Physicochemical and Optical Characterization of Aerosol Fields from Coastal Breaking Waves

Antony D. Clarke
Department of Oceanography
University of Hawaii
1000 Pope Rd.
Honolulu, HI 96822
phone: (808) 956-6215 fax: (808) 956-7112 email: tclarke@soest.hawaii.edu

Vladimir N. Kapustin
phone: (808) 956-7777 fax: (808) 956-7112 email: kapustin@soest.hawaii.edu

Award Number: N000149610320
http://pali.soest.hawaii.edu

LONG-TERM GOAL

Our long-term goal is to establish an improved understanding of the properties and factors that control marine aerosol generation processes and associated optical effects including their dependence on oceanic and environmental conditions.

OBJECTIVES

Our intent is to measure the size distribution of aerosol produced under various conditions, its 3-D spatial structure and associated optical effects. We expect to establish the production, vertical development and flux of the sea-salt aerosol in response to increased wind speeds and various environmental factors including coastal interactions.

APPROACH

Our ongoing studies have focused upon breaking waves in a coastal setting through measurement of the complete size spectra from 0.007 to 50µm using a suite of instruments operating at both dry and ambient conditions. These have been carried out at our Bellows Air Force Base (BAFB) site with its 20m tower. Size distributions and their volatility are measured with laser optical particle counters (OPC) and aerodynamic particle sizer (APS) and differential mobility analyzer (DMA). Optical properties are measured with a 3-wavelength integrating nephelometer. Lower boundary layer structure and visibility has been characterized with Vaisala Ceilometer and Visibility Meter. We also continued periodic piloted Seneca aircraft flights using our portable measurement package (meteorological sensors, two nephelometers [with and without coarse size cut at 1µm], CN counter, FSSP, GPS to measure near surface aerosol variability and complete profiles through the trade wind inversion and up to 3000m. The measurements with our new mini-OPC (Clarke et al. 2001), developed with ONR support were also recently added. More detailed near-shore spatial resolution has been periodically obtained by using our research UAV presently equipped with GPS, pressure, temperature, relative humidity, mini-nephelometer, mini-CN counter, mini OPC.

Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**
4. TITLE AND SUBTITLE **Physicochemical and Optical Characterization of Aerosol Fields from Coastal Breaking Waves**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Oceanography,University of Hawaii,,1000 Pope Rd,,Honolulu,,HI, 96822**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Our long-term goal is to establish an improved understanding of the properties and factors that control marine aerosol generation processes and associated optical effects including their dependence on oceanic and environmental conditions.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**7**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

WORK COMPLETED (2000-2001)

During this past year our studies included the analysis of the ONR Shoreline Environmental Aerosol Study (SEAS 2000) (see SEAS report,Clarke et al., 2000), evaluated extensive sea-salt measurements from prior experiments (ACE-1; NASA- PEM-Tropics) and completed development (paper submitted) of our new mini-OPC. Also, at the request of our ONR program manager (Dr. R. Ferek) we are making aerosol microphysics and optical measurements for the Rough Evaporation Duct (RED) experiment (Sept. 2001) with our instrumented Seneca aircraft and portable laboratory facility.

RESULTS

Assessment of SEAS aerosol and lidar data

SEAS was an intensive study that brought together various investigators with new instrumentation designed to enhance our capabilities in characterizing oceanic and coastal aerosol. SEAS included measurements of the aerosol lidar backscatter coefficient (Covert et al.), the aerosol phase function (Porter, Hunt et al.); size-resolved sodium chemistry on single particles (Saltzman et al.); 3-D scanning lidar system (Sharma et al.) and our measurements. At least two periods can be identified during SEAS. For SEAS period **1** (JD113-118), size distributions, wavelength dependence of scattering and resulting Angstrom exponent were typical for clean trade wind conditions. After day 118 the Angstrom exponent significantly increased, indicating changes in the aerosol size distribution. This anomalous

