GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: June 4, 1979

Project Title: In-Situ Light Scattering Techniques for Determining Aerosol Size Distributions and Optical Techniques

Project No: G-35-654 Green card

Project Director: Dr. Gerald W. Grams

Sponsor: U. S. Army Research Office; Research Triangle Park, NC 27709

Agreement Period: From 5/1/79 Until ~~4/30/82~~ 4/30/83 (R&D Performance Period)

Type Agreement: Contract No. DAAG29-79-C-0092

Amount: $239,842 ARO (Incrementally funded at $39,929) = 95% of costs
12,623*GIT G-35-339 (or 5% of total allowable costs)
$252,465 Total

Reports Required: Semi-Annual Progress Reports; Interim Technical Reports/Publication Reprints, and Final Technical Report

Sponsor Contact Person (s):

Technical Matters

Dr. Leo Alpert
Army Research Office
Geosciences
P. O. Box 12211
Research Triangle Park, N.C. 27709

Contractual Matters
(thru OCA)

Mr. Hodges T. Throckmorton
Contracting Officer
U. S. Army Research Office
P. O. Box 12211
Research Triangle Park, N. C. 27709

For patents, property & closeouts:
ONR RR - Georgia Tech

*G-35-339 companion account for cost sharing.

Defense Priority Rating: N/A

Assigned to: School of Geophysical Sciences (School/Laboratory)

COPIES TO:

- Project Director
- Division Chief (EES)
- School/Laboratory Director
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- Project Code (GTRI)
- Other

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

2-SR38490

SPONSORED PROJECT TERMINATION SHEET

Date September 20, 1983

Project Title: In-Situ Light Scattering Techniques for Determining Aerosol Size Distribution and Optical Techniques.

Project No: G-35-654

Project Director: Dr. Gerald W. Grams

Sponsor: U.S. Army Research Office

Effective Termination Date: 4/30/82

Clearance of Accounting Charges: -

Grant/Contract Closeout Actions Remaining:

NONE

- ☐ Final Invoice and Closing Documents
- ☐ Final Fiscal Report
- ☐ Final Report of Inventions
- ☐ Govt. Property Inventory & Related Certificate
- ☐ Classified Material Certificate
- ☐ Other _____

Project continued by G-35-638 because of change in overhead rates. The latter project was terminated 8-10-83.

Assigned to: Geo Sci (School/~~Laboratory~~)

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GTRI
DR. GRAMS

FORM OCA 10:781

PROGRESS REPORT

(TWENTY COPIES REQUIRED)

1. ARO PROPOSAL NUMBER: 16462-GS

2. PERIOD COVERED BY REPORT: 1 May 1979 - 31 December 1979

3. TITLE OF PROPOSAL: In-Situ Light Scattering Techniques for Determining Aerosol Size Distributions and Optical Constants.

4. CONTRACT OR GRANT NUMBER: DAAG-29-79-C-0092

5. NAME OF INSTITUTION: Georgia Institute of Technology

6. AUTHOR(S) OF REPORT: Gerald W. Grams

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

G.W. Grams, 1980: In-situ Light Scattering Techniques for Determining Aerosol Size Distributions and Optical Constants. Proceedings of the Workshop on Light Scattering by Irregularly Shaped Particles (D.W. Schuerman, ed.), Plenum Publishing Corp., New York, (in press).

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Principal Investigator;
G. W. Grams

Professional Personnel
E. M. Patterson (Research Scientist II)
C. M. Wyman (Research Technologist II)
H. M. Reynolds (Research Technologist I)

Students (1 month of support each)
B. T. Marshall
M. Zakikhani

No degrees for work based on this project were awarded during the reporting period.

16462-GS

GERALD W. GRAMS
GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF GEOPHYSICAL SCIENCES
ATLANTA, GA 30332

BRIEF OUTLINE OF RESEARCH FINDINGS

Our major emphasis during this reporting period has been on carrying out preparations for a laboratory study on non-spherical particle scattering. In this study, the Georgia Tech polar nephelometer system will measure scattering phase functions of particles of known composition that are generated under controlled conditions for which simultaneous data on optical properties including sizes and shapes will be documented.

