

PROJECT ADMINISTRATION DATA SHEET

ORIGINAL REVISION NO. _____

Project No. G-35-638 R5977-0A0 GTRC/~~STX~~ DATE 7 / 17 / 85

Project Director: Dr. Edward M. Patterson School/~~Lab~~ Geo. Sci.

Sponsor: NASA Goddard Space Flight Center, Greenbelt, MD. 20771

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Award Period: From 7/15/85 To 10/31/85 (Performance) ¹⁻³¹⁻⁸⁷ ~~11-14-86~~ 10/31/85 (Reports)

Sponsor Amount: This Change Total to Date

Estimated: \$ _____ \$ _____

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Title: Aircraft Measurements of Aerosol Scattering and Absorption

ADMINISTRATIVE DATA

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Defense Priority Rating: _____ Military Security Classification: _____

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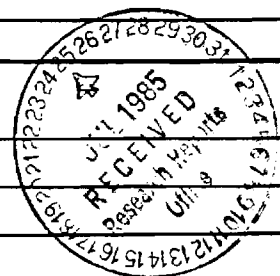
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See Attached NASA Supplemental Information Sheet for Additional Requirements.

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Equipment: Title vests with GIT if less than \$1,000 greater than \$1,000 NASA retains the right to retain titles however, none proposed.

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SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 3/10/88

Project No. G-35-638 School/~~LAB~~ Geo. Sci.

Includes Subproject No. (s) N/A

Project Director(s) E. M. Patterson GTRC/GIT

Sponsor NASA-Goddard

Title Aircraft Measurements of Aerosol Scattering and Absorption

Effective Completion Date: 1/31/87 (Performance) 1/31/87 (Reports)

Grant/Contract Closeout Actions Remaining:

- None
- Final Invoice or Copy of Last Invoice Serving as Final
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INTERIM REPORT

Aircraft Measurements of Aerosol Scattering and Absorption

NASA PROJECT

NAG 5-592
Goddard Space Flight Center
Greenbelt, MD 20771

15 July, 1985 - 15 January, 1986

Submitted by

E M Patterson
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

January 29, 1986

INTRODUCTION

The objectives of this research program have been:

1. To obtain direct data on the scattering and absorption properties of the tropospheric aerosols by in-situ scattering measurements with an integrating nephelometer and by collection of aerosol samples on filters for subsequent laboratory determination of absorption.
2. To compare these data with inferences of aerosol scattering and absorption determined from an analysis of bidirectional reflectance data for the same aerosol population.

These measurements were planned in conjunction with a series of bidirectional reflectance measurements aboard a Skyvan aircraft during the summer of 1985. The project was funded in two increments; this report covers the work done under the first funding increment.

ACCOMPLISHMENTS DURING REPORTING PERIOD

During this period the filter sampling apparatus and the integrating nephelometer (MRI model 1550) were installed aboard the NASA Skyvan aircraft and operated during data flights on 15-9-85, 19-9-85, and 20-9-85. Both the nephelometer and the air sampling system were operated successfully during these flights. In addition to the primary measurements, temperature and pressure were measured to aid in the interpretation of the primary measurements. Scattering values, pressure values, and temperatures were recorded digitally on paper tape. The usual recording rate was 1 min⁻¹; more frequent recording was used if conditions were variable.

Filter samples were collected during the flights on Nuclepore filters for the subsequent laboratory analysis of absorption by the diffuse transmission method. Inspection of the filters subsequent to the flights indicated that sufficient material was collected for the desired measurements.

A determination of the absorption from the filter samples has been started. This analysis confirms that sufficient material was collected on the low level flight legs for the determination of absorption. We were not able to collect sufficient material on the upper levels for the absorption measurements.

We have emphasized the analysis of the data for September 20. A preliminary analysis indicates that the absorption coefficient at the lowest flight level of ~500' on September 20 was $\sim 2.1 \times 10^{-5} \text{ m}^{-1}$ at 632.8 nm. In addition, a sample was collected at the Chestertown surface site between 0800 and 1100 on September 20 by Goddard personnel. This sample was very heavily loaded with a non-constant flow. Consequently, as a part of our analysis, we used the pump characteristics to estimate the flow as a function of time to determine the total air volume through the filter. The absorption determined for this sample was $\sim 3.5 \times 10^{-5} \text{ m}^{-1}$ at 632.8 nm.

A plot of the integrating nephelometer data determined at the surface site by Goddard personnel is shown as Fig. 1. The wavelength of the nephelometer data is different from that of the absorption data and so a direct comparison of the absorption and the scattering data is not appropriate at this time. The data was taken during a time of varying relative humidity, however, and it appears that a significant portion of

the variation is consistent with the variation in the scatter expected with changes in humidity. A comparison of the data in Fig. 1 with that shown in Fig. 2 (from Charlson et al, 1974) indicates that the variation in scattering is consistent with that expected for an $(\text{NH}_4)_2\text{SO}_4$ aerosol. Further work to interpret this data and to evaluate the possible effects of changing aerosol concentrations is, of course, needed.

FUTURE PLANS

It is planned to continue the analysis of the scattering data for the determination of the single scattering albedo and to determine the variation of the scattering with height. Further work with the absorption data is planned to refine our estimates of absorption.

