UK-SOLAS Cruise Report: RRS *Discovery* Cruise D313, 07 November - 06 December, 2006: DOGEE-SOLAS and SEASAW; high wind gas and aerosol fluxes in the North East Atlantic Ocean

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Disclaimer

All data in this Cruise Report are provisional; some are fully calibrated whereas others are not. No data from this report should be published or otherwise presented without the express permission of the originators (see **Individual Scientific Reports**). The full data set will eventually be lodged with the British Oceanographic Data Centre (BODC).

Acknowledgements

We would like to thank the Master, Roger Chamberlain and all of the officers, engineers and crew of RRS *Discovery* for their support and help during an especially difficult, frustrating and stressful cruise. Despite all the problems we encountered, we all felt that we were in safe hands and that we would be well looked after. Roger in particular maintained an air of optimism and enthusiasm, and he worked hard to maintain morale throughout; we never did get to play his "Murder" game though, although we all look forward to this at some future date. The Remembrance and Thanksgiving dinners were of particular note and our thanks must go to *Discovery's* catering staff for providing these and indeed an excellent standard of service throughout; the meals seemed to be the one constant in our lives, aside from the foul and unremitting weather of course!

On the technical side Chris Barnard provided expert computing back-up and was always on-hand to provide much-needed advice in several areas. Dave Teare as always, expertly discharged his CTD duties and worked tirelessly to commission the back-up CTD following irretrievable loss of the original. Dave Comben provided great back up for on-deck activities and along with Chris Barnard, successfully commissioned the emergency winch despite its several electrical problems.

Special thanks must go to Malcolm Woodward at PML for two principal reasons. Firstly, assisted by Julia Crocker at PML, Malcolm efficiently handled all pre-cruise logistics such that everything went without a hitch prior to sailing. Due to these efforts the Principal Scientist and co-Principal Investigators were able to concentrate all their efforts on planning the science. Secondly, when many of us had just about given up on the explosive bolts and were bored by news of their seemingly endless flights back and forth across the Atlantic, Malcolm continued in his single-minded quest to get them to Scotland. They finally made it, for which we are eternally grateful; without them one of the URI neutrally buoyant floats would have been irretrievably lost, along with the CTD and the late lamented PML buoys.

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Cruise Objectives

RRS *Discovery* cruise D313 involved two distinct but inter-related UKSOLAS projects: *DOGEE-SOLAS* (The UKSOLAS Deep Ocean Gas Exchange Experiment), P.I. Rob Upstill-Goddard, University of Newcastle upon Tyne, and *SEASAW* (Sea Spray and Whitecaps), P.I. Ian Brooks, University of Leeds. Both projects are primarily concerned with physical exchange processes at the air-sea interface and the determination of gas transfer velocities. Additionally SEASAW aims to quantify sea-salt aerosol source functions. The two projects thus have a common overall research goal; parameterization of the air-sea gas and aerosol exchange processes, which is essential for effectively modelling climate. Current gas exchange parameterizations have uncertainties of at least a factor of 2 at intermediate wind speeds, and much larger uncertainties at high wind speeds. For aerosols these uncertainties approach an order of magnitude. Significantly reducing them is a central goal of both the international and UK SOLAS programmes.

The rate of air-sea gas exchange is a dominant or important term in many global biogeochemical cycles yet it remains one of the major uncertainties. Important issues requiring accurate estimates of gas exchange rates include anthropogenic CO_2 uptake by the oceans (Siengenthaler and Sarmiento, 1993) and climate forcing involving other marine biogenic gases such as DMS (Charlson et al., 1987) and iodocarbons (O'Dowd et al., 2002). From the perspective of global change understanding the physical and biogeochemical controls of air-sea gas exchange is urgent, being essential to support the development of predictive biogeochemical models needed to quantify regional and global scale trace gas fluxes and feedbacks.

Although the past several years have seen substantial advances in our understanding of air-sea gas exchange these are still insufficient to adequately parameterise the fundamental controlling processes. For some gases, such as CO_2, this is now the dominating uncertainty in global budgets. Modelling the impact on global biogeochemistry of all trace gases requires a sound parameterization of their fluxes. If one were to name a single advance that would most enhance our understanding of ocean-atmosphere interactions, improving the parameterisation of air-sea exchange would be it.

Sea-salt aerosols are a significant fraction of the total atmospheric aerosol loading over the remote oceans; they play a major role in controlling the radiation budget both via direct scattering and absorption of radiation, and via their role as cloud condensation nuclei and their consequent influence on cloud microphysical properties. Effective parameterization of sea-salt aerosol generation as a function of environmental conditions is essential for correctly simulating the radiation budget over the oceans within general circulation models, both for operational forecasting and climate studies (Haywood et al. 1999).

The fluxes of both aerosols and gases across the air-sea interface depend strongly on the turbulent wind stress at the surface. Although many existing gas exchange parameterizations that relate the gas transfer velocity (k_w) solely to mean wind speed are widely used for data interpretation and in modelling, observational and theoretical evidence show such descriptions to be incomplete; air-sea exchange depends in a complex fashion on many additional factors, including wave state, the presence of surfactants, and the relative direction of wind and swell. Whitecaps and bubble bursting also directly influence aerosol generation and gas transfer. Very different values of k_w may therefore be expected at different locations at identical wind speeds. Significantly improving the existing parameterizations requires that the second order effects be included. Both *DOGEE* and *SEASAW* aim to address some of these issues by including measurements of wave state, whitecap coverage, and bubble populations. The aim is to significantly reduce the uncertainties, particularly at high wind speeds where measurement is most difficult, and where the available data are most limited.

The specific scientific objectives of D313 were as follows:

DOGEE:

- To make several estimates of the open ocean gas transfer velocity (k_w) of CO_2 at high wind speeds by means of a dual-tracer release (^3He & SF_6) with subsequent sampling underway and via the CTD rosette system.
- To measure total gas tension, dissolved O_2, and CO_2 in underway mode using the ship's non toxic seawater supply, and throughout the mixed layer using drifting mixed layer Lagrangian Floats, and to thus obtain independent estimates of air-sea gas exchange.
- To routinely record 5 to 10 second means of key meteorological variables (wind speed and direction, air temperature and humidity, sea surface temperature, IR surface temperature, downwelling long- and short-wave radiation and air pressure).
- To measure directly air-sea fluxes of CO_2, sensible heat, latent heat and momentum (by direct covariance (EC) and inertial dissipation) using AUTOFLUX, an automated sensor array developed at NOC. AUTOFLUX also routinely measures air-sea fluxes of CO_2, sensible heat, latent heat and momentum. All four turbulent fluxes are measured by EC (direct covariance). The latter two are also obtained using the inertial dissipation (ID) method. The fluxes are derived using a sonic anemometer (momentum and heat) and a Licor-7500 (H_2O and CO_2), using sampling intervals of up to 55 minutes.
- To quantify flow distortion biases in the direct flux measurements through comparison of eddy correlation latent heat fluxes to the inertial dissipation latent heat fluxes after the latter have been corrected using Computational Fluid Dynamics, and to correct other direct fluxes by analogy.

SEASAW:

- To establish the impact of various forcing parameters on the k_w values of CO_2 and O_3 and thus improve their parameterisation, and relate these k_w values to those of other trace gases via the Schmidt number.
- To determine the sea spray source function via direct eddy-covariance methods using ultrasonic anemometers alongside fast-response optical particle counters and condensation particle counters.
- To investigate the production and fate of sea spray aerosol particles very close to the ocean surface by means of 10Hz optical particle counter observations with sub-surface bubble observations.
- To utilise a single particle aerosol mass spectrometer and associated instruments to study the composition of individual aerosol particles as a means of source apportionment and to investigate interactions between the sea spray aerosol and other aerosol and gaseous components.

Additional specific objectives common to both projects are:

- To record (by video) and measure (by capacitance wave wires) whitecap coverage and wave breaking coincident with the air-sea flux measurements

- To quantify acoustically, bubble populations produced by breaking waves.

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Cruise Narrative

Discovery departed Govan in the late afternoon of 7th November 2006. The cruise track is shown in Figure 1.

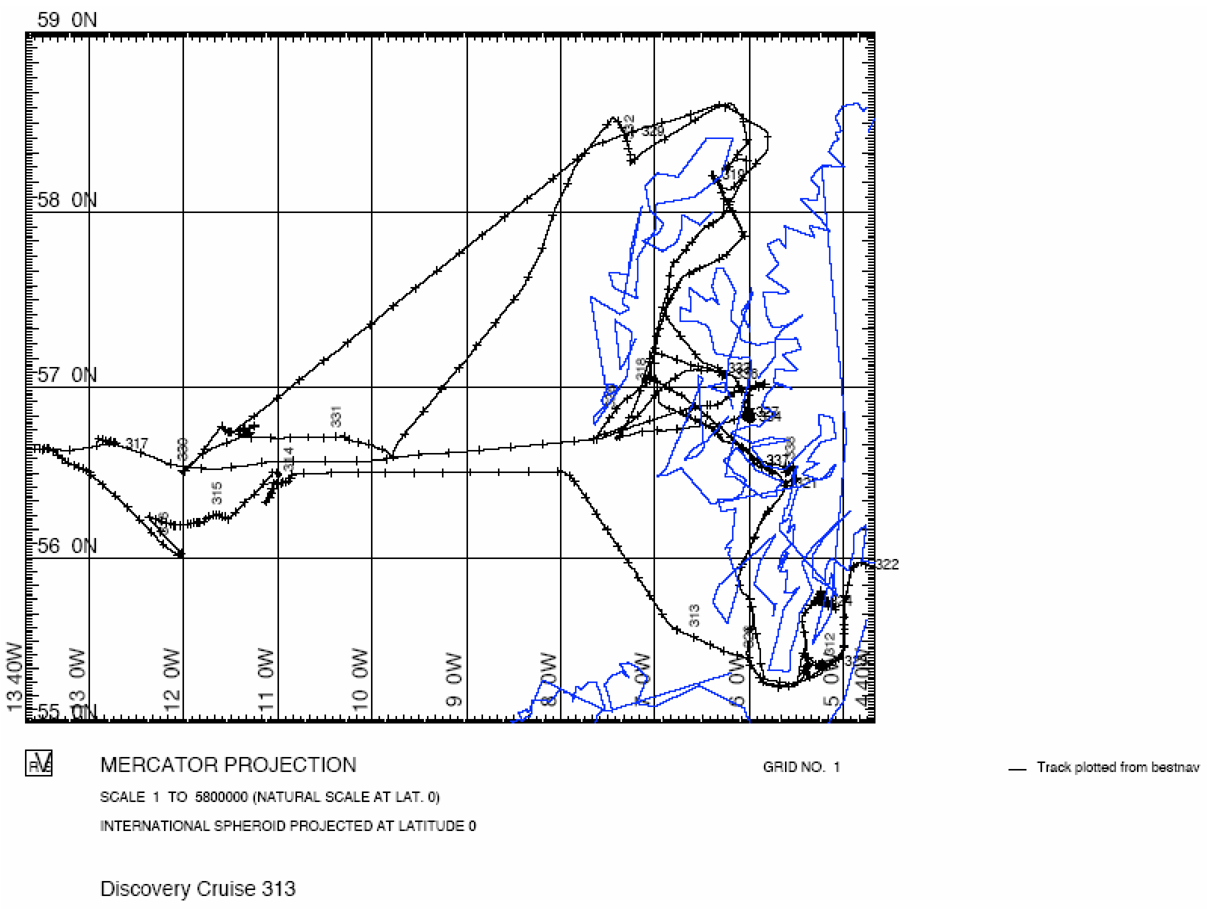


Figure 1. D313 cruise track.

Prior to sailing Malcolm Woodward had been trying to track the delivery of explosive bolts for the University of Rhode Island (URI) neutrally buoyant floats used for *in situ* N_2, O_2 and total gas tension measurements. The bolts are a safety feature that releases a weight if the floats go too deep and are in danger of being lost. Due to various paperwork and other problems the bolts unfortunately did not arrive and so the cruise commenced without them.

A shakedown station at 55.35°N, 05.39°W (a sheltered location recommended by the Master, Roger Chamberlain) allowed initial successful testing of the NOC spar buoy; the University of Leeds tethered meteorological buoy; the CTD and the PML depressor weight to be used in tracer deployment.

The next activity was to initiate a CTD and ADCP survey of a potential tracer release site (CTD stations at 56.5°N 11°W, 56°N 12°W, 56.5°N 13°W, 57°N 12°W, 56.5°N 12°W). There were initial problems with the ADCP as the 150 kHz unit failed and proved impossible to repair. The first two CTD's of the tracer survey were delayed due to bad weather and on the third (approx. 56.5°N 13°W on Sunday 12th November) the CTD system was unfortunately lost at 16 m depth during deployment due to a break in the wire some 54 metres inboard (i.e.

70 metres of wire out). Initial investigations into the specific cause of the CTD loss were inconclusive (see appendices 2 and 3).

Later that evening (Sunday 12th November) the duty engineer, during his routine inspections of the machinery spaces, noticed a wet patch on the aft collision bulkhead. The cause was a 6 mm crack, which had progressed to 50mm by breakfast time on Monday 13th with another crack running away from it. This, combined with worsening weather, forced us to make for port at Stornoway, arriving approximately 10am on Tuesday 14th, for the fault to be repaired. UKORS arranged despatch of a replacement CTD winch and additional CTD spares (bottles) for delivery to Greenock. Rakia Meister left the cruise in Stornoway for personal reasons on 15th November.

Discovery sailed from Stornoway at 0930 UTC on 16th November, arriving Greenock at 21.30 UTC Friday 17th November. Stephen Harrison left the ship in Greenock for personal reasons and electrical problems with the replacement winch delayed sailing until 19.00 UTC on Saturday 18th November.

Discovery subsequently headed for the shelter of Inchmarnock Water, located north of Arran and between Kintyre and the Isle of Bute (55.78 ^{o}N, 05.25 ^{o}W). Day-long deployments of the NOC wave and bubble spar buoy and the Leeds tethered buoy were carried out in the vicinity on Sunday 19th November. Unfortunately due to excessive forward motion during a period when *Discovery* was supposed to be hove to into wind; approximately £3000 worth of instrumentation on the tethered buoy was destroyed due to dragging of the entire buoy under water. (see **SEASAW: Some observations of cruise logistics and management,** p 70).

Weight testing of the replacement CTD winch followed on Monday 20th November off the Kintyre peninsula. A CTD deployment to 83 m followed; this was the first successful CTD station since Sunday 12th November. Water samples from the CTD were used to determine SF_6 and ^3He background concentrations, and for CO_2 and for O_2 analyses.

The subsequent return to the planned tracer release area was again delayed due to exceptionally bad weather; *Discovery* sheltered a few miles off Mallaig at approximately 57^{o}N 06^{o}W. Meanwhile we received news that the explosive bolts for the URI neutrally buoyant floats had arrived in Glasgow. Roger Chamberlain arranged for their road transfer to Mallaig and they were collected by RIB transfer on Thursday 23rd November. Following this we were obliged to make an unscheduled run back to Stornoway on Friday 24th to land a member of the ship's crew before heading around the Butt of Lewis and once more westward.

On Saturday 25th November weather conditions were at last suitable to lay the tracer patch. Two pre-release CTD's helped identify a suitable location for tracer deployment at 56.74 ^{o}N 11.30 ^{o}W. The release took place from around 05.00 UTC to around 11.00 UTC on 26th November, following delays due to problems establishing communication with the PML marker buoys. Subsequent inexplicable failure of the PML marker buoy position plotting software greatly complicated the release; it was not possible to view the relative positions of the buoys relative to *Discovery* during deployment although absolute buoy positions were being recorded.

After completing the tracer release we released one of URI neutrally buoyant floats adjacent to the tracer patch at around 12.00 UTC on Sunday 26th. This later malfunctioned due to an incorrectly rated pressure sensor supplied by the manufacturer (the float fired its explosive bolt and surfaced some time later). It continued to transmit its position hourly however.

Subsequent underway surveying for SF_6 located the tracer patch and water samples were collected for SF_6 and ^3He, CO_2 and O_2 analyses from two CTD casts. Rapidly deteriorating weather then forced return toward Stornoway and for subsequent shelter around Rhum for the next several days. Sea state on Thursday 30th November was described in the 5am shipping forecast as "phenomenal", i.e. wave heights in excess of 14 metres.

On Friday 1st December *Discovery* once more headed for the tracer release site but was again forced to return to shelter that afternoon. At just after 02.00 UTC on Saturday 2nd December *Discovery* experienced a total loss of power whilst sheltering off Rhum at 57.08 ^{o}N, 06.28 ^{o}W. Anchors were deployed and the local Coastguard and lifeboat alerted. The ship's engineers began to restore power systems some minutes later; most laboratory equipment was up and running again by around 02:30 UTC. During subsequent discussions between the Master, Chief Engineer and Principal Scientist, the Master informed that abandonment of the cruise was extremely likely. The decision was taken to remain in sheltered waters (Sound of Mull) until such time as the weather permitted safe return passage to the Govan. Passage to Govan commenced at around 13:40 UTC on Monday 4th December, *Discovery* arriving Govan around 08:00 UTC on Tuesday December 5th. Following subsequent mechanical inspections, cruise D313 was formally abandoned on Wednesday 6th December 2006.

No serious health and safety issues arose during the cruise; safe laboratory and on-deck practice was observed at all times.

Footnote: The two PML drifter buoys and the URI neutrally buoyant float released into the tracer patch could not be recovered during the cruise. Although the PML buoys ceased transmission and hence could not be recovered post-cruise, the URI float continued to transmit its position, although occasionally intermittently. It was recovered some weeks later by a local fishing vessel and returned to the owners.

D313: General hydrographic and meteorological observations

Real-time thermosalinograph data were used to select the tracer release site situated around 56.75 °N, 11.3 °W; the selected release location was in homogeneous waters to the northeast of what appeared to be a warm eddy (Figure 2).

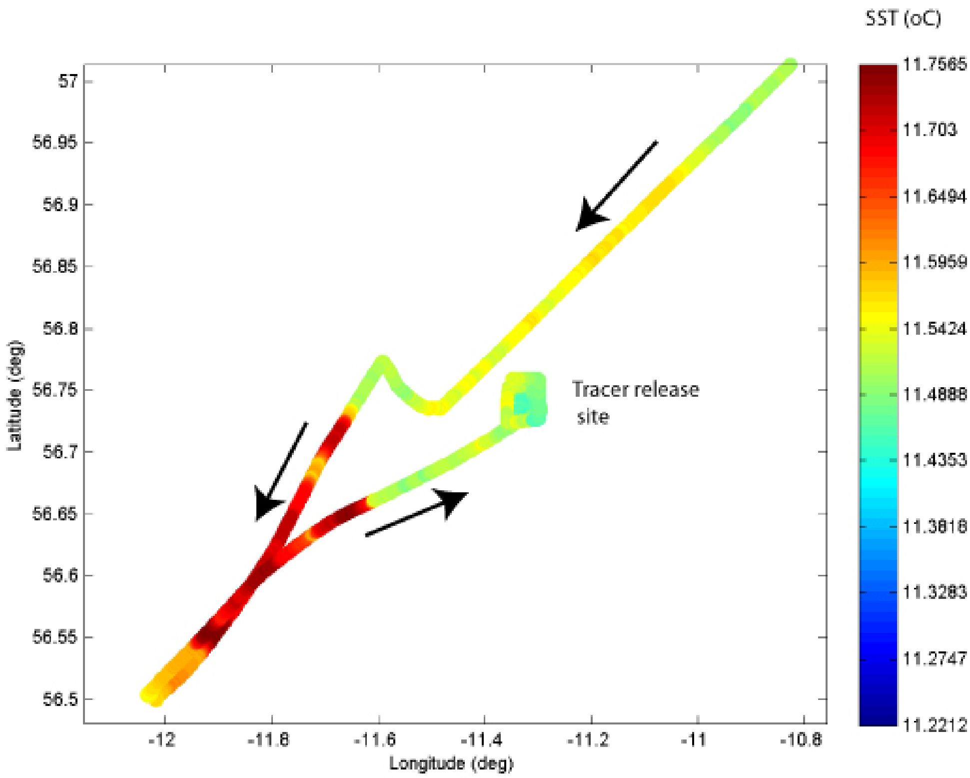


Figure 2. Thermosalinograph sea surface temperatures (SST's) in the vicinity of the tracer release area (data plot courtesy of Craig McNeil, URI).

Figure 3 shows vertical temperature and salinity data to 307m at 56.76°N, 11.36°W (station D313/13#01); this station was at the centre of the tracer release area. The data clearly indicate a mixed layer depth ~ 170m, which was typical for the region. Figure 4 is a plot of 10m wind speeds recorded by the underway SURFMET package. Mean wind speed was ~ 13 m s^{-1}; however wind speeds were in excess of 20 m s^{-1} for extended periods of the cruise. Figure 5 shows typical forecasts of sea level pressure and wind speed for early December 2006. Such conditions persisted throughout most of the cruise, precluding access to the chosen tracer release site for extended periods (see **Cruise Narrative**, p 14).

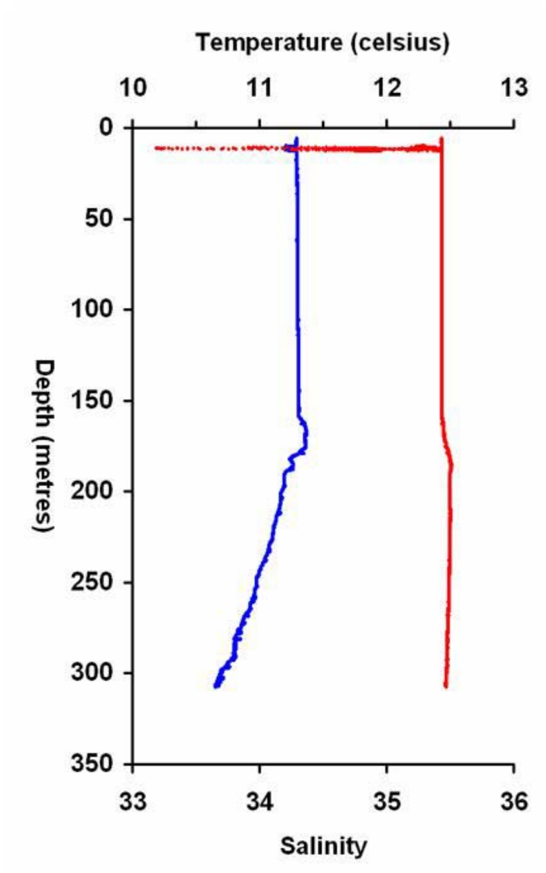


Figure 3. Temperature and salinity at 56.76°N, 11.36°W (station D313/13#01), adjacent to the centre of the tracer release site.

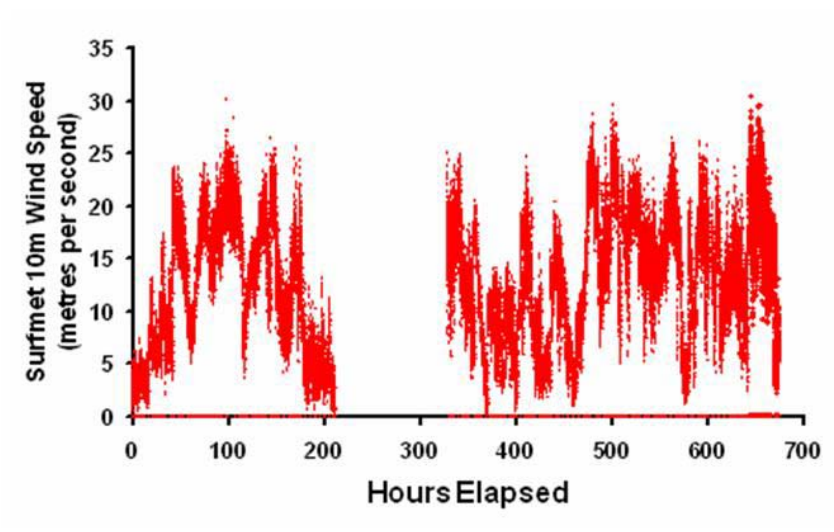
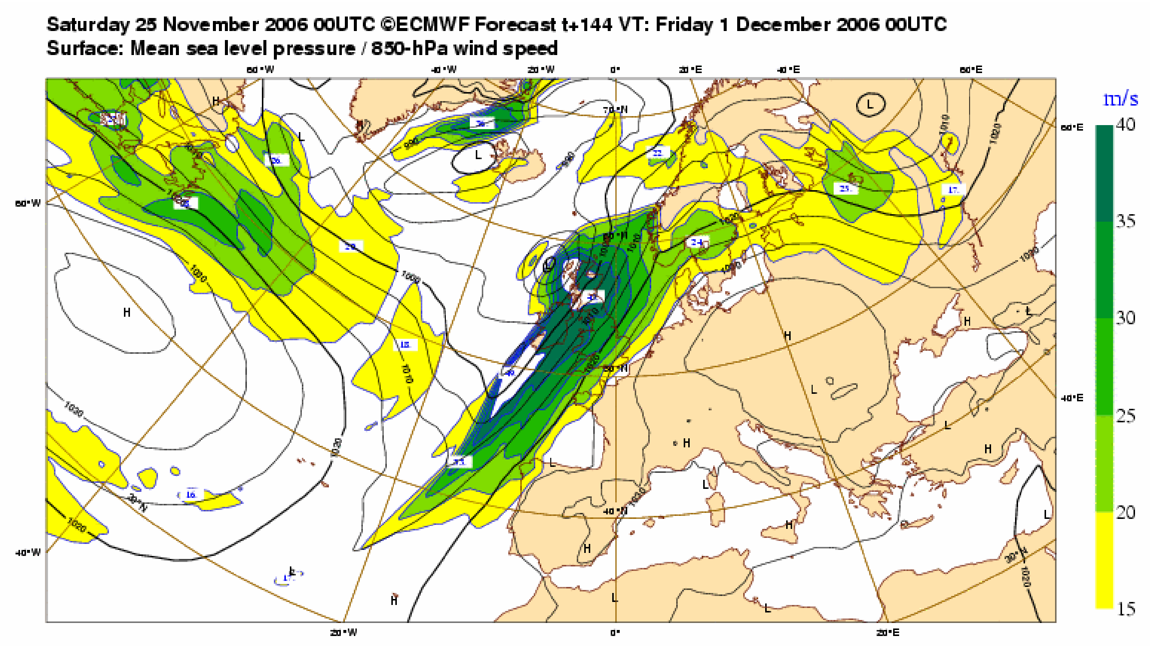


Figure 4. 10m **w**ind speeds during the cruise period.



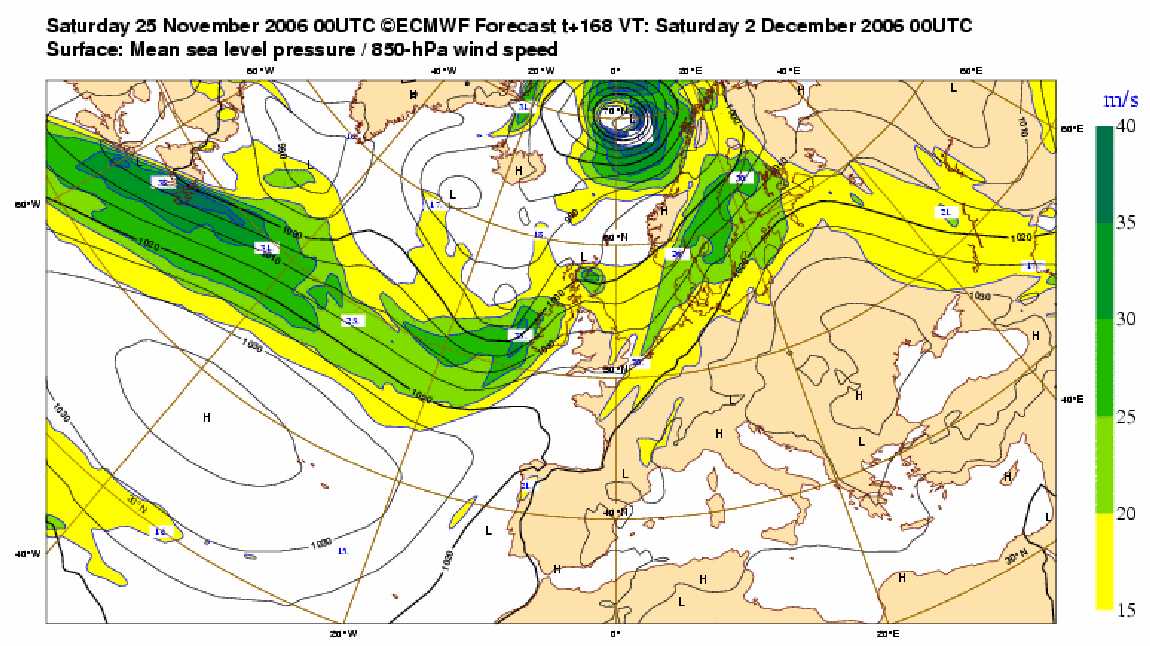


Figure 5. Typical long-range (one week) forecasts of mean sea level pressure and wind speed for the vicinity of the tracer release area.

