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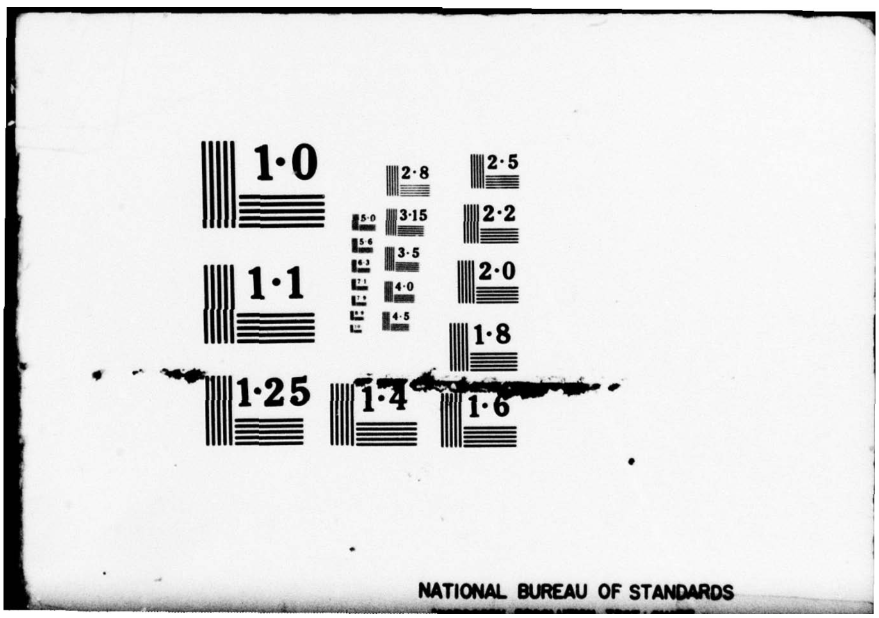
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UV SPECTROIRRADIOMETER MEASUREMENTS OF SOLAR UV FLUXES ON THE STRATCOM 8A BALLOON FLIGHT

Bach Sellers
Frederick A. Hanser
Jean L. Hunerwadel

Panametrics, Inc.
221 Crescent Street
Waltham, Massachusetts 02154

June, 1978

Final Report

UNIVERSITY OF TEXAS AT EL PASO
EL PASO, TEXAS 79968

and

U. S. ARMY ELECTRONICS COMMAND
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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
PANA-AIR-4

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
UV SPECTROIRRADIOMETER MEASUREMENTS OF SOLAR UV FLUXES ON THE STRATCOM 8A BALLOON FLIGHT

5. TYPE OF REPORT & PERIOD COVERED
Final
August 1977-June 1978

6. PERFORMING ORG. REPORT NUMBER
PANA-AIR-4

7. AUTHOR(s)

Bach Sellers
Frederick A. Hanser
Jean L. Hunerwadel

8. CONTRACT OR GRANT NUMBER(s)
U. T. E. P. Purchase Order No. TWC712249

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Panametrics, Inc.
221 Crescent St.
Waltham MA 02154

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

12. REPORT DATE
June 1978

13. NUMBER OF PAGES
26

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
University of Texas at El Paso
El Paso, Texas 79968

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release, distribution unlimited.
Reproduction in whole or in part is permitted for any purpose of the U.S. Government.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work was done through P.O. TWC712249 with the UTEP, which was funded by Contract No. DAAD07-74-C-0263 with White Sands Missile Range

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
UV Flux Measurement
Ozone Measurement
Solar UV Flux

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

A filter wheel UV Spectroirradiometer (UVS) was used to measure solar UV fluxes in 10 bandpasses in the 200-400 nm region at altitudes up to 40 km on Stratcom 8A. Ozone layer thicknesses were derived from the balloon ascent measurements and an ozone density profile obtained. Measurements at the 39-40 km float altitude before and after local noon give a solar flux in the (220±5) nm O_2-O_3 transmission window of 4.53×10^{-6} W/(cm^2-nm).

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FOREWORD

The UV Spectroirradiometer used in this work was fabricated for use in the Dept. of Transportation's Atmospheric Monitoring and Experiments Subprogram, managed by Mr. Samuel C. Coroniti, a major element of the Climatic Impact Assessment Program (CIAP). Funding was accomplished through the Office of Naval Research.

Modification and flight of the UVS on Stratcoms 6A and 7A was carried out under contract with the Atmospheric Sciences Laboratory of White Sands Missile Range. The Contracting Officer's Technical Representative was Mr. Harold N. Ballard, whose guidance throughout the course of the work contributed significantly to the success achieved.

The work reported here on Stratcom 8A was carried out under P.O. No. TWC712249 with the University of Texas at El Paso. The Technical Monitor was Mr. Miguel Izquierdo. His help and that of his associates in the installation of the UVS and the data retrieval is appreciated. The work was funded through White Sands Missile Range Contract No. DAA07-74-C-0263 with U.T.E.P. The project was titled Upper Atmospheric Research; the Project Director for U.T.E.P. was Carlos McDonald.

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1. INTRODUCTION

The UV Spectroirradiometer (UVS) flown on the Stratcom 8A balloon payload was originally developed to measure high altitude solar UV fluxes from an aircraft as part of the Climatic Impact Assessment Program (CIAP) (Ref.1.1). The UVS has previously flown on Stratcom 6A in September, 1975 (Refs. 1.2 and 1.3) and on 7A in September, 1976 (Ref. 1.4). On both these balloon flights the UVS gave measurements of the solar UV flux in the 200-400 nm region at altitudes up to 40 km. Much tabular and graphical data are contained in the referenced reports, giving the variation of UV flux with altitude and solar zenith angle.