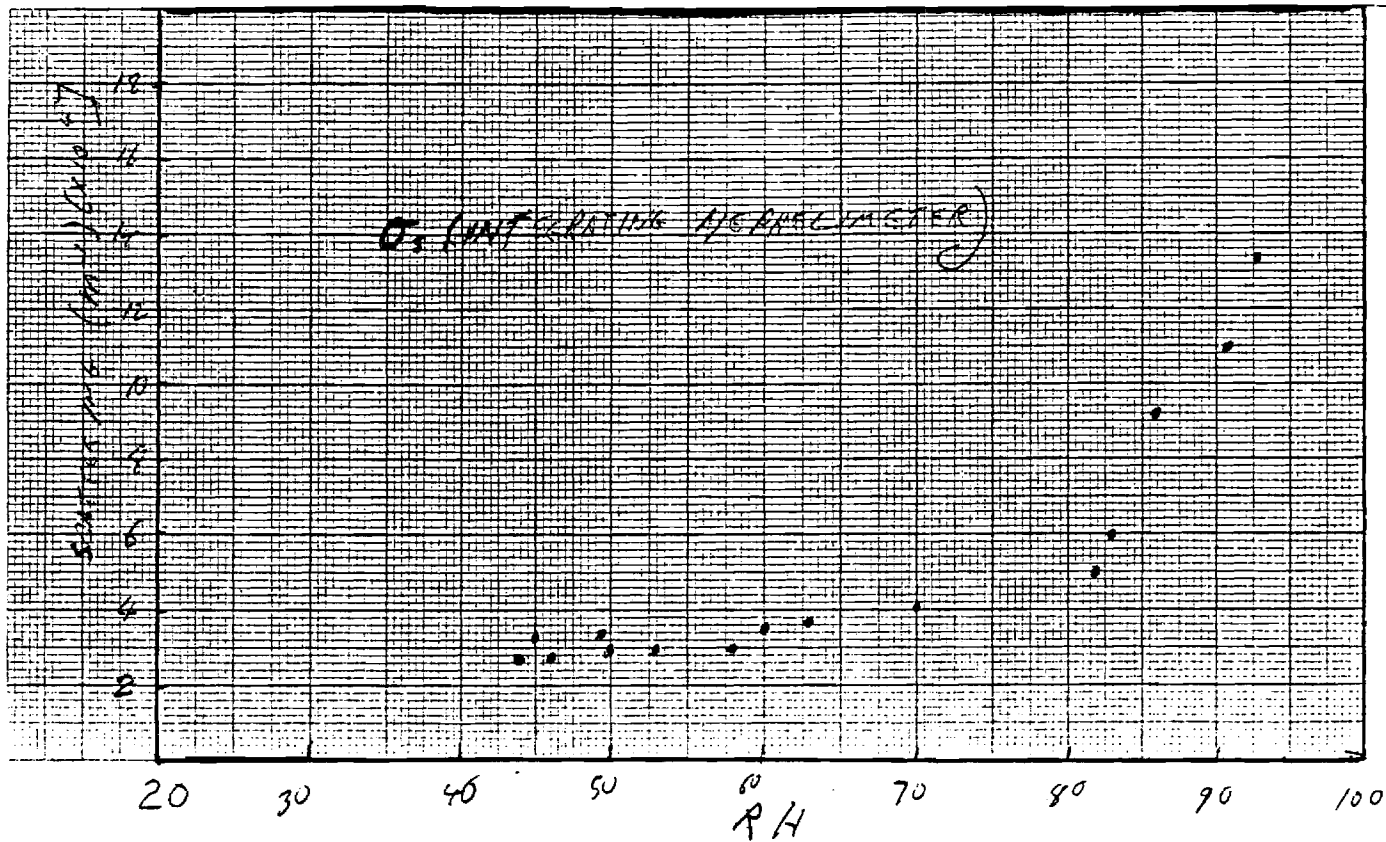


FIG 1

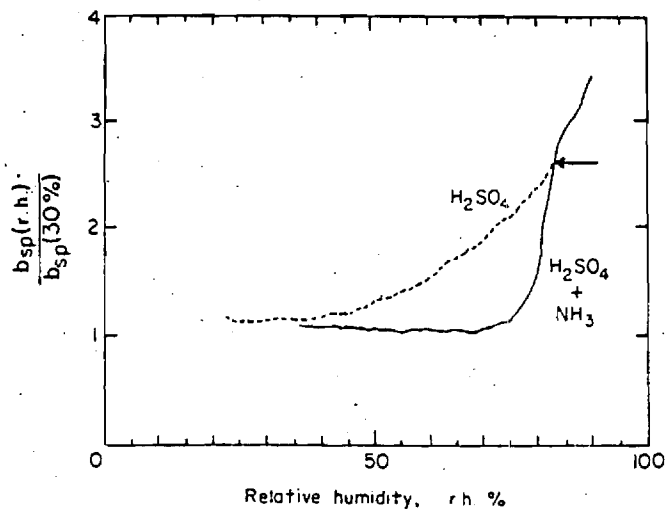


Fig. 2. Humidogram for laboratory H_2SO_4 aerosol (dashed) and for the reaction product of this H_2SO_4 and NH_3 (solid). The ordinate is the ratio of light scattering coefficient due to particulate matter at the given relative humidity [$b_{sp}(r.h.)$] to the light scattering coefficient at 30 per cent. The abscissa is relative humidity in per cent. The inflection point in the $(NH_4)_2SO_4$ curve (arrow) corresponds to the humidity at which all the particles have been converted to droplets. The increase starting at ca. 72 per cent is due to the presence of submicron particles which have a higher than bulk solubility due to curvature or is due to mixing characteristics of the flow system (7).

Aircraft Measurements of Aerosol Scattering and Absorption

Second Interim Status Report

for

NASA Project

NAG 5-592

Goddard Space Flight Center
Greenbelt, MD 20771

Edward M. Patterson
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia

Covering Period January 1, 1986 --June 30, 1986

During this period the absorption analysis of the filters collected during the aircraft flights was completed. Adequate filter loading for two of the three aircraft flight days was obtained. Measured absorption coefficients were in the range of $6 \times 10^{-3} \text{ km}^{-1}$ to $2 \times 10^{-2} \text{ km Pt}^{-1}$.

The analysis of the scattering data was also initiated during this time period. All of the scattering data appeared to be valid, although some recalibration of the nephelometer data was undertaken. A small scale study of the wavelength response of the nephelometer was also undertaken at this time. This study enabled us to estimate the effective wavelength response of the instrument and to adjust manufacturer's calibration procedures.

This work will be continued during the remainder of the contract.

Aircraft Measurements of Aerosol Scattering and Absorption

FINAL REPORT

NASA PROJECT NAG 5-592

Goddard Space Flight Center
Greenbelt, MD 20771

15 July, 1985 - 30 January, 1987

Submitted by

E. M. Patterson
School of Geophysical Sciences
Georgia Institute of Technology
Atlanta, Georgia 30332

February 10, 1988

ABSTRACT

We have measured the scattering and absorption coefficients for lower tropospheric aerosols by the use of an integrating nephelometer and diffuse transmission analysis of aerosol filter samples. These measurements were made in conjunction with a series of bidirectional reflectance and wavelength dependent turbidity measurements aboard the NASA Wallops Island Skyvan aircraft near the Chesapeake Bay in the summer of 1985.

These measurements show relatively high values of single scattering albedo, with the measured values greater than 0.9 in all cases. An analysis of the variation of the scattering with humidity changes suggests that the aerosols may be primarily ammonium sulfate.

INTRODUCTION

We are reporting the results of a set of measurements of aerosol scattering and absorption for lower tropospheric aerosols conducted aboard the NASA Wallops Island Skyvan aircraft and on the ground below the flight path of the aircraft. The objectives of this research program were:

1. To obtain direct data on the scattering and absorption properties of the lower tropospheric aerosols by in-situ scattering measurements with an integrating nephelometer and by collection of aerosol samples on filters for subsequent laboratory determination of absorption.
2. To compare these aerosol data with inferences of aerosol scattering and absorption determined from an analysis of bidirectional reflectance data for the same aerosol population.
3. To compare these aerosol data with wavelength dependent turbidity measurements.

These measurements were made to support a series of bidirectional reflectance measurements aboard the Skyvan aircraft during the summer on 1985. The measurements were made on three data flights on 15-9-85 (Day I), 19-9-85 (Day II), and 20-9-85 (Day III). The in-situ aerosol measurements were carried out successfully on all flights, and sufficient material was obtained for absorption measurements on the 19th and the 20 of September. In general, all of the objectives of the measurements were accomplished.

AIRCRAFT FLIGHTS

The Skyvan aircraft was based at Wallops Island during this experimental program. The primary measurement site was an agricultural area near Chestertown, MD. The flights for the bidirectional reflectance measurements included a ferry leg from Wallops Island to Chestertown, a set of low level flights (altitude < 1000 ft) over the test site, a climb to the maximum altitude of the aircraft (12,000 ft), an additional set of high altitude flights over the site, and a subsequent return to Wallops Island. Multiwavelength turbidity measurements were made at low and high levels and differential values were calculated. On one of the flights, (Day II) the aircraft flew the flight tracks near Wallops Island rather than over the test site.

