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In Situ Ozone Data for Comparison with Laser Absorption Remote Sensor: 1980 PEPE/NEROS Program

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ABSTRACT

Several sets of in situ ozone (O_3) measurements were made by a NASA aircraft in support of the Laser Absorption Spectrometer (LAS) remote sensor. These measurements, made during EPA's summer 1980 Persistent Elevated Pollution Episode/Northeast Regional Oxidant Study (PEPE/NEROS), were designed to provide comparative O_3 data for the LAS sensor. The LAS, which was flown on a second aircraft, remotely measured the vertical burden of O_3 from the aircraft to the surface. In situ results of the air-quality (O_3 and B_{scat}) and meteorological (temperature and dewpoint) parameters for three correlative missions in July 1980 are presented. The report summarizes the aircraft flight plans, in situ concentration profiles and vertical burdens, and measurement errors.

SUMMARY

In situ ozone (O_3) correlative measurements were made by a NASA aircraft in support of the Laser Absorption Spectrometer (LAS) remote sensor during EPA's 1980 Persistent Elevated Pollution Episode/Northeast Regional Oxidant Study (PEPE/NEROS). The purpose of the correlative measurements was to provide in situ O_3 data for comparison with the LAS remote sensor. The LAS, flown in a second aircraft, measured the vertical burden of tropospheric O_3 from the aircraft to the surface. The in situ aircraft was equipped to measure O_3, light-scattering coefficient (B_{scat}), temperature, and dewpoint. In situ results of the air-quality and meteorological parameters for three correlative missions (July 11, 14, and 15, 1980) are presented. The report describes the flight plans, discusses the accuracy and repeatability of the in situ data, summarizes each data set in graphical and statistical formats,

and presents calculations of the vertically integrated burden of O_3. The report provides in situ data in a form that can be used to evaluate the performance of the remote sensor. Presentation of the LAS remote-sensor data is beyond the scope of this report.

INTRODUCTION

As part of the National Aeronautics and Space Administration's (NASA) commitment to develop the necessary technology to exploit the capabilities of satellite systems 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 participated 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 1980. The PEPE experiment focused on the formation and transport of visibility reducing aerosols, while NEROS addressed regional-scale air mass and urban-plume characterizations with emphasis on model application. 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 platforms. Reference 2 summarizes NASA's participation.

One of NASA's remote sensors was the Jet Propulsion Laboratory's (JPL) Laser Absorption Spectrometer (LAS). The LAS measured the vertical burden of O_3 between the aircraft and the surface. During the PEPE/NEROS program, NASA also provided an in situ sampling aircraft for the evaluation of the LAS and other remote sensors.

The purpose of this report is to document the NASA in situ correlative data used in the 1980 validation of the LAS. Three sets of in situ data are presented for comparison with the LAS remote sensor data. The report discusses the in situ data and describes the in situ flight plans, measurement locations, instrumentation, and resulting atmospheric profiles for temperature, dewpoint, ozone, and B_{scat}. A brief description of the LAS remote sensor is also presented.

SYMBOLS AND ABBREVIATIONS

B_{scat} - light scattering coefficient, m^{-1}

CO_2 - carbon dioxide

e.d.t. - eastern daylight time

EPA - Environmental Protection Agency

JPL - Jet Propulsion Laboratory

LaRC - Langley Research Center

LAS - Laser Absorption Spectrometer

Lat - Latitude, °

Long - Longitude, °

MLH - mixing layer height

msl - mean sea level

NASA - National Aeronautics and Space Administration

NBS - National Bureau of Standards

NEROS - Northeast Regional Oxidant Study

NO - nitrogen oxide, ppb

NO_x - total nitrogen oxides, ppb

O_3 - ozone, ppb

PEPE - Persistent Elevated Pollution Episode

ppb - parts per billion, by volume

T - temperature, °C

T_{dp} - dewpoint temperature, °C

VOR - VHF omni range

LAS INSTRUMENTATION

The LAS is a remote-sensing instrument, designed and built to measure tropospheric ozone distributions (ref. 3, 4, and 5) from an aircraft, that has been in use since 1974. It is an active, nadir-directed instrument which measures the vertical burden of ozone between ground-level and the aircraft altitude. The basis of the measurement is differential absorption of a pair of on/off transmitted wavelengths which are selected to interact with a sharp spectral feature of the ozone band, near a wavelength of 9.5 μm. Two grating tunable waveguide CO_2 lasers provide the transmitted radiation, and two heterodyne receiver channels in the instrument respond to a small portion of the laser radiation which is backscattered off the Earth's surface below the aircraft and propagated back to the collecting telescope. A unique feature is an internal reference capability for balancing the two transmitted channel gains. Also, an enhanced signal/noise return is achieved by tilting the transmitted beams a few degrees forward so that the wavelengths of the ground-reflected return signals are Doppler-shifted with respect to the transmitted wavelengths.

The LAS participated in extensive field measurement programs conducted by LaRC in July 1978 and August 1979 (refs. 5 and 6). The primary objective of the JPL participation was to perform ozone burden measurements. This was accomplished by calibrating the LAS using ozone data measured below the LAS by the in situ instrumented aircraft. A secondary objective was to corroborate and assess the accuracy of the LAS by means of "blind" comparisons with the in situ aircraft data.

The JPL Beechcraft aircraft houses the LAS and flies at a nominal speed of 250 km/hr and altitude between 750-1500 m. The aircraft was based at Columbus, Ohio during the PEPE/NEROS program.

IN SITU INSTRUMENTATION

The in situ sensor aircraft (figure 1a) which provided the correlative measurements is a 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 various NASA air-quality programs (refs. 6, 7, and 8). The aircraft is equipped with specially designed nose probes (figure 1b) for sampling undisturbed free-stream air in front of the aircraft boundary layer. The intake is directed via teflon-lined tubing to a commercially available ozone instrument which measures ozone by a chemiluminescence reaction resulting from a gas-phase interaction between ozone and ethylene. Other instruments (figures 1c and 1d) include NO/NO_x, B_{scat} (integrating nephelometer), T (resistance probe), T_{dp} (cooled mirror), and flight parameters of altitude, heading, air speed, and time. All instrumentation are calibrated using accepted EPA or NBS procedures. For the 1980 measurements, the O_3 and B_{scat} instruments were audited by the PEPE/NEROS audit team and were within acceptable limits. Based on laboratory and quality assurance tests of the ozone instrument, the O_3 data are accurate to 10 percent absolute or ±5 ppb (whichever is largest) with a repeatability of 2 or 3 percent or ±3 ppb (whichever is largest). Table I summarizes instrument characteristics that apply to this study.

All data measured onboard the aircraft are recorded continuously on magnetic tape. The tape is digitized (10 records/s) and processed at the Langley computer facility. Further processing is done with a minicomputer, and data are reported as 10-second averages. Strip-chart recorders provide quick-look or real-time results as well as backup data recording to the tape system for the primary parameters of interest.

Flight characteristics in the data-taking mode are 250 km/hr flight speed, ascent or descent rates of less than 150 m/min., and 3 hours of data-time. Based on these flight characteristics and a 10-second data average, reported data points represent, on an average, a spatial distance of 500 m and an altitude resolution of about 25 m. All times are reported in e.d.t. During the PEPE/NEROS field programs, the Cessna was based at Columbus, Ohio.

CORRELATIVE EXPERIMENT DECRIPTION

The purpose of the in situ aircraft was to provide correlative data in support of the airborne NASA remote sensors. Since the LAS correlative flights were performed at the beginning of the summer program before any PEPE/NEROS experiments were scheduled, the flights were designed specifically and solely on correlative data considerations. These considerations resulted in the measurement of ozone concentration within a finite test volume by the in situ instrumented aircraft while the LAS flew over the volume performing O_3 burden measurements.

The basic "box-face" flight plan flown for all three correlative missions is illustrated in figure 2. The test area was a vertical plane oriented perpendicular to the wind. Surface locations A and B and altitude were selected on a daily basis depending on meteorological conditions. The flight plan for the remote sensor aircraft consisted of several constant altitude passes along leg A to B at the specified altitudes 760, 1070, and 1370 m. Approximately 45 minutes were required to complete the flight sequence. During this time, the in situ aircraft flight pattern consisted of:

(a) constant low altitude pass from leg A to B,

(b) spiral at B up to a preselected altitude,

(c) constant rate of descent pass from B to A at the low altitude,

(d) spiral at A back up to the high altitude,

(e) constant rate of descent pass from A to B, and

(f) constant low altitude pass from B to A.

Approximately 1 hour was required for this flight sequence. The correlative box-face experiment was conducted on three separate occasions. Table II summarizes flight loctions and times of the correlative flights, and figure 3 shows the geographical location for each flight.

CORRELATIVE DATA RESULTS

This section presents the data measured on board the NASA in situ aircraft for each correlative data mission. Discussions focus on defining the data most representative of the atmosphere in the correlative test area. It is not the purpose of this report to discuss the causes of the observed atmospheric behavior; however, in some cases as is appropriate and as may affect the application of the data set to remote-sensor evaluation, possible causes are suggested. Data sets are presented in chronological order, referencing the locations and flight plans of table II and figure 3. The data presented provide the in situ data to be compared with the LAS remote-sensor data.

July 11, 1980, Correlative Mission

The mission was flown as a correlative flight in support of the LAS at a location just south of Columbus, Ohio from 1058 to 1210. The test leg AB was approximately 37 km in length (table II). The in situ flight plan was the box-face pattern consisting of the vertical plane AB from about 300 to 2000 m altitude. The nominal in situ flight sequence is listed in table III and shown schematically in figure 4. The LAS flew several constant altitude passes at 1070 m.

Temperature, dewpoint, O_3, and B_{scat} profiles measured over point A are shown in figure 5. Note the strong temperature inversion as shown by the temperature increase and dewpoint decrease at about 1000 m corresponding to the top of the mixing layer height (MLH). Small-scale layering is apparent both below the MLH and within the temperature inversion layer (1000 - 1300 m). The O_3 and B_{scat} profiles show that below the MLH the concentrations are relatively constant; immediately above the MLH, the concentrations drop off rapidly, and above 1300 m they become constant again. However, there are a number of local variations in both concentrations (especially B_{scat}) that are correlated with the small-scale layering measured by the temperature and dewpoint profiles.

Measurements of O_3 and B_{scat} for the spirals at location A, the constant descent from B to A, and the constant altitude traverses near A are compared in figure 6. Note that for location A, the measurements of O_3 and B_{scat} are repeatable and consistent. However, a similar comparison at location B (figure 7) shows that, for the first spiral at B, the O_3 and B_{scat} profiles below 700 m are substantially different from those measured during the second spiral at B and previous and subsequent measurements at A (figure 6). The constant altitude legs near B performed before the first spiral and after the second spiral also confirm the localized spatial and temporal anomaly. Simultaneous measurements of NO/NO_x (not shown) indicate that there was a significant enhancement of NO in this anomalous air mass. Since NO is known to be a short-term scavenger of O_3, it is suspected that a mass of "urbanized" air consisting of fresh emissions of NO and excess aerosols (note B_{scat} enhancement) advected through the area at B between the times 1108 and 1114.

