

EPSILON LABS INC BEDFORD MA
STRATOSPHERIC AEROSOL MEASUREMENTS. (U)
DEC 80 H A MIRANDA

F/6 4/1

UNCLASSIFIED

AFGL-TR-80-0366

F19628-79-C-0130
6 NL

104
42 A
08/78

END
DATE
FILMED
5-8
DTIC

AFGL-TR-80-0366

STRATOSPHERIC AEROSOL MEASUREMENTS

Henry A. Miranda, Jr.

EPSILON LABORATORIES, INC.
4 Preston Court
Bedford, MA 01730

DECEMBER 1980

Final Report for period July 10, 1979 through October 30, 1980.

Approved for public release; distribution unlimited.

Air Force Geophysics Laboratory
Air Force Systems Command
United States Air Force
Hanscom AFB, MA 01731

LEVEL II

12

DTIC
ELECTE
APR 14 1981

E

DTIC FILE COPY

81 4 14 . 39

Qualified requestors may obtain additional copies from the Defense Technical Information Center. All others should apply to the National Technical Information Service.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

19 REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER 18) AFGL-TR-80-0366	2. GOVT ACCESSION NO. AD-A097	3. RECIPIENT'S CATALOG NUMBER 446	
4. TITLE (and Subtitle) 6) STRATOSPHERIC AEROSOL MEASUREMENTS		5. TYPE OF REPORT & PERIOD COVERED 9 Final Report 10 Jul 1979 - 30 Oct 80	
7. AUTHOR(s) 10) Henry A. Miranda, Jr.		8. CONTRACT OR GRANT NUMBER(s) 13) F19628-79-C-0130	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Epsilon Laboratories, Inc. 4 Preston Court Bedford, MA 01730	12) 23	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 668703A1 17 03	
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory Hanscom AFB, MA 01731 Monitor: William K. Vickery/LKD	11	12. REPORT DATE December 1980	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 24	
		15. SECURITY CLASS. (of this report) Unclassified	
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Stratosphere SAGE Solar extinction Aerosols Balloonborne instrumentation Size distributions Vertical aerosol profiles Particulate sizing spectrometer Aerosol concentration			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Epsilon/AFGL balloon-borne aerosol sizing spectrometer was flown on a stratospheric balloon flight on 27 May 1980 over Holloman AFB, N.M., in an attempt to correlate with the SAGE four-channel solar limb extinction experiment. Useful aerosol altitude concentration profiles were obtained within several hundred Km and several hours of the SAGE overpass subsegment point. The data indicate that particles greater than 0.4 micron diameter are absent above the tropopause (14 Km in this instance). Speculations regarding a			

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

370761

~~UNCLASSIFIED~~

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Continued from Block 20

possible explanation for this effect are offered.

Predictions of SAGE tangential extinction vs. altitude from aerosols alone have been derived from the data, and are included to facilitate correlation and comparison with those derived from aerosol models currently in vogue.

TABLE OF CONTENTS

1.	INTRODUCTION	1
1.1	System Operation	2
2.	VALIDITY OF DATA	5
2.1	Sampling Flow Correction	5
2.2	Sampling Efficiency vs. Particle Size	6
3.	RESULTS	7
	Acknowledgements	19
	References	20

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Mail and/or Special
A	

1. PROGRAM OBJECTIVES

The objectives of this program were to refurbish the Epsilon/AFGL balloon-borne aerosol sizing spectrometer, to prepare the instrument for flight, to collect aerosol data on a series of stratospheric flights conducted from Holloman AFB, New Mexico, and to reduce and analyze the data in a preliminary fashion. The instrument, featuring exceedingly high sizing resolution capable of resolving particle diameters differing by as little as 0.01μ diameter in the range between 0.25μ and 1.0μ diameter, had been under development over a period of several years and, having been flown on previous occasions, is described elsewhere (Ref. 1,2).

Because of the ongoing nature of the development, it was planned to introduce certain improvements in the hardware. One of these was to include a PCM telemetry link utilizing the AFGL balloon-borne telemetry system as a back-up to the on-board recorder. During flight, the telemetry data stream could then be processed by the AFGL PDP-11 computer at the balloon control site to provide the scientist with real-time information on background levels, total aerosol counting rate and other useful diagnostic information such as flow rate, temperatures, etc. The function of this aspect was to serve as an aid in making decisions during the balloon flight as to whether to depart from the planned flight schedule to seek new scientific targets of opportunity that might develop which otherwise would be missed entirely.

A second improvement related to the airflow sampling hardware. It was planned to discard the critical orifice and replace this component with a dynamically controlled pump whose volumetric sampling rate could be varied to offset evacuation/filling flow effects that occur as a result of balloon rise rate and/or fall rate. However, owing to the fact that the instrument had lain dormant for the past five years, the refurbishment effort was larger than anticipated. Because of this, as well as the need to explore sampling efficiency effects (described in paragraph 2.2), the installation of this modified flow system was not accomplished.

The first of two planned flights was to be launched on 27 May 1980. On this occasion the SAGE Spacecraft would be viewing within a few hundred Km of our projected sampling region at local sunset, thereby providing an opportunity of correlating our results with the solar tangential extinction

data collected by the spacecraft instrument, in a fashion similar to the "ground truth" measurement (Ref. 3). At the same time, the Ames instrumented aircraft, whose mix of instruments included a wire impactor, was to have established rendezvous with our balloon, and subsequently flown to Wyoming to rendezvous with Rosen's payload which was being used as a "ground truth" measurement for the SAGE data. Unfortunately, the Mt. St. Helens's volcanic eruption interposed, so that the Ames aircraft was diverted.

1.1 System Operation

One successful flight was conducted on 27 May 1980. The balloon was launched as late as possible (0700h MST; 1300h GMT) prior to clearing of the flightline for normal daylight operations of the airbase. This accommodated the desire to minimize the separation in both space and time between the balloon stratospheric in-situ sampling trajectory and that of the SAGE spacecraft sub-tangent region at local sunset. From this standpoint a sunrise rendezvous on 27 May would have been preferable, as the geometry of the latter would have resulted in a lesser separation. However a sunrise turn-on, owing to the associated colder spacecraft temperatures, would have involved higher power drains on the aging spacecraft system (which had already experienced component degradation), and therefore was precluded.

The balloon flight followed quite closely the intended upleg altitude profile, rising for the first 22 minutes at a rate of about 730 ft/min to the 20 Kft level, thence slowing to average rise rates of 340 ft/min up to the 38 Kft level, 310 ft/min to 68 Kft, and 250 ft/min to the 84 Kft level during the ensuing 200 minutes. The remaining rise to float altitude of 94 Kft was approached at a much slower rise rate (about 90 ft/min). Meanwhile, the general atmospheric air movement carried the balloon first in a northeasterly direction below the tropopause, (located at 14 Km; 46 Kft) in a northerly direction through the transition region, and then in a direction west by northwest in the stratosphere. Pertinent information relating to these flight parameters are listed in Table I below.

