	13:47:30	14:24:05	-8.6	1.0	12.1	0.0	0.3	5.4	0.6	0.0	8.2	10.2	13.1	219
09-11-02	09:54:55	10:40:51	-6.9	4.1	-4.1	0.0	-0.3	-10.7	-3.5	-0.7	0.5	1.3	1.4	202
09-11-02	14:00:06	14:44:40	-9.5	0.4	6.9	0.3	0.0	-0.6	-1.6	-1.6	-1.8	1.2	2.2	123
09-12-02	09:02:56	9:48:50	-4.8	5.5	-2.9	0.6	0.6	-14.3	-2.9	-1.3	0.3	1.1	1.1	196
09-12-02	13:40:59	14:25:35	-9.9	0.6	8.2	0.3	0.7	3.6	1.0	0.7	-2.2	1.6	2.7	126
09-16-02	09:10:53	9:53:44	-10.1	0.4	-4.5	0.0	-1.0	-1.7	-2.4	-0.3	2.2	1.3	2.6	239

[15] (data @2380m – data @2070m)/0.310km

09-16-02	13:49:04	14:33:07	-9.6	-0.0	1.9	0.0	0.6	8.3	0.3	0.0	2.9	2.3	3.7	232
09-17-02	09:00:23	9:43:55	-12.0	-1.7	29.4	0.3	0.0	4.1	0.3	0.3	5.4	2.7	6.0	244
09-17-02	13:44:17	14:28:37	-8.0	1.7	7.7	0.3	-1.3	-10.9	-2.9	-1.3	8.7	3.3	9.3	249
09-21-02	09:08:11	9:52:36	-0.7	11.1	-27.7	0.3	-3.3	-59.4	-14.7	-3.0	-2.5	2.6	3.6	136
09-21-02	13:46:55	14:32:42	-9.4	0.6	7.9	0.0	-0.3	15.8	-0.3	-0.3	1.1	1.8	2.1	211
09-22-02	09:04:53	9:49:32	-1.7	10.0	-11.0	0.0	-1.0	-15.4	-7.5	-0.7	-2.5	2.9	3.8	139
09-22-02	13:42:54	14:26:23	-9.8	0.4	7.2	0.0	-0.7	1.0	0.3	-0.7	3.8	2.0	4.3	243
09-25-02	09:02:45	9:47:51	-6.9	4.1	0.0	0.0	0.7	8.6	11.0	-0.3	3.3	1.1	3.5	251
09-25-02	13:56:15	14:41:26	-9.7	0.6	3.7	0.3	0.9	0.9	1.6	-0.6	2.1	2.1	3.0	225
10-09-02	09:13:01	9:57:49	-5.1	5.6	-26.0	-0.6	-7.1	-19.0	-13.8	-2.6	2.9	3.8	4.8	217
10-09-02	13:49:27	14:36:17	-9.7	0.3	1.3	0.0	-1.0	-10.4	-10.7	-1.6	6.2	3.0	6.9	245
10-10-02	09:08:30	9:56:25	-10.8	-0.6	8.7	0.3	-1.7	-12.1	-17.7	-5.5	5.1	7.0	8.7	216
10-10-02	13:53:22	14:39:17	-8.7	1.7	12.6	0.7	0.3	7.3	-0.3	-5.2	7.4	10.8	13.1	215

Table 9A: Particulate (PM3.5) Concentrations for Airplane DFP Samples
July - October, 2002
(Concentration values represent result after subtraction of average field blank)

Sample	Vol. (L-air)	$PM_{3.5}$ Concentration (nmol N or S / m^3-air)					
		NO_3^-:	NH_4^+:	WSIN:	ON-p:	TN-p:	SO_4^{2-}:
Flight #1							
7/10/02 Morning 2370m	730	4.0	7.6	11.5	< LOD	12	4.1
7/10/02 Morning 2070m	985	2.7	9.9	12.6	< LOD	13	1.8
Flight #2							
7/10/02 Afternoon 2370m	928	5.3	23.1	28.4	12	41	2.3
7/10/02 Afternoon 2070m	826	9.6	19.8	29.4	13	43	4.4
Flight #3							
7/11/02 Morning 2370m	786	2.3	7.3	9.6	19	28	2.5
7/11/02 Morning 2070m	850	5.6	20.7	26.3	23	49	2.8
Flight #4							
7/11/02 Afternoon 2370m	971	2.3	7.5	9.8	< LOD	10	6.1
7/11/02 Afternoon 2070m	1115	6.9	19.6	26.5	4	31	3.9
7/17/02 through 9/5/02		Filter Data Invalid Because of High Blank Levels					
Flight #1							
9/11/02 Morning 2370m	1031	< LOD	29.1	29.1	5	34	5.5
9/11/02 Morning 2070m	1040	1.5	16.2	17.7	33	51	8.0
Flight #2							
9/11/02 Afternoon 2370m	1033	< LOD	25.1	25.1	7	32	5.5
9/11/02 Afternoon 2070m	1138	< LOD	31.0	31.0	3	34	5.1
Flight #3							
9/12/02 Morning 2370m	1086	1.2	28.5	29.7	7	37	6.1
9/12/02 Morning 2070m	1075	0.9	21.6	22.5	8	30	7.6
Flight #4							
9/12/02 Afternoon 2370m	949	0.8	9.2	10.1	15	25	5.3
9/12/02 Afternoon 2070m	987	1.1	11.1	12.2	12	24	5.0
Flight #1							
9/16/02 Morning 2370m	926	< LOD	27.0	27.0	2	29	5.0
9/16/02 Morning 2070m	899	< LOD	19.0	19.0	< LOD	19	4.2
Flight #2							
9/16/02 Afternoon 2370m	1024	< LOD	12.7	12.7	< LOD	13	4.3
9/16/02 Afternoon 2070m	1056	< LOD	2.7	2.7	11	13	1.9
Flight #3							
9/17/02 Morning 2370m	959	< LOD	3.3	3.3	< LOD	3	2.4
9/17/02 Morning 2070m	908	< LOD	13.7	13.7	< LOD	14	5.6
Flight #4							
9/17/02 Afternoon 2370m	1055	< LOD	10.1	10.1	6	16	3.7
9/17/02 Afternoon 2070m	1051	< LOD	11.4	11.4	1	12	3.6
Flight #1							
9/21/02 Morning 2370m	1074	1.1	6.1	7.2	6	13	2.6
9/21/02 Morning 2070m	1078	2.0	4.0	6.0	< LOD	6	3.9
Flight #2							

9/21/02 Afternoon 2370m	945	1.8	2.0	3.8	1	5	2.4
9/21/02 Afternoon 2070m	935	2.2	< LOD	2.2	< LOD	2	1.9
Flight #3							
9/22/02 Morning 2370m	996	1.2	4.3	5.6	< LOD	6	0.8
9/22/02 Morning 2070m	959	< LOD	0.9	0.9	< LOD	1	2.9
Flight #4							
9/22/02 Afternoon 2370m	1051	1.3	5.3	6.5	< LOD	7	2.3
9/22/02 Afternoon 2070m	1038	< LOD	8.7	8.7	< LOD	9	2.1
Flight #1							
9/25/02 Morning 2370m	930	2.0	6.9	8.9	10	19	5.2
9/25/02 Morning 2070m	1045	3.5	11.7	15.2	5	20	2.5
Flight #2							
9/25/02 Afternoon 2370m	990	3.8	0.2	3.9	6	10	2.3
9/25/02 Afternoon 2070m	1030	1.1	2.6	3.8	21	25	2.2
Flight #1							
10/9/02 Morning 2370m	1066	< LOD	11.0	11.0	< LOD	11	1.7
10/9/02 Morning 2070m	1079	1.8	14.2	16.0	1	17	4.8
Flight #2							
10/9/02 Afternoon 2370m	1129	2.2	6.9	9.1	4	13	5.0
10/9/02 Afternoon 2070m	1199	1.8	10.0	11.8	2	13	3.4
Flight #3							
10/10/02 Morning 2370m	1072	3.1	15.1	18.3	6	24	5.2
10/10/02 Morning 2070m	1211	5.7	31.7	37.4	16	54	7.4
Flight #4							
10/10/02 Afternoon 2370m	1114	10.6	25.2	35.8	< LOD	36	7.7
10/10/02 Afternoon 2070m	1054	13.2	33.6	46.8	0.4	47	9.8
Sampling #1							
10/15/02 Morning - Plane (2070m)	1556	1.9	6.3	8.1	11	19	5.2
10/15/02 Morning - Boat	886	2.6	7.8	10.4	1	11	4.3
Sampling #2							
10/15/02 Afternoon - Plane (2070m)	1399	1.7	5.9	7.6	6	14	5.8
10/15/02 Afternoon - Boat	665	2.0	16.3	18.3	30	48	9.5
Sampling #3							
10/16/02 Morning - Plane (2070m)	1504	2.0	0.8	2.7	4	7	3.7
10/16/02 Morning - Boat	872	< LOD	1.2	1.2	< LOD	1	< LOD
Sampling #4							
10/16/02 Afternoon - Plane (2070m)	1363	1.2	4.5	5.7	< LOD	6	4.9
10/16/02 Afternoon - Boat	833	2.5	< LOD	2.5	< LOD	2	0.8
Number of Samples Collected:		52	52	52	52	52	52
# of Values Above Detection Limit:		37	50	52	34	52	51
Min Value:		< LOD	< LOD	0.9	< LOD	0.9	< LOD
Max Value:		13.2	33.6	46.8	33	54	9.8
Median Value:		1.8	10.0	11.2	3	15	4.2
Mean Value:		2.2	12.1	14.4	6	20	4.2
Standard Deviation:		2.8	9.4	10.8	8	15	2.1

Notes on $PM_{3.5}$ values:	Measured on 47 mm Zefluor Filter (2 um pore size)
NO_2^-:	Nitrite NOTE - nitrite levels were never above the instrumental detection limit and so are not included in the table above
NO_3^-:	Nitrate
NH_4^+:	Ammonium
WSIN:	Water Soluble Inorganic Nitrogen (Sum of nitrite, nitrate and ammonium)
ON-p:	Total Organic Nitrogen on the particles ON values were determined by photochemical oxidation of filter extract with 254 nm light ON = WSIN (after photooxidation) - WSIN (before photooxidation) NOTE - ON-p values are only qualitative due to high blank values
TN-p:	WSIN + ON-p NOTE - TN-p is qualitative due to inclusion of ON-p value
SO_4^{2-}:	Sulfate
Statistics:	Values < LOD were treated as zero; statistics include the four Oct. boat samples

Key to Symbols:	
< LOD	Value was below instrument's limit of detection before blank subtractions, or was a negative value after blank subtraction. Values < LOD were considered to be zero in the calculation of WSIN and TN

Table 9B: Concentrations of Gaseous N in Airplane DFP Samples
July - October, 2002
(Concentration values represent result after subtraction of average field blank value)

Sample	Vol. (L-air)	Gas Phase (nmol N / m^3-air)						Gas Phase (ppbv N)					
Flight #1		HNO_2:	HNO_3:	NH_3:	TIN:	ON-g:	TN-g:	HNO_2:	HNO_3:	NH_3:	TIN:	ON-g:	TN-g:
7/10/02 Morning 2370m	730	< LOD	< LOD	263.8	263.8	54	318	< LOD	< LOD	8.52	8.52	1.8	10.3
7/10/02 Morning 2070m	985	3.7	51.8	126.4	181.9	4	186	0.11	1.61	3.92	5.64	0.1	5.8
Flight #2													
7/10/02 Afternoon 2370m	928	< LOD	6.4	203.0	209.4	24	233	< LOD	0.21	6.62	6.82	0.8	7.6
7/10/02 Afternoon 2070m	826	< LOD	0.6	312.7	313.3	6	320	< LOD	0.02	9.92	9.94	0.2	10.1
Flight #3													
7/11/02 Morning 2370m	786	1.2	7.1	175.5	183.8	< LOD	184	0.04	0.23	5.66	5.93	< LOD	5.9
7/11/02 Morning 2070m	850	1.5	8.2	85.8	95.5	19	115	0.05	0.25	2.66	2.96	0.6	3.6
Flight #4													
7/11/02 Afternoon 2370m	971	1.4	11.9	91.7	104.9	15	120	0.04	0.39	3.00	3.43	0.5	3.9
7/11/02 Afternoon 2070m	1115	0.7	22.7	45.2	68.6	7	76	0.02	0.72	1.43	2.18	0.2	2.4
Flight #1													
7/17/02 Morning 2370m	913	< LOD	< LOD	143.7	143.7	35	178	< LOD	< LOD	4.53	4.53	1.1	5.6
7/17/02 Morning 2070m	848	< LOD	30.7	64.0	94.7	< LOD	95	< LOD	0.94	1.96	2.90	< LOD	2.9
Flight #2													
7/17/02 Afternoon 2370m	603	< LOD	34.0	99.2	133.2	15	148	< LOD	1.08	3.14	4.21	0.5	4.7
7/17/02 Afternoon 2070m	585	0.3	33.0	78.4	111.6	7	119	0.01	1.01	2.41	3.43	0.2	3.7
Flight #3													
7/18/02 Morning 2370m	666	0.7	30.8	23.6	55.1	8	63	0.02	0.93	0.71	1.66	0.2	1.9
7/18/02 Morning 2070m	682	< LOD	36.6	89.3	125.9	23	149	< LOD	1.11	2.70	3.81	0.7	4.5
Flight #1													
7/31/02 Morning 2370m	977	< LOD	24.7	16.8	41.5	< LOD	42	< LOD	0.78	0.53	1.32	< LOD	1.3
7/31/02 Morning 2070m	1041	1.5	35.2	71.8	108.5	< LOD	108	0.05	1.08	2.20	3.32	< LOD	3.3
Flight #2													
7/31/02 Afternoon 2370m	1198	1.1	32.5	119.7	153.3	8	161	0.04	1.04	3.82	4.90	0.2	5.1
7/31/02 Afternoon 2070m	1032	< LOD	23.3	20.6	43.9	94	138	< LOD	0.72	0.64	1.36	2.9	4.3
Flight #3													
8/1/02 Morning 2370m	782	2.6	24.8	44.4	71.7	< LOD	72	0.08	0.79	1.40	2.27	< LOD	2.3
8/1/02 Morning 2070m	1058	2.7	51.1	146.2	200.1	< LOD	200	0.08	1.57	4.49	6.14	< LOD	6.1

Flight #4													
8/1/02 Afternoon 2370m	1010	2.9	37.9	140.3	181.1	< LOD	181	0.09	1.21	4.49	5.80	< LOD	5.8
8/1/02 Afternoon 2070m	1002	1.6	47.0	47.1	95.7	13	109	0.05	1.46	1.46	2.97	0.4	3.4
Flight #1													
8/5/02 Morning 2370m	953	0.5	19.8	3.0	23.3	< LOD	23	0.02	0.62	0.09	0.73	< LOD	0.7
8/5/02 Morning 2070m	1046	< LOD	20.7	20.0	40.7	< LOD	41	< LOD	0.63	0.61	1.24	< LOD	1.2
Flight #2													
8/5/02 Afternoon 2370m	1008	1.2	21.7	27.6	50.5	7	58	0.04	0.68	0.86	1.58	0.2	1.8
8/5/02 Afternoon 2070m	1088	2.7	22.2	57.1	81.9	11	93	0.08	0.68	1.74	2.50	0.3	2.8
Flight #3													
8/6/02 Morning 2370m	1097	< LOD	< LOD	39.5	39.5	16	55	< LOD	< LOD	1.22	1.22	0.5	1.7
8/6/02 Morning 2070m	1089	2.3	21.1	23.3	46.7	< LOD	47	0.07	0.64	0.70	1.41	< LOD	1.4
Flight #4													
8/6/02 Afternoon 2370m	941	1.3	27.0	38.1	66.3	42	109	0.04	0.84	1.19	2.07	1.3	3.4
8/6/02 Afternoon 2070m	837	1.9	35.6	22.4	59.9	1	61	0.06	1.08	0.68	1.82	0.0	1.9
Flight #1													
8/28/02 Morning 2370m	976	2.8	27.7	15.2	45.6	6	52	0.09	0.87	0.48	1.43	0.2	1.6
8/28/02 Morning 2070m	1069	6.1	30.9	121.5	158.6	65	223	0.19	0.94	3.71	4.84	2.0	6.8
Flight #2													
8/28/02 Afternoon 2370m	824	5.8	18.9	45.3	70.0	55	125	0.18	0.60	1.44	2.23	1.7	4.0
8/28/02 Afternoon 2070m	1060	2.3	34.1	130.8	167.2	4	171	0.07	1.06	4.05	5.17	0.1	5.3
Flight #1													
9/4/02 Morning 2370m	905	< LOD	21.5	64.9	86.4	< LOD	86	< LOD	0.67	2.03	2.70	< LOD	2.7
9/4/02 Morning 2070m	865	0.2	17.8	45.2	63.2	103	166	0.00	0.54	1.37	1.92	3.1	5.0
Flight #2													
9/4/02 Afternoon 2370m	1019	0.3	27.2	50.4	77.8	33	111	0.01	0.85	1.57	2.43	1.0	3.5
9/4/02 Afternoon 2070m	926	< LOD	28.0	66.2	94.2	11	106	< LOD	0.85	2.01	2.86	0.3	3.2
Flight #3													
9/5/02 Morning 2370m	1075	< LOD	25.8	73.2	99.0	2	101	< LOD	0.80	2.27	3.07	0.1	3.1
9/5/02 Morning 2070m	970	< LOD	30.7	24.0	54.7	14	69	< LOD	0.93	0.72	1.65	0.4	2.1
Flight #4													
9/5/02 Afternoon 2370m	997	1.0	27.3	41.1	69.4	< LOD	69	0.03	0.85	1.28	2.15	< LOD	2.2
9/5/02 Afternoon 2070m	996	2.7	29.8	66.8	99.4	4	103	0.08	0.90	2.02	3.00	0.1	3.1
Flight #1													
9/11/02 Morning 2370m	1031	0.1	17.8	44.4	62.3	30	92	0.00	0.56	1.40	1.96	0.9	2.9
9/11/02 Morning 2070m	1040	< LOD	28.9	38.3	67.2	1	68	< LOD	0.88	1.17	2.05	< LOD	2.1