A summary description of the various instruments included in the Stratcom 8 series (both on balloons A and B, and on associated rockets) is available (Ref. 1.5). Preliminary results for some of the instruments were presented at a workshop in April, 1978, and a summary of those presentations (Ref. 1.6) and a supplement (Ref. 1.7) are also available. The UVS results presented in this report are identical to those given in Ref. 1.8.

The Stratcom 8A balloon was launched at about 0600 MST on 29 September 1977, reached its peak altitude, near 40 km, at about 0830, and descended gradually reaching about 30 km near midnight. Due to an inability to change battery packages by remote command, the balloon-supplied power failed shortly after 0630 on 30 September (Ref. 1.6, p 27). Hence it was not possible to obtain the UV flux variation with altitude following cut-down, as was done on Stratcoms 6A and 7A. However, the UVS operated properly for the entire first day of the flight. Good solar UV flux data and derived ozone layer thicknesses were obtained for the balloon ascent and throughout the day at float altitude, through sunset. A vertical profile of ozone density was obtained from the calculated ozone thicknesses. The 220 nm filter data at float altitude give a good measure of the solar UV flux at this wavelength on 29 September 1977.

The results obtained on Stratcom 8A are discussed below, followed by a short discussion of the importance of these type measurements.

2. STRATCOM 8A UV INSTRUMENT DESCRIPTIONS

2.1 UV Spectroirradiometer

The UVS is a filter wheel irradiometer, originally developed for high altitude aircraft use in the DOT-CIAP (Ref. 1.1). Basically, the instrument utilizes a special UV diffuser to scatter the light incident on the diffuser at an angle θ_{sd} to the diffuser axis. The scattered light passes through one of ten filter sets, located on a rotating wheel, and then into a ruggedized EMR photomultiplier. Additional positions on the wheel are provided for calibration purposes. A cross-sectional drawing of the cylindrical housing is shown in Fig. 2.1, with detection details in Fig. 2.2. For the Stratcom 8A balloon flight the UVS had a cone diffuser and quartz shield to allow vertical mounting with no sun-pointing requirement. The UVS was flown in this configuration on Stratcoms 7A and 8A, while on 6A a flat diffuser and 45^{o} aiming on a sun-oriented platform was used (Refs. 1.2, 1.3).

Table 2.1 (similar to a preliminary table in Ref. 1.5) gives a summary description of the UVS as implemented for balloon flights, along with the calibration sensitivites of the various filters for Stratcom 8A. The calibration is from a 200W quartz-iodine Standard of Spectral Irradiance (traceable to NBS), converted to solar spectral shape.

As seen in Table 2.1, an entire spectrum can be obtained in either 12 seconds or 120 seconds, depending upon whether the instrument is commanded to operate in either its fast or slow scan modes. For example, during float the slow scan mode is used, but during the rapid parachute descent, and generally during ascent, the fast scan mode is used.

2.2 Relationship of UVS to Other UV Instruments

Several other UV instruments were included on Stratcom 8A, as summarized in Ref. 1.5. Figure 2.3 is a photo taken during payload integration work; most of the UV instrumentation is located on the top. The UVS, with a black disc to obscure the balloon itself (allowed by solar zenith angle) is at the extreme left. The most directly comparable instrument, from the viewpoint of

