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A BALLOON OZONE MEASUREMENT UTILIZING AN OPTICAL ABSORPTION CELL AND AN EJECTOR AIR SAMPLER

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16. Abstract

Stratospheric ozone was measured, *in situ*, from a balloon utilizing an ultraviolet absorption cell. The instrument was carried to a 38-km float altitude from Holloman Air Force Base, Albuquerque, New Mexico on June 27, 1974. The ambient air was sampled by means of an aspirator attached to the output end of the optical cell. A nominal ozone distribution was obtained from 16 km to the float altitude of 38 km.

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INTRODUCTION

Ozone in the lower stratosphere has been routinely measured by electrochemical (Reference 1) and chemiluminescent (Reference 2) detectors attached to radiosondes. The upper limit of these soundings is determined by the attainable height of the balloon and the sampling efficiency of the mechanical air pump. At high altitudes the data from these sondes becomes uncertain (Reference 3). Rocket techniques are also employed to measure the vertical ozone distribution in the upper atmosphere (References 4 and 5).

The objective of the experiment described herein was to measure the diurnal variability of ozone at constant altitude above the concentration maximum. Since the variability was expected to be relatively small, the instrument was required to be precise as well as accurate. This experiment also involved the first attempt to utilize an air ejector pump (Reference 6) for continuous sampling of stratospheric air for trace gas measurements. A night launch and balloon float during sunrise had been planned, but, because of weather conditions, the launch occurred during the day.

INSTRUMENTATION

Ozone Detector

A Dasibi Corporation optical ozone monitor (Reference 7) was modified to be compatible with a balloon gondola prepared by the University of Denver (figure 1). The instrument was packaged to withstand the thermal and pressure environment of an ascent to 40 km, as well as to be compatible with the gondola electrical support system. Additional housekeeping functions were provided to assure photometric stability during the flight.

The instrument operates on the principle of differential optical absorption at 253.7 nm by the sampled ambient air of an onboard light source. The absorption cell length is 0.71m. Ambient air is brought into the cell through an ozone scrubber which effectively removes the ozone from the sampled air. The cell is illuminated by a mercury lamp where the light intensity