Scientific Reports

Dual tracer experiment: SF_6 and ^3He sea water saturation and release during DOGEE

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Objective: Dual volatile tracer release for estimating gas transfer velocities.

Tracer Preparation: Approximately 6.5 m^3 of seawater contained within a steel tank were saturated with sulphur hexafluoride (SF_6). The SF_6 was pumped at ~ 120 ml. min^{-1} into a glass tank headspace and vented to the atmosphere over the stern of *Discovery* in order to minimise contamination. Headspace contents were re-circulated through the tank seawater via 2 steel metal air-stones and using a leak-tight 110V diaphragm pump; flow rate was ~1 litre min^{-1}. Saturation was initiated at 15:30 UTC on 10/11/06 and ceased at 20:15 UTC on 10/11/06. The tank was then sealed but subsequent accidental leakage of seawater and gas meant that an additional SF_6 'top-up' was required between 11:00 and 17:00 UTC on 25/11/06. For future such work it is important to ensure that the tank water inlet and/or outlet valves cannot be accidentally opened; the unintended release led to an approximately thousand-fold SF_6 contamination of the ship's laboratories which took several days to decline to background levels. During the saturation procedure tank seawater samples collected in syringes at intervals were analysed by thermal conductivity detection - gas chromatography (TCD-GC) in order to ascertain when full saturation had been achieved. Due to excessive movement of the ship in the exceptionally bad weather the TCD-GC integrator baseline was not steady, hence the integrated peak areas were not considered reliable. Peak heights were therefore used to determine SF_6 concentrations relative to a 0.02% SF_6 standard. The peak heights and concentrations are shown in Figure 6. The point by which full saturation had been reached was independently established by monitoring the decline in oxygen levels during saturation. The drop in SF_6 seen in Figure 6 at the end of the final saturation is due to the addition of ^3He and its partial replacement of SF_6 in the tank seawater.

Helium-3 (^3He) was added to the tank immediately prior to the tracer release (see Figure 7). To do this the tank headspace water level was first adjusted until it was about halfway up by carefully venting some of the headspace SF_6. A total of 25 litres of ^3He were then added directly to the headspace, in aliquots of ~ 5 litres, over a period of 1-2 min. The headspace water level initially fell during this operation as a result of the increased internal headspace pressure, and then gradually rose again as ^3He dissolving into the tank water increased more rapidly than the displaced SF_6 transferred out. Once the water level had stabilised after 10 - 15 minutes a water sample was collected in order to establish the amounts of ^3He added and SF_6 removed (TCD-GC), and to check for air leaks based on the analysis of residual oxygen. The process was repeated until the desired levels of both SF_6 and ^3He were observed.

The non-toxic seawater supply was used to flush the release hose prior to tracer release. The taps were then opened slowly and closed to clear the air out of the flow meter. In order to ensure the required release depth a 60 kg depressor was attached to the hose outlet. To support the depressor weight the release hose was attached to the winch cable with duct tape (Figure 8). The non-toxic was kept running at a low rate while the hose was attached to prevent air locks. Approximately 15 m of hose was used. When ready for tracer release the tank taps were opened and the gate valve closed as quickly as possible. At this point, the non-toxic flushing line was closed off and the outflow was adjusted to the required rate (Table 1**)** using the tank outlet tap. Non-toxic flow into the header tank was adjusted as required to balance flows and prevents air-leakage into the system.

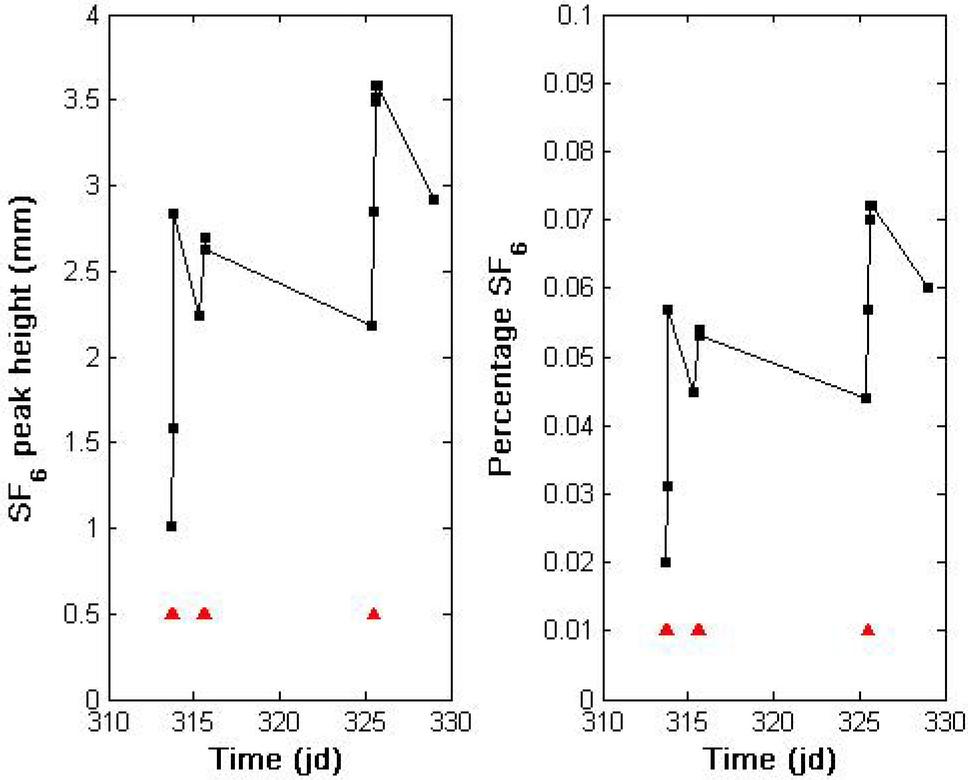

Figure 6. Change in SF_6 peak height and calculated SF_6 concentrations during the saturation period. Red triangles indicate the start of the saturations.

Table 1. Flow rates used (set by non-toxic supply to header tank) for each hour of release with actual times of release (UTC) shown.

Hour	Actual time (UTC)	Flow rate (dm^3 h^{-1})
1	04:50	750
2	05:55	900
3	06:55	1100
4	08:05	1300
5	09:05	1400
6	10:05	1400
7	11:00	n/a

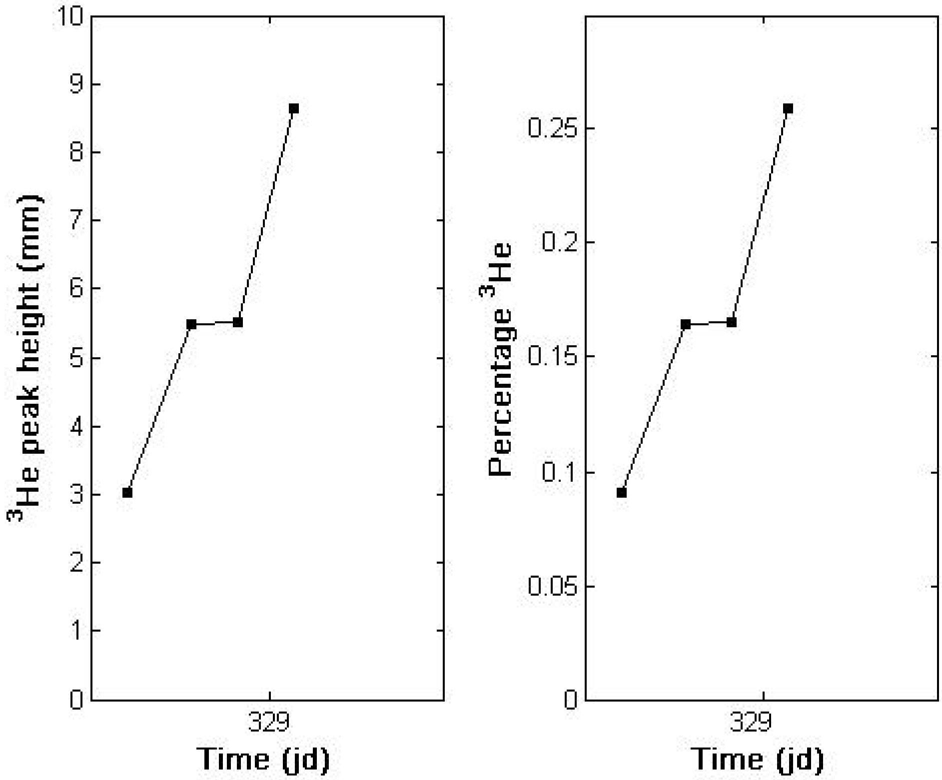

Figure 7. ^{3}He peak height and percentage concentration during ^{3}He saturation.

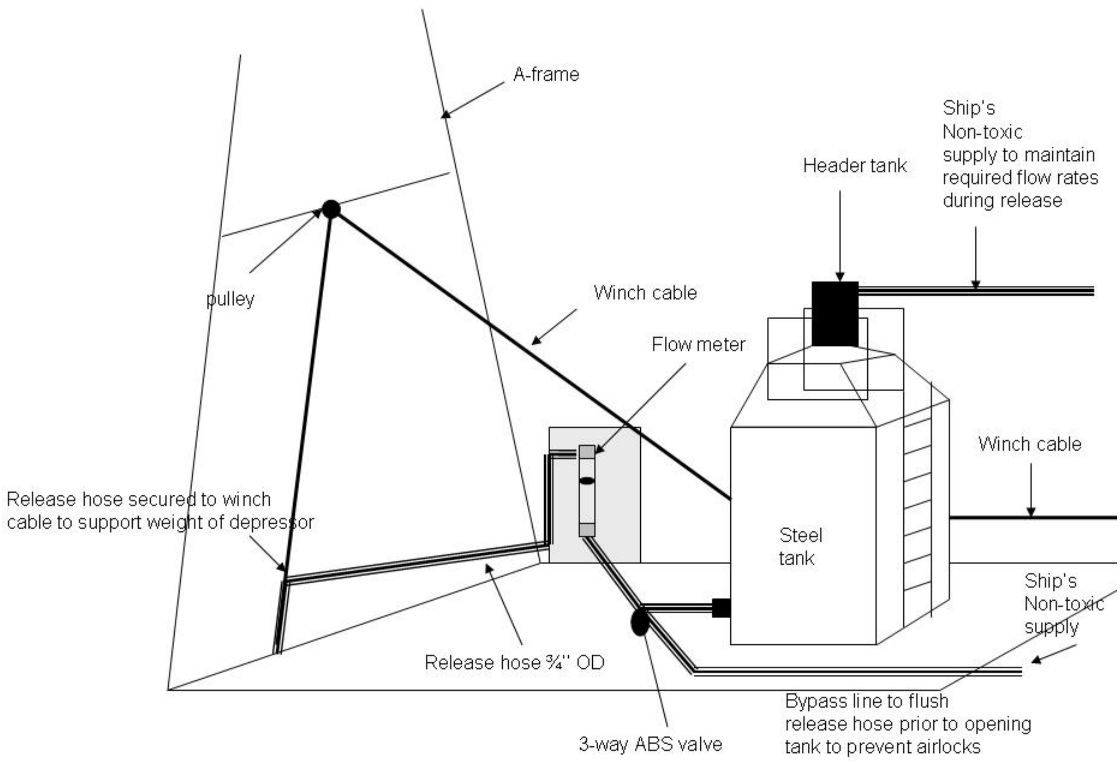

Figure 8. Schematic detail of tank, hosing and water supply during release of ^{3}He and SF_6

Tracer Release: Prior to releasing the SF_6 and ^3He tracer patch, 2 drifter buoys (WOCE, Pacific Gyre Int.) were released for subsequent patch relocation. Both buoys were equipped with ARGOS and radio transmitters to permit tracking over long and short (4-5 km) ranges, respectively. Each buoy also had a holey sock drogue suspended from its base at 20 metres to minimise wind slippage. One of the buoys had a thermistor chain attached to it with 14 T-minilog (VEMCO) temperature loggers spaced at intervals from 10 to 246 m water depth, concentrating around the observed pycnocline at 180 m. An additional logger (TD-minilog) capable of measuring pressure, as well as temperature, was included on the chain at 50 m to enable the vertical movement of the chain to be monitored during its deployment period. The buoys (ID65988 and ID67547) were released approximately 25 minutes prior to the start of the tracer release at 04:12 UTC and 04:15 UTC on 26.11.2006 (Julian Day 330.175 and 330.177 respectively).

The ~6.5 m^3 of tracer saturated seawater was released through ¾" reinforced plastic tubing with the depressor attached to its outlet end. In addition to the depressor, a TD-minilog was attached just above the outlet to monitor the release depth and temperature. The release commenced at 04:50 UTC on 26/11/06 (JD 330.201) and ceased at 11:00 UTC on 26/11/06 (JD 330.458). Over this period, the average depth of release was 6.2±1.0 m (Figure 9). In order to preclude a headspace forming within the tank during release and affecting the tracer ratio in the tank water due to phase partitioning, a non-toxic seawater supply was attached to the tank to continuously 'top-up' the tank volume. The non-toxic flow rate was increased step-wise during the deployment in order to ensure that all of the tracers were released and that they did not simply become more dilute with time. Flow rates used are listed in Table 1.

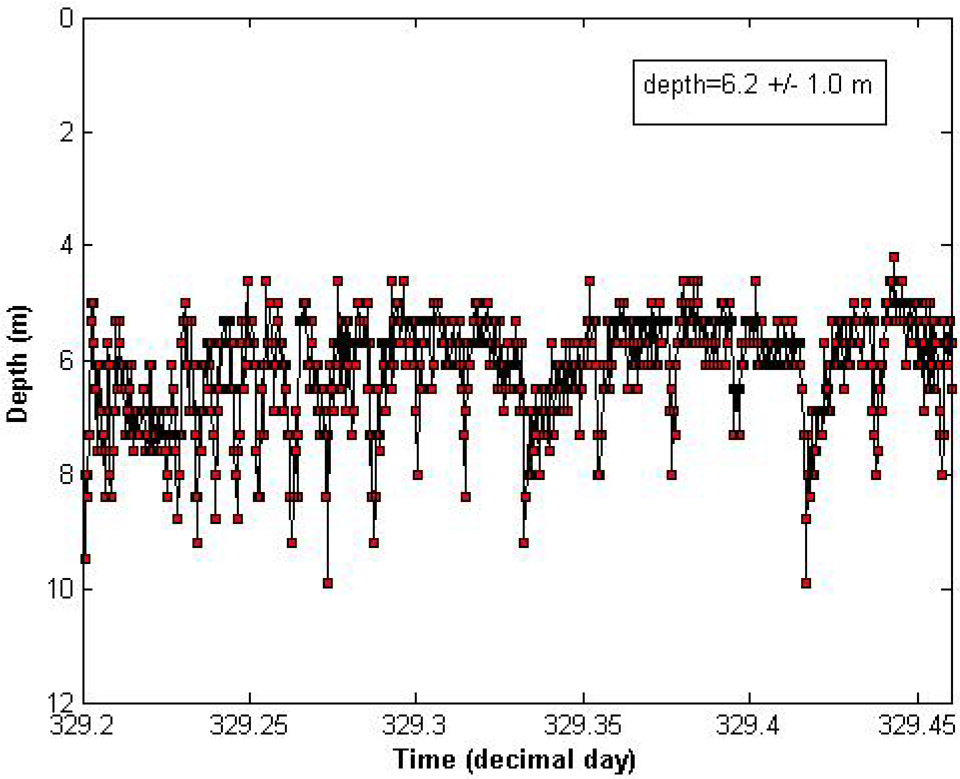

Figure 9. Depth of tracer release recorded by TD-minilog at 30 second intervals during the 5 hour release period.

The release itself was conducted according to dead-reckoning. The buoy positions (updated approximately every 5 minutes) were used as a central point of reference and *Discovery* was navigated around them in an increasingly outward spiral (Figure 10). This allowed the overall movement of water during the release period to be taken into account and prevented *Discovery* from retracing her path and possibly causing contamination of the non-toxic sea water supply by the tracers. It also allowed the initial patch dimensions to be more easily estimated post-release.

The buoy positions were used to determine water movement during the release period. The buoys moved approximately 3.2 km in a north-westerly direction (Figure 11), indicating an approximate mixed layer current speed of 0.5 km hr^{-1}. The final patch corrected for water movement was approximately 3.5 km x 5 km or 17.5 km^2. Figure 12 compares the ship track during release based on ship GPS positions (black line) with that corrected for water movement, based on buoy position updates.

Following release the positions of the buoys were tracked by ARGOS satellite with daily updates. Figure 13 shows the buoy positions up until 03/12/06.

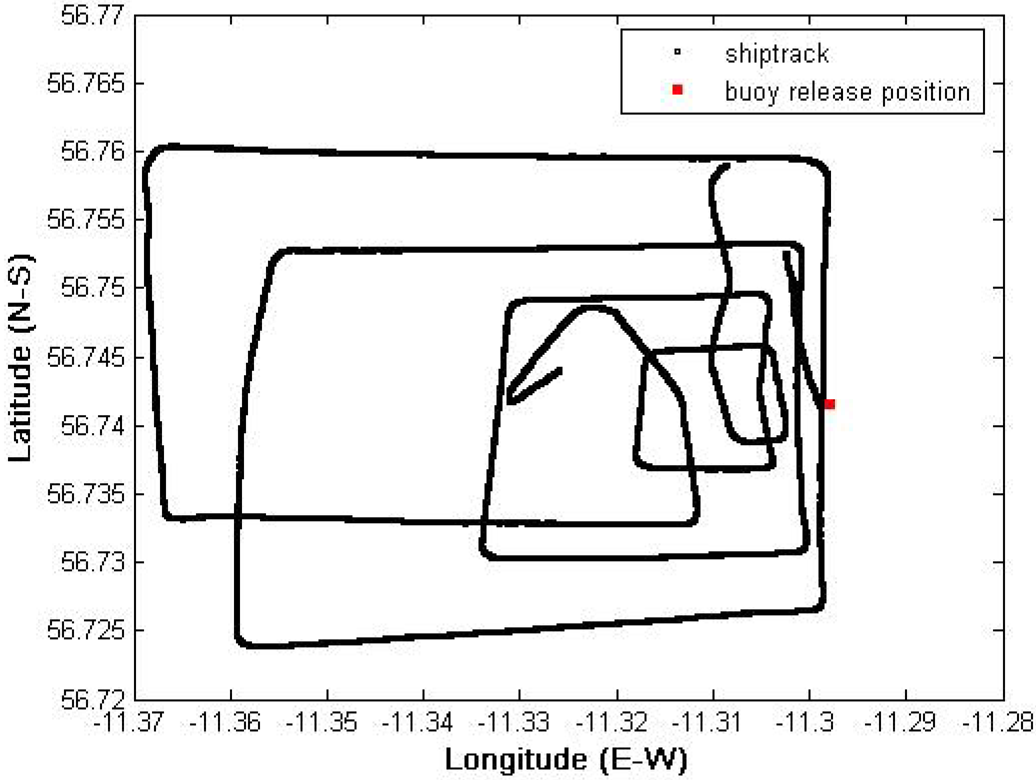

Figure 10. Ship release GPS release track with position of buoy release indicated in red.

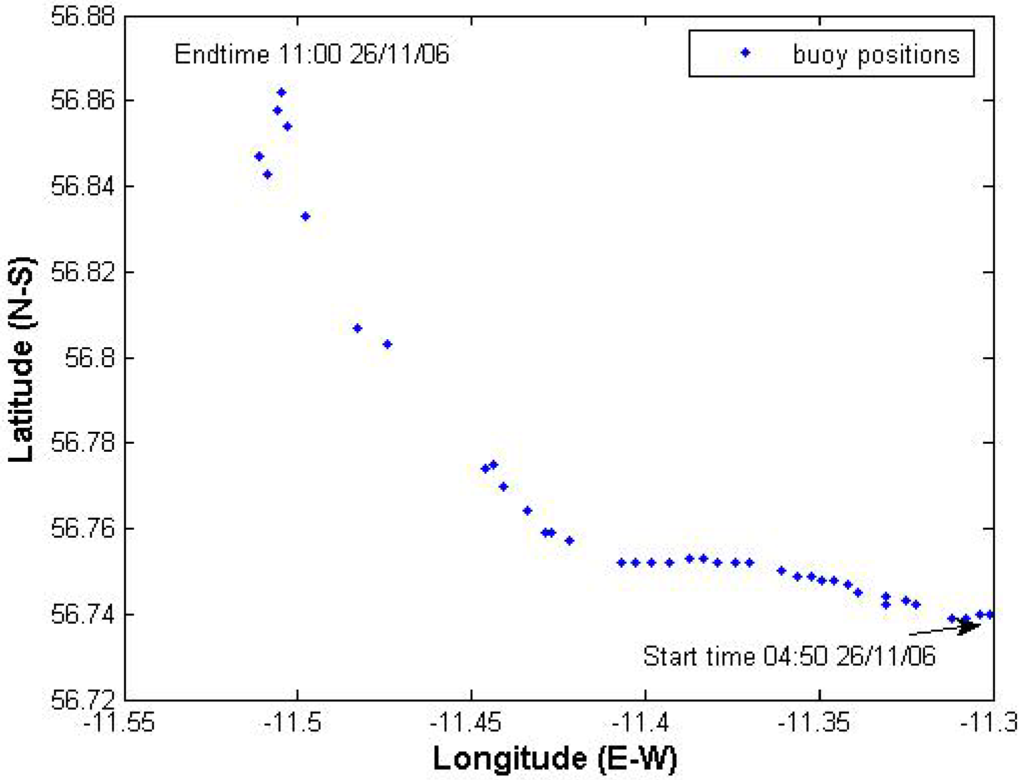

Figure 11. GPS positions from buoys during the tracer release.

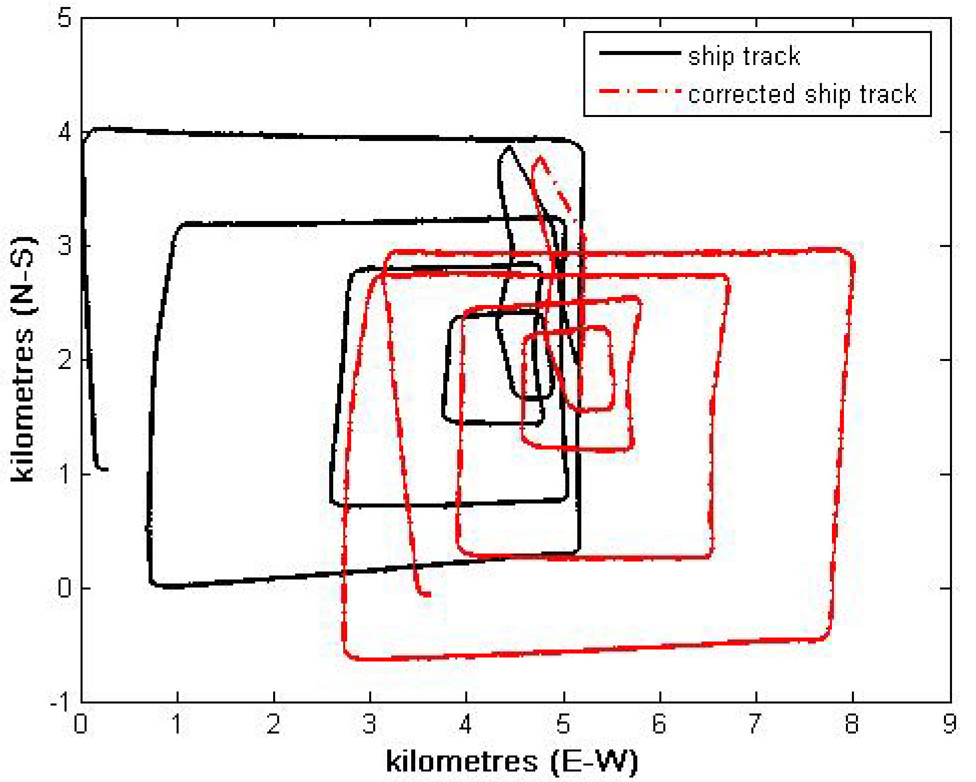

Figure 12. Ship track during release based on ship GPS positions (black line). Track corrected for water movement, based on buoy data, shown in red.

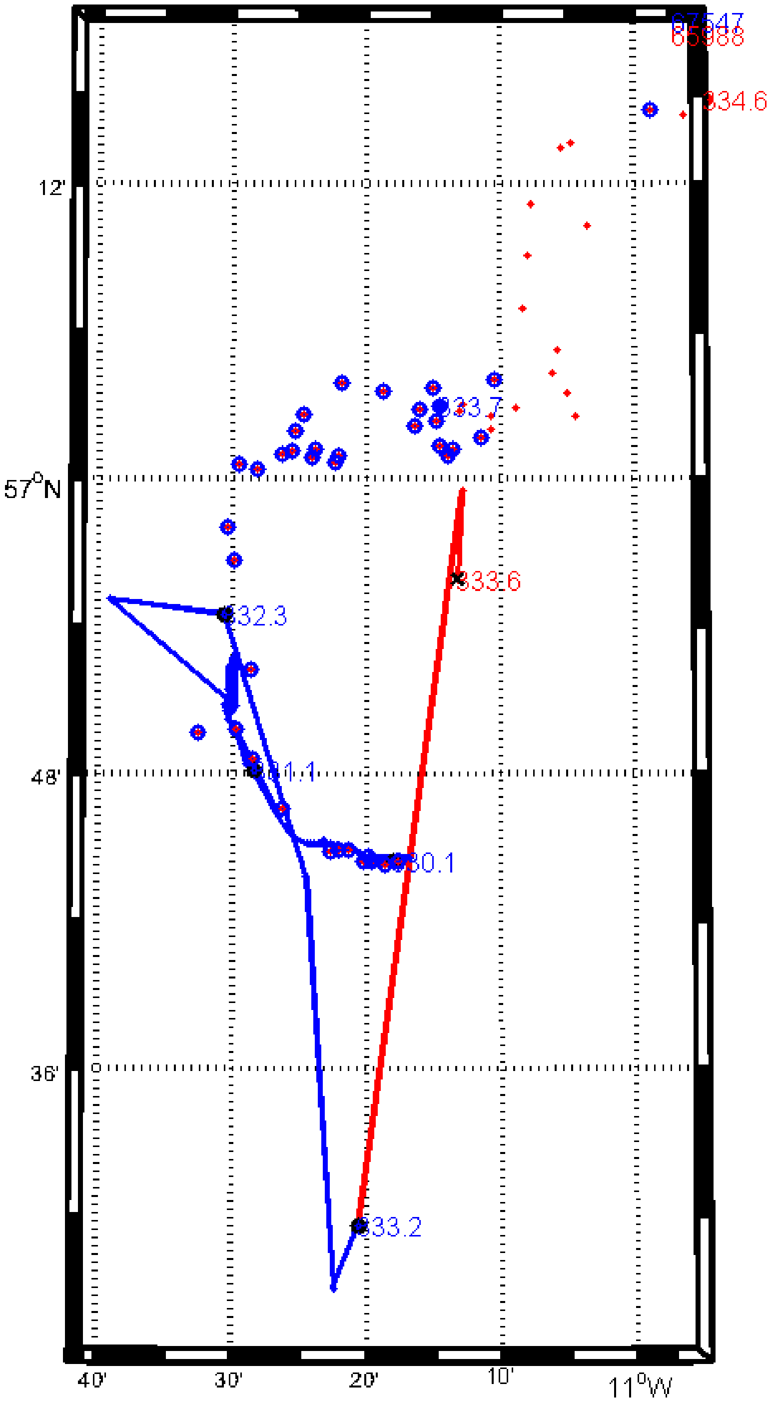

Figure 13. Argos positions from the 2 buoys deployed prior to the start of the release. ID65988 is shown in red and ID67547 in blue. The latest time points are those furthest north-east, time stamped day 334.6.

Following the tracer release and subsequent deployment of the URI neutrally buoyant float, a continuous SF_6 survey was carried out to relocate the patch centre (Figure 14). Concentrations measured in the ship's non-toxic seawater supply (6 m water depth intake) ranged from 32 to 806 fmoles dm^{-3}. Figure 14 indicates that at the time of the survey the patch was not homogeneous at the surface. Two CTD casts (Figures 15 and 16) were carried out at the patch centre determined from the continuous survey data. It seems likely that the first station was the closest to the patch centre as there were higher surface SF_6 concentrations and deeper SF_6 penetration. Examination of the temperature profiles indicated mixed layer depths of between 150 and 200 metres (see Figure 3). Interestingly, the tracers had already mixed from 6 m down to 150 within the mixed layer, indicating elevated turbulence within the upper layer which was most likely due to the high prevailing winds and the lack of structure within the top 200 metres.

