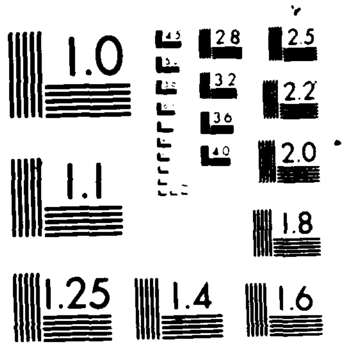
AD-A176 254 TETHERED BALLOON MEASUREMENTS MADE AT NAVAL AIR DEVELOPMENT CENTER (DECEMBER 1985)(U) NAVAL RESEARCH LAB WASHINGTON DC W P HOOPER ET AL. 29 DEC 86 1/2

UNCLASSIFIED NRL-MR-5893 F/G 4/2 NL



MICROCOPY RESOLUTION TEST CHART

Naval Research Laboratory

Washington, DC 20375-5000 NRL Memorandum Report 5893 December 29, 1986

AD-A176 254

Tethered Balloon Measurements Made at Naval Air Development Center (December 1985)

W. P. HOOPER AND H. GERBER

Atmospheric Physics Branch
Space Science Division

87 1

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NRL Memorandum Report 5893	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Naval Research Laboratory 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Washington, DC 20375-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Naval Ocean Systems Command 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) San Diego, CA 92152	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62759N PROJECT NO. 41-1109-06 TASK NO N01A RW59-551-B WORK UNIT ACCESSION NO DN639-124

11. TITLE (Include Security Classification)
Tethered Balloon Measurements made at Naval Air Development Center (December 1985)

12. PERSONAL AUTHOR(S)
Hooper, W.P. and Gerber, H.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Interim	FROM ______ TO ______	1986 December 29	99

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Tethered balloon; Ozone profiles; Aerostat; Water vapor profile (Continues)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

For six daylight periods, a meteorological package attached to a tethered balloon and radiosondes measured water vapor profiles at the Naval Air Development Center (NADC) Warminster, PA, for comparison with water vapor profiles made by a solar blind Raman laser radar (lidar). This report discusses the water vapor, temperature, scattering coefficient, and ozone profiles made with the meteorological package which was built from *in situ* dry bulb temperature, wet bulb temperature, and pressure. A nephelometer with a photopic response measured the scattering coefficient. The ozone measurements were made with an electrochemical concentration cell in a soned, loaned from the NOAA Laboratory in Boulder, CO. A 53-foot aerostat balloon carried the NRL package from the surface to 800 m. During the test period, stable and well-mixed boundary layers were observed. A warm front was profiled on the last day of the experiment.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL W.P. Hooper	22b. TELEPHONE (Include Area Code) (202) 767-2143	22c. OFFICE SYMBOL Code 4110

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

18. SUBJECT TERMS (Continued)

Temperature profiles,
Planetary boundary layer,
Water vapor statistics,
Profiles of scattering coefficient.

CONTENTS

TETHERED BALLOON MEASUREMENTS MADE AT NAVAL AIR DEVELOPMENT CENTER (DECEMBER 1985)

INTRODUCTION

NADC Scientists have built a remote water vapor profiler. This profiler uses a laser radar (lidar) to measure the Raman shifted signal from water vapor and nitrogen. The ratio of these two returns provides a measure of the mixing ratio allowing this parameter to be profiled from near the surface to 2 km. Since the lidar operates in the ultraviolet (248 nm) where ozone absorption is a maximum, and aerosol scatter is significant, the ozone and aerosol will also influence these lidar signals. The NADC experiment compared the lidar water vapor observations with standard meterological water vapor measurements.

From 5 through 11 December 1985, water vapor profiles were observed by the NADC lidar, NRL's meterological package, and radiosondes (operated by scientists from the Pacific Missile Test Center, Pt Magu, Ca). This report discusses the measurements made by the NRL package carried aloft by a 53-ft. aerostat balloon from the surface to 800 m. (The 800 m ceiling on balloon operations resulted from FAA restrictions not balloon limitations.) Investigators from the LTA International Co. operated the aerostat.

The instruments attached to the aerostat measured the water vapor, temperature, ozone, and scattering coefficient. Data from thermistors (which measured the wet and dry bulb temperature and the altimeter, which measured pressure) were combined to determine the water vapor mixing ratio . In addition, the NRL package used a nephelometer to measure the scattering coefficient and a sonde to measure ozone concentrations. These measurements allowed the influence of aerosol scattering and ozone on the lidar operations to be estimated.

Manuscript approved September 26, 1986.

INSTRUMENT DESCRIPTION

Reference 1 describes the NRL instrument package in detail. Most of the measurements made at NADC follow the measurement techniques previously discussed. Only the ozone measurements were completely new for the NRL package. A modified algorithm with a temperature correction was used to determine altitude and pressure. Unlike previous experiments, the freezing of the 'wet' bulb occurred on two profiles and, on these two profiles, the water vapor mixing ratio was determined from the ice point not dew point relationships. Only a brief instrument description is included in this report. For a more detailed description of the instrument, see reference 1.

ALTIMETER

A sensitive barometric altimeter on the aerostat balloon (Model 7000 Computer Instrument Corporation, New York, N. Y.) measures instrument height as the difference between the pressure at the instrument altitude and the surface pressure. This altimeter follows the *USSA-1962 standard atmosphere* relationship [2]:

$$p_2 = 1013.3 \; (1-2.255X10^{-5} \; z_2)^{5.256} , \tag{1}$$

where p_2 is pressure (mb) at height z_2 (m). Near the surface, this relationship is approximately:

$$p_2 = p_1 \; \exp[-(f_2-f_1)/k] , \tag{2}$$

where p_1 is surface pressure (mb), f_2 is altimeter height (ft), f_1 is surface elevation, and k is a constant ($2.464x10^4$). The aerostat elevation, f_2, is output by the altimeter and directly converted to pressure. The constant k does not come from Eq (1) but from a calibration done by Gerber; however, the calibration results are consistant with Eq (1). The temperature and water vapor profiles from the surface to the altimeter height determine the exact pressure-height relationship. The hypsometric equation [3] integrates the virtual temperature profile, T_v, to find the altimeter height, h:

$$h(p_2)-h(p_1) = -\int_{p_1}^{p_2} R \; T_v(p) \; g^{-1} \; d \; \ln(p) , \tag{3}$$

where R is the dry gas constant, and g is the gravitional constant. Cool conditions during the NADC experiment made the water vapor's contribution to virtual potential temperature negligible; thus, the temperature profile was used instead of the virtual temperature profile changing the pressure-height relationship to:

$$h(f_2) - h(f_1) = \int_{f_2}^{f_1} RT(f)\ g^{-1}\ k^{-1}\ df \ , \qquad (4)$$

where T is the temperature (K). Eqs. (2) and (4) were tested on flights 8a (12/8/85) and 12b (12/10/85) when the boundary layer appeared to be well mixed. The lapse rate in these temperature profiles was extremely close to adiabatic. On future experiments, the altimeter should be recalibrated to ensure the 'constant' has not drifted.

PSYCHROMETER

The wet bulb temperature, dry bulb temperature, and pressure measurements determine the water vapor mixing ratio. The altimeter readings, Eq. (4), are converted to pressure. Matched thermistors mounted inside two concentric heat shielding tubes measure the wet and dry bulb temperatures. By being in line with the aerostat balloon, these tubes allow the wet bulb to be wind aspirated. The water vapor mixing ratio, W (gm water vapor/kg dry air), is derived from:

$$W = 10^3\ (Mv/Md)\ (e/(p-e)) \ , \qquad (5)$$

where (Mv/Md) is the ratio of molecular weights of water and dry air (0.622), e is the atmospheric partial pressure of water vapor. The relationship [4] estimates the water vapor pressure, e_0 (mb), at temperature T (K) by using :

$$\log(e_0) = -7.90298(T_s/T-1)+5.02808\ \log(T_s/T)$$
$$- 1.3816X10^{-7}[10^{11.334\ (1-T/T_s)}-1]$$
$$+8.1328x10^{-3}[10^{-3.49149\ (T_s/T-1)}-1] + \log(e_{os}) \ , \qquad (6)$$

where T_s is the steam point (373.16 K), e_{os} is saturation vapor pressure at the steam point (1013.246 mb), and log is the logarithm base 10. When the 'wet' bulb is frozen, the vapor pressure is calculated from the ice point:

$$\log(e_0) = -9.09718\ (T_0/T-1)\ -3.56654\ \log(T0/T)\ +$$
$$0.876793\ (1-\ T/T_0) + \log(e_{i0}), \qquad (7)$$

where e_{i0} is the saturation at ice point (6.1071 mb) and T_0 is the ice point (273.16 K). The vapor pressure, e_0, observed by the wet bulb and determined by either Eq (6) or (7), is corrected for ventilation effects:

$$e = e_0 - [0.00066\ (1+0.00115\ T_w)]\ (T_d-T_w)\ p \ , \qquad (8)$$

where T_d and T_w are the temperatures (K) read by the dry bulb and wet bulb respectively. When the vapor pressure is calculated from a frozen bulb, the constants in eqn (8) are multiplied by 0.882, the ratio of latent heat of evaporation of water to that of ice.

OZONESONDE

A lightweight electrochemical concentration cell in a sonde hung below the aerostat creates a current, which is proportional to the ozone partial pressure, p_3 (mb):

$$p_3 = 4.307 \times 10^{-3}\ I\ T_b\ t, \qquad (9)$$

where I is the sensor current (micro-amps), T_b is sonde temperature (K), and t is time (s) the pump takes to force 100 ml of air through the sonde (approximately 29.5). For plotting, the ozone partial pressure is divided by the local pressure and converted to parts per billion (ppb). Prior to each flight, the sonde received new chemical solutions. A known ozone concentration is pumped through the sonde and the sonde reading for this concentration is tested. After the ozonesonde is mounted on the aerostat and before the balloon is launched, the sonde is run for five minutes with and five minutes without an ozone free filter to determine the sonde's zero reading.

NEPHELOMETER

The nephelometer uses a photographic flash lamp to uniformly illuminate the inside of an integrating sphere. The scattered light is measured by a photomultiplier, which has a field of view that goes through the center of the integrating sphere and is carefully aligned with a light trap on the opposite side of the sphere, ensuring that no directly reflected light enters the photomultiplier. A photopic interference filter on the photomultiplier allows the nephelometer to measure visibility (using Koshmieder's critera). The scattering coefficient, b_s (1/km), measured by the nephelometer is:

$$b_s = 1.22\ (V_{out} - 0.107), \qquad (10)$$

where V_{out} is the output voltage. While the nephelometer can make readings when visibility ranges from 0.330 to 90 km, the scattering volume is small (1 cm^3) and, when visibility is greater than about 50 km, the statistical properties of the scattering can vary in short time periods. To minimize the variance, the measurements were averaged for 2 minutes.

ANEMOMETER

A cup anemometer, mounted on a tail fin of the aerostat balloon, transmits pulse counts, which have been calibrated to yield the wind speed, u:

$$u = \begin{cases} 0.357\,P - 7.86 & P>36 \\ 3.86\times10^{-3}\,P^2 & P\leq 36, \end{cases} \qquad (11)$$

where P is the pulse count. The wind direction could be estimated from the orientation of the aerostat balloon; however, wind direction was not an objective of the experiment and was, therefore, not recorded. Flights 6 and 8 showed more wind speed variation than expected for the meterological conditions. This variance could be increased by the aerostat motion and balloon sheltering of the anemometer.

OBSERVATIONS

Aerostat flights were conducted on every day from 5 to 11 December 1985 except on 6 December when high winds kept the aerostat from flying. There were two flights on all flight days, except the last, one in the morning and one in the afternoon. Flight 1 was used to test instrumentation. Altimeter problems restricted measurements on Flight 2. The next eleven flights which produced useful profiles are described in Table 1 and will be discussed in more detail later in this report (for figures see Appendix A). After the first two flights, the only restrictions came from high winds and airport operations. When time permitted, profiles were made to 800 m.

The aerostat was launched from the apron of the NADC runway (40^{o}) 12' 30" N and 75^{o} 5' E, see Fig. 1) which was 114 m above sea level. The two- to three-story NADC headquarters building was 110 m northwest of the launch site and a hangar facility was 80 m northeast of the launch site. The runway was southeast of the launch site with the buildings 800 m from the site. Pennsylvania State Highway 132 was southwest (350 m) from the experimental site and the nearest buildings were 580 m from the experimental site. Outside NADC, the land has been developed as residential and light industry. The Pennsylvania State Turn Pike (I-70) was 4 km to the south.

The aerostat made constant-rate ascent and descent profiles and was held at constant altitudes to determine the water vapor mixing ratio statistics. Those statistics are listed in Table 2. Profiles of the water vapor mixing ratio, ozone, scattering coefficient, wind speed, virtual potential temperature, and natural logarithm of the scattering coefficient are plotted. The plots are labeled with the flight number and letters denoting the separate ascent/descent profiles. Most flights involved ascents to a maximum altitude followed by descent to the surface. On these flights, the ascent and descent were marked 'a' and 'b' respectively. Flights 9, 11, and 13 involved direct ascents to maximum altitude, a descent to intermediate altitudes, 're-ascent' to the maximum altitude, and a final descent to the surface; these profiles are labeled 'a', 'b', 'c', and 'd' respectively. The aerostat heights as a function of time are plotted allowing easy visualization of balloon operations. The wind speed profiles were not a major objective of this experiment and are included for informational reasons.

In general, the flights were uneventful and the profiles of water vapor mixing ratio have very little structure. Flight 13 was a major exception with an increase of the mixing ratio from 4.5 to 6.5 gm/kg at 300 m. A rapid decease from 3 to 2 gm/kg was observed at the top of Flight 7. The top of the 3 gm/kg layer deceased during the profile.

Table 1 Flight Summary

Flight (No.)	Date	Time (EST)	Fixed Heights (m)
3	12/5	0728-0945	334,454,570,691,786, 693,573,457,333
4	12/5	1220-1432	344,463,583,702,810, 708,590,475
5	12/7	0745-0942	287,391,487,585,691
6	12/7	1217-1436	309,412,533,640,726
7	12/8	0753-0928	730,625
8	12/8	1251-1431	761,617,540
9	12/9	0731-0943	525,760
10	12/9	1430-1530	741
11	12/10	0747-0943	746,321,523,743
12	12/10	1203-1258	637
13	12/11	0735-0945	759,304,598,771

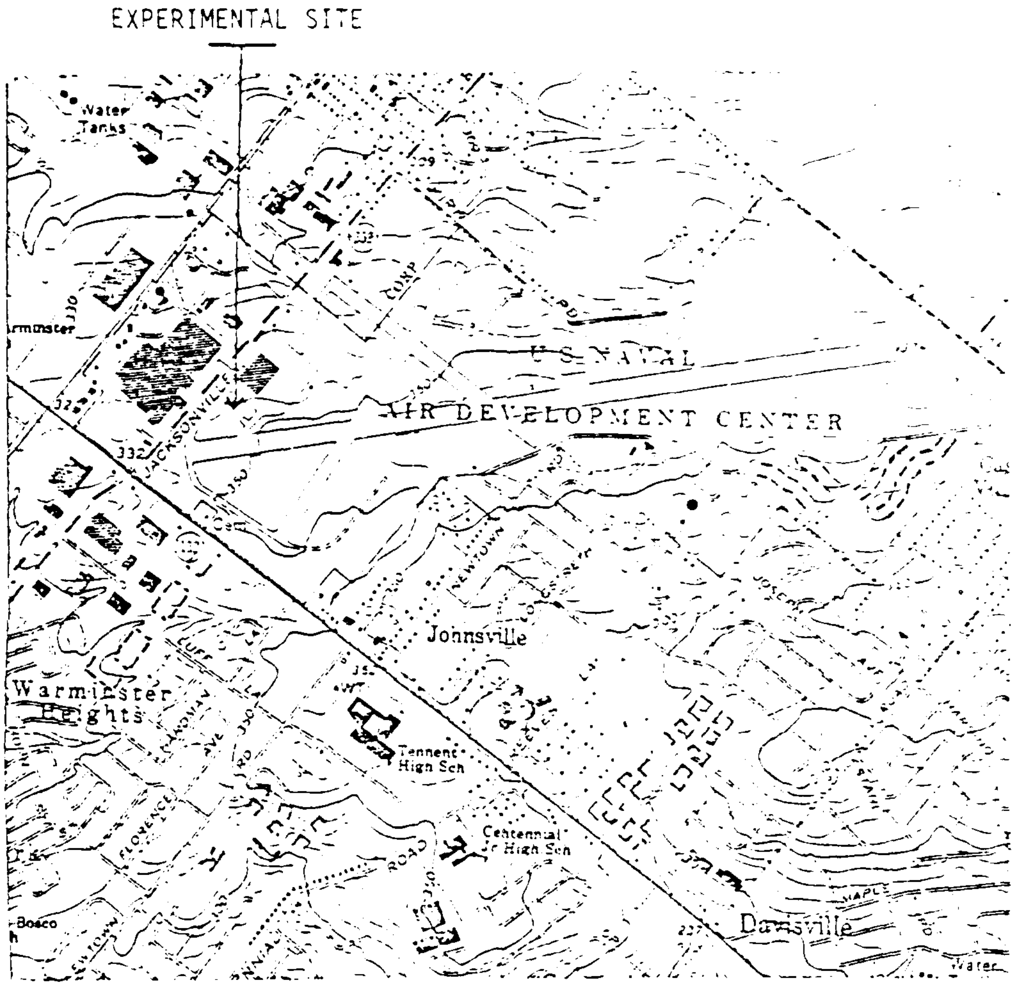

EXPERIMENTAL SITE
Water Tanks
U.S. NAVAL
AIR DEVELOPMENT CENTER
Johnsville
Warminster Heights
Tennent High Sch
Centennial Jr High Sch
Davisville

Fig. 1

TABLE 2 — FIXED LEVEL STATISTICS

Time (HHMM) Start	Stop	Height (m) Mean	Var	Mixing Ratio (gm/K) Mean	Var
		12/05/85			
0741	0749	334.0	0.6	1.43	0.01
0753	0807	454.1	0.5	1.27	0.03
0808	0818	570.3	0.8	1.11	0.13
0822	0831	691.5	0.9	0.90	0.06
0835	0845	786.1	0.8	0.76	0.05
0848	0858	693.6	1.2	1.11	0.14
0902	0912	573.3	1.4	1.27	0.04*
0916	0926	456.8	0.9	1.70	0.04*
0930	0940	333.1	0.5	2.09	0.06*
1233	1243	343.8	0.5	1.47	0.10
1247	1256	463.1	0.4	1.25	0.02
1301	1310	583.0	0.8	1.22	0.19
1314	1322	701.7	0.6	0.94	0.01
1328	1336	810.4	1.2	0.59	0.01
1339	1358	707.5	0.7	0.86	0.07
1402	1412	590.1	0.6	1.28	0.03
1416	1428	475.0	0.6	1.18	0.03
		12/07/85			
0757	0806	287.4	1.6	2.39	0.01
0811	0821	391.3	2.6	2.34	0.01
0826	0835	487.0	3.2	2.25	0.01
0840	0848	584.7	4.2	2.24	0.03
0854	0912	690.6	7.4	2.11	0.06
1232	1247	308.5	1.9	2.46	0.02
1250	1305	412.1	4.8	2.43	0.01
1310	1318	532.9	6.0	2.44	0.01
1327	1342	639.7	3.4	2.48	0.01
1350	1404	725.7	4.1	2.50	0.01

*Frozen 'Wet' Bulb

TABLE 2 (Cont'd) — FIXED LEVEL STATISTICS

Time (HHMM)		Height (m)		Mixing Ratio (gm/K)	
Start	Stop	Mean	Var	Mean	Var
		12/08/85			
0816	0838	730.3	14.0	2.31	0.09
0850	0904	625.4	4.6	2.43	0.23
1320	1341	760.5	10.3	2.74	0.08
1345	1356	616.9	6.8	2.92	0.03
1410	1416	539.8	6.2	2.94	0.03
		12/09/85			
0813	0847	524.6	0.8	3.22	0.03
0859	0914	759.5	1.2	3.52	0.01
1456	1514	740.7	34.5	3.37	0.11
		12/10/85			
0816	0824	746.4	1.6	3.37	0.02
0838	0847	320.5	0.5	3.41	0.01
0854	0905	523.2	0.6	3.50	0.02
0913	0917	742.9	0.4	3.30	0.01
1229	1236	636.8	8.0	3.46	0.05
		12/11/85			
0805	0811	758.9	2.4	6.31	0.01
0831	0836	304.0	0.7	5.17	0.05
0850	0857	598.3	2.1	6.32	0.03
0908	0916	771.0	5.6	6.45	0.02

Measurement problems were restricted to Flights 3, 5, and 11. The wet bulb froze during the descents of Flights 3 and 5 at heights 573 and 690 m respectively. The gradual increase in mixing ratio during the descent on these flights may be caused by drying of the 'ice' bulb by sublimation. On flight 11, the wet-bulb water container was dry until just before launch, and the wet-bulb equilibrium at the maximum altitude; therefore, the water vapor profile 11a is omitted.

The ozonesondes worked well throughout the observation period and seemed tied to boundary layer dynamics. For example, on Flight 5, the ascent showed a layer in which the ozone had apparently been depleted overnight, but by the descent ozone was added to this layer by mixing. While the ozone concentrations fluctuated wildly on Flights 3 and 4, the measurements appear accurate. The two flights were made with different ozonesondes. (NOAA loaned us two sondes). The calibrations prior to these flights were normal and the large variations appeared only in the ozone measurements. The ozonesonde temperature changed slowly with altitude. The only problem in the ozone measurements was anomalous negative ozone readings at the surface. On Flights 7, 9, 11, 12, and 13, the surface ozone readings with the ozone free filter were higher than the surface reading without the filter. These negative readings were probably the result of sulfur dioxide contamination [5]. The negative ozone readings were extremely small and are not expected to significantly influence the ozone profiles.

The time-height relationship of the aerostat should be taken into account when the profiles are analyzed. The ascent rate and frequent stops to measure statistics at constant heights change the appearance of the profiles. On Flight 3, the ascent to maximum altitude took 1.5 hours. An 'inversion' appears on profile 6a; however, this inversion was caused in part by the warming that took place while the aerostat was held at 300 m.

SUMMARY

The NRL package performed almost flawlessly making measurements for eleven flights and over 22 flight hours without a major instrumental failure. On many days, the water-vapor mixing ratio was almost constant. Data comparisons on these days should be possible without the spatial and temporal separations between instruments introducing large spurious differences between the measurements. Profiles from Flights 7 and 13 have 'step functions' that should be apparent on all three instruments.

The ozonesonde required considerably more work than the other instruments on the NRL package; however, the results amply justified this effort. Ozone was frequently the best indicator of the boundary layer and boundary layer mixing. The apparent discovery of sulfur dioxide (if confirmed by other observations) may have significance beyond contaminating ozone measurements. As a tri-atomic molecule, it absorbs in the ultra-violet and could also influence lidar operations. The purchase of an ozone detector as an addition to the meteorological package should be seriously considered.

This experiment illustrates the importance of the NRL meteorological package and the aerostat balloon. When used with a real-time display, the package hung below a tethered balloon has the ability to map meterological and optical parameters. Accurate measurement of these parameters is essential for both future boundary layer experiments and optical instruments tests.

ACKNOWLEDGMENTS

Paul Franchois and Walter Komhyr at NOAA loaned us two ozonesondes and taught us how to use them. Their assistance is gratefully acknowledged. Paul Goetsch operated the aerostat tethered balloon. We thank him for operating a perfect meterological instrumentation 'sky hook'.

REFERENCES

1. H. Gerber, "Tethered balloon measurements at San Nicolas Island (Oct., 1984): Instrumentation, data summary, preliminary data interpretation," NRL Report 8972, 1986. (AD-A172 226)

2. E.J. McCartney, Optics of the atmosphere: Scattering by molecules and particles. (John Wiley and Sons, New York, 1976)

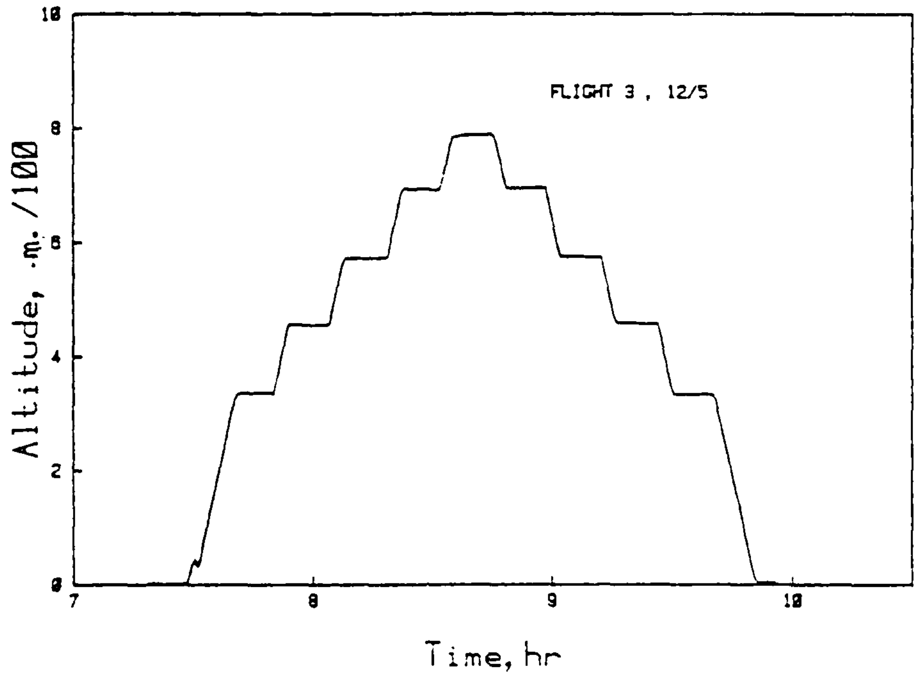
3. J.A. Dutton, The ceaseless wind: An introduction to the theory of atmospheric motion. (McGraw-Hill Inc., New York, 1976).

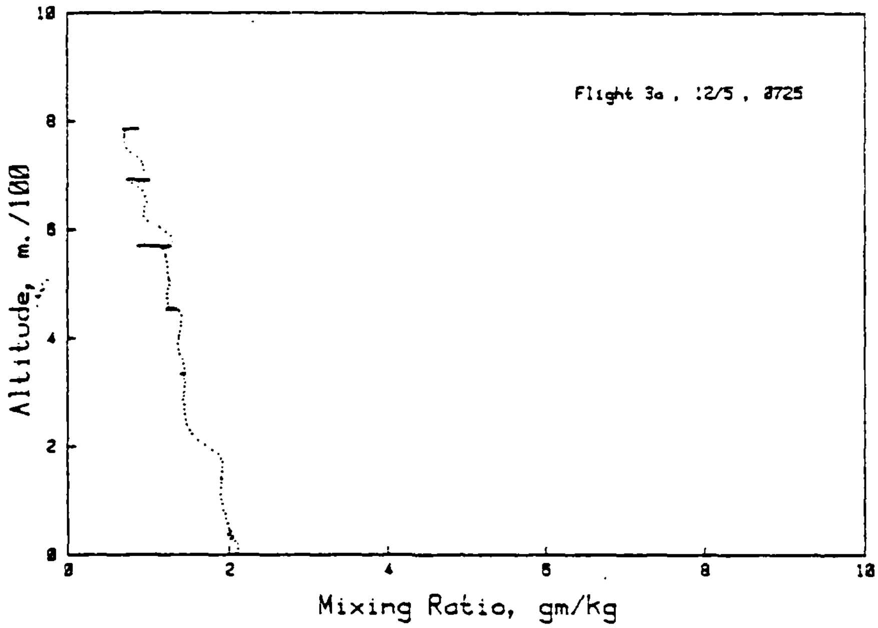
4. J.A. Goff and S. Gratch, "Formulation for the saturation vapor pressure over plane surfaces of pure water and ice," Trans. Amer. Heat. and Vent. Eng. 52, 95 (1946).

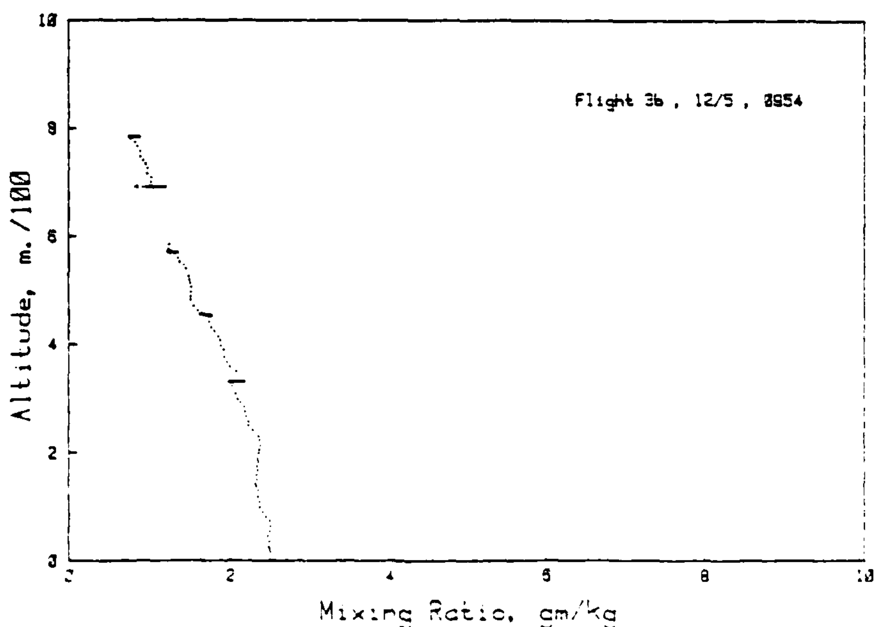
5. W.D. Komhyr (1985), Personal communications, U.S. Dept. of Commerce, NOAA, Boulder, Co.

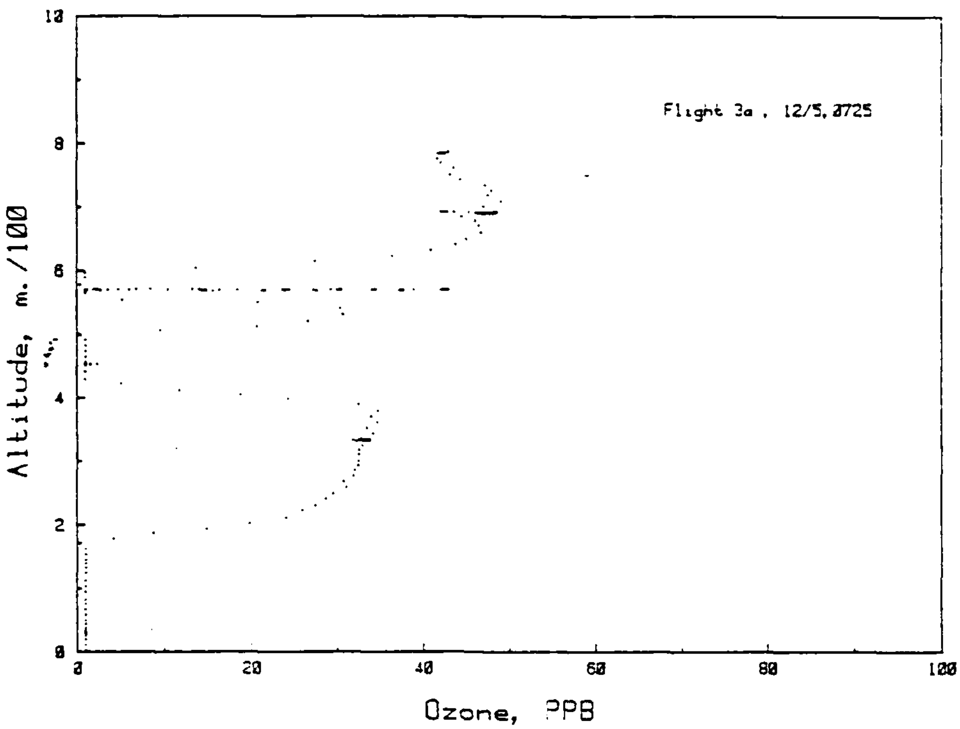
APPENDIX A - Profiles of Mixing Ratio, Ozone, Scattering Ratio, Virtual Potential Temperature, and Wind Speed

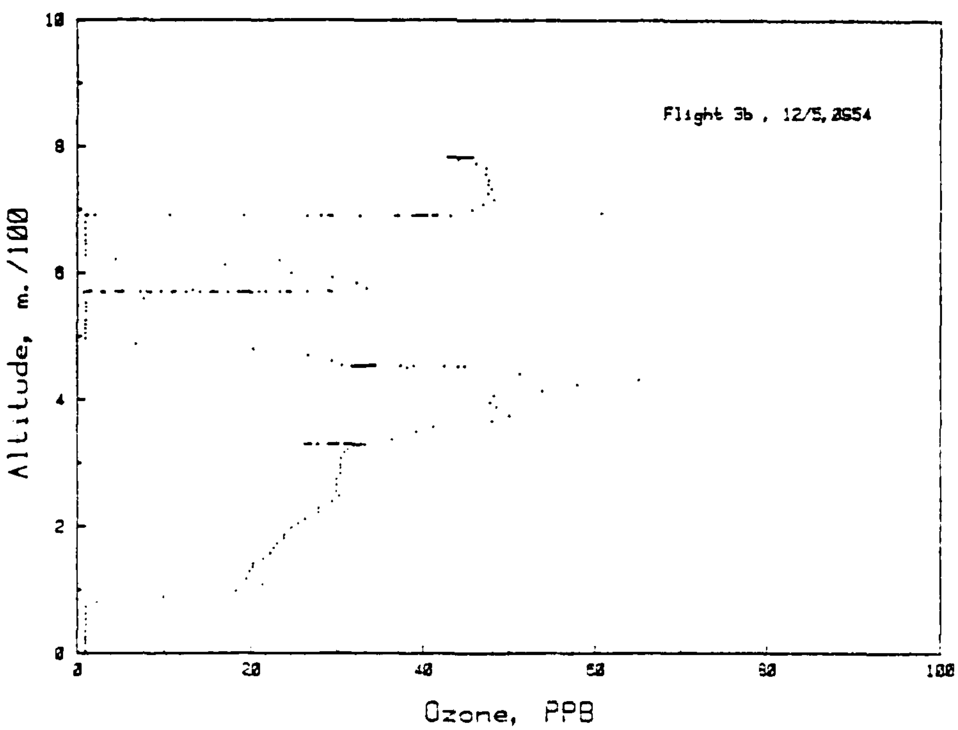
The measurements made by the 'Aerostat' tethered balloon are plotted as a function of height for the flights. The profiles are grouped by flights in chronological order from Flight 3 to 13. Each plot has a flight number, date, and time in the upper right corner. The first plot for each flight is a time-height profile followed by the mixing ratio, ozone, scattering ratio, virtual potential temperature, and wind speed profiles. The scattering ratio has a natural logarithm scale. All other plots have linear scales.