The vertical data have been grouped into 300 m altitude increments in order to determine the average, standard deviation, and error of the mean of the measurements. The average profiles are shown in figure 8 where the solid black line labelled 2 is the average of all the data (including location B). The width of the line is ± one error of the mean (one error of the mean represents the uncertainty of the mean value to a 67 percent confidence level; two error of the mean represents the uncertainty to a 95 percent confidence level). The dashed lines are ± one standard deviation. Note that the uncertainty of the profile from all the measurements increases below 1000 m, reflecting the spread of the measurements between locations A and B. A more accurate representation of the data is shown by the two branch profiles below 1000 m, labelled 1 and 3. Branch 1 corresponds to the average of the measurements near point B between 1108 and 1114; branch 3 corresponds to all of the remaining measurements. The partitioning of the data results in a much narrower uncertainty spread, comparable to that measured above 1000 m.

It should be noted that between 1118 and 1128 (table III), a power failure occurred onboard the aircraft and instrument power was lost for several minutes. This power failure and instrument "off time" did not appear to have an affect on that data beyond 1128, and is not believed to have contributed to any of the observed nonrepeatability of the O_3 and B_{scat} profiles.

Figure 8 is the best representative of the O_3 and B_{scat} profiles for leg AB and illustrates the profile uncertainties. Table V shows statistical data for the profiles of figure 8; table IV gives the statistical results for the two constant altitude (600 m) passes of leg AB. These constant altitude data are not included in figure 8 or table V.

The vertical burden of O_3 between any altitude and the ground is found by integrating the appropriate vertical profile in figure 8. Results of the calculation give the vertical burden from 0-1070 m to be: 77 ppb for all the data grouped together; 80 ppb at location B for times between 1108 and 1114; and 69 ppb for other locations and times. There is a ± 5 ppb error assigned to each burden value, which reflects the ± 5 ppb absolute accuracy associated with the instrument (see table I) and not the instrument precision or natural variability which are measured to be less. For example, two errors of the mean (95 percent confidence) is less than 5 ppb. The vertical burden O_3 values for this and other flight profiles are listed in table XII.

July 14, 1980, Correlative Mission

The mission was flown as a correlative flight in support of the LAS at a location just west of Columbus, Ohio from 1440 to 1540. The test leg AB was approximately 15 km in length (table II). The in situ flight plan was the box-face pattern consisting of a vertical plane AB from about 450 m altitude to 1800 m. The nominal flight sequence for the in situ aircraft is given in table VI and shown schematically in figure 9. The LAS flew several constant altitude passes at 760, 1070, and 1370 m.

The temperature, dewpoint, O_3, and B_{scat} profiles measured over point A are shown in figure 10. Based on the temperature and dewpoint data, the MLH is estimated to be about 1050 m with another major level above at 1300 m. Several other small-scale layers are also visible. The O_3 and B_{scat} profiles show variations which agree closely with the layering indicated from the temperature and dewpoint measurements. Both O_3 and B_{scat} are fairly uniformly mixed within the MLH. The concentrations decrease above the MLH to a layer at 1300 m and decrease further to constant values above 1500 m.

The comparison of the spirals at A and B and constant descent traverses are plotted in figure 11. Note that for altitudes above the MLH (1050 m), the O_3 and B_{scat} concentrations are repeatable. Below the MLH, there is a small, but still significant, difference between points A and B. The constant altitude traverse portions near A and B also show a slight difference between each other, but the standard deviations are such that this difference is not statistically significant.

The profiles have been averaged in 300 m increments and are plotted in figure 12. The solid black line, labelled 2, is the average ± one error of the mean of all the data (both A and B). Note that the uncertainty spread increases toward the lower altitudes. The branch, labelled 1, is the average of the data taken from spirals at A, and the branch, labelled, 3 is from spirals at B. The uncertainties are much narrower than those for the lower portion of branch 2 and approach those uncertainties measured at the higher altitudes.

The data from figure 12 are representative over the leg AB. Below the MLH (1050 m), branch 1 corresponds to values of O_3 and B_{scat} near location A; branch 3 corresponds to location B; and there is a linear variation between locations A and B. Table VIII shows the statistical results for the averaged profiles in figure 12; table VII shows the statistical results for the two constant altitude (600 m) passes on leg AB. These passes are not included in figure 12 or table VIII.

If it is assumed that the atmosphere is well mixed throughout the MLH and that O_3 is constant (79 ppb at A; 90 ppb at B), the vertical burden of O_3 from 0-760 m is calculated to be 79 ppb at A, 90 ppb at B, and 83 ppb for all data; from 0-1070 m, the burden is 78 ppb at A, 88 ppb at B, and 83 ppb for all data; and from 0-1370 m, the burden is 75 ppb at A, 82 ppb at B, and 78 ppb for all data. There is a ± 5 ppb error associated with the burden values which represent the absolute accuracy of the in situ instrument and not the instrument precision or natural variability, which are measured to be smaller. The vertical ozone burden values for this and other flights are listed in table XII.

July 15, 1980, Correlative Mission

The mission was flown as a correlative flight in support of the LAS at a location just southwest of Columbus, Ohio, from 0950 to 1030. The test leg AB was approximately 22 km in length (table II). The in situ flight plan was the box-face pattern consisting of a vertical plane AB from about 450 m altitude to 1800 m. The nominal flight sequence for the in situ aircraft is given in table IX and shown in figure 13. The LAS flew several constant altitude passes at 1070 m.

Temperature, dewpoint, O_3, and B_{scat} profiles measured over point A are shown in figure 14. The temperature and dewpoint data show that the atmosphere is divided into a number of stable layers with major layers at 800 and 1100 m. Considerable variation with altitude is measured in the ozone and B_{scat} concentration due to the restricted mixing between the vertical layers. There is a high degree of correlation among the four profiles throughout the various layers. Since the aircraft data do not go below 400 m, it is not possible to determine if the temperature inversion stops at 500 m or continues to the ground as a deep (0-900 m) surface inversion.

Even though there are large variations in the concentrations as a function of altitude, there is remarkable consistency between the measurements made at different locations and at different times. Figure 15 is a plot of all of the data measured within the box-face pattern. The vertical profiles are nearly identical at both locations A and B. The constant altitude traverse measurements at 600 m also agree closely with the spiral portions of the data.

The vertical profile measurements are grouped into 300 m altitude increments (which in this case unfortunately smoothes out some of the real structure) and averaged as shown in figure 16. Note that the major enhancements around 700 and 1200 m are retained. The data of figure 16 are recommended as representative over the leg AB. Table XI presents the average values, standard deviations, and errors of the mean. Table X shows the statistical results for the single constant altitude pass at 600 m; these data are not included in figure 16 or table X.

In order to calculate the ozone burden, it is necessary to assume the profile of ozone from 400 m to the surface. Two possibilities are considered:

1. A uniformly mixed atmosphere up to 500 m with ozone constant at 60 ppb.
2. A stable atmospheric layer from the surface to 500 m (and up to 900 m) with a linear decrease in ozone from 60 ppb at 500 m to 20 ppb at the surface.

The first case results in an ozone burden from 0-1070 m of 64 ppb; the second gives an ozone burden of 62 ppb (table XI). There is a ± 5 ppb error assigned to the burden values, which reflects the absolute error of the in situ instrument and not the instrument precision or natural variability, which are measured to be smaller. The vertical ozone burden values for this and other flights are listed in table XII.

CONCLUDING REMARKS

As part of the PEPE/NEROS summer field program, three experiments were conducted to provide in situ ozone data for correlation with the Laser Absorption Spectrometer ozone remote-sensor. These data are summarized in the report. Table XII is a summary of the O_3 burden calculations for the three experiments as obtained from the in situ O_3 data. Table XIII lists the anticipated uses of the data from the three experiments. The in situ ozone data of each of the three experiments provide an accurate and consistent set of in situ O_3 concentrations from which the basic accuracy and repeatability of the LAS can be evaluated. In addition, observed small changes (10 ppb for example) in ozone concentrations as a function of time and/or location along a flight leg, should be useful in assessing the limits of the remote sensor for detection of ozone fluctuations.

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TABLE I.- IN SITU AIRCRAFT INSTRUMENTATION (PRIME) CHARACTERISTICS AS FLOWN DURING 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	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 (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

TABLE II.- LOCATIONS AND TIMES OF CORRELATIVE FLIGHTS

Date	Time (e.d.t)	A		B	
		VOR Station	radial/distance N Lat/W Long	VOR Station	radial/distance N Lat/W Long
July 11	1100 - 1200	York	360°/72 n mi 39°51'/83°02'	York	360°/52 n mi 39°36'/83°02'
July 14	1440 - 1540	Appleton	270°/40 n mi 40°07'/83°27'	Appleton	270°/48 n mi 40°07'/83°39'
July 15	0950 - 1030	Appleton	240°/39 n mi 39°48'/83°18'	Appleton	240°/51 n mi 39°42'/83°31'

TABLE III.- CESSNA FLIGHT SCHEDULE FOR JULY 11, 1980

Time (e.d.t.)	Altitude, msl[1] (m)	Flight Leg (see figure 5)
1058 to 1101	600 to 350	spiral at A
1101 to 1104	350 to 600	spiral at A
1104 to 1108	600	constant altitude, A to B
1108 to 1111	600 to 350	spiral at B
1111 to 1118	350 to 1200	spiral at B
1118 to 1128	1200 to 1900	spiral at B (no data; instrument power failure)
1128 to 1135	1900(B) to 900(A)	constant rate of descent B to A
1135 to 1139	900 to 350	spiral at A
1139 to 1153	350 to 1900	spiral at A
1153 to 1158	1900(A) to 1000(B)	constant rate of descent A to B
1158 to 1203	1000 to 350	spiral at B
1203 to 1204	350 to 600	spiral at B
1204 to 1210	600	constant altitude B to A

1 - the msl altitude at Columbus, Ohio is 276 m

TABLE IV.- STATISTICAL DATA FOR CONSTANT ALTITUDE TRAVERSES

Approximate Mid-Point Time (e.d.t.)	Flight Leg	T (°C) Average Value	T (°C) Standard Deviation	T_{dp} (°C) Average Value	T_{dp} (°C) Standard Deviation	Altitude (m) Average Value	Altitude (m) Standard Deviation	O_3 (ppb) Average Value	O_3 (ppb) Standard Deviation	B_{scat} (m^{-1}) Average Value	B_{scat} (m^{-1}) Standard Deviation
1106	AB	27.7	.5	19.6	1.1	627	6	76	8	17.5	2.3×10^{-5}
1207	AB	28.5	.5	18.0	.9	647	11	79	3	13.5	1.2×10^{-5}