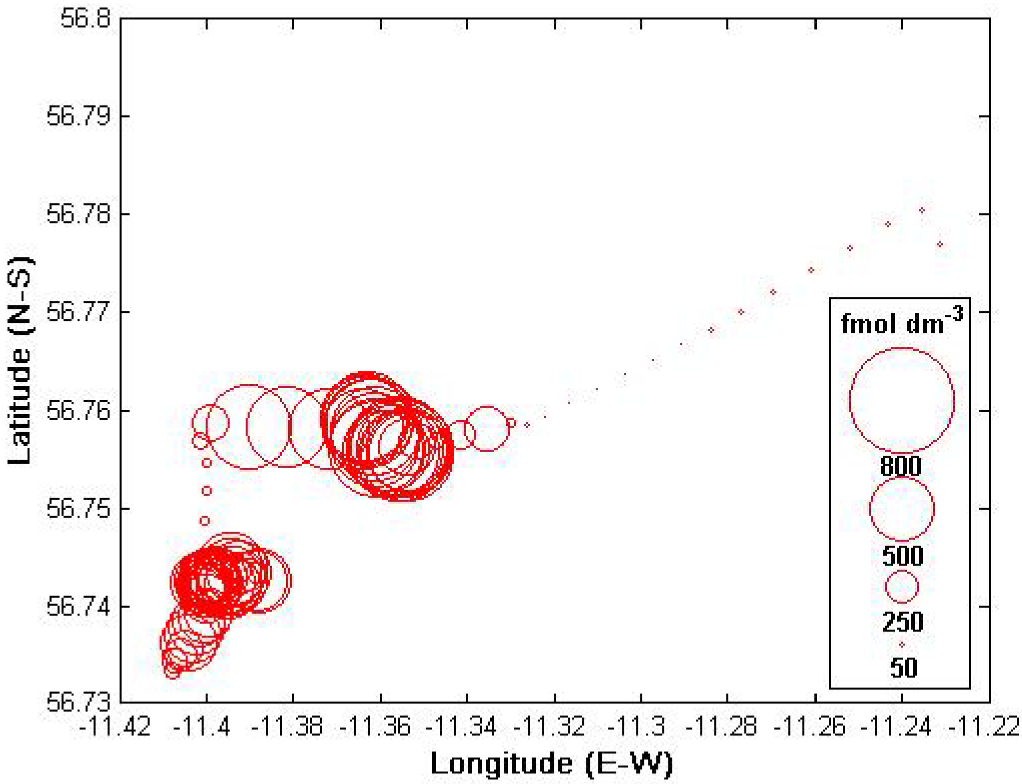

Figure 14. Post-release survey with SF_6 concentrations (fmol dm^{-3}) measured in ship's non-toxic supply (6 m water depth).

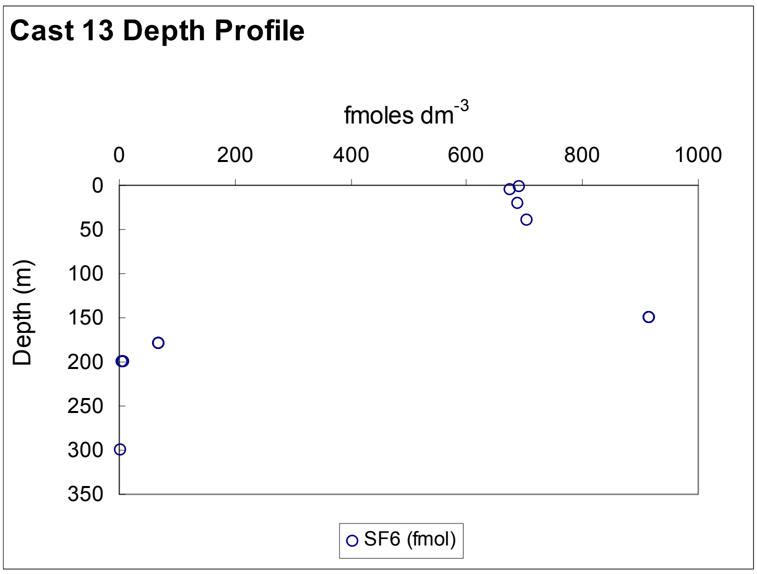

Figure 15. SF_6 concentration (fmol $litre^{-1}$) vs depth (m) at the first post-release profile at the patch centre.

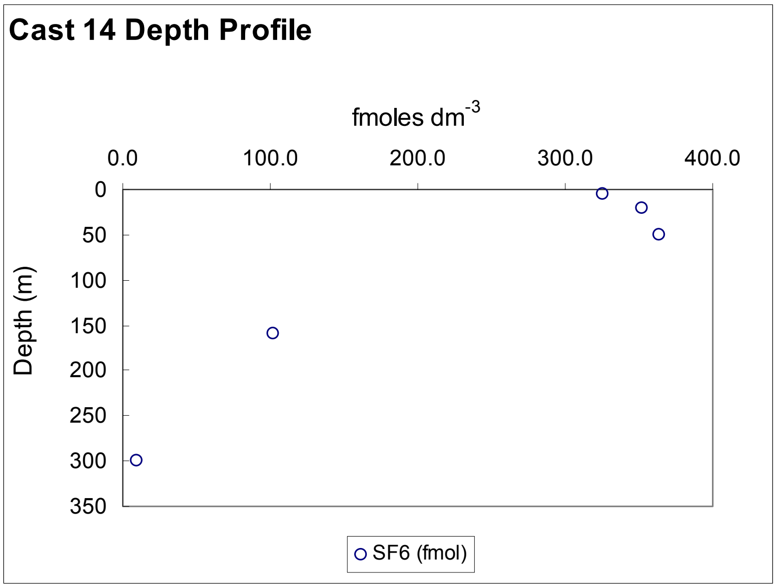

Figure 16. SF_6 concentration (fmol litre^{-1}) vs depth (m) at the second post-release profile at the patch centre.

Acknowledgements: The PML 'volatile team' would like to thank the PSO, Rob Upstill-Goddard, for all his efforts and also the Master, Roger Chamberlain, officers and crew of the RRS *Discovery* for their assistance and cooperation throughout a very difficult and trying cruise. Special thanks to the UKORS clan, Chris Barnard, Dan Comben and Dave Teare for their technical help, support and, much appreciated good humour. Finally, huge thanks to Dr Ricardo Torres, back at PML, for his invaluable help and tremendous efforts with both buoy and ADCP preparation and data processing throughout D313.

University of Rhode Island (URI) activities during DOGEE

Craig McNeil[1], Matt Horn[1] (Cruise participants)
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Description of underway instrumentation: The underway system used 3 different types of dissolved gas sensors:

I) Optode: Aanderaa Inc., for measurement of dissolved O_2. All O_2 measurements from the sampling system are calibrated to Winkler titration measurements of dissolved O_2 performed at sea and taken from the sampling container and/or samples from the rosette CTD at 5m depth (the same depth as the SW inlet from the bow).

II) UGTD and HGTD: Pro-Oceanus Systems Gas Tension Devices (GTDs), in two different configurations consisting of an 'Underway' GTD (UGTD- see ref's 1–2) and a 'Hurricane' GTD (HGTD- see ref. 3). The sensor operates by equilibrating a sample volume of air with the seawater supply using a membrane interface. The sensor measures the total dissolved air pressure in the seawater supply. Using this measurement, the dissolved O_2 from the optode, and the thermosalinograph T and S, dissolved N_2 can be estimated (see ref. 1–3).

III) NDIR-CO_2: Pro-Oceanus Systems Inc., this instrument is a newly developed sensor for measuring dissolved aqueous CO_2 in seawater using the non-dispersive infra-red absorption technique. The sensor's sample air equilibrates with the seawater using a membrane interface (see ref 4). The raw measurements are in ppm and are the measured molar fraction of CO_2 in the optical cell of the sensor. The theory for conversion of the raw data, including full humidity corrections, to in situ fCO_2 are in the process of being finalized. Only raw data are reported here.

These sensors, in combination with the thermosalinograph data, allow estimates of the 5 m depth dissolved pO_2, pN_2, and pCO_2.

Description of the Gas Floats: Two oceanographic floats from the Applied Physics Laboratory at the University of Washington in Seattle, USA (PI Eric D'Asaro) were provided for use on this cruise. The floats are of the same sort that were used successfully to measure air-sea O_2 and N_2 fluxes during Hurricane Frances (see ref's 5─6). The floats measure P, T, S, O_2, and N_2 using Seabird Electronics, Inc. CTD sensors and a Pro-Oceanus Systems, Inc. gas tension device (from which dissolved N_2 is estimated, as discussed above).

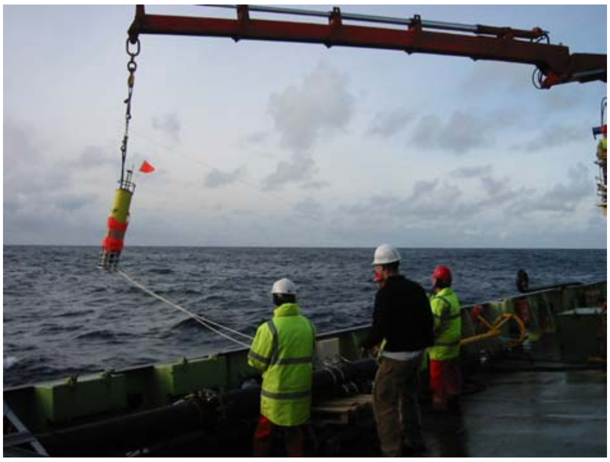

Figure 17. Deployment of float #43.

The floats are configured to profile the water column before and after a storm to provide pre- and -post dissolved gas and water column profiles. These profiles are used to estimate air-sea fluxes from budget calculations. The gas tension sensors have a long time constant that depends on duty cycle of the pump. Time constants (e-folding) vary from 2 min to 20 minutes, depending on depth, seawater temperature, and the duty cycle of the pump used to flush the membrane. During the storm the floats are made neutrally buoyant, by continually adjusting a piston that changes the float's buoyancy. Also, a drag screen is extended to ensure that the float follows the vertical eddy motions within the mixed layer. The high frequency O_2 measurements (approximately every 30 seconds) and the vertical motions of the floats provide direct covariance estimates of the air-sea O_2 fluxes.

During this cruise, only one of the floats was deployed (float #43, at noon on 26 Nov 2006 at 56 ^{o} 46.17' N , 11^o 14.896' W; see Figure 17). This was close to the centre of the tracer release site selected using real time thermosalinograph data; the tracers and float #43 were released in a region of homogeneous waters to the northeast of what appeared to be a warm eddy (see Figure 2). Following release two CTD stations were completed before heading for safe waters near shore. The return trip was in high winds and heavy seas.

Float #43 was not recovered at the end of the cruise due to engine problems with *Discovery*; however it was retrieved post-cruise (see **Cruise Narrative**, p14). Unfortunately, the float also had an incorrect (more precisely mislabelled) pressure sensor which caused the float to surface prematurely after deployment, by releasing a weight via an explosive bolt[1]. The second float had the correct pressure sensor, as it turns out, but there was insufficient opportunity to deploy it and collect useful data.

Experimental set-up of the underway system: The underway dissolved gaseous O_2, N_2, and CO_2 measurement system described above was installed in the wetlab of RRS *Discovery* close to the thermosalinograph. Several days were required to sort out problems associated with distribution of the non-toxic seawater (SW) supply to the various instruments onboard.

The SW supply to the ship comes from 2 separate pumped intakes located at the sea-chest near the bow of the ship. The water is piped to the wetlab region. The residence time of the water in the pipes depends on the total flow. We found that the dissolved gas data were corrupted, presumably by bubble dissolution along the pipes, unless the flow rate was sufficiently fast that the residence time in the pipes was short. A practical limitation was that the waste overflow water had to be drained in the lab sink, or piped overboard. The final set-up drained approximately half of the waste seawater down a drain in the aft-lab hanger and

[1] See acknowledgements.

the remainder was sent directly overboard using large diameter tubing piped to the aft-deck. The residence time of the seawater in the pipes from the bow to the sampling location was estimated at 2–3 min, using measurements of the total flow rate (sample plus waste seawater) and total volume. All systems were in final configuration after 1100h on 13 Nov 2006, during which time forward the instruments were configured as follows: the HGTD, UGTD and optode were in a 22 L flushed cylindrical orange water cooler (see ref. 2), and the CO_2 sensor was flushed directly with seawater through its membrane interface while in the wetlab sink.

Sampling timeline: Figure 18 shows when the URI/UW data were collected during the cruise. Only periods after the seawater supply was fully adjusted are shown.

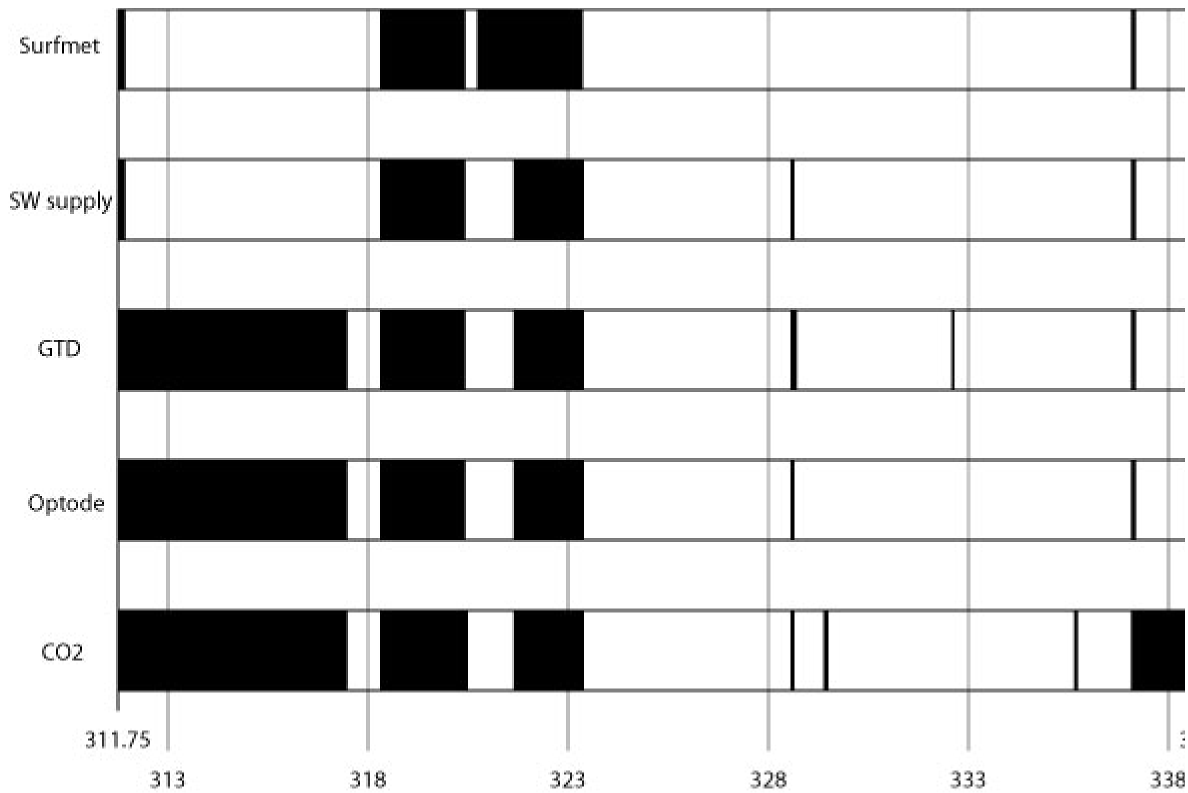

Figure 18. Timeline showing operational period when URI instrumentation was fully operational during D313. Blackout periods show when the instruments were not collecting data.

Preliminary analysis of CO_2 sensor data: Figures 19 and 20 show the CO_2 data collected during D313 using the new prototype Pro-Oceanus Systems, Inc. CO_2 sensor described in Section 1. The data are quite similar to those collected by UEA's group, besides an offset of about -32 units. Note that the measurements reported here are raw data and have not yet been corrected from various humidity and temperature corrections. The raw measurements of the CO_2 sensor are concentration of the optical cell of the NDIR board, with units of ppm of CO_2. The raw data still need to be converted to in situ pCO_2, accounting for SST changes, relative humidity changes in the optical cell of the NDIR unit, and various other corrections.

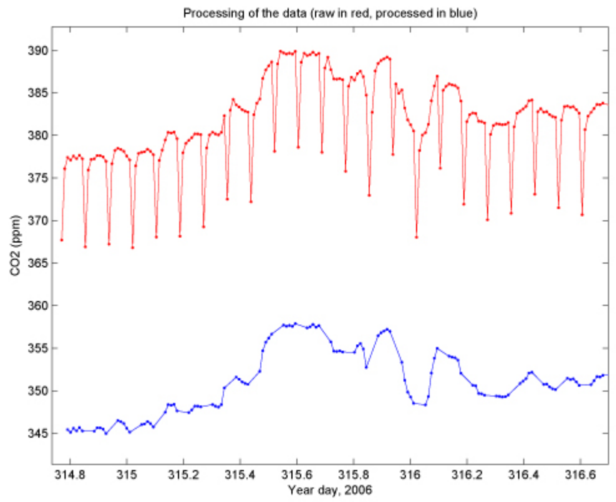

Figure 19. Raw (red) and processed (blue, offset for clarity) CO_2 data (5 m depth) from the Pro-Oceanus Systems Inc. NDIR underway system.

Figure 20. All raw CO_2 data collected during D313 with the URI CO_2 system. See figure 19 for description of line types. High values are recorded in coastal waters.

Preliminary analysis of dissolved O_2, N_2 and CO_2 in the open ocean: A summary of the underway data for the open ocean in the vicinity of the tracer release is shown in Figure 21.

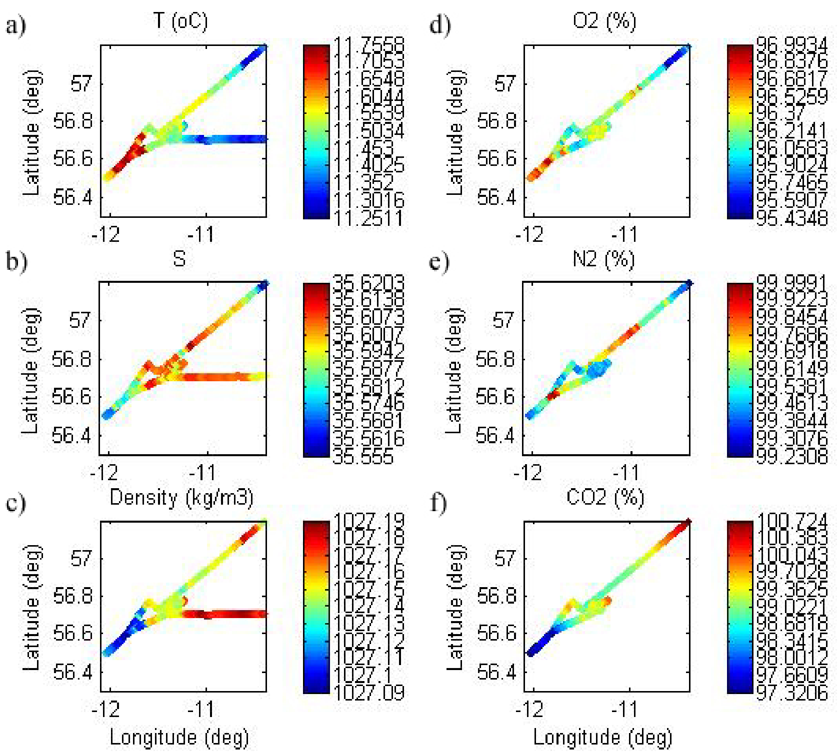

Figure 21. An overview of the 5m depth underway data collected during the tracer release site survey, showing: a) seawater temperature, b) salinity, c) seawater density, d) dissolved O_2 saturation level, e) dissolved N_2 saturation level estimated from the gas tension, T, S and O_2 data, and f) a 'crude' estimate of pCO_2 saturation level estimated using the Pro-Oceanus System's NDIR CO_2 sensor raw data. Note that the raw units of the pCO_2 sensor output concentration in ppm of CO_2 in the optical cell of the NDIR board. The data need to be converted properly to in situ pCO_2, accounting for SST changes, relative humidity changes in the optical cell of the NDIR unit and other corrections. What is shown in Figure 6f is a 'crude' estimate obtained by applying a constant offset of -32 ppm to the raw data. This offset keeps the raw URI CO_2 data in line with UEA's pCO_2 data (personal communications, Maciej Telszewski). Note that the dissolved gas data on the eastward return trip to shore, especially, were collected during very high wind speeds and sea states and were severely corrupted by bubble contamination; these data are not plotted.

This preliminary analysis shows that the open ocean waters are undersaturated in O_2 by approximately 3—4% and N_2 is about 0.5% undersaturated. Post cruise calibrations are underway to check the KIO_3 standard solution used in the Winkler titration analysis which will provide more confidence in this result. However, given that the mixed layer was cooling and deepening in a lower O_2 concentration pycnocline, one may expect both gases to be undersaturated (in the absence of bubble 'pumping' effects associated with Langmuir circulation, etc.). In the absence of N_2 stratification, the degree of undersaturation in N_2 would be attributed to the effects of mixed layer cooling 'outpacing' air-sea gas exchange (NB cooling undersaturates O_2 and N_2 by approximately 2% C^{-1} due to changes in solubility).

Note that during very high winds and sea states (perhaps 10—20 % of the open ocean data), the dissolved gas measurements were corrupted, presumably by continual dissolution of bubbles entrained in the SW supplied to the wetlab. The bubbles would be expected to make it to the sea-chest when very large waves hit the bow of the ship. This was evident from many large spikes in the data. Further analysis of the data will require application of a filter to select good from bad data. Bad data may be selected based on threshold criteria for wind speed, pitch and roll, etc.

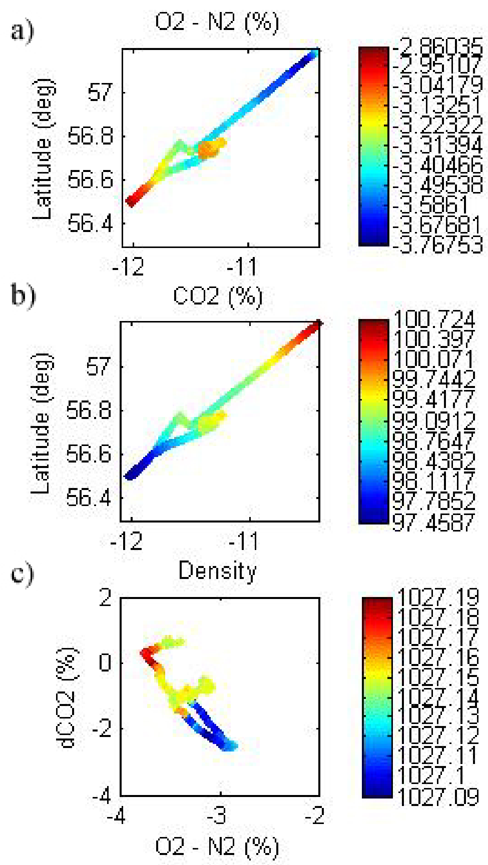

Figure 22. Preliminary analysis of 5m depth underway data collected during the tracer release site survey, showing: a) O_2 minus N_2 saturation levels, b) CO_2 saturation (see Figure 2f for details), and c) saturation anomaly from 100% of CO_2 plotted against the saturation difference between O_2 and N_2.

Because the N_2 saturation level, in the absence of changes due to mixing and pycnocline entrainment, indicates how well the surface waters are equilibrated with respect to the atmosphere, the effect on O_2 saturation of air-sea gas exchange can be mostly removed by subtracting from the O_2 saturation level the N_2 saturation level. The results are shown in Figure 22. Figure 22c provides an indication of net biological demand on the waters, color coded by the seawater density. Progressing westward, the data show that the net biological demand decreases since the absolute value of the O_2 minus N_2 undersaturation actually decreases. This decrease in net biological O_2 demand is also associated with a westward decrease in the CO_2 saturation level, as one would expect if the net biological demand decreases to the west. The strong inverse correlation between O_2 minus N_2 and CO_2 can is shown in Figure 22c.

Summary: Our major objective for the cruise was to compare air-sea gas transfer rates derived using mixed layer O_2 and N_2 budgets and float derived O_2 eddy covariance fluxes with duel-tracer ($^3He/SF_6$) derived estimates. Unfortunately, we were unable to meet this objective.

We did, however, manage to collect good underway data during the cruise. Particularly noteworthy are the data obtained using the new dissolved aqueous NDIR CO_2 sensor. We plan to make detailed comparisons of these CO_2 data with similar data collected by the other groups. We will also investigate using the dissolved O_2 and N_2 data collected on the first visit to the vicinity of the tracer release site (during 11 Nov 2006, prior to losing the rosette CTD) and the second site visit during (during 26 Nov 2006, after tracer release) to see if air-sea gas exchange rates can be constrained by budgets.

Acknowledgements: We are grateful to the captain and crew of the RRS Discovery for proving us with expert support in the face of severe weather and major technical difficulties with the ship's operations. We are also grateful to the PSO and all collaborators for the opportunity to participate in the experiment. We look forward to having the opportunity to repeat this experiment sometime in the near future.

We are indebted to the PSO, the ship's crew and others, and especially Malcolm Woodward of PML for ensuring that the delivery of explosive bolts actually made it to the ship. Without these bolts, the float would now be on the bottom of the ocean, rather than on the surface!

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4. Operating manual: Pro-Oceanus Systems, Inc. CO_2-Pro sensor, Halifax, NS, Canada (see www.pro-oceanus.com).
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AutoFlux - the autonomous air-sea interaction system

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Introduction: AutoFlux is an autonomous, stand-alone system which obtains direct, near real-time (2 hr) measurements of the air-sea turbulent fluxes of momentum and sensible and latent heat in addition to various mean meteorological parameters. The two main aims of the present deployment were 1) to continuously measure a suite of key meteorological variables (wind speed and direction, air temperature, and humidity, sea surface temperature, short wave radiation and air pressure) and 2) to measure directly the air-sea fluxes of CO_2, sensible heat, latent heat and momentum (by direct covariance (EC) and inertial dissipation). The AutoFlux system was mobilised in Govan in February 2004 prior to the start of cruise D277 and left to run autonomously until the beginning of D313. The inertial dissipation (ID) method relies on good sensor response at frequencies up to 10 Hz. The ID method has the advantage that the flux results a) are insensitive to the motion of the ship and b) can be corrected for the effects of the presence of the ship distorting the airflow to the sensors. Momentum and latent heat flux measurements have been successfully made using this method for a number of years. Sensible heat and CO_2 flux measurements are made more difficult by the lack of sensors with the required high frequency response. For these fluxes the eddy correlation (EC) method provides an alternative. This method requires good sensor response up to only about 2 to 3 Hz, but is a) very sensitive to ship motion and b) the fluxes can not be directly corrected for the effect of air flow distortion. Once EC fluxes are obtained they can be corrected for flow distortion effects by comparison with the corrected ID fluxes where available. Since the scalar fluxes (sensible and latent heat and CO_2) are all affected by flow distortion in the same fashion, only one ID scalar flux is required in order to quantify the effects of flow distortion on EC scalar fluxes.

This report describes the AutoFlux instrumentation. A brief discussion of the performance of the mean meteorological sensors is given and comparisons are made between the ship's instruments with those of AutoFlux where possible. Initial flux results are also described. Appendix A lists significant events such as periods when data logging was stopped, and Appendix B contains figures showing time series of the mean meteorological data. All times refer to UTC.

More information on air-sea fluxes and the AutoFlux project in particular can be found under;

http://www.noc.soton.ac.uk/ooc/CRUISES/AutoFlux/index.php

Instrumentation: The NOC Surface Processes team instrumented *Discovery* with a variety of meteorological sensors. The mean meteorological sensors (Table 2) measured air temperature and humidity, and wind speed and direction. The surface fluxes of momentum, heat, moisture and CO_2 were obtained using the fast-response instruments in Table 4**.** The MR3 and R3 sonic anemometers provided mean wind speed and direction data in addition to the momentum and sensible heat flux estimates**.**

To obtain EC fluxes, ship motion data from the MotionPak system was synchronised with those from the other fast response sensors. Navigation data were logged in real time at 1 second intervals, using the ship's data stream rather than the separate AutoFlux GPS and compass. These data are used to convert the relative (measured) wind speed and direction to true wind speed and direction. The ship's mean meteorological '*surfmet*' data were also logged in real time at 2 second intervals to provide access to radiometer and sea surface temperature information. The details of the ship's meteorological instruments are given in Table 5.