Flight #2													
9/11/02 Afternoon 2370m	1033	< LOD	38.0	42.5	80.5	1	82	< LOD	1.21	1.35	2.55	0.0	2.6
9/11/02 Afternoon 2070m	1138	0.2	38.0	24.9	63.1	10	73	0.01	1.17	0.77	1.95	0.3	2.3
Flight #3													
9/12/02 Morning 2370m	1086	0.2	38.9	49.8	89.0	50	139	0.01	1.22	1.56	2.78	1.6	4.3
9/12/02 Morning 2070m	1075	3.0	38.8	42.8	84.6	94	178	0.09	1.18	1.30	2.56	2.8	5.4
Flight #4													
9/12/02 Afternoon 2370m	949	2.4	36.6	34.6	73.6	32	106	0.08	1.16	1.10	2.34	1.0	3.4
9/12/02 Afternoon 2070m	987	2.9	27.7	12.6	43.3	57	100	0.09	0.86	0.39	1.34	1.8	3.1
Flight #1													
9/16/02 Morning 2370m	926	0.1	8.8	12.5	21.4	< LOD	21	0.00	0.27	0.38	0.65	< LOD	0.7
9/16/02 Morning 2070m	899	< LOD	17.1	27.2	44.3	< LOD	45	< LOD	0.51	0.81	1.32	< LOD	1.3
Flight #2													
9/16/02 Afternoon 2370m	1024	< LOD	13.4	6.2	19.6	1	21	< LOD	0.42	0.19	0.61	< LOD	0.6
9/16/02 Afternoon 2070m	1056	0.8	20.0	36.9	57.7	7	65	0.02	0.61	1.12	1.75	0.2	2.0
Flight #3													
9/17/02 Morning 2370m	959	1.2	10.2	140.5	151.9	14	165	0.04	0.32	4.35	4.70	0.4	5.1
9/17/02 Morning 2070m	908	1.2	13.7	86.4	101.2	< LOD	101	0.04	0.41	2.61	3.05	< LOD	3.1
Flight #4													
9/17/02 Afternoon 2370m	1055	3.5	18.1	55.0	76.6	1	78	0.11	0.56	1.71	2.39	< LOD	2.4
9/17/02 Afternoon 2070m	1051	0.8	24.6	46.7	72.1	< LOD	72	0.02	0.75	1.41	2.18	< LOD	2.2
Flight #1													
9/21/02 Morning 2370m	1074	5.9	31.9	11.0	48.8	< LOD	49	0.19	1.00	0.35	1.53	< LOD	1.5
9/21/02 Morning 2070m	1078	3.9	59.9	66.7	130.5	< LOD	131	0.12	1.81	2.02	3.94	< LOD	3.9
Flight #2													
9/21/02 Afternoon 2370m	945	0.8	15.0	14.3	30.0	17	47	0.02	0.48	0.45	0.95	0.5	1.5
9/21/02 Afternoon 2070m	935	2.3	24.6	55.5	82.4	8	90	0.07	0.76	1.72	2.55	0.2	2.8
Flight #3													
9/22/02 Morning 2370m	996	6.3	18.8	40.8	65.9	14	80	0.20	0.59	1.28	2.07	0.5	2.5
9/22/02 Morning 2070m	959	2.4	28.1	94.8	125.3	< LOD	125	0.07	0.85	2.87	3.80	< LOD	3.8
Flight #4													
9/22/02 Afternoon 2370m	1051	3.0	26.5	134.8	164.3	< LOD	164	0.10	0.84	4.28	5.22	< LOD	5.2
9/22/02 Afternoon 2070m	1038	2.5	27.6	74.6	104.7	7	112	0.08	0.85	2.31	3.24	0.2	3.5
Flight #1													
9/25/02 Morning 2370m	930	< LOD	9.7	3.1	12.9	1	14	< LOD	0.31	0.10	0.40	< LOD	0.4
9/25/02 Morning 2070m	1045	< LOD	13.6	57.7	71.3	6	77	< LOD	0.42	1.76	2.17	0.2	2.4

Flight #2													
9/25/02 Afternoon 2370m	990	< LOD	27.6	5.8	33.4	< LOD	33	< LOD	0.88	0.18	1.06	< LOD	1.1
9/25/02 Afternoon 2070m	1030	< LOD	22.6	46.4	69.0	1	70	< LOD	0.70	1.43	2.13	< LOD	2.2
Flight #1													
10/9/02 Morning 2370m	1066	1.0	12.9	11.1	25.0	9	34	0.03	0.40	0.35	0.78	0.3	1.1
10/9/02 Morning 2070m	1079	2.7	36.7	5.5	45.0	< LOD	45	0.08	1.10	0.17	1.35	< LOD	1.4
Flight #2													
10/9/02 Afternoon 2370m	1129	< LOD	16.1	38.7	54.8	6	60	< LOD	0.51	1.22	1.72	0.2	1.9
10/9/02 Afternoon 2070m	1199	< LOD	19.7	2.4	22.1	< LOD	22	< LOD	0.60	0.07	0.68	< LOD	0.7
Flight #3													
10/10/02 Morning 2370m	1072	1.7	28.0	173.8	203.5	6	210	0.05	0.87	5.39	6.31	0.2	6.5
10/10/02 Morning 2070m	1211	1.2	44.8	130.8	176.7	14	191	0.04	1.35	3.96	5.35	0.4	5.8
Flight #4													
10/10/02 Afternoon 2370m	1114	3.2	38.2	127.0	168.4	< LOD	168	0.10	1.19	3.95	5.23	< LOD	5.2
10/10/02 Afternoon 2070m	1054	1.5	45.1	110.6	157.1	29	186	0.04	1.36	3.34	4.75	0.9	5.6
Sampling #1													
10/15/02 Morning - Plane (2070m)	1556	< LOD	14.0	6.3	20.3	2	23	< LOD	0.42	0.19	0.61	0.1	0.7
10/15/02 Morning – Boat	886	11.5	21.9	3.3	36.6	< LOD	37	0.35	0.66	0.10	1.10	< LOD	1.1
Sampling #2													
10/15/02 Afternoon - Plane (2070m)	1399	< LOD	32.1	39.6	71.7	< LOD	72	< LOD	0.97	1.20	2.18	< LOD	2.2
10/15/02 Afternoon – Boat	665	< LOD	30.7	4.4	35.1	< LOD	35	< LOD	0.93	0.13	1.07	< LOD	1.1
Sampling #3													
10/16/02 Morning - Plane (2070m)	1504	< LOD	15.6	41.5	57.1	3	60	< LOD	0.47	1.25	1.71	0.1	1.8
10/16/02 Morning – Boat	872	0.2	17.9	150.2	168.4	9	177	0.01	0.54	4.53	5.07	0.3	5.3
Sampling #4													
10/16/02 Afternoon - Plane (2070m)	1363	0.6	31.2	36.4	68.2	1	69	0.02	0.91	1.06	1.99	< LOD	2.0
10/16/02 Afternoon – Boat	833	0.2	15.6	43.5	59.2	7	66	0.01	0.47	1.32	1.80	0.2	2.0
Number of Samples Collected:		86	86	86	86	86	86	86	86	86	86	86	86
# Values Above Detection Limit:		57	83	86	86	63	86	57	83	86	86	63	86
Min Value:		< LOD	< LOD	2.4	12.9	< LOD	14	< LOD	< LOD	0.07	0.40	< LOD	0.4
Max Value:		11.5	59.9	312.7	313.3	103	320	0.35	1.81	9.92	9.94	3.1	10.3
Median Value:		0.8	25.3	45.3	71.9	6	93	0.02	0.79	1.42	2.25	0.2	2.9
Mean Value:		1.4	25.1	65.3	91.8	13	105	0.04	0.77	2.03	2.85	0.4	3.3
Standard Deviation:		1.9	11.9	58.4	58.3	22	63	0.06	0.37	1.85	1.84	0.7	2.0

Notes on Gaseous Species:	Measured using potassium carbonate or citric acid coated denuders
HNO_2:	Nitrous Acid (from potassium carbonate coated denuder) NOTE - Value should be considered qualitative due to low sample/blank ratios
HNO_3:	Nitric Acid (from potassium carbonate coated denuder)
NH_3:	Ammonia (from citric acid coated denuder)
TIN:	Total Inorganic Nitrogen (Sum of nitrous acid, nitric acid, and ammonia)
ON-g:	Organic Nitrogen in the gas phase (sum of results from both denuders) ON-g values were determined by photochemical oxidation of denuders extracts using 254 nm light ON-g = TIN (after photooxidation) - TIN (before photooxidation) NOTE - ON-g values are only qualitative due to low sample/blank ratios
TN-g:	TIN + ON-g NOTE - TN-g is qualitative due to inclusion of ON-g value
Statistics:	Values < LOD were treated as zero; statistics include the four Oct. boat samples

Key to Symbols:	
< LOD	Value measured below instrument's limit of detection before blank subtractions, or was a negative value after subtracting blank. (Component then omitted when computing TIN, and TN)

Table 9C: Summary of Filter Blanks for DFP Particulate Samples July - October, 2002

Blanks	Filter Amount (nmol N or S per filter)					
(Grouped by sampling trip)	NO_3^-:	NH_4^+:	WSIN:	ON-p:	TN-p:	SO_4^{2-}:
7/10/02 F. Blank Day 1	1.4	5.7	7.0	0.5	7.6	< LOD
7/17/02 through 9/5/02	High and Variable Filter Blanks: No PM Data					
9/11/02 Field Blank Day 1	0.0	4.7	4.7	35.4	40.0	< LOD
9/12/02 Field Blank Day 2	1.0	2.5	3.4	21.7	25.1	2.3
9/16/02 Field Blank Day 1	0.0	2.0	2.0	13.8	15.8	< LOD
9/17/02 Field Blank Day 2	0.5	4.0	4.5	2.8	7.3	3.4
9/21/02 Field Blank Day 1	0.5	4.3	4.8	20.7	25.5	5.1
9/22/02 Field Blank Day 2	0.2	1.4	2.1	12.8	14.9	< LOD
9/25/02 Field Blank Day 1	0.7	1.3	1.9	21.1	23.0	3.4
9/26/02 Cooler Blank Day 2	0.6	1.5	2.1	30.8	32.9	1.2
10/9/02 Field Blank Day 1	2.5	9.2	11.7	16.8	28.5	4.2
10/10/02 Field Blank Day 2	0.5	1.5	2.0	7.5	9.5	8.1
10/15/02 F. Blank #1 - Plane	1.6	4.3	5.9	54.0	59.9	4.0
10/15/02 F. Blank #2 - Boat	1.0	1.0	2.0	15.2	17.2	< LOD

Filter Blank	Filter Amount (nmol N or S per filter)					
Statistics	NO_3^-:	NH_4^+:	WSIN:	ON-p:	TN-p:	SO_4^{2-}:
Number of Blanks Collected:	13	13	13	13	13	13
Min Value:	< LOD	1.0	1.9	0.5	7.3	< LOD
Max Value:	2.5	9.2	11.7	54.0	59.9	8.1
Median Value:	0.6	2.5	3.4	16.8	23.0	2.3
Mean Value:	0.8	3.3	4.2	19.5	23.6	2.4
Standard Deviation:	0.7	2.4	2.8	14.3	14.7	2.5
Mean [Sample / Blank] Ratio:	2.8	3.7	3.5	0.3	0.9	1.7

Notes on Filter Blanks: Measured from 47 mm Zefluor Filter (2 um pore size)

NO_2^-: Nitrite
NOTE - nitrite levels were never above the instrumental detection limit and so are not included in the table above

NO_3^-: Nitrate

NH_4^+: Ammonium

WSIN: Water Soluble Inorganic Nitrogen (Sum of nitrite, nitrate and ammonium)

ON-p: Organic Nitrogen on the particles
ON values were determined by photochemical oxidation of filter extract with 254 nm light
ON = WSIN (after photooxidation) - WSIN (before photooxidation)
NOTE - ON-p values are only qualitative due to high blank values

TN-p: WSIN + ON-p
NOTE - TN-p is qualitative due to inclusion of ON-p value

SO_4^{2-}: Sulfate

Statistics: Values < LOD were treated as zero; statistics include the four Oct. boat samples

Key to Symbols:

< LOD Value was below instrument’s limit of detection and was treated as zero in the calculation of WSIN and TN-p.

**Table 9D: Summary of Denuder Blanks for DFP Gas Samples
July - October, 2002**

Blanks	Denuder Amount (nmol N per denuder)					
(Grouped by sampling trip)	HNO_2:	HNO_3:	NH_3:	TIN:	ON-g:	TN-g:
7/10/02 F. Blank Day 1	< LOD	< LOD	12.5	12.5	60.3	72.8
7/18 Flown Blank 1	1.5	13.2	20.5	35.2	38.7	73.9
7/18 Flown Blank 2	1.6	15.6	40.9	58.1	< LOD	58.1
7/17/02 Field Blank Day 1	1.2	11.2	33.4	45.9	< LOD	45.9
7/31/02 Field Blank	< LOD	< LOD	50.1	50.1	14.7	64.8
8/5/02 Field Blank Day 1	< LOD	11.8	14.6	26.5	29.3	55.8
8/6/02 Field Blank Day 2	1.9	13.3	58.0	73.3	27.8	101.1
8/28/02 Field Blank Day 1	< LOD	9.8	19.5	29.3	43.5	72.8
9/4/03 Field Blank Day 1	< LOD	12.1	21.0	33.1	15.4	48.5
9/5/03 Field Blank Day 2	< LOD	10.7	18.8	29.5	35.4	65.0
9/11/02 Field Blank Day 1	< LOD	4.9	9.8	14.8	13.9	28.6
9/12/02 Field Blank Day 2	< LOD	8.1	25.3	33.4	18.8	52.3
9/16/02 Field Blank Day 1	1.4	10.5	37.8	49.7	17.0	66.7
9/17/02 Field Blank Day 2	1.2	10.9	37.4	49.5	32.3	81.8
9/21/02 Field Blank Day 1	< LOD	< LOD	28.2	28.2	18.4	46.6
9/22/02 Field Blank Day 2	1.5	12.7	29.1	43.4	38.0	81.3
9/25/02 Field Blank Day 1	3.1	13.9	26.0	42.9	11.2	54.1
9/26/02 Cooler Blank Day 2	3.4	12.6	13.5	29.6	11.9	41.5

10/9/02 Field Blank Day 1	0.7	7.0	14.4	22.0	5.8	27.8
10/10/02 Field Blank Day 2	2.9	13.2	27.7	43.7	17.4	61.1
10/15/02 F. Blank #1 - Plane	< LOD	13.0	14.3	27.4	20.7	48.1
10/15/02 F. Blank #2 - Boat	< LOD	16.6	16.2	32.8	4.5	37.3

Denuder Blank Statistics	Denuder Amount (nmol N per denuder)					
	HNO_2:	HNO_3:	NH_3:	TIN:	ON-g:	TN-g:
Number of Blanks Collected:	22	22	22	22	20	22
Min Value:	< LOD	< LOD	9.8	12.5	4.5	27.8
Max Value:	3.4	16.6	58.0	73.3	60.3	101.1
Median Value:	0.3	11.5	23.2	33.3	18.6	57.0
Mean Value:	0.9	10.1	25.9	36.9	23.8	58.4
Standard Deviation:	1.1	4.9	12.7	14.3	14.1	18.0
Mean [Sample / Blank] Ratio:	1.5	2.5	2.5	2.5	0.6	1.8

