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Evaluation of an Aureole Lidar Technique For Estimating Extinction Profiles

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EXECUTIVE SUMMARY

OBJECTIVE

Evaluate the aureole lidar technique for estimating atmospheric extinction profiles.

APPROACH

Airborne aerosol-size distribution and aureole lidar measurements were made, and the calculated aerosol extinction coefficients were compared with the aureole lidar estimations.

CONCLUSIONS

Aureole-lidar-deduced extinction coefficient profiles are similar in structure to the aerosol-spectrometer-measured profiles. The extinction magnitudes agreed reasonably well. When the near-surface aircraft aerosol measurements are averaged over a longer time, excellent agreement exists between the aureole lidar and the measured values.

RECOMMENDATIONS

Evalu[illegible] the aureole lidar for differing atmospheric conditions and geographic locations.

CONTENTS

INTRODUCTION

Lidar systems have been extensively used in an attempt to model atmospheric structure by measuring the radiation backscattered into a receiver by aerosols at different ranges within the beam of a pulse lidar. The accuracy of the calculated aerosol extinction coefficients determined by inverting the single-ended lidar returns has been questioned and cannot be assured.[1] For a single-ended lidar to become a useful operational tool, an inversion technique must be pursued which allows accurate extinction determination.

A novel single-ended lidar technique for estimating extinction profiles has been proposed by Hooper and Gerber.[2] This technique utilizes an airborne or satellite-mounted downward-looking lidar and the ocean surface reflected returns, assuming that the reflection properties of the ocean surface are known. In this technique, two detectors are used: one with a narrow field-of-view, which measures the power directly reflected off the rough ocean surface, and another with a wide field-of-view, where the directly reflected photons are blocked (aureole detector).

This report describes the initial evaluation of the accuracy of this proposed aureole lidar technique. Naval Ocean Systems Center compared nearly simultaneous measurements of atmospheric extinction made from airborne aureole lidar and aerosol spectrometer platforms. This evaluation was conducted during the KEY–90 Experiment[3] in the Florida Keys during July 1990. Profiles of measured aerosol-size distributions were used to calculate extinction coefficient profiles which were then compared with the aureole lidar estimations. Aureole lidar extinction coefficients are determined from the raw lidar return data by using Klett's[4] reverse integration algorithm, which assumes a constant backscatter-to-extinction coefficient ratio with altitude.

MEASUREMENTS

During July 1990, the KEY–90 Experiment was conducted at Marathon Florida in the Florida Keys (figure 1). On 14 July 1990, nearly simultaneous measurements of atmospheric structure were made by using the NOSC airborne platform (Piper Navajo aircraft)[5] and the Navy Research Laboratory (NRL) airborne aureole lidar platform.[2] Aerosol-size distribution measurements were made with the aircraft-mounted Particle Measurement Systems (PMS) FSSP–100 and OAP–200 aerosol-size spectrometers. The NOSC aircraft made four ascending spirals (SP1 through SP4) over the ocean east of Marathon, Florida, on a 149°T (True) radial from the Key coastline to 45 nmi. Spirals were made from an altitude of 30 to 2743 meters. Aerosol measurements were also made along a constant altitude (CA) flight on the same radial. Figure 2 shows the NOSC aircraft flight track on the 149°T radial. Table 1 gives the geographic location of the vertical spirals (indicated by SP1, SP2, etc.).

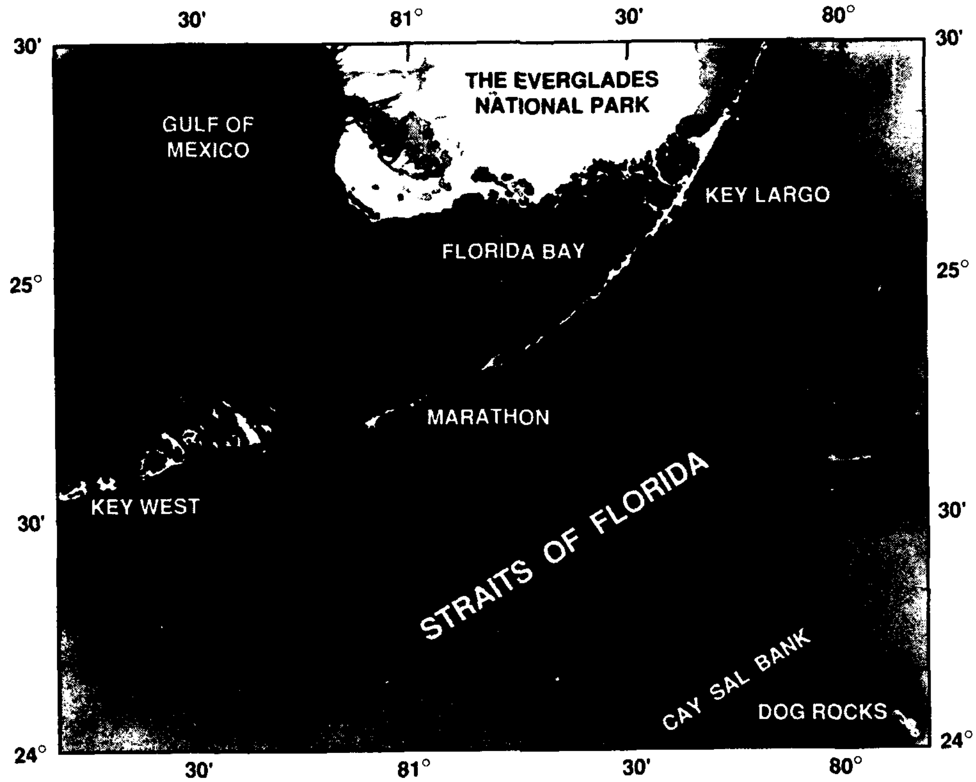

Figure 1. Florida Keys.

