

A Multi-Wavelength Mini Lidar For Measurements Of Marine Boundary Layer Aerosol And Water Vapor Fields

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LONG-TERM GOAL

Our long-term goal is to improve our understanding of dynamics of marine aerosols and water vapor fields in the coastal marine boundary layer. This can be achieved by using a calibrated multi-wavelength scanning lidar to measure the 4-D distribution of aerosol fields in the lower coastal marine boundary layer. These measurements can then be studied (in light of the meteorological conditions) to obtain a comprehensive model of the aerosol scattering properties in the coastal marine boundary layer.

SCIENTIFIC OBJECTIVES

Our scientific objectives are to collect well-calibrated lidar data sets that can be used to improve and develop models of the aerosol optical properties in the coastal marine boundary layer (MBL). Although various aerosol models exist (e.g., Gathman, 1983), most of these are for the open ocean and few if any models can describe the boundary layers aerosol optical properties where breaking waves and complex atmospheric dynamics exist. We plan to study the vertical aerosol structure in the 15-m of the atmosphere directly above the ocean surface. In order to develop models of this type, measurements are needed which can map out the aerosol optical properties over space and time as a function of wave heights and meteorological conditions.

APPROACH

Our approach is to use a scanning multi-wavelength lidar to measure the 4-D (space and time) aerosol optical fields in order to characterize the aerosol properties in a marine setting (Sharma et al., 1999; Lienert et al., 1999). These measurements have been carried out at Bellows Air Force (AFS) next to the University of Hawaii's Meteorological Tower (21° 21.848' N, 157° 42.584' W). Our focus in the past year has been to measure both continuous short term (minute) and longer-term (day) variations in the observed extinction profiles, in addition to our regular measurements at weekly intervals. We have also continued to work on and improve an absolute calibration technique using hard targets as well as perfecting a calibration technique using observed profiles of horizontal scattering. Dr. Shiv Sharma is the project director involved in all aspects of the efforts. Dr. Barry Lienert has developed the software and supervises the data collection. Dr. John Porter is involved in calibration and modeling efforts. Dr. Clarke is involved in comparisons with in situ measurements and data interpretation.

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WORK COMPLETED

- (1) A technique has been developed to apply real time calibration to obtain aerosol scattering coefficients with an accuracy of $\pm 15\%$.
- (2) Lidar and meteorological data has been collected at regular intervals during the past two years at Bellows Beach. These data include rapid (5-20 second) 2-D scans of aerosol generated close to the outer reef as well as by waves breaking on the beach.
- (3) Continuous lidar measurements were made over a 96 hour period simultaneously with aerosol size measurements by Dr. Clarke's group and also wave height and tide data recorded 1.2 km from the shoreline by Dr. Mark Merrifield (UH-Marine Sciences). Software has been developed to construct time series of averaged data in specified rectangular portions of the more than 4000 two-dimensional scans collected. Analysis of these data is still in progress but some preliminary results are presented here.
- (4) Calibrated lidar images have been created for this year's data and are now available on our lidar web site (<http://www.soest.hawaii.edu/lidar>).
- (5) Comparisons between lidar derived aerosol scattering properties and meteorological conditions have begun.

RESULTS

We have found that the lidar sensitivity can drop by a factor of up to three in periods of less than an hour, due to the outer scanner mirror becoming coated with salt spray. Our approach to this problem has been twofold:

- (1) We have developed a method of determining the lidar calibration factor from actual measurements in the horizontal direction, by assuming that the scattering out over the open ocean is reasonably uniform. If we assume that the extinction is reasonably uniform over the open ocean, we find that by adjusting the lidar calibration factor we can obtain horizontally uniform extinction due to scattering. Porter et al. (1999) have shown that this technique results in measured values that agree to within 15% of those measured using other techniques. The advantage of this calibration method is that it can be routinely applied using any horizontal scan in a series.
- (2)
- (3) We have used a Spectralon target, having a close to Lambertian response, to measure the returned pulse energy as a function of distance (Spinhirne et al., 1997). We obtain reasonable atmospheric extinction values in the range 300-600 meters. These are also consistent with simultaneous nephelometer measurements made by Dr. Clarke's group. These measurements have allowed us to determine the near-field response of our lidar system. We are attempting to model this effect theoretically as well as to extend the target calibration range out to 1 km where the near-field effect should be smaller.

