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LIGHT SCATTERING CALCULATIONS FOR THE NEPHELOMETER EXPERIMENT ON THE 1981/1982 JUPITER ORBITER-PROBE MISSION

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Principal Investigator:
Prof. Gerald W. Grams
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

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INTRODUCTION

The nephelometer to be flown on the Atmospheric Entry Probe of the Galileo spacecraft will measure the spatial distribution of the light scattered from an irradiated sample volume to determine the physical characteristics of cloud particles in that volume. The angular distribution of the light scattered in forward directions by the cloud particles will be strongly dependent on the average size of the particles and only weakly dependent on the index of refraction or the particle shape. The relative magnitude of the light scattered in backward directions and the degree of polarization of the backscattered radiation will be strongly dependent on particle shape and refractive index (especially on the absorption portion of the complex refractive index). At any given scattering angle, the amount of light scattered will be proportional to the particle density. Thus, a nephelometer that uses a variety of forward and backward scattering angles can be expected to yield information on the presence and concentrations of cloud particles, the mean radius and width of the cloud particle size distribution, and additional data on the shape and composition of the cloud particles. The inference of such properties from light-scattering data is an extremely complex problem, and this investigation encompasses a variety of numerical studies and light-scattering observations that can be applied to the interpretation of the Galileo nephelometer data.

BACKGROUND INFORMATION

The principal investigator has developed a number of light scattering instruments and data analysis techniques for the detection of aerosol layers in the atmosphere and for the determination of aerosol optical properties. In the early 1960's, he used laser-based atmospheric probing systems for studies of stratospheric aerosol particles when he worked with Giorgio Fiocco on the development of a lidar (laser radar) system as a member of the Research Laboratory of Electronics at M.I.T. This project led to the first published report on lidar observations of the stratospheric aerosol layer (Fiocco and Grams, 1964; Grams and Fiocco, 1967). In the early 1970's, as a scientist at the National Center for Atmospheric Research (NCAR), he initiated a series of research projects related to the determination of aerosol optical properties by comparing echoes from airborne flyash particles observed with a ground-based lidar and laser backscattering profiles calculated from aerosol size-number distributions determined by analysis of particles collected simultaneously on the NCAR Sabreliner research aircraft (Grams et al., 1972). A laser-based polar (multiple-angle) nephelometer was then developed and used in a study to determine the complex refractive index of airborne soil particles (Grams et al., 1974). These results have subsequently been used as input data in studies of the effect of aerosol particles on the earth's climate (Russell and Grams, 1975), on visibility reduction (Patterson et al., 1976), and on laser beam extinction (Patterson, 1977). After obtaining the soil particle data, an improved version of the polar nephelometer, capable of being operated on a pressurized aircraft, was developed (Grams, Dascher, and Wyman, 1975). This nephelometer has been operated on a variety of research platforms (NASA's Convair 990, NCAR's Electra and Sabreliner aircraft) to obtain data on the optical properties of naturally occuring aerosol particles as a function of altitude at a number of different locations; it has also been operated in a small instrumented trailer for studies of particles in polluted atmsopheres. The investigator has also carried out laboratory studies of light scattering and absorption using a variety of the atmospheric aerosols as a function of particle size, shape and refractive index (e.g., Chylek, Grams and Pinnick, 1975; Grams, 1980).

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The concept of performing a polar nephelometer observation can be explained with reference to the device described by Grams et al. (1975). The general features of this device are shown in Fig. 1. The light source is a collimated laser