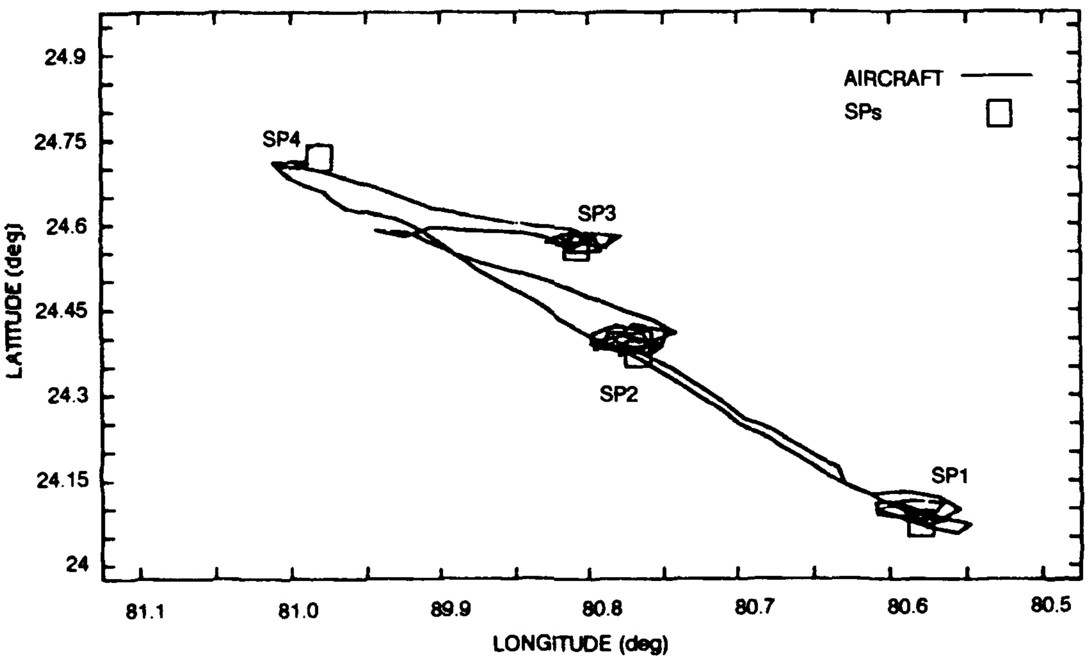

Figure 2. NOSC aircraft flight profile for 14 July 1990.

Table 1. Geographical location of aerosol-aureole lidar soundings.

Sounding	Latitude	Longitude
SP1	24° 04′ 23″	80° 34′ 48″
SP2	24° 22′ 19″	80° 46′ 01″
SP3	24° 33′ 36″	80° 48′ 29″
SP4	24° 43′ 08″	80° 58′ 52″
LD1	24° 06′ 00″	80° 34′ 48″
LD2	24° 18′ 00″	80° 34′ 48″
LD3	24° 22′ 48″	80° 47′ 24″
LD4	24° 22′ 48″	80° 46′ 48″
LD5	24° 34′ 48″	80° 52′ 48″

Air temperature, pressure, and relative humidity were measured and recorded every 5 seconds (at a height resolution of 16.3 meters for SPs and a spatial resolution of 268 meters for the CAs). A complete aerosol spectrum was obtained every 10 seconds (at a height resolution of 32.3 meters and a spatial resolution of 537 meters). The measured aerosol-size distributions were used to calculate (via MIE theory) the extinction and backscatter profiles for both SPs and CAs.

The NRL aircraft made near-simultaneous aureole lidar soundings (identified as LD1 through LD5) with the NOSC aerosol vertical profiles. The soundings were collocated as near as possible in both time and geographic location. Figure 3 shows the geographic locations of the aerosol and lidar soundings. Table 2 summarizes the time and spatial differences between soundings. For all practical purposes, considering the difficulty in collocating two airborne platforms, the soundings were taken simultaneously.

