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Tracking the Sacramento Pollutant Plume over the Western Sierra Nevada

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DISCLAIMER

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The moderately polluted days were characterized by low residual pollutant concentrations aloft in the early morning and moderate to weak vertical stratification during the day. The cleanest days had good ventilation with deep layers of near neutral stratification and moderate to strong winds.

The Sacramento pollutant plume appeared to have been within the sampling sector on all operational days. Horizontal spatial variability within the mixed layer was often significant at scales less than 5 km, suggesting that models of air flow and pollutant transformations need similar resolutions to successfully simulate the transport and fate of emissions from Sacramento.

The maximum ozone concentrations were frequently observed in the afternoon, 40 to 80 km downwind of the city, but these decreased greater than 40% at distances 120 km downwind. The reduction in concentrations over the high elevations appears due in part to lower static stabilities, deeper mixed layer depths often found at the higher elevations and horizontal spreading of the plume. Cumulative deposition of pollutants during transport toward the northeast over areas of low emissions may also play a role in reducing these concentrations. Whatever the cause, concentrations of pollution reaching the high altitude slopes of the Sierra Nevada appear to be considerably lower than the peak concentrations closer to the city.

The measured oxides of nitrogen were generally just above detection limits (~1 ppbv), except near ground level in the early morning hours, so no significant spatial or temporal variations were measurable.

ABSTRACT

The Sacramento area has an ozone air quality problem, exceeding the federal ambient air quality standard about a dozen days per year. Model simulation of events exceeding the standard has been less than desirable, in part due to the lack of knowledge of the three-dimensional distribution of meteorological and air quality variables. Given the city's location and climatic characteristics, the pollution plume from Sacramento is often directed over the Sierra foothills east-northeast of the city, with this area typically experiencing the highest local concentrations of ozone and other secondary pollutants. This study used an aircraft instrumented to measure meteorological conditions, ozone and other pollutants to examine this plume. The aircraft was flown along three vertical planes oriented perpendicular to the upslope flow at 40, 80 and 120 km downwind of the city, three times each day. A fourth flight measured the same information at 40 and 80 km downwind. These flights were conducted on seven days in the summers of 1995 and 1996. These measurements, as well as those documenting the meteorological setting and evolution of surface conditions, are presented. High residual ozone above the surface layer in the early morning hours appears to be necessary to produce afternoon concentrations in excess of 125 ppbv. The moderately polluted days were characterized by low residual pollutant concentrations aloft in the early morning and moderate to weak vertical stratification during the day. The cleaner days had good ventilation with deep layers of near neutral stratification and moderate to strong winds. The maximum ozone concentrations were frequently observed in the afternoon, 40 to 80 km downwind of the city.

EXECUTIVE SUMMARY

Aircraft measurements of meteorological and air quality variables over the western slope of the Sierra Nevada mountains were conducted northeast of Sacramento on seven days in the summers of 1995 and 1996 when the winds below 5000 m (16,200 feet) mean sea level (MSL) were directed upslope (i.e. from the southwest ±30 degrees). The flight paths were designed to obtain vertical cross sections perpendicular to the upslope flow at about 40, 80 and 120 km downwind from the city. On each operational day, four flights of about 3.5 hours length were flown between the hours of 0500 and 1900 Pacific Standard Time (PST). Operational procedures, data acquisition and data processing details are described, as are the calibration histories of the instruments.

Data from the seven days of full operations are presented in seven appendices. Each appendix contains synoptic charts of the large scale meteorological setting, hourly surface observations of wind, temperature and ozone concentrations, and vertical cross sections of potential temperature, relative humidity and ozone concentrations. Of the seven days, three were high ozone days ($O_3 > 120$ ppbv), two were moderate ozone days ($90 < O_3 < 115$ ppbv) and two low ozone days ($O_3 < 80$ ppbv) based on the maximum surface ozone concentration.

For the days sampled, several characteristics are common among days of similar air quality. High ozone occurrences appear to result from at least two days of stagnation, i.e. weak winds and strongly stable stratification in the lower atmosphere. High residual ozone above the surface layer in the early morning hours appears to be necessary to produce afternoon concentrations in excess of 125 ppbv.

personal computer (486DX, 33 Hz) and a 16 channel analog to digital converter.

Periodic calibration of the ozone and nitrogen oxides analyzers was performed as shown in Tables 2 and 3, respectively. The ozone analyzer calibrations, shown in Table 2, indicate that the ozone analyzer was within 5 ppbv on all of the calibrations except for one point on 9/7/95 and two points on 8/24/96. The ozone analyzer recorded ozone concentrations 9 ppbv higher than actual due to an intentional 9 ppbv offset used to observe negative values. Any negative values that occurred would not be recorded in the data acquisition system unless an offset was used (Dasibi, 1990, Section 6.6.4). This offset is removed during data processing. Table 3 shows the nitrogen oxides analyzer calibrations. The ozone analyzer operated without problems throughout the course of the study. The nitrogen oxides instrument was not installed in the aircraft from 8/23/95 through about 9/30/95 due to a broken ozone generator which was out for warranty repairs. Also, the flight of 7/31/96 had missing nitrogen oxides information on the last two flights because of power supply problems (probably a faulty extension cord).

An audit of the instruments, conducted by the ARB on 8/13/96, showed the ozone analyzer to be within 1.5 percent of the true value at all calibration points. Technically the nitrogen oxides analyzer failed the audit (the percent difference at 240 ppbv NO_2 was 51.7%, at 72 ppbv it was 47.2% and at 0 ppbv it was 0%), but this is because the auditors used the visual display values. Table 3a shows that the calibration percent difference for NO is not tremendously different from the audit report. Had these calibration differences been applied to the display value, the UCD instrument would have been closer to the audit values. Additionally, the nitrogen oxides data obtained during the Sierra flights were almost always near zero. During calibrations at these low concentrations, the analyzer was within a few ppbv of the true concentration and can be considered reliable for much of each aircraft flight.

Temperature and relative humidity instruments were also calibrated throughout the project using portable transfer standards. These calibrations are shown in Tables 4 and 5. Table 4 indicates that the air temperature instruments used were generally within about 3% of the calibration instrument, i.e. less than one degree Celsius error. The relative humidity was within 8% for its calibrations, as shown in Table 5. The ARB audit of the instruments, conducted on 8/13/96, showed the temperature and dew point temperature (computed from the temperature and relative humidity) were out of PSD standards (±0.5 degrees C for temperature and ±1.5 degrees C for dew point). The problem lay with a faulty temperature sensor which was replaced.

The position information was determined using the GPS instrument's output of latitude and longitude and then converting this information to nautical miles from a reference point. This reference point was the Auburn airport located near the northern boundary of the sampling area. On a few flights (cf. Table 6), the GPS information was not recorded or recorded infrequently due to problems with the GPS instrument. On these flights or the portions thereof when the GPS information was missing, the position information was estimated by using the heading and airspeed data from the aircraft between known positions. These data are flagged to indicate that the GPS was not working.

INTRODUCTION

During the warm half of the year in the Sacramento Valley, the persistent occurrence of a sea breeze and upslope winds are believed to transport pollutants into the Sierra Nevada mountains. Ground-based measurements (Van Ooy and Carroll, 1995) suggest that complex three dimensional transport of pollutants occurs. The goal of this study is to document the distribution of meteorological and air quality parameters over the mountains northeast of Sacramento from the surface to several thousand meters altitude. A Cessna 182 aircraft operated by the University of California, Davis (UCD) was equipped with ozone and nitrogen oxides analyzers along with meteorological instruments. During the last half of the summer of 1995 and the summer of 1996, air sampling flights were conducted along the western slope of the Sierra Nevada mountains, northeast of the city of Sacramento, with the goal of tracking the pollution plume from that city.

Figure 1 shows a map of the study region. The intent of the sampling program was to measure significant meteorological and air quality variables in vertical planes perpendicular to the upslope flow on days when the wind was from Sacramento up the slopes of the Sierra (wind direction from the southwest or 230 degrees). These planes were located approximately 40, 80 and 120 km northeast of the city. With this spacing and upslope wind speeds of about 5 ms^{-1} (18 km/hr), air would travel from one plane to the next in about one hour, which is the time between aircraft sampling at successive planes. This type of information is needed to better understand the interplay among scales of atmospheric motions, pollutant emission patterns and the diurnal variation in the mixed layer depth. Modelers also need to know how these interactions occur to better model these processes and need three dimensionally distributed observations to verify model predictions.

Initially, the intent was to forecast days on which high pollutant levels would likely be transported to the sample area. In 1995, the sampling crew waited many days prior to sampling on a high pollution day (the only day on which a full set of flights were conducted in 1995). Based on this experience, the plan for the 1996 summer season was to sample every Wednesday unless the weather was forecast to be unfavorable for Sacramento's pollutant plume to be transported into the Sierra Nevada.

AIRCRAFT INSTRUMENTATION

In order to accurately measure atmospheric variables, a compact high-quality instrumentation system has been developed for light aircraft. For the study, a Cessna 182 was outfitted with the instrumentation package consisting of the instruments listed in Table 1. The temperature, relative humidity and airspeed sensors are mounted on the right-hand strut of the aircraft. A 1.27 cm diameter Teflon tube enters the aircraft through the cabin ventilating system and supplies the ambient gas sample to the analyzers. A 1.2 mm diameter metal tube draws air directly into the particle sampler feeder tube, providing isokinetic sampling at airspeeds of 50 ms^{-1}. The strut-mounted instruments and both sampling tube inlets are configured in such a way as to be well outside of the propeller slipstream and aircraft exhaust. A pressure transducer and global positioning system (GPS) are mounted to the data acquisition system located in the cabin. Data acquisition is accomplished by using a small at the Auburn airport, with the last flight concluding at the Davis airport. After transitioning to the starting point at Folsom Lake (S1 in Figure 1), a vertical sounding and four horizontal transects at 330 m (1000 foot) vertical intervals were executed. This was followed by transition to and a descending sounding at S2 and three horizontal traverses. Next a transition to S3 with a descending sounding was flown, followed by three horizontal transects. Each flight concluded with a slowly descending traverse from 1980 m (6500 feet) MSL at Blue Canyon airport, along Highway 80 to Auburn airport. The final flight of the day consisted of the two spirals and the sets of horizontal transects at S1 and S2 only, plus an additional ending spiral over Folsom Lake before returning to Davis. Typical flight times (PST) for the flights were as follows: flight 1 from 0530 to 0830; flight 2 from 0900 to 1230; flight 3 from 1300 to 1530; flight 4 from 1600 to 1830.

DATA REDUCTION

The audio tapes were transcribed into text files for each flight. Hard copies of these logs were printed and contain the time, altitude and file number for each pertinent comment during a flight as well as the relevant comments. Interactive programs for data reduction (cf. Figure 2) are run to remove errors, convert the voltage data to scientific units and combine decoded navigation data with the atmospheric data.

Radiated energy associated with radio transmissions from the aircraft often puts small spikes into some of the data. These erroneous readings are corrected by interpolating between the closest valid data. Any of the data-logging channels may be corrected, but primarily the errors affect channels one through five which record fast and very fast response temperatures, airspeed, relative humidity and pressure. When one of these five channels is corrected so are the other four. A file mm-dd-nn.LOG automatically records all changes made to the original mm-dd-nn.DAS file.

Voltages recorded in the mm-dd-nn.DAS files are converted to scientific units using AC-CNVRT. Supplied with the initial altitude from the voice transcriptions, AC-CNVRT calculates altitude from the recorded pressure for the entire file. If the initial altitude for a file is unavailable, then an altitude from a corresponding pressure in a contiguous file is used. The data are converted to scientific units using the equations in Table 11. Output is to files mm-dd-nn.DAT and mm-dd-nn.NAT in the formats shown in Tables 12 and 13.

AC-CVRT2 makes the final data files, mm-dd-nn.DAC, by incorporating information from both the mm-dd-nn.DAT and mm-dd-nn.NAT files. The program applies calibration corrections, flags erroneous or missing data, calculates NO_2 from NO_X and NO data and combines the navigation data with the atmospheric data. Navigation data are presented as nautical miles from a reference position. The reference position is the Auburn airport. Table 14 shows the file format. AC-CVRT2 is run in batch mode, processing all pairs of mm-dd-nn.DAT and mm-dd-nn.NAT files for a given flight date unless the position information for the beginning of a file is missing. In this case, the data processing person manually inputs the initial latitude and longitude for each file. The remainder of the position information is then estimated from the heading and airspeed values. If valid GPS values occur later, those are used from that point in the record onward. The mm-dd-nn.DAC files are the primary

AIRCRAFT OPERATIONS AND DATA ACQUISITION

At the beginning of each flying day, the sampling instruments are turned on and warmed up prior to aircraft departure. The ozone instrument requires approximately fifteen minutes and the nitrogen oxides analyzer requires about 45 minutes of warm up. These instruments are powered by an external power source during the warm-up period. During this time, the aircraft is prepared for the flight. The time, date, location and flight information are recorded on a cassette tape. The instruments are checked by running AC-TEST which displays the current values to the screen every few seconds.

During flight, power to the instruments is supplied by an inverter which is run by a 28 volt battery mounted on the aircraft instrument rack. This battery can be switched to and charged by the aircraft alternator during a flight. When the aircraft engine is shut down, the battery continues to run the instruments for 30 minutes or more. Therefore, once the instruments are turned on at the beginning of the flight day, they are run continuously until operations cease that day.

When the aircraft is ready for take off, the sampling instruments are again checked using AC-TEST and then the data logging program, AC-DATA, is run. A flow chart for data acquisition is shown in Figure 2 and a summary of programs used with aircraft flights is shown in Table 7. To simplify this task during aircraft operation, the operator, who is also the pilot, runs A.BAT: a batch file which automatically runs AC-TEST and then AC-DATA. The operator enters the file number, sample period (typically three seconds), the navigation data sample period (30 seconds for 1995, 10 seconds for 1996) and the number of data channels to sample (11).

Just prior to departure, data logging is begun and the operator records the time, file number, altitude and the departure location on the audio tape. Periodic recording of pertinent in-flight information is also recorded on the audio tape. At the end of a flight segment, the data logging is interrupted by the operator and the time, altitude, file number and location are again noted on the audio tape. This sequence of starting and ending data logging and audio tape notations is repeated for each flight segment as determined by the operator. (Generally, the flight segments were either horizontal transects or vertical profiles for a given location.) Each file can last up to approximately 30 minutes. All times are Universal Coordinated Time (UTC) unless otherwise noted. The data stream includes time as seconds from midnight on the day identified in UTC for each scan. (PST = UTC - 8 hours). These data files are named mm-dd-nn.DAS and mm-dd-nn.NAV where "mm" is the month, "dd" is the day and "nn" is the file number. Data variables for these files are shown in Tables 8 and 9.

FLIGHT PATTERNS

On one day in 1995 and six in 1996, four flights per day were made over the Sierra northeast of Sacramento in the area shown in Figure 1. The sequence of altitudes and headings is listed in Table 10 and shown in Figure 3. The flights were conducted between about 0500 and 1900 PST. Table 6 lists the flight dates, a number of key variables and relevant comments. Each day's initial flight began at the Davis airport. After this early morning flight, three additional flights were made to sample during late morning, afternoon, and early evening hours. Each of these three additional flights started files were then used with SURFER6 (Golden Software Inc.) contouring programs to create the cross sections. The process includes first the gridding of each meteorological or air quality variable onto a rectangular x-z grid and then the generation of contours for the gridded data. The gridding process used inverse distance squared interpolation with a large horizontal anisotropy factor. The latter was chosen to force the analysis to recognize that most atmospheric fields tend to have large vertical gradients but tend to form semi-homogeneous layers, i.e. the atmosphere is composed of nearly horizontal layers having characteristics that vary slowly within the layer. Note, however, that in all of these plots, strong gradients or other detailed structures at the corners and vertical or lateral boundaries of the analyzed domain are not significant but artifacts of the gridding and contouring algorithms. To help distinguish between artifacts of the plot routines and real structures, the aircraft flight paths and hence the locations of the sampling points are shown on all cross sections. Note also that the along-slope (east-west) cross sections represent an elapsed time of about 2.5 hours between the S1 and S3 data. The step-like appearance of the contour-fields in many of the figures reflects the amount of mixed layer growth during this time interval.

For the discussions here, the mixed layer depth was determined from examination of the soundings of temperature and relative humidity at S1, S2 and S3, as well as the obvious limits to vertical mixing seen in the relative humidity and ozone cross sections.

UC DAVIS WIND FINDING PROCEDURE

In order to accurately characterize and analyze the air pollution situation on a given day, wind speed and direction aloft are necessary. Since there are limited sounding stations for obtaining these measurements, use of aircraft air speed and heading coupled with independent position information can be used to estimate winds aloft. The three instruments used to determine wind information are a thermal anemometer for airspeed (accuracy of 0.4 m/s), an electronic compass for magnetic heading (accuracy of 2 degrees), and a Global Positioning System (GPS) for position (accuracy of 10 meters). Since the air speed is much higher that the expected wind speeds, small errors in the heading information can produce large errors in the estimated winds. In addition, when the aircraft is banked (turning) the magnetometer cannot compensate for the inclination to the earth's magnetic field since it senses the apparent gravity, which is not vertical. During the study, the GPS was sampled every 10 seconds (30 seconds in 1995 flights) and the other variables were sampled approximately every 3 seconds. If the aircraft was turned during the period between GPS samples, then the wind velocities and directions would be inaccurate for that period. The wind analysis proceeds in several steps: one to assure that the heading is constant (± 5 degrees) and one to assure the GPS ground tracks are also constant in direction between successive GPS samples.

Systematic errors in the air speed and heading appear as a strong dependance of the wind speed and direction on the aircraft heading. For example, if the winds are constant at a given altitude, then by flying the aircraft in a square pattern and computing the winds using the data from the straight legs, the wind speed and directions on each leg should be equal. If they are not, then one can add small offsets to the heading and small corrections to the air speed calibration coefficient in such a way that the wind becomes essentially constant for all four legs of the square flight path. This procedure archived data files.

DATA ANALYSIS

Several types of data were analyzed in the course of this study and are presented in appendices A to G. The first set consists of surface or upper air, constant pressure maps and is used to establish the synoptic setting for the days on which flights were conducted, including the winds aloft. The second are surface observations of wind, temperature and at some locations ozone concentrations, taken near or within the sampling area shown in Figure 1. These provide a continuous history of the near ground events for the day. The third set consists of the maximum one hour averaged ozone concentrations in the greater Sacramento area, which serves to identify the regional air quality for each operational day. The fourth are the aircraft data which are presented in the form of vertical cross sections, one at each of the transect lines, S1, S2 and S3, and one vertical east-west cross section extending from S1 to S3.

The contour maps for the 500 mb and 850 mb surfaces were generated at UCD using gridded data obtained from the National Center for Atmospheric Research (NCAR) for the first two operational days (8-31-95 and 7-03-96). The Oakland and Reno soundings for these days were also obtained from NCAR allowing us to determine the winds aloft at these two locations. For the remaining five operational days, DIFAX maps prepared by the National Weather Service (NWS) were saved to provide the same information plus a surface analysis map.

The NWS/FAA data at McClellan AFB (MCC) and Blue Canyon airport (BLU) contain wind speed, wind direction and surface temperature reported as the current value at the stated hour. These two sites essentially form the southwest and northeast corners of the area of interest. Unfortunately, these data were unavailable for 8-31-95. For the other days, the hourly readings are intermittently missing at MCC and frequently missing at BLU. Three sites in or near the sample area are operated as combined air quality and meteorological observing sites (Rocklin, Roseville and Placerville). These sites report hourly averaged temperature, ozone concentrations and resultant (vector average) wind speeds and directions. These hourly data were plotted versus time for the 24 hours of each observing day. The CARB has recently distributed CD-ROM discs containing air quality data for all observing sites in the state and several programs to display these data. Using these we prepared maps showing the maximum hourly averaged ozone for all observing sites in the greater Sacramento area. The sites presented include the three for which diurnal concentration plots were made.

For the cross-sections aligned perpendicular to the terrain slope, aircraft data were grouped by their proximity to the transect lines shown in Figure 1. All data recorded within 2.5 km horizontally of the transect lines are used to create the vertical cross sections. These include the downward spiral near the midpoint of each traverse, the traverses themselves and climbing and descending paths from the end of one segment to the beginning of another. For the along-slope cross-section, data taken within squares 6, 6 and 8 km on a side and centered on S1, S2 and S3, respectively, were averaged over 30 meter deep layers. These cross section data files contain x, z position data plus potential temperature, relative humidity, ozone concentration and other variables that are not plotted or shown here. These foothill site reaching 108 ppbv ozone the previous day. Although the 500 mb flow field suggests good ventilation with large scale lifting likely, the lower altitudes had weak flows. The subsidence that presumably accompanied the 500 mb ridge which had just moved east of the region, left behind a very stable lower atmosphere, allowing low mixing depths and a decoupling of the lower level flow from that aloft. The net effect of these conditions is to limit export of the prior day's pollutants as well as current day's emissions and to confine these pollutants in a relatively shallow mixed layer. Lower level winds are directed from Sacramento upslope through the sample area producing hourly peak ozone concentrations of approximately 120 ppbv at the surface at the downwind edge of the city and more than 140 ppbv aloft. While pollution levels at S1 and S2 are high in the afternoon hours, they are much lower at S3. Since the general wind speeds on this day were low, the air passing through S1 and S2 may not have arrived at S3 in time to be sampled there by the aircraft. The lower concentrations observed at S3 are partly due to greater vertical mixing depths often found at S3, plus the cumulative effect of surface deposition, which can be quite important in fully convective boundary layers, and the effect of horizontal diffusion. We do not believe that low transport speeds are the primary cause of the lower concentrations observed.

In the summer of 1996, we sampled two poor air quality days (maximum hourly average >125 ppbv), two moderately polluted days (maximum surface hourly average ~ 92 ppbv) and two clean days (maximum surface hourly averaged ozone < 80 ppbv).

The worst air quality day we encountered was July 24, 1996. The synoptic scale pattern was one of light wind speeds and probable subsidence persisting for several days. The conditions of light winds kept pollutants in the region while high static stabilities limited the depth of the mixed layer. The early morning data show an elevated layer of high ozone concentrations (90 - 100 ppbv) left over from the day before. As the day progresses, upslope winds develop, the boundary layer becomes more unstable and ozone concentrations east of the city increase. The Sacramento plume is well within our sample sector, but displaced more toward the southern side as the winds are west-southwest instead of southwest, the direction straight up the middle of the sampling area. Hourly averaged peak concentrations increase across the city toward the foothills, being 80-85 ppbv downtown, 120 ppbv at the eastern edge of the city, 114 ppbv in Roseville, 123 ppbv in Rocklin and 133 ppbv in Placerville. As one travels further east, ground level data are not available but the concentrations appear to decline further up the slope. Even though the air flow was weak, we believe there was enough elapsed time to bring these high pollutant levels to these altitudes. However, the observed peak concentrations at S3 are considerably lower than the downslope areas.

The conditions on August 7 also led to high ozone concentrations over the western Sierra. The mixed layers at S1 and S2 were relatively shallow, trapping emissions and products close to the ground at least as far as S2. We found relatively low concentrations at S3 throughout the day. The winds this day were more westerly, so the center of the Sacramento plume may have passed along the southern edge of the sample area, and may have missed the southern edge of the transects at S3. However, we also note that the static stability at S3 was much weaker than at the other transects, which would also account for the low concentrations measured there.

We note that on the three days of highest ozone concentrations in or immediately downwind of the amounts to an in situ calibration of the wind finding calculation. In addition to these systematic errors, turbulence induced variations in aircraft attitude and aircraft slipping and skidding motions all contribute non-systematic errors in the wind finding calculations.

In practice, we analyze wind data from all our flights and determine after the fact the heading offset and air speed corrections needed to minimize the variation of wind vectors with aircraft heading. These values can then be applied to the entire year's data set. There also is a weak altitude dependence such that the airspeed and heading corrections were 105.9%, 106.9%, -1.0 and -3.3 degrees at 1490 m and 2960 m, respectively for 1995 and 104.9%, 105.8%, -1.8 and -4.8 degrees at 1180 m and 2540 m for 1996. These values are linearly interpolated with altitude in the wind calculations. These average correction values were applied to the data presented here. The winds reported are averaged over 1000 meter increments for each transect and are tabulated in appendices A through G.

Wind data estimated by the aircraft have been compared with wind data derived from a 449-MHZ radar wind profiler during a field experiment at Victorville, California in early August, 1995 (Carroll and Dixon, 1997). Initial comparisons with the profiler show that about 55% of the aircraft wind directions were within ± 20 degrees of the profiler system and about 75% were within ± 45 degrees. For wind speeds, about 45% were within 2 ms^{-1} for the two methods and 86% were within ±5 ms^{-1}.

These comparisons show that the aircraft winds are approximate but still useful in that the directions are in the correct octant more than half the time and in the correct quadrant over 85% of the time. As for the speeds, the error bars are much larger in the sense that the uncertainty represents a significant fraction of the speeds expected near the ground. (Subsequent comparison (8/98) of our aircraft estimated winds with data from the wind profiler at Franklin Field show our wind speed to be about 50% higher than reference values.)

RESULTS

The first flight of this project was curtailed when unforecast thunderstorms developed over the study area. Flying the full routes, however, demonstrated some inefficiencies with the original sequence and less than optimal aircraft operational parameters. As a result, the vertical sequence of horizontal legs was reversed to be from the top down rather than from low to high.

The September 18, 1995 flight was coordinated with a test flight of the NASA DC-8 equipped with a Doppler lidar, wind mapping system. The UCD flight was to fly a few soundings and transects at S3 while the DC-8 flew along the crest to map the wind field 20 km to the east and to the west of the crest. Unfortunately, the lidar malfunctioned and the flight was curtailed with no wind data obtained and the UCD aircraft was on station for only a short time.

During the summer of 1995, one day (8-31-95) met our forecast criteria and for which all systems worked well with a full data set being acquired. It turned out that this was one of the worst air quality (ozone) days of the year. The lower atmosphere had been stagnant for at least two days, with one

Given the distribution of maximum hourly ground level ozone concentrations observed during our operational days, it is clear that the Sacramento pollutant plume was directed toward our sample area on all sampling days, although on several days the centerline may have been more toward one side or the other. While the number of samples is small, several patterns are apparent in the data. It is clear from the surface data and that taken aloft that ozone concentrations increase as the plume travels across the city and continues downwind, reaching peak values about 30 miles downwind from the city edge. Farther downwind (i.e. upslope), concentrations decrease significantly, dropping 40 % or more over the next 10 miles of travel. Our data do not allow full evaluation of why the concentrations drop off, but in most cases, the mixed layers over the higher elevations are deeper and the atmosphere is less stable in general over the higher slopes. Other effects such as deposition rates exceeding formation rates and horizontal mixing may also be important.

Days having very high ozone concentrations are those that start with high ozone concentrations in a residual layer (carryover) and with the lower atmosphere having a high static stability. The former implies that such events need to be the culmination of situations in which emissions and secondary pollutants accumulate in the lower atmosphere for at least two days, i.e light and variable low altitude winds. The latter requires the presence of strong sinking motion, at least at the onset of the event, and no subsequent lifting, so that the lower atmosphere remains stable. Conversely, days with high static stability, light winds and high maximum temperatures but which do not have a pool of aged pollutants aloft at the start of the day will not experience very high ozone concentrations.

If the static stability is low in the lower atmosphere, it is highly probable that residual pollutants will be in short supply at the beginning of the day, the mixed layer will grow quickly to above average depth and ozone concentrations will remain well below 90 ppbv.

The horizontal dimensions of the Sacramento plume appear to be slightly narrower than the width of our sampling area. While at the lowest altitudes some of the decrease in ozone concentration at the ends of the traverses might be attributable to NO emissions from I-80 on the north and US 50 on the south, its not likely that scavenging would be effective at a few hundred meters above these highways.

There are significant variations in ozone concentrations at horizontal scales as small as a few kilometers horizontally. Vertical layering is also quite prominent, except in the mixed layer on the most unstable days. The implication to the modeling community is that horizontal model resolutions of less than five kilometers may be needed if the plume from the city and its impact on the western Sierra Nevada is to be fully resolved.

While most of the equipment functioned well, the nitrogen oxides monitor typically hovered about its lower detection limit (~ 1 ppbv). The few exceptions were in thin, early morning ground based layers of higher NO values. Hence these data were not plotted. In hindsight, an instrument with a much greater sensitivity was needed. The wind finding capability of the instrumentation used is of limited utility. New technology is becoming available to improve this capability which we hope to evaluate in the near future.

city, that the peak concentrations occur about 30 miles downwind of the city. We also note that over the higher slopes (ground altitude ≥1200 m MSL), the peak concentrations are 40 to 50 ppbv less than those peak values. We also note the afternoon mixed layer thicknesses (H_m - Z_{gnd}) at S2 and S3 are about equal on these days. The reduction in concentrations from S2 to S3 could be due to a) slower upslope transport than we assume, b) transport out of the sample sector by wind directions significantly different than from the southwest, thereby missing the S3 line, c) cumulative reduction in pollutant species due to deposition coupled with low precursor emissions and d) the effect of horizontal diffusion as the material moves northeastward. We believe the latter two to be the more likely.

The two moderately polluted days (7-31 and 8-15, 1996) would seem to have the characteristics expected for a high ozone event: light winds at the surface and aloft and high surface temperatures. In fact, one major difference separates these two from the high ozone days: the lower atmosphere is much less stable. As a result, the residual layer in the early morning hours is deeper, very well mixed and does not contain high concentrations of the previous day's ozone. As the day progresses, the mixed layer develops rapidly, mixing emissions and products vertically and limiting the concentrations of ozone both at the ground and aloft. In fact, on 7-31 the mixed layer top exceeds the altitudes sampled by the aircraft. While it is not obvious from the 500 mb flow, there must have been a fair degree of large scale lifting to produce the weak static stability found. On both moderate ozone days, the Sacramento plume appears to have traveled into the sample area, albeit more to the northern side on 8-15, so it is unlikely that we missed it.

The two low pollution days (7-03 and 7-18, 1996) are just good ventilation days. Moderate to strong winds at all levels and deep vertical mixing due to weak static stabilities. Also, there was very little residual pollutant seen in the early morning hours at most locations. The one exception was the occurrence of moderately high ozone concentrations aloft at S3 during the first flight. We cannot tell from whence these came but they were gone later, probably transported away as well as mixed in the very unstable layers that were present though most of the day.

If it proves desirable to place a wind profiler and ozone sounder east of Sacramento in the future to provide continuous estimates of upslope fluxes, the area around Georgetown appears to be a good location. To document fluxes further upslope, Volcanoville would be a good choice.

CONCLUSIONS

Scheduling complex field observations on set days, with the option to cancel based on adverse forecasted conditions, appears better than trying to respond to forecasted special events on short notice. The former allows a greater variety of conditions to be sampled and is much easier for the field crews to be well rested, organized and prepared for the operational days. Relying on the former in 1996, we obtained data for two instances each of three levels of air quality. In the first season, while we did catch a highly polluted day, we spent a lot of effort on daily forecasting while trying to function with a high degree of scheduling uncertainty.

TABLE 1
UCD AIRCRAFT INSTRUMENTATION SYSTEM

VARIABLE	SENSOR	MANUFACTURER	USEFUL RANGE	ACCURACY
Pressure (Altitude)	Capacitive	Setra	- 30 to 3650 meters	± 0.3 mb ± 3 meters
Temperature	Platinum RTD	Omega Engineers	- 20 to 50 °C	± 0.5 °C
Relative Humidity	Capacitive	Met One	0 to 100%	± 3% between 20 and 85%
Air Speed	Thermal Anemometer	T. S. I.	15 to 77 ms^{-1}	± 0.4 ms^{-1}
Heading	Heading Sensor / Electric Compass	Precision Navigation	0 to 360 °	± 2 °
Position	Global Positioning System (GPS)	Garmin 10-05 Board Set	± 90 ° Latitude ± 180 ° Longitude	Position = 15 m (100 m with Selective Availability) Veloc. = 0.2 ms^{-1}
Particle Concentration	Optical counter	Climet CI-3100-0112	d > 0.3 µm d > 3.0 µm	± 2% of count
Ozone Concentration	U. V. absorption	Dasibi 1008 AH	0 to 999 ppbv	3 ppbv
Nitrogen Oxides Concentration	Gas-phase chemiluminescence	Monitor Labs ML 9841A	0 to 500 ppbv	0.5 ppbv or 1% of reading

REFERENCES

Carroll, J.J and A.J. Dixon, 1997. Aircraft Measurements in Support of the NOAA 2-D Lidar Demonstration. Final report to the California Air Resources Board, interagency agreement #94-320, 70 pages.

Dasibi Environmental Corp., 1990. Series 1008 U.V. Photometric Ozone Analyzer Operating and Maintenance Manual. Dasibi Environmental Corp., Glendale, CA.

Van Ooy, D.J. and J.J. Carroll, 1995. The Spatial Variation of Ozone Climatology on the Western Slope of the Sierra Nevada. *Atmospheric Environment* 29 (II), 1319 - 1330.

TABLE 3a
NITRIC OXIDE (NO) CALIBRATIONS

Date	Calibration Setting (ppbv)	NO (ppbv)	NO_x (ppbv)	NO_2 (ppbv)	NO % Difference[1]	NO_x % Difference[1]
10/12/95	287	498.7	495.7	-3.0	73.8	72.7
	96	140.8	139.5	-1.3	46.6	45.3
	49	83.7	83.0	-0.7	70.7	69.4
	10	24.0	24.0	0.0	140.0	140.0
10/26/95	287	475.0	487.7	12.7	65.5	69.9
	96	132.3	134.7	2.3	37.8	40.3
	49	81.7	81.7	0.0	66.7	66.7
	10	24.0	23.7	-0.3	140.0	136.7
	0	6.5	6.5	0.0		
1/21/97	287	474.7	482.0	7.3	65.4	67.9
	96	133.3	133.7	0.3	38.9	39.2
	49	82.0	81.7	-0.3	67.3	66.7
	10	23.0	22.7	-0.3	130.0	126.7
	0	6.7	5.7	-1.0		

TABLE 3b
NITROGEN DIOXIDE (NO_2) CALIBRATIONS

Date	Calibration Setting (ppbv)	NO (ppbv)	NO_x (ppbv)	NO_2 (ppbv)	NO_x% Difference[1]	NO_2 % Difference[1]
10/19/95	287	20.3	232.6	212.3	-19.0	-26.0
	96	11.3	69.3	58.0	-27.8	-39.6
	49	9.0	43.5	34.5	-11.2	-29.6
	10	9.0	13.0	4.0	30.0	-60.0
10/25/95	287	17.0	244.7	227.7	-14.8	-20.7
	96	10.0	70.5	60.5	-26.6	-37.0
	49	9.0	45.0	36.0	-8.2	-26.5
	10	8.3	13.3	5.0	33.3	-50.0
	0	7.0	5.0	-2.0		
10/26/95	287	17.0	254.3	237.3	-11.4	-17.3
	96	10.0	73.3	63.3	-23.6	-34.0
	49	9.7	47.3	37.7	-3.4	-23.1
	10	8.3	14.0	5.7	40.0	-43.3
	0	7.5	7.5	0.0		

[1] Percent difference = 100 * (NO_2 - calibration setting) / calibration setting.

TABLE 2
OZONE ANALYZER CALIBRATIONS

Date	PC Setting[1]	PC Value[1]	AH Value[2]	CPU Value[3]	Percent Difference[4]
07/18/95	200.0	200.3	199.7	201.0	0.3
	150.0	150.0	149.7	150.3	0.2
	100.0	99.7	99.7	99.7	0.0
	50.0	48.2	47.8	47.8	-0.8
	0.0	9.3	9.0	9.0	-2.7
07/25/95	200.0	201.7	204.7	202.3	0.3
	150.0	151.7	153.7	149.7	-1.3
	100.0	99.7	101.7	97.0	-2.7
	50.0	49.3	50.0	47.0	-4.7
	0.0	8.7	8.7	9.3	7.7
08/08/95	200.0	199.3	201.0	199.0	-0.1
	150.0	147.3	148.7	147.0	-0.2
	100.0	97.7	98.7	93.7	-4.1
	50.0	49.0	49.3	46.0	-6.1
	0.0	10.0	8.7	5.3	-46.7
08/11/95	200.0	201.0	202.7	199.0	-1.0
	150.0	149.3	151.7	147.7	-1.1
	100.0	99.0	98.3	94.3	-4.7
	50.0	48.3	48.7	43.7	-9.7
	0.0	10.7	11.3	8.3	-21.9
09/07/95	200.0	199.7	197.0	195.0	-2.3
	150.0	149.3	148.0	144.0	-3.6
	100.0	99.3	98.0	94.0	-5.4
	50.0	50.0	48.7	46.3	-7.3
	0.0	9.7	9.0	5.7	-41.4
06/28/96	200.0	200.5	201.0	201.5	0.5
	150.0	150.0	149.7	149.7	-0.2
	100.0	100.0	99.0	99.0	-1.0
	50.0	50.0	50.0	50.0	0.0
	0.0	7.6	9.0	9.0	18.4
08/24/96	150.0	146.3	148.3	144.0	-1.6
	50.0	49.0	49.0	44.3	-9.5
	0.0	9.0	8.0	6.0	-33.3
	0.0	10.0	8.5	0.0	-100.0
	150.0	149.3	148.7	141.1	-5.5
01/31/97	200.0	201.7	202.3	204.3	1.3
	150.0	150.0	150.0	152.0	1.3
	100.0	100.3	101.0	103.0	2.7
	50.0	49.3	49.3	51.3	4.1
	0.0	9.7	9.0	10.0	3.4

[1] PC = reference analyzer (ppbv).
[2] AH value = Dasibi analyzer display (ppbv).
[3] CPU = data logger record of Dasibi output (ppbv).
[4] Percent difference = 100 * (CPU - PC value) / PC value.

