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In Situ Correlative Measurements for the Ultraviolet Differential Absorption Lidar and the High Spectral Resolution Lidar Air-Quality Remote Sensors: 1980 PEPE/NEROS Program

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SUMMARY

In situ correlative measurements made with a NASA aircraft in support of two NASA airborne remote sensors participating in the Environmental Protection Agency's 1980 Persistent Elevated Pollution Episode (PEPE) and Northeast Regional Oxidant Study (NEROS) field program are presented. The purpose of the in situ measurements was to provide data for evaluation of the performance of the Ultraviolet Differential Absorption Lidar and the High Spectral Resolution Lidar remote sensors for measuring mixing layer height and ozone and aerosol concentrations in the troposphere during the 1980 PEPE/NEROS program. The in situ aircraft was equipped to measure temperature, dewpoint temperature, ozone concentrations, and light scattering coefficient (B_{scat}). Results for 10 in situ correlative missions (July 24 through August 13, 1980) are presented. The report discusses the in situ data, describes the in situ aircraft flight plans, and presents each data set in graphical and tabular form. The report provides in situ data from which the respective remote sensors may be evaluated. Remote sensor aircraft flight plans and data are not included in the report.

INTRODUCTION

As part of the National Aeronautics and Space Administration's (NASA) continuing commitment to develop the necessary technology to utilize remote sensors and satellite platforms to monitor the Earth's environment, a number of air-quality remote sensors are under development and evaluation. As part of this remote-sensor technology development program, several NASA remote sensors were used in the Environmental Protection Agency's (EPA) 1980 Persistent Elevated Pollution Episode (PEPE) and Northeast Regional Oxidant Study (NEROS) field program during July and August. The PEPE experiment focused on the formation and transport of visibility reducing aerosols while the NEROS experiment addressed regional-scale air mass and urban-plume characterizations with emphasis on collecting data for model validation. Reference 1 discusses the EPA programs.

NASA's participation in the programs was in several areas, including applications of both remote and in situ sampling. Two of NASA's participating remote sensors were the Langley Research Center (Langley) Ultraviolet Differential Absorption Lidar (UV-DIAL) and the High Spectral Resolution Lidar (HSRL). The UV-DIAL, an ozone concentration and mixing layer height sensor, and the HSRL, an aerosol sensor, flew onboard the Wallops Flight Center Electra aircraft making tropospheric measurements below 4 km altitude. The UV-DIAL is a Langley inhouse-developed sensor, while the HSRL is being developed under contract by the University of Wisconsin. The participation of these sensors in the PEPE/NEROS program occurred at an early stage in the development and field evaluation of each sensor; therefore, Langley provided its own in situ sampling aircraft to provide correlative measurements for evaluation of the remote sensors.

This report documents the NASA in situ correlative data to be used in the evaluation. Ten sets of in situ data are presented. The report discusses only the in situ data, describes in situ flight plans, locations, and instrumentation, and presents atmospheric profiles for temperature, dewpoint temperature, ozone concentrations and B_{scat}. A brief description of each remote sensor is also presented.

SYMBOLS AND ABBREVIATIONS

B_{scat}	-	light scattering coefficient, m^{-1}
e.d.t.	-	eastern daylight time
EPA	-	Environmental Protection Agency
HSRL	-	High Spectral Resolution Lidar
Langley	-	Langley Research Center
NASA	-	National Aeronautics and Space Administration
NBS	-	National Bureau of Standards
NEROS	-	Northeast Regional Oxidant Study
O_3	-	Ozone, ppb by volume
PEPE	-	Persistent Elevated Pollution Episode
T	-	temperature, °C
T_{dp}	-	dewpoint temperature, °C
UV or uv	-	ultraviolet
UV-DIAL	-	Ultraviolet Differential Absorption Lidar

SAMPLING AIRCRAFT AND SENSORS

Remote Sensor Aircraft and Sensors

The UV-DIAL and HSRL were flown onboard the NASA Wallops Flight Center Lockheed Electra aircraft. The Electra is a four-engine aircraft built for passenger service, but modified for research missions. It is equipped with numerous viewing ports for the sensors, special equipment racks for the large and heavy remote-sensor components, and a large electrical power generator. The aircraft is pressurized and equipped with various navigational avionics. Typical flights for the PEPE/NEROS missions were approximately 6 hours, at cruising speeds of 600 km/hr, and altitudes up to 4 km. The aircraft was based at and operated by the Wallops Flight Center during the field program.

The UV-DIAL is discussed in reference 2. Briefly, it is a laser system consisting of two frequency-doubled Nd:YAG lasers optically pumping two high-efficiency pulsed dye lasers which are in turn frequency doubled into the ultraviolet. The outputs of the pulsed dye lasers are tuned to a pair of strong/weak absorption lines of ozone for the ozone concentration measurement. Total backscatter from the atmospheric aerosols provides a measurement of mixing-layer height. The backscattered return signals are collected by a telescope, directed onto photomultiplier tubes, digitized, and stored on high-speed magnetic tape. The data acquisition system provides real-time calculations of ozone concentrations below the aircraft and/or the mixing layer height.

The HSRL is an optically pumped oscillator-amplifier dye laser (ref. 3) which measures optical properties associated with atmospheric aerosols. Specifically, it measures the spatial distribution of the extinction coefficient by distinguishing the laser backscatter of aerosols from that of air molecules. Backscatter is analyzed by a high-resolution, two channel Fabry-Perot polyetalon spectrometer through a receiver telescope. One channel detects photons scattered by the aerosols and the other, spectrally broadened scatter from air molecules (based on Doppler shifts). Interferometers are used to meet the spectral resolution and flux handling requirements of the receiver. The data acquisition system consists of a minicomputer, digital magnetic tape, and a real-time graphic display screen.

In Situ Aircraft and Instrumentation

The in situ sensor aircraft (figure 1) is a light, twin-engine, fixed-wing Cessna 402 chartered and outfitted by Langley for air-quality measurements. The aircraft has been in operation since 1974, participating in numerous NASA air-quality programs (ref. 4, 5, and 6). The flight crew consisted of the pilot, a flight coordinator/principal investigator, and an instrument technician. During the PEPE/NEROS field programs, Cessna missions were based either at Columbus, Ohio, or Hampton, Virginia (Langley).

The primary measurements were O_3 concentrations (chemiluminescent technique), B_{scat} (integrating nephelometer), T (resistance probe), T_{dp} (cooled mirror), and flight parameters of altitude, heading, air speed, and time. References 4, 5, and 6 describe the instrumentation. The air sample for the nephelometer is heated in the inlet to vaporize liquid droplets. All instruments were calibrated using accepted EPA or NBS procedures. Table I presents the characteristics of the instruments as used in the study. The O_3 and B_{scat} instruments were audited by the PEPE/NEROS audit team and were within acceptable limits.

All data measured onboard the aircraft were recorded continuously on magnetic tape for later processing in the Langley computer facility. The tape was digitized (10 records/s) and the data are reported as 10-second averages. Strip-chart recorders provided backup recording for the primary measurements as well as the capability for quick-look or real-time analysis. Correlative data missions were flown at 200 km/hr, at ascent or descent rates of less than 150 m/min., and for as long as 3 hours. Based on these flight characteristics and the 10-second data averaging interval, individual data points represent a spatial distance of 0.5 km and an altitude vertical resolution of about 25 m.

IN SITU CORRELATIVE DATA EXPERIMENTS AND RESULTS

Since the purpose of the in situ aircraft was to provide correlative data in support of the airborne NASA remote sensors, flight locations and times were selected solely on remote-sensor requirements. Constraints affecting the in situ aircraft flight plan selection were (1) the PEPE/NEROS flight plan assigned to the Electra aircraft, (2) the range of the in situ aircraft, and (3) weather and flight safety considerations.

Typically, based on the Electra's PEPE/NEROS flight plan, one or more locations were selected for correlative measurements. The in situ aircraft take-off time and location were selected so that it could arrive on station a few minutes prior to the Electra overflight of the location in support of its PEPE/NEROS mission. Correlative locations were either fixed geographical points or short (20 to 60 km) flight legs beneath the assigned Electra flightpath. Generally, in situ data (0.3 to 2.5 km altitude) were obtained as the remote-sensor aircraft overflew the correlative area at about 3 km altitude. The in situ data flights required 20 to 60 minutes on station, while remote-sensor overflights took 1 to 5 minutes. Table II presents the flight locations and times of the in situ aircraft for its ten correlative missions. Locations are given in terms of latitude and longitude as well as in terms of aircraft navigational stations (ref. 7, 8, and 9).

Four basic flight plans were used to obtain the in situ data. Each was designed to obtain vertical profiles of O_3 concentration, B_{scat}, T, and T_{dp} in the correlative area as well as to provide some indication of the variation of these profiles with location and time. Figure 2 describes these flight plans. Plan 1 was used for those missions where the correlative data were required at a fixed geographical point; plans 2 through 4 were used for those missions in which a short flight leg was designated as the test area. Altitudes and flight-leg lengths shown in figure 2 are nominal values. Actual values were selected on a mission-to-mission basis, subject to many considerations.

July 24, 1980, Correlative Mission

Flight plan 1, figure 2a, was flown at correlative locations A and B (table II), approximately 100 km apart. Table III presents the flight sequence. Data (T, T_{dp}, O_3, and B_{scat}) from the repetitive spirals at each location were in good agreement (see figure 3, location A and figure 4, location B). Differences between the data profiles at either location and for any of the four measured parameters are considered insignificant, and within the instrument measurement and aircraft operational uncertainties. Figures 5 and 6 present envelopes of the O_3 and B_{scat} data at A and B. Each envelope encompasses all the 10-second averaged data points measured at A and B. Table IV shows statistical results for these envelopes. These results were obtained by dividing the atmosphere into the indicated altitude increments and calculating the average and standard deviation of the parameter in each altitude range. Also shown in the table are the number of 10-second averaged data points included in each calculation.

While the results at either A or B were repeatable at their respective locations, the results at A and B, 100 km apart, did not agree with each other. This is readily seen in figure 7, a comparison plot of a single spiral at A and B. Important points between the results at A and B are as follows:

1. Both locations show a temperature inversion at about 2.5 km altitude with very dry air above the inversion.

2. The temperature inversion noted at A and 1.2 km altitude is not as apparent at B, and may not exist at B.

3. Ozone concentrations are approximately 65 ppb at B and 40 ppb at A.

4. B_{scat} profiles at A and B are significantly different in shape and absolute values, with values at B being higher at all altitudes.

In the discussion of subsequent data sets and when appropriate, the data envelope concept (figures 5 and 6) and the corresponding statistical presentation of the envelope data (table IV) will be used without additional explanation. In each case when used, the envelope or statistical treatment includes only spiral data at a location or along a flight leg. Constant altitude traverse data (see flight plans 2, 3, and 4) are not included. In addition, when repetitive data at a location (i.e., two consecutive spirals) or along a flight leg (i.e., spirals at the leg end-points) are judged to be repeatable and similar within measurement uncertainties, only one data set (i.e., spiral at one location) representative of that location or flight leg is presented.

July 25, 1980, Correlative Mission

Flight plan 1 was used for the mission at locations A and B, approximately 220 km apart. Table V presents the flight sequence. As was the case for the July 24 flight, results at each location were repeatable, indicating little atmospheric variation during the 30-minute sampling period. Figure 8 and 9 show the O_3 and B_{scat} envelope plots at A and B. Envelope statistical data are given in table VI. Figure 10 compares T, T_{dp}, O_3, and B_{scat} results at A and B. The first three are quite similar but the B_{scat} results are considerably different.

July 31, 1980, Correlative Missions

Two remote-sensor flights and correlative missions were flown on July 31. Correlative flights were flown at approximately 1400 and 2200 e.d.t. using flight plan 2 for each location (table II). Table VII presents the mission flight sequences.

For the 1400 e.d.t. mission, the correlative data were measured along leg BC, 50 km in length. Point A, 26 km from location C on leg BC, was selected for spiral data. Figure 11 shows representative atmospheric profiles at A. Repetitive spirals at A gave similar results. Figure 12 and table VIII(A) show the data envelopes at A and the corresponding statistical data, respectively. Significant observations from figures 11 and 12 are (1) the temperature inversion at about 1.5 km altitude and the observed sharp decreases in O_3 and B_{scat} values above the inversion, (2) the narrow O_3 and B_{scat} data envelopes, and (3) the uniformity of O_3 and B_{scat} values with respect to altitude, below the inversion and extending to the surface.

The constant altitude (0.27 and 0.58 km) traverses of leg BC indicated that B_{scat} was higher at B than at C. The variation appeared to be approximately linear with distance along BC. As observed from the 0.58 km altitude traverse, B_{scat} at C was $2.5 \times 10^{-1}\ m^{-1}$, and at B was $3.5 \times 10^{-4}\ m^{-1}$. The 0.27 km altitude traverse confirmed this variation and B_{scat} averages and standard deviations (0.27 km traverse) were $3.4 \pm 0.3 \times 10^{-4}\ m^{-1}$ for leg AB and $2.9 \pm 0.2 \times 10^{-4}\ m^{-1}$ for leg AC. No O_3 variations were observed during these constant altitude traverses as ozone averages and standard deviations for the constant altitude traverses were 94 and 95 ppb ±2 or 3 ppb. Table VIII(B) gives the statistical envelope data for the spirals at A (figure 12) and the short spirals at the leg end-points B and C. Table VIII(B) shows data only to 610 m altitude (extent of the short spirals at B and C); data beyond 610 m are the same as those in table VIII(A).

Figures 11 and 12 and table VIII(A) provide the correlative data for remote sensor comparison at A. If leg BC, as a whole, is selected for comparison, the proper data to use are those of table VIII(B), up to an altitude of 610 m and those of table VIII(A), above 610 m altitude.

For the later mission, the correlative data were measured along leg AB, 55 km in length. Point C, 28 km from A on leg AB, was selected for spiral data. Figure 13 shows representative data at point C. Data envelopes are given in figure 14. Observations from the data are (1) the temperature inversions at approximately 0.8, 1.8, and 2.3 km altitude and the resulting layering effects observed from the O_3 and B_{scat} data, (2) the decrease in B_{scat} from about 0.8 km to the surface, and (3) the relatively narrow data envelopes at C. Table IX gives the envelope statistical data for the spirals at A, B, and C.

For the most part, little variation in O_3 or B_{scat} values was observed during the 1-hour sampling period or spatially along leg AB, and, as such, the data at C are representative of the entire leg AB. A possible exception is O_3 concentrations below the 0.8-km inversion. The data indicate that O_3 concentrations below 0.8 km may be decreasing with time during the mission. Although the purpose of this report is not to present an analysis of atmospheric events, the observations supporting this conclusion are presented below.

1. The decrease in B_{scat} and O_3 (especially O_3) from about 0.8 km to the surface (table IX) suggests the presence of a stable layer (0.8 km to the surface) with poor vertical mixing, possibly the familiar nocturnal layer.

2. The time of the mission (2200 e.d.t.) and expected radiational cooling of the surface during a summer night are conditions supporting the potential formation of a nocturnal layer.

3. Constant altitude traverses of leg AB indicated about a 12 ppb decrease in O_3 over a 30-minute period. The 0.6 km constant altitude traverse AB at about 2100 e.d.t. showed the O_3 average and standard deviation to be 137 ±5 ppb; 30 minutes later, the AC traverse at 0.6 km altitude resulted in 125 ±4 ppb.

4. The small standard deviations for these O_3 averages (±4 and 5 ppb), suggest that the O_3 decrease with time is occurring throughout the entire leg AB.

August 2, 1980, Correlative Mission

Flight plan 2 was used for the mission, and the correlative data were measured along leg AB, 60 km in length. Point C, 33 km from location A on leg AB, was selected for spiral data. Table X presents the flight sequence. In situ O_3 data were not obtained during the mission. Figure 15 shows spiral data at C; these data are representative of the entire leg AB. A temperature inversion at about 1-km altitude is noted as well as the low B_{scat} values above the inversion. Figure 16 shows the B_{scat} data envelope at C; statistical data for this envelope and the spirals at A and B are shown in table XI. Close examination of the data of figures 15 and 16 shows some dewpoint temperature and B_{scat} variations in the altitude range between 0.8 and 1.2 km. Flight notes by the aircraft crew indicate local plume(s) in the vicinity of location C at about 1-km altitude. The sources of these plumes are probably industrial activities in the city of Franklin, Virginia. While these plumes appear to have little effect on the reported B_{scat} data, their existence and potential effects should be considered in any comparison of in situ and remote-sensor results. The local plume(s) was not detected during the constant altitude (0.28 and 0.6 km) traverses of the test leg in which the B_{scat} average was 1.2 to 1.3 x 10^{-4} m^{-1} with standard deviations of 0.06 x 10^{-4} m^{-1}.

August 5, 1980, Correlative Mission

Flight plan 2 was used for the mission, and measurements were made along leg AB, 43 km in length. Point C, 22 km from location A on leg AB was selected for spiral data. Table XII presents the flight sequence. Figure 17 shows spiral results at C and is representative of the results along the entire leg AB. Figure 18 shows the data envelopes at C; table XIII shows the statistical data for spirals at A, B, and C. O_3 and B_{scat} values along AB showed little variation with time or location as constant altitude (0.27 and 0.57 km) traverses resulted in standard deviations of less than 4 ppb (O_3) and 0.7 x 10^{-5} m^{-1} (B_{scat}). Important features of the data are (1) the temperature inversions at about 0.6 and 2.6 km altitude, (2) the O_3 decrease to the surface below the 0.6 km inversion (probably a nocturnal layer, not yet dissipated by surface heating), (3) the uniform (with altitude) O_3 and B_{scat} values between about 1 and 2.6 km altitude, and (4) the relatively narrow data envelopes.

August 7, 1980, Correlative Mission

Flight plan 3 (with minor modifications) was used for the mission on test leg AB, 37 km in length. Table XIV shows the flight sequence. Flight plan 3 provides four separate measurements of atmospheric vertical structure along leg AB: (1) spiral at B; (2) constant rate of descent leg B to A; (3) spiral at A; and (4) constant rate of descent leg A to B. Figures 19 through 22 present the data from these flight sequences. Each data set shows (1) a temperature inversion at about 1.5 km altitude, with dry air above the inversion, (2) a sizeable decrease in O_3 and B_{scat} above the inversion as compared to below, and (3) generally a decrease in B_{scat} from about 0.6 km to the surface. The $B_{(scat)}$ and O_3 envelopes for these data are shown in figure 23. The B_{scat} envelope is wider than earlier envelopes, and a few data points have been omitted in the construction of the envelopes (shown on figure 23). These points are outside the general trend of the data base and, in the authors' opinion, do not warrant equal weight in the construction of the envelope. Table XV shows statistical data for figure 23 and includes the previously omitted data. The constant altitude (0.3 km) traverses of leg AB resulted in O_3 and B_{scat} averages and standard deviations of 99 ±6 ppb and 1.8 ±0.2 x 10^{-4} m^{-1} (A to B traverse) and 95 4 ppb and 1.9 ±0.2 x 10^{-4} m^{-1} (B to A traverse).

August 12, 1980, Correlative Mission

Flight plan 3 was the basis for the correlative mission, but inflight modifications were made. The test location, leg AB, was 37 km in length. Only one constant altitude traverse of leg AB was flown and the first leg of the flight was a constant rate of ascent traverse of leg C to A. Point C, approximately 35 km from location B, was selected and located by the flight crew as the 68° radial, 59 km from the Coefield, North Carolina, VOR aircraft navigational station. Table XVI presents the flight sequence.

