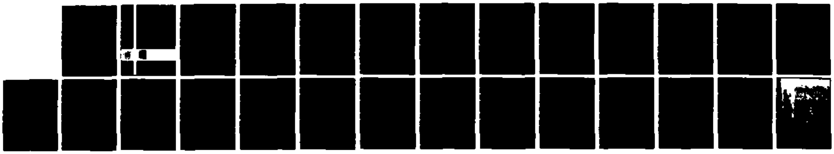
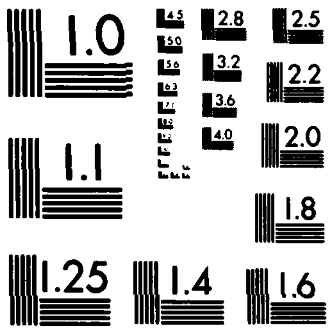
AD-A132 889 MEASUREMENTS OF OPTICAL PROPERTIES OF PARTICULATES IN AN ARID REGION(U) ARIZONA UNIV TUCSON ENGINEERING EXPERIMENT STATION J A REAGAN 31 AUG 83 ARO-15520.1-GS 1/1

UNCLASSIFIED DAAG29-82-K-0081 F/G 4/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD A132 889

MEASUREMENTS OF OPTICAL PROPERTIES OF PARTICULATES IN AN ARID REGION

Final Report

John A. Reagan

31 August 1983

U.S. Army Research Office

Contract DAAG-29-82-K-0081

The University of Arizona
Department of Electrical & Computer Engineering
Tucson, AZ 85721

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A132 889
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) MEASUREMENTS OF OPTICAL PROPERTIES OF PARTICULATES IN AN ARID REGION	5. TYPE OF REPORT & PERIOD COVERED FINAL 15 March 1982 to 30 April 1983
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) John A. Reagan	8. CONTRACT OR GRANT NUMBER(s) DAAG-29-82-K-0081
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Arizona, Dept. of Electrical & Computer Engineering, Tucson, AZ 85721	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office, Post Office Box 12211, Research Triangle Park, NC 27709	12. REPORT DATE 31 August 1983
	13. NUMBER OF PAGES 22
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)	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)

NA

18. SUPPLEMENTARY NOTES

THE VIEW, OPINIONS AND/OR FINDINGS CONTAINED IN THIS REPORT ARE THOSE OF THE AUTHOR(S) AND SHOULD NOT BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION, POLICY, OR DECISION, UNLESS SO DESIGNATED BY OTHER DOCUMENTATION.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aerosol extinction coefficient
Atmospheric optical properties
Lidar remote sensing
aerosols
particulates
lidar
extinction

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

Aerosol extinction profiles and aerosol extinction-to-backscatter ratio, S_a, values have been determined for numerous days over the period May, 1979 to May, 1982 in Tucson, AZ via slant-path lidar measurements. These results have been analyzed to obtain a model aerosol extinction profile and a model S_a value. The model extinction profile is characterized by rapidly, nearly linearly decreasing extinction through a 3km mixing layer (decreasing from

0.018/km^{-1} at 200 m to 0.003/km^{-1} at 3km), and a much more slowly decreasing extinction above the mixing layer. The mixing layer optical depth is about 0.04, and the optical depth to the maximum observation height (19km) is about 0.07. The inverse variance weighted S_a value is about 25, and the majority of the S_a determinations fell between 20 and 35. A limited number of cooperative lidar and balloon-borne cascade impactor measurements have also been made to investigate aerosol size distribution and refractive index properties and their effects on the lidar observations. Impactor measurements made at different heights and times over several days yielded size distributions that were generally similar in shape, the distributions being perturbed Junge types with a dominance of coarse mode particles causing a bulge in the distributions in the large particle range. The particle complex refractive index estimates obtained from the combined impactor and lidar measurements yielded an average real part of about 1.45 and imaginary part of 0.005.

MEASUREMENTS OF OPTICAL PROPERTIES OF PARTICULATES IN AN ARID REGION

Final Report

John A. Reagan

31 August 1983

U.S. Army Research Office

Contract DAAG-29-82-K-0081

The University of Arizona
Department of Electrical & Computer Engineering
Tucson, AZ 85721

APPROVED FOR PUBLIC RELEASE:

DISTRIBUTION UNLIMITED.