Notes on Denuder Blanks: Measured using potassium carbonate or citric acid coated denuders

HNO_2: Nitrous Acid (from potassium carbonate coated denuder)
NOTE - Value should be considered qualitative due to low sample/blank ratios

HNO_3: Nitric Acid (from potassium carbonate coated denuder)

NH_3: Ammonia (from citric acid coated denuder)

TIN: Total Inorganic Nitrogen (Sum of nitrous acid, nitric acid, and ammonia)

ON-g: Total Organic Nitrogen in the gas phase (sum of results from both denuders)
ON-g values were determined by photochemical oxidation of denuders extracts using 254 nm light
ON-g = TIN (after photooxidation) - TIN (before photooxidation)
NOTE - ON-g values are only qualitative due to low sample/blank ratios

TN-g: TIN + ON-g
NOTE - TN-g is qualitative due to inclusion of ON-g value

Statistics: Values < LOD were treated as zero; statistics include the four Oct. boat samples

Key to Symbols:

< LOD Value was below instrument's limit of detection.
(Component then omitted when computing TIN, ON and TN)

TABLE 10
Summary of the 2003 boat data

Date	Start Time (PST)	End Time (PST)	Temp. (C)	Rel Hum (%)	Pressure (mb)	NO (ppbv)	NOy (ppbv)	PC1[16] (N x10^6/m^3)	PC2[17] (N x10^4/m^3)	MassFlow (slpm)
01-24-03	14:05:14	14:59:51	4.1	81.4	816.0	3.0	5.3	27.1	8.5	20.1
01-26-03	10:56:16	11:57:16	4.1	93.2	817.6	2.3	7.1	42.4	7.8	19.5
01-26-03	12:24:55	13:25:20	5.2	79.4	816.7	2.6	7.0	39.1	4.7	19.4
01-27-03	09:19:49	11:06:17	8.6	59.7	811.7	1.6	4.2	10.9	6.9	19.1
02-05-03	11:26:48	13:19:19	1.1	6.5	807.9	2.3	4.2	15.2	4.3	19.1
02-05-03	14:42:36	16:23:50	2.3	7.0	807.2	2.1	4.3	6.2	---	19.9
03-03-03	10:52:18	12:51:00	2.1	39.1	801.0	2.3	3.0	15.4	---	19.0
03-03-03	13:40:46	15:40:16	1.5	49.2	799.6	4.3	6.0	16.4	---	19.7
03-07-03	10:33:56	12:41:14	6.4	13.6	806.4	2.2	3.9	9.2	---	20.2
03-07-03	13:51:24	15:46:39	7.7	18.3	805.6	1.9	4.3	11.0	---	19.9

Note: denuder-filter pack results are not included because of high blank levels measured during the 2003 boat sampling.

[16] PC1 represents the number of particles with diameters > 0.3 µm
[17] PC1 represents the number of particles with diameters > 3.0 µm

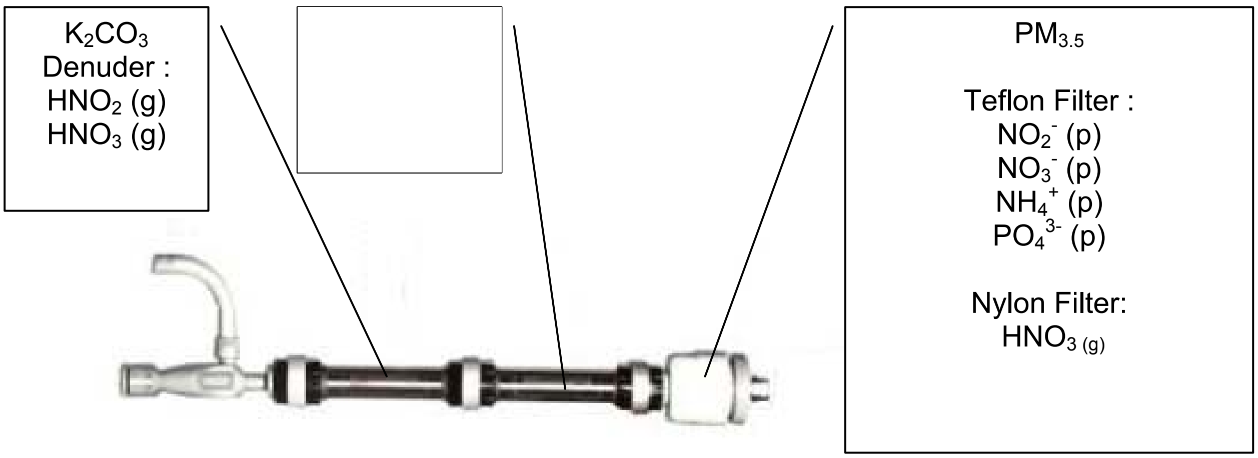

FIGURE 1. View of denuder filter pack (DFP) assembly.

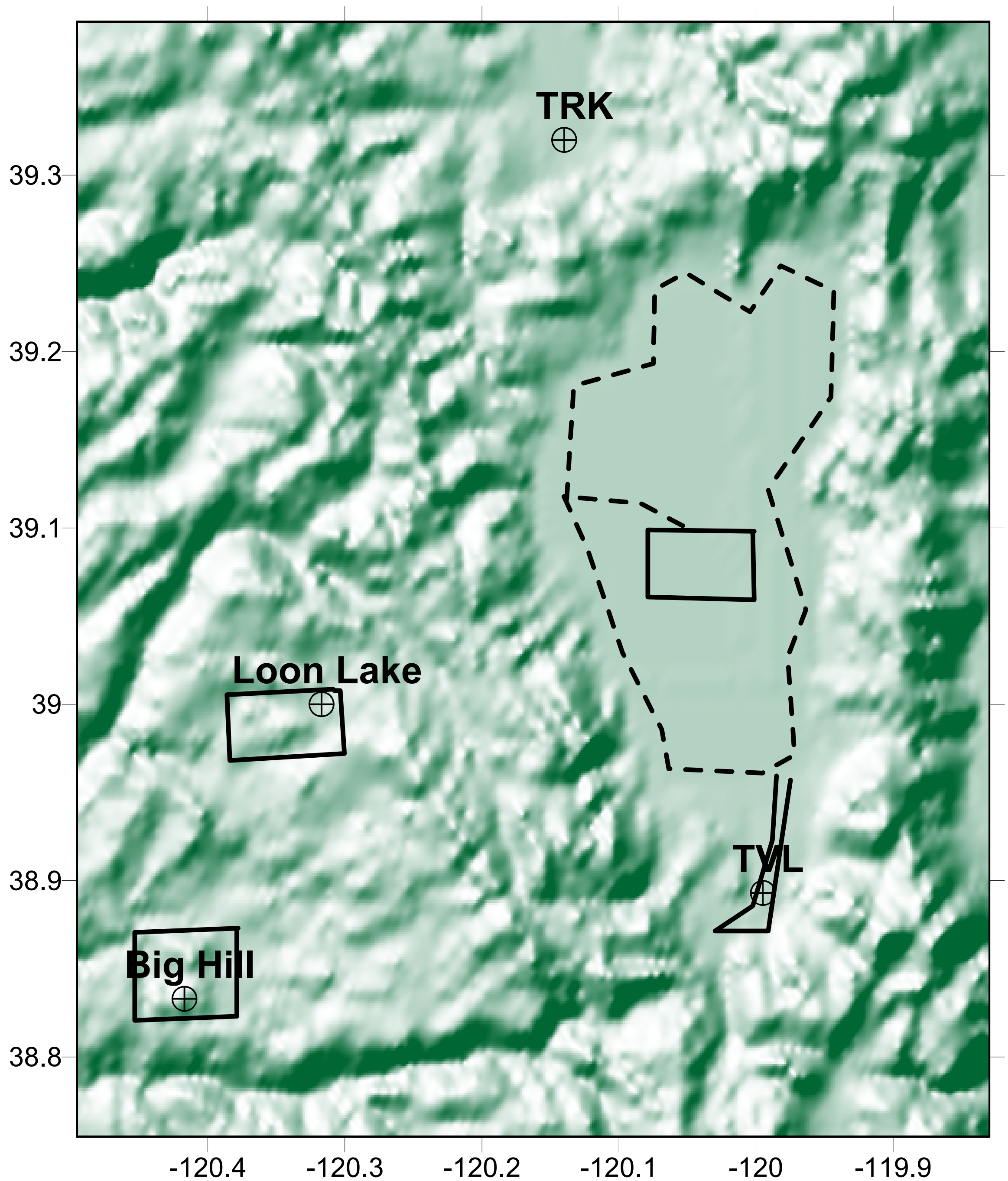

FIGURE 2. Map of the Tahoe region showing typical flight paths for vertical sampling (solid lines) and horizontal, DFP sampling (dashed line, at 2070 and 2380 m MSL). Rectangular "spirals" are used to allow straight legs needed for wind measurement.

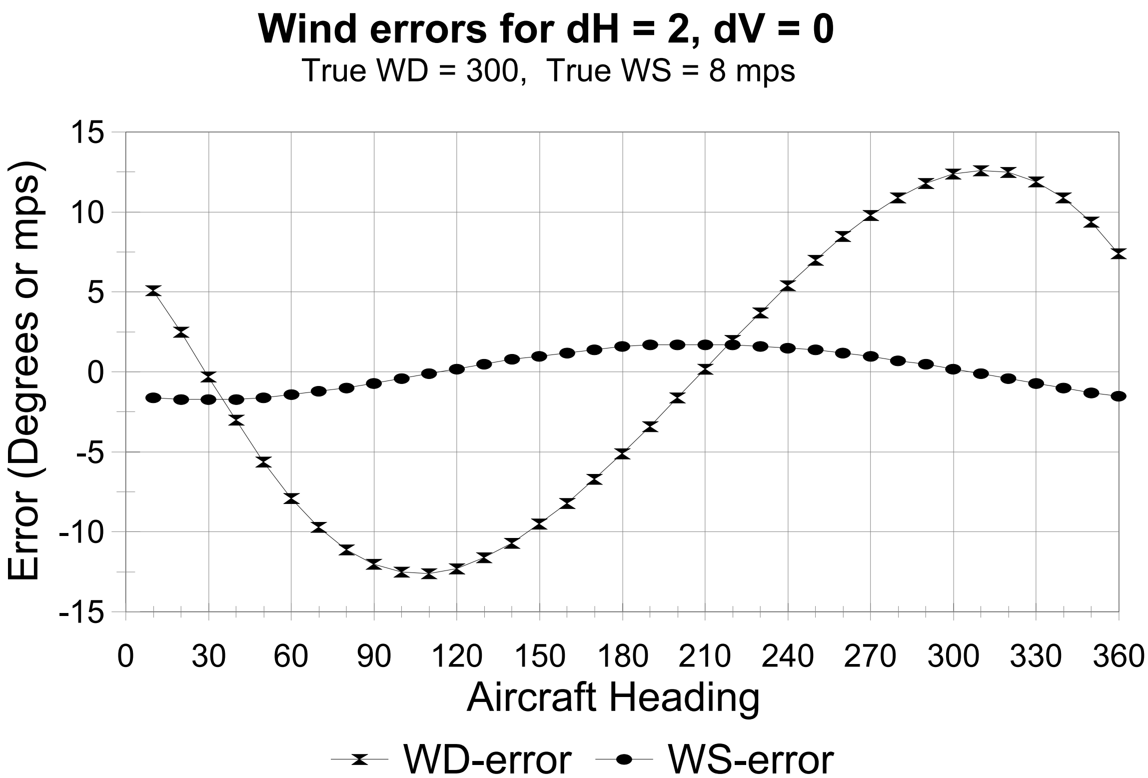

FIGURE 3. Computed wind speed (WS) and direction (WD) errors as a function of aircraft heading for a heading error of 2 degrees and no airspeed error.

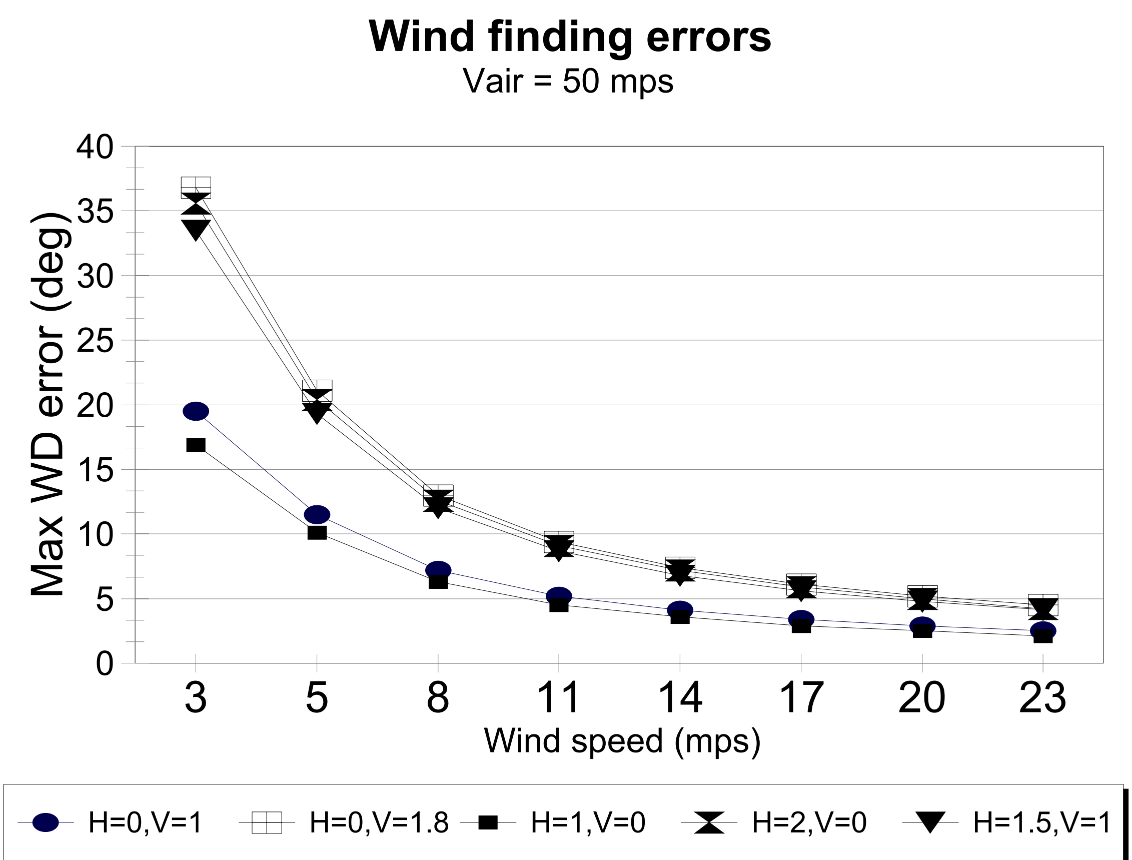

FIGURE 4. Computed maximum wind direction (WD) error versus wind speed for five sets of heading errors (H, degrees) and airspeed errors (V, ms^{-1}).

