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NASA-JSC Ozone Observations for Validation of Nimbus 7-LIMS Data

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SUMMARY

Ozone data were obtained by the NASA Lyndon B. Johnson Space Center from a series of balloon flights dedicated to the validation of limb infrared monitoring of the stratosphere data from the Nimbus 7 satellite. Four balloon flights were launched from Palestine, Texas, and a fifth flight was launched from Cold Lake, Alberta, Canada.

The NASA Lyndon B. Johnson Space Center ozone instrument uses ultraviolet absorption photometry to measure ozone with an accuracy of 8.2 percent and a precision less than 3.1 percent. The mixing-ratio profiles were measured during both ascent and descent of the balloons, but those measured during descent most nearly met the validating criteria. The study showed a 56-percent increase in the mixing ratio at 29 kilometers from the fall of 1978 to the spring of 1979.

INTRODUCTION

The Nimbus 7 satellite was launched on October 24, 1978. One of the instruments onboard, the limb infrared monitor of the stratosphere (LIMS), measured stratospheric concentrations of ozone (O_3), water vapor (H_2O), nitroxyl (NO_2), and nitric acid (HNO_3). The LIMS, which was turned on just after launch and collected acceptable data until the latter part of April 1979, was turned off early in June 1979.

During the lifetime of LIMS, a program was conducted using ground-based observations, rocket flights, and balloon flights to validate its data. One of the balloon platforms, the LIMS instrument package (LIP), contained five instruments to measure O_3, H_2O, and HNO_3. One of these, the Lyndon B. Johnson Space Center (JSC) ozone instrument, uses ultraviolet absorption photometry to measure ozone with an accuracy of 8.2 percent and a precision less than 3.1 percent below 35 kilometers. Above 35 kilometers, the accuracy is about 10 percent.

Validation criteria chosen by the LIMS principal scientists called for correlative measurements to be made in the pressure range from 10 000 to 20 N/m^2 (100 to 0.2 millibars) within 3 hours of a Nimbus 7 overpass and within 2° (great arc distance) of its geographical location. The criteria were approximately met during four flights of the LIP. In addition, ozone data were obtained by the JSC instrument placed on the flight of a University of Minnesota balloon platform during a Nimbus overpass. A University of Minnesota mass spectrometer on that platform also observed the ozone profile.

Invaluable participation by Kenneth Roark as instrument and field engineer is gratefully acknowledged. His dedicated effort permitted the obtaining of excellent data even under the severe conditions encountered at Cold

Lake, Alberta, Canada, in January 1979. The assistance of David Rainey in reduction and analysis of the data is also gratefully acknowledged.

In compliance with NASA's publication policy, the original units of measure have been converted to the equivalent value in the Système International d'Unités (SI). As an aid to the reader, the SI units are written first and the original units are written parenthetically thereafter.

MEASUREMENT CONCEPT

The JSC ozone instrument, which has a temporal resolution of approximately 8 seconds, employs ultraviolet absorption photometry to measure ozone in situ. A rotary vane exhaust pump is used to pull air through the absorption cell. The absorption cell, the light source, the detectors, the detector electrometer boards, and the ozone scrubber used in the instrument are from a Dasibi ozone monitor. The digital electronics and the power system were redesigned to use 28-volt direct-current electrical power, and the entire instrument was repackaged for operation on a balloon platform. Data are transmitted to ground by way of a pulse-code-modulation telemetry system.

Two operational steps are used to measure the absorption of ultraviolet light from a mercury vapor lamp. The dominant spectral line from the mercury lamp is at 253.65 nanometers (2536.5 angstroms), where the ozone photoabsorption cross section is greatest. During the first step, air is diverted by a solenoid through a scrubber that chemically removes all the ozone. The unattenuated light intensity passing through the absorption cell is measured by a sample detector. Light is measured until a preset integrated number of counts is accumulated by the sample counter. The integrated, unattenuated intensity is designated by I_o. During the same period, a control detector measures the amount of light through a controlled, repeatable environment. The number of counts accumulated in the control detector's counter during the first step is designated by C_o. In the second step, however, air is not passed through the ozone scrubber. The sample and control detectors are again operated simultaneously until the control counter counts down from C_o to zero. Using the control detector in this way helps reduce effects of variations in the light intensity. During the second step, light passing through the absorption cell is absorbed by ozone in its path. Thus, the sample counter counts down from I_o to a residual value ΔI after the control counter has counted down to zero. The attenuated light intensity is $I = I_o - \Delta I$. The detectors are operated in the current-measuring mode rather than in the pulse-counting mode. The counts refer to the number of times a capacitor is charged and discharged.

The column content of ozone in the absorption cell is obtained from Beer's law; i.e.,

$$\left[O_3\right]\ell = \frac{1}{\sigma} \ln \frac{I_o}{I} \tag{1}$$

where $[O_3]$ is the average ozone density in the cell, ℓ is the length of the absorption path, and σ is the ozone photoabsorption cross section.

The range of ozone concentrations in the stratosphere is low enough and absorptions are small enough that the logarithm term in equation (1) can be accurately approximated by

$$\ln \frac{I_o}{I} \simeq \frac{I_o - I}{I_o}$$

$$= \frac{\Delta I}{I_o} \tag{2}$$

Substituting equation (2) into equation (1) and solving for the ozone number density, one obtains

$$[O_3] = \frac{\Delta I}{\ell \sigma I_o} \tag{3}$$

The mixing ratio of ozone in the absorption cell is obtained from

$$f = \frac{[O_3]}{[M]}$$

where $[M]$ is the total density of air in the cell. The value of $[M]$ is obtained from

$$[M] = \frac{p}{kT}$$

where p is the pressure in the cell, k is Boltzmann's constant, and T is the temperature. The mixing ratio of ozone in the cell is assumed to be the same as that in the outside ambient air. Collecting terms, the mixing ratio as obtained by the instrument is given by

$$f = \frac{\Delta I k T}{\ell \sigma I_o p} \tag{4}$$

INSTRUMENTAL PRECISION AND ACCURACY

Instrumental precision is determined by random uncertainties in the measured parameters. Those parameters in equation (4) which vary randomly are ΔI, T, and p. The uncertainty in ΔI is one count. For the LIP flights with maximum altitudes of about 35 kilometers, the minimum values of ΔI observed were about 50 counts. Thus, the uncertainty in ΔI was less than 2 percent. The temperature of the absorption-cell wall, and therefore of the air inside, was measured within 0.3 K or with a maximum uncertainty in the stratosphere of 0.14 percent. Pressure in the cell was not measured directly; however, the outside ambient pressure was measured with a maximum uncertainty of 2.1 percent. A differential pressure drop across the absorption cell was measured during the flight but did not contribute significantly to the random error in the pressure determination. Combining the random uncertainties, a total instrumental precision of less than 3.1 percent is obtained.

An assumption that the pressure in the cell is equal to the pressure outside the cell introduces a maximum systematic error of about 3 percent. Another possible systematic error can occur from assuming the mixing ratio is the same outside the cell as it is inside. Behl (ref. 1) has measured a 7.0 ± 0.5 percent loss of ozone by chemisorption on the inlet plumbing system of the laboratory Dasibi ozone monitor, but that system contains an aerosol trap which is not used in the JSC instrument. However, the actual amount of ozone loss in the inlet plumbing of the JSC instrument has not been measured. Therefore, this possible systematic error must be admitted.

The measured length of the absorption path ℓ was 71.0 ± 0.3 centimeters. The ozone photoabsorption cross section was obtained by averaging results from four independent measurements reviewed by Griggs (ref. 2), and the value 11.44 ± 0.12 × 10^{-18} cm^2/molecule was obtained. Combining uncertainties and systematic errors, an instrumental accuracy of 8.2 percent below 35 kilometers is obtained. Because the two possible systematic errors cause an underestimate of the mixing ratio, the probable error is 2.4 to -8.2 percent. Above 35 kilometers, the accuracy is about 10 percent.

The instrumental resolution is basically determined by the preset value of I_o that is used. For the LIP flights, I_o was fixed at 68 800 counts. This value defines a resolution for measuring ozone densities in the absorption cell of 1.8 × 10^{10} molecules/cm^3. Mixing ratios depend on total air densities, which vary with altitude. Thus, the instrumental resolution varies from 0.004 p/m volume at a total pressure of 1200 N/m^2 (12 millibars) at 15 kilometers to 0.1 p/m volume at 500 N/m^2 (5 millibars) at about 35 kilometers.

RESULTS AND DISCUSSION

Mixing-ratio profiles were obtained for both ascent and descent of the balloons. Three flights were launched from Palestine, Texas (latitude 31.8° N). These were LIP II, LIP III, and LIP V. The dates of the launches were October 30, 1978, November 8, 1978, and April 5, 1979, respectively. The LIP

IV flight was launched from Cold Lake, Alberta, Canada (latitude 54.2° N), on February 8, 1979. The times of the descent profiles were chosen to coincide with the overpass of the Nimbus 7 satellite. Thus, the criteria were most nearly met for validating the LIMS data during descent. Another platform was also launched from Palestine, Texas, November 2, 1978, onboard a University of Minnesota balloon and also coincided with an overpass of Nimbus 7.

Tables I to IV give the ozone profiles for ascent and descent of the four LIP flights. The means and standard deviations as well as the number of observations are given for 0.5-kilometer altitude intervals. The altitudes listed are the midpoints of the intervals. In computing the means, the F-test was applied to remove spurious data. Table V gives similar data for the flight of the University of Minnesota balloon.

Figures 1 to 4 are graphs showing individual measurements of the mixing ratio for ascent and descent profiles of the four LIP flights. Figure 5 shows similar data for the University of Minnesota flight. The ordinates show both altitude and pressure.

Figures 6 to 9 show the data from tables I to IV in graphic form. The means for 0.5-kilometer altitude intervals are plotted at the midpoints of the intervals with error bars of 1 standard deviation. Figure 10 shows comparable data for the University of Minnesota flight shown in table V.

By comparing data from the four LIP flights, temporal variations in the ozone profiles are observed. The LIP II and LIP III flights were made within 9 days of each other. Their ozone profiles are remarkably similar in the regions from 20 to 27 kilometers and from 30 to 35 kilometers. However, in the region from 27 to 30 kilometers, the mean mixing ratios decrease by about 0.6 p/m volume or 9 percent between the two flights. The same decrease is present on the University of Minnesota flight, which occurred 3 days after LIP II. There is a large difference between the LIP III and LIP V profiles, which were both measured from Palestine, Texas, the former in early November 1978 and the latter in early April 1979. Below about 26 kilometers, the profiles are similar, and at 35 kilometers, the mixing ratios have about the same value. However, at 29 kilometers, the mixing ratio between LIP III and LIP V increases by 3.2 p/m volume, which is an increase of 56 percent.

The ascent and descent profiles for each flight are very similar, and the mean values at the same altitude are within the instrumental uncertainty in almost all cases. One exception is a spike at 29.5 kilometers on LIP IV that appears to move down by about 1 kilometer from ascent to descent, a period of about 2.5 hours. The LIP IV profile shows a great amount of structure with differences of almost 2 p/m volume within 1 kilometer. There is a particularly sharp spike, with a magnitude of about 1 p/m volume, at 20 kilometers in both the ascent and the descent profiles.

The ascent rates of the balloons were faster than the descent rates. For example, on LIP III, the balloon went from 20 to 30 kilometers in 35 minutes. But, during descent, 79 minutes were required to descend from 30 to 20 kilometers. During the ascent profiles, the deviations about the mean values were about the same magnitude as the instrumental uncertainties. However, during descent, the deviations were significantly greater than the instrumental uncertainties, an indication of temporal variations over short periods. An example can be seen in the LIP V flight. The slope of the mixing-ratio profile is about zero between 31 and 30 kilometers, where 14 minutes were required to descend 1 kilometer, whereas ascent from 30 to 31 kilometers required only 5 minutes. Typical standard deviations in that interval during descent were about 6 percent. The mean values agreed within about 2 percent from ascent to descent, and typical standard deviations during ascent were less than 1.5 percent. Thus, temporal variations of several percent are indicated. No engineering parameters of the instrument indicated a degraded performance during that time. Further, the LIP V descent profile was measured at night (i.e., near local midnight), whereas the LIP II and LIP III flights occurred in the daytime.

In comparing the LIP II, LIP III, and LIP V ascent profiles, a significant difference in the standard deviations of the means is apparent. The standard deviations for LIP II and LIP III are smaller than those for LIP V, and the ascent rate for LIP V was about 50 percent slower than on LIP II and LIP III. The longer observational period within the 0.5-kilometer intervals and the greater deviations on LIP V also indicate variations on the order of tens of minutes.

CONCLUDING REMARKS

Ozone mixing-ratio profiles were obtained during ascent and descent of a series of balloon flights. The descent profiles were scheduled to coincide with the overpass of the Nimbus 7 satellite so that data from the limb infrared monitor of the stratosphere experiment could be validated. Results from five such flights are reported, four from Palestine, Texas (latitude 31.8° N), and one from Cold Lake, Alberta, Canada (latitude 54.2° N). Similar profiles measured during the balloon ascents are also reported for comparison.

Comparison of profiles from two flights made within 9 days in the fall of 1978 was very similar except between 27 and 30 kilometers, where a difference of 0.6 p/m volume was observed. A comparison of the results from a flight in the fall of 1978 and another in the spring of 1979 showed dramatic differences between 26 and 35 kilometers. At 29 kilometers, the mixing ratio decreased during that 5-month period by 3.2 p/m volume, or 56 percent. Although ascent and descent profiles for a flight were usually similar, a spike observed on ascent near 29.5 kilometers appeared to move downward and was observed near 28.5 kilometers during descent. The time between observations was about 2.5 hours.