Figures 24 through 27 show data from the portion of the flight providing atmospheric vertical profile information. Temperature inversions are shown at approximately 2.1 and 3 km altitude, but not in all data sets. These inversions are relatively weak (a few tenths °C) which may account for their absence in some data sets. Ozone data of figures 24 through 27 show similar vertical structure, indicating little variation with time or location along legs AB and AC. Envelope plots of the O_3 data are shown in figure 28. Figure 28(a) includes only leg AB data (spiral at A, spiral at B, and constant rate of descent leg B to A), while figure 28(b) includes these data and the constant rate of ascent C to A data.

The B_{scat} profiles of figures 24 through 27 are similar with the exception of the C to A ascent leg (figure 24). In this profile, evidence of a temperature inversion at 2.1-km altitude is shown by the large decrease in B_{scat} (not seen in the other profiles) above this altitude. In addition, a sizeable B_{scat} peak is observed at about 3 km altitude (figure 24). This peak, when viewed on a time-resolved plot, suggests a well-defined plume or layer, high in aerosol concentrations, but having normal, ambient O_3, T, and T_{dp} values. The location of the observed peak is only a few kilometers from location A, but yet, is not readily observed in the spiral A data (figure 25). Figure 29 is the B_{scat} envelope for the data of figures 25, 26, and 27, and excludes the ascent C to A data. Table XVII is the B_{scat} statistical data and includes the C to A ascent data. The single constant altitude (1.5 km) traverse of leg AB resulted in averages and standard deviations of 72 ±4 ppb (O_3) and 1.7 ±0.1 x 10^{-4} m^{-1} (B_{scat}).

August 13, 1980, Correlative Missions

Three remote sensor, Electra aircraft missions were flown on August 13. Two of the missions, at 1300 and 1700 e.d.t., were supported by in situ correlative data flights. Flight plan 4 was used for both missions, but at a different location for each mission. Table XVIII shows the flight sequences.

The correlative leg AB for the 1300 mission was 27 km in length. Atmospheric profiles at A and B were similar (see figure 30 for A only) indicating little variation in O_3, B_{scat}, T, or T_{dp} with time or location. Figure 30 is representative of the results for leg AB. Notable points concerning these data are (1) the temperature inversion at about 2-km altitude, (2) the relatively dry air above the inversion as compared to below, and (3) the sizeable B_{scat} peaks observed (both at A and B) at about 2.4-km altitude. This B_{scat} peak suggests an aerosol-rich layer in the correlative data area. The altitude extent of this layer is not well defined as data above 2.4 km are not available. However, the data do indicate that the aerosol layer is characteristic of the entire correlative leg AB. Figure 31 shows the envelope data (A and B spirals); table XIX shows the corresponding statistical data. The constant altitude (0.9 km) traverse of leg AB showed averages and standard deviations of 66 ±4 ppb (O_3) and 1.5 ±0.2 x 10^{-4} m^{-1} (B_{scat}).

The correlative leg AB for the 1700 mission was 37 km in length. Figures 32 and 33 show the spiral results at A and B. Data from both spirals at each location are shown. The data at A (figure 32) show that the O_3 and B_{scat} results are not repeatable. Both spirals indicate a temperature inversion at about 2-km altitude, but below the inversion, O_3 and B_{scat}, results between the two spirals (only 10 to 15 minutes apart) are significantly different. The cause of this nonrepeatability at A is not defined and is unacceptable for providing correlation with O_3 remote-sensor data and only marginal for B_{scat} data. The statistical results for the data envelopes at A are given in table XX(A). As indicated, standard deviations are large with some O_3 standard deviations being 40 to 50 percent of the average values.

Figure 33 shows the results at B where repetitive spirals produced improved comparisons. The temperature inversion at B is at about 2.3-km altitude. Figure 34 shows data envelopes at B (narrow envelopes) and table XX(B) gives the statistical data. Standard deviations at B are small as compared to those at A. Table XX(C) shows the statistical results for leg AB (data at A and B). The influence of the data at A on the calculations is readily observed by the large standard deviations. Averages and standard deviations for the AB constant altitude (0.6 km) traverse were 77 ±5 ppb (O_3) and 2.2 ±0.2 x 10^{-4} m^{-1} (B_{scat}). This traverse did not show sizeable variations in O_3 or B_{scat} along leg AB, but was flown at an altitude below the observed variations at A.

For correlative data purposes, it is recommended that in situ and remote sensor data be compared only at point B as the data indicate little time variability in atmospheric vertical structure at B. The in situ data do not define the extent of the variability observed at A as it effects leg AB.

CONCLUDING REMARKS

In situ data from ten correlative data aircraft missions flown during the 1980 PEPE/NEROS program have been presented. The in situ data obtained in support of two NASA air-quality remote sensors, the UV-DIAL and HSRL, provide a data base to assess the performance of both sensors during the PEPE/NEROS program. Data sets, ozone concentration, light-scattering coefficient, temperature, and dewpoint temperature from each mission have been analyzed, condensed to a manageable quantity, and presented in both graphical and tabular formats to provide a description of atmospheric vertical structure in the correlative data test location. In addition, each data set is described in a manner that identifies those pertinent facts about the in situ data and the atmosphere that should be considered for evaluating each remote sensor. In most cases, each data set provides an adequate, accurate, and concise description of the measured atmospheric parameters.

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TABLE I: CHARACTERISTICS OF IN SITU AIRCRAFT INSTRUMENTATION

FLOWN IN THE 1980 PEPE/NEROS PROGRAM

Measured Parameter	Calibration Technique	Range	Absolute Accuracy[a]	Precision	Response Time[d]
temperature	liquid bath	-30 to +30° C	0.5° C	0.1° C	less than 1 s
dewpoint temperature	humidity chamber	-100 to +100° C	0.5° C	0.1° C	2 °C/s
ozone concentration	gas phase titration[b]	0 to 300 ppb	10 percent or 5 ppb[c]	2 percent or 3 ppb[c]	3 s
light scattering coefficient[e] (B_{scat})	filtered air and freon gas	0 to 1×10^{-3} m^{-1}	10 percent or 2×10^{-6} m^{-1} [c]	2 percent or 2×10^{-6} m^{-1} [c]	0.2 s

a absolute accuracy based on calibration uncertainties
b gas phase titration (O_3 to NO) traceable to National Bureau of Standard NO source
c whichever is the largest
d response time to 90 percent of signal, unless noted otherwise
e heated inlet to vaporize liquid droplets; instrument characteristicss based on laboratory results using filtered air and freon gas

TABLE II: FLIGHT LOCATIONS FOR IN SITU AIRCRAFT FOR CORRELATIVE MISSIONS

Date	Flight Leg Locations				Flight Plan (fig. 2)
	Location A		Location B		
	(radial/n.mi.)[a]	(latitude/longitude)	(radial/n.mi.)[a]	(latitude/longitude)	
July 24	Newcome VOR 0°/ 0	38° 10' N/ 82° 55' W	Henderson VOR 90°/ 2	38° 45' N/ 81° 59' W	1
July 25	Mansfield VOR 101°/21	40° 48' N/ 82° 20' W	Henderson VOR 90°/ 2	38° 45' N/ 81° 59' W	1
July 31[d]	Kenton[b] VOR 292°/ 8	39° 16' N/ 75° 41' W	Kenton VOR 270°/33	39° 9' N/ 76° 13' W	2[c]
July 31[e]	Harcum VOR 103°/15	37° 25' N/ 76° 24' W	Harcum VOR 296°/15	37° 32' N/ 77° 0' W	2
Aug. 2	Franklin VOR 260°/18	36° 38' N/ 77° 22' W	Franklin VOR 80°/14	36° 47' N/ 76° 44' W	2
Aug. 5	Franklin VOR 197°/31	36° 13' N/ 77° 8' W	Franklin VOR 197°/ 8	36° 35' N/ 77° 3' W	2
Aug. 7	Snow Hill VOR 170°/ 4	37° 59' N/ 75° 27' W	Snow Hill VOR 350°/16	38° 19' N/ 75° 34' W	3
Aug. 12	Cofield VOR 232°/10	36° 16' N/ 77° 2' W	Cofield VOR 52°/10	36° 29' N/ 76° 43' W	3[c]
Aug. 13[d]	Rosewood VOR 203°/ 4	40° 14' N/ 84° 4' W	Rosewood VOR 203°/20	39° 59' N/ 84° 9' W	4
Aug. 13[e]	Rosewood VOR 137°/67	39° 28' N/ 83° 28' W	Rosewood VOR 137°/47	39° 43' N/ 83° 38' W	4

[a] referenced to aeronautical charts (refs. 7, 8, and 9)
[b] for July 31 (first mission) coordinates shown are for location C
[c] minor modifications to flight plan were made
[d] mission 1
[e] mission 2

TABLE III: CESSNA FLIGHT SEQUENCE FOR JULY 24, 1980 CORRELATIVE MISSION

Time (e.d.t.)	Altitude (m)	Flight Leg
1200 to 1204	1000 to 500	spiral at A
1204 to 1217	500 to 2400	spiral at A
1217 to 1226	2400 to 1400	spiral at A
1226 to 1307	1400	constant altitude A to B
1327 to 1336	900 to 300	spiral at B
1336 to 1350	300 to 2400	spiral at B
1353 to 1402	2400 to 1000	spiral at B

TABLE IV: ENVELOPE STATISTICAL DATA: JULY 24, 1980

A. Location A

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation O_3 (ppb)	$B_{(scat)}$ (m^{-1})
305 to 457	422	6	40 ± 2	8.1 ± 0.4 x 10^{-5}
457 to 610	532	12	39 ± 3	7.3 ± 0.6 x 10^{-5}
610 to 762	682	12	39 ± 2	6.5 ± 0.7 x 10^{-5}
762 to 914	843	12	39 ± 2	7.1 ± 0.5 x 10^{-5}
914 to 1067	984	10	37 ± 4	7.1 ± 0.7 x 10^{-5}
1067 to 1219	1143	5	39 ± 5	6.5 ± 2.3 x 10^{-5}
1219 to 1372	1309	13	35 ± 5	3.5 ± 1.2 x 10^{-5}
1372 to 1524	1457	11	38 ± 4	2.8 ± 1.1 x 10^{-5}
1524 to 1679	1603	13	36 ± 3	1.8 ± 0.2 x 10^{-5}
1679 to 1829	1760	15	35 ± 3	1.7 ± 0.3 x 10^{-5}
1829 to 1981	1909	13	36 ± 4	1.6 ± 0.2 x 10^{-5}
1981 to 2134	2058	13	37 ± 3	1.9 ± 0.3 x 10^{-5}
2134 to 2286	2213	11	37 ± 2	1.3 ± 0.2 x 10^{-5}
2286 to 2438	2344	11	43 ± 3	1.2 ± 0.2 x 10^{-5}

TABLE IV: Concluded.

B. Location B

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation	
			O_3 (ppb)	B(scat) (m^{-1})
305 to 457	373	10	69 ± 2	$15.5 \pm 1.3 \times 10^{-5}$
457 to 610	535	12	67 ± 3	$15.5 \pm 1.9 \times 10^{-5}$
610 to 762	696	14	61 ± 7	$14.7 \pm 1.1 \times 10^{-5}$
762 to 914	858	35	67 ± 4	$14.1 \pm 0.7 \times 10^{-5}$
914 to 1067	1016	14	68 ± 3	$13.5 \pm 0.6 \times 10^{-5}$
1067 to 1219	1138	12	66 ± 3	$13.6 \pm 0.5 \times 10^{-5}$
1219 to 1372	1299	13	65 ± 2	$12.9 \pm 0.5 \times 10^{-5}$
1372 to 1524	1452	11	66 ± 4	$11.6 \pm 1.3 \times 10^{-5}$
1524 to 1679	1594	11	64 ± 3	$10.5 \pm 0.7 \times 10^{-5}$
1679 to 1829	1753	11	62 ± 2	$8.4 \pm 1.0 \times 10^{-5}$
1829 to 1981	1913	11	61 ± 3	$7.6 \pm 1.4 \times 10^{-5}$
1981 to 2134	2050	12	62 ± 3	$7.1 \pm 1.4 \times 10^{-5}$
2134 to 2286	2199	10	61 ± 3	$5.6 \pm 0.9 \times 10^{-5}$
2286 to 2438	2359	11	58 ± 5	$3.0 \pm 1.0 \times 10^{-5}$

TABLE V: CESSNA FLIGHT SEQUENCE FOR JULY 25, 1980 CORRELATIVE MISSION

Time (e.d.t.)	Altitude (m)	Flight Leg
1120 to 1124	1050 to 450	spiral at A
1124 to 1137	450 to 2450	spiral at A
1137 to 1144	2450 to 1350	spiral at A
1144 to 1240	1350	constant altitude A to B
1240 to 1248	1350 to 2450	spiral at B
1248 to 1302	2450 to 150	spiral at B
1302 to 1310	150 to 1350	spiral at B

TABLE VI: ENVELOPE STATISTICAL DATA: JULY 25, 1980

A. Location A

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation O_3 (ppb)	$B_{(scat)}$ (m^{-1})
305 to 457	415	5	71 ±2	8.4 ±0.5 x 10^{-5}
457 to 610	530	10	72 ±2	7.7 ±0.2 x 10^{-5}
610 to 762	679	12	71 ±3	7.8 ±0.3 x 10^{-5}
762 to 914	829	11	71 ±5	7.8 ±0.3 x 10^{-5}
914 to 1067	984	10	68 ±2	8.0 ±0.4 x 10^{-5}
1067 to 1219	1157	6	70 ±4	8.9 ±0.1 x 10^{-5}
1219 to 1372	1317	10	72 ±5	8.5 ±0.9 x 10^{-5}
1372 to 1524	1446	11	73 ±5	7.6 ±1.0 x 10^{-5}
1524 to 1679	1603	13	56 ±9	2.8 ±2.5 x 10^{-5}
1679 to 1829	1752	11	47 ±3	0.4 ±0.5 x 10^{-5}
1829 to 1981	1902	11	49 ±2	0.3 ±0.2 x 10^{-5}
1981 to 2134	2056	13	50 ±4	0.5 ±0.2 x 10^{-5}
2134 to 2286	2208	12	56 ±3	0.3 ±0.2 x 10^{-5}
2286 to 2438	2346	11	55 ±3	0.2 ±0.2 x 10-5

TABLE VI: Concluded.

B. Location B

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation O_3 (ppb)	$B_{(scat)}$ (m^{-1})
152 to 305	242	7	64 ± 1	$20.8 \pm 0.8 \times 10^{-5}$
305 to 457	382	11	65 ± 2	$20.1 \pm 0.6 \times 10^{-5}$
457 to 610	529	12	64 ± 2	$20.1 \pm 0.6 \times 10^{-5}$
610 to 762	674	10	65 ± 2	$19.6 \pm 0.7 \times 10^{-5}$
762 to 914	841	14	67 ± 1	$19.5 \pm 1.0 \times 10^{-5}$
914 to 1067	990	13	70 ± 3	$19.4 \pm 0.5 \times 10^{-5}$
1067 to 1219	1140	12	73 ± 3	$19.5 \pm 0.6 \times 10^{-5}$
1219 to 1372	1307	18	75 ± 4	$17.9 \pm 2.0 \times 10^{-5}$
1372 to 1524	1439	13	75 ± 2	$14.3 \pm 0.8 \times 10^{-5}$
1524 to 1679	1603	12	68 ± 3	$9.4 \pm 2.4 \times 10^{-5}$
1679 to 1829	1751	10	62 ± 6	$3.8 \pm 2.2 \times 10^{-5}$
1829 to 1981	1910	12	56 ± 4	$0.7 \pm 0.4 \times 10^{-5}$
1981 to 2134	2056	13	54 ± 5	$0.4 \pm 0.2 \times 10^{-5}$
2134 to 2286	2215	11	58 ± 2	$0.3 \pm 0.2 \times 10^{-5}$
2286 to 2438	2368	13	56 ± 2	$0.3 \pm 0.1 \times 10^{-5}$

TABLE VII: CESSNA FLIGHT SEQUENCE FOR JULY 31, 1980 CORRELATIVE MISSIONS

A. First Mission

Time (e.d.t.)	Altitude (m)	Flight Leg
1325 to 1338	2300 to 300	spiral at A
1338 to 1345	300	constant altitude A to B
1345 to 1348	300 to 600	spiral at B
1348 to 1400	600	constant altitude B to C
1400 to 1401	600 to 300	spiral at C
1401 to 1408	300	constant altitude C to A
1408 to 1409	300 to 100	spiral at A
1409 to 1426	100 to 2700	spiral at A
1426 to 1430	2700 to 2300	spiral at A

B. Second Mission

Time (e.d.t.)	Altitude (m)	Flight Leg
2056 to 2109	600	constant altitude A to B
2109 to 2112	600 to 300	spiral at B
2112 to 2125	300	constant altitude B to A
2125 to 2128	300 to 600	spiral at A
2128 to 2134	600	constant altitude A to C
2137 to 2140	600 to 150	spiral at C
2140 to 2158	150 to 2700	spiral at C
2158 to 2212	2700 to 600	spiral at C

TABLE VIII: ENVELOPE STATISTICAL DATA: JULY 31, 1980 (FIRST MISSION)

A. Location A

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation O_3 (ppb)	$B_{(scat)}$ (m^{-1})
152 to 305	262	5	95 ± 2	$33.0 \pm 2.1 \times 10^{-5}$
305 to 457	375	12	95 ± 2	$30.1 \pm 1.2 \times 10^{-5}$
457 to 610	531	12	94 ± 4	$31.4 \pm 1.7 \times 10^{-5}$
610 to 762	686	13	94 ± 4	$30.6 \pm 3.0 \times 10^{-5}$
762 to 914	845	12	94 ± 3	$29.4 \pm 1.5 \times 10^{-5}$
914 to 1067	995	12	93 ± 2	$28.6 \pm 2.0 \times 10^{-5}$
1067 to 1219	1138	11	91 ± 2	$29.2 \pm 2.0 \times 10^{-5}$
1219 to 1372	1292	11	92 ± 4	$29.8 \pm 1.9 \times 10^{-5}$
1372 to 1524	1447	13	82 ± 8	$20.8 \pm 6.7 \times 10^{-5}$
1524 to 1679	1603	11	72 ± 2	$13.9 \pm 9.4 \times 10^{-5}$
1679 to 1829	1755	12	60 ± 6	$6.9 \pm 4.9 \times 10^{-5}$
1829 to 1981	1914	13	53 ± 3	$2.6 \pm 0.8 \times 10^{-5}$
1981 to 2134	2070	12	52 ± 3	$2.8 \pm 0.5 \times 10^{-5}$
2134 to 2286	2198	12	56 ± 3	$3.0 \pm 0.4 \times 10^{-5}$
2286 to 2438	2371	6	57 ± 3	$3.0 \pm 0.2 \times 10^{-5}$
2438 to 2591	2507	7	58 ± 4	$3.4 \pm 0.6 \times 10^{-5}$
2591 to 2743	2657	5	64 ± 5	$4.8 \pm 0.4 \times 10^{-5}$

B. Leg BC

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation O_3 (ppb)	$B_{(scat)}$ (m^{-1})
0 to 152	119	4	94 ± 2	$32.5 \pm 0.6 \times 10^{-5}$
152 to 305	233	10	92 ± 6	$31.7 \pm 2.5 \times 10^{-5}$
305 to 457	390	25	98 ± 4	$30.9 \pm 3.0 \times 10^{-5}$
457 to 610	529	26	99 ± 6	$31.3 \pm 2.9 \times 10^{-5}$

TABLE IX: ENVELOPE STATISTICAL DATA FOR LEG AB: JULY 31, 1980 (SECOND MISSION)