TABLE V.- STATISTICAL DATA FOR PROFILES: LEG AB, JULY 11, 1980

Average Altitude, m	Number of Data points	Average Value ± Standard Deviation					
		O_3, ppb			B_{scat}, x 10^{-5} m-1		
		All	B[1]	A[2]	All	B[1]	A[2]
195[3]	—	77[3]	61[3]	82[3]	15.2[3]	18.7[3]	13.7[3]
389	43	77 ± 10	61 ± 5	82 ± 2	15.2 ± 2.4	18.7 ± .8	13.7 ± .8
532	57	78 ± 8	66 ± 4	81 ± 3	15.5 ± 2.4	19.1 ± .9	14.2 ± 1.0
676	33	78 ± 6	70 ± 5	79 ± 3	15.7 ± 2.1	18.5 ± 1.0	14.5 ± 1.3
839	25	76 ± 6			15.8 ± 1.9		
911	24	77 ± 4			12.5 ± 3.5		
1147	25	61 ± 7			4.8 ± 3.3		
1305	23	47 ± 4			1.8 ± .3		
1450	19	46 ± 3			2.0 ± .3		
1602	24	45 ± 3			1.9 ± .3		
1746	22	44 ± 2			1.8 ± .3		
1871	14	45 ± 3			2.0 ± .2		

1 - between 1108 and 1114 only
2 - all data, except B[1]
3 - assumed

TABLE VI.- CESSNA FLIGHT SCHEDULE FOR JULY 14, 1980

Time (e.d.t.)	Altitude, msl (m)	Flight Leg (see figure 10)
1440 to 1451	2000 to 600	spiral at A
1451 to 1456	600	constant altitude A to B
1456 to 1505	600 to 1800	spiral at B
1507 to 1511	1800(B)to 1400(A)	constant rate of descent, B to A
1511 to 1517	1400 to 500	spiral at A
1517 to 1526	500 to 1800	spiral at A
1527 to 1531	1800(A)to 1400(B)	constant rate of descent A to B
1531 to 1536	1400 to 600	spiral at B
1536 to 1540	600	constant altitude B to A

TABLE VII.- STATISTICAL DATA FOR CONSTANT ALTITUDE TRAVERSES

Approximate Mid-Point Time (e.d.t.)	Flight Leg	Average Value ± Standard Deviation				
		T (°C)	T_{dp} (°C)	Altitude (m)	O_3 (ppb)	B_{scat} (m^{-1})
1453	AB	28.4 ± .4	14.9 ± .6	573 ± 33	86 ± 6	$9.7 \pm .6 \times 10^{-5}$
1538	AB	28.5 ± .2	14.9 ± .5	594 ± 4	79 ± 4	$9.3 \pm .5 \times 10^{-5}$

TABLE VIII.- STATISTICAL DATA FOR PROFILES: LEG AB, JULY 14, 1980

Average Altitude, m	Number of Data points	Average Value ± Standard Deviation					
		O_3, ppb			B_{scat}, x 10^{-5} m^{-1}		
		All	B	A	All	B	A
215[1]	—	83[1]	90[1]	79[1]	9.4[1]	10.1[1]	9.0[1]
428	6	83 ± 6	90 ± 5	79 ± 1	9.4 ± .6	10.1 ± .1	9.0 ± .2
571	32	83 ± 4	90 ±	79 ± 2	8.9 ± .7	10.4 ± .4	8.7 ± .4
681	32	84 ± 8	91 ± 3	77 ± 3	9.3 ± 1.2	10.6 ± .6	8.4 ± .2
840	32	83 ± 8	90 ± 6	77 ± 4	9.4 ± 1.1	10.5 ± .8	8.7 ± .5
995	31	79 ± 6			8.8 ± .9		
1114	31	68 ± 7			6.5 ± 1.8		
1272	18	61 ± 4			4.8 ± .8		
1447	31	51 ± 4			2.2 ± .2		
1604	32	55 ± 4			2.6 ± .2		
1760	32	57 ± 3			2.5 ± .2		

[1] - assumed

TABLE IX.- CESSNA FLIGHT SCHEDULE FOR JULY 15, 1980

Time (e.d.t.)	Altitude, msl (m)	Flight Leg (see figure 14)
0949 to 0958	600	constant altitude A to B
0958 to 1007	600 to 1800	spiral at B
1008 to 1012	1800(B) to 1050(A)	constant rate of descent
1013 to 1017	1050 to 450	spiral at A
1017 to 1026	450 to 1800	spiral at A
1026 to 1030	1800(A) to 1350(B)	constant rate of descent A to B

TABLE X.- STATISTICAL DATA FOR CONSTANT ALTITUDE TRAVERSES

Approximate Mid-Point Time (e.d.t.)	Flight Leg	Average Value ± Standard Deviation				
		T (°C)	T_{dp} (°C)	Altitude (m)	O_3 (ppb)	B_{scat} (m^{-1})
0953	AB	30.8 ± .1	17.5 ± .8	600 ± 3	74 ± 5	$2.6 \pm .1 \times 10^{-4}$

TABLE XI.- STATISTICAL DATA FOR PROFILES: LEG AB, JULY 15, 1980

Average Altitude, m	Number of Data points	Average Value ± Standard Deviation			
		O_3, ppb		B_{scat}, x 10^{-4} m^{-1}	
		I	II	I	II
205[1]	—	60[1]	40[1]	18.9[1]	16.0[1]
407	5	60 ± 4		18.9 ± 0.5	
542	17	61 ± 6		22.7 ± 2.5	
689	17	74 ± 6		22.0 ± 3.2	
835	18	70 ± 10		19.0 ± 7.4	
986	19	61 ± 11		11.3 ± 2.7	
1139	18	82 ± 6		18.3 ± 1.5	
1291	18	72 ± 7		17.8 ± 3.5	
1455	23	65 ± 7		18.6 ± 2.8	
1599	27	55 ± 10		16.7 ± 3.1	
1753	25	45 ± 3		12.0 ± 2.5	
1840	7	44 ± 2		11.2 ± 2.2	

[1] assumed

TABLE XII.- AVERAGE BURDEN OF O_3 UP TO LAS FLIGHT ALTITUDES

Altitude+ Range, m	O_3 Average Burden, ppb*							
	July 11			July 14			July 15	
	All	B	A	All	B	A	I	II
0 - 760	77	80	69	83	90	79	64	62
0 - 1070				83	88	78		
0 - 1370				78	82	75		

+ - determined from LAS flight altitude

* - all burden values have uncertainties of ± 5 ppb

TABLE XIII.- SUMMARY OF ANTICIPATED CORRELATIVE USES OF IN SITU DATA

Date	Basic Instrument Accuracy/Repeatability	Detection of small O_3 changes	
		Time	Spatially
July 11	✓	✓	✓
July 14	✓	X	✓
July 15	✓	X	X

✓ - appropriate

X - not appropriate

Figure 1.- (a) In situ aircraft; (b) nose probes; (c) instrumentation within main cargo area; and (d) forward compartment instrumentation.

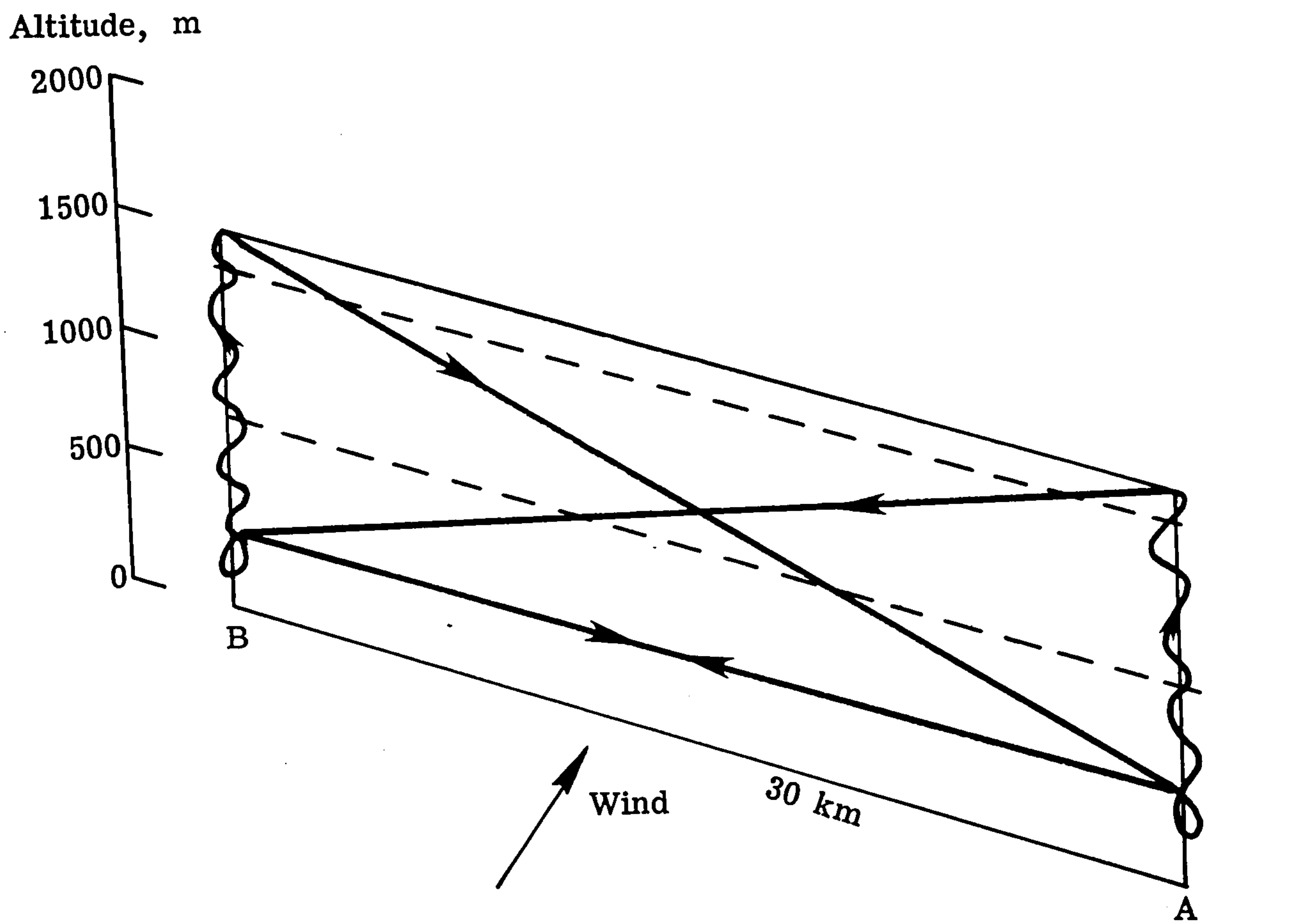

Figure 2.- Correlative box-face flight pattern for LAS remote sensor (---) and in situ aircraft (——)