TABLE OF CONTENTS

LIST OF TABLES AND ILLUSTRATIONS

1. INTRODUCTION AND STATEMENT OF PROBLEM

This is a final report on Grant DAAG-29-78-G-0195 and follow on Contract DAAG-29-82-K-0081, Optical Properties of Atmospheric Particulates in Arid Regions, prepared for the U.S. Army Research Office. The purpose of this study was to experimentally investigate the optical properties of particulates in arid regions via slant-path lidar measurements made in Tucson with the University of Arizona lidar. The primary goals of this work were to

a) obtain slant-path lidar measurements for approximately 100 days

b) analyze the lidar data to retrieve profiles of aerosol extinction, σ_a, and the aerosol extinction to back-scatter ratio, S_a, for the middle and lower troposphere, and

c) obtain statistical estimates of the mean and variance of σ_a and S_a.

In addition to the lidar data collection and analysis, two important auxiliary efforts were also included as a part of the study. One was to obtain direct measurements of aerosol size distributions via balloon-borne cascade impactor measurements made in the same region probed by the lidar. These measurements were to be made to aid in interpreting the lidar observations, particularly the lidar derived S_a values. The other was to make use of spectral solar radiometer measurements made under a cooperative NSF funded study to also aid in interpreting the lidar observations. The spectral aerosol optical depths obtained from the solar radiometer measurements provide a cross check on the lidar derived optical depth as well as provide information about the aerosol size distribution.

Efforts to achieve the goals given above have been largely successful. Most of the results obtained from this study have already been reported in various proceedings, and a list of these publications will be given in a later section. A summary of the results is given in the following section.

2. SUMMARY OF RESULTS

Attempts were made to collect lidar slant-path data on approximately 125 days during the period May, 1979 through May, 1982. Of these attempts, complete sets of slant-path data were acquired for about 105 days. Data for over 70 days proved eventually to be successful in that they were reducible by the slant-path lidar technique (Spinhirne et al., 1980).

During the period 4-10 April, 1980, a successful cooperative experiment was conducted in Tucson which included lidar and balloon-borne cascade impactor measurements of aerosols. The balloon system was supplied by NASA Langley Research Center through an interagency agreement attached to the grant. The purpose of the joint experiment was to obtain "direct" measurements of aerosol properties to aid in interpreting the lidar observations.

The principal results obtained from the above mentioned observations fall into three areas:

1) Profiles of aerosol or particulate extinction, including standard deviation estimates, have been extracted from the successful lidar slant-path observations. These profiles have been statistically analyzed to obtain a model extinction profile.

2) Mixing layer aerosol extinction-to-backscatter ratios, including standard deviation estimates, have been extracted from the successful lidar slant-path observations. These ratios have been statistically analyzed to obtain values which can be used to model lidar observations.

3) The lidar and balloon-borne cascade impactor measurements have been analyzed to investigate the effect of various aerosol physical properties on the lidar extinction profile and extinction-to-back-scatter ratio retrievals. Refractive index values have also been estimated by combining the impactor size distribution measurements with the lidar derived aerosol extinction-to-backscatter ratios.

Additional information regarding the results obtained for each of these three areas is given in the following subsections.

2.1 Results of Extinction Profile Retrievals

The average aerosol extinction profile obtained from approximately 50 days of lidar observations is shown graphically in Fig. 2.1 and tabulated in 0.2 km intervals (through 7 km) in Table 2.1. The Rayleigh or molecular extinction profile is included in Fig. 2.1 for comparison. The profile is a weighted average determined by inverse variance weighting. This seemed to be the most appropriate way to average in that standard deviations were available for each of the extinction profiles included in the average. Such weighting effectively reduces the contribution of days with larger uncertainties, but it also biases towards lower extinction values. The data set used in the average was also screened to some extent in that days were not included for which the slant-path solution technique had difficulty obtaining a solution or produced a solution with an unreasonably low (10 or less) aerosol extinction-to-backscatter ratio.