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation O_3 (ppb)	Average Value ± Standard Deviation $B_{(scat)}$ (m^{-1})
152 to 305	243	12	111 ± 7	44.3 ± 3.9 x 10^{-5}
305 to 457	386	32	116 ± 8	49.2 ± 3.3 x 10^{-5}
457 to 610	525	29	124 ± 7	51.5 ± 2.8 x 10^{-5}
610 to 762	701	8	106 ± 14	51.9 ± 6.8 x 10^{-5}
762 to 914	836	15	93 ± 5	39.0 ± 2.4 x 10^{-5}
914 to 1067	991	12	84 ± 4	32.5 ± 5.6 x 10^{-5}
1067 to 1219	1137	12	79 ± 5	13.9 ± 5.2 x 10^{-5}
1219 to 1372	1297	13	72 ± 4	5.6 ± 1.3 x 10^{-5}
1372 to 1524	1454	11	70 ± 4	4.9 ± 0.3 x 10^{-5}
1524 to 1679	1597	11	66 ± 4	5.6 ± 1.0 x 10^{-5}
1679 to 1829	1752	14	64 ± 7	5.3 ± 1.1 x 10^{-5}
1829 to 1981	1906	13	76 ± 11	10.0 ± 2.4 x 10^{-5}
1981 to 2134	2060	11	87 ± 4	12.2 ± 0.5 x 10^{-5}
2134 to 2286	2216	12	87 ± 3	12.2 ± 0.9 x 10^{-5}
2286 to 2438	2359	13	88 ± 3	8.9 ± 0.6 x 10^{-5}
2438 to 2591	2510	12	85 ± 4	7.9 ± 0.2 x 10^{-5}
2591 to 2743	2666	13	79 ± 3	7.6 ± 0.2 x 10^{-5}

TABLE X: CESSNA FLIGHT SEQUENCE FOR AUGUST 2, 1980 CORRELATIVE MISSION

Time (e.d.t.)	Altitude (m)	Flight Leg
1214 to 1225	600	constant altitude B to A
1225 to 1227	600 to 300	spiral at A
1227 to 1243	300	constant altitude A to B
1243 to 1245	300 to 600	spiral at B
1245 to 1251	600	constant altitude B to C
1251 to 1254	600 to surf	spiral at C
1254 to 1312	surf to 2700	spiral at C
1312 to 1325	2700 to 600	spiral at C

TABLE XI: ENVELOPE STATISTICAL DATA FOR LEG AB, AUGUST 2, 1980

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation O_3 (ppb)	Average Value ± Standard Deviation $B_{(scat)}$ (m^{-1})
n0 to 152	80	10	---------[1]	$13.7 \pm 0.5 \times 10^{-5}$
152 to 305	234	12	---------	$12.9 \pm 0.6 \times 10^{-5}$
305 to 457	385	25	---------	$12.4 \pm 0.5 \times 10^{-5}$
457 to 610	539	24	---------	$12.3 \pm 0.4 \times 10^{-5}$
610 to 762	679	12	---------	$12.0 \pm 0.6 \times 10^{-5}$
762 to 914	839	13	---------	$11.7 \pm 0.8 \times 10^{-5}$
914 to 1067	994	9	---------	$12.5 \pm 1.0 \times 10^{-5}$
1067 to 1219	1150	11	---------	$10.5 \pm 1.5 \times 10^{-5}$
1219 to 1372	1297	11	---------	$7.6 \pm 1.2 \times 10^{-5}$
1372 to 1524	1450	11	---------	$5.7 \pm 1.1 \times 10^{-5}$
1524 to 1679	1603	11	---------	$4.1 \pm 1.6 \times 10^{-5}$
1679 to 1829	1757	9	---------	$3.9 \pm 0.7 \times 10^{-5}$
1829 to 1981	1906	11	---------	$3.6 \pm 0.6 \times 10^{-5}$
1981 to 2134	2060	10	---------	$4.3 \pm 0.2 \times 10^{-5}$
2134 to 2286	2213	12	---------	$4.6 \pm 0.4 \times 10^{-5}$
2286 to 2438	2359	10	---------	$4.5 \pm 0.4 \times 10^{-5}$
2438 to 2591	2507	11	---------	$3.9 \pm 0.7 \times 10^{-5}$
2591 to 2743	2671	12	---------	$2.4 \pm 0.3 \times 10^{-5}$
2743 to 2895	2811	9	---------	$2.0 \pm 0.1 \times 10^{-5}$

[1] no O_3 data measured during the mission

TABLE XII: CESSNA FLIGHT SEQUENCE FOR AUGUST 5, 1980 CORRELATIVE MISSION

Time (e.d.t.)	Altitude (m)	Flight Leg
0930 to 0946	600	constant altitude A to B
0946 to 0949	600 to 300	spiral at B
0949 to 1004	300	constant altitude A to B
1004 to 1009	300 to 600	spiral at A
1009 to 1017	600	constant altitude A to C
1017 to 1022	600 to surf	spiral at C
1022 to 1047	surf to 3400	spiral at C
1047 to 1109	3400 to 600	spiral at C

TABLE XIII: ENVELOPE STATISTICAL DATA FOR LEG AB: AUGUST 5, 1980

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation	
			O_3 (ppb)	β(scat) (m^{-1})
0 to 152	91	13	47 ± 2	$14.7 \pm 0.4 \times 10^{-5}$
152 to 305	250	25	45 ± 6	$14.4 \pm 0.5 \times 10^{-5}$
305 to 457	379	27	47 ± 4	$14.6 \pm 0.4 \times 10^{-5}$
457 to 610	543	38	58 ± 5	$12.8 \pm 1.0 \times 10^{-5}$
610 to 762	685	11	64 ± 2	$11.4 \pm 0.8 \times 10^{-5}$
762 to 914	840	13	64 ± 2	$10.9 \pm 0.5 \times 10^{-5}$
914 to 1067	992	12	69 ± 3	$10.8 \pm 2.1 \times 10^{-5}$
1067 to 1219	1138	16	66 ± 3	$10.4 \pm 1.9 \times 10^{-5}$
1219 to 1372	1293	14	65 ± 2	$8.6 \pm 0.8 \times 10^{-5}$
1372 to 1524	1443	13	67 ± 5	$8.8 \pm 0.2 \times 10^{-5}$
1524 to 1679	1595	13	65 ± 3	$8.3 \pm 0.2 \times 10^{-5}$
1679 to 1829	1746	12	66 ± 2	$8.3 \pm 0.3 \times 10^{-5}$
1829 to 1981	1902	13	65 ± 3	$8.5 \pm 0.2 \times 10^{-5}$
1981 to 2134	2055	12	66 ± 3	$8.4 \pm 0.3 \times 10^{-5}$
2134 to 2286	2210	15	66 ± 4	$8.7 \pm 0.2 \times 10^{-5}$
2286 to 2438	2359	12	65 ± 3	$8.8 \pm 0.4 \times 10^{-5}$
2438 to 2591	2510	13	60 ± 3	$9.2 \pm 0.4 \times 10^{-5}$
2591 to 2743	2669	13	57 ± 2	$8.0 \pm 1.2 \times 10^{-5}$
2743 to 2895	2817	12	56 ± 2	$5.8 \pm 0.3 \times 10^{-5}$
2895 to 3048	2967	12	54 ± 3	$5.3 \pm 0.3 \times 10^{-5}$
3048 to 3200	3127	14	55 ± 4	$5.1 \pm 0.5 \times 10^{-5}$
3200 to 3353	3279	12	54 ± 4	$4.3 \pm 1.2 \times 10^{-5}$
3353 to 3505	3377	5	55 ± 4	$2.5 \pm 0.3 \times 10^{-5}$

TABLE XIV: CESSNA FLIGHT SEQUENCE FOR AUGUST 7, 1980 CORRELATIVE MISSION

Time (e.d.t.)	Altitude (m)	Flight Leg
1737 to 1746	450	constant altitude A to B
1746 to 1747	450 to 150	spiral at B
1747 to 1759	150 to 1800	spiral at B
1759 to 1808	1800(B) to 600(A)	constant rate of descent B to A
1808 to 1811	600 to 100	spiral at A
1811 to 1824	100 to 1800	spiral at A
1824 to 1836	1800(A) to surf(B)	constant rate of descent A to B
1836 to 1838	surf to 300	spiral at B
1838 to 1849	300	constant altitude B to A

TABLE XV: ENVELOPE STATISTICAL DATA FOR LEG AB, AUGUST 7, 1980

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation O_3 (ppb)	Average Value ± Standard Deviation $B_{(scat)}$ (m^{-1})
0 to 152	106	22	94 ± 3	$16.8 \pm 1.1 \times 10^{-5}$
152 to 305	225	36	97 ± 4	$17.7 \pm 2.5 \times 10^{-5}$
305 to 457	384	22	98 ± 3	$21.1 \pm 3.8 \times 10^{-5}$
457 to 610	540	23	101 ± 4	$25.3 \pm 3.4 \times 10^{-5}$
610 to 762	682	24	102 ± 4	$27.5 \pm 2.3 \times 10^{-5}$
762 to 914	832	27	101 ± 3	$26.9 \pm 2.2 \times 10^{-5}$
914 to 1067	991	25	101 ± 4	$26.8 \pm 3.4 \times 10^{-5}$
1067 to 1219	1143	25	98 ± 3	$25.6 \pm 3.7 \times 10^{-5}$
1219 to 1372	1300	27	94 ± 4	$23.9 \pm 3.9 \times 10^{-5}$
1372 to 1524	1446	24	75 ± 20	$15.6 \pm 8.0 \times 10^{-5}$
1524 to 1679	1601	28	46 ± 11	$1.2 \pm 1.0 \times 10^{-5}$
1679 to 1829	1744	27	42 ± 3	$0.7 \pm 0.2 \times 10^{-5}$

TABLE XVI: CESSNA FLIGHT SEQUENCE FOR AUGUST 12, 1980 CORRELATIVE MISSION

Time (e.d.t.)	Altitude (m)	Flight Leg
1108 to 1130	900(C) to 3000(B)	constant rate of ascent, C to A
1130 to 1142	3000 to 1500	spiral at A
1142 to 1151	1500	constant altitude A to B
1151 to 1203	1500 to 3000	spiral at B
1203 to 1215	3000(B)to 1500(A)	constant rate of descent, B to A

TABLE XVII: ENVELOPE STATISTICAL DATA FOR LEG AB: AUGUST 12, 1980

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation	
			O_3 (ppb)	$B_{(scat)}$ (m^{-1})
914 to 1067	1050	2	71 ± 2	$13.8 \pm 0.0 \times 10^{-5}$
1067 to 1219	1129	8	70 ± 3	$13.6 \pm 0.2 \times 10^{-5}$
1219 to 1372	1299	8	67 ± 3	$14.5 \pm 0.9 \times 10^{-5}$
1372 to 1524	1446	7	67 ± 3	$17.0 \pm 0.9 \times 10^{-5}$
1524 to 1679	1597	31	68 ± 5	$17.4 \pm 1.6 \times 10^{-5}$
1679 to 1829	1756	28	72 ± 6	$17.8 \pm 1.2 \times 10^{-5}$
1829 to 1981	1903	31	72 ± 6	$17.5 \pm 1.7 \times 10^{-5}$
1981 to 2134	2054	28	70 ± 3	$17.2 \pm 1.1 \times 10^{-5}$
2134 to 2286	2206	28	67 ± 3	$17.0 \pm 1.0 \times 10^{-5}$
2286 to 2438	2358	26	65 ± 5	$15.7 \pm 3.1 \times 10^{-5}$
2438 to 2591	2516	28	63 ± 5	$14.5 \pm 3.6 \times 10^{-5}$
2591 to 2743	2675	29	64 ± 4	$14.3 \pm 3.4 \times 10^{-5}$
2743 to 2895	2811	29	62 ± 5	$12.0 \pm 3.6 \times 10^{-5}$
2895 to 3048	2959	34	61 ± 3	$10.1 \pm 2.4 \times 10^{-5}$
3048 to 3200	3075	32	58 ± 3	$10.3 \pm 7.9 \times 10^{-5}$

TABLE XVIII: CESSNA FLIGHT SEQUENCES FOR AUGUST 13, 1980 CORRELATIVE MISSIONS

A. First Mission

Time (e.d.t.)	Altitude (m)	Flight Leg
1237 to 1247	900 to 2400	spiral at A
1249 to 1256	2400 to 900	spiral at A
1256 to 1306	900	constant altitude A to B
1306 to 1314	900 to 2400	spiral at B
1318 to 1329	2400 to 600	spiral at B

B. Second Mission

Time (e.d.t.)	Altitude (m)	Flight Leg
1619 to 1632	600 to 2400	spiral at A
1633 to 1646	2400 to 600	spiral at A
1646 to 1652	600	constant altitude, A to B
1652 to 1703	600 to 2400	spiral at B
1703 to 1717	2400 to 600	spiral at B

TABLE XIX: ENVELOPE STATISTICAL DATA FOR LEG AB: AUGUST 13, 1980 (FIRST MISSION)

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation O_3 (ppb)	Average Value ± Standard Deviation $B_{(scat)}$ (m^{-1})
610 to 762	730	5	65 ± 2	18.5 ± 0.3 x 10^{-5}
762 to 914	868	10	66 ± 3	16.6 ± 1.3 x 10^{-5}
914 to 1067	977	28	64 ± 4	14.6 ± 2.1 x 10^{-5}
1067 to 1219	1140	20	66 ± 5	13.9 ± 1.7 x 10^{-5}
1219 to 1372	1293	18	65 ± 3	13.3 ± 1.7 x 10^{-5}
1372 to 1524	1448	18	64 ± 4	12.5 ± 1.5 x 10^{-5}
1524 to 1679	1596	18	63 ± 4	11.9 ± 2.8 x 10^{-5}
1679 to 1829	1747	18	62 ± 3	10.2 ± 3.0 x 10^{-5}
1829 to 1981	1901	18	55 ± 6	9.0 ± 3.7 x 10^{-5}
1981 to 2134	2061	23	51 ± 7	6.2 ± 4.0 x 10^{-5}
2134 to 2286	2215	21	42 ± 5	2.3 ± 1.4 x 10^{-5}
2286 to 2438	2369	23	36 ± 2	7.8 ± 10.6 x 10^{-5}

TABLE XX: ENVELOPE STATISTICAL DATA: AUGUST 13, 1980 (SECOND MISSION)

A. Locaton A

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation	
			O_3 (ppb)	$B_{(scat)}$ (m^{-1})
457 to 610	602	5	77 ± 7	24.1 ± 4.3 x 10^{-5}
610 to 762	671	19	75 ± 6	21.9 ± 3.4 x 10^{-5}
762 to 914	834	13	72 ± 7	23.1 ± 3.1 x 10^{-5}
914 to 1067	989	14	64 ± 11	23.7 ± 2.1 x 10^{-5}
1067 to 1219	1143	13	54 ± 20	24.3 ± 1.7 x 10^{-5}
1219 to 1372	1304	13	50 ± 25	23.8 ± 1.0 x 10^{-5}
1372 to 1524	1444	11	52 ± 26	24.7 ± 1.0 x 10^{-5}
1524 to 1679	1592	12	76 ± 3	23.4 ± 1.7 x 10^{-5}
1679 to 1829	1766	13	70 ± 3	19.8 ± 1.3 x 10^{-5}
1829 to 1981	1905	8	73 ± 4	16.1 ± 1.4 x 10^{-5}
1981 to 2134	2045	11	70 ± 10	14.9 ± 1.3 x 10^{-5}
2134 to 2286	2209	11	60 ± 3	12.1 ± 1.1 x 10^{-5}
2286 to 2438	2362	12	48 ± 9	6.1 ± 2.9 x 10^{-5}
2438 to 2591	2461	5	50 ± 6	1.3 ± 0.5 x 10^{-5}

TABLE XX: Continued

B. Location B

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation: O_3 (ppb)	Average Value ± Standard Deviation: $B_{(scat)}$ (m^{-1})
457 to 610	596	4	86 ± 1	26.4 ± 0.7 x 10^{-5}
610 to 762	700	11	88 ± 2	25.7 ± 0.7 x 10^{-5}
762 to 914	839	15	87 ± 2	25.9 ± 0.5 x 10^{-5}
914 to 1067	997	12	87 ± 3	25.5 ± 0.6 x 10^{-5}
1067 to 1219	1154	12	87 ± 2	24.9 ± 0.7 x 10^{-5}
1219 to 1372	1298	12	87 ± 4	24.4 ± 0.8 x 10^{-5}
1372 to 1524	1452	13	85 ± 5	23.5 ± 1.7 x 10^{-5}
1524 to 1679	1604	11	79 ± 4	20.0 ± 1.3 x 10^{-5}
1679 to 1829	1740	11	73 ± 3	17.9 ± 1.0 x 10^{-5}
1829 to 1981	1914	12	74 ± 4	14.8 ± 1.0 x 10^{-5}
1981 to 2134	2053	10	66 ± 10	11.4 ± 4.2 x 10^{-5}
2134 to 2286	2211	11	50 ± 12	4.4 ± 2.4 x 10^{-5}
2286 to 2438	2361	11	40 ± 8	2.2 ± 0.5 x 10^{-5}
2438 to 2591	2456	5	35 ± 3	1.7 ± 0.2 x 10^{-5}

TABLE XX: Concluded

C. Leg AB (Spiral A and B data)

Altitude Range (m)	Altitude Average (m)	Number of Data Points	Average Value ± Standard Deviation O_3 (ppb)	Average Value ± Standard Deviation $B_{(scat)}$ (m^{-1})
457 to 610	600	9	81 ± 7	25.1 ± 3.3 x 10^{-5}
610 to 762	682	30	80 ± 8	23.3 ± 3.3 x 10^{-5}
762 to 914	837	28	80 ± 9	24.6 ± 2.6 x 10^{-5}
914 to 1067	993	26	74 ± 14	24.5 ± 1.8 x 10^{-5}
1067 to 1219	1148	25	70 ± 22	24.6 ± 1.3 x 10^{-5}
1219 to 1372	1301	25	68 ± 26	24.1 ± 1.0 x 10^{-5}
1372 to 1524	1448	24	70 ± 24	24.0 ± 1.5 x 10^{-5}
1524 to 1679	1598	23	78 ± 4	21.8 ± 2.3 x 10^{-5}
1679 to 1829	1754	24	71 ± 3	18.9 ± 1.5 x 10^{-5}
1829 to 1981	1910	20	74 ± 4	15.3 ± 1.3 x 10^{-5}
1981 to 2134	2049	21	68 ± 10	13.3 ± 3.4 x 10^{-5}
2134 to 2286	2210	22	55 ± 10	8.2 ± 4.3 x 10^{-5}
2286 to 2438	2361	23	44 ± 9	4.2 ± 2.9 x 10^{-5}
2438 to 2591	2458	10	43 ± 9	1.5 ± 0.4 x 10^{-5}

Figure 1. [illegible] sampling aircraft.