When the present ARO contract was initiated, our nephelometer system could measure aerosol scattering phase functions in the angular range $15° \leq \theta \leq 165°$ for scattering in the plane perpendicular to the electric vector of a linearly polarized laser beam. Since then, the nephelometer has been modified as part of a project sponsored by a grant from the NASA Langley Research Center in which we measured scattering phase functions of stratospheric aerosol particles in the 9-13 km altitude interval at Poker Flats, Alaska, on NCAR's Sabreliner aircraft during July 1979 as part of the ground-truth program for the SAGE (Stratospheric Aerosol and Gas Experiment) sensor on the AEM-B satellite. Modifications made for the above NASA study now enable us to obtain nephelometer measurements over the range $10° \leq \theta \leq 170°$ for either the perpendicular or the parallel scattering plane.

With regard to generating aerosol particles in the laboratory, several tasks were accomplished during the reporting period. First, we ordered and received a commercial system for generating monodisperse aerosol particles. This is a vibrating orifice aerosol generator (TSI model 3050) which has been designed to disperse liquid droplets of known composition. Secondly, we initiated a laboratory project to test a variety of techniques for generating aerosol polydispersions using simple atomizer systems; Dr. R. G. Pinnick of the Army's Atmospheric Sciences Lab at White Sands provided us with technical advice on suitable equipment and materials for generating the polydisperse aerosols.

We have recently been communicating with Alessandro Coletti of Consiglio Nationale delle Ricerche (Italy's National Research Council) in Rome. Dr. Coletti has constructed and used a polar nephelometer for aerosol scattering studies in his own laboratory; he would like to spend a year as a visiting scientist in our group beginning on or about 1 April 1980. We would be extremely pleased to have him visit Georgia Tech, and we are presently working with our administrators on procedures for making a formal offer to Dr. Coletti to visit our group and participate in our research program. Dr. Coletti's organization can provide the first 3 months of his salary for the year's visit; we are presently exploring a variety of opportunities for providing financial support for the remainder of his year's salary. Assuming that we will be successful in completing arrangements for Dr. Coletti's visit, we anticipate that he would be heavily involved in our laboratory study of light scattering by non-spherical particles during his stay in the U.S.

During the reporting period, the principal investigator attended two meetings that were of direct interest to this project. In June 1979, he attended a workshop on irregular particle scattering at Albany, New York. Two papers were presented at the meeting: one of these papers described our plans for laboratory studies of nonspherical particle scattering; the second paper (co-authored with P. Chýlek) discussed the possible effects of nonspherical particle shapes on the interpretation of observations of scattering phase functions of dust particles in the Martian atmosphere. In September 1979, the principal investigator attended the 1979 CSL Scientific Conference on Obscuration and Aerosol Research held at the Aberdeen Proving Ground in Maryland and presented a paper on in-situ aerosol measurements with polar nephelometers. The conference proceedings for the irregular particle scattering workshop will include a written version of the principal investigator's discussion of our ARO project; an abstract of that paper is appended to this report.

Attachment to: First Semi-Annual Progress Report for
U.S. Army Contract No. DAAG-29-79-C-0092

Publication Information:

G. W. Grams, 1980: In-Situ Light Scattering Techniques for Determining Aerosol Size Distributions and Optical Constants. Proceedings of the Workshop on Light Scattering by Irregularly Shaped Particles (D.W. Schuerman, ed.), Plenum Publishing Corp., New York (in press).

ABSTRACT: Our Atmospheric Optics Group at Georgia Tech has initiated a research program to improve existing instrumentation and data analysis techniques for obtaining in-situ data on size distributions and optical properties of airborne particles. This work is based on the use of laser polar nephelometers to measure scattering phase functions for aerosols of known size, shape, and composition to provide input data for testing the validity of a variety of techniques for calculating scattering by non-spherical particles.