TABLE I

Balloon flight parameters for RV-1 flight on 27 May 1980

Time		Altitude		Balloon location		Remarks
MST	GMT	Kft	Km	Lat (N)	Long (W)	
0700	1300	4.0	1.22	33°00'	106°08'	At surface
0800	1400	20.0	6.1	33°18'	105°49'	On northeasterly track
0830	1430	37.0	11.3	33°32'	105°32'	" " "
0900	1500	45.0	13.72	33°41'	105°19'	Commence north by northeasterly track
-	-	-	14.0	-	-	Level of Tropopause
0915	1515	50.5	15.4	33°50'	105°14'	Farthest eastward advance of balloon
0930	1530	58.5	17.8	33°55'	105°19'	Commence North by northwesterly track
1030	1630	80.7	24.6	33°56'	105°30'	Commence West by northwesterly track
1100	1700	89.84				Continue on " " " " "
1130	1730	93.34	28.45	33°58'	105°48'	" " " " " "
1144	1744	94.14	28.7	34°00'	105°58'	" " " " " " at float
1200	1800	"	"	34°02'	106°09'	" " " " " "
1230	1830	"	"	34°05'	106°23'	" " " " " "
1300	1900	"	"	34°08'	106°40'	" " " " " "
1325	1925	"	"	34°11'	106°48'	" " " " " "
1949	0149	-	25	34°00'	102°54'	SAGE satellite sub tangent point

We have not as yet obtained information concerning the exact SAGE satellite sub tangent point track for this sunset pass. However, on the basis of gross orbital information (inclination: 55°; altitude: 548-660 Km; and period: 96.8 min), it can be shown that this point track advances along the Earth-Sun terminator, which is tilted about 20° from the meridian (or along ENE by WSW direction) toward the end of May, at a rate of about 4.3 Km/sec. Thus, during the approximate 20-second period occupied by the spacecraft in sweeping through the altitude profile of interest, the satellite sub tangent point covers a distance along this direction of about 90 Km. Its location (for the 25 Km level) at local sunset (about 1949h MST) was predicted to be at 34°N Lat, 102°54' W Long. This point was approximately 207 Km from the distance of closest approach of the balloon (which applies to the 14 Km level). However it should be kept in mind that this distance is not necessarily meaningful owing to the temporal and spatial factors, and the local wind velocity. A perhaps more meaningful parameter is the separation between the

location of a given parcel of (previously sampled) air at the subsequent time of local sunset, and that of the spacecraft sub-tangent "point". This separation distance can be estimated for each altitude on the assumption that the wind velocity vector measured at the time of sampling (and at the altitude of sampling), remained unchanged during the ensuing elapsed time till sunset. The parameters used for calculating these respective separation distances are listed in Table II.

TABLE II

Calculated separation between sampling point
and satellite sub-tangent point at local sunset

<u>Altitude</u> (Km)	<u>Time increment</u> (MST)	<u>Average</u> <u>Windspeed</u>	<u>Wind</u> <u>Direction</u>	<u>Approximate extrapol-</u> <u>ated location of air</u> <u>parcel at local sunset</u>		<u>Sep</u> <u>Dist.</u>
6.1-13.7	1430h-1500h	1.11 Km/min	From SW	36°50'	100°30'	380 Km
13.7-15.4	1500h-1515h	0.80 "	" SW	36°20'	103°00'	250 Km
15.4-17.8	1515h-1530h	0.80 "	" SE	36°40'	106°20'	410 Km
17.8-24.6	1530h-1630h	0.31 "	" ESE	34°10'	106°40'	330 Km
24.6-28.4	1630h-1730h	0.47 "	" ESE	34°12'	106°54'	370 Km
28.4-28.7	1730h-1900h	0.89 "	" ESE	34°25'	107°35'	420 Km

The intended flight altitude profile was to be roughly symmetric in time with respect to float altitude, the downleg portion commencing about one half hour after reaching float. Since the capacity of the on-board tape recorder and battery power source was about 10 hours, the flight was scheduled to terminate at about 1700h MST. The flight was prematurely terminated about one hour after reaching float altitude owing to a rupture in the helium release mechanism electrical circuitry.

During the last hour of the flight, the normal heating of the balloon contents caused continued expansion and resultant further buoyant rise. The associated prolonged solar heating of the payload contents, coupled with the reduced conductivity of the continually diminishing atmospheric density, resulted in accelerated temperature rise of the laser housing. Fortunately, parachute recovery conditions (in particular, the lower tropospheric wind vector) permitted termination of the flight early enough to prevent permanent damage to the laser and the associated high voltage circuitry. Successful recovery of the payload was effected by carefully choosing the termination time so as to place the payload touch-down point in terrain that was convenient for recovery.

Plans for a second flight were cancelled upon discovery that the volumetric sampling flow reduced with an increase in altitude. Tests conducted after the flight in the environmental chamber indicated that this was repeatable, and also that the same effect could be reproduced with the spare pump. Despite all subsequent attempts to account for this effect in terms of various hypotheses (outgassing of volatile contaminants, component malfunction, etc.), no satisfactory explanation has emerged. In spite of this difficulty we were able to satisfy ourselves that the data collected during this flight were entirely valid (see Paragraph 2.1).

The telemetry link functioned satisfactorily in that the anticipated diagnostic information was received. However, it was found in pre-flight preparations that the data encoder sampling rate selected for this particular flight produced data bit rates that exceeded the data-handling capability of the PDP-11 hardware/software system. As a result, the real-time scientific information that could be presented to the scientist was unsatisfactory. On the other hand, the diagnostic data presentation format was adequate and served its purpose well.

A Tectronix 7000 series oscilloscope operated in X-Y storage mode was made available to us as a back-up to the PDP-11 system. This functioned well enough to indicate that the concept of presenting the requisite real-time scientific data is viable, given that the computer is provided with an adequate hardware/software interface.

As a further check on the telemetry function, the telemetered data, recorded on the TM tape in 10-bit digital form, was processed at the WSMR computer by stripping out the aerosol counter data to produce a 9-track IBM-360 compatible format tape. This latter tape was prepared; but priority considerations have not permitted a thorough check of this tape to ascertain the sequence of the quality of the data transfer from reformatting operations.

2. VALIDITY OF DATA

2.1 Sampling Flow Correction

The possibility that the unexplained occurrence of lower sampling flow rates at increased altitudes might have degraded the validity of the particle sizing output because of resultant pulse width stretching and related pulse height reduction associated with peak detection gating effects, was explored. A careful re-examination of experimental laboratory data collected several

years ago was conducted. This previous work involved the simulation of reduced sampling flow rate effects by slowing the transit of particles of different known sizes across the sensing gap. These tests indicated that appreciable degradation of particle sizing accuracy does not occur until the volumetric sampling flow rate is reduced to a value less than about $1/3 \text{ cm}^3/\text{sec}$. Below this value, a correction factor which is a function of the output particle size would have to be utilized. Since all data reported here were collected at higher sampling flowrates, it was not necessary to apply a flow rate correction factor.

2.2 Sampling Efficiency vs. Particle Size

Previous stratospheric data collected with this device indicated that the observed aerosol size distributions were characterized by exceedingly high slopes (Ref. 4). This raised some questions among members of the scientific community with regard to the sampling efficiency of our device (Ref. 5). These questions contained the implicit assumption that our device would somehow result in larger particles being selectively lost in the sampling tube walls as the sampling tube entrance inlet moves vertically through the atmosphere on its upleg or downleg portion of the flight.

Heuristic calculations were performed to examine this possibility on theoretical grounds. These indicated that such an effect was extremely unlikely. However since these calculations necessarily involved rather severe simplifying assumptions, and since more detailed calculations would have involved significant additional expense, it was decided to resort instead to experiment. Accordingly, an apparatus was designed and fabricated to simulate the flow of air across the inlet tube.

The apparatus consisted of two annular cylinders, the inner of which could rotate with respect to the outer one. Rotation was induced with the aid of a commercial magnetic stirrer arrangement and a small magnet firmly attached to the inner cylinder. Viscosity of the air in contact with the smooth surface of this inner rotating cylinder would set up a cylindrical flow field within the annular region. The annular airspeed as a function of radius was measured with a specially fabricated and calibrated pilot tube.

The sampling tube was inserted within this region at a point where the lateral airspeed was 170 cm/sec (which corresponds to a balloon rise and/or

fall rate of about 340 ft/sec). and the system was sealed, evacuated and brought to atmospheric pressure (after introducing 1 cm³ of room air to yield a particulate concentration of about 1 per cm³ comparable to that observed at elevated altitudes) with dry, filtered nitrogen so as to provide a particle-free ambient.