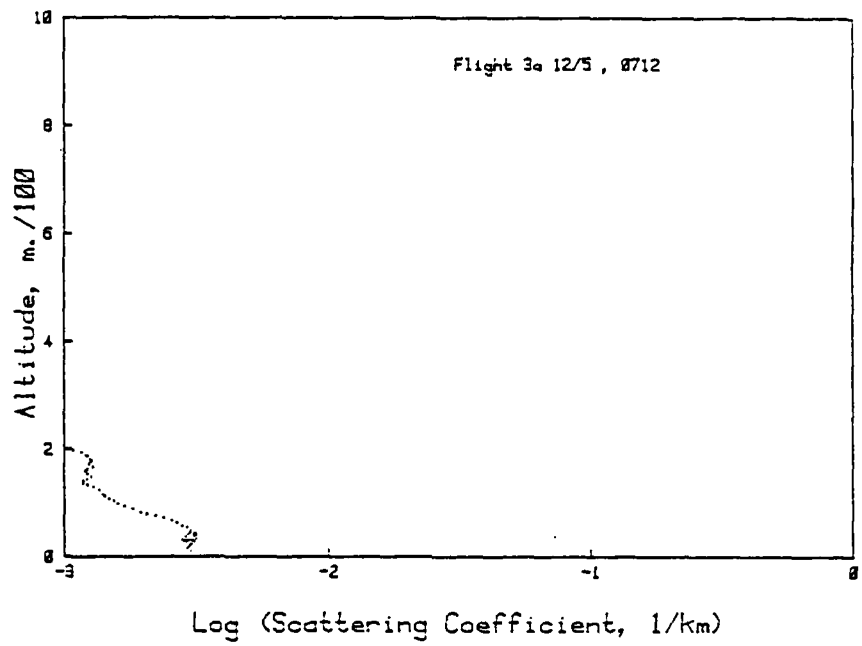

FLIGHT 3 , 12/5
Altitude, m. /100
Time, hr
10
8
6
4
2
0
7
8
9
10

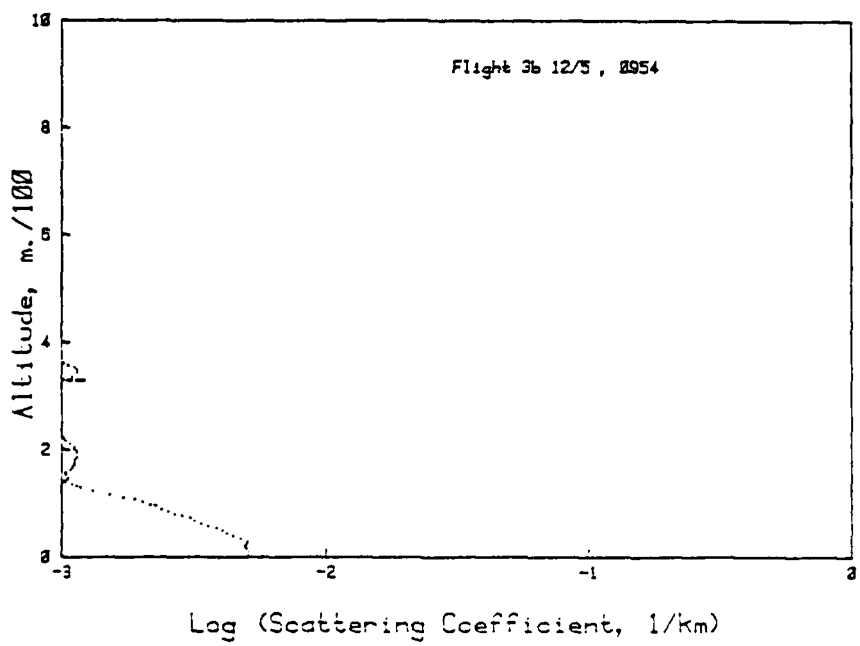

Flight 3a , 12/5 , 0725
Altitude, m./100
Mixing Ratio, gm/kg

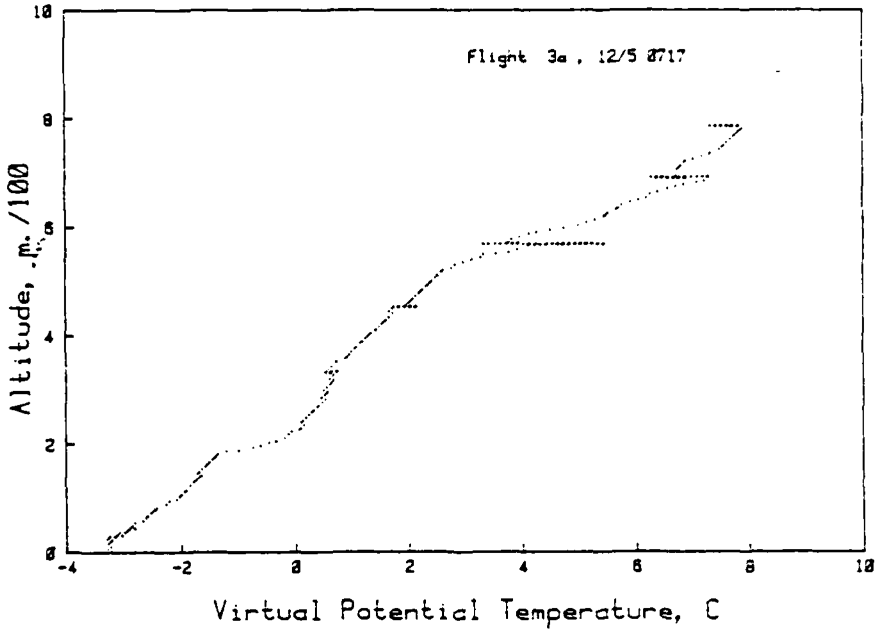

Flight 3b , 12/5 , 0954
Altitude, m./100
Mixing Ratio, gm/kg

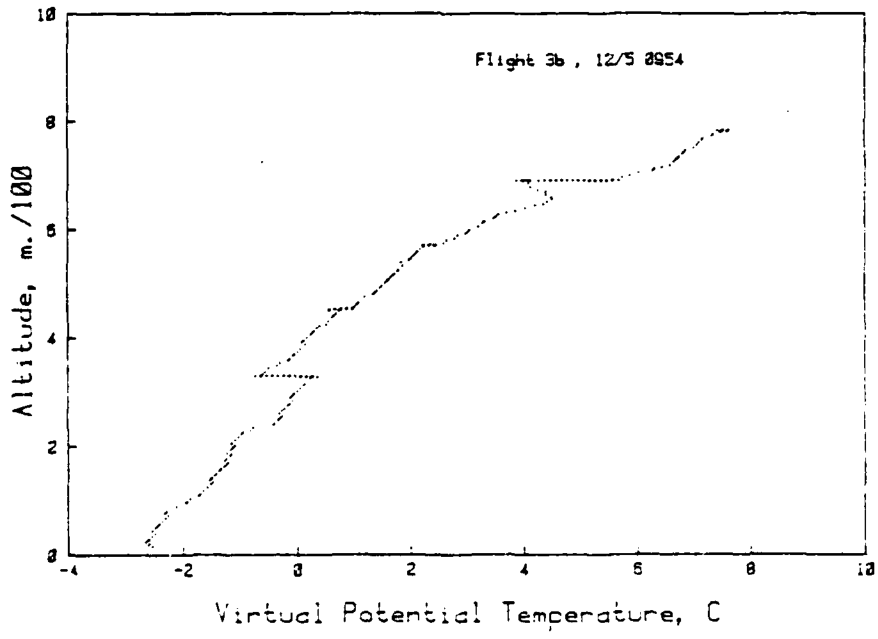

Flight 3a , 12/5, 0725
Altitude, m./100
Ozone, PPB
0
2
4
6
8
10
0
20
40
60
80
100

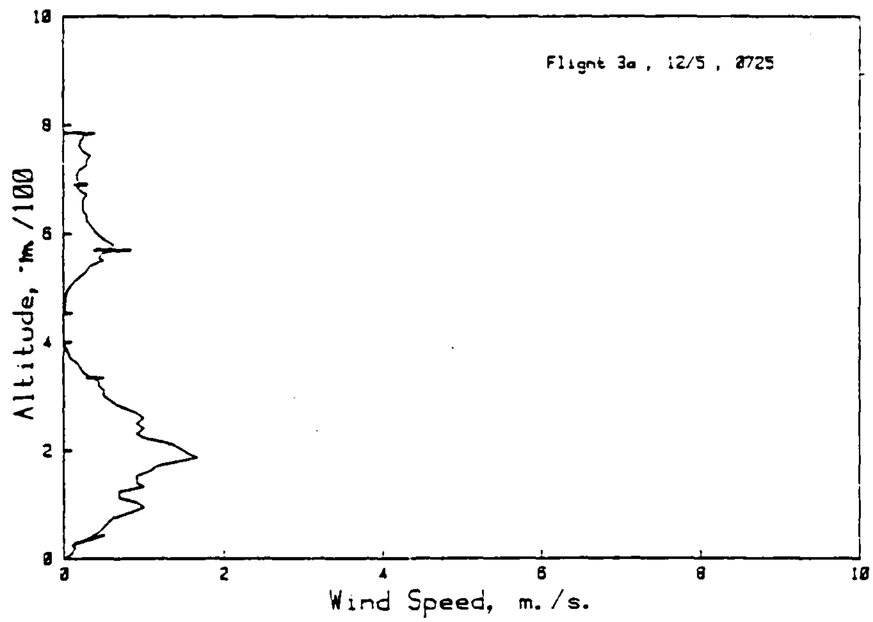

Flight 3b , 12/5, 2654
Altitude, m./100
Ozone, PPB
0
2
4
6
8
10
0
20
40
50
60
100

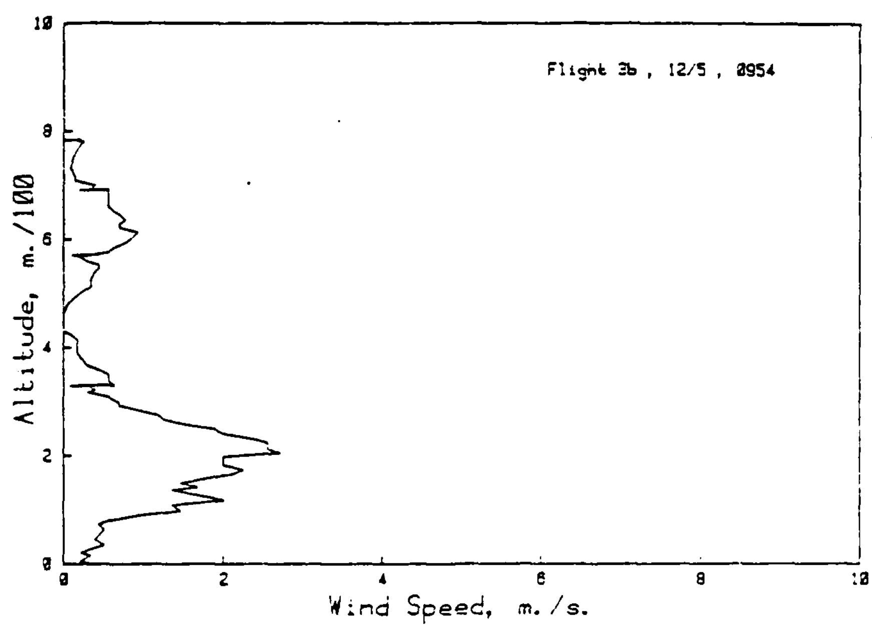

Flight 3a 12/5 , 0712
Altitude, m./100
Log (Scattering Coefficient, 1/km)

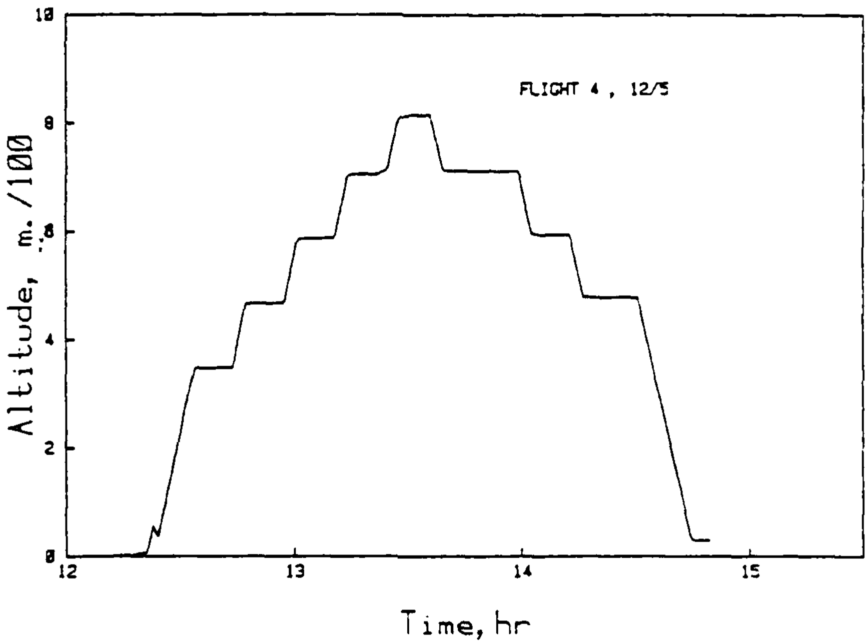

Flight 3b 12/5 , 0954
Altitude, m./100
Log (Scattering Coefficient, 1/km)


Flight 3a , 12/5 0717
Altitude, m./100
Virtual Potential Temperature, C

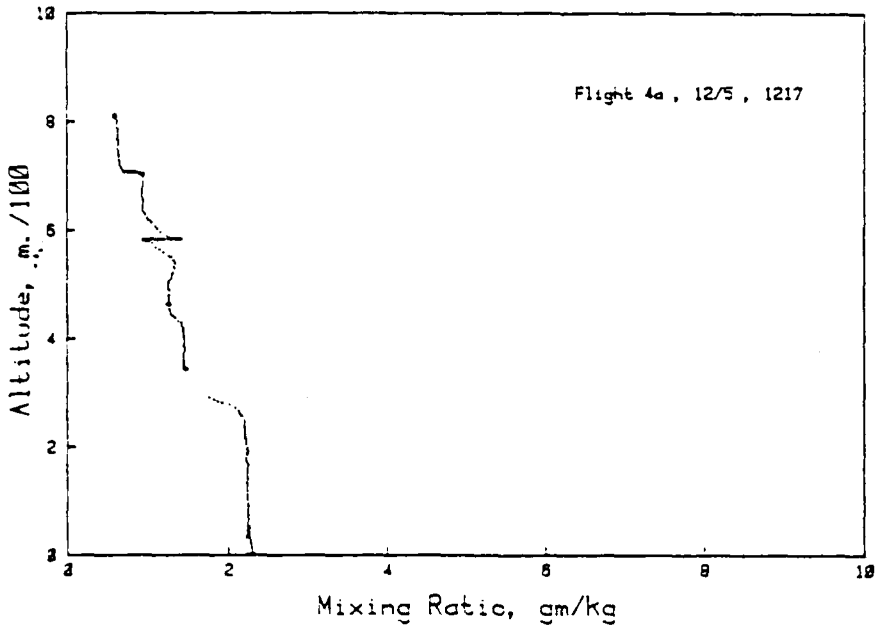

Flight 3b , 12/5 0954
Altitude, m./100
Virtual Potential Temperature, C

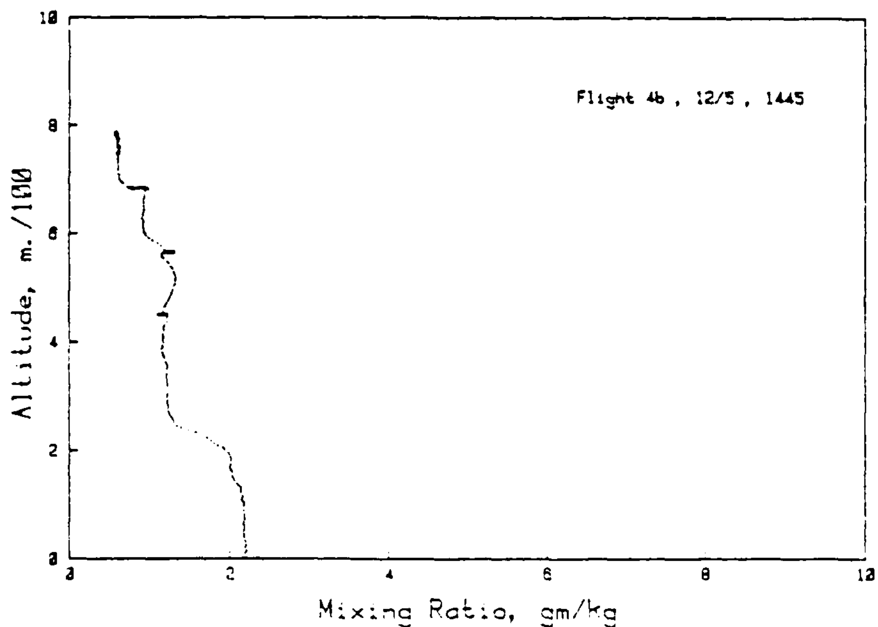

Flight 3a , 12/5 , 0725
Altitude, m./100
Wind Speed, m./s.

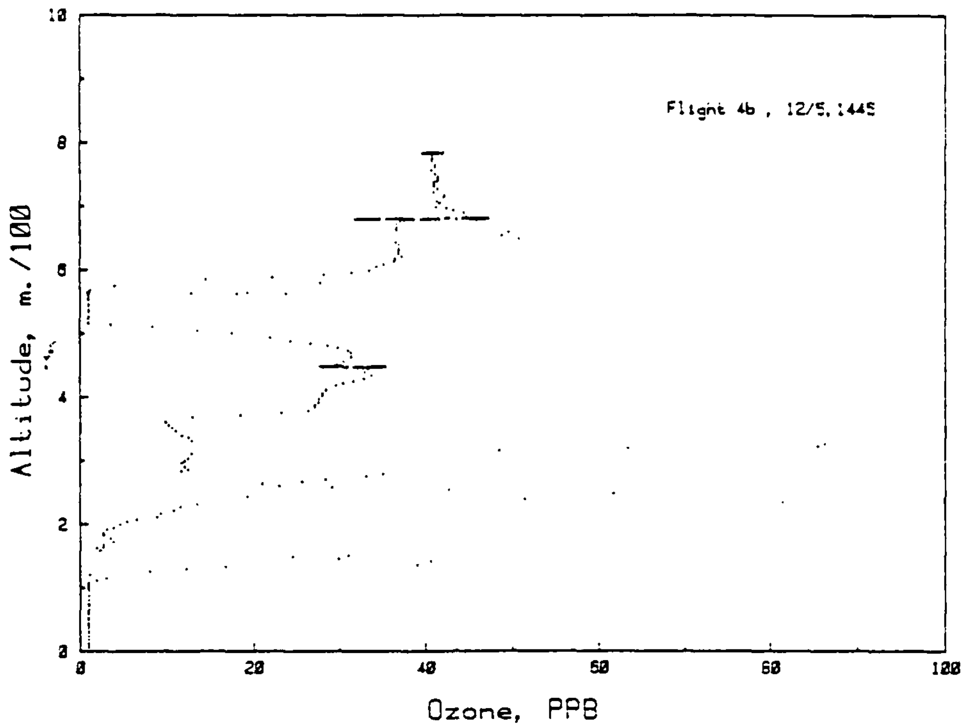

Flight 3b , 12/5 , 0954
Altitude, m./100
Wind Speed, m./s.



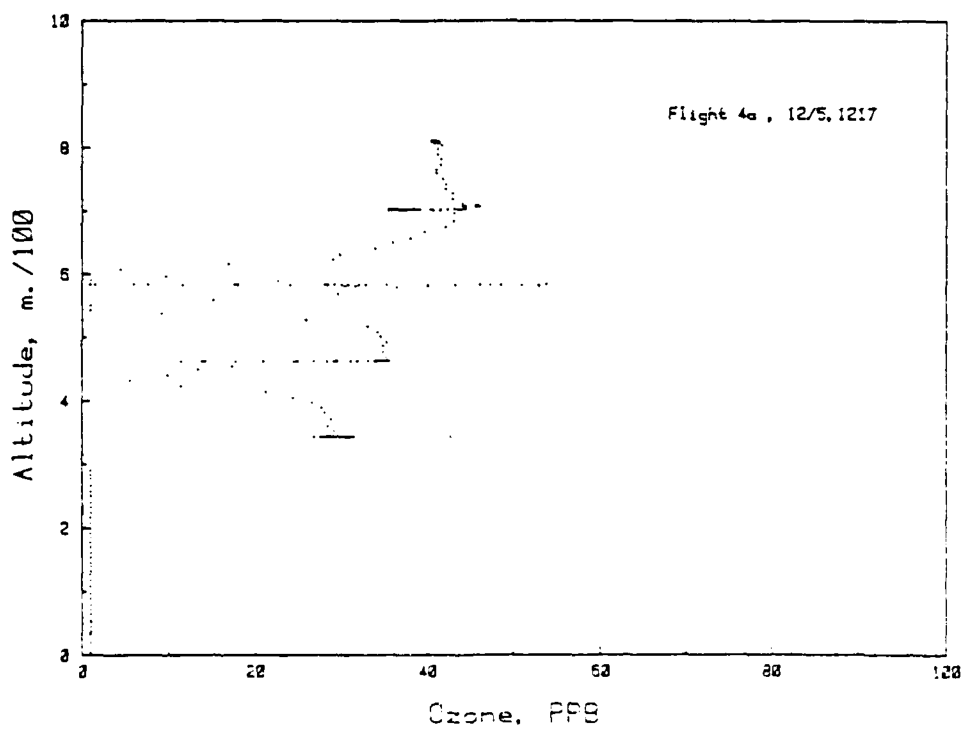
FLIGHT 4 , 12/5
Altitude, m./100
Time, hr
0
2
4
6
8
10
12
13
14
15


Flight 4a , 12/5 , 1217
Altitude, m./100
Mixing Ratio, gm/kg

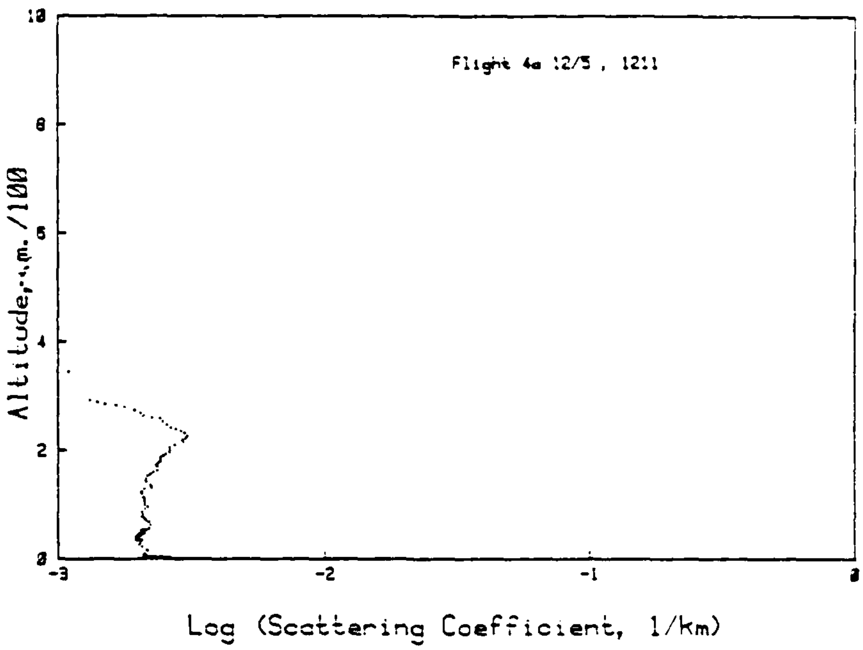

Flight 4b , 12/5 , 1445
Altitude, m./100
Mixing Ratio, gm/kg

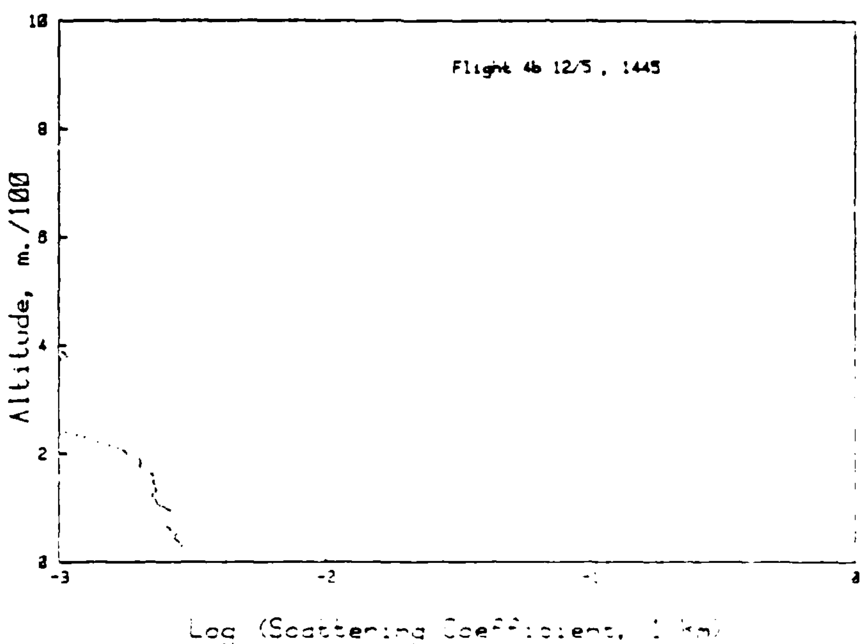


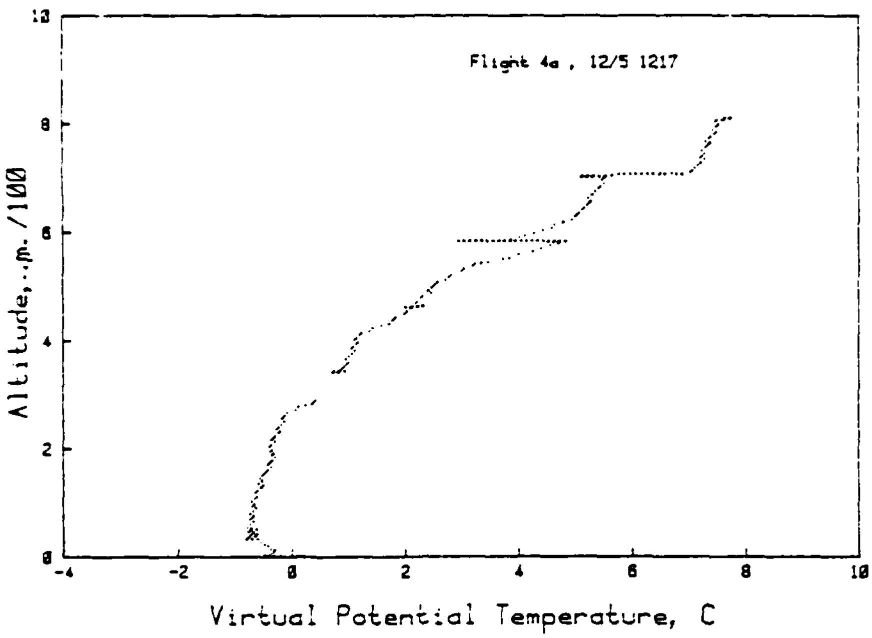
Flight 4b , 12/5, 1445
Altitude, m./100
Ozone, PPB

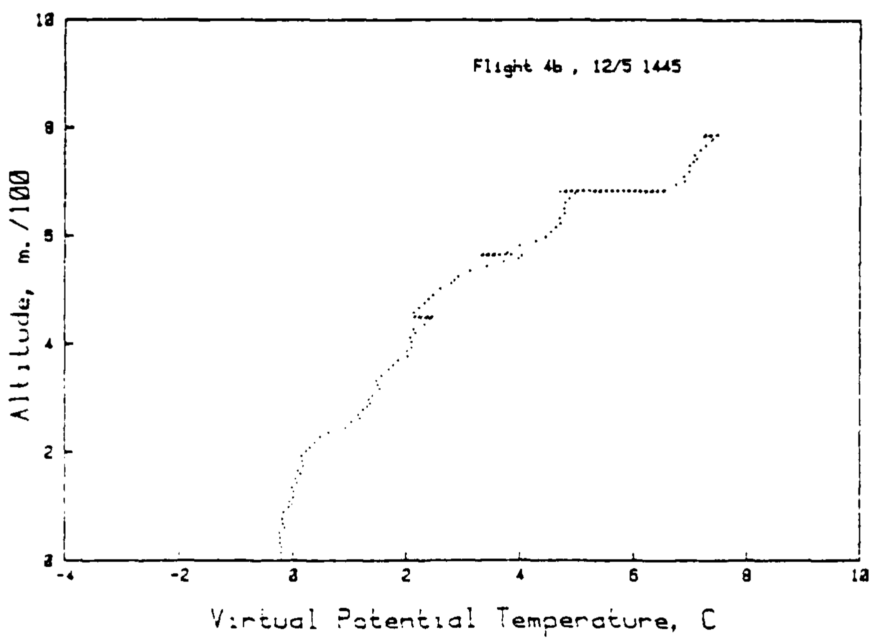


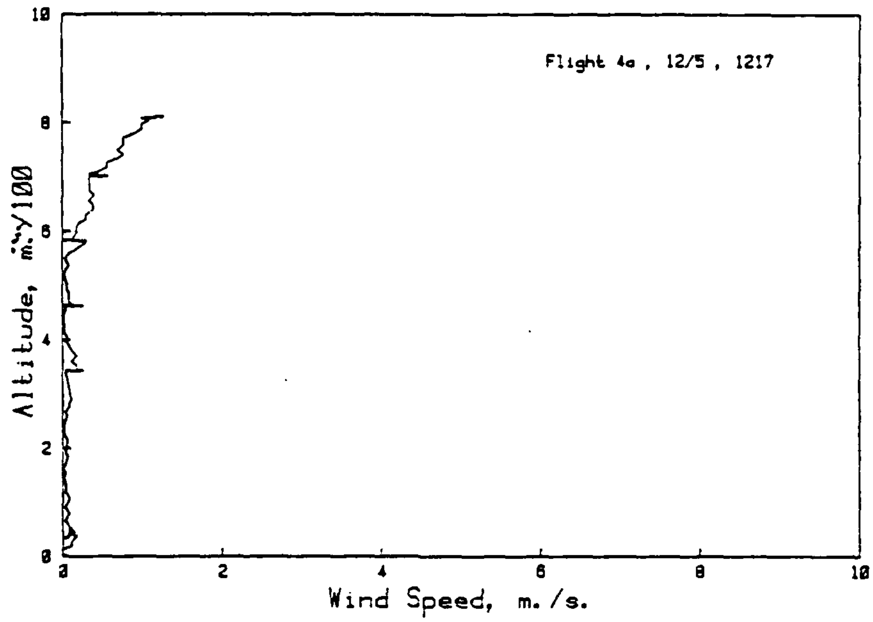
Flight 4a , 12/5, 1217
Altitude, m./100
Ozone, PPB

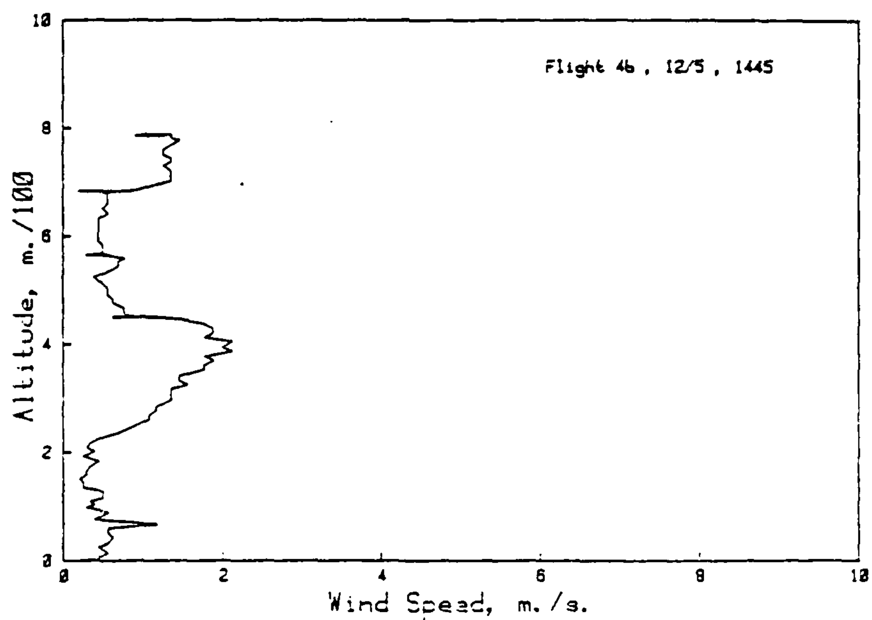

Flight 4a 12/5 , 1211
Altitude, m./100
Log (Scattering Coefficient, 1/km)

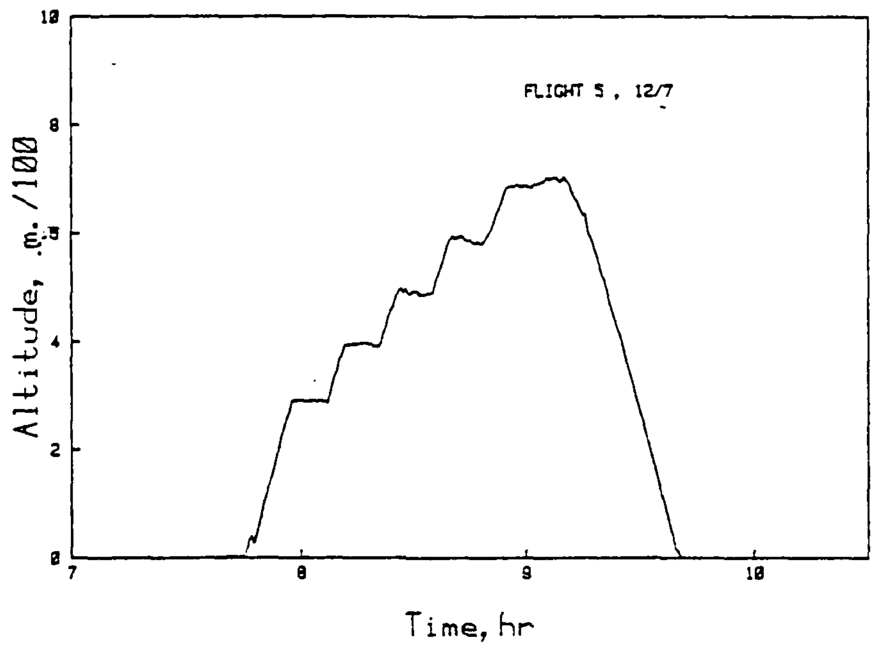

Flight 4b 12/5 , 1445
Altitude, m./100

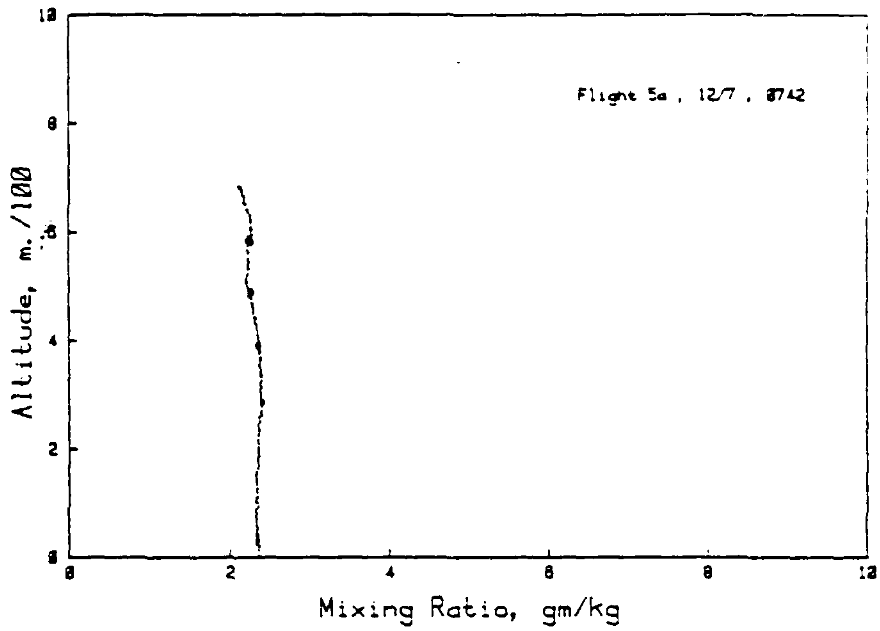

Flight 4a , 12/5 1217
Altitude, m./100
Virtual Potential Temperature, C


Flight 4b , 12/5 1445
Altitude, m./100
Virtual Potential Temperature, C

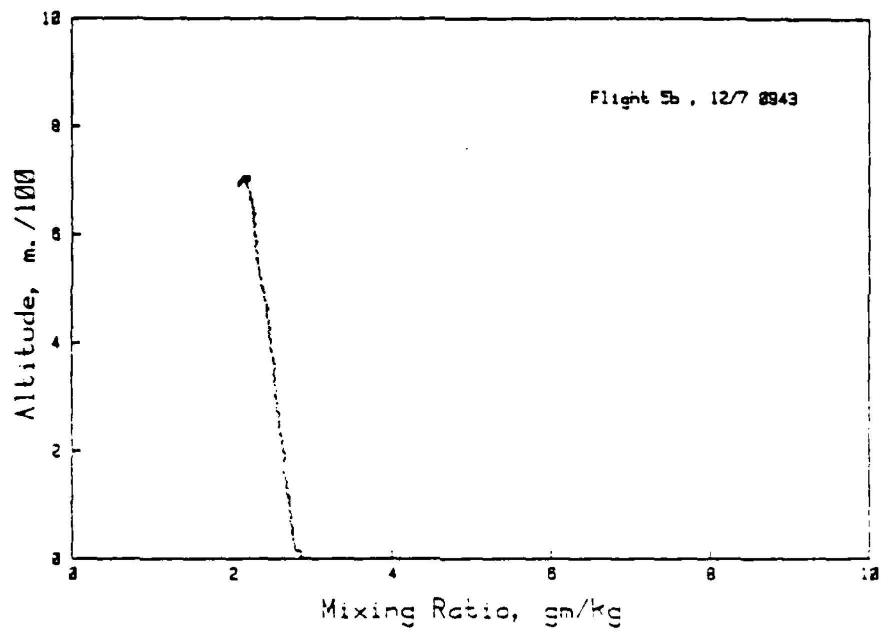

Flight 4a , 12/5 , 1217
Altitude, m./100
Wind Speed, m. /s.


Flight 4b , 12/5 , 1445
Altitude, m./100
Wind Speed, m. /s.