EXPERIMENTAL DISCUSSION

The aerosol measurement apparatus on the Skyvan included an integrating nephelometer, MRI Model 1550, (Ahlquist and Charlson, 1968) and an air sampling system to provide nephelometer sample air and to provide for the collection of aerosol samples during flight. In addition to the primary measurements, temperature and pressure in the sampling lines were monitored to aid in the interpretation of the primary measurements. Total scattering values, pressure values, and air temperatures were recorded digitally on paper tape during the flight. The usual data recording rate was 1 min^{-1} ; more frequent recording was used if conditions were variable.

The ground-based aerosol measurements included an integrating nephelometer similar to the one on the aircraft and an aerosol sampling system for filter collection. The ground based system was operated by NASA personnel, and the analysis of the ground-based data was done at Georgia Tech.

The integrating nephelometer provides a continuous record of a truncated total scatter for the aerosol and the air. The truncation involves the angles near 0° and near 180° . The truncation occurs because of the geometry of the source and detector optics. The instrument is calibrated by means of Rayleigh scattering from air and from Freon, and so the truncation will be a problem only for possible scatterers with a large fraction of their scattered light in the near forward direction. No such problem was expected for the measurements discussed here.

The nephelometer is a broadband instrument with an effective mean wavelength of approximately 490 nm. (Ahlquist and Charlson, 1969). This differs from the earlier estimated effective wavelength of 460 nm. and required some modification in the manufacturers recommended calibration procedures. Specifically, the Rayleigh scattering measured during calibration is actually approximately 80% of the value assumed in the calibration procedures; and so all values of measured scattering must be reduced to 80% of the direct calibration values. Such an adjustment was made during data analysis.

The filter samples were collected onto Nuclepore (TM) filters. In general, three samples were collected for each flight: one during the initial ferry flight, one during the low level flight over the test site, and one during the climb and upper level flight legs. The subsequent laboratory analysis of optical absorption was accomplished by means of the diffuse transmission techniques discussed by Patterson and Marshall (1982). The diffuse transmission measurements were made at a wavelength of 632.8 nm. Single scattering

albedos were calculated from the absorption and the scattering data. The two data sets were for different wavelengths, however, 490 nm for the nephelometer and 632.8 for the absorption data. Both data sets were converted to a common wavelength of 550 nm for single scattering albedo calculations assuming a $1/\lambda$ dependence for the absorption coefficients and a $1/\lambda^{1.3}$ for the scattering coefficients.

DATA AND ANALYSIS

The scattering data measured during this program is presented in a series of plots of scattering as a function of altitude or as a function of time during a constant altitude flight track. The absorption data are presented as average values for the time the filter was exposed. Absorption was determined only for samples collected within the haze layers; we were not able to collect sufficient material at the higher flight levels for the absorption determinations. We will discuss the absorption and the scattering data by flight days. In our discussion, we emphasize the analysis of the data for the Day III flight (20-9) since that is the flight for which the most complete data set exists. Each of the other two days are also discussed, however.

Day III Scattering and Absorption Data

Nephelometer data measured aboard the aircraft during the Day III flights are shown in Figs. 1, 2, and 3. Fig. 1 shows the time sequence of nephelometer data measured during the ferry flight from Wallops Island to Chestertown; the data represent the scattering at an altitude of ~3400 ft. Fig. 2 shows the time sequence for the low level Chesterton data for an altitude of ~600 ft. The 600 ft altitude nephelometer data in Fig. 2 show a range of variation between $\sim 0.25 \text{ km}^{-1}$ and $\sim 0.4 \text{ km}^{-1}$, which is much more variation than that seen in the 3,400 ft data.

The aerosol scattering data obtained during the climb from 600 to 12,000 ft at the conclusion of the low level Chestertown runs are shown in Fig. 3. The curve shows a decrease in scattering from the 600 ft. value of $\sim 0.32 \text{ km}^{-1}$ to a value of $\sim 0.22 \text{ km}^{-1}$ that is then approximately constant throughout the haze layer which extends up to ~4500 ft decreasing to mid tropospheric values above 5000 ft. Although data were collected up to 12,000 ft, the data above 6,000 ft do not differ significantly from the Rayleigh scattering for air; and so in this and subsequent figures, we show the data only to ~6,000 ft. We would also point out that the somewhat high 600 ft data point in Fig. 3 is an average value for the 600 ft flight tracks; the lower values measured during the 600 ft flight tracks are quite similar to those measured at higher altitudes in the haze layer.

A plot of the integrating nephelometer data determined at the surface site prior to and during the Day III aircraft flights is shown in Fig. 4. This data showed a decrease with time during the morning that is correlated with a decrease in relative humidity. We have shown the surface data as a plot of the measured scattering vs relative humidity. It appears that a significant portion of the variation is consistent with the variation in scatter expected with changes in relative humidity. A comparison of the Fig. 4 data with that shown in Fig. 5 (from Charlson et al, 1974) indicates that the variation in scattering is consistent with that expected for an $(\text{NH}_4)_2\text{SO}_4$ aerosol. The values measured under low humidity conditions at the surface site are consistent with the aircraft measurements.

Absorption coefficient values were 0.019 km^{-1} at 500 ft and 0.009 km^{-1} at 3400 ft. By comparison the measured surface value was 0.035 km^{-1} . The surface value is more uncertain than the aircraft samples since the sample was very heavily loaded with a non-constant flow. Consequently, it was necessary, as part of the analysis, to estimate the flow as a function of time to determine the total air volume through the filter.

As discussed above the filter and the nephelometer data were converted to 550 nm values for the calculation of single scatter albedo. Resulting values are 0.96 for the 3,400 ft data and 0.92 for the 800 ft data. We have not calculated a value of single scattering albedo for the surface data due to the questions concerning the data discussed above.

Day II Scattering and Absorption Data

Nephelometer data between 500 ft and 6,000 ft for the Day II flight are shown in Fig. 6. The depth of the haze layer is quite similar to that seen on the 20th, but the aerosol scattering values, though approximately constant through the haze layer, are much less than those seen on the 20th. The average aerosol scattering coefficient measured during the 500 ft low altitude flight track was 0.11 km^{-1} . The measured absorption coefficient for the low altitude was 0.006 km^{-1} . The 550 nm single scattering albedo was calculated to be 0.931 at 500 ft; it is reasonable to assume that this value and is approximately constant throughout the haze layer.

Day I Scattering Data

Nephelometer data between 500 and 6,000 ft for the Day I flight are shown in Fig. 7. This day showed the least aerosol loading of the three flight days, with the average scattering in the haze layer only about 0.02 km^{-1} . Aerosol

filter loadings were too light to determine absorption data for this flight.

Meteorological Data for Aircraft Flight Days

Soundings for the 20th and the 19th of September are shown in Figs 8 and 9. In each case the haze layer coincides with a region of relatively moist air, and the haze layer is topped with an inversion near 4,000 ft that provides a well defined upper boundary to the haze layer.