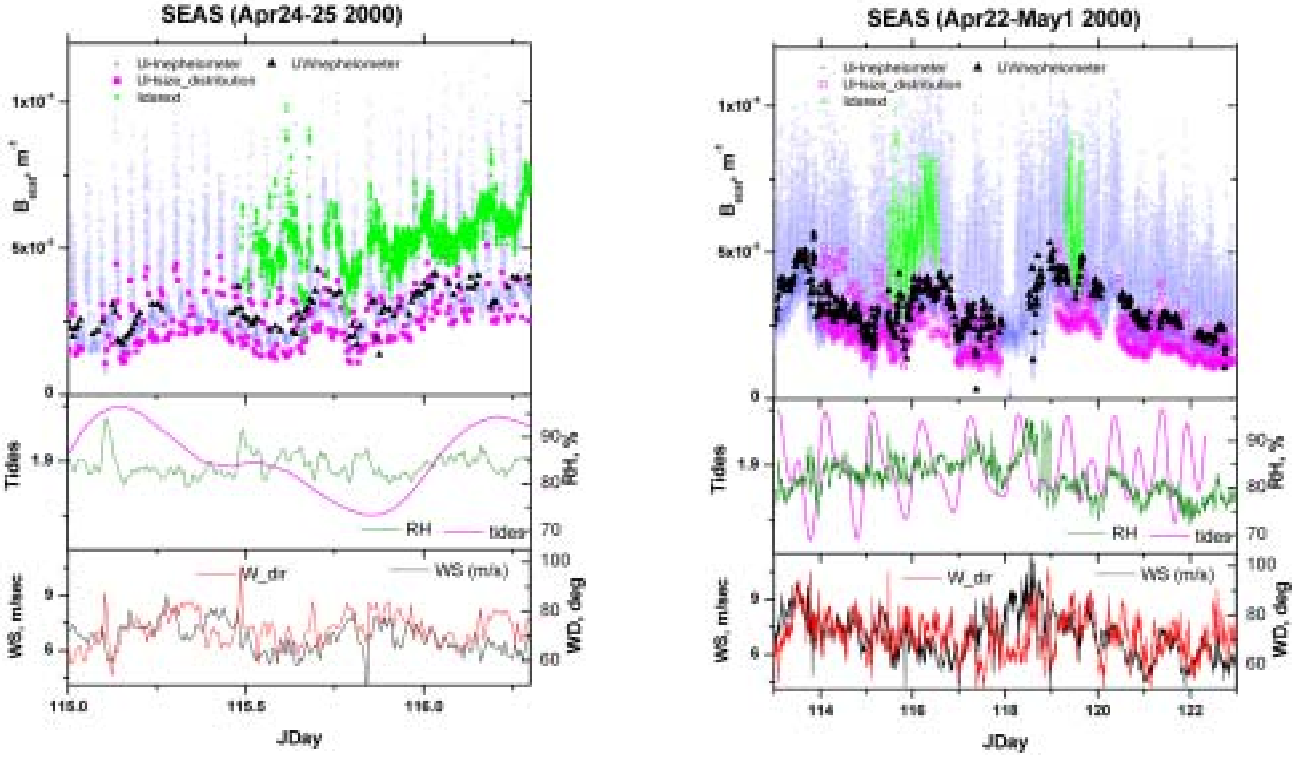

Figure 1. Time series of several SEAS environmental and optical parameters: Top panel – UH nephelometer scattering cycled through 3 heights on tower (blue), UW nephelometer at middle 10m level (black), extinction coefficients from DMA and OPC size distributions (magenta) and from lidar measurements (green); middle panel – tides (magenta) and RH (green); bottom panel – wind speed (black) and wind direction (red).

aerosol behavior – high Angstrom exponent, large accumulation mode of aerosol size distribution persisted until the end of SEAS (JD118 – 123, SEAS period **2**). For the entire SEAS period the wind direction was easterly (oceanic clean sector) and wind speed had some correlation with light scattering.

Our tower instrumentation provided characterization of the aerosol from three altitudes, at the top (20m), middle (10m), and lower (5m) section of the tower. The top level was unaffected by coastal wave breaking while the lower was often dominated by this and the middle occasionally so. **Figure 1** shows related SEAS data for JD115 (**Fig.1a**) and for the entire SEAS period (**Fig.1b**). The wide range of UH nephelometer scattering is due to the cycling through aerosol form the three tower heights. Nephelometer scattering at middle (10m) level for UW (black triangles) and UH (blue dots) instruments are in reasonable agreement. The extinction coefficient calculated from DMA and OPC size distributions (magenta) at10m is lower, apparently due to higher coarse particle losses in OPC. The extinction coefficient inferred from the Sharma upwind lidar measurements (green dots) is higher but lies within the range of UH nephelometer scattering variability from different heights on the tower.