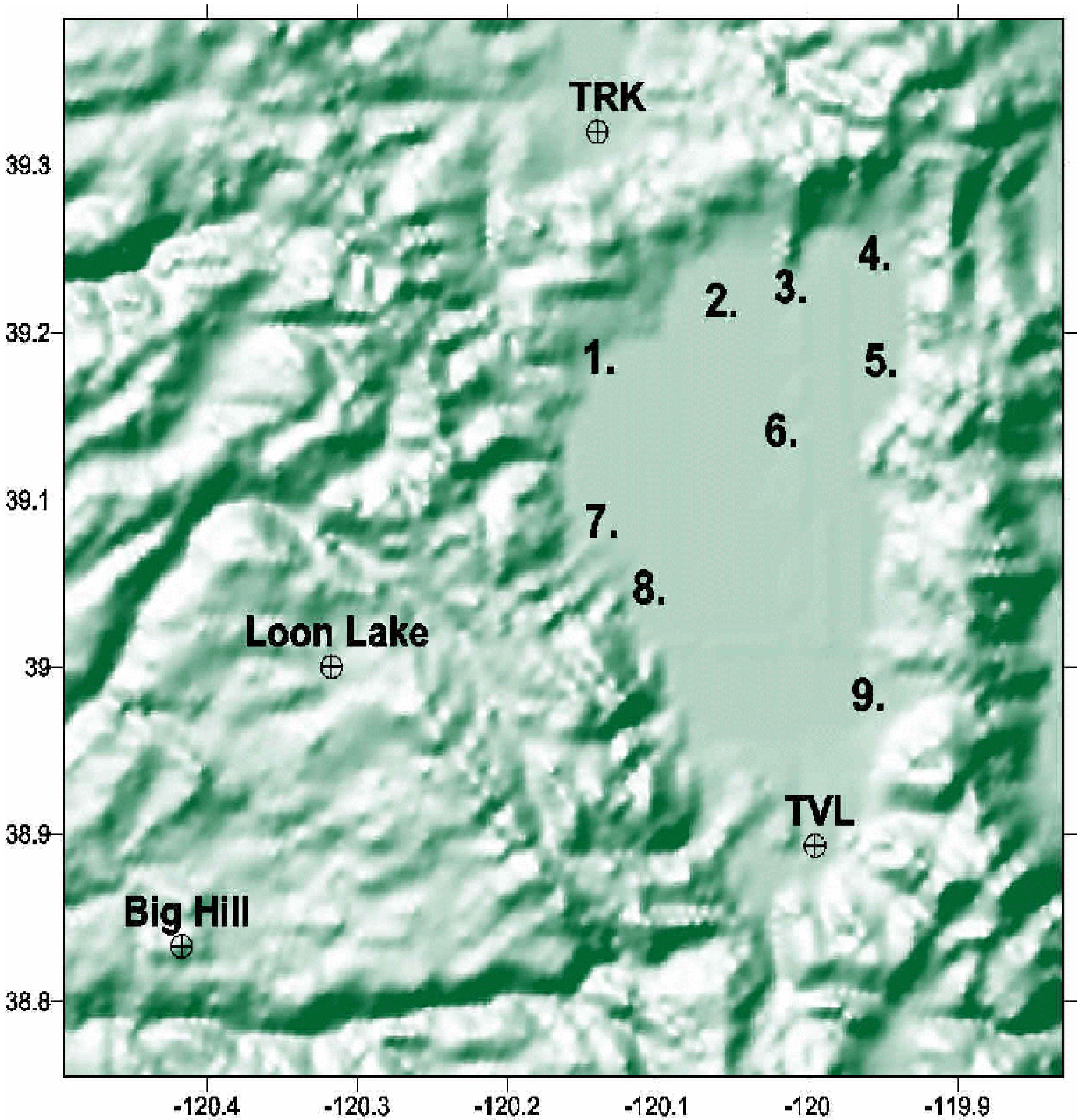

FIGURE 5. Map of the Lake Tahoe area showing locations of sites referenced in text. TVL refers to Tahoe Valley Airport and TRK to the Truckee airport. Numbered sites are as follows: 1. Tahoe City Marina, 2. Carnelian Bay, 3. Stateline Point, 4. Incline Village, 5. Sand Harbor, 6. Buoy (TB1), 7. Meeks Bay, 8. Sugar Pine Point, and 9. Cave Rock.

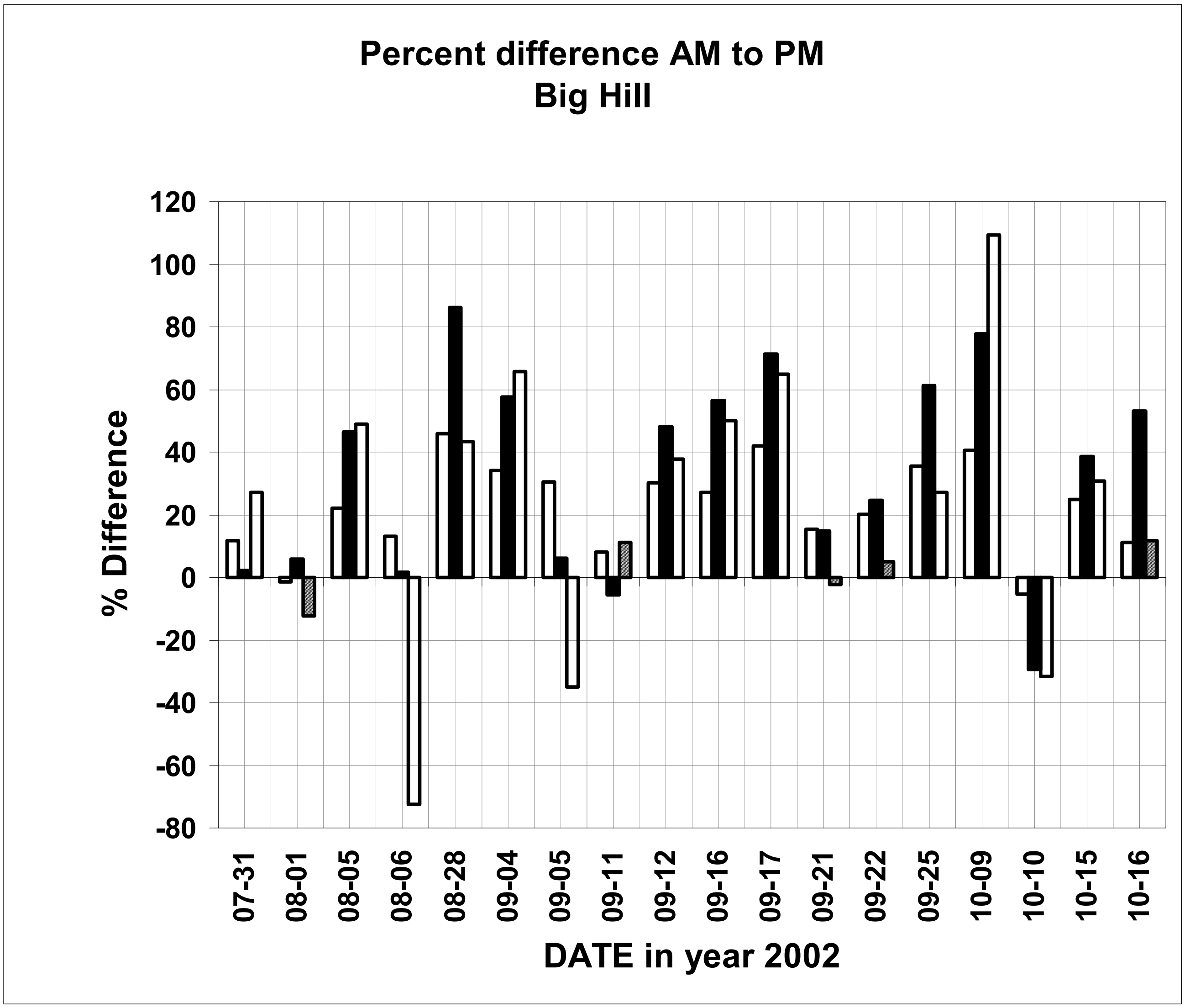

FIGURE 6A. Plots of the percent change in pollutant concentrations of Ozone (open bars), NOy (solid bars) and Finer Particles (PC1, cross-hatched bars) between the morning and afternoon soundings for 18 days of paired observations at Big Hill. The "% Difference" on a given day was calculated as [(PM Concentration – AM Concentration)/(Average of AM and PM Concentrations)] × 100%.

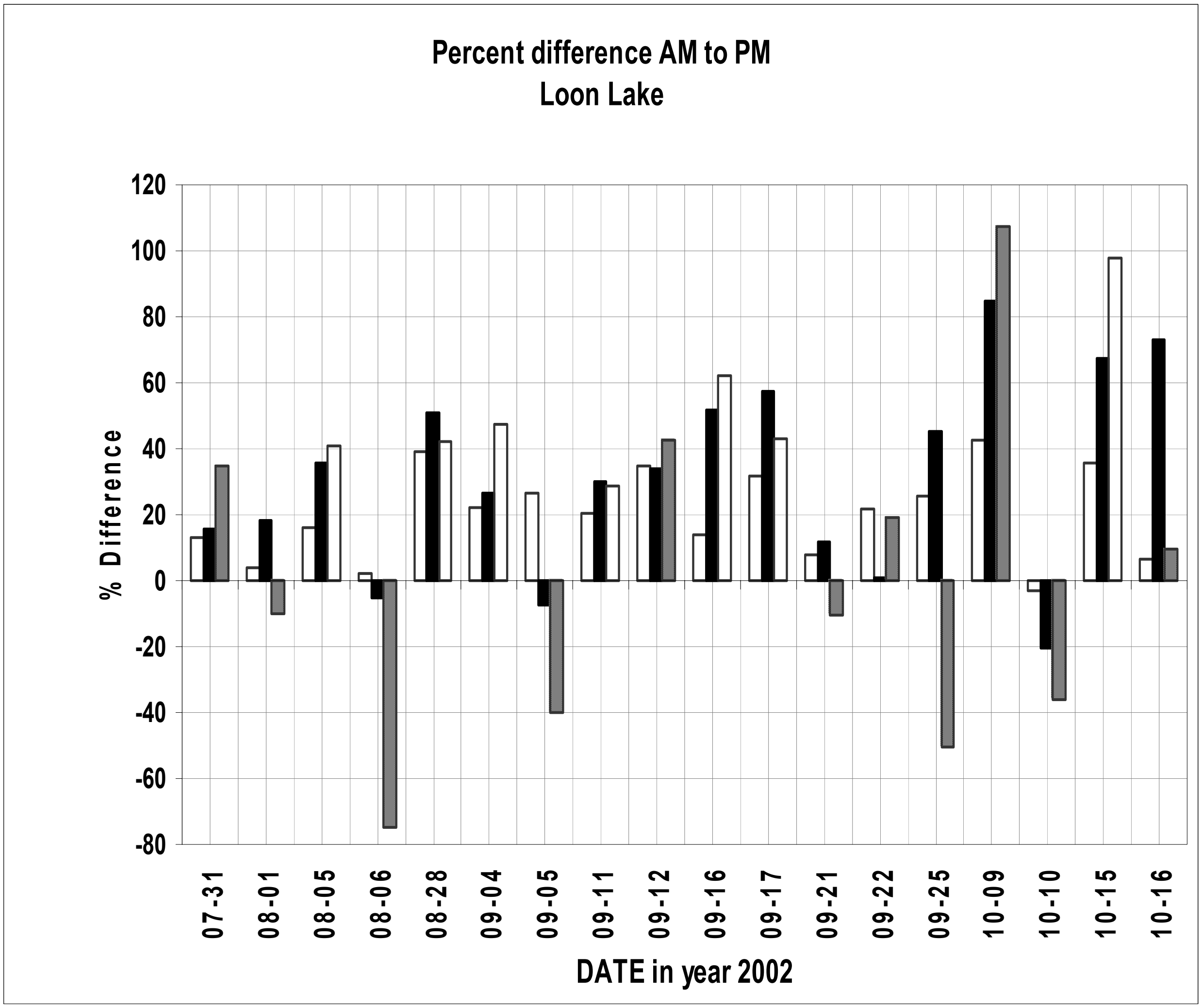

Figure 6B. Plots of the percent change in pollutant concentrations of Ozone (open bars), NOy (solid bars) and Finer Particles (PC1, cross-hatched bars) between the morning and afternoon soundings for 18 days of paired observations at Loon Lake. The "% Difference" on a given day was calculated as [(PM Concentration – AM Concentration)/(Average of AM and PM Concentrations)] × 100%.

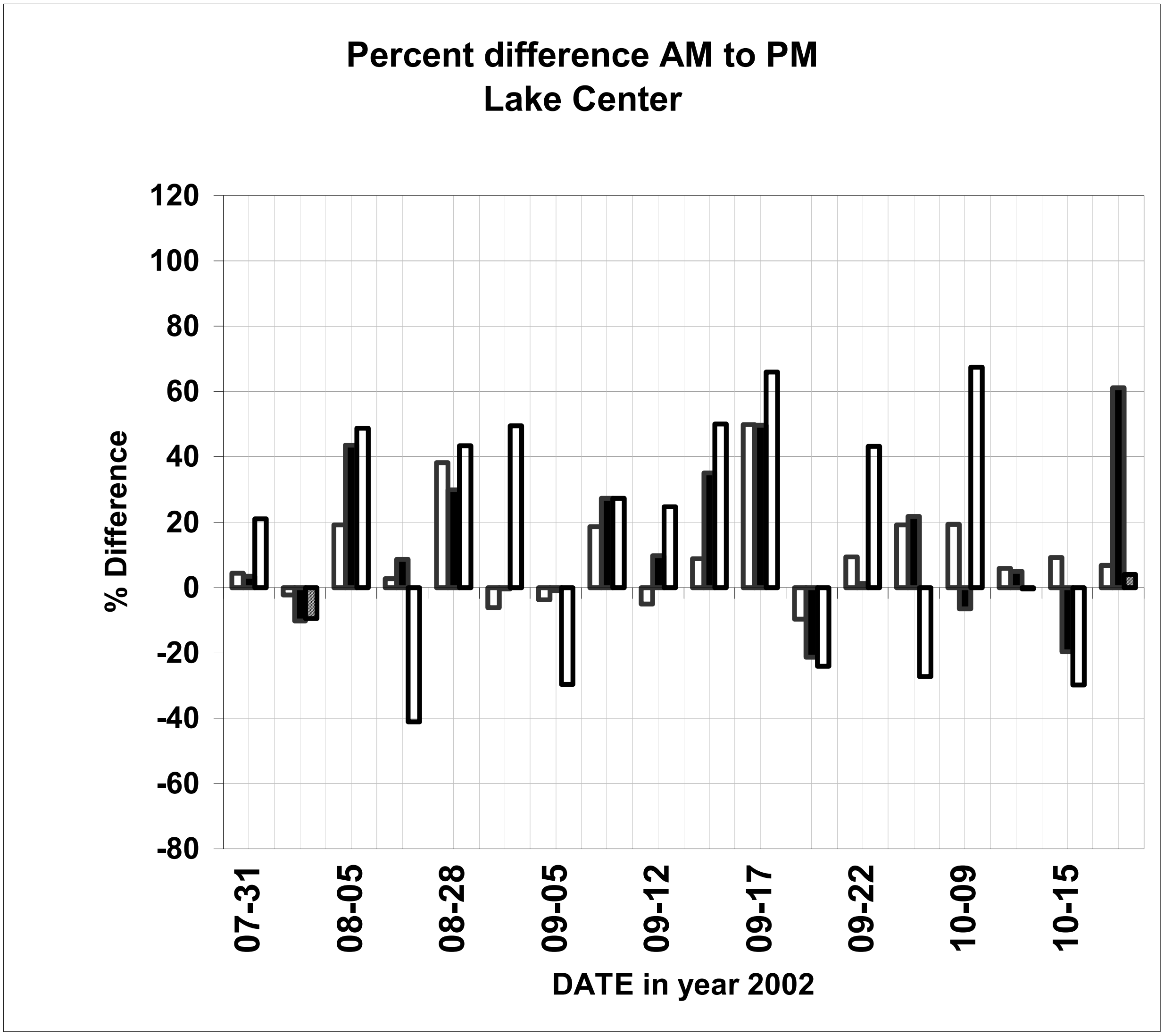

FIGURE 6C. Plots of the percent change in pollutant concentrations of Ozone (open bars), NOy (solid bars) and Finer Particles (PC1, cross-hatched bars) between the morning and afternoon soundings for 18 days of paired observations over the center of Lake Tahoe. The “% Difference” on a given day was calculated as [(PM Concentration – AM Concentration)/(Average of AM and PM Concentrations)] × 100%.