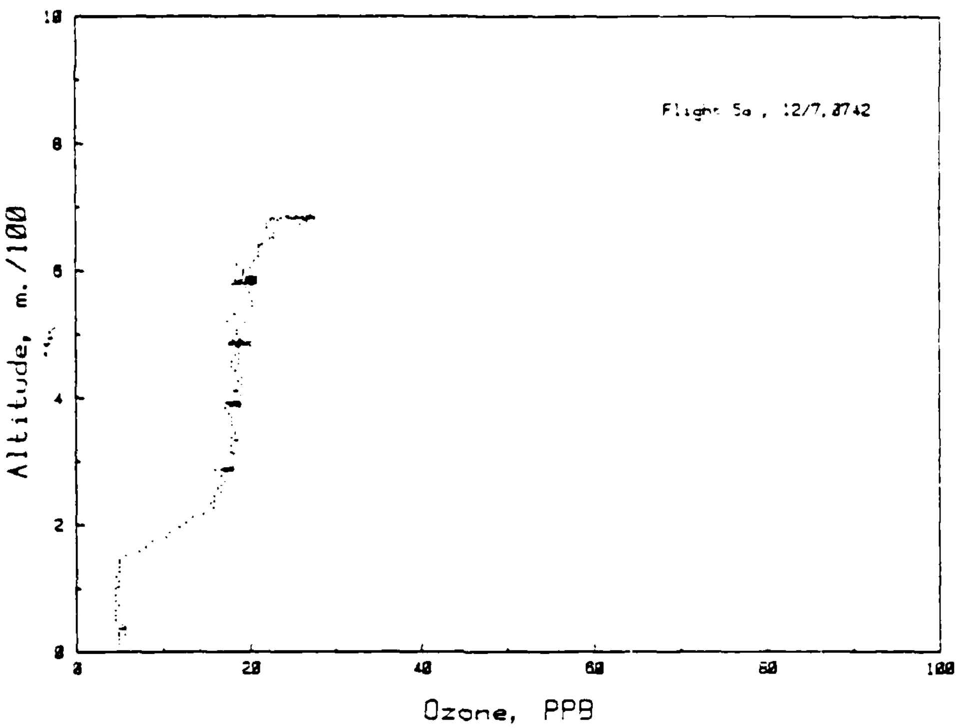

FLIGHT 5 , 12/7
Altitude, m. /100
Time, hr
0
2
4
6
8
10
7
8
9
10

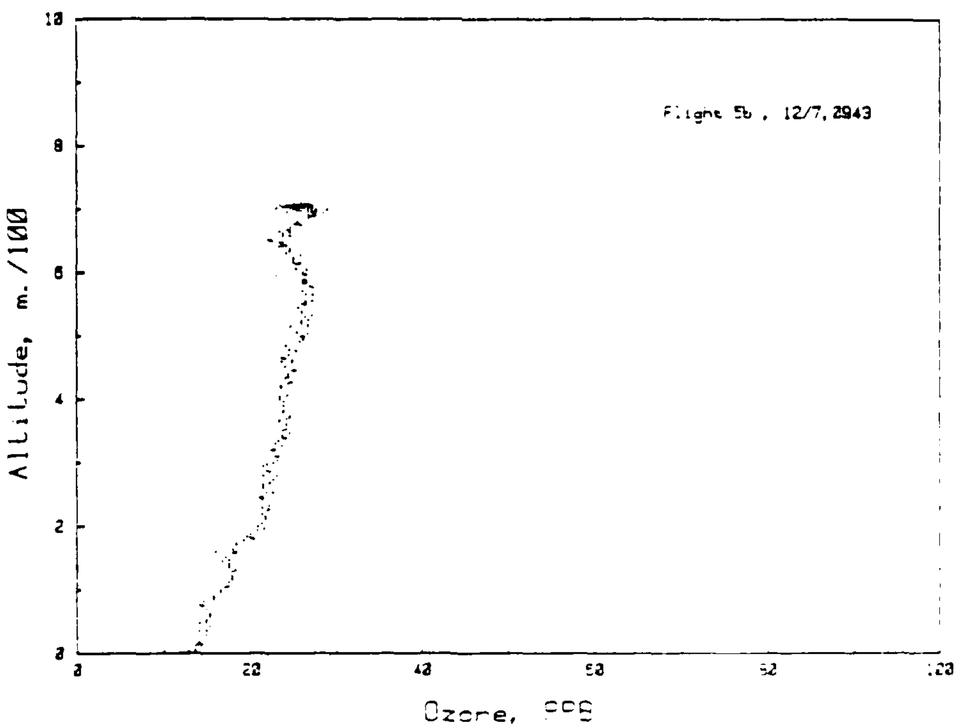


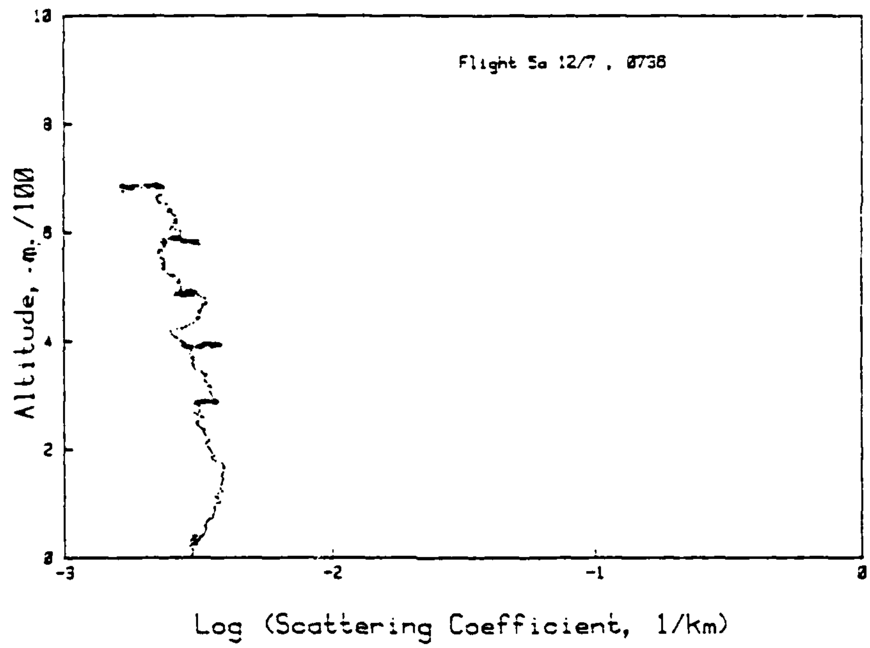
Flight 5a , 12/7 , 0742
Altitude, m./100
Mixing Ratio, gm/kg

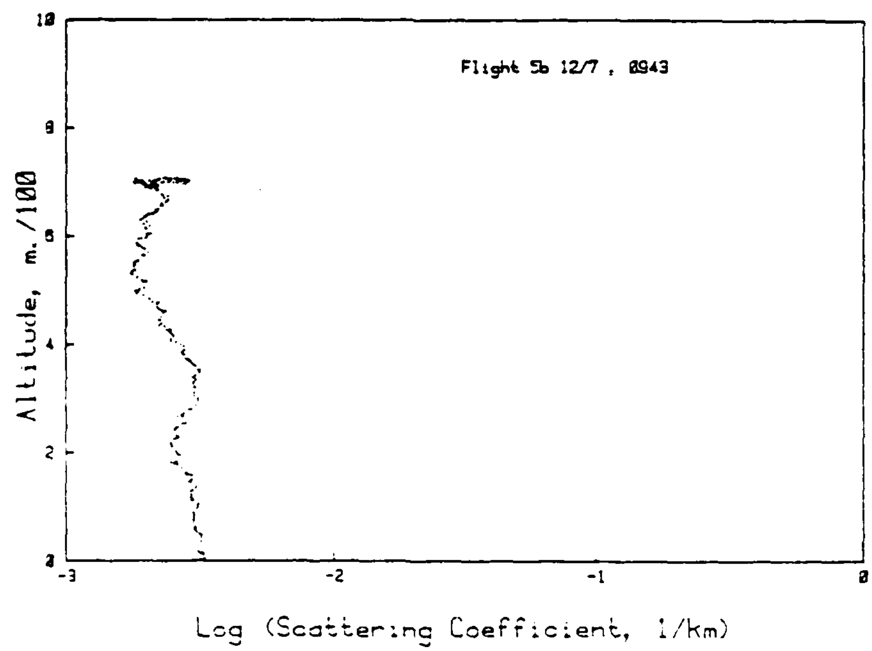


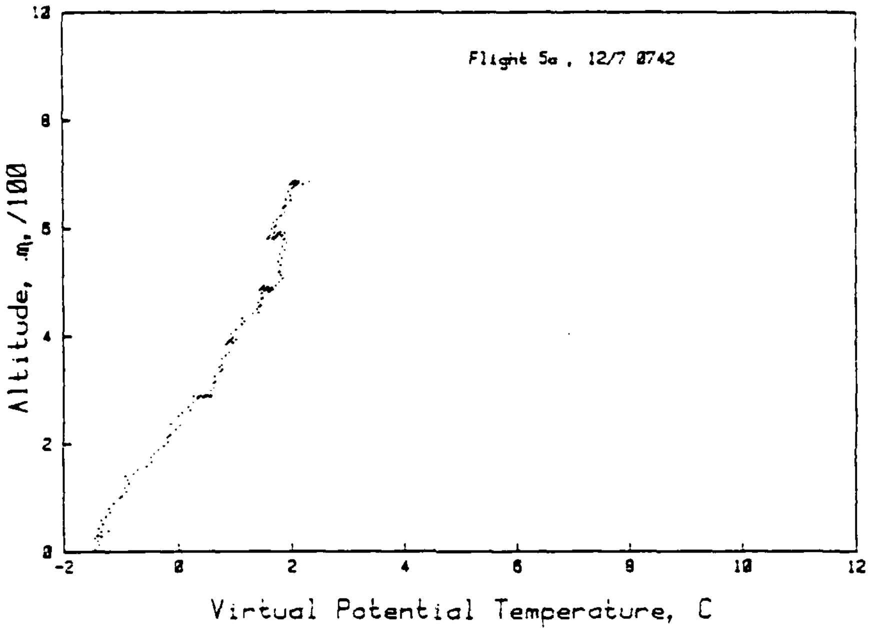
Flight 5b , 12/7 0943
Altitude, m./100
Mixing Ratio, gm/kg

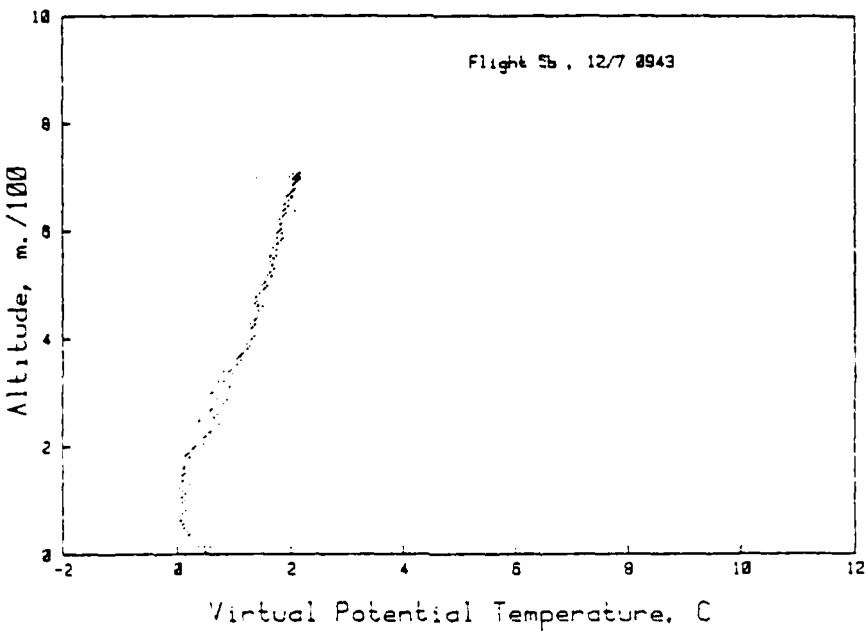

Flight 5a , 12/7, 0742
Altitude, m./100
Ozone, PPB
0
2
4
6
8
10
0
20
40
60
80
100

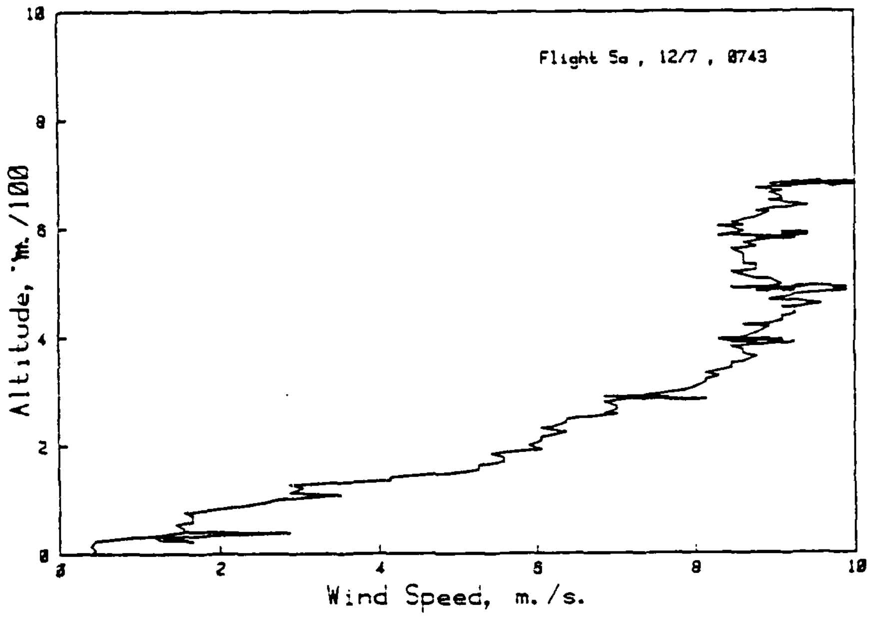

Flight 5b , 12/7, 2043
Altitude, m./100
Ozone, PPB
0
2
4
6
8
10
0
20
40
60
80
100

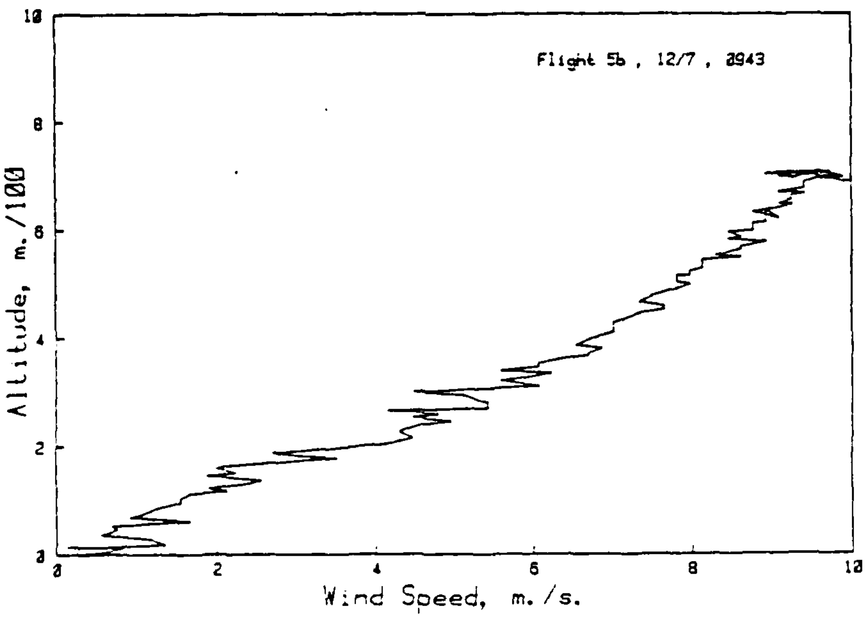

Flight 5a 12/7 , 0738
Altitude, m./100
Log (Scattering Coefficient, 1/km)

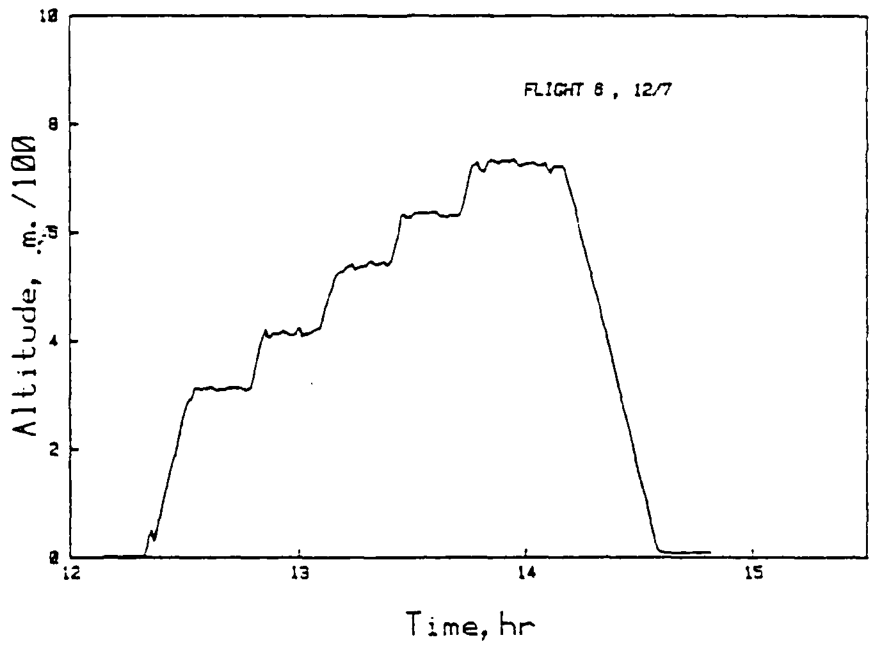

Flight 5b 12/7 , 0943
Altitude, m./100
Log (Scattering Coefficient, 1/km)

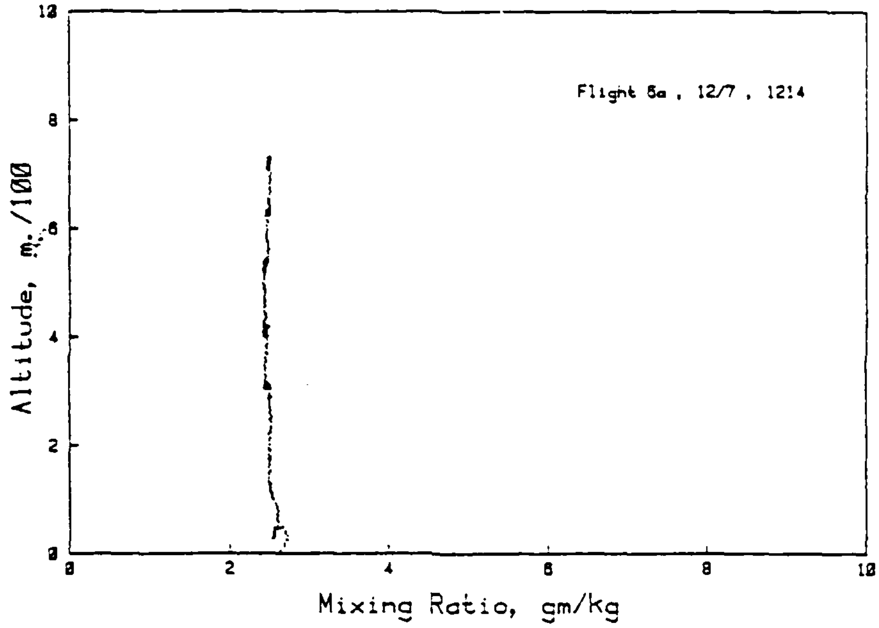

Flight 5a , 12/7 0742
Altitude, m./100
Virtual Potential Temperature, C
-2
0
2
4
6
8
10
12

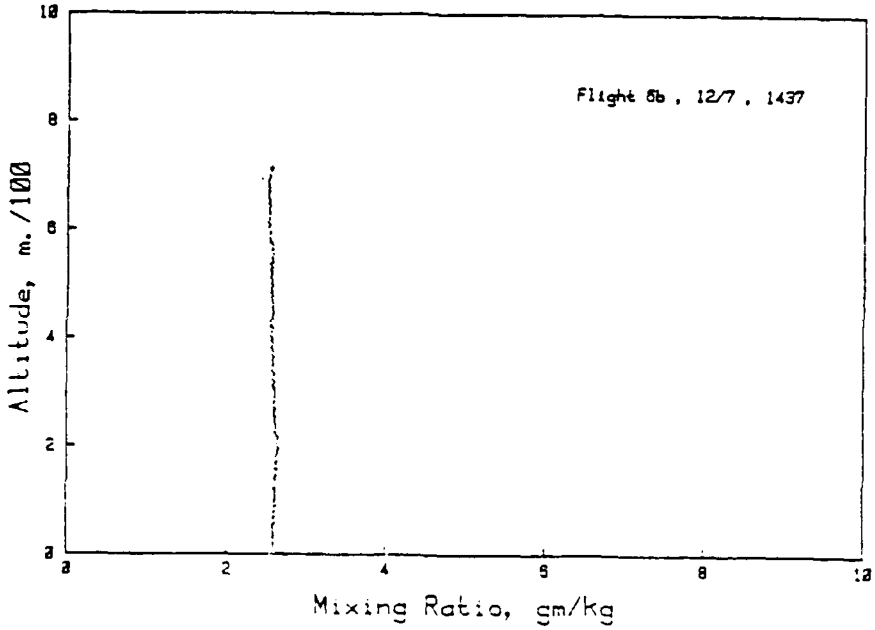

Flight 5b , 12/7 0943
Altitude, m./100
Virtual Potential Temperature, C
-2
0
2
4
6
8
10
12

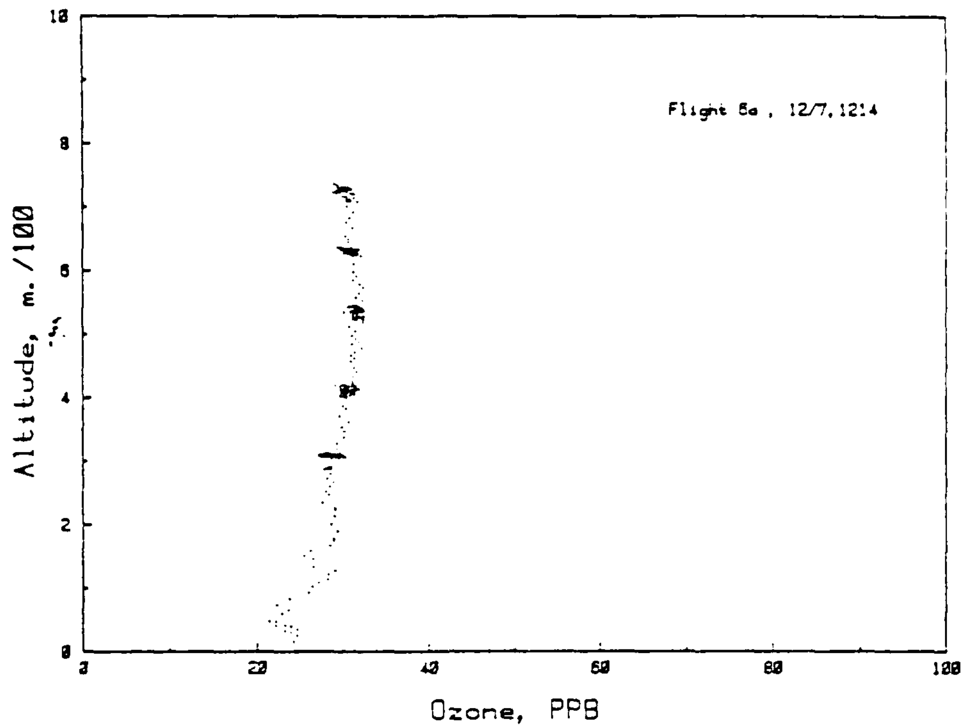

Flight 5a , 12/7 , 0743
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10

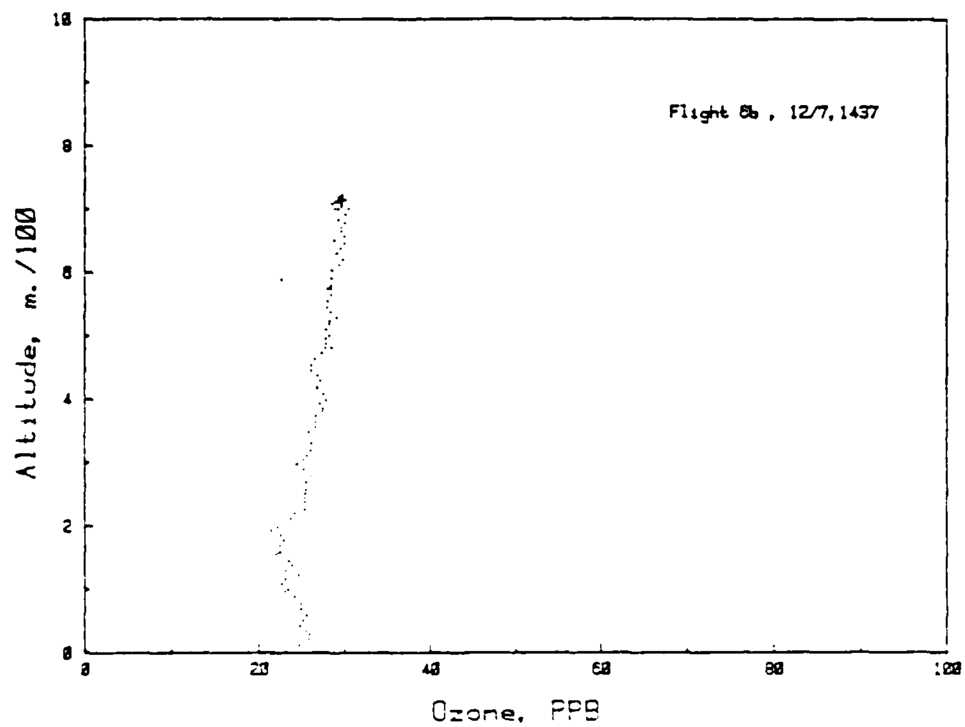

Flight 5b , 12/7 , 0943
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10

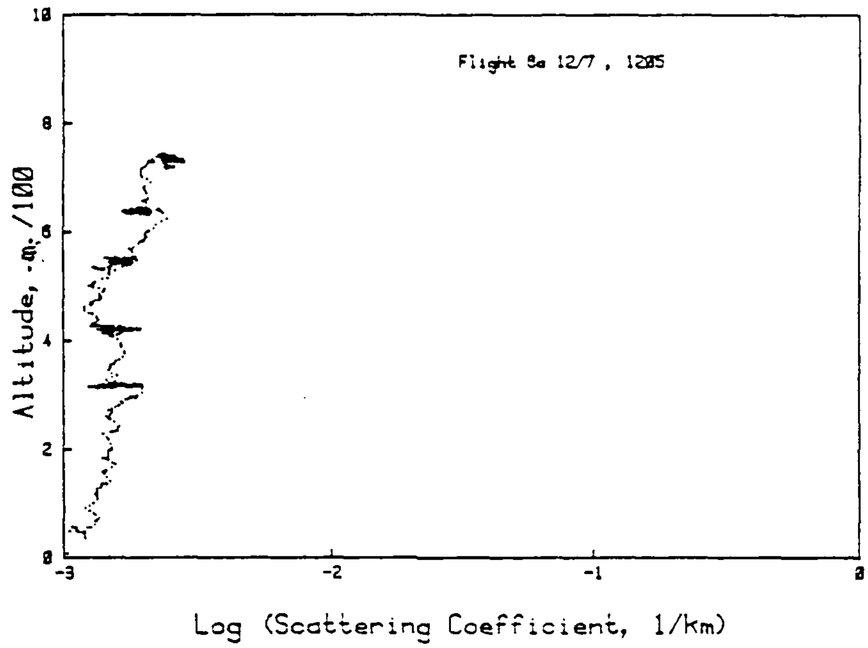

FLIGHT 8 , 12/7
Altitude, m. /100
Time, hr
0
2
4
6
8
10
12
13
14
15

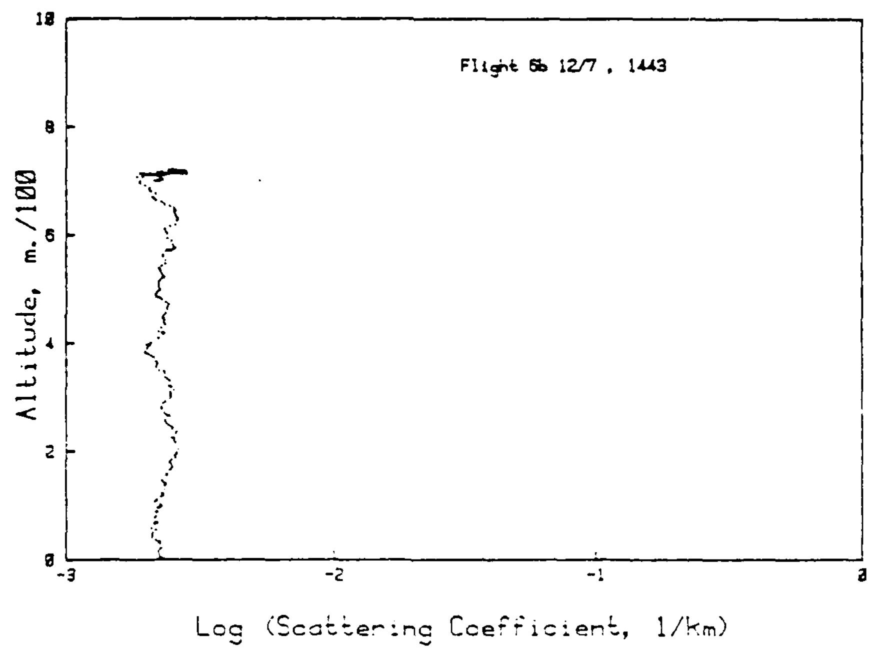

Flight 6a , 12/7 , 1214
Altitude, m./100
Mixing Ratio, gm/kg

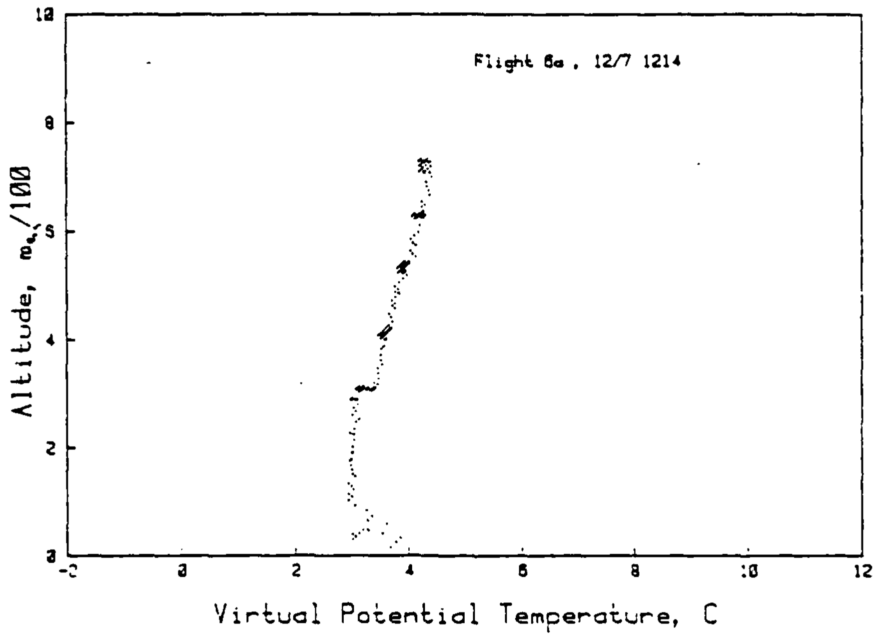

Flight 6b , 12/7 , 1437
Altitude, m./100
Mixing Ratio, gm/kg

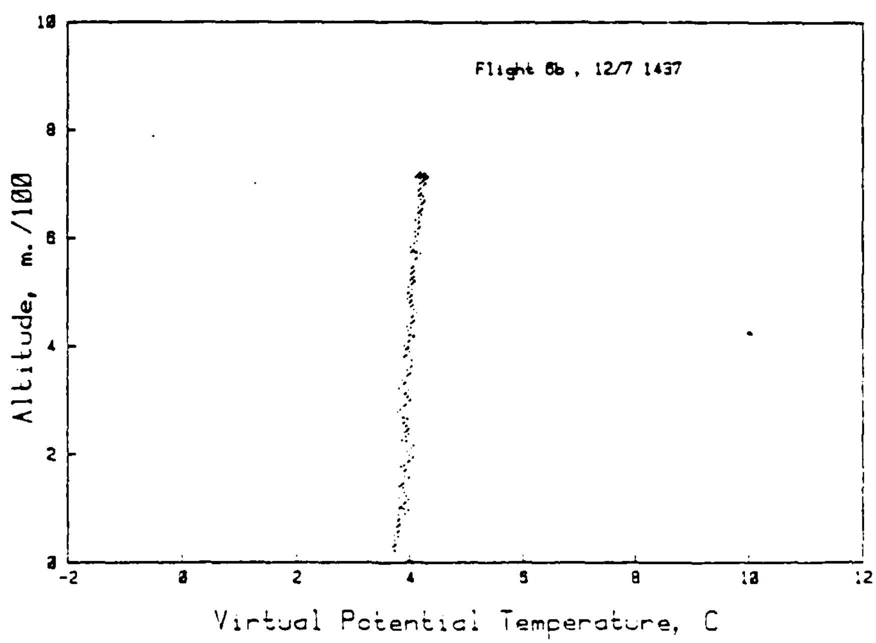

Flight 8a , 12/7, 1214
Altitude, m./100
Ozone, PPB

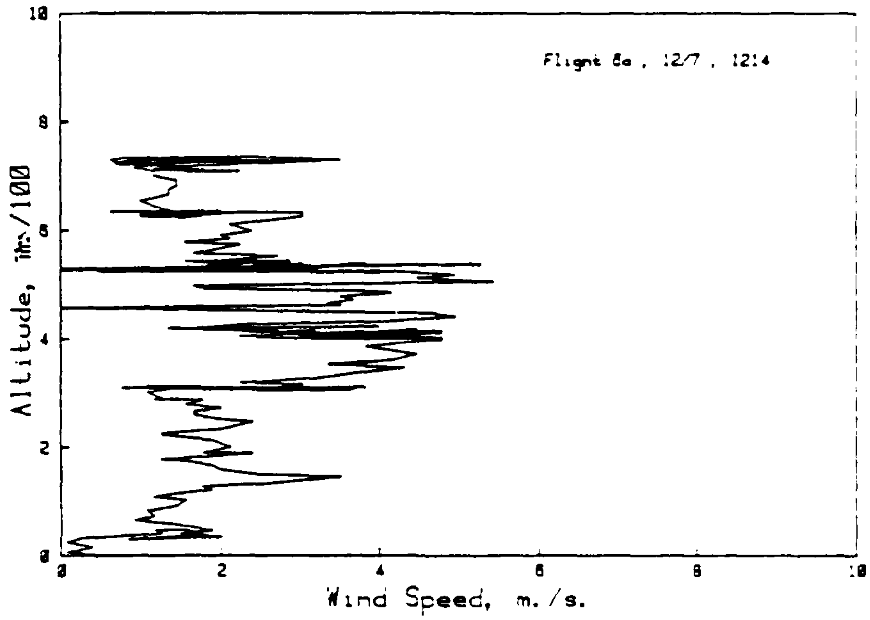

Flight 8b , 12/7, 1437
Altitude, m./100
Ozone, PPB

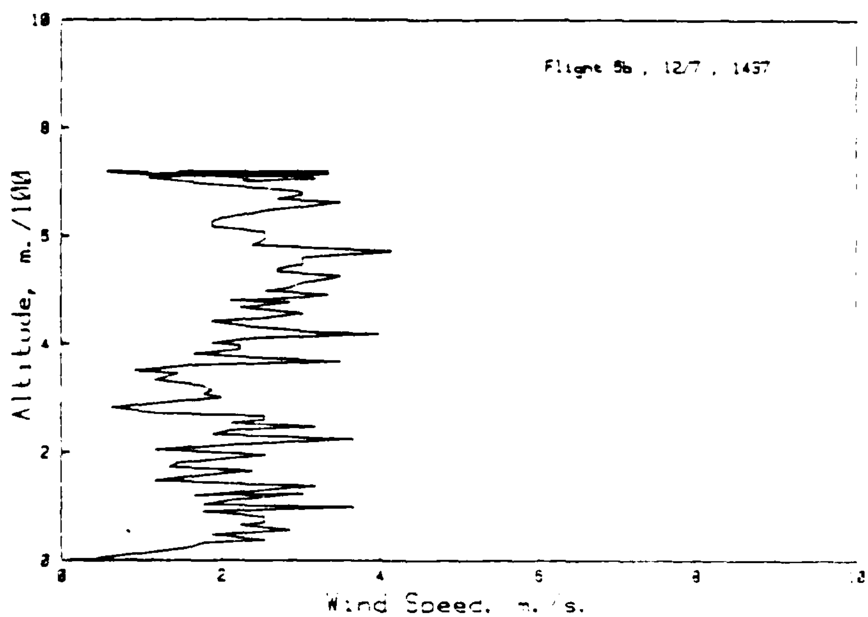

Flight 6a 12/7 , 1205
10
8
6
4
2
0
Altitude, m./100
-3
-2
-1
0
Log (Scattering Coefficient, 1/km)

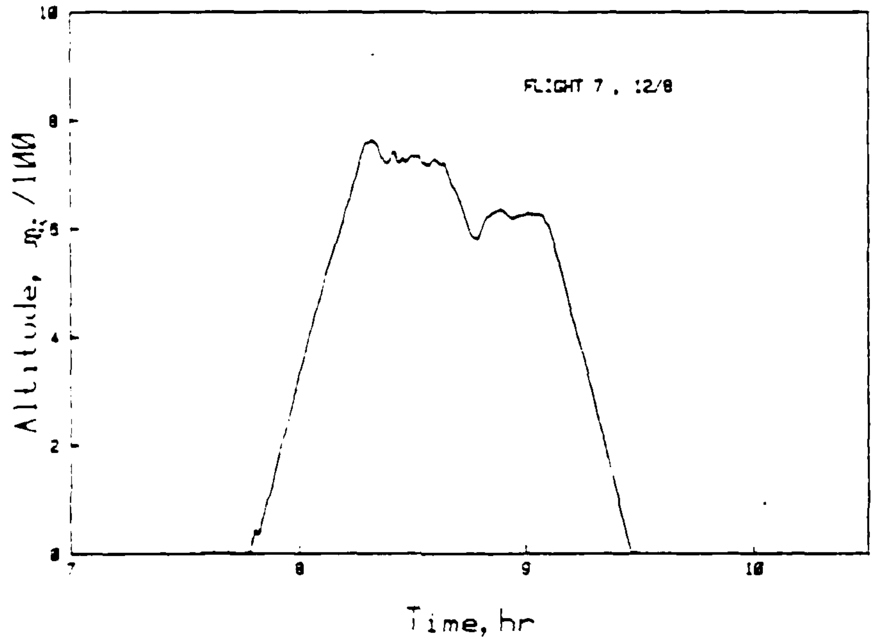

Flight 6b 12/7 , 1443
10
8
6
4
2
0
Altitude, m./100
-3
-2
-1
0
Log (Scattering Coefficient, 1/km)