As can be seen in Fig. 2.1, the average extinction profile has a mixing layer height of about 3.0 km. The optical depth for the mixing layer is 0.04, and the total optical depth (through 19.0 km) is 0.07. These values as well as the extinction profile itself are similar to the results obtained earlier (Spinhirne et al., 1980) for a preliminary data set of 20 days of lidar observations made over the period 1974 through 1976. Although the extinction

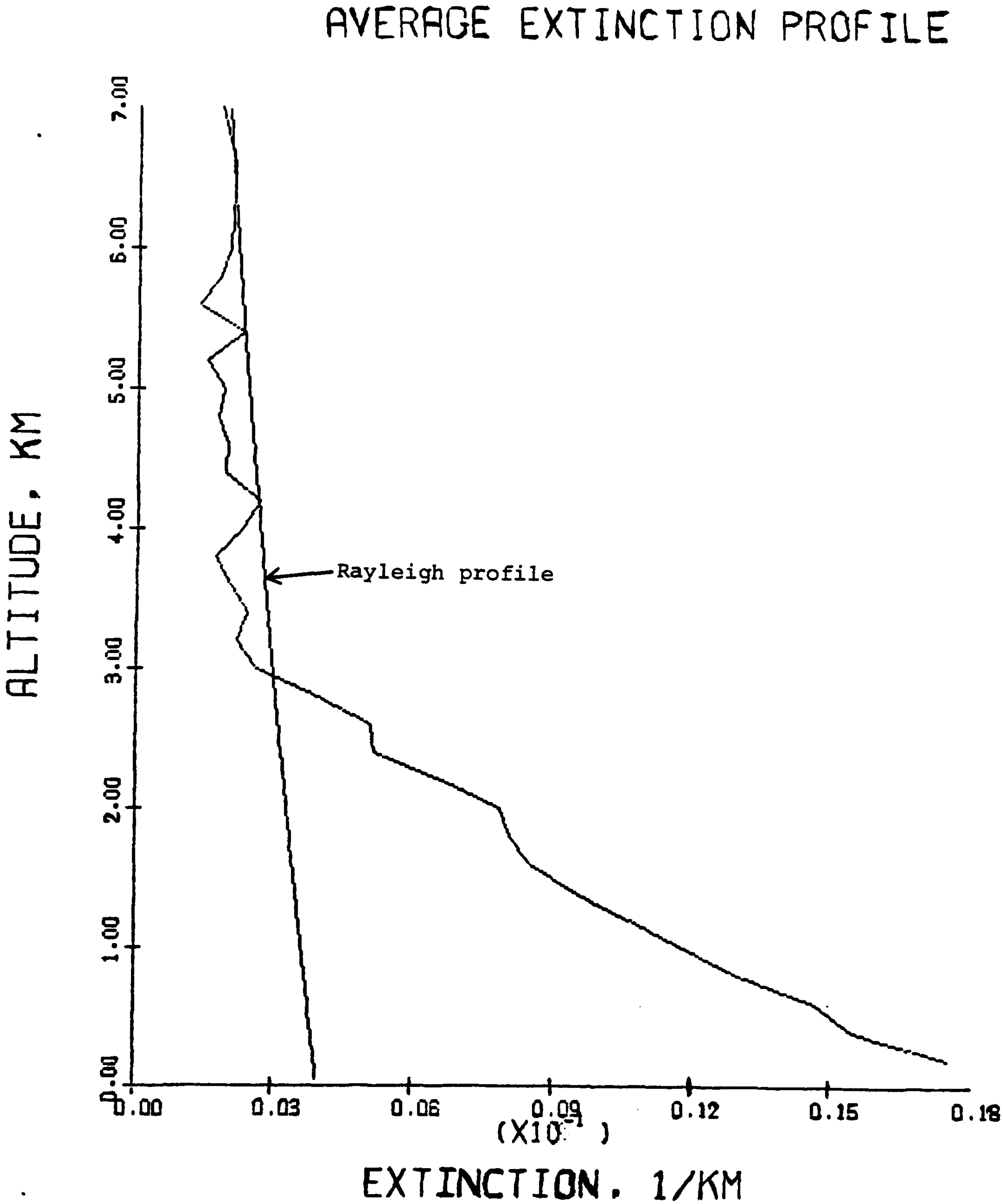


Figure 2.1 Average aerosol extinction profile for slant-path lidar measurements made in Tucson, AZ between May, 1979 and May, 1982. The altitudes are above ground level for Tucson.

Table 2.1 Average[1] aerosol extinction coefficient for slant-path lidar measurements made in Tucson, AZ between May, 1979 and May, 1982.