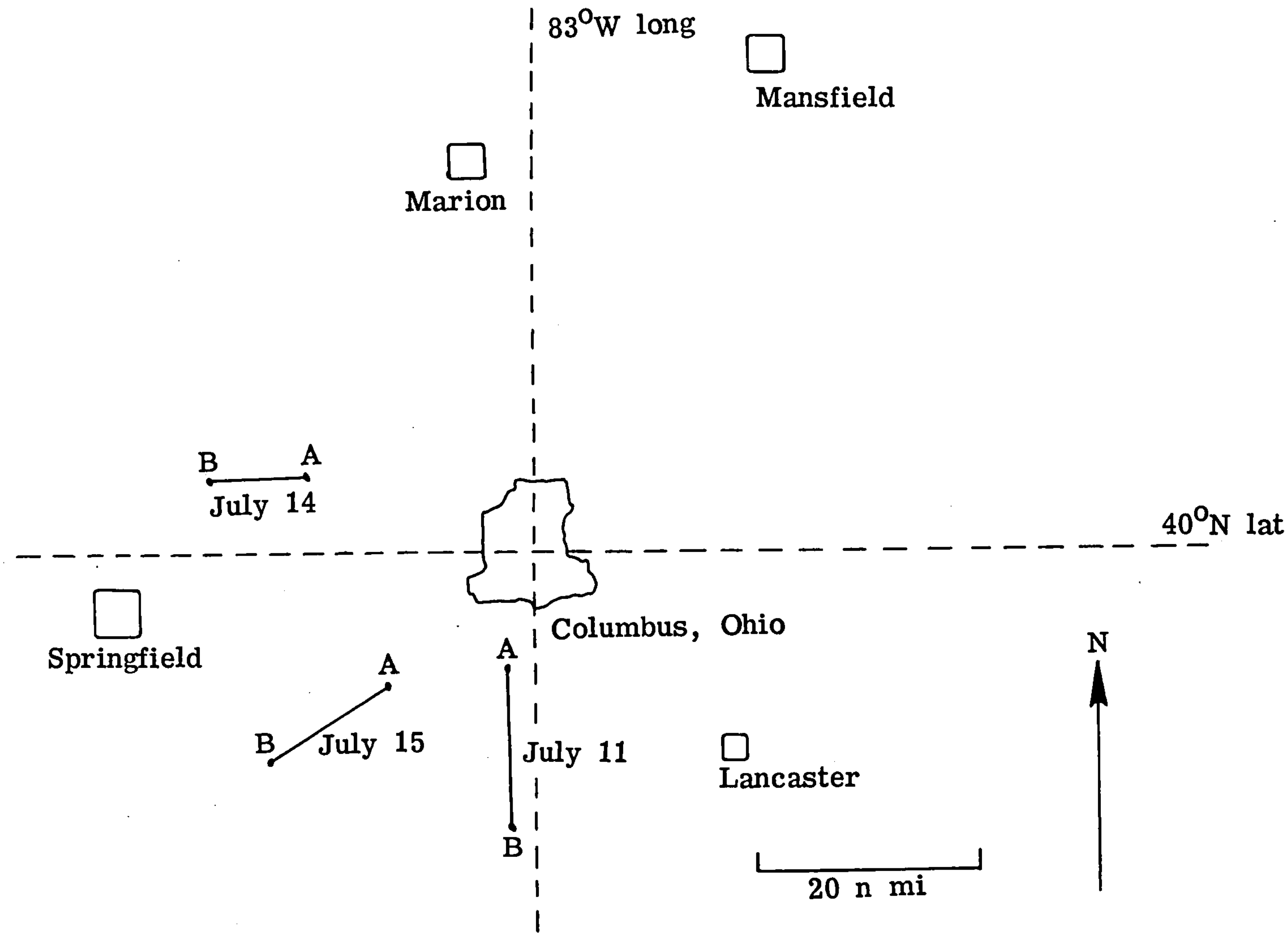

Figure 3.- Geographic locations of correlative measurements.

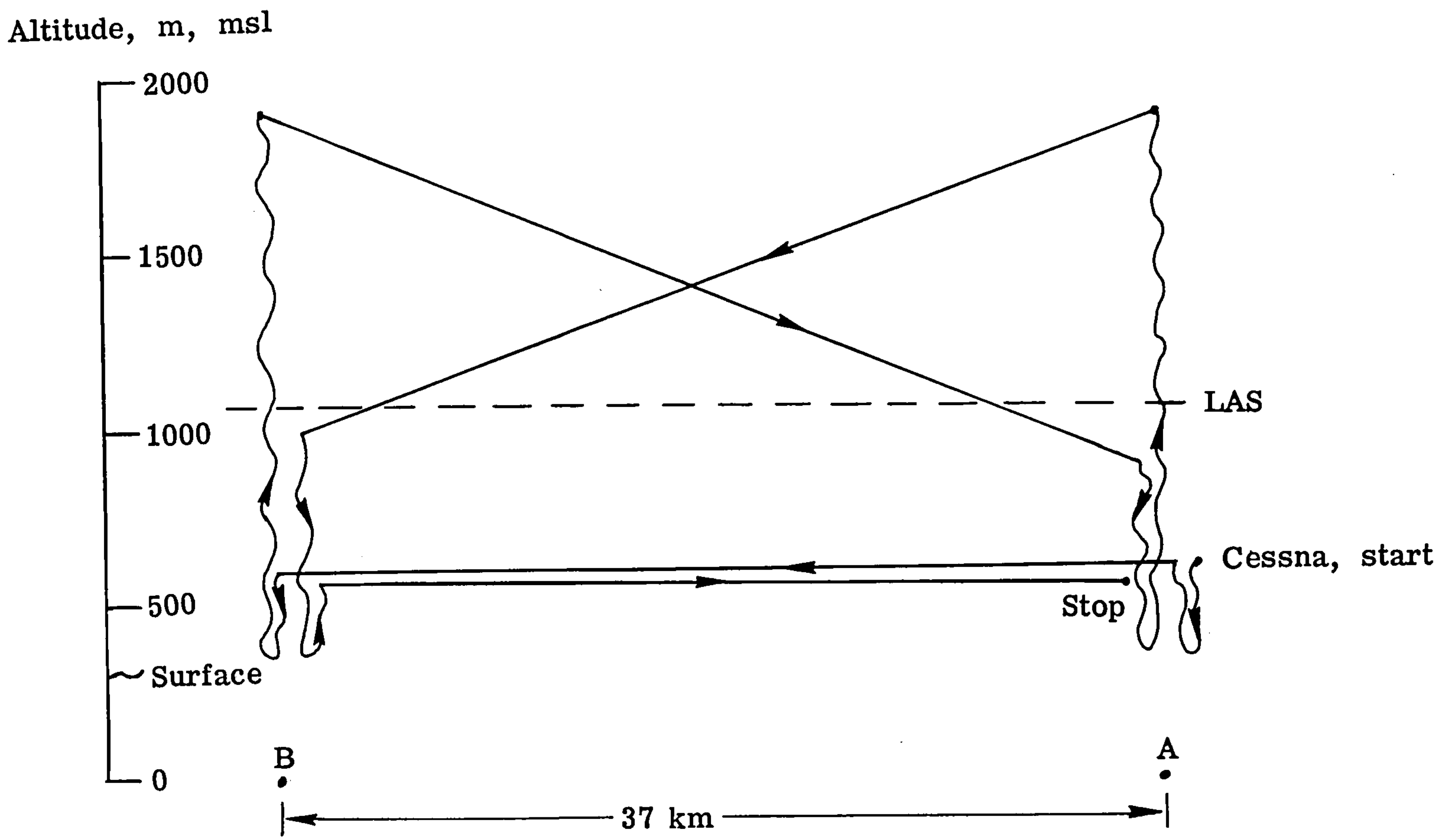

Figure 4.- Box-face pattern, July 11, 1980.

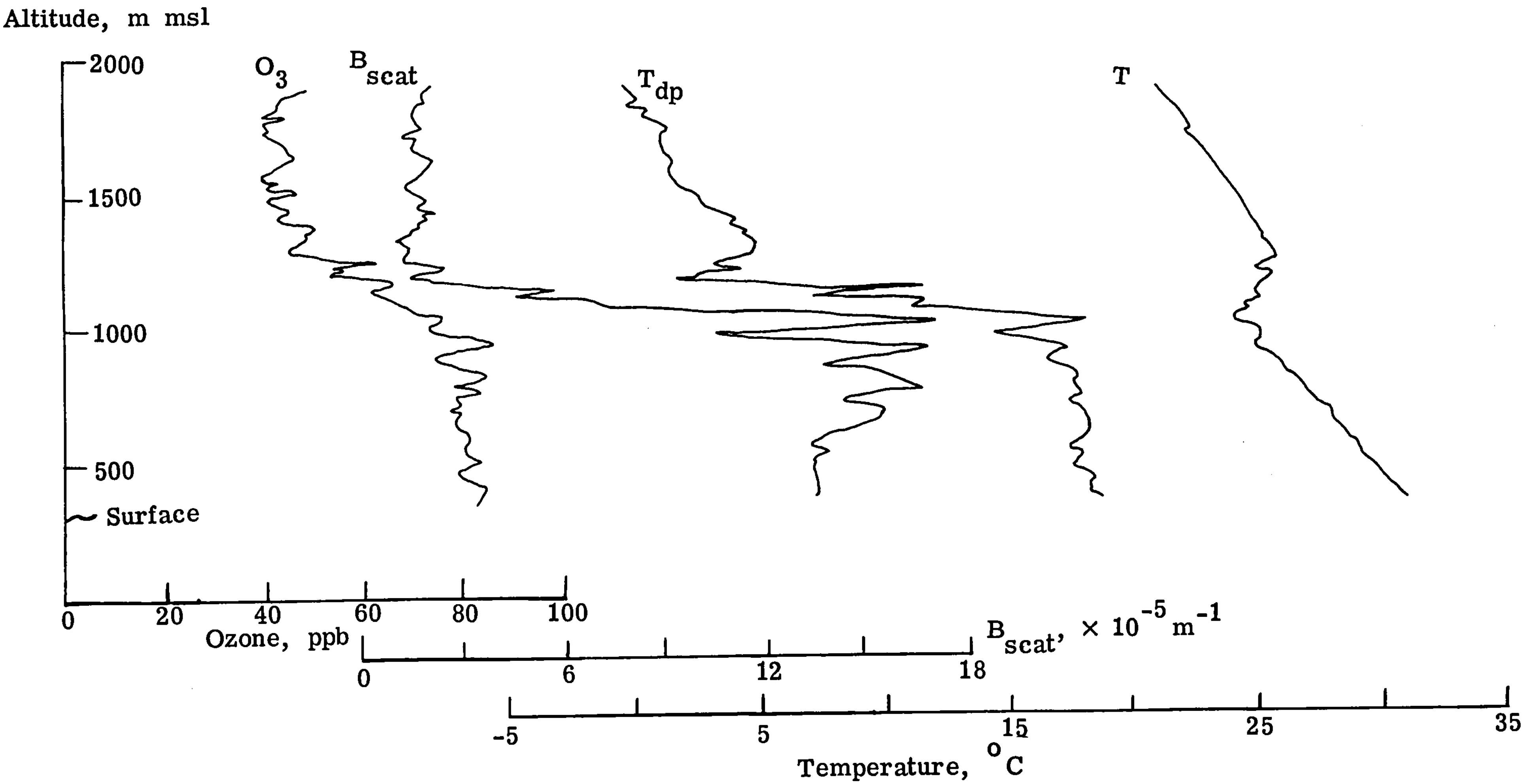

Figure 5.- Vertical profiles of O_3, B_{scat}, T_{dp}, and T for single spiral at location A, July 11, 1980.