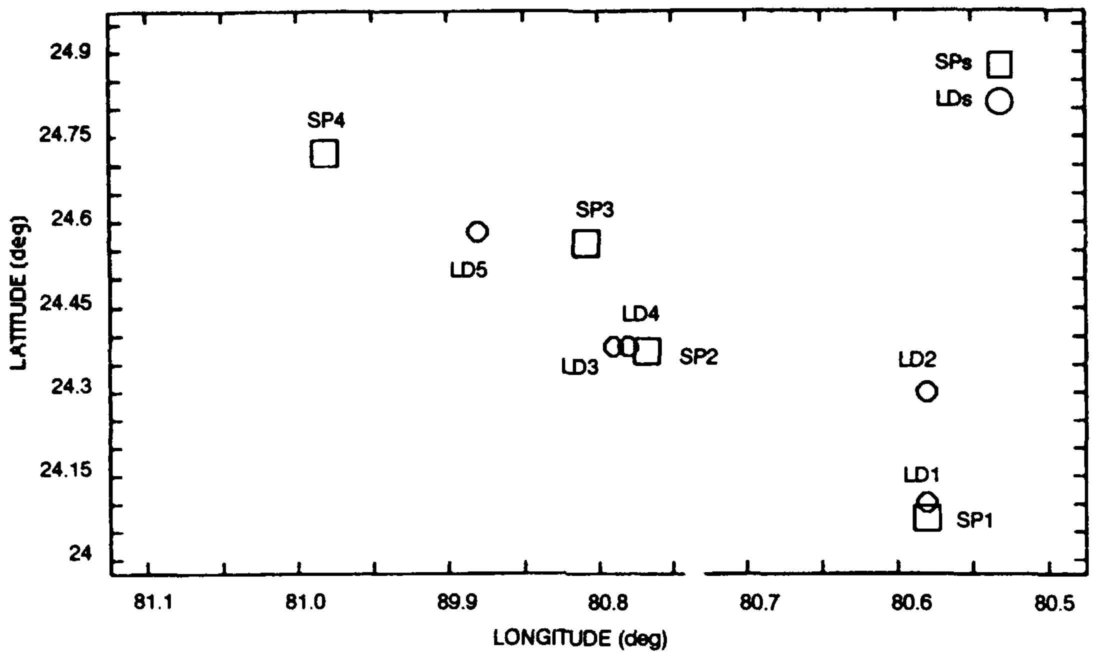

Figure 3. Spiral-lidar sounding positions.

Table 2. Time and spatial differences in aerosol-aureole lidar soundings.

SP'S (GMT)	LD'S (GMT)	ΔT (min)	ΔD (nmi)
1037:00 (SP1)	1038:56 (LD1)	1.9	1.6
1037:00 (SP1)	1044:51 (LD2)	7.9	13.6
1104:25 (SP2)	1058:28 (LD3)	6.0	1.3
1104:25 (SP2)	1121:42 (LD4)	17.3	0.9
1132:04 (SP3)	1121:42 (LD4)	10.4	10.9
1132:04 (SP3)	1139:46 (LD5)	7.7	4.1

DATA PRESENTATION

Figures 4, 5, 6, and 7 show the vertical soundings of air temperature and relative humidity for spirals SP1 through SP4, respectively. Over the 45-nmi radial, the temperature profiles showed little horizontal variation and no sharp temperature inversions. Below 350–400 meters (the well-mixed layer), the relative humidity changed very little over the path. Above 400 meters, large differences occurred, indicating cellular structure along the path. This has been verified by independent vertical lidar soundings taken at Marathon, Florida.[5] High cirrus clouds existed over the entire region (100% cover), with scattered cumulus below 2743 meters. More cumulus existed farther to sea than along the Keys.

Figure 8 shows the comparison of the aerosol extinction profiles for SP1 and the lidar LD1 and LD2. LD1 was taken within 2 minutes and 1.6 nmi of SP1. Large differences occur between the two profiles, especially in the magnitude of the extinction coefficients above the surface level. Both profiles showed the top of the mixing layer at 400 meters and preserved the structural detail above 400 meters, i.e., the decrease in extinction with height to approximately 1200 meters, the minimum extinction between 1200 and 1400 meters, and the increasing extinction above 1400 meters. The average aerosol extinction, taken over a CA path of 5 nmi either side of the SP1 location, is indicated in figure 8. Excellent agreement near the surface exists between the average, SP1, and LD1 extinction values. Also shown in figure 8 is the LD2 profile (offset by 8 minutes and 13.6 nmi). The surface extinction value is less than the SP1 value. The profile does not reflect the same structural features as the SP1 aerosol data, e.g., the mixing layer top at 600 meters instead of 400 meters and the continued decrease of extinction with altitude above 1400 meters. These differences could result from the horizontal variability over the 13.6-nmi separation.

Extinction coefficients, calculated by using the Klett's reverse integration technique, require a constant backscatter (β) to extinction coefficient (σ) ratio with altitude. Figure 9 shows the β-to-σ ratio for the aerosol data take at SP1. For this data set the β-to-σ ratio is not constant with altitude. From the surface to 1000 meters the ratio varied between 0.03 and 0.053. Above 1000 meters, the ratio variations were much greater. This, in part, may result from the statistical sampling problems encountered with the PMS spectrometers.[6] In regions of low aerosol densities. However, in the first 350–400 meters where the aerosol density is larger, the β-to-σ ratio is still not constant. Since the ratio is not constant, errors would be introduced in the inverse integration technique used to calculate the aureole lidar extinction.