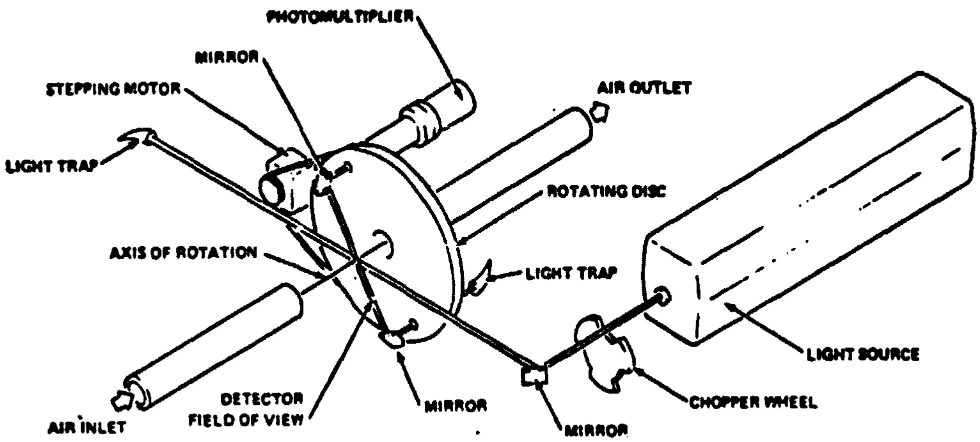

Fig. 1: Schematic illustration of the Georgia Tech laser polar nephelometer (from Grams, Dascher, and Wyman, 1975).

beam and the detector optical system defines a narrow field of view (0.5° half-angle). A photon-counting system measures a photomultiplier's pulse rate with the light beam both on and off; the difference in measured pulse rates is directly proportional to the intensity of the light scattered from the volume common to the intersection of the laser beam and the detector field of view. Measurements are made at different scattering angles by rotating the detector relative to the direction of propagation of the light beam.

RESULTS

We carried out a numerical study that was designed to establish the extent to which measurements of the light scattered from a collimated beam at certain angles by cloud particles can be related to particle size distributions and aerosol optical properties that are characteristic of a variety of possible cloud forms in the atmosphere of Jupiter. Parametric calculations for a variety of different scattering angles and assumed particle sizes and compositions indicated that the particle scattering cross sections for any angle within approximately 10° of the forward-scattering angle $\theta = 45°$ can be used to estimate the total scattering cross section to better than a factor of 1.5 for wavelength $\lambda = 0.9$ μm for particles with mean radii in the range from 0.01 μm to 10 μm and imaginary refractive indices from $n_{im} = 0$ to about $n_{im} = 0.002$; representative results that serve to illustrate this behavior are shown in Table 1. For larger n_{im} values, particles with radii larger than 1 μm exhibited scattering efficiencies that became progressively smaller when either the particle size or the value of n_{im} was increased--to the point at which total scattering cross sections would be underestimated by almost an order of magnitude at the radius r = 10 μm and the imaginary refractive index $n_{im} = 0.1$; representative results for the higher n_{im} values are shown in Table 2. This behavior at large n_{im} and large radius values is, in fact, quite similar to the response of the "integrating nephelometer" instruments commonly used in urban air pollution studies. The above results apply to very narrow size distribution functions, and we expect that even better agreement between integrated scatttering cross sections and 45° measurements would be obtained for wider size distribution functions.

We were also involved in several field measurement programs (sponsored by contracts and grants from other organizations) during the present study. Three of these programs are of special interest to the Galileo nephelometer experiment: (1) A cloud detecting nephelometer patterned after one used on the Pioneer Venus multi-probe mission was flown in Alaska on a number of high-altitude balloon experiments during August 1978 to search for nacreous clouds in the 30 to 35 km altitude region as part of a balloon experiment coordinated by D. G. Murcay (University of Denver) for data on stratospheric constituents.

Table 1. Variation of the aerosol phase function with mean particle size for non-absorbing spherical particles with refractive index 1.5-0i. Results are shown for the wavelenth 0.9 μm and a narrow log-normal size distribution function with geometeric standard deviation σ_g = 1.1 and the indicated values of the geometric mean radius r_g. All phase function values have been divided by the corresponding Rayleigh-scattering phase function values at each scattering angle for convenience in studying the range of variability of the Mie-scattering phase function with the particle size.