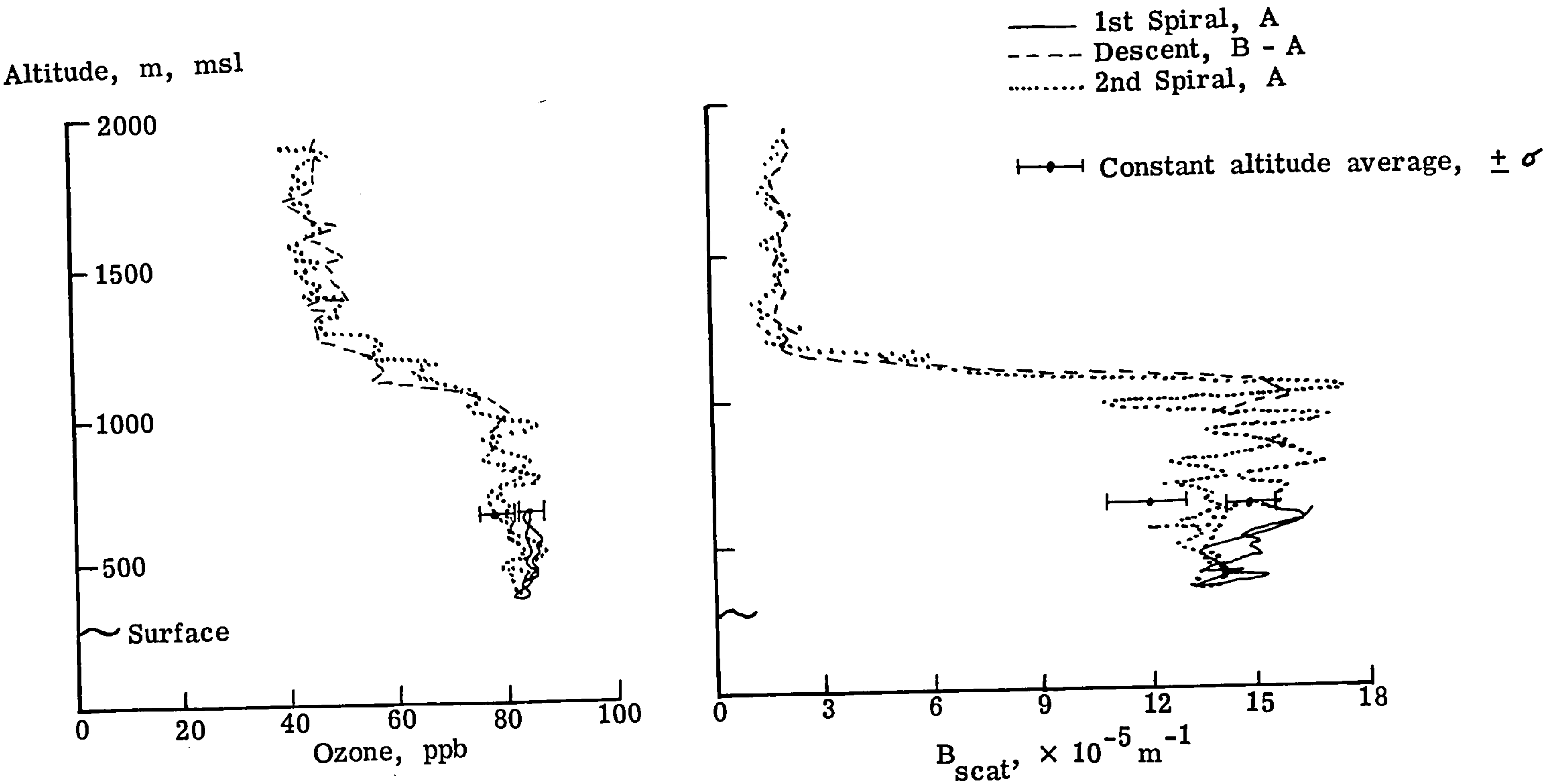

Figure 6.- Vertical profiles of O_3 and B_{scat} for all measurements near location A, July 11, 1980.

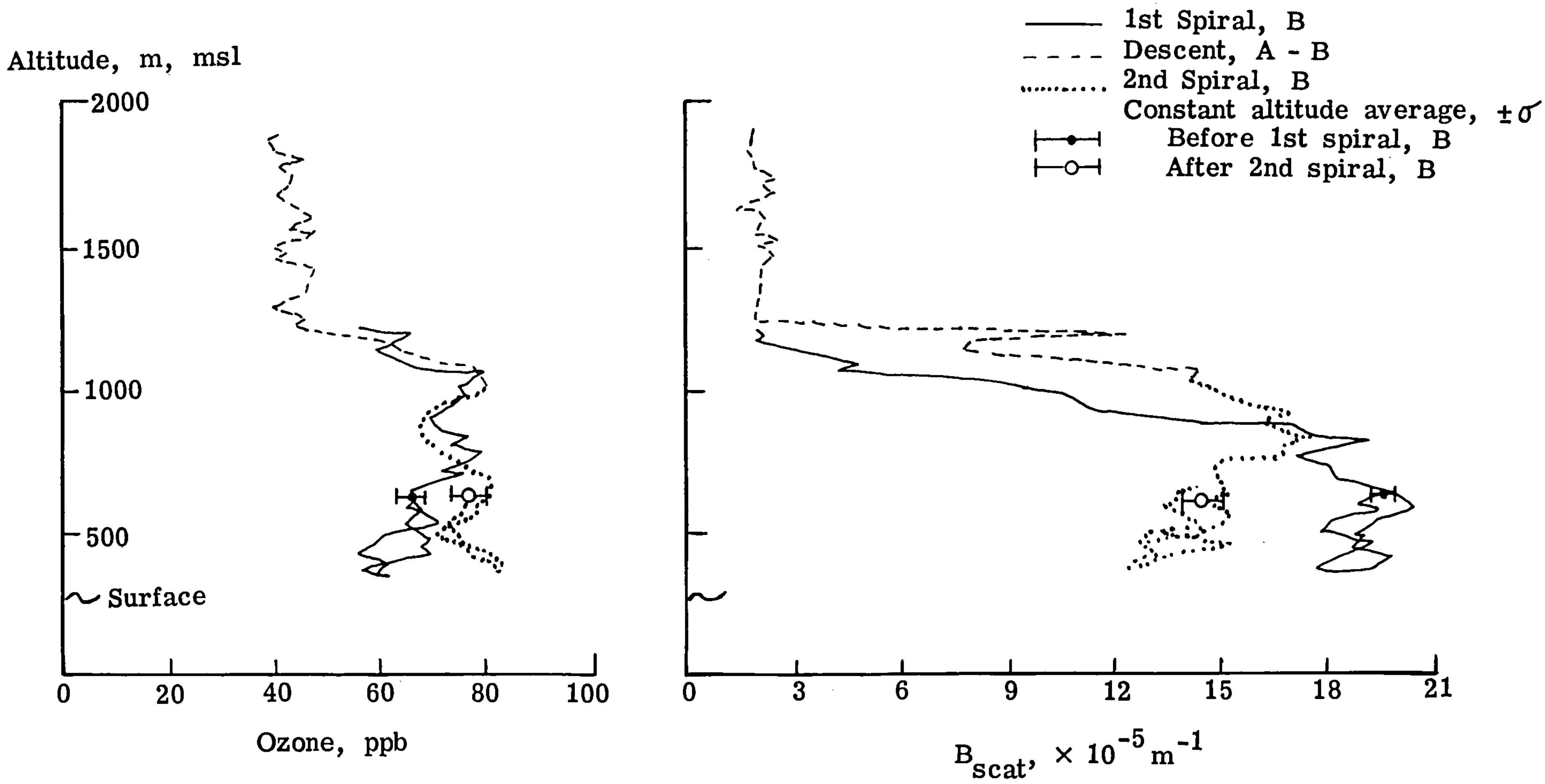

Figure 7.- Vertical profiles of O_3 and B_{scat} for all measurements near location B, July 11, 1980.

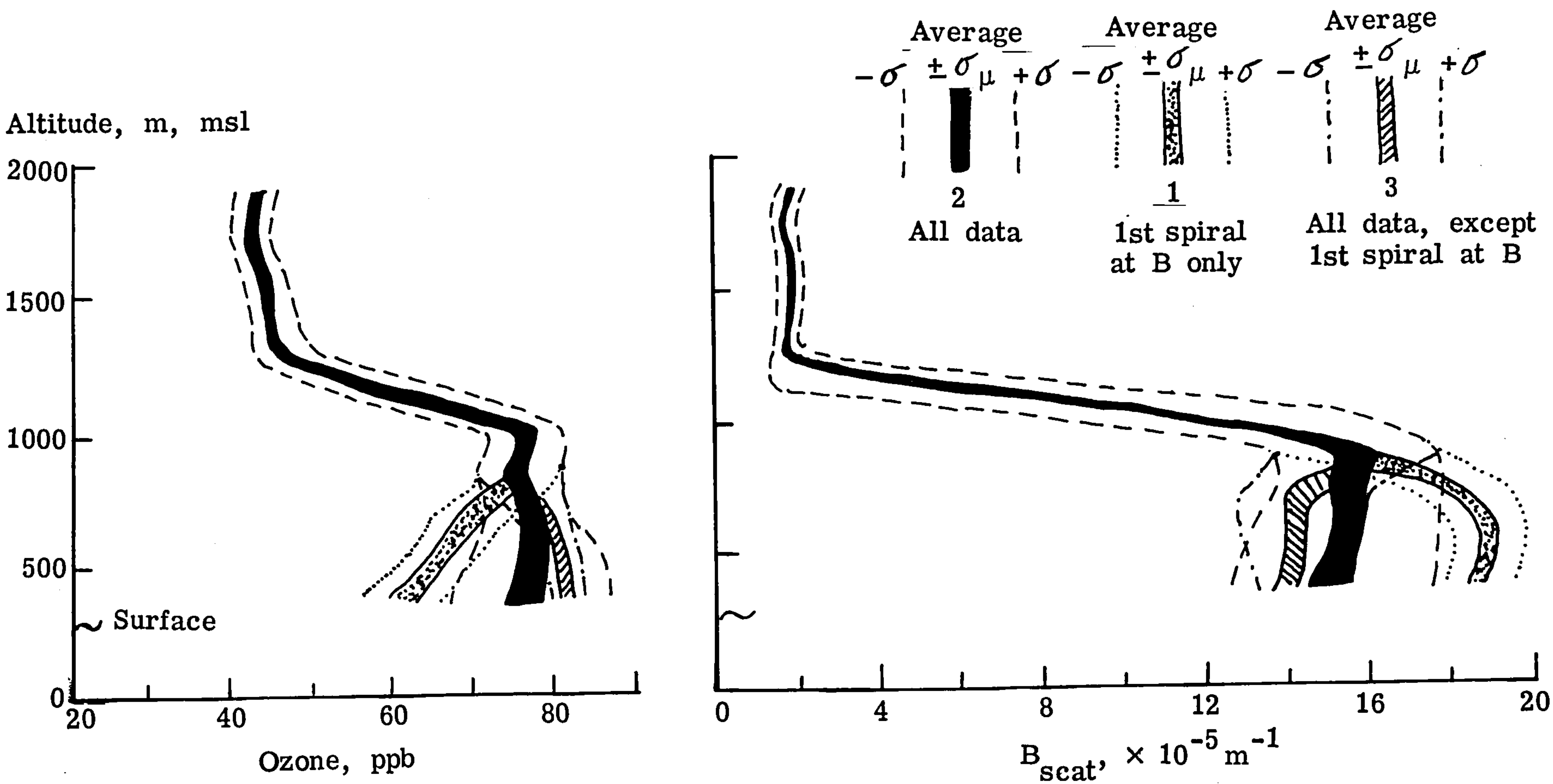

Figure 8.- Vertical profiles of averaged O_3 and B_{scat} for all data, July 11, 1980.