At Bellows Beach an outside reef 1.8 km offshore causes the largest waves to break on the reef's high points. Between this reef and the shore there is deeper water before the waves break again on the sand beach. Figure 2 shows a horizontal scan of extinction coefficient taken over this reef on

6/10/99. The red plumes of aerosol are being carried in the prevailing wind at 6 m/s. produced by waves breaking on the protruding reefs. The average height of the laser beam is 6 m above the water. To examine the vertical structure of the plume in Figure 2, we performed a series of short vertical scans (0-3 degrees), each scan taking 6 seconds. Three frames of this time sequence are shown in Figure 3.

A movie has been made of 100 frames of the data in Figure 3. This can be viewed on our web site (under "Bellows Data") at <http://www.soest.hawaii.edu/lidar>. An interesting feature in Figure 3 is the height to which the aerosol plumes appear to rise. This rapid rise in the salt plumes is somewhat

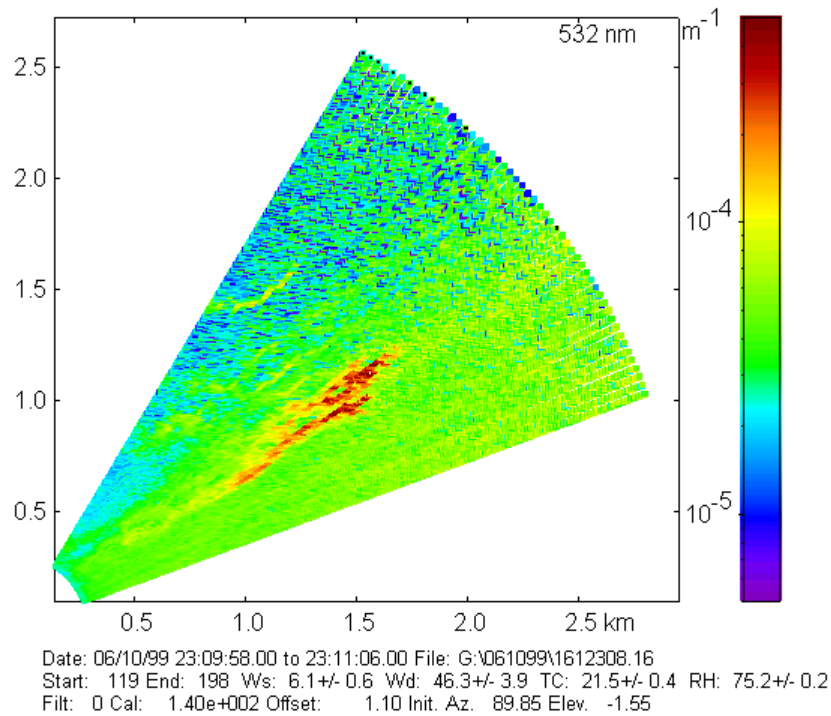


Figure 2. Horizontal lidar scan of the extinction at Bellows Beach on 6/10/99 at 2309 hrs HST. The red patch is an aerosol plume generated by waves breaking on a reef 1.8 km from shore.

dramatic and surprising, and is related to atmospheric turbulence and stability (de Leeuw, 1989). Further studies of these meteorological relationships are being carried out.

We also performed measurements along the beach adjacent to the lidar site, two frames of which are shown in Figure 4. The laser beam was oriented approximately parallel to the shoreline, 10-20 m from the water where 0.3-0.5 m waves break continuously. Vertical plumes about 4-5 m high and 3-10 m wide are evident at intervals of 20-50 m. The plumes' sizes change rapidly with time and they rarely persist for longer than the frame interval of 20 seconds. This scan sequence clearly demonstrates the ability of our lidar system to detect plumes having dimensions down to 5 m or less.

In order to examine the diurnal variation due to tides, temperature, etc., we scanned a vertical profile in the upwind direction (50° E) continuously for 96 hours. We are still analyzing the

resulting data, which resulted in over 4000 vertical scans at approximately two-minute intervals. To process this large quantity of data (>2 Gbytes), we modified the existing software to average the extinction in specified rectangular squares and output the resulting time series. Some of the results are shown in Figure 5. There appears to be a fairly pronounced diurnal variation in the integrated extinction that correlates quite well with temperature. The data also includes a section during the first evening where the wind direction (not shown) changed from onshore to offshore.