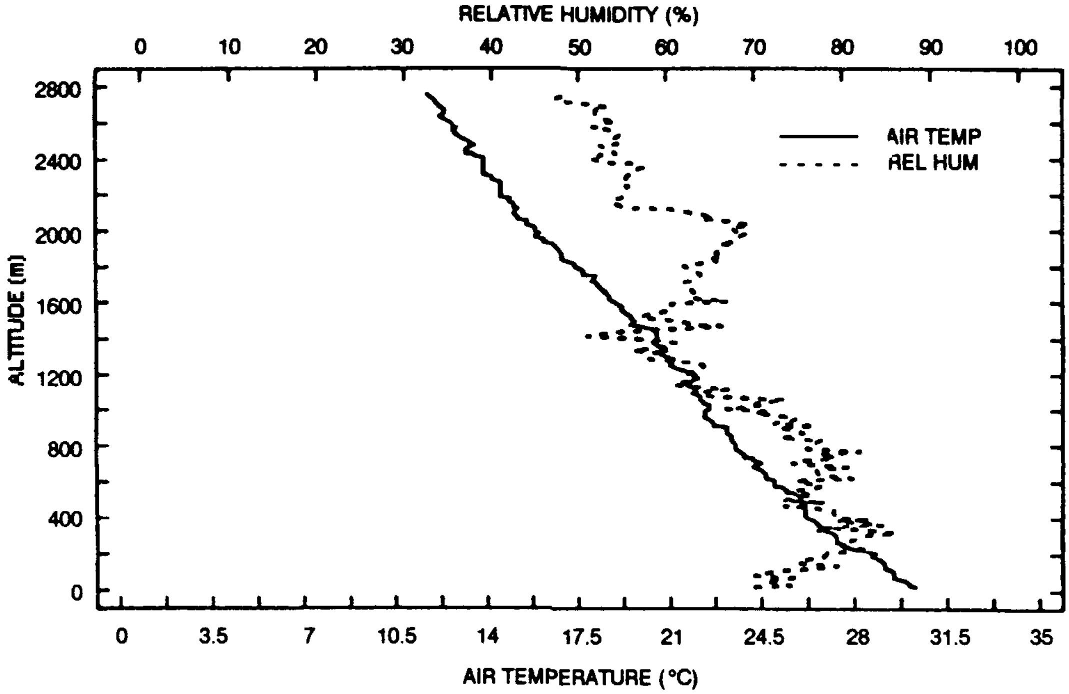

Figure 4. AT and RH profiles for SP1.

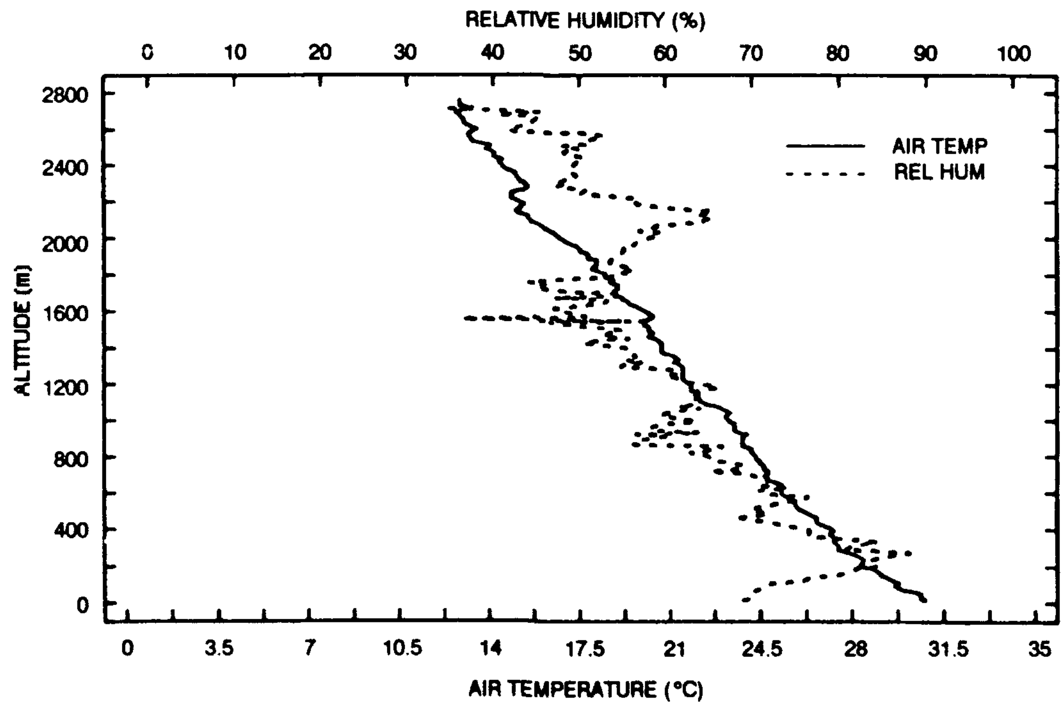

Figure 5. AT and RH profiles for SP2.

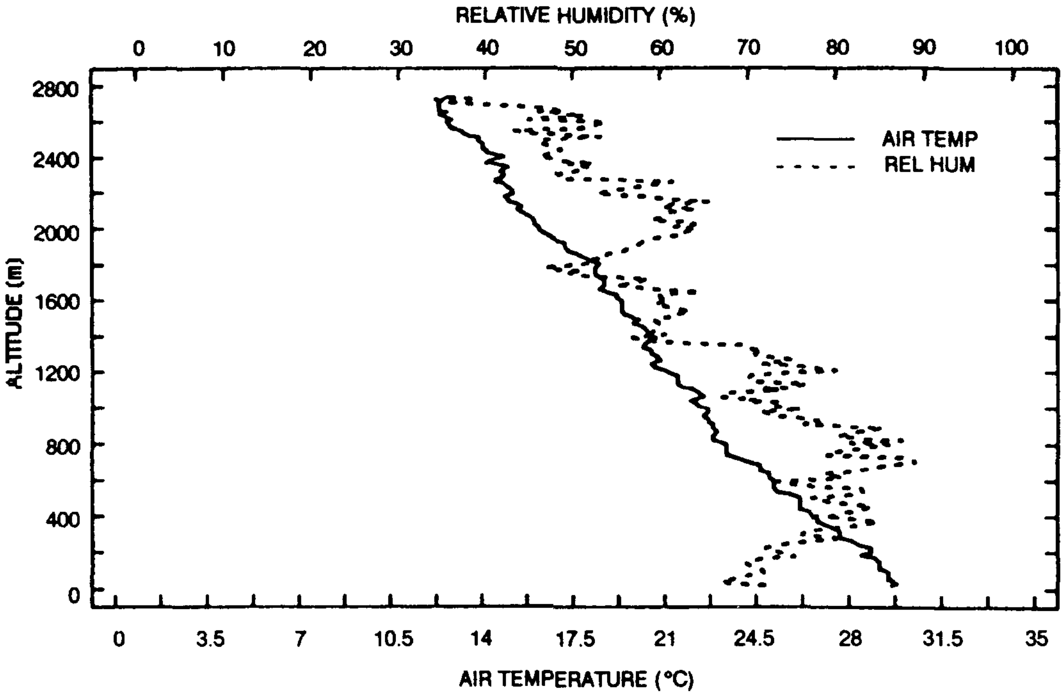

Figure 6. AT and RH profiles for SP3.