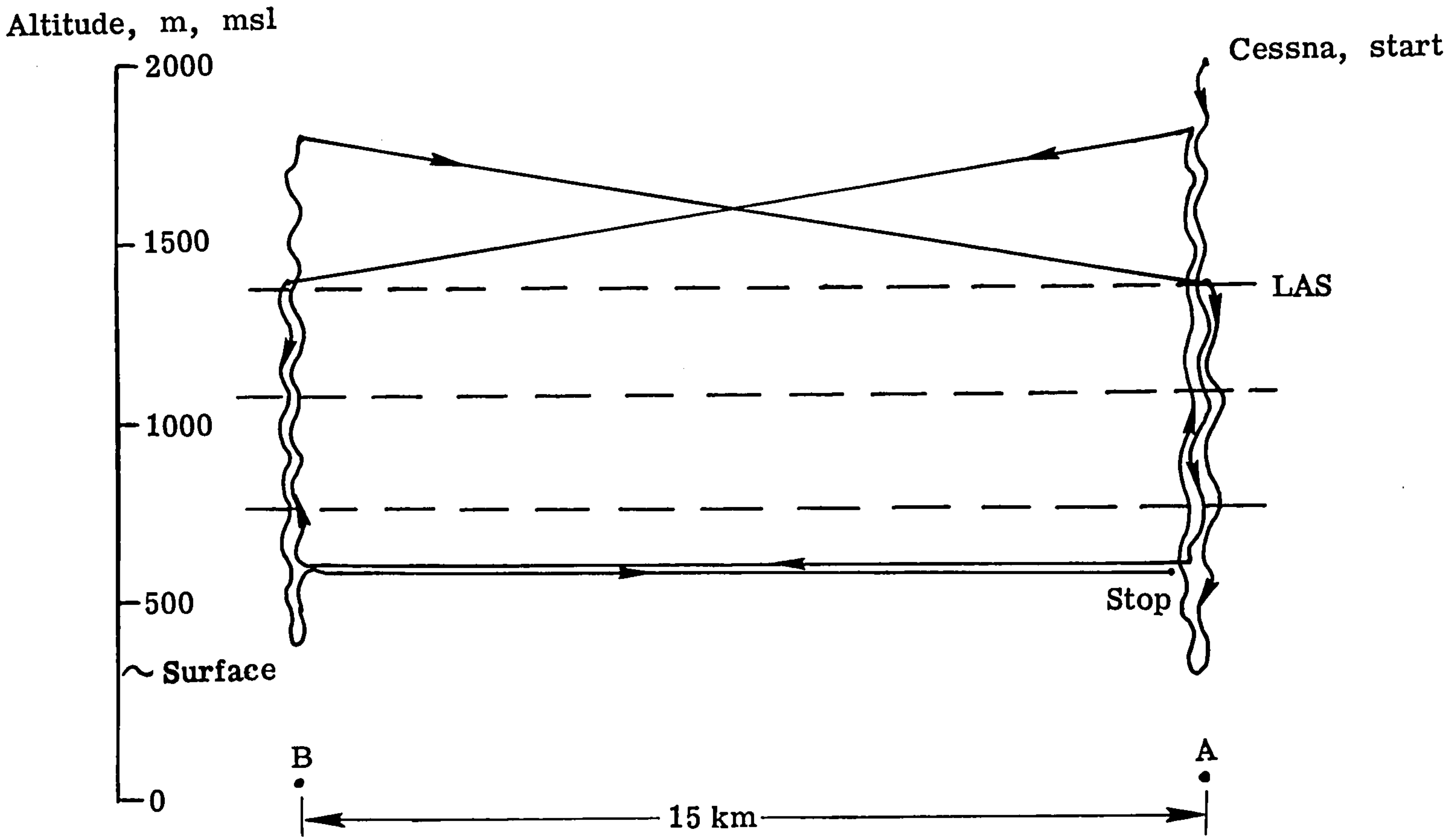

Figure 9.- Box-face pattern, July 14, 1980.

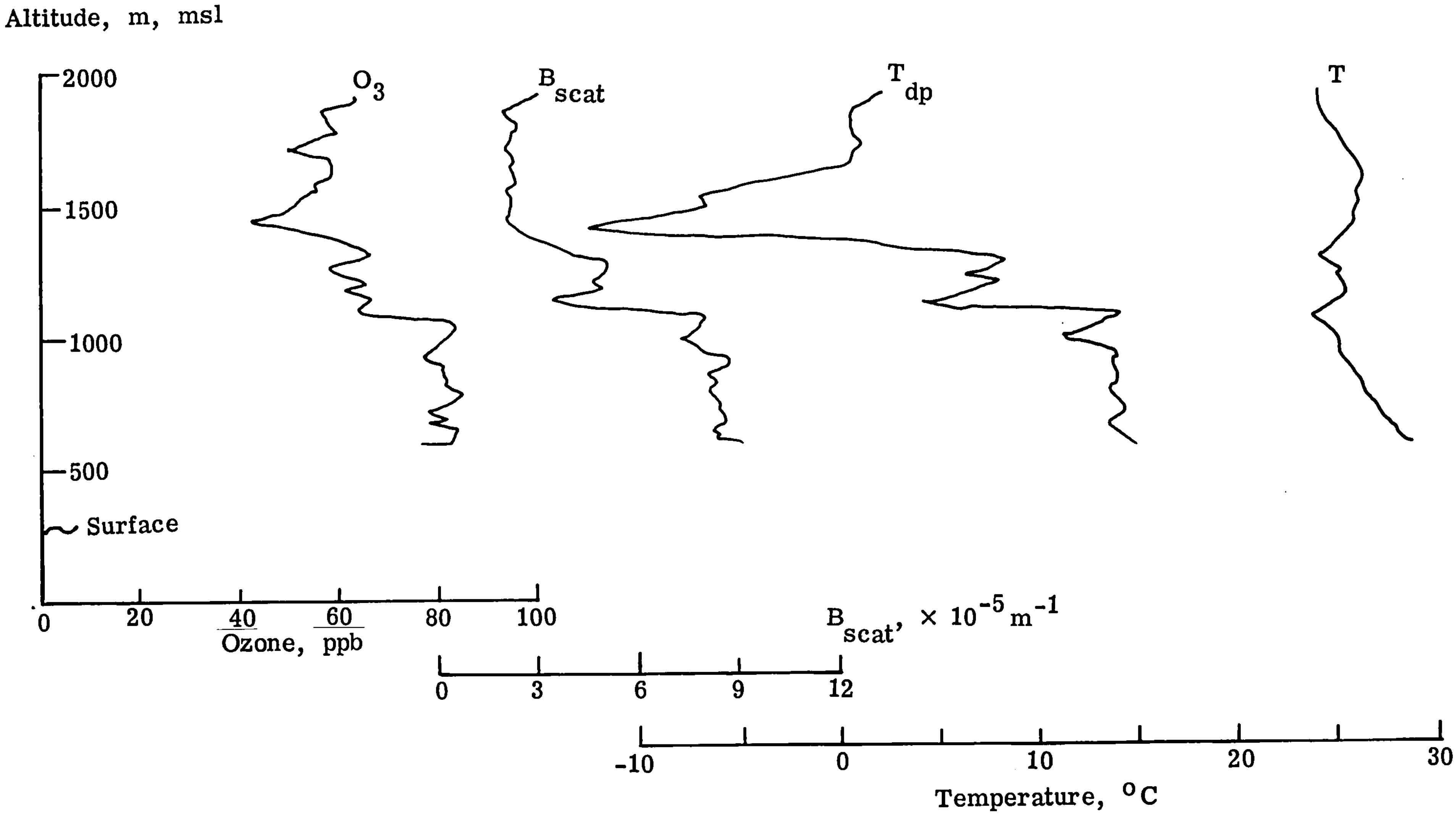

Figure 10.- Vertical profiles of O_3, B_{scat}, T_{dp}, and T for single spiral at location A, July 14, 1980.