The largest amount of structure was observed on the high-latitude flight, the profile of which contained several sharp spikes that varied by as much as 2 p/m volume within 1 kilometer. Standard deviations of means obtained by averaging over 0.5-kilometer intervals were larger for descent profiles than for ascent profiles. For ascent profiles, 0.5 kilometer was transited typically in about 2.5 minutes and standard deviations were within the instrumental precision; i.e., 3 percent. However, for the descent profiles, about 7 minutes were required to transit 0.5 kilometer and the standard deviations were about 6 percent, which indicates temporal variations of a few percent on a scale of 7 minutes.

Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
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TABLE I.- OZONE PROFILE AVERAGED OVER 0.5-KILOMETER INTERVALS, LIP II

(October 30, 1978, Palestine, Texas)

Midpoint altitude, km	Mean mixing ratio, p/m vol	Standard deviation, p/m vol	No. of observations
	Ascent		
21.000	1.79006	0.05936	7
21.500	2.01201	0.04354	11
22.000	2.21760	0.10324	12
22.500	2.56785	0.13407	12
23.000	3.00857	0.16149	14
23.500	3.38949	0.08721	12
24.000	3.75974	0.11582	14
24.500	4.18326	0.16015	13
25.000	4.59308	0.13407	14
25.500	4.83369	0.19507	14
26.000	5.41239	0.17522	12
26.500	5.72198	0.12969	12
27.000	5.97160	0.08872	10
27.500	6.28911	0.07194	12
28.000	6.28594	0.13497	17
28.500	6.43134	0.11785	12
29.000	6.43008	0.11320	8
29.500	6.17368	0.08884	2
30.000	6.47420	0.10109	16
30.500	6.44218	0.12327	20
31.000	6.47037	0.15653	23
31.500	6.50968	0.08082	10
32.000	6.58023	0.15865	13
32.500	6.79040	0.18956	23
33.000	7.09879	0.15184	17
33.500	7.26029	0.22078	21
34.000	7.04713	0.08500	24
34.500	6.85063	0.14590	15
35.000	6.69042	0.38709	50
35.500	6.72469	0.10472	23

TABLE I.- Concluded

Midpoint altitude, km	Mean mixing ratio, p/m vol	Standard deviation, p/m vol	No. of observations
Descent			
20.000	1.57676	0.01136	5
20.500	1.65751	0.21280	42
21.000	1.90639	0.05624	31
21.500	2.17528	0.24588	50
22.000	2.54097	0.31318	34
22.500	2.81230	0.27027	48
23.000	2.99695	0.17844	2
25.000	4.99723	0.00000	1
25.500	5.00770	0.25800	21
26.000	5.29604	0.30835	23
26.500	5.80686	0.48888	36
27.000	6.19238	0.44305	42
27.500	6.49127	0.10267	27
28.000	6.34285	0.43820	50
28.500	6.50172	0.15068	26
29.000	6.45662	0.41163	42
29.500	6.49438	0.15136	28
30.000	6.31707	0.38896	50
30.500	6.04180	0.78810	37
31.000	6.24505	0.41582	50
31.500	6.34906	0.40311	46
32.000	6.43217	0.38082	50
32.500	6.83116	0.44401	50
33.000	7.24004	0.47100	50
33.500	6.99687	0.41653	50
34.000	7.60818	0.09093	2
35.000	6.76786	0.50762	43
35.500	6.78290	0.14016	28

TABLE II.- OZONE PROFILE AVERAGED OVER 0.5-KILOMETER INTERVALS, LIP III

(November 8, 1978, Palestine, Texas)

Midpoint altitude, km	Mean mixing ratio, p/m vol	Standard deviation, p/m vol	No. of observations
Ascent			
19.500	1.08764	0.02421	6
20.000	1.26740	0.07971	16
20.500	1.61479	0.12633	14
21.000	1.90045	0.09686	11
21.500	2.22042	0.11397	14
22.000	2.48002	0.09958	16
22.500	2.88014	0.14778	13
23.000	3.24397	0.06526	11
23.500	3.65004	0.15133	15
24.000	4.07656	0.13224	10
24.500	4.37360	0.06158	12
25.000	4.59944	0.07924	13
25.500	4.94669	0.18150	14
26.000	5.51388	0.08074	16
26.500	5.67072	0.06421	6
27.000	5.60014	0.05993	10
27.500	5.61367	0.06298	3
28.000	5.64805	0.00000	1
28.500	5.60945	0.00000	1
29.000	5.71476	0.12336	10
29.500	5.96783	0.08631	10
30.000	6.02728	0.06704	13
30.500	6.28064	0.19738	9
31.000	6.70913	0.08763	8
31.500	6.56586	0.09955	13
32.000	6.72846	0.10939	14
32.500	6.77137	0.15623	15
33.000	6.74096	0.12650	11
33.500	6.81881	0.08440	13
34.000	6.81161	0.09389	18
34.500	6.87969	0.08821	12
35.000	6.89824	0.41961	44

TABLE II.- Concluded

Midpoint altitude, km	Mean mixing ratio, p/m vol	Standard deviation, p/m vol	No. of observations
Descent			
21.000	1.69574	0.22828	45
21.500	2.02628	0.06835	23
22.000	2.27146	0.25175	39
22.500	2.61259	0.13833	25
23.000	3.04428	0.36447	34
23.500	3.69813	0.06866	19
24.000	3.91004	0.07452	15
24.500	4.18165	0.06233	30
25.000	4.49365	0.13981	27
25.500	5.00512	0.15622	25
26.000	5.29759	0.05305	30
26.500	5.34281	0.06341	31
27.000	5.49655	0.17170	23
27.500	5.87208	0.11689	27
28.000	5.62304	0.08557	30
28.500	5.58777	0.05956	18
29.000	5.56519	0.08117	27
29.500	5.65772	0.38315	41
30.000	5.89933	0.41011	39
30.500	6.05786	0.43248	35
31.000	6.31120	0.39632	44
31.500	6.36474	0.39218	46
32.000	6.49104	0.39224	50
32.500	6.43689	0.38191	50
33.000	6.50516	0.40006	46
33.500	6.73749	0.38409	50
34.000	6.72826	0.37890	50
34.500	6.75608	0.38492	50
35.000	6.89489	0.40176	50

TABLE III.- OZONE PROFILE AVERAGED OVER 0.5-KILOMETER INTERVALS, LIP IV

(February 8, 1979, Cold Lake, Alberta, Canada)

Midpoint altitude, km	Mean mixing ratio, p/m vol	Standard deviation, p/m vol	No. of observations
Ascent			
12.000	0.23483	0.03003	7
12.500	0.36110	0.03869	17
13.000	0.51876	0.10503	14
13.500	0.51437	0.20763	14
14.000	0.43792	0.10569	16
14.500	0.69453	0.06922	13
15.000	0.78264	0.03997	18
15.500	0.99817	0.10987	12
16.000	1.24269	0.13831	15
16.500	1.45105	0.06914	16
17.000	1.44356	0.15471	22
17.500	1.54306	0.56884	8
18.000	1.92085	0.38040	17
18.500	2.48699	0.33849	19
19.000	3.35188	0.28301	17
19.500	3.45847	0.11211	16
20.000	3.96526	0.12278	15
20.500	4.47829	0.18813	14
21.000	4.97015	0.16449	17
21.500	5.19397	0.03284	15
22.000	5.17447	0.05400	18
22.500	5.45206	0.24791	19
23.000	5.12974	0.10334	15
23.500	5.51558	0.20125	19
24.000	5.68350	0.14589	13
24.500	5.86388	0.13823	16
25.000	5.71805	0.07063	14
25.500	6.32421	0.23921	16
26.000	7.11294	0.43990	20
26.500	5.85823	0.46678	19
27.000	5.63141	0.09087	16
27.500	5.67507	0.23171	14
28.000	5.21247	0.05047	14
28.500	5.44569	0.13038	18
29.000	6.17706	0.64390	18
29.500	6.73373	0.10974	22
30.000	5.92918	0.51335	25
30.500	5.17483	0.13065	31
31.000	5.41451	0.47521	30
31.500	6.60256	0.20292	13
32.000	6.63718	0.49207	36
32.500	6.27480	0.16925	20
33.000	5.72271	0.21334	27
33.500	5.49565	0.10275	16
34.000	5.23327	0.35454	46

TABLE III.- Concluded

Midpoint altitude, km	Mean mixing ratio, p/m vol	Standard deviation, p/m vol	No. of observations
Descent			
17.000	1.44106	0.18518	9
17.500	1.32685	0.46609	10
18.000	1.76623	0.44594	34
18.500	2.16668	0.30491	50
19.000	2.89745	0.43091	37
19.500	3.13276	0.29983	45
20.000	3.51399	0.34301	50
20.500	4.19279	0.33773	45
21.000	4.67180	0.32268	50
21.500	4.80491	0.33978	44
22.000	4.86748	0.39454	38
22.500	5.07117	0.39006	48
23.000	4.82044	0.10855	29
23.500	4.92033	0.40358	37
24.000	5.36216	0.06228	19
24.500	5.31389	0.41123	40
25.000	5.51566	0.26375	24
25.500	5.69397	0.21100	19
26.000	6.68789	0.31725	26
26.500	5.43220	0.51932	39
27.000	5.36151	0.17566	27
27.500	4.98531	0.14993	28
28.000	5.67513	0.56265	41
28.500	6.48782	0.55862	35
29.000	6.42521	0.47545	36
29.500	6.22773	0.47174	36
30.000	5.35648	0.54334	50
30.500	4.79458	0.33059	50
31.000	4.78759	0.33526	50
31.500	6.05850	0.12066	29
32.000	6.18760	0.40152	18
32.500	5.74223	0.41722	50
33.000	5.40173	0.44299	45
33.500	4.99988	0.58886	50
34.000	5.27378	0.37632	50

TABLE IV.- OZONE PROFILE AVERAGED OVER 0.5-KILOMETER INTERVALS, LIP V

(April 5, 1979, Palestine, Texas)

Midpoint altitude, km	Mean mixing ratio, p/m vol	Standard deviation, p/m vol	No. of observations
Ascent			
10.000	0.04115	0.00516	12
10.500	0.05070	0.00546	8
11.000	0.06779	0.01153	10
11.500	0.04948	0.03337	18
12.000	0.06203	0.01597	11
12.500	0.20823	0.12490	19
13.000	0.20883	0.15556	13
13.500	0.13277	0.00906	15
14.000	0.13806	0.01437	21
14.500	0.10997	0.01513	13
15.000	0.12206	0.01943	18
15.500	0.17503	0.02372	11
16.000	0.20540	0.01550	15
16.500	0.22977	0.01408	7
17.000	0.41870	0.17088	19
17.500	0.63216	0.17034	6
18.000	0.67643	0.14233	18
18.500	1.10701	0.43264	40
19.000	1.37545	0.53235	33
19.500	2.11574	0.48243	19
20.000	2.58188	0.25793	25
20.500	2.23318	0.10242	17
21.000	2.58379	0.18575	17
21.500	2.59213	0.08992	14
22.000	3.09270	0.25958	5
22.500	3.42658	0.14841	17
23.000	4.00561	0.20081	27
23.500	4.30613	0.04278	11
24.000	4.57374	0.29543	19
24.500	5.12509	0.12045	25
25.000	5.49024	0.05249	19
25.500	5.72852	0.08101	22
26.000	6.14626	0.17556	24
26.500	6.74562	0.29011	15
27.000	7.15727	0.30910	20
27.500	7.70233	0.11839	19
28.000	7.93532	0.15621	16
28.500	8.33954	0.27680	15
29.000	8.86653	0.10885	22
29.500	8.78178	0.12897	17
30.000	8.82460	0.10733	16
30.500	8.92696	0.12817	19
31.000	8.82536	0.20546	20
31.500	8.58480	0.24873	11
32.000	8.32599	0.30305	26
32.500	8.46521	0.19391	20
33.000	8.29579	0.27717	22
33.500	8.20248	0.53731	33
34.000	7.91534	0.09164	30
34.500	7.81811	0.08593	8
35.000	7.49967	0.41042	50
35.500	7.19811	0.17221	19

TABLE IV.- Concluded

Midpoint altitude, km	Mean mixing ratio, p/m vol	Standard deviation, p/m vol	No. of observations
Descent			
19.500	2.58262	0.00248	2
20.000	2.79618	0.24513	50
20.500	2.25248	0.54652	50
21.000	2.41274	0.24675	24
21.500	3.11657	0.33948	50
22.000	3.14454	0.29103	50
22.500	3.83749	0.29716	21
23.000	4.17441	0.04256	22
23.500	4.27729	0.33683	39
24.000	4.67146	0.34221	50
24.500	5.20848	0.35493	44
25.000	5.47282	0.41412	33
25.500	5.77211	0.37114	48
26.000	6.26403	0.45964	34
26.500	6.99015	0.62950	38
27.000	7.08131	0.50725	35
27.500	7.49941	0.40329	50
28.000	7.84182	0.49798	41
28.500	8.76185	0.44434	47
29.000	8.54348	0.44605	50
29.500	8.64162	0.50372	36
30.000	8.79904	0.44920	50
30.500	8.59278	0.53438	36
31.000	8.35661	0.44259	50
31.500	8.49820	0.52799	40
32.000	8.15568	0.45391	50
32.500	8.27347	0.44988	50
33.000	8.10492	0.45813	50
33.500	7.94630	0.42538	50
34.000	7.82026	0.41490	50
34.500	7.64735	0.40602	50
35.000	7.32665	0.44652	50