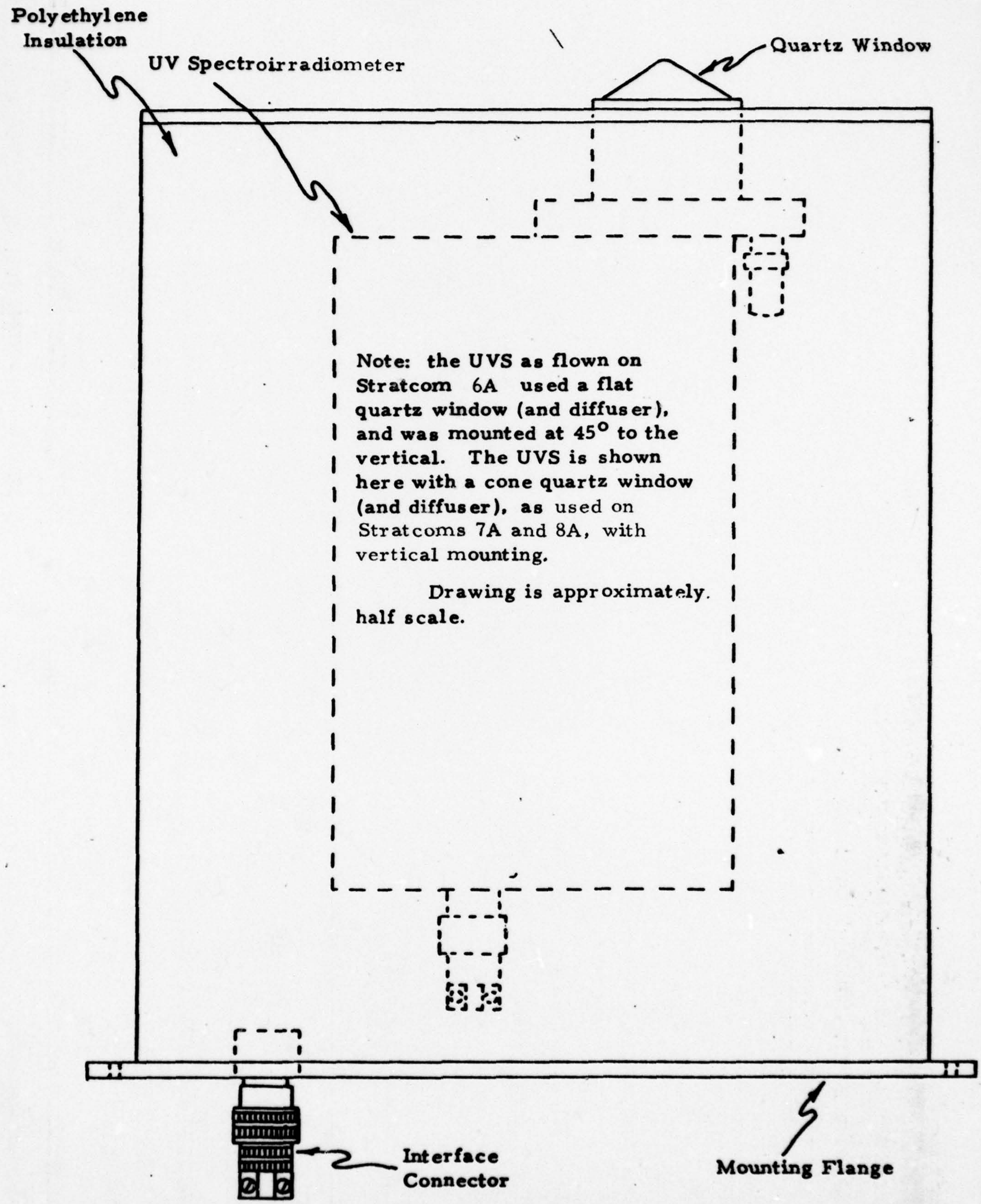

Fig. 2.1 Outline Drawing of UVS Mounted Inside Thermally Insulating Container.

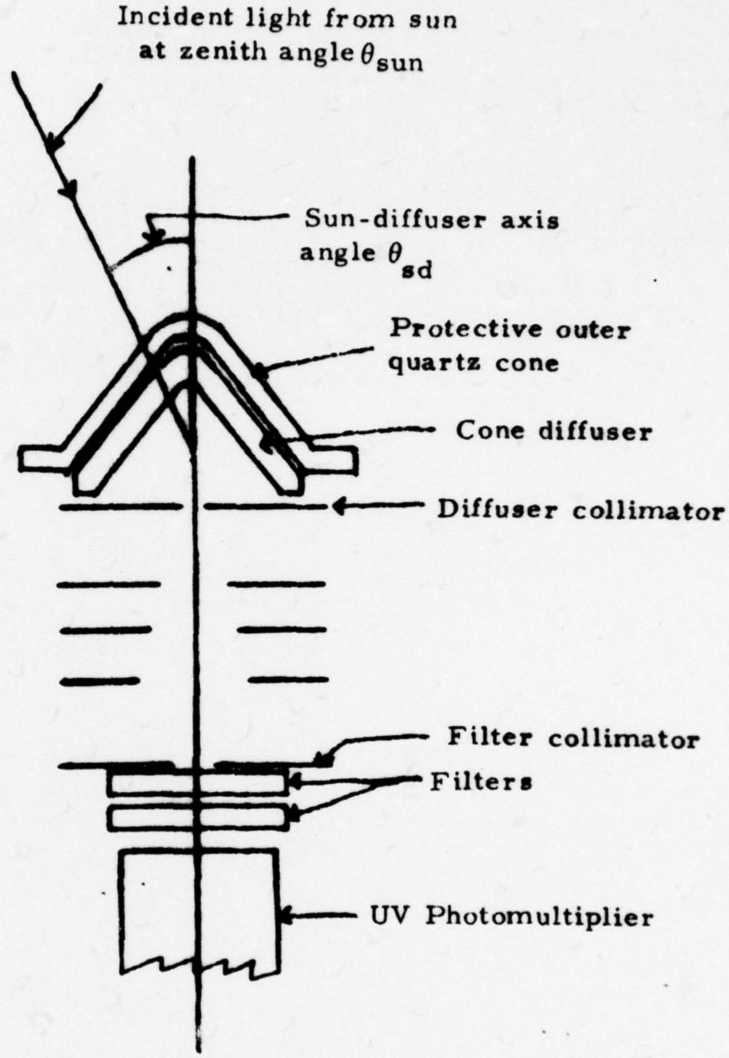

Fig. 2.2 Detailed Layout of Conical Diffuser, Collimators, Filters and Photomultiplier

objective, is the Sandia Grating Spectrometer (we use the nomenclature on the photograph in Ref. 1.6, p 16). The SGS also uses a conical diffuser and a disc to obscure the balloon. In Fig. 2.3 the SGS is next to the UVS; its aperture is covered temporarily by foil. It scans from 190 to 290 nm with about 1 nm resolution. The primary spectral region of interest for the SGS is below 240 nm, where the chlorofluoromethanes are dissociated. The SGS has been under development for several years and has been flown on previous Stratcom balloons.