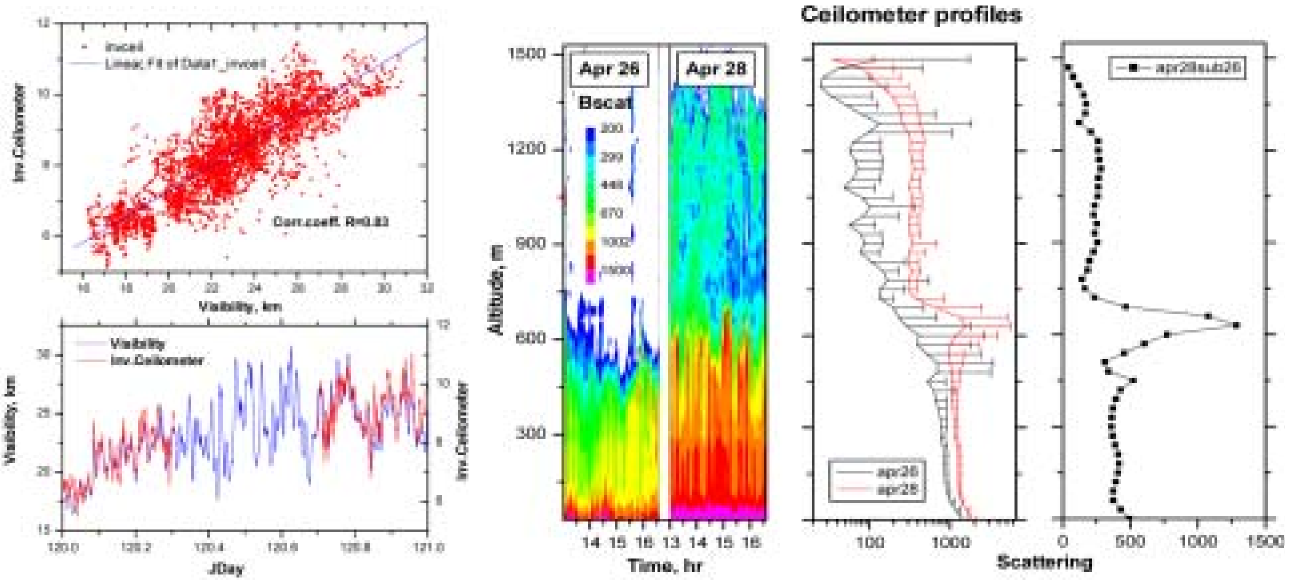

Figure 2. a. Ceilometer vs. visibility meter data; b. Stratified ceilometer data from SEAS before (JD117-Apr26) and during (Apr28) pollution event, averaged vertical profiles and their difference.

During SEAS and post SEAS periods (April-October 2000) we evaluated two new Vaisala instruments - a Ceilometer CT25K and Weather Sensor FD12P (Visibility Meter) operated in continuous mode. The Ceilometer measures cloud-bottom heights and inferred vertical extinction (905nm) based upon pulsed diode laser lidar technology. The bottom figure in **Figure 2a** shows inverse ceilometer backscatter (related to extinction) at the lowest range bin (ca. 30m alt.) and Visibility Meter extinction (14m) derived from forward scatter at 35deg. Ceilometer data with noise at high solar zenith angles was excluded from the comparison and the resulting visibility inferred by both instruments revealed high degree of correlation R =0.83 (**Fig. 2a**, top). This shows that both instruments worked well and that effective calibration of the Ceilometer is possible and it can provide not only cloud-bottom heights but also aerosol visibility and extinction profiles throughout the MBL. We then took time periods before and after the JD118 pollution event and deleted all periods with cloud clutter. The remaining

Ceilometer data were combined and smoothed (**Fig. 2b** - left panel) to reveal enhanced concentrations in the buffer layer between the surface layer and inversion during this event (Fig.2b – middle and right panels). Differences in profiles before and after event (far right) reveal similar enhanced aerosol up to 1,500m (a result of long-range transport) and modify the optical properties of the marine aerosol in the central Pacific MBL. These autonomous instruments appear ideal for shipboard and field use.

Sea-salt aerosol and RED experiment

In our previous reports the analysis of BAFB coastal data for sea-salt and associated optics often do not exhibit a simple wind speed dependence. In order to better understand this process we have recently examined near-surface open-ocean sea-salt data we collected as part of other experiments (ACE-1; PEM-Tropics). Simple wind speed parameterizations were found to be inadequate to predict individual profiles at a given time but grand average profiles (line fits) stratified by wind speed did reveal clear wind speed dependence (**Figure 3a**). These analyses will be presented at the 2001 Fall AGU and should result in a paper submitted in early 2002.