Height[2] (km)	Aerosol Extinction (km^{-1})	Height[2] (km)	Aerosol Extinction (km^{-1})
.20	1.75×10^{-2}	4.20	2.67
.40	1.55	4.40	1.93
.60	1.47	4.60	1.96
.80	1.31	4.80	1.77
1.00	1.19	5.00	1.91
1.20	1.07	5.20	1.52
1.40	9.49×10^{-3}	5.40	2.31
1.60	8.56	5.60	1.38
1.80	8.10	5.80	1.79
2.00	7.88	6.00	2.04
2.20	6.64	6.20	2.06
2.40	5.18	6.40	2.10
2.60	5.10	6.60	2.09
2.80	3.98	7.00	1.81
3.00	2.64	7.50	1.57
3.20	2.25	8.00	5.71×10^{-4}
3.40	2.44	8.50	5.52
3.60	2.08	9.00	5.27
3.80	1.72	9.50	5.01
4.00	2.33	10.00	4.76

Optical depth through 2.8km (mixing layer) is 0.04 and through 19.0km (maximum measurement height) is 0.07.

[1]Weighted average (inverse variance weighting).

[2]Height above ground level in Tucson, AZ which is 732m above sea level.

profile presented here is only for a wavelength of 694 nm, extinction profiles for other wavelengths can be inferred by making use of spectral solar radiometer optical depth data also acquired in Tucson (King et al., 1980). In particular, analysis of the solar radiometer data reveals that the aerosol spectral optical depth, $\tau_a(\lambda)$, varies with wavelength, λ, for $\sim 400\text{nm} < \lambda < 1000$ nm to a good approximation as

$$\tau_a(\lambda) = K\lambda^{-n}$$

where K is a proportionality constant and n is approximately 0.5. It is suggested that this relationship be used to scale the extinction profile values to other wavelengths.

2.2 Results of Aerosol Extinction-to-Backscatter Ratio Retrievals

Aerosol extinction-to-backscatter ratio, S_a, values obtained from 70 days of slant-path lidar observations made over the period May 1979 to May 1982 are plotted in Fig. 2.2 over a 12 month "generic" year interval. The S_a values for the 20 days of lidar observations reported by Spinhirne et al. (1980) are included in the figure for comparison. Monthly and some other averages of S_a are given in Table 2.2. Averages were not computed for months with less than 4 observations. The majority of the S_a values are concentrated between 15 and 35, but additional groupings occur between about 40 to 60 and 12 or less. The overall