Relation to Visibility Measurements

One measure of the confidence that can be placed in the optical measurements is the degree of agreement that can be seen between the calculated values of extinction and the observed visibility. We calculated a value of 0.29 km^{-1} at 600 ft and 0.23 km^{-1} at 1000 ft and higher for the 550 nm aerosol extinction on Day III and 0.10 through the haze layer on Day II. These extinction values correspond to visual ranges of 13-16 km for Day III and 35 km on Day II. By comparison visibilities were estimated at 11 km over the test site on Day III and 30 km on Day II. Because of the lower aerosol loadings on Day I, no valid visibility comparisons could be made. Overall, the agreement is quite good.

CONCLUSIONS

The results of the optical measurements can be summarized in terms of the data presented in Tables I and II. Table I shows the directly measured scattering and absorption values and Table II shows the values inferred for 550 nm. We have also calculated the extinction values for 500 nm for the 19th and the 20th flights. These values are also shown in Table II. Single scattering albedo values were also calculated from the data. The calculated values were 0.92 for the 600 ft Day III data, 0.96 for the 1000 ft and higher Day III data, and 0.93 for the Day II data throughout the haze layer. In general, the haze layers appear to have relatively high single scatter albedo values. Comparison of the optical measurements with aircraft visibility estimates showed good agreement.

ACKNOWLEDGEMENTS

We would like to thank R. Ferrare and R. Frasier for their help in carrying out this experimental work. We would also like to thank the staff of the Wallops Island Flight Facility for their help in integrating the equipment with the Skyvan aircraft.

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Ahlquist, N. C., and R. J. Charlson, 1969: Measurement of the wavelength dependence of atmospheric extinction due to scatter, Atm. Environ., 3, 551-564.

Charlson, R. J., A. H. Vanderpol, D. S. Covert, A. P. Waggoner, and N. C. Ahlquist, 1974: $H_2SO_4/(NH_4)_2SO_4$ background aerosol: Optical detection in St. Louis region, Atm. Environ., 8, 1257-1267.

Patterson, E. M., and B. T. Marshall, 1981: Diffuse reflectance and diffuse transmission measurements of aerosol absorption at the First International Workshop on light absorption by aerosol particles, Appl. Opt., 21, 387-393.

Table I
Directly Measured Aerosol Optical Quantities
(all units in km^{-1})

	Scattering Coefficient (490 nm)	Absorption Coefficient (632.8 nm)
Day III		
600 ft	.312	.019
1000+ ft	.258	.009
Day II		
Haze Layer	.110	.006

Table II
 550 nm Optical Quantities
 (all units in km^{-1})

	Scattering Coefficient	Absorption Coefficient	Extinction Coefficient
Day III			
600 ft	.268	.022	.290
1000+ ft	.221	.010	.231
Day II			
Haze Layer	.094	.007	.101

FIGURE CAPTIONS

1. Nephelometer scattering vs time for the 3400 ft altitude flight tracks on 20-9-85.
2. Nephelometer scattering vs time for the 500 ft altitude flight tracks on 20-9-85.
3. Nephelometer scattering vs altitude for the Day III flight.
4. Surface based nephelometer measurements at Chestertown, MD for 20-9-85.
5. Humidogram for laboratory sulfuric acid aerosol and for an ammonium sulfate aerosol. The ordinate is the ratio of light scattering coefficient due to particulate matter at the given relative humidity to the light scattering coefficient at 30%. The abscissa is the relative humidity in per cent. (From Charlson, et al, 1974).
6. Nephelometer scattering vs altitude for the Day II flight.
7. Nephelometer scattering vs altitude for the Day I flight.
8. Meteorological Sounding for 20-9-85 (Flight Day III)
9. Meteorological Sounding for 19-9-85 (Flight Day II)