The inner cylinder was spun to the predetermined speed, and the air was sampled continuously, (during which the pressure in the chamber was reduced accordingly, owing to the hermetic seal). At the end of a one-minute sampling period approximately, the rotation was stopped, and as soon as the airspeed had reduced to zero, the second sample was recorded. Five such alternate samples were collected; meanwhile the total pressure was reduced by about 0.4 atmosphere.

The results are depicted in Figure 1. These indicate that no significant difference in both concentration as well as size distribution could be detected over the range of pressures explored. From this it may be concluded that the apprehensions prevalent in the community with regard to sampling efficiency effects are largely without basis in fact.

3. RESULTS

The data have not been fully reduced as yet. However, certain salient features have become evident from this preliminary analysis that are of considerable significance and hence of interest to the scientific community. These are summarized here.

As seen from Figure 2, which depicts the integral output for three sizes ($\geq 0.3\mu$ diam, $\geq 0.4\mu$ and $\geq 0.5\mu$ respectively) as a function of altitude, it appears that above 14 Km, the location of the tropopause, all trace of particles greater than 0.4μ diameter disappears. These results are being reported in the open literature (Ref. 6) in the hope of generating a substantive discussion of the size distribution discrepancies between our data and those derived with other instrumentation.

Since there has been relatively little injection of particulates into the stratosphere within recent years, and since the terminal fall rate of a 0.4μ diameter particle of density = 2 is a few Km/year at 18 Km, the absence of all such particles in the stratosphere, (i.e., above 14 Km) is plausible. The presence of 0.3μ particles, (under this hypothesis) would

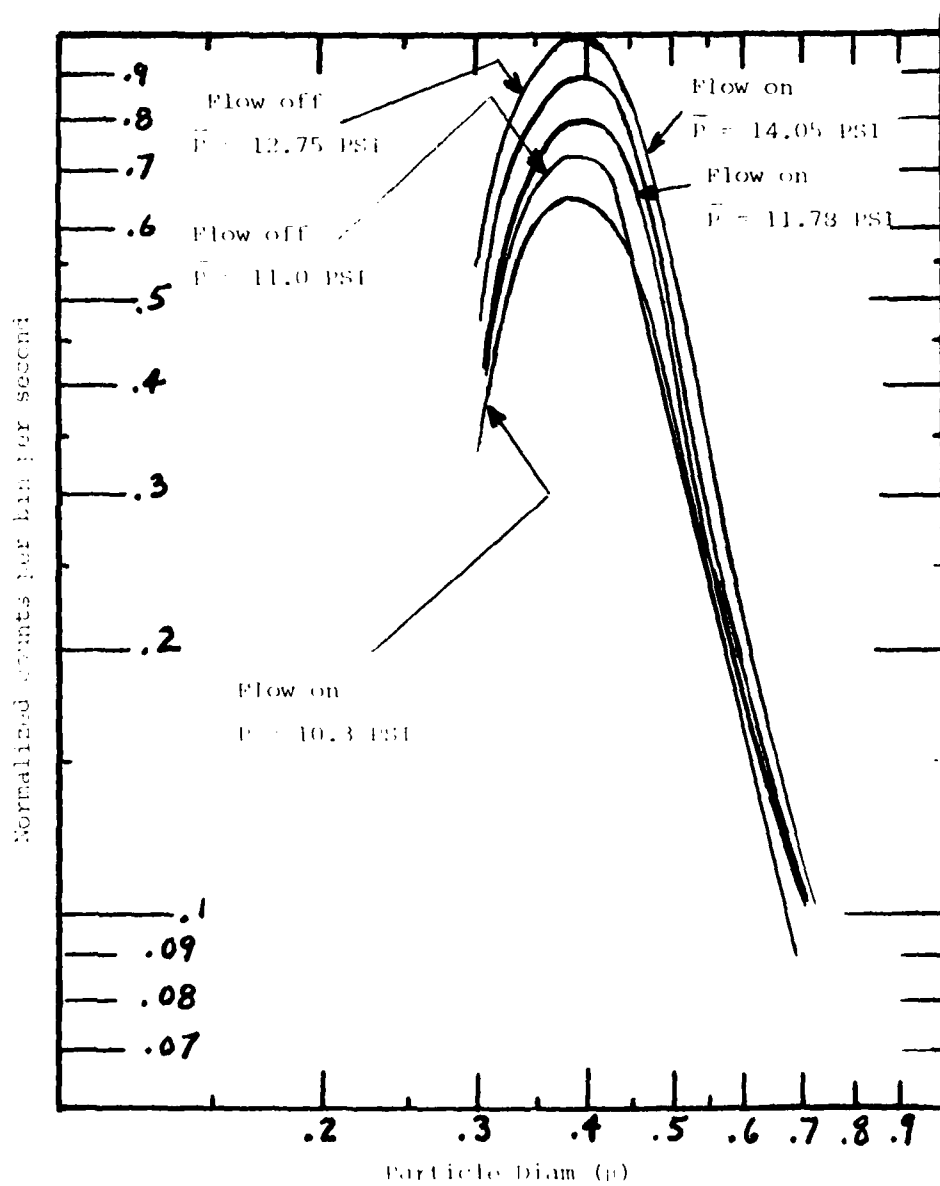
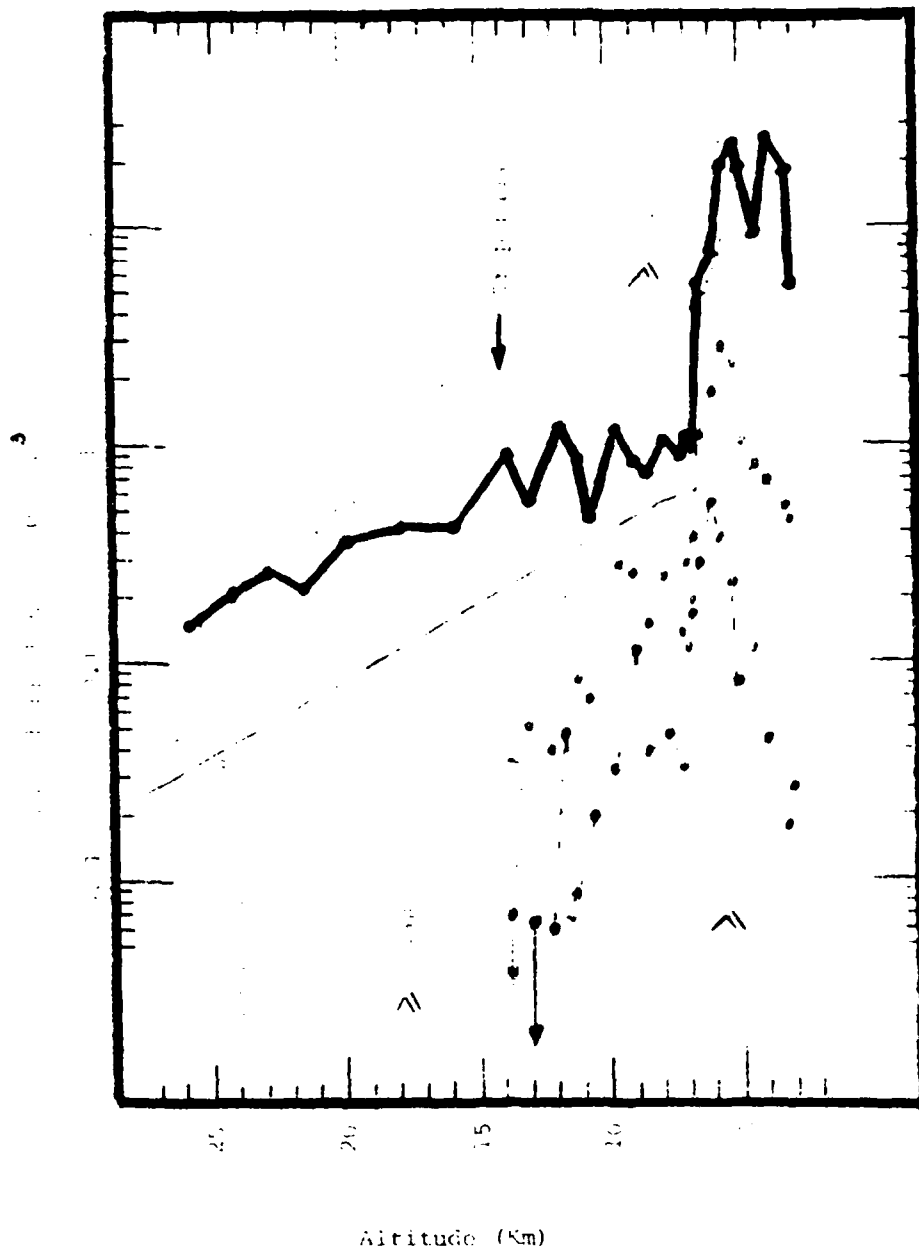