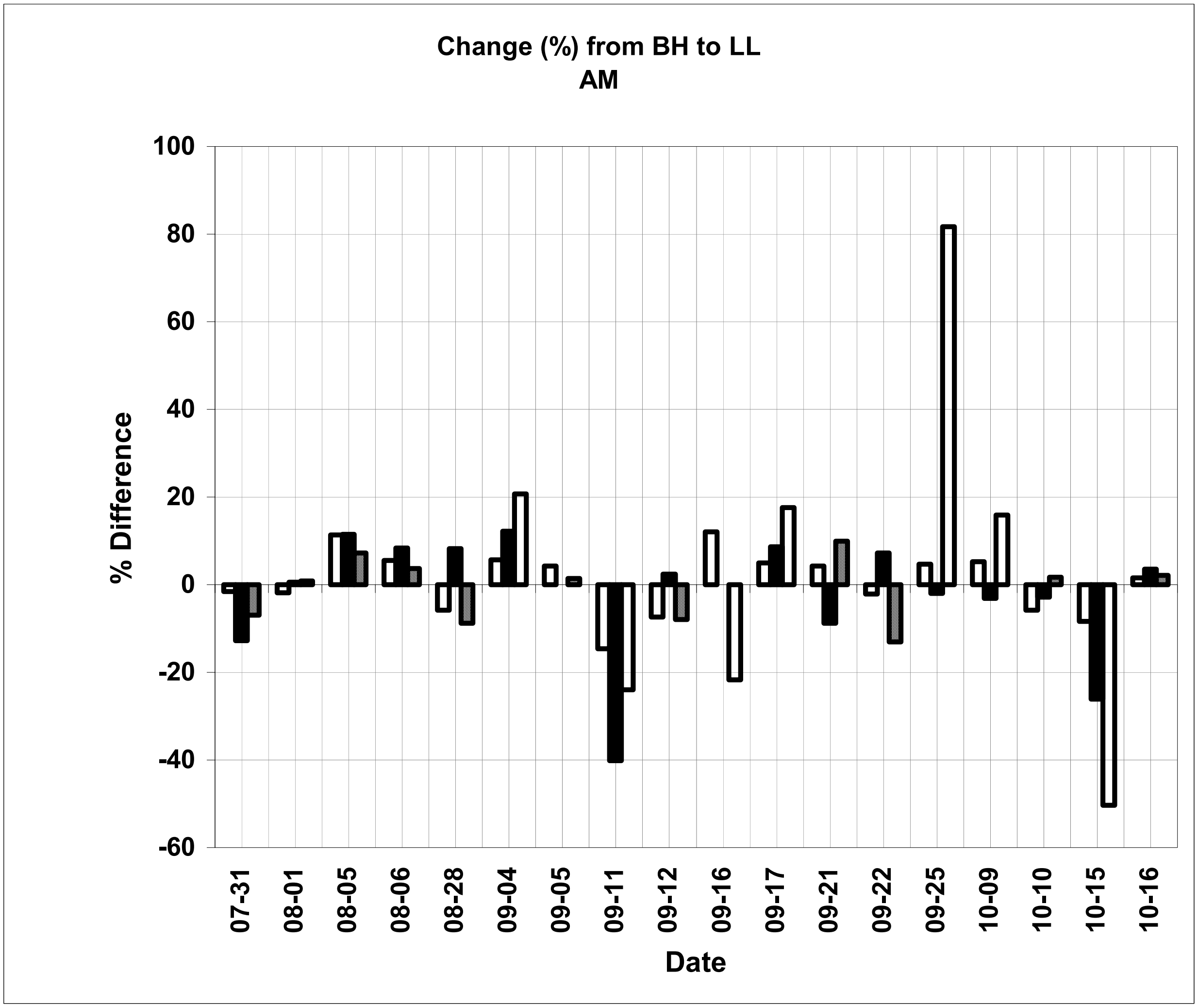

FIGURE 7A. Plots of percent difference in concentrations of Ozone (open bars), NOy (solid bars) and Finer Particles (PC1, cross-hatched bars) during the morning sounding between Big Hill (BH) and Loon Lake (LL). The "% Difference" on a given day was calculated as [(LL Concentration – BH Concentration)/(Average of LL and BH Concentrations)] × 100%.

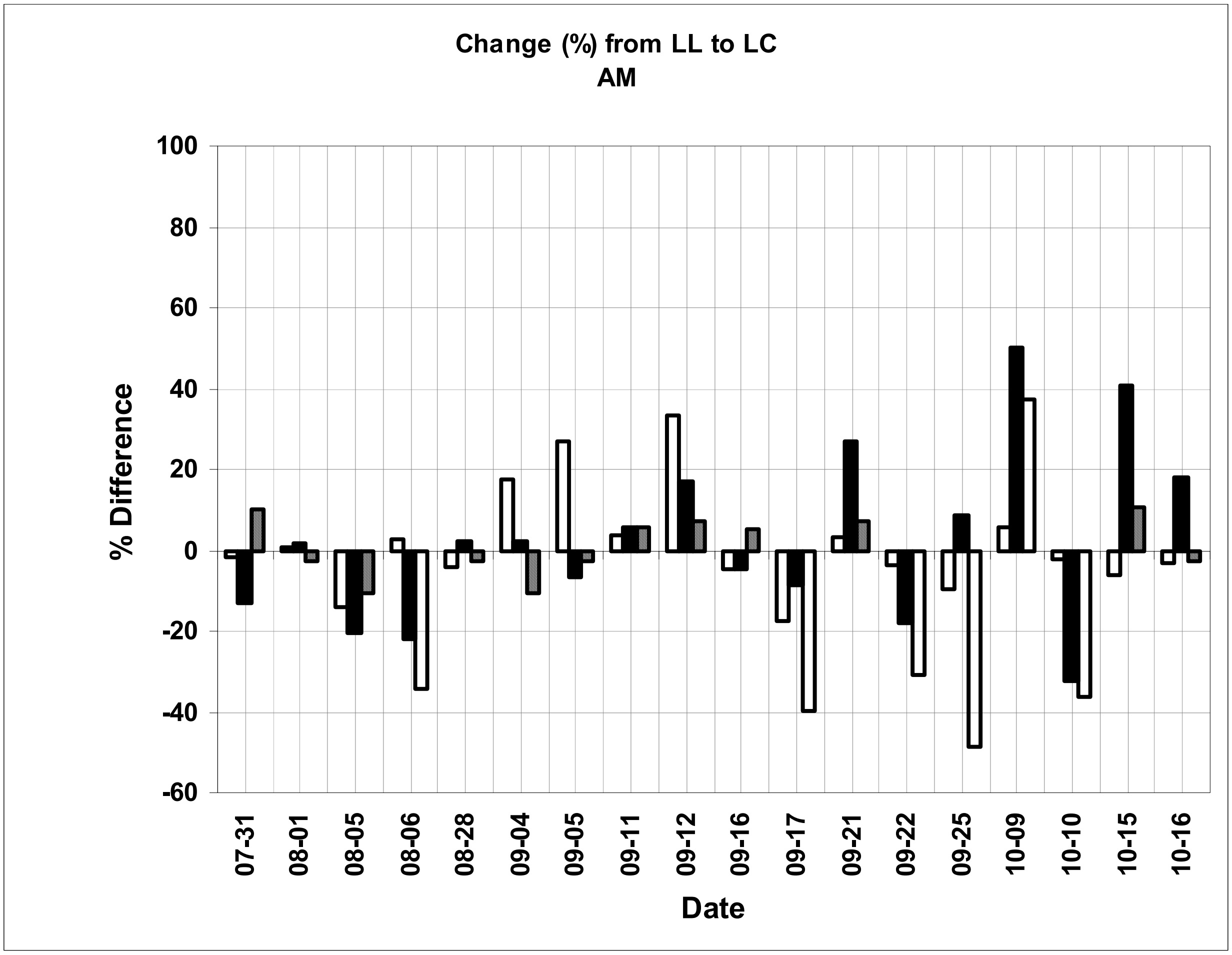

FIGURE 7B. Plots of percent difference in concentrations of Ozone (open bars), NOy (solid bars) and Finer Particles (PC1, cross-hatched bars) during the morning sounding between Loon Lake (LL) and Lake Center (LC). The "% Difference" on a given day was calculated as [(LC Concentration – LL Concentration)/(Average of LC and LL Concentrations)] × 100%.

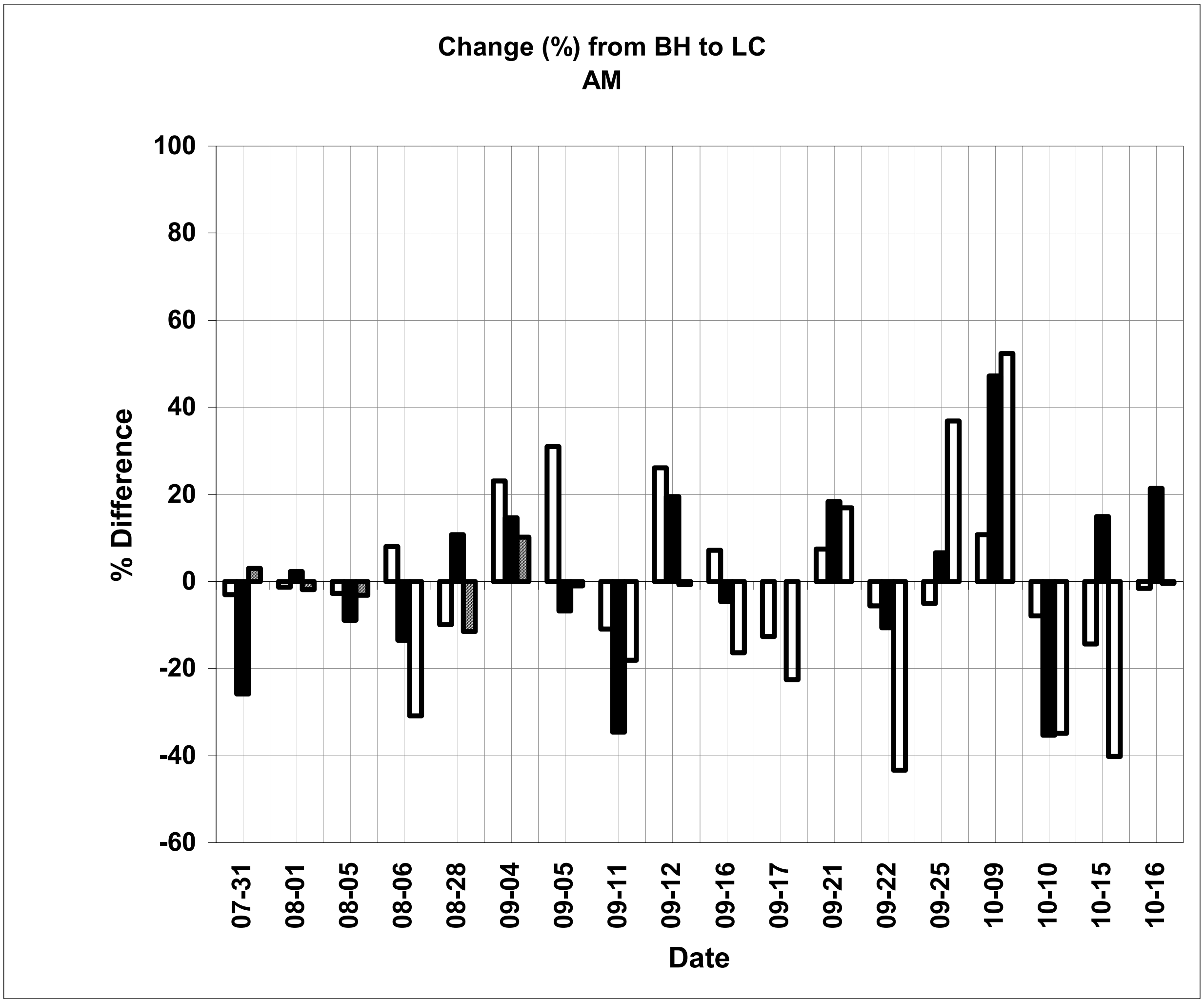

FIGURE 7C. Plots of percent difference in concentrations of Ozone (open bars), NOy (solid bars) and Finer Particles (PC1, cross-hatched bars) during the morning sounding between Big Hill (BH) and Lake Center (LC). The "% Difference" on a given day was calculated as [(LC Concentration – BH Concentration)/(Average of LC and BH Concentrations)] × 100%.

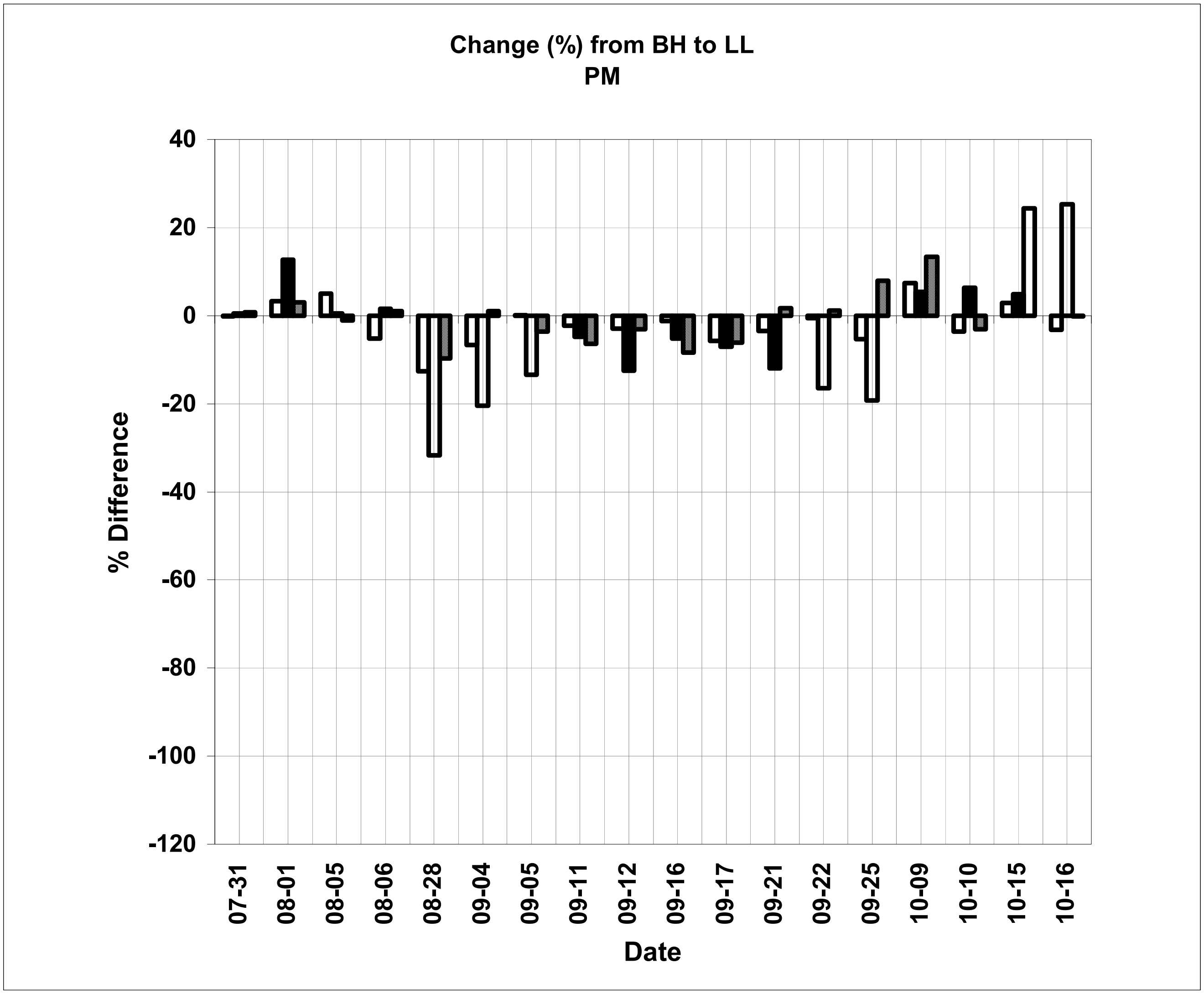

FIGURE 8A. Plots of percent difference in concentrations of Ozone (open bars), NOy (solid bars) and Finer Particles (PC1, cross-hatched bars) during the afternoon sounding between Big Hill (BH) and Loon Lake (LL). The "% Difference" on a given day was calculated as [(LL Concentration – BH Concentration)/(Average of LL and BH Concentrations)] × 100%.

