A Multi-Wavelength Mini Lidar for Measurements of Marine Boundary Layer Aerosol and Water Vapor Fields

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LONG-TERM GOALS

Our long-term goal is to improve our understanding of dynamics of marine aerosols and water vapor fields in the coastal marine boundary layer using a scanning lidar and meteorological parameters.

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). Various aerosol models exist (e.g., Fitzgerald, 1989), but few are appropriate for coastal regions. We are studying the vertical aerosol structure in the 15-m of the atmosphere directly above the ocean surface.

APPROACH

We are using 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., 2001). These measurements have been carried out at Bellows Air Force (AFS) next to the University of Hawaii's Meteorological Tower (21^{o} 21.848' N, 157^{o} 42.584' W). We are able to study the spatial structures of the aerosol scattering fields out to distances of up to 10 km from the shore. The scanning lidar data enables us to place the aerosol characteristics being observed by the shore-based instruments in the context of much larger scale variability in the aerosol scattering fields. Dr. Shiv Sharma is the project director involved in all aspects of these efforts. Dr. Barry Lienert has developed the software and supervises the data collection. Dr. John Porter is involved in calibration and modeling of the data.

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14. ABSTRACT
Our long-term goal is to improve our understanding of dynamics of marine aerosols and water vapor fields in the coastal marine boundary layer using a scanning lidar and meteorological parameters.

15. SUBJECT TERMS

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WORK COMPLETED DURING 2002

(1) We have processed lidar and meteorology data during the SEAS experiment to develop a better understanding of the coastal optical properties at Bellows beach (Porter et al., 2002).

(2) We have completed a preliminary study of the relationship between plume height over a reef with wind speed (Sharma et al., 2002)

(3) We have derived reliable sea salt size distributions from genetic inversion of polar nephelometer data (Lienert et al, 2002).