Figure 1: Annular Flow Test Results
(Diluted room air)
April, 1980



then seem to indicate that a separate source for these smaller particles is operative, at least in the particular air mass sampled in these measurements. It should be noted that the Mt. St. Helens debris cloud did not pass anywhere near our location (Ref. 7). Thus our measurements may safely be said to represent quiescent stratospheric conditions.

On the basis of our aerosol size distributions versus altitude, we have been able to predict the tangential solar extinction of the SAGE measurements at all four wavelength channels (namely: 1.0μ , 0.6μ , 0.45μ and 0.385μ), versus altitude. This is shown in Figure 3. The main purpose of this exercise is to determine whether the size distributions characteristically observed by our instrument correlate well with spacecraft data, as a means of substantiating the validity of our results. These predicted extinction values have been forwarded to messrs M. P. McCormick and L. McMasters; and we are awaiting the SAGE raw solar extinction data in exchange.

If our data are substantiated, greater credence can be given to our contention that these extinction predictions will differ considerably from model values (Ref. 8) presently incorporated in the data reduction algorithm for inverting the SAGE solar extinction data to derive lateral and vertical profiles of NO_2 and O_3 concentration. The algorithm utilizes the 1-micron channel as a measure of the aerosol contamination (since at this wavelength neither of the above two minor atmospheric constituents absorbs appreciably); and contribution to the extinction in the remaining three wavelength channels arising from aerosols is derived from an assumed size distribution model which differs considerably from that which we have observed.

As might be expected from the steeper size distribution that are observed by our instrument, the corresponding SAGE aerosol extinction versus wavelength would be correspondingly greater at shorter wavelengths (or conversely, lesser at longer wavelengths). Other important implications of steep size distributions (e.g., the strong impact upon source/sink exchange between solid and vapor state of volatile atmospheric constituents) can also readily be envisioned.

Finally, the altitude profiles for depicting the absolute particle concentration each of 7 adjacent 0.01 micron diameter sizing bins covering the range between 0.30 and 0.36 microns diameter, inclusive, are presented in Figures 4 through 10, respectively. Superimposed on each is the profile of

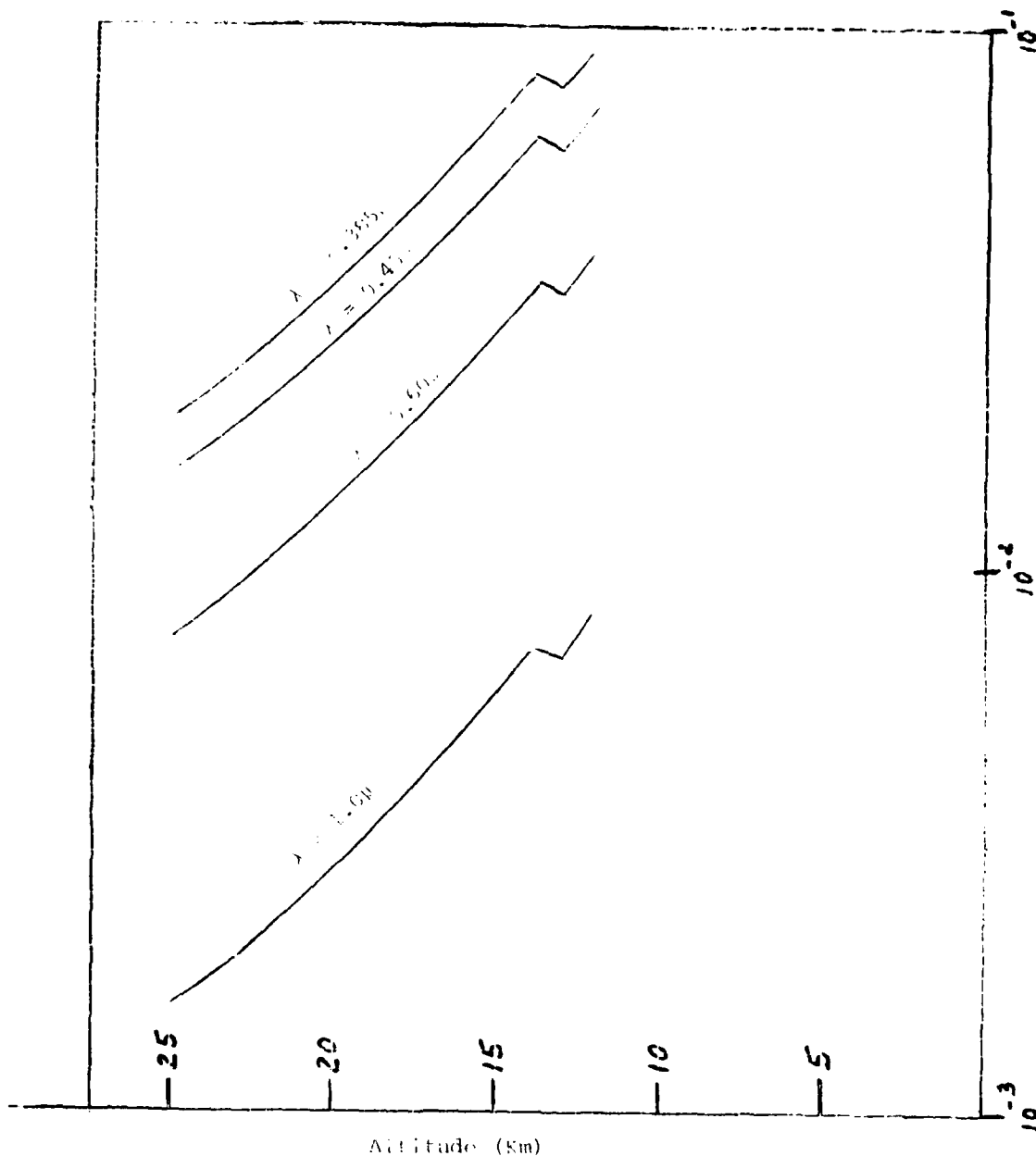


Figure 3: Predicted altitude profiles of tangential extinction due to aerosols alone ($>0.3\mu$) for the SAGE solar viewing photometers on 27 May/80 in the vicinity of Holloman AFB, N. M. (105° - 106° W, 33° - 33.5° N)

RV-1 27May/80

Launch: 0700 local

0.30 μ Diam.

