# 12.4 EDDY CORRELATION MEASUREMENTS OF SEA-SPRAY AEROSOL FLUXES DURING SEASAW

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## 1. INTRODUCTION

Most estimates of sea spray aerosol source functions (SSSF) have used indirect means to infer the rate of production as a function of wind speed. Only recently has the technology become available to make high rate measurements of aerosol concentration suitable for direct eddy correlation determination of the particle flux. During the Sea Spray and Whitecap (SEASAW) study cruises a new compact aerosol spectrometer (CLASP) was collocated with a sonic anemometer on the foremast of the RRS Discovery. Two research cruises were undertaken in the NE Atlantic on board the RRS Discovery: D313 (November 7 to December 2 2006), and D317 (March 21 to April 12, 2007) (Brooks, 2007a).

CLASP produces a 16-channel aerosol size spectrum ($0.05 < r < 3.5$ micrometers) at a rate of 10 Hz, allowing the calculation of size segregated aerosol fluxes via eddy correlation. During the two cruises direct eddy covariance estimates of sea spray fluxes were obtained in the open ocean at mean 10-metre wind speeds of up to 23 m $s^{-1}$ alongside estimates of the whitecap fraction, measurements of the ship motion and background meteorology and aerosol concentrations.

## 2. SCIENTIFIC BACKGROUND

Sea spray is an especially important aerosol because, with the exception of dust, it is the largest single source of aerosol mass injected into the atmosphere (Hoppel et al., 2001). When sea spray is produced at the ocean's surface, heat and water mass, plus associated chemicals, bacteria and viruses, are transferred from the ocean to the atmosphere. The transfer of heat, water vapour and momentum across the air–sea interface is crucial because of their influence on the intensity of tropical cyclones. Over the open oceans sea salt aerosol are the dominant scatterer of incoming solar radiation (Haywood et al. 1999) and can modify marine stratocumulus clouds – one of the largest sources of uncertainty in climate predictions. Sea salt plays a significant role in marine stratocumulus microphysics and chemistry (O'Dowd et al. 1999), and can also provide a substantial sink for atmospheric trace gases, both natural and man made (O'Dowd et al. 2000).

At present there are substantial variations, roughly 5 order of magnitude for micron sized particles, in the values of the SSSFs available in the literature as a function of wind speed. Wind speed is the dominating controlling factor to the production sea spray aerosols however there are other variables such as, wind history, sea-state, the presence of organics and surfactants, water temperature, gas saturation, rain, surface-layer stratification – all of which are poorly understood. It is difficult to determine the extent to which the differences in the SSSF are influenced by sampling location or the range of meteorological conditions, such as wind speed. Measurements have typically suffered from a high degree of uncertainty and the challenge of obtaining direct observations near the air-sea interface at high sea states; these confounding effects have made the determination of empirical SSSFs difficult (SOLAS 2004).

## 3. MEASUREMENTS

A flux system including a single Gill R3A sonic anemometer, a LiCOR 7500, a miniature aerosol optical particle counter (CLASP), and two motion sensing packages, was installed at the top of the foremast, on the RSS Discovery, approximately 21 m above the waterline. Figure 1 shows the flux system on top of the foremast with the CLASP units, sonic anemometer and motions packs indicated.

**Figure 1.** The flux installation on the foremast. The CLASP inlets are situated just below the LICOR

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The CLASP instrument, shown in Figure 2, is a compact aerosol spectrometer that uses a 780 nm wavelength (20 nm variance) solid-state laser to produce aerosol spectra between 0.05 and 3.5 μm in radius at a frequency of 10 Hz (Brooks et al. 2007). A high flow rate of 3 liters per minute, without pulsation, provided by Miniature Rotary Vane pumps manufactured by Rietschle Thomas, provides the high sample volume necessary to sample sufficient particles for direct size resolved aerosol fluxes to be determined effectively. A thermal mass-flow device is fitted to control the flow through the scatter cell. It consists of an exposed heater element and a reference resistor. The heated element loses heat at a rate that is a function of flow speed; allowing a precise flow rate to be determined via calibration and controlled during operation Particle concentrations are adjusted for any variation in flow rate during processing.. Each CLASP instrument is 25 × 8 × 6 cm and the aerosol is drawn into the internal scatter cell by a 6 mm internal diameter metal tubing 40 cm in length.

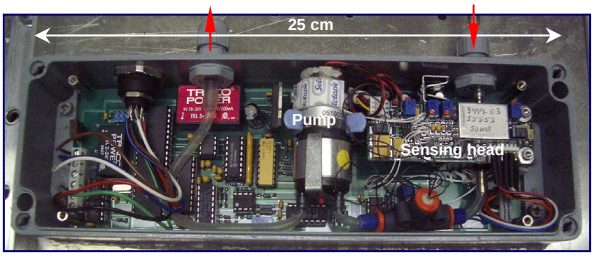


**Figure 2**. Internal layout of CLASP unit, red arrows indicate sample flow into the sensor head and exhaust from pump.

To succeed in making turbulence measurements at sea from a moving platform the velocity imposed by the motion of the ship must be removed from the wind speed measurements made by the sonic anemometer. Two motion packs were located on arms off the back of the plate on the foremast as part of the flux system. This mounting arrangement was required to remove the magnetic compasses within the motions packs from immediate distortion effects of the steel mast and plate. The motion packs consisted of a pitch, roll, and electronic compass module coupled to a custom built control and communications board incorporating a set of 3-axis accelerometers with a resolution of 1 mill-g (Brooks, 2007b). They provide pitch, roll, heading and linear accelerations along the x, y, and z axis at 20 Hz. Further details are provided in Brooks et al. (2007b)