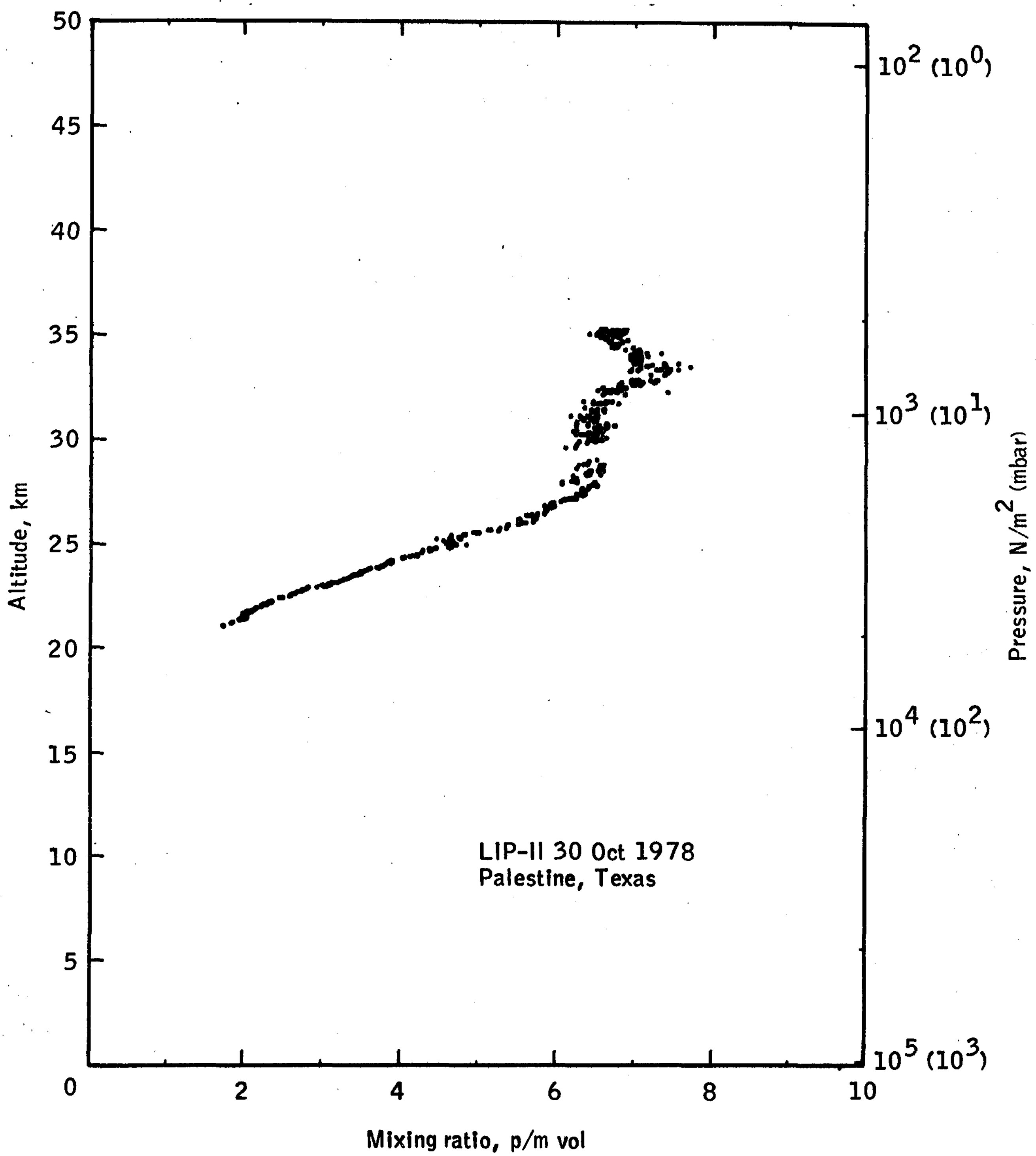
TABLE V.- OZONE PROFILE AVERAGED OVER 0.5-KILOMETER INTERVALS, UNIVERSITY OF MINNESOTA FLIGHT

(November 2, 1978, Palestine, Texas)

Midpoint altitude, km	Mean mixing ratio, p/m vol	Standard deviation, p/m vol	No. of observations
	Ascent		
19.50	1.017	0.068	7
20.00	1.241	0.095	13
20.50	1.604	0.074	11
21.00	1.940	0.113	13
21.50	2.317	0.119	13
22.00	2.683	0.106	11
22.50	2.927	0.080	10
23.00	3.414	0.217	13
23.50	3.810	0.044	11
24.00	4.075	0.090	10
24.50	4.445	0.149	14
25.00	4.662	0.034	11
25.50	4.890	0.076	11
26.00	5.111	0.057	13
26.50	5.399	0.109	11
27.00	5.318	0.070	11
27.50	5.467	0.067	13
28.00	5.706	0.036	13
28.50	5.911	0.098	13
29.00	5.945	0.095	12
29.50	6.017	0.057	10
30.00	6.177	0.087	12
30.50	6.413	0.075	14
31.00	6.416	0.053	13
31.50	6.467	0.056	12
32.00	6.540	0.052	10
32.50	6.628	0.089	11
33.00	6.734	0.093	11
33.50	6.831	0.096	17
34.00	6.799	0.072	9
34.50	6.911	0.111	11
35.00	6.942	0.075	11
35.50	7.039	0.071	15
36.00	7.073	0.276	21
36.50	6.680	0.149	15
37.00	6.491	0.091	10
37.50	6.476	0.120	14
38.00	6.359	0.161	10
38.50	6.929	0.680	9
39.00	6.097	0.406	20
39.50	5.970	0.404	31
40.00	5.691	0.627	24

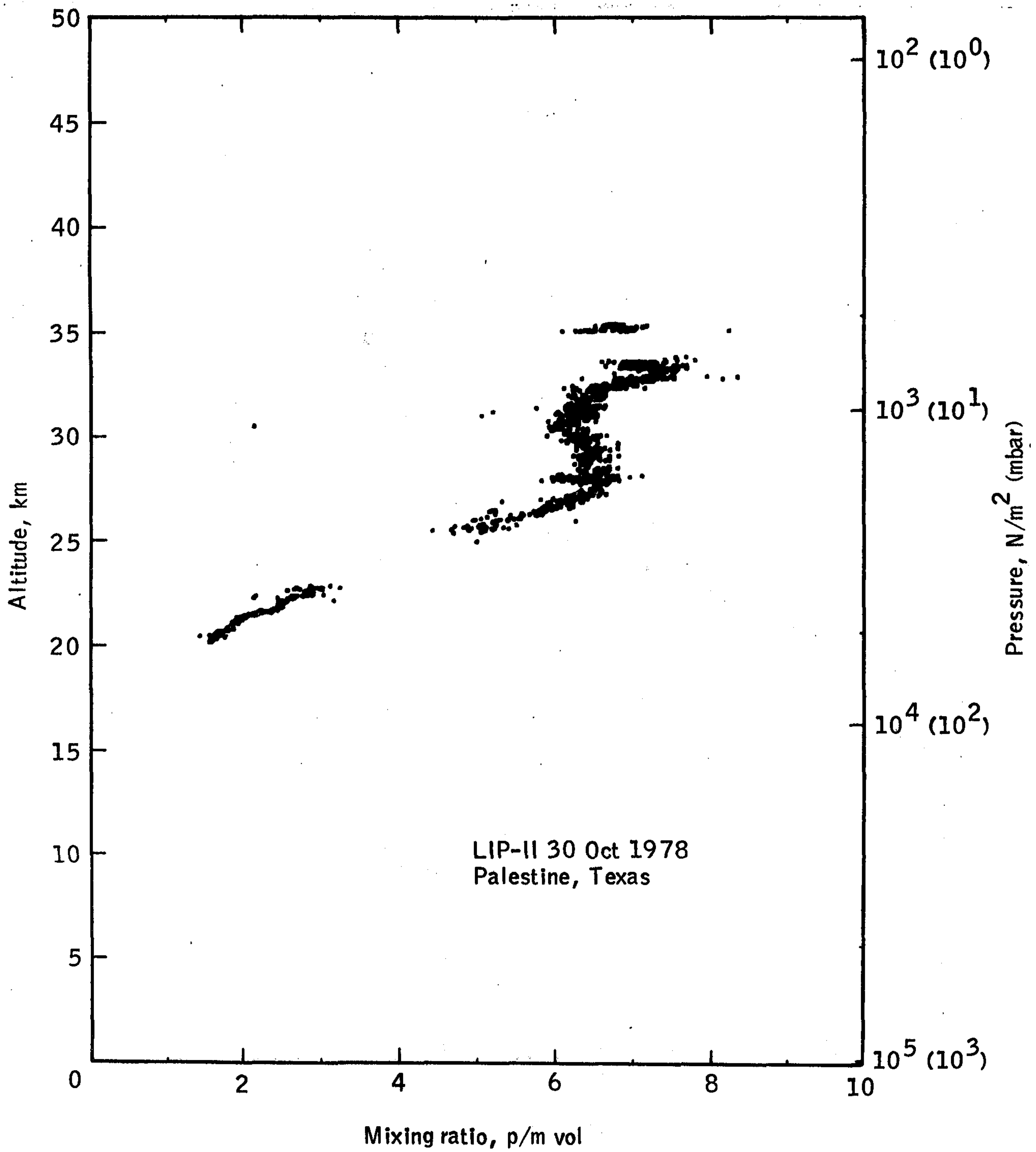
TABLE V.- Concluded

Midpoint altitude, km	Mean mixing ratio, p/m vol	Standard deviation, p/m vol	No. of observations
Descent			
21.00	1.907	0.001	2
21.50	2.095	0.116	27
22.00	2.354	0.112	33
22.50	2.699	0.130	30
23.00	2.977	0.090	22
23.50	3.203	0.101	30
24.00	3.617	0.088	40
24.50	3.911	0.066	46
25.00	4.096	0.059	29
25.50	4.421	0.075	32
26.00	4.630	0.048	21
26.50	4.770	0.052	24
27.00	5.214	0.220	20
27.50	5.294	0.068	22
28.00	5.261	0.075	25
28.50	5.302	0.133	28
29.00	5.334	0.056	30
29.50	5.577	0.086	28
30.00	5.787	0.043	27
30.50	5.871	0.044	19
31.00	5.947	0.030	21
31.50	6.266	0.164	26
32.00	6.493	0.113	22
32.50	6.581	0.072	35
33.00	6.701	0.157	25
33.50	6.881	0.089	48
34.00	6.575	0.085	35
34.50	6.697	0.081	28
35.00	6.774	0.112	34
35.50	6.685	0.105	45
36.00	6.670	0.117	35
36.50	6.520	0.121	50
37.00	6.465	0.165	29
37.50	6.418	0.216	35
38.00	6.302	0.121	37
38.50	5.892	0.174	50



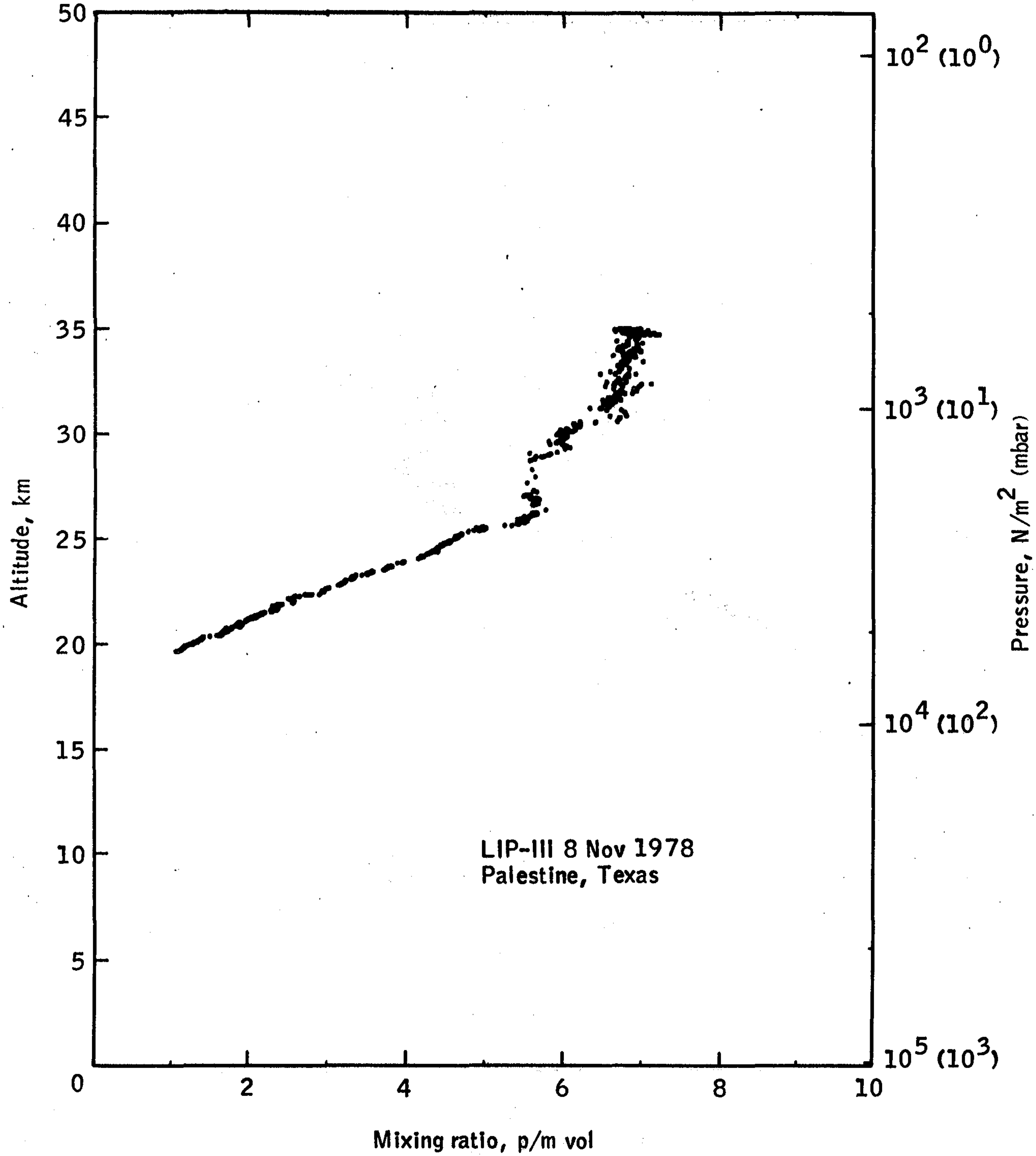
(a) Ascent.