RESULTS

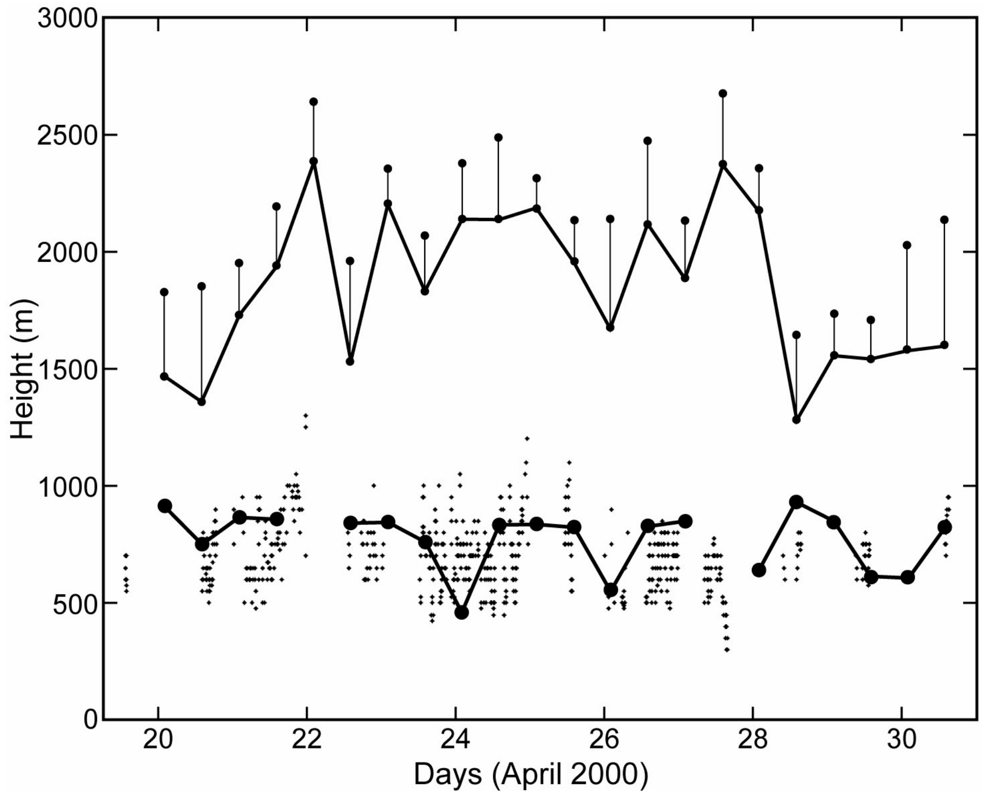

Figure 1. Height of the top of the mixed layer derived from lidar 2-D scans (black dots) and Lihue, Kauai National Weather Service sonde data (blue circles). The height of the trade wind inversion base and top (from the Lihue soundings) are also shown in the upper portion of the figure. The mixed layer height varies between 300 and 1300 m, while the trade wind inversion height varies between 1400 and 2300 m, with an average thickness of about 300 m. No obvious correlation is apparent between the mixed layer and trade wind inversion heights.

During the SEAS experiment (4/19/2000-4/23/2000) different investigators brough their instruments together for a focused study of coastal marine aerosols. During this period the spatial and temporal distribution of coastal aerosols was measured by the University of Hawaii scanning lidar (Sharma et al., 2001) providing several interesting features of coastal marine aerosols. One of the prominent features which is evident in the lidar data is a mixed layer from the surface up to approximately 500 m height. It is important to understand the physics of this layer in order to explain processes occuring in the lowest 15 m (Kepert and Fairall, 1999). Models of the mixed layer thickness have often portrayed it as gradually varying as the air mass is advected. Our lidar data during the SEAS experiments suggested that it actually varied significantly over short temporal and spatial scales. This is illustrated in Fig. 1 which shows the height of the mixed layer derived from the lidar data as well as from soundings (on Lihue, Kauai) during the SEAS experiment. The height of the base and top of the trade wind inversion is also shown for the Kauai soundings. The rapid variability suggests cloud scale processes may be responsible for these variations. Further studies are needed to investigate these rapid variations.