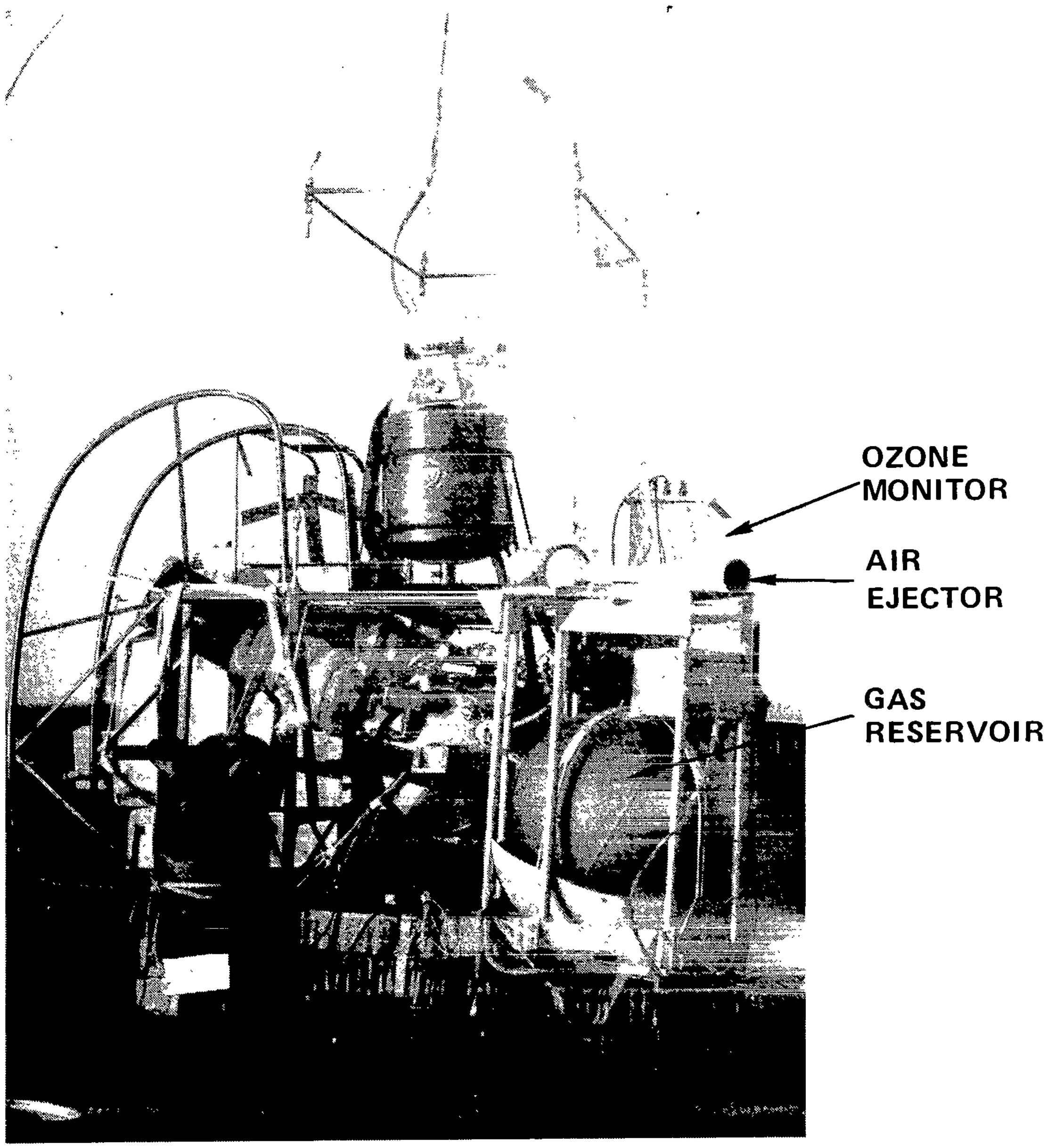

Figure 1. Balloon-borne gondola.

is measured at the end of the cell by a photodiode. The intensity of this light is converted to a frequency which is stored in a counter when the level reaches a predetermined number of counts. This level is determined by a second detector that monitors the lamp output directly, establishing a reference.

At the end of a 5-second interval, during which time the sampled air (ozone removed) has flushed the cell, a switch is activated to allow ambient air containing ozone to enter the cell continuously for an additional 5 seconds. At this time the attenuated light intensity due to ozone absorption is detected and the counter counts back down for the time determined by the light source monitor detector. The remaining counts are then proportional to the ozone. The source monitor detector removes any instability in the light source. This process may be described analytically by the following, where:

N = counts proportional to the light intensity
A = $133 cm^{-1}$ (base 10), ozone absorption coefficient at 253.7 nm (Reference 8)
L = absorption cell length = 71.0 cm
C = ozone concentration

From Beer's Law:

$$N = N_0 e^{-ALC}$$

$$N(up) = N_0, \text{ when } C = 0$$

$$N(down) = N_0 (1 - ALC), \text{ when } ALC << 1$$

Then $N(up) - N(down) = N_0 ALC$, which is proportional to the instrument output recorded during the flight. The instrument gain is set so that $N_0 AL = 1$. Therefore, the output is directly proportional to ozone concentration with corrections for the optical cell temperature and pressure during the flight.

Air Sampler

Devices for air sampling at an altitude of 40 km are virtually nonexistent. Large fans become inefficient above 30 km and cryopumping is impractical if large air samples are required. An air sampler utilizing the aspirator principle was selected for this experiment because it could move substantial amounts of air near 40 km, and had been flown previously for stratospheric carbon^{14} measurements (Reference 6). The principle feature of this unit is a jet of high-velocity primary gas (nitrogen for this experiment) which is ejected into a mixing tube, expands, and, by turbulent exchange of momentum, creates a pressure drop at the back end of the instrument. This causes ambient air to be drawn through the instrument. A diagram of the flight package is shown in figure 2 (flowmeter and manometer were utilized in an altitude test chamber but not in flight). The thermoconductivity-type flowmeter created no additional pressure drop in the system, but became insensitive to flow above a simulated altitude of about 35 km. Instrument pressure drop becomes critical to instrument performance and subsequent data reduction since this value becomes comparable to the ambient pressure. For example at 30 km and 38 km the instrument pressure drop was 0.036 N/m^2 and 0.027 N/m^2, respectively while the ambient atmospheric pressure at these levels is 0.12 N/m^2