All data were acquired continuously, using a 58 minute sampling period every hour (the remaining 2 minutes being used for initial data processing), and logged on “ruby”, a Sunfire V210 workstation. Processing of all data and calculation of the ID fluxes was performed automatically on “ruby” during the following hour. Program monitoring software monitored all acquisition and processing programs and automatically restarted those that crashed. A time sync program was used to keep the workstation time synchronised with the GPS time stamp contained in the navigation data. Both “ruby” and all the AutoFlux sensors were powered via a UPS.

All of the instruments were mounted on the ship’s foremast (Figure 23) in order to obtain the best exposure. The psychrometers, radiation sensors and the fast response sensors were located on the foremast platform. The heights of the instruments above the foremast platform were: R3 sonic anemometer, 2.11 m; MR3 sonic anemometer 2.81 m; psychrometers 1.85 m; both Licor H_2O / CO_2 sensors 1.21 m.

Mean meteorological parameters:

Air temperature and humidity: Two wet- and dry-bulb psychrometers were installed on the foremast and performed well until day 317 when the starboard psychrometer wet bulb stopped wicking due to the water bottle detaching from the instrument. The bottle was found on deck and replaced during the port call in Stornaway (JD 319). Due to a replacement sensor failing during mobilisation in Govan, the starboard psychrometer (serial number 1031) was replaced with a psychrometer with an offset in the wet bulb temperature measurement. The difference between the wet bulb temperatures showed that starboard psychrometer wet bulb read high by 0.3ºC (standard deviation of 0.23ºC). The difference between the dry bulb temperatures was only 0.024ºC (standard deviation of 0.29ºC). The standard deviation was large due to occasional drips from the wet bulbs falling on the dry bulbs. The problem was circumvented by the automatic processing which selects the higher of the two temperatures.

The humidities calculated by the psychrometers were compared to the measurements made using the AutoFlux and surfmet Vaisala sensors. The AutoFlux Vaisala humidity was the more accurate of the two and read low by 2.5% (standard deviation of 1.9%). The ship’s Vaisala read high by 5.3% (standard deviation of 2%). A comparison of the humidity measured by the two Vaisala sensors showed the surfmet Vaisala read high by 7.7% (standard deviation of 1.8%). The last calibration performed on the surfmet Vaisala was February 2003 so it was replaced at the end of the cruise on day 339 (Table 5).

The air temperatures measured by the two Vaisala sensors agreed to within 0.07 ºC (standard deviation of 0.19ºC) of the best psychrometer measurements. In addition, the difference between the two Vaisala temperature measurements was only 0.02ºC (standard deviation of 0.14ºC). Therefore, the Vaisala air temperature sensors performed well during the cruise and are close to the accuracy of the psychrometer air temperature measurements.

Wind speed and direction: There were three anemometers mounted on the foremast platform (Figure 24). On the port side were the ship’s propeller anemometer and the fast response MR3 sonic anemometer. A R3 sonic anemometer was located on the starboard side. Both sonic anemometers measured all three components of wind speed and both are calibrated on a regular basis. The Starboard R3 anemometer was the best exposed and will be used as the reference instrument in the following comparison. The measured wind speeds (uncorrected for ship speed) from the MR3 sonic anemometer was compared to those from the Starboard R3 in Figure 24, which shows the wind speed ratio (measured / R3 measured) against relative wind direction. A wind blowing directly on to the bows is at a relative wind direction of 180 degrees. For a bow-on wind, the MR3 sonic read high by about 2 %. Some of the biases will be due to flow distortion. Accurate flow distortion corrections have yet to be determined for the precise anemometer locations, but previous work (Yelland et al. 2002) has shown that the bias at the MR3 sonic anemometer sites should be between -1 and +2%. Figure 24 also clearly shows the effects for flow distortion are, as expected, very sensitive to the relative wind direction. Since the R3 and MR3 sonics were located on opposite sides of the foremast extension to the ship's anemometer, roughly 50% of the trend in wind speed error seen in the latter is actually due to the variation in flow distortion with wind direction at the R3 anemometer site. The large dips in the speed ratios at 90 and 270 degrees are due to the MR3/R3 anemometers being in the wake of the foremast extension for winds from the port and starboard beams respectively. Figure 25 shows the difference in relative wind direction as measured by each anemometer compared to that from the R3. For bow-on winds the R3 and MR3 agree to with 8 degrees, but the ships anemometer appear to be misaligned by 14 degrees. The difference in the relative wind direction is greater than other cruises by 6 degrees and was explained by a misalignment of the R3 sonic during mobilisation in Govan. The R3 sonic was orientated to the previous cruise alignment at the end of the D313.

TIR and PAR sensors: The ship carried two total irradiance sensors, one (Ptir) on the port side of the foremast platform and the other (Stir) on the starboard. These measure downwelling radiation in the wavelength ranges given in Table 5. A comparsion of the TIR short-wave sensors showed that both sensors were in good agreement. The daily mean difference in the measured short-wave values were below 1 W/m^2 (standard deviation 1.4 W/m^2). In addition to the TIR sensors the ship carried two PAR sensors measure downwelling radiation in the wavelength ranges given in Table 5. The Starboard PAR sensor read high by 1 W/m^2 (standard deviation of 1.65 W/m^2). Both PAR sensors read approximately 2 W/m^2 high during the night when zero W/m^2 should have been measured. It was not possible to check the serial numbers on the PAR sensors during the cruise so it is not clear if the correct calibrations were applied.

Sea surface temperature: Sea surface temperature (SST) data from the thermosalinograph (TSG) were logged on the AutoFlux system as part of the "surfmet" data stream. The TSG was flushed through with fresh water at 11:00hr on day 318 and remained off until Day 320 when the ship sailed from Stornaway. The system was also turned off from day 321 to 323 whilst the ship was alongside in Greenock. The system was cleaned with chemicals on day 338 at 12:35hr.

Ship borne wave recorder (SBWR): The SBWR was switched on prior to the ship leaving Govan. Raw and processes data were logged internally and half hourly wave statistics were transferred automatically to the AutoFlux system via a serial link. The raw data was backed up periodically during the cruise. The largest wave measured during the cruise was 17 m peak to trough on Day 315.

Initial flux results:

Inertial dissipation (ID) flux measurements: The ID momentum flux obtained from the starboard R3 sonic anemometer is shown in Figure 26 where the drag (transfer) coefficient is shown against the true wind speed corrected to a height of 10 m and neutral atmospheric stability. The drag coefficient is defined as (10^3 * momentum flux / wind speed^2). The mean drag to wind speed relationship from previous cruises (Yelland et al., 1998) is also shown. Figure 27 shows the ID latent heat flux obtained from the Licors H_2O data. The agreement with results from previous experiments is good.

Figure 28 shows the **ID sensible heat flux** obtained from the R3 and MR3 sonic anemometer temperature data. In this case the measured fluxes are biased high. This is due to high frequency noise contaminating the temperature spectra at all frequencies above about 2 Hz.

Eddy correlation (EC) flux measurements: The EC fluxes will be worked up post-cruise.

Summary: The following cruise objectives were met:

a) Meteorological measurements of the key variables were made (wind speed and direction, air temperature and humidity, short wave radiation, sea surface temperature and air pressure).

b) Direct measurements of the air-sea fluxes of sensible heat, latent heat and momentum fluxes were made using the inertial dissipation method. Direct covariance fluxes of these fluxes and CO2 will be performed post cruise.

Acknowledgements: The AutoFlux system was developed under MAST project MAS3-CT97-0108 (AutoFlux Group, 1996).

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Table 2. The mean meteorological sensors: From left to right the columns show; sensor type, channel number, rhopoint address, serial number of instrument, calibration applied, position on ship and the parameter measured.

Sensor	Channel, variable name	Address	Serial No.	Calibration $Y = C0 + C1*X + C2*X^2 + C3*X^3$	Sensor position	Parameter (accuracy)
Psychrometer 1	1 pdp1	$ARD	IO2002 DRY	C0 -10.317577 C1 3.813829E-2 C2 2.1886071E-6 C3 -8.3582403E-11	Starboard side of foremast platform	Wet and dry bulb air temperatures and humidity (0.05°C)
Psychrometer 1	2 pwp1	$BRD	IO2002 WET	C0 -10.039858 C1 3.8108075E-2 C2 2.2737121E-6 C3 -1.1847905E-10		
Psychrometer 2	3 pds2	$CRD	IO1031 DRY	C0 -8.7927838E-1 C1 3.8586783E-2 C2 1.9026379E-6 C3 -5.6938427E-11	starboard side of foremast platform	Wet and dry bulb air temperatures and humidity (0.05°C)
Psychrometer 2	4 pws2	$DRD	IO1031 WET	C0 -1.278481 C1 3.850882E-2 C2 2.285053E-6 C3 -4.528215E-11		
Vaisala	5	$ERD	X4120001 Hum	C0 0.0 C1 0.1	port side of foremast platform	0 – 100 %
Vaisala	6	$FRD	X4120001 Air	C0 -39.65 C1 0.1		-20-60 degC

Table 3: Mean differences between the temperature and humidity sensors.

Difference from psychrometers	Mean difference	Standard deviation
AutoFlux Vaisala humidity	2.5% low	1.9%
Ship's Vaisala humidity	5.3% high	2.0%
AutoFlux Vaisala temperature	0.05ºC high	0.16ºC
Ship's Vaisala temperature	0.07ºC high	0.19ºC
Difference from AutoFlux Vaisala	Mean difference	Standard deviation
Ship's Vaisala humidity	7.7 % high	1.8 %
Ship's Vaisala temperature	0.02ºC high	0.14 ºC

Table 4. The fast response sensors.

Sensor	Program	Location	Data Rate (Hz)	derived flux / parameter
Gill R3 Research Ultrasonic Anemometer serial no. **000227**	Gillr3mpd	starboard side of foremast platform	20 Hz	momentum and sensible heat
Licor-7500 CO_2 / H_2O sensor serial **no. 75H0614**	licor3		20 Hz	latent heat and CO_2
Gill MR3 Research Ultrasonic Anemometer serial no. **000 ?**	gillmr3d	Port side of foremast platform	20 / 100 Hz	momentum and sensible heat
Licor-7500 CO_2 / H_2O sensor serial **no. 75H0**	licor3b		20 Hz	latent heat and CO_2
MotionPak ship motion sensor serial no. 0682	via gillr3mpd		20 Hz	EC motion correction

Table 5. The ship's meteorological sensors

Name	Sensor	Type	Serial no.	Sensitivity	Cal
STIR	Kipp & Zonen CM6B (335 – 2200 nm)	Pyranometer	047462	11.84 μV/W/m2	8.4459459E4
PTIR	Kipp & Zonen CM6B (335 – 2200 nm)	Pyranometer	047463	10.63μV/W/m2	9.4073377E4
PPAR	Skye energy sensor (400-700nm)	PAR	28558 (not checked)	1mV/100W/m2	
SPAR	Skye energy sensor (400-700nm)	PAR	28557 (not checked)	1mV/100W/m2	
Pressure	Vaisala PTB100A	Barometric	S361 0008 **(U1420016?)**	800–1060 mbar	
wind speed	Vaisala WAA151	Anemometer	P50421	0.4-75 m/s	
Wind Dir	Vaisala WAV151	Wind Vane	S21208	-360 deg	
Air temp	Vaisala HMP44L	Temp	U 185 0012	-20-60 degC	slope 1.0891 offset: 1.78
	Replaced on J339 with Vaisala HMP44L		A2150009	-20-60 degC	slope: 1.044 offset: -0.6
humidity	Vaisala HMP44L	Humidity	U 185 0012	0-100%	slope 1.0891 offset: 1.78
	Replaced on day339 with Vaisala HMP44L		A2150009	0-100%	slope: 1.044 offset: -0.6

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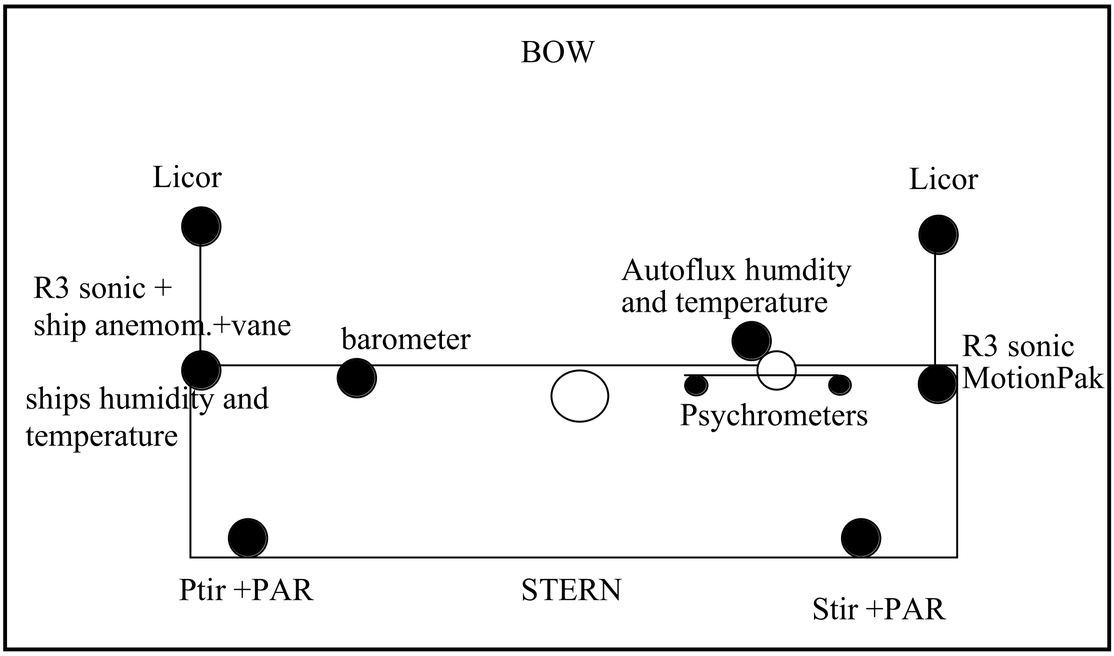

Figure 23. Schematic plan view of the foremast platform, showing the positions of the sensors.

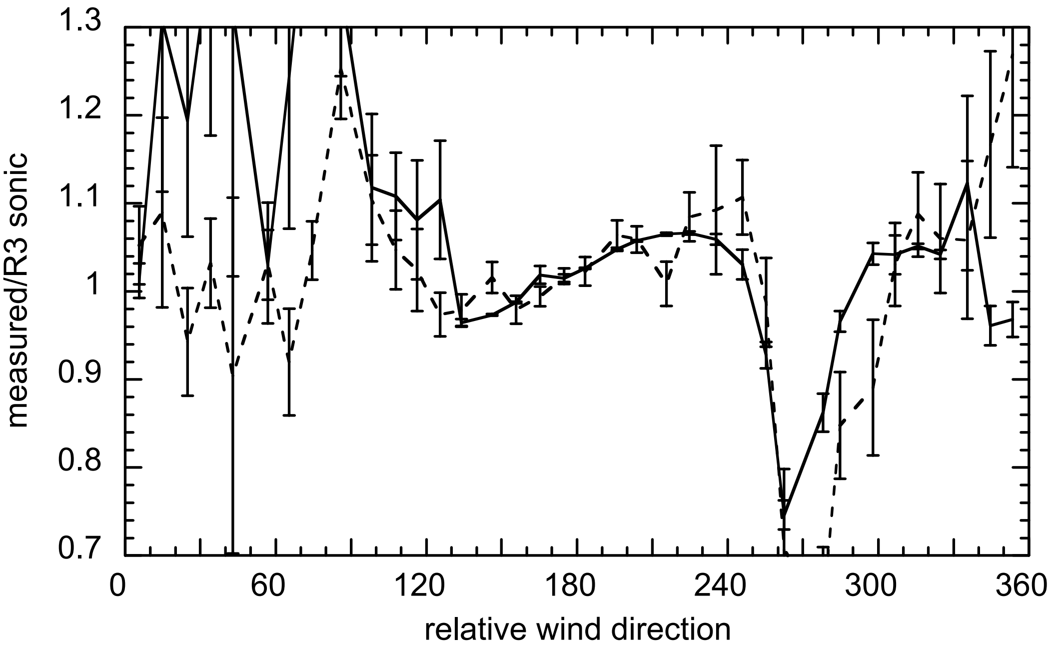

Figure 24. Measured wind speed / wind speed from the R3 sonic, MR3 sonic (bold line) and ship's anemometer (dashed line) each binned against relative wind direction. Only open ocean data is displayed and error bars indicate the standard deviation of the mean. A relative wind direction of 180 degrees indicates a flow directly on to the bow of the ship.

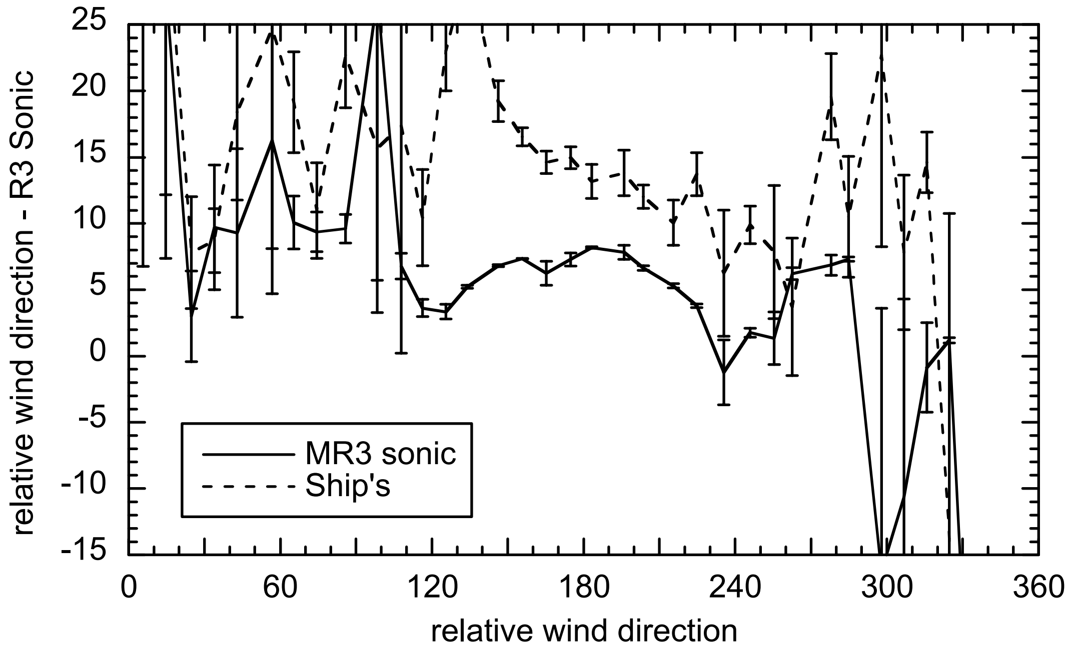

Figure 25. As Figure 23 but showing the difference (measured – R3 sonic) in the relative wind direction.

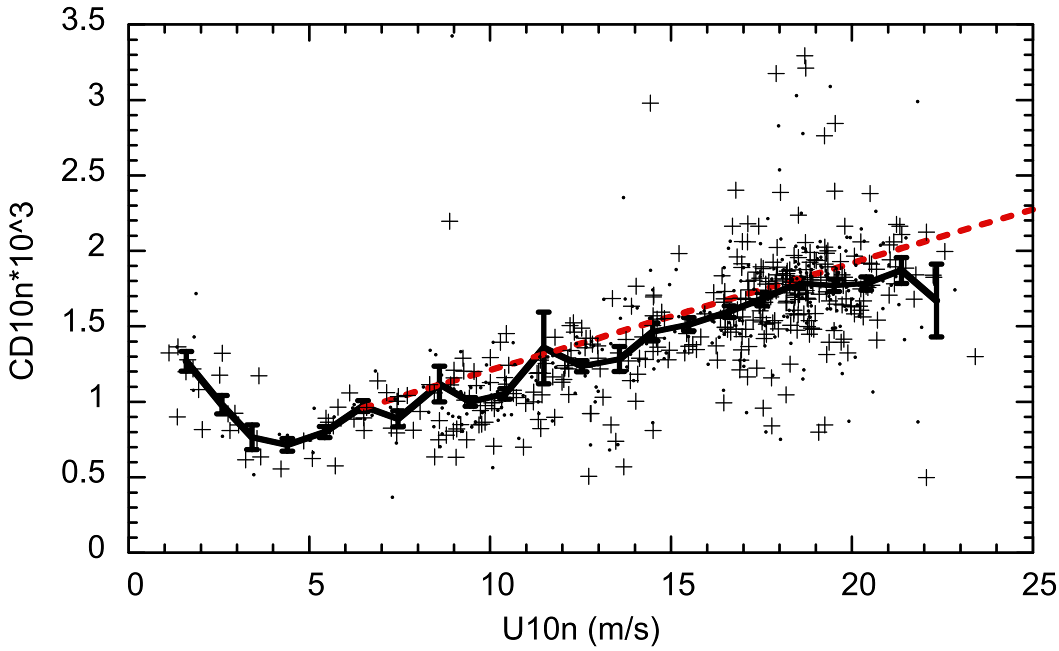

Figure 26. Fifteen minute averaged values of the measured Inertial Dissipation drag coefficient from the R3 sonic (dots) and the MR3 sonic (crosses), plus the mean results of both instruments (solid line) binned against the 10 m neutral wind speed. The Yelland et al. (1998) relationship is shown by the dashed line.

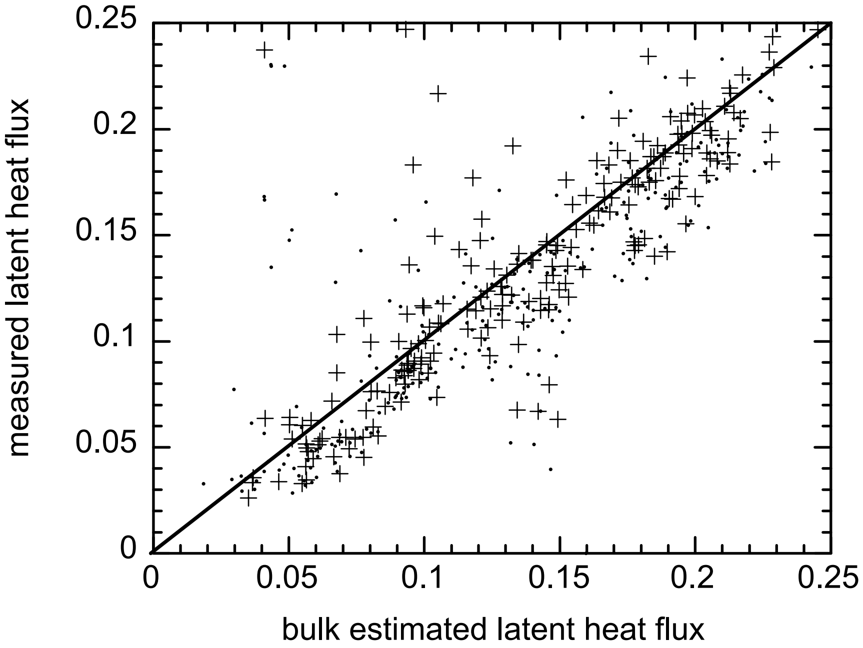

Figure 27. Inertial dissipation (ID) measurements of the kinematic latent heat flux from starboard Licor (dots) and the port Licor (crosses) shown against a flux estimated from a bulk formula (Smith, 1988).

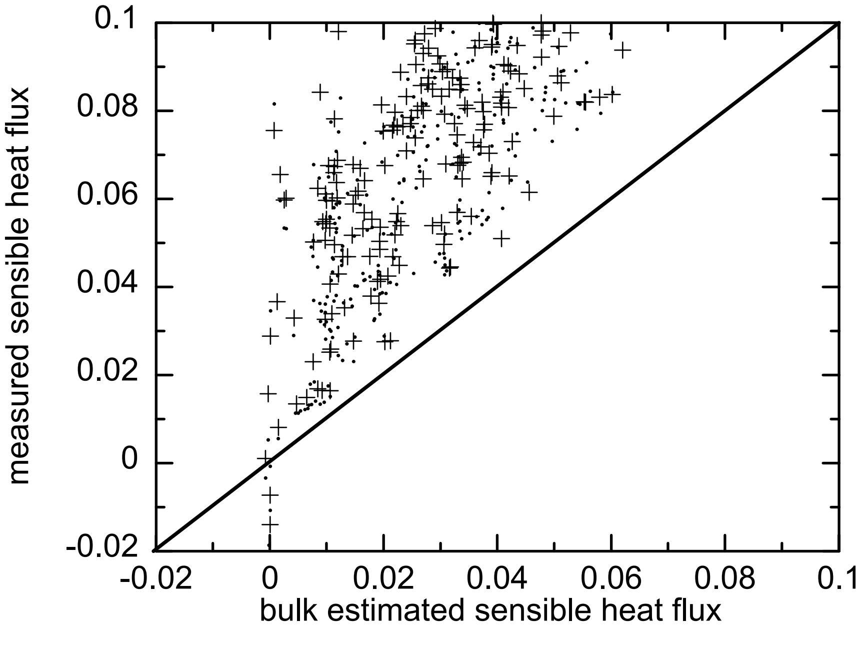

Figure 28. Inertial dissipation (ID) measurements of the kinematic sensible heat flux from the R3 Sonic (dots) and the MR3 sonic (crosses) shown against a flux estimated from a bulk formula (Smith, 1988).

Appendix A. List of significant events:

Day 310: One day before sailing from Govan, the Script.plotR3 paused for a 'y/n prompt' mid afternoon while generating Iridium stats and the flux data for all hours of day 310. Overwrote file and all ok.
Day 317: Starboard Pychrometer 1031 reservoir dried out due to reservoir bottle detaching from the instrument. Bottle found on deck and re-attached to instrument on Day 319. MR3 sonic Tx continuously flashing. Power cycled interface unit to little effect. Flashing eventually stopped. MR3 logging program hung. Rebooted Ruby and power cycled the switch.
Day 319: Intermittent MR3 fault. Checked cables on foremast and found slight water ingress on data cable.
Day 336: No ships heading (gyro read 666). Sbwr hung – power cycled interface unit and restarted program.

Table 6. Day and time when sensors were cleaned.

Licor cleaned	TIR sensors cleaned
311 09:00	311 09:00
319 14:00 to 15:00	319 14:00 to 15:00
339 approx 14:00	339 approx 14:00

Appendix B. Time series of mean meteorological and air-sea flux data:

Figures 29-33 show time series of 1 minute averages of the mean meteorological data. Only basic quality control criteria have been applied to these data. Each page contains four plots showing different variables over a five day period.

Top panel - the best wet (pwUSE) and dry (pdUSE) bulb temperatures from the two psychrometers plus sea surface temperature (sst) from the TSG.

Upper middle panel - downwelling radiation from the two shortwave TIR sensors and the two longwave sensors, all in W/m^2.

Lower middle panel - relative wind direction (reldd = 180 degrees for a wind on the bow) and true wind direction (TRUdd) from the starboard R3 anemometer. The ship's true heading is also shown.

Bottom panel - relative (spdENV) and true wind (TRUspd) speeds in m/s from the starboard R3 anemometer. The ship's speed over the ground is also shown in m/s. When the relative wind direction was to port of the bow the significant flow distortion is apparent as steps in the true wind speed.

