12.3 AN OVERVIEW OF THE SEA SPRAY, GAS FLUX, AND WHITECAP (SEASAW) FIELD STUDY

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1. INTRODUCTION

The Sea Spray, Gas Flux, and Whitecap (SEASAW) study is concerned with the measurement of the air-sea fluxes – in particular the physical exchange of trace gases and aerosols across the air-sea interface – under high wind conditions. It is part of the international Surface Ocean Lower Atmosphere Study (SOLAS). Two research cruises were undertaken in the NE Atlantic on board the RRS Discovery (Figure 1): November 7 to December 2, 2006 (cruise D313), and March 21 to April 12, 2007 (D317). Figure 2 shows a map of the cruise tracks for both cruises. D313 was shared with another UK SOLAS project: the Deep Ocean Gas Exchange Experiment (DOGEE) and was severely constrained by a long period of exceptionally bad weather and high seas – among the worst in a decade – that forced the ship to seek shelter amongst the Western Isles for extended periods of time, so that much of the data collected was from sheltered coastal waters rather the open ocean. D317 spent a full 3 weeks in the open ocean, but did not experience such high wind speeds.

Direct eddy covariance measurements of turbulent fluxes were obtained under 15-minute averaged 10-metre wind speeds of up to 23 ms^{-1} during D313, and 18 ms^{-1} during D317; these are among the highest wind speeds of any direct CO_2 flux measurements to date.

Figure 1. The RRS Discovery in port in Stornoway, Isle of Lewis, during cruise D313.

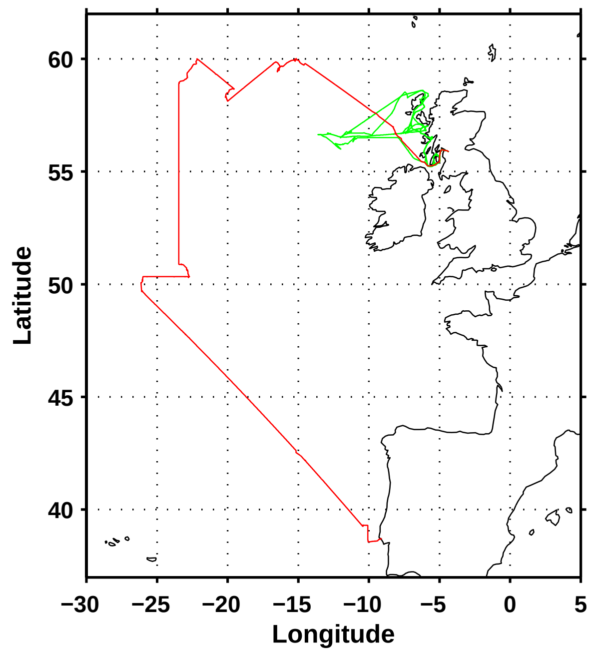

Figure 2. Cruise tracks for D313 (green) and D317 (red)

2. SCIENTIFIC BACKGROUND

Physical exchange processes at the air-sea interface have an important controlling influence on the concentrations of gases and aerosol particles in the atmosphere and hence on the radiative balance of the Earth and global climate. The oceans are a major sink for CO_2 – approximately half of the CO_2 generated by human activity is absorbed by the oceans. The net uptake of CO_2 is the result of a complex pattern of seasonally varying regional sinks and sources. The controlling processes for the exchange rate are complex: wind speed is the most important factor, but the uncertainty is at least a factor of two. The uncertainty is greatest at high wind speeds due to the lack of direct observational estimates with which to

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constrain parameterizations; almost all the available data is for wind speeds less than 10 m s^{-1}. Other factors affecting the gas transfer rate include the extent of whitecap coverage, the presence of surfactants, water temperature and properties of near-surface turbulence on both sides of the air-sea interface.

Sea-salt aerosols are the dominant scatterer of solar radiation over the open ocean (Haywood et al. 1999), dominate the particulate mass concentration in unpolluted marine air, and contribute approximately 44% to the global aerosol optical depth. The interaction between aerosol and clouds also has a major impact on climate. The largest contribution to this so-called indirect aerosol effect comes from marine stratocumulus, and is one of the largest sources of uncertainty in climate predictions. Sea salt aerosol 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). The source functions for sea salt aerosol remain rather poorly characterized, with an uncertainty in production rate as a function of wind speed of about a factor of five for micron-sized particles, and rather greater for smaller particles. As with the gas transfer velocity, wind speed is the dominant controlling factor, but there are many other influences – wave state, the presence of organics and surfactants, water temperature, gas saturation, rain, surface-layer stratification – all of which are poorly understood.

