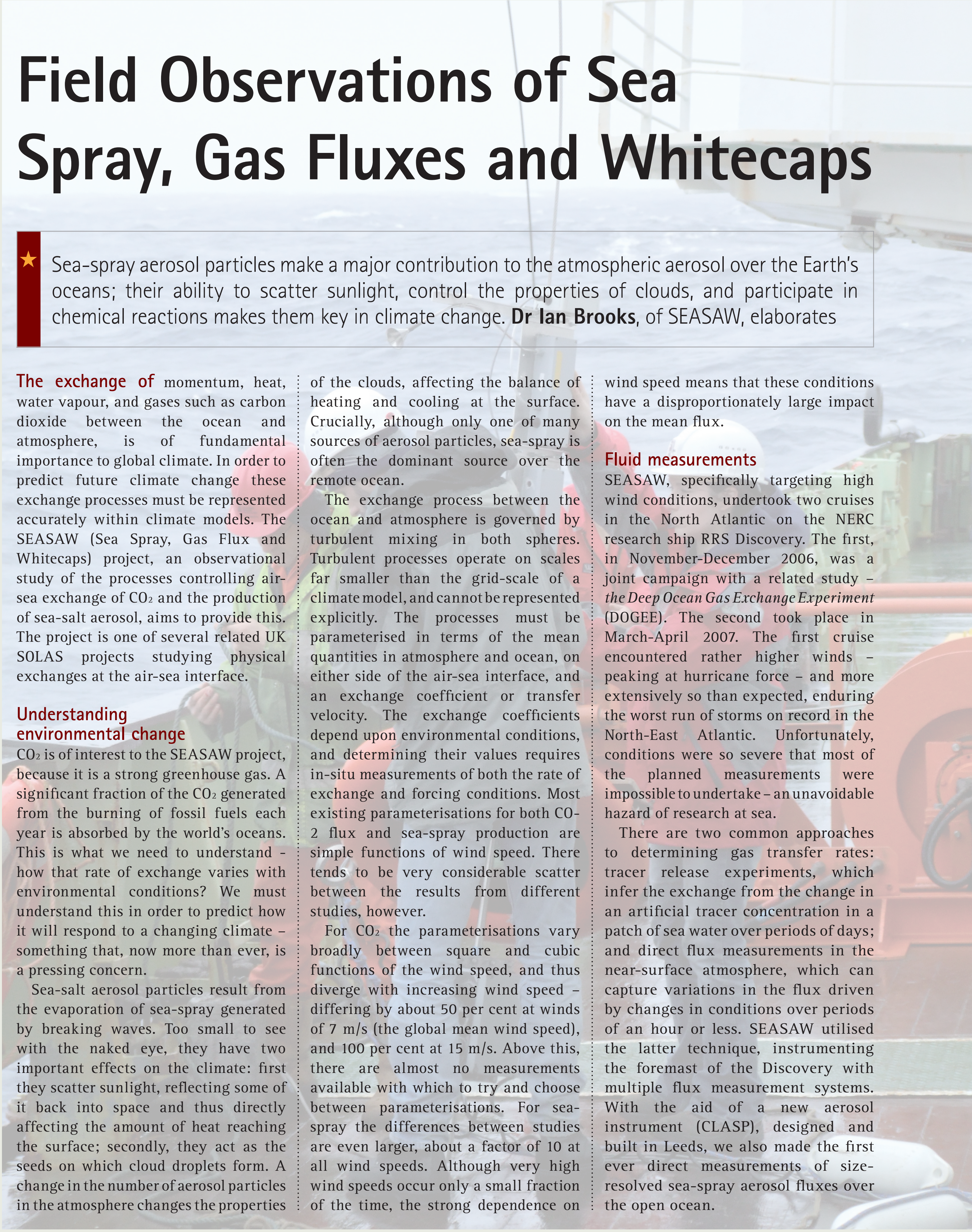

Field Observations of Sea Spray, Gas Fluxes and Whitecaps

★ Sea-spray aerosol particles make a major contribution to the atmospheric aerosol over the Earth's oceans; their ability to scatter sunlight, control the properties of clouds, and participate in chemical reactions makes them key in climate change. **Dr Ian Brooks**, of SEASAW, elaborates

The exchange of momentum, heat, water vapour, and gases such as carbon dioxide between the ocean and atmosphere, is of fundamental importance to global climate. In order to predict future climate change these exchange processes must be represented accurately within climate models. The SEASAW (Sea Spray, Gas Flux and Whitecaps) project, an observational study of the processes controlling air-sea exchange of CO_2 and the production of sea-salt aerosol, aims to provide this. The project is one of several related UK SOLAS projects studying physical exchanges at the air-sea interface.