TABLE 6
SUMMARY OF AIR QUALITY AND METEOROLOGICAL DATA FOR FLIGHT DATES

		MAXIMUM O_3 (ppbv)			WIND (dd-ff knots)				
DATE	App.	Area[1]	Foothill[1]	Aircraft	Foothills	850 mb	500 mb	Aircraft	Comments
7-28-95 Friday	----	----	----	----	----	----	----	----	Initial test flight. Power problems, weather poor with thunder storms to NE.
8-31-95 Thursday	A	120 [108]	120 [108]	153	WSW-3	S - 8	SSW-33	S-10	Area's highest ozone observation lies within the sample sector.
9-18-95 Monday	----	----	----	----	----	----	----	----	NASA DC-8 joint flight, odd flight paths
7-03-96 Wednesday	B	81 [105]	66 [105]	148	SSW-5	W-13	SW-18	SSW-18	Ozone aloft decreases during day. Strong winds in higher levels, weak in lower layers.
7-18-96 Thursday	C	69 [66]	66 [64]	106	WNW-5	WNW-15	WSW-30	SW-17	Windy, bumpy, unstable day. Good ventilation
7-24-96 Wednesday	D	133 [119]	133 [119]	165	WSW-3	WSW-10	WSW-15	SW-18	Early GPS problems. Worst air quality day encountered.
7-31-96 Wednesday	E	91 [108]	68 [108]	93	W-5	W-10	SW-25	SW-17	Neutrally stratified all day, deep mixing, moderate winds. Max ozone within city.
8-07-96 Wednesday	F	127 [95]	105 [95]	115	WNW-3	SSW-10	SSW-10	SSW-15	Shallow mixed layer in afternoon, peak ozone SE of city, cross wind.
8-15-96 Thursday	G	93 [110]	87 [98]	108	SW-3	W-10	SW-10	SSW-16	Max ozone NNE of city, Mixed layer lowers during day.

[1] Concentrations in brackets [ ] are the previous day's maximum.

TABLE 4
AIR TEMPERATURE CALIBRATIONS

Date	Temperature[1] (Ta) (°C)	Temperature[2] (T') (°C)	Calibration Temperature (°C)	Ta Percent Difference[3] (%)	T' Percent Difference[4] (%)
7/03/95	17.0	23.3	23.9	-28.9	-2.5
7/19/95	25.7	25.0	25.8	-0.6	-3.2
7/27/95	35.4	34.5	33.9	4.4	1.7
8/08/95	38.4	37.6	37.8	1.6	-0.3
8/10/95	26.2	26.0	26.1	0.2	-0.6
8/11/95	38.6	38.3	37.6	2.6	1.9
6/21/96	On this date a calibration showed Ta to be ~ .5 C higher than the calibration temperature and T' to be ~ .5 C less than the calibration temperature.				

TABLE 5
RELATIVE HUMIDITY CALIBRATIONS

Date	Relative Humidity (RH) (%)	Calibration Relative Humidity (CRH) (%)	Percent Difference[5] (%)
6/29/95	59.9	62.8	-4.6
7/18/95	75.0	74.9	0.1
7/19/95	70.0	75.3	-7.0
7/19/95	11.5	11.3	2.1
7/27/95	24.4	26.4	-7.6
8/08/95	15.0	15.0	0.0

[1] Ta is the primary temperature probe (fast response).
[2] T' is the secondary temperature probe (very fast response).
[3] Ta percent difference = 100 * (Ta - calibration temperature) / calibration temperature.
[4] T' percent difference = 100 * (T' - calibration temperature) / calibration temperature.
[5] Percent difference = 100 * (RH - CRH) / CRH.

TABLE 8

AIRCRAFT DATA FILE VARIABLE LIST
FOR
mm-dd-nn.DAS

HEADER VARIABLES

MONTH, DAY, YEAR, FILE NUMBER, NUMBER OF CHANNELS, DATA SAMPLE PERIOD, NAV SAMPLE PERIOD, SCAN NUMBER

INDEX	VARIABLE	UNITS
1	TIME [1]	SECONDS
2	TURBULENCE 1	MILLIVOLTS
3	TURBULENCE 2	MILLIVOLTS
4	TURBULENCE 3	MILLIVOLTS
5	AVE. TEMP. (T')	MILLIVOLTS
6	AIRSPEED	MILLIVOLTS
7	REL. HUMIDITY	MILLIVOLTS
8	PRESSURE	MILLIVOLTS
9	AVE. TEMP. (Ta)	MILLIVOLTS
10	NO	MILLIVOLTS
11	NOx	MILLIVOLTS
12	OZONE	MILLIVOLTS
13	PARTICLES > 0.3	MILLIVOLTS
14	PARTICLES > 3.0	MILLIVOLTS
15	HEADING	MILLIVOLTS
16	EVENT MARKER	MILLIVOLTS

[1] Seconds since midnight in UTC.

TABLE 7
AIRCRAFT DATA PROCESSING PROGRAMS AND DATA FILES

PROGRAM	INPUT FILES	OUTPUT FILES	COMMENTS
AC-TEST	N/A	N/A	Prints the data to the screen at approximately five second intervals to verify data logging.
AC-DATA	N/A	mm-dd-nn.DAS mm-dd-nn.NAV	Aircraft data logging program (*.DAS is the primary data. *.NAV is navigation data).
AC-CRRCT	mm-dd-nn.DAS	mm-dd-nn.DAS mm-dd-nn.LOG	Corrects radio transmission data spikes.
AC-CRRCF	mm-dd-nn.DAS	mm-dd-nn.DAS	Corrects format of files not formatted efficiently by AC-CRRCT.
AC-CRRT2	mm-dd-nn.DAC	mm-dd-nn.DAC	Similar to AC-CRRCT but uses *.DAC files.
AC-CNVRT	mm-dd-nn.DAS mm-dd-nn.NAV	mm-dd-nn.DAT mm-dd-nn.NAT	Converts voltages to scientific units and decodes GPS nav data. Requires initial altitude of file.
AC-CVRT2	mm-dd-nn.DAT mm-dd-nn.NAT	mm-dd-nn.DAC	Makes calibration corrections, flags erroneous data and combines navigation data with other variables. *.DAC files are main working files.
ACDACLST	mm-dd-nn.DAC	DAC-LIST.TXT	Makes list of all *.DAC files.
AC-SCAL2	mm-dd-nn.DAC	mm-dd-nn.SCL	Plots vertical soundings of aircraft data using GRAPHER. Requires GRAPHER files for operation.
AC-LOOK	mm-dd-nn.DAC	N/A	User selected screen plots and print summaries of data.
AC-LOOK2	mm-dd-nn.DAC	N/A	AC-LOOK plus additional plot of aircraft heading and direction.
AC-LOOK3	mm-dd-nn.DAC	N/A	AC-LOOK plus shows airspace boundaries used in AC-SURF2 to separate data into transects.
AC-WIND	mm-dd-nn.DAC	N/A	Shows wind speed and direction data calculated from aircraft heading, airspeed and track info.
AC-WIND2	mm-dd-nn.DAC	mm-dd-nn.WND AIRHDCOR.DAT	Minimizes RMS of calculated wind to find airspeed and heading corrections for more accurate wind calculations. Edit AIRHDCOR.DAT to include only useful files (those with multiple track directions).
AC-WIND4	mm-dd-nn.DAC	mm-dd-nn.W10 mm-dd-nn.W20 AIRCORA1.DAT AIRCORA2.DAT	Same as AC-WIND2 except that it is done for two different altitude ranges: < 7000 feet msl and >= 7000 feet msl. Valid (useful) files are calculated automatically.
AC-ASHDG	AIRHDCOR.DAT AIRCORA1.DAT AIRCORA2.DAT	N/A	Calculates average airspeed and heading correction values to use for entire data set. Output is to screen only.
AC-WIND3	mm-dd-nn.DAC	mm-dd-nn.WN2 TOTWN2.DAT	Applies airspeed and heading correction values to wind calculations as f(alt). Input corr't values from AIR*.DAT. Output is for each valid GPS leg.
AC-SURF	mm-dd-nn.EWT mm-dd-nn.NS*	mmdd-xyz.DAT	Creates input file for SURFER program to plot 2D cross sections.
AC-SURF2	mm-dd-nn.DAC	mmdd-xyz.DAT	Creates input file for SURFER program to plot 2D cross sections. Separates data by transects using boundaries shown in AC-LOOK3.
AC-AVEDD	mm-dd-nn.WN2	mmdd-n.DAT	Calculates the average aircraft derived winds over three altitude ranges for the three transects in each flight for the Sierra data.

TABLE 10
SIERRA FLIGHT ROUTE

Location	Altitude (feet MSL)	Altitude (meters MSL)	Course (degrees magnetic)	Distance (nm)
S1 Sounding	5500 to 1000	1675 to 305	N/A	N/A
S1 Reposition	1000 to 4500	305 to 1370	135	5
S1 Transect	4500	1370	315	13
S1 Transect	3500	1065	135	13
S1 Transect	2500	760	315	13
S1 Transect	1500	455	135	13
S1 - S2 Traverse	1500 to 6500	455 to 1980	010	19
S2 Sounding	6500 to 2600	1980 to 790	N/A	N/A
S2 Reposition	2600 to 5500	790 to 1675	315	9
S2 Transect	5500	1675	135	20
S2 Transect	4500	1370	315	20
S2 Transect	3500	1065	135	20
S2 - S3 Traverse	3500 to 9500	1065 to 2895	010	23
S3 Sounding	9500 to 5500	2895 to 1675	N/A	N/A
S3 Reposition	5500 to 8500	1675 to 2590	135	16
S3 Transect	8500	2590	315	28
S3 Transect	7500	2285	135	28
S3 Transect	6500	1980	315	28
S3 - Auburn	6500 to 1500	1980 to 455	200	26

TABLE 9

AIRCRAFT DATA FILE VARIABLE LIST FOR mm-dd-nn.NAV

HEADER VARIABLES

MONTH, DAY, YEAR, HOUR, MINUTES, SECONDS (GMT), FILE NUMBER

REPEATING VARIABLES

TIME, PRESSURE 1, PRESSURE 2, TEMPERATURE (Ta or T'), V-COMPONENT OF AIRSPEED, U-COMPONENT OF AIRSPEED

GPS WORD 1

GPS WORD 2: TIME (HR, MN, SEC), LATITUDE, LONGITUDE, GROUND SPEED, TRUE TRACK, MAGNETIC VARIATION

COMPASS WORD: MAGNETIC HEADING, PITCH, ROLL [1]

[1] While data called "roll" is recorded, it is not a valid indicator of aircraft bank angle.

TABLE 12

AIRCRAFT DATA FILE VARIABLE LIST
FOR
mm-dd-nn.DAT

HEADER VARIABLES
MONTH, DAY, YEAR, FILE NUMBER, NUMBER OF SCANS

	VARIABLE	UNITS
1	TIME[1]	SECONDS
2	AVE. TEMP. (Ta)	° C
3	AVE. TEMP. (T')	° C
4	AIRSPEED	ms^{-1}
5	PRESSURE	mb
6	ALTITUDE	FEET MSL
7	REL. HUMIDITY	%
8	SPEC. HUMIDITY	g/Kg
9	NO	ppbv
10	NO_X	ppbv
11	OZONE	ppbv
12	HEADING	DEGREES (MAG)
13	PARTICLES > 0.3	$Nx10^6/m^3$
14	PARTICLES > 3.0	$Nx10^3/m^3$
15	rmsT (.1 sec)	° C
16	rmsV (.1 sec)	ms^{-1}
17	rmsRH (.1 sec)	%
18	EVENT MARKER	MILLIVOLTS

[1]Seconds since midnight in UTC.

TABLE 11 DATA CONVERSION		
VARIABLE	EQUATION	SCIENTIFIC UNITS
Pressure	P = millivolts * 0.09997 + 600	millibars
Altitude	Z = - (0.96*P + 7470)*ln(P/1013.25)/0.3048 + Zcorr Where Zcorr = Zinitial (for the first altitude)	feet
Temperature 1	Ta = millivolts * 0.172 - 18.5	°C
Temperature 2	T' = millivolts * 0.1423 - 19.15	°C
Relative Humidity	RH = millivolts / 10	%
Airspeed	V = millivolts * 0.01524 * 1013/P * (Ta + 273.15)/294.25	ms^{-1}
Heading	HDG = millivolts * 0.072	deg. magnetic
Nitric Oxide	NO = millivolts * 0.05	ppbv
Oxides of Nitrogen	NO_X = millivolts * 0.05	ppbv
Ozone	O_3 = millivolts - 9	ppbv
Particles d > 0.3 μm	PC1 = millivolts * 11307 / 1000000	# * $10^6/m^3$
Particles d > 3.0 μm	PC2 = millivolts * 113.1 / 1000	# * $10^3/m^3$

TABLE 14

AIRCRAFT DATA FILE VARIABLE LIST FOR mm-dd-nn.DAC

HEADER VARIABLES

MONTH, DAY, YEAR, FILE NUMBER, SCAN NUMBER, SITE NUMBER, SCALE VALUE

	VARIABLE	UNITS
1	TIME	SECONDS
2	AVE. TEMP. (Ta)	° C
3	AVE. TEMP. (T')	° C
4	AIRSPEED	ms^{-1}
5	PRESSURE	mb
6	ALTITUDE	FEET MSL
7	REL. HUMIDITY	%
8	SPEC. HUMIDITY	g/Kg
9	NO	ppbv
10	NO_2	ppbv
11	OZONE	ppbv
12	HEADING	DEGREES (MAG)
13	PARTICLES > 0.3	$Nx10^6/m^3$
14	PARTICLES > 3.0	$Nx10^3/m^3$
15	rmsT (.1 sec)	° C
16	rmsV (.1 sec)	ms^{-1}
17	rmsRH (.1 sec)	%
18	rmsT (3 sec)	° C
19	rmsV (3 sec)	ms^{-1}
20	rmsRH (3 sec)	%
21	X - POSITION [1]	NAUTICAL MILES
22	Y - POSITION [1]	NAUTICAL MILES
23	EVENT MARKER	—
24	GPS INDEX	—

[1] Relative to reference location.

TABLE 13

AIRCRAFT DATA FILE VARIABLE LIST
FOR
mm-dd-nn.NAT

HEADER VARIABLES
MONTH, DAY, YEAR, HOUR, MINUTES, SECONDS (GMT),
FILE NUMBER

INDEX	VARIABLE	UNITS
1	TIME	SECONDS
2	GMT	HR, MIN, SEC
3	GPS ALTITUDE	METERS
4	AVE PRESS ALT	METERS
5	INST PRESS ALT	METERS
6	LATITUDE DEG	DEGREES
7	LATITUDE MIN	MINUTES
8	LONGITUDE DEG	DEGREES
9	LONGITUDE MIN	MINUTES
10	GROUND SPEED	ms^{-1}
11	TRUE TRACK	DEGREES TRUE
12	TRUE HEADING	DEGREES TRUE
13	V-AIRSPEED	ms^{-1}
14	U-AIRSPEED	ms^{-1}
15	PITCH	DEGREES
16	ROLL [1]	DEGREES

[1] While data called "roll" is recorded, it is not a valid indicator of aircraft bank angle.

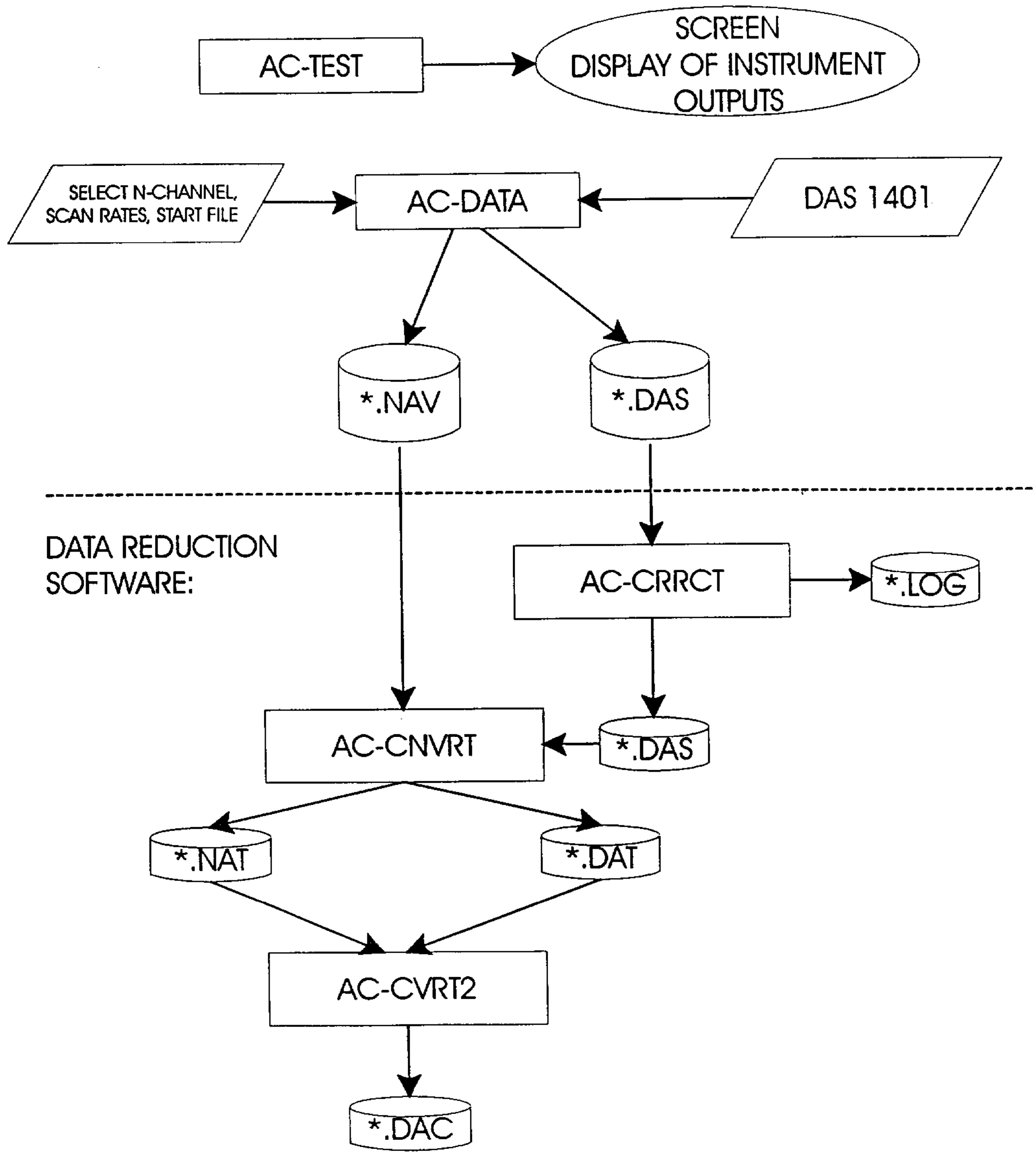


Figure 2: Flowchart showing UCD aircraft data acquisition and reduction software.

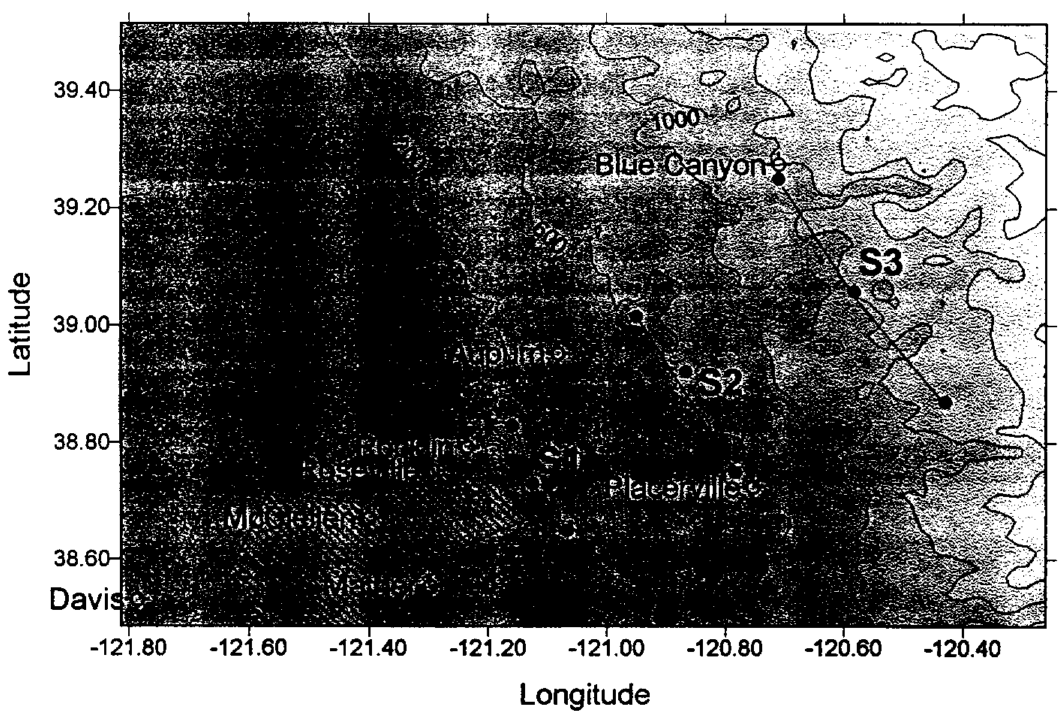


Figure 1: Regional map showing locations of surface observation sites, key landmarks and aircraft transect lines. Elevation contour lines are in meters above mean sea level, and the hatched area is the Sacramento urban area.

Appendices A to G

The following appendices contain detailed descriptions of the data for each sampling day, each following the same format. They also contain tables and graphical presentations of data from various sources. The format of each appendix is as follows:

Narrative:
I. Synoptic Setting.
II. Surface observations.
III. Vertical cross sections.
IV. Synopsis.

Table: Estimated layer averaged winds, altitude of lowest mixing height (H_m) and mixed layer depth (D_m, relative to mean terrain altitude) from the aircraft data.

Figures:
0400 PST (12Z) Synoptic analyses.
1600 PST (00Z) Synoptic analyses.
All Days
500 mb height field (meters, contour interval (CI) = 60 meters)
850 height field (meters, CI = 30 meters)
All days after 7-03-96
600 mb winds aloft (speeds in knots)
Surface map (Isobars in mb, CI = 4 mb)

Hourly winds (knots) and temperatures (C) at McClellan (MCC) and Blue Canyon (BLU).

Hourly averaged resultant wind (knots), temperature (C) and ozone (ppbv) at Placerville, Rocklin and Roseville.

Maps showing maximum hourly averaged ozone concentrations (ppbv) for inland central California for each flight day.

Vertical cross sections of potential temperature (K), relative humidity (%) and ozone (ppbv) for three north-south transect lines and one east-west cross section at three times per day plus two north-south transect lines for the last flight of the day (42 plots/day).
Figures are in chronological order and sequence from S1 to S2 to S3, followed by the east-west cross sections through S1, S2 and S3.
Topography under the average traverse path is shown as dark blocks at base of each section.

APPENDIX A:
August 31, 1995 Sierra Nevada Transect Flights

I. Synoptic setting:

At 0400 PST (12Z), there was a cut-off low at 500 mb off the California coast (130 degrees west and 43 degrees north) with a ridge just east of California. A weak 850 mb cut off low was also present at the same location with a very flat height field over the sample area. The winds at 500 mb were relatively strong, south-southwest at 26 to 29 knots. Conversely, the 850 mb winds were light, from the northwest at 3 knots.

At 1600 PST (00Z), the 500 mb height field was quite similar to that at 12Z but for a strengthening of the high pressure east of the state. At 850 mb, a second low center was analyzed centered just north of the sample area. Winds at 500 mb strengthened, being south-southwest at 33 to 41 knots. The 850 mb winds shifted to be southerly at 8 knots.

II. Surface observations:

At the foothill sites, the predawn winds were light (< 3 knots) from the southeast at Roseville, east at Placerville, and northeast at Rocklin. At 0800 PST, the winds shifted about 180 degrees at all three sites, were approximately southwest from 1100 to 1600 PST, then more westerly till about 1900, then shifted to the southeast by 2100 PST. Peak temperatures were between 31 and 34 C. Ozone concentrations at Rocklin and Roseville reached 120 ppbv by 1600 PST then decreased quickly to 30 ppbv by 2000 PST. At Placerville, ozone peaked later (1900 PST) at 120 ppbv, then fell back in the evening to about 80 ppbv.

III. Vertical Cross sections:

Flight 1: At S1, the atmosphere was fairly stable throughout the vertical range of the section, with at least two layers of enhanced stability, 600 to 700 m and 1200 to 1300 m. There is some evidence for a near surface nocturnal inversion as well. Relative humidity was generally low, falling to near zero above the upper stable layer. Ozone concentrations were high in the layer above 700 m, with one small pocket greater than 100 ppbv near the center of the section. At S2, a strong near ground inversion was detected topping at 700 m, probably the same layer as detected at S1, enhanced by nocturnal surface cooling. A second layer of enhanced stability was present between 1200 and 1600 m. Again, the relative humidity values were low throughout the section and near zero above the upper stable layer. The peak ozone concentrations (~80 ppbv) occurred in the layer contained between the two stable layers. At S3, the atmosphere was near neutral up to about 2000 m where a layer of moderately enhanced stability was seen. The ozone concentrations show a high degree of spatial variability with peak concentrations less than 70 ppbv except for one small pocket that peaked at about 90 ppbv near 2500 m. The east-west section shows essentially horizontal potential temperature isotherms with the lower stable layer intersecting the topography at about 1300 m elevation, with the polluted residual layer also held below this altitude.

Flight 2: The atmosphere below 1500 m was still quite stable at S1, with at least two layers of enhanced stability: 700 to 1000 m and 1250 to 1400 m. Peak ozone concentrations were found between these two layers with values in excess of 100 ppbv. At S2, the atmosphere below 1500 m had near neutral stability and both relative humidity and ozone were well mixed. Peak values were seen toward the northwest end of the transects with a local maximum greater than 100 ppbv at 1250 m. At S3, the atmosphere was relatively warm and near neutral below a capping inversion based near 2300 m. Below this altitude, there was a great deal of small scale spatial variability, especially in the ozone concentrations which were less than 80 ppbv. The air below 2300 m appears to be in free convection with strong thermals present. Note the vertical oscillations in the aircraft's tracks. The east-west section of relative humidity and ozone shows the growth of the mixed layer at all elevations with a pocket of higher ozone above the surface at S3.

Flight 3: By mid afternoon at S1, the atmosphere, at least up to 2000 m had become much less stable, and was near neutral up to about 1100 m. The relative humidity field was very well mixed throughout the section. Ozone concentrations were very high below about 1000 m, exceeding 130 ppbv at the lower altitudes over the center half of the sampled area. At S2, the atmosphere was near neutral up to about 1600 m with strong thermal activity (small scale spatial variations and wavy flight path). Ozone concentrations were high below 1500 m reaching a local maximum of 140 ppbv. At S3, the free convection layer was capped at about 2400 m, with moderately high ozone concentrations (80 - 90 ppbv) found below 2300 m.

The east-west section shows warming at all locations (lowering of the potential temperature isotherms) and increasing ozone concentrations all along the slope.

Flight 4: At S1, the late afternoon stability was neutral below a capping stable layer based at 1100 m. The relative humidity was low and well mixed. High ozone concentrations were seen below 1100 m with peak values greater than 140 ppbv aloft and greater than 130 ppbv near the ground. At S2, the lowest transect data is missing, but it appears that the mixed layer was capped at 1400 m with ozone values in the mixed layer reaching values of at least 130 ppbv.

IV. Synopsis:

At first glance, the strong southwesterly flow aloft (500 mb) would suggest a low probability of an air pollution episode. However, the proximity of the 500 mb ridge to the east suggests that the large scale vertical velocity was probably near zero. The light winds at 850 mb (1500 m) and below suggests a decoupling of the flow at 500 mb (5800 m) from that at lower altitudes. The strong stability in the lower layers measured in the morning, coupled with the high ozone concentrations found in the residual layer aloft suggest that the day prior was one in which subsidence and light winds restricted ventilation. In fact, the 500 mb height field for the prior afternoon shows a ridge centered over the sample area. The high concentrations of ozone found aloft and near the surface appear to be the result of accumulation of multi-day emissions and products, coupled with weak winds and relatively low mixing depths.

Surface temperatures were not particularly high, but still very high ozone values were measured at the surface stations as well as aloft. A broad plume of pollutants was transported up the Sierra slopes at least as far as S2. At S3, the plume was still evident but concentrations were lower, and generally below the state ambient air quality standard (AAQS). The deep convection at S3 is probably the main reason for these reduced concentrations.

TABLE A-1

8-31-95
Averaged Aircraft Data

	Time (PST)	Location	Altitude (m MSL)	Direction	Speed (knots)	H_m (m MSL)	D_m (m AGL)
Flight 1	0600	S1	600	155	8	245	95
		S2	1350	155	9		
	0700		1500	170	13	760	610
	0800	S3	1850	135	9	<1500	250
			2500	170	16		
Flight 2	1000	S1	650	170	10	610	460
			1400	170	14		
	1100	S2	1500	170	11	1400	850
	1200	S3	1850	180	8	2200	950
			2500	180	17		
Flight 3	1400	S1	650	175	10	975	825
			1500	185	26		
	1500	S2	1500	176	10	1525	975
	1600	S3	1800	140	7	2200	950
			2500	165	18		
Flight 4	1800	S1	650	200	13	1100	950
			1350	175	9		
	1900	S2	1600	135	12	1675	1125

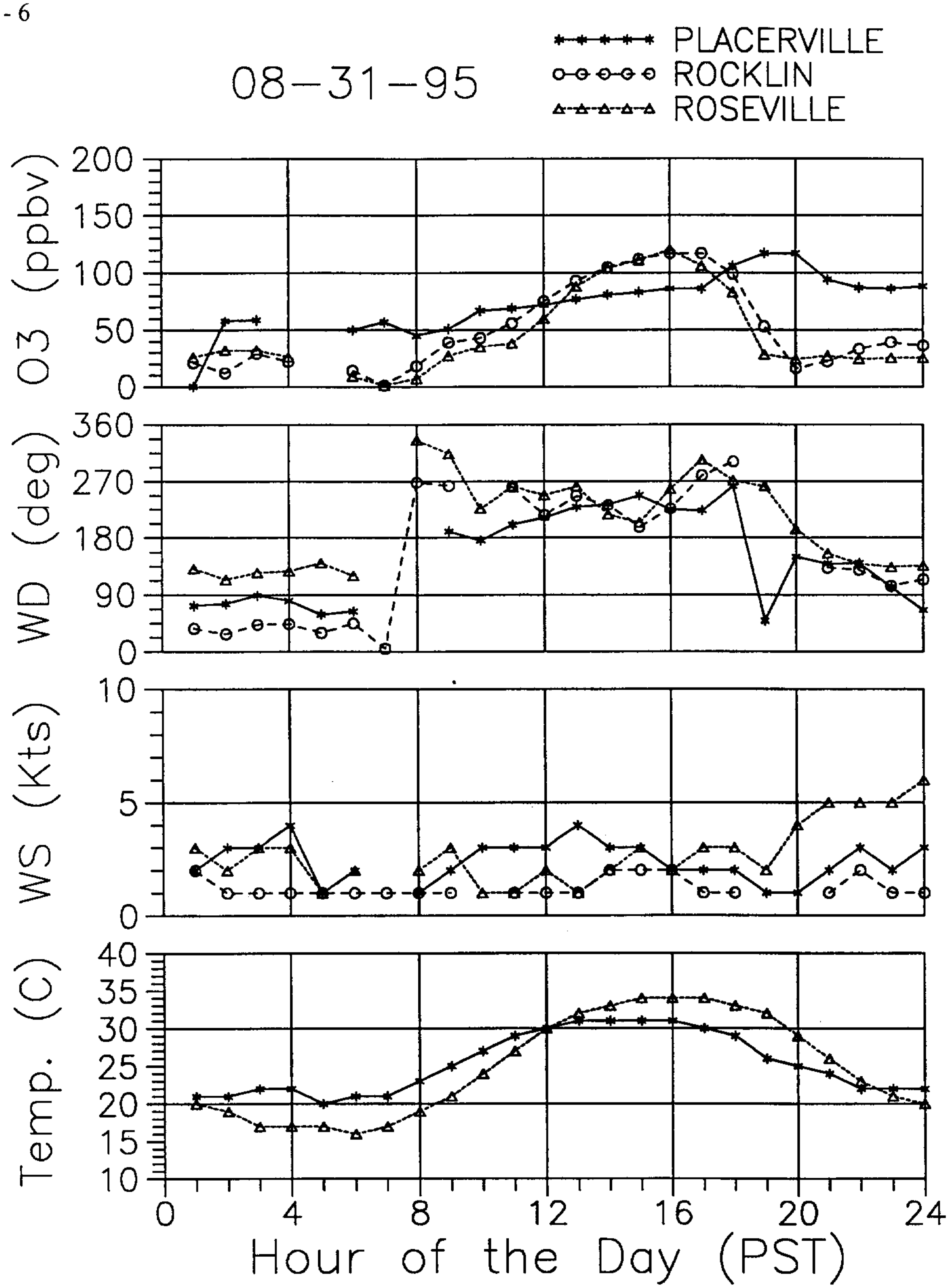


Figure A-3: Plot of hourly averaged data for the three foothill ground stations versus time of day (PST) for 8-31-95.

Figure A-4a: Maximum hourly averaged ozone concentrations in central California on 8-30-95.