Bubble bursting is the primary mechanism for the generation of sea salt aerosols (Blanchard and Woodcock 1957; Monahan 1968), and plays a significant role in enhancing gas transfer rates (Woolf 1997). The relationships between meteorological conditions, sea state, and whitecap properties must thus be considered as we try and improve the parameterizations of both air-sea gas fluxes and sea spray source functions (Woolf 2005).

3. MEASUREMENTS

The core of the SEASAW measurement program was the determination of the fluxes of CO_2 and aerosol particles, as well as momentum, heat, and water vapour, via both inertial dissipation and eddy covariance techniques. Other measurements included the mean background aerosol spectrum between approximately 3 nm and 300 μm (radius), aerosol chemical composition via volatility and single particle mass spectrometry, mean meteorological conditions, surface wave state, whitecap fraction, detailed measurements of wave spectra, bubble size spectra, and aerosol spectra over individual whitecaps, and mean CO_2 concentrations in the atmosphere and ocean. The majority of the measurements were made continuously throughout the cruises, with a smaller subset being made during short deployments of two different buoy systems.

3.1. Turbulent Flux Measurements

Two separate flux systems were installed on the foremast of the Discovery: the NOC AutoFlux system consist of two Gill R3A sonic anemometers mounted at either side of the foremast platform at about 18 m above the waterline. LiCOR 7500 open path gas analyzers are mounted just below and forward of each sonic anemometer, and a Systron Donner MotionPak motion sensing package is mounted at the base of the starboard sonic anemometer.

A second flux system, installed by the University of Leeds, consisted of a single Gill R3A sonic anemometer, a LiCOR 7500, a miniature aerosol optical particle counter (CLASP), and two custom-built motion sensing packages, all mounted at the top of the foremast about 21 m above the waterline. Both flux systems are described in more detail by Brooks et al. (2007).

The CLASP instrument produces an aerosol size spectrum in 16 channels between 0.05 and 3.5 μm radius at a sample frequency of 10 Hz enabling direct size resolved aerosol fluxes to be determined via eddy correlation (Norris et al. 2007a,b).

During D317 a new Fast Lightweight Ozone Sensor (FLOS) was also installed on the foremast with an inlet just aft of the sonic anemometer, alongside those for the aerosol probes. Based on a wet chemiluminescence technique (Takayanagi, 2003) it operates at 20 Hz, enabling turbulent fluxes of ozone to be estimated via eddy correlation.

3.2. Background Aerosol and Aerosol Composition

The mean size spectra of the background aerosol were measured by an extensive suite of instrumentation spanning particle radii from 3 nm to about 300 μm. A PMS OAP and FSSP were sited on the monkey island, at approximately the same height above the surface as the CLASP instrument on the foremast. A 46 mm diameter sample line ran from the mast above the bridge to a container laboratory sited on the fo'c'sle deck, just aft of the bridge. Isokinetic inlets tapped off the flow from the main inlet to a PMS PCASP, TSI 3762 CPC, TSI 3025 CPC, Grimm CPC, Grimm dust monitor, and an Aethalometer to monitor black carbon loading.

Information on aerosol chemical composition was determined by a TSI Aerosol Time-Of-Flight Mass Spectrometer (ATOFMS), and volatility system in which a PMS PCASP is coupled to a heated inlet. The latter heats the incoming aerosol stream in a 15-minute cycle to temperatures between about 40ºC and 900ºC; information on chemical composition and mixing mode are determined from the changes in spectral shape and total particle number as different chemical constituents volatilize at characteristic temperatures or the particles suffer mechanical breakdown and shatter (Brooks 2002).