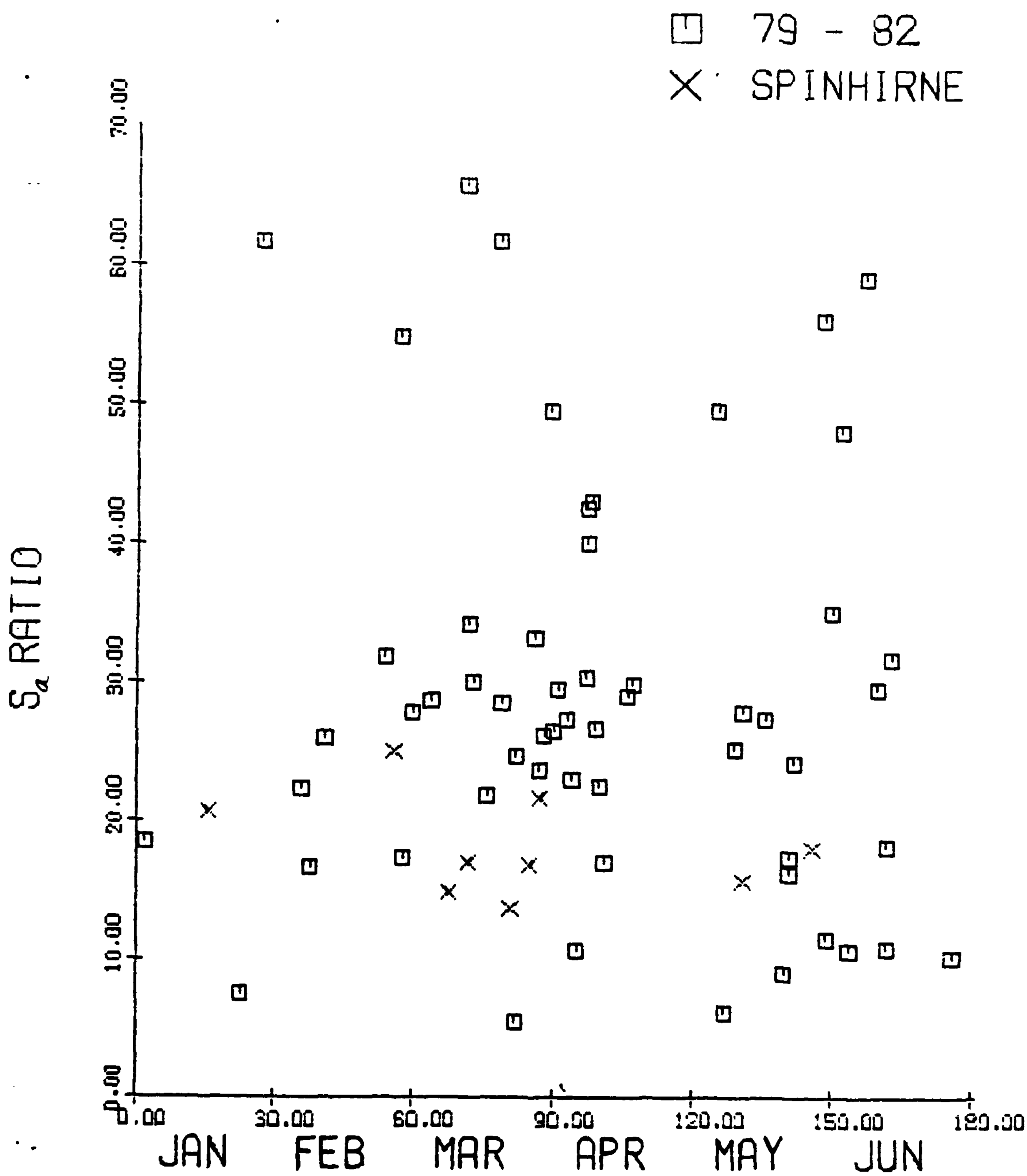


Figure 2.2 Mixing layer aerosol extinction-to-backscatter ratio, S_a, values determined from slant-path lidar measurements made between May, 1979 and May, 1982. Values are presented on a generic year basis.