Figure 1.- Ozone profile obtained on LIP II.



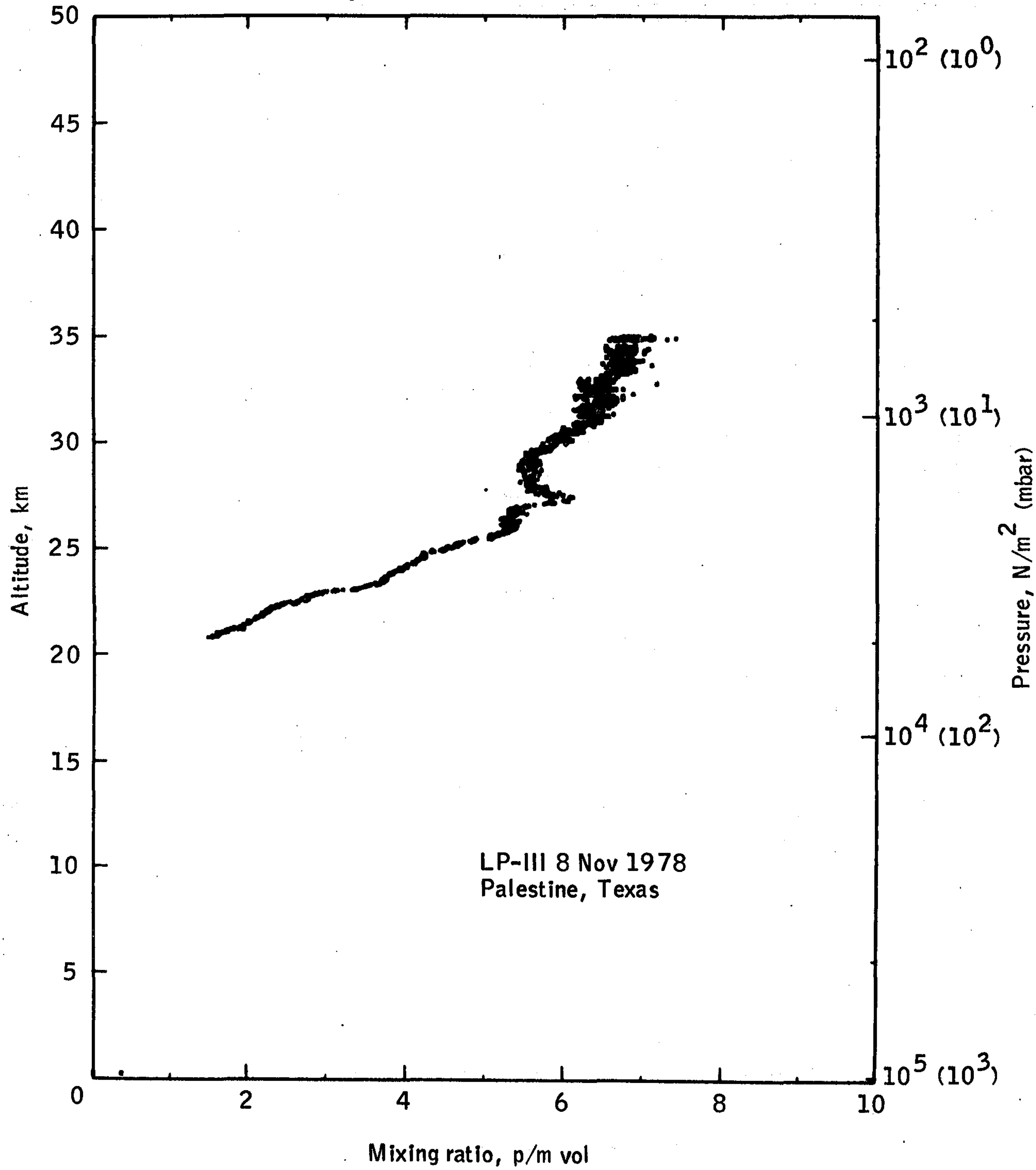
(b) Descent.

Figure 1.- Concluded.



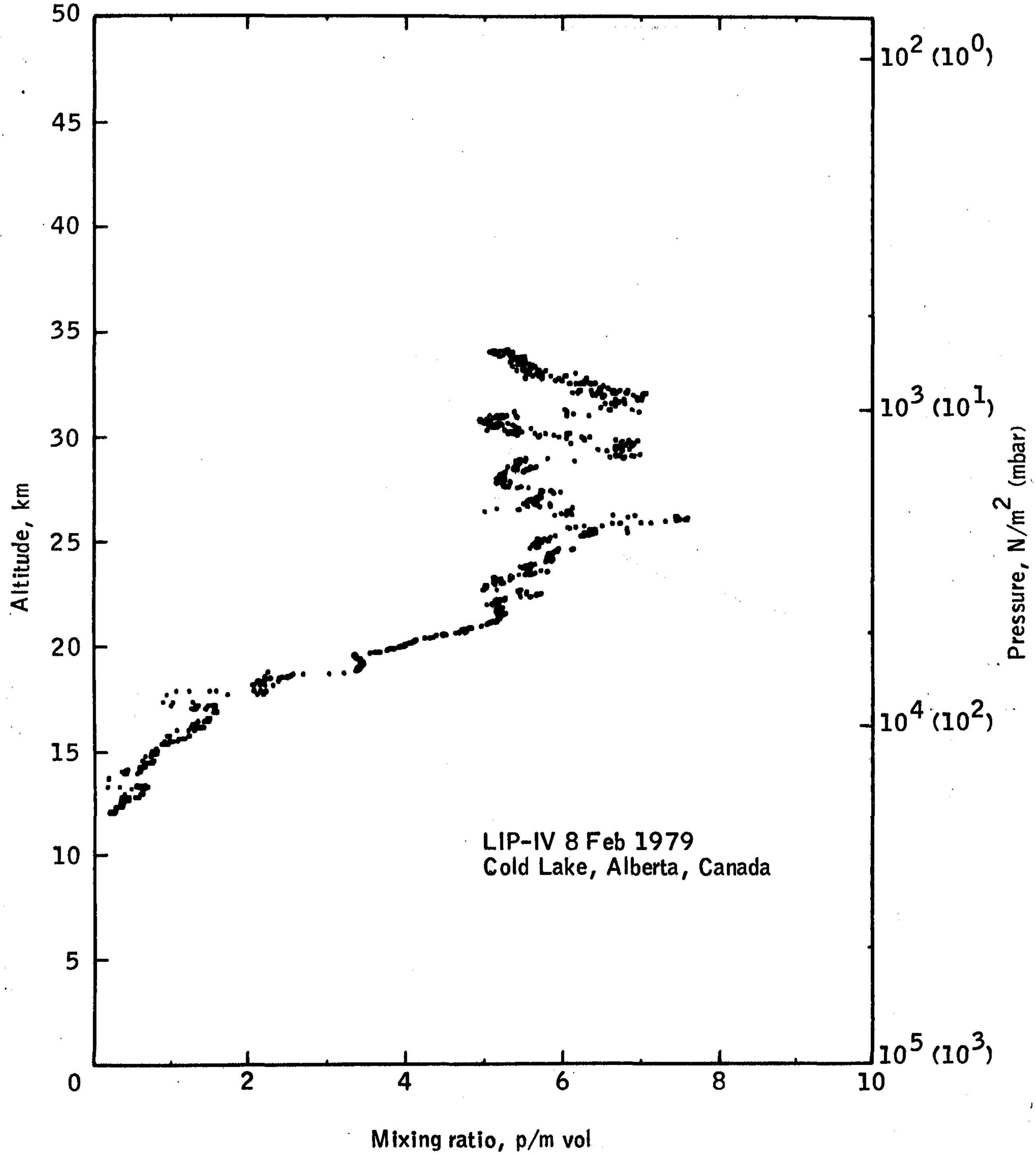
(a) Ascent.

Figure 2.- Ozone profile obtained on LIP III.



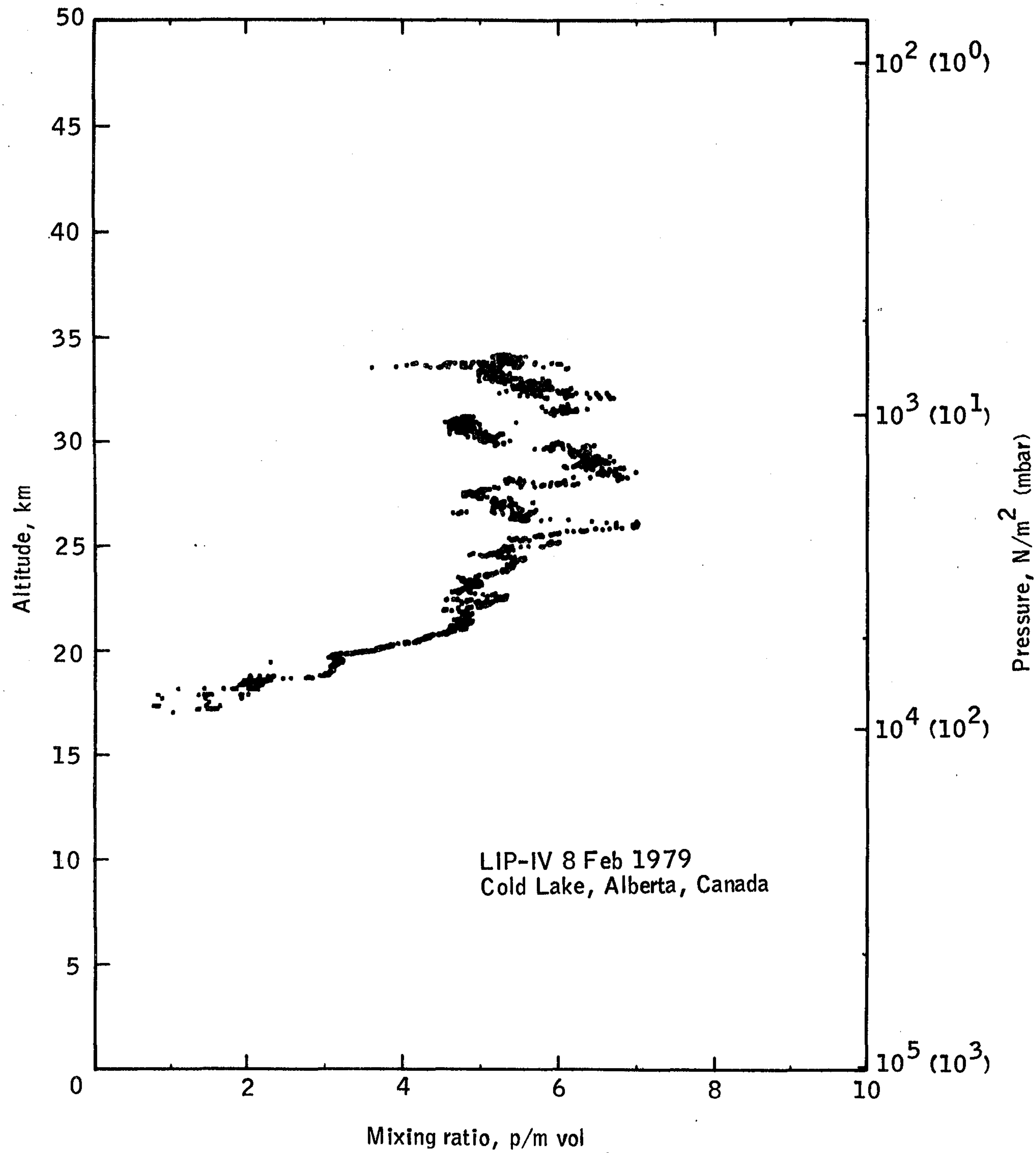
(b) Descent.

Figure 2.- Concluded.