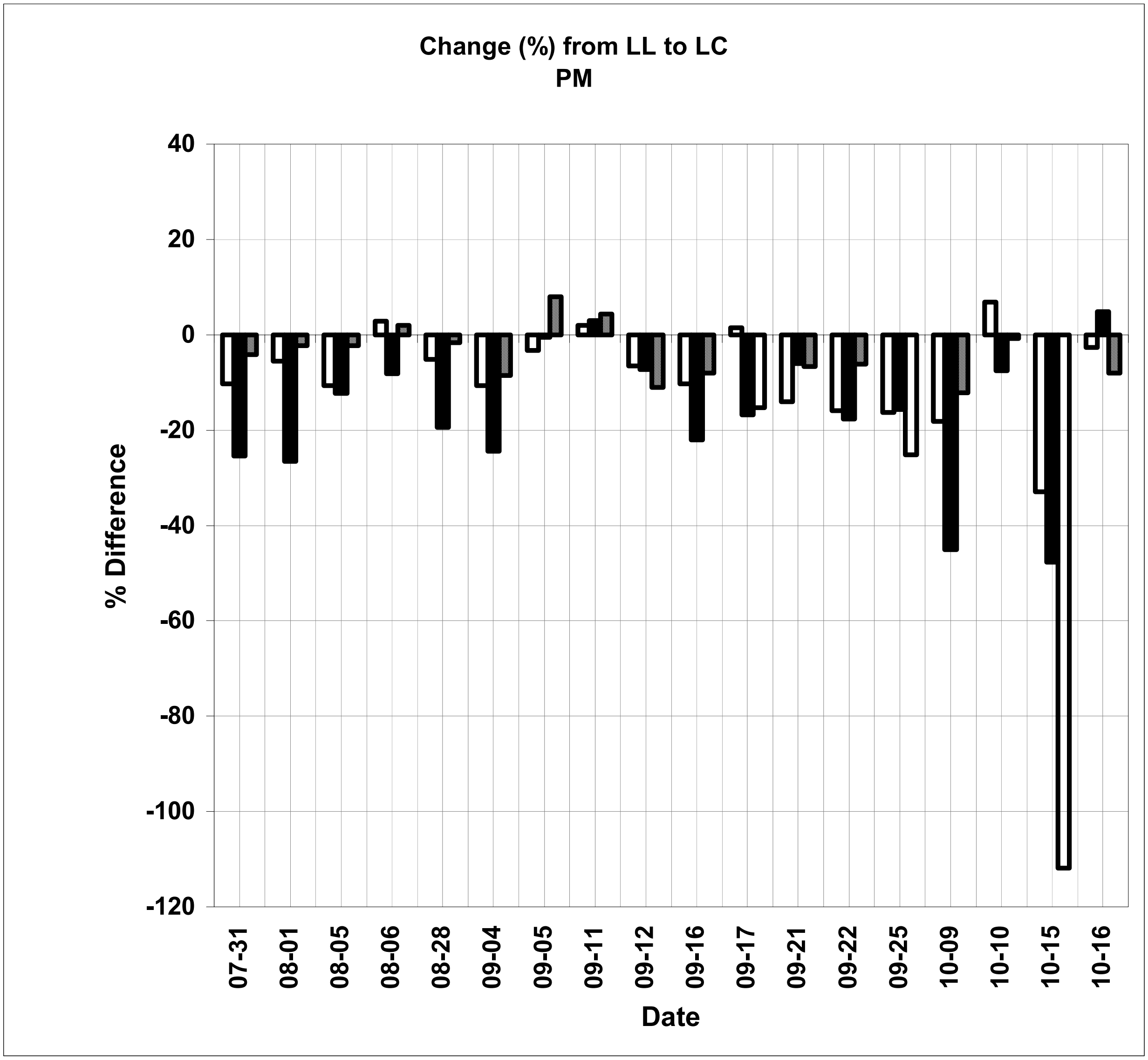

FIGURE 8B. Plots of percent difference in concentrations of Ozone (open bars), NOy (solid bars) and Finer Particles (PC1, cross-hatched bars) during the afternoon sounding between Loon Lake (LL) and Lake Center (LC). The "% Difference" on a given day was calculated as [(LC Concentration – LL Concentration)/(Average of LC and LL Concentrations)] × 100%.

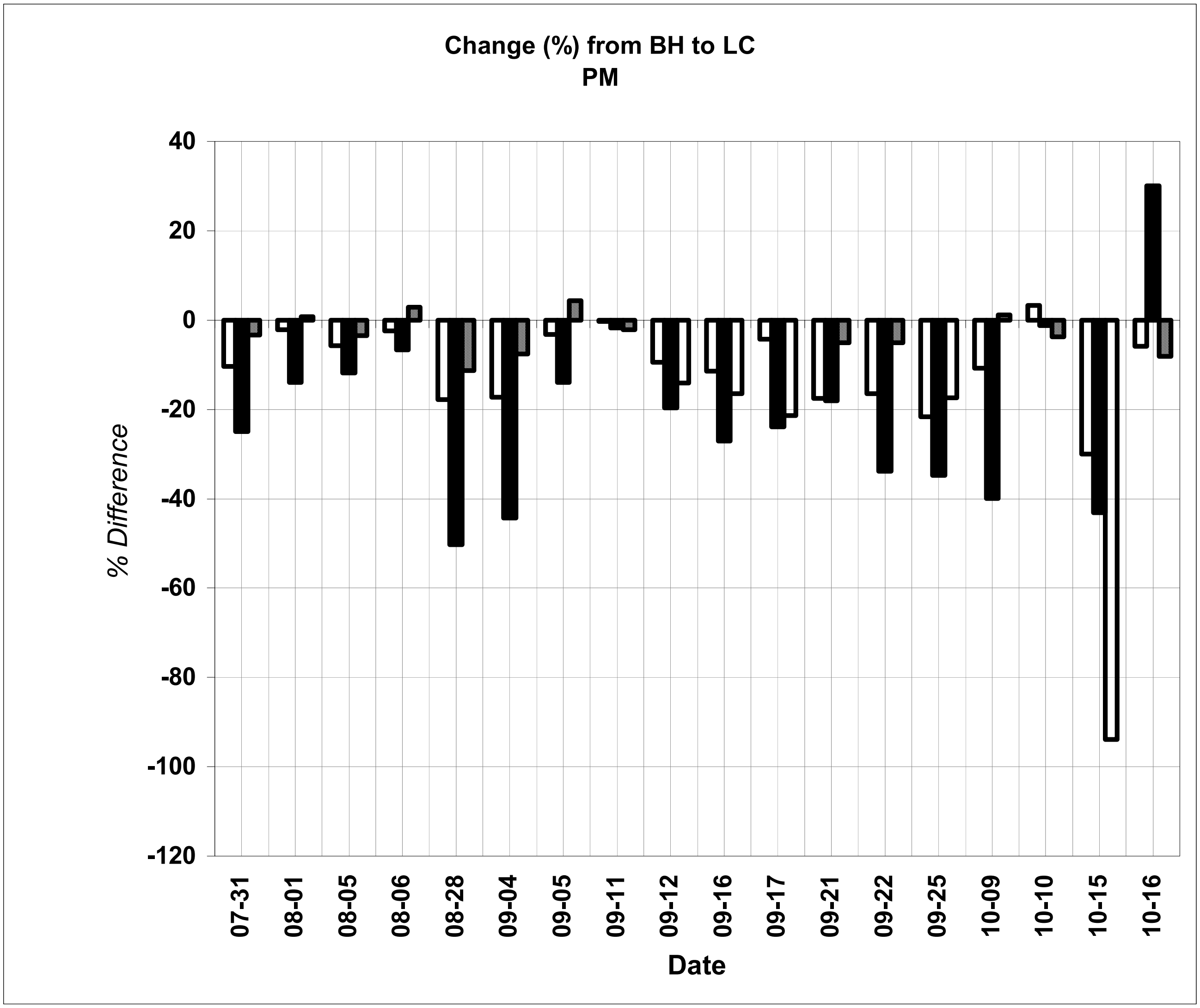

FIGURE 8C. Plots of percent difference in concentrations of Ozone (open bars), NOy (solid bars) and Finer Particles (PC1, cross-hatched bars) during the afternoon sounding between Big Hill (BH) and Lake Center (LC). The "% Difference" on a given day was calculated as [(LC Concentration – BH Concentration)/(Average of LC and BH Concentrations)] × 100%.

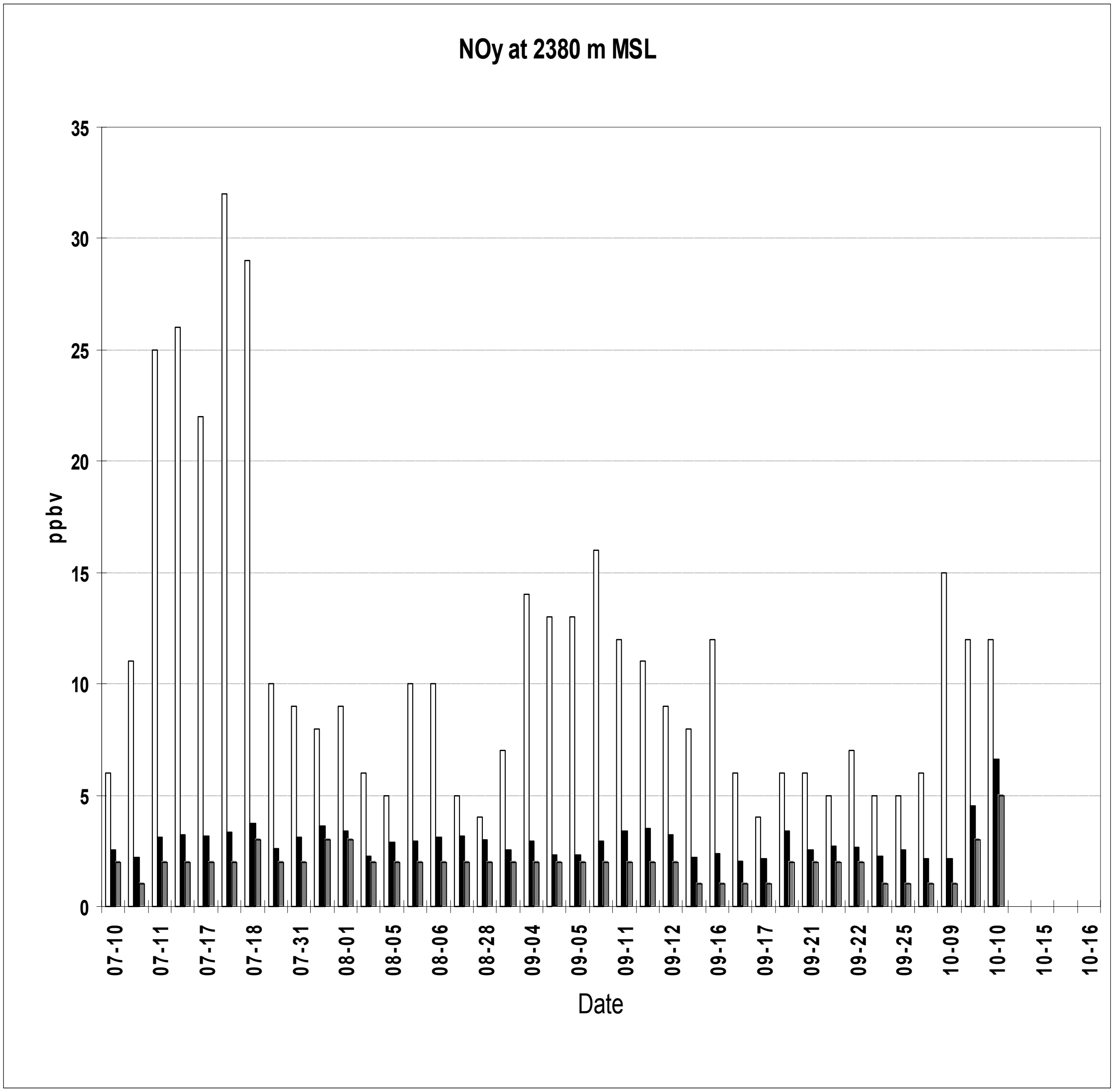

FIGURE 9A. Maximum (open bars), mean (solid bars), and minimum (cross-hatched bars) NOy concentrations versus date measured during horizontal traverses over the lake during the denuder sampling at about 2380 m MSL altitude. Note that each date includes two sets of bars: one for the morning and one for the afternoon.

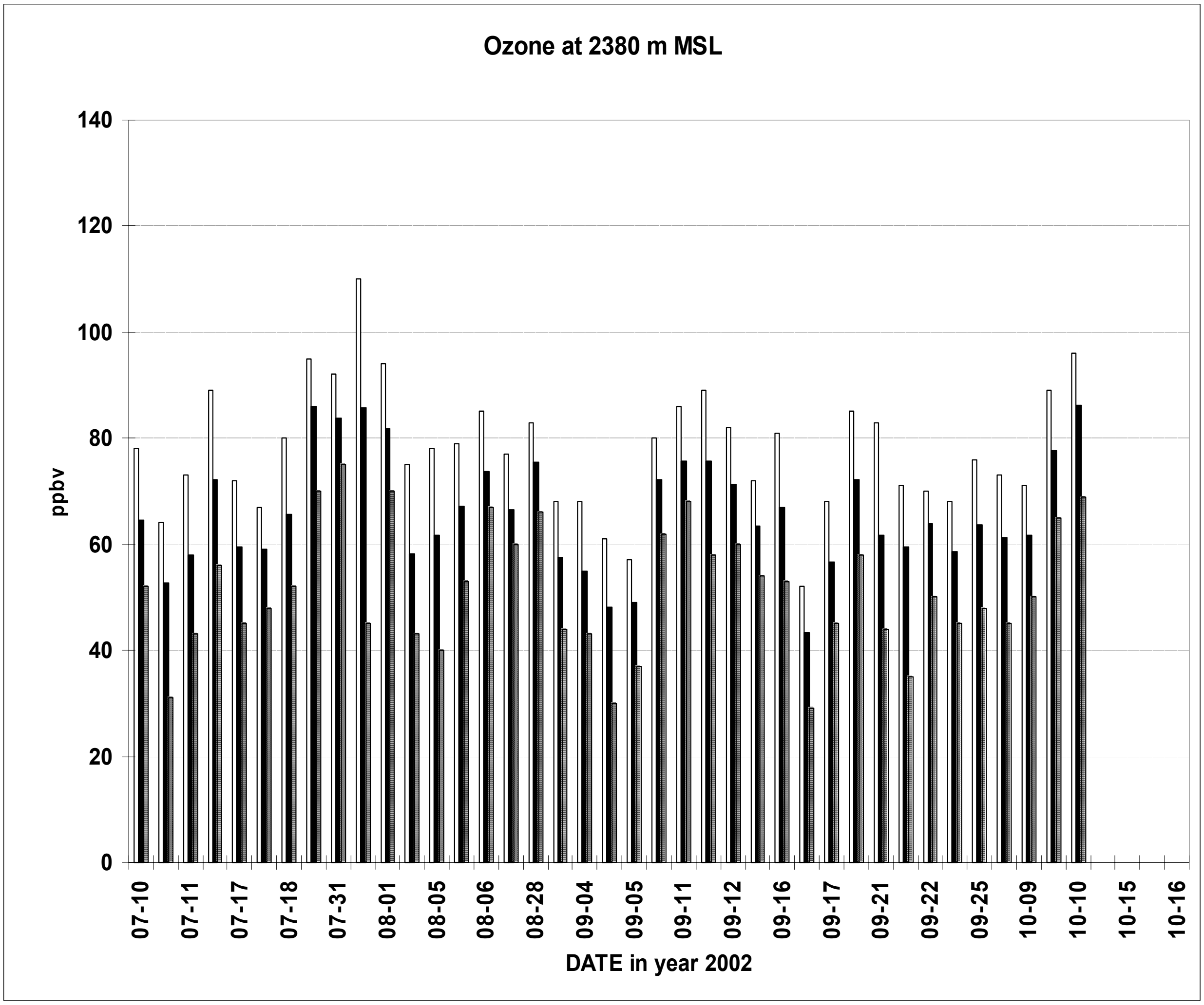

FIGURE 9B. Maximum (open bars), mean (solid bars), and minimum (cross-hatched bars) of ozone concentrations versus date measured during horizontal traverses over the lake during the denuder sampling at about 2380 m MSL altitude. Note that each date includes two sets of bars: one for the morning and one for the afternoon.