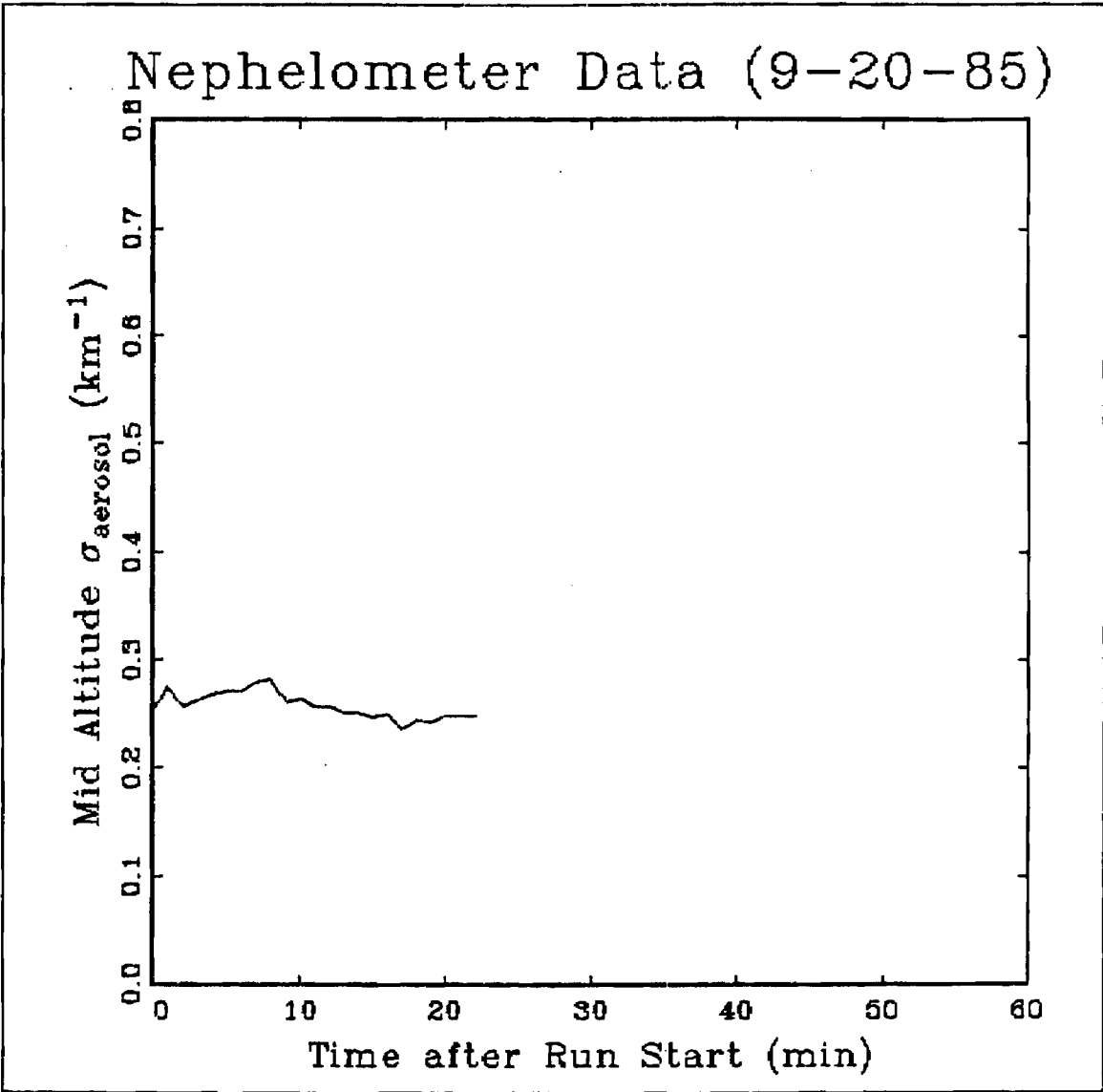


Fig. 1

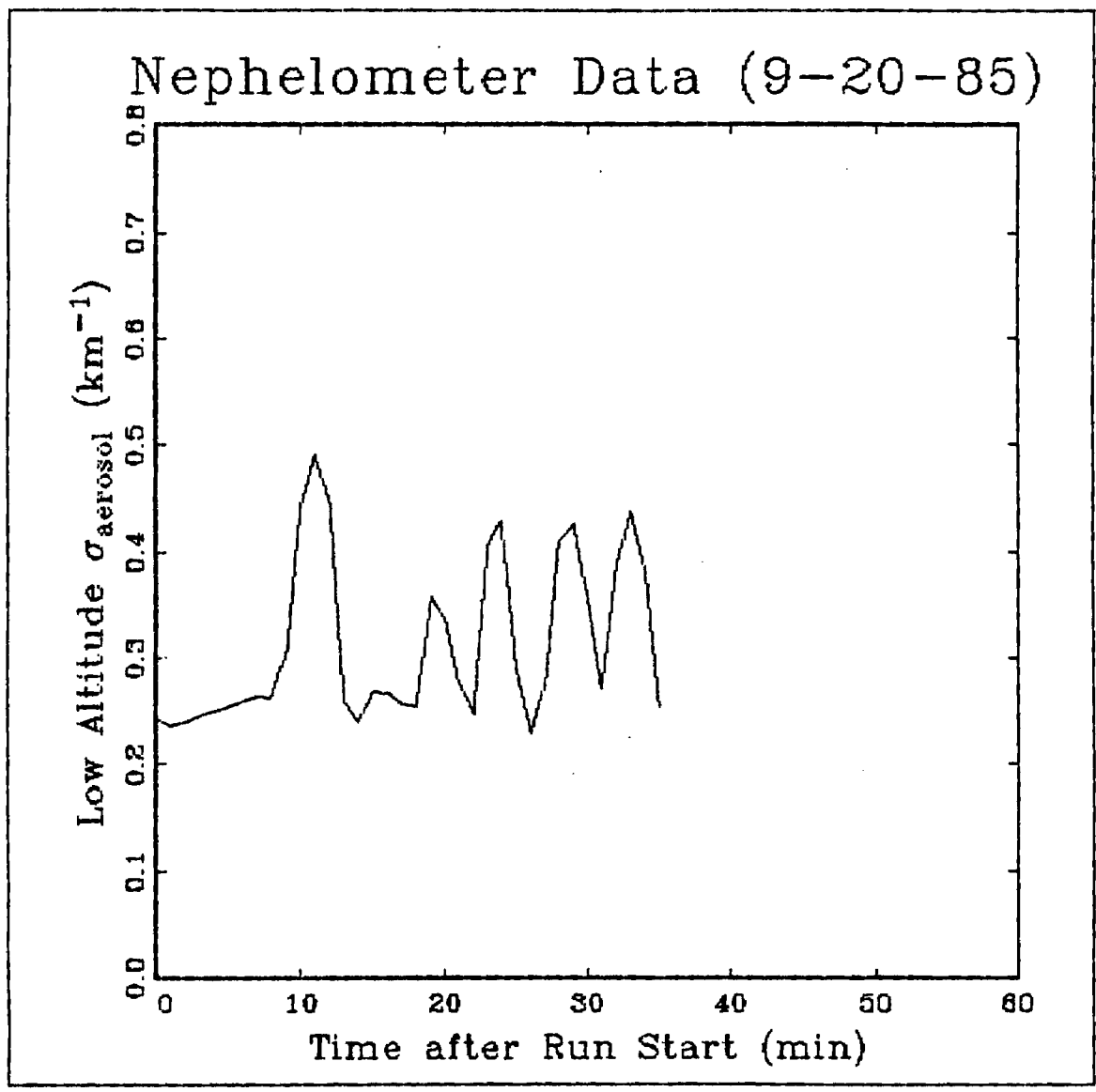


Fig. 2

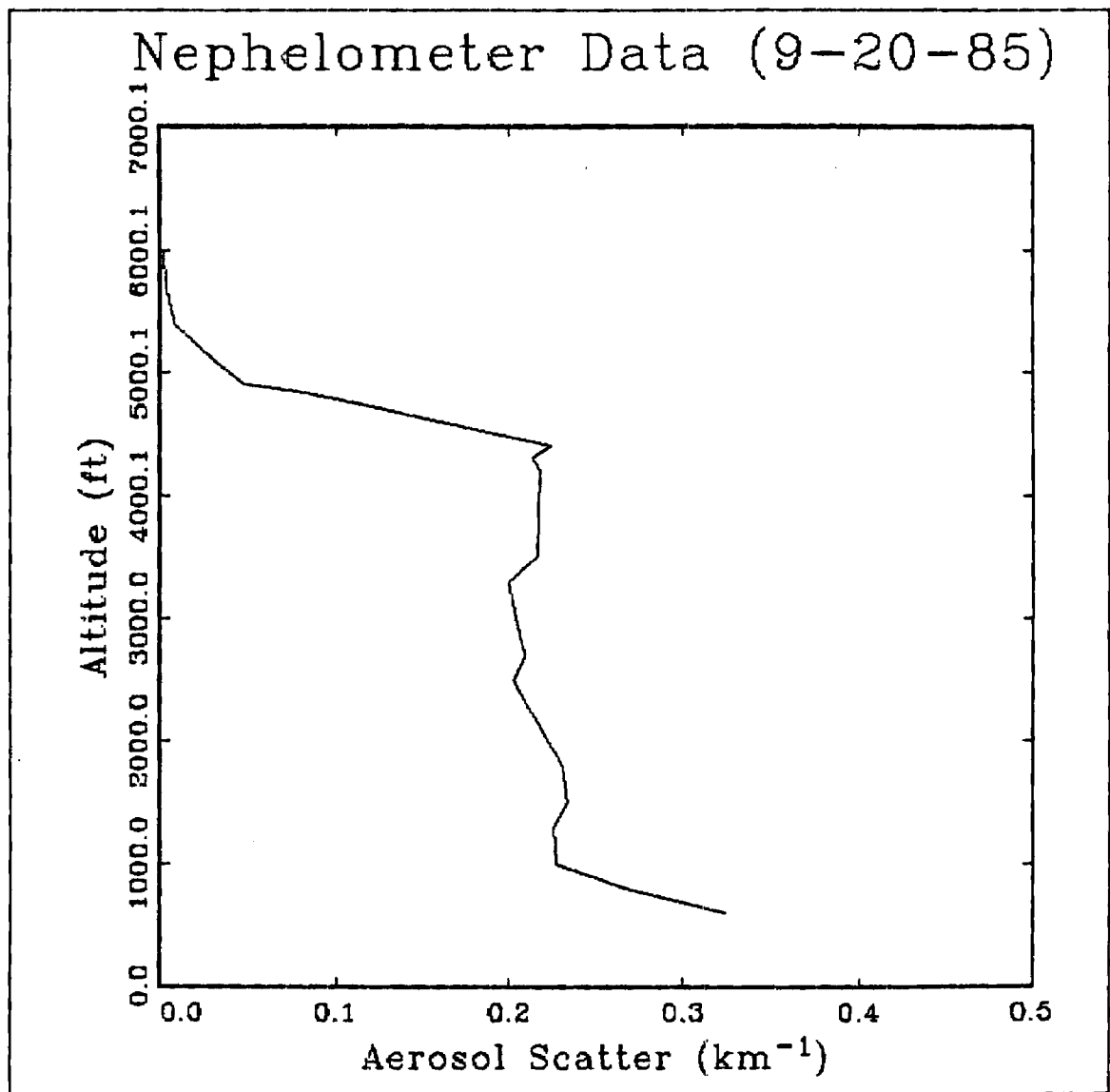