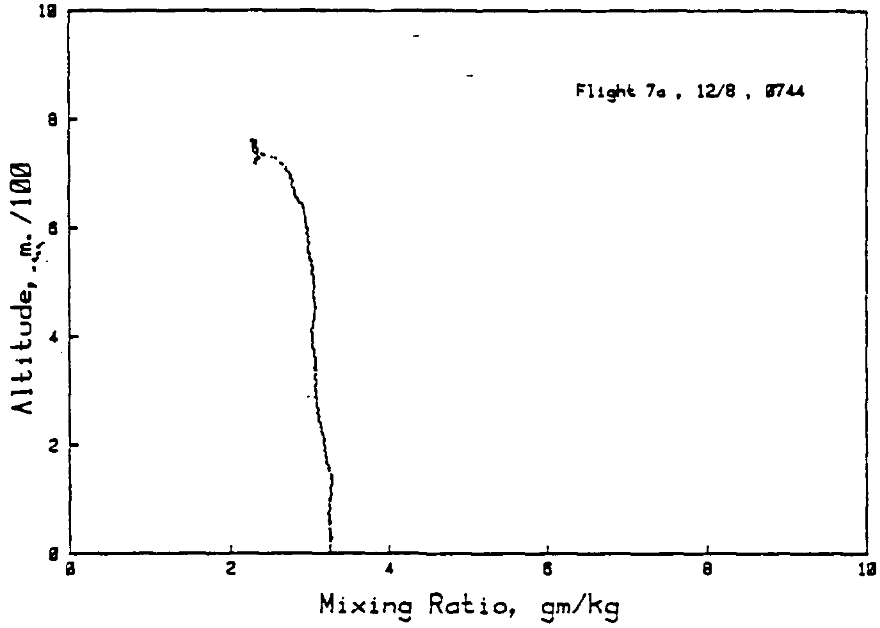

Flight 6a , 12/7 1214
Altitude, m./100
Virtual Potential Temperature, C

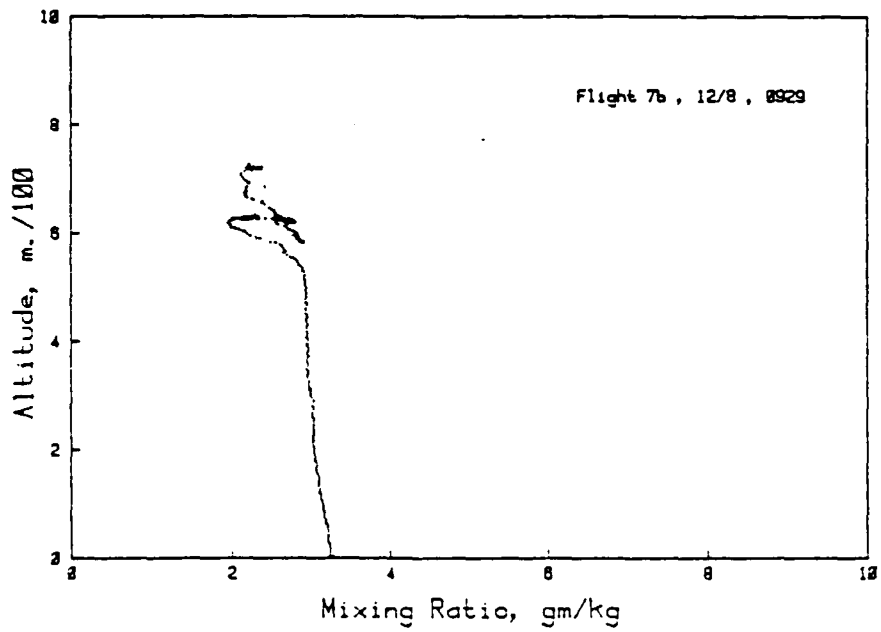

Flight 6b , 12/7 1437
Altitude, m./100
Virtual Potential Temperature, C

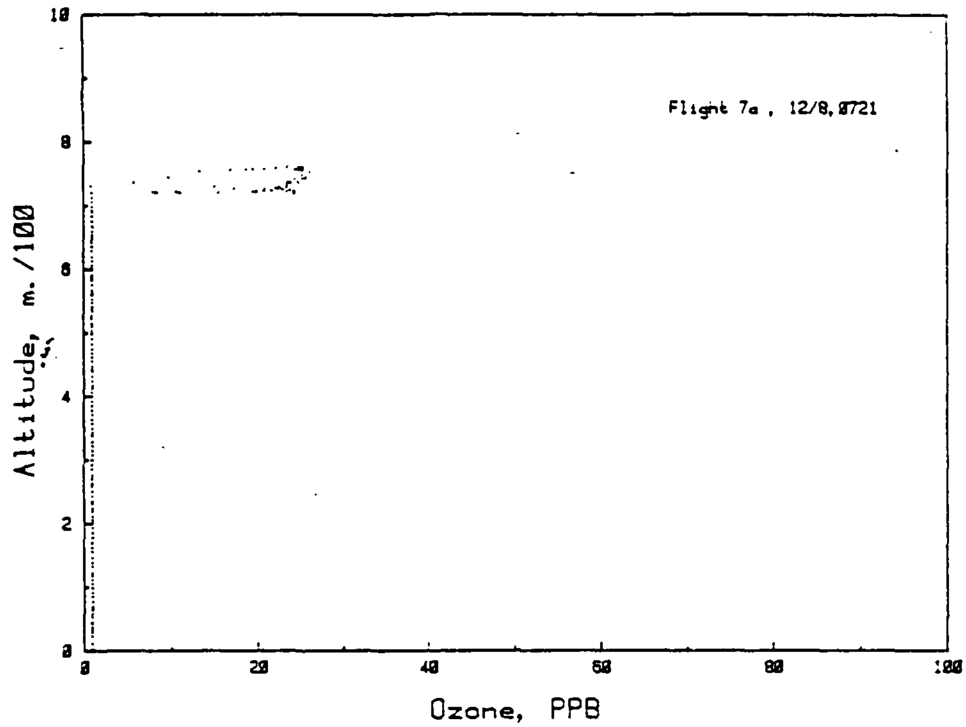

Flight 6a , 12/7 , 1214
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10

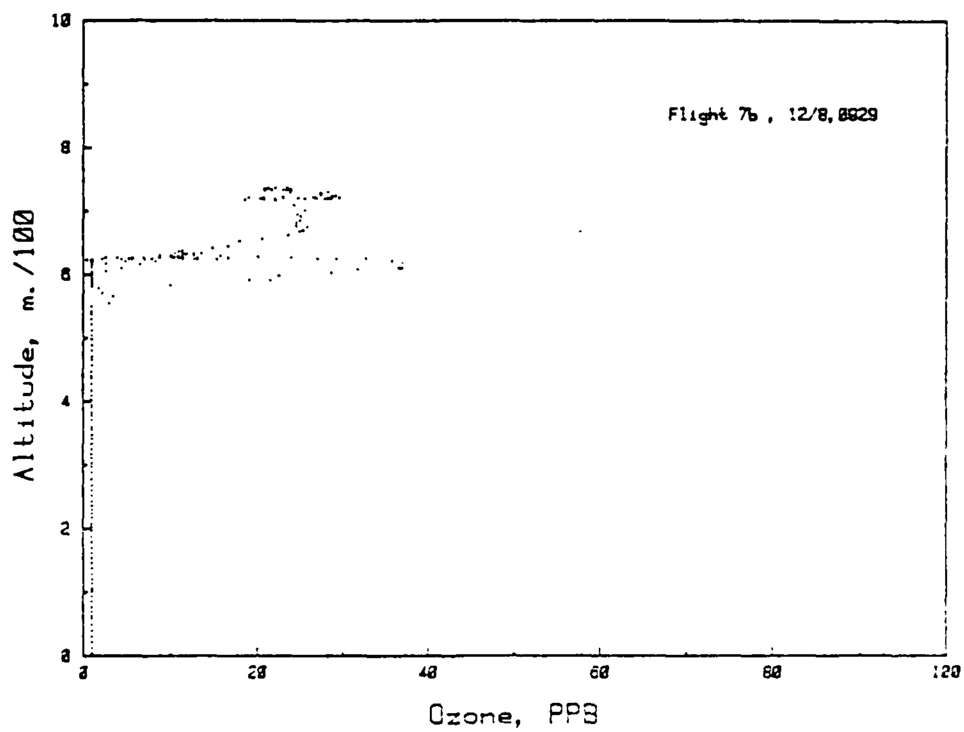

Flight 5b , 12/7 , 1457
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10

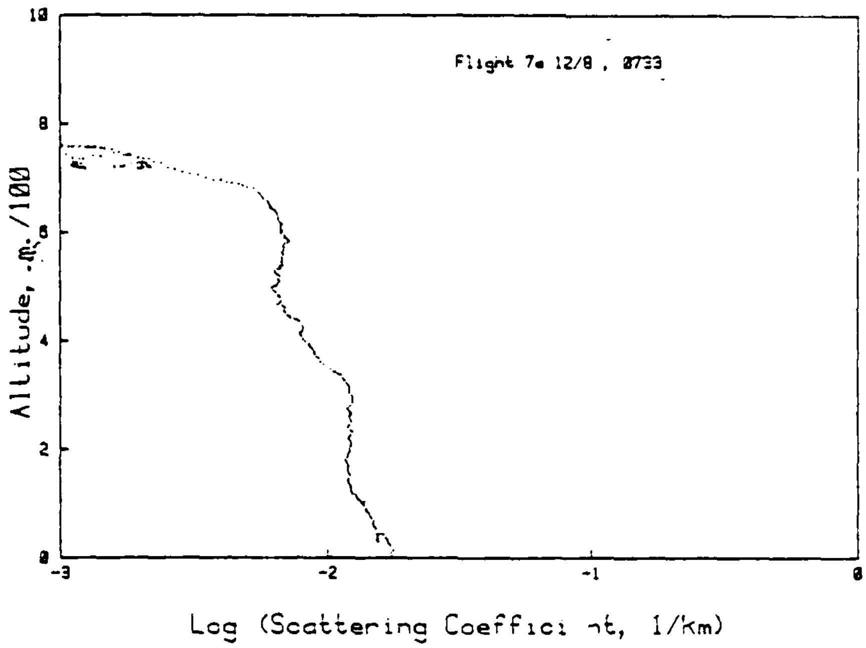

FLIGHT 7 , 12/8
Altitude, m /100
Time, hr
10
8
6
4
2
0
7
8
9
10

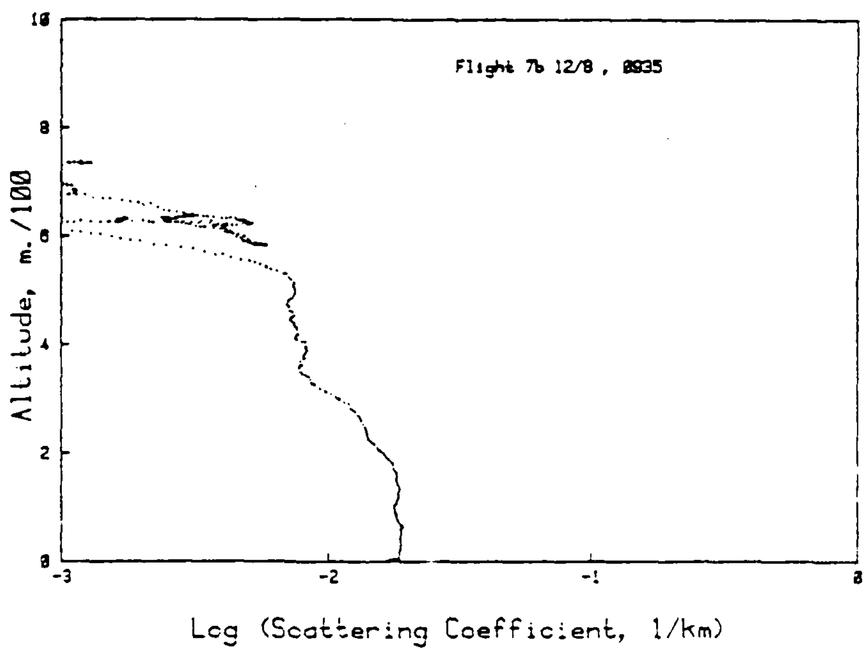

Flight 7a , 12/8 , 0744
Altitude, m./100
Mixing Ratio, gm/kg
0
2
4
6
8
10

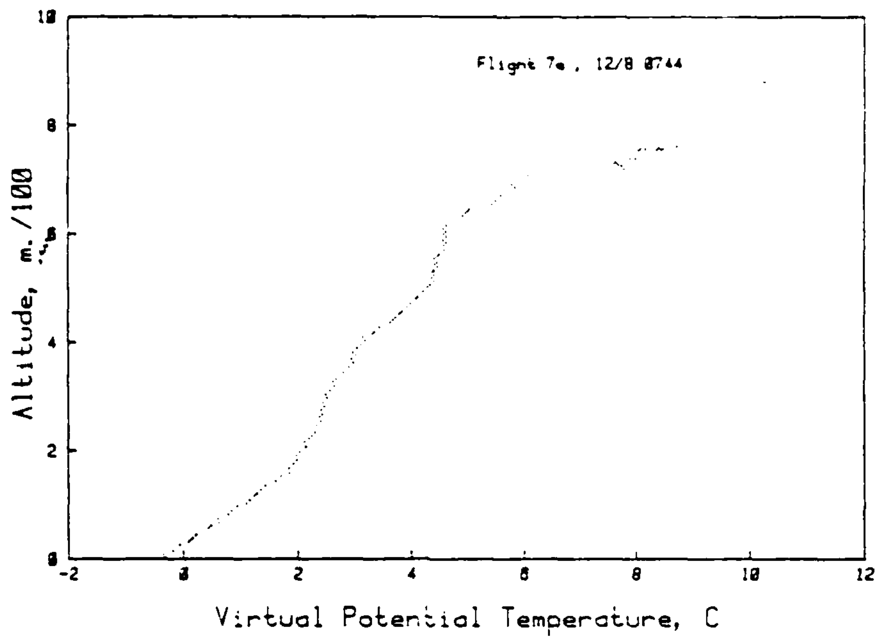

Flight 7b , 12/8 , 0929
Altitude, m./100
Mixing Ratio, gm/kg
0
2
4
6
8
10

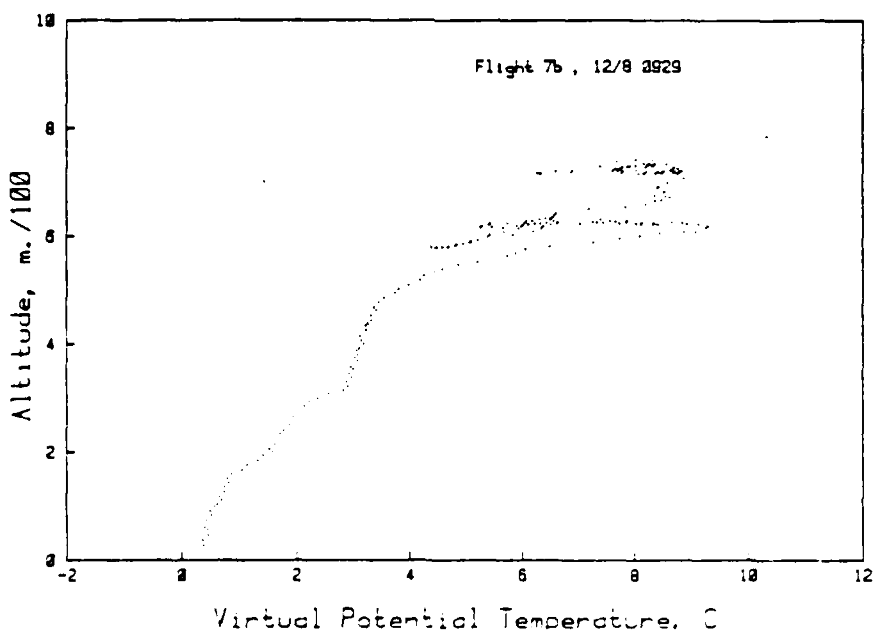

Flight 7a , 12/8,0721
Altitude, m./100
Ozone, PPB
0
2
4
6
8
10
0
20
40
60
80
100

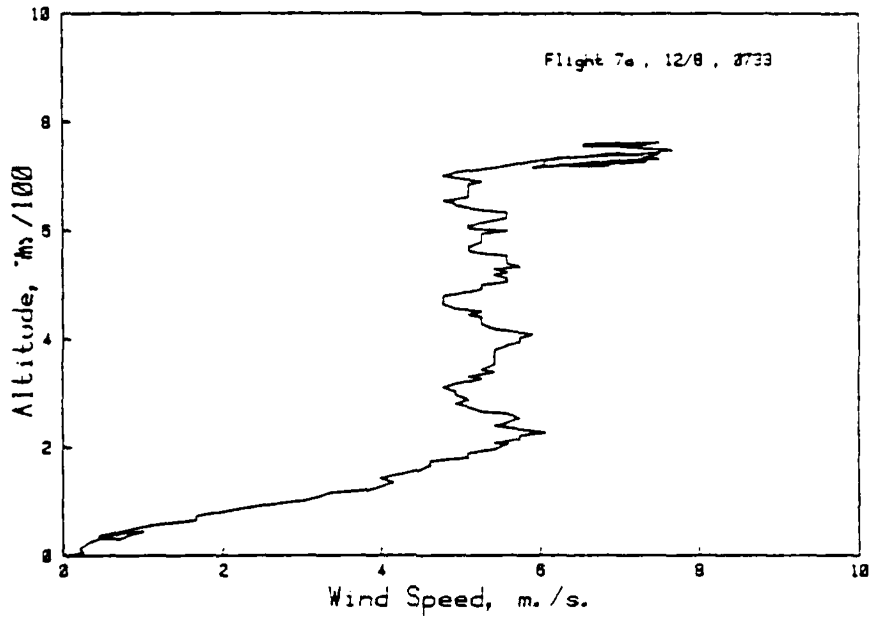

Flight 7b , 12/8,0829
Altitude, m./100
Ozone, PPB
0
2
4
6
8
10
0
20
40
60
80
120


Flight 7a 12/8 , 0733
Altitude, m./100
Log (Scattering Coefficient, 1/km)

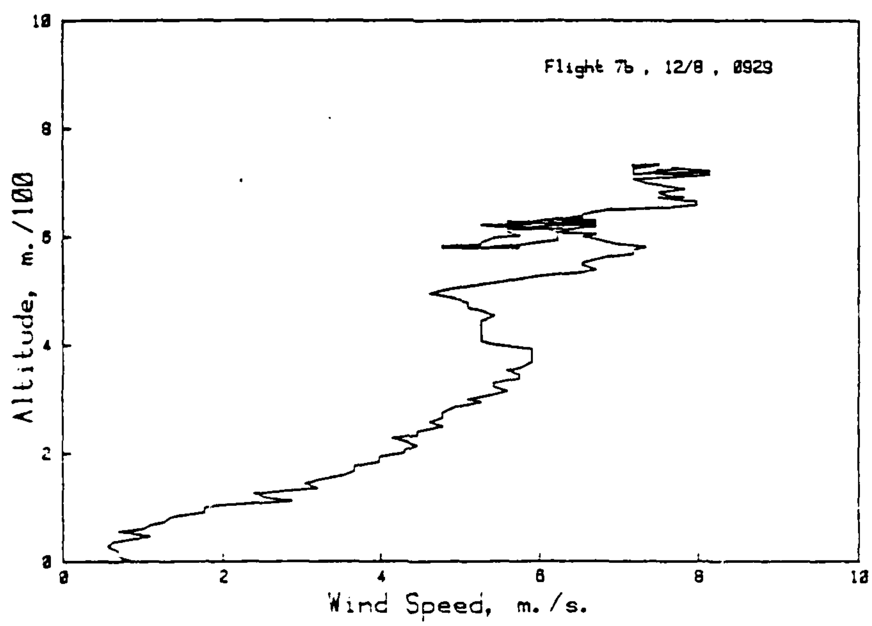

Flight 7b 12/8 , 0935
Altitude, m./100
Log (Scattering Coefficient, 1/km)


Flight 7a , 12/8 0744
Altitude, m./100
Virtual Potential Temperature, C

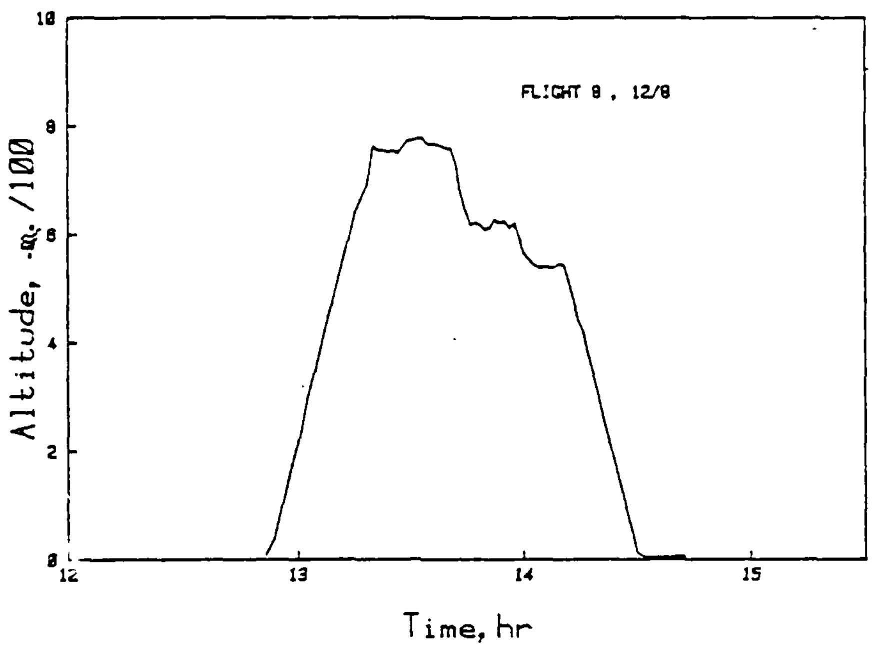

Flight 7b , 12/8 0929
Altitude, m./100
Virtual Potential Temperature, C



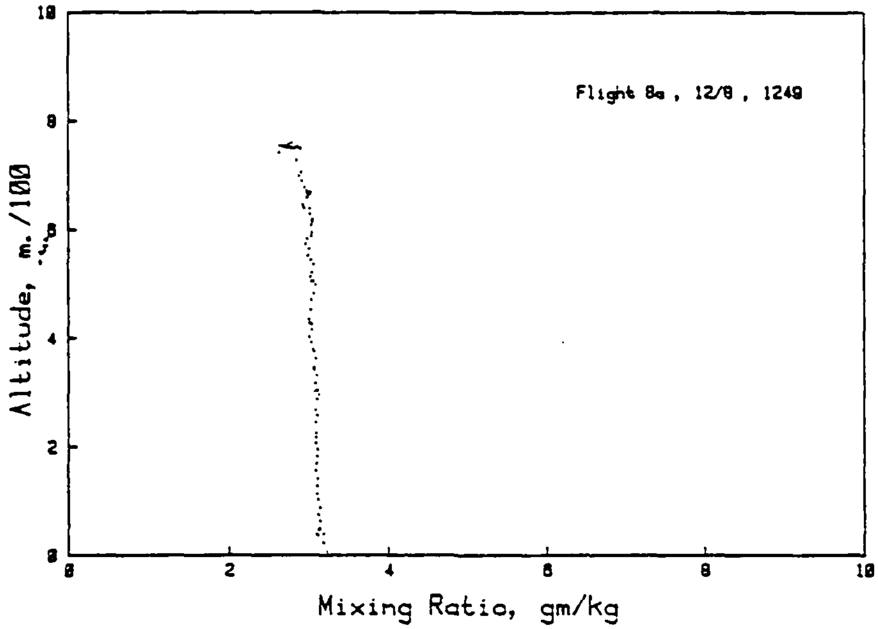
Flight 7a , 12/8 , 0733
Altitude, m./100
Wind Speed, m./s.

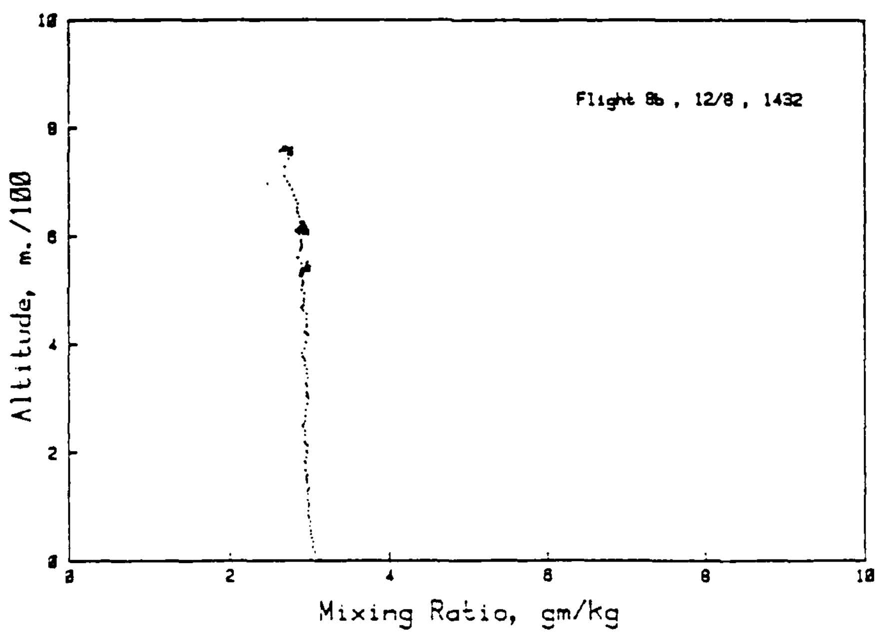


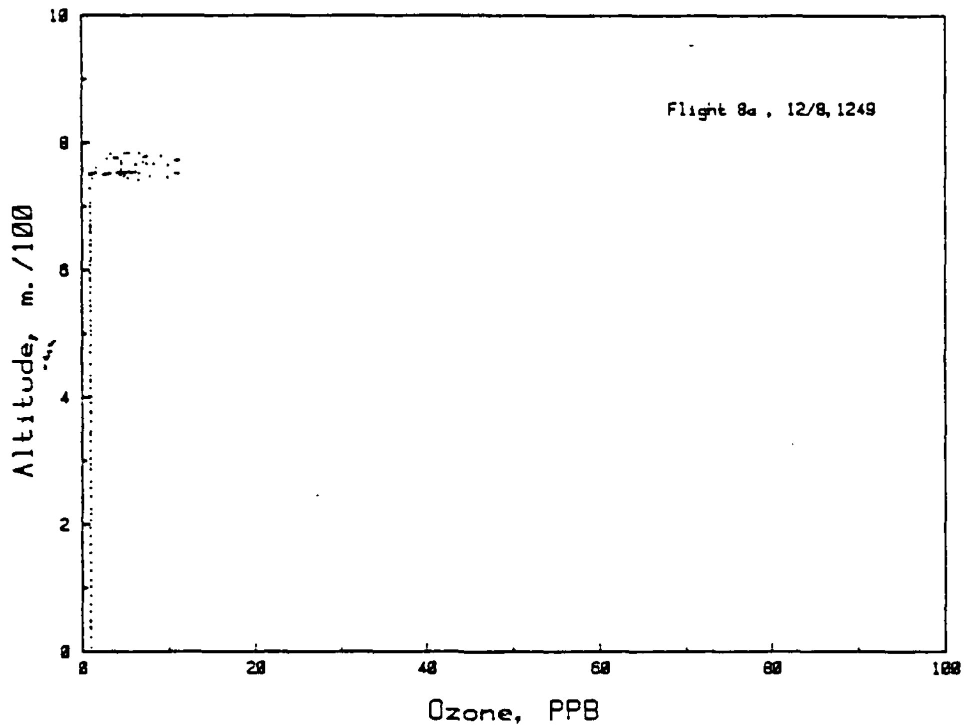
Flight 7b , 12/8 , 0929
Altitude, m./100
Wind Speed, m./s.

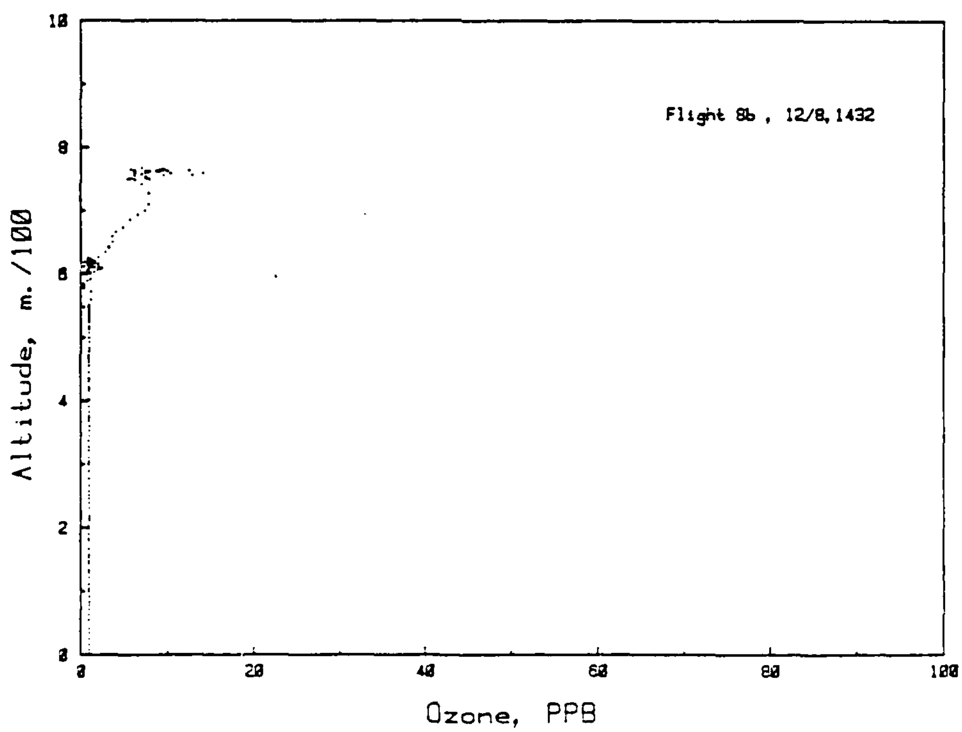


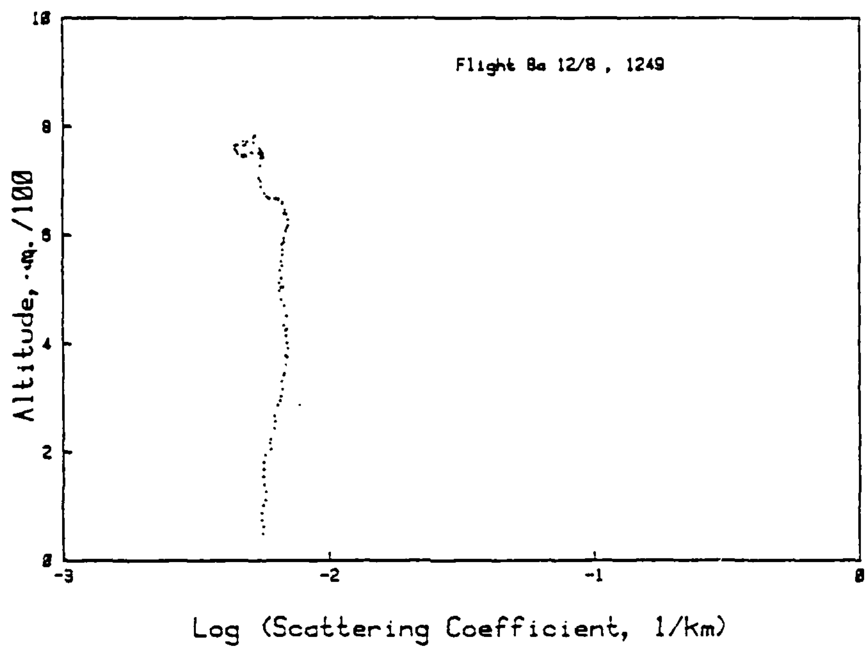
FLIGHT 8 , 12/8
Altitude, m /100
Time, hr
10
8
6
4
2
0
12
13
14
15

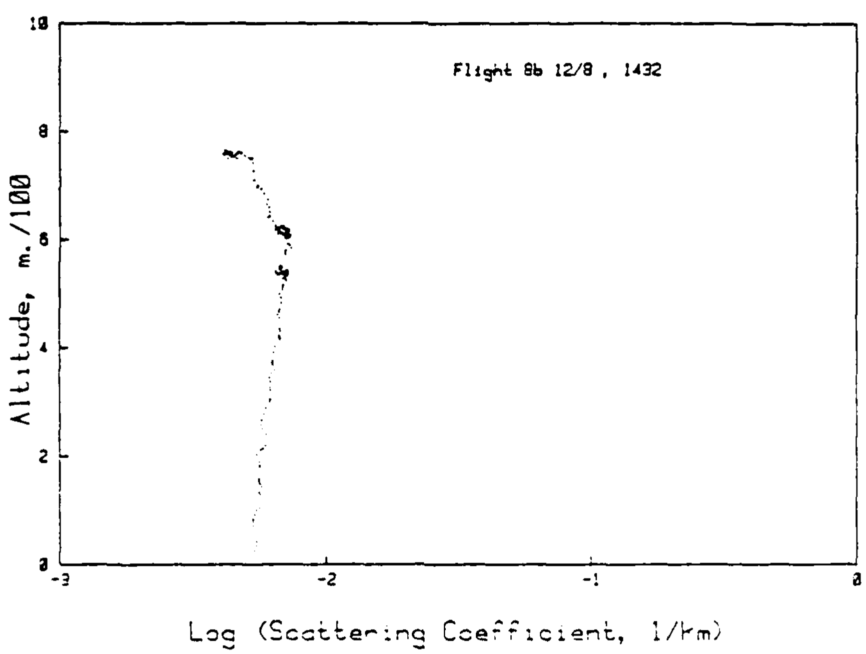

Flight 8a , 12/8 , 1249
Altitude, m./100
Mixing Ratio, gm/kg

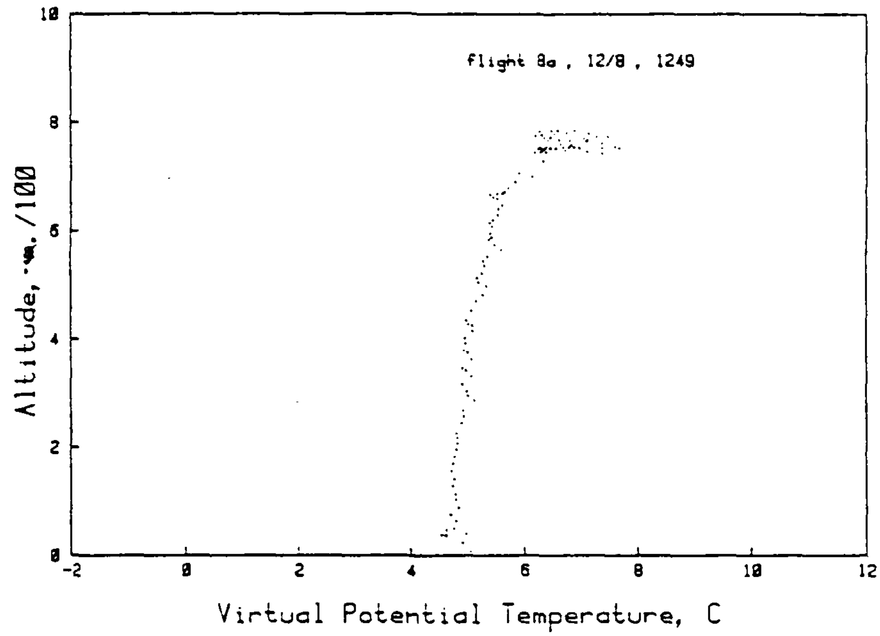

Flight 8b , 12/8 , 1432
Altitude, m./100
Mixing Ratio, gm/kg


Flight 8a , 12/8, 1249
Altitude, m./100
Ozone, PPB
0
2
4
6
8
10
20
40
60
80
100

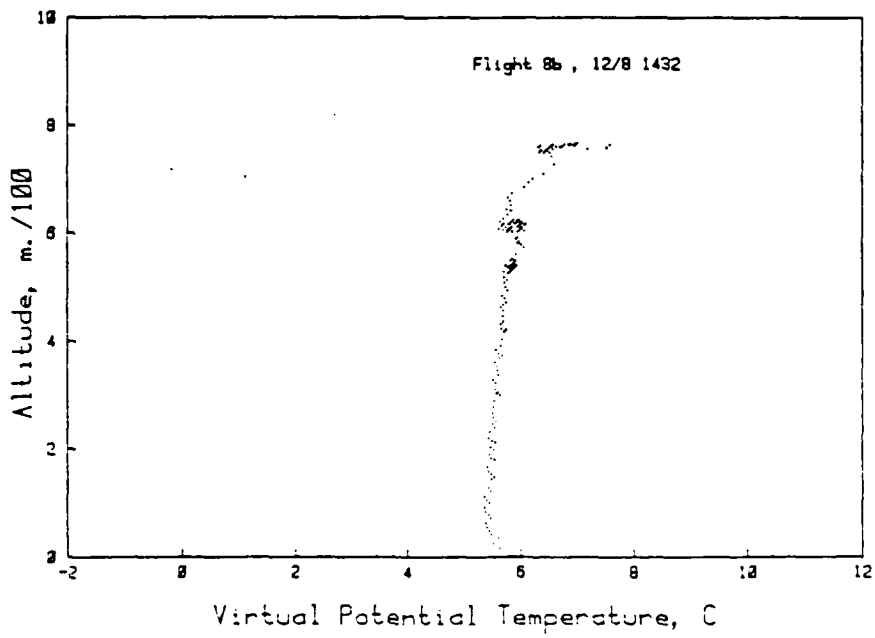

Flight 8b , 12/8, 1432
Altitude, m./100
Ozone, PPB
0
2
4
6
8
10
20
40
60
80
100


Flight 8a 12/8 , 1249
Altitude, m./100
Log (Scattering Coefficient, 1/km)
10
8
6
4
2
0
-3
-2
-1
0

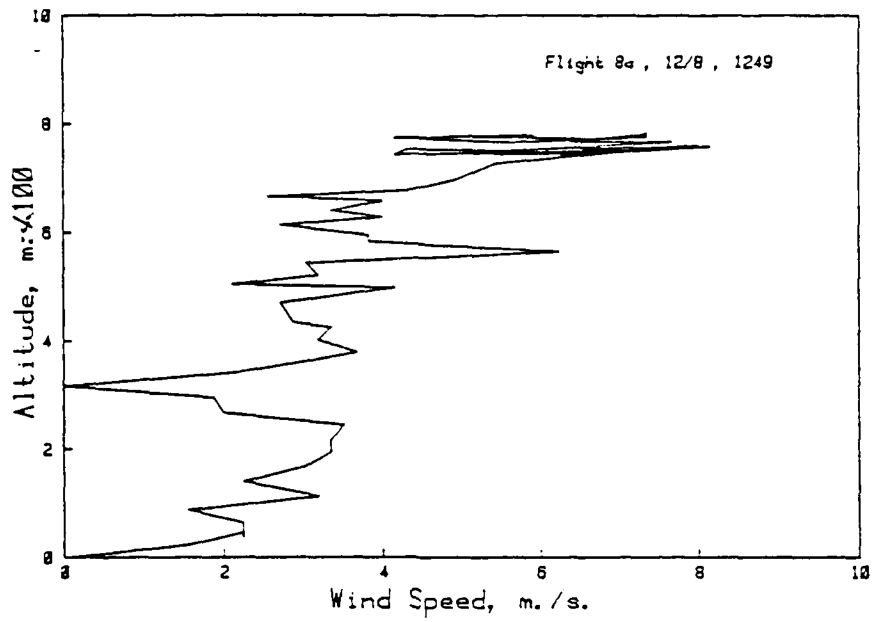

Flight 8b 12/8 , 1432
Altitude, m./100
Log (Scattering Coefficient, 1/km)
10
8
6
4
2
0
-3
-2
-1
0



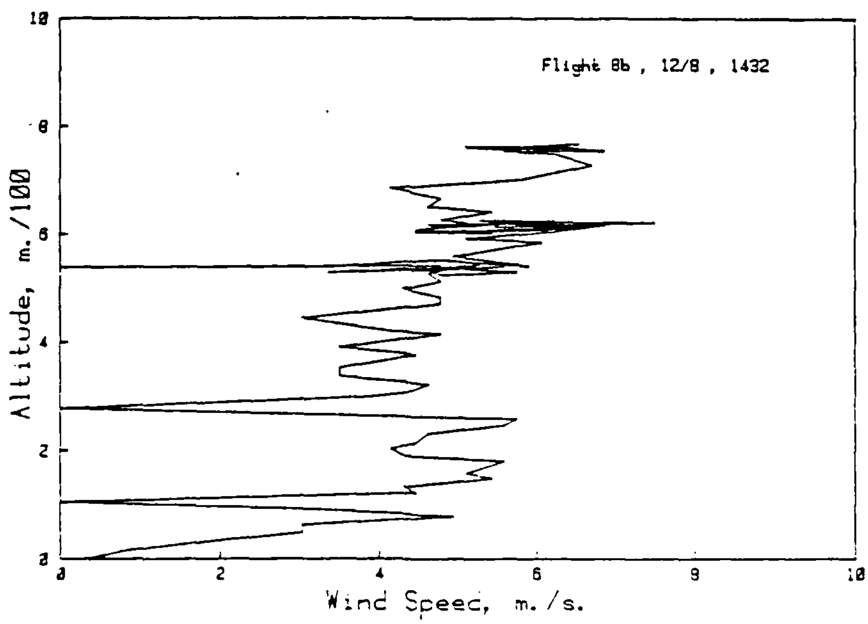
flight 8a , 12/8 , 1249
Altitude, m./100
Virtual Potential Temperature, C



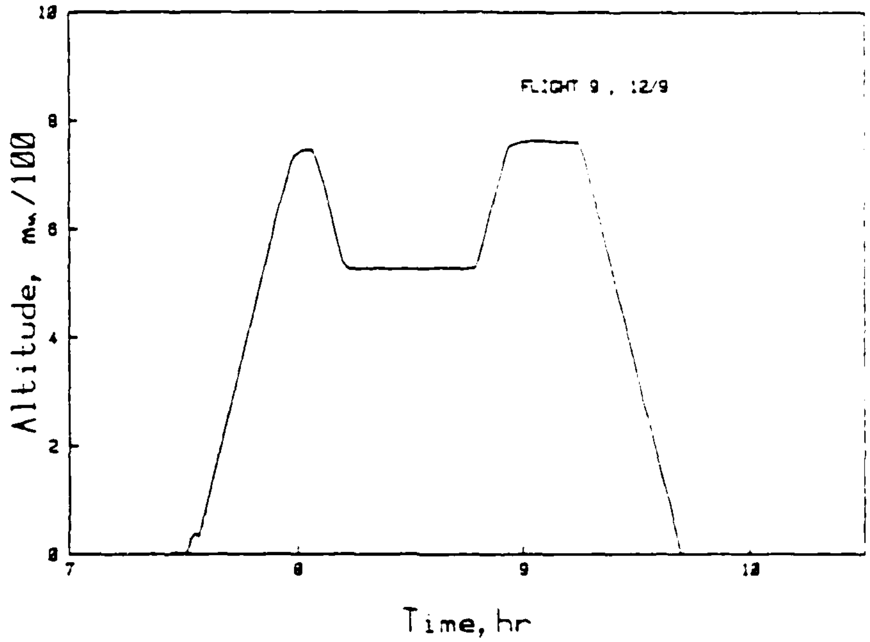
Flight 8b , 12/8 1432
Altitude, m./100
Virtual Potential Temperature, C

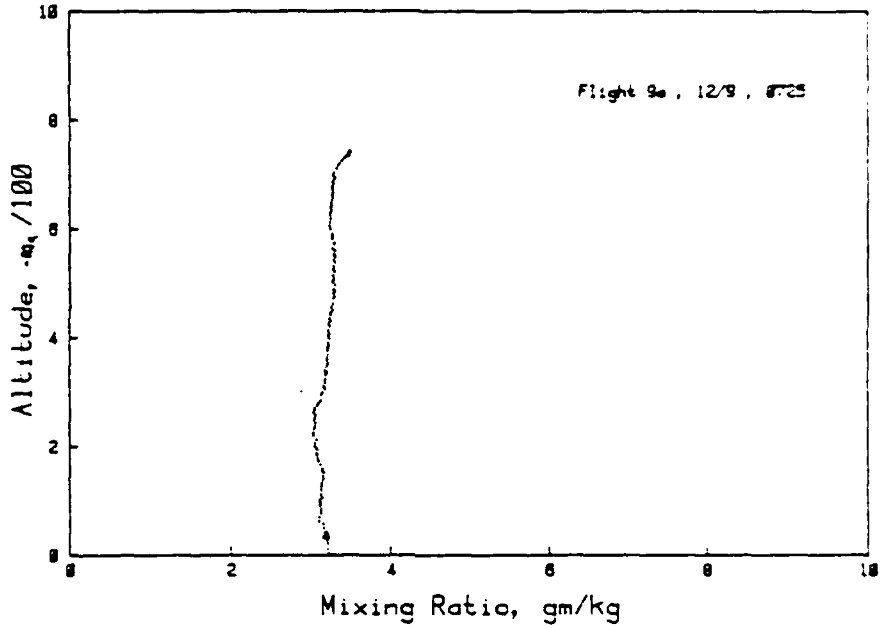


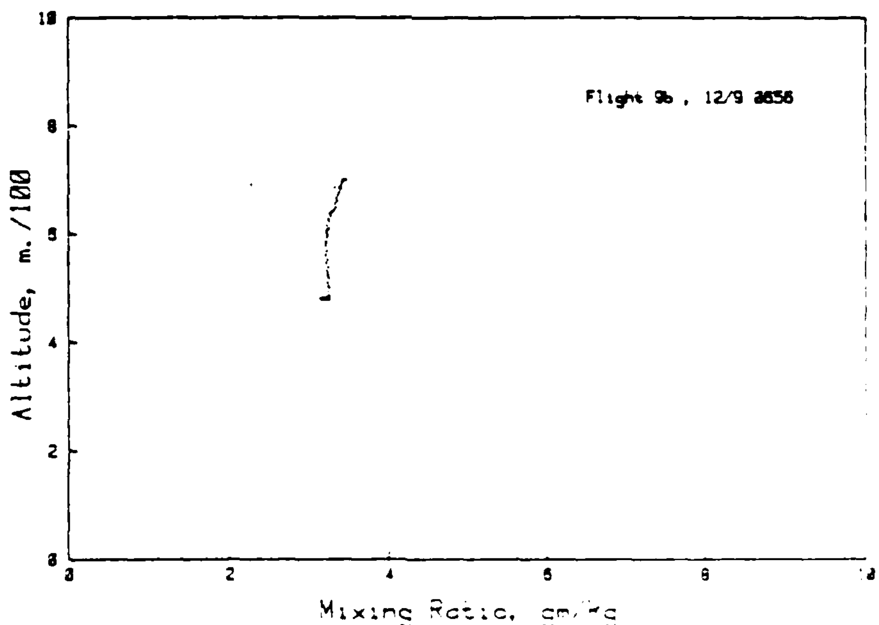
Flight 8a , 12/8 , 1249
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10