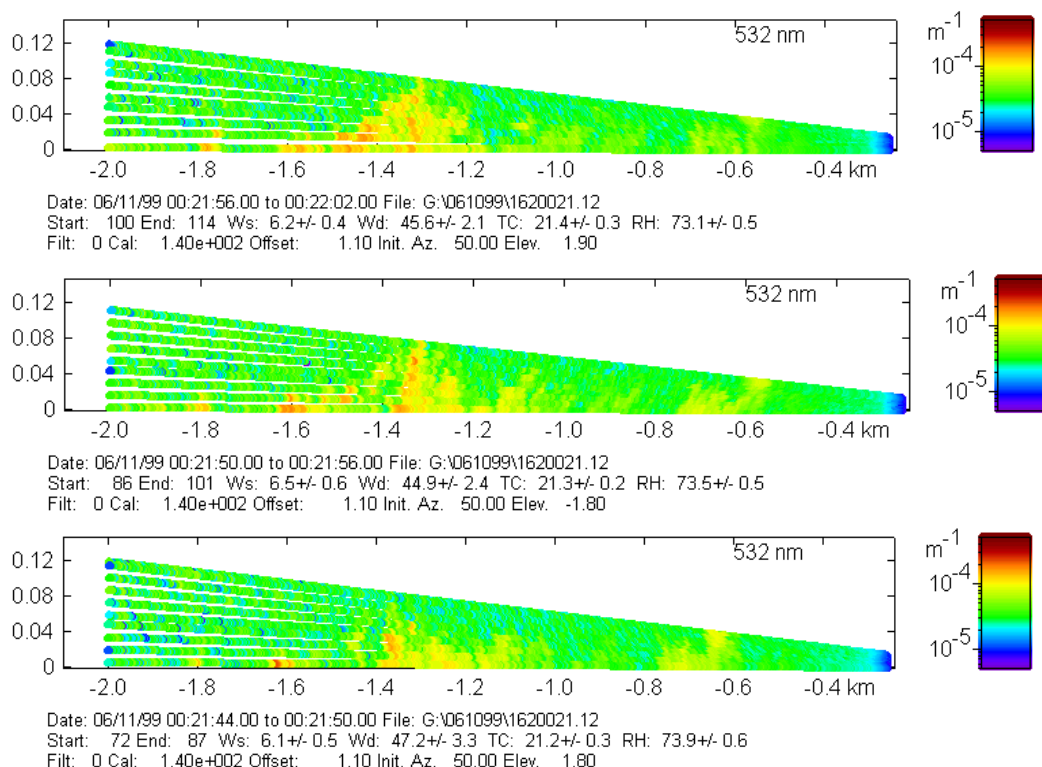


Figure 3. Time sequence of three vertical scans performed over the reef (50° E) about 1 hour after the horizontal scan in Figure 2. Note the plumes of aerosol rising to heights of 80 m in the middle frame.

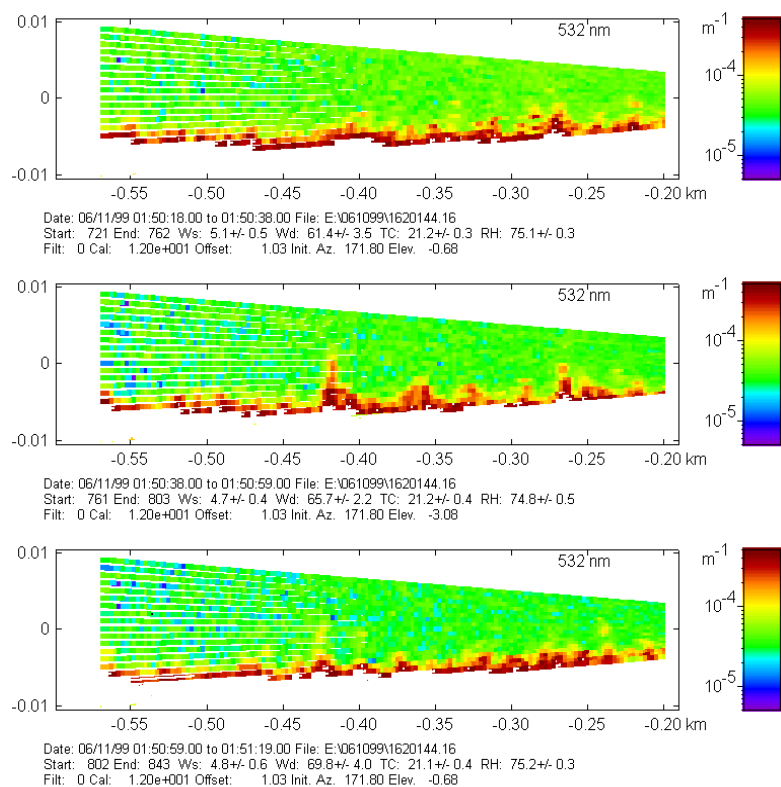


Figure 4. Vertical scan time series at 20 second intervals. These three scans were taken along the beach on the same evening as the data in Figure 3.