PROGRESS REPORT

(TWENTY COPIES REQUIRED)

1. ARO PROPOSAL NUMBER: 16462-GS

2. PERIOD COVERED BY REPORT: 1 January 1980-30 June 1980

3. TITLE OF PROPOSAL: In-Situ Light Scattering Techniques for Determining Aerosol Size Distributions and Optical Constants.

4. CONTRACT OR GRANT NUMBER: DAAG-29-79-C-0092

5. NAME OF INSTITUTION: Georgia Institute of Technology

6. AUTHOR(S) OF REPORT: Gerald W. Grams

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

G. W. Grams, 1980: In-situ Light Scattering Techniques for Determining Aerosol Size Distributions and Optical Constants. Light Scattering by Irregularly Shaped Particles (D. W. Schuerman, Ed.), Plenum Publishing Corp., New York, pp. 243-246.

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Principal Investigator: G. W. Grams
Professional Personnel:
E. M. Patterson (Research Scientist II)
C. M. Wyman (Research Technologist II)
H. M. Reynolds (Research Technologist I)
Student:
B. T. Marshall

No degrees for work based on this project were awarded during the reporting period.

Dr. Gerald W. Grams 16462-GS
Georgia Institute of Technology
School of Geophysical Sciences
Atlanta, GA 30332

BRIEF OUTLINE OF RESEARCH FINDINGS

During this reporting period, we concentrated on our program for measurements of scattering phase functions of particles of known composition generated under controlled laboratory conditions with simultaneous documentation of aerosol optical properties including size and shape. When this work began, the Georgia Tech nephelometer system could measure aerosol scattering phase functions for the angular range $15° \leq \theta \leq 165°$ for the plane perpendicular to the electric vector of a linearly polarized laser beam of wavelength $\lambda = 0.633$ μm. Modifications made during the previous reporting period extended the nephelometer capabilities to allow a scattering-angle range $10° \leq \theta \leq 170°$ for both scattering planes (perpendicular and parallel to the electric vector of the incident radiation).

With regard to generating aerosol particles in the laboratory, the vibrating orifice particle generating system (TSI Model 3050) has been installed, and it is presently being used with our aerosol measurement system to generate monodisperse liquid droplets of known composition. We also started work on a very promising continuous-flow system for generating polydisperse aerosol particles based on equipment developed for use in the First International Workshop on Light Absorption by Aerosol Particles at Colorado State University (CSU) during the time period 28 July-8 August 1980 under sponsorship of the Radiation Commission of the International Association of Meteorology and Atmospheric Physics (IAMAP). We plan to operate our aerosol optics system at Ft. Collins during that workshop with travel funds provided by CSU through a grant from the National Science Foundation.

Alessandro Coletti of Italy's CNR (National Research Council) is now spending a year as a visiting scientist in our group. Dr. Coletti has constructed and used a polar nephelometer for aerosol scattering studies in his own laboratory in Rome. He will be heavily involved in our ARO study of light scattering by nonspherical particles. We are currently modifying Coletti's nephelometer for use with the Georgia Tech breadboard polar nephelometer test system. By replacing the helium-neon laser originally used in his nephelometer by the continuous-wave dye laser in our breadboard system, his instrument can be used during our nonspherical particle scattering experiments to measure phase functions versus wavelength for the wavelengths $0.55 \leq \lambda \leq .65$ μm for scattering angles $15° \leq \theta \leq 165°$ in the plane parallel to the electric vector of the dye-laser beam. At the same time, the Georgia Tech nephelometer measures phase functions at $\lambda = 0.633$ μm at scattering angles $10° \leq \theta \leq 170°$ in both the parallel and the scattering planes. These experiments at Georgia Tech will begin during the fall quarter using the continuous-flow system for generating polydisperse aerosol particles composed of non-absorbing salt particles, absorbing particles of methylene blue, and mixtures of the two types of particles. For carrying out intercomparisons between the observations and several of the ad hoc theories for scattering by irregular particles, we are now writing a FORTRAN computer program to calculate phase functions by the technique proposed by Pollack and Cuzzi (J. Atmos. Sci., 37, 868-881, 1980). We already have programs for the ad hoc procedure proposed by Chylek et al. (Science, 193, 480-482, 1976). Our laboratory data will be compared with both of the proposed techniques for calculating light scattering by irregular, randomly oriented particles.