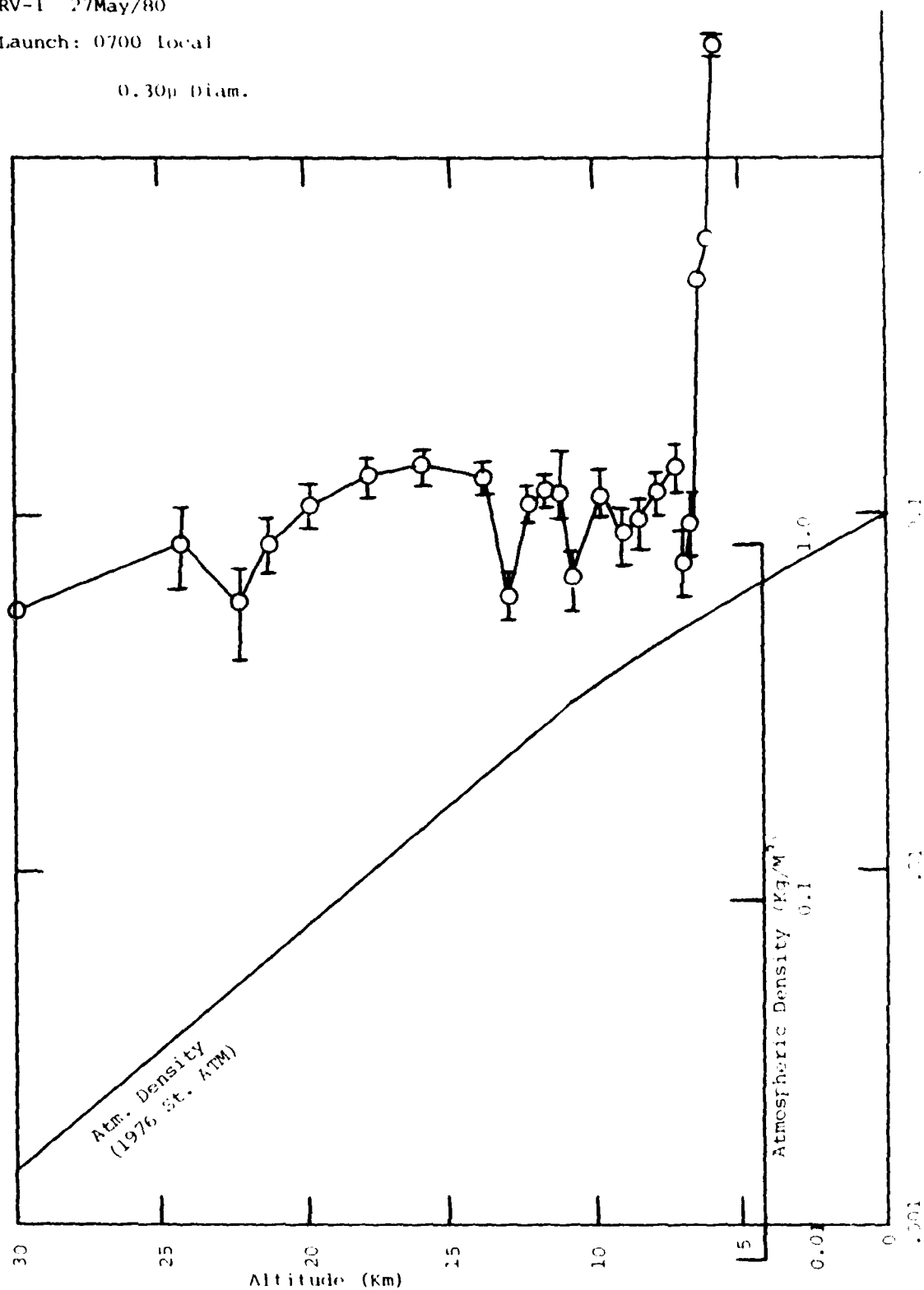


FIGURE 4: Altitude profile of 0.30 micron particle concentration.