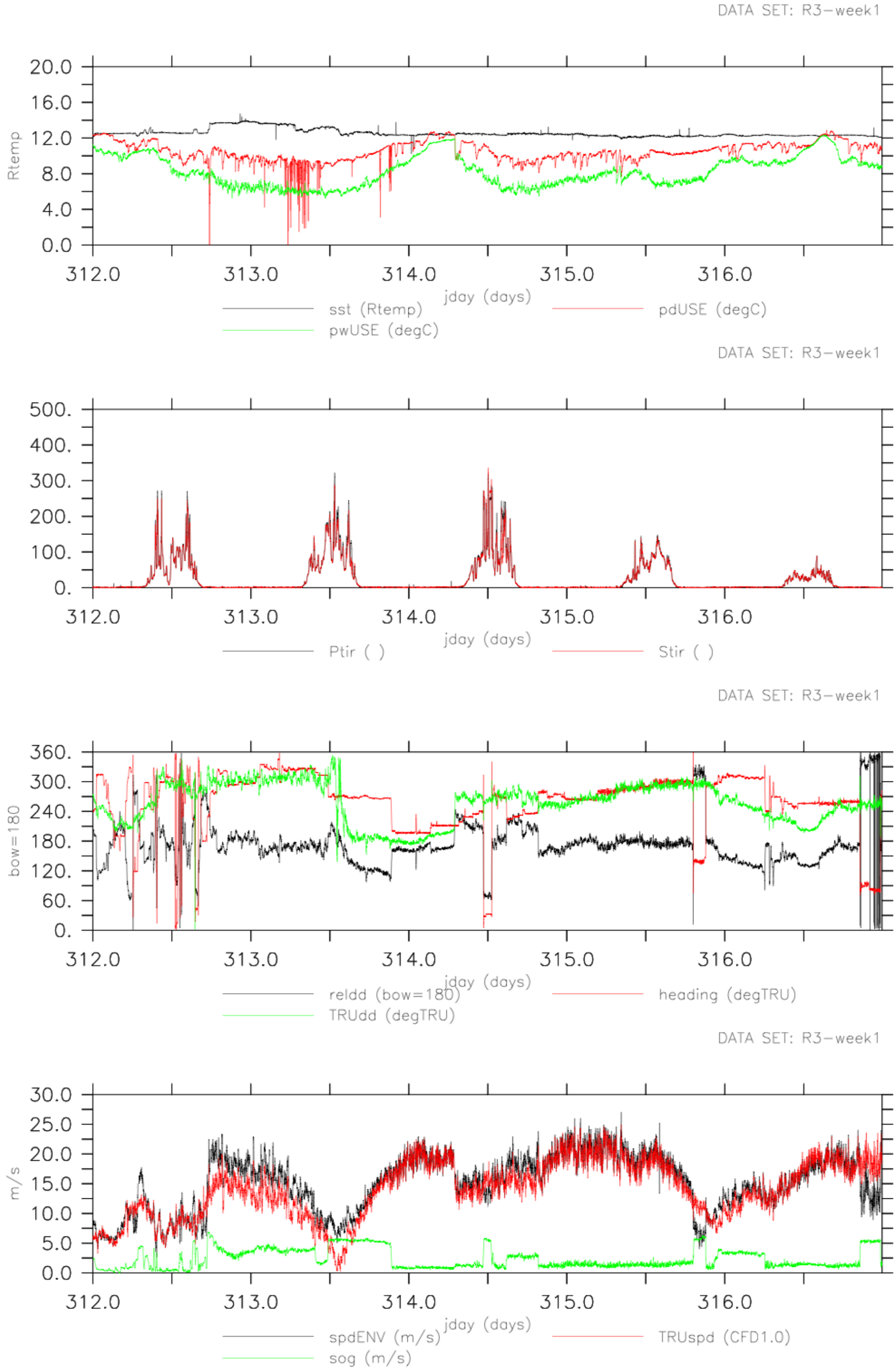

Figure 29. Mean meteorological data for days 312 to 317.

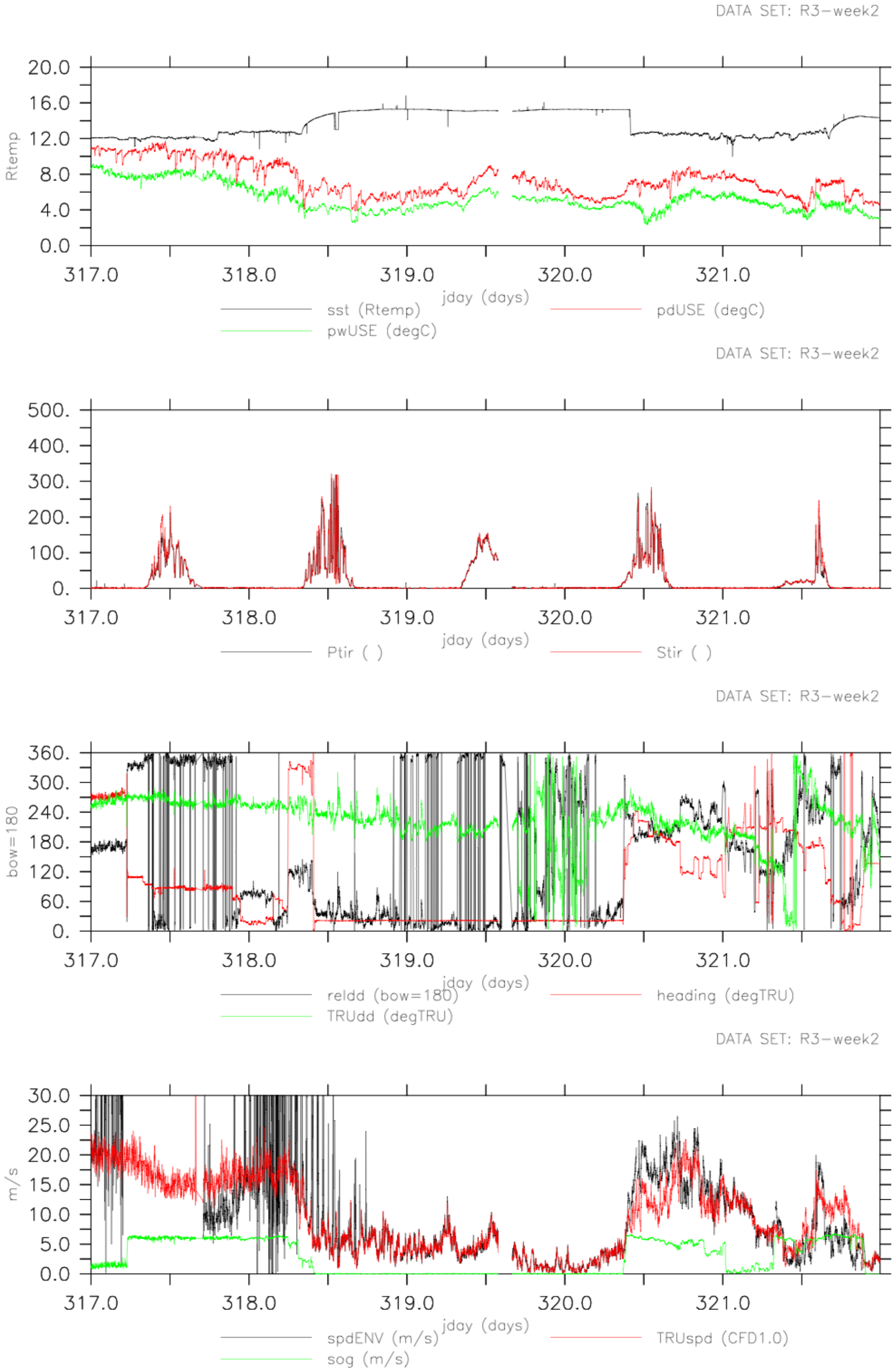

Figure 30. Mean meteorological data for days 317 to 322.

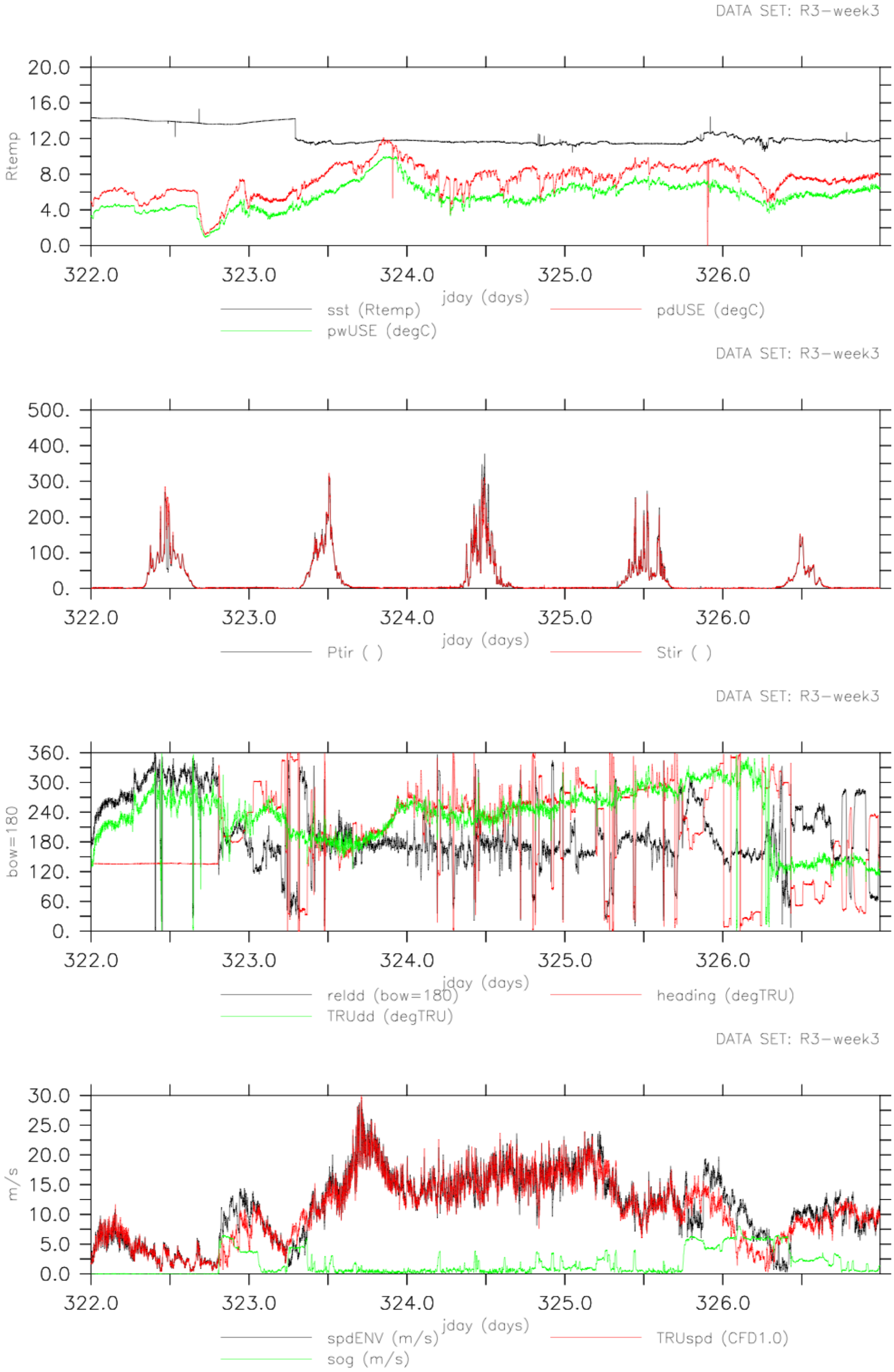

Figure 31. Mean meteorological data for days 322 to 327.

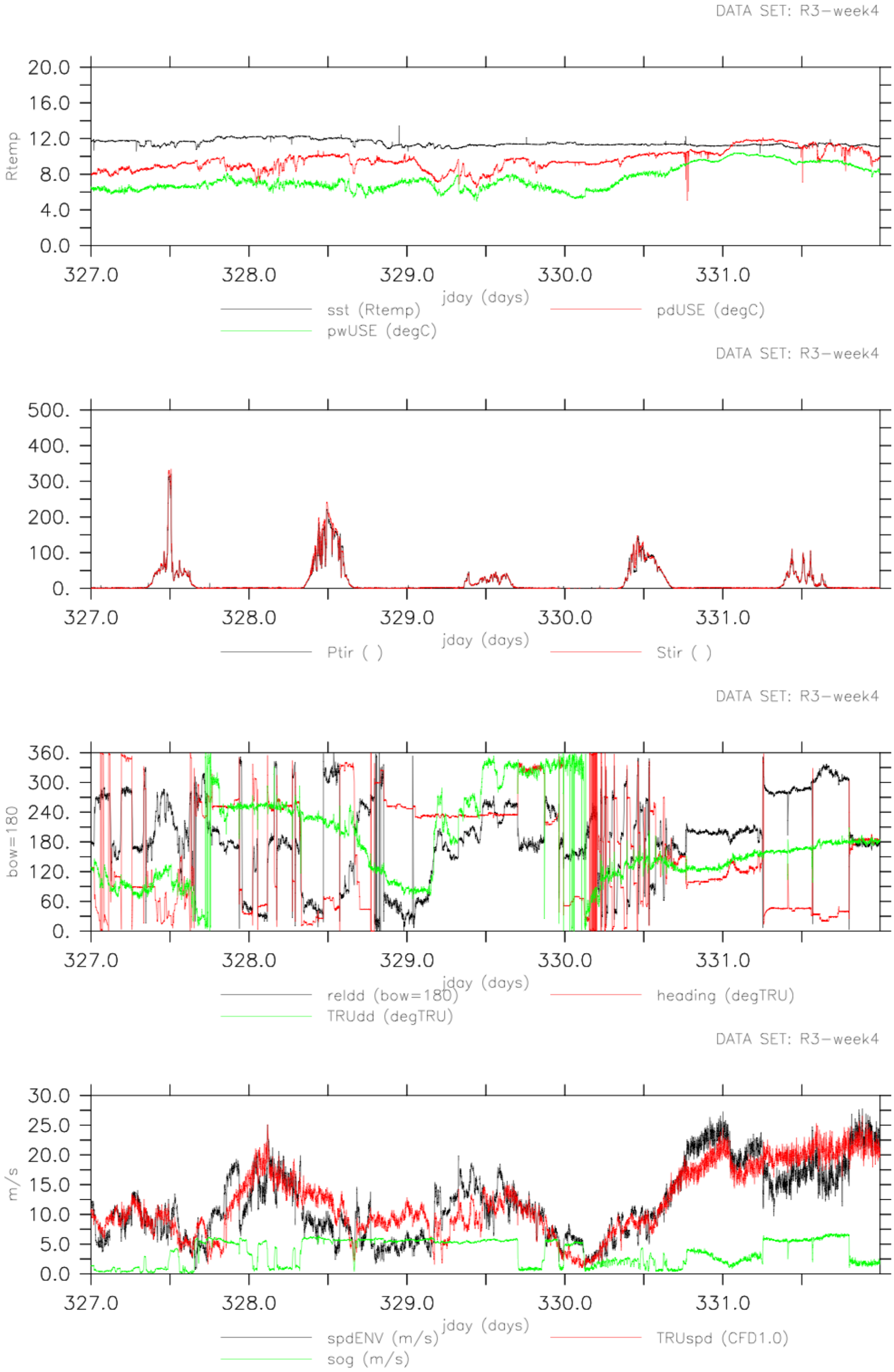

Figure 32. Mean meteorological data for days 327 to 332.

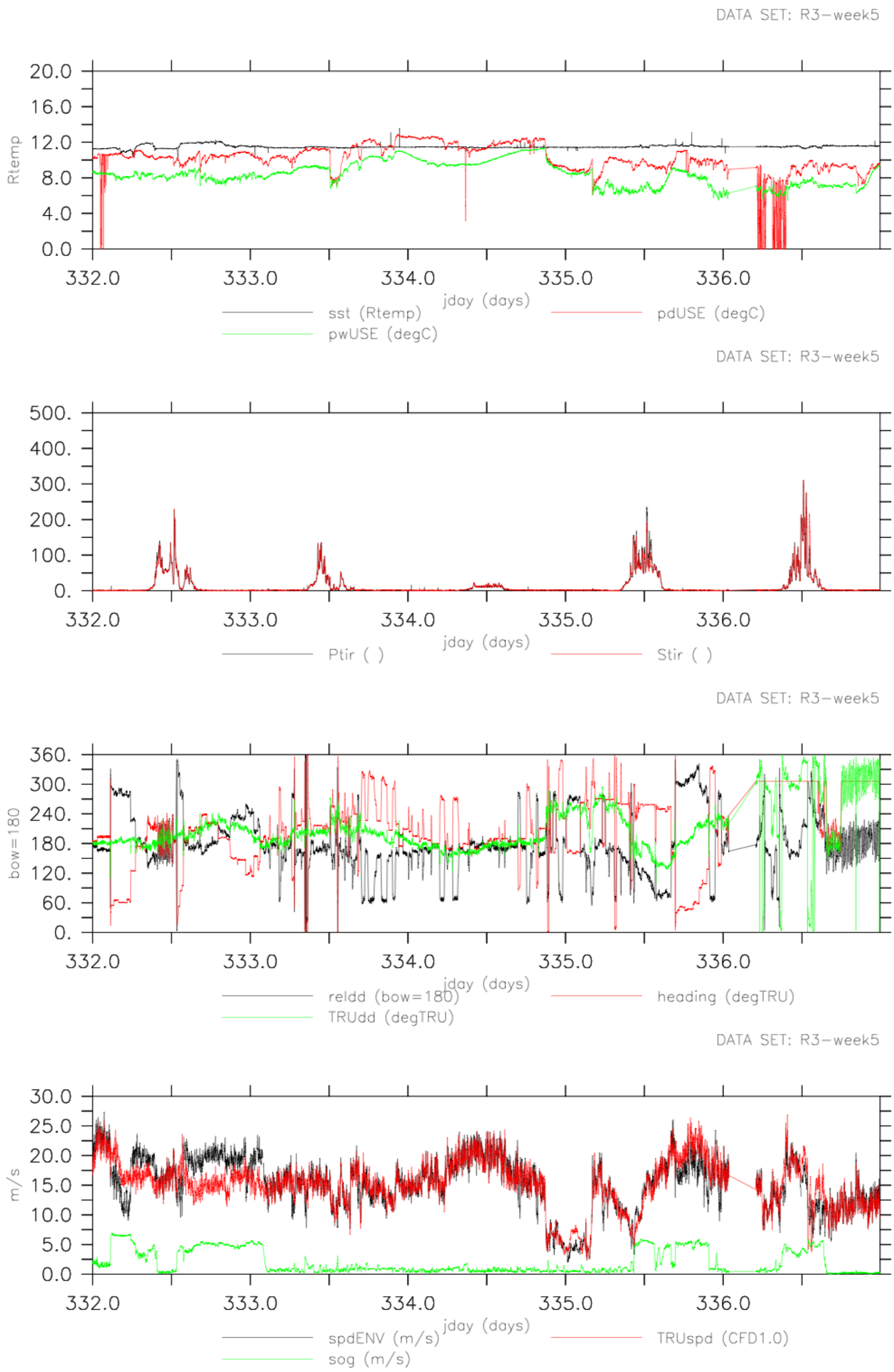

Figure 33. Mean meteorological data for days 332 to 337.

Wave Buoy

Ben Moat[1], David Coles[2], Stephen Harrison[1], Dan Comben[1]

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Introduction: A spar buoy has been developed and instrumented at NOC to simultaneously record (by video) and measure (by capacitance wave wires) wave breaking. In addition, the buoy has been instrumented with a system developed by ISVR to quantify the bubble populations produced by breaking waves both at the sea surface and beneath it using acoustic methods. The aim is to develop and improve parameterisation of wave breaking and its contribution to gas exchange. The buoy has been designed to log all data internally and be independent of the ship. Maximum deployment times are approximately 3 days, but this will be increased for future cruises. The spar buoy is a unique design and its performance and systems are evaluated in the following sections.

The spar buoy: The spar buoy is 11 m in length and constructed of Aluminium to save weight (Figure 34). The buoy floated vertically in the water and used a vane to help orientate the buoy into the wind (Figure 35a).

Two 12 V and one 24V battery were located at the base of the buoy and were used to power the instruments and logging systems. The buoy was ballasted by a 40 kg weight deployed 20 m below its base for deployment numbers 1 to 5 (Table 7). Due to the shallow water depth during deployment 6 the ballast was raised to a height of 10 m below the base.

The transducers for the acoustic system are oriented upwards to face the sea surface and are mounted on the silver aluminium plate above the batteries on the base of the buoy. An array of three hydrophones is used to measure the signals from the transducers and can be seen in the middle of the buoy. The acoustic system electronics were located in a pressure housing directly behind the transducers.

Three 4 m wave wires stretched along most of the top yellow section and were used to measure the wave height relative to the buoy. The three wave wires are perpendicular to each other and separated by a distance of 0.1 m (Figure 35b). The orange dome contained the wave wire electronics, a digital video recorder and a stills camera to record the images of the waves and identify breaking waves.

The large hoop above the dome is used for buoy recovery. To aid recovery the buoy was located by an Argos positioning system, which is used for radio directional finding and emails a position every hour. In addition, a strobe light was installed.

Instrumentation:

Wave breaking system: Waves heights, buoy motion and compass data were logged to a 1 Gbyte flash card at 40.96 Hz and 8 Hz respectively. Data were written to the card in 10 minute sections. The logger system clock was checked against the ships time before each deployment and the offset from GMT is recorded in Table 7. The wave wires were calibrated in Govan dock on day 307, before the start of the cruise. During passage between the working area and Stornaway all three wave wires were damaged by the waves breaking over the aft deck. These were replaced and calibrated in Greenock on day 327. The calibrations applied are shown in Table 8. The wires connecting the individual wave wires to the logging system were colour coded in the following manner, wave wire 0 (blue), wave wire 1 (green) and wave wire 2 (red).

Table 8. Calibrations applied to the wave wire data.

	Wave wire	Height=m*(register)+c	
		m	c
Govan (Day 307)	0	0.000070320	0.33000
	1	0.000070230	0.23590
	2	0.000070260	0.33340
Greenock (Day 327)	0	0.000068953	0.33467
	1	0.000069901	0.28587
	2	0.000069972	0.35520

The base of the dome was transparent allowing the camera systems to record the waves travelling past the wave wires. The JVC Everio GZ-GM77EK hard disk camcorder recorded video to an internal hard disk in Mpeg 2 format and will last approximately 37 hours before the disk is full. The Nikon Coolpix 5400 stills camera recorded 16 images at 648x486 over a period of 7 seconds (2.3 images per second) with a 7 second pause in-between. The images are arranged onto a single image, in a 4x4 matrix, at a 5 Mpixels resolution. The images will fill the 2 Gbyte card in approximately 17 hours. The cameras times are not yet synchronised with the logging time and were found to be 18 seconds fast (video camera) and 7 mins and 11 seconds slow (stills camera) on day 327. To identify breaking waves the camera times have to be syncronised with the logger times. Therefore, for these deployments the cameras and logger times were synchronised by noting the times when all systems entered the water. This will be modified for later cruises (see **Future Improvements**, below).

The logging system and cameras were initialised in the lab and the dome sealed by a number of bolts. The system was taken out on deck and connected to the buoy. Water ingress into the dome was not encountered during the deployments, even when the dome was repeatedly submerged beneath the surface during recovery on JD 333.

Acoustic system: The system was controlled by a PC situated inside the main pressure housing. Matlab routines, which create waveforms and output them through a data acquisition (DAQ) card, are compiled to executable files and then set to run on start up of the computer. The signals are then amplified and sent into the water through transducers. They are then recorded by the hydrophones and stored on a hard drive. Once the buoy is back onboard the ship, the data can be downloaded for processing.

Equipment used had the requirement of being able to measure change in attenuation and sound speed at different points in the bubble clouds. The signal sent into the water was a train of 14 pulses of varying frequency. The frequencies ranged from 3 kHz to 197 kHz. Each pulse was 1 ms long, and the separation between the pulses was 20 ms. Figure 36 shows a typical recording received by the hydrophones. There is a large variation in the amplitude of the pulses due to the differing sensitivities of the three transducers used to transmit the pulses into the water. Table 9 shows the frequencies used and the bubble radii whose resonances they correspond too.

Table 9. Bubble sizes used in the experiment and their corresponding resonant frequencies

Bubble Radius / μm	Frequency / kHz
1107	3
474	7
332	10
184	18
138	24
115	29
87	38
72	46
50	66
39	85
28	118
25	135
21	160
17	197

.

Spar buoy performance: A total of five deployments were made during the cruise. A test deployment (D313#001 and D313#002) was performed in the Mull of Kintyre (Figure 35a) and showed that launching the buoy in the lee of the ship (wind over the port beam) should not be attempted as the ship drifted over the top of the buoy. The preferred method is to deploy with ship's starboard beam facing the wind so the ship is blown away from the buoy. A summary of the deployments are contained in Table 7.

During deployments visual inspection of the buoy was made and showed that the buoy was being driven through the water in high winds. The hydrodynamic flow over the wind vane caused the buoy to orient the wave wires downwind of the buoy – not what was expected. Before the last deployment (D313#006) the wind-wave was moved further up the wave buoy to lessen this hydrodynamic effect. As a result the aerodynamic effect increased and caused the buoy to orientate itself at 90 degrees to the waves. This problem will be addressed before the next cruise.

Initial Results:

Wave wire system: The quality of the wave wire data and basic wave statistics were calculated during the cruise using Matlab scripts. For example, the significant wave height (Hs) increased from 0.7 m to 1.1 m during deployment 5 and agreed well with the ship borne wave recorder. Breaking waves (e.g. Figure 37) were identified from stills camera images (Figure 38). A method to automate the system will be developed post cruise.

Acoustic system:

The system has proved that it can function very well in oceanic waters and transmit, receive and record acoustic pulses over a wide range of frequencies.

Future improvements:

Before future cruises the following will be investigated:
1) Synchronising the times for all the wave wire systems with each other.
2) The orientation of the buoy into the wind.
3) Improved power management.

Summary:

The buoy and its systems were unique and significant progress was made in evaluating the buoy design and the measurements made. These included:

1) Successful trial buoy deployments.

2) Waves height where successfully measured from all three wave wires and a number of breaking waves identified using camera systems.

3) The acoustic system has proved that it can function very well in oceanic waters and transmit, receive and record acoustic pulses over a wide range of frequencies.

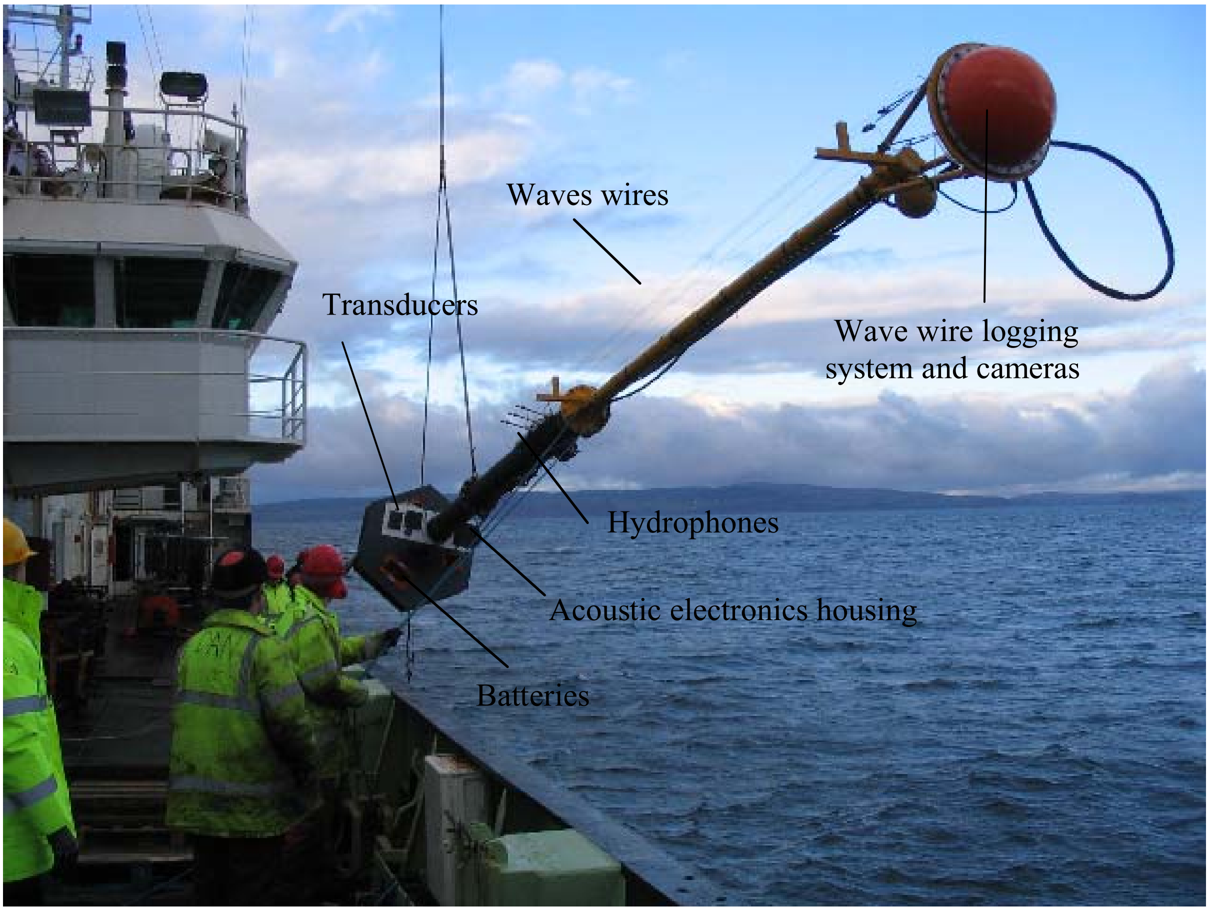

Figure 34. The wave buoy being launched on day 312.

Table 7. Buoy deployments during the cruise.