Fig. 3

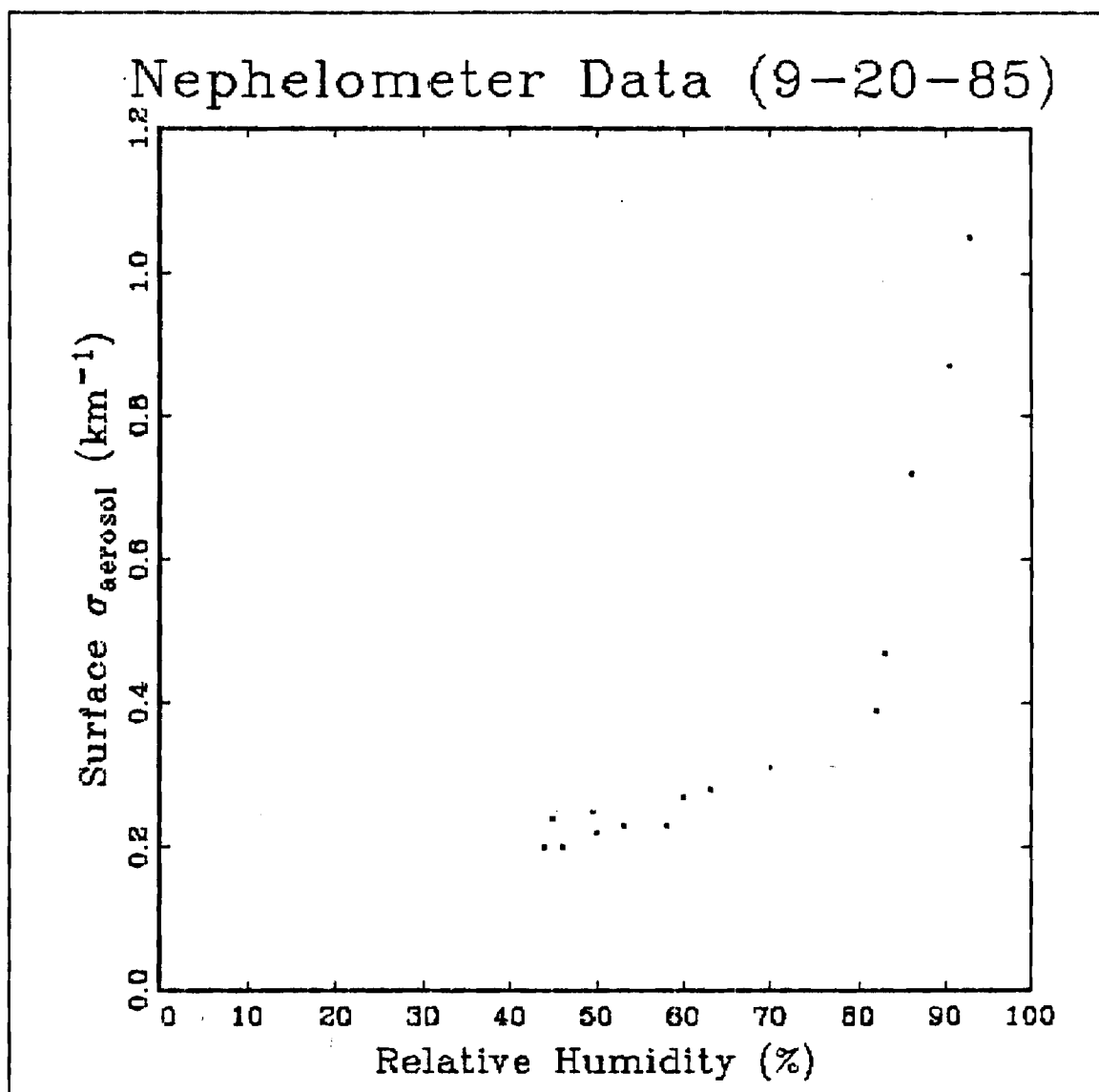


Fig. 4

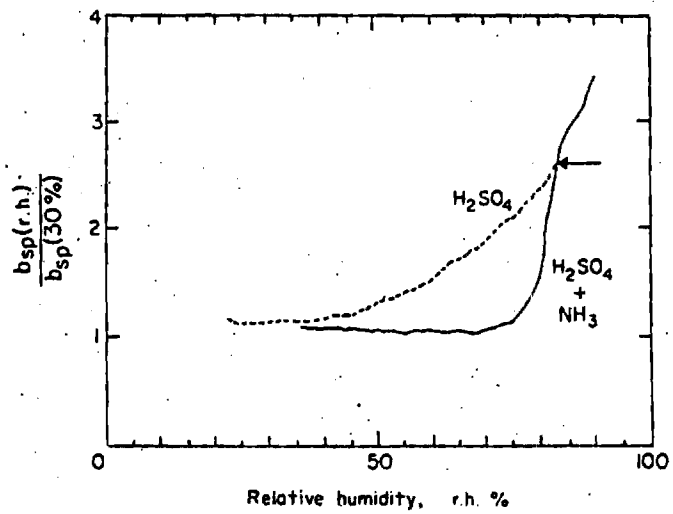


Fig. 5