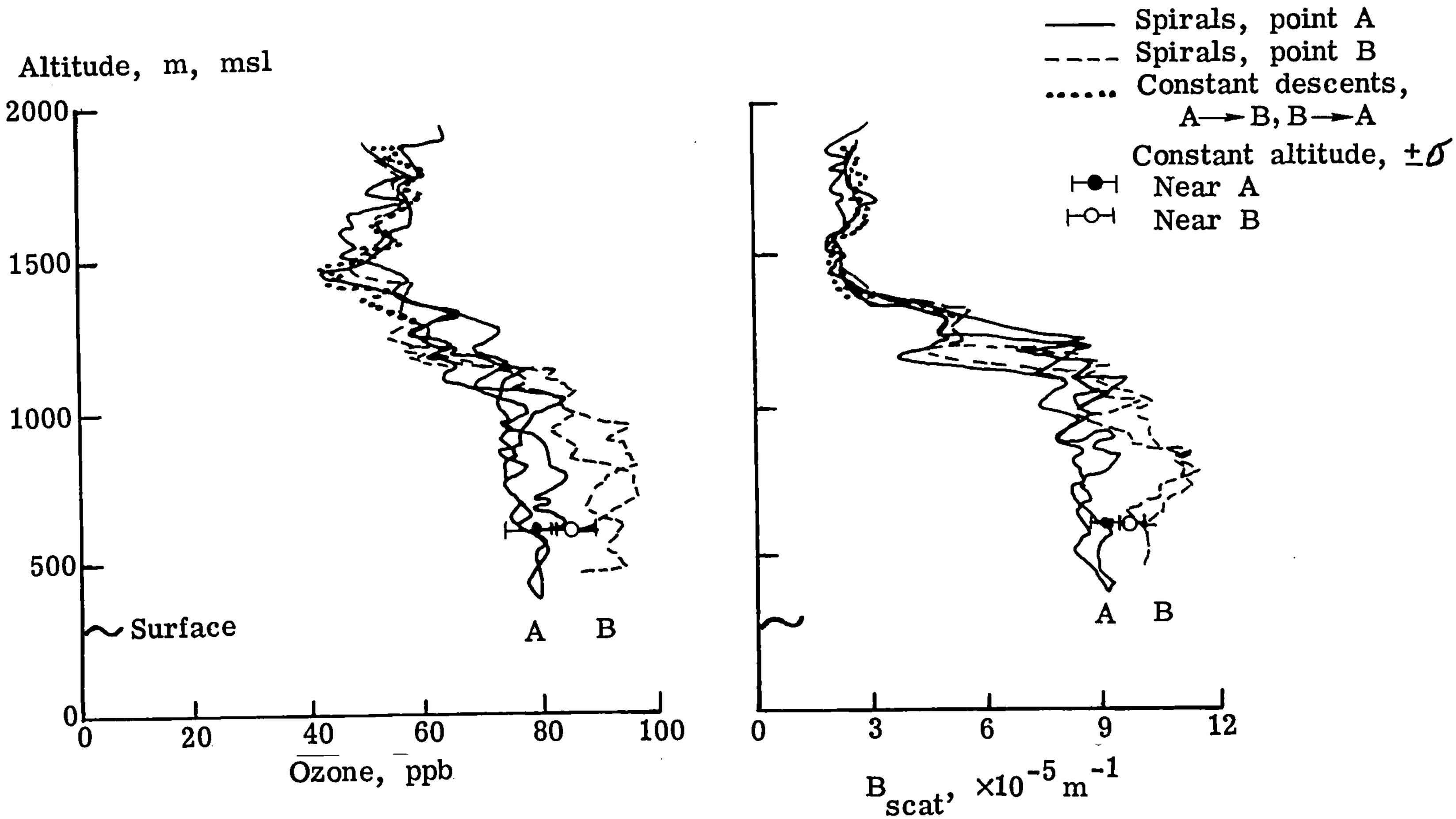

Figure 11.- Vertical profiles of O_3 and B_{scat} for all data, July 14, 1980.

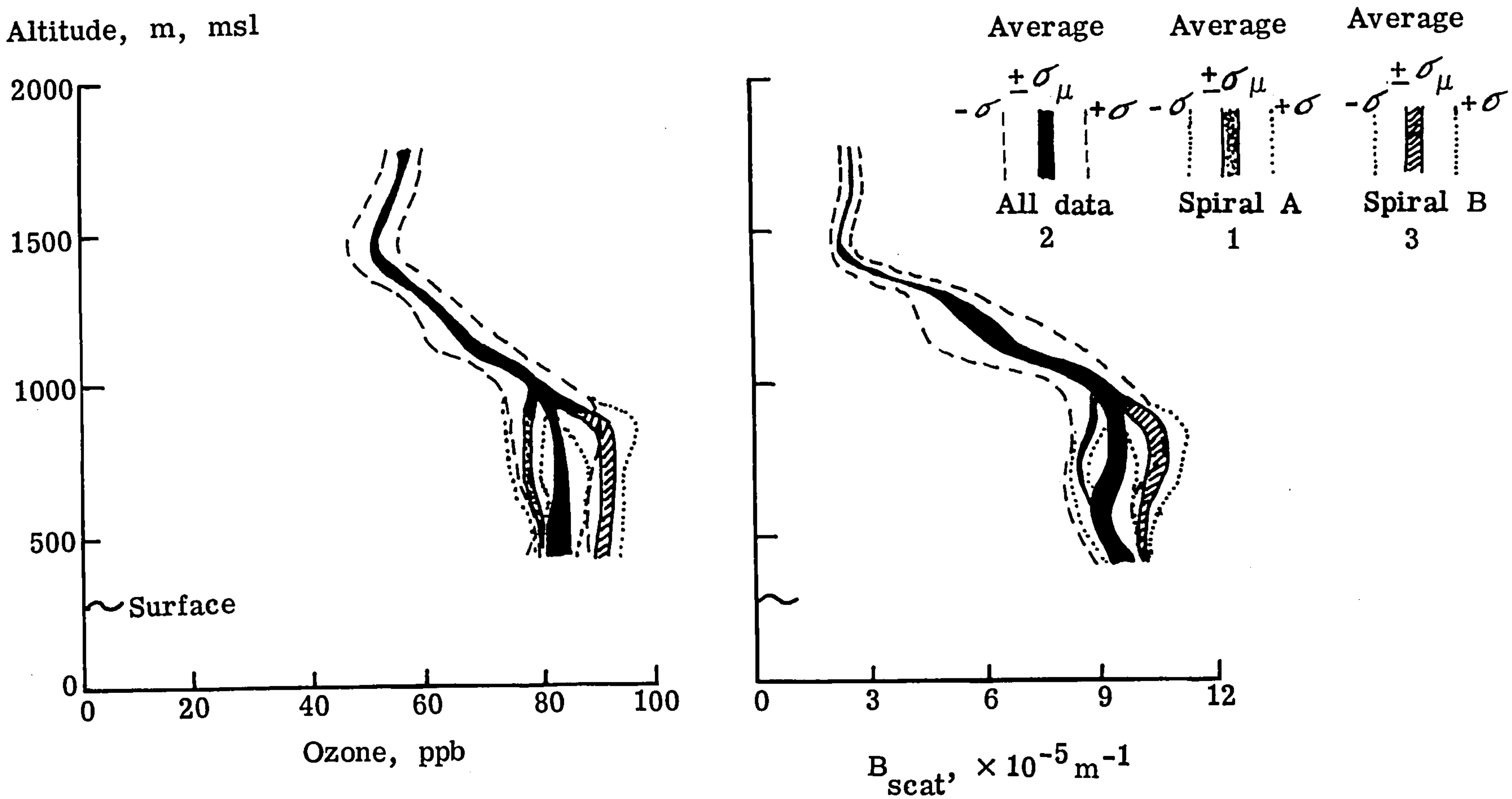

Figure 12.- Vertical profile of averaged O_3 and B_{scat}, July 14, 1980.

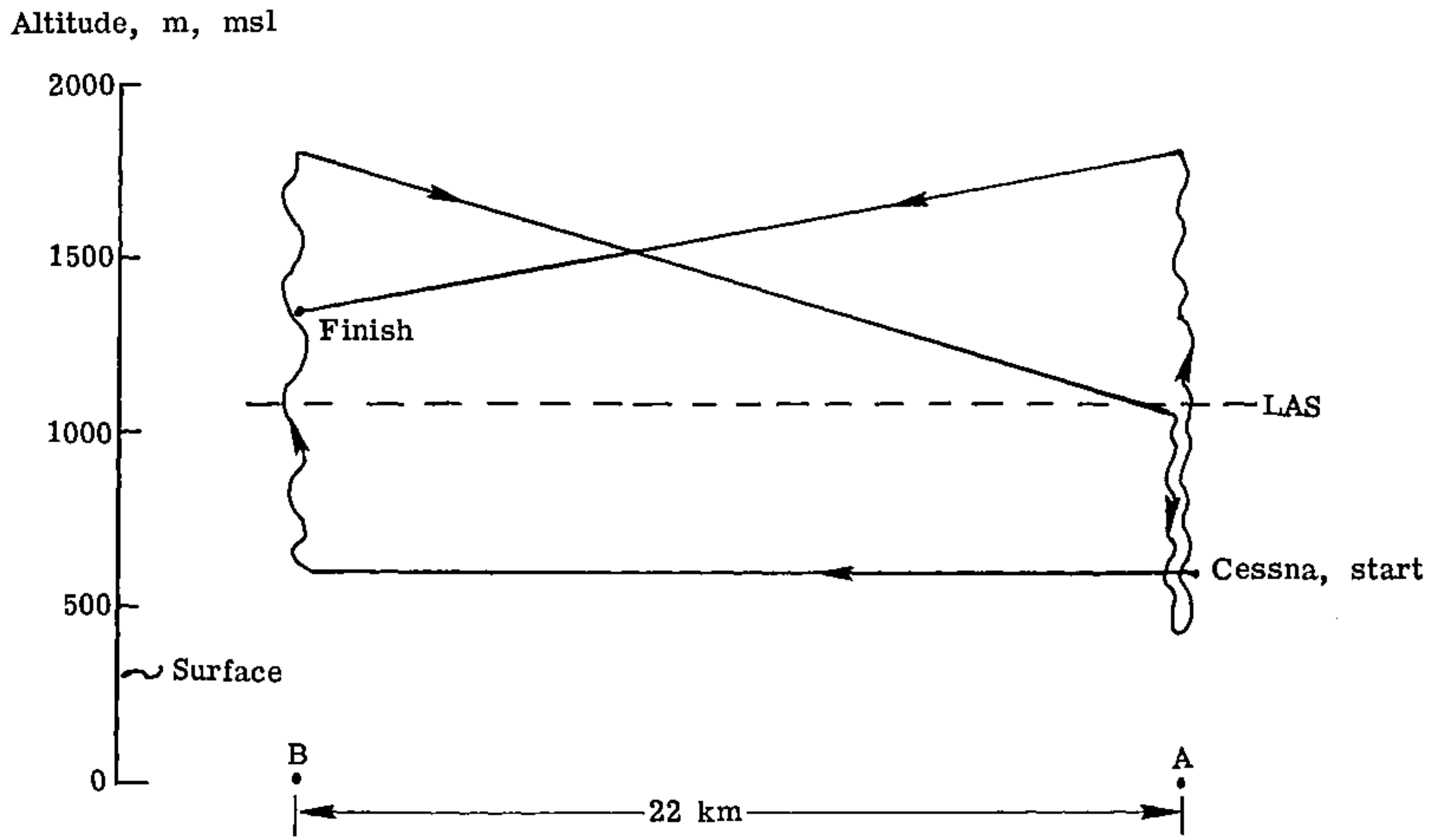

Figure 13.- Box-face pattern, July 15, 1980.