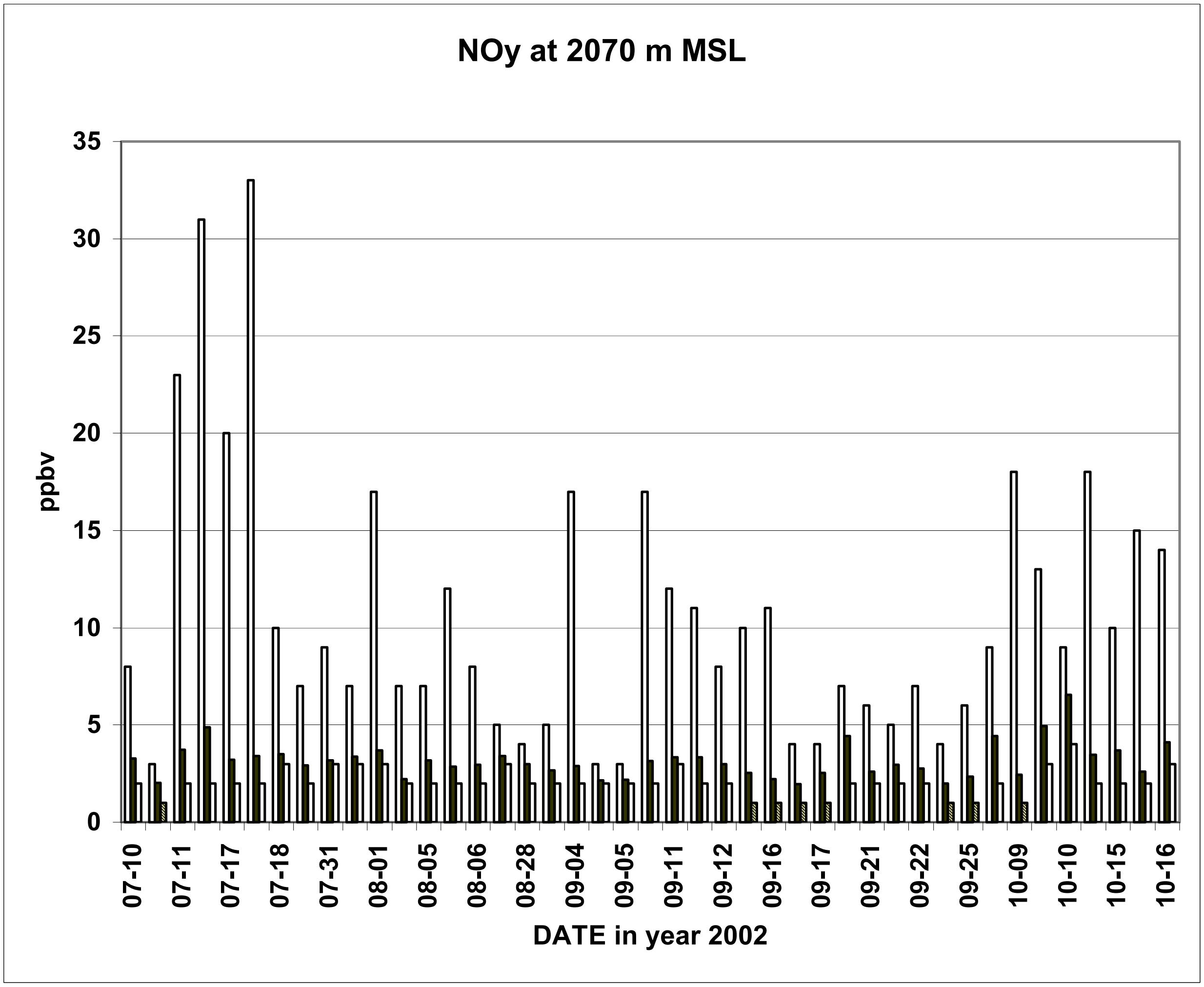

FIGURE 9C. Maximum (open bars), mean (solid bars) and minimum (cross-hatched bars) of NOy concentrations versus date measured during horizontal traverses over the lake during the denuder sampling at about 2070 m MSL altitude. Note that each date includes two sets of bars: one for the morning and one for the afternoon.

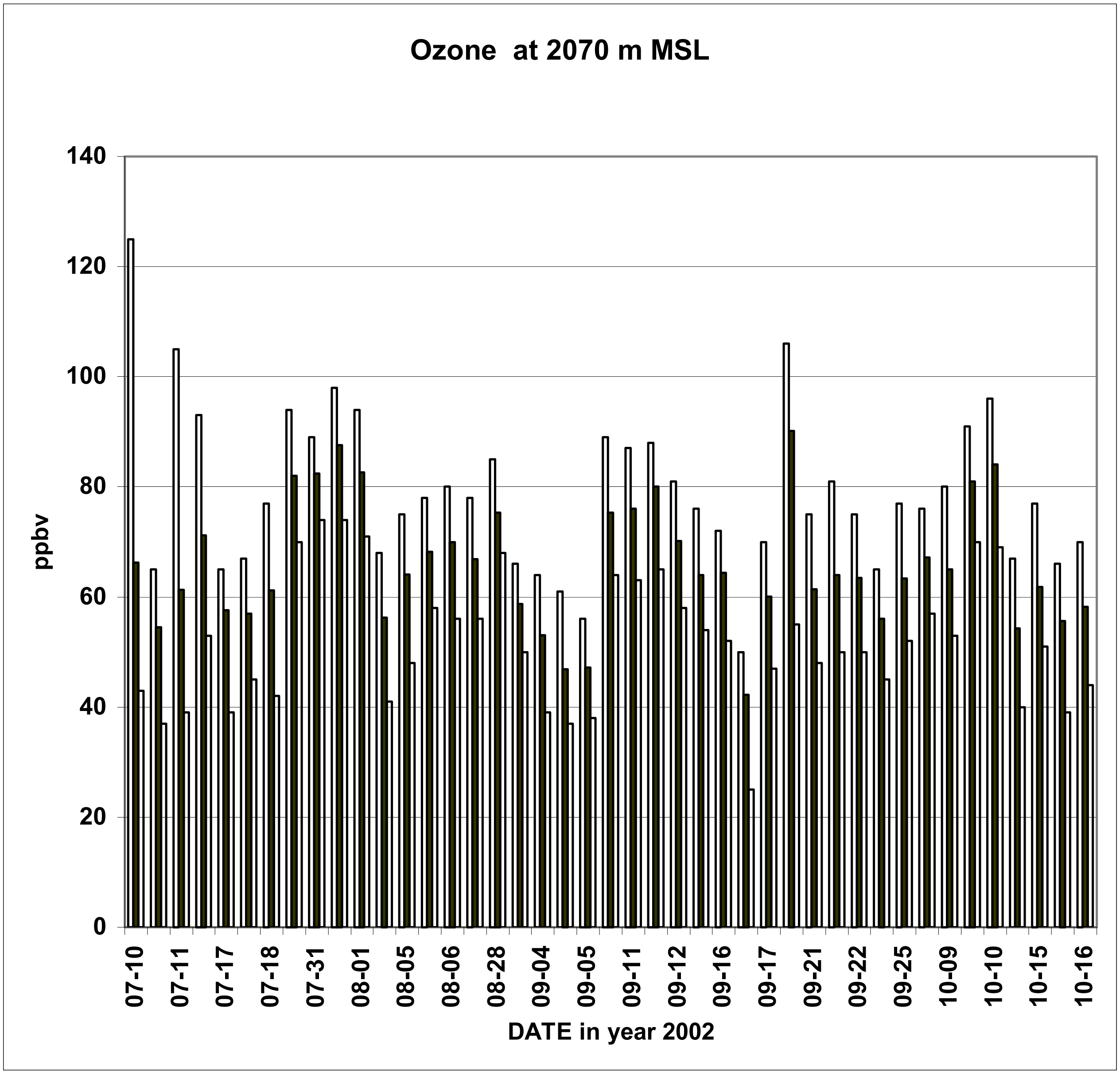

FIGURE 9D. Mean (solid bars), maximum (open bars) and minimum (cross-hatched bars) of ozone concentrations versus date measured during horizontal traverses over the lake during the denuder sampling at about 2070 m MSL altitude. Note that each date includes two sets of bars: one for the morning and one for the afternoon.

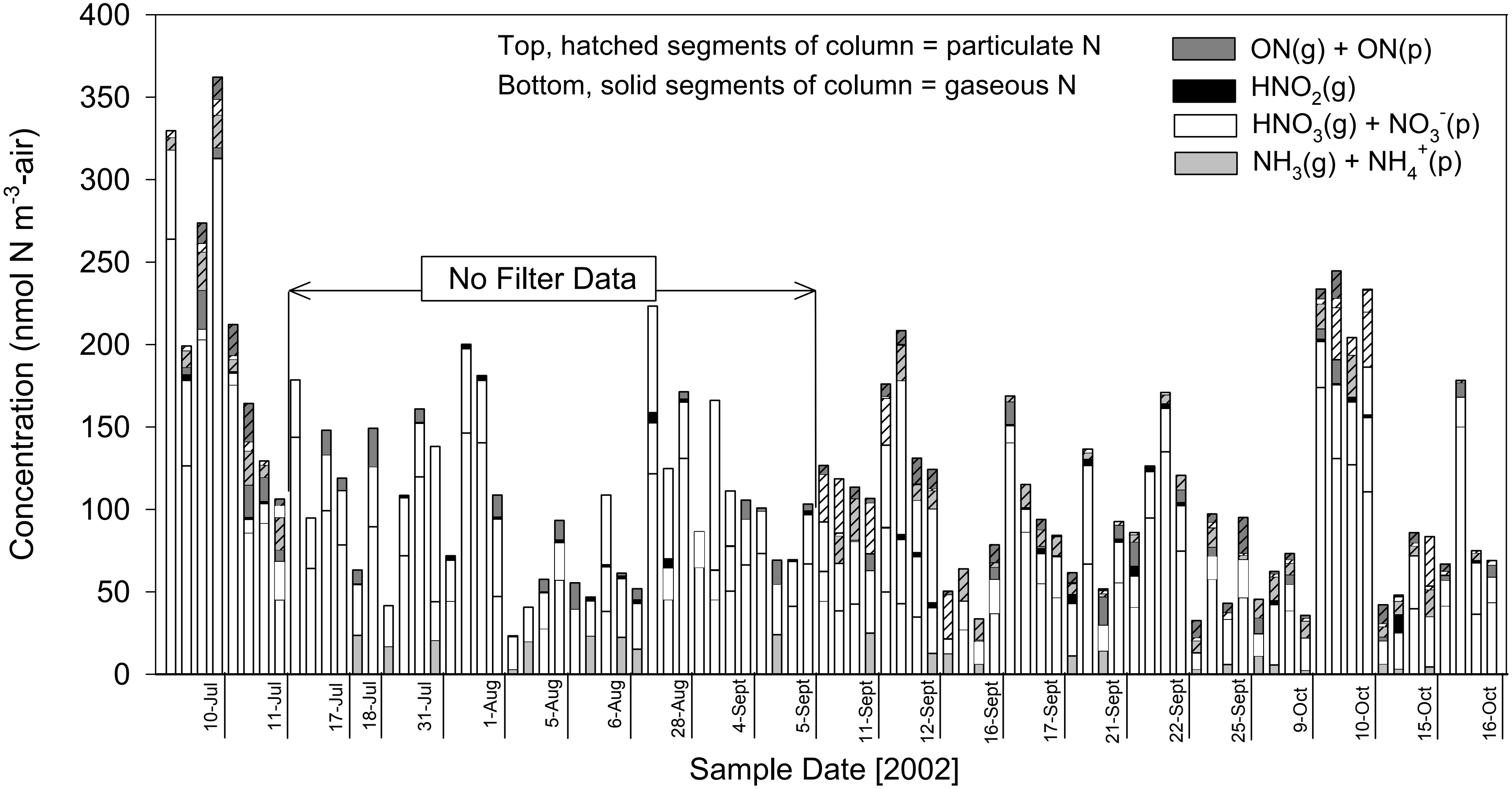

FIGURE 10. Concentrations of N Species in Gas Phase and $PM_{3.5}$ over the Tahoe Basin. Typically there are four samples per date listed; plotted left to right these are: morning at 2380m and 2070m MSL and afternoon at 2380m and 2070m MSL. The exceptions to this convention are on July 18 (morning only samples) and on 15 and 16 October (where sampling altitudes (above the lake) were 180m (i.e., 2070m MSL) and 2 m (by boat)). N speciation each day is given by the different colored portions of the bars. The open portions represent gaseous species, while the hatched portions represent particulate species.

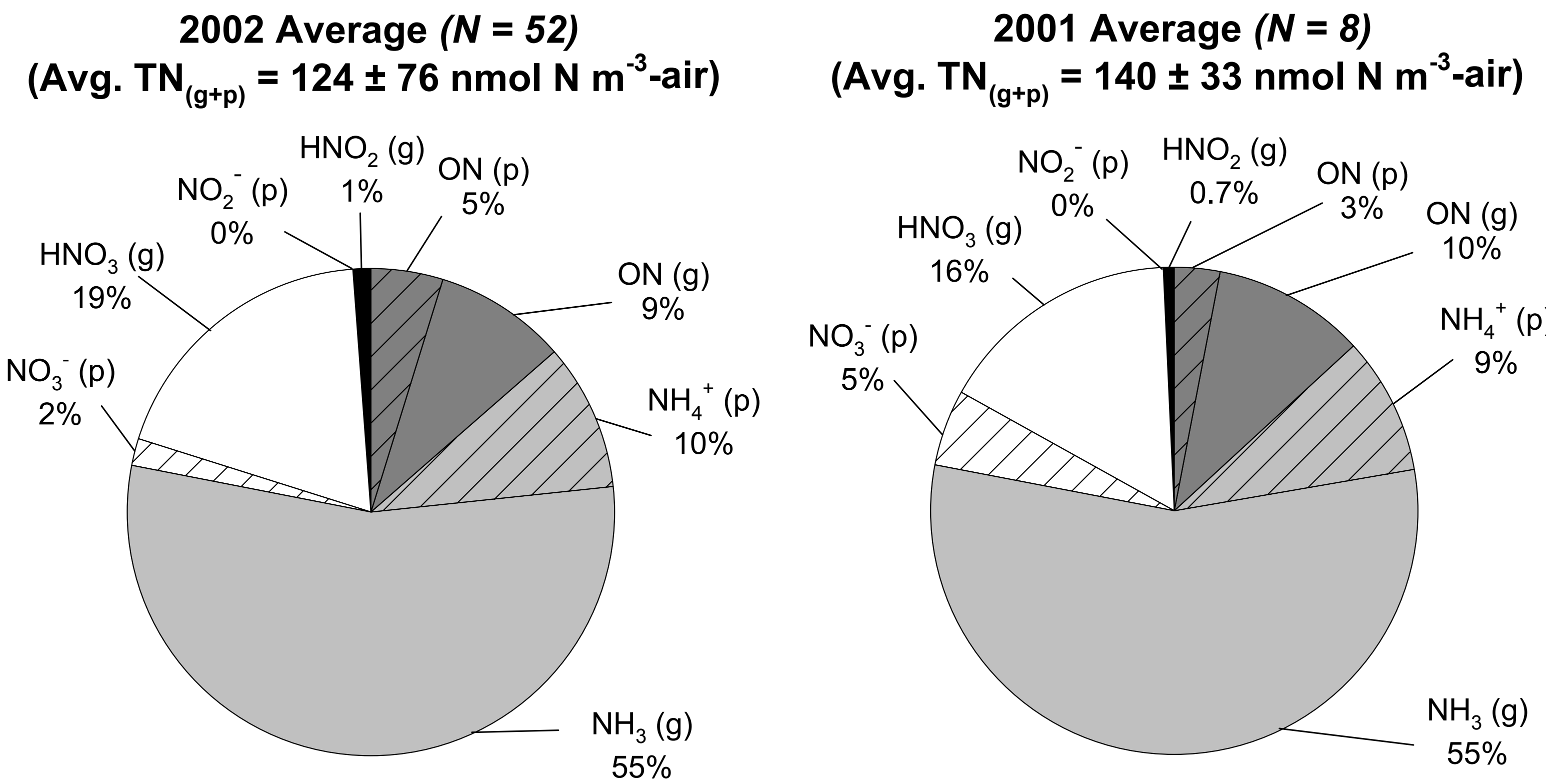

FIGURE 11. Average total gaseous and particulate nitrogen (TN_{g+p}) concentrations (± 1σ) and speciation for the 2002 sampling campaign (left pie) and during a smaller campaign during the summer of 2001 (right pie; Zhang et al., 2002). The 2002 TN average and speciation include only those DFP samples with both gaseous and particulate data (i.e., they do not include samples collected from July 17 – September 5, which had no particulate data). Totals do not necessarily add to 100% because of rounding.