r_g (μm)	35^o	$37\frac{1}{2}^o$	40^o	$42\frac{1}{2}^o$	45^o	$47\frac{1}{2}^o$	50^o	$52\frac{1}{2}^o$	55^o
0.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.02	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00
0.03	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.01
0.04	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.02
0.05	1.05	1.05	1.05	1.05	1.05	1.04	1.04	1.04	1.04
0.06	1.09	1.08	1.08	1.08	1.08	1.07	1.07	1.07	1.06
0.08	1.14	1.13	1.13	1.12	1.12	1.12	1.11	1.10	1.10
0.10	1.22	1.21	1.21	1.20	1.19	1.18	1.18	1.17	1.16
0.13	1.36	1.35	1.34	1.33	1.31	1.30	1.28	1.27	1.25
0.16	1.62	1.59	1.57	1.55	1.52	1.50	1.47	1.44	1.41
0.20	2.08	2.03	1.99	1.94	1.89	1.84	1.78	1.73	1.67
0.25	2.56	2.47	2.38	2.29	2.20	2.10	2.00	1.90	1.80
0.32	2.82	2.65	2.47	2.30	2.13	1.96	1.80	1.64	1.49
0.40	3.07	2.74	2.42	2.12	1.84	1.59	1.35	1.14	.96
0.50	2.51	2.05	1.65	1.31	1.04	.83	.67	.55	.47
0.63	1.40	1.07	.86	.75	.69	.68	.69	.70	.70
0.79	1.22	1.32	1.41	1.44	1.41	1.33	1.20	1.06	.91
1.0	2.36	2.15	1.86	1.58	1.35	1.21	1.14	1.12	1.11
1.3	.99	1.04	1.09	1.11	1.07	1.00	.92	.85	.80
1.6	.98	.87	.80	.76	.72	.67	.63	.60	.57
2.0	1.76	1.50	1.31	1.17	1.06	.95	.86	.77	.71
2.5	1.32	1.22	1.07	1.01	.98	.89	.78	.72	.69
3.2	1.27	1.19	1.07	.94	.89	.85	.77	.69	.65
4.0	1.27	1.26	1.16	1.02	.97	.89	.79	.75	.67
5.0	1.33	1.24	1.09	1.03	.90	.86	.77	.72	.67
6.[illegible]	1.33	1.22	1.11	1.00	.94	.82	.81	.68	.66
7.9	1.29	1.23	1.12	1.01	.94	.86	.79	.69	.62
10.0	1.31	1.16	1.08	1.05	.99	.91	.82	.72	.64

Table 2. Same as Table 1 except for absorbing spheres with refractive index 1.5-0.1i

r_g (μm)	35°	37½°	40°	42½°	45°	47½°	50°	52½°	55°
0.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.02	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.00
0.03	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.01
0.04	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.02
0.05	1.05	1.05	1.05	1.05	1.05	1.04	1.04	1.04	1.04
0.06	1.09	1.08	1.08	1.08	1.08	1.07	1.07	1.07	1.06
0.08	1.14	1.13	1.13	1.13	1.12	1.12	1.11	1.11	1.10
0.10	1.22	1.22	1.21	1.20	1.20	1.19	1.18	1.17	1.16
0.13	1.37	1.36	1.35	1.33	1.32	1.31	1.29	1.28	1.26
0.16	1.64	1.62	1.59	1.57	1.54	1.52	1.49	1.46	1.43
0.20	2.11	2.07	2.02	1.97	1.91	1.86	1.80	1.74	1.68
0.25	2.61	2.52	2.42	2.32	2.21	2.11	2.00	1.89	1.79
0.32	2.98	2.78	2.58	2.38	2.18	1.99	1.81	1.64	1.47
0.40	3.17	2.80	2.44	2.11	1.81	1.54	1.29	1.07	.88
0.50	2.54	2.02	1.58	1.21	.92	.69	.53	.41	.34
0.63	1.19	.81	.58	.46	.42	.43	.46	.50	.53
0.79	.54	.67	.81	.91	.95	.91	.83	.71	.59
1.0	1.20	1.15	.97	.75	.56	.43	.38	.33	.41
1.3	.42	.28	.24	.28	.32	.34	.32	.28	.24
1.6	.26	.27	.26	.21	.17	.15	.14	.14	.14
2.0	.40	.29	.24	.22	.20	.17	.15	.14	.12
2.5	.30	.26	.21	.19	.18	.16	.14	.13	.12
3.2	.24	.21	.18	.16	.15	.13	.12	.11	.11
4.0	.22	.19	.18	.15	.14	.13	.12	.11	.10
5.0	2.1	.18	.16	.14	.13	.12	.11	.11	.10
6.3	.19	.17	.15	.14	.13	.12	.11	.10	.10
7.9	.18	.16	.15	.13	.12	.11	.11	.10	.10
10.0	.17	.15	.14	.13	.12	.11	.11	.10	.09

(2) We operated the Georgia Tech airborne polar (multi-angle) nephelometer on the NCAR Sabreliner aircraft over Sondrestrom, Greenland, during November 1978 as part of a ground-truth experiment for the SAM II (Stratospheric Aerosol Measurement II) sensor on the Nimbus-7 satellite. (3) We operated the multi-angle nephelometer on the same aircraft in Poker Flat, Alaska, during July 1979 as part of the ground-truth program for validating observations made by both the SAM-II and SAGE (Stratospheric Aerosol and Gas Experiment) sensors.