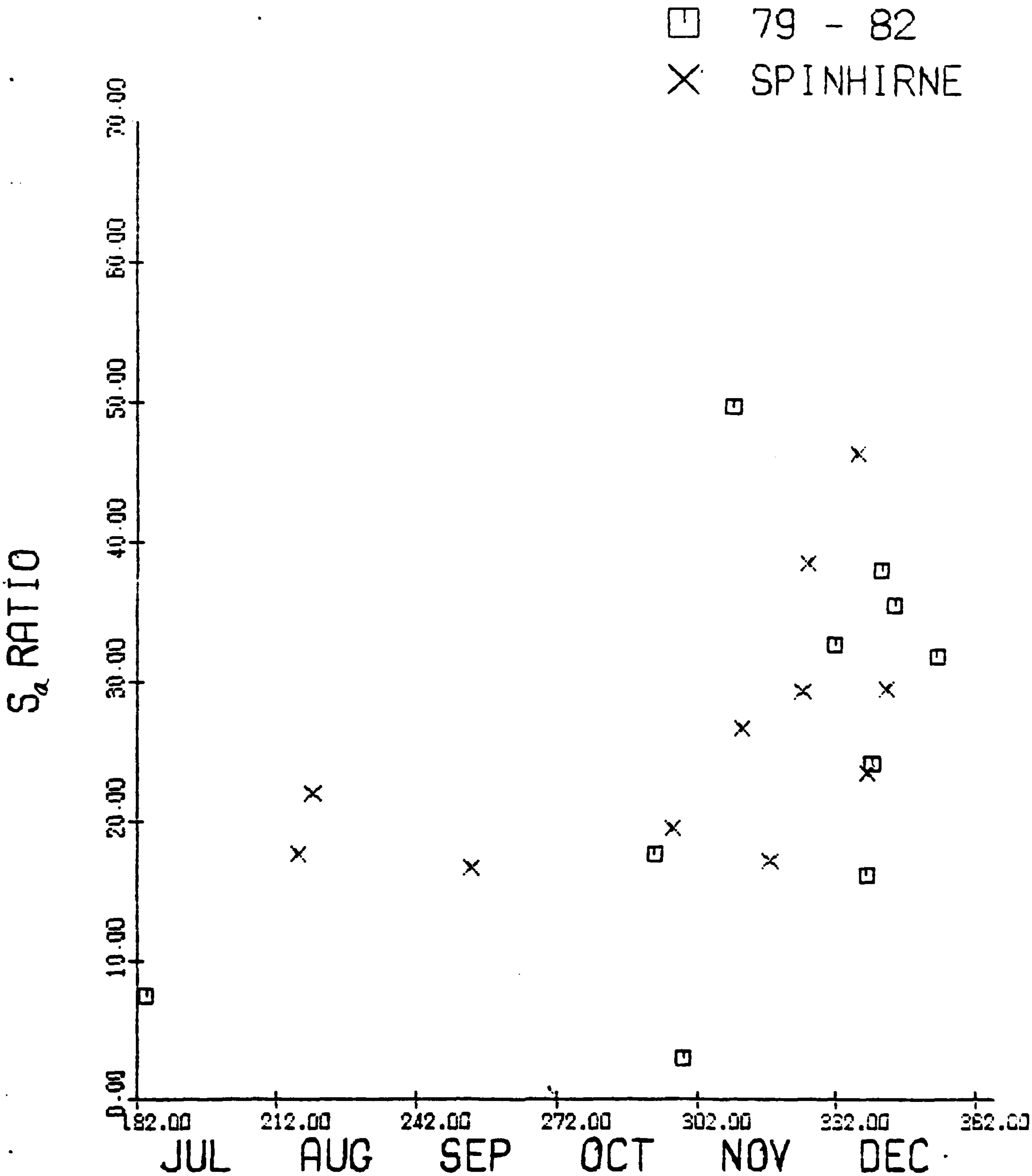


Figure 2.2 Continued

Table 2.2 Statistical properties of S_a values derived from lidar observations in Tucson, AZ between May 1979 and May 1982.

Month	Number of Observations	Arithmetic Mean and Standard Deviations S_a	Weighted* Mean of S_a
January	4	46.3 ± 41.3	25.0
February	7	28.2 ± 13.0	25.9
March	14	32.9 ± 16.0	32.4
April	13	28.6 ± 9.4	28.2
May	12	25.5 ± 15.4	23.9
June	10	37.1 ± 26.4	16.5
July	1	—	—
August	0	—	—
September	0	—	—
October	2	—	—
November	2	—	—
December	5	29.2 ± 8.9	29.0
Total	70	30.7 ± 18.4	25.1

Arithmetic Average for $10 < S_a < 45$ is 25.6 ± 8.2

Arithmetic Average for $S_a > 45$ is 62.0 ± 14.4

***Weighted by inverse variances of S_a values.**

weighted average (25.1) is almost the same as the arithmetic average of 25.6 for the main grouping of values between 15 and 45. With the exception of June, the monthly averages do not display any trends that differ significantly from the overall averages (Jan. is discounted because of so few observations). Thus, $S_a \approx 25$ appears to be a representative value for most of the observations. This value is slightly higher but not greatly different than the weighted mean of 19.5 obtained by Spinhrine et al. (1980) for 20 days of preliminary lidar observations.

The very low S_a values are questionable for two reasons. First, they generally were obtained for very clear days with low optical depths (mixing layer optical depths $\lesssim$ 0.02). The slant-path solution technique doesn't work very well under such conditions because the aerosol contribution to the overall lidar signal (molecular plus aerosol) is too small to be accurately retrieved. Secondly, model calculations for representative aerosol size distribution shapes and refractive index values do not yield S_a values less than about 10 (for a wavelength of 694nm). Results of these model studies also indicate that S_a values in the 10 to 20 range typically occur for particle size distributions dominated by larger, coarse mode particles (i.e., log-normal type distributions), higher real refractive index values (real components of ~1.54), and little or no absorption. Such conditions can occur when high winds and strong convective mixing add additional desert dust to the atmosphere. Values of S_a in the 20 to 35 range, which is where the majority of observations fall, correspond more to size distributions with less dominant coarse mode particle concentrations (i.e., perturbed Junge or two-slope type distributions), somewhat lower real refractive index values (~1.45 to 1.50), and still fairly low absorption (imaginary index component values <~0.005). This is compatible with both acid sulfate and soil type particles. Larger values of S_a ($S_a > 40$) generally indicate stronger absorption (imaginary index components in the range ~ 0.005 to ~ 0.01). Occurrences of larger S_a values generally coincided with stagnant high pressure or strong winter inversion conditions when urban derived absorbing materials such as soot could accumulate in the atmosphere. Additional information regarding S_a and related size distribution and refractive index effects are given in the next subsection and the papers by Spinhirne et al. (1980) and Reagan et al. (1983).