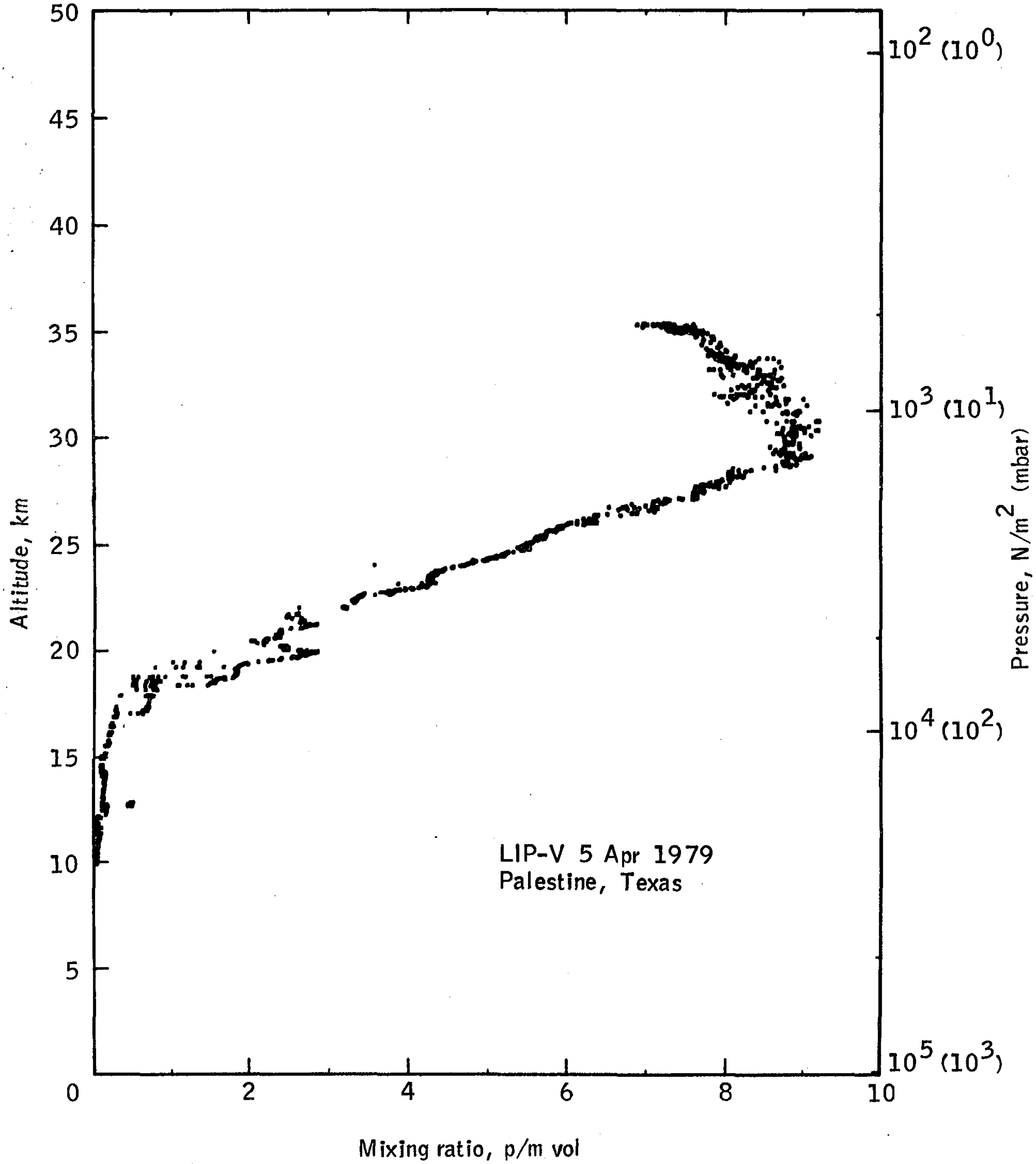
(a) Ascent.

Figure 3.- Ozone profile obtained on LIP IV.



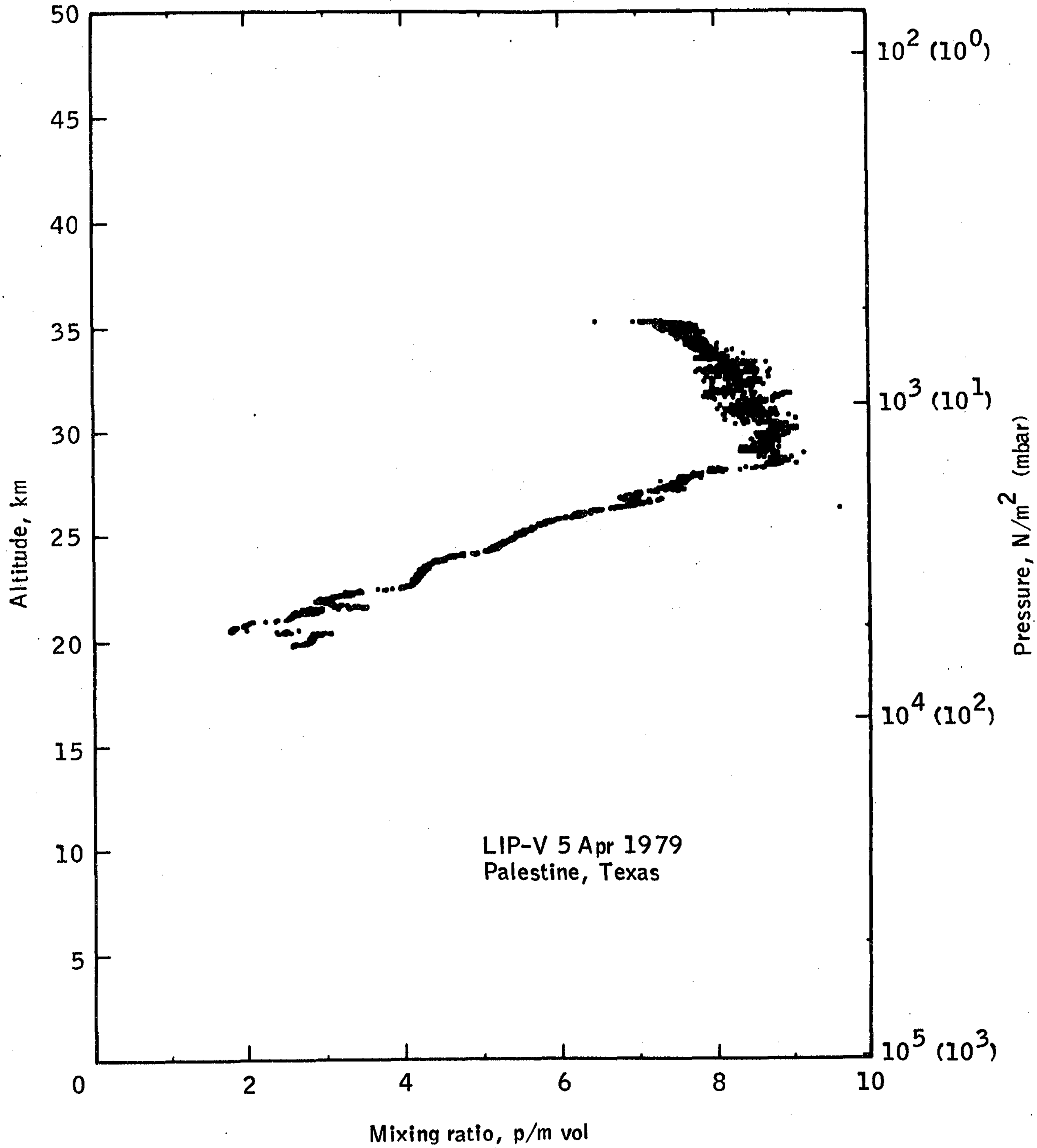
(b) Descent.

Figure 3.- Concluded.



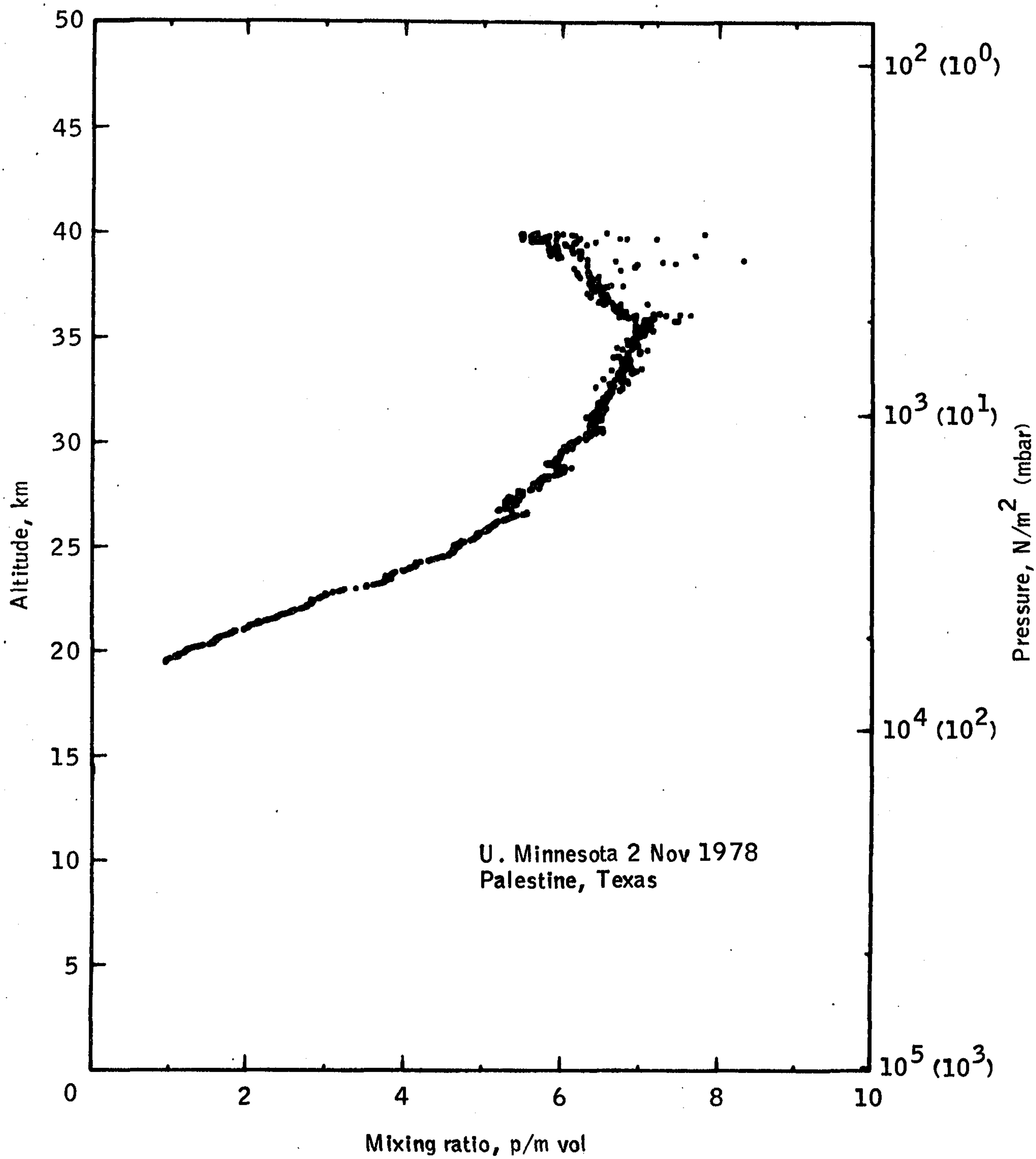
(a) Ascent.

Figure 4.- Ozone profile obtained on LIP V.



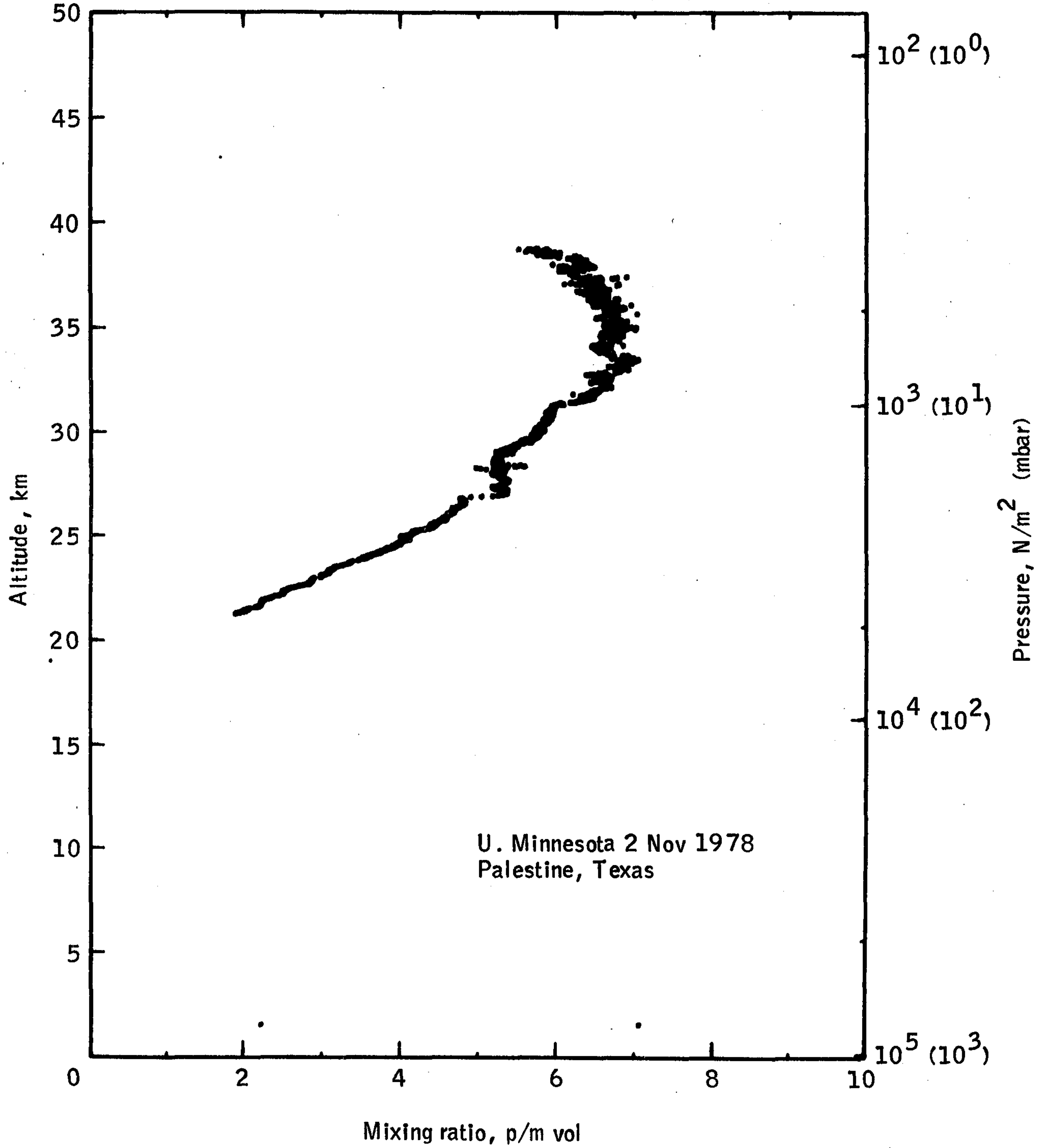
(b) Descent.