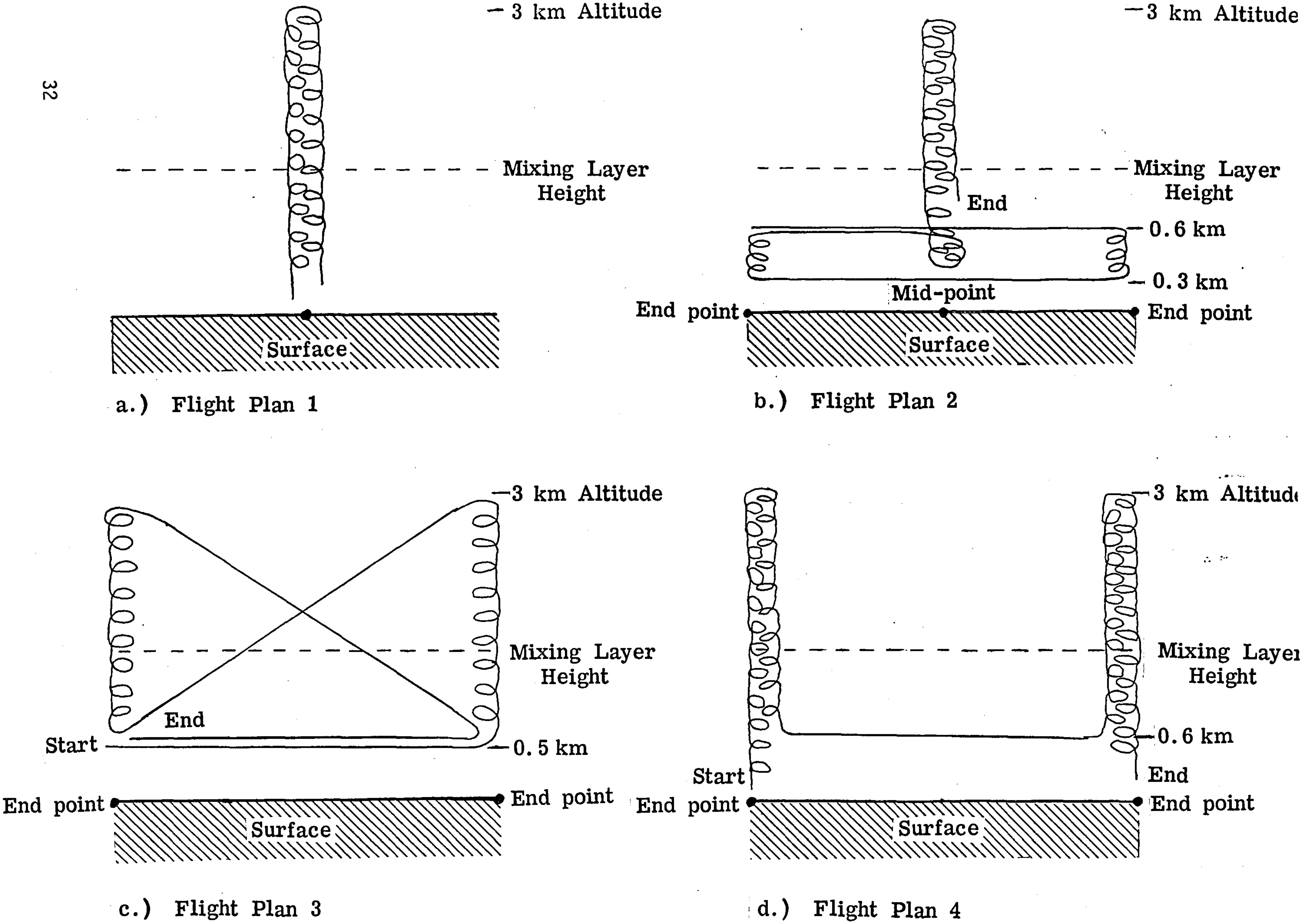


Figure 2. - In situ flight plans.

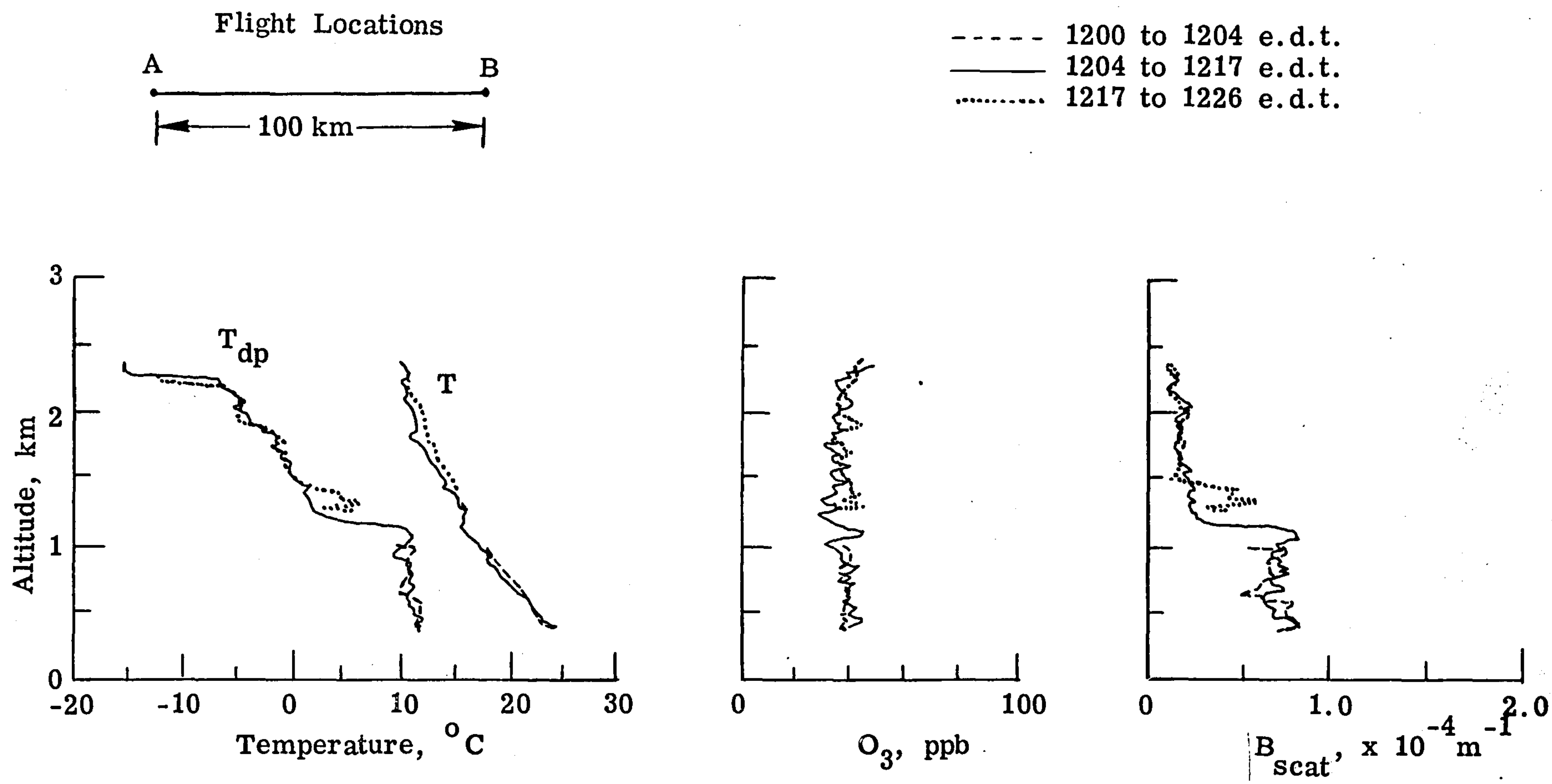


Figure 3. - Spiral data at A, July 24, 1980.

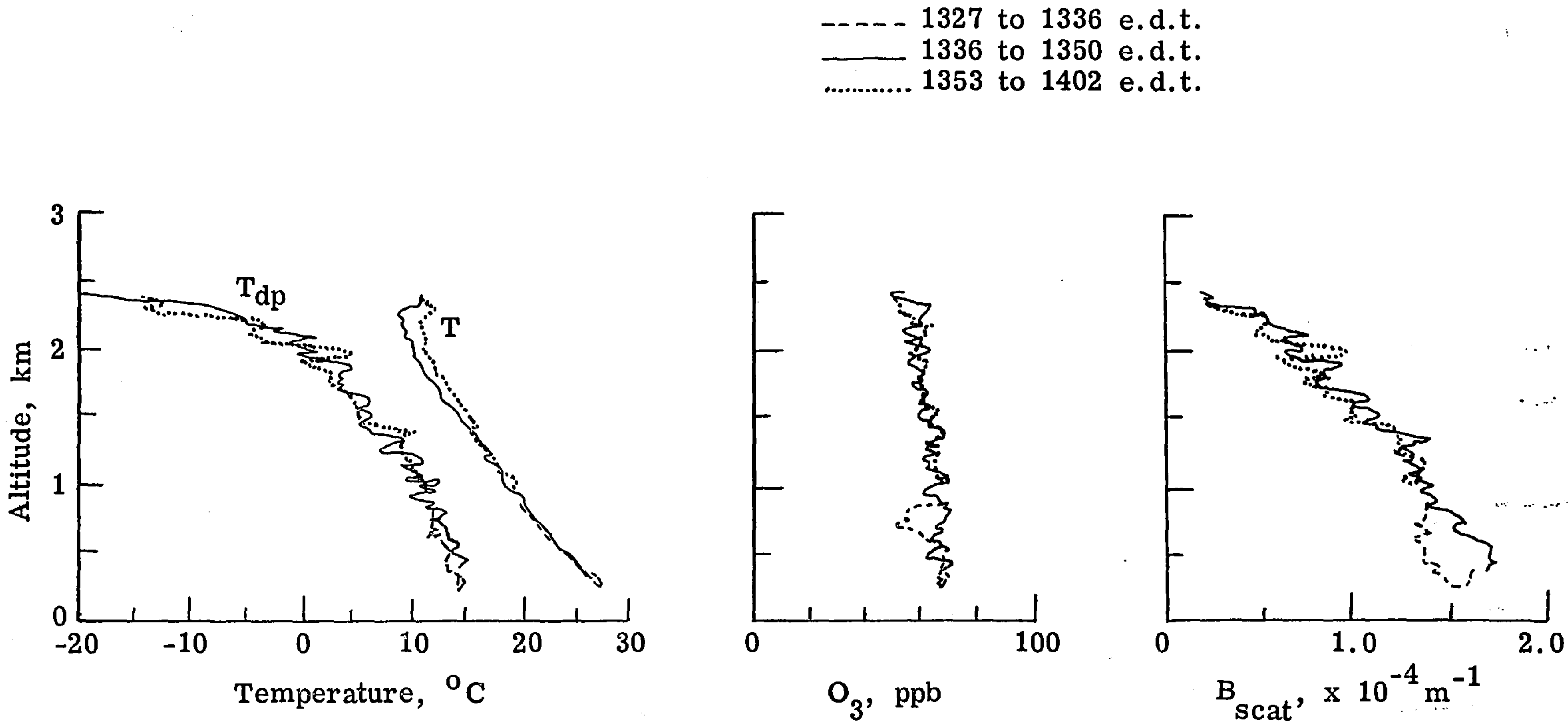


Figure 4. - Spiral data at B, July 24, 1980.

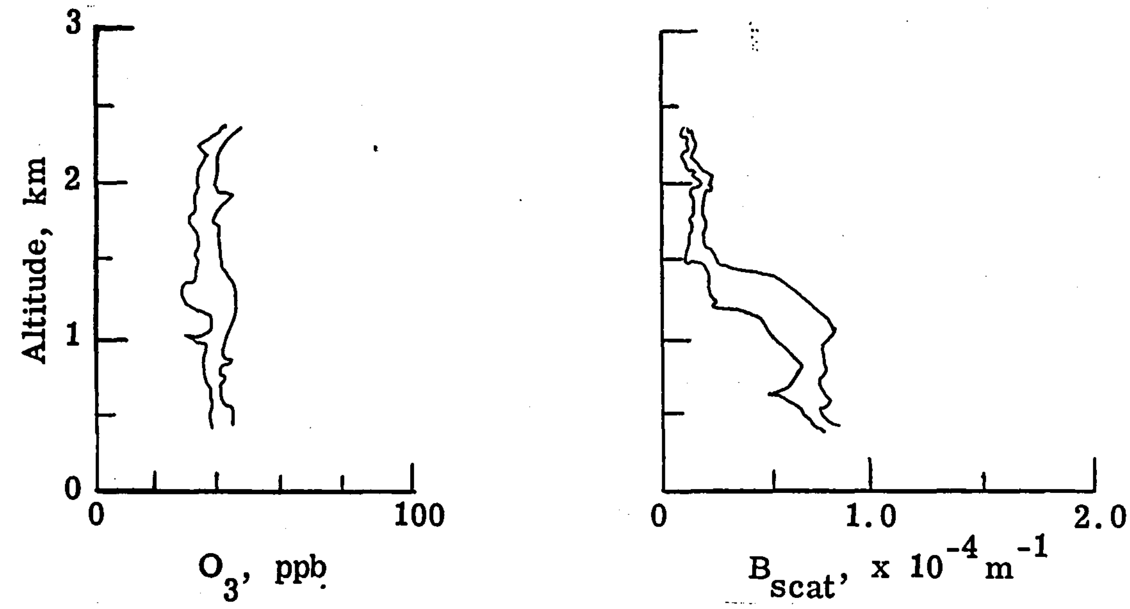


Figure 5. - Data envelopes at A, July 24, 1980.

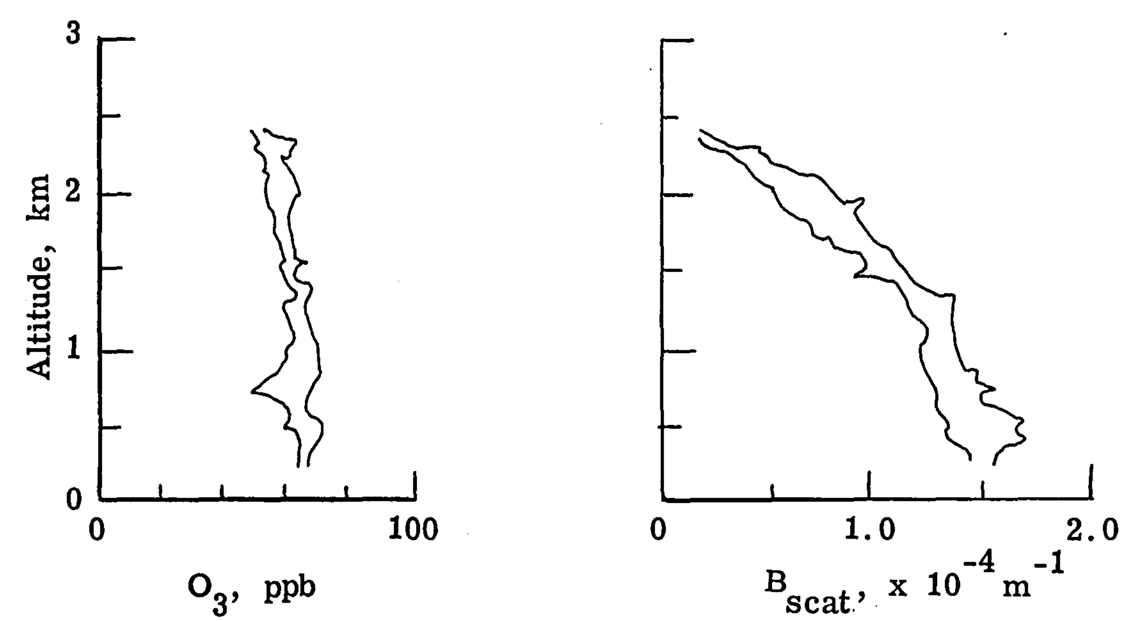


Figure 6. - Data envelopes at B, July 24, 1980.

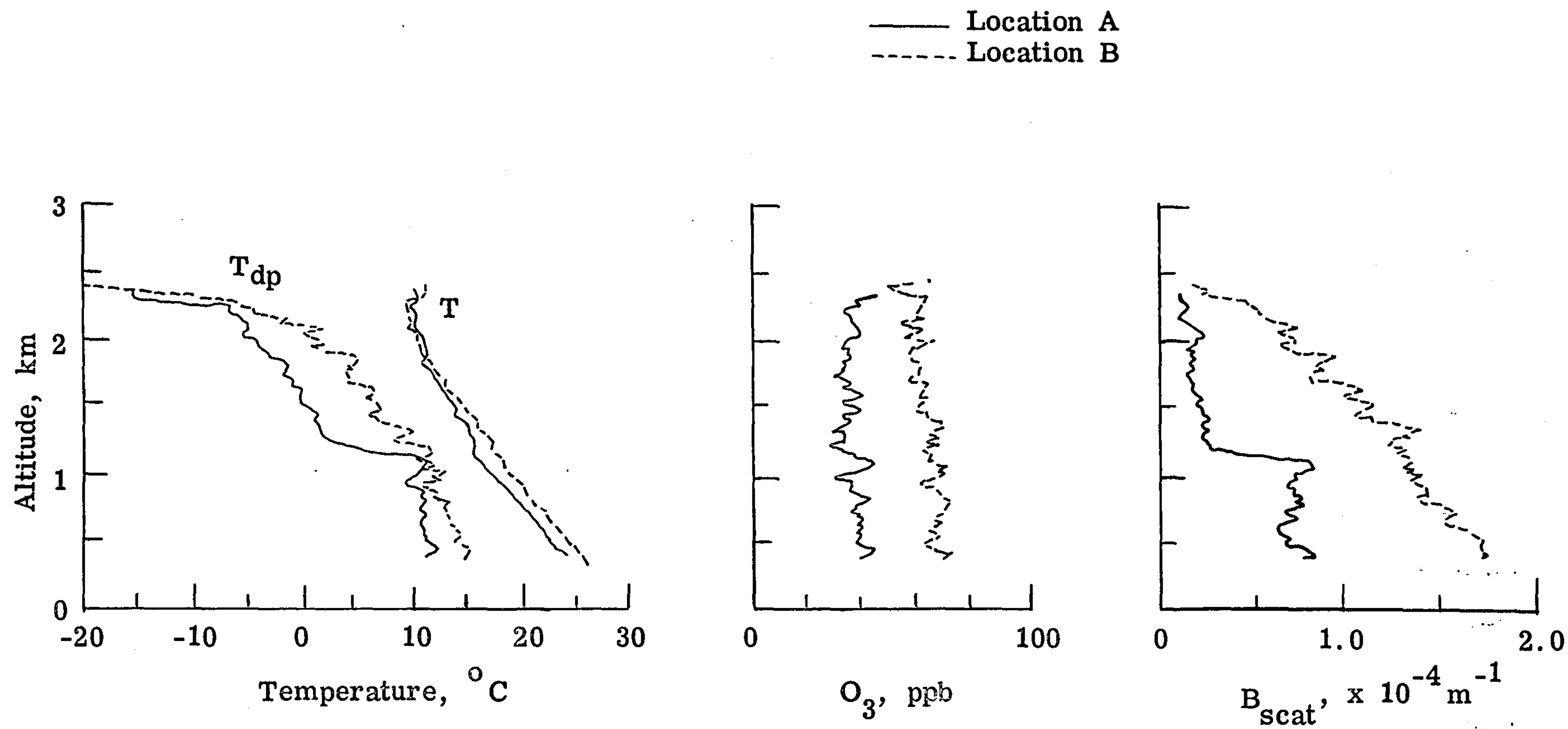
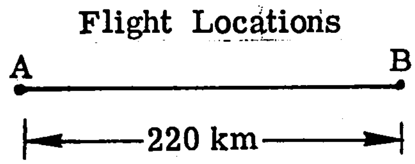


Figure 7. - Comparison of results at A and B, July 24, 1980.