2.3 Results of Lidar and Balloon-Borne Cascade Impactor Measurements

The results of the lidar and balloon-borne cascade impactor experiment are detailed in a manuscript submitted to Aerosol Science and Technology (Reagan et al., 1983). The aerosol size distributions obtained from the impactor data were found to be all rather similar in form even though the impactor measurements were made at different heights and times over a period of several days. The distributions displayed a dominance by coarse mode particles and were similar to the perturbed Junge (i.e., two-slope or Junge plus a log normal type distributions) distributions obtained by inverting spectral solar radiometer measurements (King et al., 1978).

Aerosol extinction profiles and extinction to backscatter ratios obtained from the lidar measurements displayed significant changes over the several days of the experiment. The observed variations were fairly representative of the results obtained over three years of lidar measurements. The standard deviations obtained for the extinction profiles were generally low (15 to 30%) and indicated that the homogeneity constraints on the lidar retrieval technique were reasonably well met. By combining the lidar derived aerosol extinction to backscatter ratios and the impactor size distributions, an estimate was obtained of the aerosol particle refractive index for each lidar observation. This analysis indicated that the observed day to day variations in the aerosol extinction to backscatter ratio were largely due to changes in particle refractive index (i.e., particle composition) rather than a change in the shape of the aerosol size distribution.

The real part of the estimated refractive index (for a wavelength of 694nm) was typically 1.45 with a mean of 1.47. This value is reconcilable with both acid sulfate and soil type particles. Energy dispersive X-ray analysis of the particles deposited on the impactor stages for particle sizes contributing most significantly to the lidar signal revealed that the particles contained both sulfur and soil type elements (Al,Si,Ca, & Mg). Estimates of the imaginary refractive index component (again for a wavelength of 694nm) were equally divided between 0.00 and 0.01 (i.e., mean of > ~ 0.005). Imaginary index values of 0.01 or less are in agreement with values obtained for the 500 to 700 nm wavelength range from a number of other desert aerosol experiments. As sulfur and soil type particle constituents are largely nonabsorbing in this wavelength range, the non-zero imaginary index values may be due to minute amounts of soot intermixed with the other particle components. Finally, the lidar measurements yielded aerosol extinction values that were somewhat higher but still in fair agreement with the aerosol extinction coefficients computed from the impactor size distribution measurements.

2.4 Additional Reports

All of the significant findings of the research performed under Grant DAAG-29-78-G-0195 and Contract DAAG-29-82-K-0081 have been presented in this report or are detailed in the publications connected with this research (these publications are listed in the next section). However, work is continuing to further analyze and assess some of the results of this research, and additional publications are anticipated from this work. In particular, two manuscripts are now in preparation which should be ready for submission to journals in a few months. The titles of these manuscripts are given below:

"Aerosol Extinction to Backscatter Ratios: Measurements and Calculations" (Reagan et al., to be submitted to Appl. Opt.)

"Slant-Path Lidar Observations Made in Tucson, AZ from 1979 to 1982" (Reagan et al., to be submitted to J. Appl. Meteor.)

3. PUBLICATIONS OF WORK PERFORMED UNDER GRANT AND CONTRACT

Reagan, J. A., T. V. Bruhns, R. M. Schotland, and B. M. Herman, 1979: Some results of continuing lidar slant-path measurements at Tucson, Arizona. Paper presented at 9th Intl. Laser Radar Conf., Munich, West Germany, July 2-6, 1979.

Reagan, J. A., T. V. Bruhns, D. D'Sousa, and G. P. Box, 1980: Extinction properties of tropospheric aerosols over Tucson, Arizona as determined by lidar measurements. Paper presented at 10th Intl. Laser Radar Conf., Silver Spring, MD, Oct. 6-9, 1980.

Reagan, J. A., 1981: Determination of particulate backscatter and extinction profiles from monostatic lidar measurements. Proc. Tri-service Lidar Workshop (P. B. Ulrich, Ed.), pp. 127-131, DoD, Tucson, AZ, Feb. 3-5, 1981.