Figure 4.- Concluded.



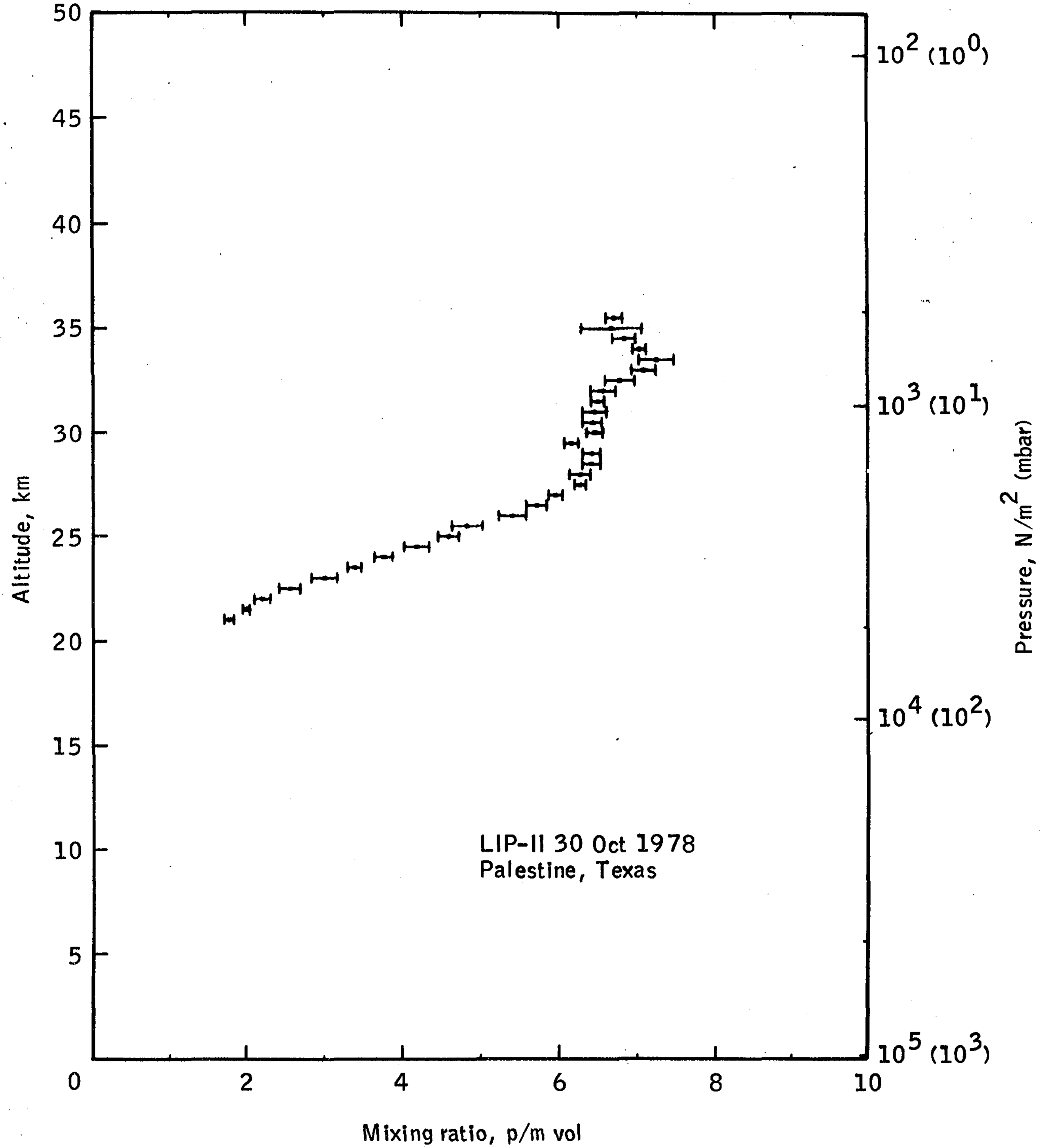
(a) Ascent.

Figure 5.- Ozone profile obtained on University of Minnesota flight.



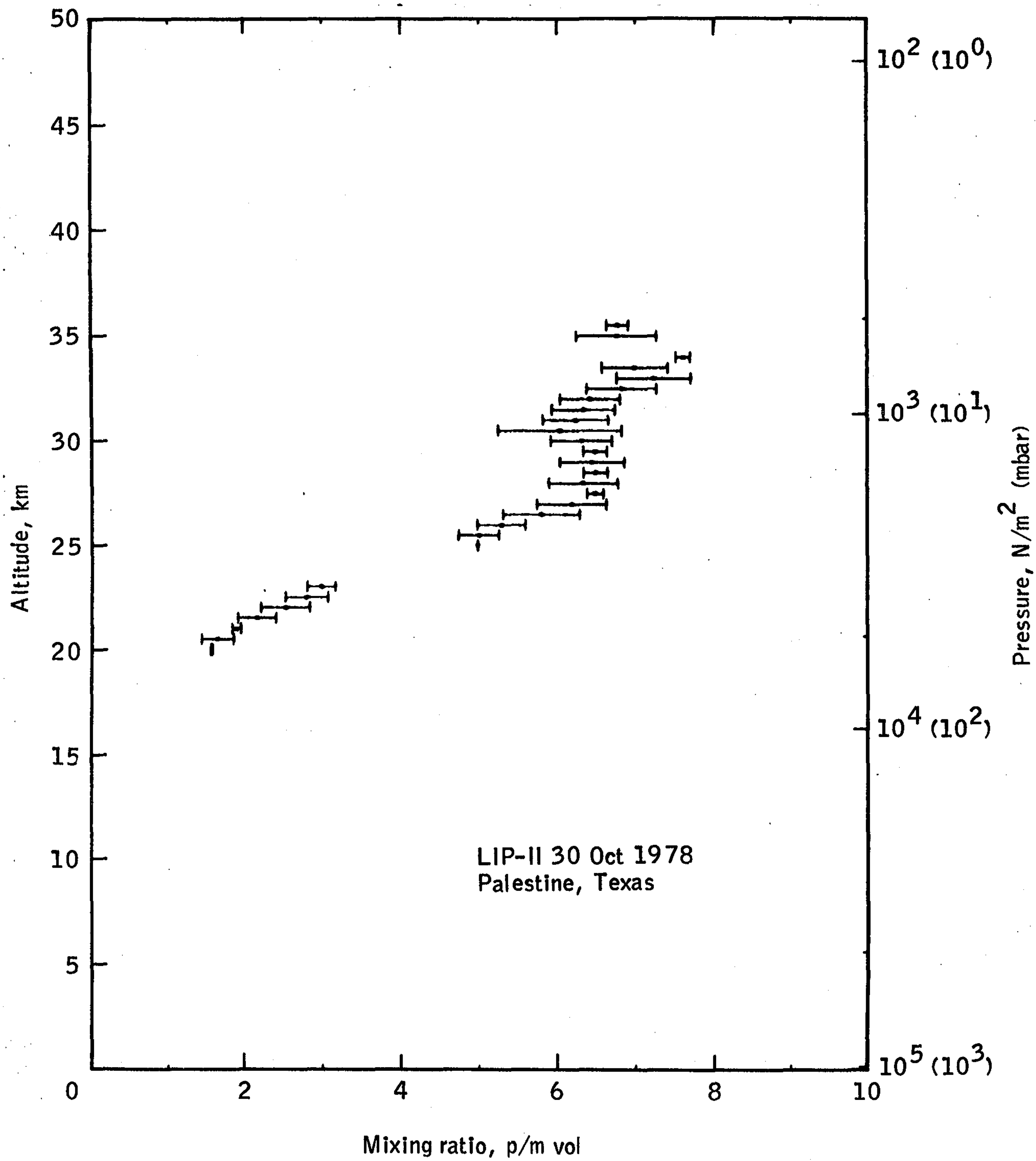
(b) Descent.

Figure 5.- Concluded.



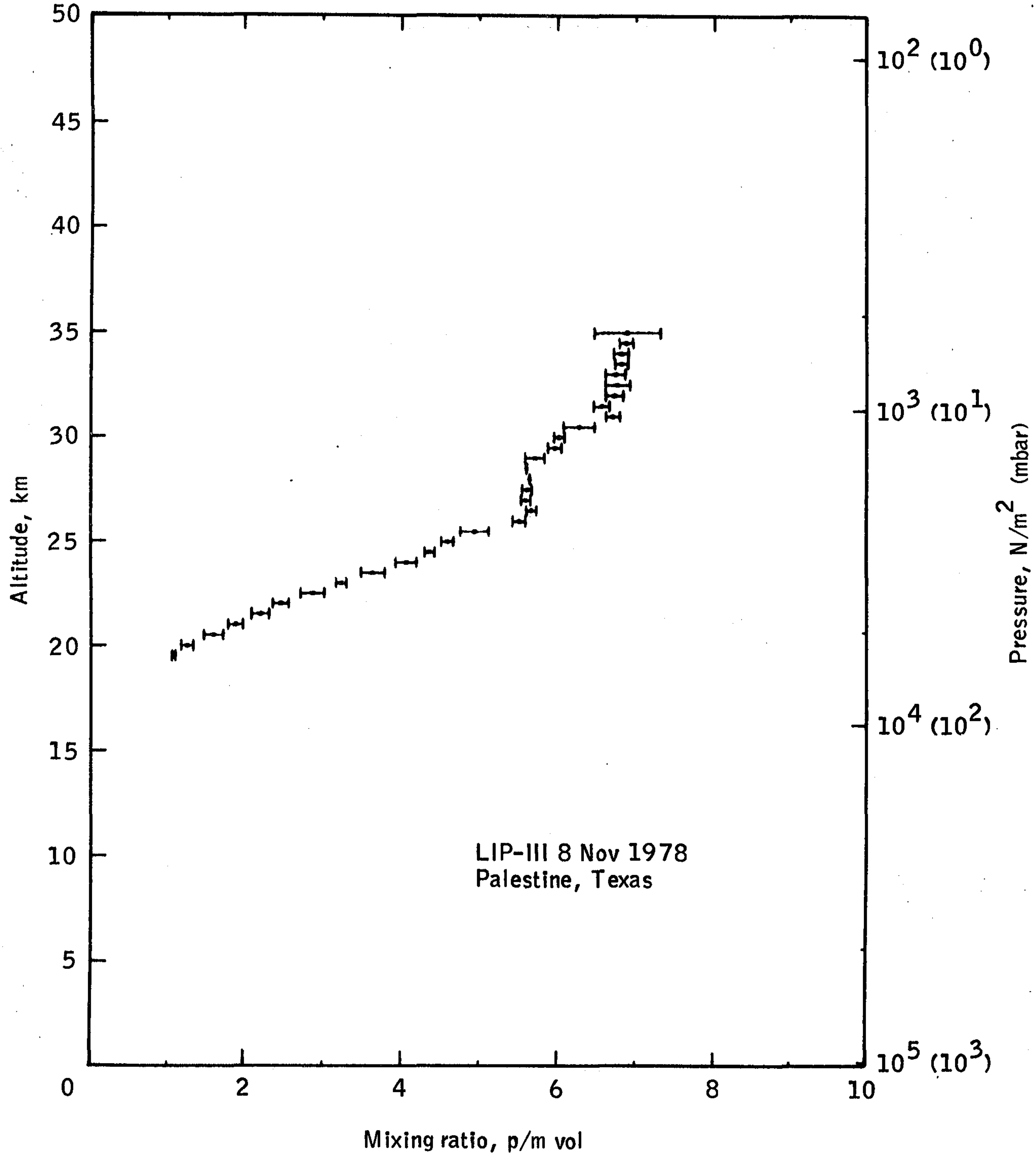
(a) Ascent.

Figure 6.- Ozone profile averaged over 0.5-kilometer altitude intervals for LIP II.