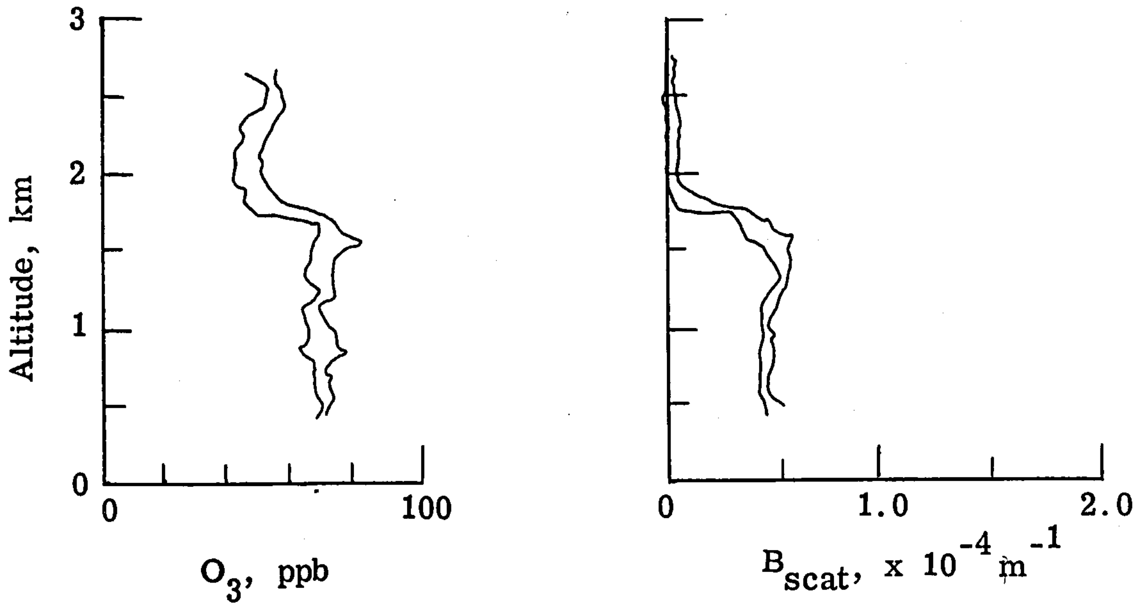


Figure 8. - Data envelopes at A, July 25, 1980.

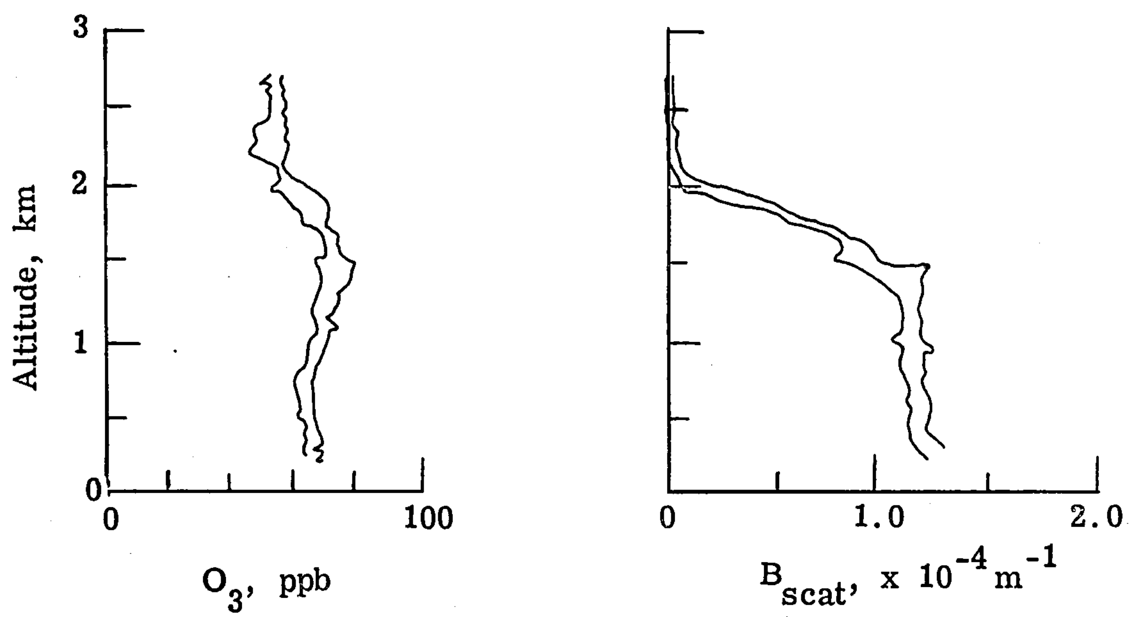


Figure 9. - Data envelopes at B, July 25, 1980.

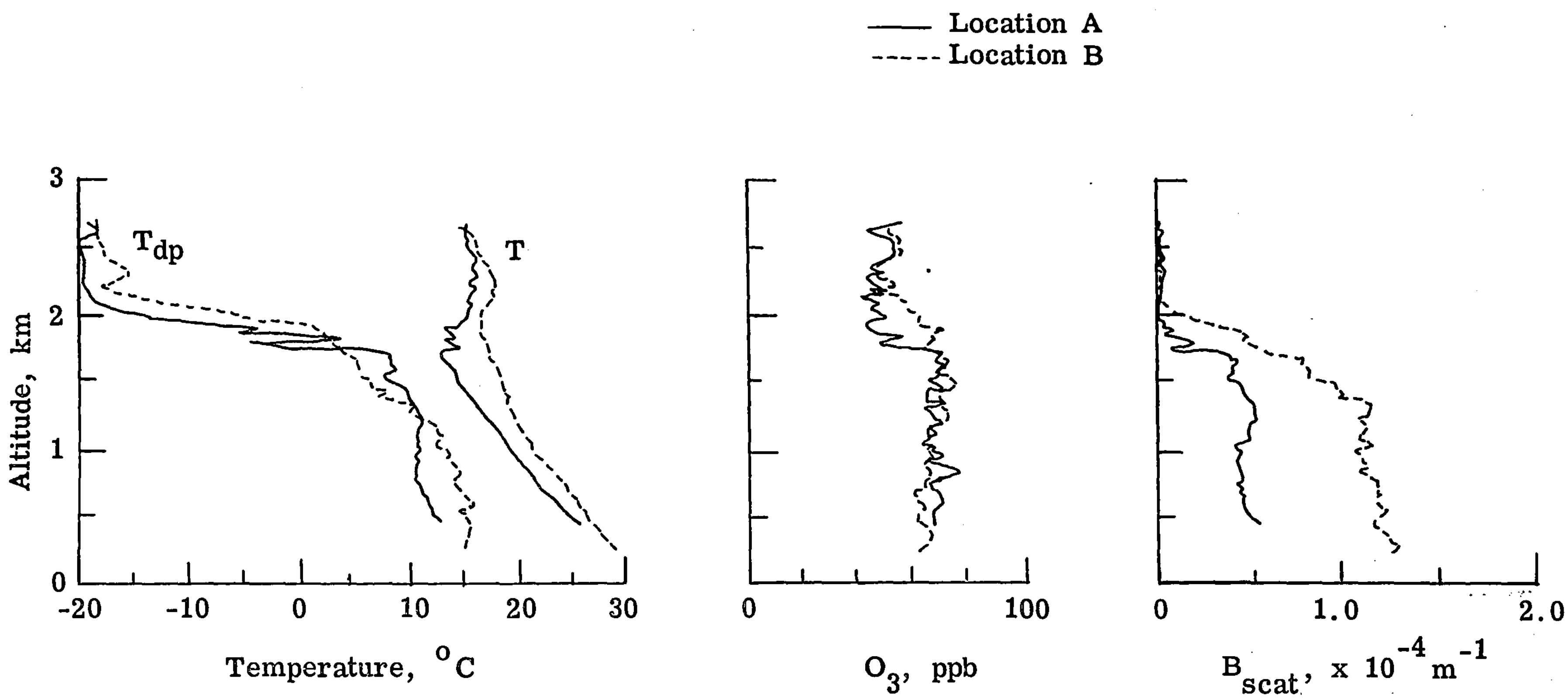


Figure 10. - Comparison of results at A and B, July 25, 1980.

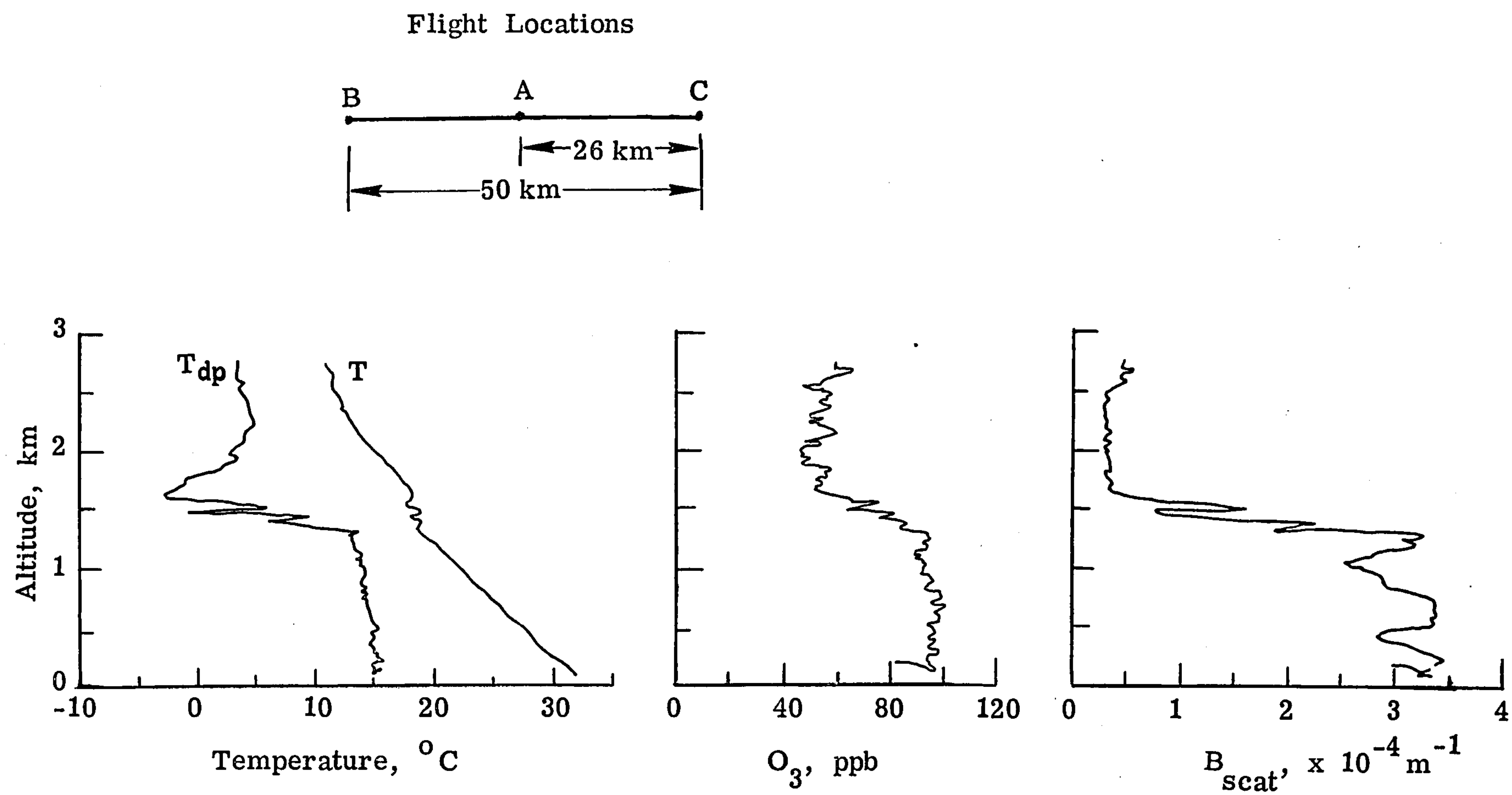


Figure 11. - Spiral data at A, first mission, July 31, 1980.

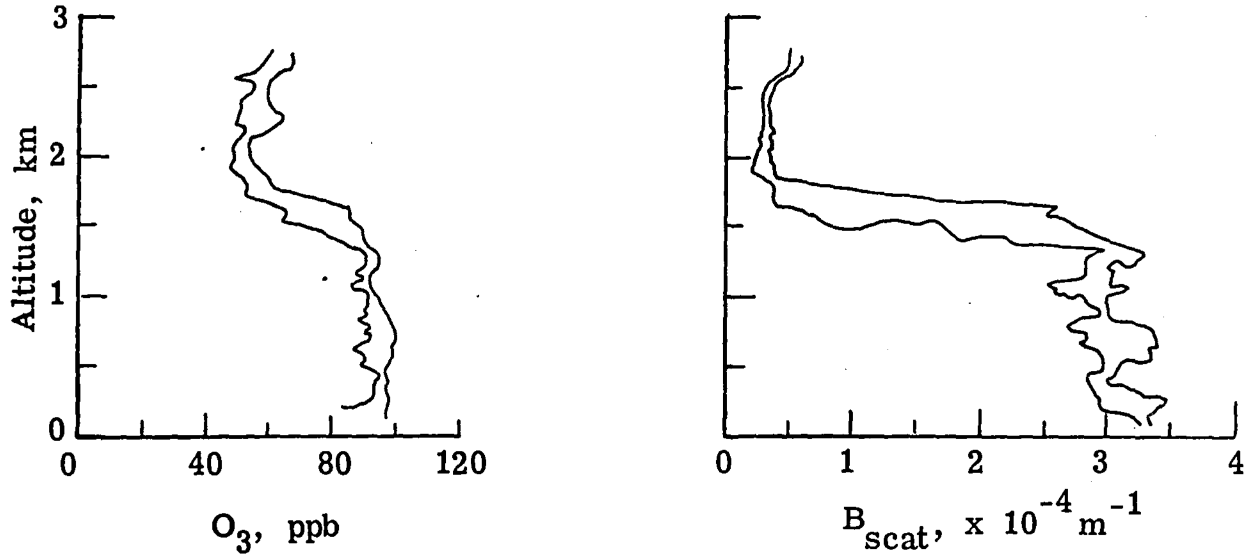


Figure 12. - Data envelopes at A, first mission, July 31, 1980.

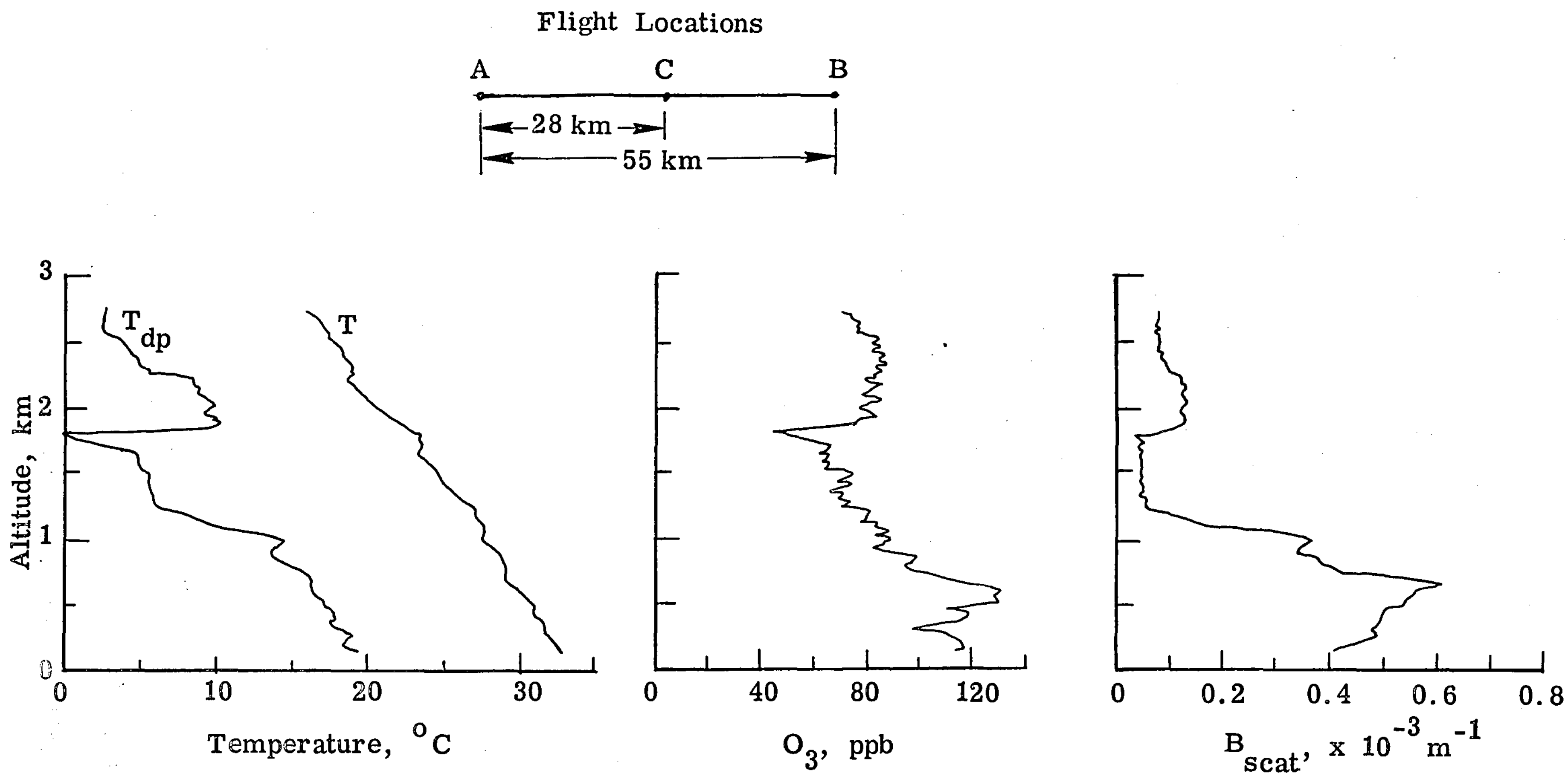


Figure 13. - Spiral data at C, second mission, July 31, 1980.

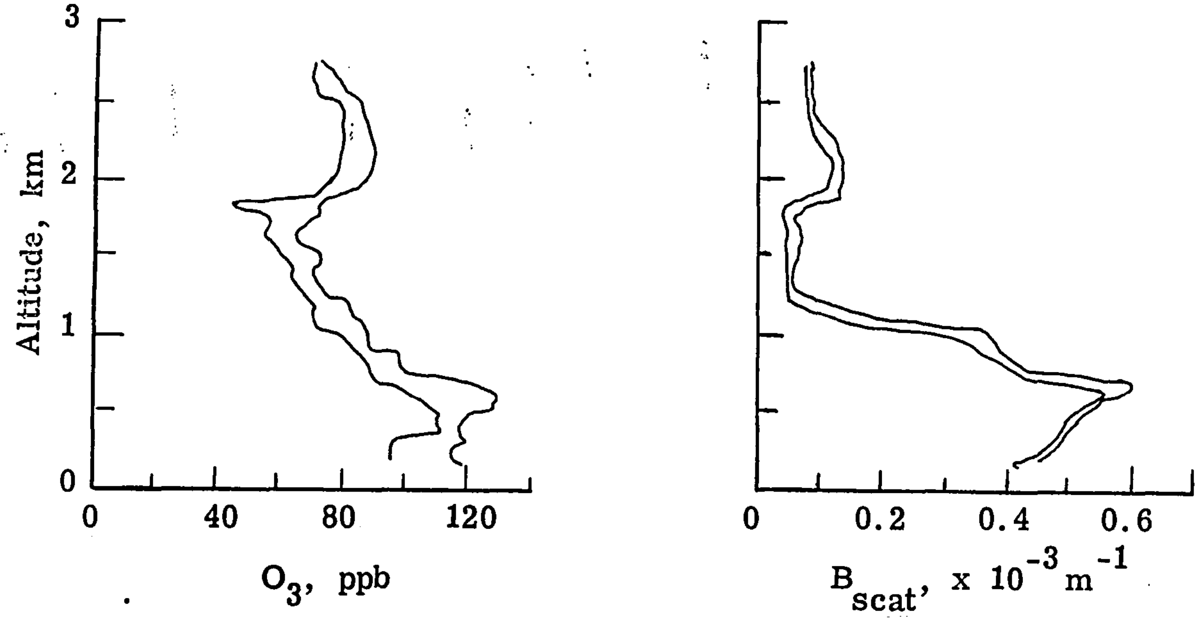


Figure 14. - Data envelopes at C, second mission, July 31, 1980.