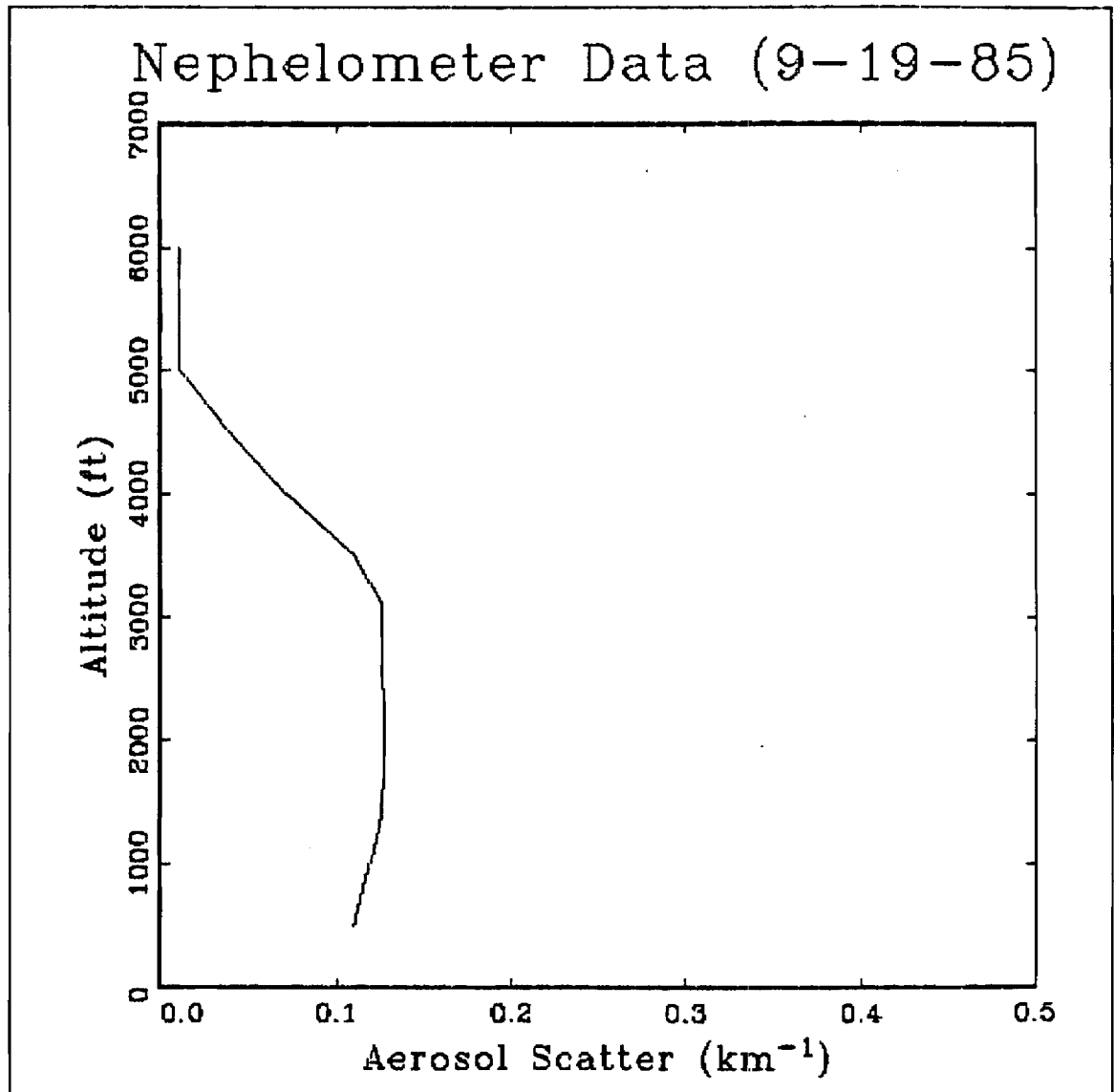


Fig. 6

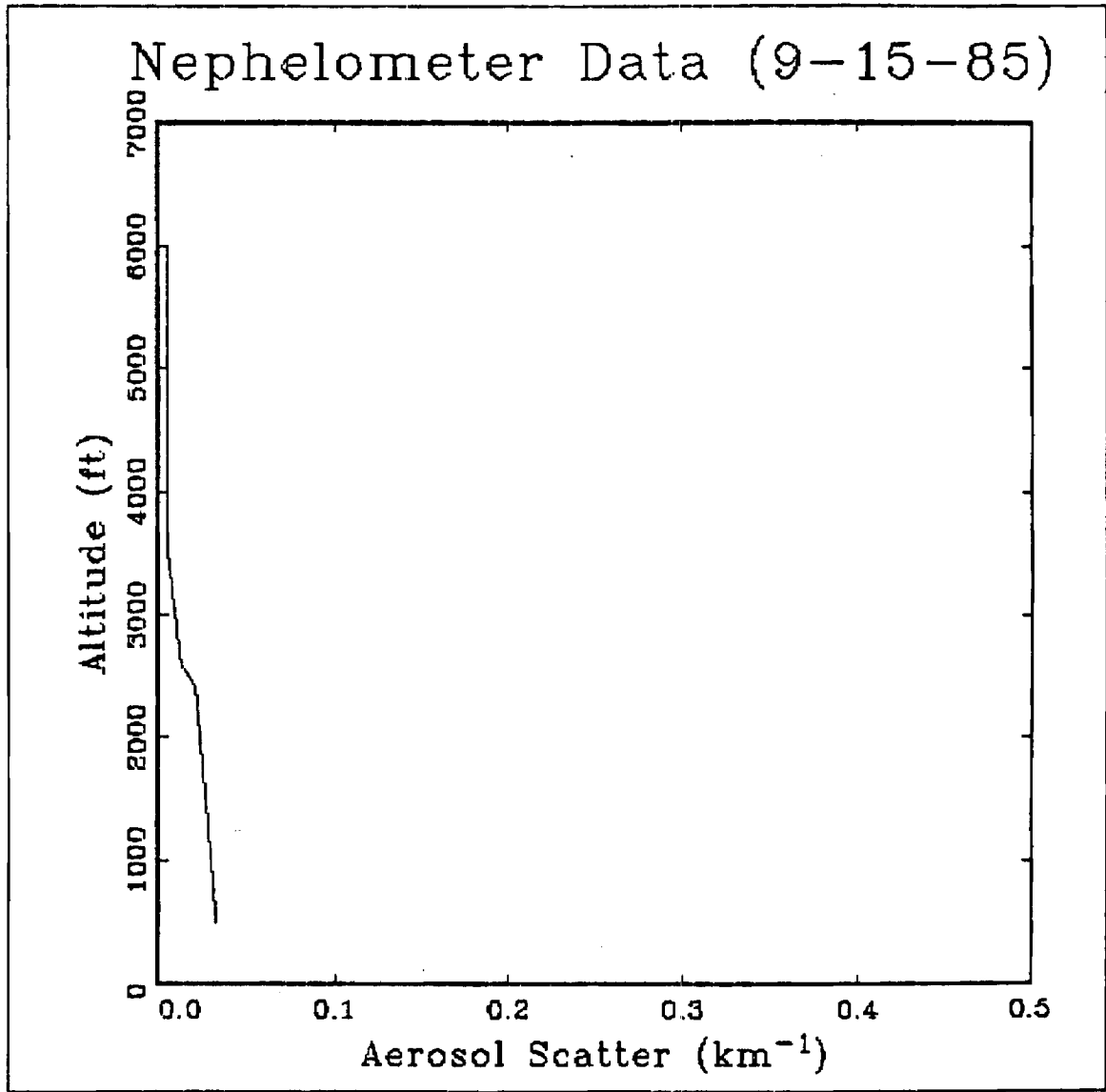
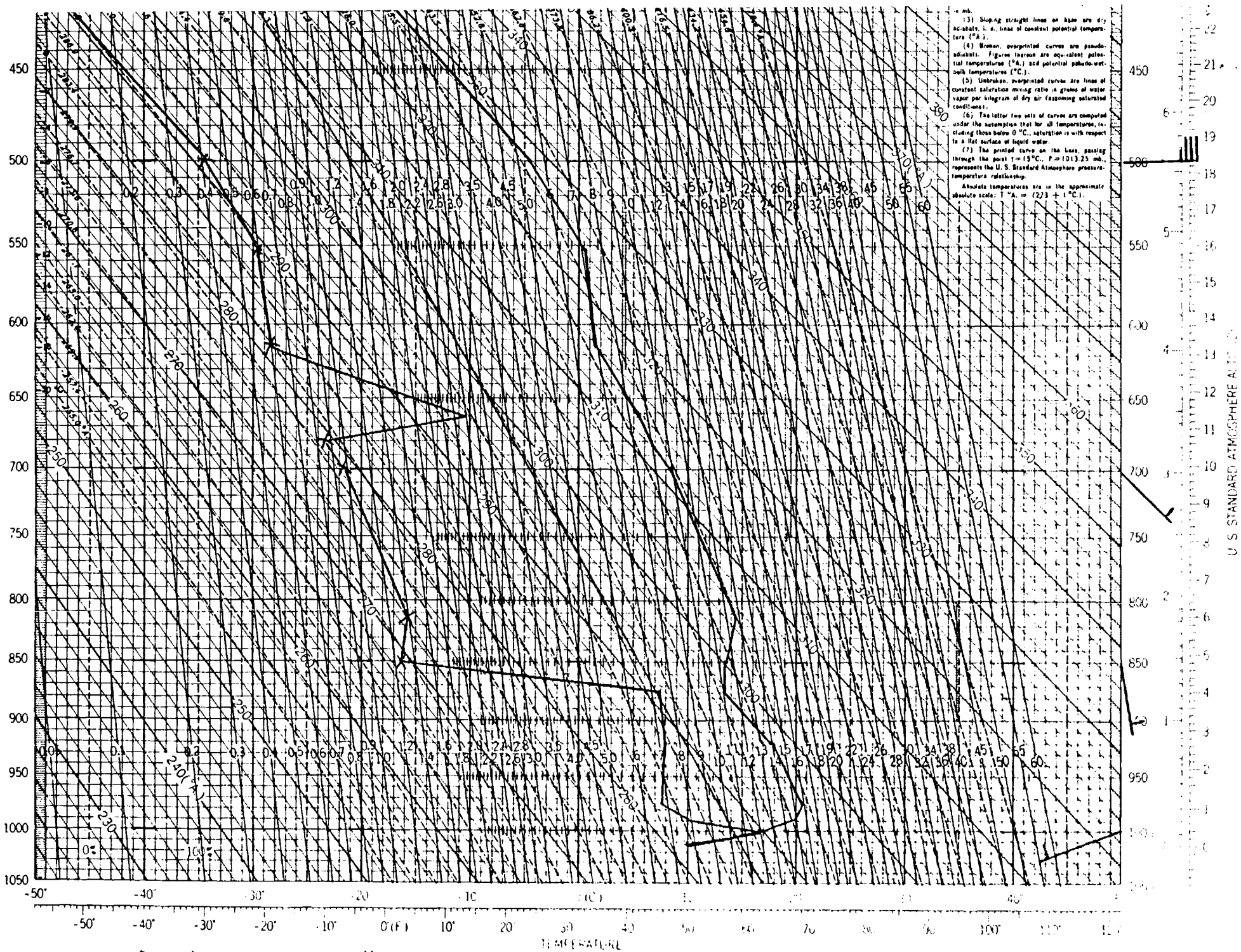