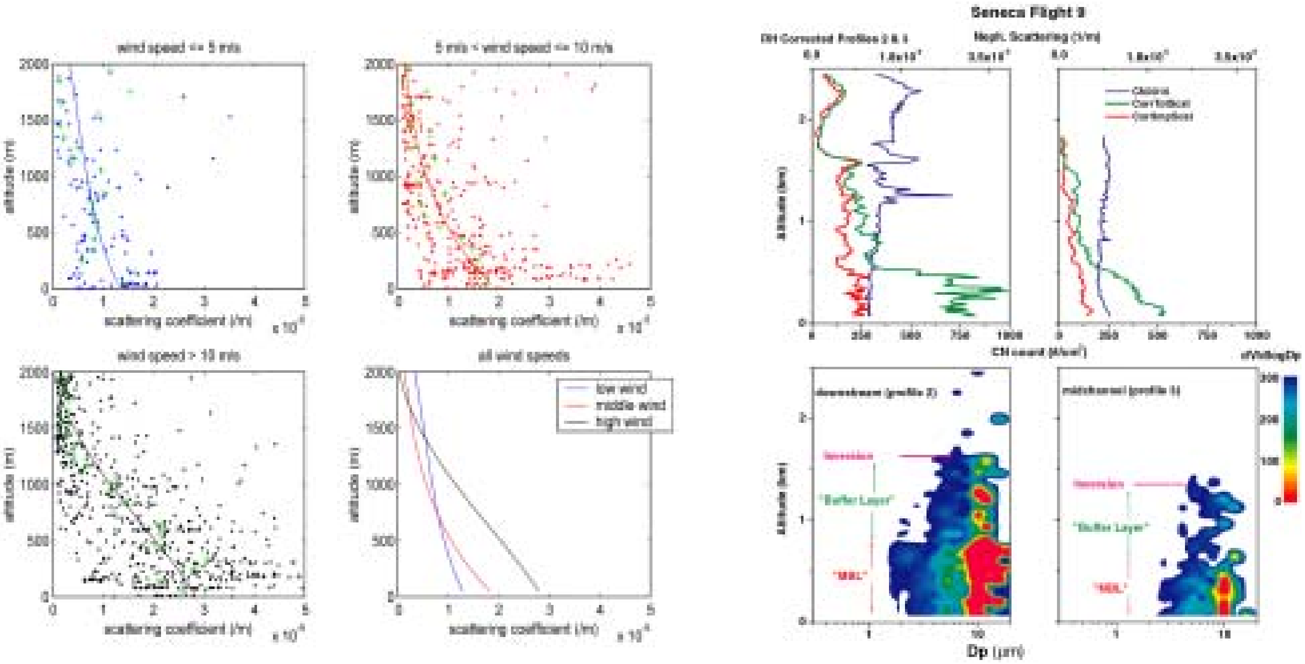

Figure 3. a. Vertical profiles of light scattering data and averages during all of ACE-1. b. Aerosol size distributions and light scattering from total and submicron aerosol in the Alinuihaha channel.

The real variability in the ACE1 measurements stimulated investigation of a unique opportunity offered by accelerated flow in the Alinuihaha channel between the Big Island of Hawaii and Maui. The E-W orientation of the trade winds accelerates the wind flow in this channel over a 100km path about 30km wide while upwind conditions are generally steady for about 1000km. This provides a possibility to examine the interaction of suddenly increased wind speed on the ocean surface wave breaking and bubble production. We recently initiated an exploratory flight to test this notion and **Figure 3b** shows vertical profiles of aerosol volume distributions made at two points along the axis of the Alinuihaha Channel during elevated winds. These profiles reveal the increase of MBL sea-salt and associated light extinction along with its vertical development downwind. Hence, repeated flights under diverse wind conditions could provide data that will allow us to quantitatively link bubble production to wind speed and to sea-salt production and its vertical development (fluxes) in a pseudo-Lagrangian sense.