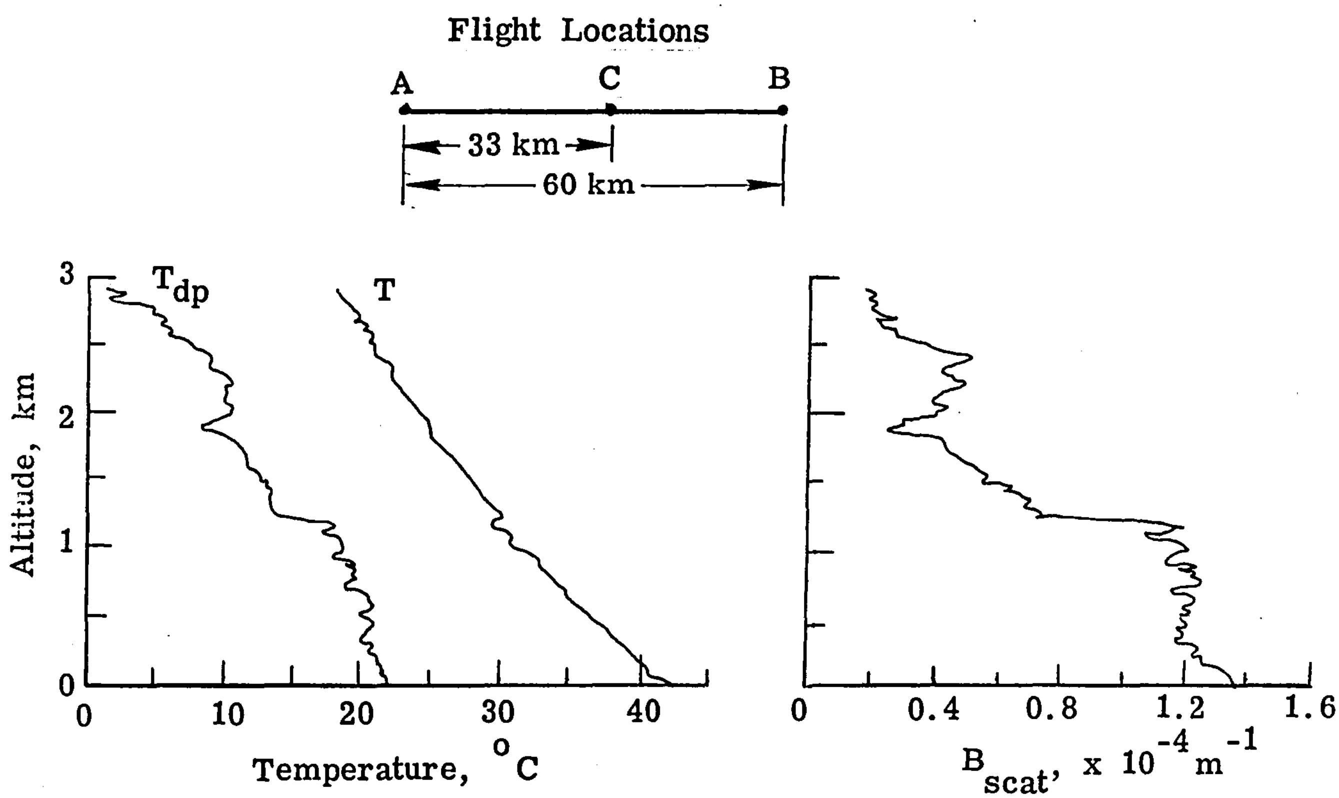


Figure 15. - Spiral data at C, August 2, 1980.

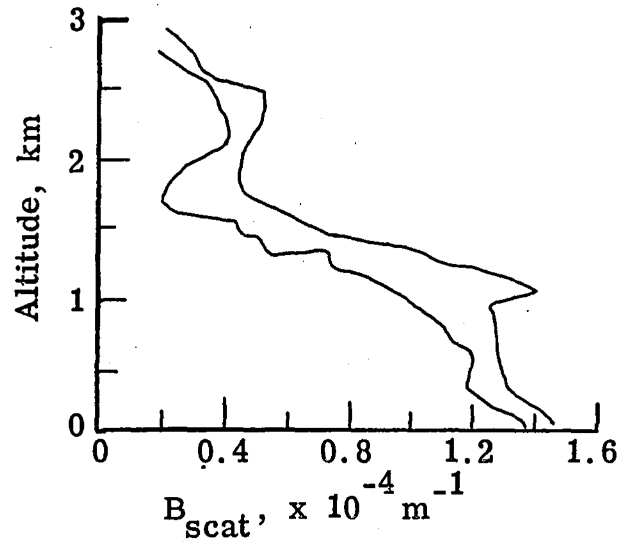


Figure 16. - B_{scat} data envelope at C, August 2, 1980.

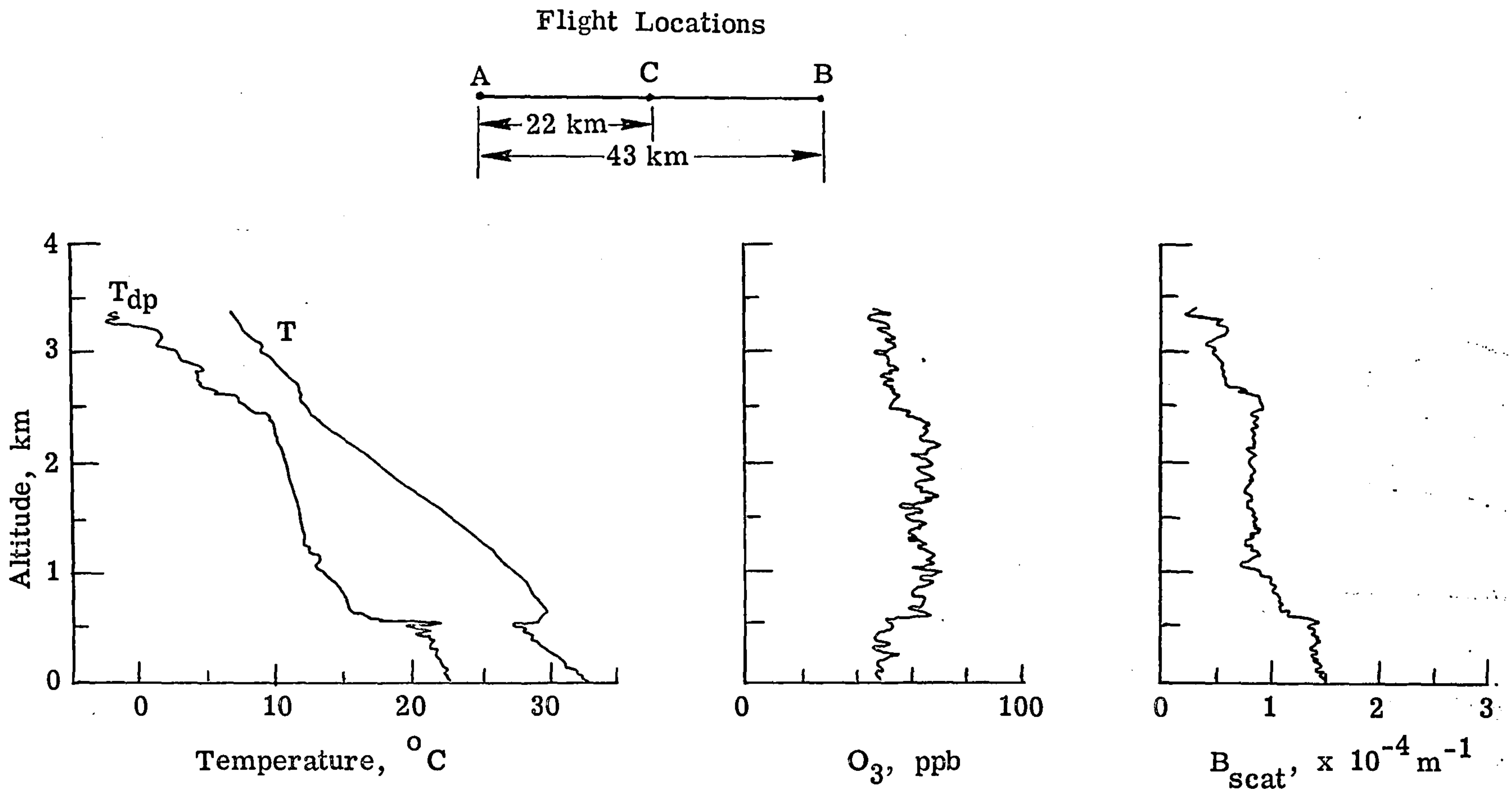


Figure 17. - Spiral data at C, August 5, 1980.

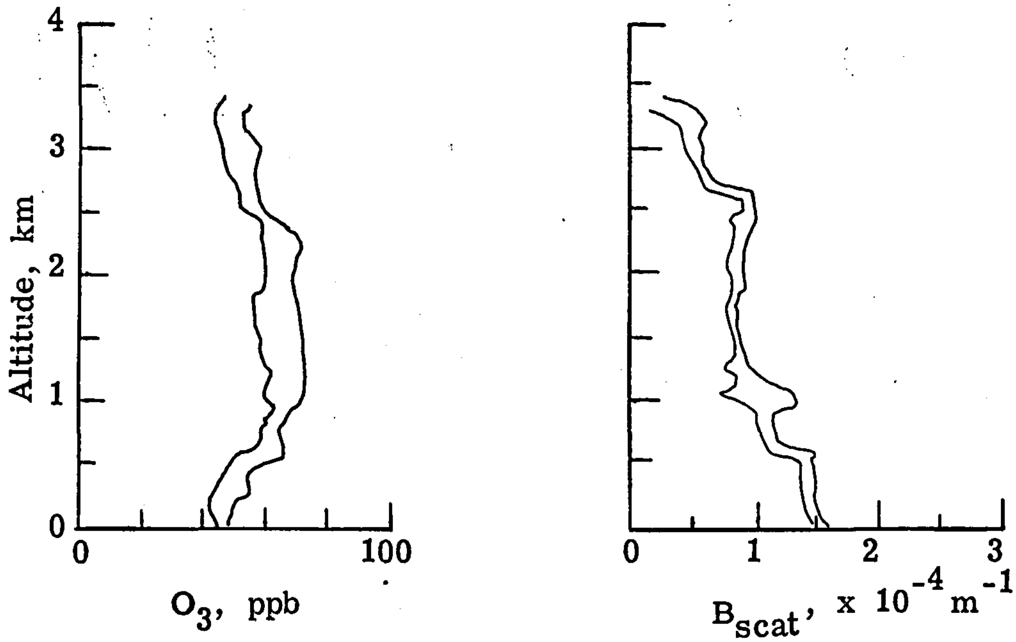


Figure 18. - Data envelopes at C, August 5, 1980.

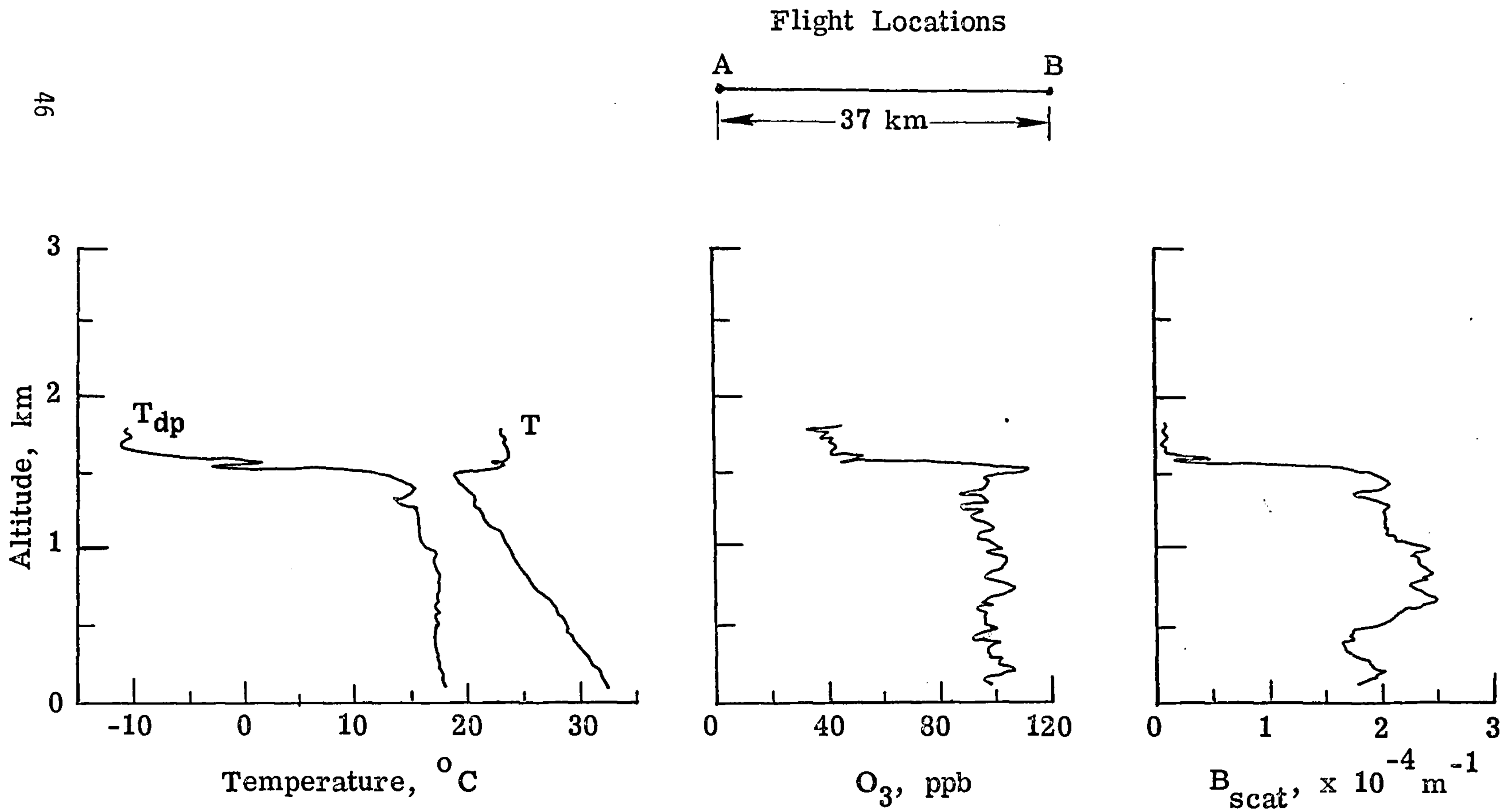


Figure 19. - Spiral data at B, August 7, 1980.

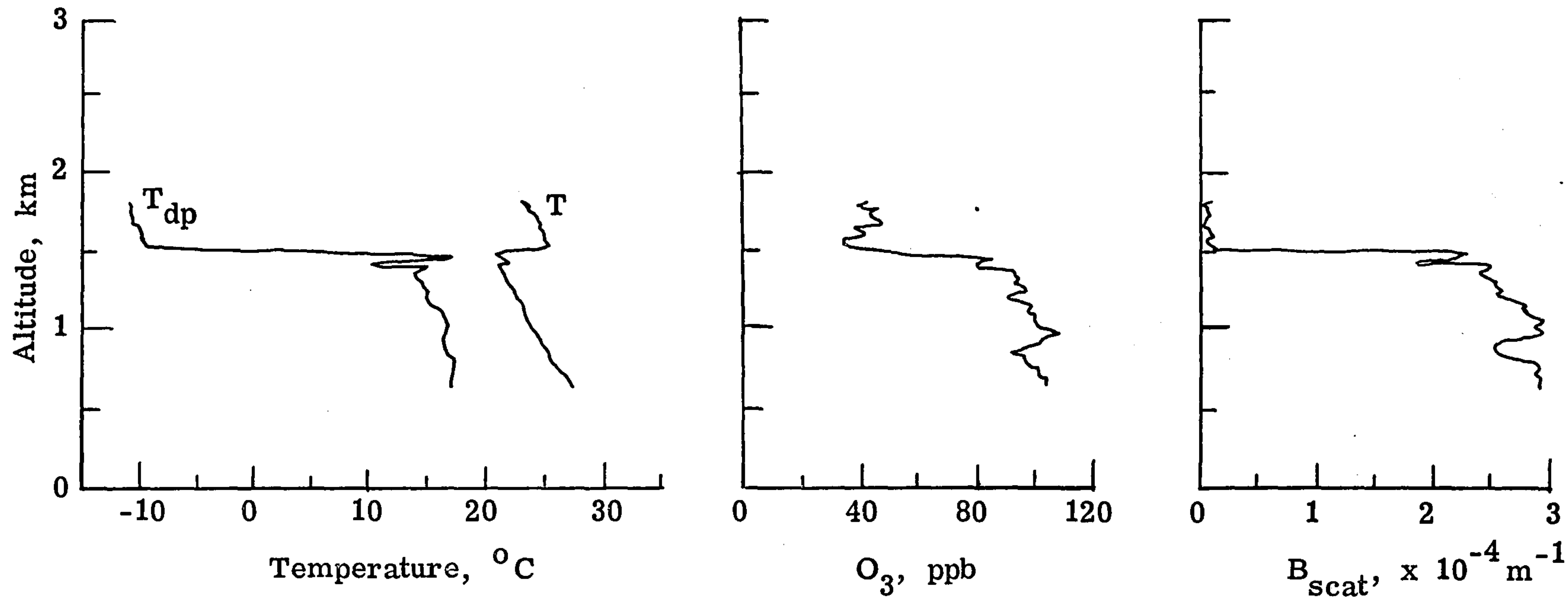


Figure 20. - Descent leg B to A data, August 7, 1980.

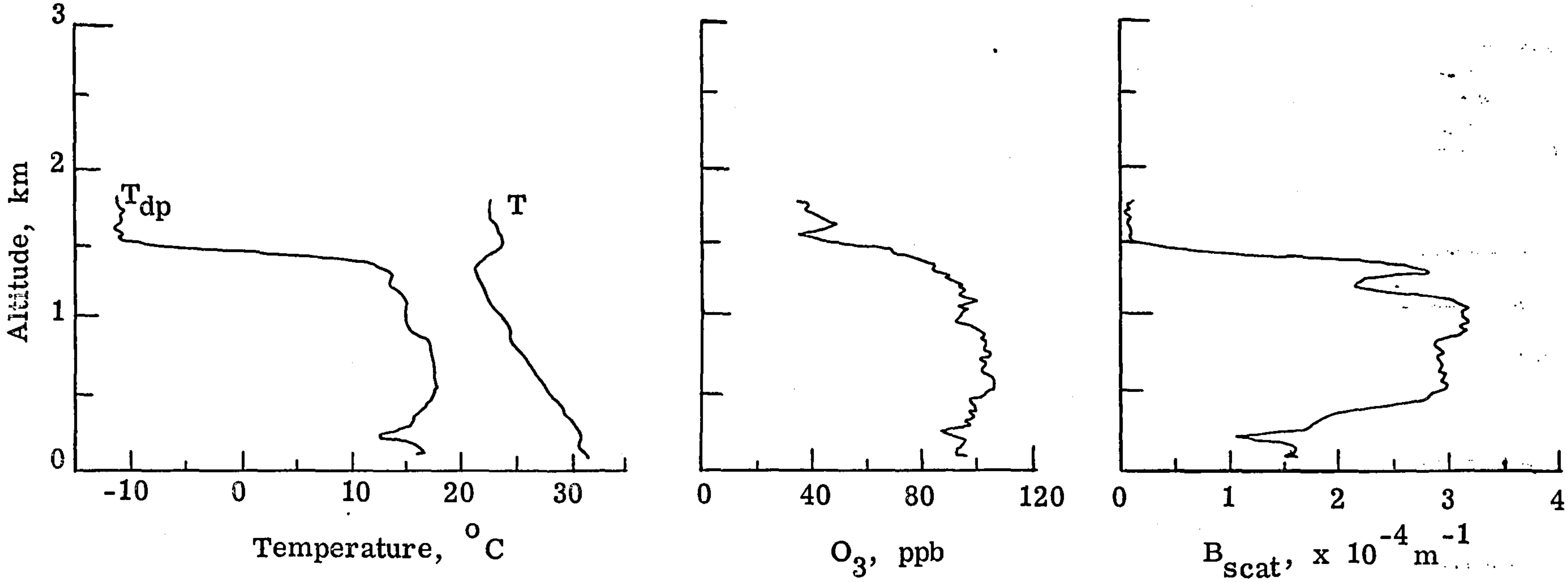


Figure 21. - Spiral data at A, August 7, 1980.