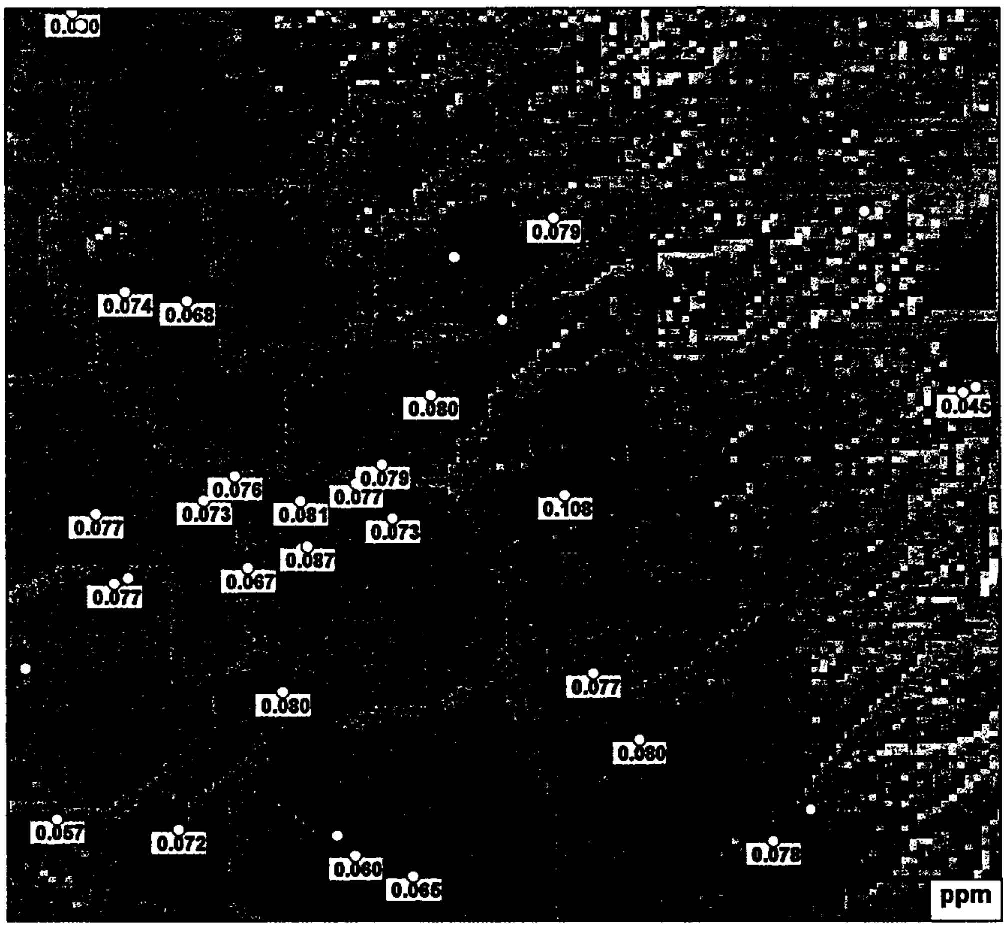
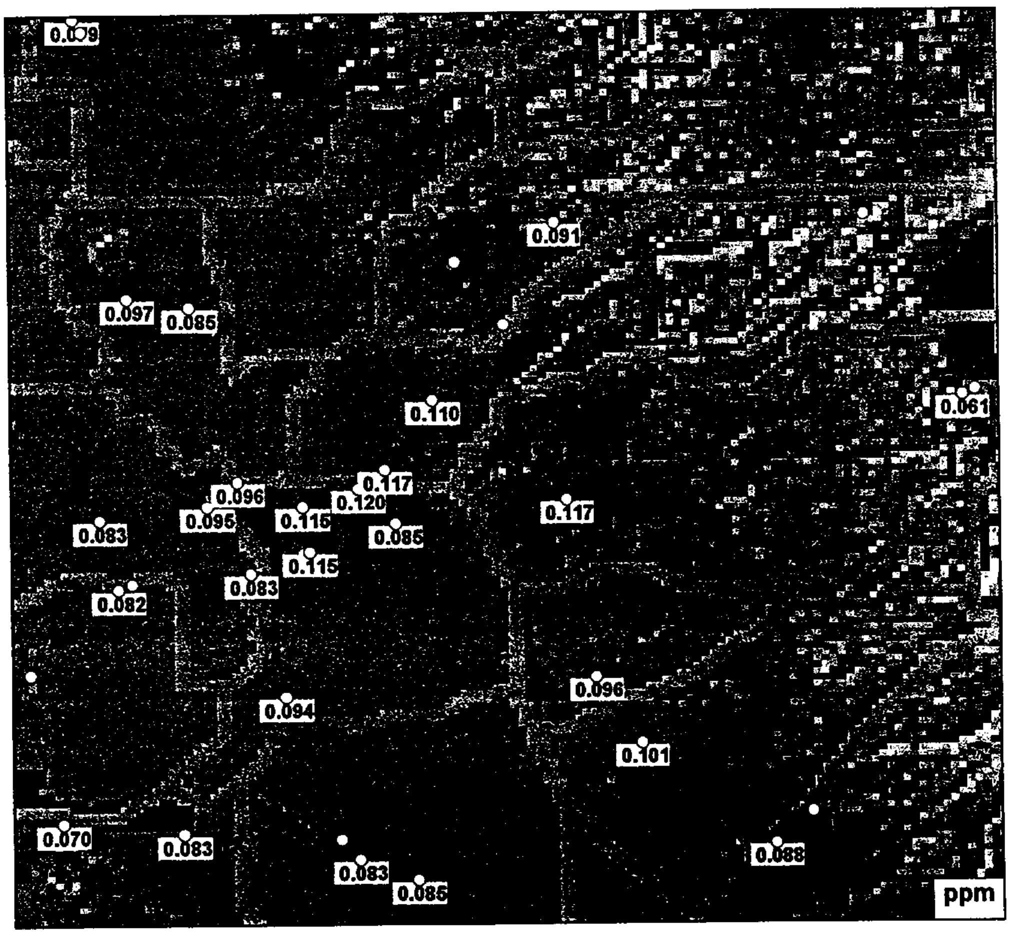


Figure A-4b: Maximum hourly averaged ozone concentrations in central California on 8-31-95.



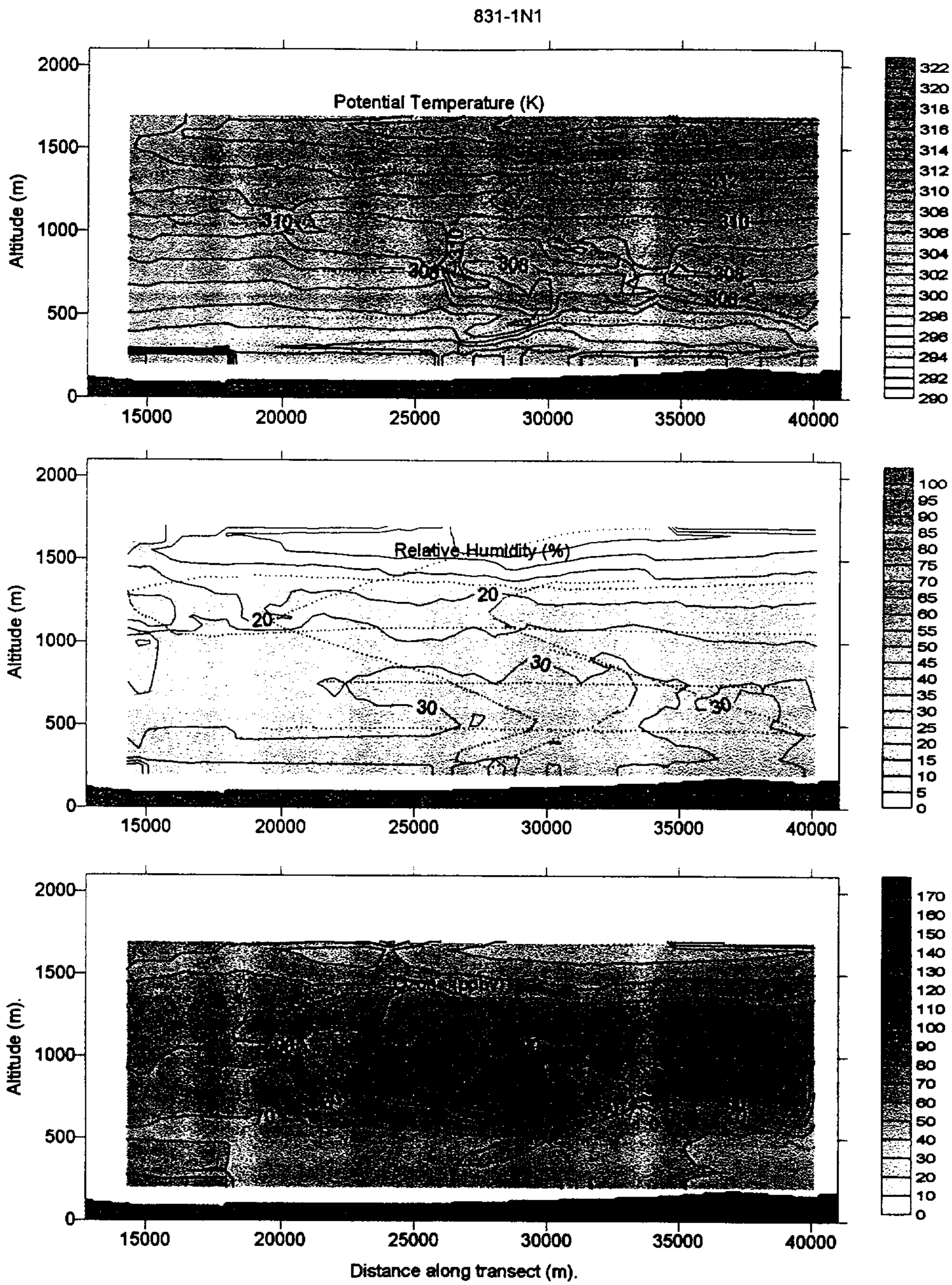


Figure A-5a: Vertical cross sections for flight 1 at S1 on 8-31-95.

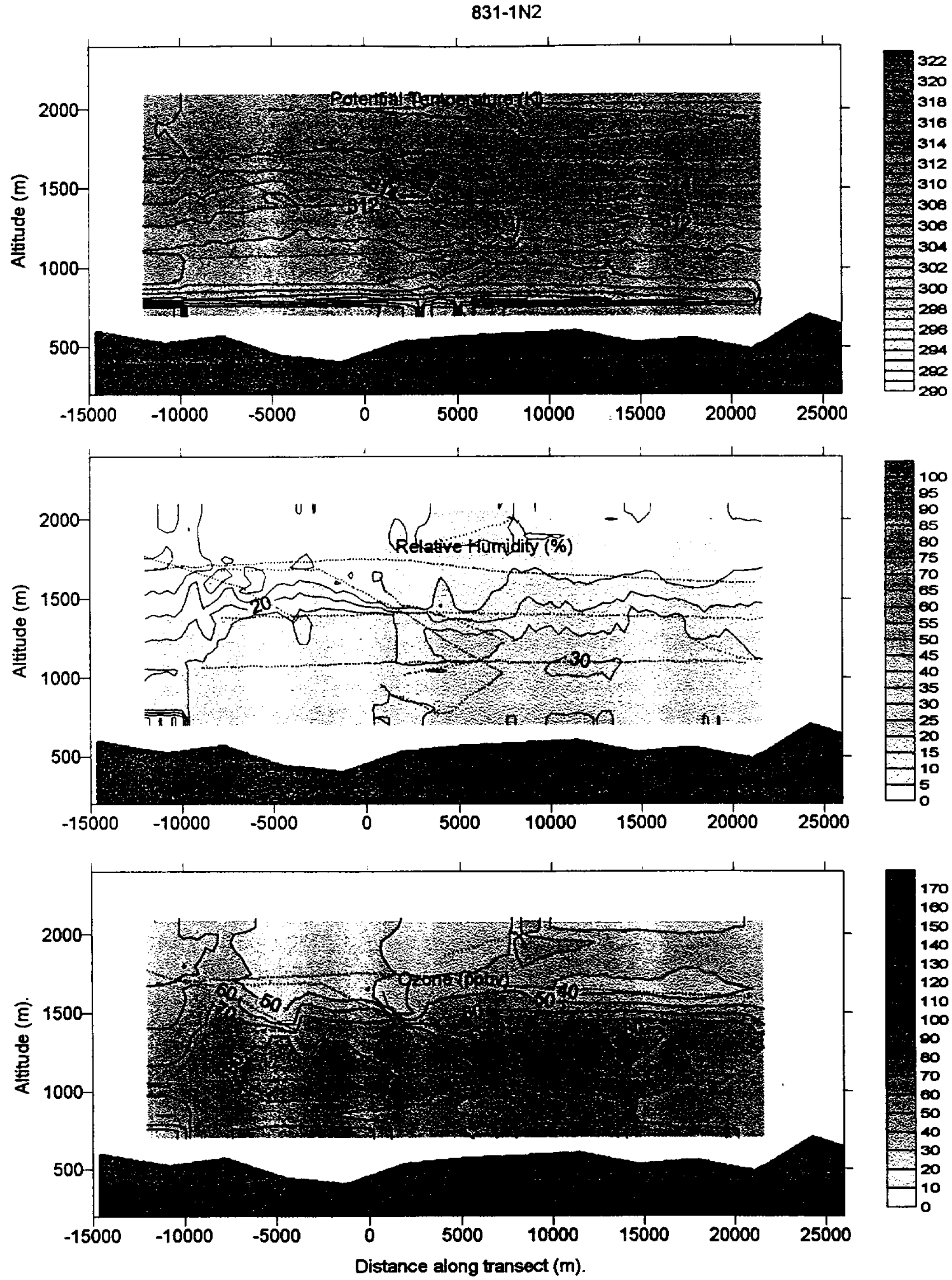


Figure A-5b: Vertical cross sections for flight 1 at S2 on 8-31-95.

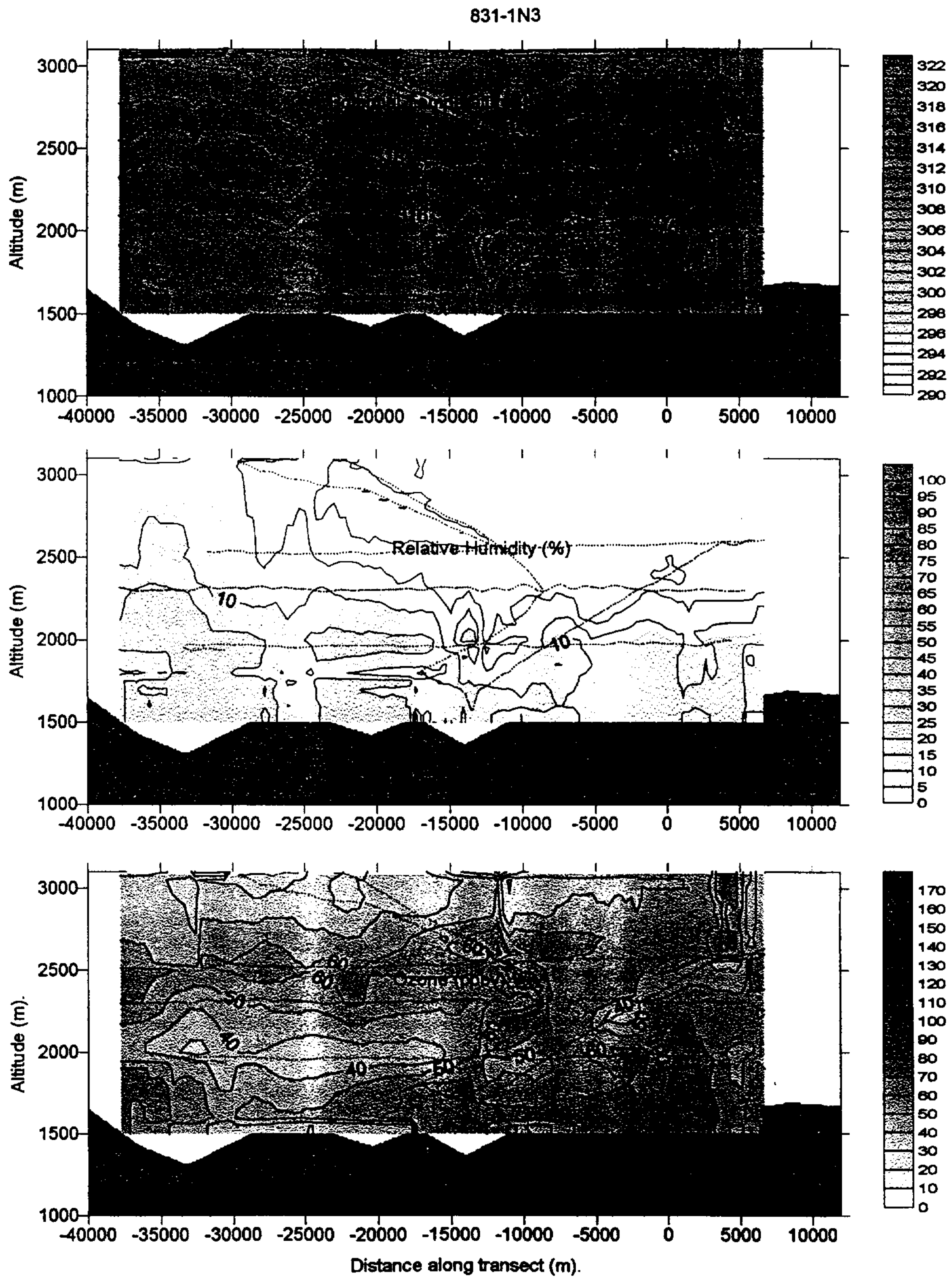


Figure A-5c: Vertical cross sections for flight 1 at S3 on 8-31-95.

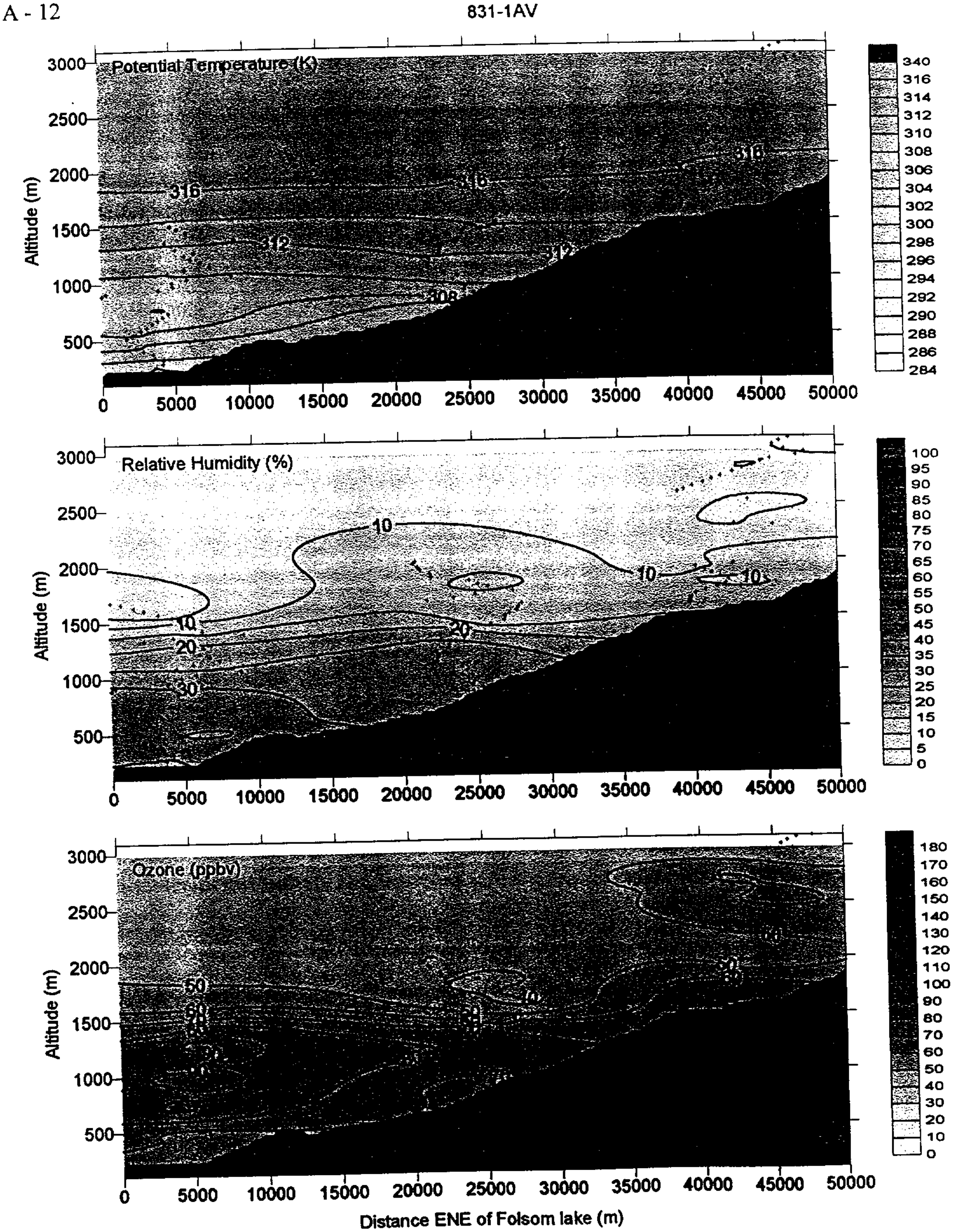


Figure A-5d: Vertical east-west cross sections for flight 1 on 8-31-95.

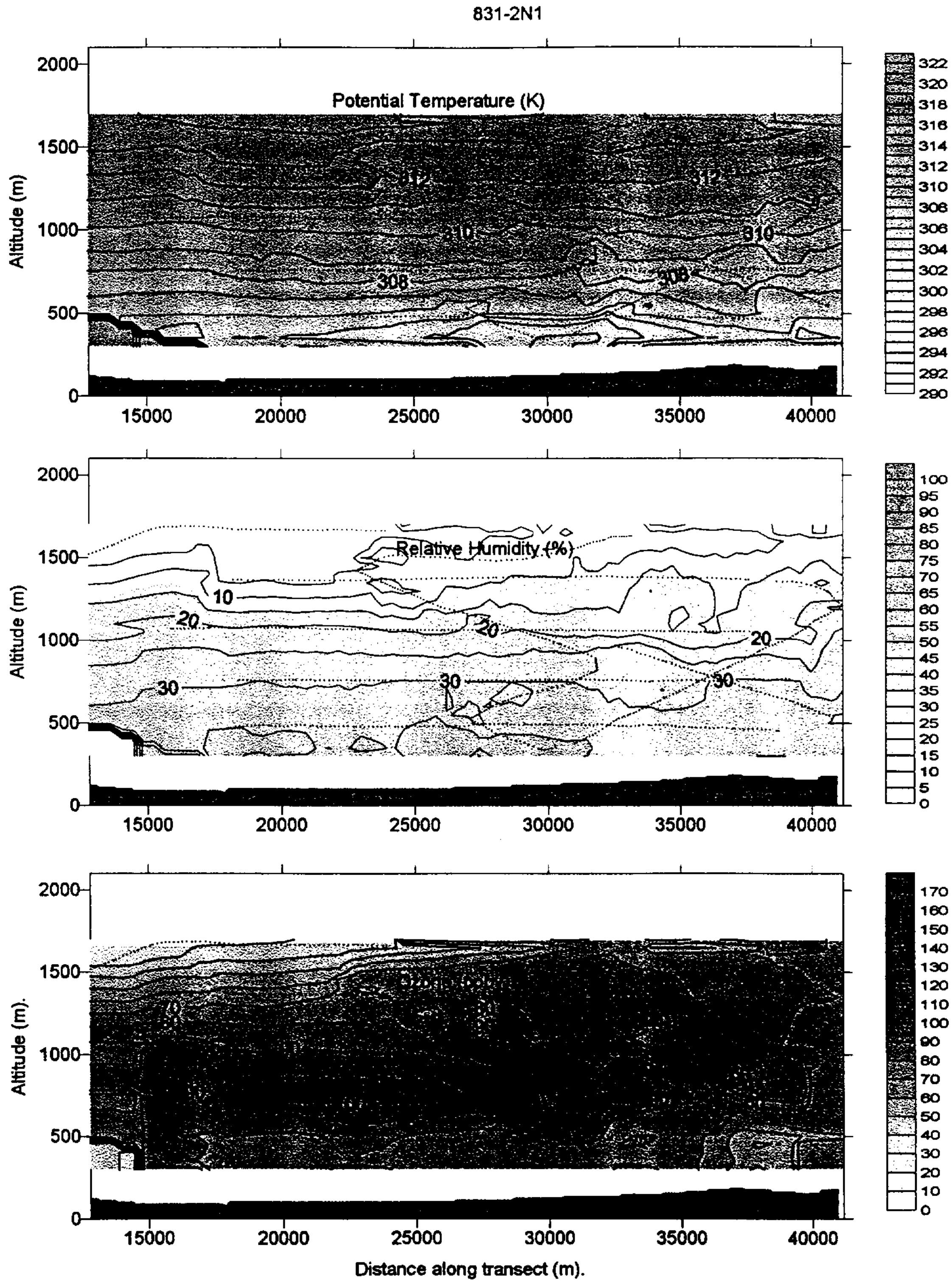


Figure A-6a: Vertical cross sections for flight 2 at S1 on 8-31-95.

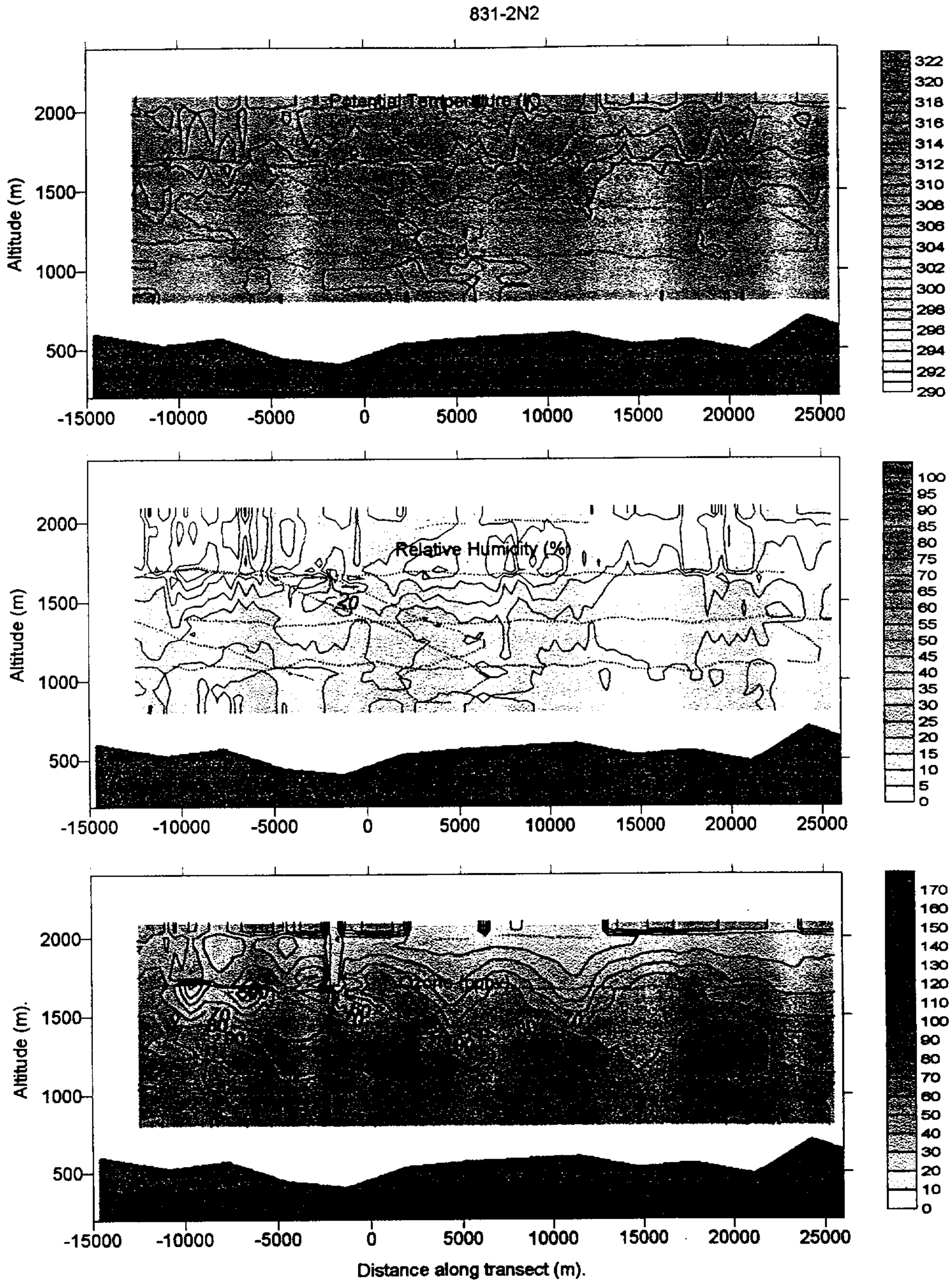


Figure A-6b: Vertical cross sections for flight 2 at S2 on 8-31-95.

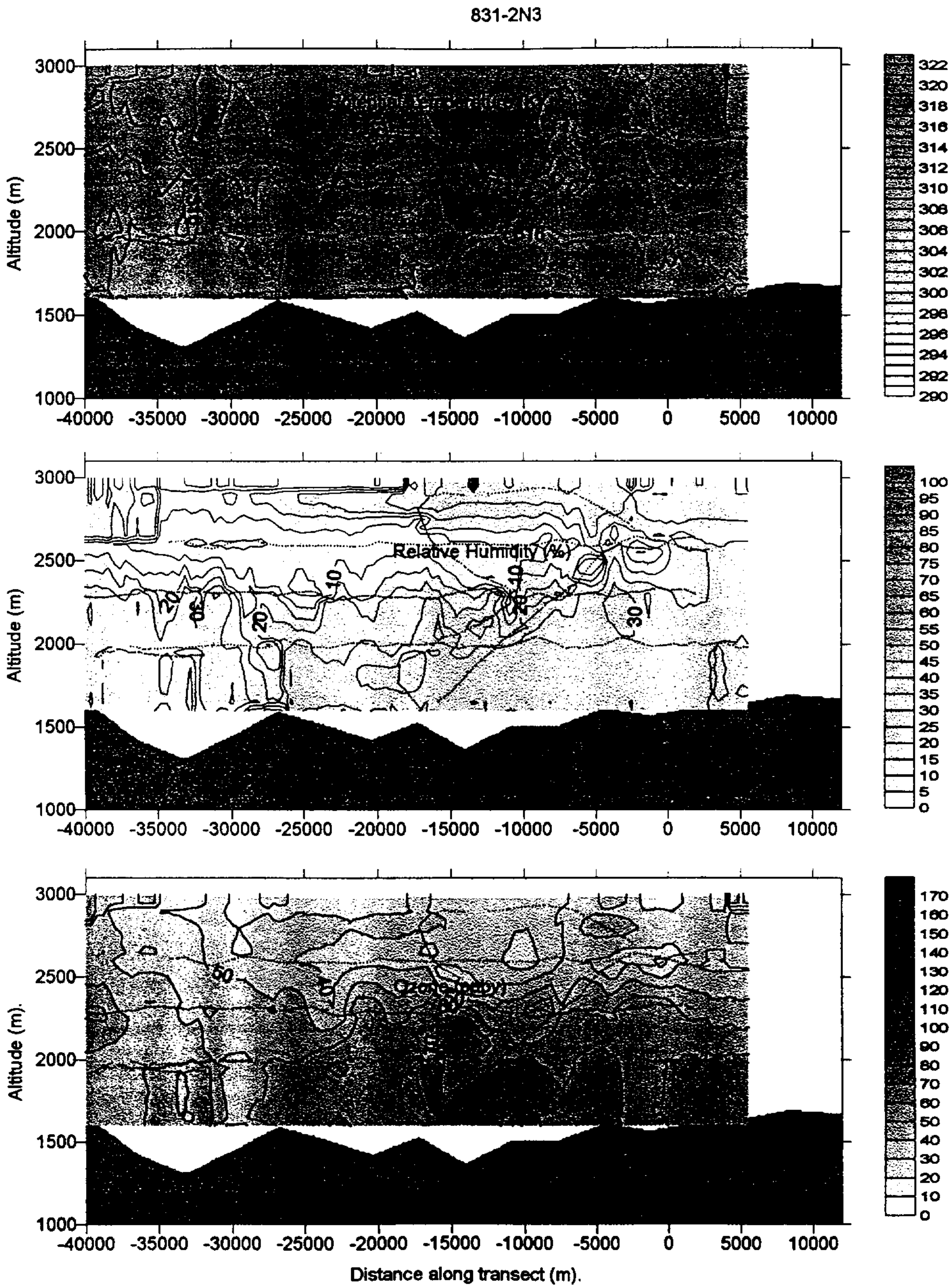


Figure A-6c: Vertical cross sections for flight 2 at S3 on 8-31-95.

831-2AV

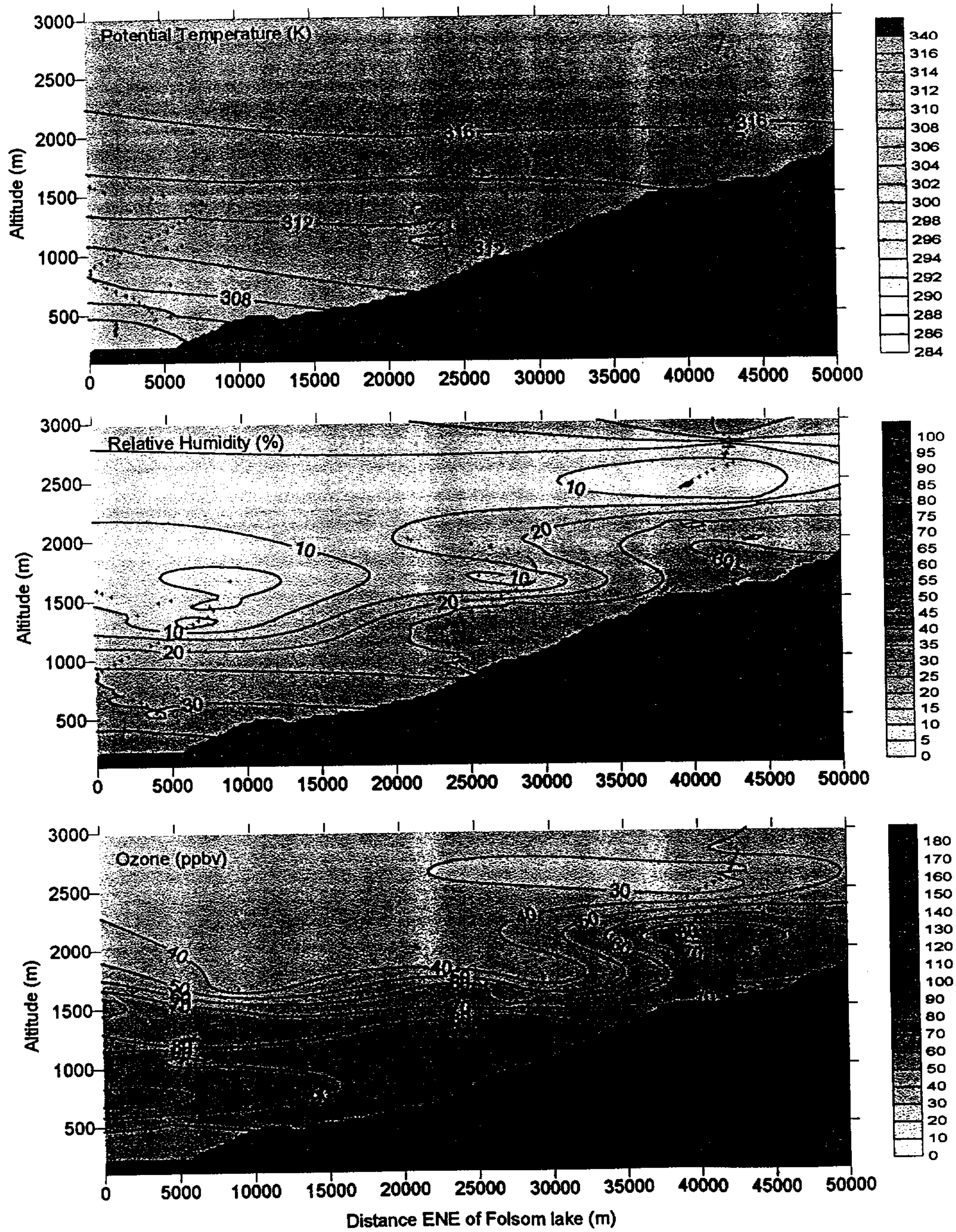


Figure A-6d: Vertical east-west cross sections for flight 2 on 8-31-95.

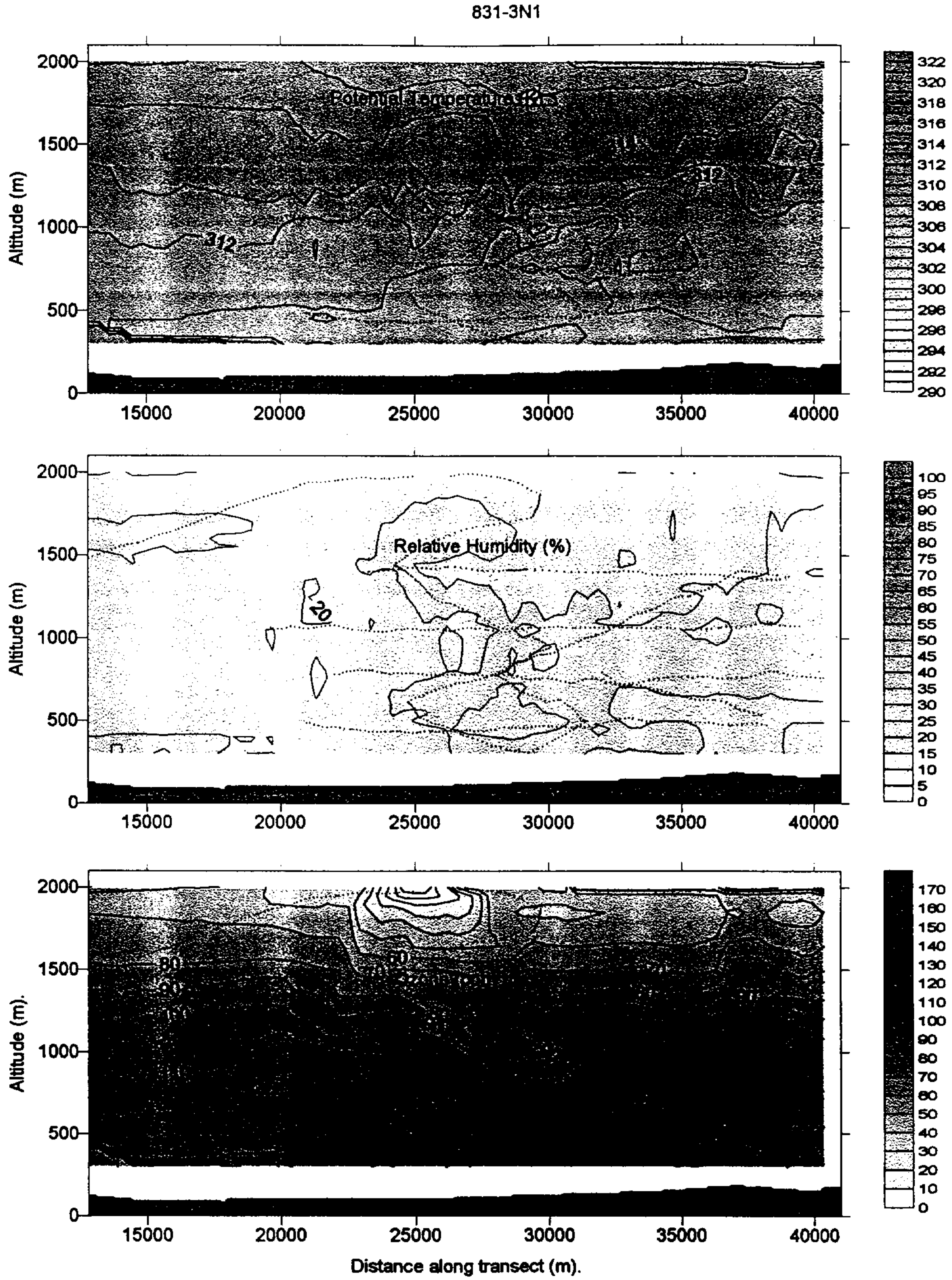


Figure A-7a: Vertical cross sections for flight 3 at S1 on 8-31-95.