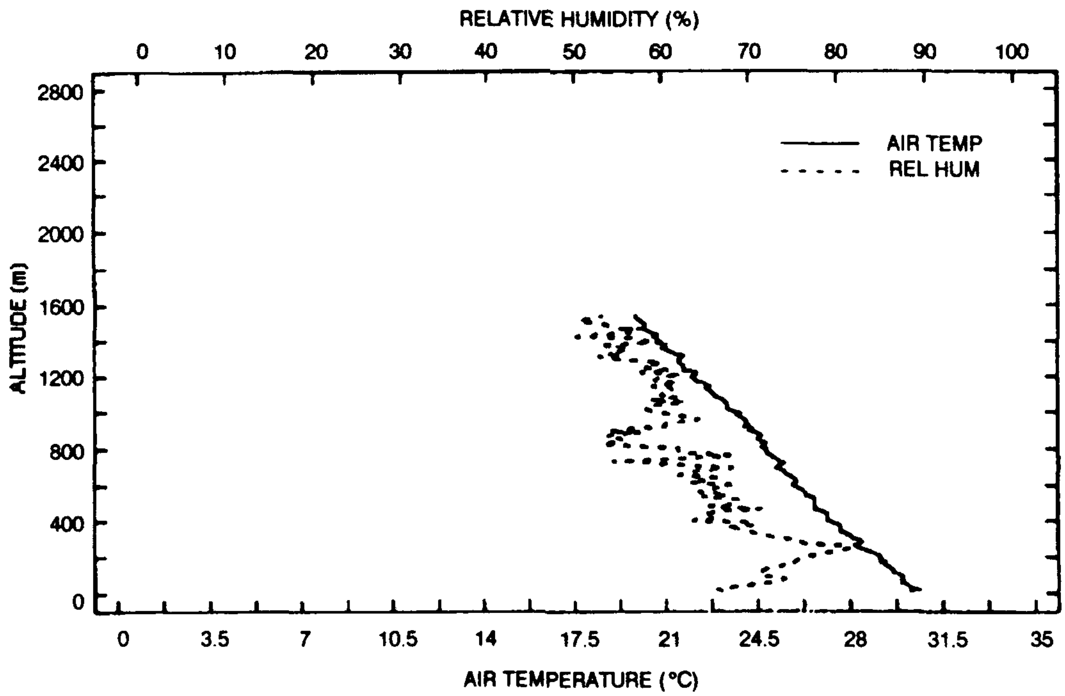

Figure 7. AT and RH profiles for SP4.

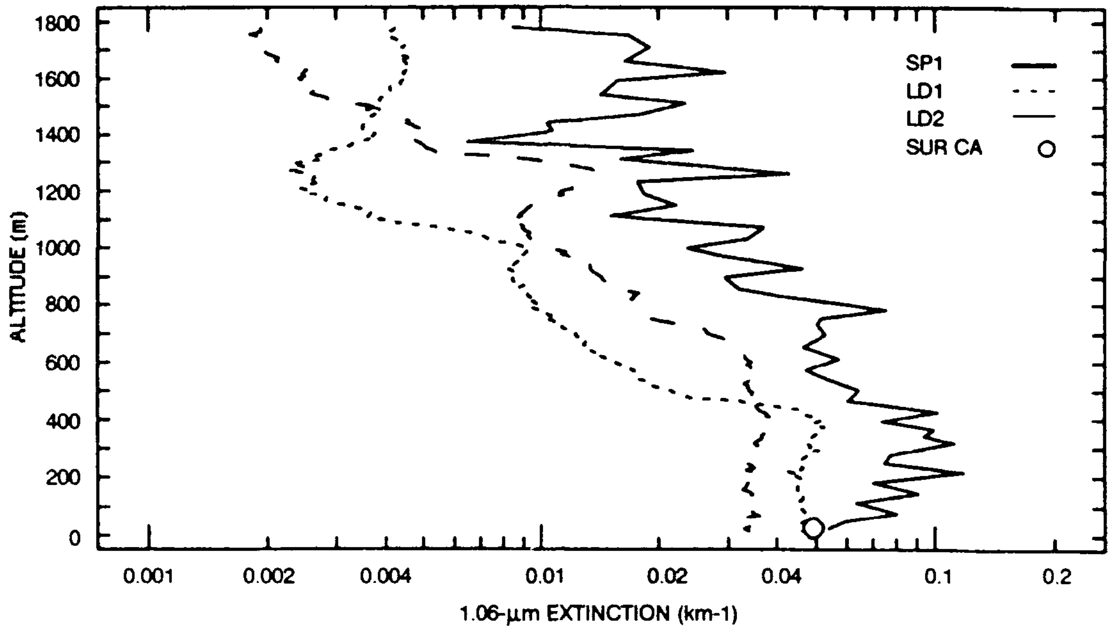

Figure 8. Aerosol and aureole lidar extinction profiles compared to SP1.