## 4. RESULTS

Aerosol spectra from CLASP are compared with those from a PMS PCASP with a sample inlet at approximately the same level above the surface. (Figure 3) Excellent agreement between the spectra give confidence in the CLASP measurements. Particle fluxes are estimated for each channel via the eddy covariance technique. Examination of the cospectra

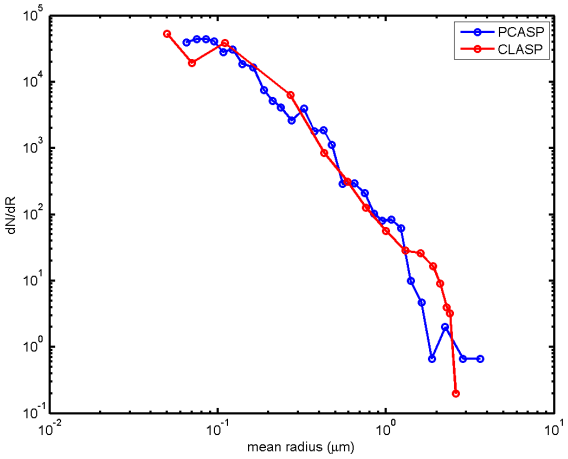


**Figure 3**, A comparison of the measured spectra from CLASP to a PMS PCASP during D317.

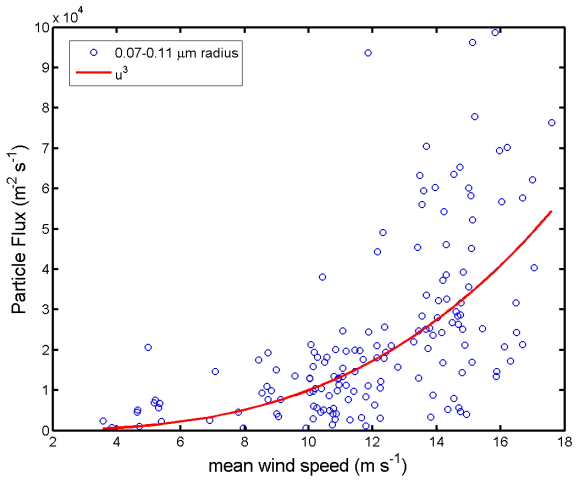


**Figure 4**. The sea spray flux data showing its cubic dependence on local wind speed.

indicate that a 20-minute averaging period is sufficient to include all turbulent scales contributing to the flux. After screening the data for acceptable mean wind directions relative to the ship (± 40º of the bow), and stationarity of the flow, fluxes are calculated for each 20 minute interval. Initial estimates of the flux for the size range 0.07-0.11 μm are shown as a function of wind speed in figure 4. A fitted curve indicates that the fluxes follow the expected cubic relationship with wind speed.

Figure 5 shows a comparison of preliminary flux estimates as a function of particle size with direct measurements from a coastal site – the 560-m pier at the Army Corps of Engineers Field Research Facility (FRF) in Duck, North Carolina – and a range of parameterizations of the sea spray source functions from the literature. We believe these to be the first direct eddy covariance estimates of size-resolved aerosol particle fluxes to be made in the open ocean. The SEASAW flux estimates show a well defined distribution, within the limits of the range of

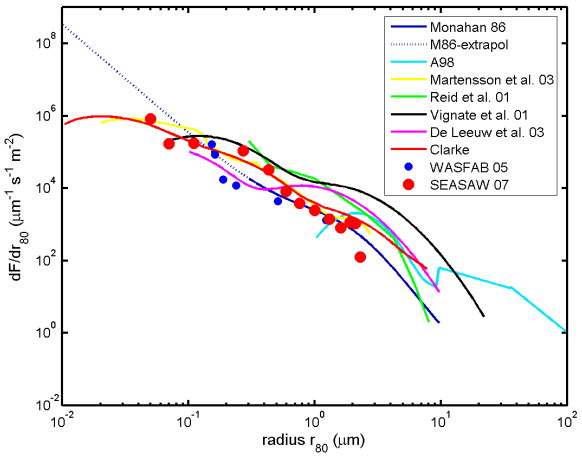


**Figure 5**. Comparison of preliminary flux estimates as a function of particle size for $U_{10}$ = 5 m $s^{-1}$, with those from a coastal site (WASFAB 06) and a number of recent parameterizations from the literature.

parameterizations. These results demonstrate the viability of making direct aerosol flux estimates from ships Further analysis is ongoing to refine the flux estimates and formulate a source function. Additional measurements will be required over a wide range of conditions to fully characterize sea spray aerosol production rates.

## ACKNOWLEDGEMENTS

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