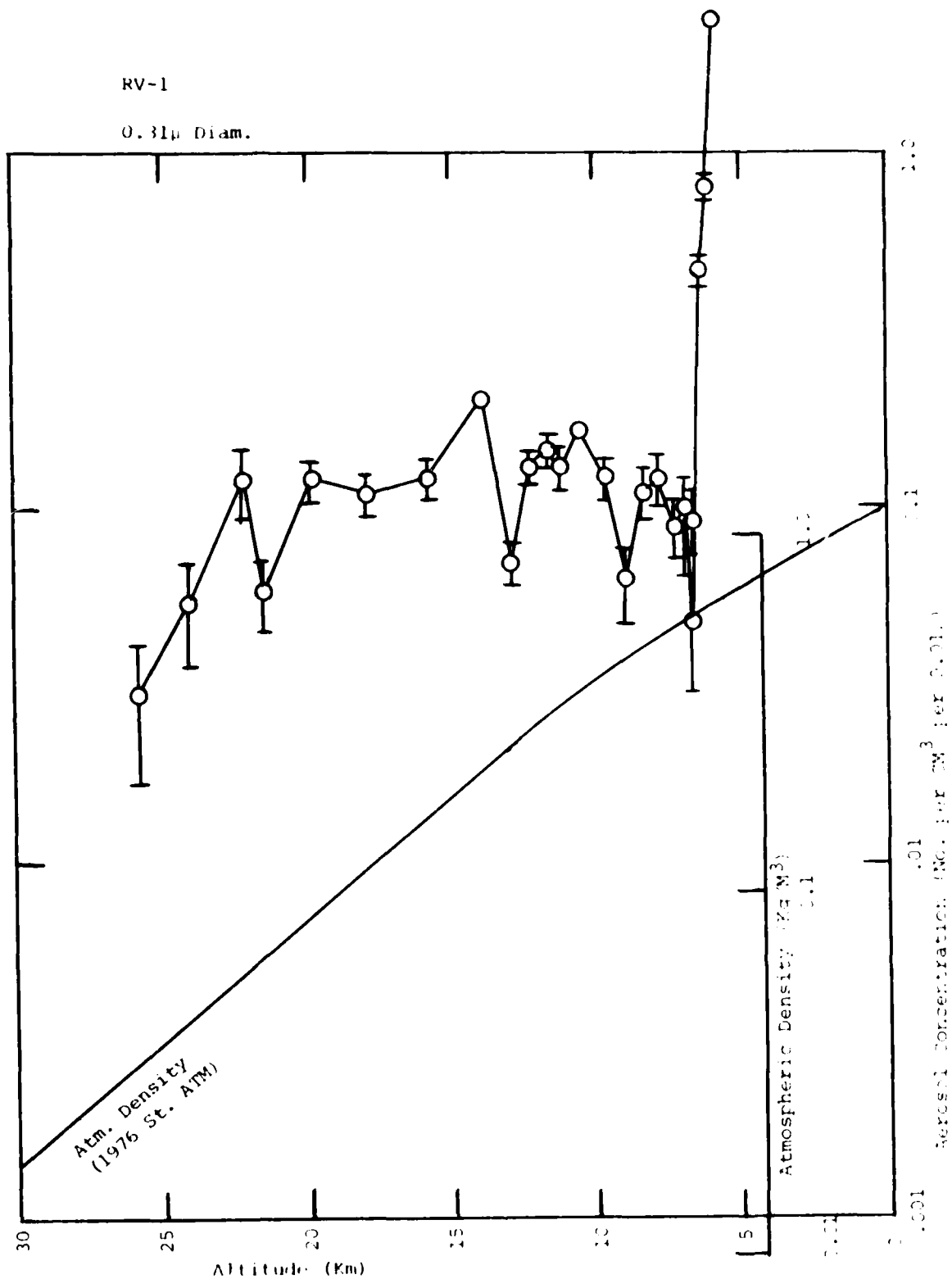


FIGURE 5: Altitude Profile of 0.31 micron Particle Concentration

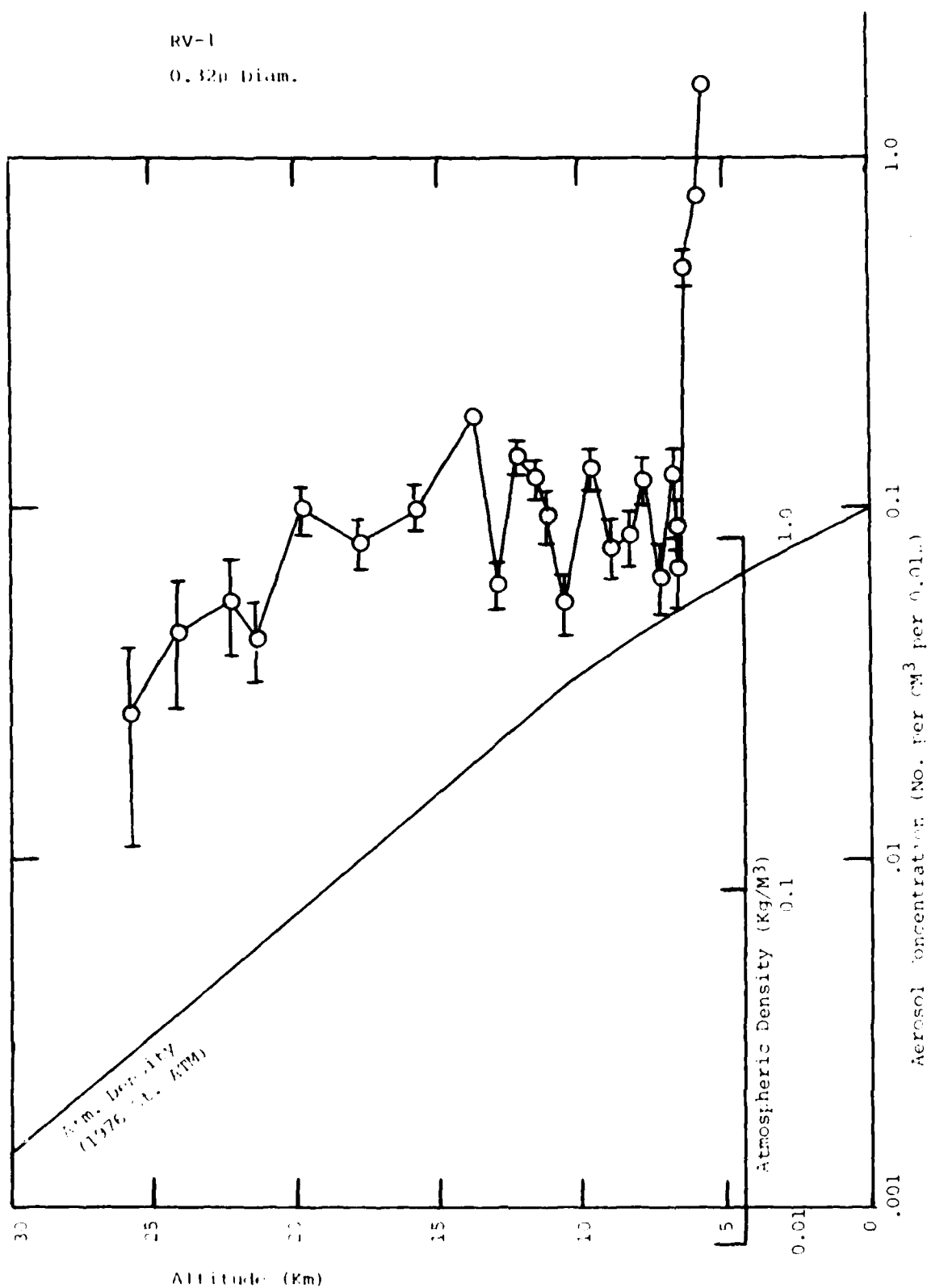


FIGURE 6: Altitude profile of 0.32 micron Particle Concentration

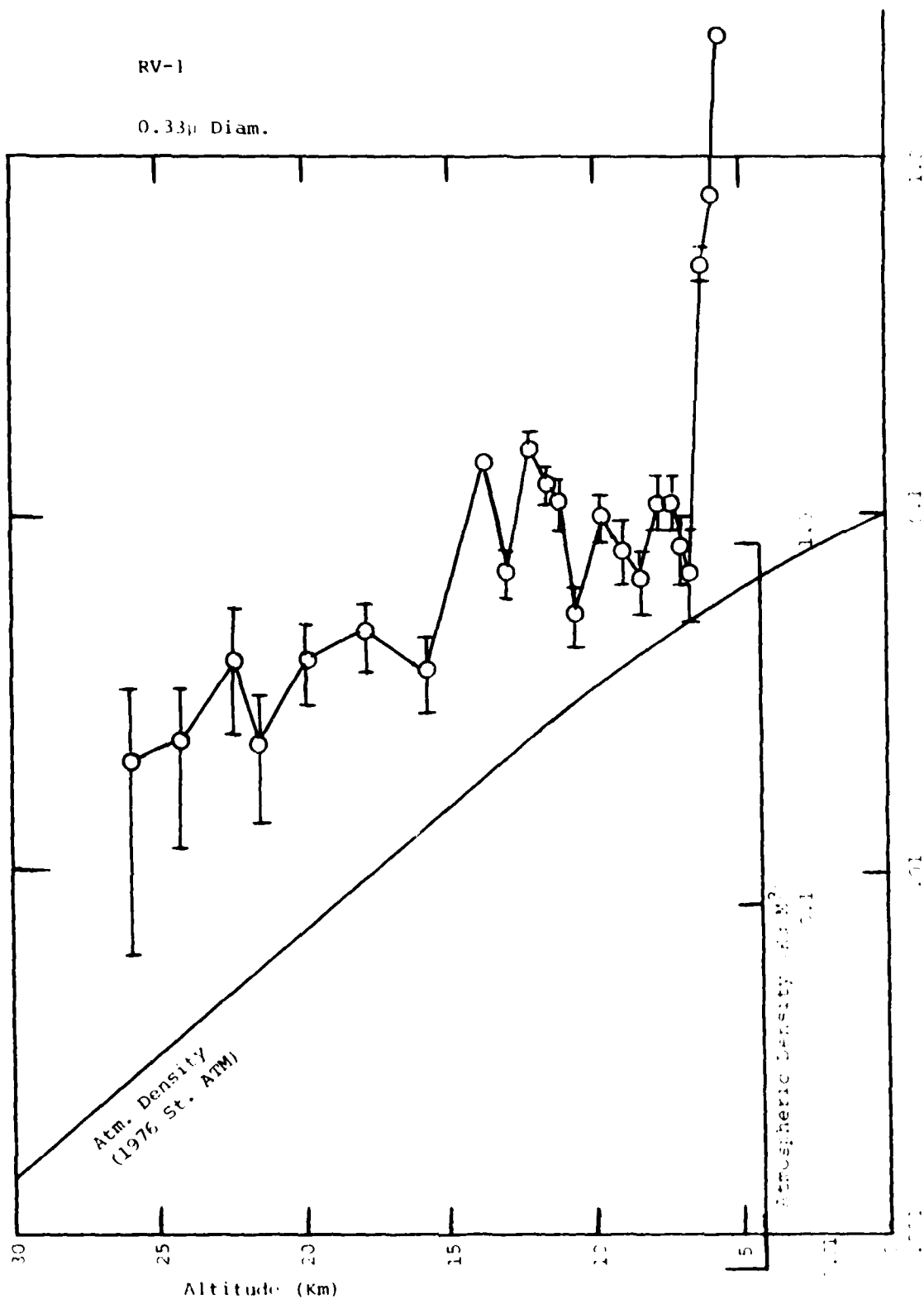


FIGURE 1. Altitude Profile of Aerosol Particle Concentration

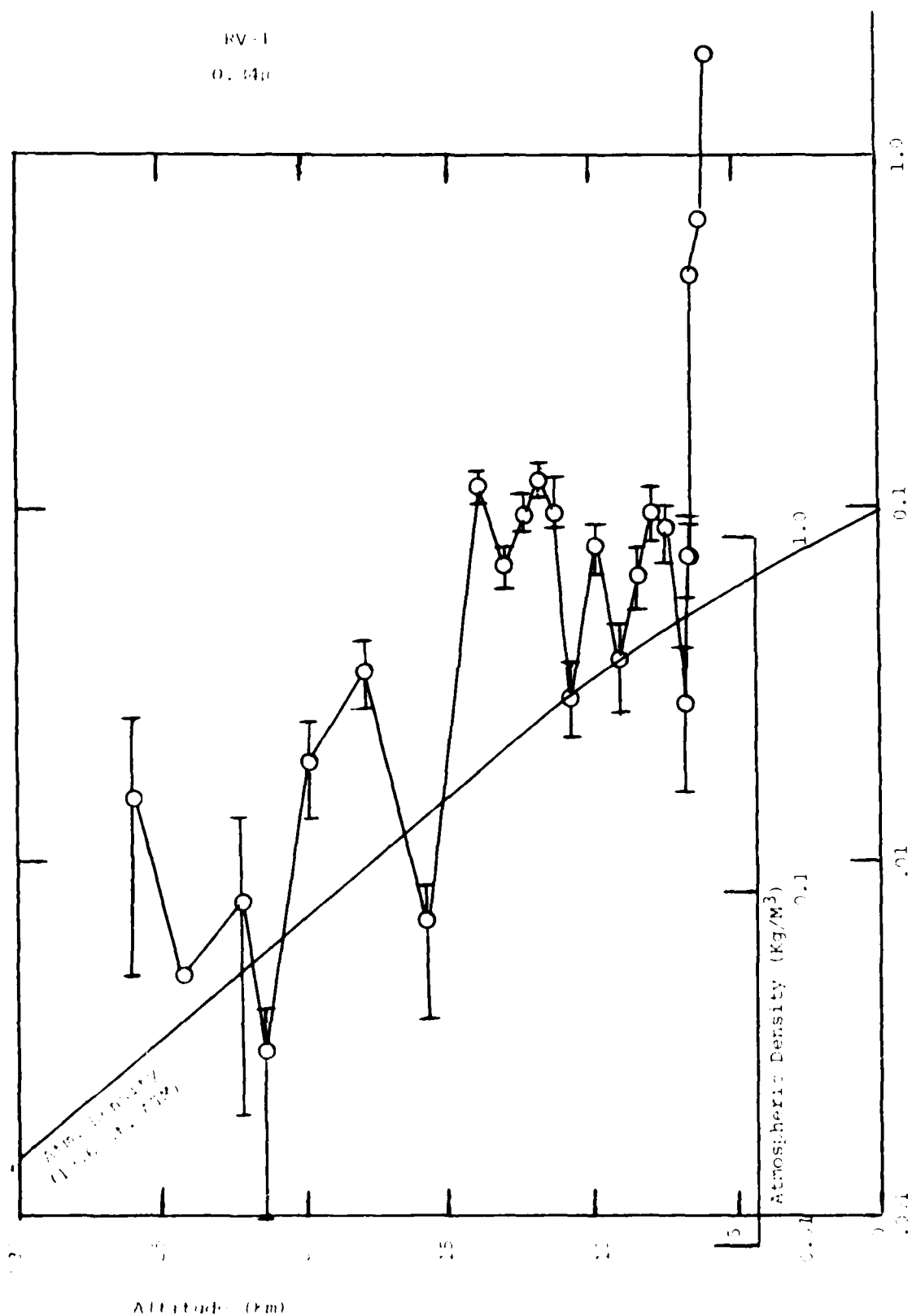


FIGURE 5: Altitude Profile of 0.24 micron Particle Concentration

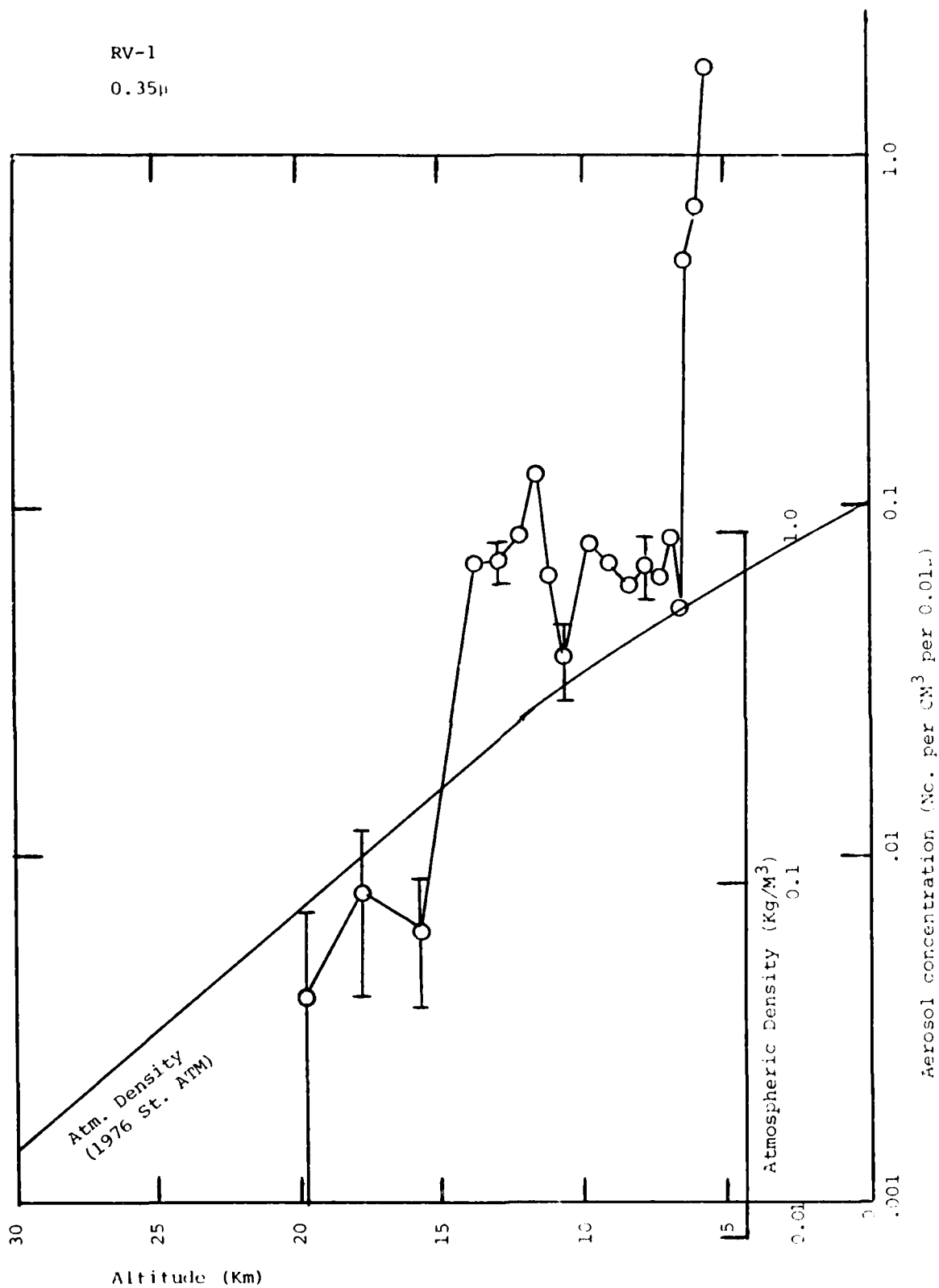


FIGURE 9: Altitude Profile of 0.35 micron Particle Concentration

RV-1
0.36μ

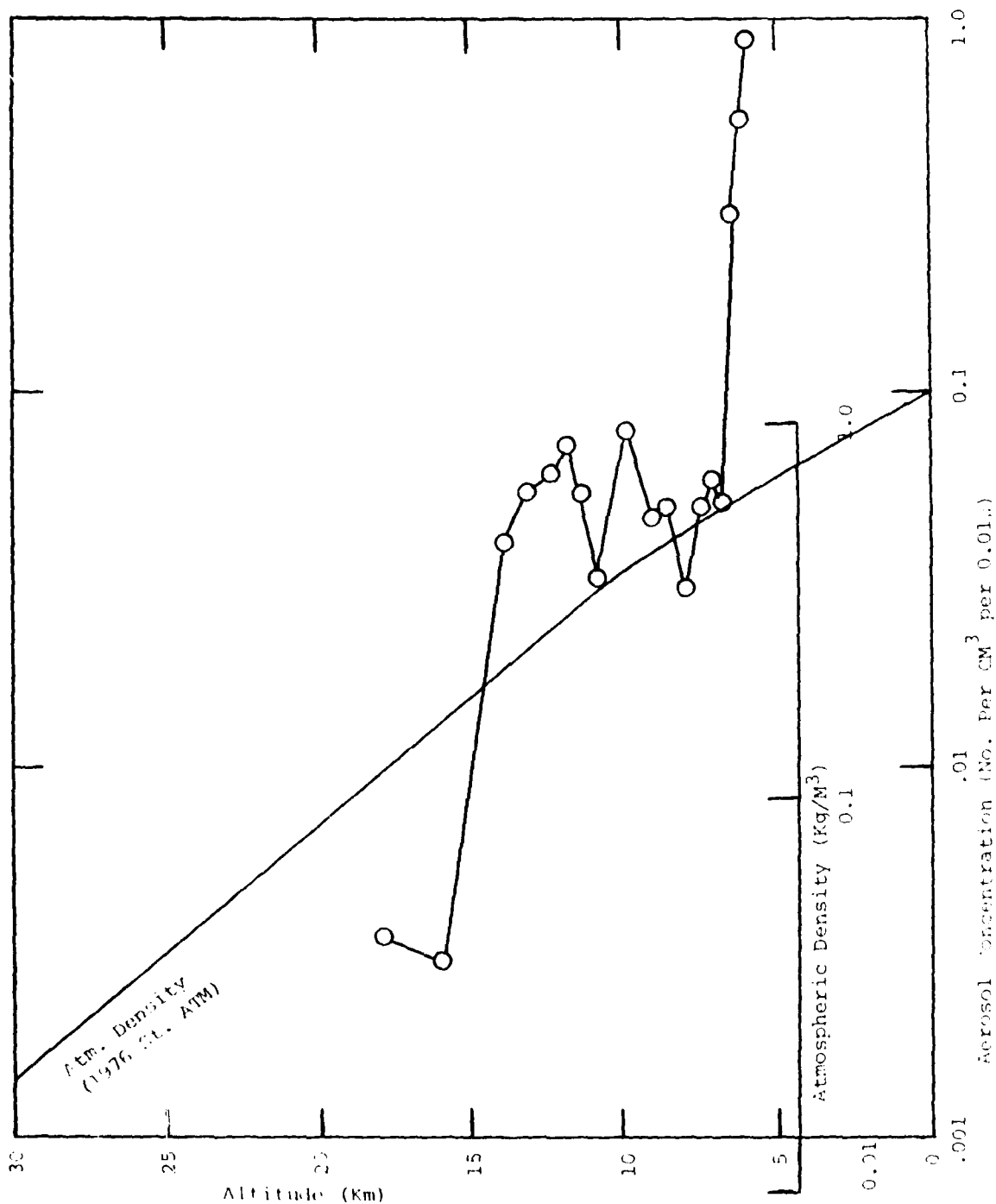


FIGURE 10: Altitude Profile of 0.36 micron Particle Concentration

atmospheric density taken from the US Standard Atmosphere, 1976 Model, which can be used to derive the altitude profile of mixing ratio. These plots show several interesting features: 1) the usual extremely sharp drop of concentration within the first 2-3 kilometers above the surface (i.e., between 6-7 Km) 2) a general tendency toward increasing concentration beyond this break-point (with minor but very definite fluctuations in each case), which amounts to a very broad but very shallow peak at about 15 Km (which is distinctly visible in the 0.30, 0.31 and, to a lesser extent, in the 0.32 plot) 3) a progressive tendency for larger particles to experience a fall-off in concentration