Mini-OPC

This year we also developed, tested and deployed a prototype custom mini-OPC and inlet system for in-situ aircraft studies of aerosol. The unit employs a solid-state laser coupled to a custom designed logarithmic amplifier, electronics and sample inlet configuration (**Figure 4a**). Comparison with size distributions obtained concurrently using a LAS-X (inside aircraft) and FSSP (mounted on wing) optical particle counter were undertaken as part of the 2001 TRACE-P experiment sampling both pollution and dust aerosol near Japan (**Figure 4b**). Low particle losses provided improved characterization of large aerosol than possible with the LAS-X while the simpler optics and high flow rate provided superior statistics than the FSSP. Its small size, low power, low cost, versatility, wide size range and high resolution makes it ideal for a range of airborne and surface applications.

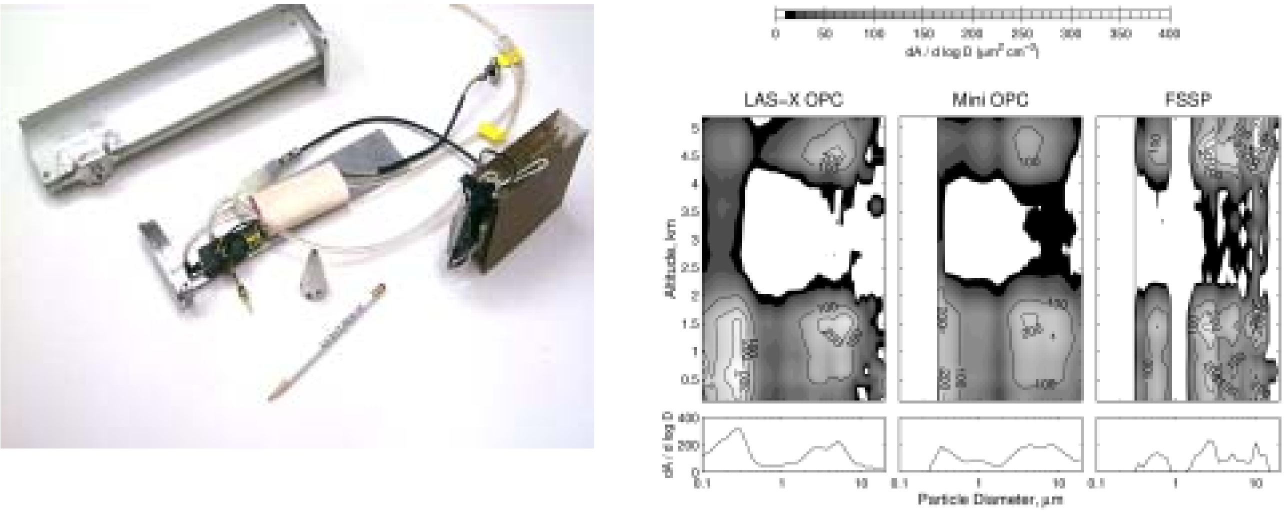

Figure 4. a. Exploded view of wing strut with mini-OPC, electronics, inlet cone, RH sensor; b.Concentration contours of surface area as measured by the LAS-X, the mini-OPC and FSSP for a vertical profile near Japan on TRACE-P. The reduced sensitivity below 0.3um have been masked off on the latter two instruments. An example of a distribution from each instrument as measured at 1.2km is also included below each panel for clarity.

IMPACT/APPLICATION

SEAS highlighted new techniques used to measure marine aerosol and to derive aerosol scattering and extinction values. Comparisons of extinction and size data with Visibility and Ceilometer data should provide a sound physical basis for the use/interpretation of these autonomous instruments. We also believe our new mini-OPC is a valuable contribution to smaller and better particle sizing instruments.

RELATED PROJECTS

Our BAFB coastal measurements, some Seneca light aircraft and RPV flights are often directly linked with Dr. S. K. Sharma’s Lidar project ONR #N000149610317, Dr. John Porter’s radiation project NASA-NAG-56340. New collaboration with SIO (Terrill and Melville) is expected to lead to a valuable new capability in establishing links between aerosol oceanic source terms and aerosol effects.

PUBLICATIONS

Clarke, A. et al., New instruments and tools for measurement of marine aerosol microphysics, chemistry and optical effects, Ocean Optics XV, Musee Oceanographique Monaco, Oct. 16–20, 2000,Office of Naval Research, *USA, pp.10.*

Antony D. Clarke, Norman C. Ahlquist, Steven Howell and Ken Moore,
A Miniature Optical Particle Counter for In-Situ Aircraft Aerosol Research, Submitted to Journal of Atmospheric and Oceanic Technology , June 20, 2001.