Other activities during the reporting period included extensive preparations for participation in the IAMAP Workshop on Light Absorption by Aerosol Particles. Although our polar nephelometer does not directly measure aerosol absorption, we had previously reported progress on procedures for determining the complex refractive index of spherical aerosol particles by analysis of light scattering data (Grams et al., J. Appl. Meteorol., 13, 459-471, 1974). As a result, we were invited to participate in the workshop and, since our participation would allow us to obtain practical experience in working with the continuous-flow aerosol generation system developed for the measurements at the workshop, we agreed to participate. In our next report, we will summarize the results of the light scattering data obtained during the CSU workshop and we will report on a series of light scattering observations of nonspherical particles obtained in our laboratory at Georgia Tech.

PROGRESS REPORT

(TWENTY COPIES REQUIRED)

1. ARO PROPOSAL NUMBER: 16462-GS

2. PERIOD COVERED BY REPORT: 1 July 1980 - 31 December 1980

3. TITLE OF PROPOSAL: In-Situ Light Scattering Techniques for Determining Aerosol Size Distributions and Optical Constants

4. CONTRACT OR GRANT NUMBER: DAAG-29-79-C-0092

5. NAME OF INSTITUTION: Georgia Institute of Technology

6. AUTHOR(S) OF REPORT: Gerald W. Grams

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

None

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Principal Investigator: G.W. Grams

Professional Personnel: E.M. Patterson (Research Scientist II)
C.M. Wyman (Research Technologist II)

Student: B.T. Marshall

No degrees for work based on this project were awarded during the reporting period.

Dr. Gerald W. Grams 16462-GS
Georgia Institute of Technology
School of Geophysical Sciences
Atlanta, GA 30332

BRIEF OUTLINE OF RESEARCH FINDINGS

During the reporting period, we measured scattering phase functions of particles of known size, shape and composition generated under controlled laboratory conditions. A Berglund-Liu vibrating orifice generator (TSI model 3050) generates monodisperse aerosol particles for a variety of salts and non-volatile liquids. A polydisperse particle generator (based on a system developed for use at Colorado State University during Summer 1980 for the First International Workshop on Light Absorption by Aerosol Particles) operated with solutions of sodium chloride, ammonium sulfate, methylene blue and DOP also provides a wide variety of particle sizes and optical constants for our polar nephelometer observations.

Two different nephelometers are used to observe the scattering phase functions. The Georgia Tech laser nephelometer (described in our original proposal) measures light scattering at angles between 10° and 170° in two polarization planes--one perpendicular and one parallel to the electric vector of a polarized He-Ne laser beam of wavelength 633nm. The other polar nephelometer is provided by Alessandro Coletti of Italy's CNR (National Research Council) who is visiting our laboratory and who now plays a major role in our ARO laboratory program. Dr. Coletti's device obtains observations at angles between 15° and 165° for one polarization plane using a high power Ar^+ laser with wavelengths of 488 and 514.5nm and a continuous wave dye laser which can be tuned over the 550-650nm wavelength interval. Improvements in the nephelometer data management system has allowed a direct link between the laboratory instruments and our school's Data General ECLIPSE minicomputer so that we can check daily results by displaying scattering phase function observations in graphical form at the end of each nephelometer experiment.