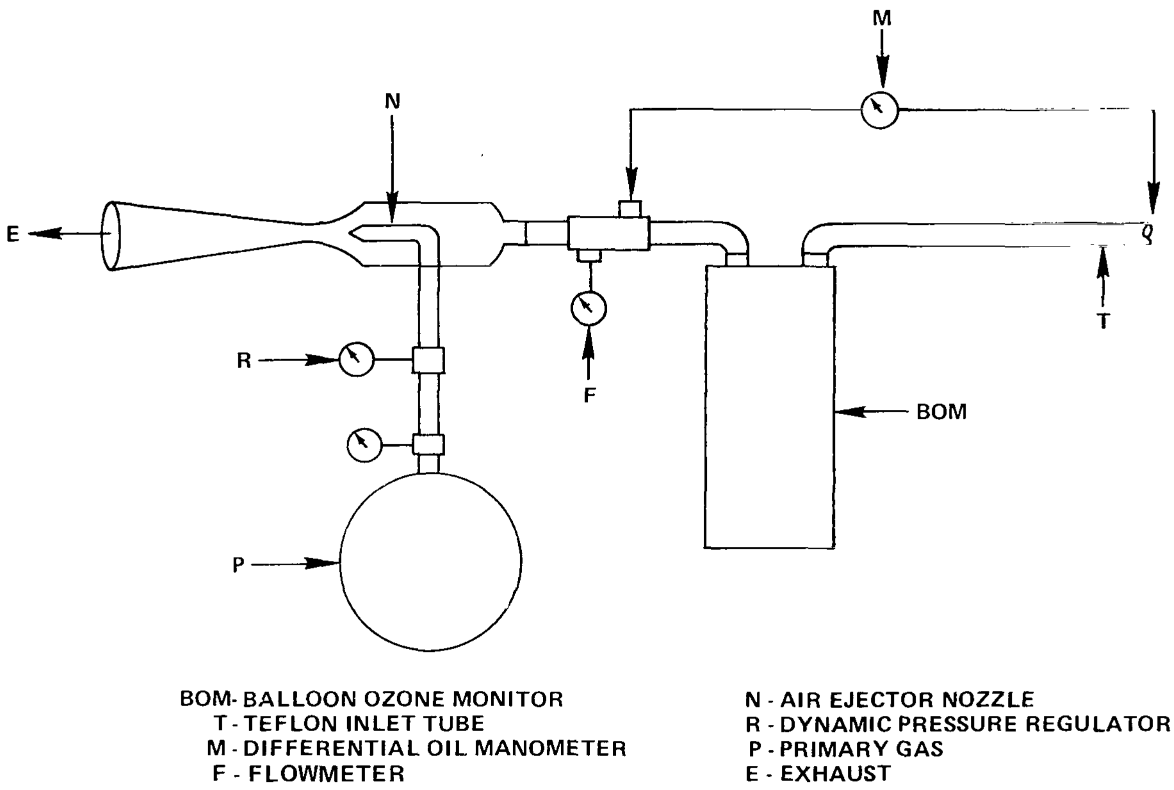

Figure 2. Schematic of balloon-borne ozone experiment.

and 0.037 N/m^2, respectively (100 mb = $1 N/m^2$). The pressure drop across the monitor as a function of altitude is shown in figure 3 and was used in the flight data reduction. This pressure drop is a function of the dynamic pressure set at the injector nozzle. The optimum dynamic pressure represents a trade-off in air sampling time and flow rate. A 4-hour sampling time was achieved with a 9.07-kg (20-lb) dynamic pressure and a reservoir pressurized to 1315.42 kg (2900 lbs).*