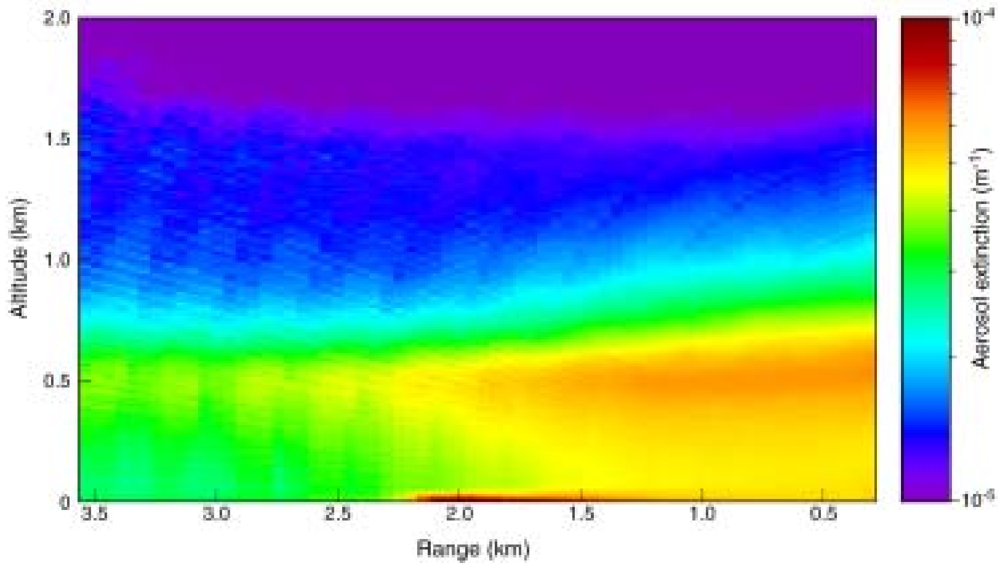

***Figure 2. Spatial distribution of lognormal average aerosol scattering coefficient derived from the scanning lidar (for the whole SEAS lidar data set). The beach is a range zero (on the right) and the outer reef is at 2 km range. The left side of the image is upwind of the lidar site. The extinction in the 500 m thick mixed layer (~$2x10^{-5}$ m^{-1}) increases by a factor of about three at distances less than 2 km from the coastline. The 30 m thick region at the surface, 1.5-2.2 km from the coast, is due to spray from waves breaking on reefs*.**

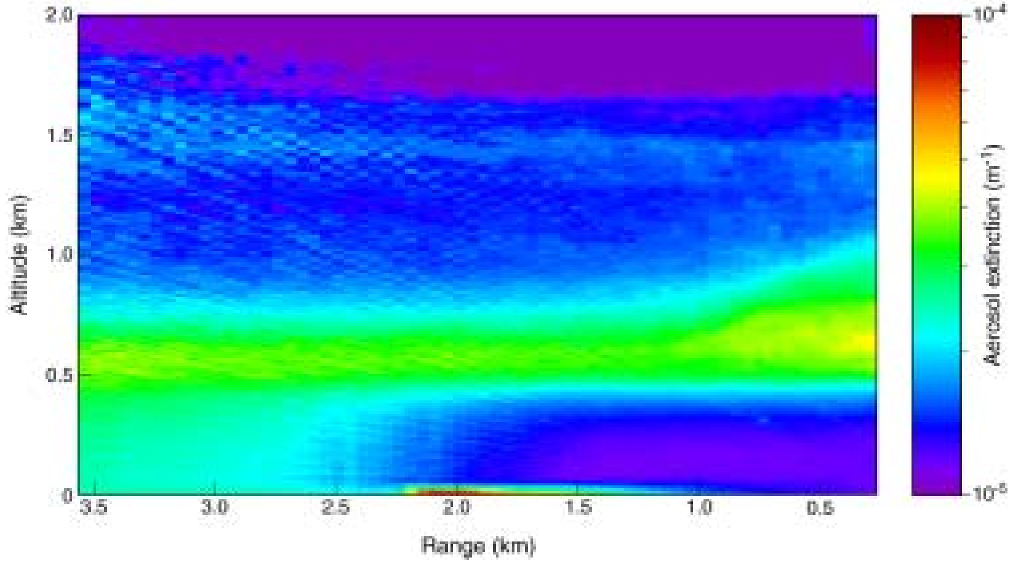

Figure 3. Same as Figure 3 but showing the lognormal standard deviation. Standard deviations in the mixed layer are 1-2x10^{-5} m^{-1}, increasing to 4x10^{-5} m^{-1} at heights of 400-800 m and to 1x10^{-4} over the reef. The larger variability in the bottom left of the image is an artifact of poor signal to noise. This has since been improved through the use of a logarithmic amplifier.

We studied the statistical variability of the aerosol fields at Bellows over a five day period during the SEAS experiment (Porter et al., 2002). We have calculated the lognormal average and the lognormal standard deviation of aerosol scattering coefficients in rectangular boxes spanning a complete vertical section (Figs. 2 and 3). It is evident that island blocking is causing enhanced scatter (orange region in Fig. 2) to develop 2 km from the coastline. This region is not apparent in the standard deviation plot in Fig. 3, indicating that is a persistent feature in the offshore aerosol. Visual observations during SEAS suggest that is related to cloud development. The enhanced scatter persists all the way down to sea level, possibly as a result of cloud-related drizzle or virga. The spray from breaking waves over the reefs (red region near the surface at 1.3-2.2 km range) remains below 30 m for the trade wind conditions during SEAS (~7 m/s). Large standard deviations in this region (Fig. 3) indicate that the reef spray scatter varied eposodically with tide level and wave height.