Reagan, J. A., C. L. Goldsmith, A. J. Anderson, and J. P. Garcia, 1982: Particulate extinction and backscatter properties determined from lidar measurements. Paper presented at 11th Intl. Laser Radar Conf., Madison, WI, June 21-25, 1982.

Reagan, J. A., 1982: Results of lidar and tethered balloon measurements of particulate properties near Tucson, AZ. Paper presented at 1982 CSL Scientific Conference on Obscuration and Aerosol Research, Aberdeen Proving Ground, MD, June 21-25, 1982,

Reagan, J. A. and B. M. Herman, 1983: Monostatic and bistatic lidar techniques for remote sensing of aerosols. Aerosol Sci: Technol., 2, pp. 197-198, April 18-22, 1983.

Reagan, J. A., M. Apte, T. V. Bruhns, and O. Youngbluth, 1983: Lidar and balloon-borne cascade impactor measurements of aerosols: A case study. Paper submitted for publication to Aerosol Sci. Technol., Aug., 1983.

Related Publications

King, M. D., D. M. Byrne, B. M. Herman and J. A. Reagan, 1978: Aerosol size distributions obtained by inversion of spectral optical depth measurements. J. Atmos. Sci., 35, 2153-2167.

King, M. D., D. M. Byrne, J. A. Reagan and B. M. Herman, 1980: Spectral variation of optical depth at Tucson, Arizona between August 1975 and December 1977. J. Appl. Meteor., 19, 723-732.

Spinhirne, J. D., J. A. Reagan, and B. M. Herman, 1980: Vertical distribution of aerosol extinction cross section and inference of aerosol imaginary index in the troposphere by lidar technique, J. Appl. Meteor., 19, 426-438.

4. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED

Principal Investigator

John A. Reagan*†, Professor of Electrical and Computer Engineering

Ph.D. Student

Thomas V. Bruhns*, Ph.D. Student in Electrical & Computer Engineering. Should complete degree work by May, 1984.

M.S. Student

Alan Anderson*, M.S. Student in Computer Science - Degree Awarded

Madhav Apte†, M. S. Student in Electrical & Computer Engineering. Should complete degree work by May, 1984.

Gail Box*, M. S. Student in Computer Science. She returned to Australia before completing degree work.

Daniel D'Souza*, M. S. Student in Computer Science - Degree Awarded

John Garcia*†, M. S. Student in Electrical & Computer Engineering. Should complete degree work by May, 1984.

Charles L. Goldsmith*, M. S. Student in Electrical & Computer Engineering. Degree awarded

Robert Sullivan*, M. S. Student in Electrical & Computer Engineering. Left school without completing degree work.

Undergraduate Sudents

Charles L. Goldmith*, Electrical Engineering Undergraduate who has received B.S.E.E. degree and stayed on project for M.S. work.

Robert Leibowitz*, Electrical Engineering undergraduate who has received B.S.E.E. degree.

Michael Lundstord*, Electrical Engineering undergraduate who has left school.

Thang B. Nguyen*, Electrical Engineering undergraduate who has received B.S.E.E. degree.

Marilee Roell†, Electrical Engineering undergraduate who is now in her junior year. She initially worked as a high school student under the ARO supported Academy of Science Research and Engineering Apprenticeship Program.

*Received support from Grant DAAG-29-78-G-0195.

†Received support from follow-on Contract DAAG-29-82-K-0081.

5. REFERENCES

King, M. D., D. M. Byrne, B. M. Herman and J. A. Reagan, 1978: Aerosol size distributions obtained by inversion of spectral optical depth measurements. J. Atmos. Sci., 35, 2153-2167.

King, M. D., D. M. Byrne, J. A. Reagan and B. M. Herman, 1980: Spectral variation of optical depth at Tucson, Arizona between August 1975 and December 1977. J. Appl. Meteor., 19, 723-732.

Reagan, J. A., M. Apte, T. V. Bruhns, and O. Youngbluth, 1983: Lidar and balloon-borne cascade impactor measurements of aerosols: A case study. Paper submitted for publication to Aerosol Sci. Technol., August 1983.

Spinhirne, J. D., J. A. Reagan and B. M. Herman, 1980: Vertical distribution of aerosol extinction cross section and interence of aerosol imaginary index in the troposphere by lidar technique. J. Appl. Meteor., 19, 426-438.

END

FILMED

10-83

DTIC