FLIGHT RESULTS

A $3 \times 10^{+5}$ -cubic meter balloon was launched from Holloman Air Force Base, Albuquerque, New Mexico on June 27, 1974, at 0715 MDT with an average ascent rate of 0.27 km/min to 38 km, and began descent at 1230 MDT. Ascent ozone data began at 16 km, when barometric switches activated the air sampler. A tabulation of measured ozone density as a function of altitude is shown in table 1. Figure 4 shows this measurement and a model compiled by Krueger and Minzner.† The ozone concentration remained essentially constant at the ceiling altitude

*Pressure gage reading.

†Krueger, A. J. and R. A. Minzner, "A Mid-Latitude Ozone Model for the 1976 U. S. Standard Atmosphere," accepted for publication by *J. Geophys. Res.*, Oceans and Atmospheres, 1976.

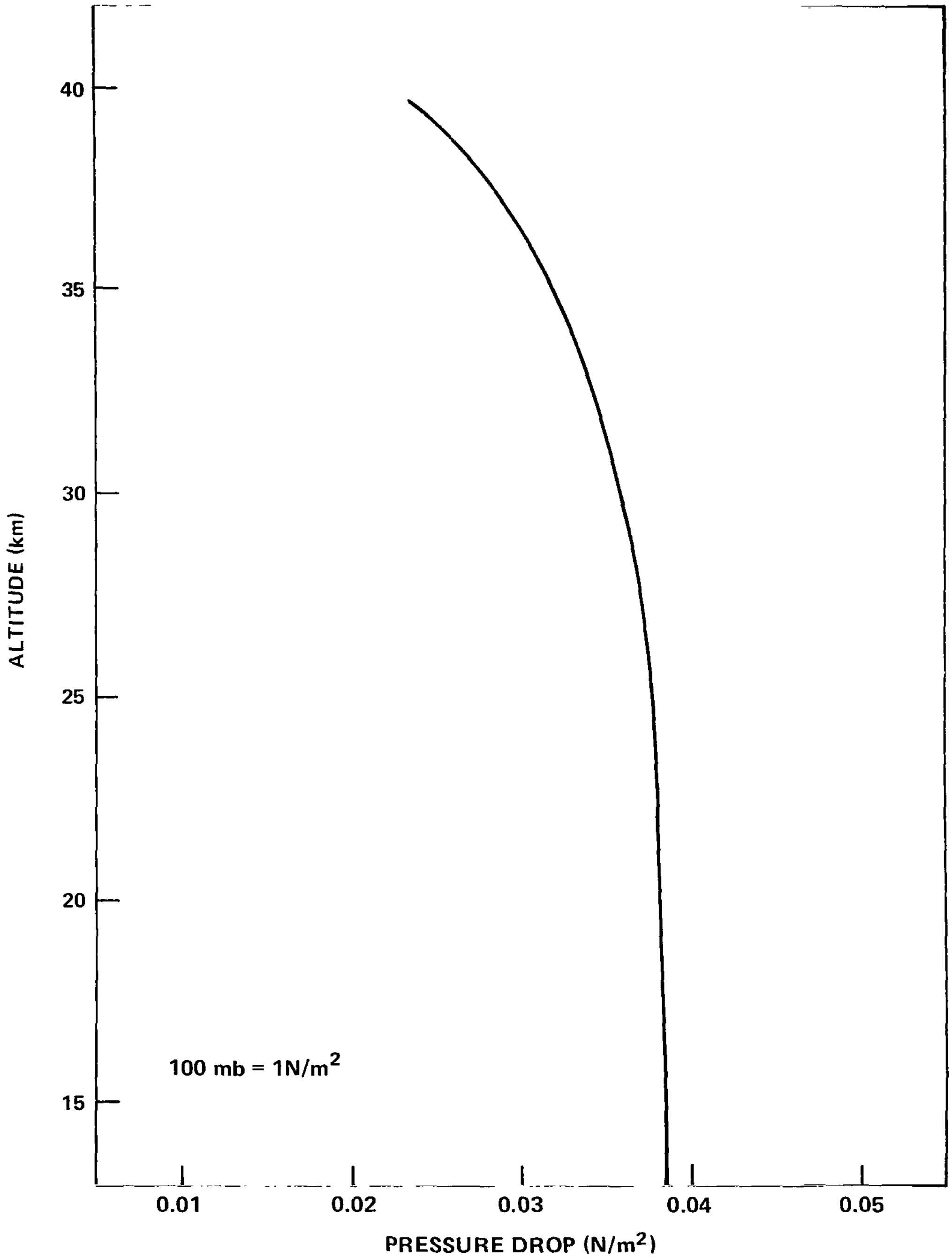

Figure 3. Pressure drop in optical ozone monitor with 9.07-kg (20-lb) dynamic pressure at air ejector nozzle.

Table 1
Ozone Density versus Altitude

Altitude (km)	Ozone Density (molecule/m^3) x 10^{-18}	Altitude (km)	Ozone Density (molecule/m^3) x 10^{-18}
17.0	1.12	28.0	3.98
17.5	1.58	28.5	3.82
18.0	2.29	29.0	3.39
18.5	3.20	29.5	3.19
19.0	4.08	30.0	2.97
19.5	3.58	30.5	2.80
20.0	3.94	31.0	2.57
20.5	4.57	31.5	2.32
21.0	4.59	32.0	2.17
21.5	4.53	32.5	2.01
22.0	4.45	33.0	1.83
22.5	4.64	33.5	1.75
23.0	4.64	34.0	1.51
23.5	4.69	34.5	1.46
24.0	4.85	35.0	1.41
24.5	4.71	35.5	1.22
25.0	4.90	36.0	1.09
25.5	4.79	36.5	1.09
26.0	4.72	37.0	0.899
26.5	4.56	37.5	0.806
27.0	4.37	38.0	0.693
27.5	4.10		