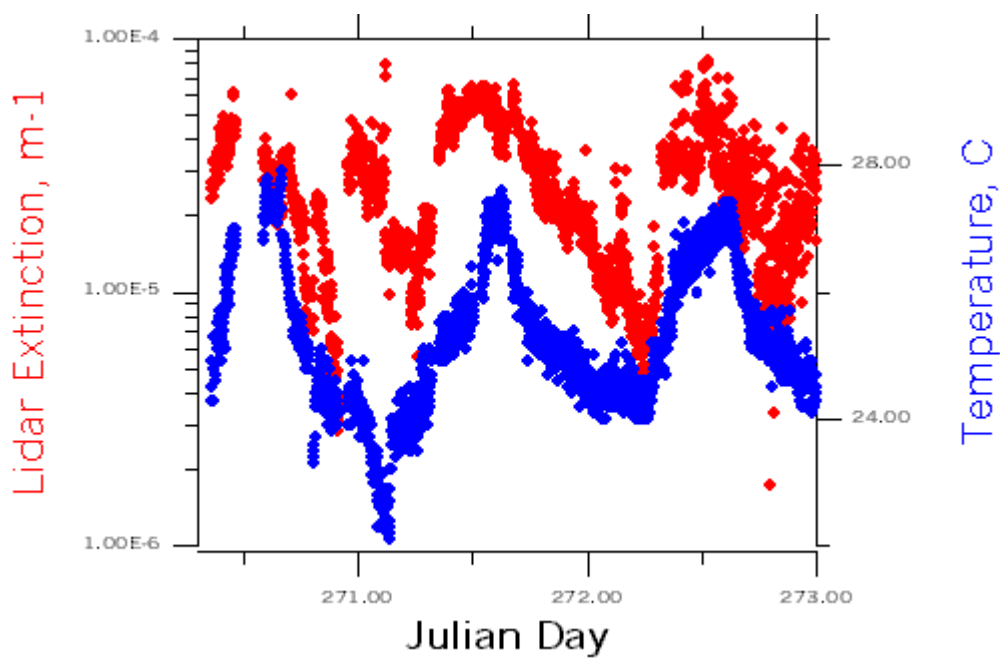


Figure 5. Time series of the extinction integrated over a rectangle 500-600m from the lidar and 0-100 m high

IMPACT/APPLICATION

Our efforts are characterizing the important features needed to adequately model the optical characteristics of the coastal marine environment. The 3-D patterns of aerosol fields that we have observed suggest that the distribution of aerosols in the mixing layer is strongly influenced by plumes which can rise as much as 100 m above reef-generated waves.

TRANSITIONS

Our lidar measurements are linked to two ONR projects. The proposal “Physicochemical and Optical Characterization of Boundary Layer Aerosol Fields” (PI: Antony Clarke) will provide data which can help to calibrate our lidar measurements. We are collaborating with Dr. Kusieli Shifrin at OSU to derive aerosol size distribution with our multi-wavelength measurements.

RELATED PROJECTS

- 1) We (PI: Shiv Sharma) are developing a water vapor DIAL lidar system under the project “Center for the study of water vapor fields and their radiative effects over Hawaii”. This project is funded by NASA and will be operational along with our existing ONR lidar system. This enhanced capability will improve the utility of the ONR lidar to provide rapid measurements of water vapor in the atmosphere.
- 2) We (PI: John Porter) are currently funded by NASA, in two separate efforts, to test satellite derived products from the SeaWiFS and various EOS-AM satellite sensors. This is part of the SIMBIOS effort and the EOS-AM validation effort. The lidar measurements are being used to provide support for these efforts.
- 3) We (PI: Barry Lienert) have obtained funding from NOAA/Sea Grant College for developing an airborne lidar system to measure oceanic fluorescence and hydrological properties.

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PUBLICATIONS

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