Launch No	Day	Launch Time (GMT)	Logger Offset from GMT (seconds)	Deployment Lat (N)	Deployment Long (W)	Recovery Time (GMT)	Recovery Lat (N)	Recovery Long (W)	Comments
D313#001	307		n/a	-	-	-	-	-	Calibration Govan (George V Dock)
D313#002	312	08:50	-123	55° 19’ 11.74	005° 23’ 58.92	08:55	55° 19’ 11.74	005° 23’ 58.92	Aborted launch as the ship drifted over the buoy. Reoriented ship to wind and re-deployed buoy immediately. (see D313#003)
D313#003	312	09:35	-123	55° 20’ 24.90	005° 24’ 06.03	11:00	55° 21’ 00.64	005° 22’ 58.32	No data from wave wire 1 (loose connection). No stills images (unknown digisnap fault). No acoustic data due to the screen saver interrupting the acquisition system.
D313#004	322	11:07	-138			11:23	-	-	Wave wires replaced and calibrated in Greenock Dock.
D313#005	323	09:48	-79	55° 46’ 58.85	005° 14’ 44.58	11:59	55° 47’ 47.72	005° 14’ 21.07	Wave wire logger stopped 10 minutes after the dome was bolted to the buoy (possible loose connection see D313#008. Pre-amp gain too high on acoustic system.
D313#006	324	10:47	-80	55° 44’ 07.52	005° 12’ 00.7	14:30	55° 44’ 31.87	005° 09’ 53.41	Wave wire 1 damaged on recovery and was replaced. No acoustic data from high frequency band.
D313#007	327	09:51	n/a	56° 52’ 09.58	006° 01’ 07.51	10:14	56° 52’ 09.58	006° 01’ 07.51	Test of acoustic section only. All three frequencies worked ok.
D313#008	333	13:09	-92	56° 49.73017’	006° 00.12459’	15:06	56° 49.88807’	005° 58.68812’	Fixed loose connection to logger board. Wave wires and acoustic system functioned perfectly.

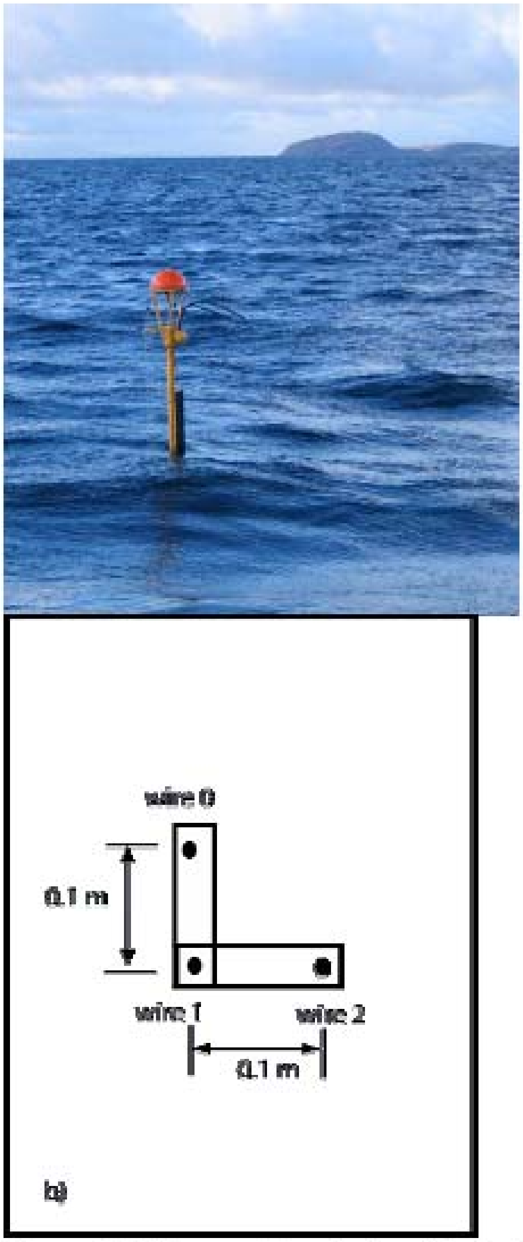

Figure 35 a) The wave buoy deployed in the Mull of Kintyre during day 312 and b) the configuration of the three wave wires (looking from above).

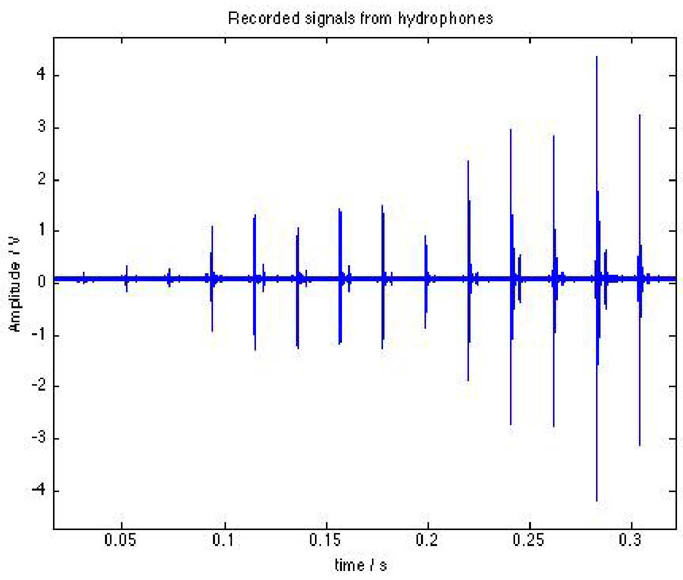

Figure 36. Measured pulses from the acoustic system. 14 pulses can be seen in the recording, each pulse increasing in frequency. The pulses are 1 ms long and separated by 20 ms. Recordings from different hydrophones can be compared to measure attenuation and this information can be used to calculate the bubble population.

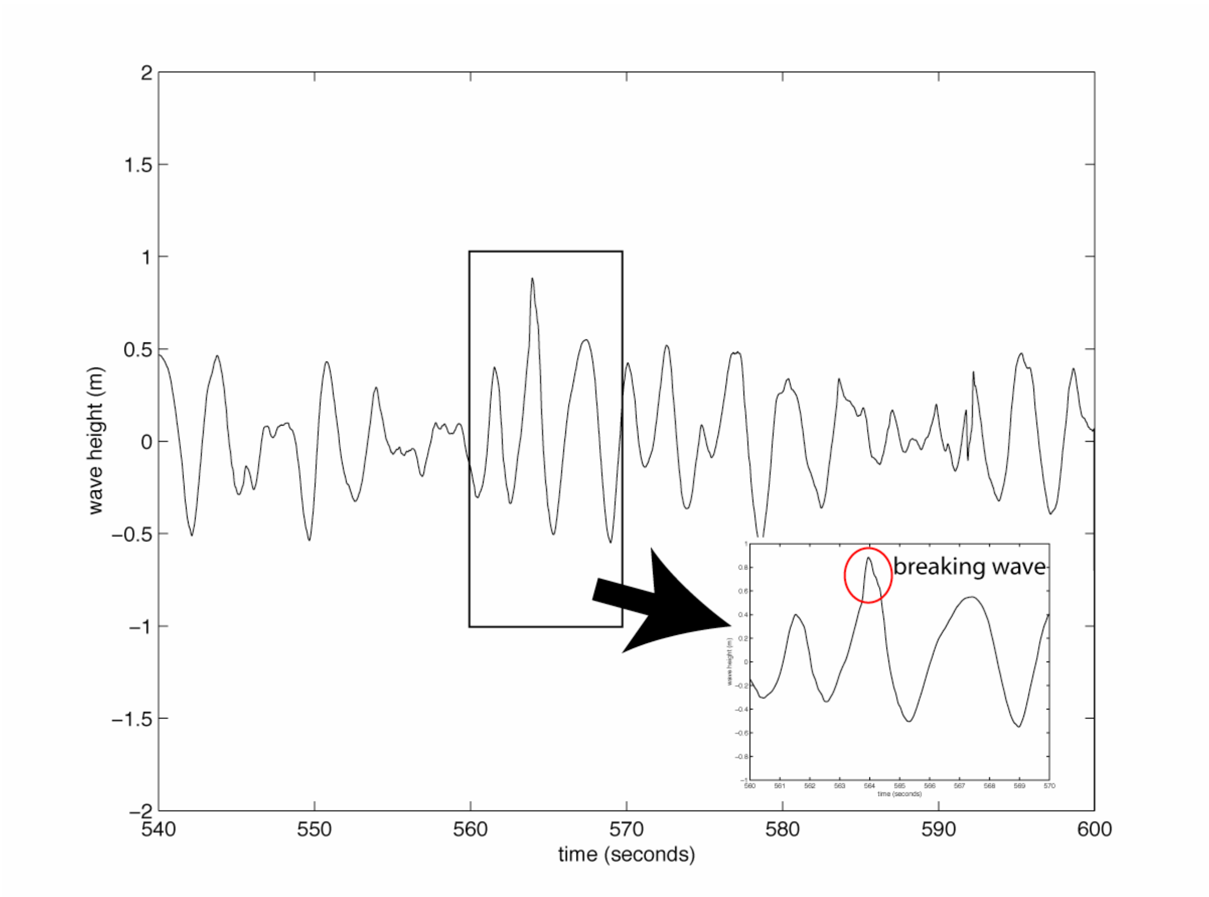

Figure 37. A 1 minute example of a wave trace from wire 0. The inset panel shows a breaking wave identified from video and stills camera images.

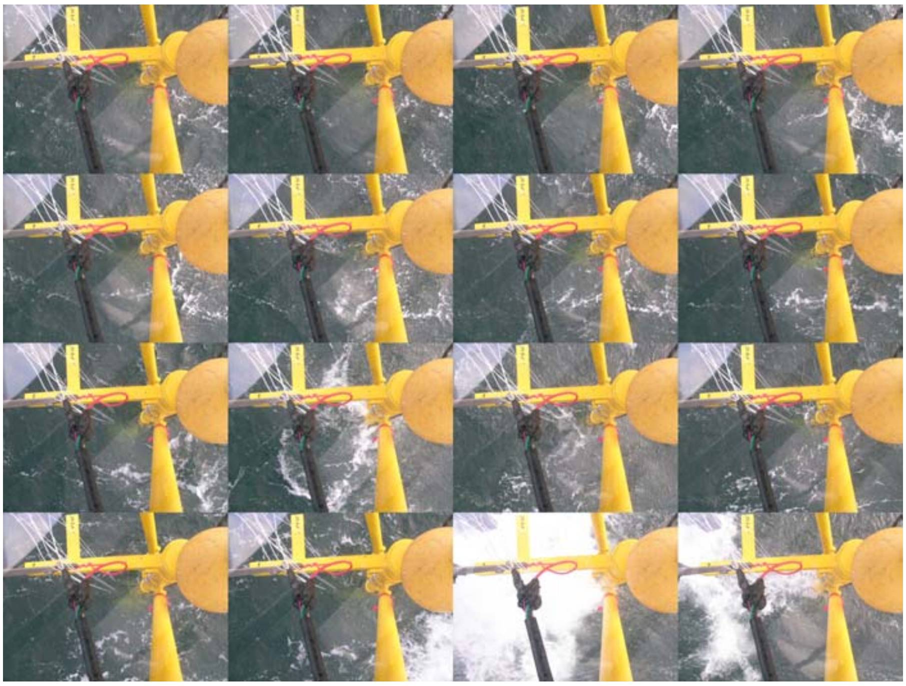

Figure 38. Images from the stills camera showing the breaking wave shown in Figure 36. Each image is taken at approximately 0.5 seconds intervals.

Whitecapping Cameras

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Introduction: Two Nikon Coolpix 8800 cameras were installed on the bridge to measure the whitecap fraction of breaking waves at the sea surface. The cameras were located on the port side of the bridge at a height of 13 m above the sea surface. Camera 1 was set at an angle of 22 degrees from the horizontal so that the top of the image was set to the horizon. Camera 2 was angled as far down as was possible without including any of the ship in the image and corresponded to 29 degrees from the horizontal. Images were taken directly abeam at a resolution of 3Mpixels every 30 seconds during daylight hours and recorded to internal 1 Gb flash cards. The cameras generated 1.6 Gb of data per day, which was transferred to an external disk and the ships UNIX systems daily.

Data Processing: The basic assumption is that for each image all pixels with grey levels above a certain threshold value correspond to whitecaps, and all other elements in the image having grey levels below that threshold correspond to non-whitecap areas (Figure 39). It is relatively straightforward to determine the threshold value by visually inspecting each image in turn using image-processing software. Unfortunately it is impractical to do this for the 46,000 images collected from both cameras during the cruise. Therefore the aim is to automate the process to determine a threshold level for each image and determine the whitecap coverage.

Matlab scripts were used to process 1000 images over a wind speed range of 10 to 20 ms^{-1} from Camera 1 during day 324. Unfortunately, the horizon was included in the images when the ship rolled. This effect and the waves produced by the ship moving through the water were removed by selecting a horizontal strip (85% of the image height) across the middle of the image. A moving threshold based on the rate of change of the intensity of each image was selected to identify the white cap coverage from the background sea surface. Even with a downwelling shortwave of less than 200 W/m^2 Sun glint corrupting the image proved to be a major problem. As every image cannot be inspected for sun glint and it was partially removed from the data by only selecting white cap coverage below 25 %. Further work will be performed post cruise to remove the remaining sun glint from the images and determine the whitecap fraction.

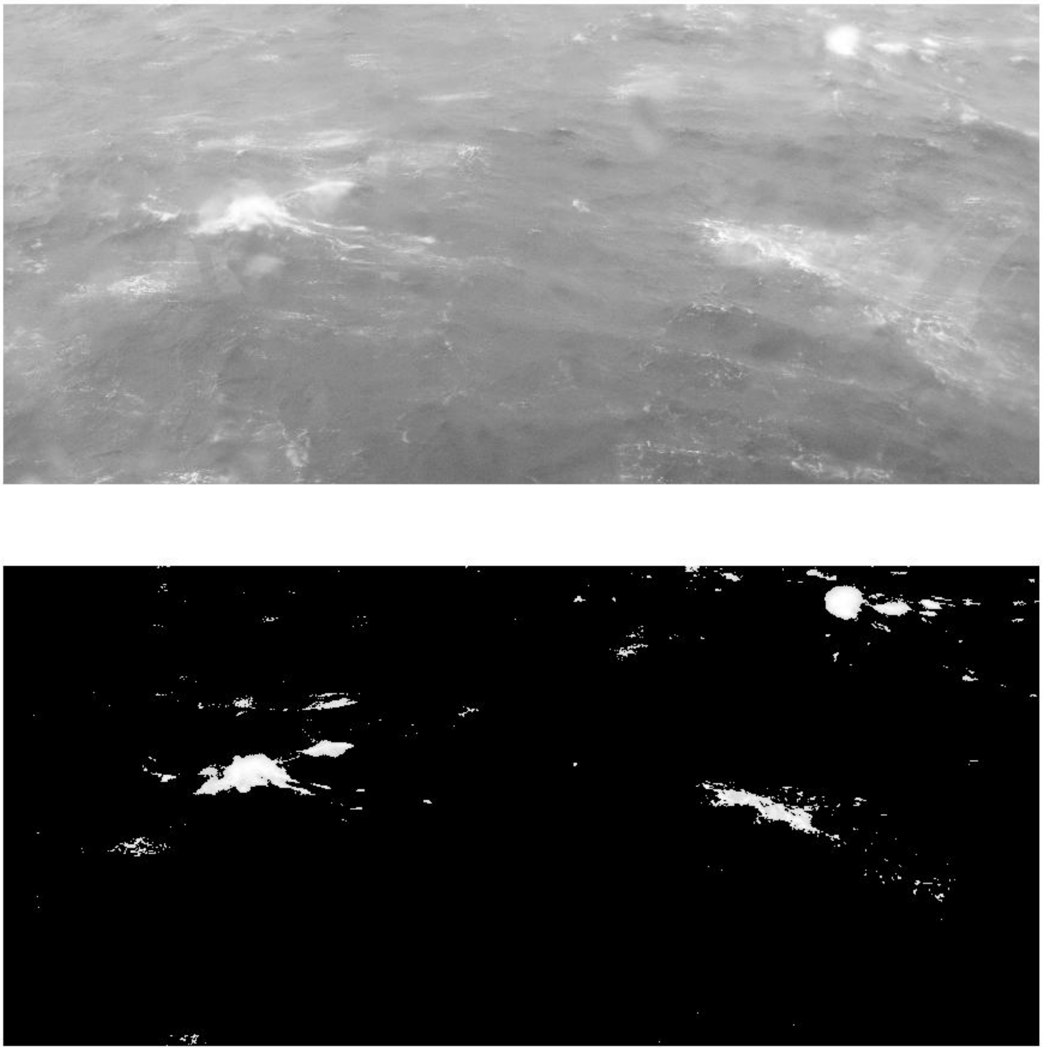

Figure 39. a) An image of the sea surface taken by the forward bridge camera during day 315 and b) the corresponding processed white cap image.

Surface-active substances by AC Voltammetry / Polarography

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The intention prior to the cruise was to test an AC voltammetry/Polarography system at sea. The system is setup to indirectly measure the concentration of surface active substances in natural water samples by referencing to a known surfactant, in this case Triton-X-100.
Electrochemical methods are notoriously inconsistent and the main aims during the cruise were to test its performance and reliability during sea going conditions.
Crucially the system performed better than expected even during the worst weather conditions and a number of successful calibrations were completed throughout the cruise. However a number of issues were raised. The Ag/AgCl 3M KCl reference electrode dried out far quicker than usual whilst on board perhaps due to the air conditioning atmosphere. This problem has been rectified for the next cruise by investing in soak bottles which will now enable the electrode to remain immersed in KCl whilst keeping the electrical contacts dry. A second problem was that after approximately 3 weeks the mercury started to oxidise (something which led to further problems following the cruise). This usually happens over a longer time period, up to 6 months. Replacing the mercury usually solves this problem; however this is less of an option at sea. In this instance though it was recognised that the root cause was that oxygen-free nitrogen feeding the mercury reservoir was being switched off regularly. In future the nitrogen must remain on to avoid such problems recurring.

During the cruise it was also possible to conduct a number of experiments with seawater bought aboard using a Niskin bottle. These experiments showed clear surfactant enrichments in microlayers allowed to form in plastic buckets, further proof that the system worked well at sea.

COCO, a continuous pCO_2 instrument during DOGEE-SOLAS D313

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The CO_2 instrument: The instrument (Figure 40) consists of:

- The instrument cabinet in the laboratory, which includes the LICOR drawer, the mechanical drawer, and the electronics interface,
- a coolbox, next to the instrument cabinet.
- a laptop, close to the instrument cabinet.
- The equilibrator above a sink in the laboratory, connected to the ship's non-toxic seawater supply,
- Two calibration gases in the laboratory,
- An air line from the monkey island,
- A GPS on the monkey island.

Tubing and electronical cables connect the components of the instrument.

Figure 40. The CO_2 instrumentation as installed during D313.

Measurement principles:

- The CO_2 detector, a LICOR 6262, measures the absorption of infrared radiation by CO_2 content in a gas, e.g. within air. The higher the absorption, the more CO_2 is in the air. The LICOR also measures the moisture content of the gas. The gas is partly dried before detection to prevent condensation inside the detector.

- The LICOR detects the mixing ratio of CO_2 in a gas. To measure CO_2 in seawater, the CO_2 in water is brought into equilibrium or 'equilibrated' with the CO_2 content of a headspace. This is done in a gas-exchanger, the "equilibrator". The equilibrator should be put in a sink. For the measurement of CO_2 in seawater, gas is circulated through the equilibrator and the LICOR for about 40 min, during which equilibration is reached. Data are recorded continuously during this time. At the end of each run a final reading is taken at zero flow and at atmospheric pressure.

- The LICOR also determines the CO_2 content of marine air.

- Two calibration gases contain a certified amount of CO_2 at ~250 and ~450 ppm (μmol mol^{-1}) CO_2 in compressed dry air. These standards are analysed regularly throughout the measurement routine to compensate for detector drift. These CO_2 levels have been chosen, because they are just below and just above (most) natural CO_2 values in air and seawater.

- The measurements are done automatically and the results are continuously saved on the laptop. The data is backed up at least every three days via flash card or wireless network connection.

- Data are time stamped in GMT by a GPS. If the GPS connection fails, the CO_2 program will still run but will use the computer clock for time stamping the data.

- Additional parameters are recorded with each CO_2 measurement, i.e. equilibrator temperature and equilibrator pressure.

- Accurate measurement of seawater temperature ('remote temperature'), and salinity by the ship's thermosalinograph are essential for the accurate measurement of surface water pCO_2.

Analysis routines:

The measurement cycle:

The program carries out pCO_2 analyses by repeating a routine of analyses. In the routine the CO_2 content of seawater, air, seawater, the 250 calibration gas, seawater, air, seawater, and finally the 450 calibration gas are determined successively. Once the routine has been completed, the program starts again at the beginning of the routine.

Each routine lasts about 3 hours (Table 10).

Table 10. Contents of the routine for pCO_2 analysis.

No of replicates	Parameter	Approximate duration [min]
1 x	pCO_2 in seawater	30
1 x	pCO_2 in air	16
1 x	pCO_2 in seawater	30
1 x	250 ppm standard	15
1 x	pCO_2 in seawater	30
1 x	pCO_2 in air	16
1 x	pCO_2 in seawater	30
1 x	450 ppm standard	15
Total		~3 hours

Data output file layout: The data are saved in the .txt file. Table 11 lists the contents of the columns in the result files.

Table 11. Contents of the example result file COCOA0**.txt in directory C:\documents\CO2\pCO2\ COCO\Results.

Column	Contents	Unit	1	2	3
1	File	#	A028	A028	A028
2	Run	#	422	422	422
3	Parameter	#	EQU	EQU	EQU
4	Date (GMT)	[dd/mm/yy]	10/11/2006	10/11/2006	10/11/2006
5	Time (GMT)	[hh:mm:ss]	06:58:12	06:59:01	06:59:52
6	Latitude (GPS)	[dd.mms]	56.264491	56.264428	56.264291
7	NorS (North or South)	#	N	N	N
8	Longitude (GPS)	[ddd.mms]	11.028684	11.028687	11.028658
9	EorW (Eats or West)	#	W	W	W
10	Ship's Speed (GPS)	[knots]	0	0	1.1
11	Ship's Course (GPS)	#	284.2	284.2	206.3
12	Magnetic Variation	#	9.4	9.4	9.4
13	EorW (East or West)	#	W	W	W
14	Salinity (or NaN)	#	NaN	NaN	NaN
15	SWTemperature (or NaN)	[ºC]	20.45	20.45	20.45
16	SwOxygen (or NaN)	[umol/kg]	304.21	304.69	306.16
17	InstrTemp?	[?]	-16021	-16025	-16036
18	InstrTempV	[V]	2.5554	2.5548	2.5531
19	InstrTempC	[ºC]	25.26	25.26	25.24
20	Equ1Temp	?	-24842	-24836	-24835
21	Equilibrator 1TempV	[V]	1.2094	1.2103	1.2105
22	Equilibrator 1TempC	[ºC]	12.67	12.68	12.68
23	EngRmTemp?	[?]	-16888	-16848	-16855

24	EngRmTempV	[V]	2.4231	2.4292	2.4281
25	EngRmTempC	[ºC]	23.96	24.02	24.01
26	Equilibrator 2Temp?	[?]	-24709	-24710	-24705
27	Equilibrator 2TempV	[V]	1.2297	1.2296	1.2303
28	Equilibrator 2TempC	[ºC]	12.68	12.68	12.68
29	Mass flow controller	[V]	0.486	0.555	0.529
30	Mass flow controller	[ml/min]	87.870588	100.86152	95.966388
31	Pressure 1	[V]	4.1829	4.1852	4.1891
32	Pressure 1	[mbar]	1,018.30	1,018.50	1,018.90
33	Pressure 2	[V]	-5	-5	-5
34	Pressure 2	[mbar]	100	100	100
35	LICOR CO2mV	[mV]	0	0	0
36	LICOR CO2Pa	[Pa]	348.16	359.87	361.64
37	LICOR CO2ppm	[umol/mol]	348.16	359.87	361.64
38	LICOR H2OmV	[mV]	0	0	0
39	LICOR H2OkPa	[kPa]	-6.098	-4.992	-4.802
40	LICOR H2Ommol	[mmol/mol]	-6.098	-4.992	-4.802
41	LICOR PresNaN	#	NaN	NaN	NaN
42	LICOR Pressure	[mbar]	1013.71	1013.08	1013.93
43	LICOR TempNaN	#	101.371	101.308	101.393
44	LICOR Temperature	[ºC]	0.2475	0.2475	0.2472
45	LICOR DewNaN	#	NaN	NaN	NaN
46	LICOR DewNaN	#	NaN	NaN	NaN
47	LICOR Dewpoint	[ºC]	1.3847	1.3827	1.3855
48	NaN	#	NaN	NaN	NaN
49	NaN	#	NaN	NaN	NaN
50	NaN	#	NaN	NaN	NaN
51	NaN	#	NaN	NaN	NaN
52	NaN	#	NaN	NaN	NaN
53	NaN	#	NaN	NaN	NaN
54	NaN	#	NaN	NaN	NaN
55	NaN	#	NaN	NaN	NaN
56	NaN	#	NaN	NaN	NaN
57	NaN	#	NaN	NaN	NaN
58	NaN	#	0	0	0

Data processing: Microsoft Office Excel and Matlab version 6.5 were used. The data processing sequence was similar to that followed by Ute Schuster and Dorothee Bakker during previous research cruises with UEA's underway pCO_2 system onboard. Atmospheric pressure and LICOR drift corrections were applied onboard. Preliminary data still need to be corrected for temperature and humidity.

Preliminary results: Figure 41 shows atmospheric and marine pCO_2 values for first two weeks of the cruise. Two port calls and several hours spent in the shallow waters due to the extremely difficult weather conditions made us spend most of the time in coastal waters. Due to low speed of the vessel and strong winds from the aft air inlet was collecting artificially CO_2 enriched samples.

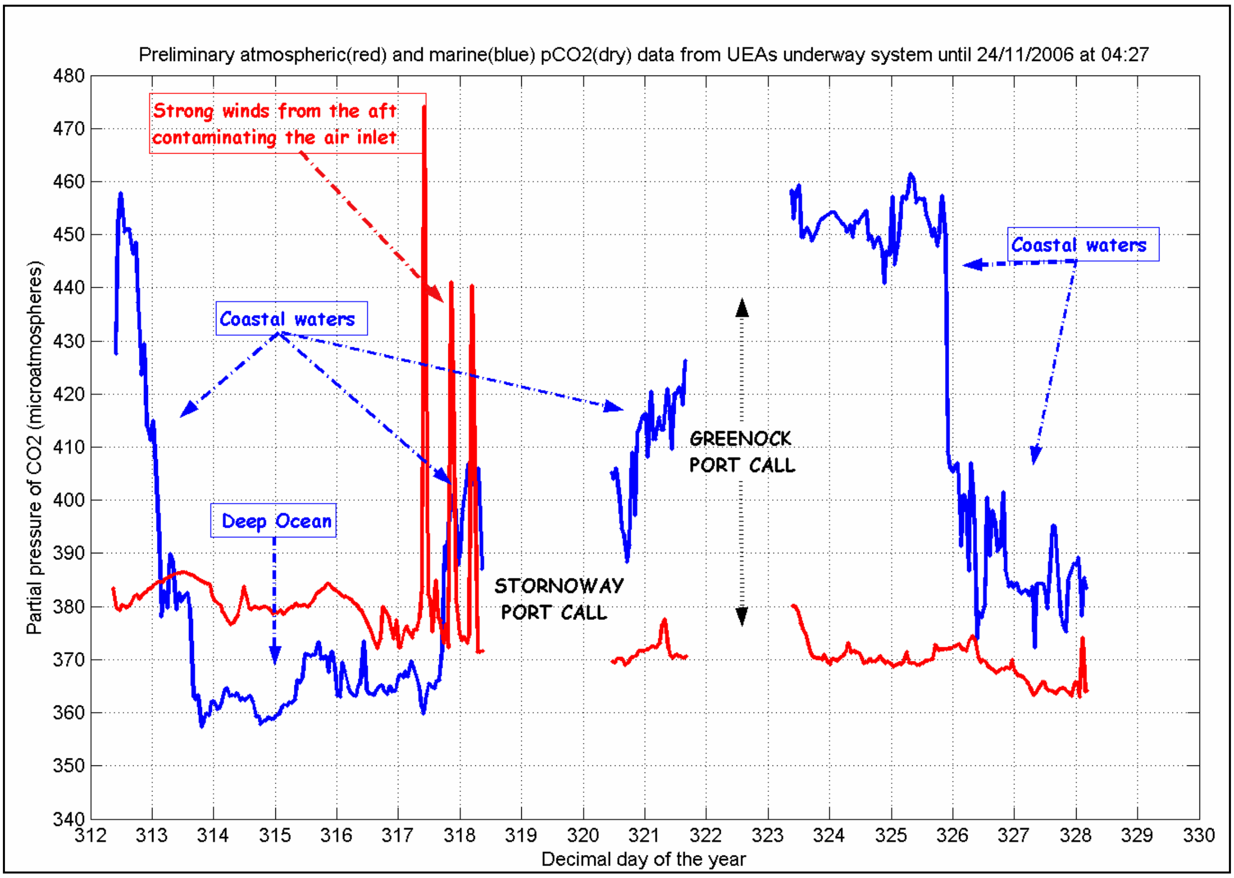

Figure 41. Preliminary pCO_2 results from first two weeks of D313.