Table 2.1

UVS Summary Description for Balloon Flights

Instrument:

The Panametrics ultraviolet spectroirradiometer uses a filter wheel and a UV photomultiplier to obtain the incident UV flux in 10 spectral regions between 220 and 400 nm. It is similar to the instrument flown on the first STRATCOM balloon, except that a conical diffuser has been added so that light is received from all azimuths and from a zenith angle of 20° to more than 90° (light scattered from the overhead balloon is blocked by a shield). The precise position of the optical axis is deduced by use of data from the levelness and magnetometer sensors; the solar zenith angles needed for data analysis are calculated as a function of location (radar data) and time. Intensity is measured up to 4 orders of magnitude down from the unattenuated solar flux. The 12 positions of the filter wheel are sampled at 1 second each during ascent of the balloon and during parachute descent following cut-down, and at 10 seconds each during float. The filters are as follows:

Wheel Position	Filter set average wavelength (nm)	Filter set bandwidth (nm)	Solar Calibration sensitivity, Stratcom 8A (A/(W/(cm^2-nm)))
1	220	10	5.034×10^{-1}
2	289.3	2	1.217×10^{-2}
3	291.8	2	7.213×10^{-2}
4	297.4	2	7.923×10^{-2}
5	302.0	2	2.253×10^{-2}
6	306.8	2	1.791×10^{-2}
7	311.7	2	1.144×10^{-2}
8	329.7	2	6.691×10^{-3}
9	371.6	28	3.574×10^{-3}
10	401.9	26	1.369×10^{-3}
11	Calibration checks - 2 light levels and 6 voltage levels		
12	Dark current measurement		

Two or more individual filters used in tandem actually form each filter set, in order to reduce "leakage flux" problems.

Table 2.1 (cont'd)

Other information:

Voltage:	28 ± 4 Volts D. C.		
Power consumption:	Electronics	19W (1 sec/sample)	9W (10 sec/sample)
	Heaters	62W	
	Max. total	81W	or 71W
	Heaters are used to control the internal temperature at $+20^{o}C$ with the external temperature as low as $-70^{o}C$.		
Weight:	10.5 pounds; with insulation: 26 pounds		
Size:	6" dia. x 10" deep cylinder; with insulation: 12" dia. x 15" deep		

Objectives:

The altitude dependence of the UV flux is measured for the following purposes:

1. Photochemical calculations of reaction rates related to the various stratospheric species measured as part of the chemical modelling effort.

2. Verification and development of radiation transport models.

3. Determination of ozone overburden as a function of altitude to be compared with similar data from other instruments. In addition, the measured variations of the overburden can be used to calculate local ozone densities for comparison with in-situ measurements.

4. The measurements in the 220 nm window give an indication of the variability of the ultraviolet solar flux and its relationship to the daily sunspot number (Rz), its 27-day average, and/or solar flares.

Fig. 2.3 Stratcom 8A Payload During Integration Work.

Preliminary results for Stratcom 8A have been presented (Ref. 1.7). The UVS makes a single, accurate measurement near 220 nm (Section 4 below), but from the viewpoint of photochemistry the high resolution measurements near 300 nm [dissociation of O_3 to produce $O(^1D)$] and coverage up to 400 nm [dissociation of NO_2 to produce $O(^3P)$ - see Ref. 2.1] are of principal importance. The application of UVS measurements to determination of $O(^1D)$ photoproduction in the troposphere (measurements made from an aircraft platform) is discussed in Ref. 2.2. For purposes of verifying atmospheric photochemical models the SGS and UVS are highly complimentary.

The third instrument from the left on the top in Fig. 2.3 (small, light colored box) is the Colorado Filter Photometer. Its principal objective is determination of the ozone profile; it uses a flat plate diffuser and four filters: 320, 305, 300, and 288 nm. The UVS can also be used in this manner (Section 4 below; see also Ref. 2.3), and a comparison of all Stratcom 8 ozone profile data available (including the Colorado Filter Photometer as well as in-situ probes) was made by Reed (Ref. 1.7).

The large rectangular box on the right top in Fig. 2.3 contains the Utah State Sky Spectrometer. The instrument is intended to scan in wavelengths from 200 to 310 nm and between zenith and horizon. Since it contains no solar pointing mechanism, the principal measurements made are of diffuse ("sky") radiation. Measurements of such scattered light (which constitutes a maximum of about 10% of the total downward-going radiation in the stratosphere) could be compared with theoretical results for purposes of development of radiation transport theory. In the troposphere such diffuse radiation is a much larger fraction of the total radiation. A comparison of theory and experiment using UVS measurements (Ref. 2.2) has, in fact, shown significant differences.

Stratcom 8A also carried a set of Utah State Filter Photometers. One viewed upward (filters at 292.5, 297.5 and 300.0 nm) for purposes of determining total ozone and the other downward (filters at 300, 350, 400 and 450 nm) for purposes of measuring albedo.

Data from the Utah State Sky Spectrometer and Filter Photometers were not reduced in time to be included in the April, 1978 Workshop summaries (Refs. 1.6 and 1.7).

3. DATA ANALYSIS PROCEDURE

The UVS signals are converted to downward going fluxes as described in Refs. 1.1, 1.2 and 1.3. For the Stratcom balloon flights the fluxes are also divided by $\cos\theta_{sun}$, θ_{sun} being the solar zenith angle, so that the high altitude response is the direct solar flux attenuated only by O_3 and O_2. The ratios of the UV fluxes are used to calculate the vertical thickness of the ozone layer above the balloon altitude. Differences of ozone thicknesses (Ref.2.3) calculated for different altitudes allows the vertical ozone density profile to be obtained.

At the highest altitudes the 220 nm filter results are used to obtain the unattenuated solar flux at (220 ± 5) nm. This is done by plotting the logarithm of the measured flux against the pressure (at the UVS altitude)/$\cos\theta_{sun}$, which latter is proportional to the attenuation path length. The extrapolation of the straight line portion (high altitude, small θ_{sun}) of the data to zero pressure gives the solar flux unattenuated by O_3 and O_2.