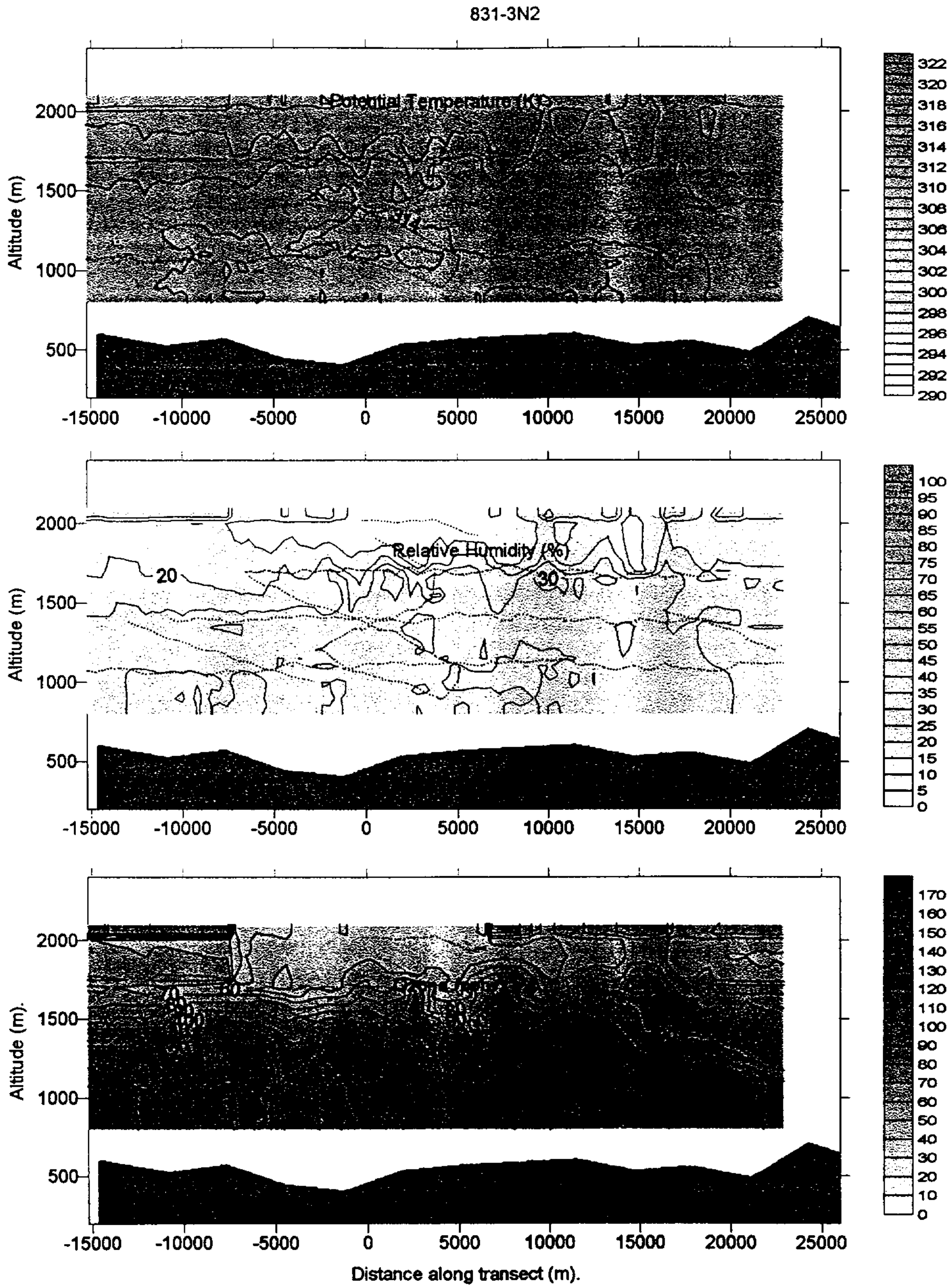


Figure A-7b: Vertical cross sections for flight 3 at S2 on 8-31-95.

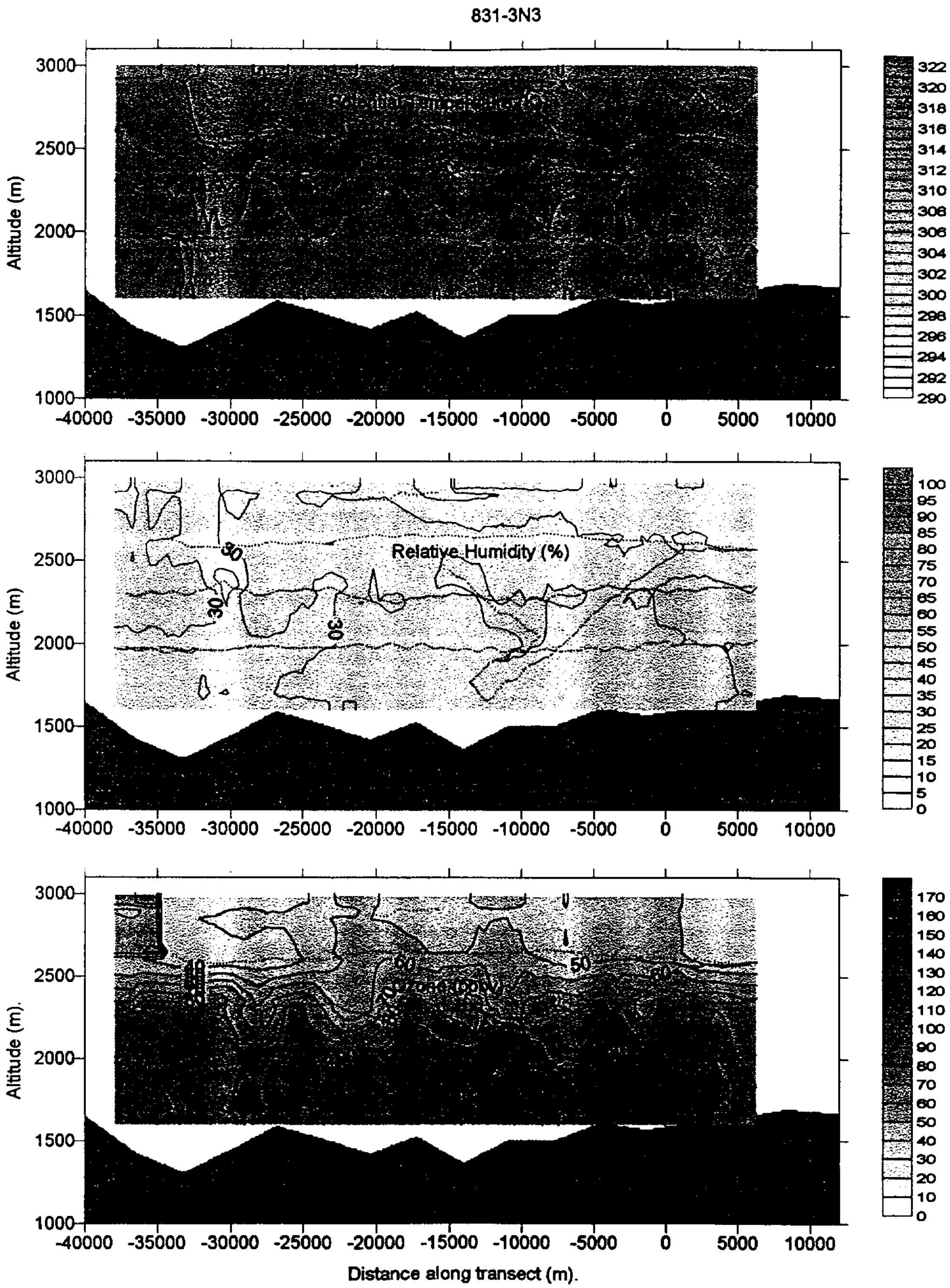


Figure A-7c: Vertical cross sections for flight 3 at S3 on 8-31-95.

831-3AV

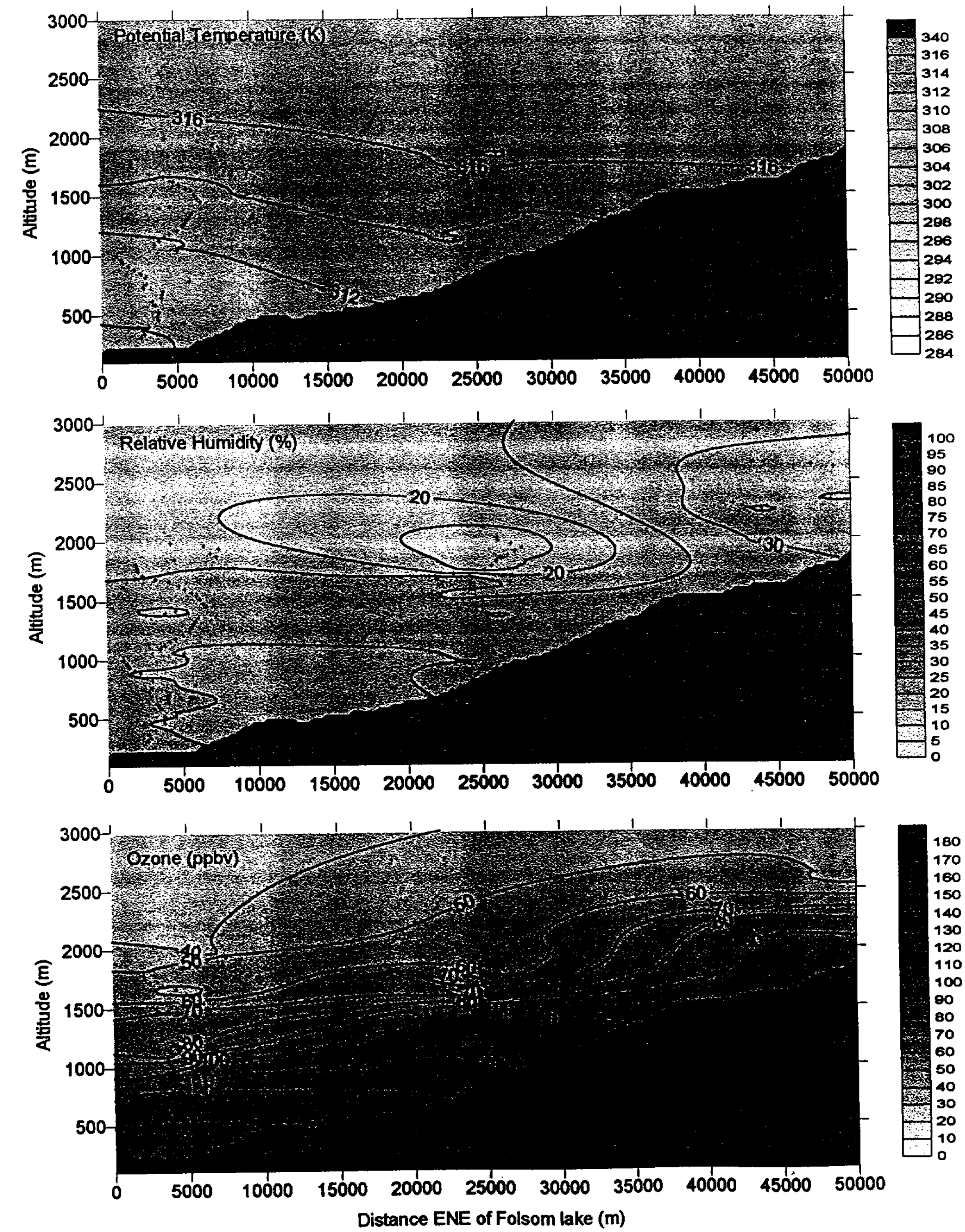


Figure A-7d: Vertical east-west cross sections for flight 3 on 8-31-95.

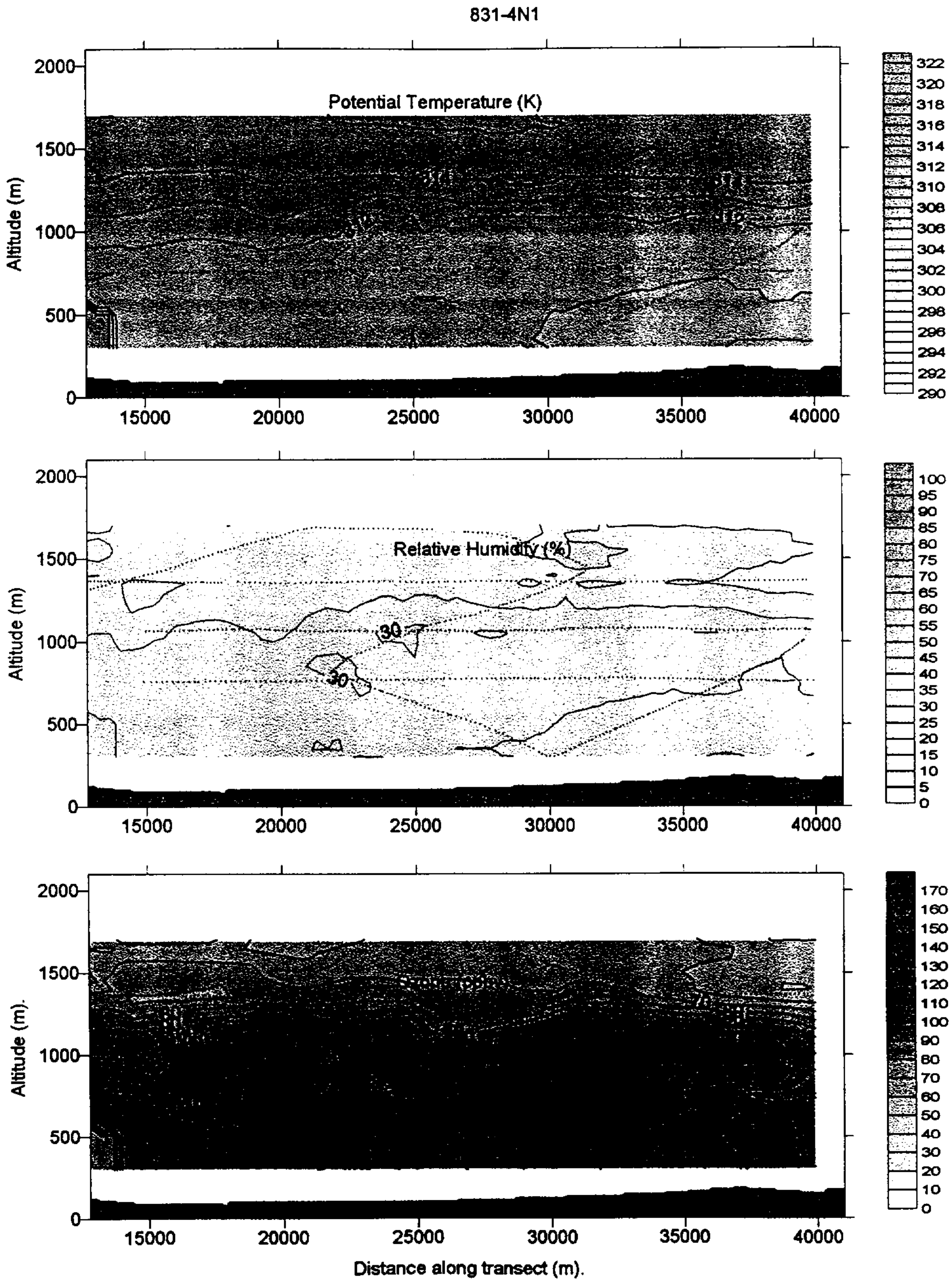


Figure A-8a: Vertical cross sections for flight 4 at S1 on 8-31-95.

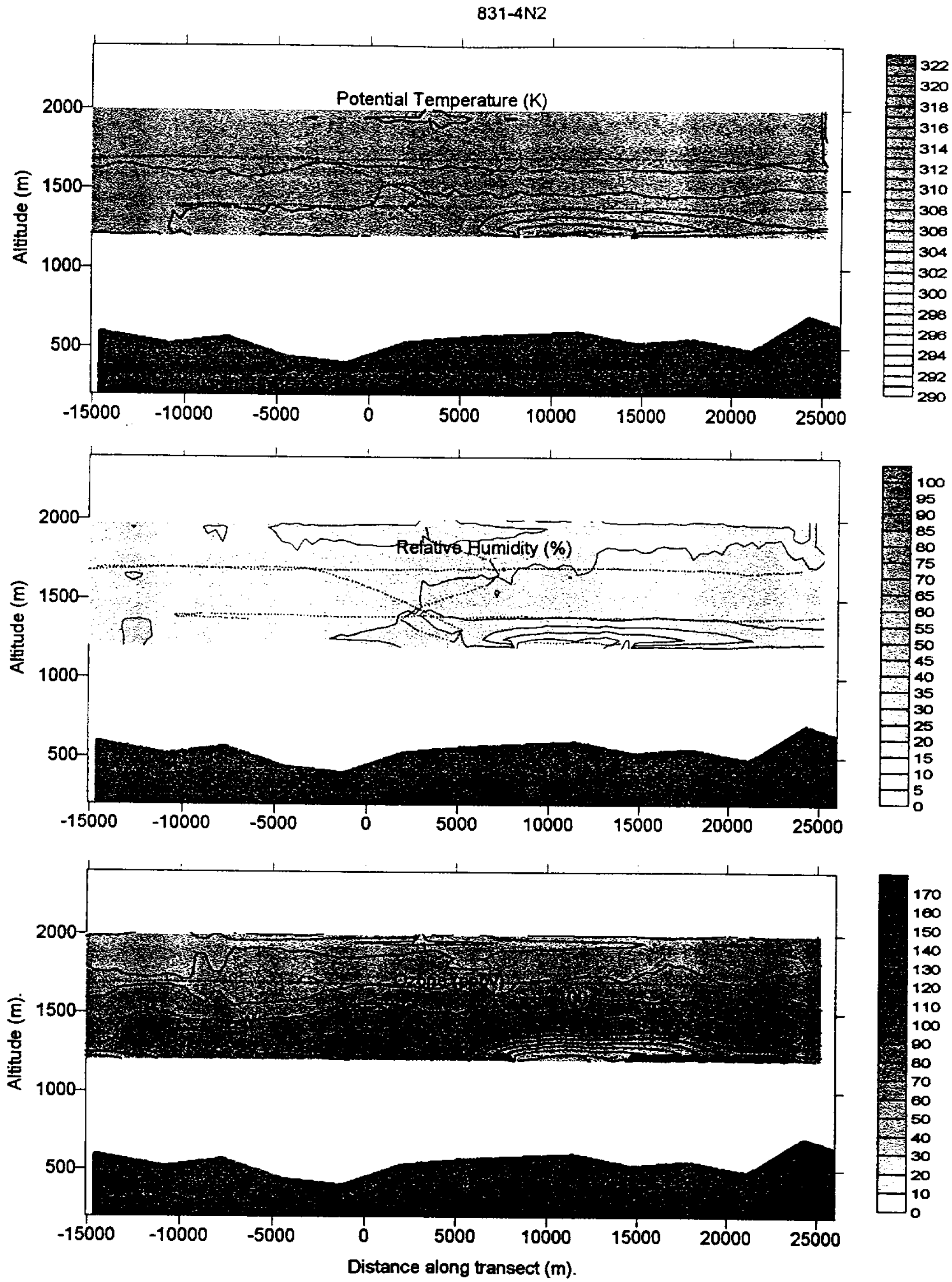


Figure A-8b: Vertical cross sections for flight 4 at S2 on 8-31-95.

APPENDIX B:
July 3, 1996 Sierra Nevada Transect Flights

I. Synoptic setting:

0400 PST (12Z): A moderately strong trough was approaching the coast, as evident on the 500 and 850 mb charts. Winds at 500 mb were from the south-southwest to southwest between 18 (OAK) and 27 (RNO) knots and from the west at 12 knots at 850 mb (OAK). By 1600 PST (00Z), the 500 mb trough was closer to the coast but still offshore with the 500 mb winds at RNO and OAK essentially unchanged from 12Z. At 850 mb, a small amplitude short wave trough was just off the coast with winds at OAK west-northwest at 13 knots. The conditions suggest weak, synoptic scale rising motion over the area.

II. Surface observations:

Data for McClellan (MCC) were only available after noon. The winds were from the south at 1300 PST then from the southwest from 1600 to 1800 PST then shifted slowly to southerly by 2100 PST. Speeds at MCC were between 5 and 10 Knots. High temperature at MCC was 35 C for the day. Data from Blue Canyon (BLU) were largely missing but for the mid afternoon, winds appear to have been from the southwest at 5 to 7 knots.

At the foothill sites, surface winds were from the southeast until mid morning, shifting to about south-southwesterly through the afternoon. Wind speeds varied among sites from light 2-4 knots at Placerville to 5 to 7 knots at Roseville. We believe the wind speed data from Rocklin are incorrect. High temperatures in the foothills were in the low to middle 30's (C). Except during the predawn hours and near 1700 PST, ozone concentrations were less than 50 ppbv.

III. Vertical Cross sections:

Flight 1: At S1, a very strong stable layer was found at 500 to 600 m, with moderately stable layers immediately above and below this layer. Humidity above the stable layer decreased to near zero. Ozone concentrations were less than 50 ppbv everywhere except for a thin layer at about 1200 m. At S2, the strong inversion was not seen but could have been present below the flight tracks. Relative humidity was low and fairly well mixed. Ozone however shows several pockets of high concentration (greater than 80 ppbv), including a thin layer at 1300 m with values reaching 90 ppbv. At S3, the atmosphere was near neutral and ozone was highly variable but with several pockets with concentrations greater than 90 ppbv. The east-west sections reinforce the perception that the previous day's pollution layer was at the higher elevations to the east. Similar patterns in relative humidity suggest these ozone concentrations were not the result of new photochemical activity as the day progressed.

Flight 2: At S1 the strong stable layer was still evident between 500 and 800 m, with low, fairly well mixed relative humidity and ozone fields. At S2, there was a moderately stable layer at 1500 m, which capped the higher values of relative humidity and ozone below. At S3 it appears that free convection was beginning to dominate the vertical structure. Deep vertical mixing and low ozone concentrations were also seen in the east-west section suggesting the "flushing" of pollutants out of the area.

Flight 3: The stable layer at S1 was nearly erased, but still trapped relative humidity and ozone below its base of about 800 m. At S2, the atmosphere was essentially neutral with well mixed relative humidity and the maximum ozone concentrations reached about 60 ppbv near the base of the sampled region. At S3, the atmosphere appears to have been in free convection: nearly isothermal potential temperature field, high spacial variability at small scales for the tracer variables (relative humidity and ozone). The east-west section shows the highest, but relatively moderate, concentrations over the easternmost area. Presumably, this was the result of the transport of well-mixed air plus chemical evolution.

Flight 4: At S1, the atmosphere was neutral up to about 1200 m (1000 m AGL) and was slightly stable above, but enough to keep the higher relative humidity values and ozone concentrations below 1200 m. Note that the higher concentrations of ozone (less than 70 ppbv) were at the lower altitudes and in the northern half of the sampled section. The conditions at S2 were very similar to those at S1, except that the mixed layer reached an altitude of about 1600 m (1000 m AGL)

IV. Synopsis:

The approach of the trough aloft probably was accompanied by large scale vertical lifting that acted to destabilize the lower atmosphere. The low inversion seen at S1 in flight 1 had the characteristics of a subsidence inversion (strong vertical gradient in potential temperature and very low relative humidity above). This layer dissipated during the day due to both the presumed lifting and surface heating. The relatively high ozone values seen aloft at S2 and S3 in the early morning were likely the remnants of the previous days mixed layer contaminants being advected to the northeast out of the area. In fact, as the day progressed, the concentrations decreased significantly aloft, indicating enhanced ventilation due to both moderate winds aloft and deep vertical mixing.

Table B-1

7-03-96
Averaged Aircraft Data

	Time (PST)	Location	Altitude (m MSL)	Direction	Speed (knots)	H_m (m MSL)	D_m (m AGL)
Flight 1	0500	S1	600	180	20	550	400
			1200	215	18		
	0600	S2	1500	195	21	760	210
	0700	S3	1800	20	23	< 1600	350
			2350	205	28		
Flight 2	1000	S1	600	205	16	490	340
			1350	210	17		
	1100	S2	1500	200	18		
	1200	S3	1900	205	20		
			2500	215	20		
Flight 3	1300	S1	600	205	16	670	520
			1200	215	17		
	1400	S2	1500	210	17	1220	670
	1500	S3	1900	225	20		
			2350	210	23		
Flight 4	1700	S1	750	215	19	1220	1070
			1400	210	14		
	1800	S2	1500	210	16	1675	1425

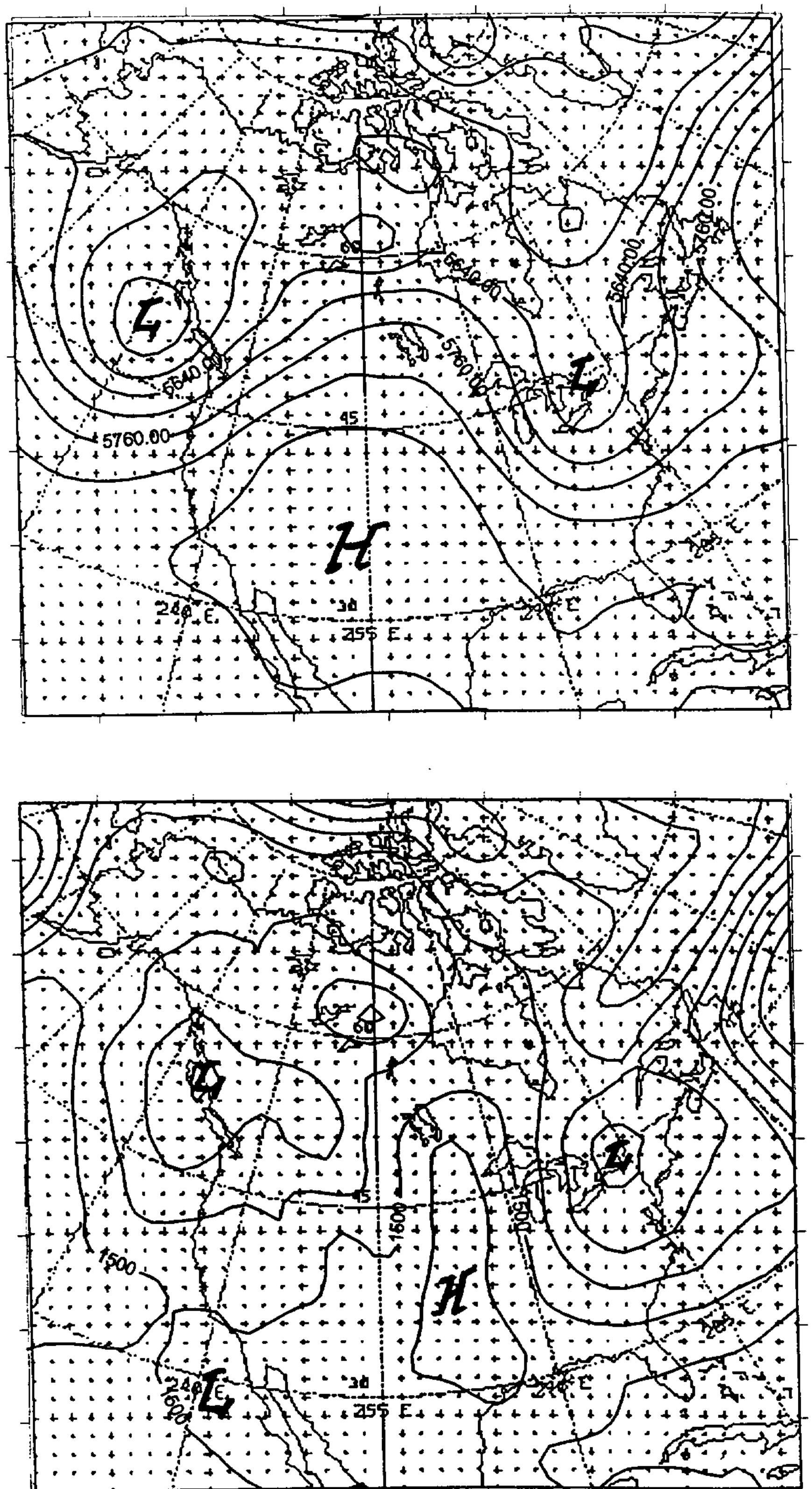


Figure B-1: 500 mb height field (upper) and 850 mb height field (lower) for 0400 PST 7-03-96 (12Z).

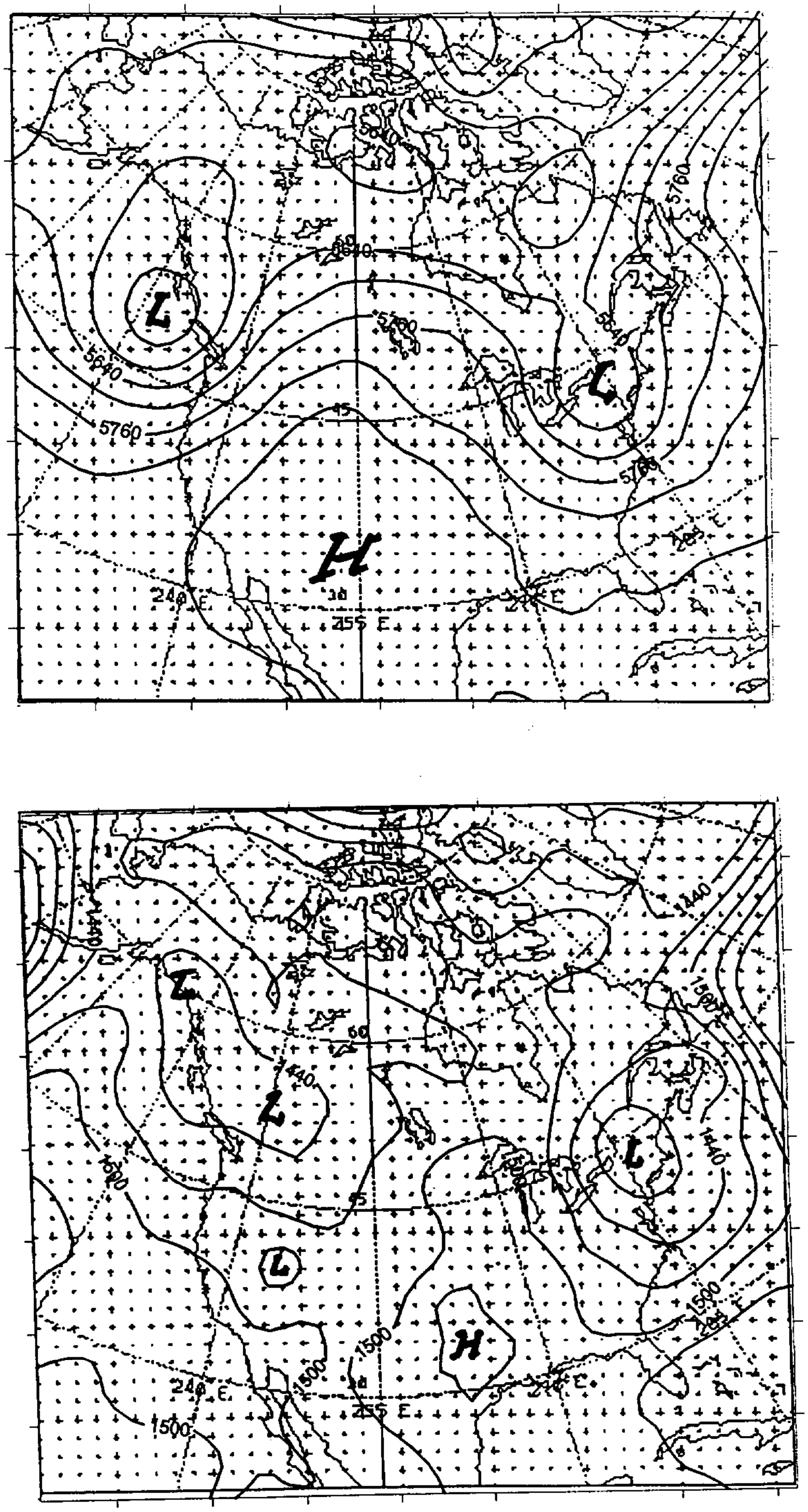
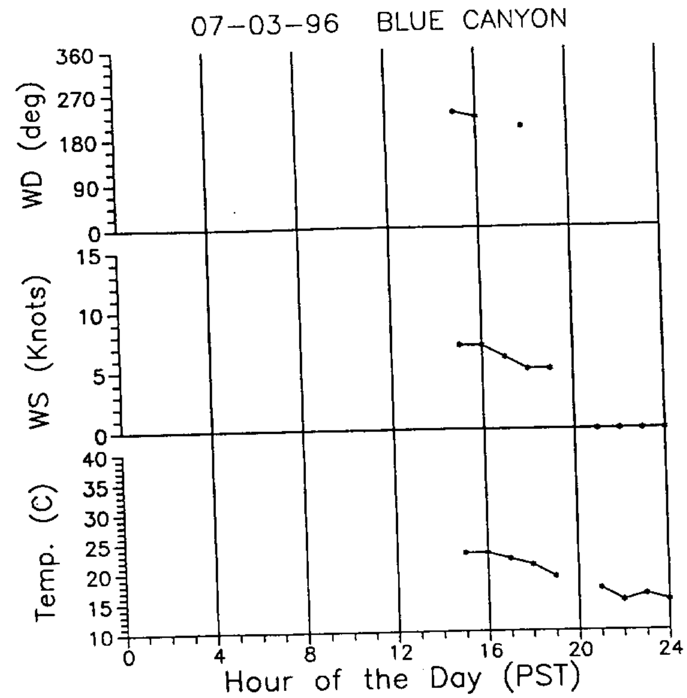


Figure B-2: 500 mb height field (upper) and 850 mb height field (lower) for 1600 PST 7-03-96 (00Z).



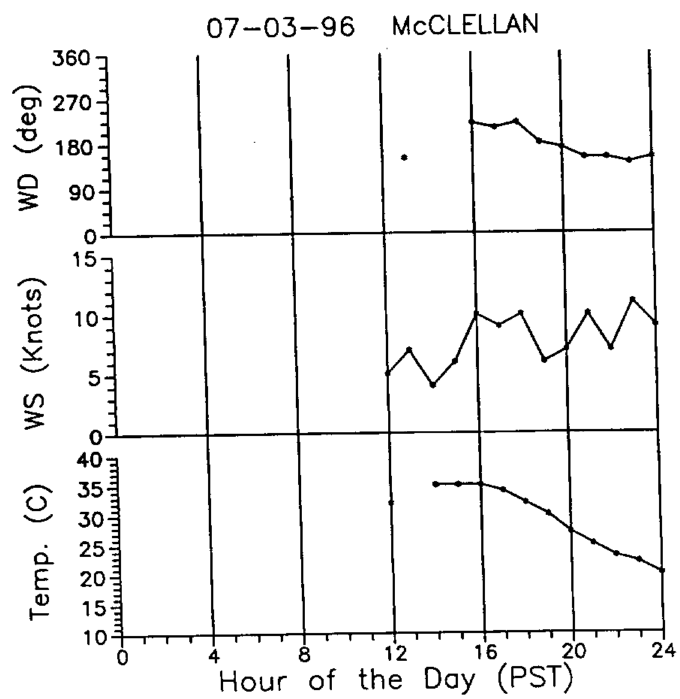


Figure B-3: Plot of wind and temperature data observed on the hour at Blue Canyon (upper) and McClellan (lower) on 7-03-96.