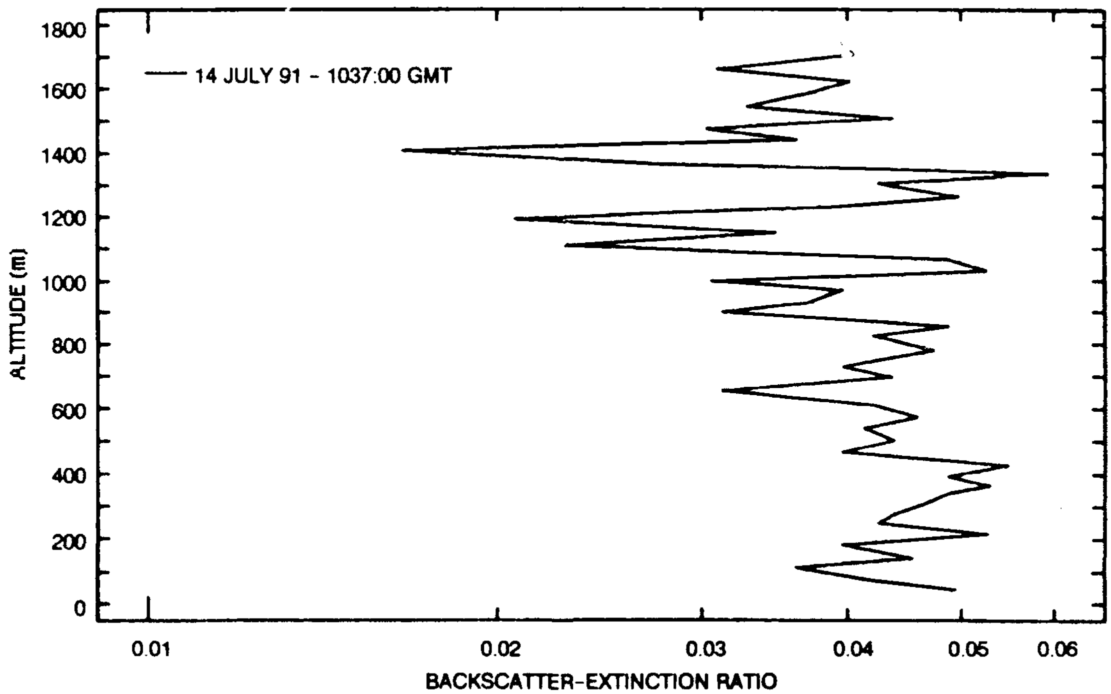

Figure 9. Backscatter-to-extinction-coefficient ratio for SP1.

Figures 10 and 11 show a similar comparison for the data taken at the SP2 position. LD3 was displaced from SP2 by 6.0 minutes and 1.3 nmi; LD4 by 17.3 minutes and 0.9 nmi. Below 700 meters, the aerosol extinction drops off rapidly with decreasing altitude, while the aureole extinction for both LD3 and LD4 increased. However, the aerosol average (aerosol data averaged over a path of 5 nmi either side of SP2) is in excellent agreement with the aureole data. The low values of the extinction below 700 meters are thought to result from low aerosol concentrations in cellular plumes that were encountered during this data period. Above 700 meters, the aureole lidar extinction slopes for LD3 and LD4 are similar to those of the aerosol data (smoothed), but differ in magnitude. From 30 to 1200 meters the LD3 and LD4 extinction are in excellent agreement with each other. The β-to-σ ratio (figure 11) was constant up to approximately 500 meters where larger variations started to occur. This, in part, could result from the statistical sampling problem.[6]

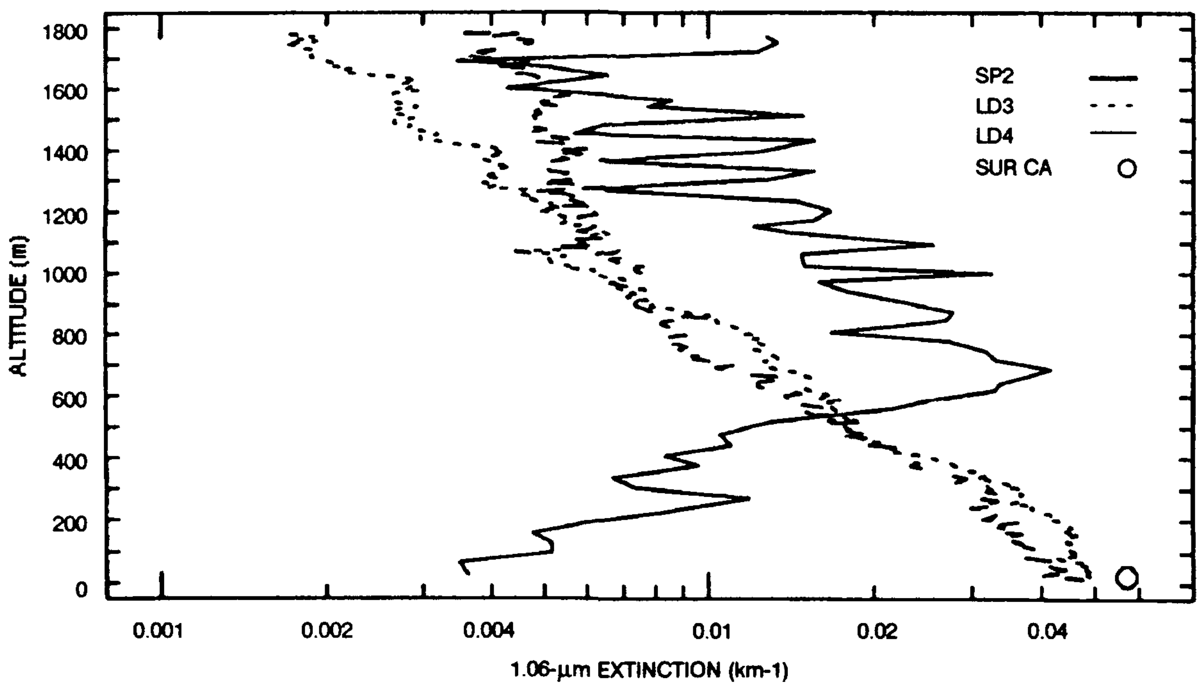

Figure 10. Aerosol and aureole lidar extinction profiles compared for SP2.