4. RESULTS

The Stratcom 8A UV fluxes derived by the above procedure were placed in tabular form (similar to those in Refs. 1.2-1.4) for purposes of further analysis. Some of the results are given in Fig. 4.1, where the measured UV fluxes at four wavelengths are shown as a function of altitude. The solar zenith angle is also decreasing during ascent, so the solar fluxes increase partly because of the decreasing slant path through the ozone layer above the balloon. The major effect on the shorter wavelengths (292 and 307 nm) is the decrease in ozone attenuation as the balloon rises through the stratospheric ozone layer.

The ozone thicknesses calculated from the measured UV fluxes have been used to calculate the vertical ozone density profile plotted in Fig. 4.2. The altitude bars show the altitudes contributing to each density calculation, the ozone density is an effective average over that altitude range. The density

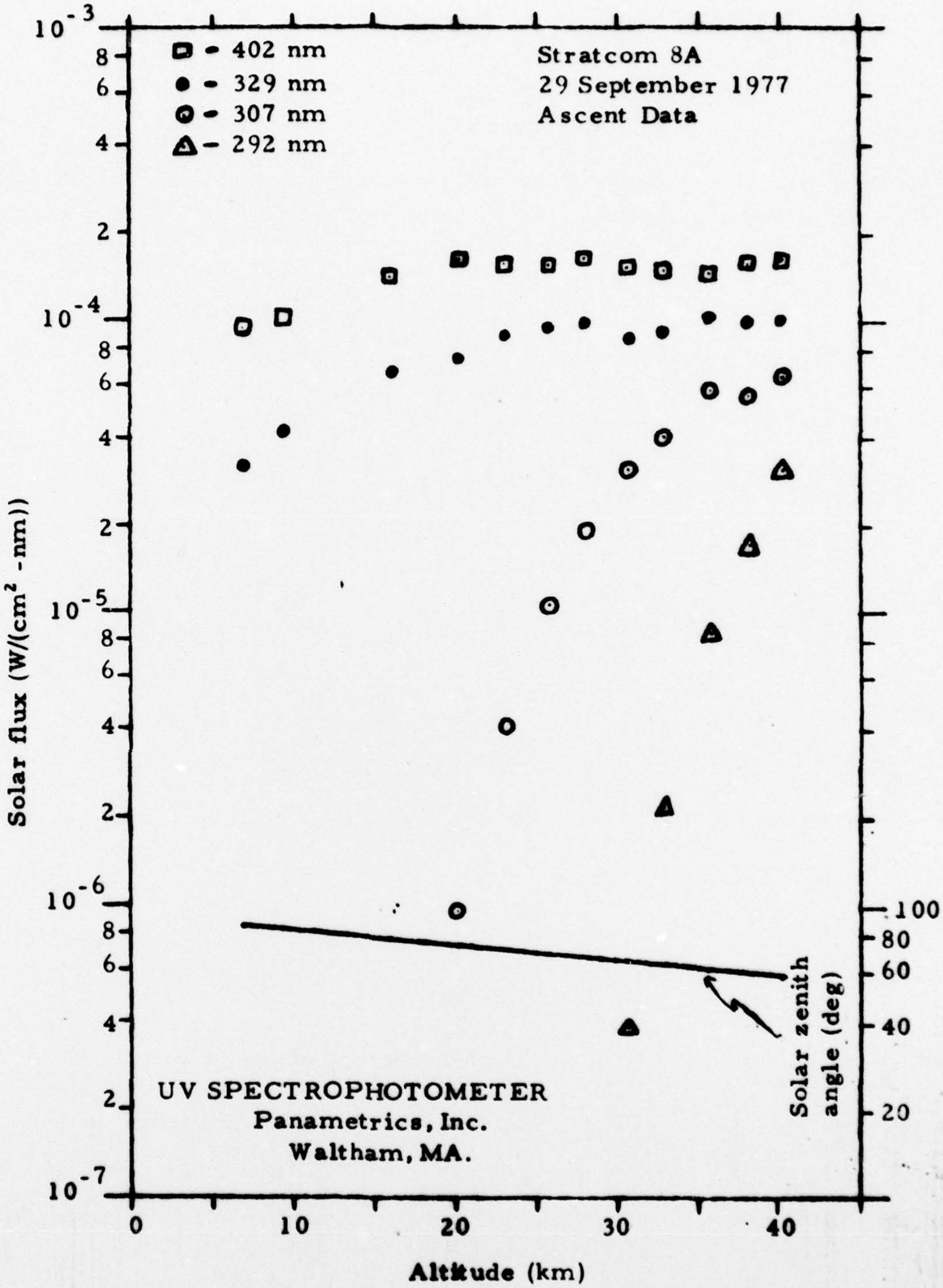

Fig.4.1 Measured UVS Solar Fluxes during Ascent of Stratcom 8A.