During the phase function measurements, an isokinetic sampling system collects aerosol particles onto Nucleopore filters which are then analyzed by weight to obtain total mass and by scanning electron microscope photomicrographs of the filter surfaces for determining particle sizes and shapes. These detailed studies are required for comparisons between our optical measurements and theorical predictions of aerosol scattering phase functions. We routinely use computer programs for comparing our data with Pollack and Cuzzi's semiempirical theory (J. Atmos. Sci.,37, pp. 868-881, 1980) and Chylek's ad hoc theory (Science, 198, pp. 480-482, 1976) for describing light scattering by randomly oriented non-spherical particles.

Our group participated in the "First International Light Absorption Workshop" at Colorado State University during the time period July 28 - August 8, 1980. We carried out a preliminary analysis of the workshop nephelometer data to obtain optical parameters such as asymmetry factors and scattering cross sections (Grams and Coletti, NRL/CSU Workshop Report to NSF, 1981). Similar analyses of in-situ observations of stratospheric aerosol particles on the NCAR Sabreliner aircraft have also been published (Grams, Geophys. Res. Lett.,80, pp. 13-14, 1981). Future studies of our nephelometer data will consider other optical properties of the airborne particles using our standard Mie-scattering programs as well as the above-described programs for non-spherical particles.

G 35-654

PROGRESS REPORT

(TWENTY COPIES REQUIRED)

1. ARO PROPOSAL NUMBER: 16462-GS

2. PERIOD COVERED BY REPORT: 1 January 1981-30 June 1981

3. TITLE OF PROPOSAL: In-Situ Light Scattering Techniques for Determining Aerosol Size Distributions and Optical Constants

4. CONTRACT OR GRANT NUMBER: DAAG-29-79-C-0092

5. NAME OF INSTITUTION: Georgia Institute of Technology

6. AUTHOR(S) OF REPORT: Gerald W. Grams

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

None

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Principal Investigator: Gerald W. Grams

Professional Personnel: E. M. Patterson (Research Scientist II)
C. M. Wyman (Research Technologist II)
A. Coletti (Visiting Scientist)

Student: B. T. Marshall

No degrees for work based on this project were awarded during the reporting period. The above-named student is expected to complete a Master's thesis during the next reporting period.

Dr. Gerald W. Grams 16462-GS
Georgia Institute of Technology
School of Geophysical Sciences
Atlanta, GA 30332

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During the reporting period, we completed a set of measurements of scattering phase functions of nonspherical particles in the size range of 1- to 5-μm diameter (approximate Mie size parameters $5 < x < 25$) for sodium chloride, ammonium sulfate, methylene blue and nigrosin dye. The first two compounds were selected as non-absorbing materials that are also widely present in nature; the other two were selected as absorbing compounds with relatively large values of the imaginary component of the complex refractive index.

The results of the measurements have been processed as a set of about 250 plots, each representing mean values and standard deviations for phase function observations in two polarization planes. The following studies have been performed for each of the observed polar scattering diagrams:

- aerosol scattering asymmetry factors, ratios of particle scattering to molecular scattering, and calibration constants for each of the two planes of polarization of the nephelometer have been evaluated using procedures described by Grams (Geophys. Res. Lett., 8, pp.13-14, 1981)
- observed phase functions have been compared with a modified form of the Pollack and Cuzzi (J. Atmos. Sci., 37, pp.868-881, 1980) semi-empirical theory for nonspherical particles, as described by Grams and Coletti (NRL/CSU Workshop Report to NSF, 1981);
- observed phase functions have been used to test an inversion procedure (using Mie theory) to evaluate size distributions of equivalent spherical particles following a numerical scheme similar to that of King et al., (J. Atmos. Sci., 35, pp.2153-2167, 1978).

We are in the process of preparing a report on our observations. The report will include a description of our procedure for generating the aerosol particles and conducting the light scattering observations. In addition, we expect to include figures showing the general character of the aerosol phase functions observed in the laboratory, comparing the observations and the semi-empirical theories for calculating light scattering by nonspherical particles.