Figure 3. The NOC spar buoy. Wave wires are located on the right of the image. The underside of the dome is transparent and contains still and video cameras to image the region around the wave wires

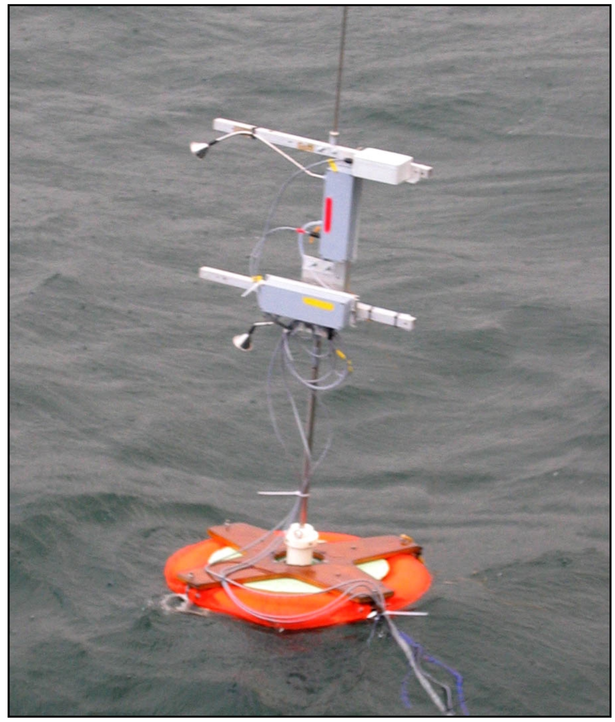

Figure 4. The Leeds aerosol buoy. CLASP aerosol probes are located in the grey enclosures with inlets at approximately 0.5 and 1 m; the motion pack .

3.3. Buoy Measurements

Two separate buoy systems were operated during SEASAW: a free drifting, 10-meter long spar buoy, and a much smaller tethered buoy. The spar buoy (figure 3), developed at NOC, was instrumented with three wave wires to measure the detailed wave field at a resolution of 3 mm; tilt meters and 3-component accelerometers to measure the motion of the buoy; downward facing digital still and video cameras to provide high resolution imagery of the waves and whitecaps around the wave wires, and a subsurface acoustic bubble measurement system (Moat et al. 2007). A total of 5 deployments were made during D313 to measure wave breaking and whitecap processes.

The tethered buoy (figure 4) was instrumented with two CLASP systems to measure aerosol spectra close to the surface – at heights between about 0.5 and 1 m above the surface. With a time resolution of 0.1 seconds they are able to identify bursts of particles associated with individual whitecaps. A bubble imaging system recorded bubble size spectra at a depth of approximately 0.4 to 0.5 m below the surface. Images are recorded in bursts of 100 frames at 20 frames per second alternating with binarization and saving of the images. The binary images are later processed to estimate size spectra over specified time intervals. A motion pack, identical to that incorporated in the foremast turbulence system, records the motion of the buoy allowing it's position on the waves, and wave heights to be determined. Digital images were recorded via a webcam at 1 second intervals to provide a visual record of the conditions experienced by the buoy and aid in later interpretation of the data. The buoy is free floating, but held in a fixed location by a weighted cable suspended from a ship's crane. This passed through the buoy's central column, allowing it to ride freely up and down the cable with the waves, while being maintained close to vertical.

3.4. Mean Conditions

Mean meteorological measurements were provided from multiple systems sited on the foremast and on the monkey island, and included wind speed and direction, air temperature and relative humidity, barometric pressure, and incoming solar radiation. Mean ocean properties include wave state from a Ship Borne Wave Recorder (SBWR); this couples measurements of pressure below the waterline with those of the ships motion to provide a continuous record of wave height. pCO_2 measurements in both air and water were provided by one of two systems; during D313 the UEA pCO_2 system was used, while a new permanent underway system developed by the Plymouth Marine Lab under the auspices of the NERC Centre for Observations of Air-Sea Interactions and Fluxes (CASIX) ran alongside it; during D317 only the CASIX system was used. Sea surface temperature, and salinity were measured from the same pumped sea water feed that supplies the pCO_2 systems.

The whitecap fraction on the ocean surface was recorded photographically at 30-second intervals during daylight hours by two digital cameras mounted on the bridge. The whitecaps are identified via image processing techniques, and the fractional area calculated over 10 minute averaging periods.

4. SUMMARY

Preliminary results from SEASAW are presented in a series of papers in this volume: aerosol flux measurements and sea spray source functions (Norris et al. 2007b), near surface aerosol and bubble measurements (Norris et al. 2007c), wave and whitecap measurements from the NOC spar buoy (Moat et al. 2007), CO_2 gas flux measurements (Bloom et al. 2007), and basic turbulence measurements under high seas (Brooks et al. 2007).

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