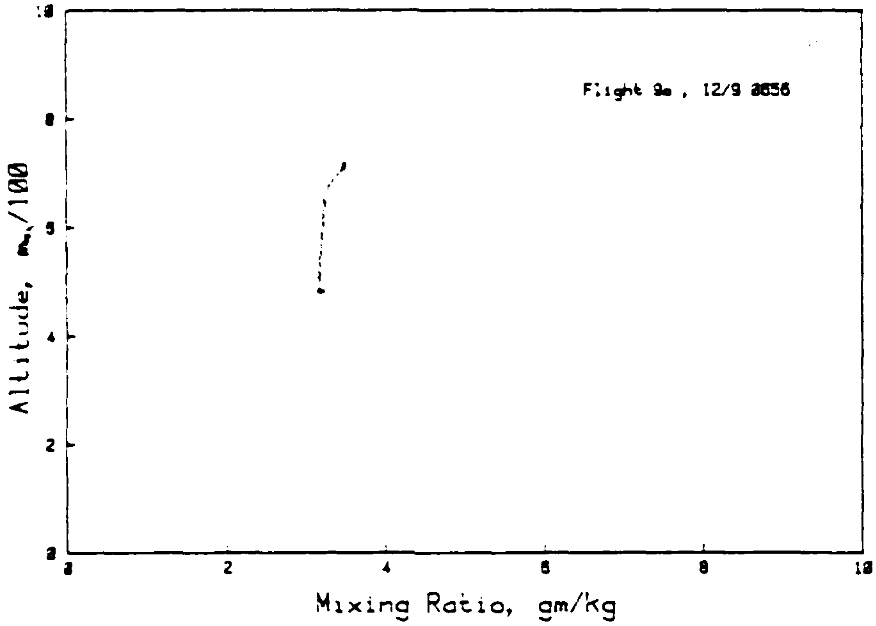


Flight 8b , 12/8 , 1432
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10

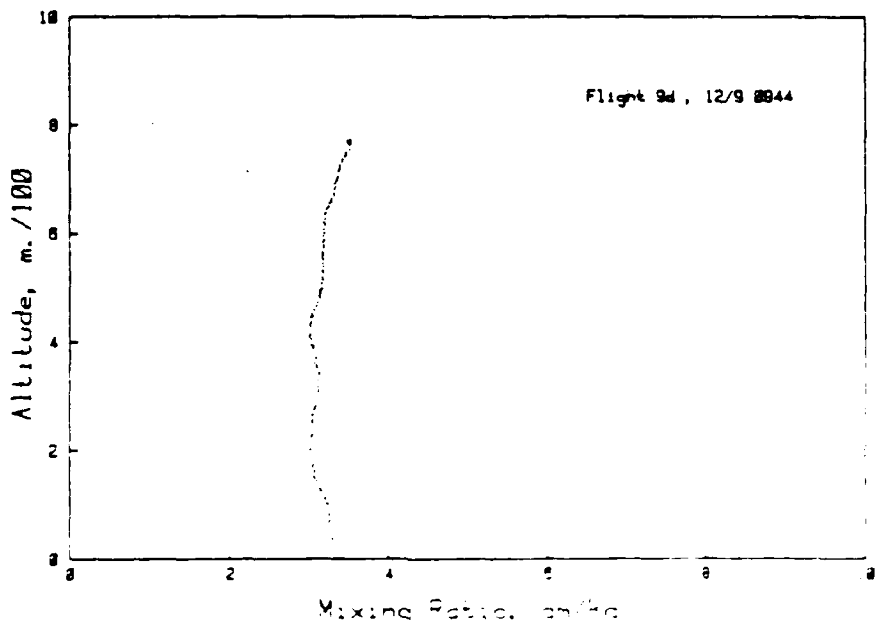

FLIGHT 9 , 12/9
Altitude, m./100
Time, hr
10
8
6
4
2
0
7
8
9
10


Flight 9a , 12/9 , 0725
Altitude, m./100
Mixing Ratio, gm/kg
0
2
4
6
8
10

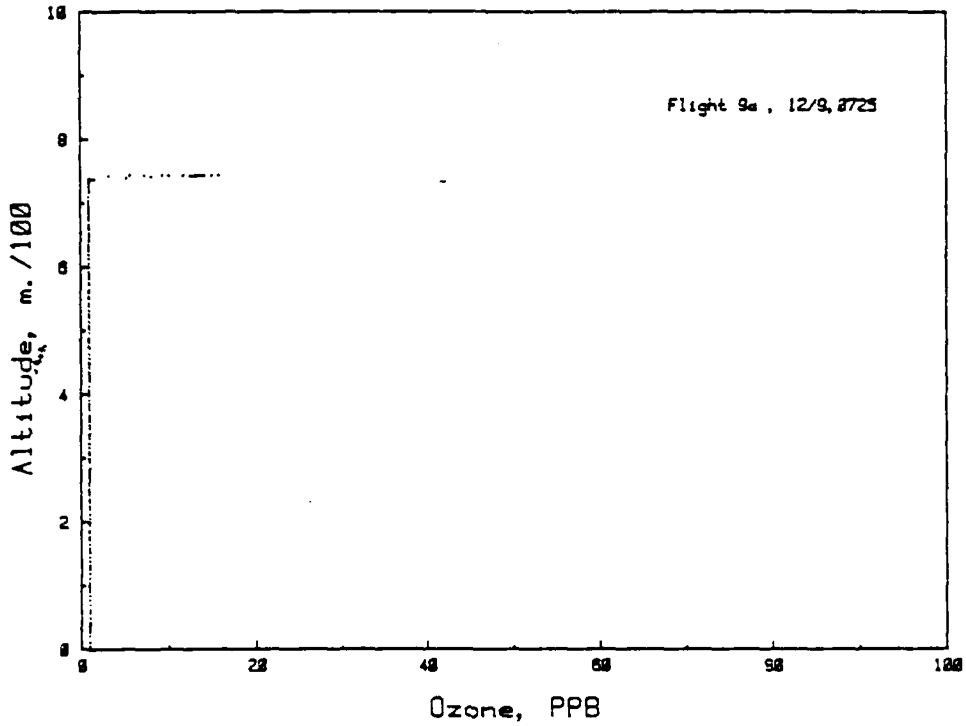

Flight 9b , 12/9 0856
Altitude, m./100
Mixing Ratio, gm/kg
0
2
4
6
8
10



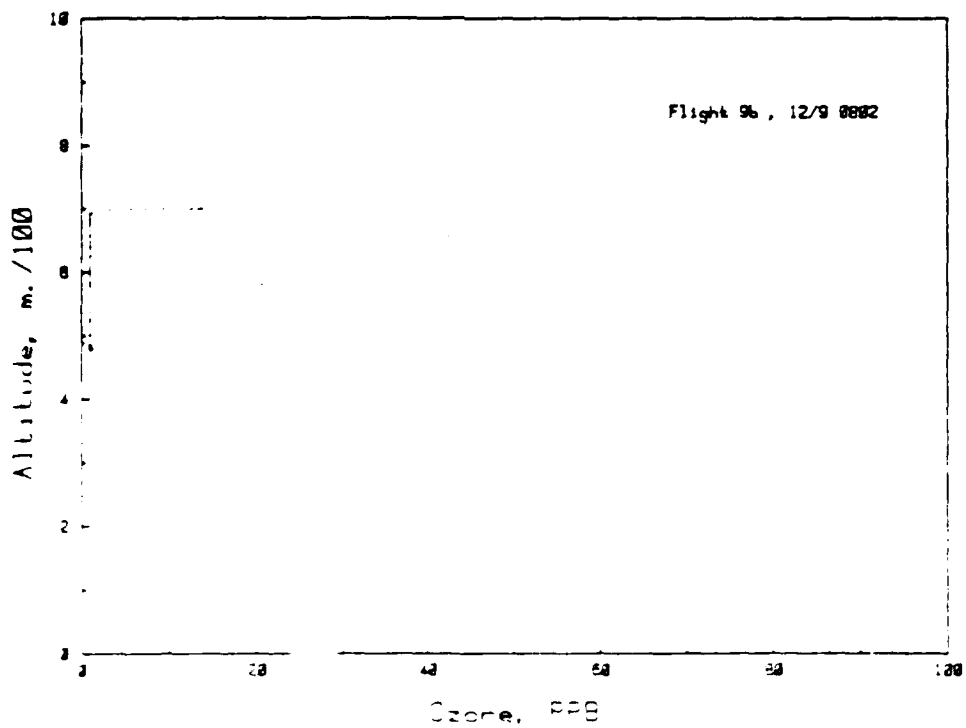
Flight 9e , 12/9 0056
Altitude, m./100
Mixing Ratio, gm/kg



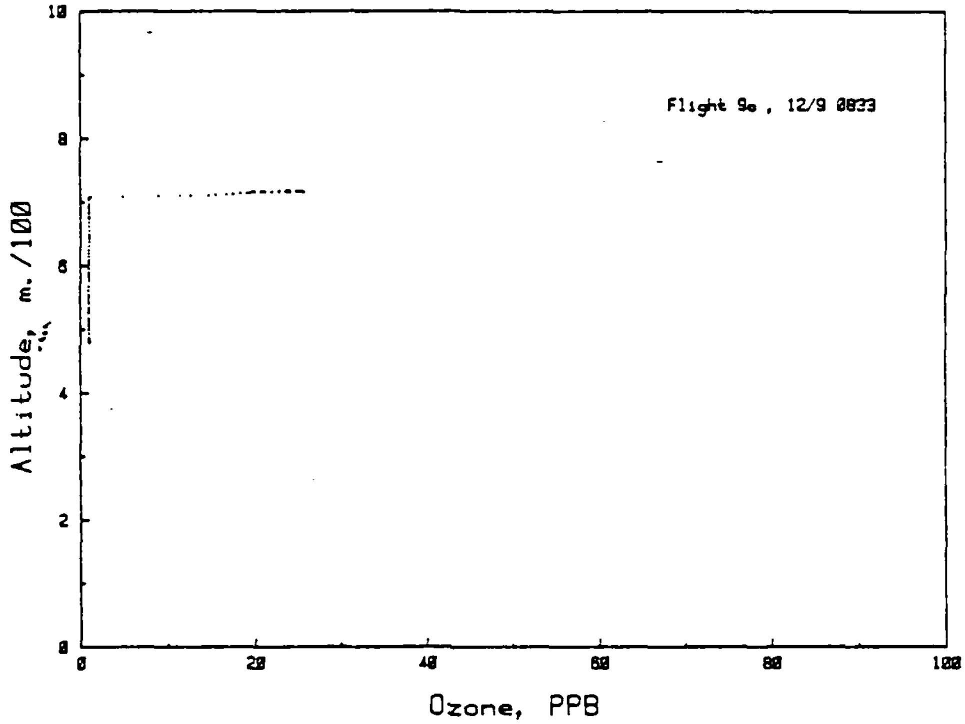
Flight 9d , 12/9 0044
Altitude, m./100

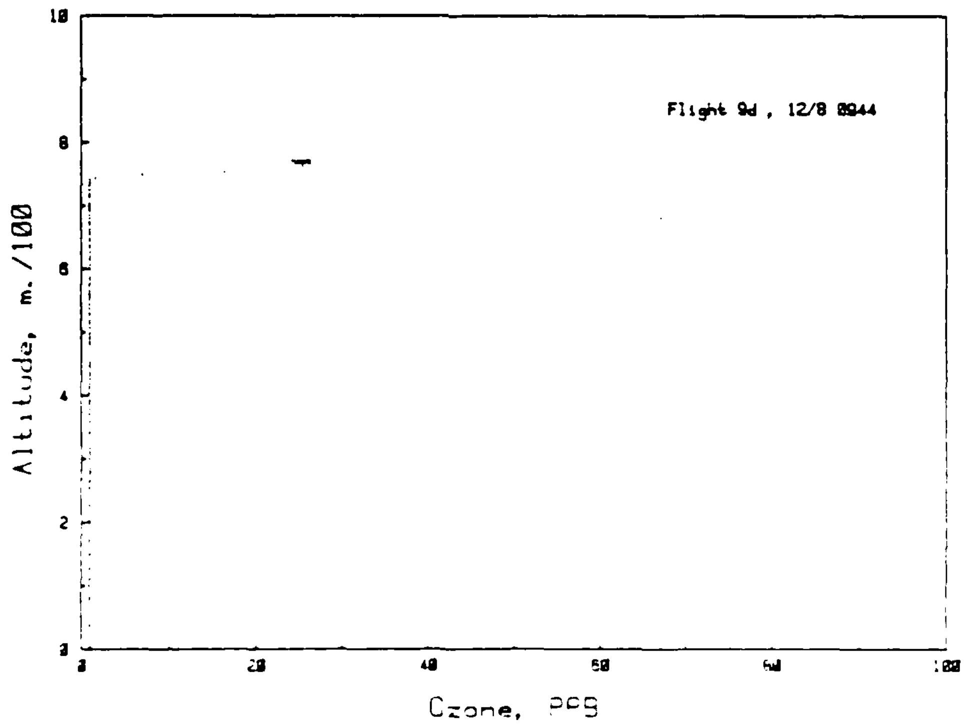


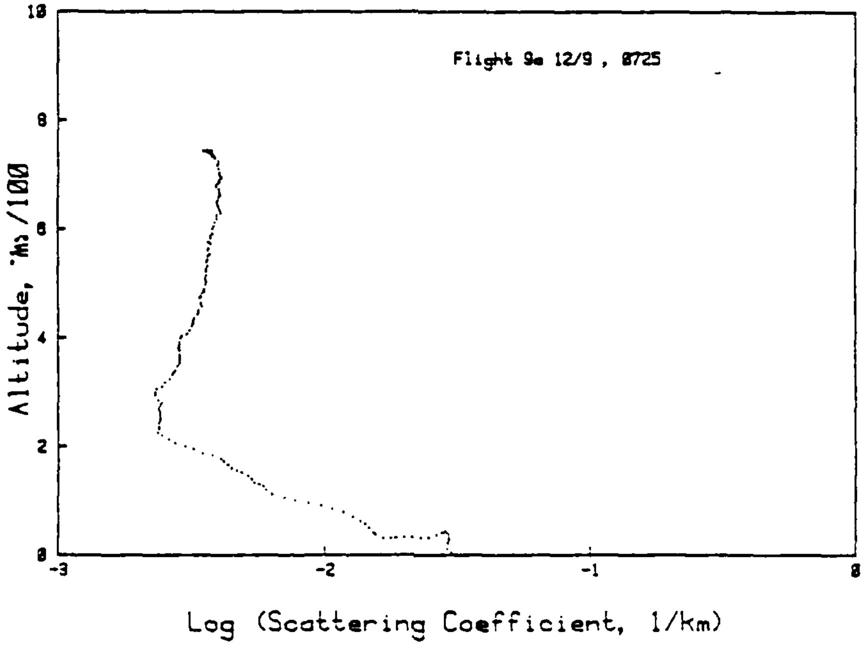
Flight 9a , 12/9, 0725
Altitude, m./100
Ozone, PPB

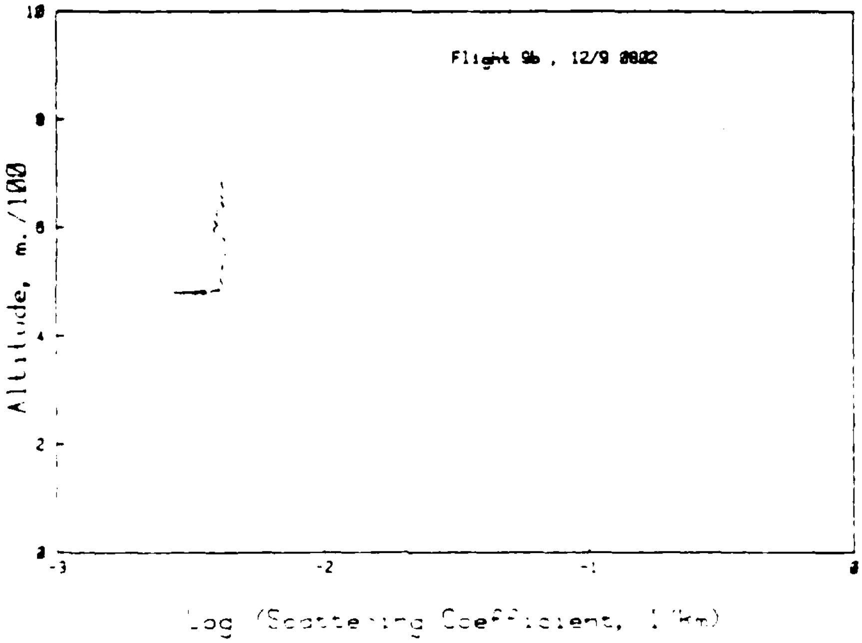


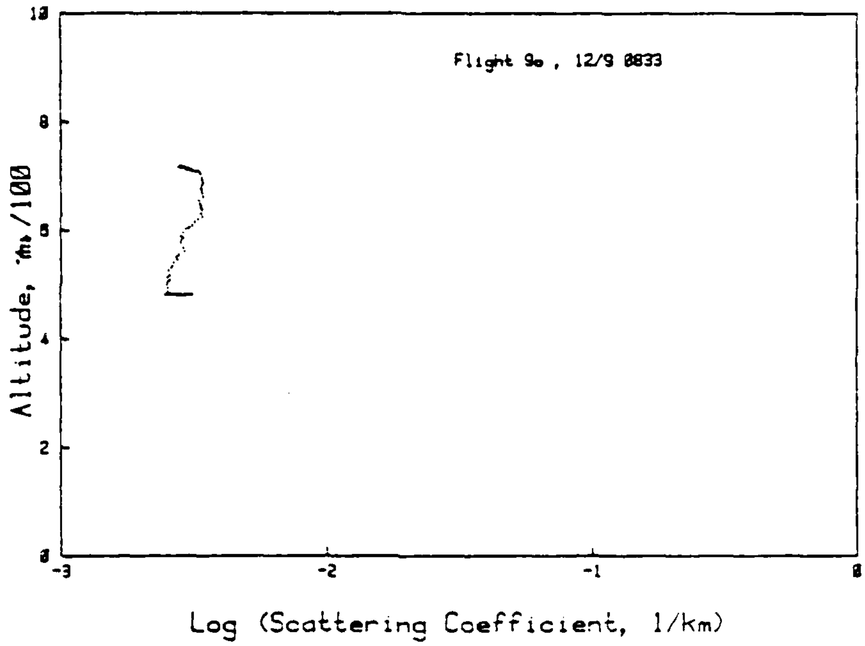
Flight 9b , 12/9 0802
Altitude, m./100
Ozone, PPB

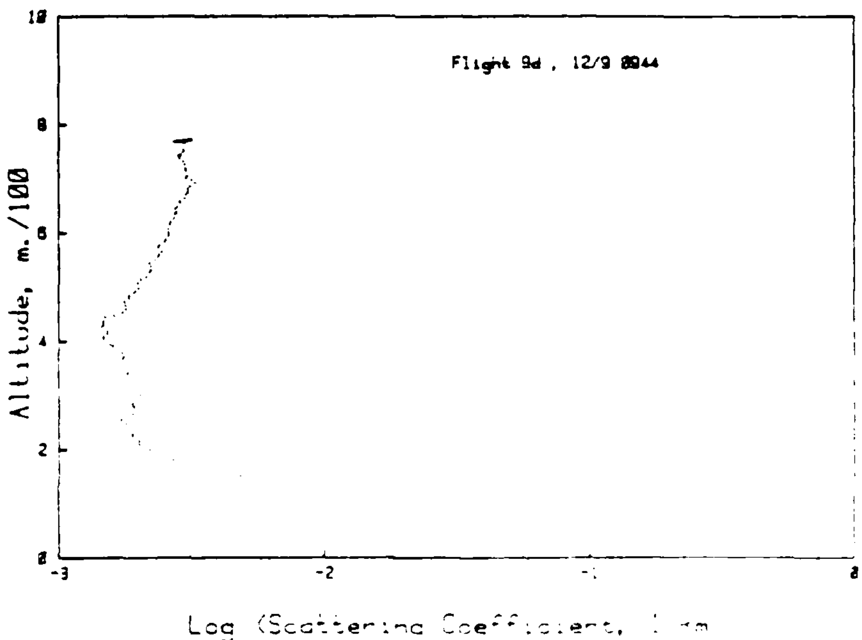

Flight 9c , 12/9 0833
Altitude, m./100
Ozone, PPB

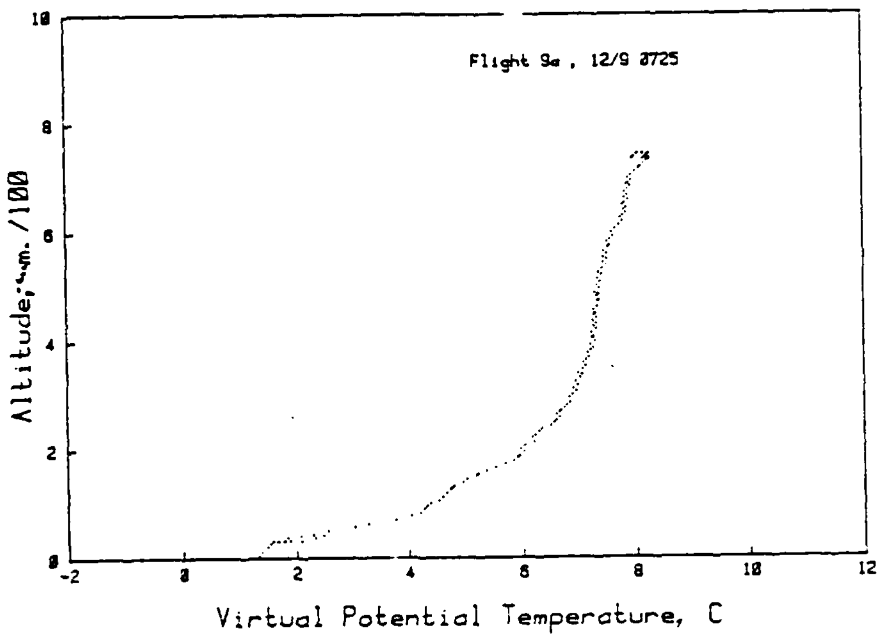

Flight 9d , 12/8 0944
Altitude, m./100
Ozone, PPB

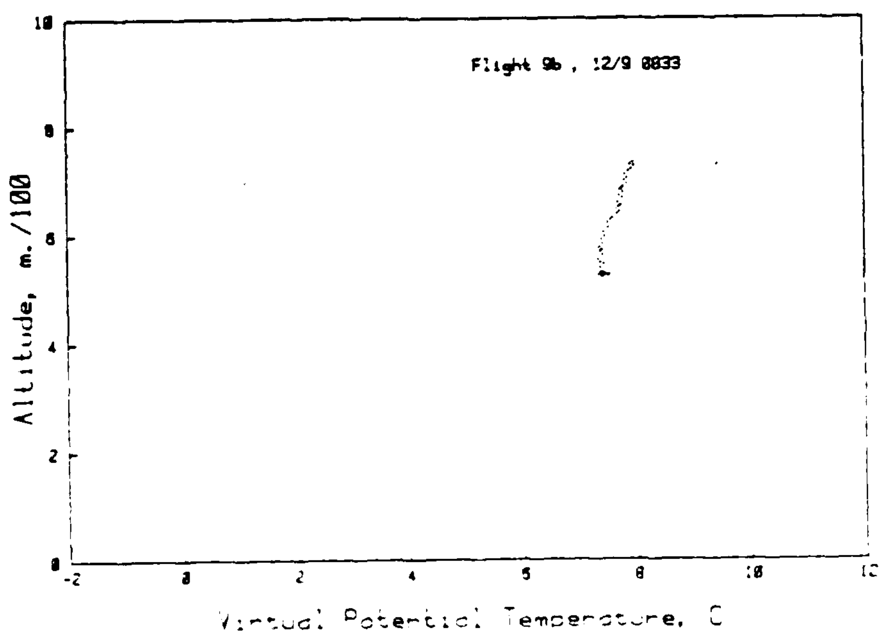

Flight 9a 12/9 , 0725
Altitude, m/100
Log (Scattering Coefficient, 1/km)

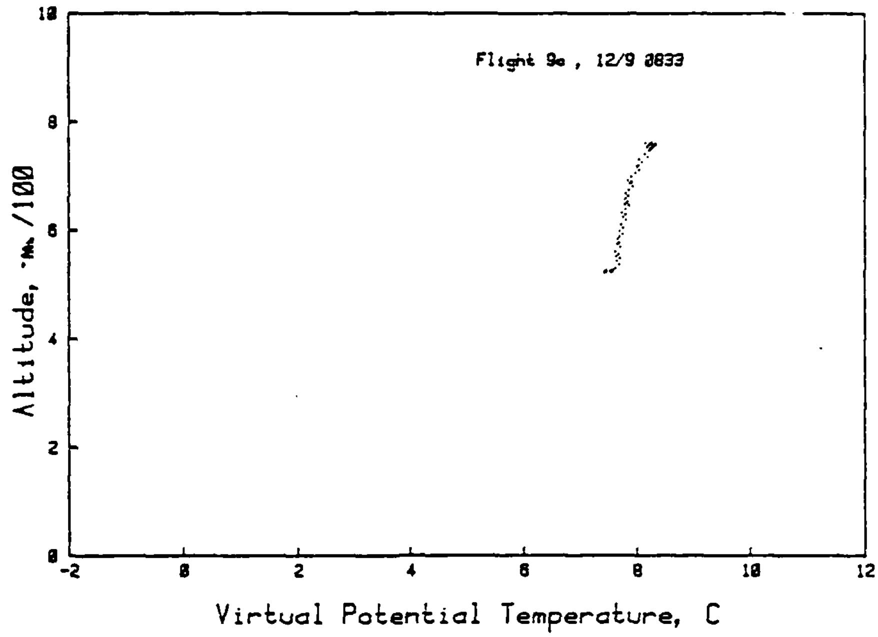

Flight 9b , 12/9 0802
Altitude, m./100
Log (Scattering Coefficient, 1/km)


Flight 9c , 12/9 0833
Altitude, m./100
Log (Scattering Coefficient, 1/km)

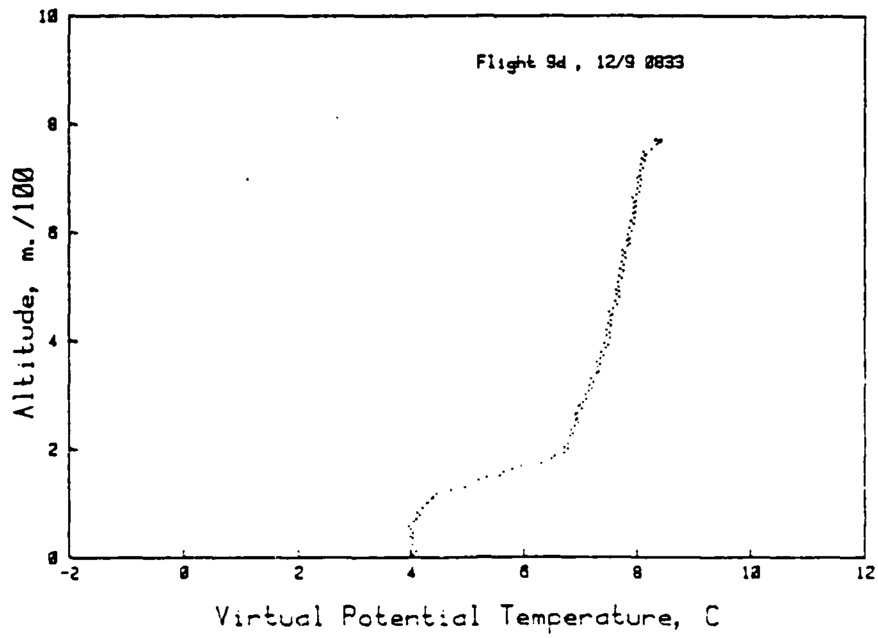

Flight 9d , 12/9 0844
Altitude, m./100


Flight 9a , 12/9 0725
Altitude, m./100
Virtual Potential Temperature, C
-2
0
2
4
6
8
10
12

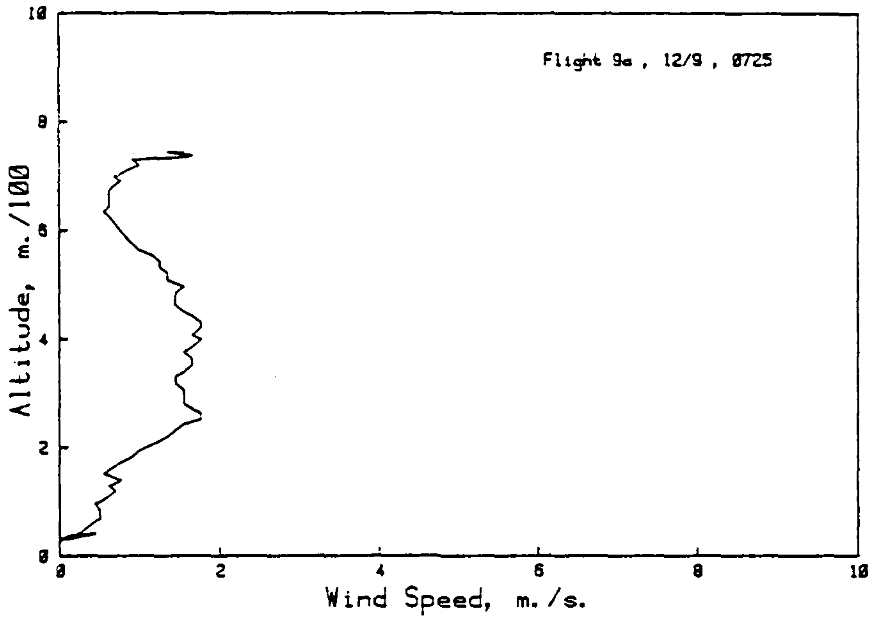

Flight 9b , 12/9 0833
Altitude, m./100
Virtual Potential Temperature, C

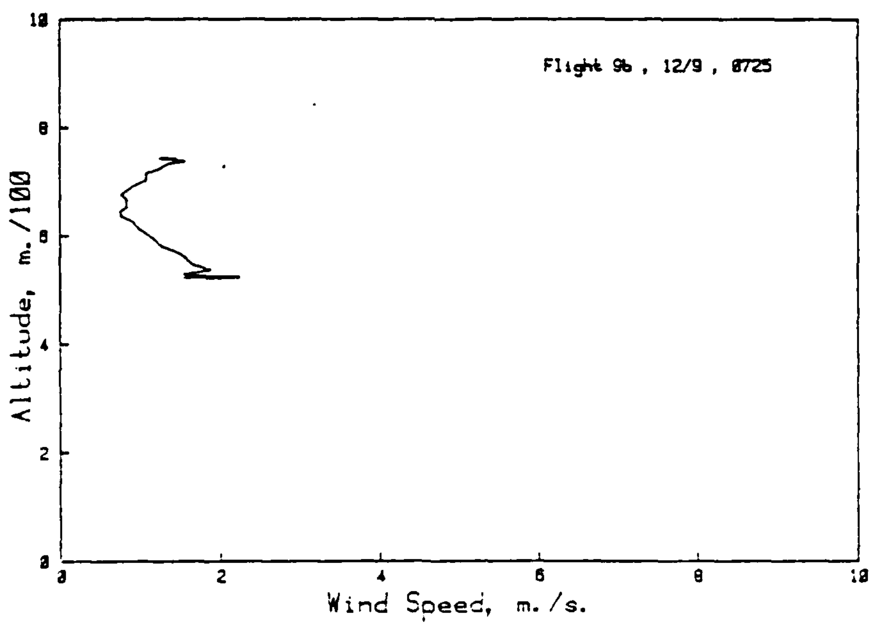


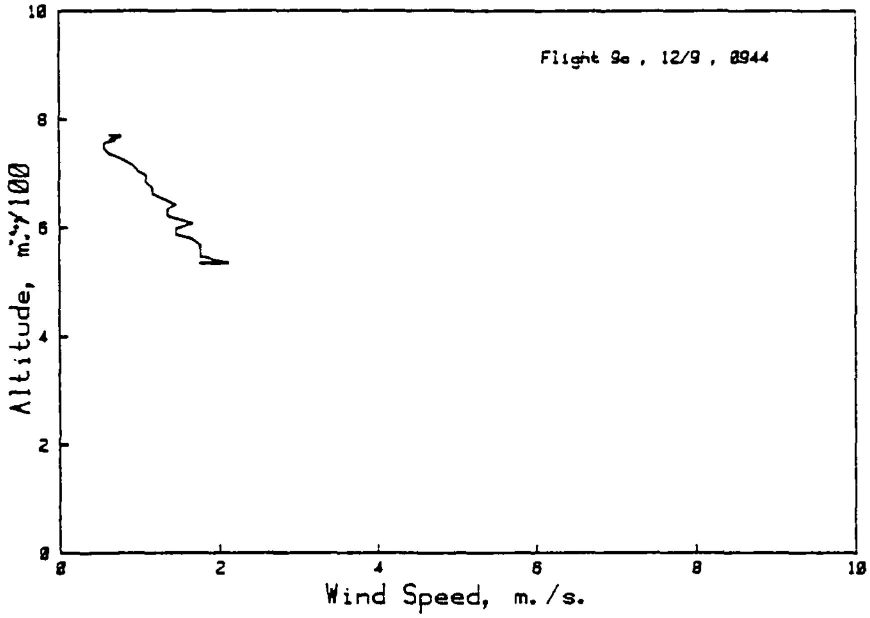
Flight 9c , 12/9 0833
Altitude, m./100
Virtual Potential Temperature, C

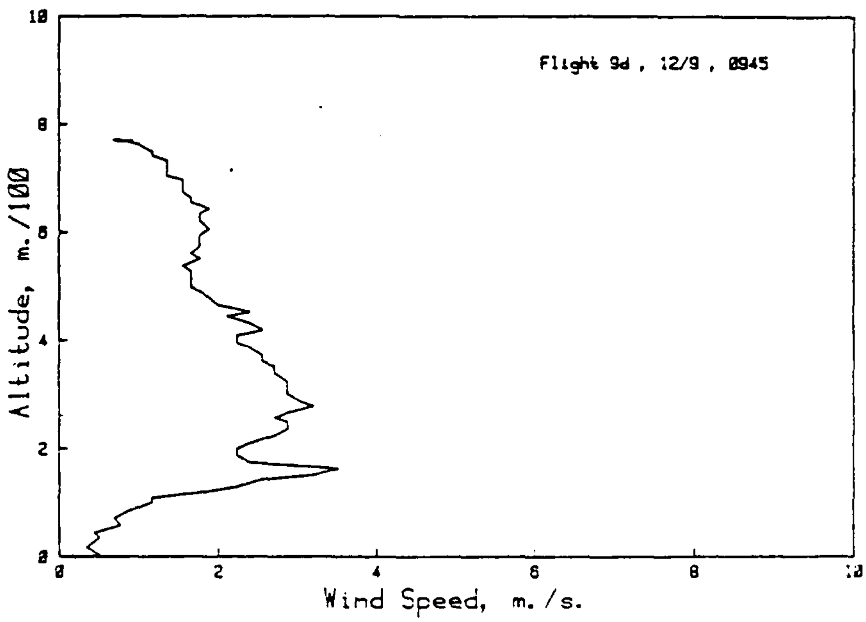


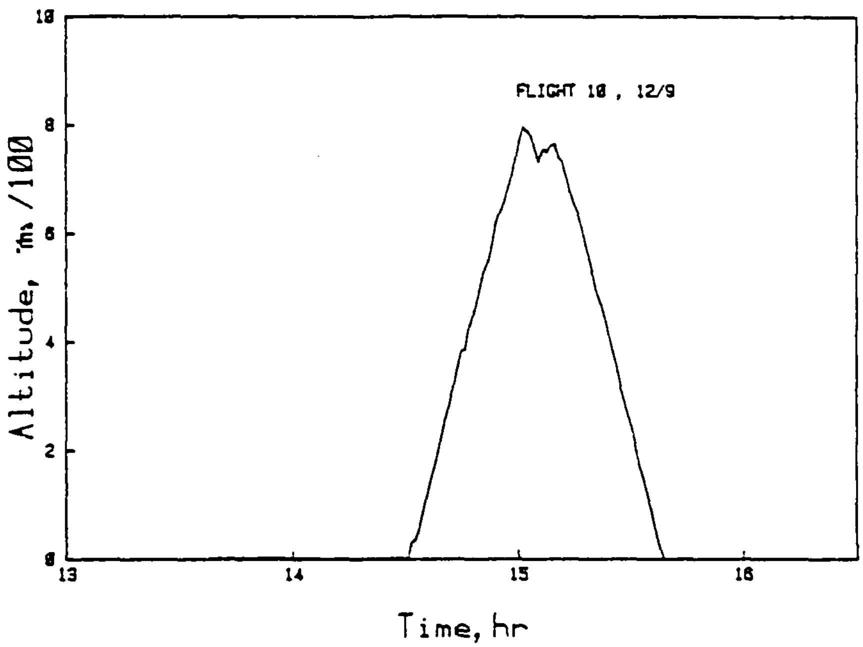
Flight 9d , 12/9 0833
Altitude, m./100
Virtual Potential Temperature, C