Understanding environmental change

CO_2 is of interest to the SEASAW project, because it is a strong greenhouse gas. A significant fraction of the CO_2 generated from the burning of fossil fuels each year is absorbed by the world's oceans. This is what we need to understand - how that rate of exchange varies with environmental conditions? We must understand this in order to predict how it will respond to a changing climate – something that, now more than ever, is a pressing concern.

Sea-salt aerosol particles result from the evaporation of sea-spray generated by breaking waves. Too small to see with the naked eye, they have two important effects on the climate: first they scatter sunlight, reflecting some of it back into space and thus directly affecting the amount of heat reaching the surface; secondly, they act as the seeds on which cloud droplets form. A change in the number of aerosol particles in the atmosphere changes the properties of the clouds, affecting the balance of heating and cooling at the surface. Crucially, although only one of many sources of aerosol particles, sea-spray is often the dominant source over the remote ocean.

The exchange process between the ocean and atmosphere is governed by turbulent mixing in both spheres. Turbulent processes operate on scales far smaller than the grid-scale of a climate model, and cannot be represented explicitly. The processes must be parameterised in terms of the mean quantities in atmosphere and ocean, on either side of the air-sea interface, and an exchange coefficient or transfer velocity. The exchange coefficients depend upon environmental conditions, and determining their values requires in-situ measurements of both the rate of exchange and forcing conditions. Most existing parameterisations for both CO2 flux and sea-spray production are simple functions of wind speed. There tends to be very considerable scatter between the results from different studies, however.

For CO_2 the parameterisations vary broadly between square and cubic functions of the wind speed, and thus diverge with increasing wind speed – differing by about 50 per cent at winds of 7 m/s (the global mean wind speed), and 100 per cent at 15 m/s. Above this, there are almost no measurements available with which to try and choose between parameterisations. For sea-spray the differences between studies are even larger, about a factor of 10 at all wind speeds. Although very high wind speeds occur only a small fraction of the time, the strong dependence on wind speed means that these conditions have a disproportionately large impact on the mean flux.

Fluid measurements

SEASAW, specifically targeting high wind conditions, undertook two cruises in the North Atlantic on the NERC research ship RRS Discovery. The first, in November-December 2006, was a joint campaign with a related study – *the Deep Ocean Gas Exchange Experiment* (DOGEE). The second took place in March-April 2007. The first cruise encountered rather higher winds – peaking at hurricane force – and more extensively so than expected, enduring the worst run of storms on record in the North-East Atlantic. Unfortunately, conditions were so severe that most of the planned measurements were impossible to undertake – an unavoidable hazard of research at sea.

There are two common approaches to determining gas transfer rates: tracer release experiments, which infer the exchange from the change in an artificial tracer concentration in a patch of sea water over periods of days; and direct flux measurements in the near-surface atmosphere, which can capture variations in the flux driven by changes in conditions over periods of an hour or less. SEASAW utilised the latter technique, instrumenting the foremast of the Discovery with multiple flux measurement systems. With the aid of a new aerosol instrument (CLASP), designed and built in Leeds, we also made the first ever direct measurements of size-resolved sea-spray aerosol fluxes over the open ocean.

Sea spray rolling off waves by the NERC research ship – RRS Discovery

Wind speed is not the only factor affecting gas fluxes and aerosol production. Sea-salt aerosol particles are generated from the bursting of bubbles in the whitecaps formed by breaking waves. Wave state depends not only on the current local wind, but the wind history over the previous day or two and on swell generated by distant storms. Few previous studies of gas fluxes or aerosol production have made measurements of the wave state. While the SEASAW analysis is not yet complete, it does suggest that the wave state has a marked influence on the production of aerosol, independent of the wind speed. Whitecaps are also believed to enhance gas transfer due to the increased surface area available for gas to diffuse across when bubbles are entrained below the surface by breaking waves. In order to try and estimate the impact of wave breaking on the gas flux we need to estimate the fraction of the sea surface covered by whitecaps. Digital cameras were used to record images of the sea surface every 30 seconds; image processing techniques were then used to estimate the whitecap fraction. To examine the whitecaps and breaking waves in more detail, a small tethered buoy was deployed over the side of the ship. This buoy supported a bubble-imaging camera below the ocean surface that provided estimates of bubble sizes and concentrations, in addition to a CLASP aerosol probe about one metre above the surface to measure the aerosol plumes generated by waves breaking around the buoy.

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The results

The SEASAW project has generated a large data-set that will take several years to analyse in full. The multiple interacting factors that influence air-sea exchange and the inherently variable nature of the processes means that reducing the uncertainty in flux parameterisations is ultimately a problem of statistics, and even larger data-sets are going to be required to fully account for all the relevant processes. We are already planning our return to sea. ★

At a glance

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