at ever lower altitudes, 4) the suggestion of a secondary steep drop between 14 and 15½ Km commencing at 0.31 micron and becoming increasingly pronounced at each successively larger size, and finally 5) the fact that the atmospheric density profile does not appear to be strongly correlated with that of any of the particle sizes. The data represented in this form were smoothed and then used as inputs for the extinction calculations shown in Figure 3.

ACKNOWLEDGEMENTS

I wish to thank my colleague, Mr. John Dulchinos of Epsilon Laboratories, for the vigorous application of his considerable instrumentation talents and expertise throughout this program, and all other Epsilon participants for their assistance. I am also grateful to Mr. T. Mansfield of the Aerospace Instrumentation Division, Balloon Design and Flight Analysis Branch, to Mr. A. Giannetti and Mr. A. Griffith of the Balloon Instrumentation Branch for their cooperation during the field exercises, and to Captain K. Pieri and all personnel of the balloon launch crew at Detachment 1, Holloman AFB for their attentive concern to all our many technical needs during our stay. Special appreciation is also due to both Mr. W. K. Vickery of the Aeronomy Division, Composition Branch, without whose interest and support this exercise could not have been conducted, and to Mr. F. Dearborn of the same branch, for their close interaction during the course of this program.

REFERENCES

1. Miranda, H. A., Jr., Dulchinos, J., and Miranda, H. P., "Stratospheric Balloon Aerosol Particle Counter Measurements", Final Report, Contract No. F19628-73-C-0138, Nov. 1973.
2. Miranda, H. A., Jr., and Dulchinos, J., "Balloon Measurements of Stratospheric Aerosol Size Distributions Following a Volcanic Dust Incursion", Final Report, Contract No. F19628-75-C-0004, Aug. 1975.
3. McCormick, M. P., et. al., "Satellite Studies of the Stratospheric Aerosol", Bull. Am. Met. Soc. 60, 1038 (1979).
4. Miranda, H. A., Jr., and Fenn, R., "Stratospheric Aerosol Sizes", Geophys. Res. Lett., 1, 201 (1974).
5. Harris, F. S., "Measured and Analytical Distributions of Stratospheric Aerosols: A Review and Commentary", Paper delivered at A Topical Meeting Atmospheric Aerosols: Their Optical Properties and Effects, Williamsburg, VA, Dec. 13-15, 1976. P-MA2-1
6. Miranda, H. A., Jr., "Stratospheric Aerosol Measurements", Submitted for publication to Geophys. Res. Lett.
7. EOS, Vol. 61, No. 31, July 29, 1980, pp 555-7.
8. Chu, W. P. and McCormick, M. P., "Inversion of Stratospheric Aerosol and Gaseous Constituents from Spacecraft Solar Extinction Data in the 0.38 - 1.0 μ m Wavelength Region", Applied Optics, 18, 1404 (1979).

ATE
LMED
-8