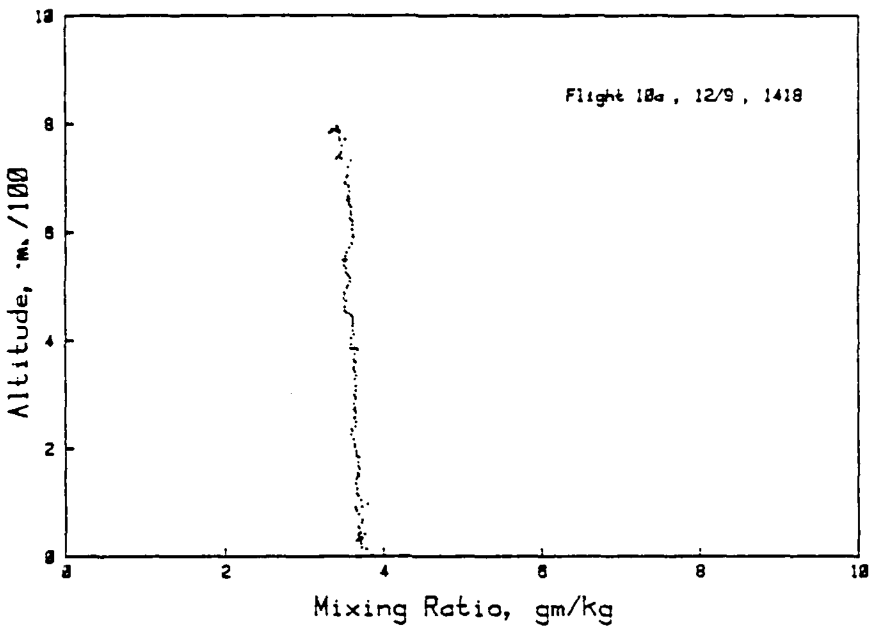

Flight 9a , 12/9 , 0725
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10

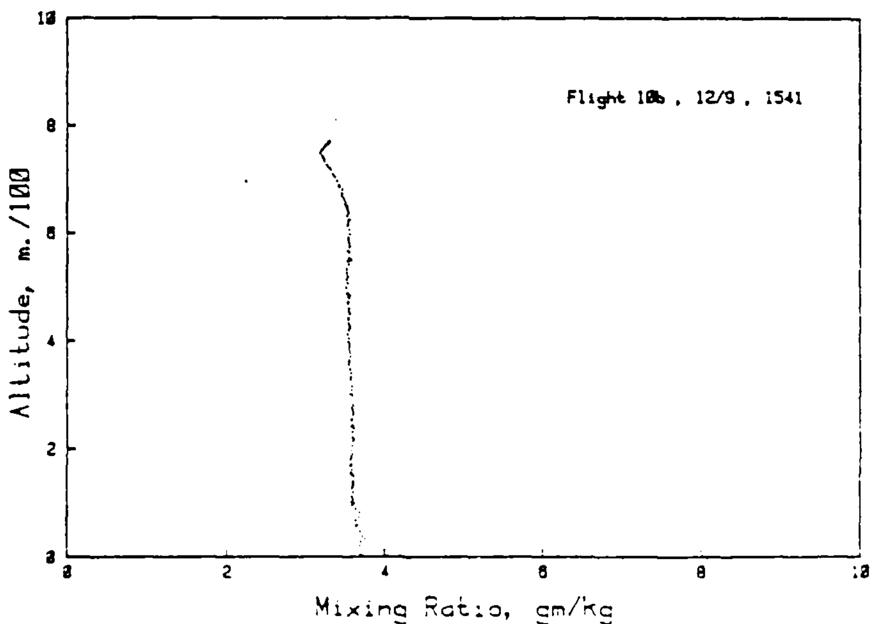

Flight 9b , 12/9 , 0725
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10

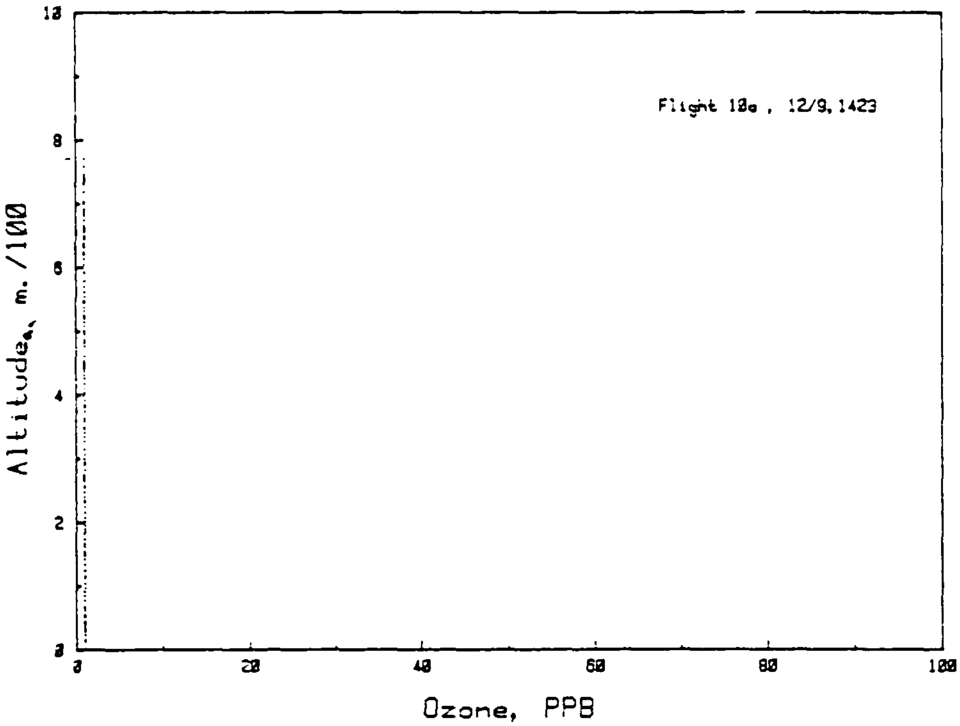

Flight 9c , 12/9 , 0944
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10


Flight 9d , 12/9 , 0945
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10

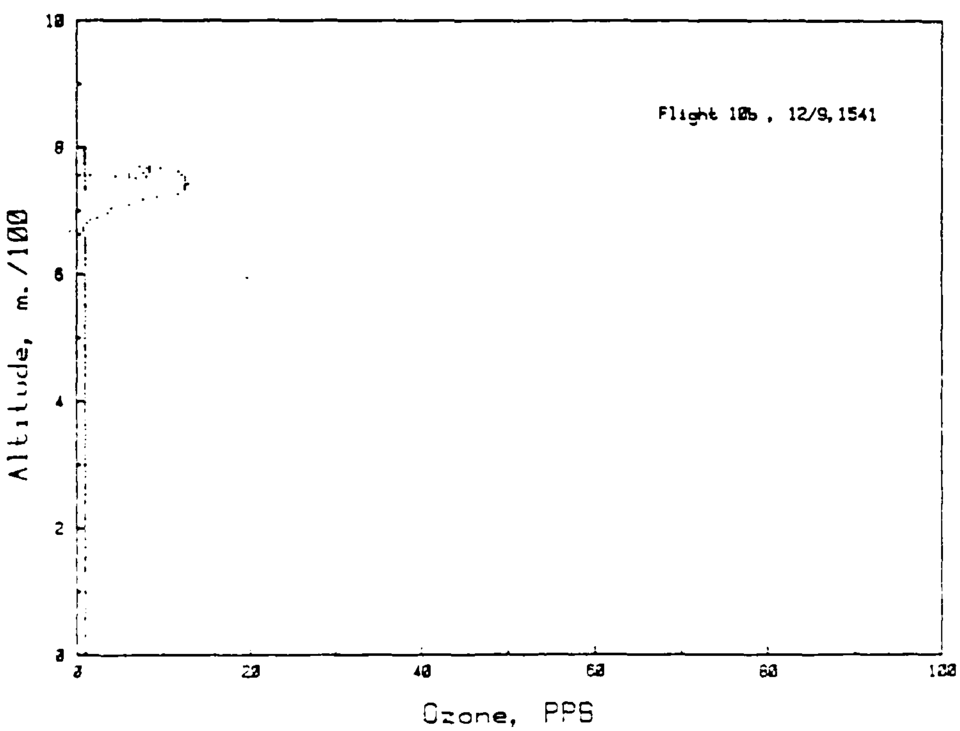

FLIGHT 10 , 12/9
Altitude, m /100
Time, hr


Flight 10a , 12/9 , 1418
Altitude, m./100
Mixing Ratio, gm/kg

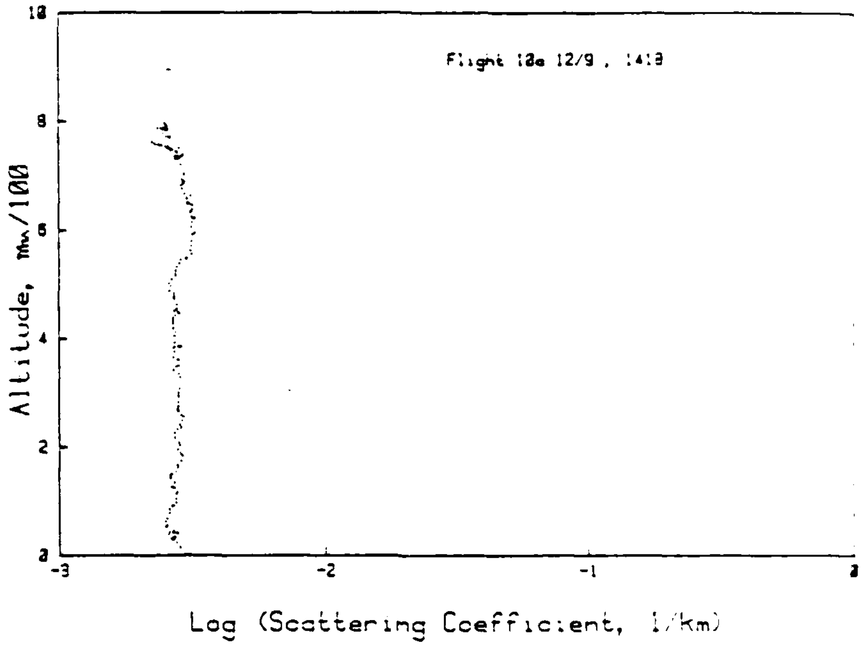

Flight 10b , 12/9 , 1541
Altitude, m./100
Mixing Ratio, gm/kg

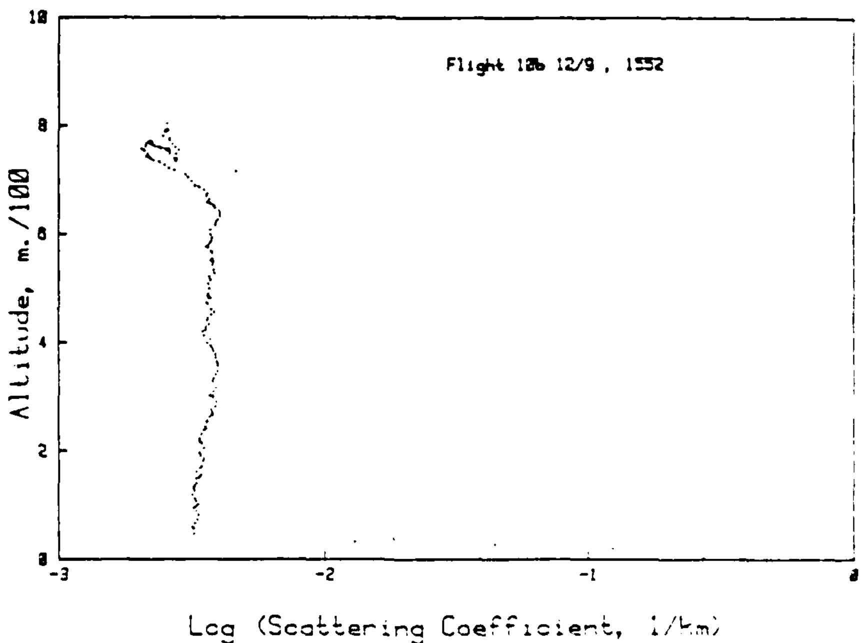


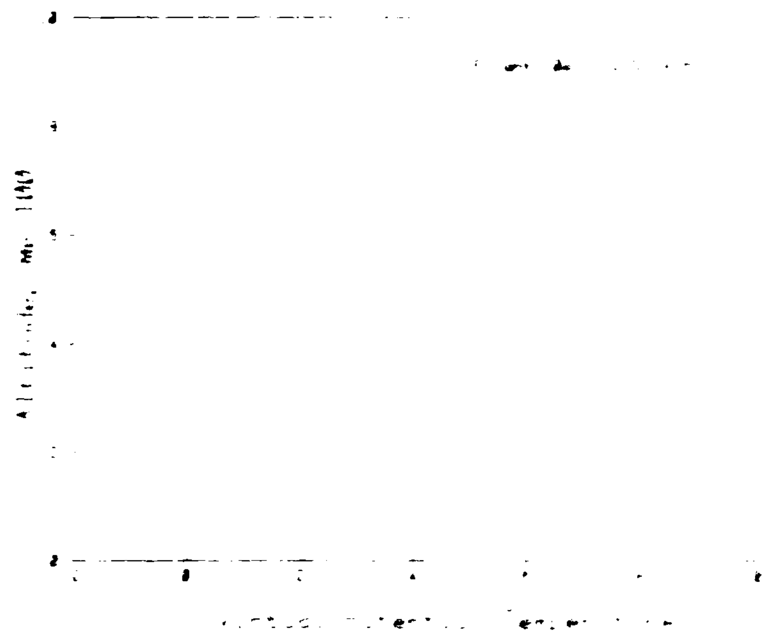
Flight 10a , 12/9, 1423
Altitude, m. /100
Ozone, PPB

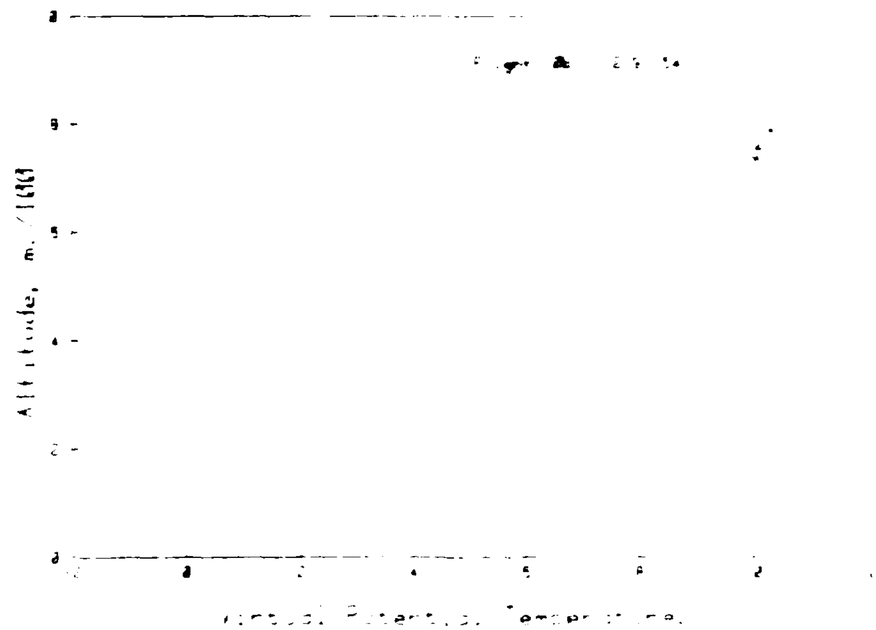


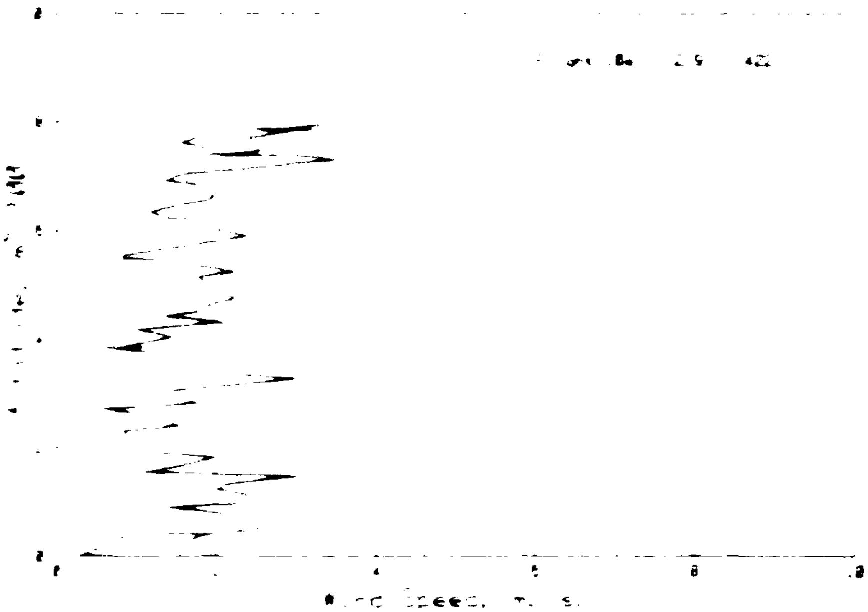
Flight 10b , 12/9, 1541
Altitude, m. /100
Ozone, PPB

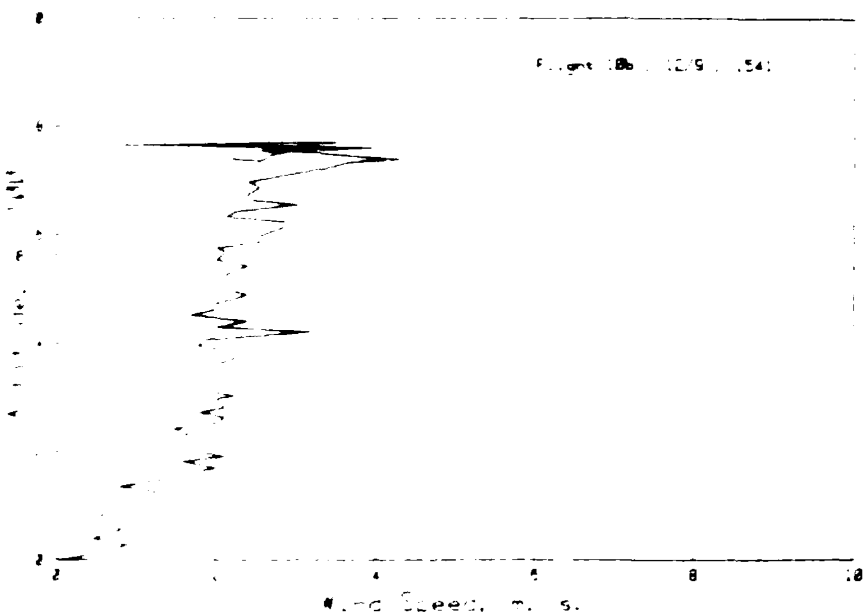

Flight 10a 12/9 , 1419
Altitude, m./100
Log (Scattering Coefficient, 1/km)

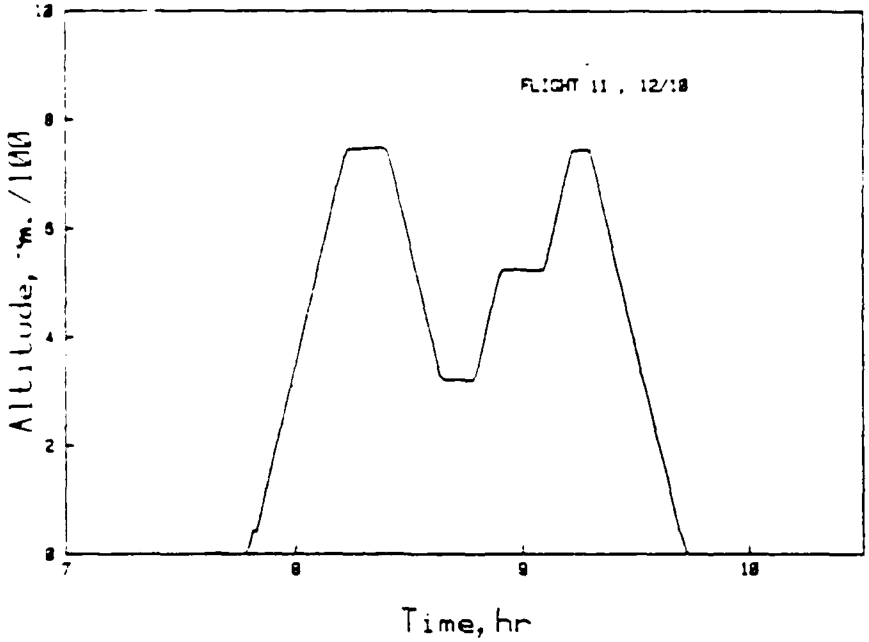

Flight 10b 12/9 , 1552
Altitude, m./100
Log (Scattering Coefficient, 1/km)

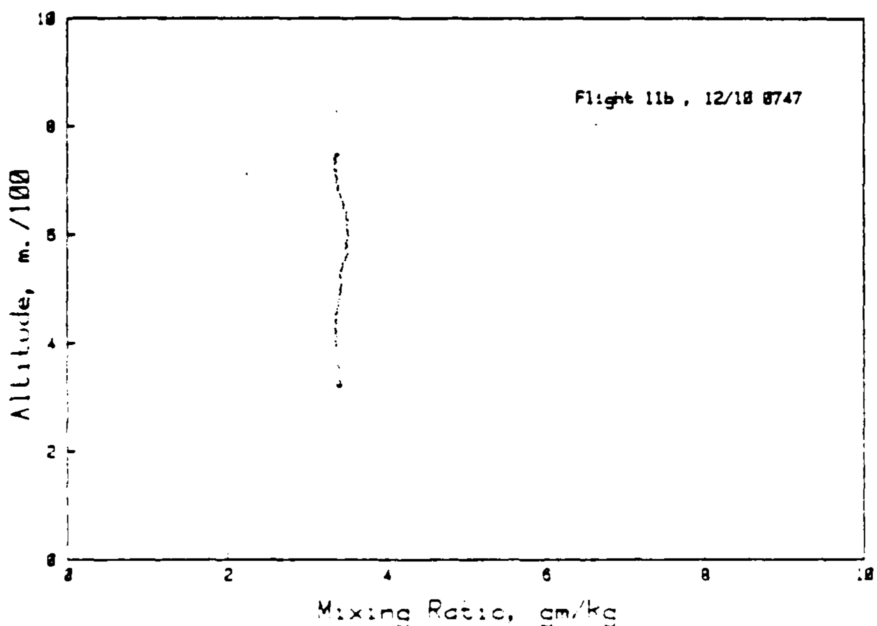


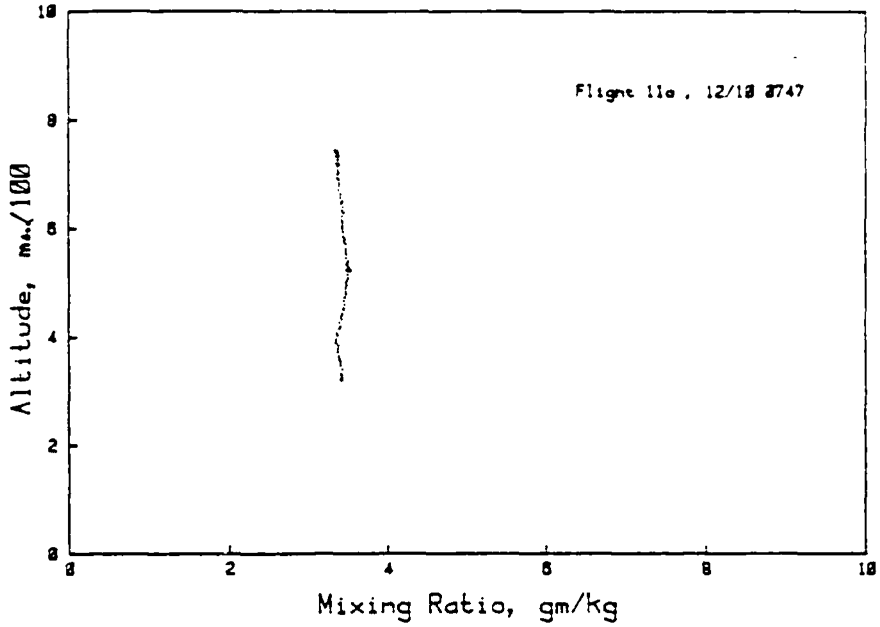


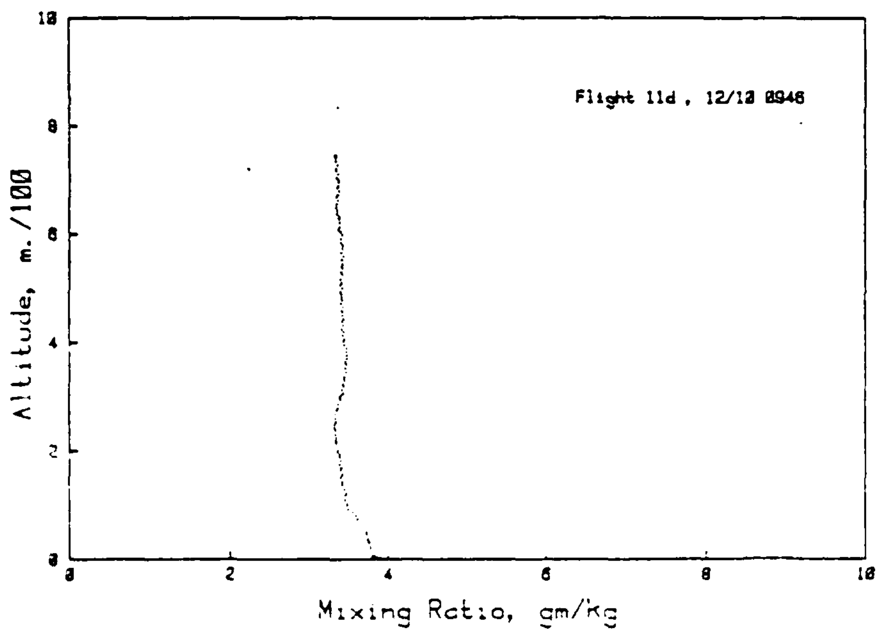


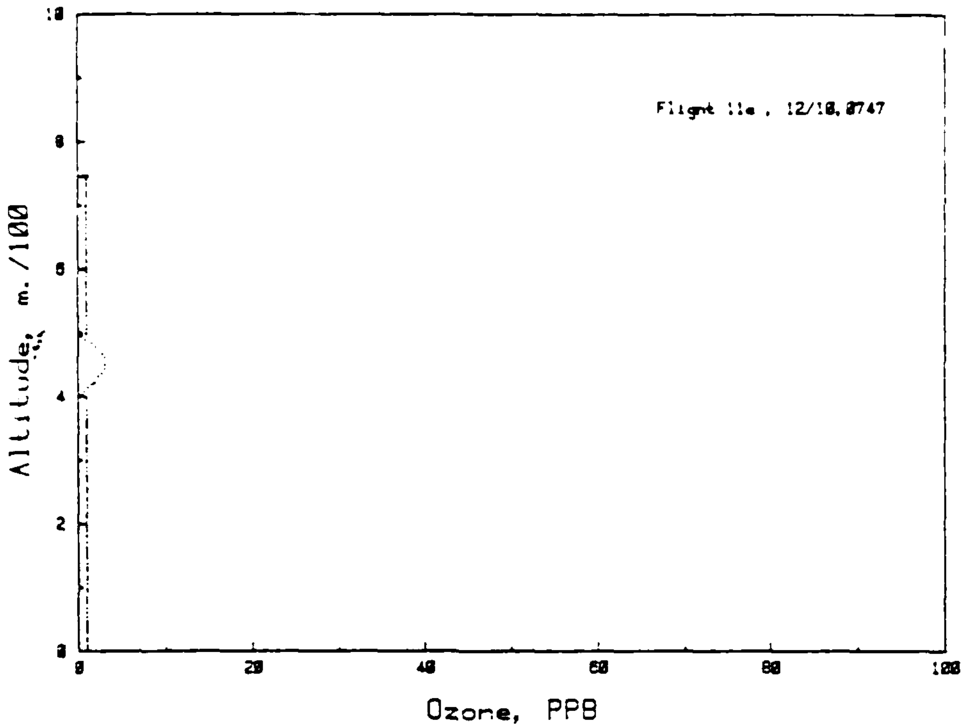



FLIGHT 11 , 12/10
Altitude, m. /100
Time, hr
0
2
4
6
8
10
7
8
9
10

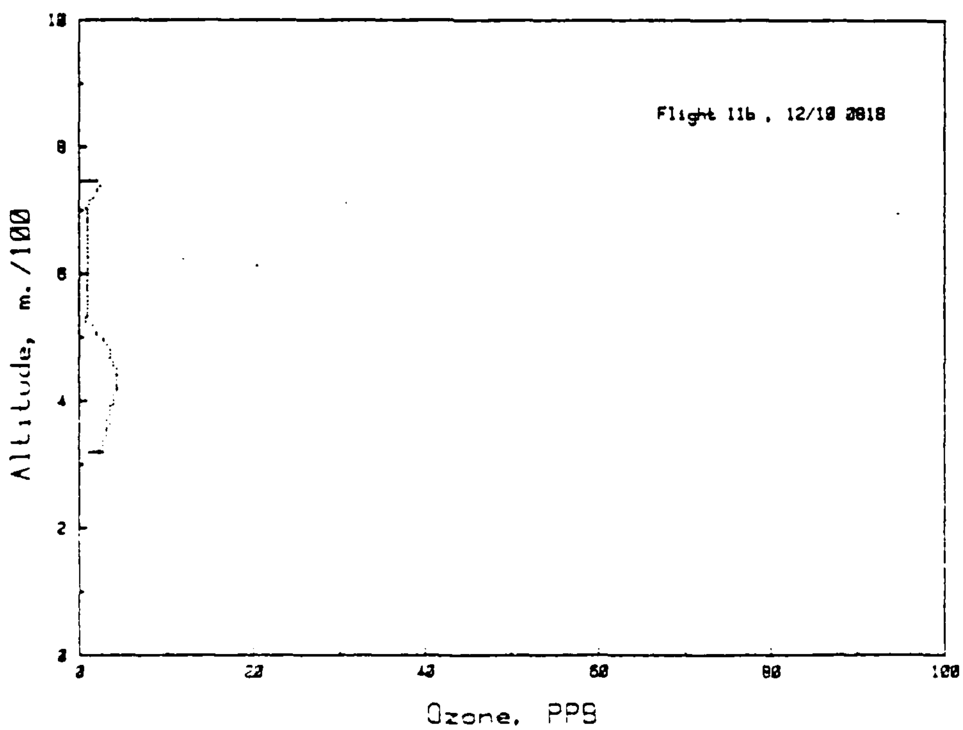

Flight 11b , 12/10 0747
Altitude, m. /100
Mixing Ratio, gm/kg
0
2
4
6
8
10


Flight 11a , 12/10 0747
Altitude, m./100
Mixing Ratio, gm/kg
0
2
4
6
8
10

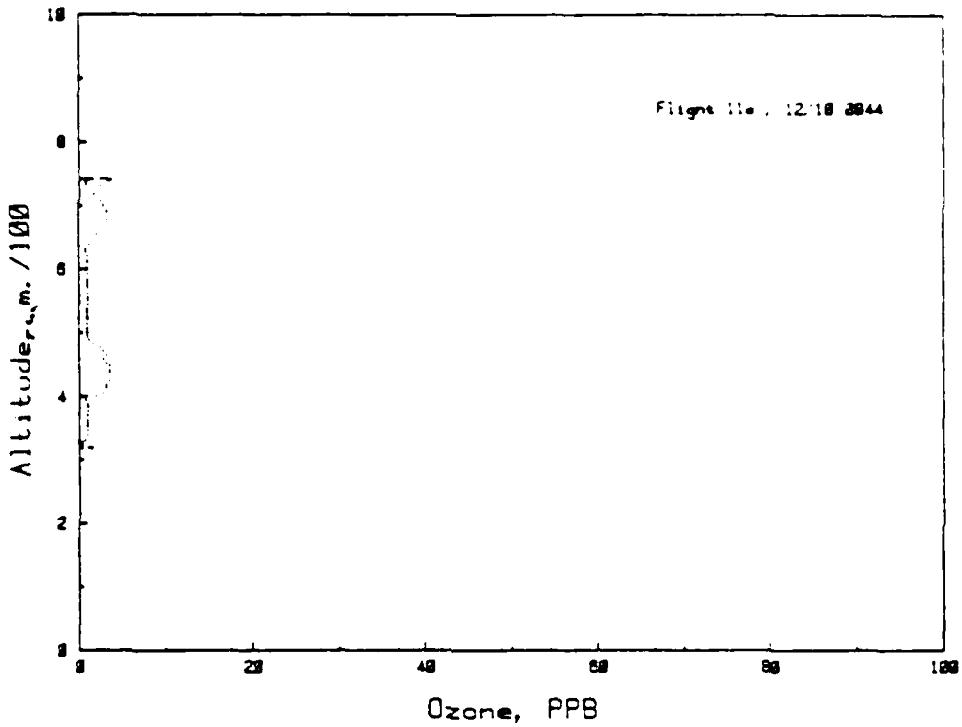

Flight 11d , 12/10 0946
Altitude, m./100
Mixing Ratio, gm/kg
0
2
4
6
8
10



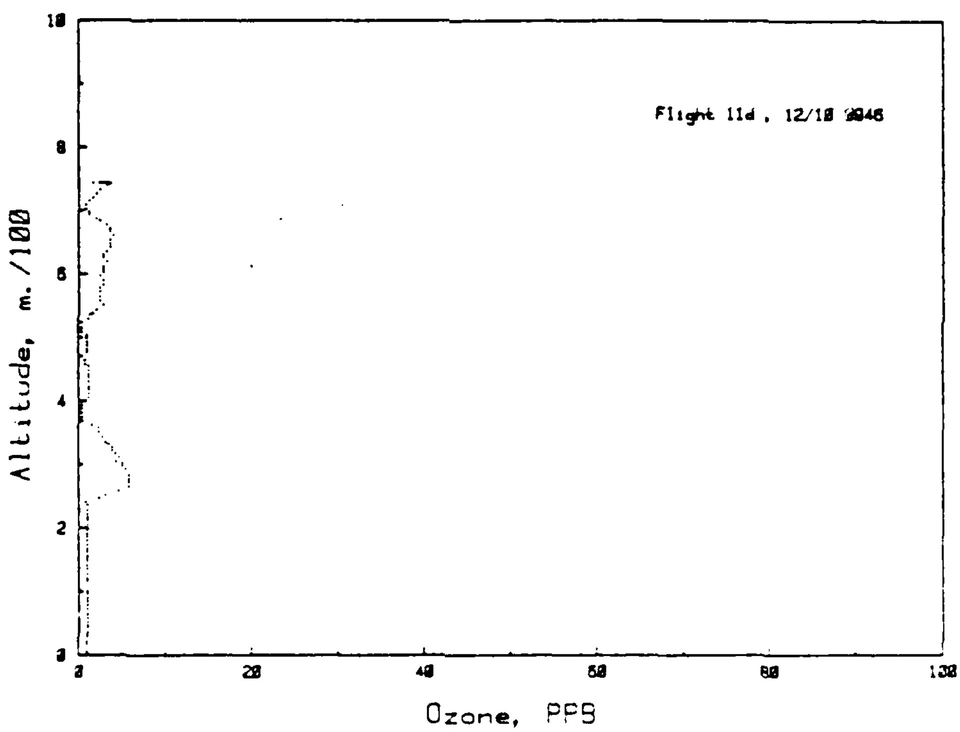
Flight 11a , 12/18,0747
Altitude, m. /100
Ozone, PPB



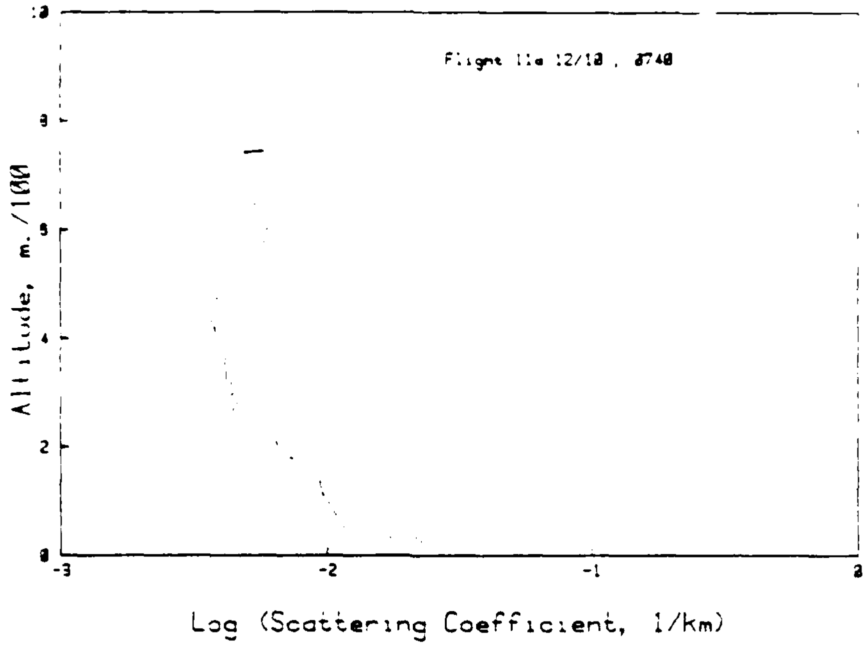
Flight 11b , 12/18 0818
Altitude, m. /100
Ozone, PPB



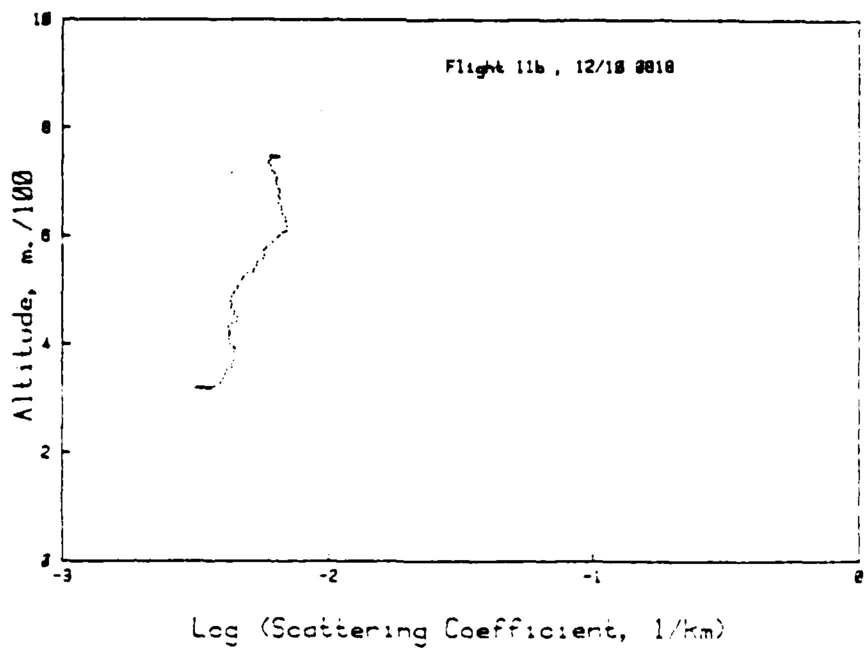
Flight 11c, 12/10 0044
Altitude, m. /100
Ozone, PPB



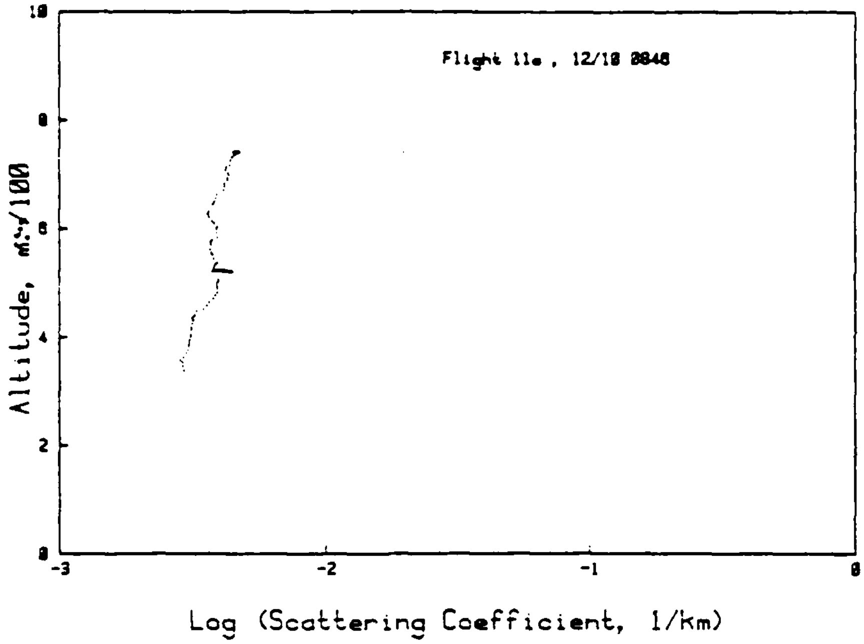
Flight 11d, 12/10 0046
Altitude, m. /100
Ozone, PPB