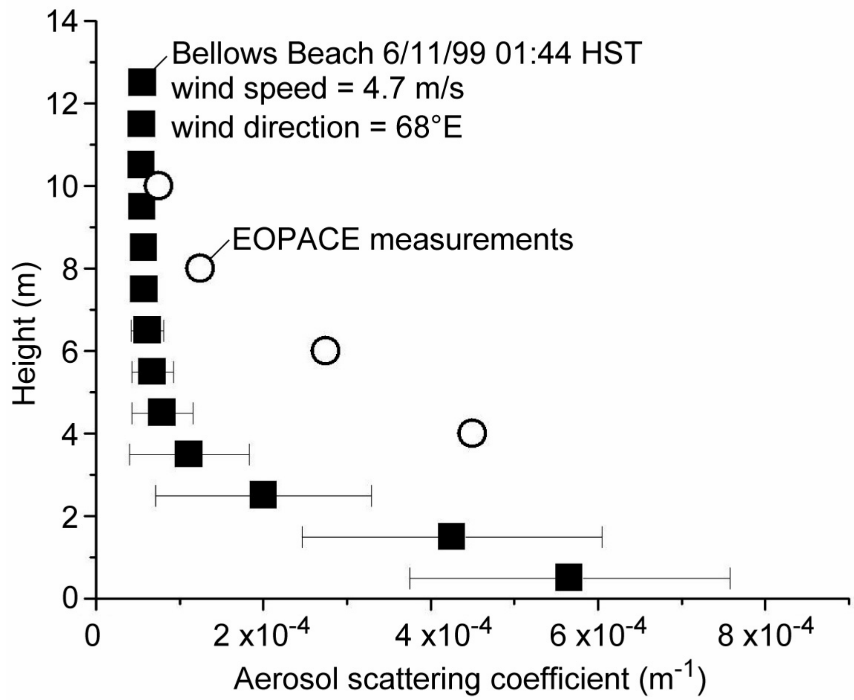

Figure 4. Vertical distribution of aerosol extinction over the waves breaking on Bellows Beach (squares) and the those obtained during the EOPACE experiment over the waves at Script Pier, San Diego , California (circles). The extinction at Bellows increases from $5x10^{-5}$ m^{-1} at heights greater than 7 m to $6x10^{-4}$ m^{-1} at a height of 1m. The EOPACE extinctions increase from $7x10^{-5}$ m^{-1} at a height of 10 m to $4x10^{-4}$ m^{-1} at 4 m, the lowest height measured.

A vertical profile of extinction (532 nm) directly over waves breaking on the beach was made from lidar data collected on 6/11/99 and is shown in Fig. 4. The extinctions measured during the EOPACE (Electro-optical Propagation Assessment in Coastal Environments) experiment are also shown. During the EOPACE experiment the spray concentrations were larger possibly due to the lighter winds (~ 2m/s) versus the 4.7 m/s winds during the Bellows Beach measurements. The waves at Scripps Pier are also generally larger than those at Bellows Beach. Assuming a wind speed of 5 m/s results in an average salt mass flux of 807 µg m^{-2} sec^{-1} from Bellows Beach waves which is within the range of 4562-1034 µg m^{-2} sec^{-1} reported by de Leeuw et al., (2000) for breaking waves at Scripps Pier, California.

During the SEAS experiment we also measured the aerosol phase function (at 532 nm) with a polar nephelometer (Porter et al., 1998). Inversion of the polar nephelometer data (Lienert et al. ,2002) resulted in a coarse mode number size distribution (center wet diameter~1.8µm) which was in agreement with inversions of our lidar data (Shifrin et al., 2002) as well as direct measurements (Clarke et al., 2002) of the aerosol size distribution after inlet loss corrections. Fig. 5 shows the measured phase function (due to aerosol and molecular scatter) along with the total phase function calculated from the aerosol inversions. By successfully fitting this data in the angular range 140-180, we are able to place much better constraints on the coarse mode size distribution than could be achieved with lidar measurements at 532 and 1064 nm wavelength.