We are now conducting additional experiments with sodium chlorate and various combinations of solutions of sodium chloride, ammonium sulfate, and absorbing dyes such as nigrosin and methylene blue to allow a wider range of imaginary refractive index values. We have also purchased a photoacoustic cell for in-situ measurements of absorption coefficients of aerosol particles; when this device becomes operational, we hope to conduct simultaneous measurements with the polar nephelometer data. In those experiments, we would also plan to collect particles onto Nucleopore filters for subsequent laboratory studies using a modification of the method described by Lin (Appl. Opt., 12, pp.1355-1363, 1973) in which a laser beam is used rather than a conventional light source to illuminate the filter.

The principal investigator, along with Dr. Edward Patterson of our Atmospheric Optics group at Georgia Tech, attended the 1981 CSL Conference on Observation and Aerosol Research. While at the conference, discussions with Dr. Peter Barber of the University of Utah resulted in a plan for incorporating Dr. Barber's computer program for calculating light-scattering by ellipsoidal particles into our analysis programs. Dr. Barber has kindly sent a copy of his program to us and the program is now being modified for use in our computer. This work is still in a preliminary state, but we hope that adding this new approach in our project will lead to some interesting research activities in the future.

G 35-654

PROGRESS REPORT

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1. ARO PROPOSAL NUMBER: 16462-GS

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5. NAME OF INSTITUTION: Georgia Institute of Technology

6. AUTHOR(S) OF REPORT: Gerald W. Grams

7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS PERIOD, INCLUDING JOURNAL REFERENCES:

None

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Principal Investigator:	G. W. Grams
Professional Personnel:	E. M. Patterson
	A. Coletti
Student:	B. T. Marshall
Degrees Awarded:	B. T. Marshall, Master of Science in Geophysical Sciences; Title: Characterization and regional climatic implications of tropospheric aerosols.

Dr. Gerald W. Grams 16462-GS
Georgia Institute of Technology
School of Geophysical Sciences
Atlanta, GA 30332

BRIEF OUTLINE OF RESEARCH FINDINGS

During the reporting period, we performed additional measurements of scattering phase functions of particles in the size range from about 1 μm to 5 μm diameter (i.e., with approximate Mie size parameters $5 < x < 25$). The chemical composition of the particles was varied by mixing solutions of orginic dyes (nigrosine and methylene blue) with non-absorbing salts (sodium chloride, ammonium sulfate, and potassium chlorate). The total set of measurements now forms a catalog of phase functions for almost 60 different combinations of particle size and complex refractive index. Each phase function is the result of an average over about 10 double scans of the instrument; the standard deviation of each experimental point is usually of the order of 10% or less.

On the basis of the experience acquired in performing the data analysis with the algorithms described in the previous reporting period, we have developed an improved version of our analysis program that carries out the following tasks:

- catalogs the phase function data, and computes values of aerosol scattering asymmetry factors and ratios of particle scattering to molecular scattering with better than 10% precision over the Mie size parameter range $1 < x < 28$.
- fits the experimental data with theoretical curves derived from the Pollack and Cuzzi semi-empirical theory (modified to include polarization information).
- interprets the phase function observations in terms of the basic process of diffraction, reflection and transmission of the light in each polarization plane.
- estimates the scattering cross section and single scattering albedo of the particles.

Several new developments in our laboratory are of interest to the present project. A new version of the polar nephelometer, built under NASA sponsorship to fly on their U2 aircraft for aerosol-climate experiments, was modified for ground-based operation and successfully operated during the SMOKE WEEK IV tests in Huntsville, Alabama, during the first week in November. We are now implementing procedures for transferring data from the built-in data recording system on the U2 nephelometer the disk recording system on the School of Geophysical Science's Data General ECLIPSE minicomputer. We are also intercomparing the U2 nephelometer and the old nephelometer using laboratory-generated aerosol particles as a means of calibrating the new device. Finally, the computer program for light scattering by ellipsoidal particles provided by Dr. Peter Barber is now under test; we believe that this new numerical facility will significantly improve our capabilities for interpreting the phase function observations.