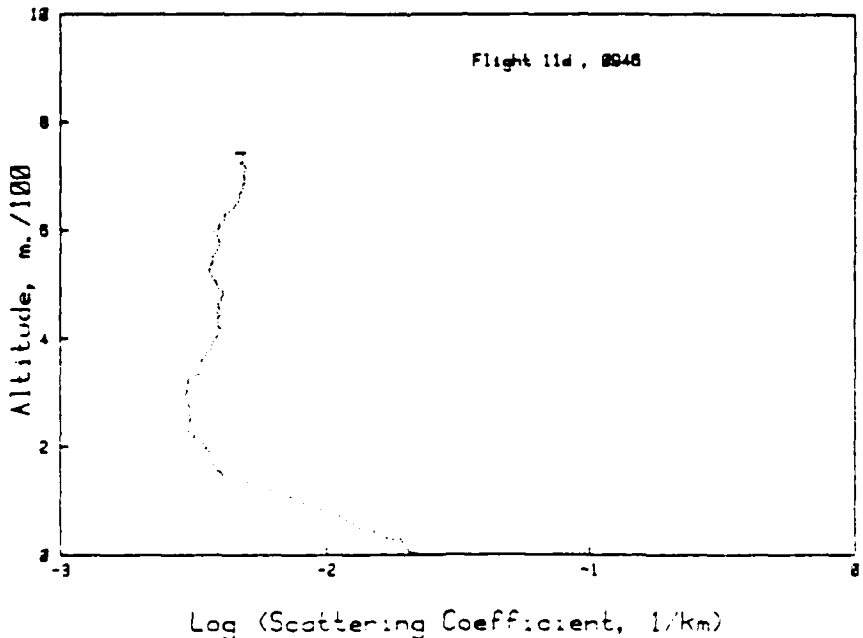


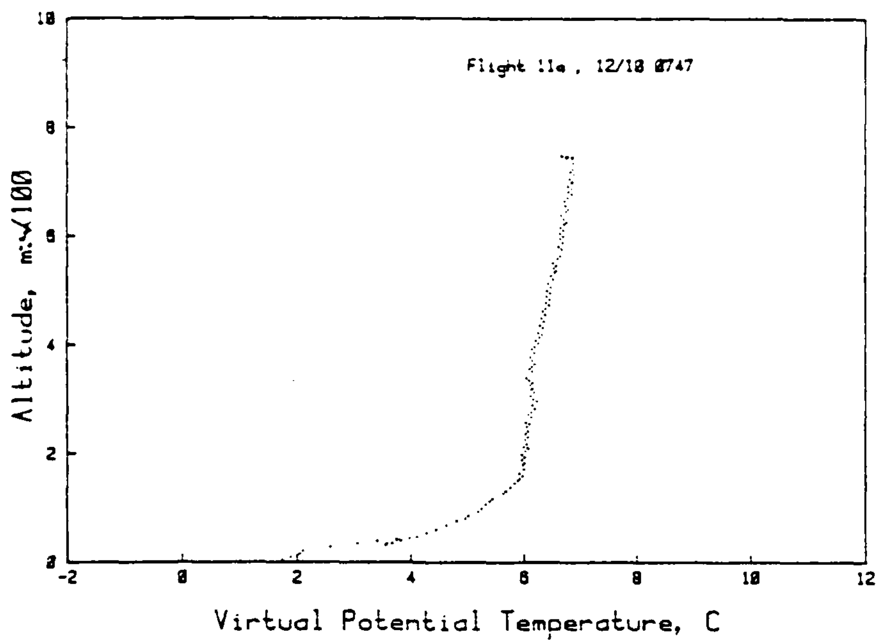
Flight 11a 12/18 , 0740
Altitude, m./100
Log (Scattering Coefficient, 1/km)

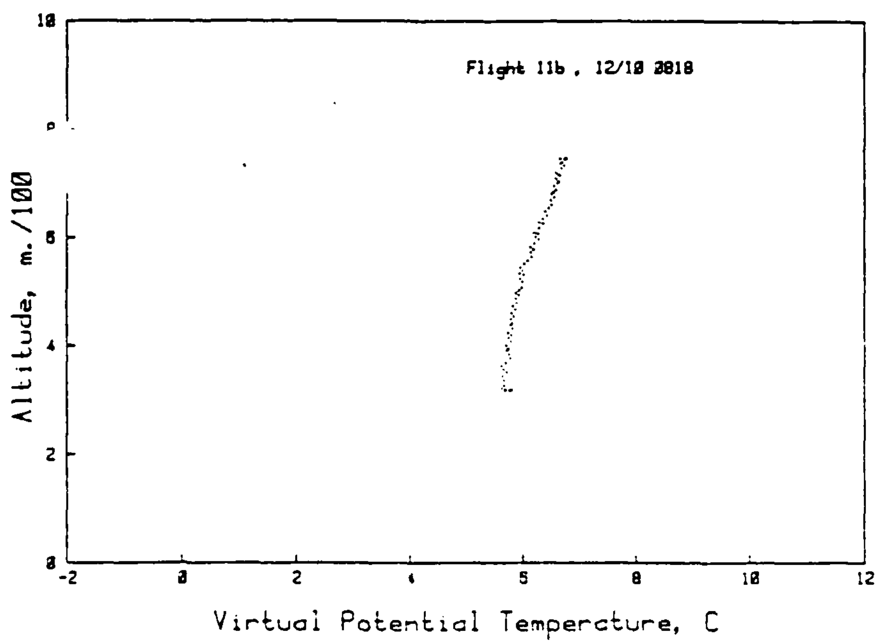


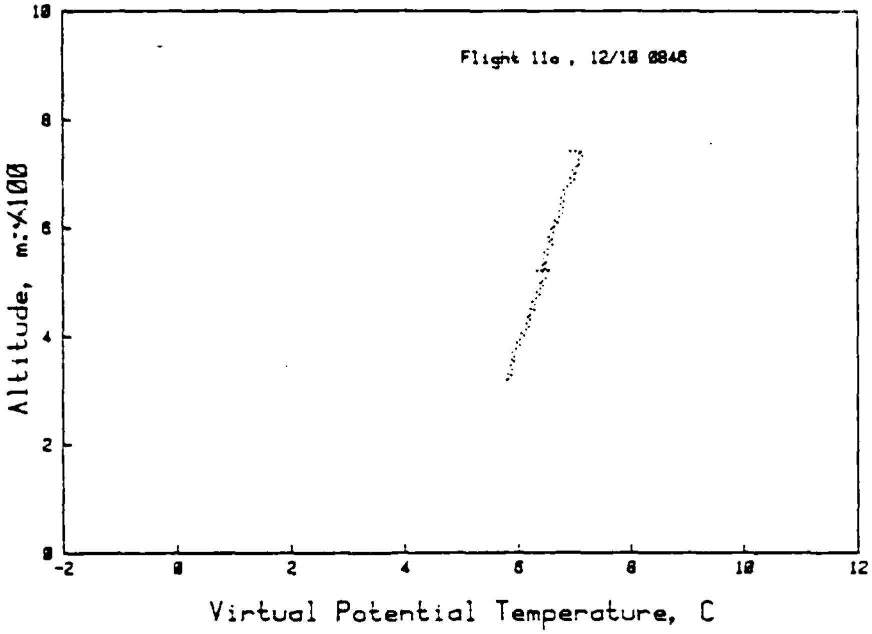
Flight 11b , 12/18 0818
Altitude, m./100
Log (Scattering Coefficient, 1/km)


Flight 11e , 12/18 0848
Altitude, m./100
Log (Scattering Coefficient, 1/km)

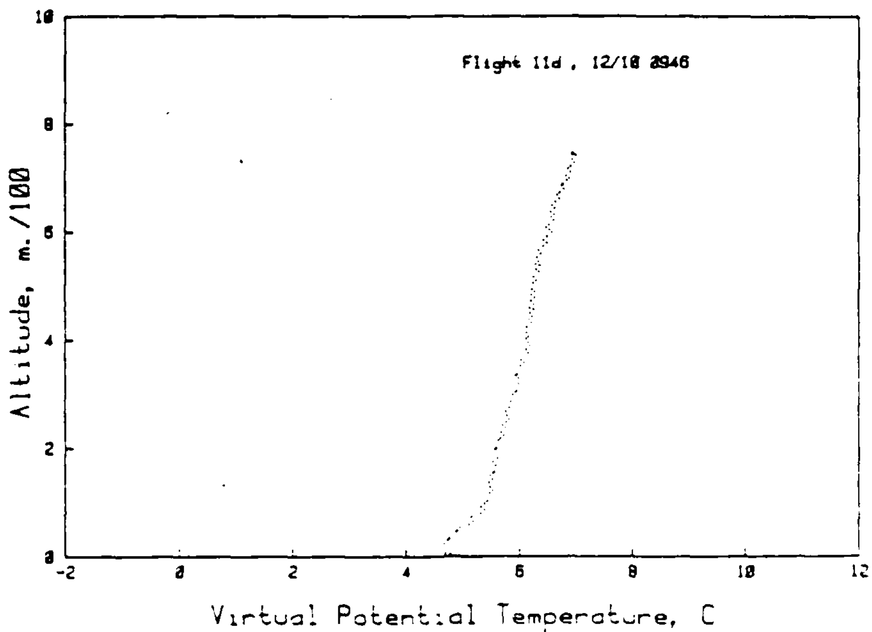

Flight 11d , 0846
Altitude, m./100
Log (Scattering Coefficient, 1/km)


Flight 11a , 12/18 0747
Altitude, m./100
Virtual Potential Temperature, C

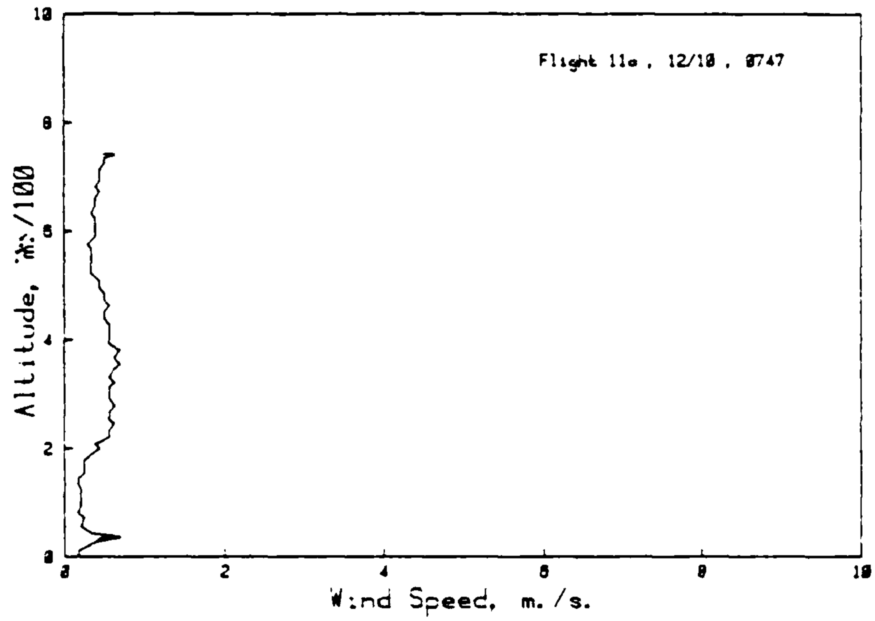

Flight 11b , 12/18 0818
Altitude, m./100
Virtual Potential Temperature, C

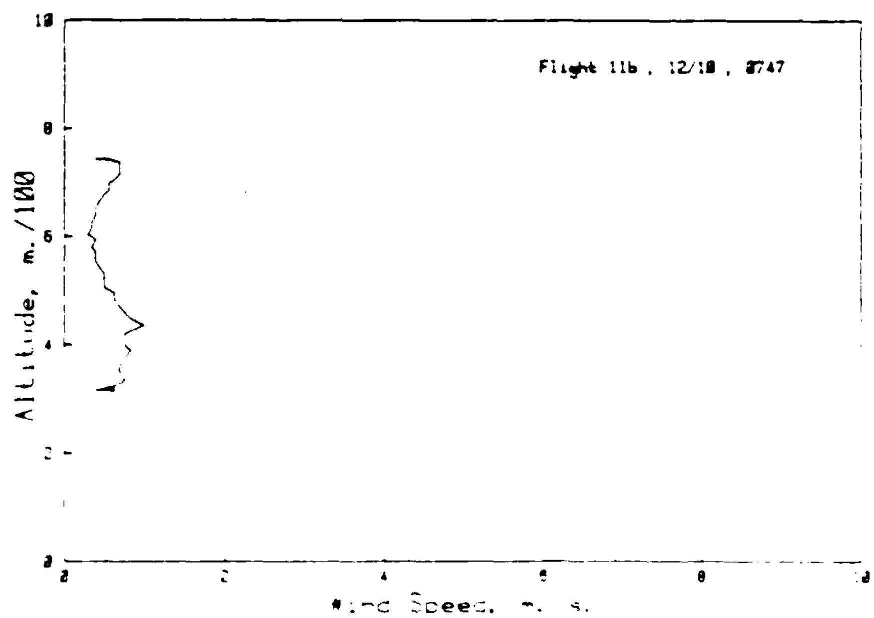


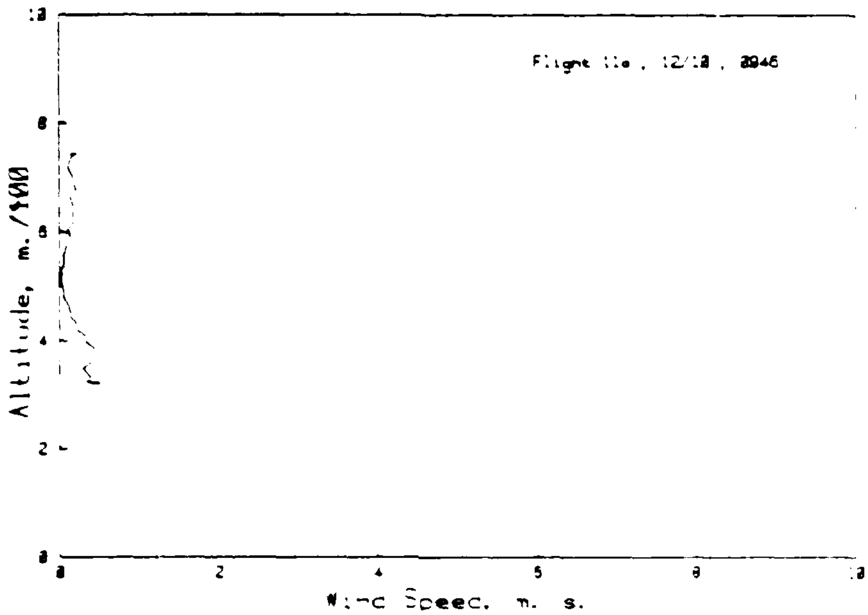
Flight 11c , 12/18 0846
Altitude, m./100
Virtual Potential Temperature, C

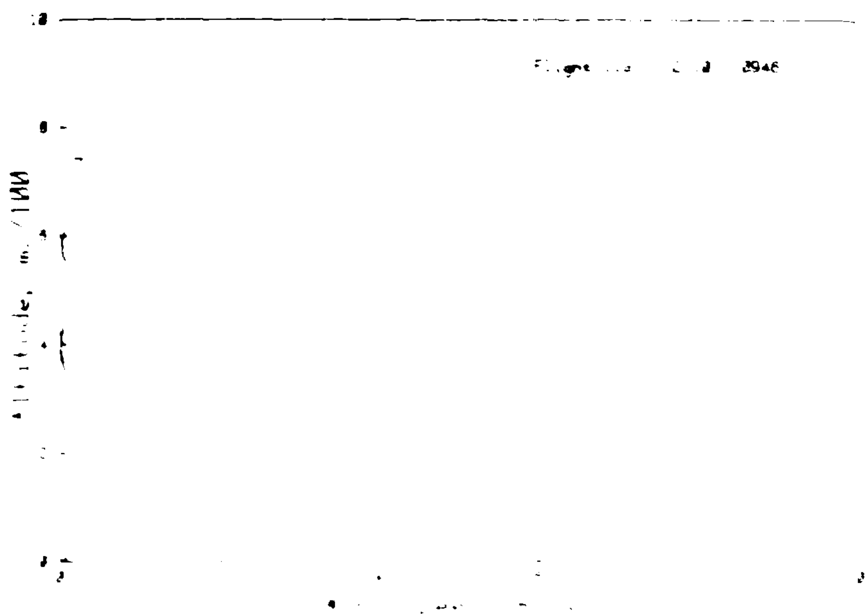


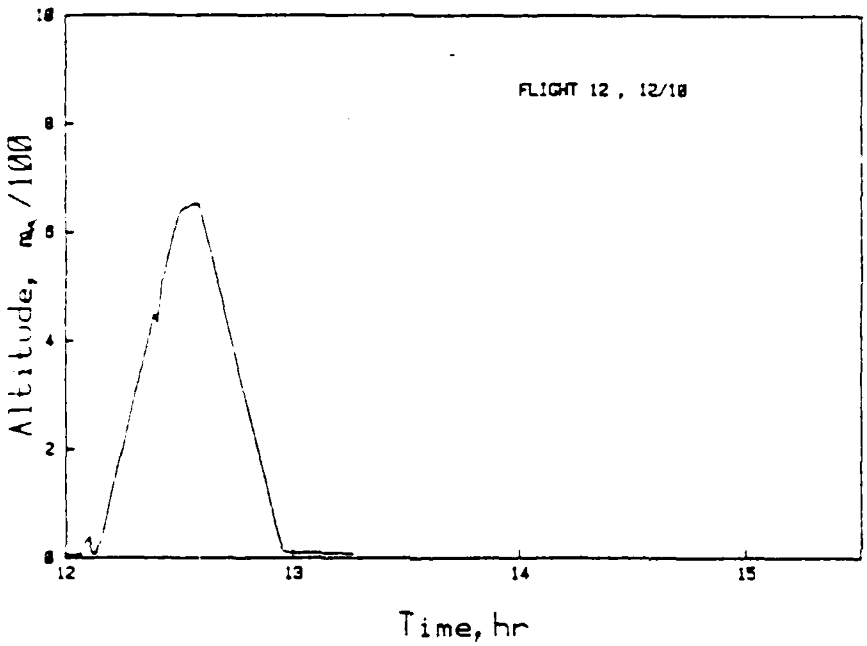
Flight 11d , 12/18 0946
Altitude, m./100
Virtual Potential Temperature, C

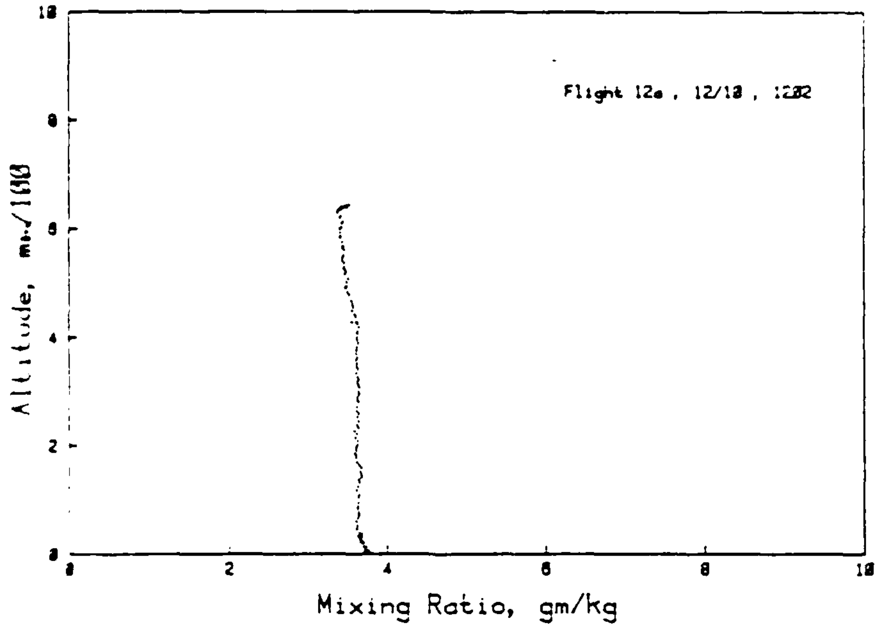

Flight 11a , 12/10 , 0747
Altitude, m./100
Wind Speed, m./s.


Flight 11b , 12/10 , 0747
Altitude, m./100

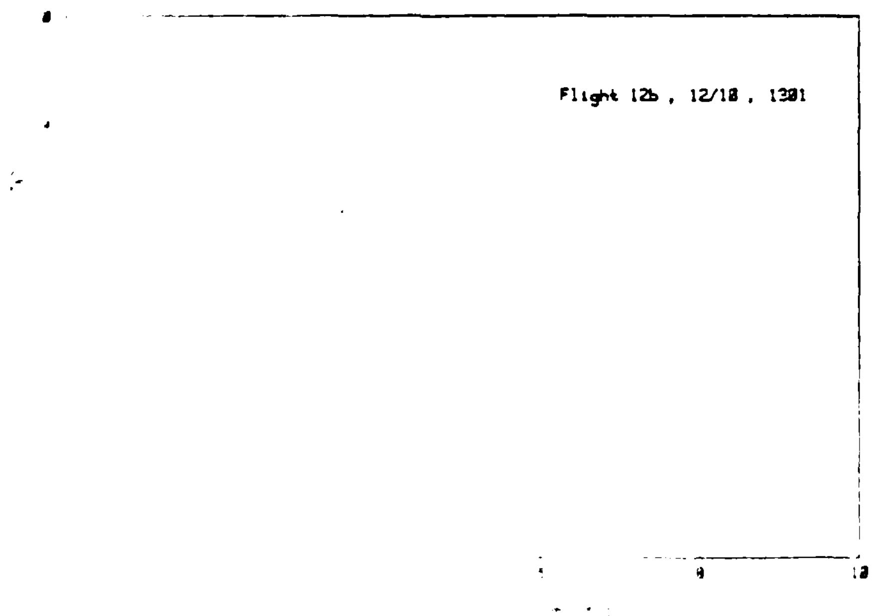

Flight 11e , 12/10 , 0946
Altitude, m./100
Wind Speed, m. s.


0946

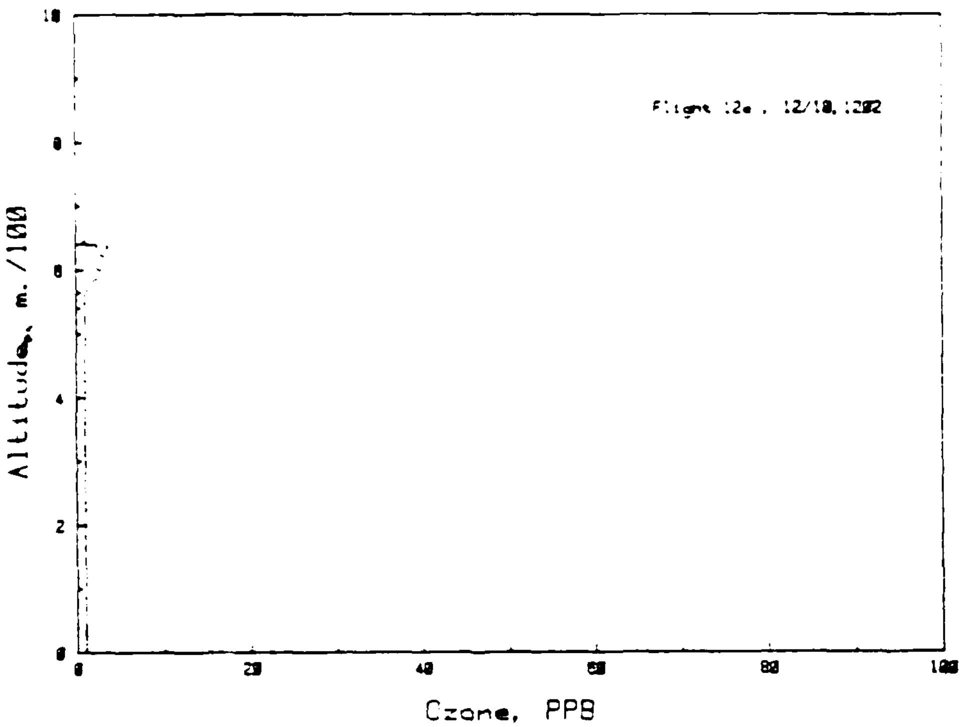

FLIGHT 12 , 12/18
Altitude, m /100
Time, hr
12
13
14
15
2
4
6
8
10

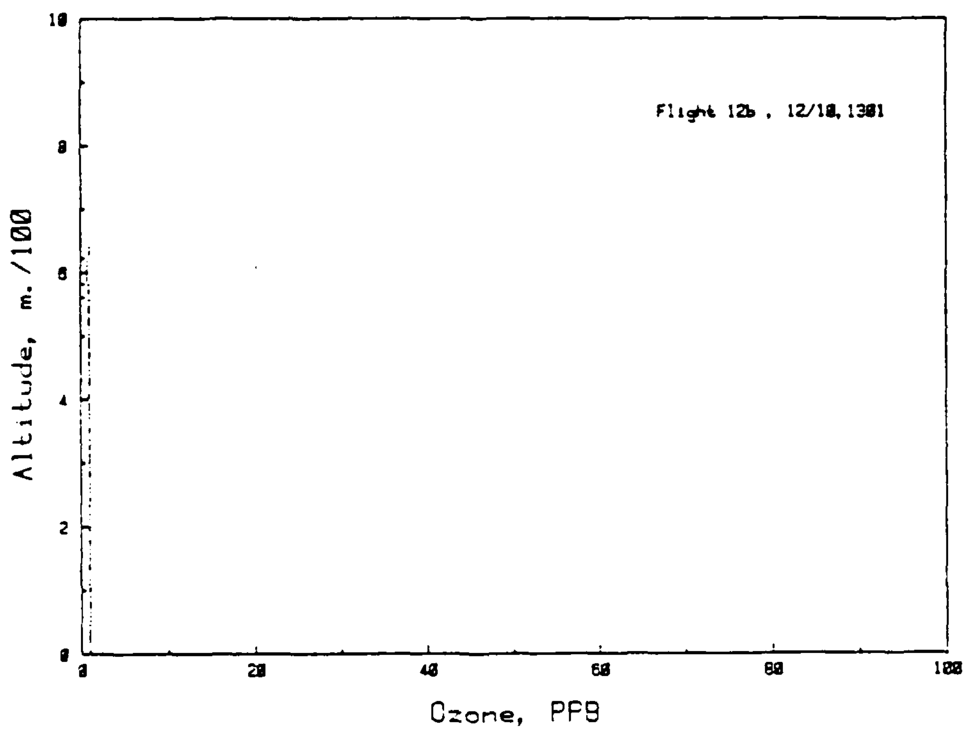


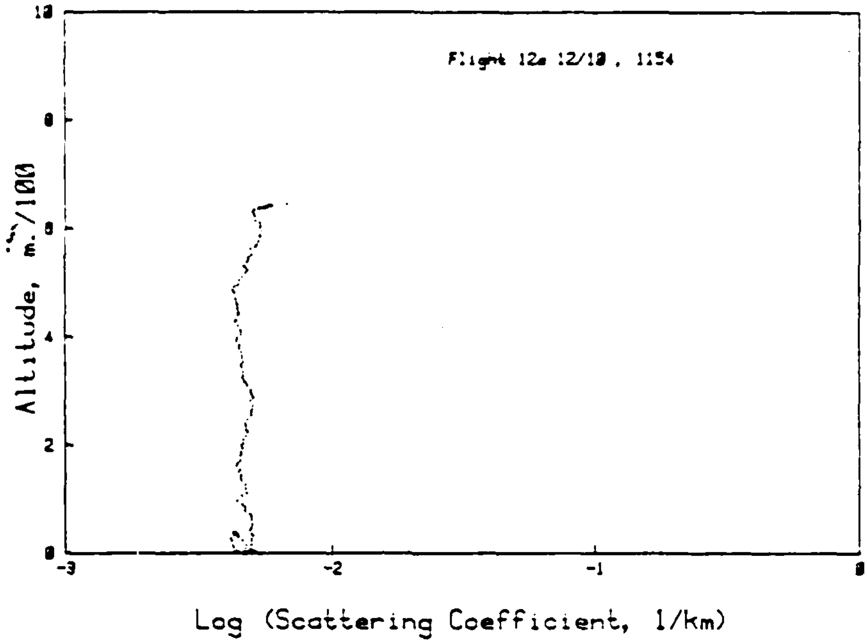
Flight 12a , 12/18 , 1202
Altitude, m./100
Mixing Ratio, gm/kg

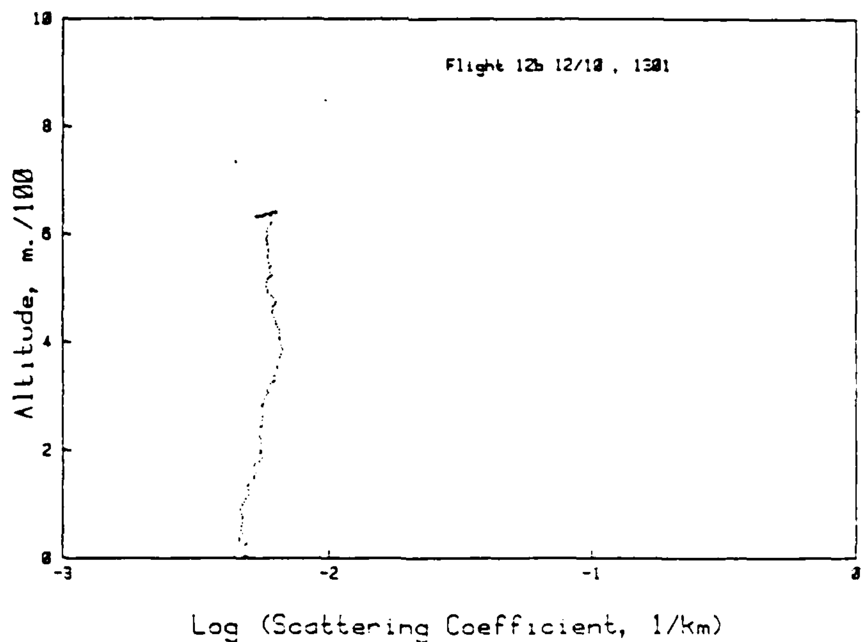


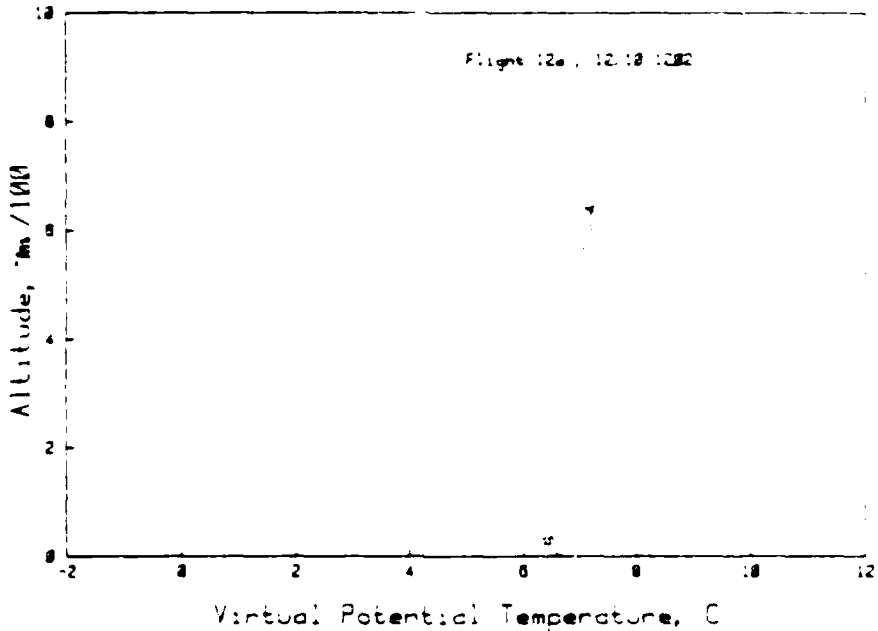
Flight 12b , 12/18 , 1301

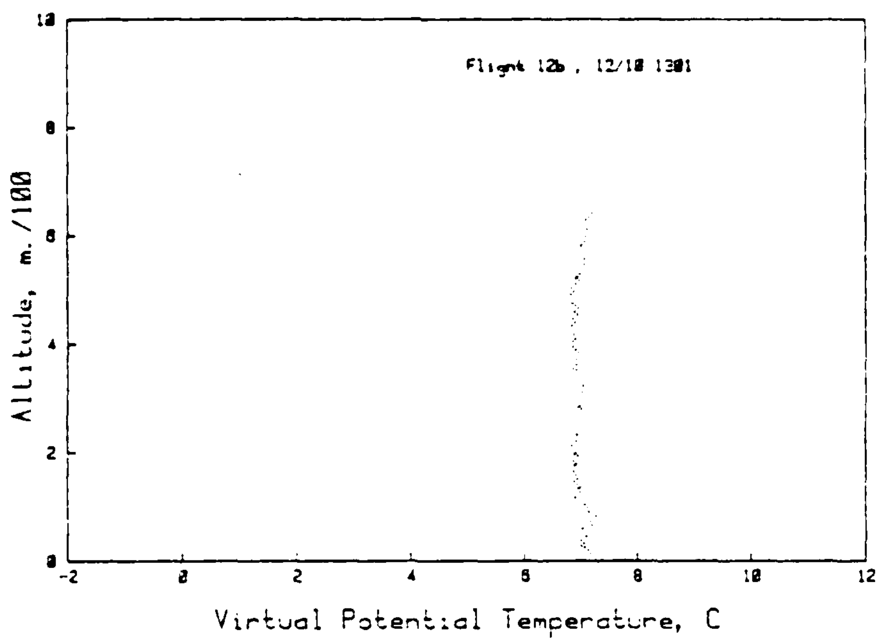

Flight 12a , 12/18, 1202
Altitude, m. /100
Czone, PPB

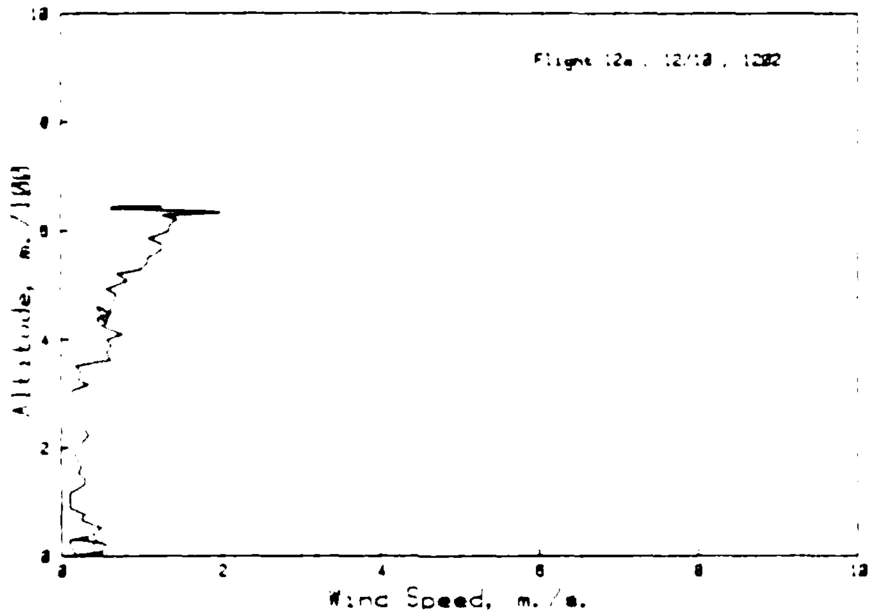

Flight 12b , 12/18, 1301
Altitude, m. /100
Ozone, PPB

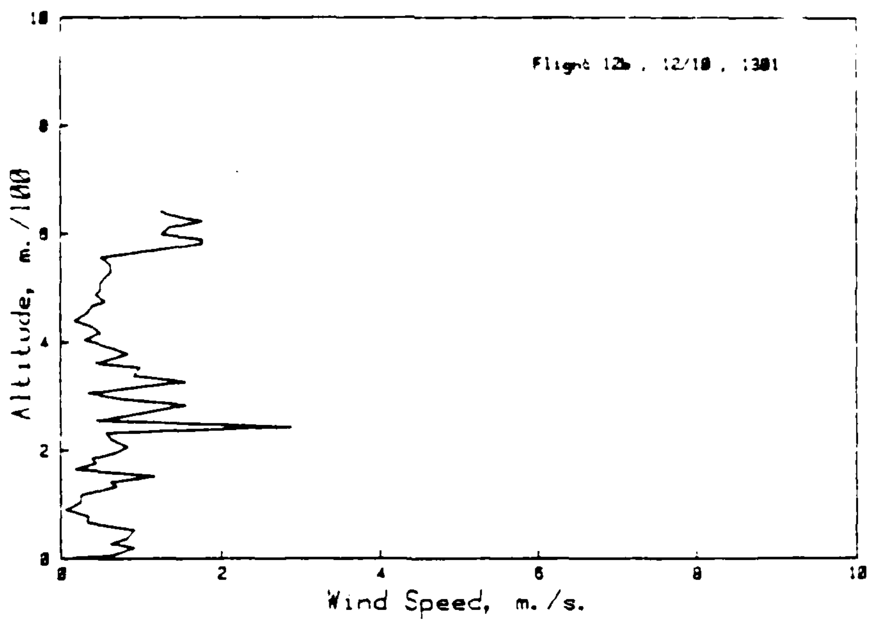

Flight 12a 12/10 , 1154
Altitude, m./100
10
8
6
4
2
0
-3
-2
-1
0
Log (Scattering Coefficient, 1/km)

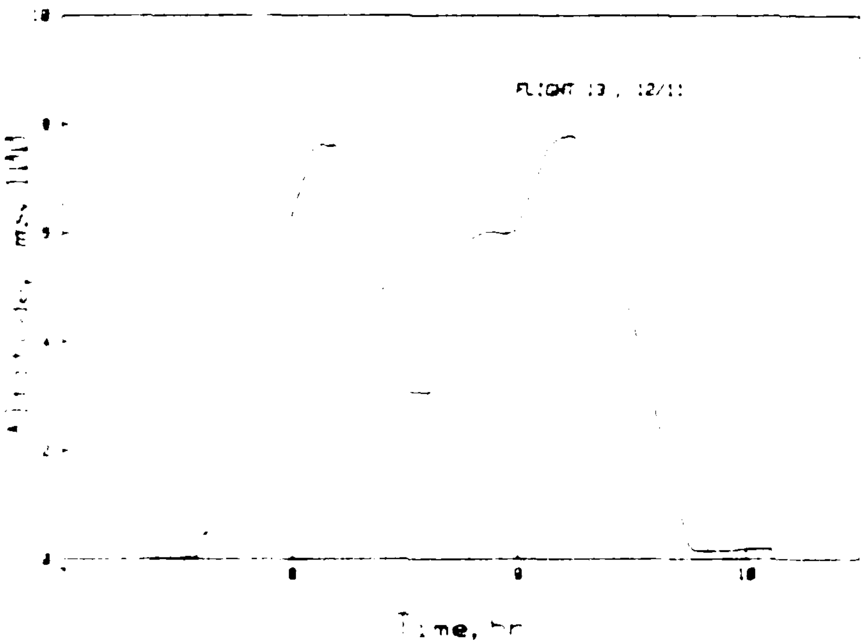

Flight 12b 12/10 , 1301
Altitude, m./100
10
8
6
4
2
0
-3
-2
-1
0
Log (Scattering Coefficient, 1/km)


Flight 12a , 12/10 1202
Altitude, m./100
Virtual Potential Temperature, C

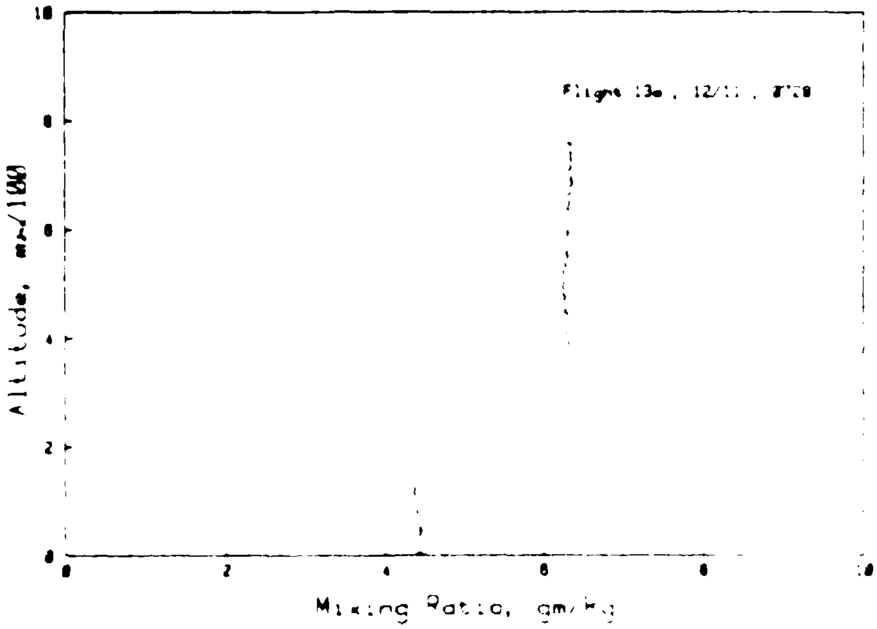

Flight 12b , 12/10 1301
Altitude, m./100
Virtual Potential Temperature, C

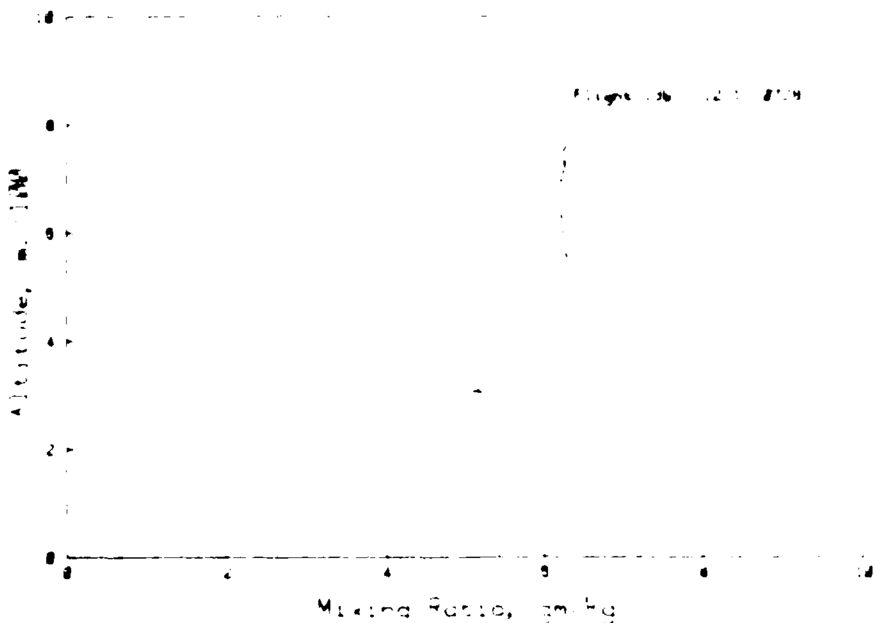

Flight 12a , 12/10 , 1202
Altitude, m./100
Wind Speed, m./s.