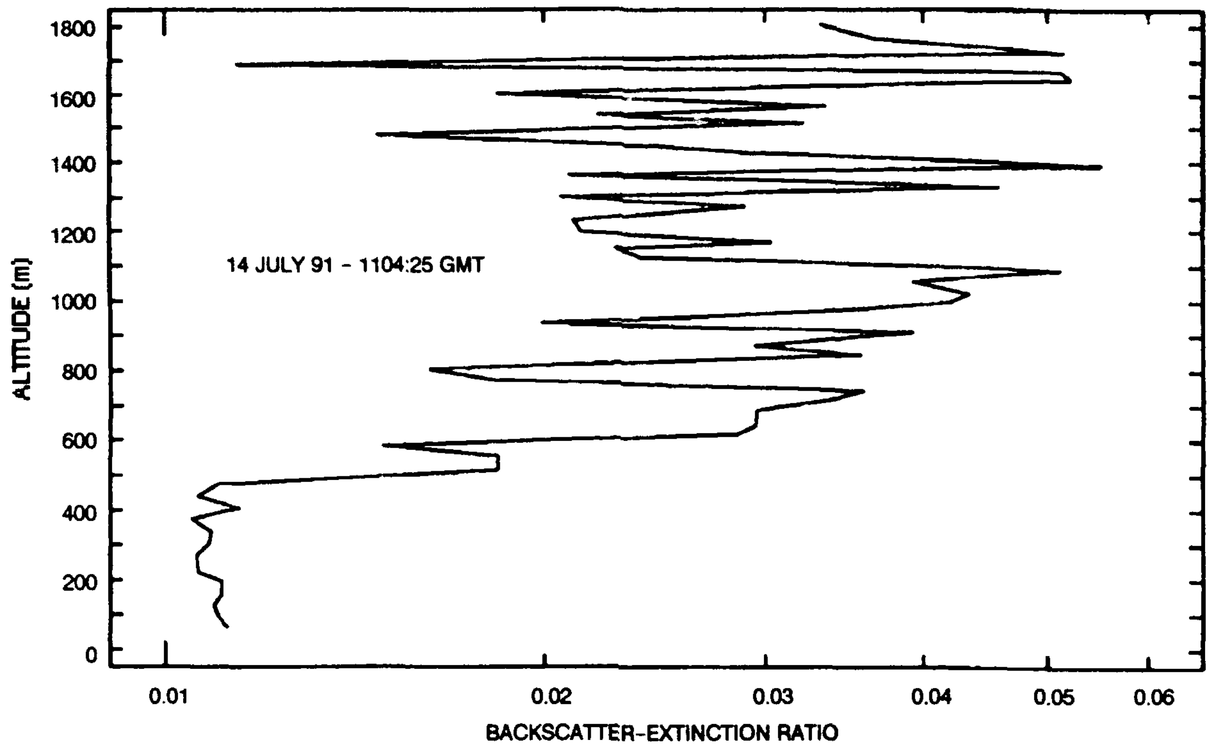

Figure 11. Backscatter-to-extinction-coefficient ratio for SP2.

Similar comparisons of the aerosol extinction data at SP3 and the aureole lidar positions LD4 and LD5 (10.4 min and 10.9 nmi and 7.7 minutes and 4.1 nmi separation, respectively) are shown in figures 12 and 13. Similar characteristics to the SP2 comparison exist, i.e., the magnitude of the aerosol extinction drops off below 400 meters, and the average surface aerosol extinction agrees well with the aureole lidar results. The aureole lidar soundings below 1200 meters were nearly identical except that the LD5 sounding showed an apparent increase of aerosols between 200 meters and 600 meters. Above 200 meters the magnitude of the aureole extinction was less than the aerosol extinction, a pattern that was observed in the previous comparisons. The slopes, however, from 400 meters to 1300 meters were similar (smoothed aerosol data). The β-to-σ ratio for these data varied with altitude and was not constant. Such large variations would result in large errors in the reverse integration technique.