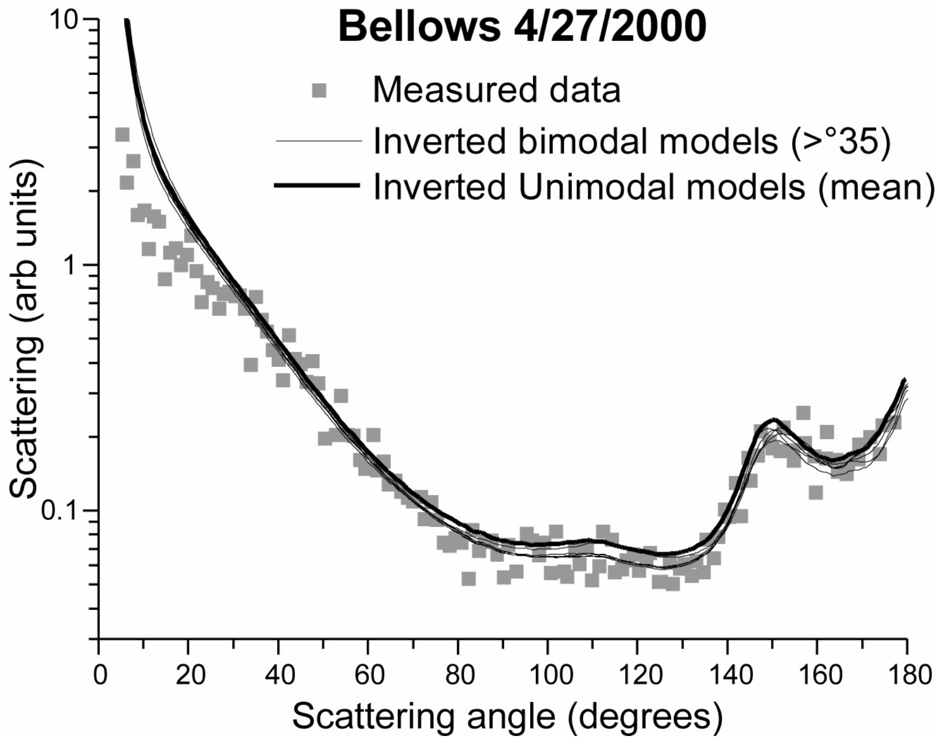

Figure 5. Measured and predicted (for bimodal and unimodal inverted lognormal aerosol models) total (aerosol plus molecular) angular scattering 5m above sea level on Bellows Beach. The poor fit for scattering angles less than 30º (data is 20% lower than theoretical) is due to improper calibration of an attenuation filter which was used in the early version of the polar nephelometer. The majority of the remainder of the data is within 15% of the theoretical curves.

TRANSITIONS

We are presently carrying out further studies of plume height and spatial distribution as a function of wind speed. These studies will be carried out using the extensive lidar data set collected at Bellows from 1999-2002. We have already shown that wavelengths below ~1 µm are not sufficient to resolve the coarse mode sea salt (Lienert et al., 2001). However, we have found that the addition of a 9.25 µm lidar channel dramatically improves the constraints on the coarse mode size distribution. Further work in this area is planned.

RELATED PROJECTS

Our lidar efforts are closely related to the work being carried out by Dr. Antony Clarke. We are comparing our lidar measurements with his *in situ* aerosol size distribution measurements as well as our polar nephelometer inversion results. These independent constraints on the aerosol size distributions at Bellows form an essential part of our ongoing efforts to interpret the high-quality multi-wavelength lidar data we acquired in 2001. We are also continuing our cooperation with Dr. Kuseil Shifrin's group.

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