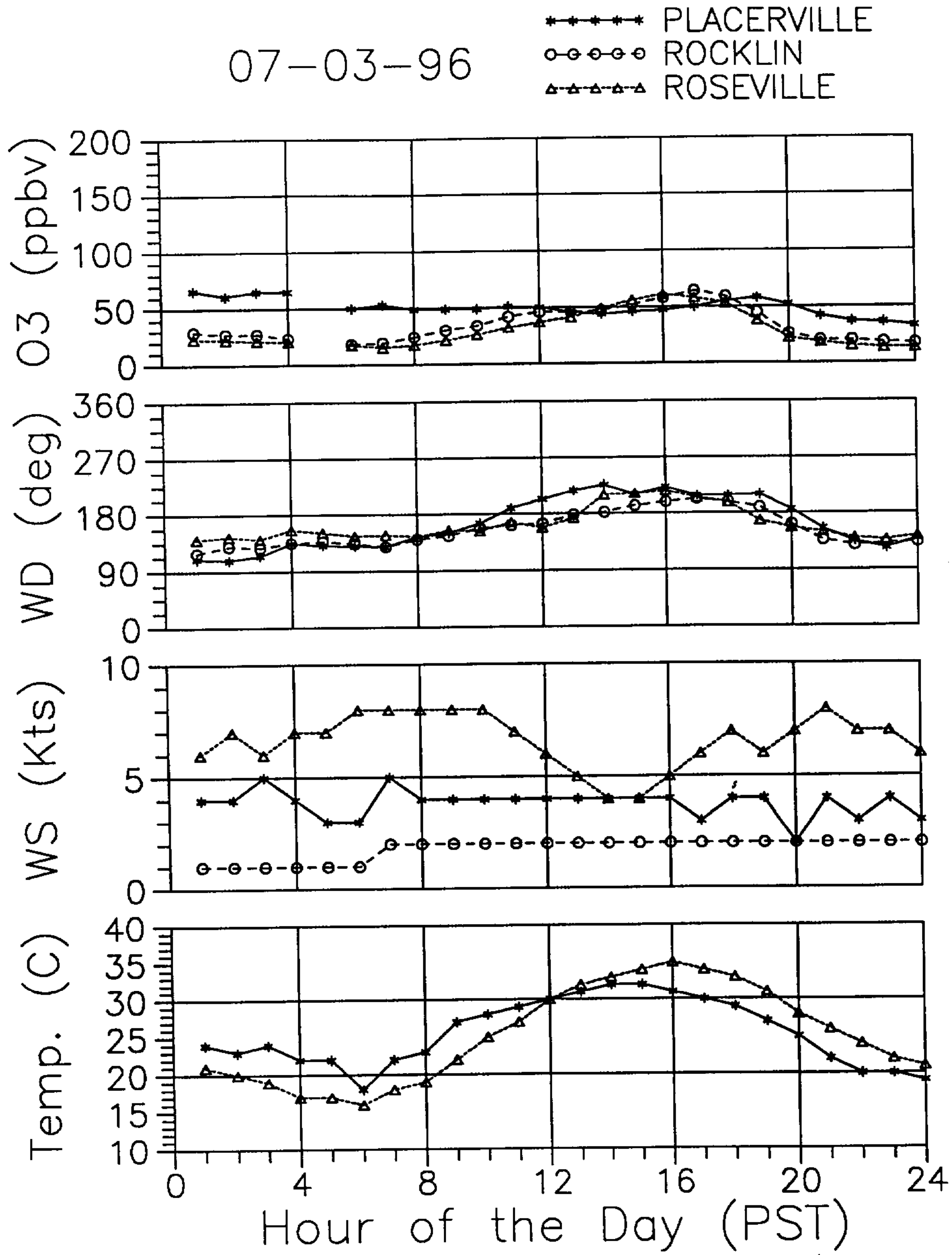
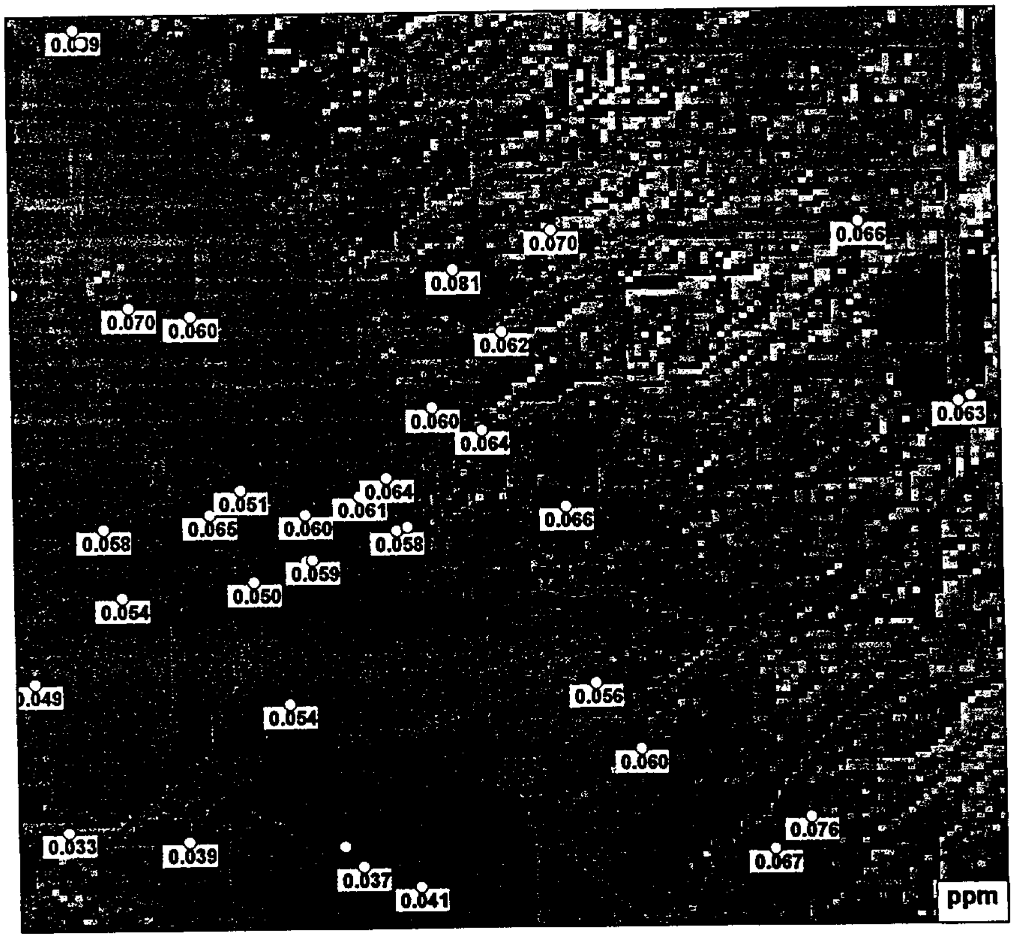


Figure B-4: Plot of hourly averaged data for the three foothill ground stations versus time of day (PST) for 7-03-96.

Figure B-5: Maximum hourly averaged ozone concentrations in central California on 7-03-96.



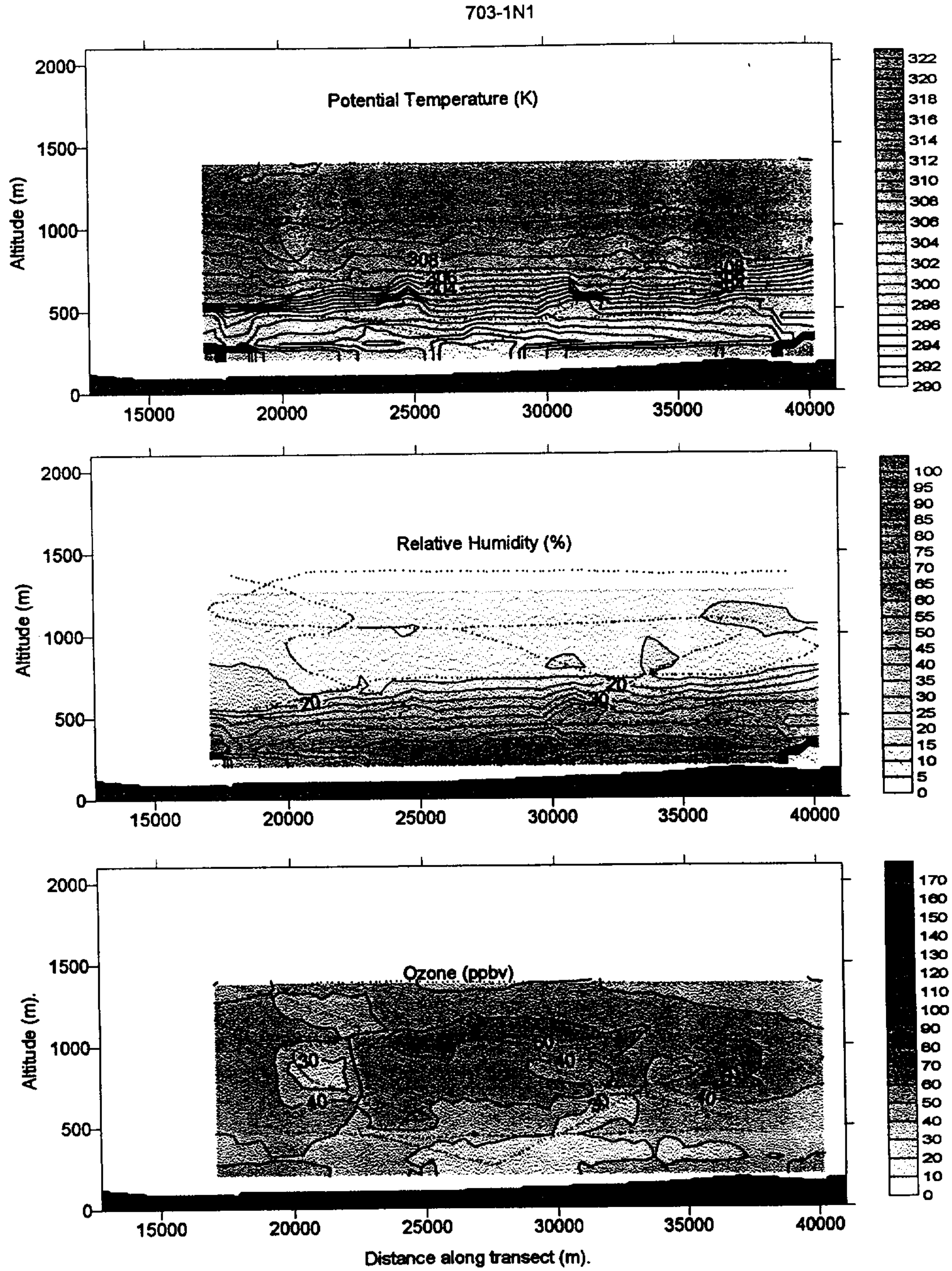


Figure B-6a: Vertical cross sections for flight 1 at S1 on 7-03-96.

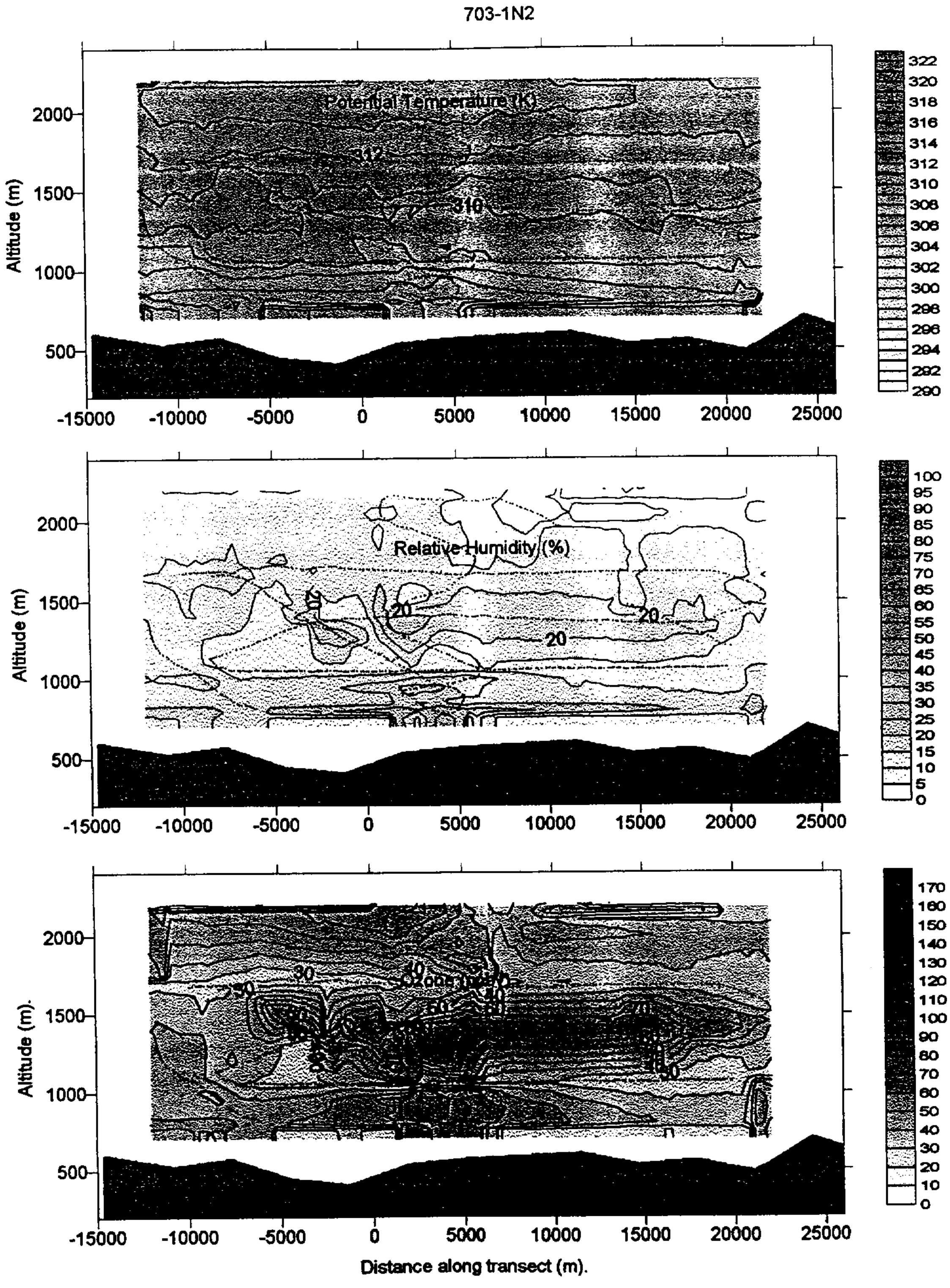


Figure B-6b: Vertical cross sections for flight 1 at S2 on 7-03-96.

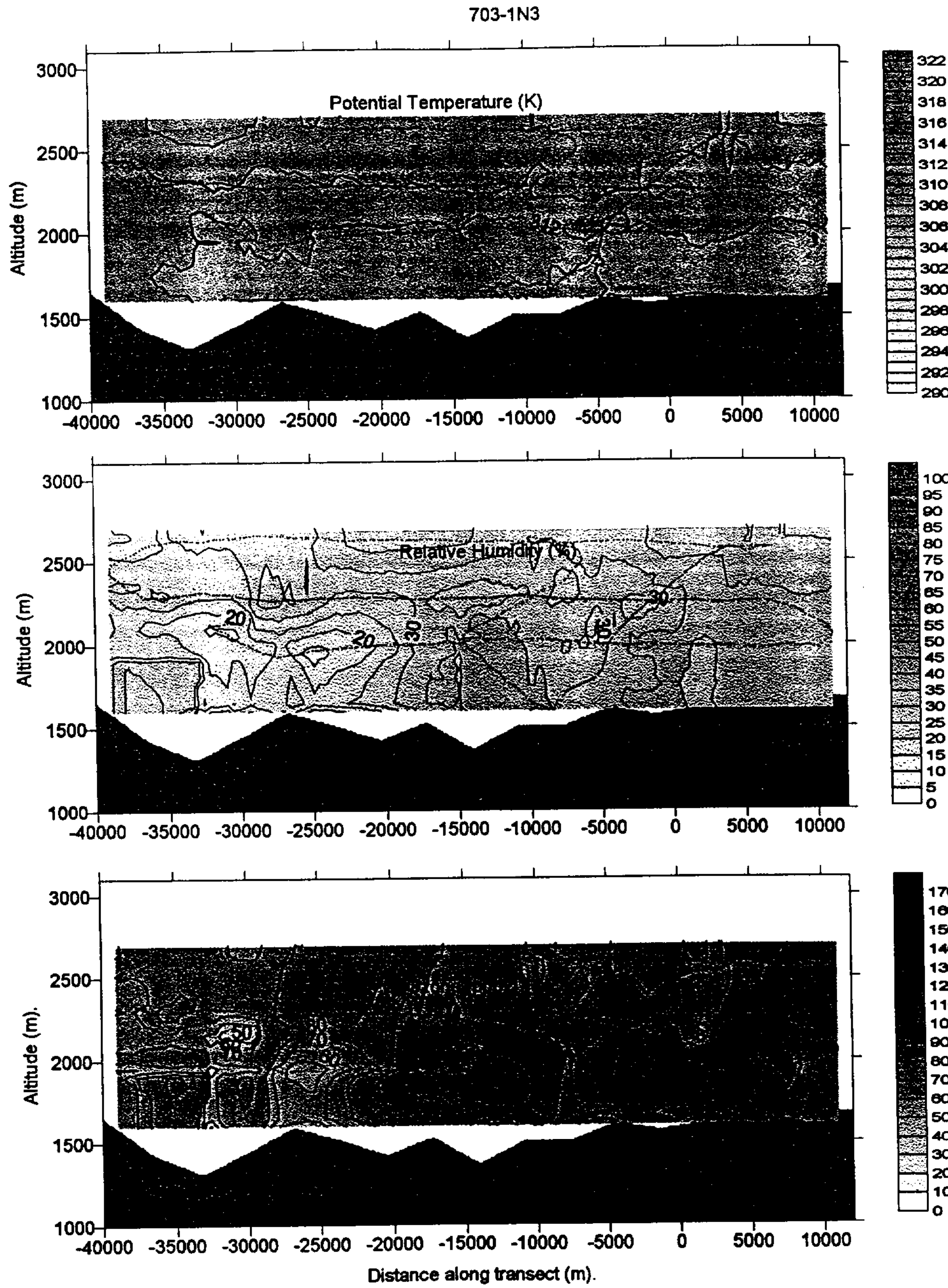


Figure B-6c: Vertical cross sections for flight 1 at S3 on 7-03-96.

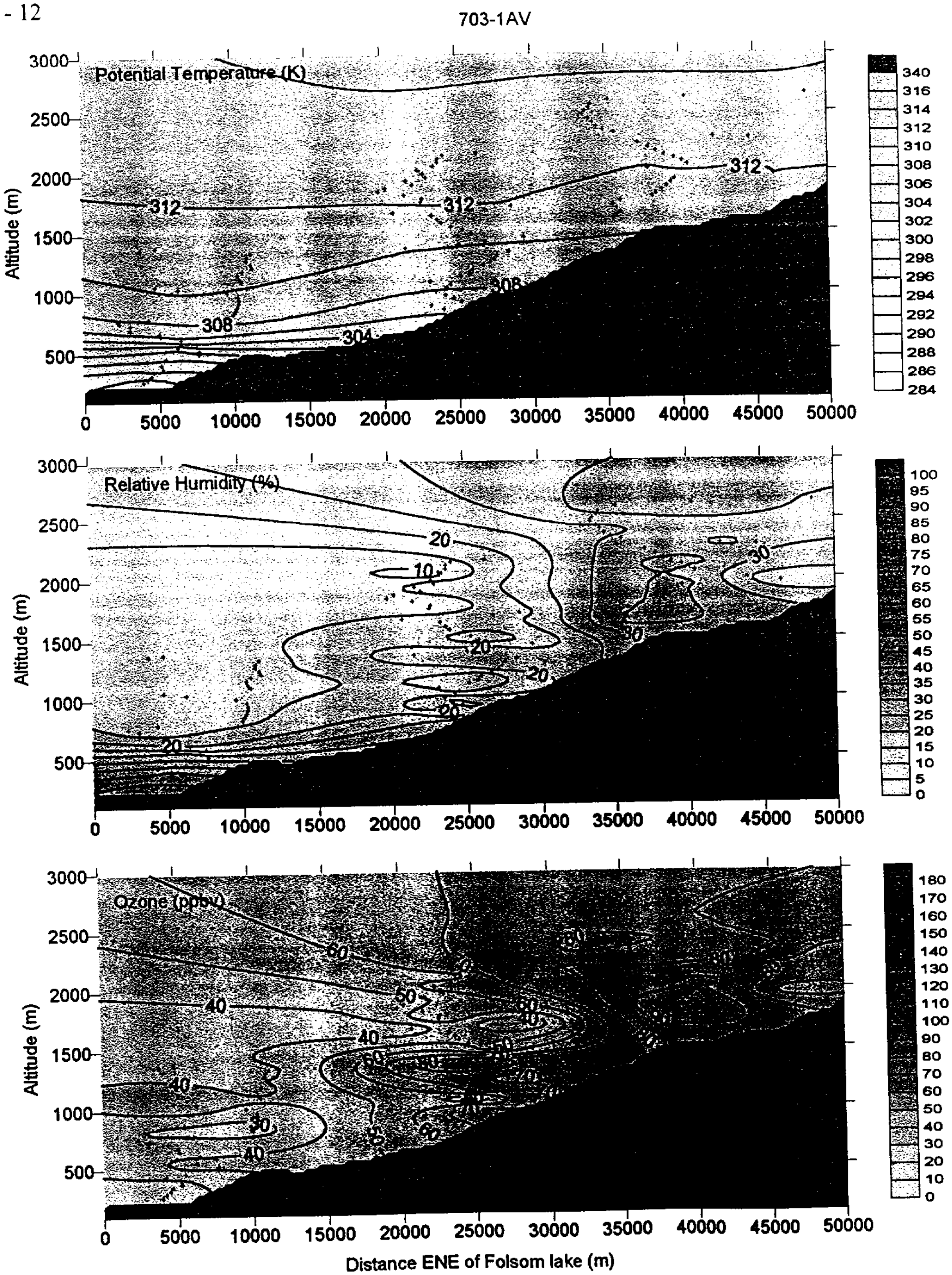


Figure B-6d: Vertical east-west cross sections for flight 1 on 7-03-96.

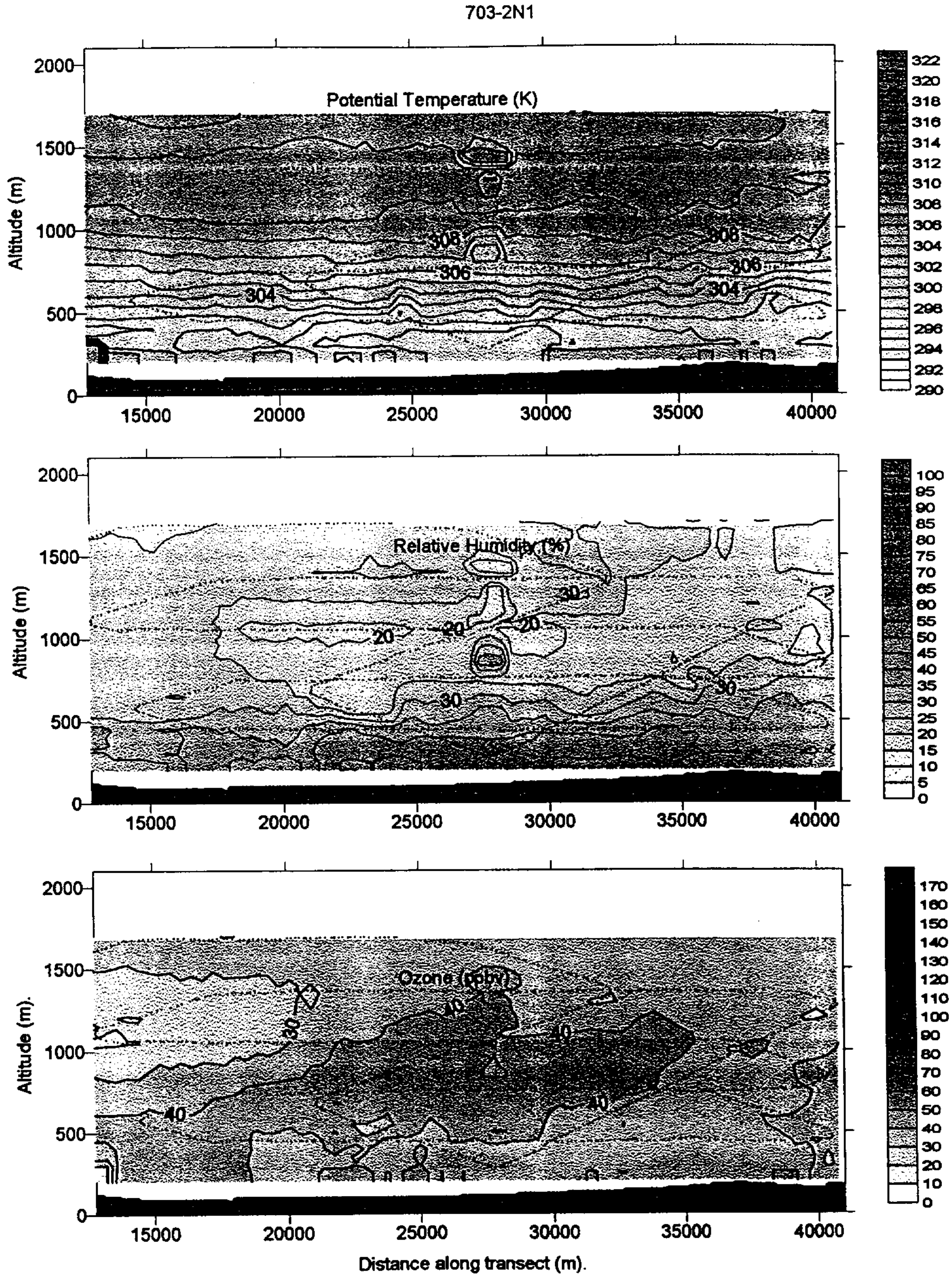


Figure B-7a: Vertical cross sections for flight 2 at S1 on 7-03-96.

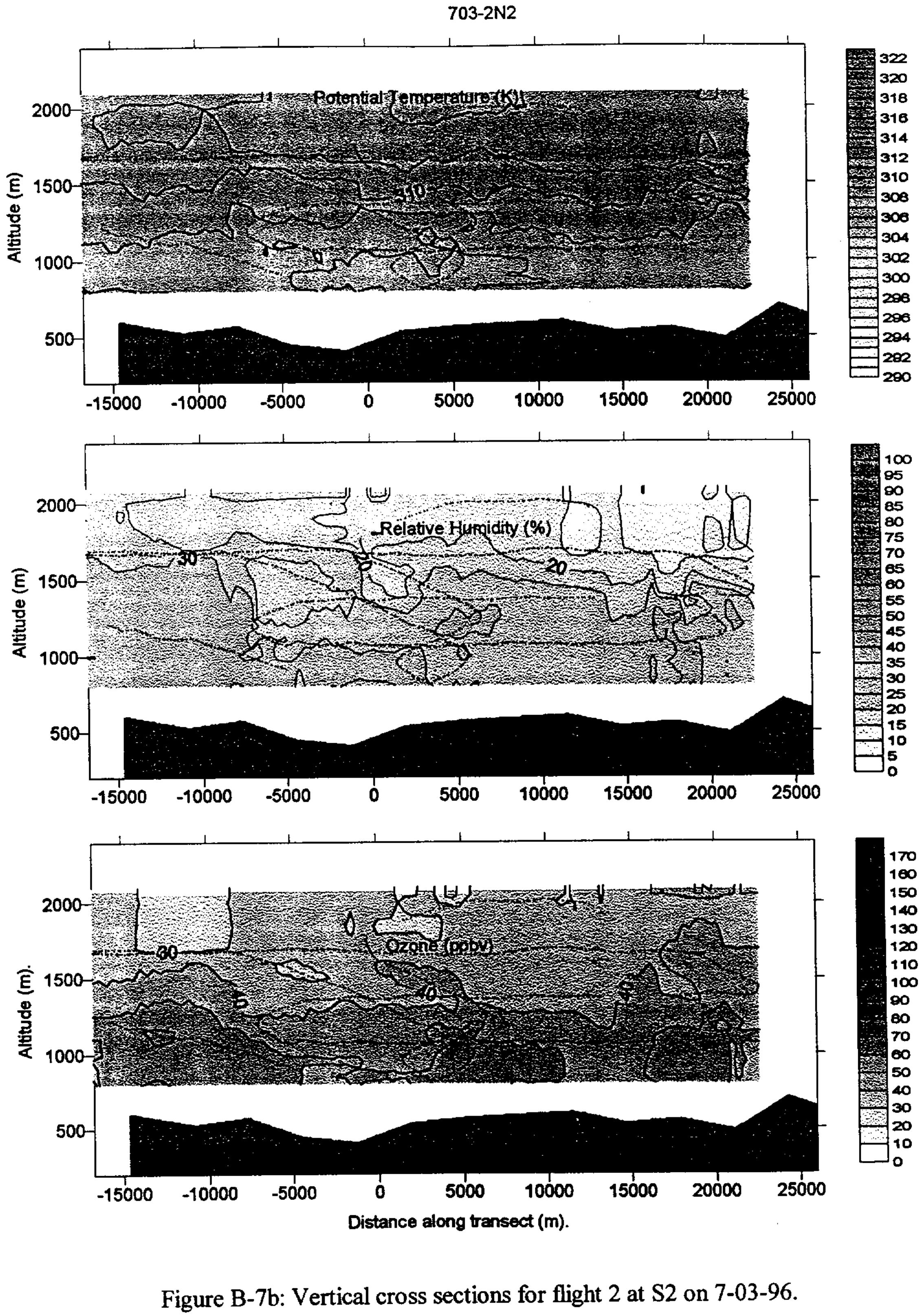


Figure B-7b: Vertical cross sections for flight 2 at S2 on 7-03-96.

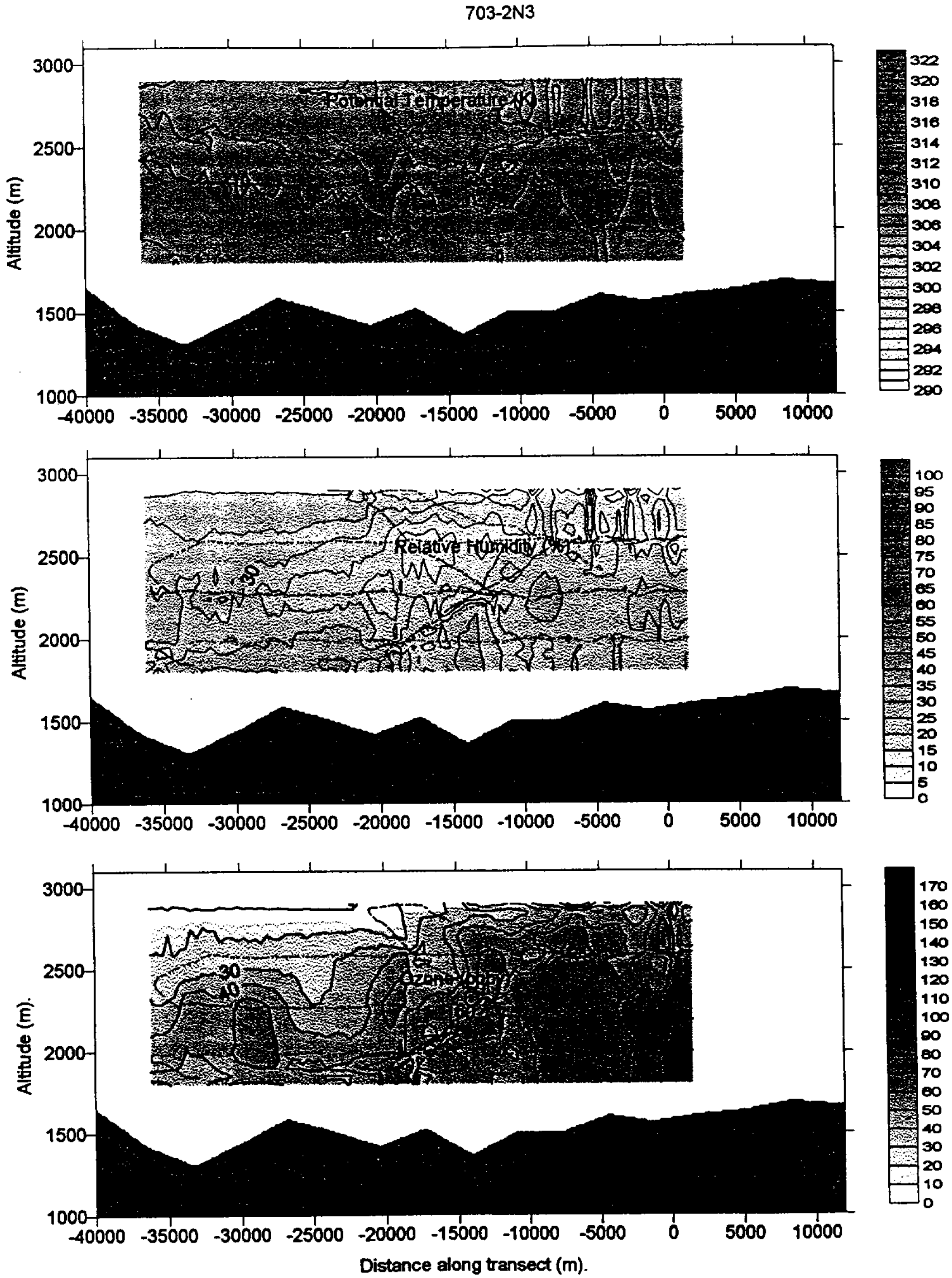


Figure B-7c: Vertical cross sections for flight 2 at S3 on 7-03-96.

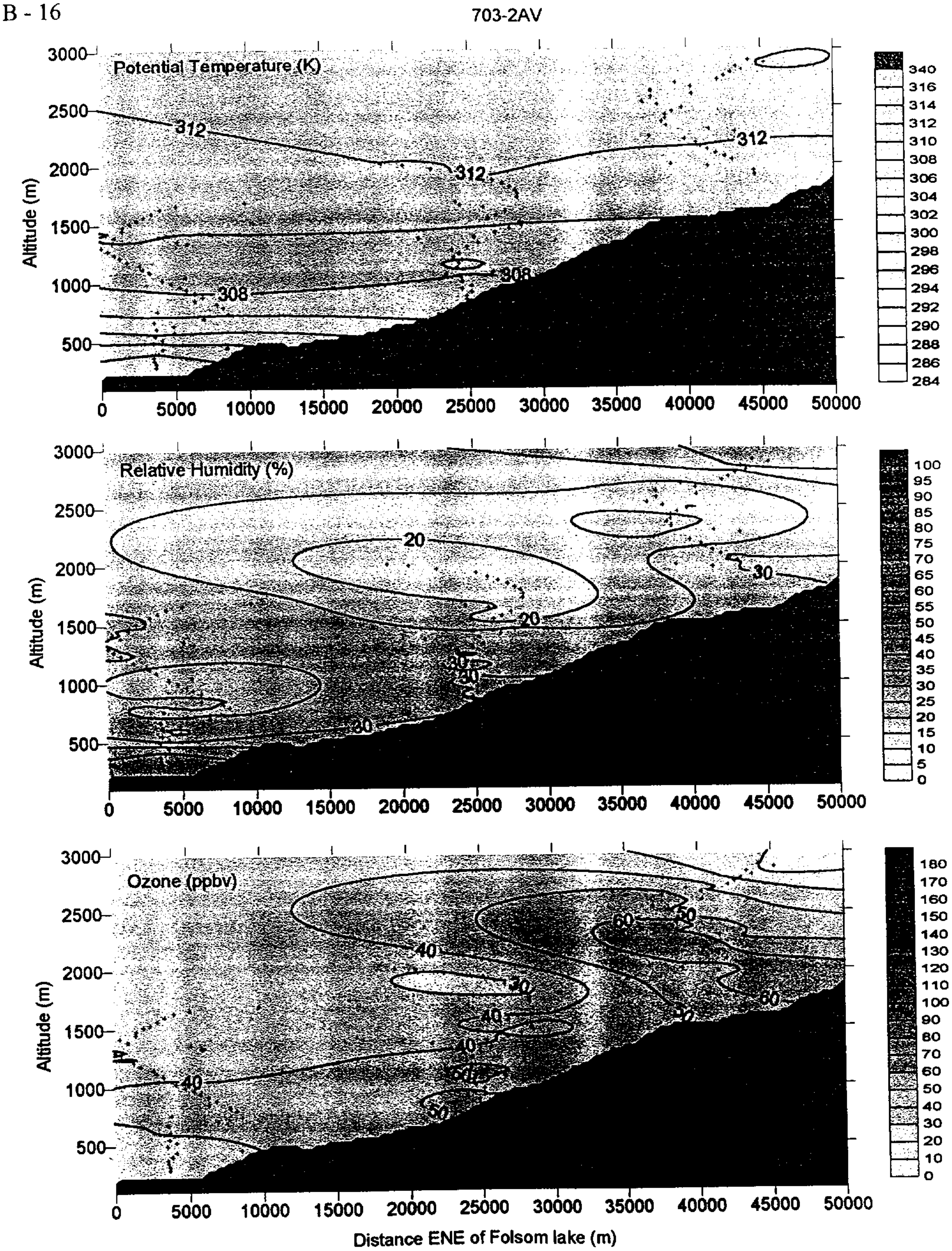


Figure B-7d: Vertical east-west cross sections for flight 2 on 7-03-96.