Discreet samples for other carbon system parameters: 8 doubled water samples were collected from each CTD cast (5). Depths varied but the deepest sampled depth was always 500 meters. Other depths were chosen according to the depth of the mixed layer. 3 samples were collected from above of the mixed layer depth, another 3 followed the changes in temperature and salinity and the last one was collected from below the mixed layer.

Samples will be analyzed in the laboratory. Total alkalinity and Dissolved Inorganic Carbon will be measured.

SEASAW

Ian Brooks, Institute for Atmospheric Science, School of Earth and Environment, University of Leeds, LS2 9JT

Scientific approach and measurements: A novel approach of SEASAW was to deploy a new, light weight and compact aerosol instrument (CLASP) developed at Leeds for measuring eddy covariance aerosol fluxes. Previous studies of sea-spray source functions used indirect methods to infer the source function by observing the mean aerosol population over hours to days. The size and integration times of most aerosol instrumentation precludes direct measurement of the vertical turbulent aerosol flux via eddy covariance. SEASAW utilised three CLASP instruments collocated with a sonic anemometer and LiCOR7500 gas analyzer on the foremast RRS *Discovery* to make direct measurements of the aerosol flux in 16 size bins between 0.1 and 3.5 μm radius.

Background aerosol spectra between 3nm and ~300μm (radius) were obtained from a suite of instruments. The largest particles were measured with Particle Measuring Systems (PMS) FSSP and OAP probes located on deck above the bridge. All other aerosol instruments were located in a container lab on the port side forecastle deck with a 40mm diameter inlet run from the monkey island to provide an air sample uncontaminated by ship exhausts at approximately the same level as the turbulence instruments.

The electrical conductivity of air results from the balance between charged molecular cluster ion production and their removal by aerosol particles, and has a strong sensitivity to aerosol number concentration. Electrical conductivity and background electric field strength data were provided by two instruments on loan from Reading University. An electrostatic field mill mounted on the foremast with the turbulence instrumentation allowed measurement of the electric field and a Programmable Ion Mobility Spectrometer (PIMS) mounted above the bridge provided conductivity measurements. Data for North Atlantic air electrical conductivity from the early to mid twentieth century show a temporal decrease attributed to increasing aerosol but the measurements ended around forty years ago. Data from D313 should extend the time series to > 100 years; this will enable inferring long-term large scale changes in aerosol loading over the North Atlantic. Associated with the long-term conductivity change is one in the atmospheric electric field; such data can provide corroborating evidence of changes in the conductivity, and information on the generation of charge in the marine atmospheric surface layer.

SEASAW also aimed to make direct estimates of the CO_2 flux under high wind speed conditions via the eddy correlation technique.

Instrumentation:

***Foremast Flux system*:**

- Gill R3A sonic anemometer – 3D turbulent wind components at 50Hz
- LiCOR 7500 open path gas analyzer – H_2O and CO_2 concentrations at 20Hz
- CLASP aerosol probe – 16-bin aerosol spectra at 10Hz, 0.1 and 3.5 μm radius
- motion pack – 3-axis linear accelerations, pitch, roll, and heading at 20Hz.
- JCI 131 electrostatic field meter

***Background Aerosol*:**

- TSI ATOFMS – single particle aerosol mass spectrometer providing chemical composition
- PMS FSSP
- PMS OAP
- PCASP
- TSI 3762 CPC
- TSI 3025 CPC
- Grim CPC
- Grim dust monitor
- PIMS III Programmable Ion Mobility Spectrometer

***Aerosol Composition*:**

- Aethalometer
- VACC – PMS PCASP and volatility system providing chemical composition and mixing mode information via changes in aerosol spectra with temperature

***Aerosol Buoy*:**

- 2 CLASP aerosol probes with inlets at ~0.5 and 1m above the surface
- Subsurface bubble camera provided by TNO – photographic images of bubble populations at ~0.4m below the surface

Results: We were fortunate that the atmospheric sampling and measurement systems were far less restricted by weather conditions than the oceanographic measurements, thus we were able to collect data throughout most of the cruise. However, the very limited time spent in the open ocean severely restricted the volume of data collected for our primary science goals to a few tens of hours. The best operational conditions in the open ocean were obtained during the first few days of the cruise, before all of our measurement systems were fully operational.

Measurements: Turbulence instrumentation has been run almost continuously during the entire cruise. During the overnight transit out of Govan the magnetic compasses in the motion packs were run in calibration mode – this enables the automatic correction for magnetic field distortion by the ship. Both motion packs achieved good calibrations. The turbulence system runs continuously, saving data to 1-hour files. The system was stopped approximately twice daily in order to transfer data from the logging system on the mast back to a PC in the main lab. Time synchronisation with other data systems was ensured by syncing the logging system clock to the ship's time server several times an hour. None of the instruments on the mast have suffered any problems. There was concern prior to the cruise that the CLASP aerosol instruments would degrade with time due to accumulation of salt on the optics; however, the first unit has produced consistent data throughout, and the backup units have not been required.

Much of the aerosol instrumentation has been run with new interface electronics for the first time, and with entirely new logging software; this was brought on stream gradually during the first few days at sea to allow testing and modification of the new software, and has subsequently run continuously during the cruise, with intermittent periods of downtime for individual instruments due to technical problems.

The tethered buoy has only been deployed three times. The initial deployment on the morning of November 19 was cut short due to operations by fishing vessels requiring the Discovery to relocate, but allowed the motion pack compass to be calibrated. A second deployment on the afternoon of November 19 allowed the collection of data for approximately 3 hours, during a period of increasing winds and whitecapping. This should provide a good data set for studying whitecap and aerosol production. The bubble camera was not operated during this deployment due to corrosion of a cable connector. The cable was repaired and the camera operational for the third deployment on November 20. Approximately one hour of data was collected during this deployment, before it was cut short by a ship manoeuvre that dragged the buoy entirely underwater. In theory the CLASP units are waterproof, and the only damage that should result from water being drawn into the system is to the carbon vane pump. The upper CLASP unit survived the submersion, and after replacement of the pump and cleaning of the optics is operational again. The lower unit suffered from the failure of a seal around the flow sensor under the pressure of water during the submersion, spraying seawater across the electronics of the sensor head, ruining the entire unit. Operationally, it was found that deployment from the aft knuckle crane was possibly the worst site for the intended measurements: the location suffers from upwelling of water from the props around the stern; this severely modifies the surface wave field so that for substantial periods of time the buoy is not measuring waves typical of surrounding environment. Deployment from further forward would be a better option for future operations.

Preliminary Results:

Turbulence: The turbulence data require substantial processing before meaningful results can be produced, but some selected example data are shown below. In order to derive turbulent transport statistics the motion of the ship must be removed from the measurements of airflow by the sonic anemometer, and the measurements rotated into a stationary geodetic coordinate system. This is achieved through merging the high frequency measurements of ship attitude and motion obtained from the motion pack with the low frequency ship motion data from the navigation system, and removing the resultant velocity from the measured air velocity. The motion pack measures pitch, roll, heading and 3 linear acceleration components. Integration of the accelerations provides 3 velocity components, but requires careful filtering to remove the accumulating error that results from any bias or offset in the zero levels of the accelerometers. Figure 42 shows the power spectrum of the vertical velocity of the ship during a one hour period. The wave motion stands out as a clear peak at approximately 0.2 Hz (~5 second wave period). Figure 43 shows the power spectrum of the vertical wind component for the same period; a -5/3 slope is indicated for comparison – this defines the inertial subrange. No evidence of ship motion is visible in the spectrum. Figures 44 and 45 show cospectral energy densities and the running integral of the spectral energy – which shows the cumulative flux as a function of frequency – for the vertical velocity variance, and the wind stress for the same period as figures 42 and 43.

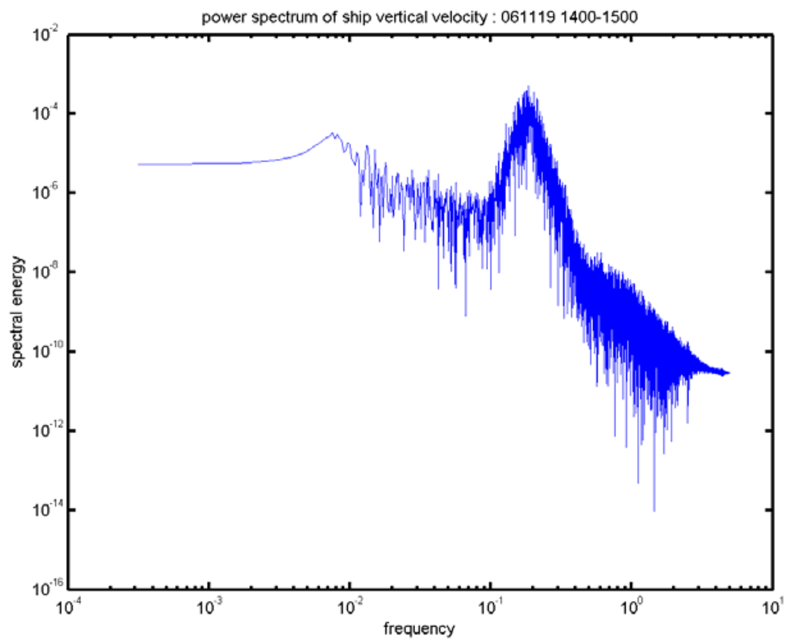

Figure 42. Power spectrum of ship vertical velocity

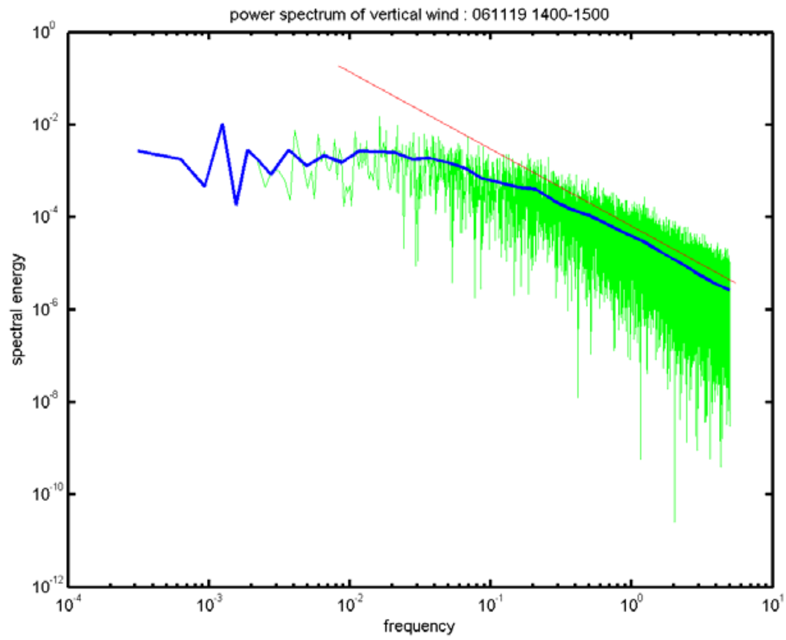

Figure 43. Power spectrum of vertical wind component (green), the bin-averaged spectrum (blue) and -5/3 slope (red) for comparison.

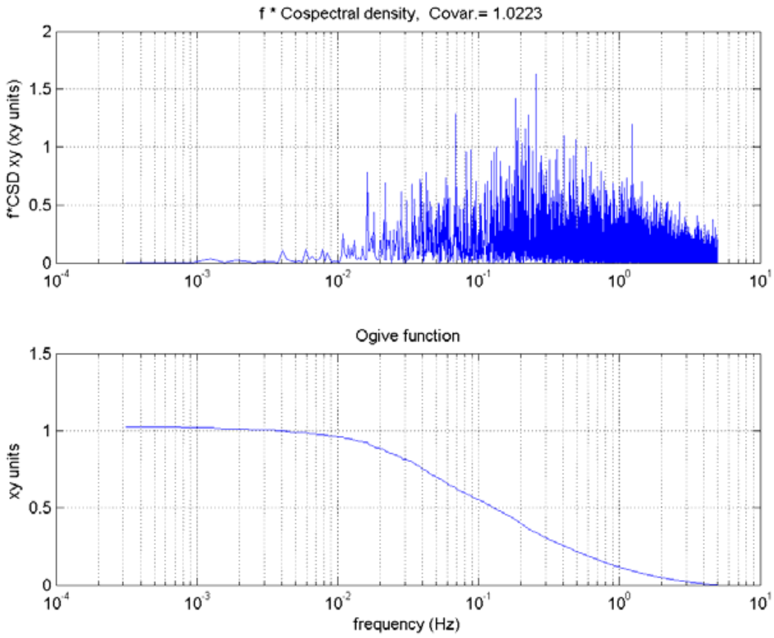

Figure 44. cospectral density and cumulative flux as a function of frequency (ogive) for the vertical velocity variance.

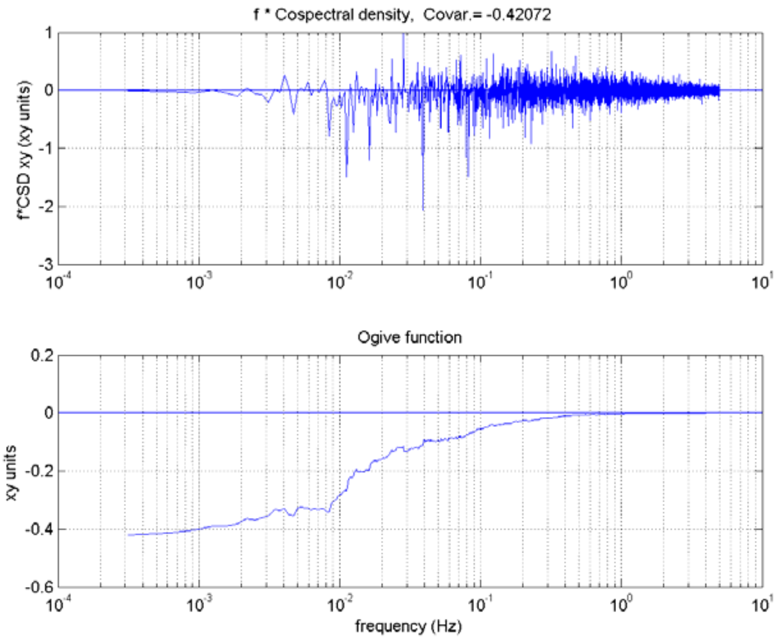

Figure 45. cospectral density and cumulative flux as a function of frequency (ogive) for the wind stress.

Figure 46 shows power spectra of ship vertical velocity and vertical wind speed from November 11, during a period in the open ocean with approximately 10-m waves. In this case there is a significant signal from the wave motion in the vertical wind after the motion correction has been applied. It is not yet clear exactly what is going on. There are several possible explanations to investigate: that the motion correction algorithm is inadequate; that there is significant ship-attitude dependent flow distortion that is not accounted for by the motion correction; or that the measurements are within the wave-boundary layer, where the mean flow follows the topography of the large-scale waves, so that the wave-signal in the vertical wind is a true representation of the flow.

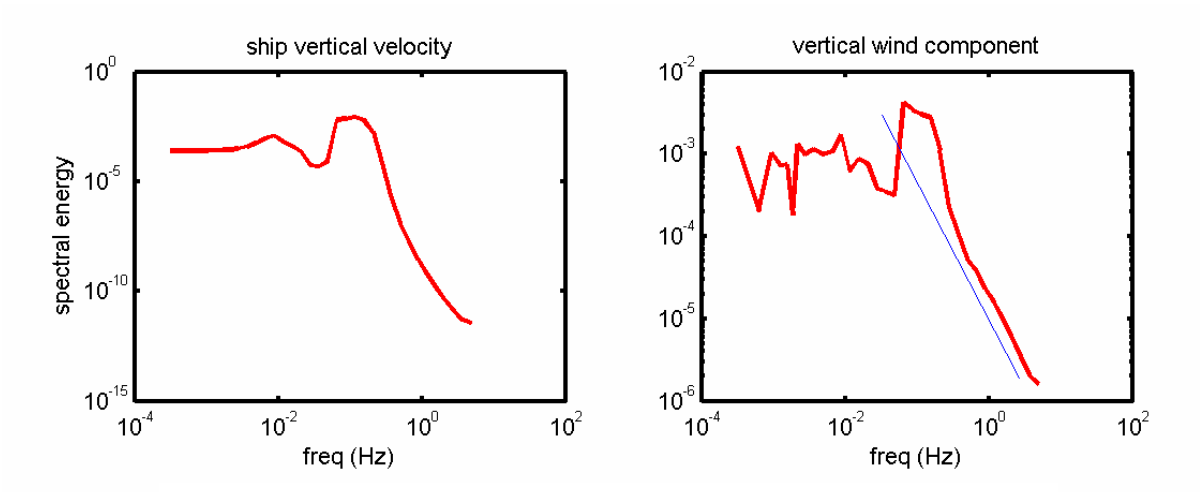

Figure 46. Power spectra of ship motion and vertical wind under conditions of 10-m waves, showing the influence of the waves on the vertical wind component

Aerosol: The aerosol data require significant processing and quality control before they can be interpreted, but some quick-look preliminary data are shown below. Figure 47 shows 1-hour averaged size spectra from three different instruments (PCASP, FSSP, OAP) covering the larger aerosol size ranges. Figure 48 shows 1-hour average spectra from the CLASP instrument on the foremast.

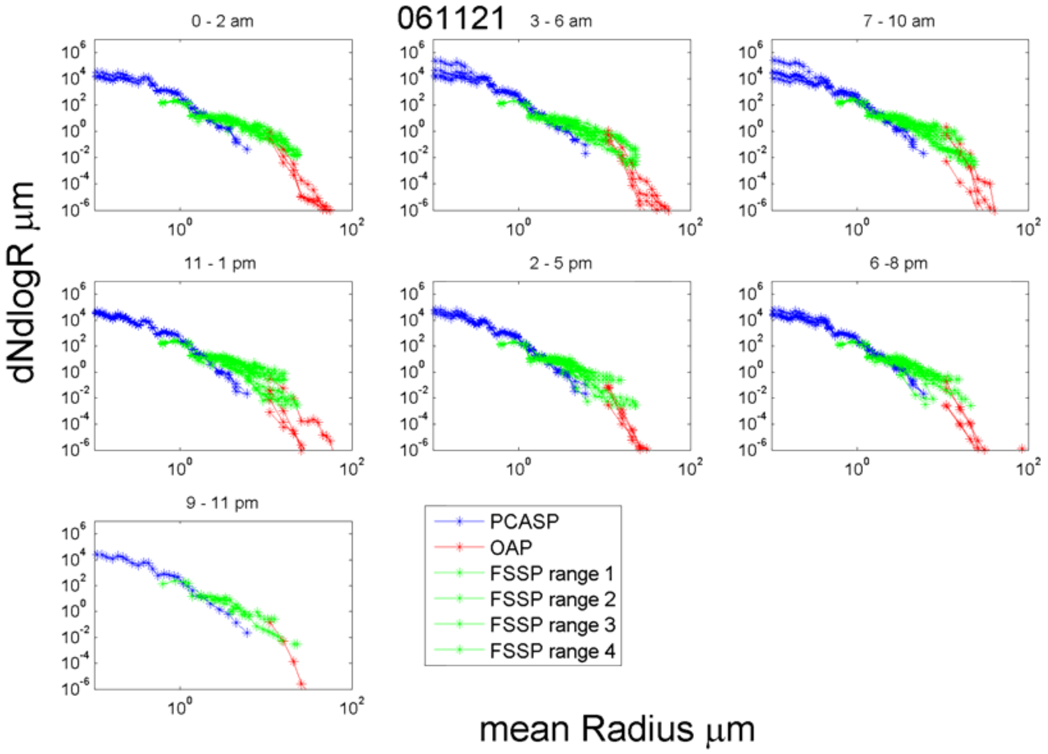

Figure 47. Preliminary aerosol size spectra

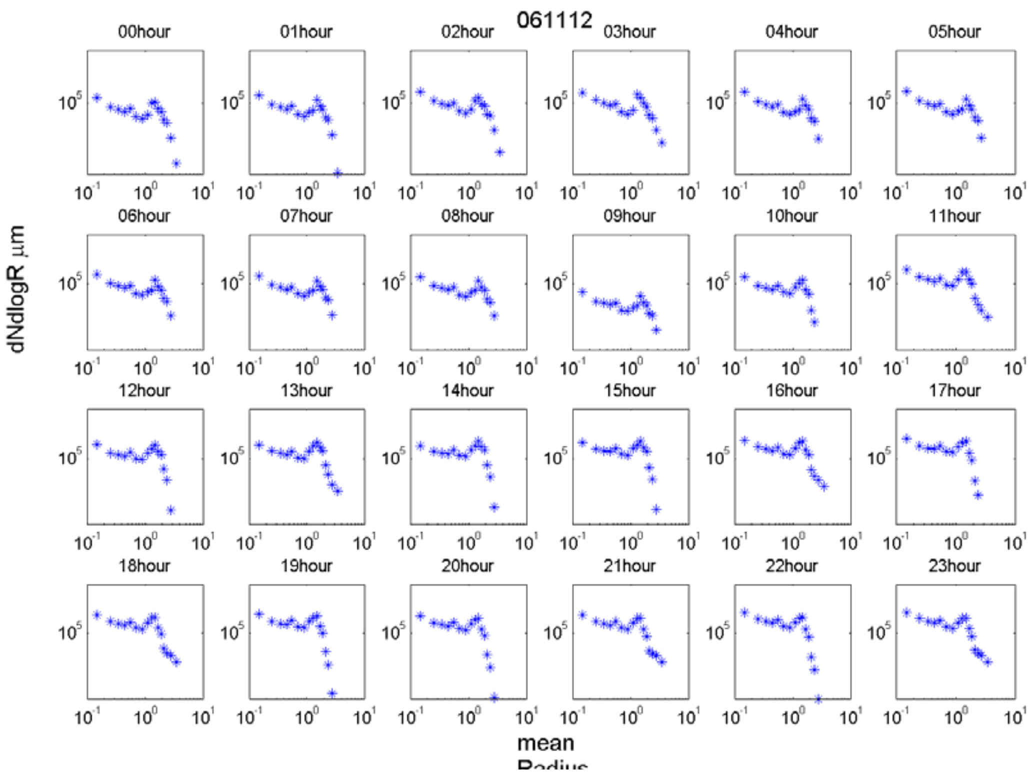

Figure 48. Preliminary size spectra from the CLASP instrument on the foremast

Bubble imaging: The bubble camera on the tethered buoy takes bursts of approximately 2000 photographic images over a period of a few minutes, then applies a thresh-holding algorithm to produce a simple binary black/white images (figure 49); these are then processed to derive size spectra for each measurement interval (figure 50).

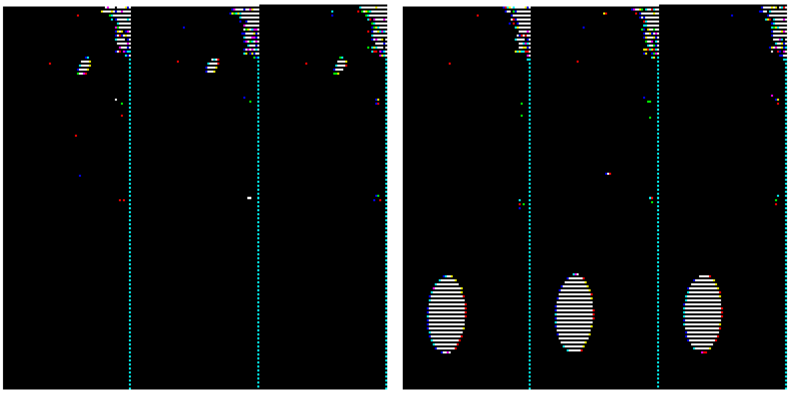

Figure 49. Binary images of bubbles from the TNO imaging system.

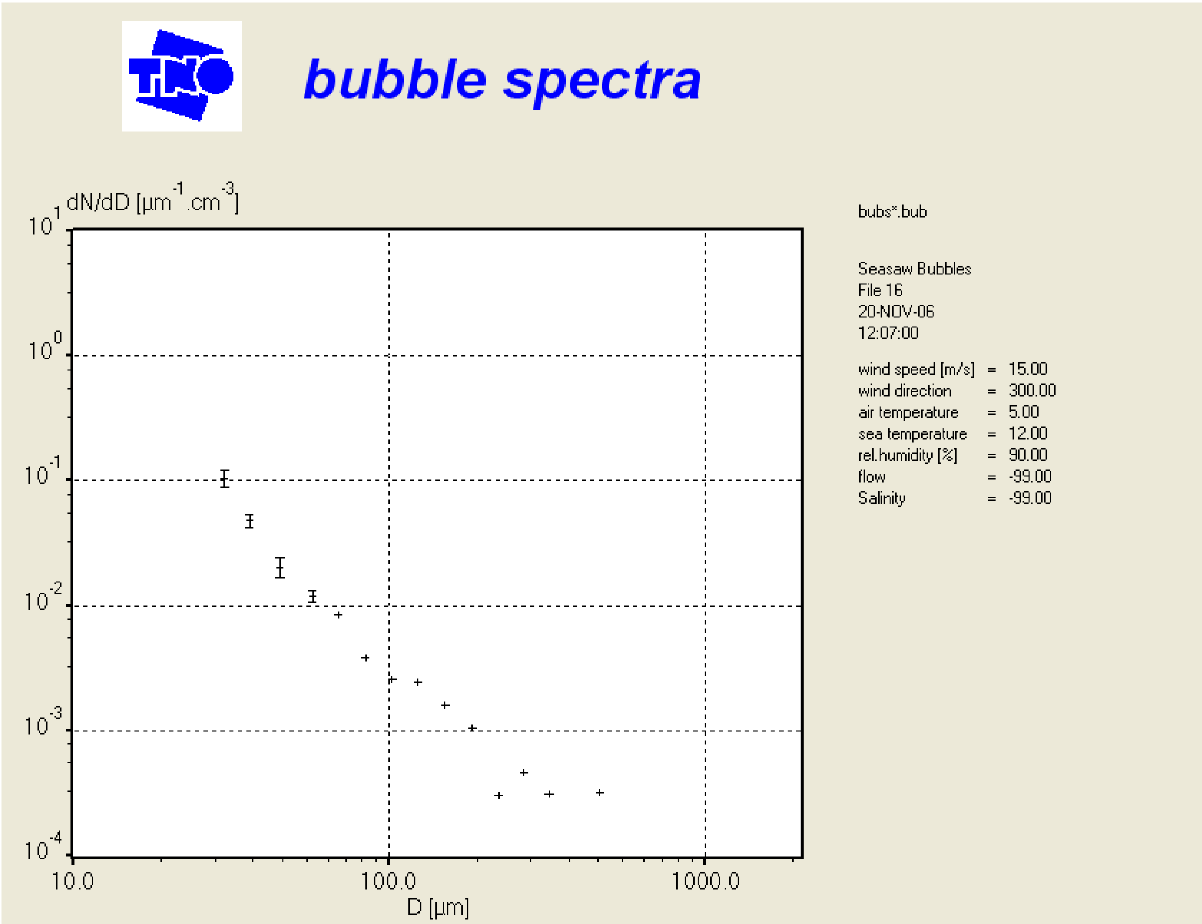

Figure 50. Bubble size spectrum

Some observations of cruise logistics and management.

- **Mobilisation:** During the cruise planning meeting in July, it was emphasised to us that Leeds would be the first to start installing and that we needed to be on the quayside with our kit at 8:30am on November 2nd, we confirmed to Malcolm that we would be there at that time about a week prior to mobilisation. It was disappointing to find on arrival that no one on the ship was expecting us.

- **Problems:** Problems with initial installation of the container lab on the forward port side container slot delayed installation of the lab kit by almost a day. It appears that the container we used had never been used in that slot before, and it was discovered that the door could not be opened. The crew did a good job of sorting out the problem – moving another equipment installation and repositioning the container.

- The air conditioning to the container failed early in the cruise, due to a burst water pipe, resulting in a small flood (fortunately damaging only paperwork), and overheating of the container, causing some of the instruments to shut down. Dan Comben is to be thanked for sorting out repairs at a time when he was extremely busy dealing with problems on the replacement CTD winch.

- Approximately £3000 worth of instrumentation on our tethered buoy was wrecked during its first fully operational deployment by excessive forward motion of the ship during a period when we were supposed to be hove to into wind, dragging the entire buoy under water.

We have been very impressed with the support provided by the entire ship's crew and the UKORS technical support staff. They have all been a pleasure to work with: their friendly and cheerful help and guidance, and willingness to sort out any and all problems during a cruise beset with problems, has made life very much easier for everyone from Leeds.