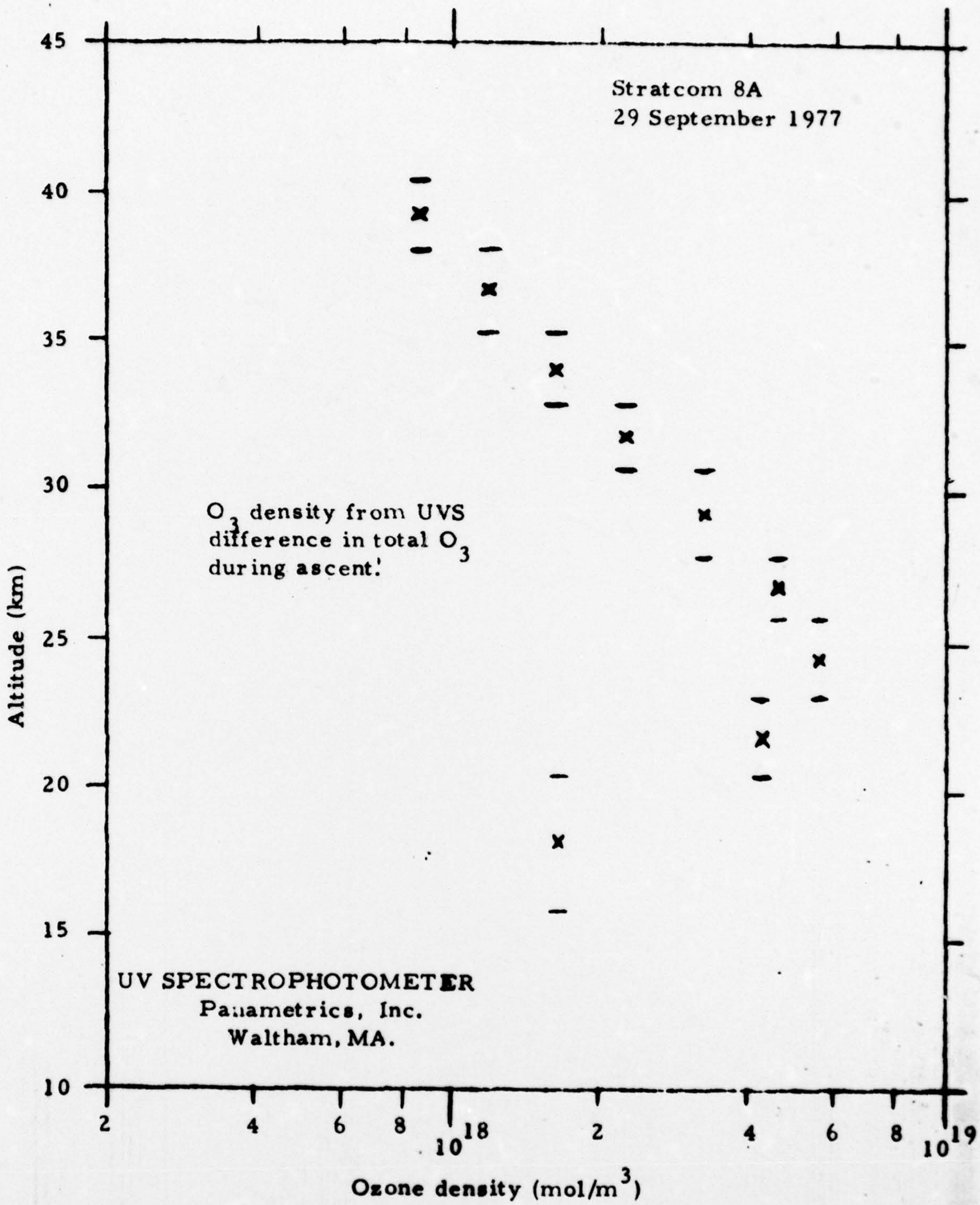

Fig. 4.2 Vertical Ozone Density Profile from UVS Data for Stratcom 8A Ascent.

values are estimated to be accurate to about $\pm 10\%$.

The 220 nm solar flux measurements are shown in Fig. 4.3. Here the measurements at float altitude are plotted against $P/\cos\theta_{sun}$ on a semilog scale. The straight line fit for $P/\cos\theta_{sun} < 10$ mb gives 4.53×10^{-6} W/(cm^2-nm), with the ascent-sunrise data and the sunset data both giving about the same result. This result is compared with others during the last ten years in Table 4.1. Also shown in the table are the solar activity as measured by the Zürich sunspot number and 2800 MHz flux measured at Ottawa - both obtained from Ref. 2.4.

Table 4.1

Solar Flux at 220 nm vs Solar Activity

Solar Flux at 220 nm (± 5 nm) (W/(cm^2-nm))	Zürich Sunspot Number	Ottawa 2800 MHz Solar Flux (10^{-22} W/(m^2-Hz))	Date of measurement MM/DD/YY	Data Source and comments
4.19×10^{-6}	0	76.8	9/(24-25)/75	Previous Stratcom UVS results, Ref. 1.4
3.27×10^{-6}	18	73.6	9/28/76	
4.39×10^{-6}	33	89.5	5/16/73	Avg. for date, Ref. 2.5
4.53×10^{-6}	63	99.4	9/29/77	Stratcom 8A
4.91×10^{-6}	65	125.2	9/23/72	Avg. for date, Ref. 2.5
9.16×10^{-6}	115	139.5	5/10/68 4/19/69 10/3/69	Data for all dates averaged together, Ref. 2.6
5.78×10^{-6}	168	209.2	6/15/70	Ref. 2.7

The 220 nm solar flux data in Table 4.1 show an increase in flux with either sunspot number or the 2800 MHz flux. The one high point from Ackerman et al. (Ref. 2.6) is slightly anomalous, as the shorter wavelength part of their measurement does not show as large a deviation from other measurements. This strong deviation at 220 nm for the Ref. 2.5 data is especially noticeable in