In these experiments, simultaneous observations of aerosol particles in the stratosphere were made by a variety of aerosol instruments on the Sabreliner, on the NASA Ames Research Center U2 aircraft, the NASA Wallops Flight Center P-3 aircraft, and on balloon packages launched by the University of Wyoming. As a result of the Sondrestrom and Poker Flat experiments, data on scattering phase functions, lidar backscattering cross sections, extinction cross sections, number densities, and size distributions for aerosol particles in the lower stratosphere are now available for use in testing algorithms for analyzing phase function data from nephelometer experiments.

Under a contract from the U.S. Army White Sands Missile Range, we also developed a laboratory polar nephelometer system for measuring the scattering phase functions of natural and artificially generated aerosol particles. We are currently carrying out a laboratory program sponsored by the U.S. Army Research Office in which our laboratory polar nephelometer system is being used for light-scattering studies on the effect of particle shape on aerosol scattering phase functions. Measured angular scattering patterns with simultaneous documentation of the size, shape, and refractive index of the laboratory-generated particles studied in our Army program are also available for use in testing algorithms for analysis of data from the Galileo nephelometer experiment.

Finally, we should mention that, as part of the NASA Aerosol Climate Experiment (ACE) program, a new version of the instrument flown on the Sabreliner experiments has been developed. The purpose of building the new instrument has been to perform direct measurements of angular scattering functions for stratospheric aerosol particles by operating a laser polar nephelometer on one of NASA's U-2 (or ER-2) aircraft. Observations of aerosol optical properties at altitudes accessible to U-2 aircraft are expected to provide data for use in radiative transfer calculations for models of the effects of stratospheric aerosol particles on the radiation budget of the atmosphere, and thereby, on the climate of the Earth.

To obtain the stratospheric aerosol observations, a number of improvements to the "old" nephelometer were incorporated in the design of the new "U2" instrument: (1) The original nephelometer measured angular scattering functions in only one scattering plane (usually the plane parallel to the electric vector of the linearly polarized laser beam); modifications made in 1979 (Grams, 1981) permitted measurements of the angular scattering patterns for both scattering planes (perpendicular and parallel to the electric vector of the source beam). The new "U2" nephelometer also performs the phase function observations in both scattering planes. (2) The original nephelometer measured angular scattering patterns for angles from 15° to 165° from the direction of propagation of the source beam; the 1979 modifications increased the angular range to cover scattering angles from 10° to 170°. The new device covers the angular range from less than 5° to more than 175° from the propagation direction. (3) The original nephelometer measured angular scattering functions by sequentially rotating a photomultiplier detector through 31 preselected angles (33 angles after the 1979 modifications); approximately 20 minutes were required to measure a complete phase function for 5-degree increments of the scattering angle. The new device obtains simultaneous measurements for over 100 different angle intervals, and it reduces the observation time to less than one minute for particles in the stratospheric aerosol layer.

The construction of the U2 nephelometer has been completed and the device has already flown on a test flight on the U2 during October 1981. The first data flights on the U2 are to occur by mid-1982. These data flights will be part of the ACE measurement program. In that regard, the plans for the forthcoming ACE missions include simultaneous operation of a variety of instruments on the U2 including observations of particle size distributions by the NASA Ames wire impactor system, a quartz crystal microbalance, and a single particle optical counter. Also included in the complement of U2 instruments are devices for measuring aerosol composition, aerosol absorption coefficients, condensation nucleus concentrations and concentrations of a variety of gaseous constituents such as water vapor and certain sulfur-bearing molecules (e.g., COS and SO_2) that are involved in aerosol formation processes. As in the case of the Sabreliner data, we expect to continue our work through other sponsored projects. Again, the extensive data sets to be collected routinely during the ACE aircraft missions can be used to test algorithms for inferring aerosol size, shape, and composition from the observed aerosol light-scattering functions measured with the Galileo nephelometer.