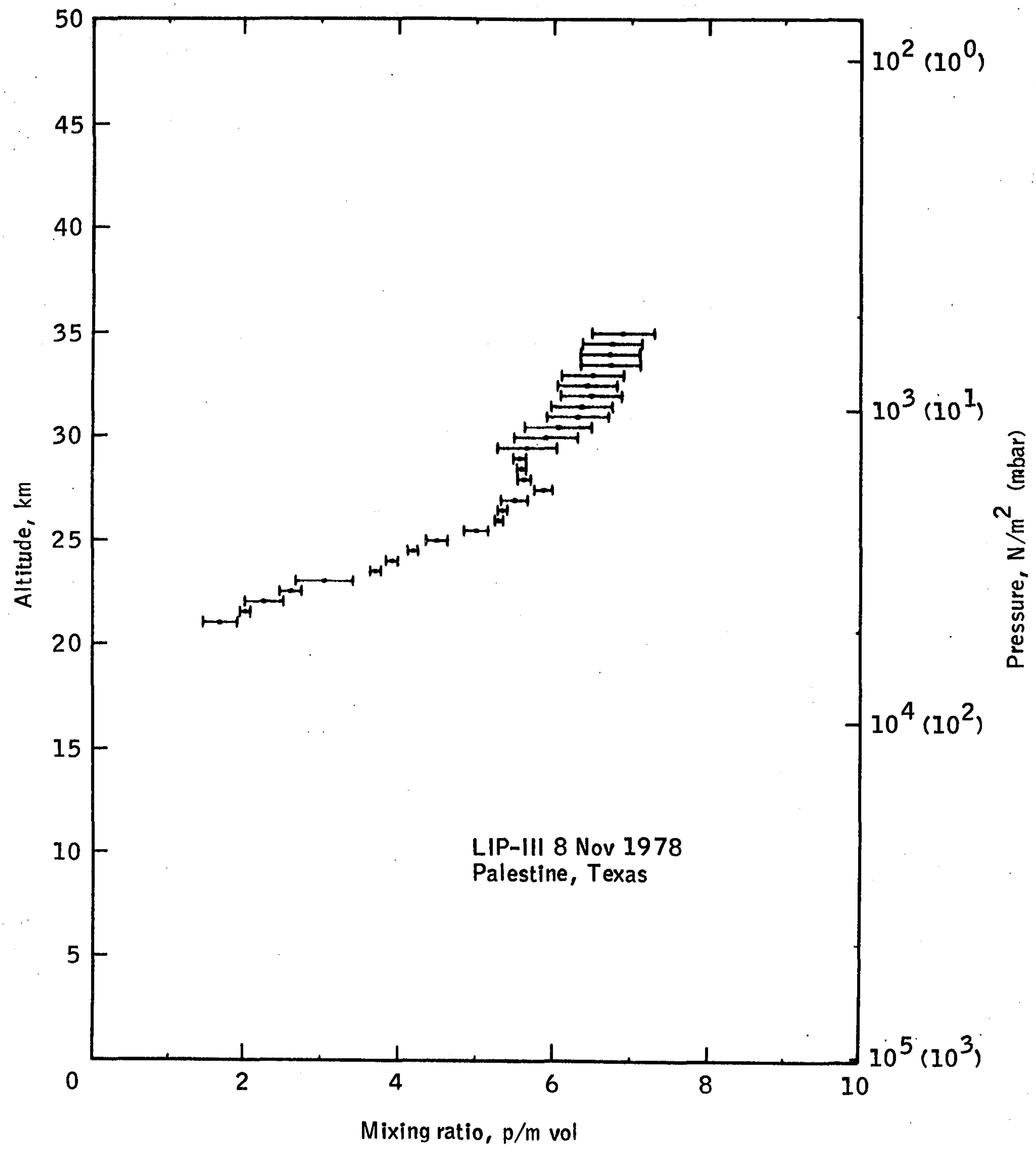
(b) Descent.

Figure 6.- Concluded.



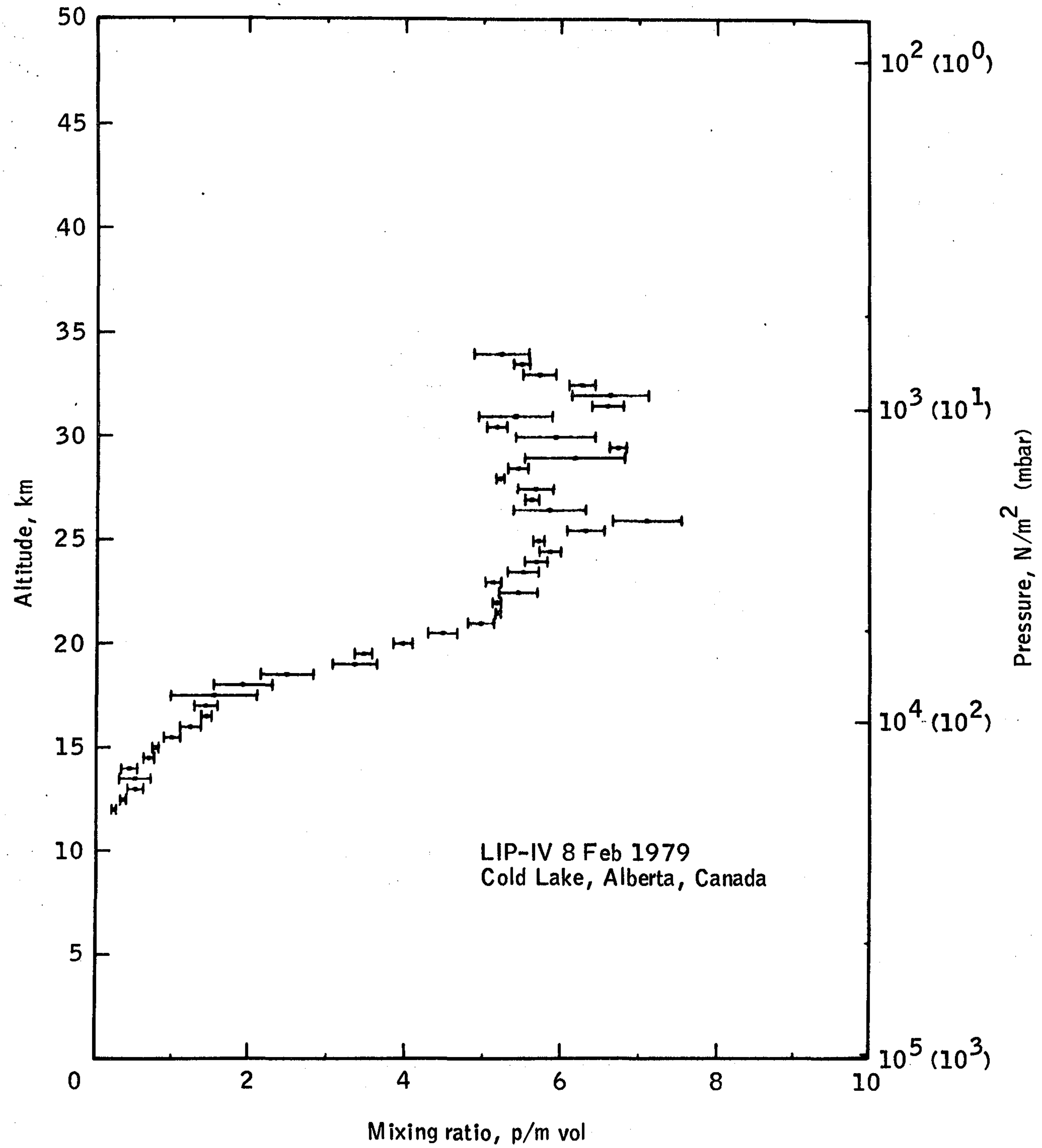
(a) Ascent.

Figure 7.- Ozone profile averaged over 0.5-kilometer altitude intervals for LIP III.



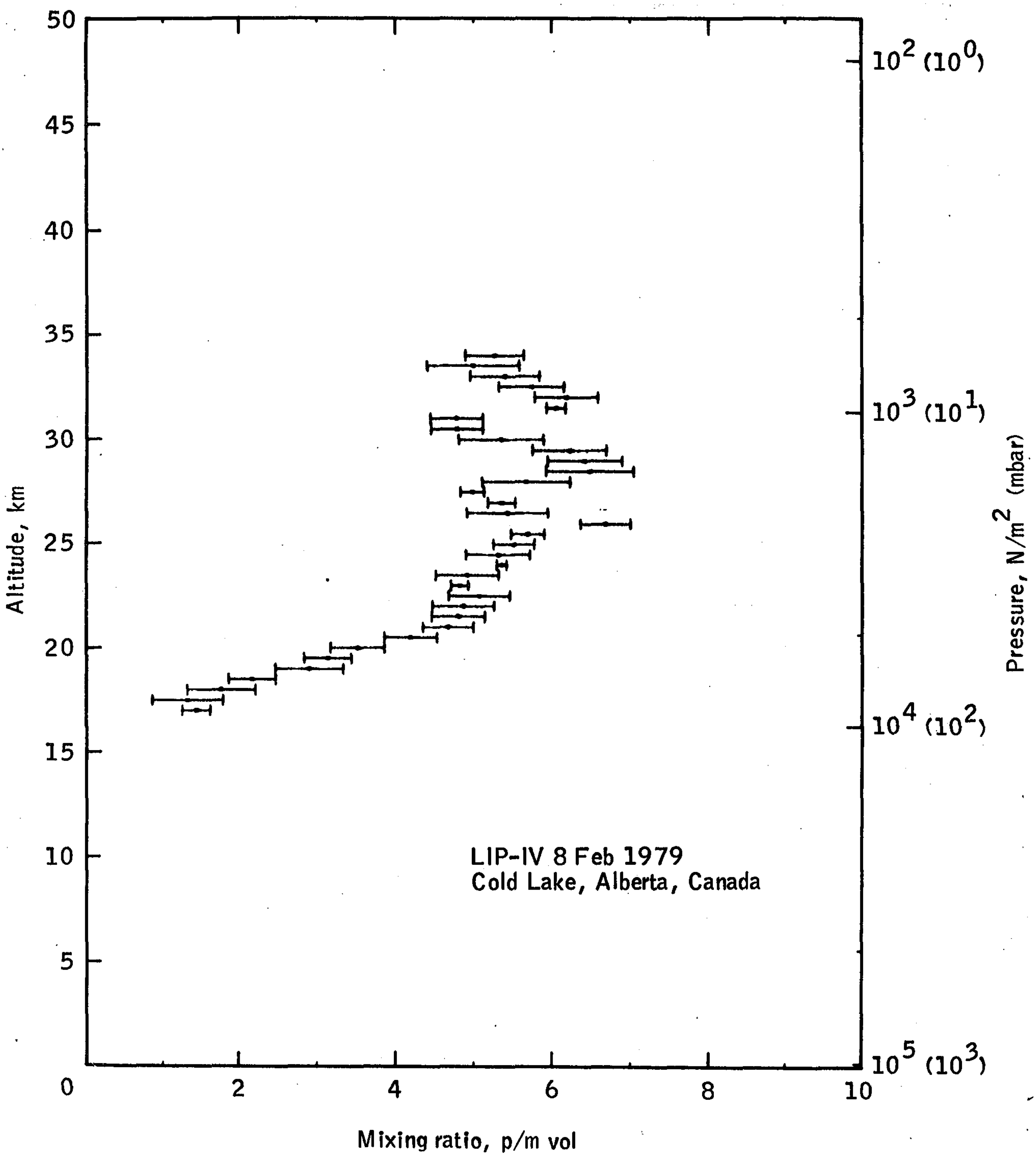
(b) Descent.

Figure 7.- Concluded.



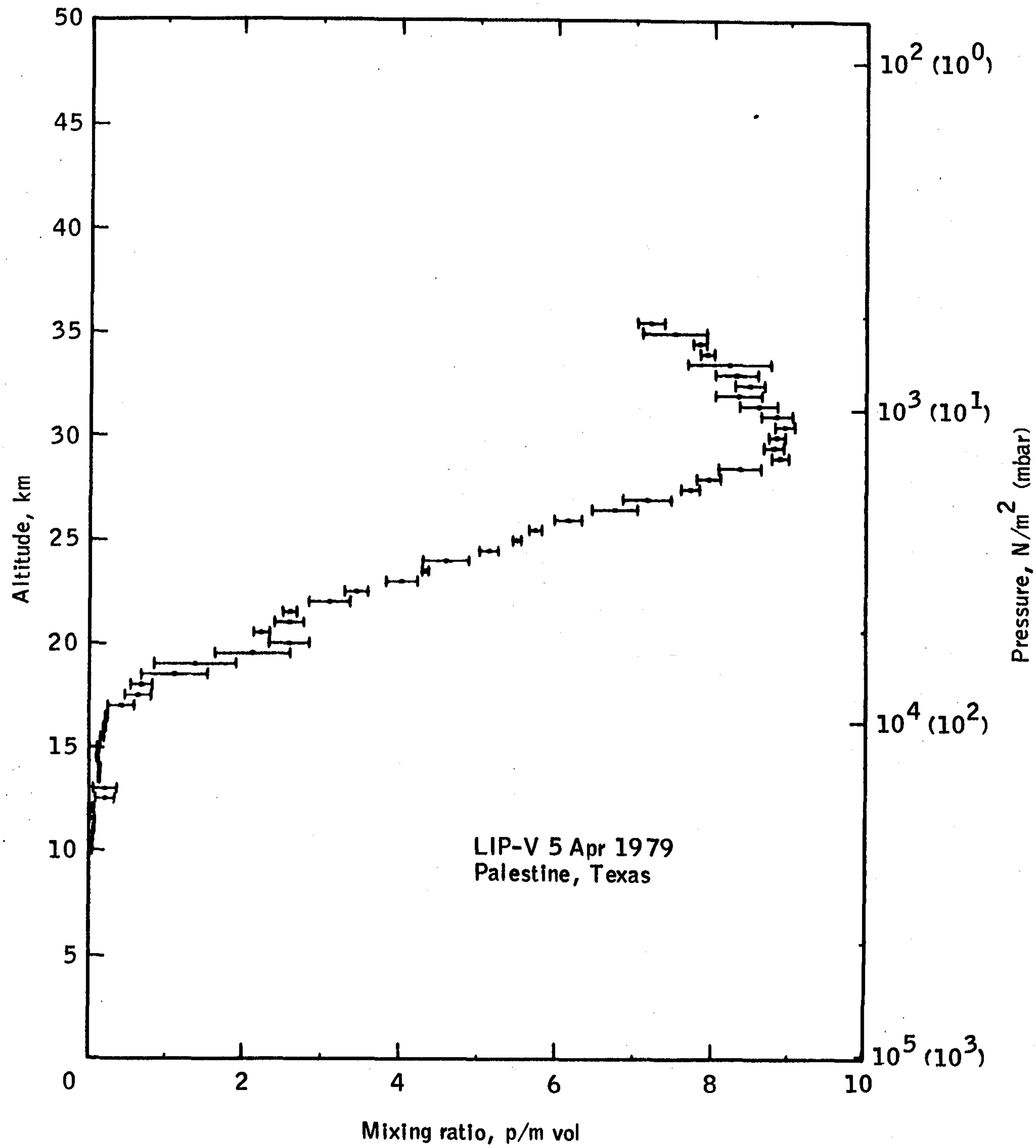
(a) Ascent.