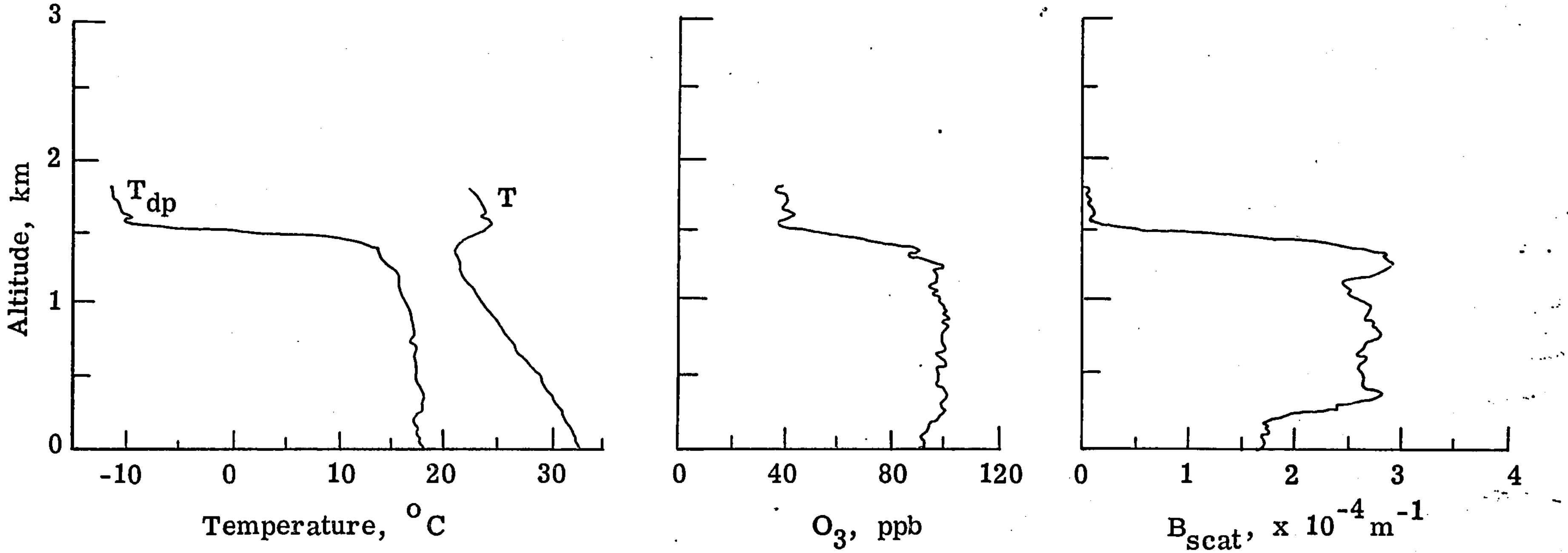


Figure 22. - Descent leg A to B data, August 7, 1980.

× Data points omitted from envelope plots

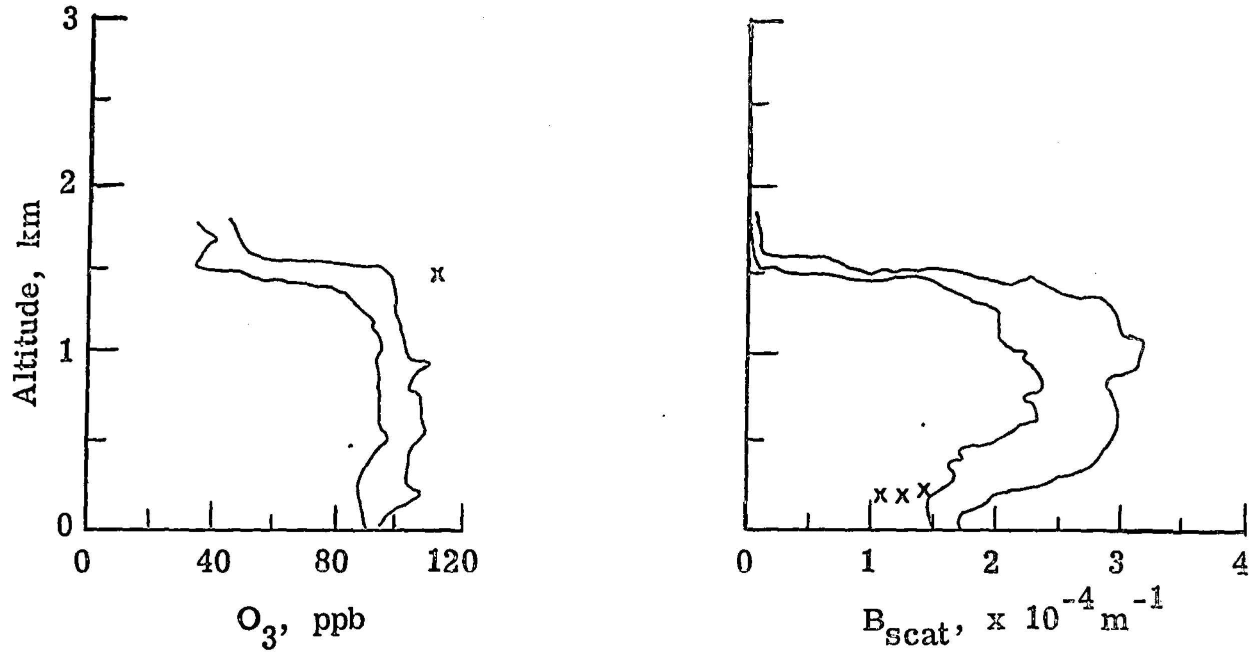


Figure 23. - Data envelopes, leg AB, August 7, 1980.

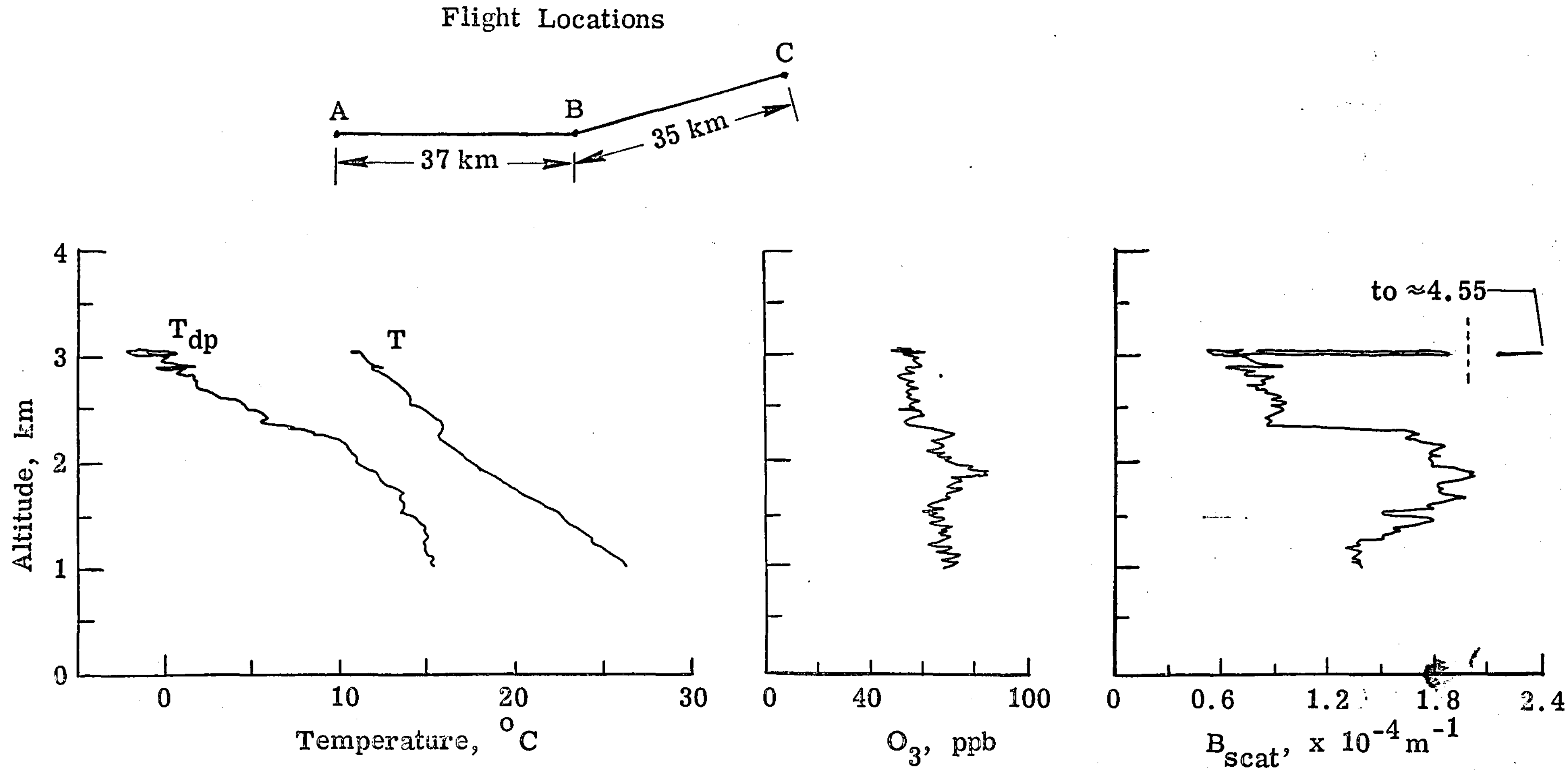


Figure 24. - Ascent leg C to A data, August 12, 1980.

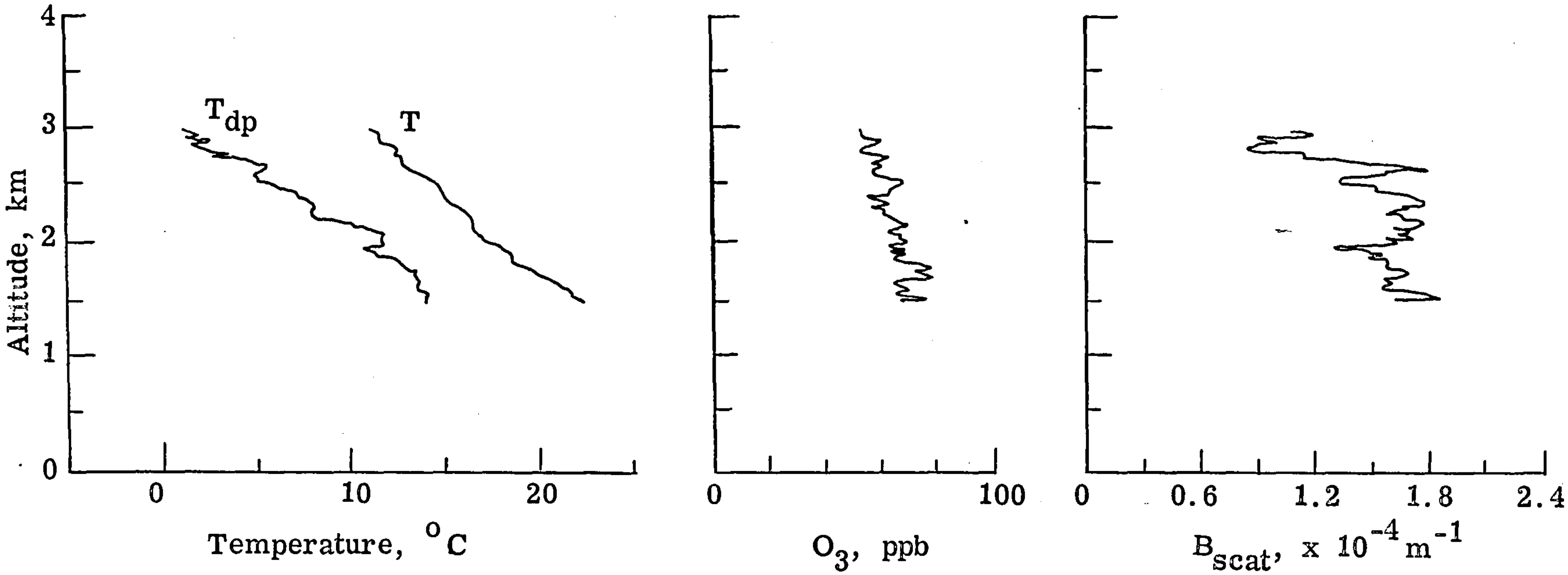


Figure 25. - Spiral data at A, August 12, 1980.

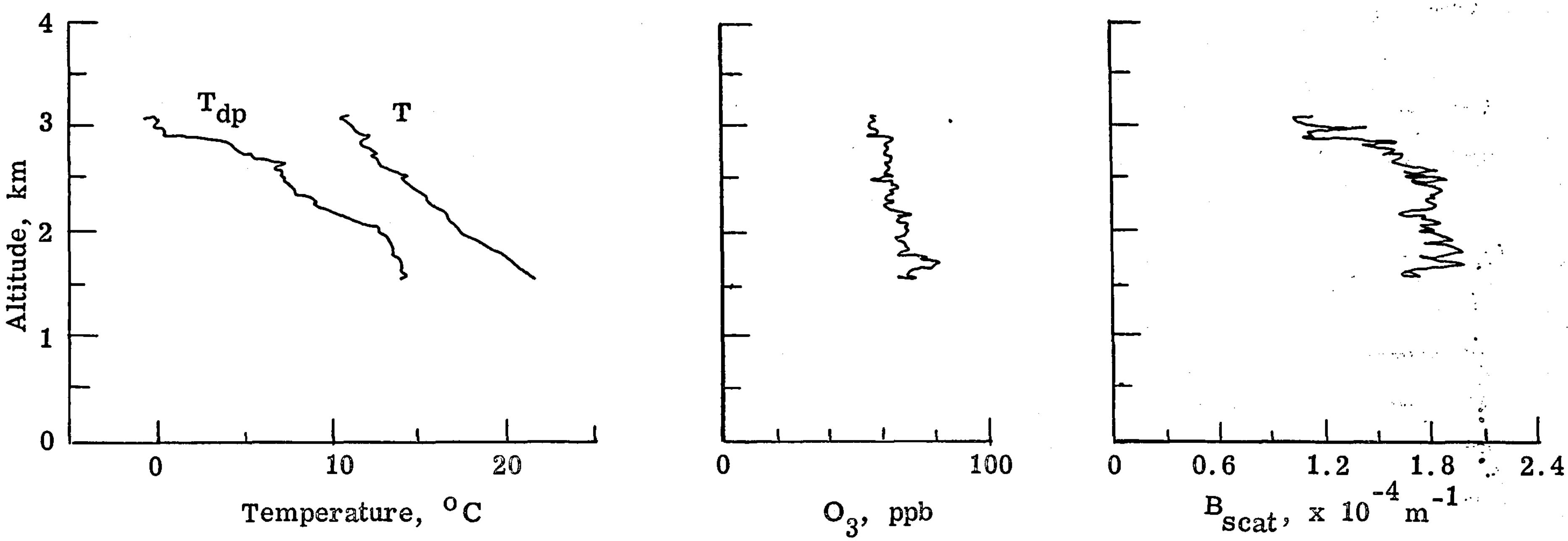


Figure 26. - Spiral data at B, August 12, 1980.

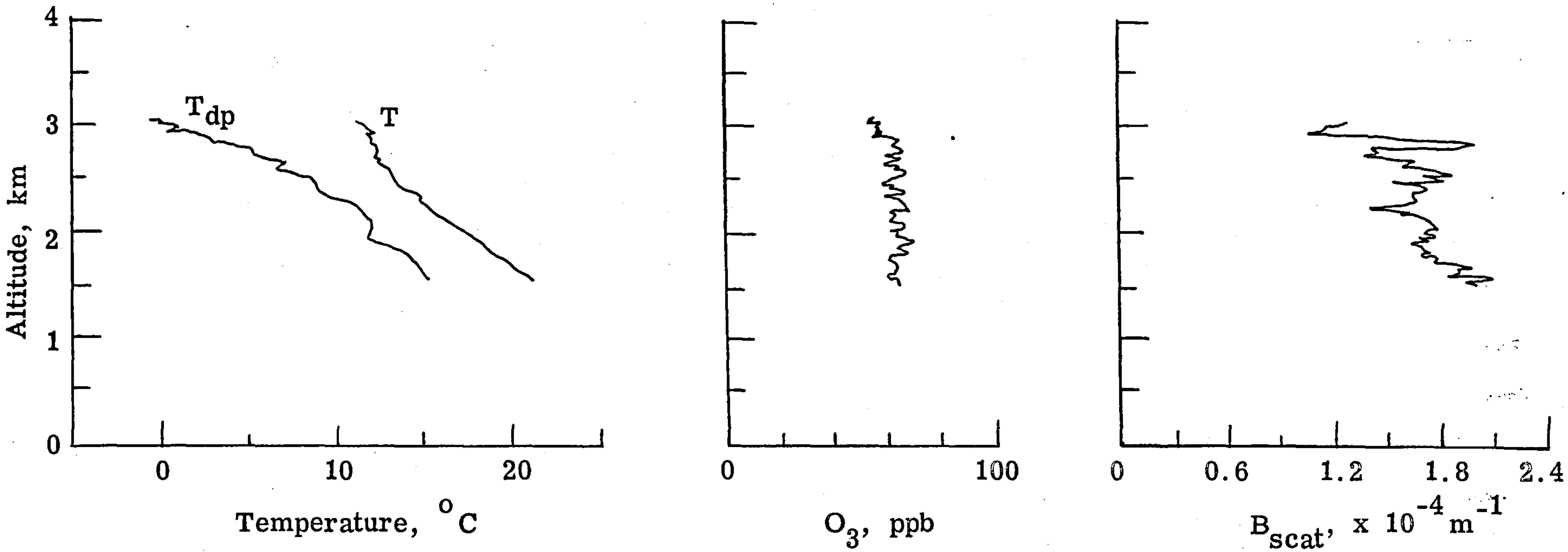


Figure 27. - Descent leg B to A, August 12, 1980.