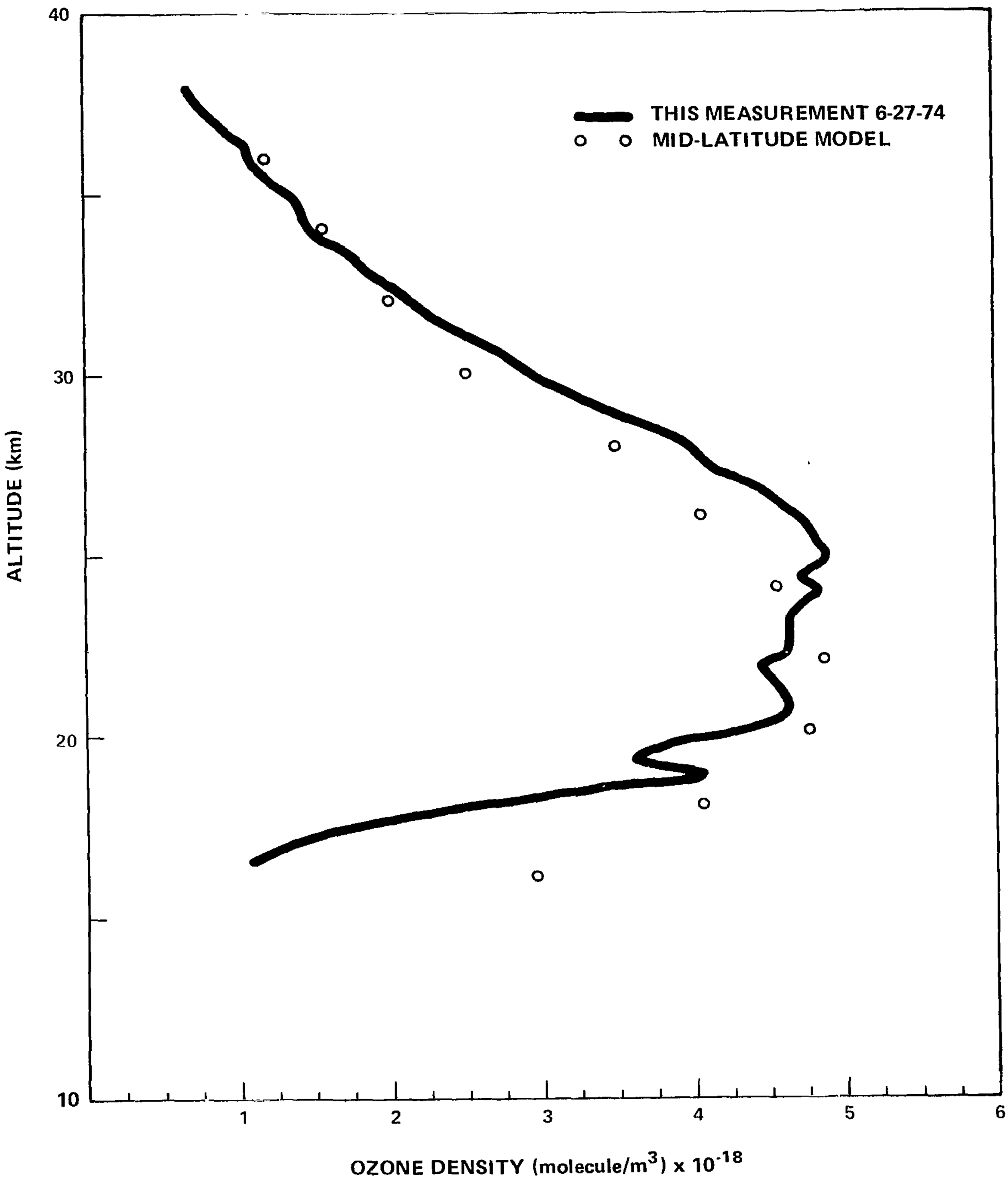

Figure 4. Ozone density versus altitude.

until about 1200 MDT at which time the balloon support system was shut down. No descent data were obtained.

Errors due to uncertainties in the flow and unaccountable ozone losses in the inlet system above an altitude of 35 km cannot be evaluated for this flight. The altitude chamber tests with the aspirator were not conclusive above this altitude since the flowmeter became insensitive. Instrument pressure drop data and extrapolation of flow data obtained in the altitude chamber to 40 km indicated there would be sufficient volume flow to ventilate the optical cell. Ozone fluxes, but not pressures expected in flight, were simulated on the ground and approximately 15-percent ozone losses were measured in the Teflon inlet system. These losses were taken into account in the flight data reduction, but could be greater at lower pressures because of higher diffusion rates. In either case, insufficient flow or additional ozone losses would cause an undermeasurement of the ambient ozone by an additional amount. Below about 35 km, where flow data are available, the combined systematic error is 13 percent. This value is derived from the square root of the sum of the independent errors or uncertainties in the following: electronics (signal to noise, gain, linearity, etc.), the measured 15 percent loss in the inlet system, ozone scrubber efficiency, leaks in the inlet system, absorbtion cell temperature, and pressure drop determined from the altitude chamber test. The pressure drop error is the most significant. Utilization of a suitable pressure gage would result in an improved measurement accuracy better than 10 percent.

Comparison of the data with the reference model shows reasonably good agreement. The ozone distribution below the maximum is highly influenced by dynamical processes, in particular, the height of the tropopause. The measurement was performed near 32° N in June, while the model represents a seasonal average at a latitude of 45° N. The tropopause was near 16.5 km at the time of the measurement, thus accounting for the lower measured values below the ozone maximum.

CONCLUSION

An *in situ* measurement of ozone was accomplished on a balloon platform to an altitude of 38 km, utilizing an air ejector to provide the ambient air sample. The measurement is absolute since it is based on the attenuation of light by ozone in spectral region where the absorption coefficient is well established. The flight resulted in a vertical ozone distribution which is comparable with levels of ozone measured by other techniques. Errors in the data, mainly near floating altitude, are due to uncertainties in providing adequate flow and unaccountable losses of ozone in the inlet system. These uncertainties could be removed by additional altitude chamber tests and the use of a more sensitive flow measurement.

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