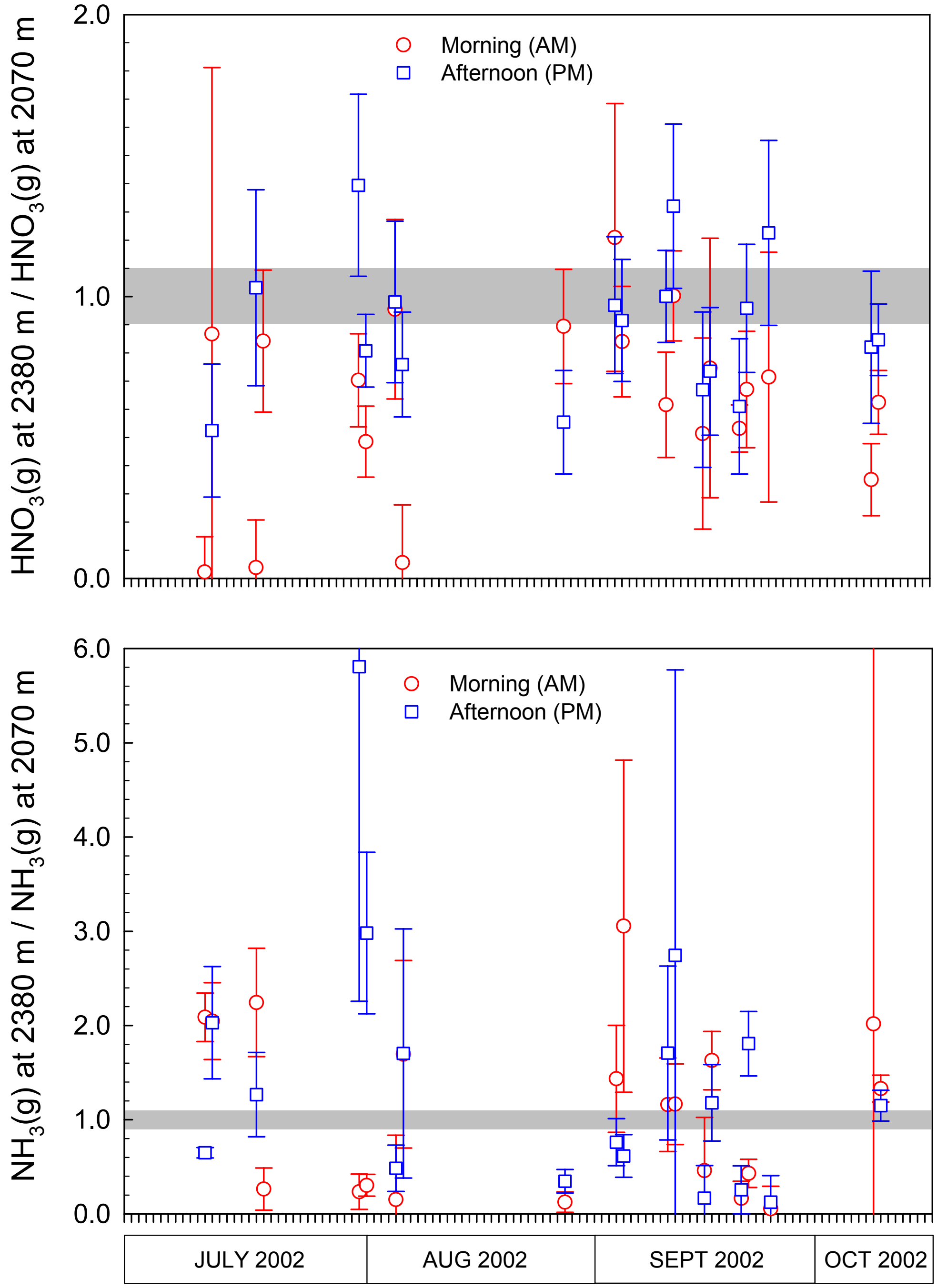

FIGURE 12. Ratio of the concentration measured at 2380 m to that measured at 2070 m during a given flight for gaseous nitric acid (top plot) and gaseous ammonia (bottom plot). Error bars represent estimated ±1σ, calculated by propagating standard deviations estimated from field blanks (see text). The HNO_3 plot does not include one outlier of 5.5 (10 July); for three samples (10 and 17 July and 06 August), values of HNO_3 were below the detection limit was and were replaced with the limit of detection. The NH_3 plot does not include one outlier of 15.9 (09 October).

Appendix A

Calibration Data

for

Ozone and Nitrogen Oxides Analyzer

Calibrations

TABLE A-1
Ozone Analyzer Calibration Data

Date	Calibration Concentration (ppbv)	Calibrator Concentration (ppbv)	Analyzer Concentration (ppbv)	Data Logger Concentration (ppbv)	Percent Difference (%)[18]
09/25/01	200	200.3	195.7	196.7	-1.8
	150	150.3	145.3	146.0	-2.9
	100	99.3	95.7	96.3	-3.0
	50	50.0	47.3	47.3	-5.3
	0	11.0	8.7	9.7	-12.1
06/20/02	200	199.7	194.7	196.0	-1.8
	150	150.7	146.0	147.0	-2.4
	100	100.3	95.0	96.0	-4.3
	50	50.3	46.7	47.3	-6.0
	0	10.7	8.0	9.0	-15.6
07/09/02	200	199.7	197.7	200.7	0.5
	150	149.7	145.7	148.0	-1.1
	100	99.3	97.7	99.7	0.3
	50	50.0	47.0	49.0	-2.0
	0	10.7	8.3	9.0	-15.6
07/29/02	200	200.0	195.0	198.0	-1.0
	150	150.0	145.0	147.0	-2.0
	100	100.0	94.0	96.0	-4.0
	50	50.7	44.7	46.0	-9.2
	0	13.7	7.0	8.0	-41.5
08/19/02	200	201.7	195.0	197.7	-2.0
	150	149.7	144.0	145.7	-2.7
	100	99.3	96.7	98.7	-0.7
	50	49.7	47.0	48.0	-3.4
	0	11.3	8.0	9.0	-20.6
09/13/02	200	200.3	196.3	199.0	-0.7
	150	149.7	142.7	145.0	-3.1
	100	100.3	94.7	96.7	-3.7
	50	50.3	46.7	47.7	-5.3
	0	10.3	7.7	8.7	-16.1
09/24/02	200	200.0	195.0	197.3	-1.3
	150	150.0	144.3	145.3	-3.1
	100	99.7	95.3	96.3	-3.3
	50	49.7	46.7	47.3	-4.7

[18] Percent differences ($100 * \{[O_3]_{data\_logger} - [O_3]_{calibrator}\} / [O_3]_{calibrator}$) appear large at low concentrations since the denominator is of comparable magnitude to the instrument noise.

	0	9.3	8.0	9.0	-3.6
10/22/02	200	200.7	195.7	198.3	-1.2
	150	150.0	145.3	147.3	-1.8
	100	99.7	95.3	97.7	-2.0
	50	50.3	45.7	47.0	-6.6
	0	12.7	8.3	9.3	-26.3
7/15/03	200	200.0	191.0	194.0	-3.0
	150	150.0	143.3	146.3	-2.4
	100	100.0	95.0	97.0	-3.0
	50	49.7	47.0	49.0	-1.3
	0	12.3	9.7	11.0	-10.8

TABLE A-2
Nitrogen Oxides Analyzer Calibration Data

Date	NO (NO_y) Calibration Concentration (ppbv)	NO Data Logger Concentration (ppbv)	NO Difference[19] (percent)	NO_y Data Logger Concentration (ppbv)	NO_y Difference[20] (percent)	Difference between NO & NOy Channels[21] (percent)
09/25/01	175.4	169.9	-3.1	181.9	3.7	-6.6
	175.4	170.2	-3.0	181.8	3.6	-6.4
	175.4	171.5	-2.2	183.0	4.3	-6.3
	121.3	120.9	-0.3	129.0	6.3	-6.3
	121.3	121.1	-0.2	129.4	6.7	-6.4
	121.3	120.9	-0.3	128.4	5.9	-5.8
	71.8	71.4	-0.6	75.9	5.7	-5.9
	71.8	71.2	-0.8	75.7	5.4	-5.9
	71.8	70.5	-1.8	75.4	5.0	-6.5
	20.6	19.2	-6.8	20.7	0.5	-7.2
	20.6	19.3	-6.3	20.9	1.5	-7.7
	20.6	19.3	-6.3	20.7	0.5	-6.8
	0	-0.7		0.2		
	0	-0.7		0.3		
	0	-0.2		0.2		
	175.4	172.7	-1.5	182.4	4.0	-5.3
	175.4[22]	75.3		184.8		
06/20/02	175.4	152.4	-13.1	166.3	-5.2	-8.4
	175.4	151.9	-13.4	166.1	-5.3	-8.5
	175.4	152.4	-13.1	167.4	-4.6	-9.0
	121.3	107.0	-11.8	117.8	-2.9	-9.2
	121.3	107.4	-11.5	116.6	-3.9	-7.9
	121.3	108.1	-10.9	117.8	-2.9	-8.2
	121.3	108.2	-10.8	118.0	-2.7	-8.3
	71.8	62.4	-13.1	68.1	-5.2	-8.4
	71.8	62.3	-13.2	68.3	-4.9	-8.8
	71.8	62.4	-13.1	67.7	-5.7	-7.8
	20.6	15.3	-25.7	17.2	-16.5	-11.0
	20.6	15.5	-24.8	17.3	-16.0	-10.4

[19] Percent difference = (100 * $\{[NO]_{data\_logger} - [NO]_{calibrator}\} / [NO]_{calibrator}$).
[20] Percent difference = (100 * $\{[NO_y]_{data\_logger} - [NO_y]_{calibrator}\} / [NO_y]_{calibrator}$).
[21] Percent difference between NO and NOy channels = (100 * $\{[NO]_{data\_logger} - [NO_y]_{data\_logger}\} / [NO_y]_{data\_logger}$).
[22] Note double entries at end of group are converter efficiency checks.

	20.6	15.3	-25.7	17.1	-17.0	-10.5
	0	-0.7		0.1		
	0	-0.7		0.2		
	0	-0.7		0.1		
	175.4	153.3	-12.6	166.7	-5.0	-8.0
	175.4	68.0		171.5		
07/09/02	175.4	157.3	-10.3	170.1	-3.0	-7.5
	175.4	157.0	-10.5	168.8	-3.8	-7.0
	175.4	157.9	-10.0	170.8	-2.6	-7.6
	121.3	110.3	-9.1	118.9	-2.0	-7.2
	121.3	109.5	-9.7	118.3	-2.5	-7.4
	121.3	109.6	-9.6	117.7	-3.0	-6.9
	71.8	62.8	-12.5	68.2	-5.0	-7.9
	71.8	63.3	-11.8	68.2	-5.0	-7.2
	71.8	63.4	-11.7	68.0	-5.3	-6.8
	20.6	15.2	-26.2	16.9	-18.0	-10.1
	20.6	15.8	-23.3	17.2	-16.5	-8.1
	20.6	15.6	-24.3	17.0	-17.5	-8.2
	0	-0.9		-0.1		
	0	-1.0		-0.4		
	0	-0.8		-0.3		
	175.4	155.0	-11.6	167.4	-4.6	-7.4
	175.4	55.2		171.0		
07/29/02	175.4	152.8	-12.9	165.5	-5.6	-7.7
	175.4	152.3	-13.2	165.3	-5.8	-7.9
	175.4	153.1	-12.7	165.3	-5.8	-7.4
	121.3	108.3	-10.7	116.6	-3.9	-7.1
	121.3	108.4	-10.6	116.5	-4.0	-7.0
	121.3	108.4	-10.6	117.2	-3.4	-7.5
	71.8	62.3	-13.2	67.0	-6.7	-7.0
	71.8	62.1	-13.5	66.9	-6.8	-7.2
	71.8	61.7	-14.1	66.8	-7.0	-7.6
	20.6	14.8	-28.2	16.5	-19.9	-10.3
	20.6	15.0	-27.2	16.7	-18.9	-10.2
	20.6	15.0	-27.2	16.5	-19.9	-9.1
	0	-0.9		-0.4		
	0	-0.8		-0.5		
	0	-0.8		-0.4		
	175.4	154.5	-11.9	166.6	-5.0	-7.3

	175.4	67.8		169.2		
08/19/02	175.4	154.8	-11.7	170.4	-2.9	-9.2
	175.4	154.7	-11.8	170.5	-2.8	-9.3
	175.4	154.5	-11.9	170.0	-3.1	-9.1
	121.3	109.6	-9.6	120.6	-0.6	-9.1
	121.3	109.3	-9.9	120.1	-1.0	-9.0
	121.3	109.1	-10.1	120.0	-1.1	-9.1
	71.8	63.5	-11.6	69.4	-3.3	-8.5
	71.8	63.0	-12.3	69.1	-3.8	-8.8
	71.8	62.8	-12.5	69.3	-3.5	-9.4
	20.6	15.2	-26.2	17.3	-16.0	-12.1
	20.6	15.2	-26.2	17.3	-16.0	-12.1
	20.6	15.2	-26.2	17.0	-17.5	-10.6
	0	-0.8		-0.4		
	0	-0.7		-0.4		
	0	-0.8		-0.4		
	175.4	156.2	-10.9	171.7	-2.1	-9.0
	175.4	68.7	-60.8	175.5	0.1	
09/13/02	175.4	154.0	-12.2	166.2	-5.2	-7.3
	175.4	153.4	-12.5	167.1	-4.7	-8.2
	175.4	155.6	-11.3	168.9	-3.7	-7.9
	175.4	155.3	-11.5	168.7	-3.8	-7.9
	175.4	155.1	-11.6	168.5	-3.9	-8.0
	121.3	109.2	-10.0	118.4	-2.4	-7.8
	121.3	110.7	-8.7	120.0	-1.1	-7.8
	121.3	110.0	-9.3	119.2	-1.7	-7.7
	71.8	62.8	-12.5	68.5	-4.6	-8.3
	71.8	63.0	-12.3	68.1	-5.2	-7.5
	71.8	62.9	-12.4	68.1	-5.2	-7.6
	20.6	15.4	-25.2	17.1	-17.0	-9.9
	20.6	15.3	-25.7	16.9	-18.0	-9.5
	20.6	15.2	-26.2	17.0	-17.5	-10.6
	0	-0.8		-0.4		
	0	-0.9		-0.5		
	0	-0.9		-0.4		
	175.4	158.5	-9.6	172.2	-1.8	-8.0
	175.4	69.6		173.9		
09/24/02	175.4	155.9	-11.1	172.5	-1.7	-9.6

	175.4	155.1	-11.6	172.7	-1.5	-10.2
	175.4	155.2	-11.5	172.1	-1.9	-9.8
	121.3	109.6	-9.6	121.7	0.3	-9.9
	121.3	109.7	-9.6	121.2	-0.1	-9.5
	121.3	109.5	-9.7	121.0	-0.2	-9.5
	71.8	62.9	-12.4	69.7	-2.9	-9.8
	71.8	62.9	-12.4	69.3	-3.5	-9.2
	71.8	62.8	-12.5	69.6	-3.1	-9.8
	20.6	16.0	-22.3	17.8	-13.6	-10.1
	20.6	15.8	-23.3	17.8	-13.6	-11.2
	20.6	15.8	-23.3	17.8	-13.6	-11.2
	0	-0.2		0.2		
	0	-0.5		0.1		
	0	-0.4		0.1		
	175.4	155.5	-11.3	172.1	-1.9	-9.6
	175.4	62.6	-64.3	173.5	-1.1	
10/22/02	175.4	152.7	-12.9	170.8	-2.6	-10.6
	175.4	153.5	-12.5	171.0	-2.5	-10.2
	175.4	153.1	-12.7	170.8	-2.6	-10.4
	121.3	107.6	-11.3	119.9	-1.2	-10.3
	121.3	108.6	-10.5	121.1	-0.2	-10.3
	121.3	108.8	-10.3	121.1	-0.2	-10.2
	71.8	62.3	-13.2	69.7	-2.9	-10.6
	71.8	62.3	-13.2	69.7	-2.9	-10.6
	71.8	62.4	-13.1	69.3	-3.5	-10.0
	20.6	15.3	-25.7	17.4	-15.5	-12.1
	20.6	15.5	-24.8	17.3	-16.0	-10.4
	20.6	15.3	-25.7	17.3	-16.0	-11.6
	0	-0.5		-0.1		
	0	-0.5		-0.3		
	0	-0.5		-0.1		
	175.4	153.7	-12.4	171.5	-2.2	-10.4
	175.4	66.0	-62.4	173.8	-0.9	
01/23/03	175.4	136.9	-21.9	149.5	-14.8	-8.4
	175.4	137.0	-21.9	149.6	-14.7	-8.4
	175.4	136.7	-22.1	149.7	-14.7	-8.7
	121.3	95.4	-21.4	104.8	-13.6	-9.0
	121.3	95.4	-21.4	104.7	-13.7	-8.9

	121.3	95.7	-21.1	104.8	-13.6	-8.7
	71.8	54.2	-24.5	59.1	-17.7	-8.3
	71.8	54.5	-24.1	59.2	-17.5	-7.9
	71.8	54.0	-24.8	58.9	-18.0	-8.3
	20.6	11.5	-44.2	12.9	-37.4	-10.9
	20.6	11.5	-44.2	13.2	-35.9	-12.9
	20.6	11.6	-43.7	13.3	-35.4	-12.8
	0.0	-0.5		0.0		
	0.0	-0.4		0.1		
	0.0	-0.5		0.0		
	175.4	135.9	-22.5	149.1	-15.0	-8.9
	175.4	62.5		151.3		
07/15/03	175.4	121.7	-30.6	155.6	-11.3	-21.8
	175.4	122.5	-30.2	154.9	-11.7	-20.9
	175.4	122.3	-30.3	155.3	-11.5	-21.2
	121.3	86.3	-28.9	109.0	-10.1	-20.8
	121.3	85.6	-29.4	108.8	-10.3	-21.3
	121.3	86.2	-28.9	109.0	-10.1	-20.9
	71.8	49.7	-30.8	64.1	-10.7	-22.5
	71.8	49.1	-31.6	61.8	-13.9	-20.6
	71.8	48.9	-31.9	61.7	-14.1	-20.7
	20.6	11.9	-42.2	14.4	-30.1	-17.4
	20.6	11.5	-44.2	14.5	-29.6	-20.7
	20.6	11.6	-43.7	14.6	-29.1	-20.5
	0	0.0		0.2		
	0	0.1		0.2		
	0	0.0		0.2		
	175.4	121.8	-30.6	154.5	-11.9	-21.2
	175.4	44.6		158.8		