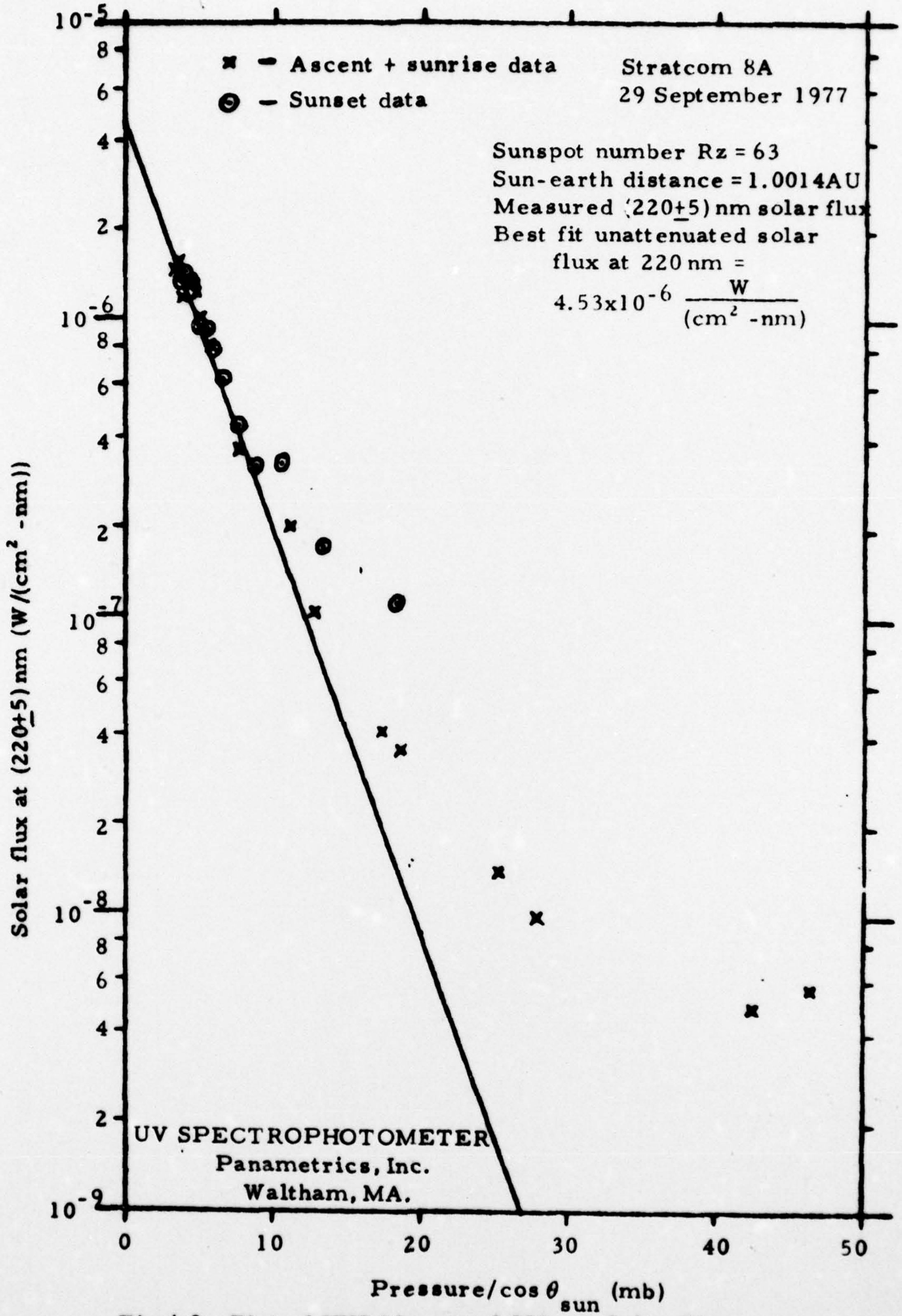

Fig.4.3 Plot of UVS Measured 220 nm Solar Flux vs Attenuation Pathlength in Atmosphere.

comparisons, e.g., Fig. 9 in Ref. 2.8. The trend shown in Table 4.1 suggests an approximate doubling of the 220 nm solar flux as the sunspot number rises from 0 to 200, or the 2800 MHz flux goes from about 70 to 250 (10^{-22}W/(cm^2-Hz)). This trend is also suggested by the data plots of Simon (Ref. 2.8), although he believes that such a conclusion is somewhat ambiguous. Evidence for about 50% variability near 200 nm during the solar cycle has also been presented by Heath and Thekaekara (Ref. 2.9; see also Fig. 17, Ref. 2.10).

Because the data come from several different instruments used by different investigators, cross-calibration errors to some extent mask the solar flux variability. Thus the UVS data become quite important, as the same instrument is used each time, being calibrated before each measurement. Thus far the UVS data are for low to moderate solar activity. Measurements with the UVS during the coming years at high solar activity (sunspot maximum) would thus be extremely valuable for determining solar flux variability at 220 nm.

5. CONCLUSIONS

There are now three sets of UVS-measured data on the atmospheric transmission of the UV fluxes at the wavelengths in Table 2.1 (Stratcom 6A, Refs. 1.2 and 1.3; Stratcom 7A, Ref. 1.4; Stratcom 8A, present report). At the time of Stratcom 6A (1975) only three other vertical profiles of UV flux had been made in the stratosphere (of which we are aware): Brewer and Wilson (Ref. 5.1), Simon (Ref. 2.5) and Ackerman et al. (Ref. 2.6). Those measurements emphasized, principally, the 200 nm region. It was our opinion that much useful information on the objectives listed in Table 2.1 could be obtained by more detailed measurements. The UVS results now available provide far more coverage in wavelength, altitude, and solar zenith angle than any of the previous work, and discussion of the application of these results to some of the Table 2.1 objectives has been presented in our reports (Refs. 1.2-1.4). At this time it is not known whether the Stratcom balloon series will continue, and, if it does, whether the UVS will be part of the payload. We note, however, that the UVS is now a proven stratospheric UV flux measurement instrument. Furthermore, in the last few years recommendations have appeared confirming that UV flux measurements in the stratosphere are, in fact, essential to obtaining the objectives listed in Table 2.1. These have appeared in summaries of Government-organized studies (Refs. 2.10, 5.2-5.6), conferences on specific atmospheric problems (Refs. 5.7 and 5.8), and in papers on various investigations associated with UV flux and the stratosphere (Refs. 2.8, 5.9-5.13), as follows:

1) Photochemical Calculations - It has been observed that it is necessary to include the effects of multiple scattering in the calculation of dissociation rates [Ref. 5.14, 2.10 (p 144), 5.7 (p 41)], and such effects have been included in theoretical work. It has also been recommended that in-situ measurements of the important UV radiation be made along with the various important gaseous species [Ref. 5.7 (p 20, 75, 77, 83); Ref. 5.10 (p 1146); Ref. 5.11 (p 368)]. Calculations using theoretical radiation transport methods have been made (Refs. 5.15, 5.16) for the latitude and time of the Stratcom launches (32°N, September). The UVS-derived fluxes were not used directly, although a comparison of the high altitude (~37 km) UVS-measured Stratcom 6A spectrum with the theoretical derivation was made (Ref. 5.15) with good results. A very useful task would be to employ the method presented in Ref. 2.2 for use of the UVS experimental fluxes to make the photoproduction rate calculations for the various species of interest, and then compare them with the theoretical results in Refs. 5.15 and 5.16.

2) Radiation Transport Model Verification and Development - It was observed in Ref. 5.4 (p 51) that various, though presumably similar, procedures have been used for calculation of UV radiation transport in the atmosphere. Confirmation of these procedures has not been made, and should be [Ref. 5.6 (p 23); Ref. 5.13 (p 3); Ref. 5.10 (p 1146); Ref. 5.5 (p 546); Ref. 5.9, (p 230)]. This was emphasized in 1977, Ref. 2.10 (p 120), where it is stated that "Experimental measurements of the solar flux at specific altitudes in the stratosphere are required for verifying the calculated attenuated solar flux at that altitude." This conclusion was reached

by a working group chaired by L. R. Megill in that NASA GSFC-organized study. It was also noted there (Ref. 2.10, p 120) that "Megill et al. have obtained solar flux data as a function of wavelength and angle with respect to the line of sight with the sun." This apparently refers to the diffuse radiation data recorded by the Utah State Sky Spectrometer on Stratcom 8A. Although those data were not reduced in time for the Stratcom 8A workshop (Ref. 5.18), as noted in Section 2 above, when reduced the data will be useful for comparison with theoretical transport models of the diffuse solar flux component in the stratosphere (maximum of about 10% of downward going flux). It should also be noted, however, that UVS data from all three of the last Stratcom series balloons have been reduced and reported (Refs. 1.2-1.4, 1.8 and present report). These would provide a very useful data base for comparison of the theoretical and experimentally-measured variation of downward going UV flux with altitude and solar zenith angle in the stratosphere.

3) Ozone Overburden Determination - As discussed in Section 4 above, interference filter instruments such as the UVS and the Colorado Filter Photometer can be used to determine the altitude profile of the O_3 density. This is accomplished by taking differences of total ozone amounts measured at two different altitudes. For the UVS the minimum altitude resolution possible is about ± 1 km. Naturally, this technique becomes less accurate as the distance increases below the peak in the ozone profile. Measurements of this type can, of course, assist in the verification of results from satellite-borne instruments like the BUV; for example, the methods of deriving the ozone profiles [Ref. 5.9; Ref. 5.17 (p 9)] and for providing needed "ground-truth" for the total ozone measurements [Ref. 2.10 (p 55); Ref. 5.12 (p 82)]. Balloon-borne instruments such as the UVS are ideal for this application, because they can be calibrated both before and after the flight - thus providing a cross-calibration of the satellite UV flux determination as well as the methods of determining ozone.

4) 220 nm Solar Cycle Associated Variability - A comparison of the UVS-derived values of extraterrestrial 220 nm fluxes with those of other investigators has been given in Table 4.1. As noted there, a recent summary of measurements in this region, and of future needs for measurements, has been provided by Simon (Ref. 2.8). This need has also been emphasized in several other places [Ref. 2.10 (p 116); Ref. 5.7 (p 41, 60 and 75); Ref. 5.13 (p 3); Ref. 5.9 (p 228, 230); Ref. 5.5 (p 346)]. Therefore, it is highly desirable to make additional 220 nm measurements with the UVS, as well as other UV Spectroirradiometers. during the coming sunspot maximum to provide more conclusive data on this variation.

In summary, the UVS has provided useful 200-400 nm UV spectrum measurements on the last three Stratcom balloons. These data have been analyzed for UV solar cycle associated variability (Table 4.1) and to determine the ozone density profile (Fig. 4.2). We believe that these spectral measurements should be used in a study (1) for comparison of the experimental flux variation with altitude and solar zenith angle with similar results from radiation transport theories, and (2) for determination of important stratospheric photodissociation rates (O_3 and NO_2, in particular) for comparison with values already calculated for the same altitudes on the basis of transport theory [Refs. 5.15, 5.16 and 2.10 (p 147), for example]. The instrument should also be included in stratospheric balloon experiments where 200-400 nm fluxes are to be measured reliably and with good precision. Because the Sandia Grating Spectrometer only provides measurements in the 190-290 nm region, the UVS measurements in the 290-400 nm region, and the single accurate 220 nm flux measurement, are highly complimentary. Such further measurements would be of considerable utility in interpreting photochemical models, determination of ozone density profiles, and in determining the degree of solar cycle associated UV flux variability in the 200 nm region.

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