Figure 8.- Ozone profile averaged over 0.5-kilometer altitude intervals for LIP IV.



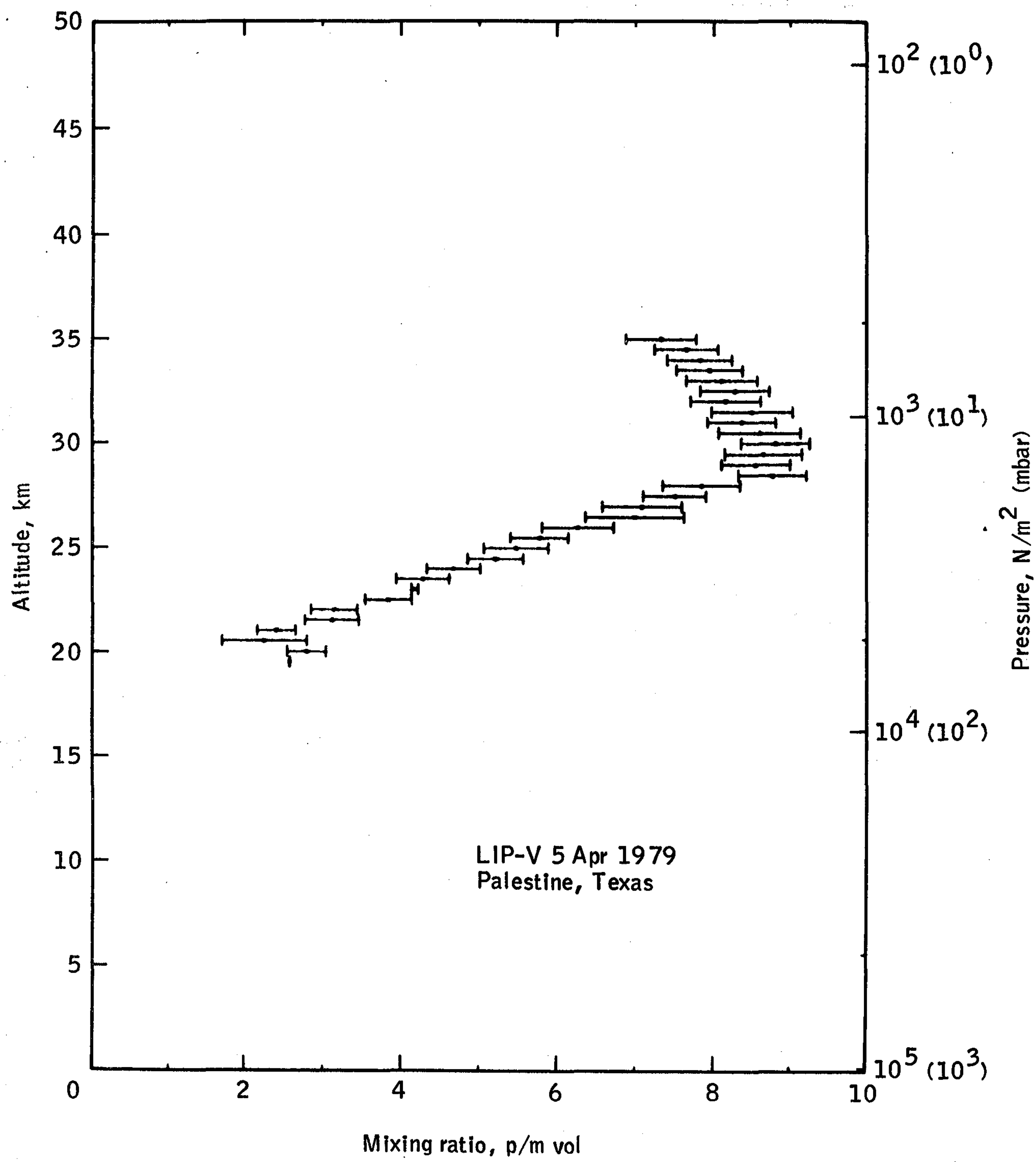
(b) Descent.

Figure 8.- Concluded.



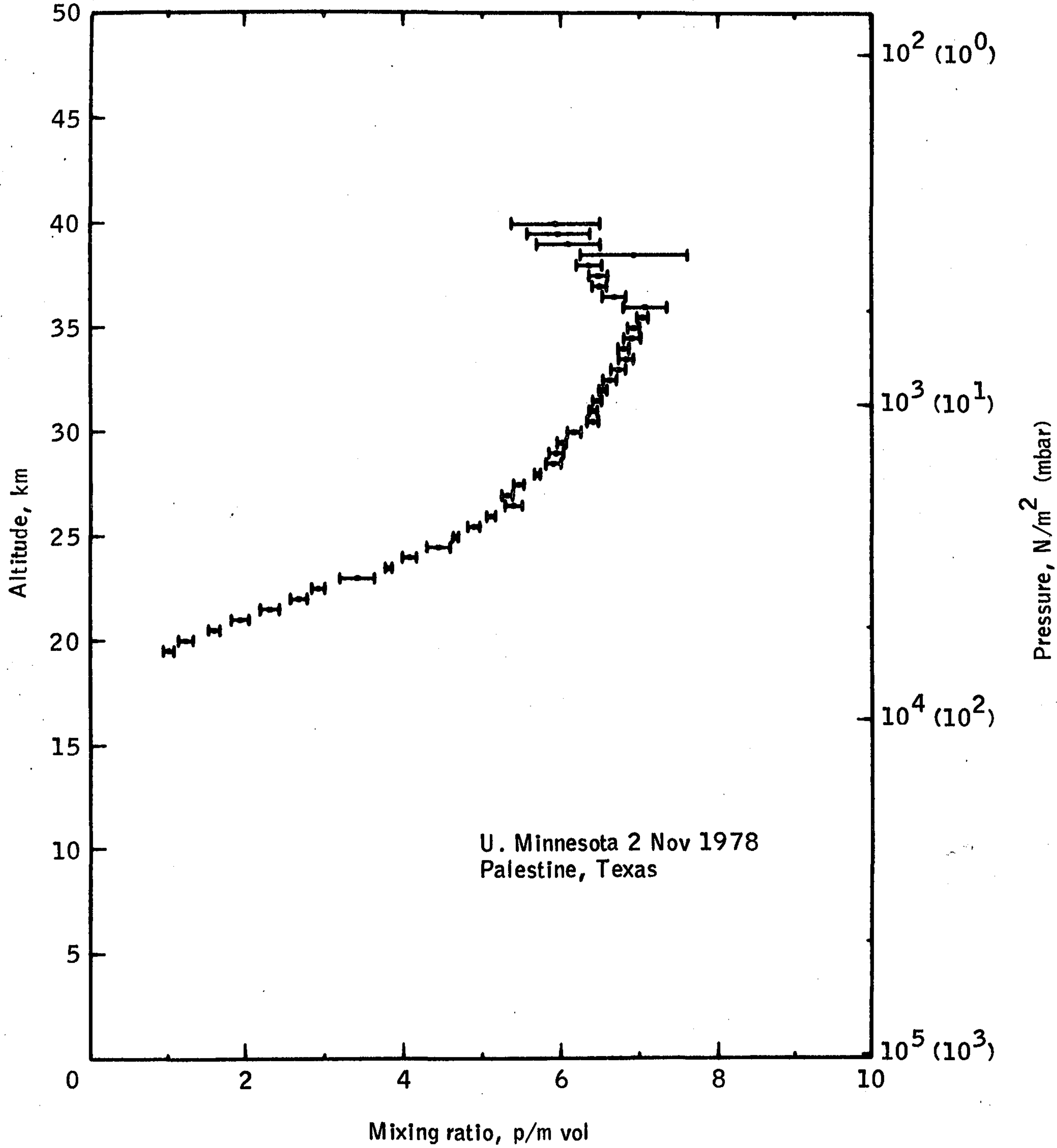
(a) Ascent.

Figure 9.- Ozone profile averaged over 0.5-kilometer altitude intervals for LIP V.



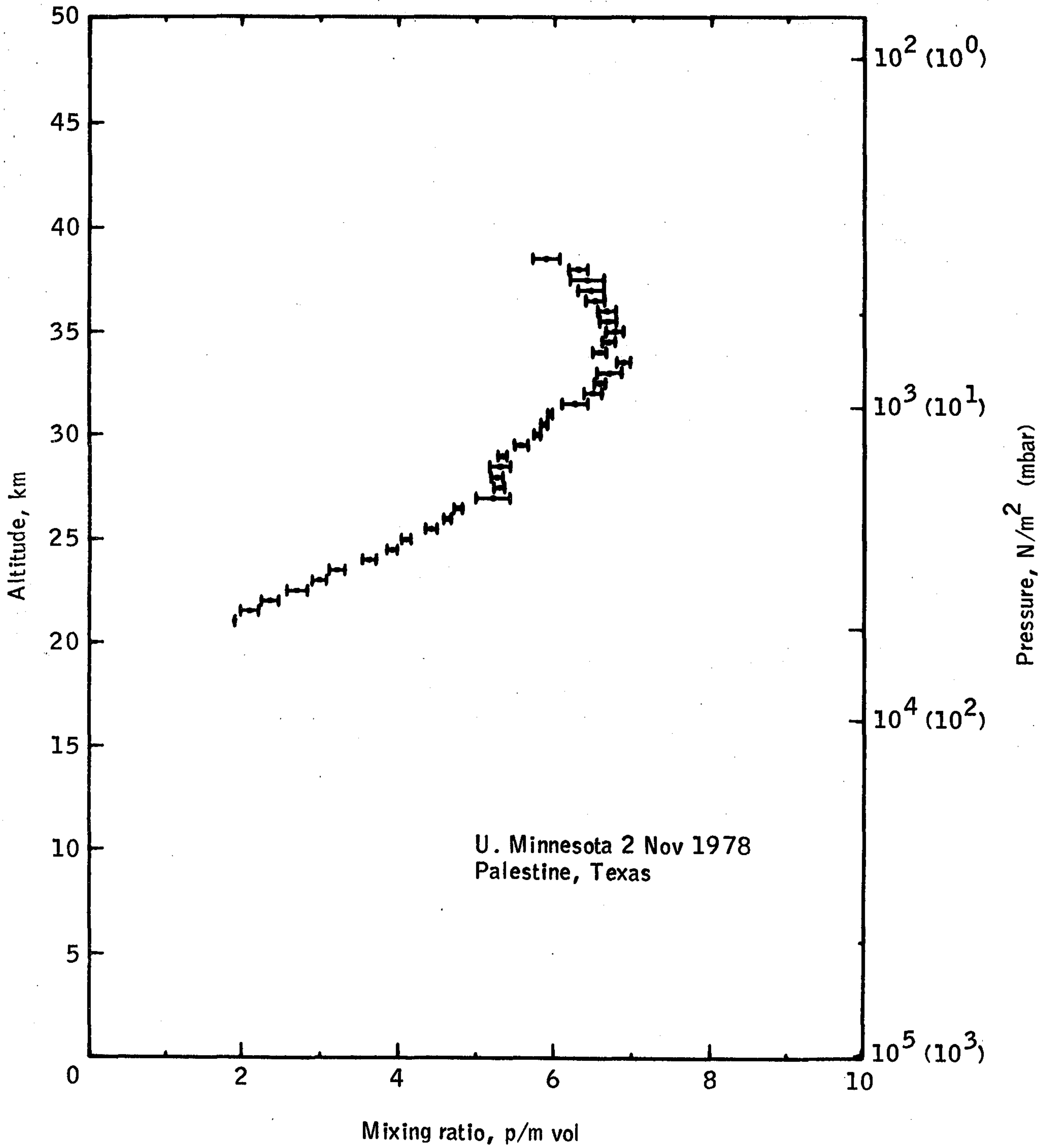
(b) Descent.

Figure 9.- Concluded.



(a) Ascent.

Figure 10.- Ozone profile averaged over 0.5-kilometer altitude intervals for the University of Minnesota flight.



(b) Descent.

Figure 10.- Concluded.

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16. Abstract

A series of balloon flights undertaken to validate data received from the limb infrared monitor of the stratosphere instrument aboard the Nimbus 7 satellite is discussed. Ozone data profiles, which included altitude, pressure, and mixing ratio, obtained during both ascent and descent of the balloons are reported. The measurement concept, instrumental uncertainties, and temporal variations observed for several time periods are discussed.

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