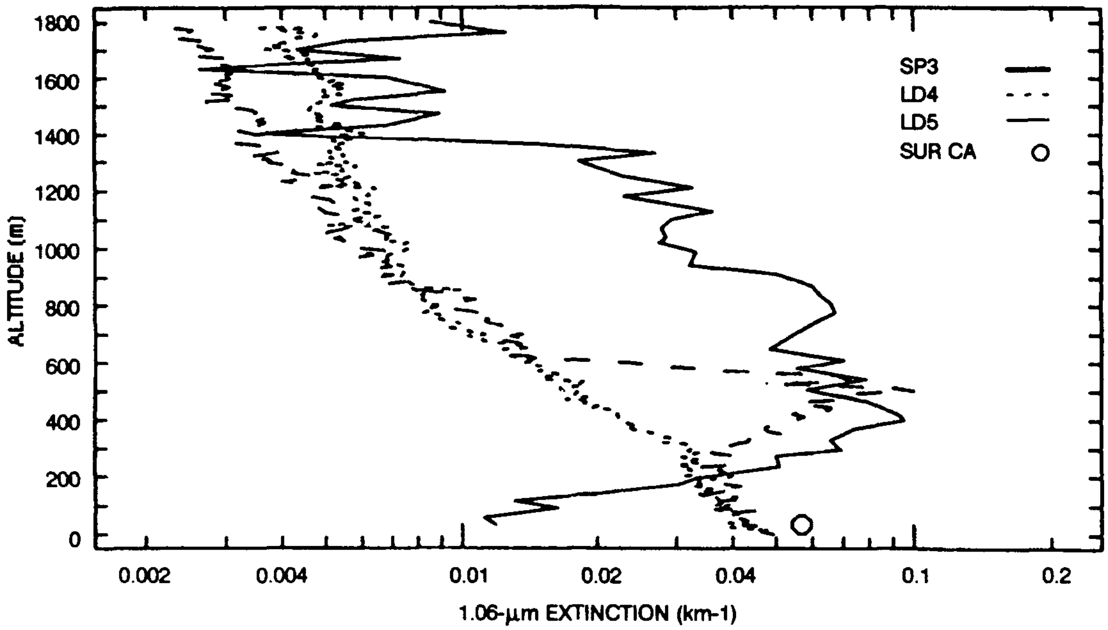

Figure 12. Aerosol and aureole lidar extinction profiles compared for SP3.

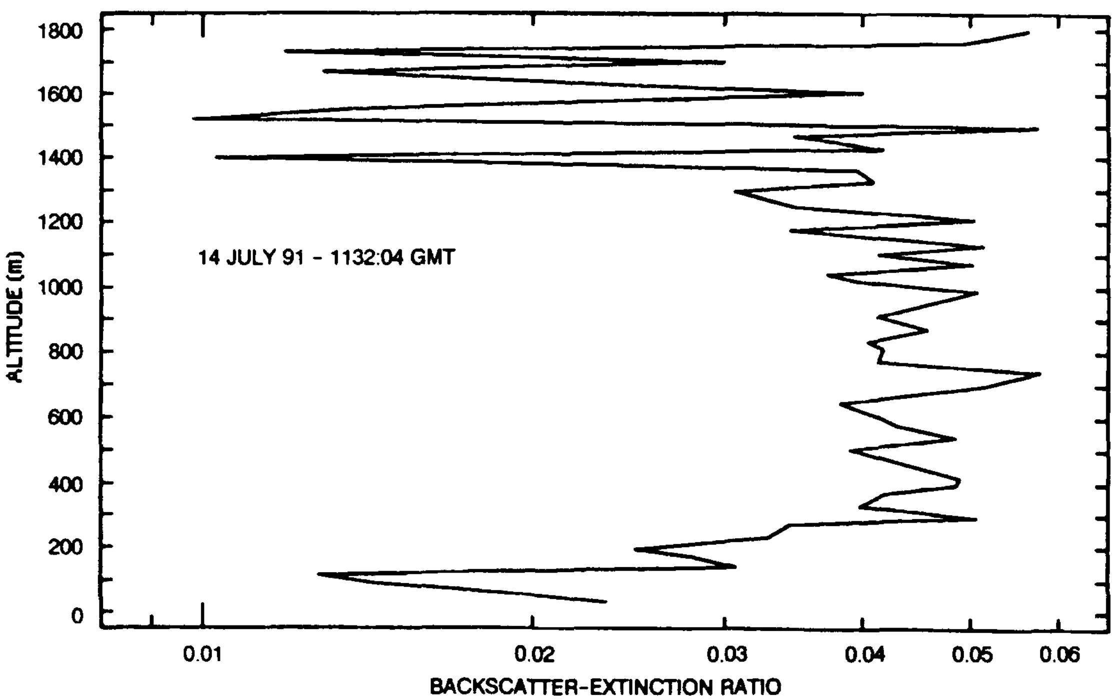

Figure 13. Backscatter-to-extinction-coefficient ratio for SP3.

CONCLUSIONS

Profiles of measured aerosol-size distributions were used to calculate extinction coefficients which were compared with simultaneous aureole lidar observations. Aureole lidar estimated extinction coefficient profiles are similar in structure to the PMS-measured profiles and agreed reasonably well in extinction magnitude, especially near the ocean surface. When the near-surface aircraft aerosol measurements are averaged over a longer time, excellent agreement exists between the aureole lidar and the PMS-measured values. Profiles of backscatter-to-extinction coefficient ratios with altitude were not constant, as required by the reverse integration technique for deducing the aureole lidar extinction values.

RECOMMENDATIONS

To adequately test and evaluate the aureole lidar, differing atmospheric conditions and geographic locations must be considered.

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An aureole lidar technique for estimating extinction profiles was developed at the Naval Research Laboratory, Washington, DC. This technique was evaluated by making nearly simultaneous measurements of atmospheric extinction from the NRL airborne Aureole Lidar Platform and the NOSC Airborne Platform, which utilizes the Particle Measuring Systems (PMS), Inc., aerosol spectrometers. Profiles of measured aerosol-size distributions were used to calculate extinction coefficients and were compared with the aureole lidar estimations. Aureole lidar estimated extinction coefficient profiles are similar in structure to the PMS-measured profiles and agreed well in extinction magnitude. When the near-surface aircraft aerosol measurements are averaged over a longer time, excellent agreement exists between the aureole lidar and the PMS-measured values.

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