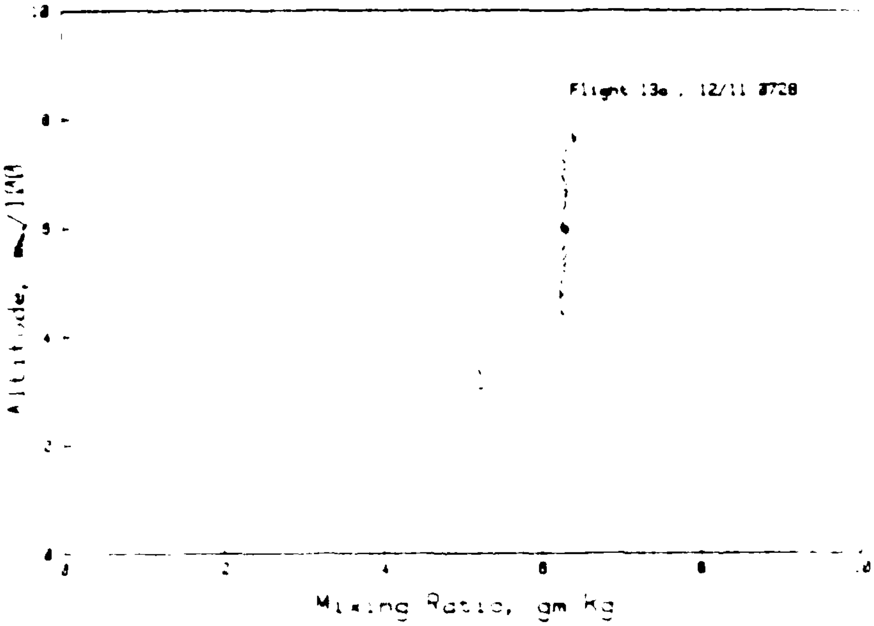

Flight 12b , 12/10 , 1301
Altitude, m./100
Wind Speed, m./s.

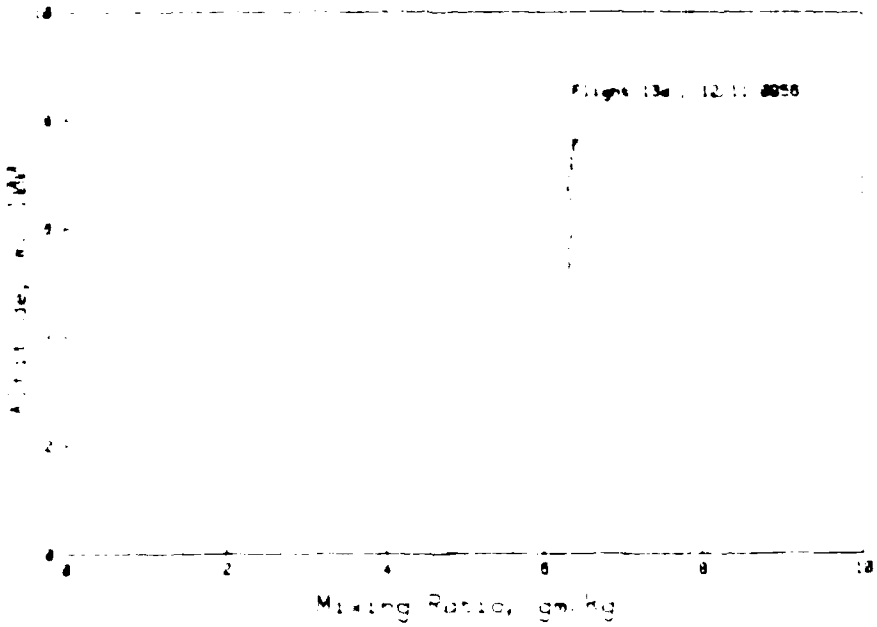


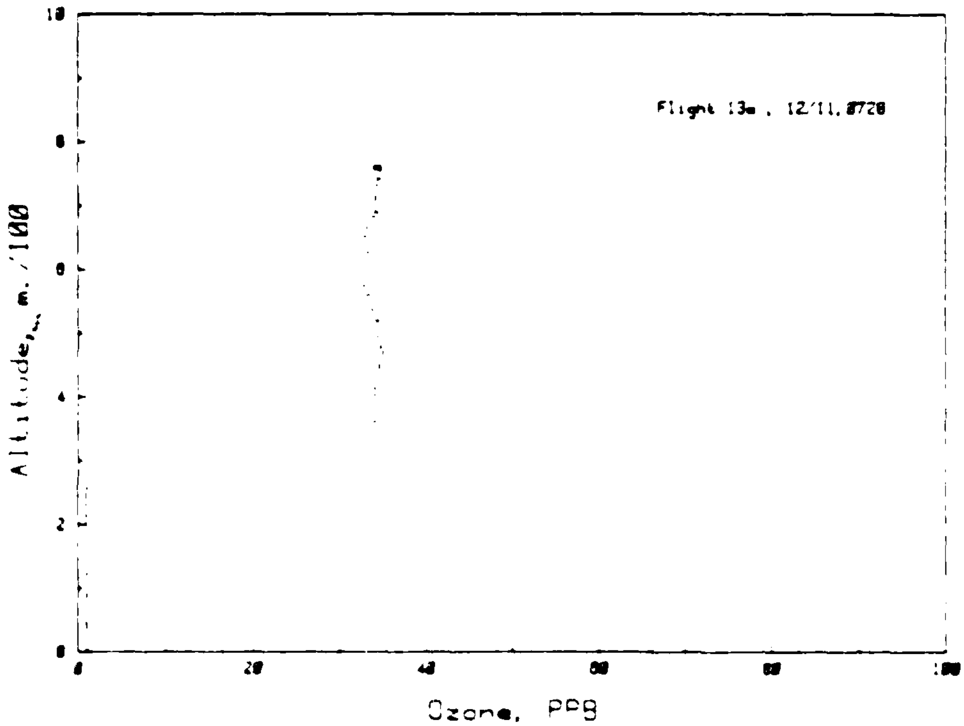
84


Altitude, m/1000
Mixing Ratio, gm/kg

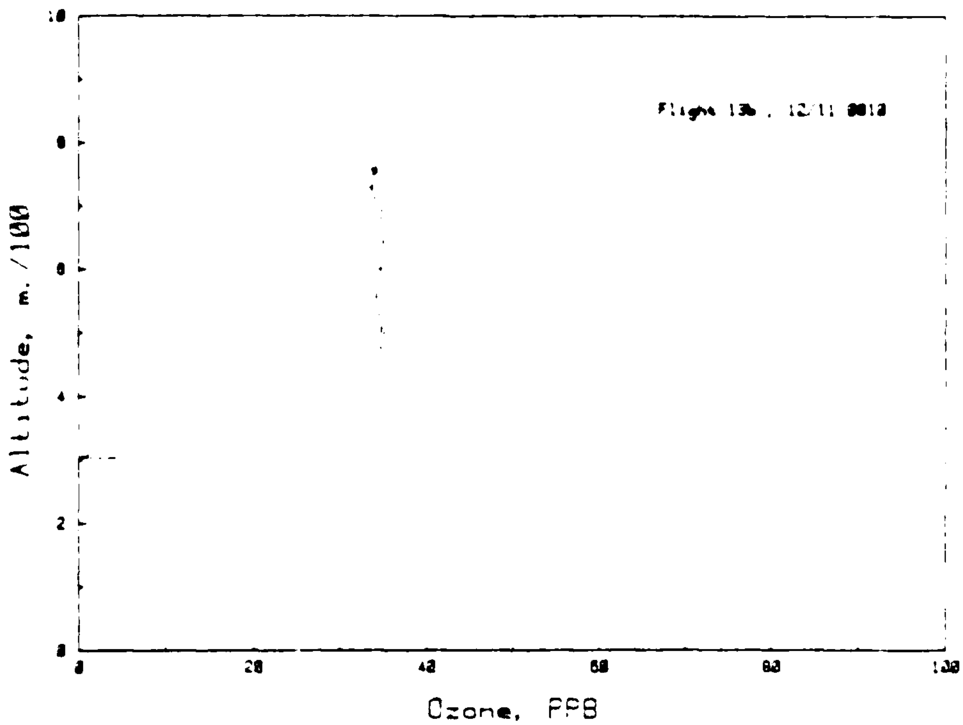

Mixing Ratio


Flight 13a , 12/11 0728
Mixing Ratio, gm/kg

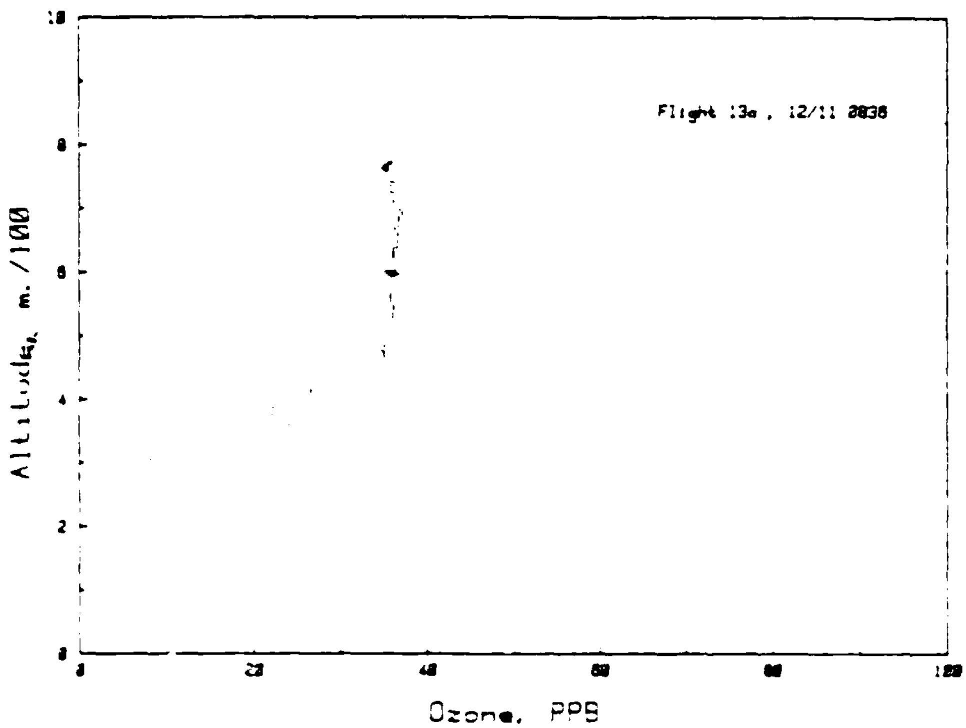

Mixing Ratio, gm/kg

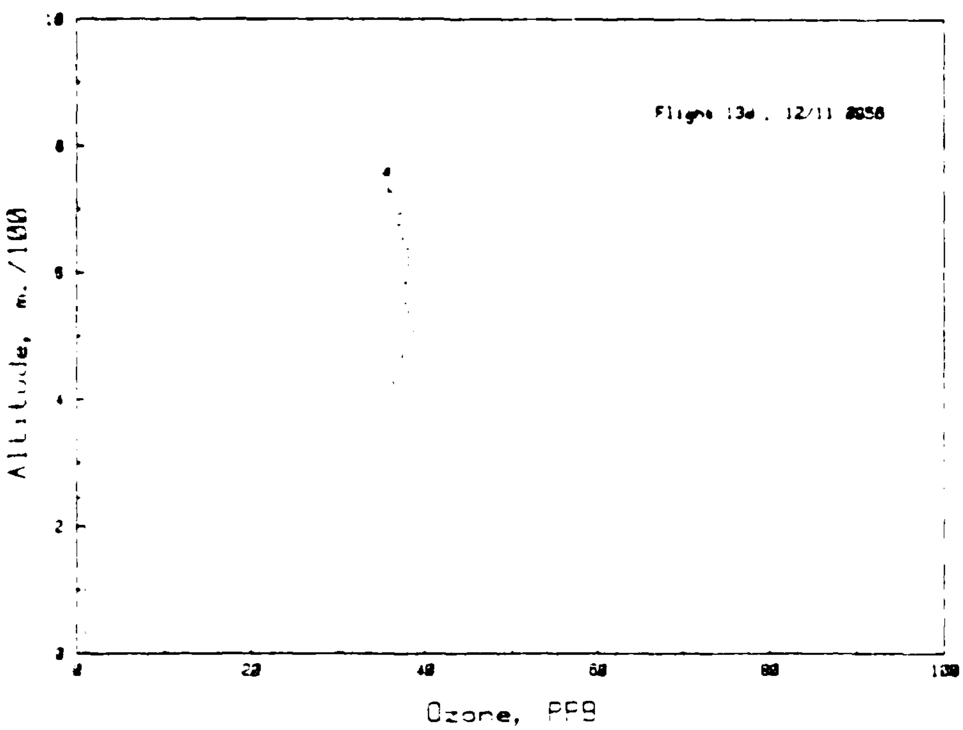


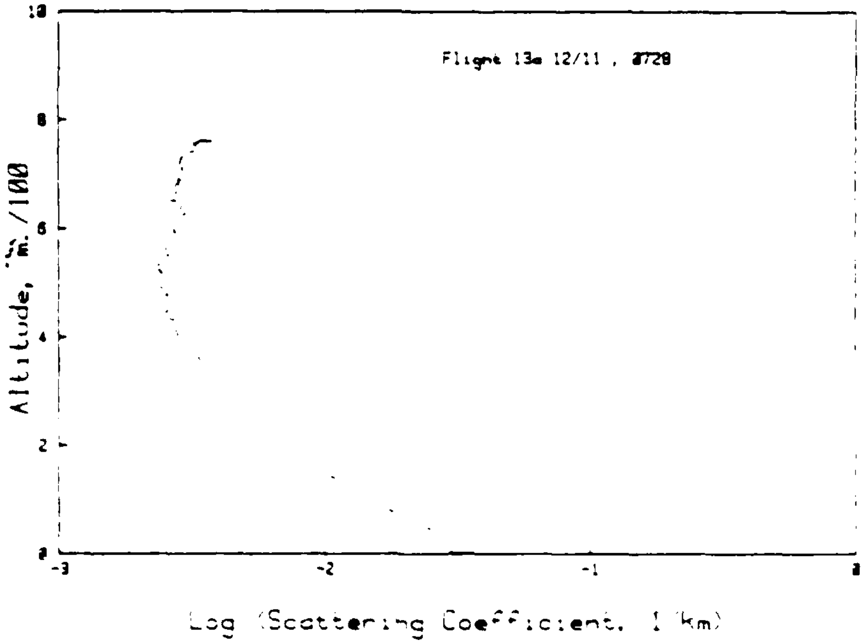
Flight 13a , 12/11,0720
Altitude, m./100
0
2
4
6
8
10
0
20
40
60
80
100
Ozone, PPB

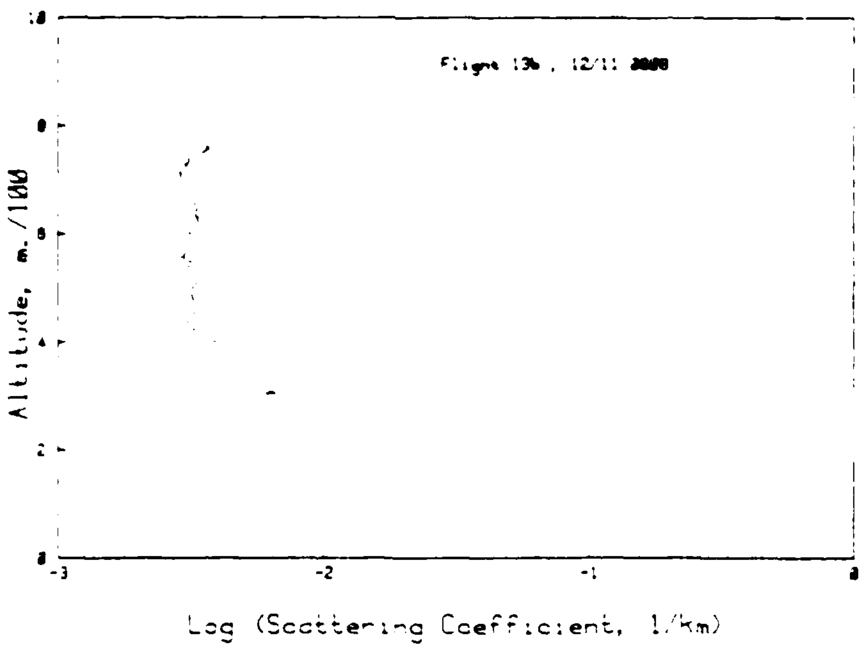


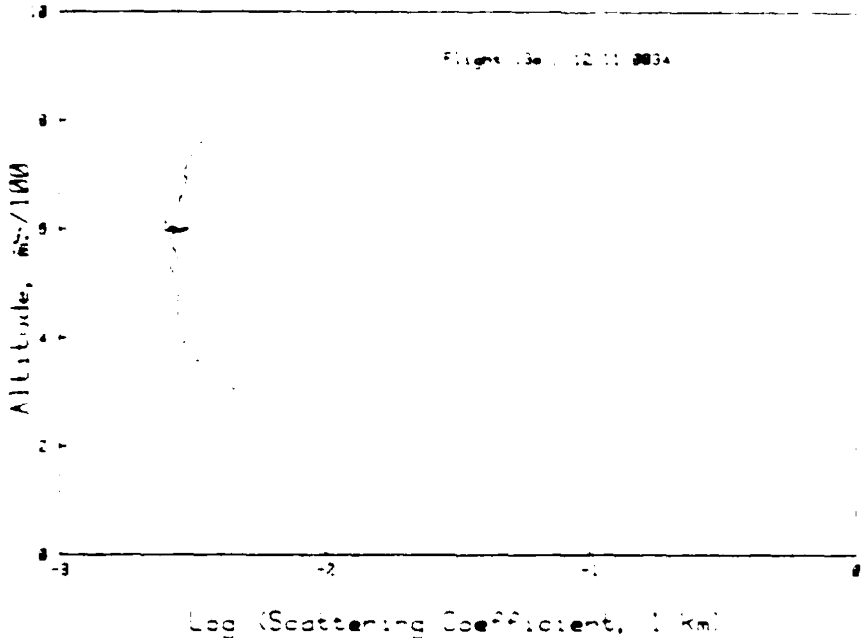
Flight 13b , 12/11
Altitude, m./100
0
2
4
6
8
10
0
20
40
60
80
100
Ozone, PPB

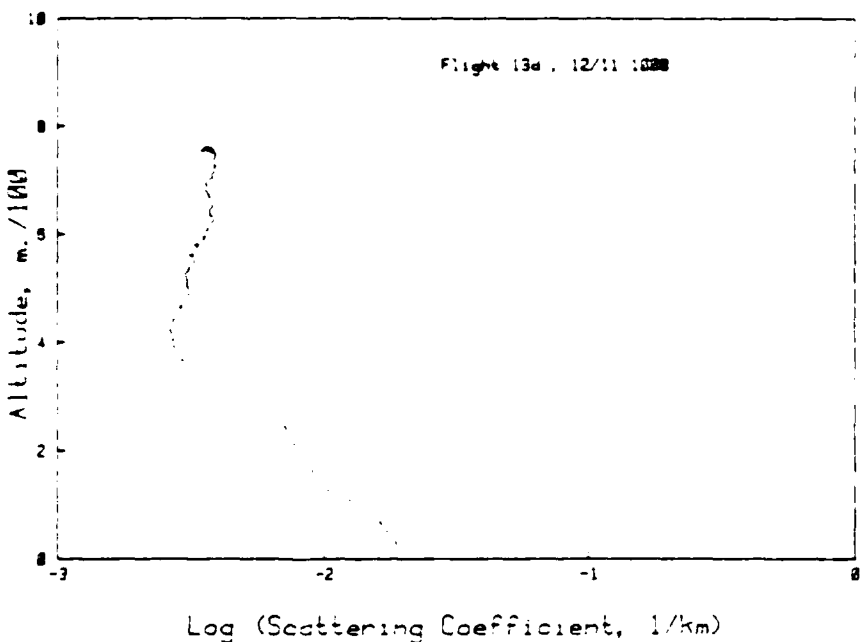

Flight 13a , 12/11 0838
Altitude, m./100
Ozone, PPB

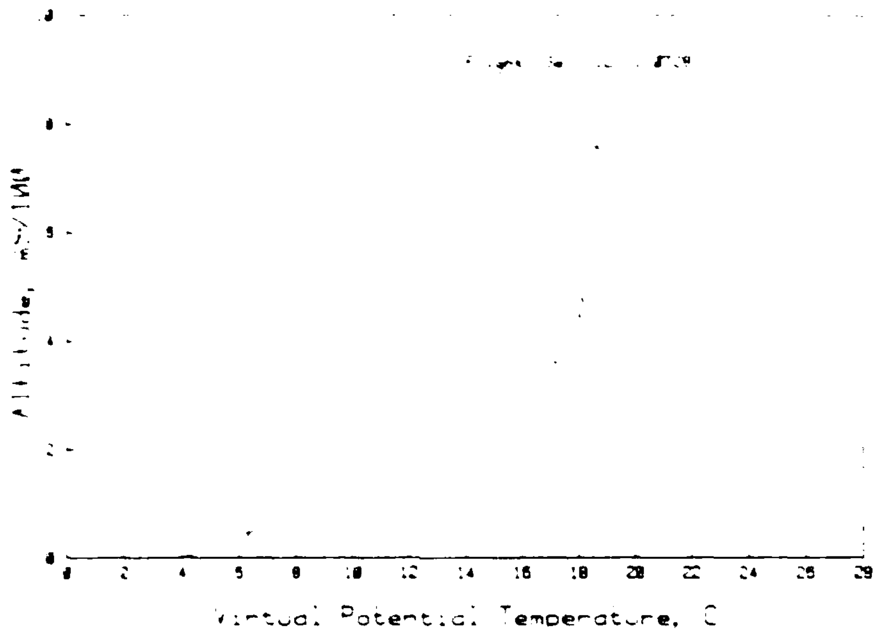

Flight 13a , 12/11 0858
Altitude, m./100
Ozone, PPB

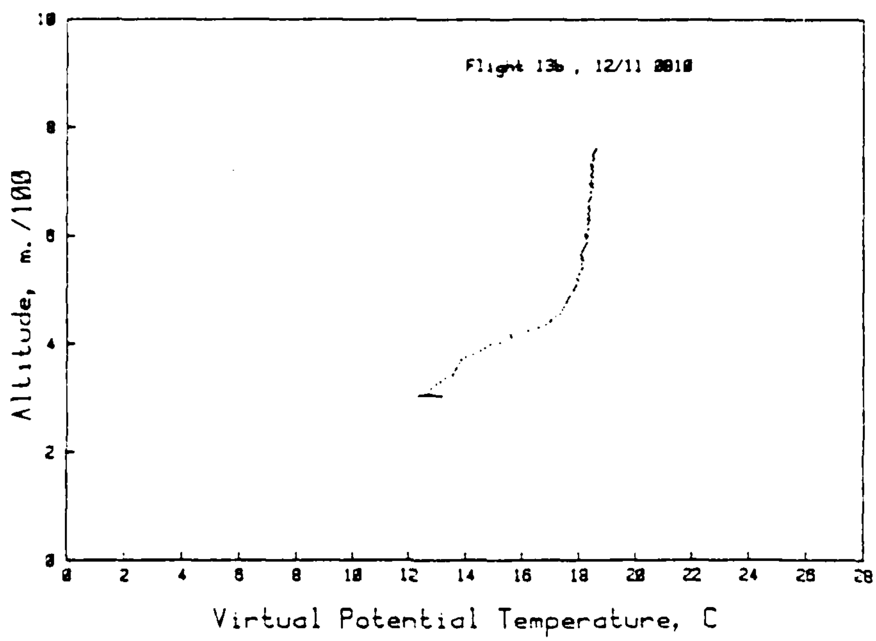

Flight 13a 12/11 , 0728
Altitude, m./100
Log (Scattering Coefficient, 1/km)

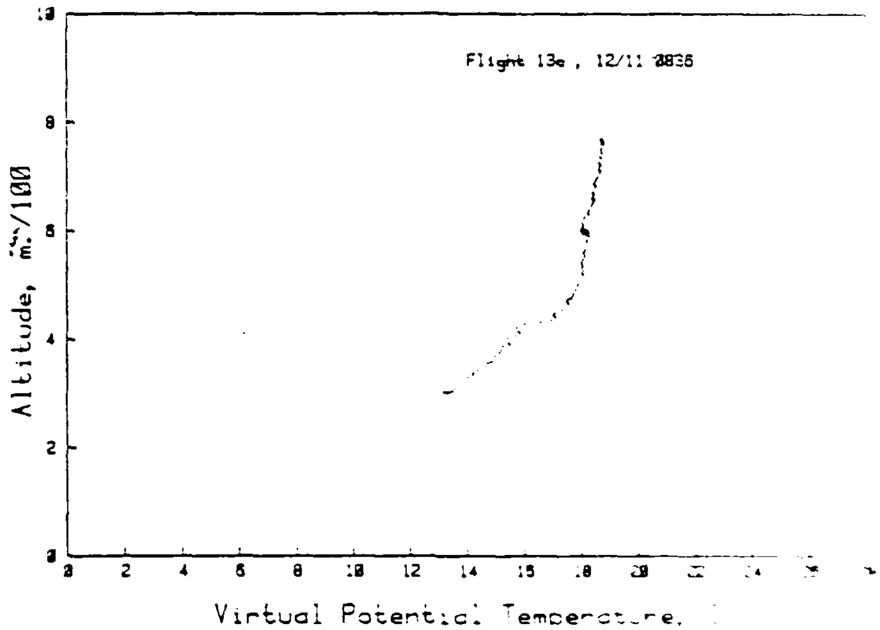

Flight 13b , 12/11 0800
Altitude, m./100
Log (Scattering Coefficient, 1/km)

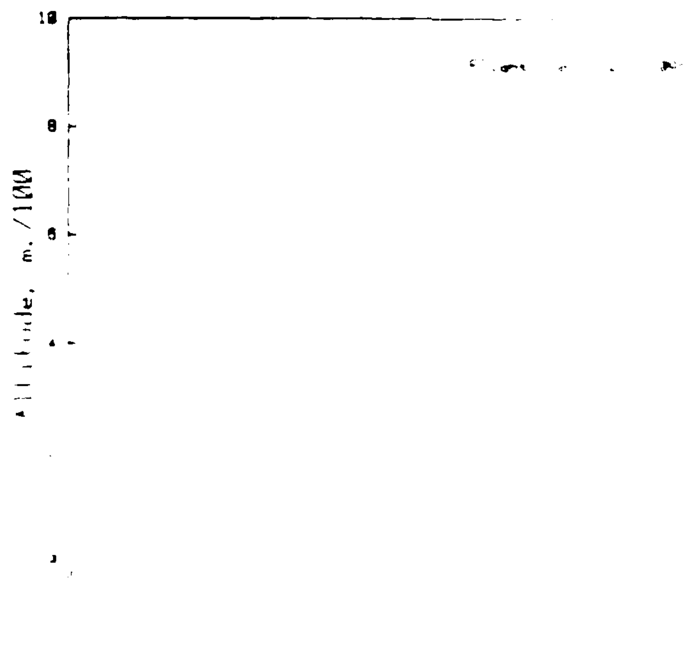

Altitude, m./1000
10
8
6
4
2
0
-3
-2
-1
0
Log (Scattering Coefficient, 1/km)


Flight 13d , 12/11
Altitude, m./1000
10
8
6
4
2
0
-3
-2
-1
0
Log (Scattering Coefficient, 1/km)


Virtual Potential Temperature, C

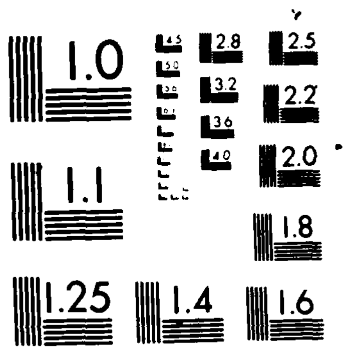

Flight 13b , 12/11 0010
Altitude, m./100
Virtual Potential Temperature, C


Flight 13e , 12/11 0836
Altitude, m./100
Virtual Potential Temperature,

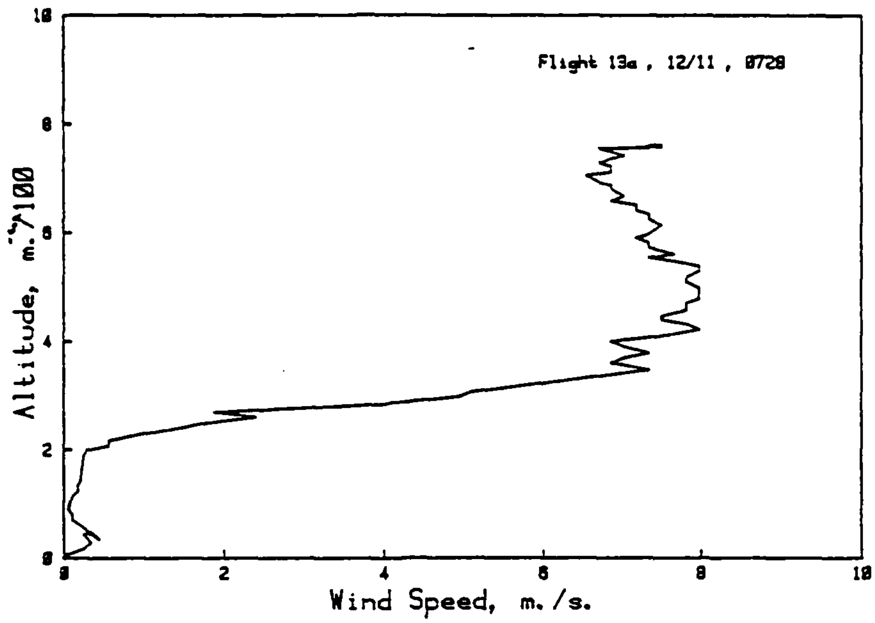

Altitude, m./100

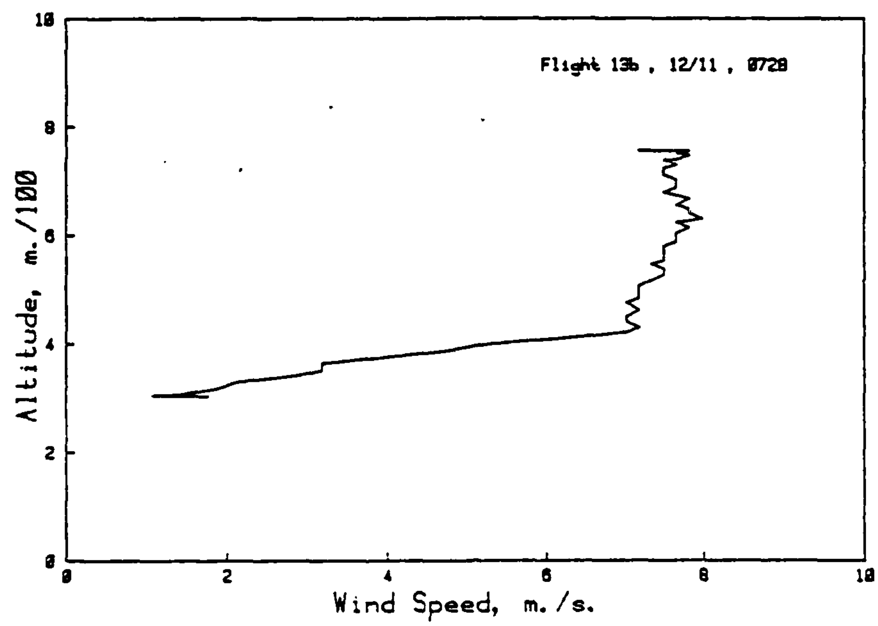
AD-A176 254 TETHERED BALLOON MEASUREMENTS MADE AT NAVAL AIR DEVELOPMENT CENTER (DECEMBER 1985)(U) NAVAL RESEARCH LAB WASHINGTON DC W P HOOPER ET AL 29 DEC 86 2/2

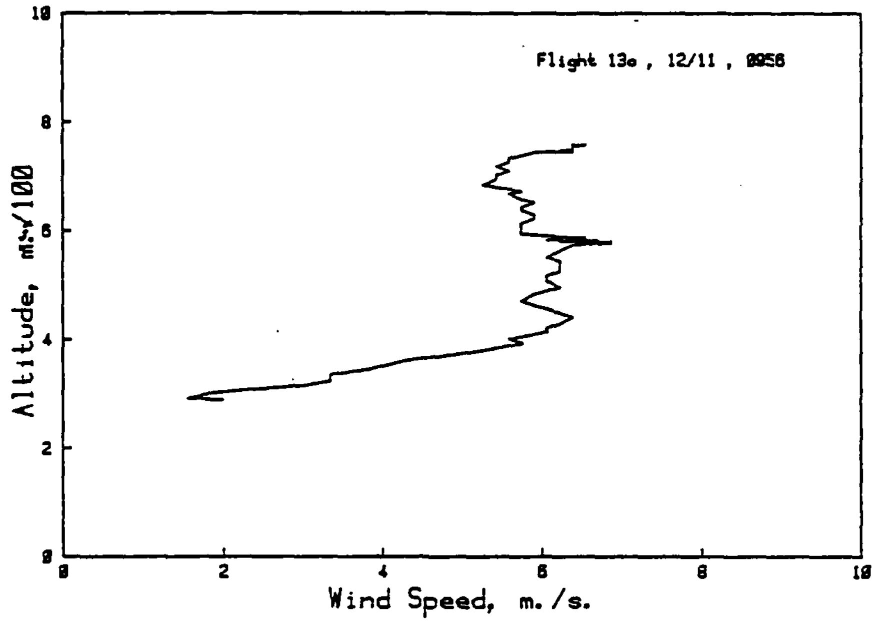
UNCLASSIFIED NRL-MR-5893 F/G 4/2 NL

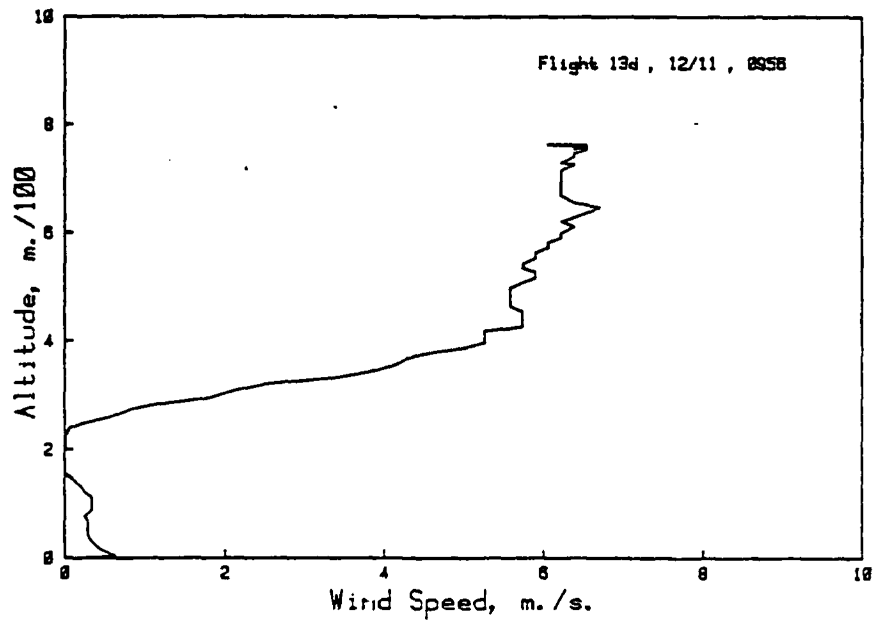


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A


Flight 13a , 12/11 , 0728
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10


Flight 13b , 12/11 , 0728
Altitude, m./100
Wind Speed, m./s.
0
2
4
6
8
10


Flight 13c , 12/11 , 0958
Altitude, m./100
Wind Speed, m./s.


Flight 13d , 12/11 , 0958
Altitude, m./100
Wind Speed, m./s.

END
3-87
DTIC