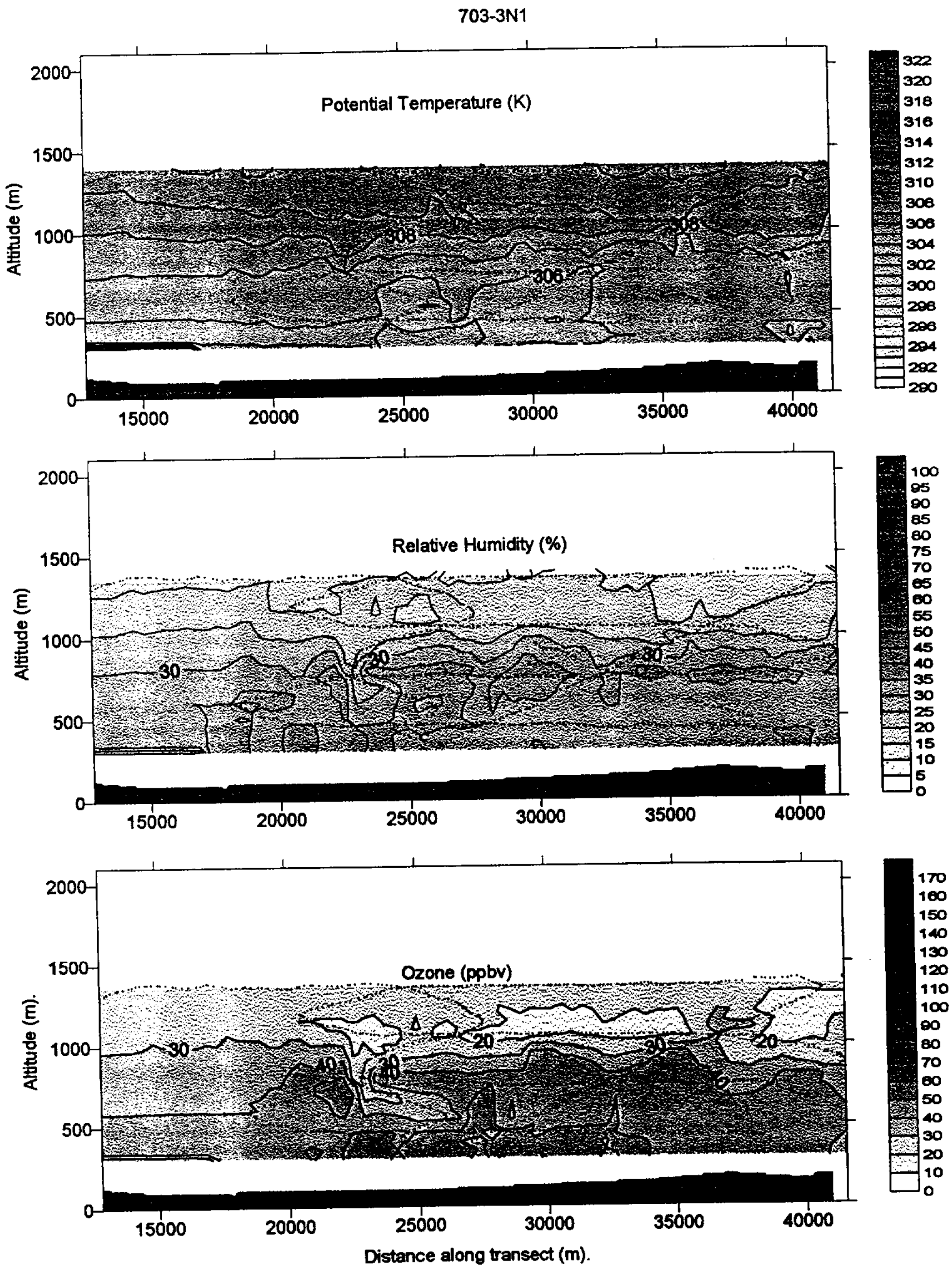


Figure B-8a: Vertical cross sections for flight 3 at S1 on 7-03-96.

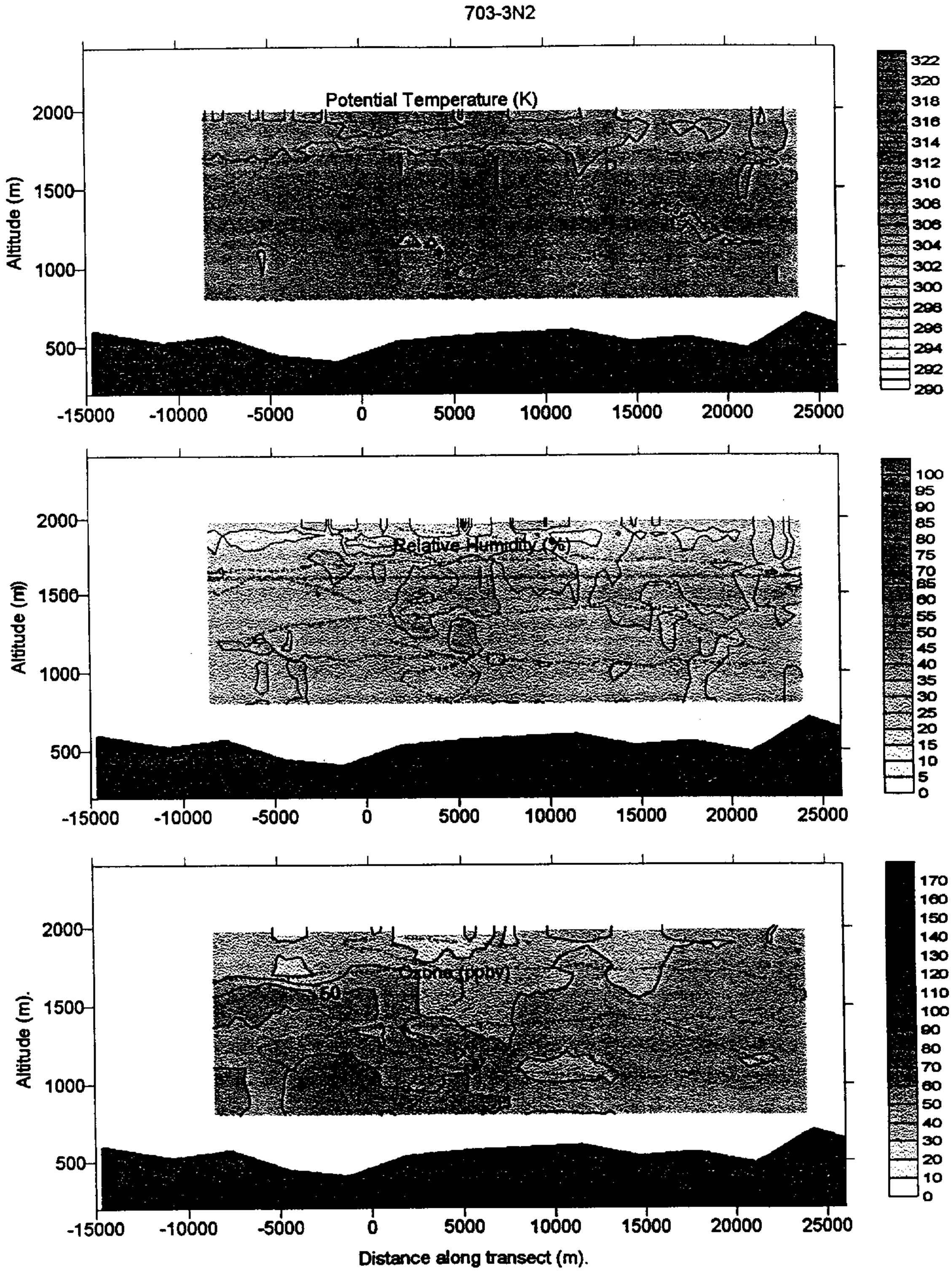


Figure B-8b: Vertical cross sections for flight 3 at S2 on 7-03-96.

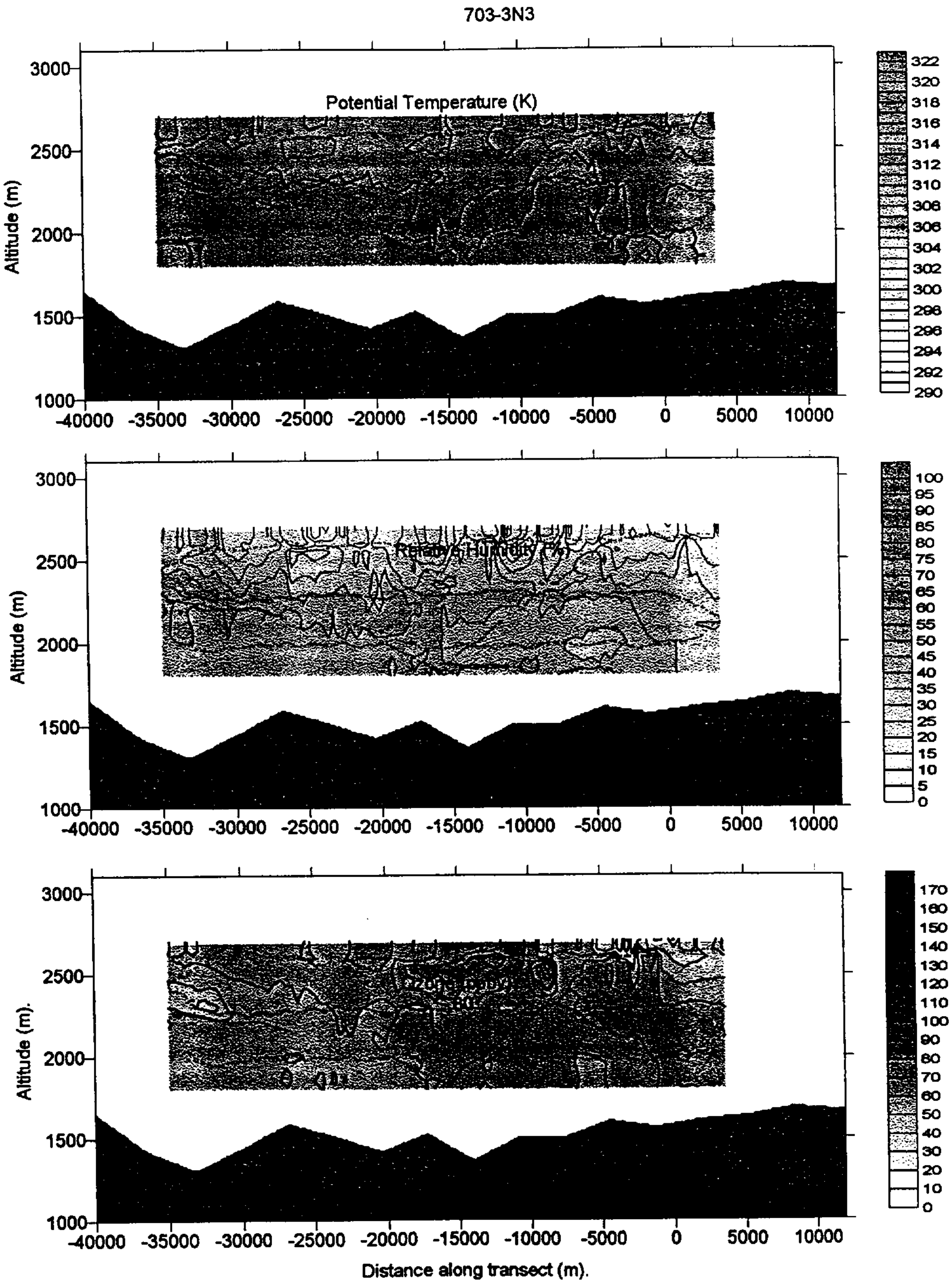


Figure B-8c: Vertical cross sections for flight 3 at S3 on 7-03-96.

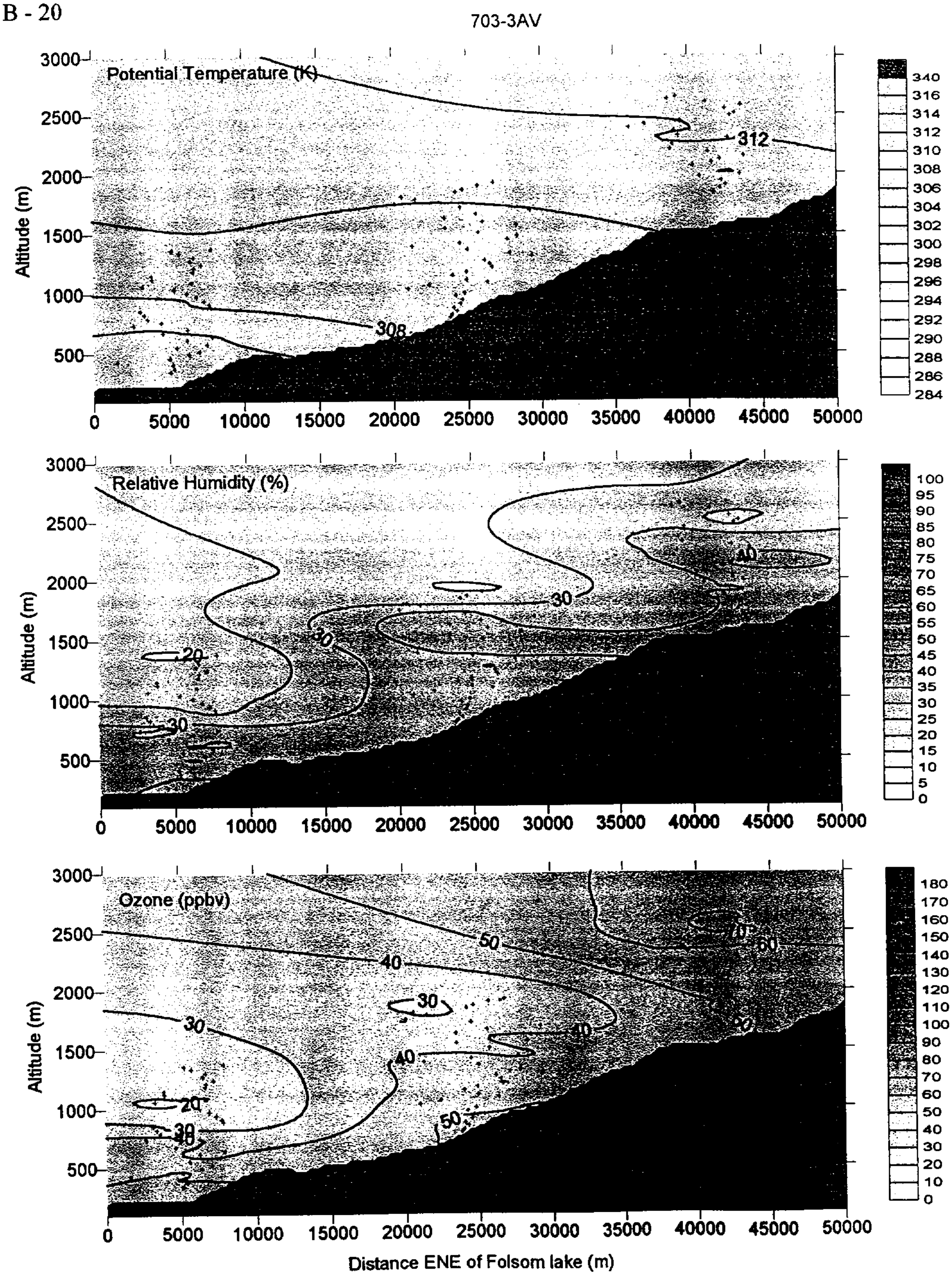


Figure B-8d: Vertical east-west cross sections for flight 3 on 7-03-96.

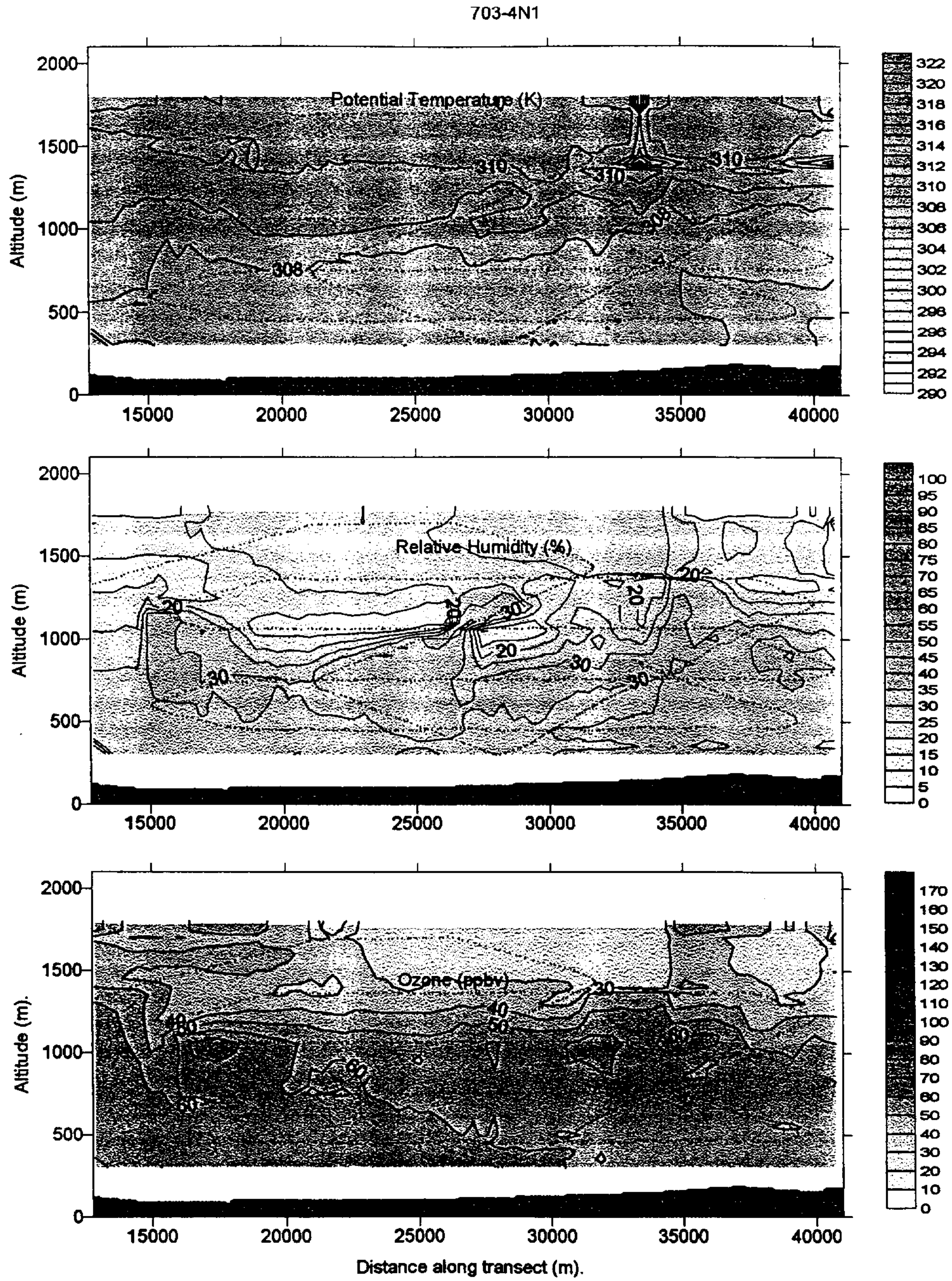


Figure B-9a: Vertical cross sections for flight 4 at S1 on 7-03-96.

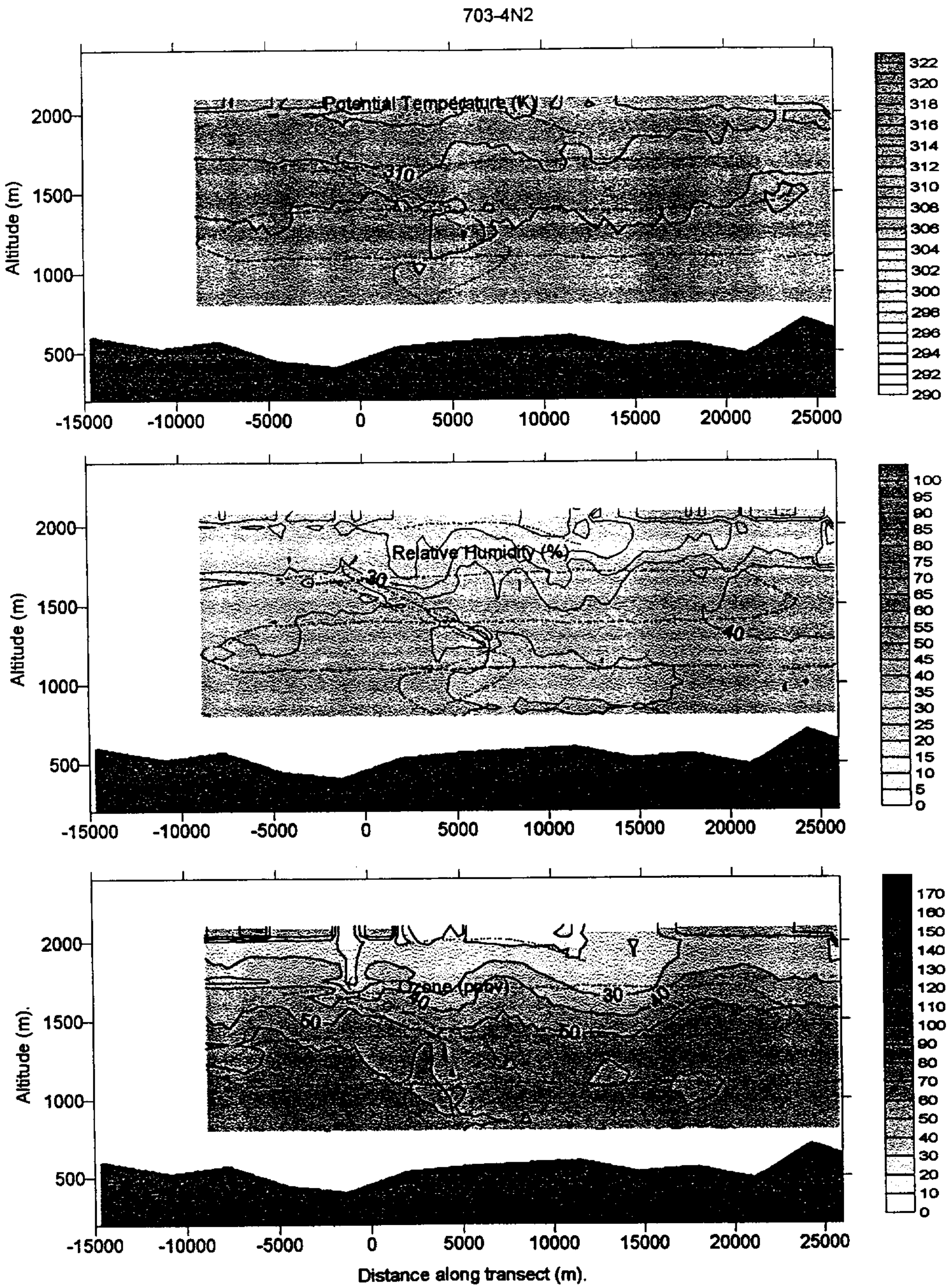


Figure B-9b: Vertical cross sections for flight 4 at S2 on 7-03-96.

APPENDIX C:
July 18, 1996 Sierra Nevada Transect Flights

I. Synoptic setting:

At 0400 PST (12Z), a well developed, 500 mb trough was located off the California coast (~125 west longitude) with a strong height gradient over the sampling area. Winds at 500 mb were from the west-southwest at 40 knots. At 4267 m (14,000 ft or 600 mb), winds over the sampling area were west-southwesterly at 30 knots. At 850 mb, the height field was flat over the area with northwesterly winds at 20 knots over San Francisco and calm over Reno. At the surface, a weak cold front had just passed through the sample area.

At 1600 PST (00Z), the main 500 mb trough was still off the coast with a short wave trough approaching the sample area. Winds aloft were still west-southwesterly but about 10 knots slower. At 850 mb, there was a hyperbolic point over the Sacramento Valley with winds from the west or west-northwest (10-20 knots). At the surface, a cold front moved to the southeast, high pressure built off the coast producing a moderately strong west to east pressure gradient force. Surface winds were between westerly and northwesterly at about 10 knots in the region.

These conditions should produce low altitude transport of emissions from Sacramento to the sample area with speeds about 10 to 20 knots, depending on altitude. The strong troughing should also induce large scale upward motion throughout the region, producing near neutral stability in the lower layers and deep mixing depths. I.e. this should be a low pollution day in the sample area.

II. Surface observations:

The winds in Sacramento (MCC) were from the southwest until about 1000 PST then westerly to northwesterly to north at 5 to 10 knots to 2000 PST. After 2000 PST, the winds were light and southerly. At Blue Canyon, the limited data available show winds from the southwest (230 at 8 knots) during the daytime shifting to weak easterly at 2100 PST. At Placerville, the winds were light and from the north-northeast until about 0700 PST shifting to light westerlies at 1000 PST. After 2000 PST, the winds shifted to the east and northeast and were light. At Rocklin and Roseville, the winds prior to 0800 PST were from the southeast at 5 knots and were similar to Placerville the rest of the day.

These wind data indicate that near ground flow would only act to transport Sacramento emissions to the southern side of the sample area and only between 1000 and 1900 PST. At the high altitude side of the sample area, upslope flows of about 8 knots were present during the daylight hours, indicating that it was likely that trajectories from Sacramento should have been at least partially within the sample area.

Surface ozone concentrations were low, peaking at 50 to 55 ppbv between 1200 and 2000 PST. The maximum value among the three sites (~55 ppbv) was at Placerville at 1600 PST, i.e. on the southern side of the sample area.

III. Vertical Cross sections:

The early morning flight (1) found weak stable layers at 500 and 1000 m over Folsom Lake (S1) as seen in both the potential temperature fields and the relative humidity distribution: i.e. high relative humidity for altitudes less than 500 m, moderate relative humidity for altitudes between 500 and 1000 m and very dry above 1000 m. Relatively low ozone concentrations were seen, with an isolated maximum of 80 ppbv within the upper stable layer. At S2, the upper stable layer (302 - 306 isotherms) was found at about the same altitude with similar relative humidity distributions to the data along S1. Note that significant portions of the upper horizontal transects are missing so that the contours in the upper portions of left side of the figures are not reliable. A low altitude ozone maximum (70 ppbv) was found near the northwest end of the lower traverse.

At S3, the atmosphere was near neutral except for a shallow layer of increased static stability between 2300 and 2500 meters. The effect of this capping layer is clearly seen in the relative humidity plot. A small pocket of high ozone (60 - 80 ppbv) was found at the altitude of this layer near the northwest end of the traverses. The east-west section shows the low, mixed layer depth, intersecting the slope at about 900 m elevation. A second limiting layer appears to be at about 2500 m (cf. relative humidity plot).

For flight 2, S1, the atmosphere was near neutral below about 700 m and above about 1400 meters, with a pair of more stable layers in between. In the regions of good data coverage, the relative humidity and ozone were well mixed below 700 m and above 1400 m. Highest ozone concentrations (50 - 60 ppbv) were within the layer of increased stability. At S2, the significant features were very similar, except for more pronounced, small scale local maxima and minima. At S3, the aircraft data show a very high degree of spatial variability at small scales. The in-flight voice logs contain frequent comments about rough air and turbulence. These observations indicate quite active thermal activity with the aircraft slicing through well developed, deep up and down drafts that effectively mix material vertically but produce the spotty patterns seen in these plots for relative humidity and ozone. The east-west section shows the apparent migration of the upper level maximum seen over Folsom in flight 1 to the S3 area. At S3, the shallow mixed layer capped at about 2300 m was still seen.

For flight 3, the same conditions and effects were seen as for flight 2. The effect of the up and down drafts can also be seen in the wave-like path of the aircraft at S2 and S3. For flight 4, the efficient mixing was again evident with the highest concentrations of ozone being found aloft, below or within a layer of increased static stability. In the east-west section, the continued mixed-layer deepening is seen in the stair-step patterns for both relative humidity and ozone.

Note that the ozone concentrations measured by the aircraft at low altitude agree well with the hourly averaged concentrations measured at the ground stations.

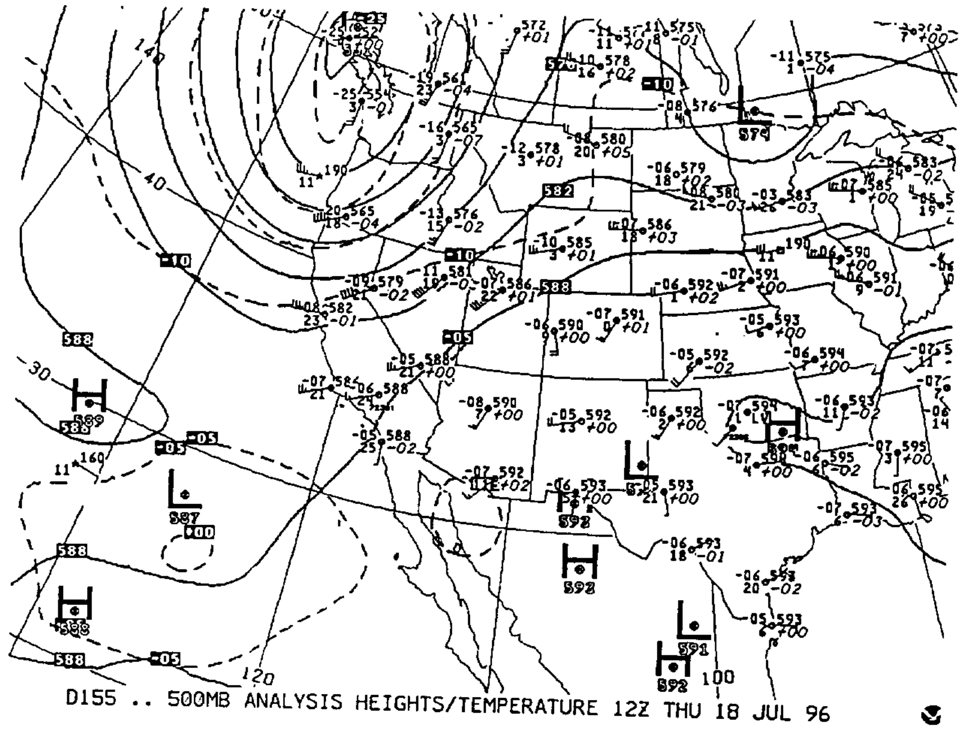
IV. Synopsis:

While the general flow pattern was favorable for transport of Sacramento emissions to the sample area, the weak static stability over the area allowed for efficient deep mixing of these effluents. This coupled with the moderate wind speeds prevented the buildup of high ozone concentrations near the ground. The highest concentrations of ozone found were just below or within elevated layers of enhanced stability and were below the state ambient standard. We infer that synoptic scale lifting induced by the 500 mb trough west of the sample area was responsible for the weak stratification seen. The strong ventilation must also have been present during the time preceding our operations as no significant ozone was present aloft in the early morning hours, further reducing the likelihood of formation of high ozone amounts during the sampled day.

Table C-1

7-18-96
Averaged Aircraft Data

	Time (PST)	Location	Altitude (m MSL)	Direction	Speed (knots)	H_m (m MSL)	D_m (m AGL)
Flight 1	0500	S1	600	200	20	490	340
			1350	220	30		
	0600	S2	1500	135	16	1035	485
	0700	S3	1850	200	27	2200	950
			2500	215	26		
Flight 2	1000	S1	650	210	14	975	825
			1400	200	16		
	1100	S2	1500	200	16	1400	850
	1200	S3	1850	215	16	2285	1035
			2500	215	20		
Flight 3	1300	S1	600	220	16	1400	1250
			1450	215	17		
	1400	S2	1500	200	17	1830	1280
	1500	S3	1900	230	16	2500	1250
			2400	220	18		
Flight 4	1700	S1	750	230	16	1340	1190
			1600	210	14		
	1800	S2	1500	200	16	1675	1125



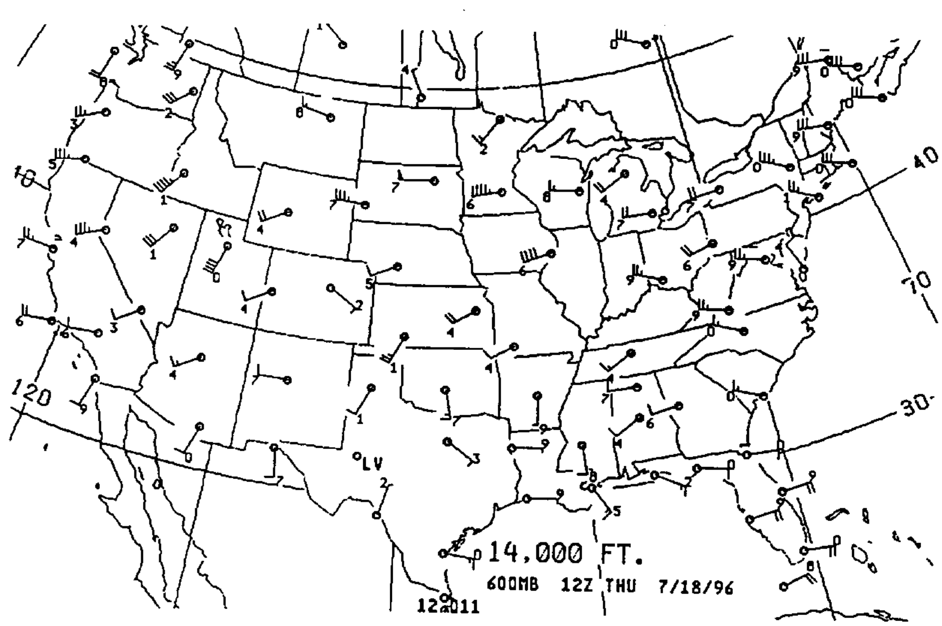
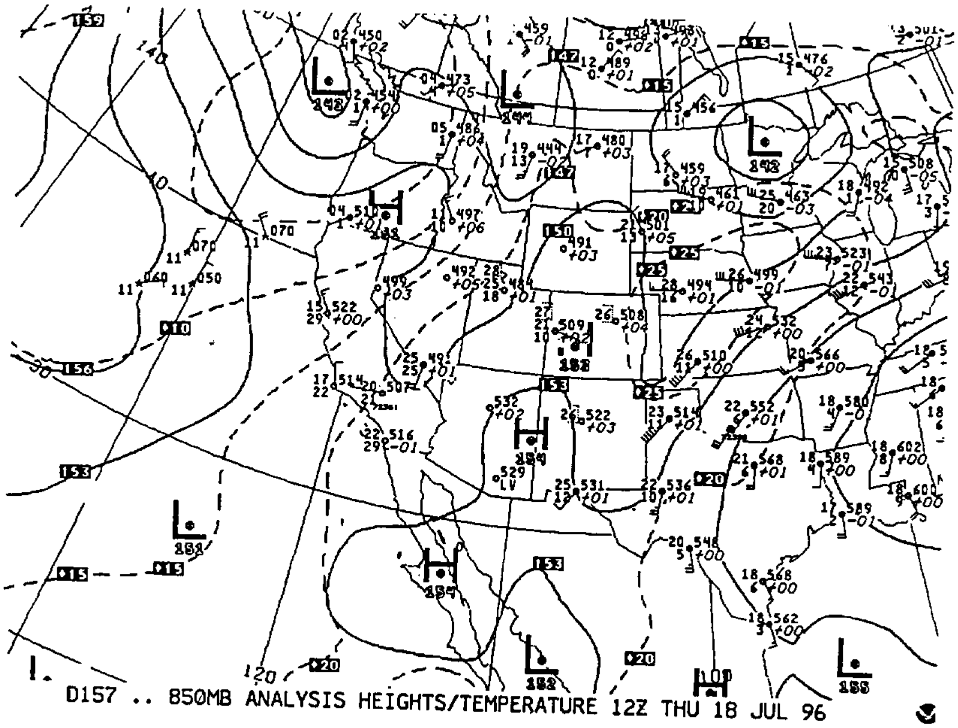


Figure C-1a: 500 mb height field for (upper) and 600 mb winds aloft analysis (lower) for 0400 PST 7-18-96 (12Z).