CONCLUSIONS

Our approach emphasizes the use of actual observations of the angular distribution of light scattered by aerosol particles obtained in a variety of laboratory and field measurement programs for which parameters on particle size, shape, and refractive index are well established and documented. These observations are a by-product of on-going laboratory and field measurement programs that are sponsored by contracts and grants from other organizations; this data base will continue to grow and by the time that the Galileo mission is carried out, we anticipate that the data base will include a wide range of aerosol parameters including combinations that can be regarded as being representative of aerosol parameters for the Galileo observations. We believe that the above approach will prove to be a cost-effective method for testing algorighms for analyzing scattering data to be obtained during the Galileo mission and for establishing a high level of confidence in the interpretation of the nephelometer data.

Although this grant has officially ended, we do plan to continue our work with laboratory-generated and natural aerosol particles. Our on-going efforts in the area are expected to provide more insight into the basic physics of light scattering processes for use in interpretation of data to be obtained during the Galileo mission.

REFERENCES

Chylek, P., G. W. Grams, and R. G. Pinnick, 1976: Light scattering by irregular randomly oriented particles. Science, 193, 480-482.

Fiocco, G. and G. W. Grams, 1964: Observations of the aerosol layer at 20 km by optical radar. J. Atmos. Sci., 21, 323-324.

Grams, G. W., 1980: In situ light scattering techniques for determining aerosol size distributions and optical constants. In Light Scattering by Irregularly Shaped Particles (D. W. Schuerman, ed.), Plenum Publishing Co., pp. 243-246.

Grams, G. W., 1981: In situ measurements of scattering phase functions of stratospheric aerosol particles in Alaska during July 1979. J. Geophys. Res., 8, 13-14.

Grams, G. W., I. H. Blifford, Jr., D. A. Gillette, and P. B. Russell, 1974: Complex index of refraction of airborne soil particles. J. Appl. Meteor., 13, 459-471.

Grams, G. W., I. H. Blifford, Jr., B. G. Schuster, and J. J. DeLuisi, 1972: Complex index of refraction of airborne flyash determined by laser radar and collection of particles at 13 km. J. Atmos. Sci., 29, 900-905.

Grams, G. W., A. J. Dascher, and C. M. Wyman, 1975: Laser polar nephelometer for airborne measurements of aerosol optical properties. Opt. Eng., 14, 85-90.

Grams, G. W. and G. Fiocco, 1967: Stratospheric aerosol layer during 1964 and 1965. J. Geophys. Res., 72, 3523-3542.

Patterson, E. M., 1977: Atmospheric extinction between 0.55 and 10.6 μm due to soil-derived aerosols. Appl. Optics, 16, 2414-2418.

Patterson, E. M., D. A. Gillette, and G. W. Grams, 1976: On the relation between visibility and the size number distribution of airborne soil particles. J. Appl. Meteor., 15, 470-478.

Russell, P. B., and G. W. Grams, 1975: Application of soil dust optical properties in analytical models of climate change. J. Appl. Meteor., 14, 1037-1043.

Project-Related Publication List

All the papers published during this grant that are relevant to the subject of this investigation are listed below:

Grams, G. W. and A. Coletti, 1982: Analysis of nephelometer data obtained at the First International Workshop on Light Absorption of Aerosol Particles. In Light Absorption by Aerosol Particles (H.E. Gerber and E. E. Hindman, editors), Spectrum Press, Hampton, VA (in press).

Patterson, E. M., B. A. Bodhaine, A. Coletti, and G. W. Grams, 1982: Volume scattering ratios determined by the polar and the integrating nephelometer: A comparison. Appl. Optics, 21, 396-397.

Grams, G. W., 1981: In-situ measurements of scattering phase functions of stratospheric aerosol particles in Alaska during July 1981, Geophys. Res. Lett., 8, 13-14.

Grams, G. W., 1980: In-situ light scattering techniques for determining aerosol size distributions and optical constants. In Light Scattering by Irregularly Shaped Particles (D. W. Schuerman, Ed.), Plenum Publishing Co., pp. 243-246.

Chylek, P. and G. W. Grams, 1978: Scattering by nonspherical particles and optical properties of Martian dust. Icarus, 36, 198-203.

Grams, G. W. and J. M. Rosen, 1978: Instrumentation for in-situ measurements of the optical properties of stratospheric aerosol particles. Atmospheric Technology, 9, 35-54.