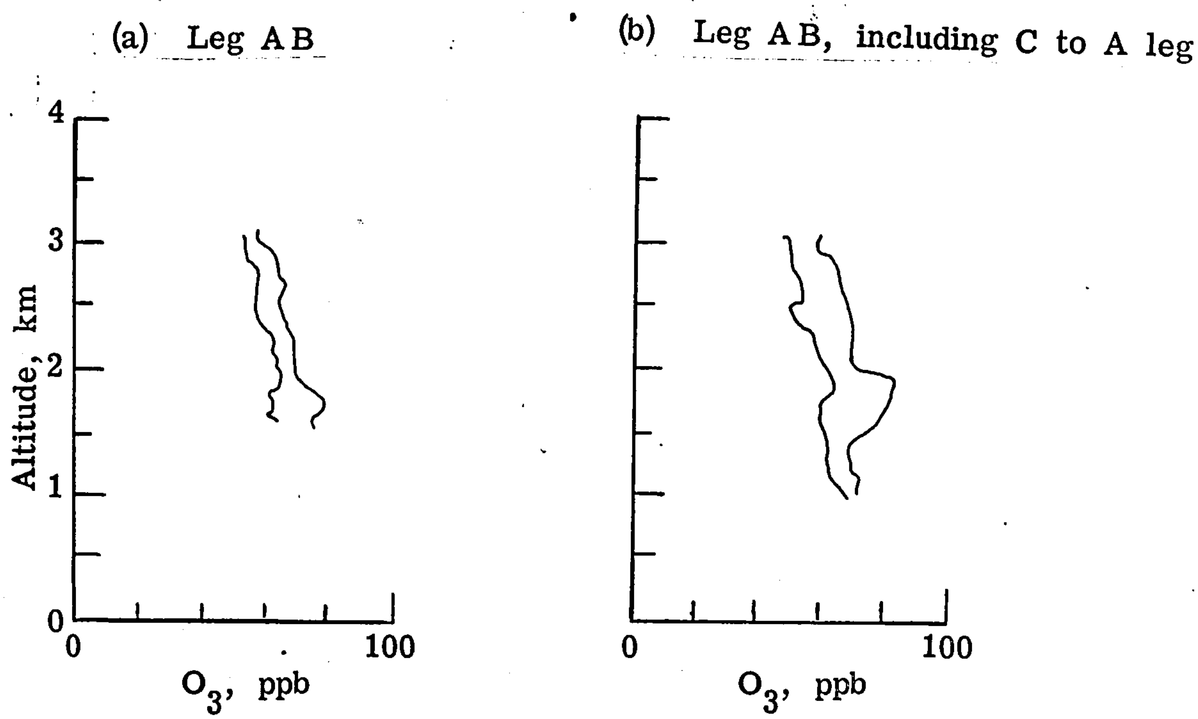


Figure 28. - O_3 data envelopes, August 12, 1980.

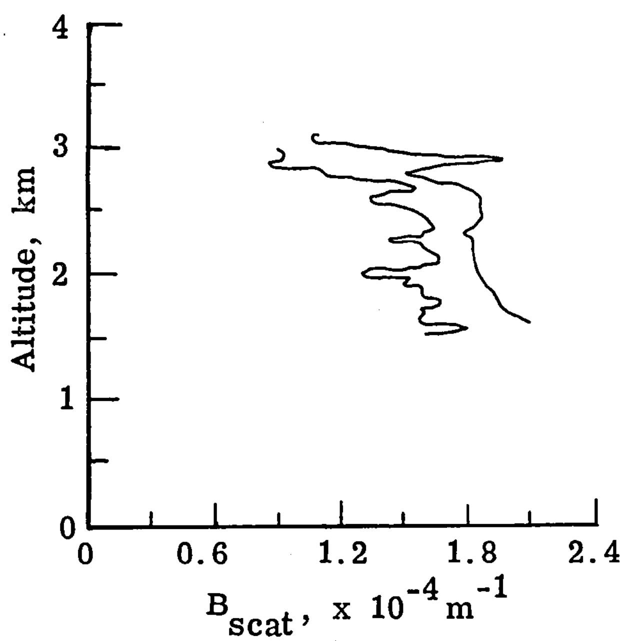


Figure 29. - B_{scat} data envelope, leg AB, August 12, 1980.

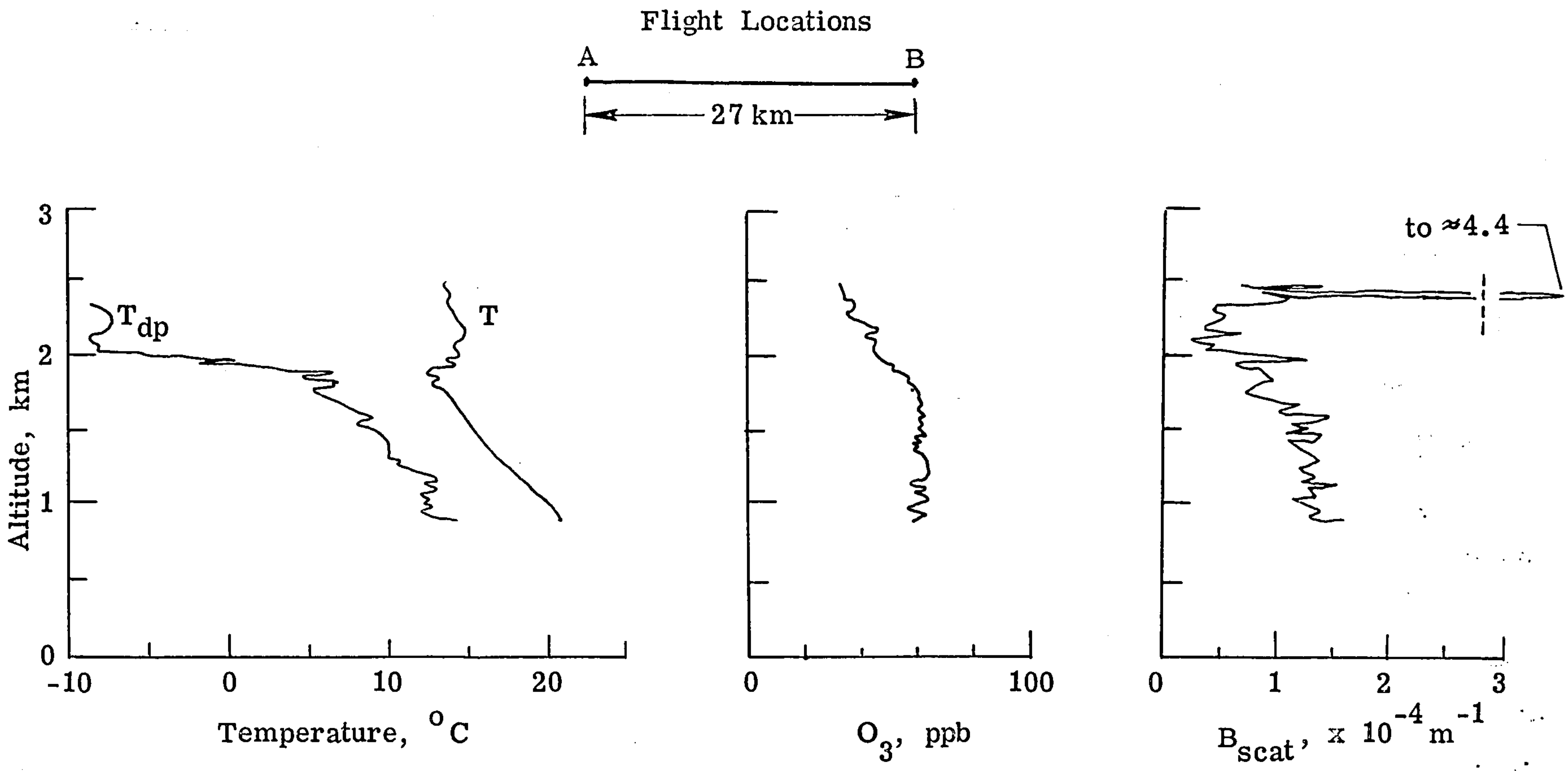


Figure 30. - Spiral data at A, 1400 e.d.t., August 13, 1980.

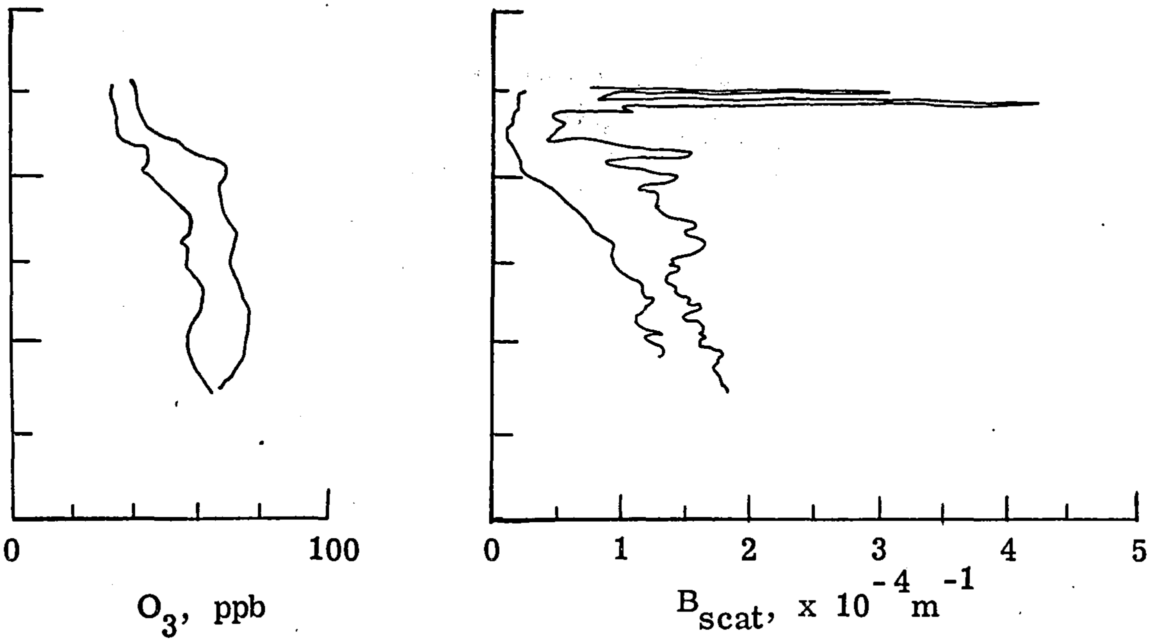


Figure 31. - Data envelopes, leg AB, 1400 e.d.t., August 13, 1980.

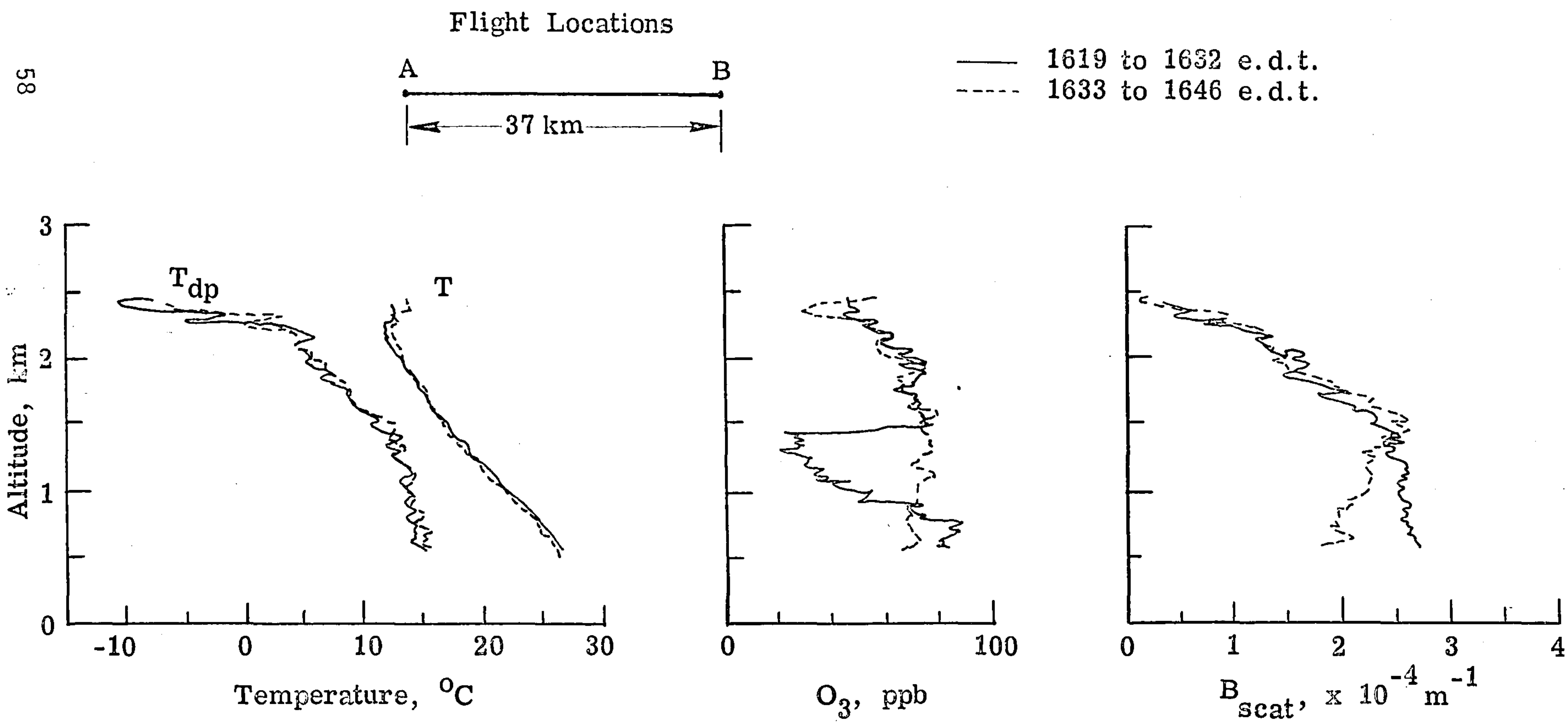


Figure 32. - Spiral data at A, 1700 e.d.t., August 13, 1980.

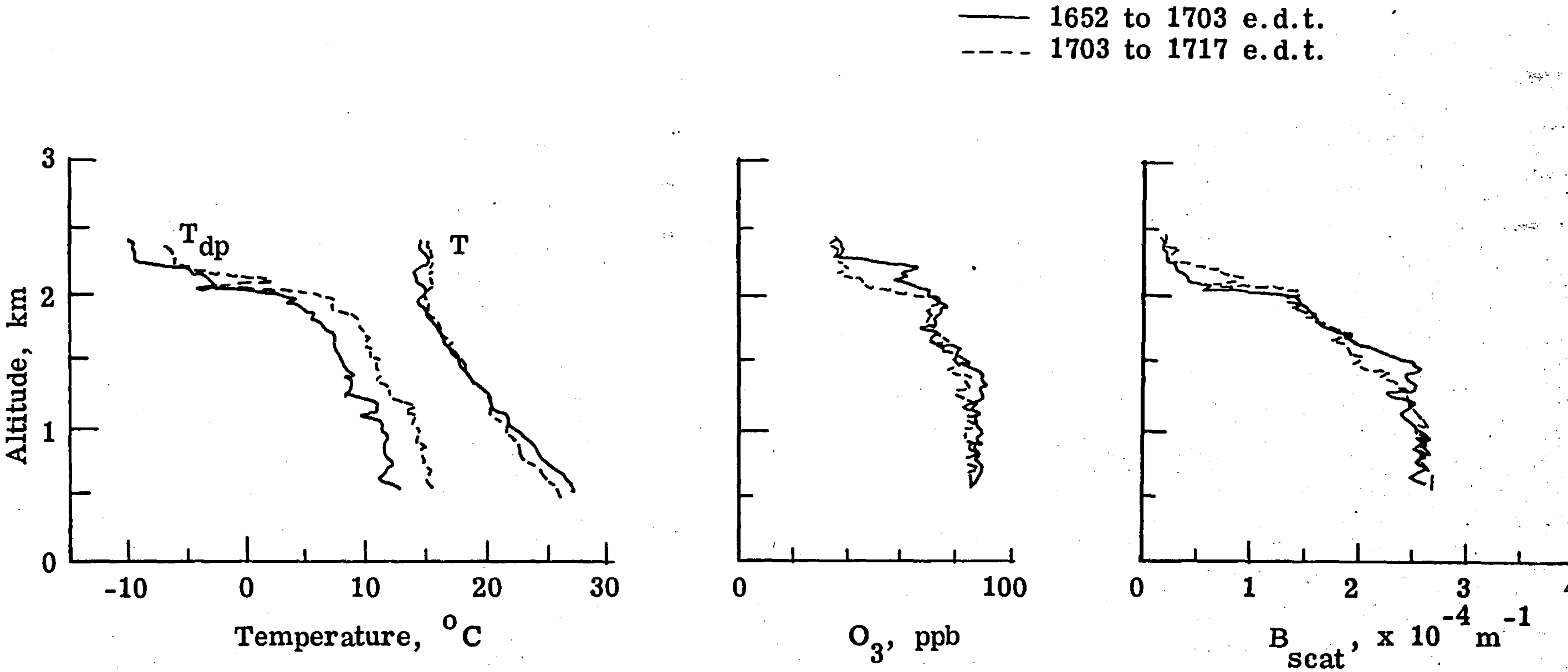


Figure 33. - Spiral data at B, 1700 e.d.t., August 13, 1980.

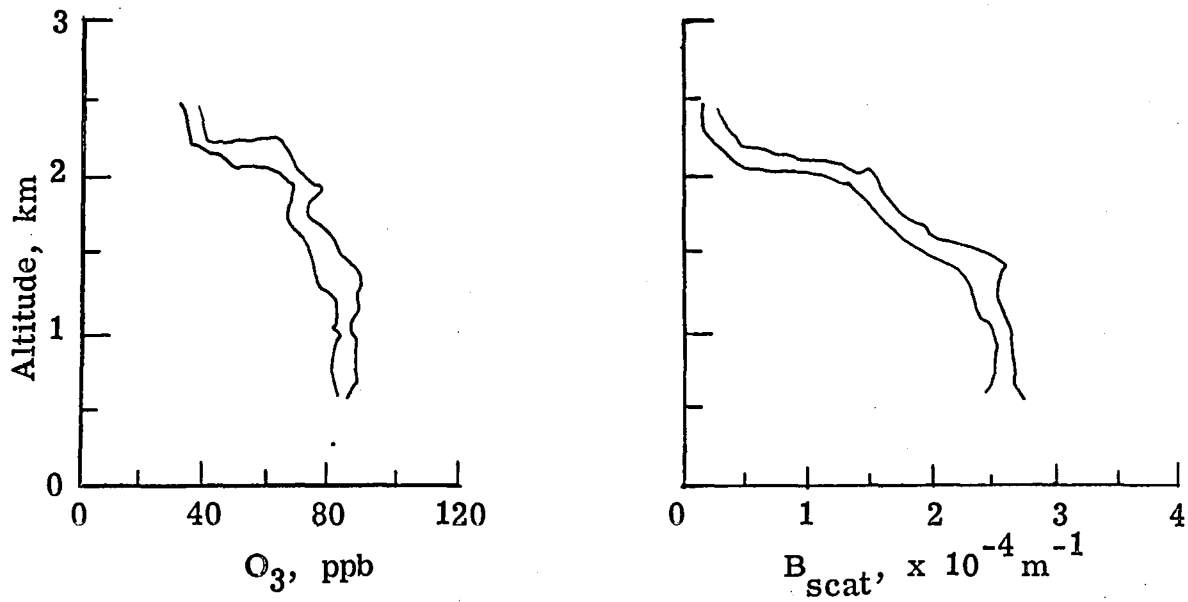


Figure 34. - Data envelopes at B, 1700 e.d.t., August 13, 1980.

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15. Supplementary Notes

16. Abstract

In situ correlative measurements made with a NASA aircraft in support of two NASA airborne remote sensors participating in the Environmental Protection Agency's 1980 Persistent Elevated Pollution Episode (PEPE) and Northeast Regional Oxidant Study (NEROS) field program are presented. The purpose of the in situ measurement effort was to provide data for evaluation of the performance of the Ultraviolet Differential Absorption Lidar and the High Spectral Resolution Lidar remote sensors for measuring mixing layer height, and ozone and aerosol concentrations in the troposphere during the 1980 PEPE/NEROS program. The in situ aircraft was instrumented to measure temperature, dewpoint temperature, ozone concentrations, and light-scattering coefficient (B_{scat}). In situ measurements for ten correlative missions (July 24 through August 13, 1980) are presented. The report discusses the in situ data, describes the in situ aircraft flight plans, and presents each data set in graphical and tabular format.

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