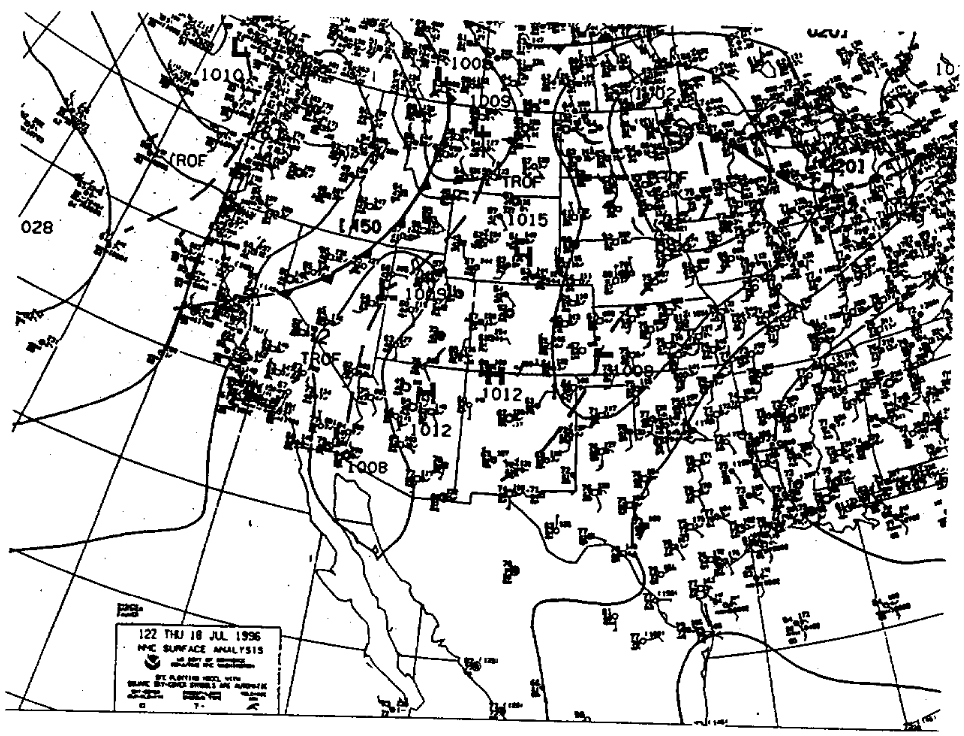
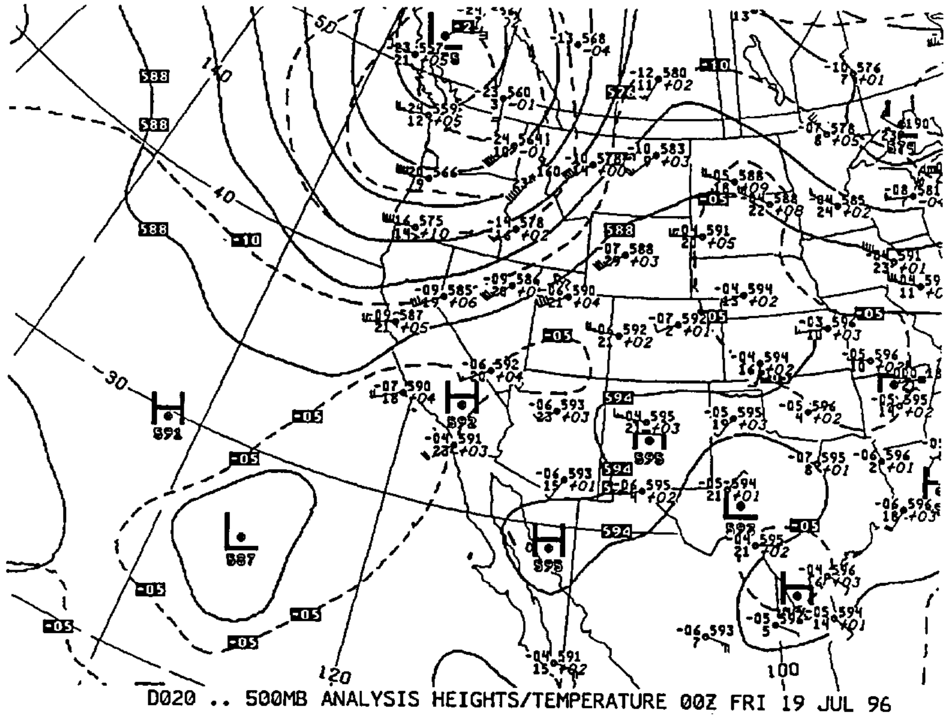


Figure C-1b: 850 mb height field (upper) and surface analysis map (lower) for 0400 PST 7-18-96 (12Z).



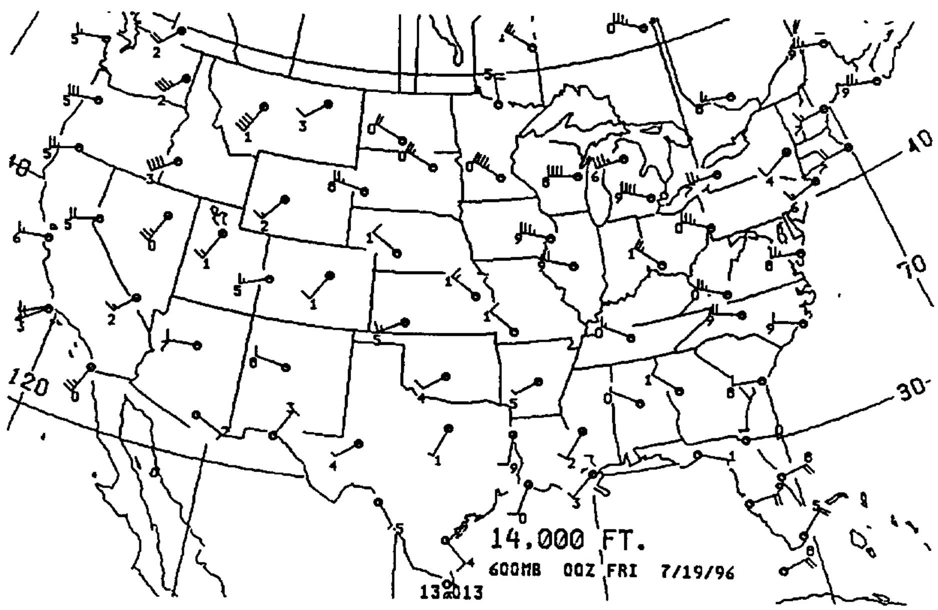
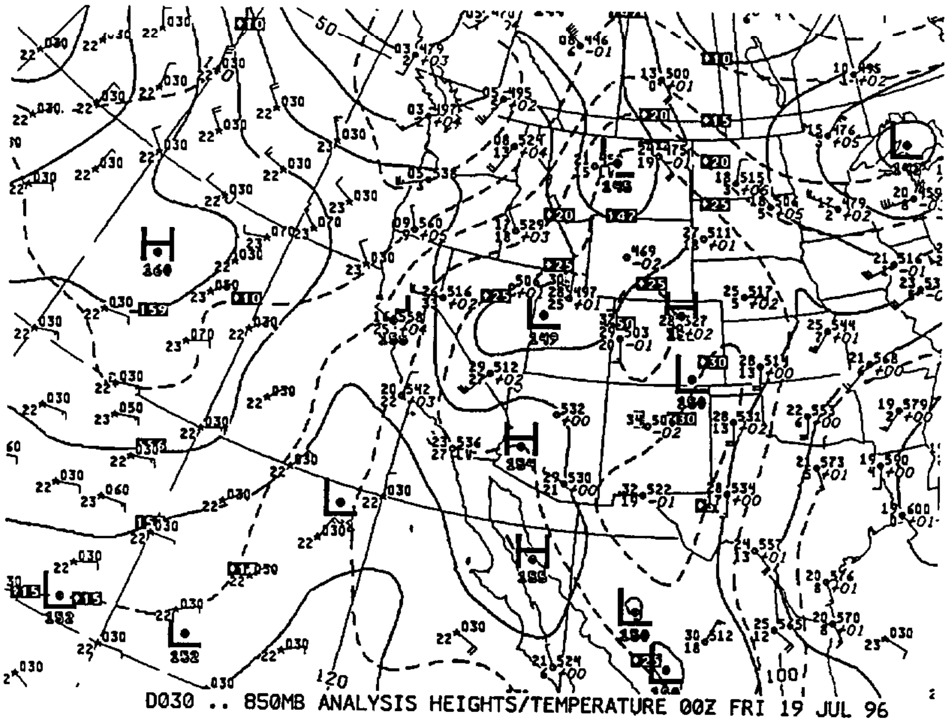


Figure C-2a: 500 mb height field (upper) and 600 mb winds aloft analysis (lower) for 1600 PST 7-18-96 (00Z).



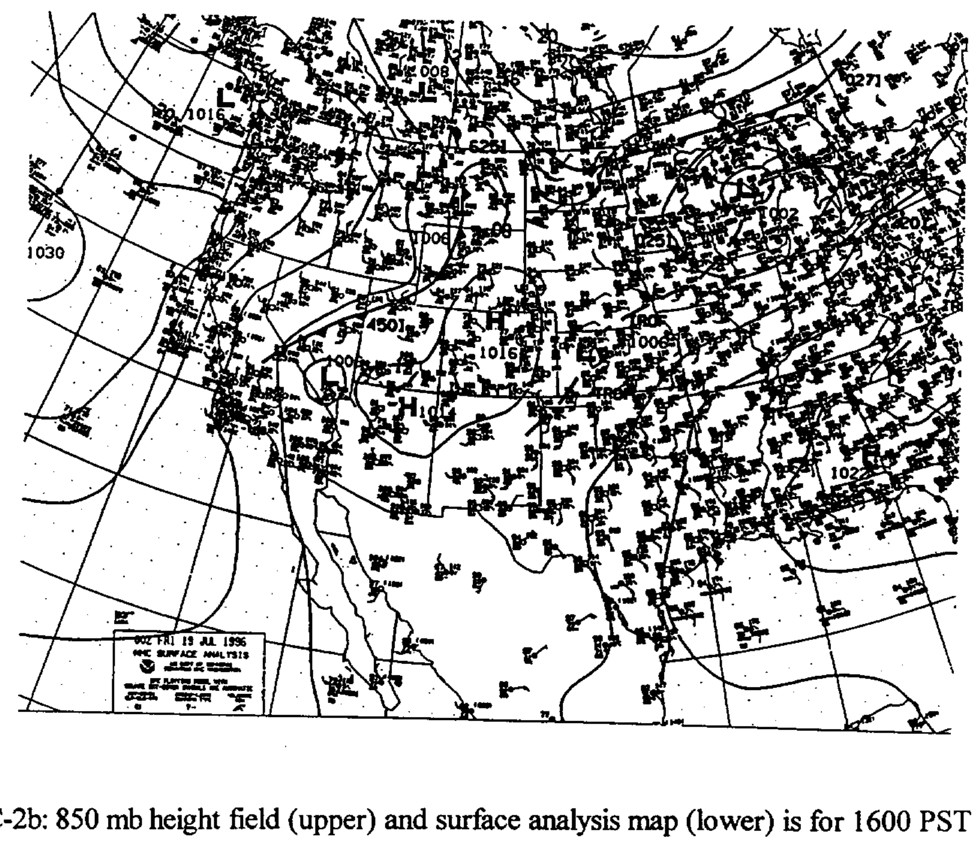
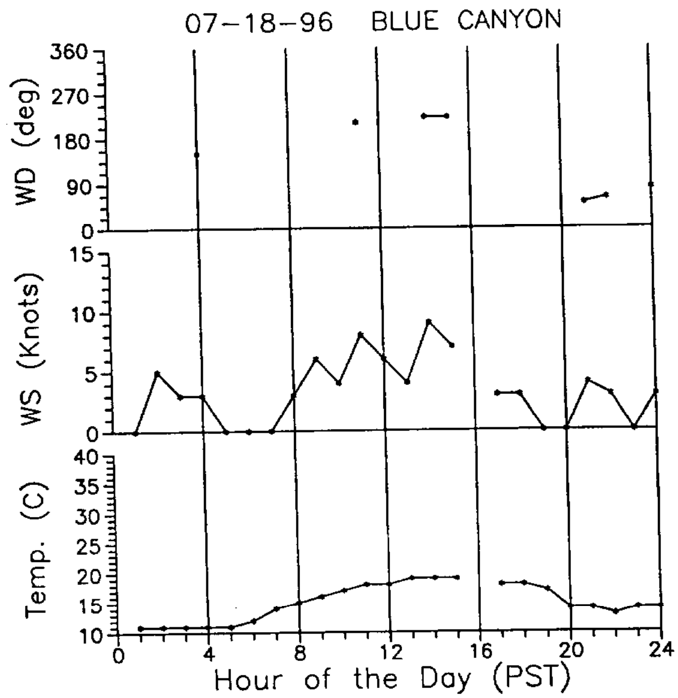


Figure C-2b: 850 mb height field (upper) and surface analysis map (lower) is for 1600 PST 7-18-96 (00Z).



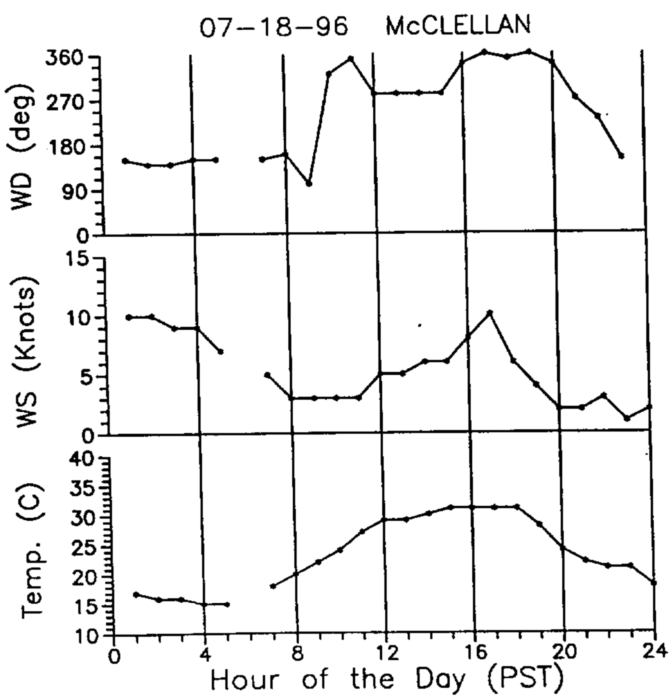


Figure C-3: Plot of wind and temperature data observed on the hour at Blue Canyon (upper) and McClellan (lower) on 7-18-96.

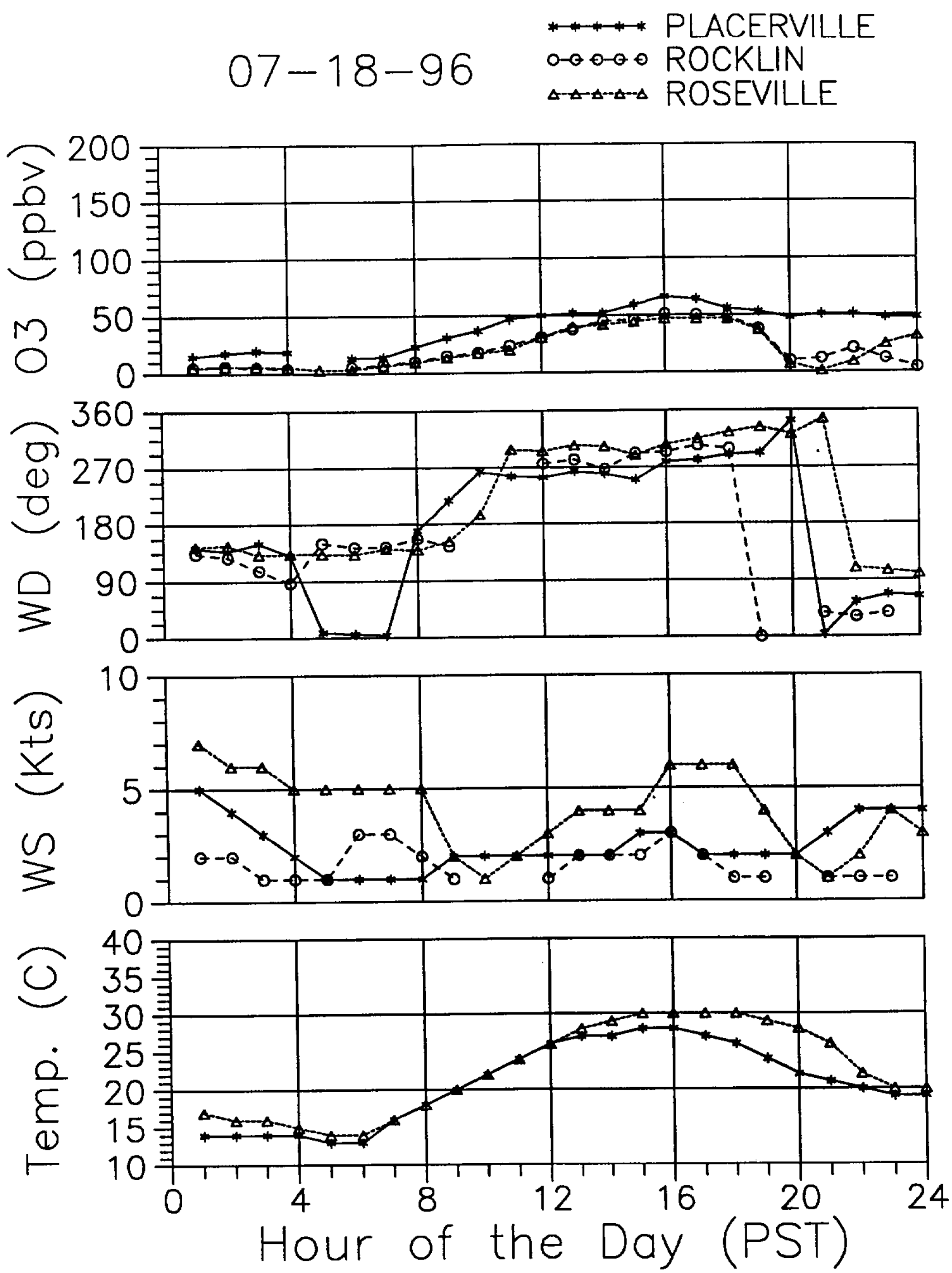
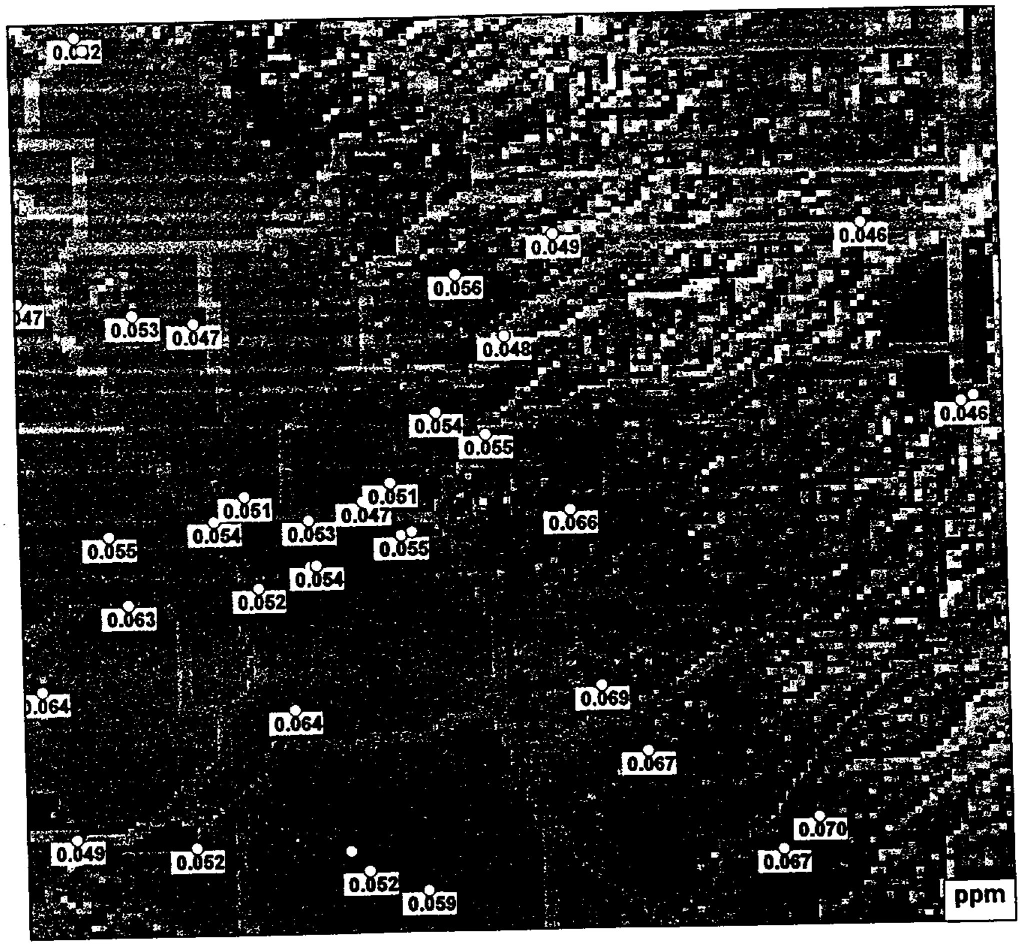


Figure C-4: Plot of hourly averaged data for the three foothill ground stations versus time of day (PST) for 7-18-96.

Figure C-5: Maximum hourly averaged ozone concentrations in central California on 7-18-96.



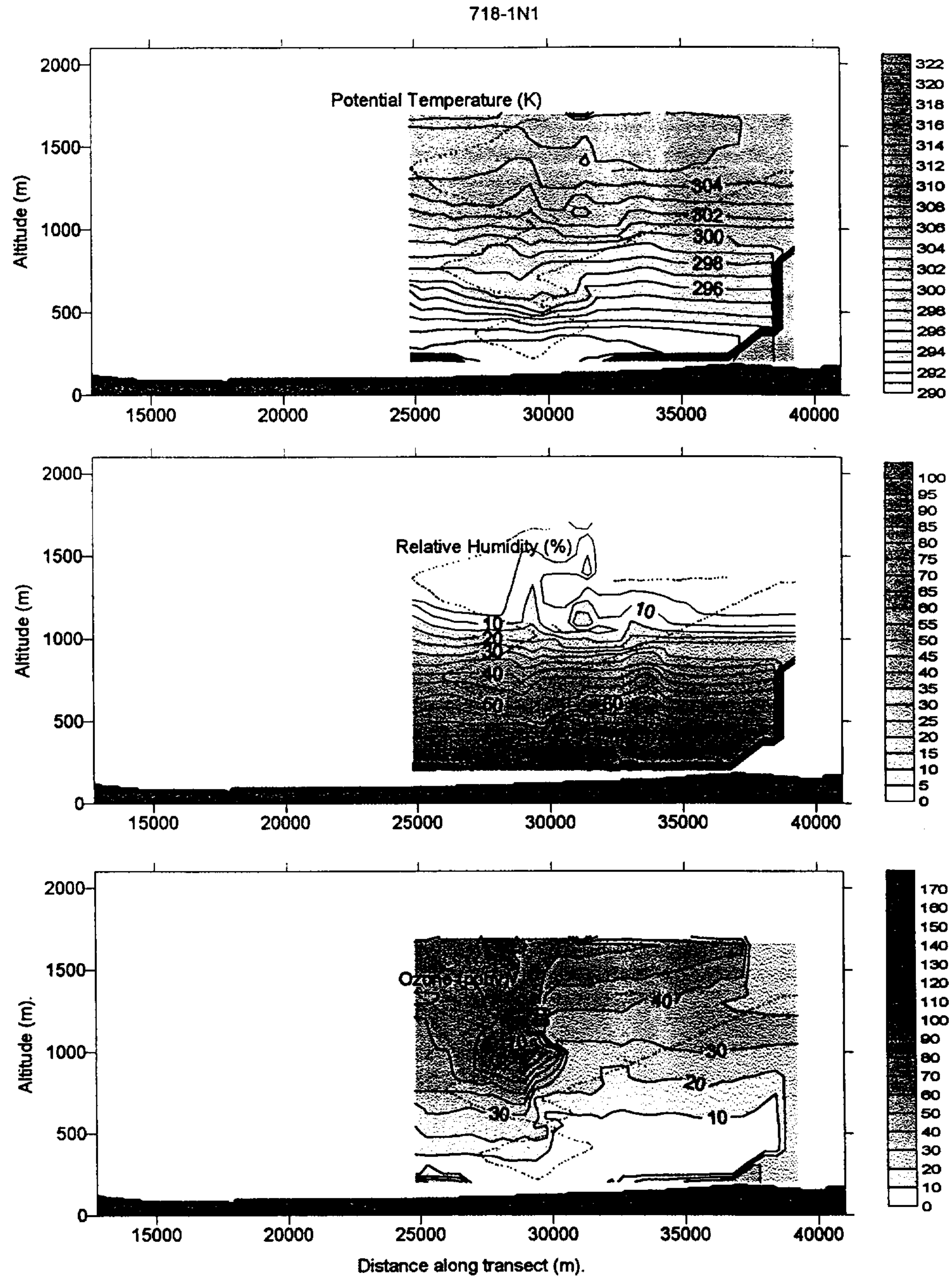


Figure C-6a: Vertical cross sections for flight 1 at S1 on 7-18-96.

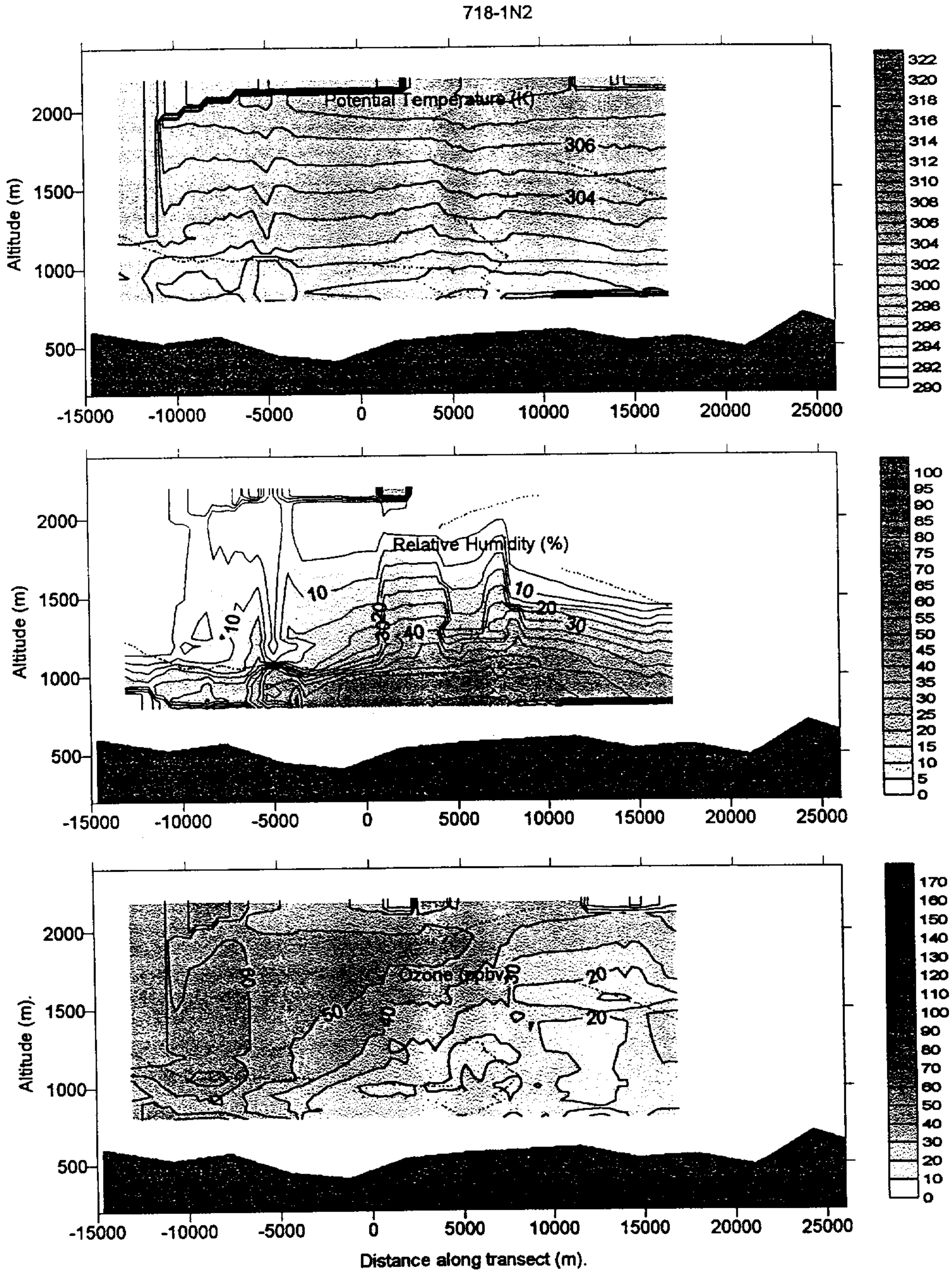


Figure C-6b: Vertical cross sections for flight 1 at S2 on 7-18-96.

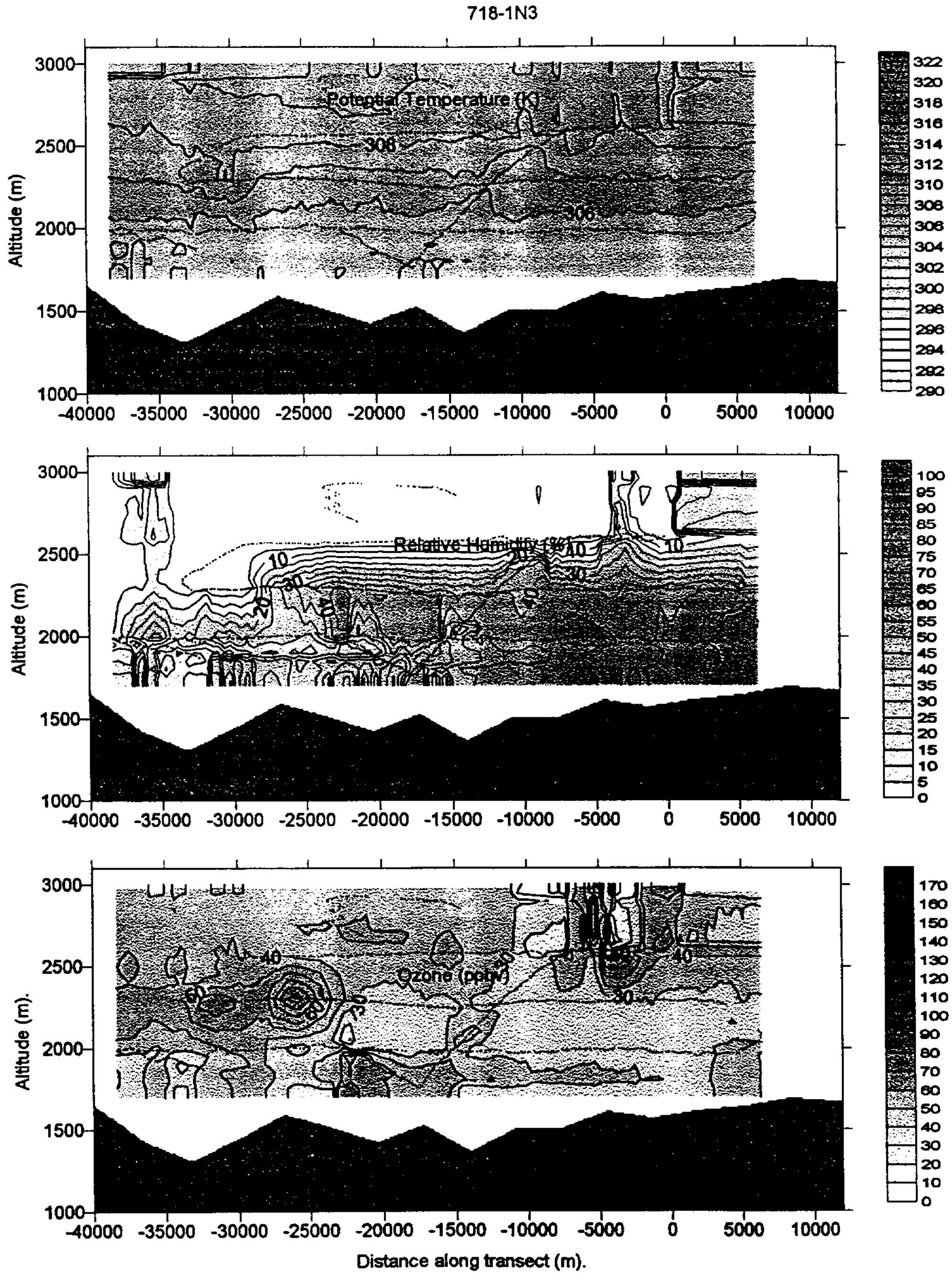


Figure C-6c: Vertical cross sections for flight 1 at S3 on 7-18-96.

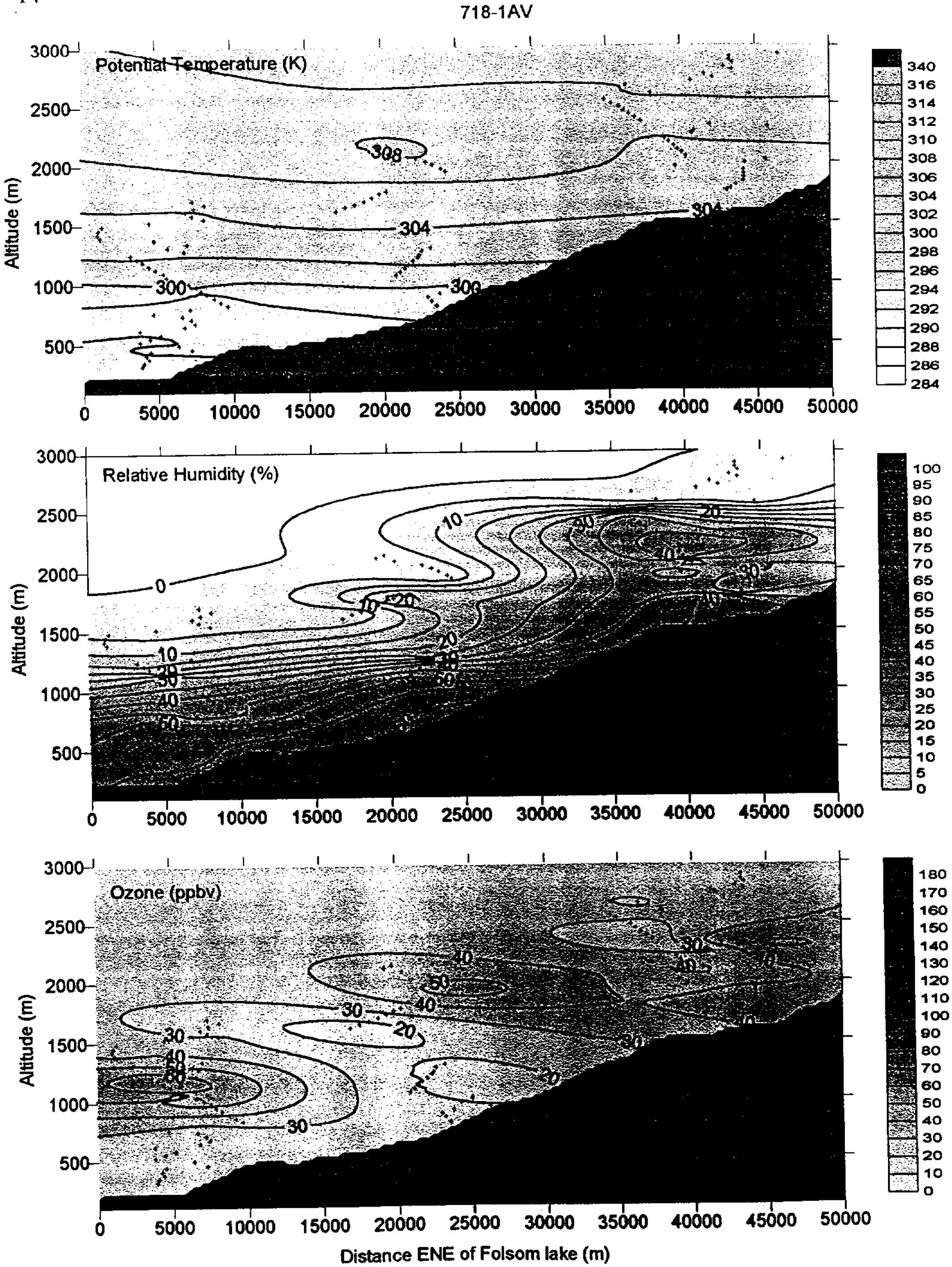


Figure C-6d: Vertical east-west cross sections for flight 1 on 7-18-96.