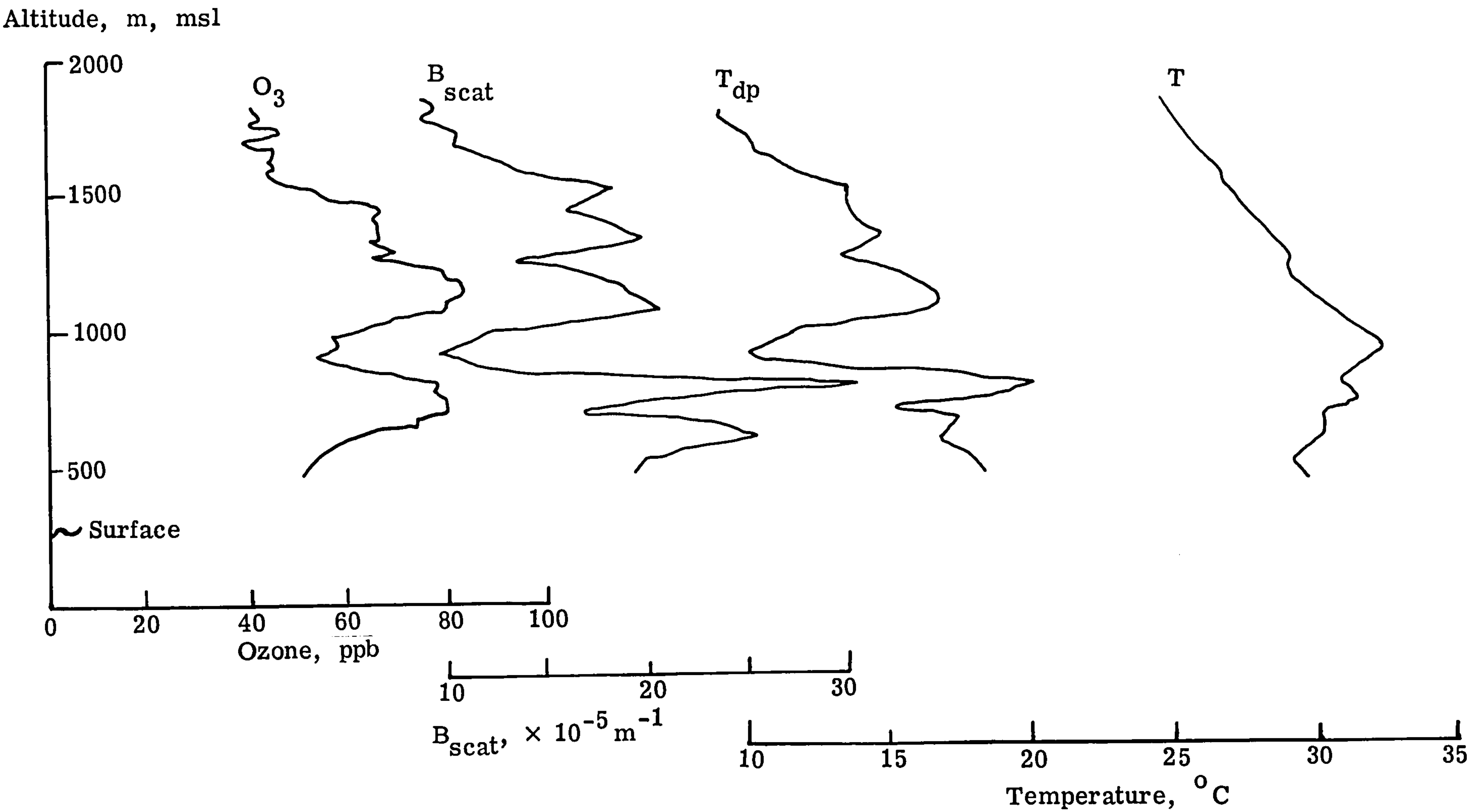

Figure 14.- Vertical profiles of O_3, B_{scat}, T_{dp}, and T for single spiral at location A, July 15, 1980.

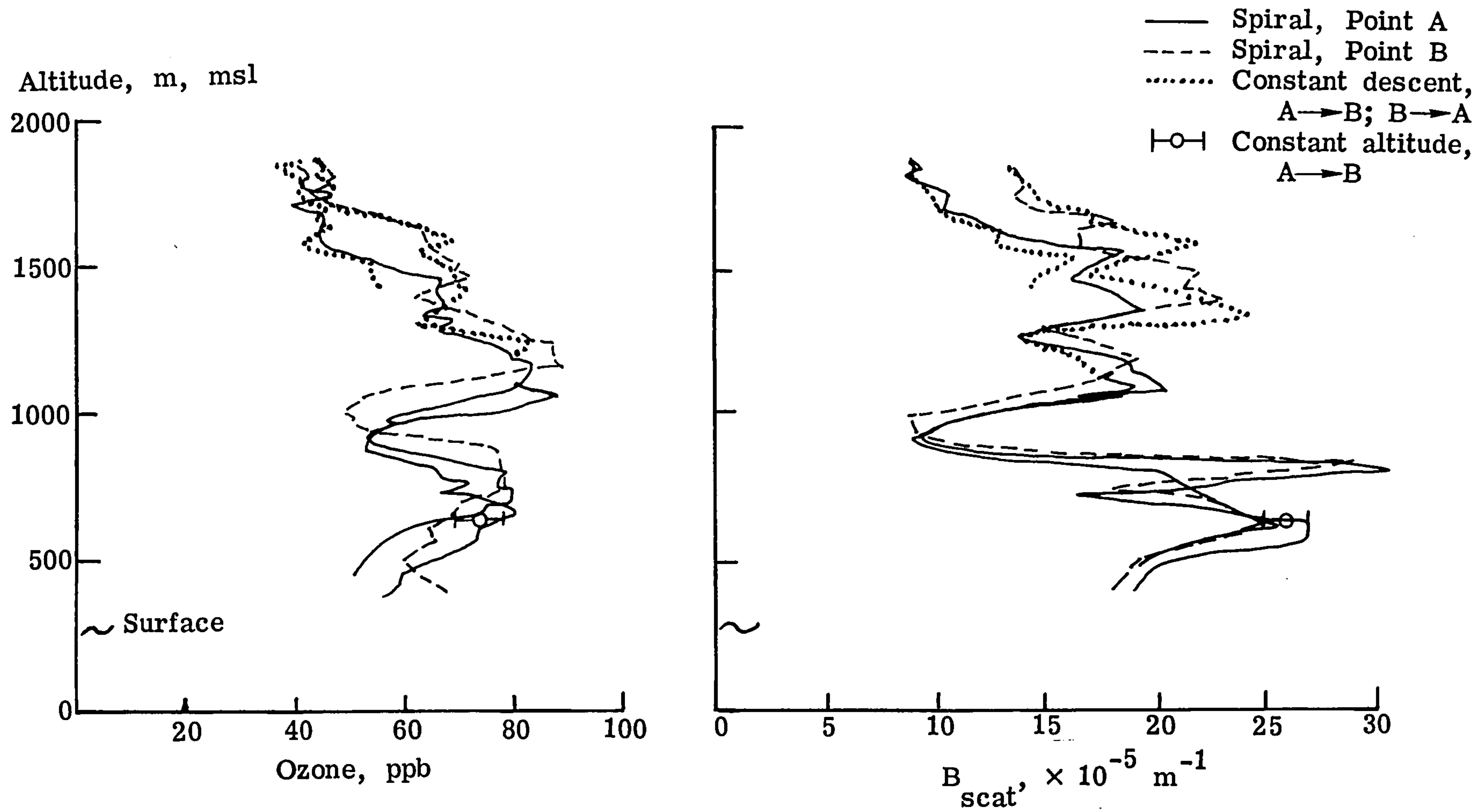

Figure 15.- Vertical profiles of O_3 and B_{scat} for all data, July 15, 1980.

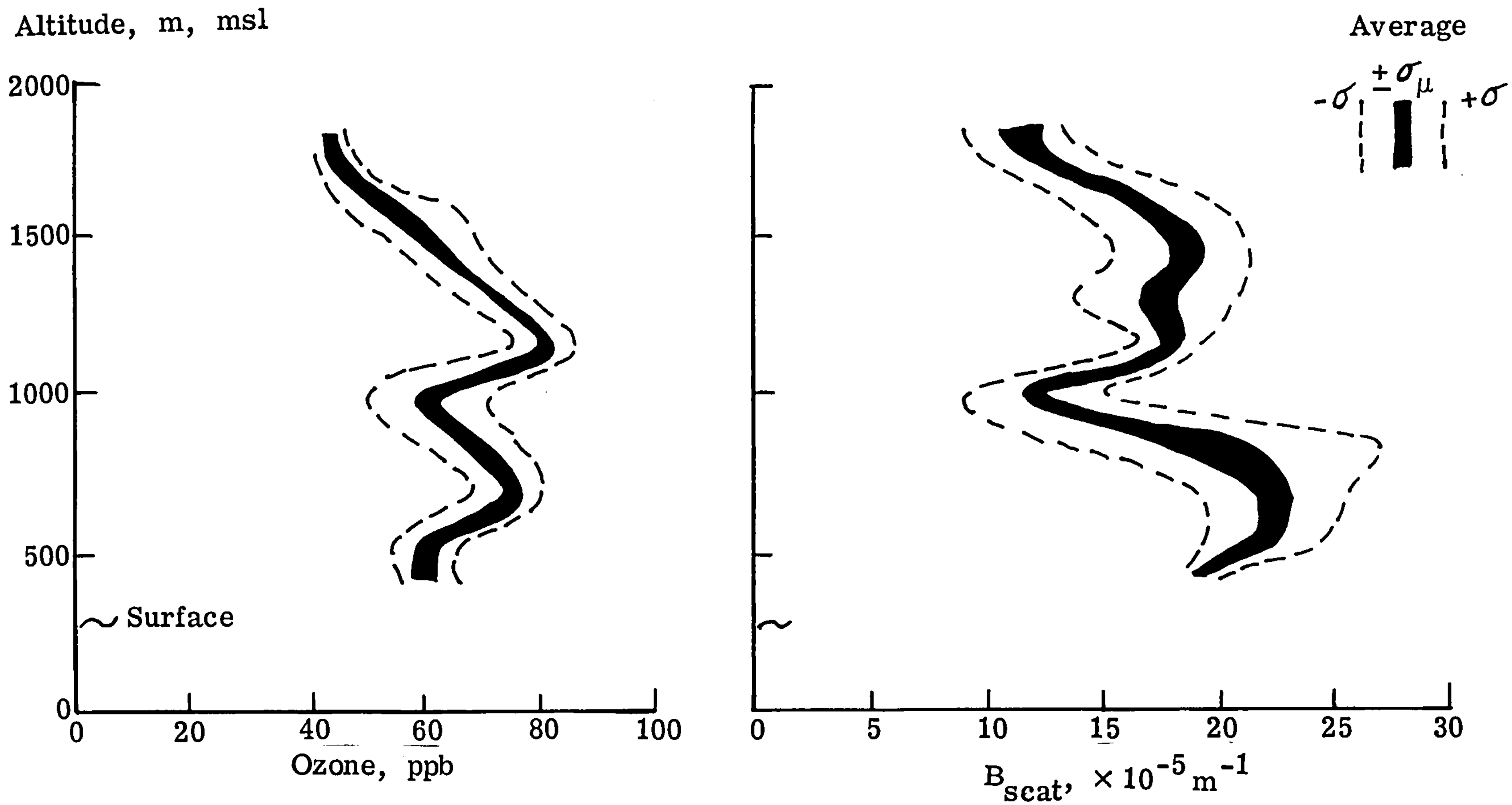

Figure 16.- Vertical profiles of averaged O_3 and B_{scat}, July 15, 1980.

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16. Abstract

Several sets of in situ ozone (O_3) measurements were made by a NASA aircraft in support of the Laser Absorption Spectrometer (LAS) remote sensor. These measurements, made during EPA's summer 1980 Persistent Elevated Pollution Episode/Northeast Regional Oxidant Study (PEPE/NEROS), were designed to provide comparative O_3 data for the LAS sensor. The LAS, which was flown on a second aircraft, remotely measured the vertical burden of O_3 from the aircraft to the surface. In situ results of the air-quality (O_3 and B_{scat}) and meteorological (temperature and dewpoint) parameters for three correlative missions in July 1980 are presented. The report summarizes the aircraft flight plans, in situ concentration profiles and vertical burdens, and measurement errors.

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