Fig. 7

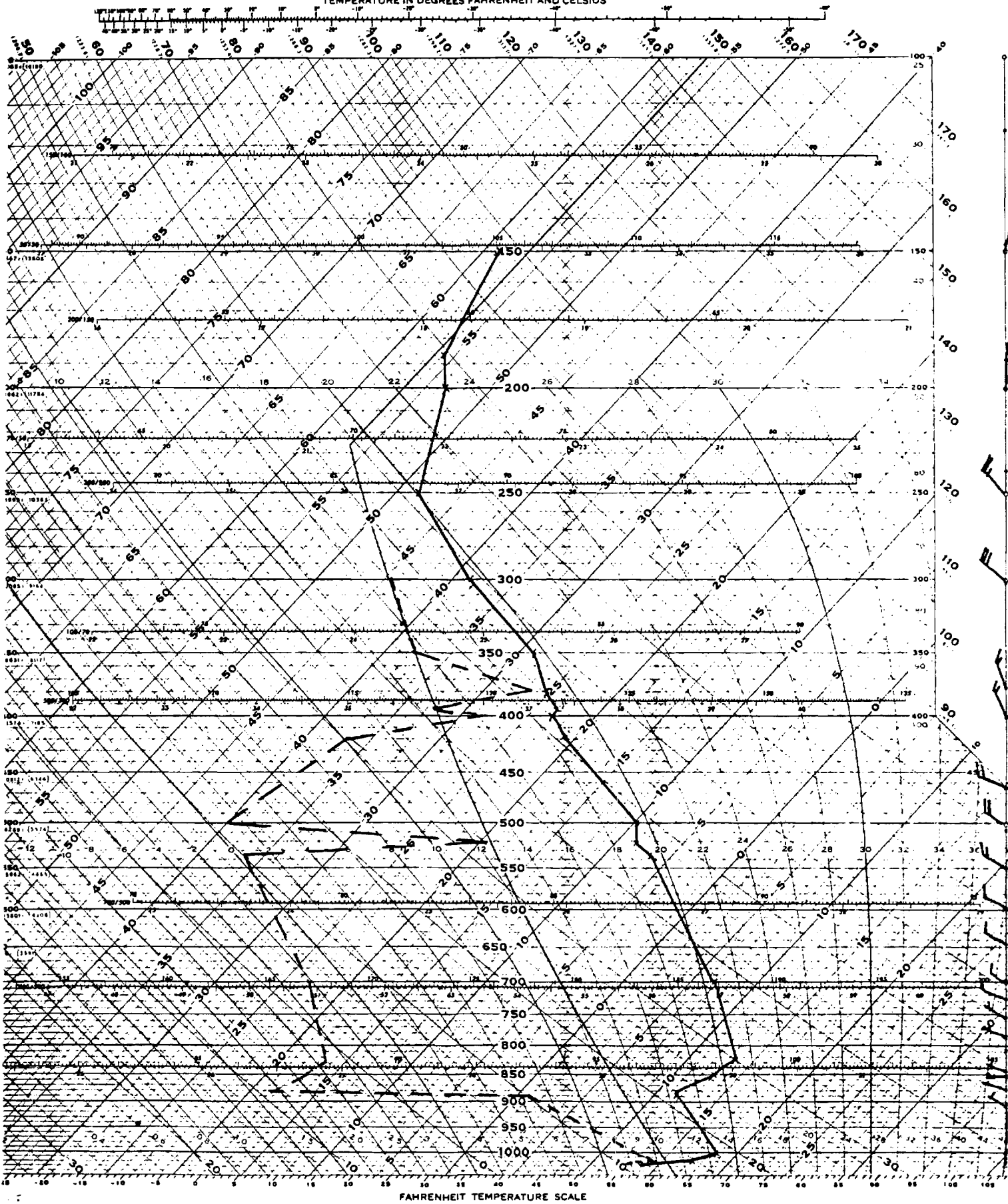


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Fig. 8

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 TEMPERATURE IN DEGREES FAHRENHEIT AND CELSIUS



72402 WAL 12Z 9/19/85 Fig. 9
 NUMBER STATION TIME (GCT) DATE (GCT)

Wallis Is, VA

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