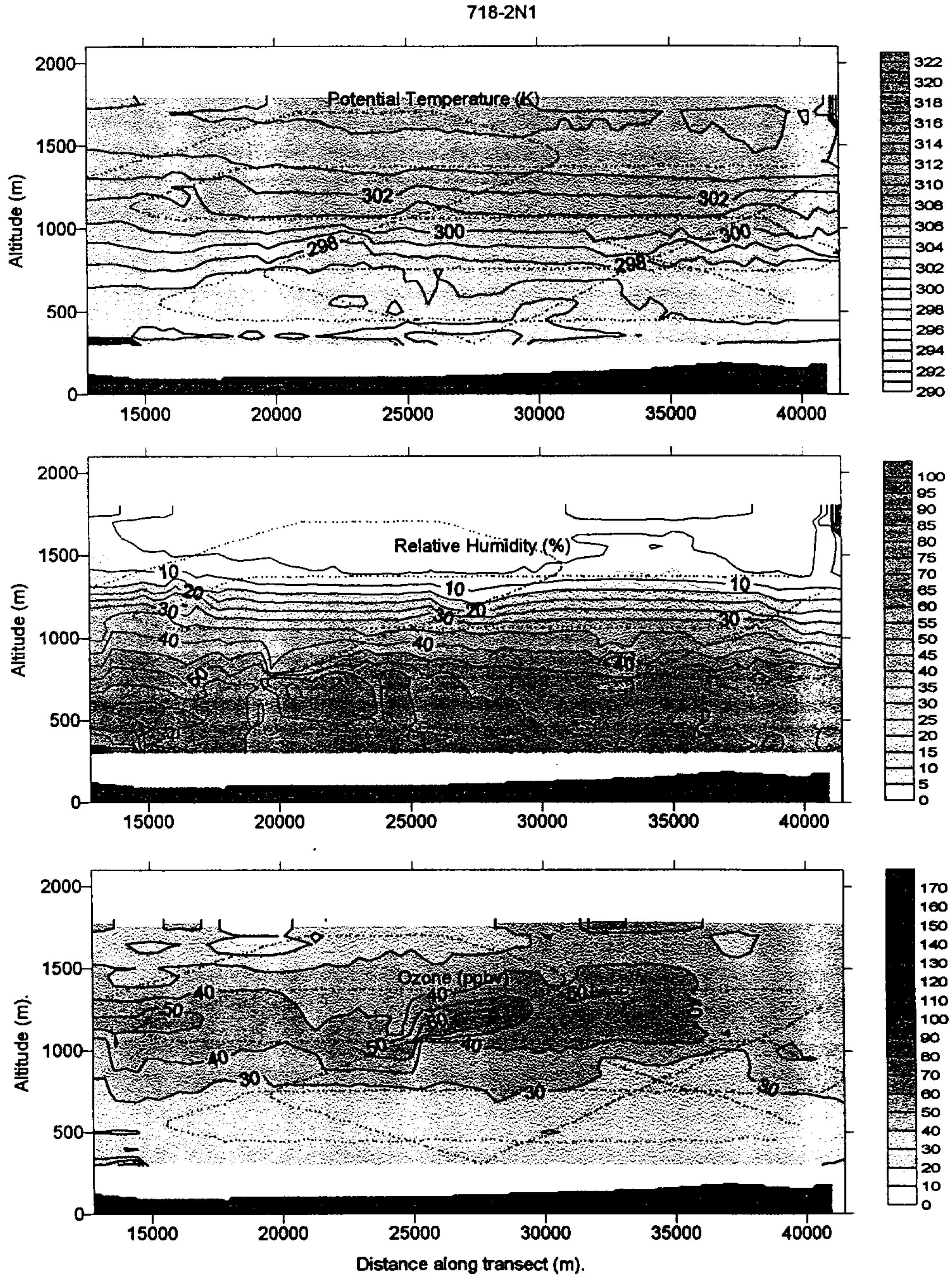


Figure C-7a: Vertical cross sections for flight 2 at S1 on 7-18-96.

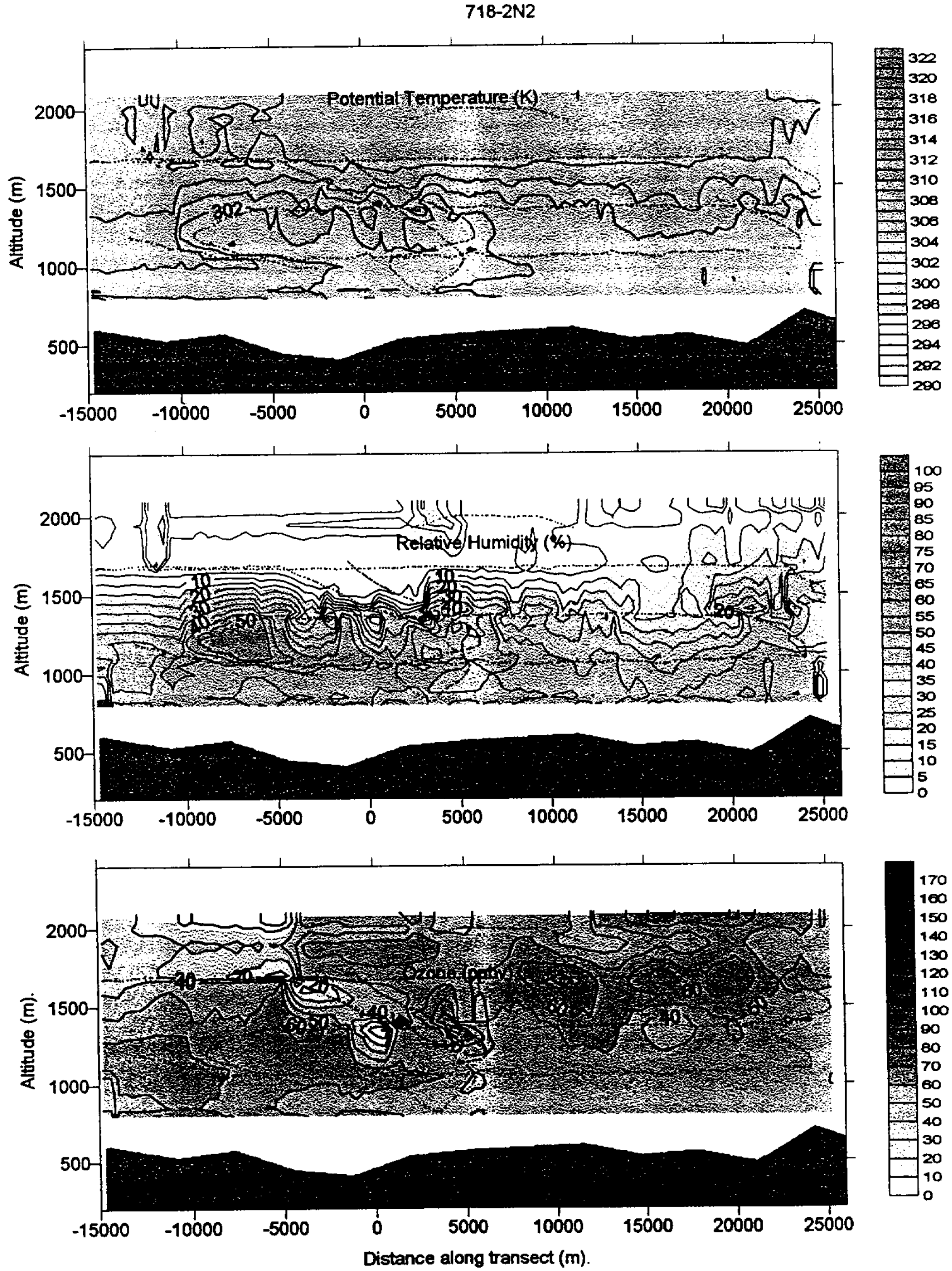


Figure C-7b: Vertical cross sections for flight 2 at S2 on 7-18-96.

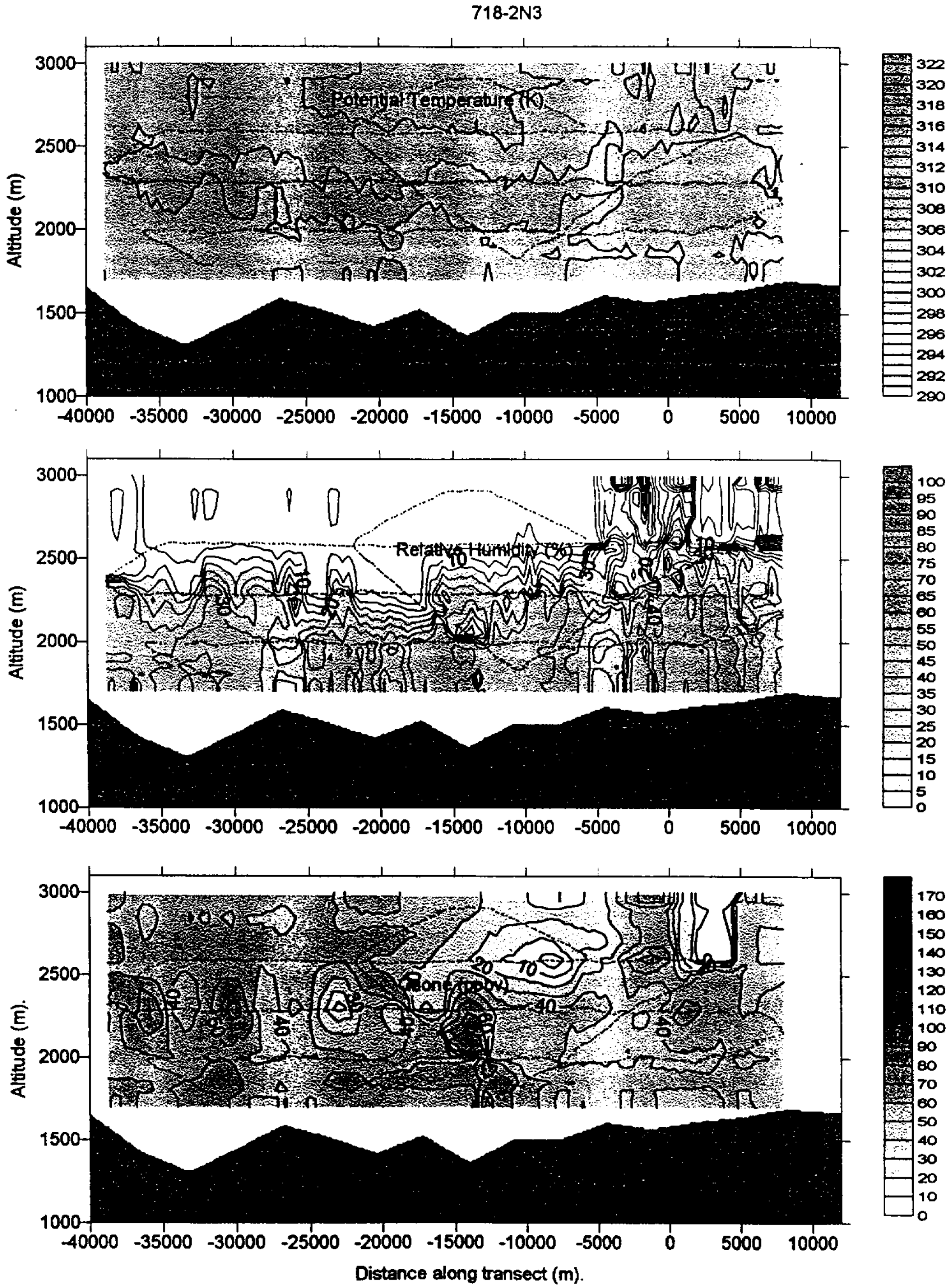


Figure C-7c: Vertical cross sections for flight 2 at S3 on 7-18-96.

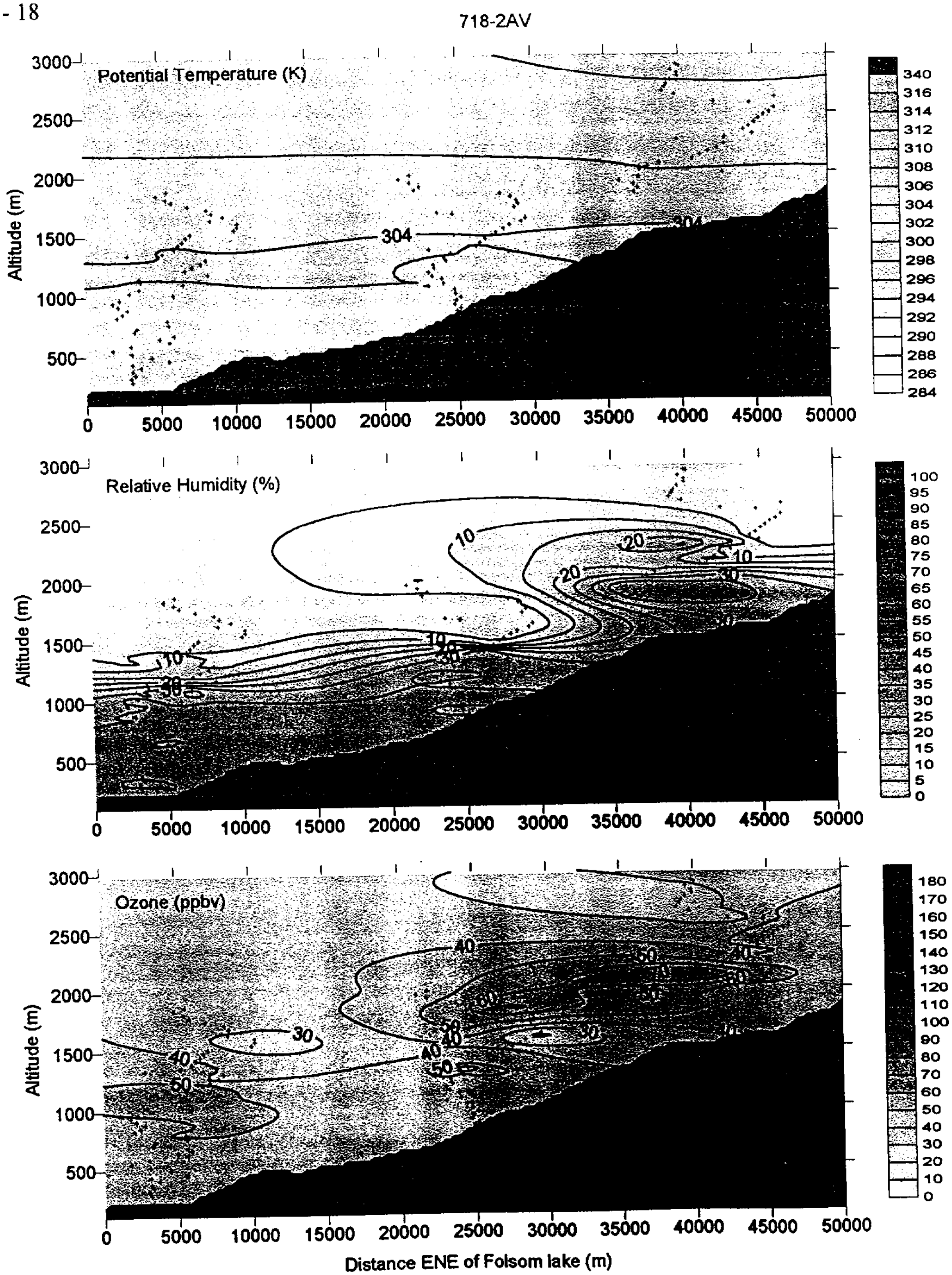


Figure C-7d: Vertical east-west cross sections for flight 2 on 7-18-96.

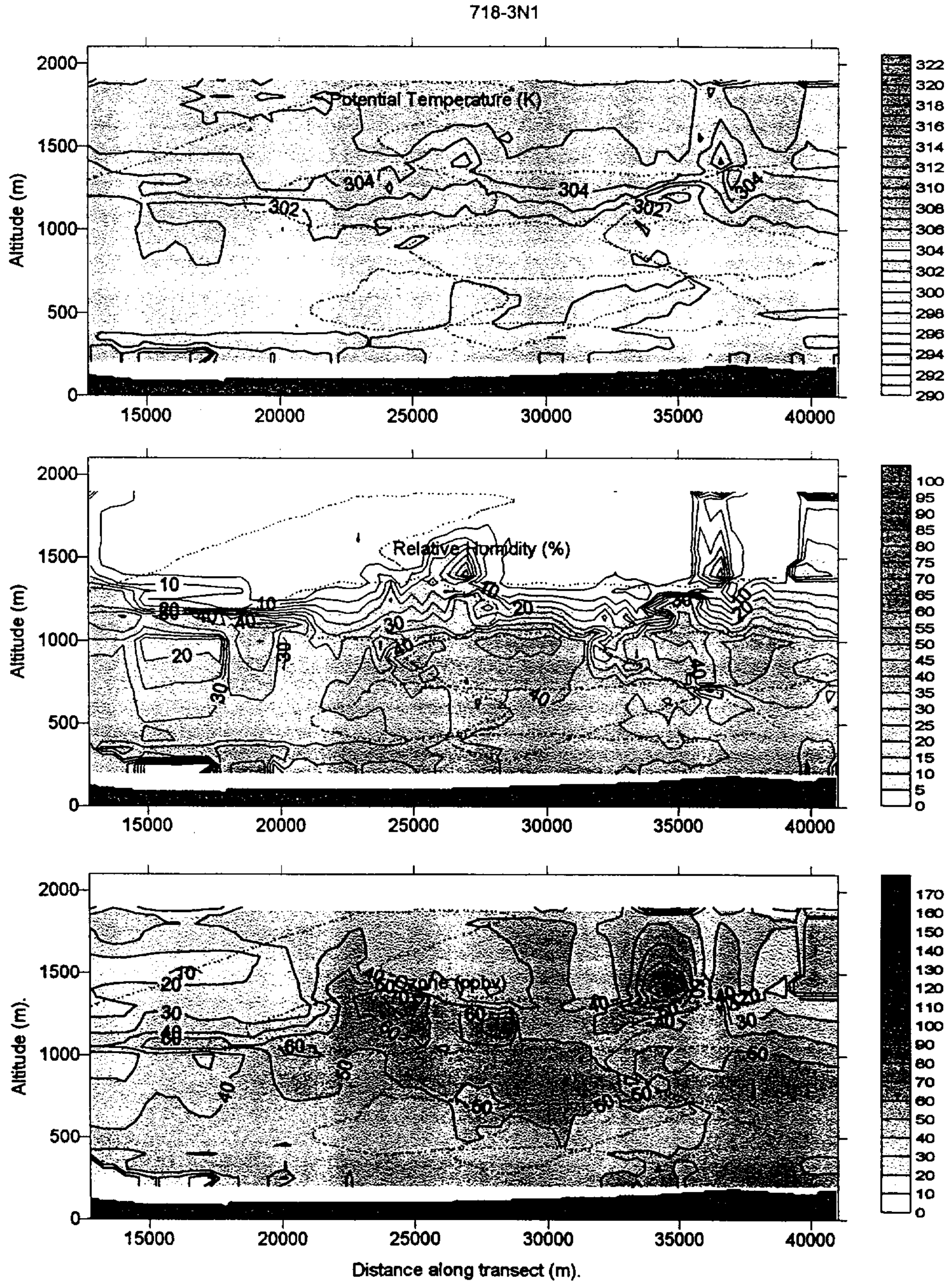


Figure C-8a: Vertical cross sections for flight 3 at S1 on 7-18-96.

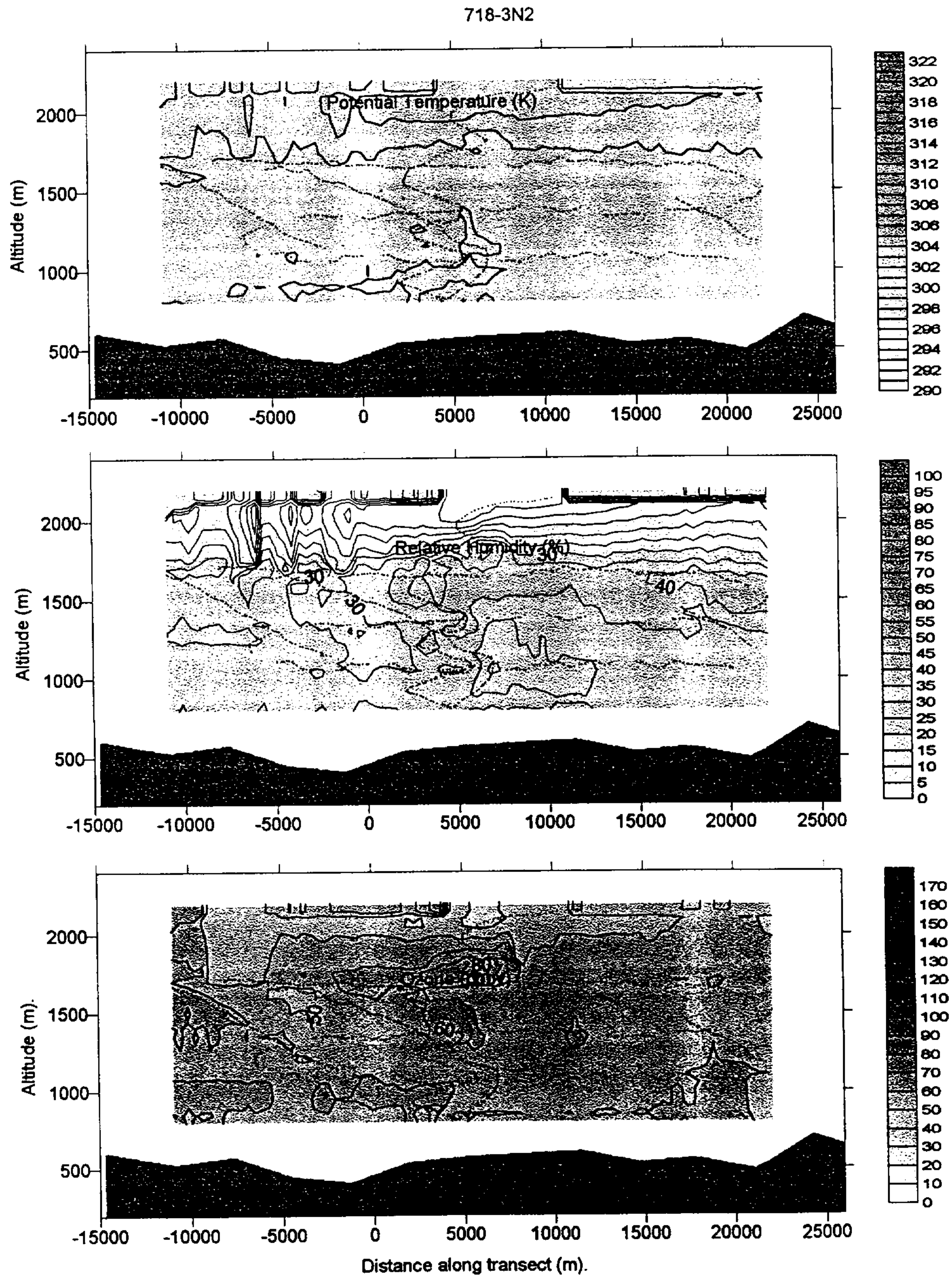


Figure C-8b: Vertical cross sections for flight 3 at S2 on 7-18-96.

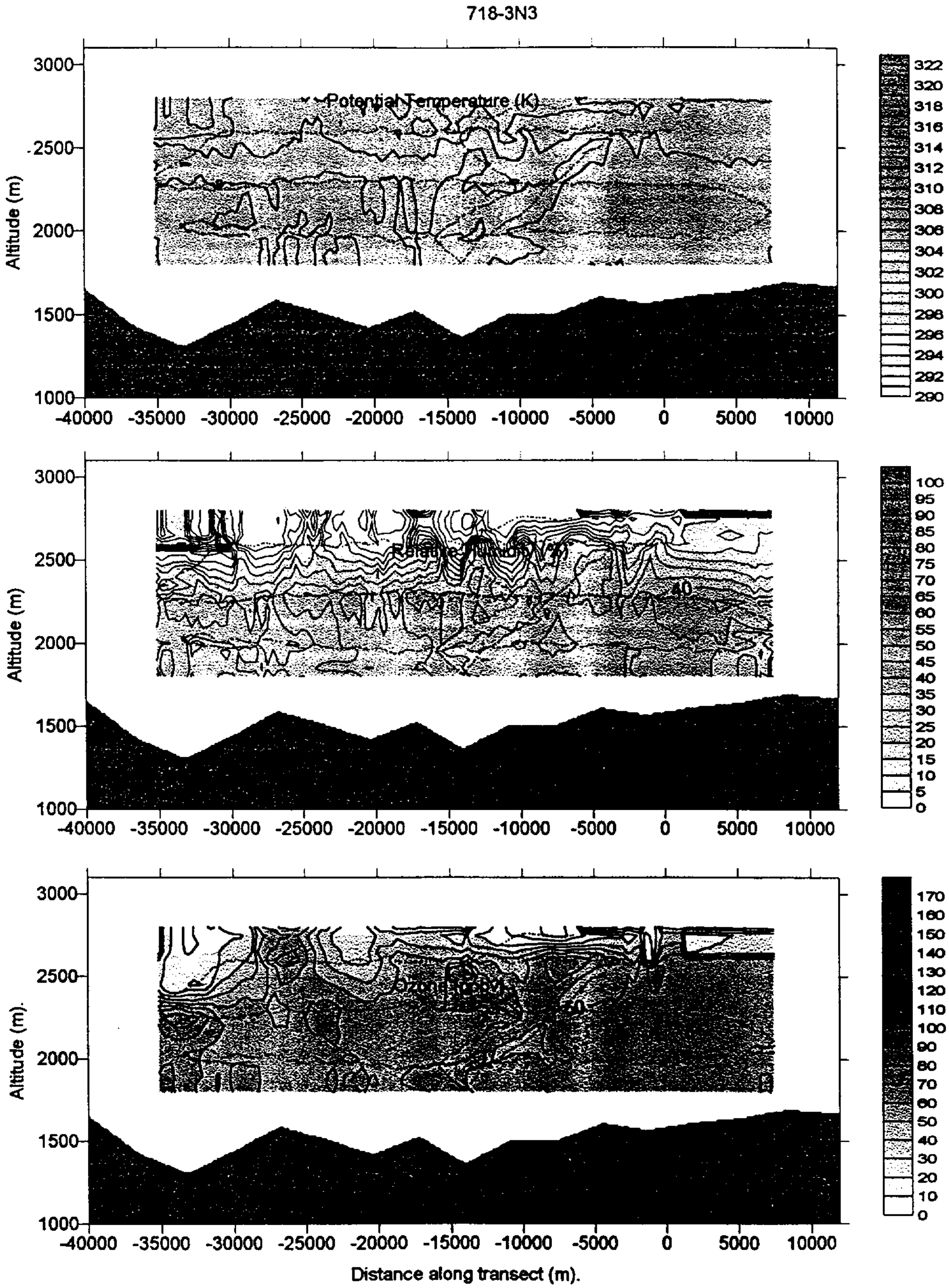


Figure C-8c: Vertical cross sections for flight 3 at S3 on 7-18-96.

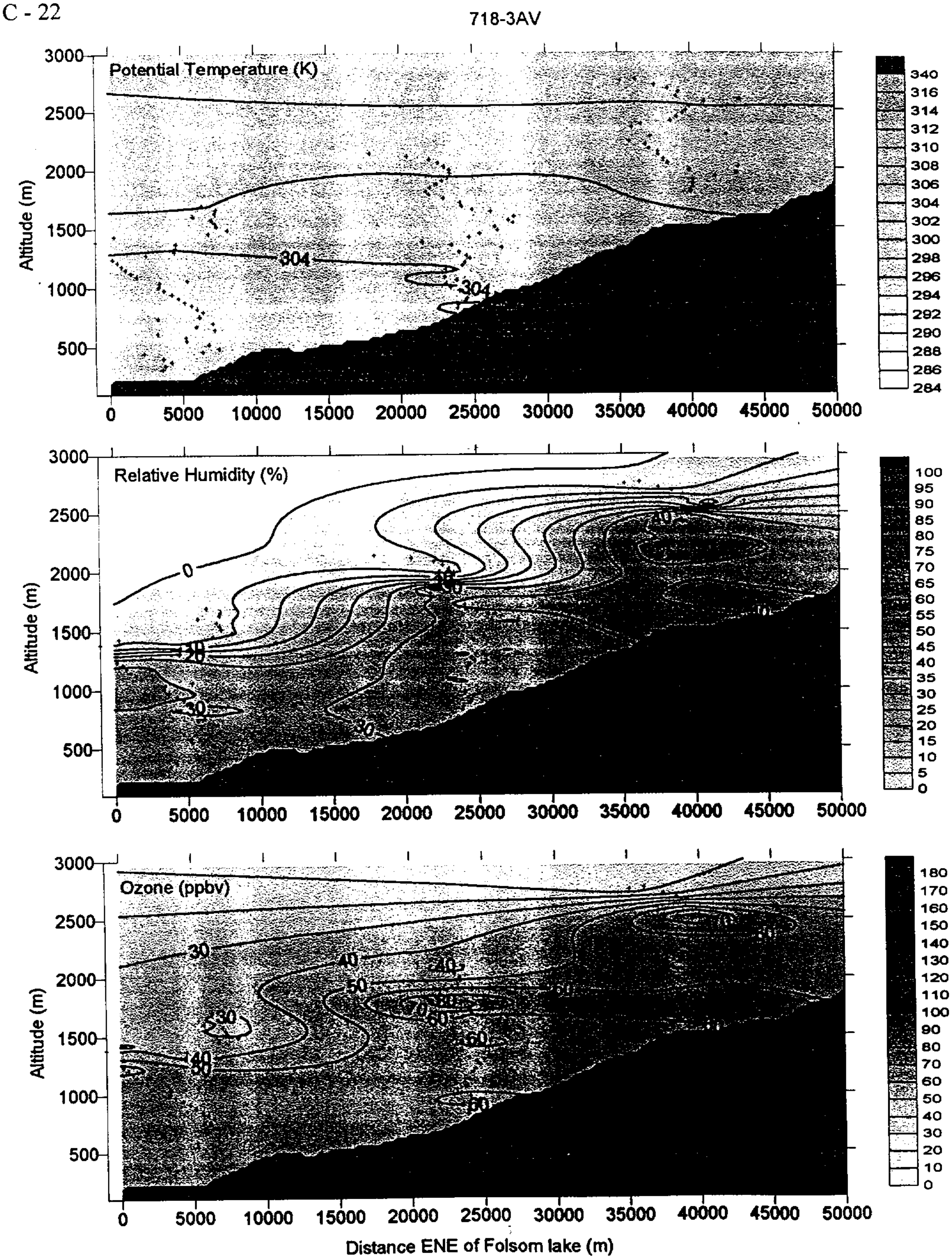


Figure C-8d: Vertical east-west cross sections for flight 3 on 7-18-96.

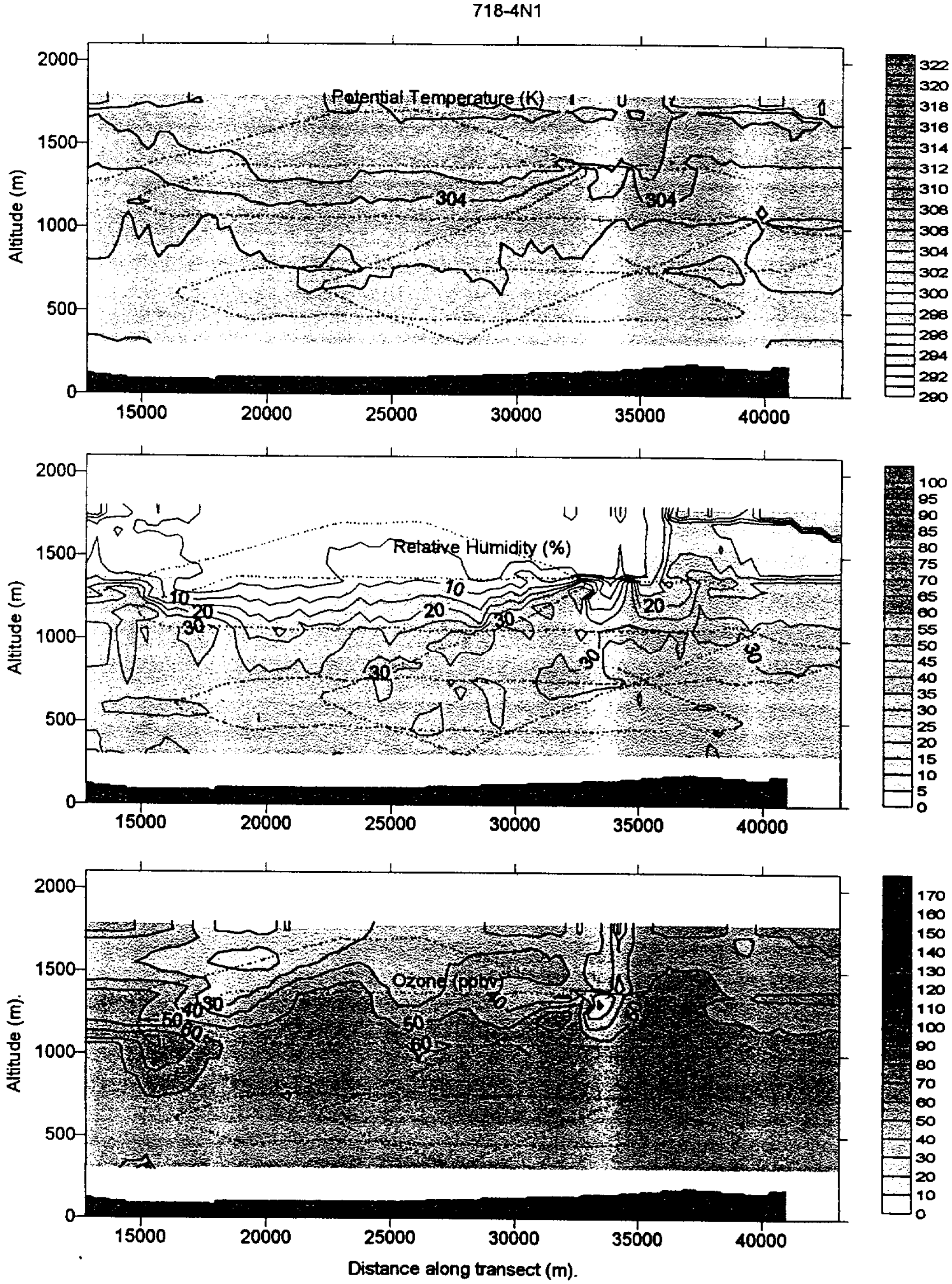


Figure C-9a: Vertical cross sections for flight 4 at S1 on 7-18-96.

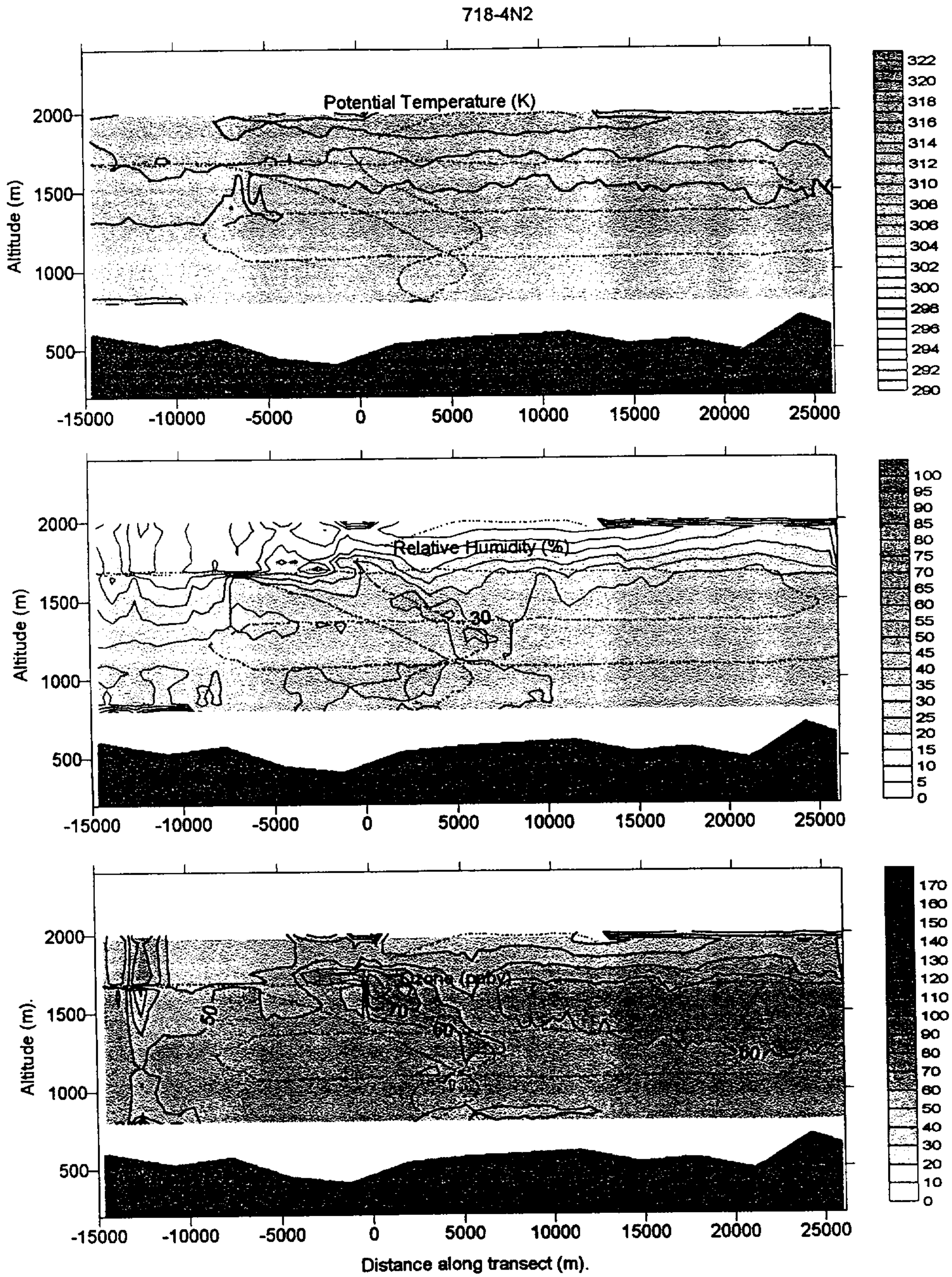


Figure C-9b: Vertical cross sections for flight 4 at S2 on 7-18-96.