Computing and Instrumentation Report: D313

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RVS LEVEL ABC System: The LEVEL ABC system is a system comprised of multiple components that can be adjusted and altered to suit the needs of the cruise in progress. The system is due to be retired due to its age and the difficulty in acquiring spares. The ABC system is created of 3 tiers:

- Level A - The Level A's role in the system is to acquire the data from an instrument, parse the data stream into the necessary format to be recorded by the level B and also place a timestamp on each piece of data. The instruments are connected to the Level A's via RS-232 and are also connected to the level B in the same way. This allows simple interrogation of messages when attempting to track a problem with the system.

- Level B - The level B is sent all data from the Level A's and allows you to view all the data as it is coming in. The Level B allows the backup of the data to magnetic disks which are backed up on the Level C in compressed Zip format. The Level B transmits the data to the Level C and the data is parsed directly into the RVS data files that we use now. All data, errors, comments can be viewed for each individual instrument.

- Level C - The level C system is a Sun Solaris 10 UNIX Workstation discovery1 also known as ABCGATE. The RVS software suite is available on this machine. This suite of software allows the processing, editing and viewing of all data within the RVS data files. This system also has monitors that allow us to ensure that the level C is receiving data from the level B.

The Level A's acquire their timestamp from a Radio code GPS Clock that is distributed via the RVS Master / Slave Clock System.

The ABC system still remains the main data logging format for the ship, this is being run in parallel with the new Ifremer Techsas Sensor Acquisition System. This system is currently being proven and a database of drivers being built to enable us to interface with the instruments on board.

This system will then become the primary system for data logging.

For this cruise the Level A system were used to log:

1) Trimble GPS 4000 DS Surveyor (gps_4000)
2) Ashtec ADU-2 multi antenna GPS with attitude (gps_ash)
3) Ashtec GPS G12 integral to the FUGRO Seastar DGPS receiver (gps_g12)
4) Simrad EA500 Precision Echo Sounder (ea500d1)

5) NMFD Surface-water and Meteorology instrument suite (surfmet)
6) NMFD Winch Cable Logging And Monitoring CLAM (winch)
7) Gyronmea (gyronmea)
8) Chernikeef Log – Ship's speed through water (log_chf)

The RVS level ABC system suffered no major issues during the cruise with the exception of the full loss of power to all ships systems, total loss of data was around 2 hours for most instruments, mainly due to the need to reset almost all devices that are used in the data logging process. During the power outage the computer room clean supply was turned off incase of spiking in order to protect equipment. This was successful and no further damage occurred to the ABC system or the Ifremer Techsas system.

Ifremer Techsas System: The Ifremer data logging system is the system that will inevitably replace the existing Level A + B system while for the most part the Level C will remain as the main system for outputting, viewing and editing the acquired data.

The Techsas software is installed on an industrial based system with a high level of redundancy. The operating system is Red Hat Enterprise Linux Edition Release 3. The system itself logs data on to a RAID 0 disk mirror and is also backed up from the Level C using a 200GB / 400GB LTO 2 Tape Drive. The Techsas interface displays the status of all incoming data streams and provides alerts if the incoming data is lost. The ability exists to broadcast live data across the network via NMEA.

The storage method used for data storage is NetCDF (binary) and also pseudo-NMEA (ASCII). At present there are some issues on some data streams with file consistency between the local and network data sets for the ASCII files. NetCDF is used as the preferred data type as it does not suffer from this issue.

The Techsas data logging system was used to log the following instruments:

1) Trimble GPS 4000 DS Surveyor (converted to RVS format as gps_4000)
2) Chernikeef EM speed log (converted to RVS format as log_chf)
3) Ships Gyrocompass (converted to RVS format as gyronmea)
4) Simrad EA500 Precision Echo Sounder
5) NMFD Surface-water and Meteorology (SURFMET) instrument suite
6) University of Rhode Island Aanderaa Oxygen Optode (optode)
7) University of Rhode Island Underway Gas Tension Device (UGTD)
8) University of Rhode Island Hurricane Gas Tension Device (HGTD)

This system is still being trial run by the ship fitted systems as the replacement to the aging RVS system, no major issues occurred during this cruise and no substantial data losses occurred. The data losses that did occur were minor at most. Techsas on 2 separate instances did suffer from a Graphical User Interface crash. During this time the Techsas logging process continues however no visible indications of its status are available. The only option in this case is to restart the software which causes around a 2 minute data loss. This occurred twice during the cruise and was rectified each time with out any further issues. During the cruise a second known issue with the system occurred, this issue is the loss of the complete logging system, the computer essentially freezes and must be restarted by power cycling the whole system, and this can result in much more data loss as the system can take some time to restart. I believe this was caused by an error in the network as techsas logs all data to a remote unit on the level C (discovery1). This is the first time that we have been able to ascertain the reason behind this type of issue and it should now be possible to lower the possibility of it happening again. The third issue that techsas suffered from was the complete loss of power due to the ship wide blackout. At the beginning of the cruise the Techsas system was attached to a UPS system, however that had during the mobilization time caught on fire and was removed from service. As was the on board spare due to a fault indicator after the fire. Had the UPS have not been damaged Techsas would have stayed online during the power outage however not recording data due to the rest of the systems being unpowered, it would however had allowed logging to resume at a slightly earlier time.

Techsas NetCDF to RVS Data Conversion: During this cruise there is no reliance upon the data provided by Techsas, however it has been included on the data archive in the standard rvs form using a piece of software used to make it compatible with the RVS ASCII data structure. The University of Rhode Island instruments were logged using the Techsas system and had to be converted to the RVS format in order to be able to create data logs that included multiple variables from other RVS streams.

An in house application was used to handle the conversion of NetCDF files to the RVS format. This was then parsed back to the data file and was processed as normal. These 2 new applications being ncvars and nclistit.

These new binaries require to environment variables in order to function:

$NCBASE – the base for the NetCDF binaries system, set to /rvs/def9

$NCRAWBASE – the base for the raw data files, set to /rvs/pro_data/TECHSAS/D313/NetCDF

The existing $PATH variable must also include the path to the nc binaries, the path /rvs/def9/bin was appended to the $PATH variable.

All Techsas data file names are in the format of YYYYMMDD-HHMMSS-name-type.category with the data/timestamp being the time the file was created by Techsas.

The files were each processed in the following way for this cruise:

nclistit 20060813-000001-gyro-GYRO.gyr - | sed s/head/heading > $DARAWBASE/gyro.225

At this stage the data are converted to the correct format and its header replaced by the header required by the RVS software suite.
Another issue with the conversion of the files to the RVS format is that the top timestamp is always outputted as 00 00/ 00:00:00. The file outputted with nclistit is then edited in VI in order to alter that timestamp to the correct time and day. This is done as it would not be imported into the RVS data format with this timestamp error.

The file is then passed to the titsil application which simply reads the data from the text file that was created and enters it as records in the RVS data file.

cat $DARAWBASE/gyro.225 | titsil gyronmea –

This command reads the gyro.225 file in the /rvs/raw_data directory and passes it to titsil for input in the gyronmea file. The – dictates that all variables will be included.

The TECHSAS system was set to create a new file for each day, however on days when errors occurred multiple files were created as that is normal practice for Techsas when it is restarted.

During this cruise techsas was successfully used to log 3 new sensors bought on board by the University of Rhode Island, after slight tinkering due to differences in data output (lost in translation in e-mail correspondence) the logging procedure began and there were few issues with techsas logging these instruments. Despite having checked the devices cabling and route to the system some confusion at the beginning of the cruise resulted in the 2 of the devices (both Gas Tension devices) being logged by the opposite name. The devices were swapped at the beginning of the cruise and it is now apparent that they should not have been. This is easily rectified using the RVS systems applications.

Fugro Seastar DGPS Receiver: The Fugro Seastar is the source of custom differential corrections based on its position fixed by its internal Ashtec G12 GPS module. It outputs corrections via RS-232 using the standards RTCM message. The message is distributed among all GPS receivers where they are used to compute their own DGPS positions.

The Fugro Seastar functioned correctly throughout the cruise. There have been issues with this system previously not detecting the correct satellites due to location. However in this instance it performed correctly and differential positions were calculated throughout the cruise.

Trimble 4000 DS Surveyor: The Trimble 4000DS is a single antenna survey-quality advanced GPS receiver with a main-masthead antenna. It uses differential corrections from the Fugro Seastar unit to produce high quality differential GPS (DGPS) fixes. It is the prime source of scientific navigation data aboard RRS Discovery and is used as the data source for the ships display system (SSDS.)

The system was unaffected by the ships blackout and remained online throughout the cruise. The alarms on the units needed to be reset before the system would broadcast the time across the SSDS system.

Ashtec ADU-2: This is a four antenna GPS system that can produce attitude data from the relative positions of each antenna and is often used to correct the VMADCP for ship motion. Two antennae are on the Bridge Top and two on the boat deck.
The Ashtec system worked reliably throughout the cruise with some gaps that are quite usual with this system due to the amount of calculations necessary. No Large data gaps are present. The ADU-2 forms part of the bestnav system which is an assembly of multiple GPS signals including the gyronmea and emlog stream in order to calculate the best possible position, speed heading pitch and roll of the ship.

The Ashtec was one of the last devices to be successfully restored to logging status, this was due to the issue of baud rates when the Level A is reset, normally this would not be needed but the power outage meant that the systems baud rate needed to be adjusted from the default to its required rate, this was done following the restoration of other systems on board and the system worked reliably for the entire cruise.

Gyronmea: The ships gyro system is linked to the scientific system by the way of a digital to serial buffer box located in the comms room, during the blackout on day 336 the system malfunctioned and was displaying a ‘666’ on the SSDS, the ships gyro system works on 2 separate gyro units which are connected to a switch system and 2 distrbution boards. These boards can be fed from either Gyro. Out system is fed from Gyro distribution board number 2 which was originally connected to gyro 2. During the power failure gyro 2 was damaged and was not giving out any data, the gyro was looked at by the ETO and was again passing data, however it was noticed that the gyro was unstable and so removed from service. An attempt to connect to gyro 1 for the SSDS and scientific logging was made, however the digital serial converter appeared to be damaged also and is still at the present time not in full working order, spare parts are currently in transit from base and repairs will be conducted where possible after their arrival.

Due to the issues at the end of the cruise with Gyronmea the bestnav has been calculated twice, the gyro bestnav only exists up to the point of power failure, the gps_ash bestnav exists up to the end of the cruise at Glasgow.

Dartcom satellite imaging system: The Dartcom system is a able to receive signals from satellites that take images of cloud coverage, these images can be used to see the type of atmospheric and weather conditions nearby. During the power failure the Dartcom satellite was being automatically controlled by the dartcom HRPT grabbing software. The system is known to be easily damaged while the system has no power and the ship rolls which can cause the satellite to come crashing down. The dartcom system has not been working correctly since the blackout and no satellite images have been grabbed since, the issues involved are:

1) Unable to contact the ships network from the controlling pc to gather satellite pass prediction data.
2) Unable to communicate with the orbit system itself.

It is possible that the system is in fine working order and simply having issues since the incident however closer inspection is required before the full extent can be ascertained.

RDI Ocean Surveyor 75KHz Vessel Mounted ADCP (VMADCP): Data from the RDI Ocean Surveyor was logged throughout the cruise and backed up to the /data32 shared data area. The VMADCP data was available for access through a samba share on Discovery2ng known as D313ADCP. The ADCP 75 was setup to follow the settings of the previous cruise with some slight alterations to depth and bin count. This was done to get a more accurate reading based on information obtained from Ricardo Torres.

RDI Ocean Surveyor 150KHz Vessel Mounted ADCP (VMADCP): Upon activating the system at the beginning of the cruise the system appeared to have several issues of rejecting each beam that was sent out. This issue was also joined by a warning saying High Transmitter Current. Another issue was the condition of an aging machine that he DAS software ran on, the computer was failing to boot DOS and claiming to be unable to find a hard disk drive. During the Stornoway port call a spare was sent up from base and that was used to replace the computer system. However the issues of the ADCP unit still existed. An attempt was made to swap out all circuit boards with the available spares and this did not change the error messages coming out. The ADCP 150 at present is in an unusable state and will require inspection before its next use.

Chernikeef EM log: The Chernikeef EM log is a 2-axis electromagnetic water speed log. It measures both longitudinal (forward-aft) and transverse (port – starboard) ships water sped.

The EM log was not calibrated prior to the cruise and was reading at -0.8 knots astern when alongside (-0.8 knots)

During my last cruise there was an issue with the Chernikeef logging system due to an update to the firmware of the log_chf. This was due to an additional character being inbuilt that TECHSAS was not aware of and so could not parse the transverse speed what so ever. During the port call between D308 – D309 this was corrected and TECHSAS now logs the speeds correctly. The Level A system was used to log the emlog on this cruise, this issue never occurred with the Level A system as it has been designed in such a way that it understands changes to the incoming data string.

Simrad EA500 Precision Echo Sounder (PES): The PES system was used throughout the cruise however due to weather conditions the hull transducer was not always able to perform its function as well, the PES fish would normally be used in this case but due to the amount of roll that the ship was doing due to rough weather there was a good chance of damage occurring to the system. And so the hull transducer was used throughout the cruise.

The PES outputs its data to a stream called ea500d1.

The ea500d1 PES fish was put out at 2006 335 134530 and returned onboard at 2006 335 16:33:00, the fish was only put out due to us attempting to use the CTD wire on a test to get precision depth readings in shallow water to avoid snagging the wire on the ocean floor. The echo sounder was off for about 10 minutes around the time of deployment and recovery to ensure it didn't ping while being recovered.

Surfmet System: This is the NMFD surface water and meteorology instrument suite. The surface water component consists of a flow through system with a pumped pickup at approx 5m depth. TSG flow is approx 25 litres per minute whilst fluorometer and transmissometer flow is approx 3 l/min. Flow to instruments is degassed using a debubbler with 40 l/min inflow and 10/l min waste flow.

The meteorology component consists of a suite of sensors mounted on the foremast at a height of approx 10m above the waterline. Parameters measured are wind speed and direction, air temperature, humidity and atmospheric pressure. There is also a pair of optical sensors mounted on gimbals on each side of the ship. These measure total irradiance (TIR) and photo-synthetically active radiation (PAR).

The surfmet system was not operational for the entire cruise for surface sampling, this was due to us being so close to land that the non toxic pumps were turned off.

Surfmet non toxic was initially turned on around 10PM on 06 311.
Surfmet non toxic off 06318 07:47:00
Surfmet Fresh Water flush on 06 318 11:03:30
Surfmet Fresh Water Flush off 06 318 11:18:40
Surfmet non toxic supply on 06 320 1000

Non Toxic Supply off at 06 321 110:00
Non Toxic Supply On at 06 323 08:28
Non Toxic Supply off 06 338 12:00

The Total Irradiance Sensors and PAR Sensors were cleaned during the Glasgow port call and Ben Moat at:

311 09:00

Then at Stornoway on:

319 14:00 – 15:00

I also cleaned the TIR and PAR sensors on: 06 311 14:00

And also again at end of cruise 06 339 13:30 – 14:30 pm

The non toxic pumps were off on day 338 12:00 and were cleaned with DECON 90, Surfmet and all other instruments were off before this occurred.

During the end of cruise demobilization the air temperature / humidity sensor was changed. Please see the Surfmet sensor listing for the details of this. The sensor was changed at the end of the cruise and so the cal for the other sensor is included.

Network Services: During the cruise there were no issues of any kind with the wired network system. Several technicians and scientists made successful use of the network and all systems were able to connect to the network.

Some users reported 'attacks' against their computers from a computer on the ships network, this is due to the TECHSAS systems logging method for NMEA and NetCDF data. The system works by parsing the incoming data and broadcasting it to the network for capture by the recording process. This is done so that one signal may be input and logged on systems that are networked but share no other connection. The 'attack' issue occurs when software such as Norton does not receive the full message string and so does not know to ignore it.

Wireless network: Previous known network issues had been addressed prior to the cruise allowing the existing system to continue to work uninterrupted. Wireless worked throughout the cruise where available having rectified a fault with one of the wireless access points on the Forecastle Deck.

E-mail system: The email system worked fairly well for the entire length of the cruise. Some issues were noticed when the ship was heading in an easterly direction. Email transfers would take a long time on these courses or not occur at all.

Data Storage: Two USB external hard drives are being use as a RAID 0 mirror hosted by Discovery3 at the /data32 export. The mirror uses the modern meta device commands available in Solaris 10. This increases storage robustness by providing another layer of redundancy at the online storage level. The maintenance and administration of the disk set is minimal and the performance more than adequate.

All cruise data except for the /rvs path were stored on this storage area. Access was given to scientists to some of the folders via Samba shares.

Level C data were logged to the discovery1 internal disk as was Techsas.

Data Backups: Backups of Level B data tapes were taken as required when the tapes became full, usually once every 2 days. These were archived compressed data files in /rvs/raw_data/levelb/Tape*.Z

Daily backups of the Level C data was done as a tar file to DLT tape. The following paths were included in the tar file:

/rvs/raw_data
/rvs/pro_data
/rvs/def7/control
/rvs/users

In addition to the redundancy provided by the RAID 0 pair, daily backups of the /data32 directory were done by a level tar of the file system to the LTO 2 tape. The whole disk was backed up not just current cruise data.

The LTO2 system was backed up on a daily basis in a rolling 2 tape system.

Data Archiving: The proposed data archive will consist of the following components.

1) All CTD data
2) All ADCP data
3) All TECHSAS NMEA and NetCDF data files

All data were written to DVD with 4 copies made.
1 copy for BODC
1 copy for PSO
1 copy for PML
1 copy for Leeds
1 copy for UEA
1 copy for RRS DISCOVERY
1 copy for return to NOC

Cruise Website: During the cruise a website was produced in order to display images, videos and information regarding the cruise and the activities that were to occur and the weather that was to come. The site was hosted using apache on the discovery2ng package server.

The site address was http://discovery2ng.discovery/d313/

The site can be used elsewhere however it was created using a proprietary software package available on the Mac OS X. The software is called Rapid Weaver available from RealMac software.

CTD Report: D313

A total of 9 CTD casts were performed (this includes cast 05#02 where the CTD was lost). Both systems performed well with no instrument changes required.

CTD 0758: The CTD package comprised of the following instruments. Seabirb 911+ CTD with dual temperature and conductivity sensors. Seabird carousel type SBE 32. RDI 300Khz workhorse ADCPs, one upward looking and one downward looking. Chelsea instruments Alphatracka (transmissometer) and Aquatracka (fluorometer). Wetlabs light back sensor type BBRTD. PML 2pie PAR light sensors, for down welling and up welling light. Benthos altimeter type 915T. Twenty four 10 litre OTE Water bottles. The Seabird secondary T\C duct had an inline seabird oxygen sensor type SBE 43 fitted for casts D313_02#04 to D313_05#01 (inclusive).

CTD 0803: The second CTD system used to replace the above was essentially the same except for having no ADCPs and only 22 water bottles. After cast D313_08#02 the oxygen sensor was fitted to the secondary T\C duct, this was done for accessibility reasons.

UKORS Instrumentation Report: D313

Dave Teare, UKORS Sensors & Moorings Group, National Oceanography Centre, Southampton.

CTD Operations: A total of 9 CTD profiles were carried out.

Stainless Steel CTD Frame: The stainless steel frame configurations were as follows:

For casts D313_02#4, D313_03#01, D313_04#01 and D313_05#01

- Sea-Bird 9/11 *plus* CTD System
- 24 by 10L Ocean Test Equipment External Spring Water Samplers
- Sea-Bird 43 Oxygen Sensor
- Chelsea MKIII Aquatracka Fluorometer
- Chelsea MKII Alphatracka 25cm path Transmissometer
- OED LADCP Pressure Case Battery Pack
- RD Instruments Workhorse 300 KHz Lowered ADCP (downward-looking master configuration)
- RD Instruments Workhorse 300 KHz Lowered ADCP (upward-looking slave configuration)
- Benthos Altimeter
- WetLabs BBRTD back scatter sensor
- IOS 10KHz beacon
- PAR sensors, up-whelling and down-whelling

For casts D313_08#02, D313_09#02, D313_10#02, D313_13#01 and D313_14#01

- Sea-Bird 9/11 *plus* CTD System
- 22 by 10L Ocean Test Equipment External Spring Water Samplers
- Sea-Bird 43 Oxygen Sensor
- Chelsea MKIII Aquatracka Fluorometer
- Chelsea MKII Alphatracka 25cm path Transmissometer
- WetLabs BBRTD back scatter sensor
- PAR sensor, up-whelling and down-whelling

The pressure sensor is located 30cm from the bottom of the water samplers, and 119cm from the top of the water samplers (for 10L bottles). The oxygen sensor was fitted to the secondary ducting for all cast on CTD 0782, and for the first cast on CTD-0803. The sensor was then swapped to the primary duct for all cast thereafter. This was done so that the sensor could be easily removed for periodic zero and calibration checks (winkler)

Stainless Steel CTD Frame Instrument Configuration: The Sea-Bird CTD configuration can be found in the relevant con files on the D313 SeaBird data disk.

Event Log: Individual casts that had no outstanding events or sensor changes are not logged here.

D313_02#04. Initial test cast. All water bottle lanyards found to be tight. This may account for the poor salinity tie-ups

D313_05#01. The complete CTD system was lost due to poor weather\winch malfunction. Therefore no water samples taken.

D313_10#01. The cast was aborted as the water column proved to be unsuitable for gas tracer release.

D313_14#01. Unfortunately insufficient water was left for sampling.

D313 Seabird data processing: The following processes were applied to the data files, these are included in the 'DATA FILES' folder.

1) Datcnv: Downcast, upcast and bottle files. Converted to ASCII

2) Align: Oxygen was advanced 6 seconds for all casts

3) **Bottle summary**: All recorded sensor data, plus temperature difference, conductivity difference, Lat, Long, Julian day, elapsed time (seconds) and Scan count. Derived Salinity for primary and secondary.

4) **Cell thermal mass:** Applied

5) **Derive:** The following parameters were derived using primary and secondary data sets where applicable. Salinity, Potential temperature, density (sigma-t Kg m^3). Depth (m), Oxygen (ml\l) and salinity difference.

Appendix 1: Station details, activities and water samples collected

a = SF_6; b = ^3He; c = CO_2 (UEA), d = O_2/CO_2 (URI)

Date	Time (UTC)	Station I.D. & event N^o	Latitude	Longitude	Equipment Deployed	Comments	Water Samples
08/11/06	08:45	D313/01/#01	55.31^o N	05.41^o W	NOC Spar buoy	Test deployment	
08/11/06	09:40	D313/02/#01	55.34^o N	05.42^o W	NOC Spar buoy	Test deployment	
08/11/06	11:45	D313/02/#02	55.36^o N	05.38^o W	Leeds Tethered Met Buoy	Test deployment	
08/11/06	13:01	D313/02/#03	55.36^o N	05.37^o W	PML drifter #65988	Test deployment	
08/11/06	13:01	D313/02/#04	55.35^o N	05.36^o W	UKORS CTD	Test deployment	**c,d**
08/11/06	14:30	D313/02/#05	55.35^o N	05.36^o W	URI mini CTD	Test deployment	
08/11/06	16:30	D313/02/#06	55.33^o N	05.40^o W	PML depression weight	Test deployment	
10/11/06	13:08	D313/03/#01	56.50^o N	11.01^o W	UKORS CTD 364 m	Survey: 1st CTD	**c,d**
11/11/06	13:08	D313/04/#01	56.00^o N	12.00^o W	UKORS CTD 502m	Survey: 2nd CTD	**c,d**
12/11/06	06:51	D313/05/#01	56.50^o N	13.00^o W	UKORS CTD 16m	Survey: 3rd CTD: lost @ 16m	
19/11/06	09:43	D313/06/#01	56.78^o N	05.25^o W	NOC Spar buoy		
19/11/06	10:57	D313/06/#02	56.78^o N	05.23^o W	Leeds Tethered Met Buoy		
20/11/06	10:00	D313/07/#01	55.75^o N	05.23^o W	URI hand-held Niskin		**c,d**
20/11/06	10:44	D313/07/#02	55.74^o N	05.20^o W	NOC Spar buoy	Stopped recording after 10 min.	
20/11/06	11:12	D313/07/#03	55.74^o N	05.23^o W	Leeds Tethered Met Buoy	Inlet damaged by wave wash	
21/11/06	08:42	D313/08/#01	55.76^o N	05.23^o W		Test dip of weighted winch	
21/11/06	14:20	D313/08/#02	55.75^o N	05.28^o W	UKORS CTD 83m	Background ^3He and SF_6	**a,b,d**
21/11/06	15:20	D313/08/#03	55.75^o N	05.28^o W	URI mini CTD		**d**
25/11/06	17:22	D313/09/#01	56.74^o N	11.50^o W		Test dip of weighted winch	**a,b,d**
25/11/06	17:22	D313/09/#02	56.74^o N	11.50^o W	UKORS CTD 400m	Background ^3He and SF_6	**a,b,c,d**
25/11/06	17:22	D313/10/#01	56.74^o N	12.02^o W	UKORS CTD 230m		**c,d**
25/11/06	17:22	D313/10/#01	56.74^o N	12.02^o W	UKORS CTD 230m		

26/11/06	04:12	D313/11/#01	56.74° N	11.30° W	Deploy PML buoy #88		
26/11/06	04:15	D313/11/#01	56.75° N	11.30° W	Deploy PML buoy #47		
26/11/06	04:50	D313/11/#01	56.75° N	11.30° W	Commence tracer release		
26/11/06	11:00	D313/11/#01	56.75° N	11.31° W	Complete tracer release		
26/11/06	12:00	D313/12/#01	56.42° N	11.25° W	Deploy URI Float		
26/11/06	14:03	D313/13/#01	56.76° N	11.36° W	UKORS CTD 300m	Tracer Patch ^3He and SF_6	**a,b,c,d**
26/11/06	16:20	D313/14/#01	56.74° N	11.39° W	UKORS CTD 300m	Tracer Patch ^3He and SF_6	**a,b,**
29/11/06	11:13	D313/15/#01	56.86° N	06.01° W	URI hand-held Niskin	Surfactant sampling	
29/11/06	11:19	D313/15/#02	56.86° N	06.01° W	URI hand-held Niskin	Surfactant sampling	
29/11/06	11:22	D313/15/#03	56.86° N	06.01° W	URI hand-held Niskin	Surfactant sampling	
29/11/06	13:11	D313/15/#04	56.83° N	06.01° W	NOC Spar buoy		
29/11/06	14:15	D313/15/#05	56.86° N	05.98° W	URI hand-held Niskin	Surfactant sampling	

Appendix 2: Incident and investigation reports on CTD loss

RRS DISCOVERY INCIDENT & INVESTIGATION REPORT

NMF Sea Systems

INCIDENT Report No: 053

Type: Loss of CTD System and 70 metres of cable (16 m of wire out)	**Date:** 12/11/06	**Time:** 0701 (UT)
Geographical Position: 56 30N 013 00W	**Geographical Location:** NE Atlantic	
Location on Ship: Winch Room - CTD traction Winch – one full turn from the outboard end.		
Weather: Wind 240˚ x 25/30 knots – Sea rough, swell confused 3-4 metres – Direction 300˚ T	**Course:** Head to wind when event occurred	**Speed:** 0.25-0.5 knots
Activity: Having heaved the CTD to a few metres below the surface from the 10 metre start point, the CTD was being veered back to the required depth for the station (anything between 300-500 metres)		
NATURE OF INCIDENT: **CTD cable break** - Total Loss of the CTD system in 2300 metres of water at a wire out of 16 metres. Total wire loss 70 metres. The break position was a full complete turn into the traction winch (I turn away from leaving the traction winch and entering the rest of the winch room). See Photographs attached.		

Investigative Preamble:

Pre deployment inspections were carried out in winch room and hangar top, also when paying out to the 10 metre mark.

The weather was marginal, but not too bad. The swell was a different direction to the wind giving too much rolling when head to wind, so as per the Risk assessment (reviewed 2004) the Bridge (Master) only gave permission and clearance to deploy when headed to swell 300˚. The CTD was, then, deployed head to swell and when the CTD was overside the vessel was brought back into wind so that the vessel would not 'ride the cable' due to the wind being on the port side when heading to swell. There was some 'snatching' of the cable when overside near the surface; the CLAM records show there was no undue stresses due to this, bearing in mind that the CLAM system samples at 1 second intervals, a quick 'snatch' might have been missed.

Investigative Interview : Conducted by R. Chamberlain (Master) in Quiet Room and Library at 1045 UT 01211/06, assisted by K. Jethwa (Safety Officer)

Those Present represented those people involved in the above incident – They were:
Richard Warner, Ch/Off, Dan Comben, TLO, Dave Teare, Tech, Chris Barnard, Tech, Iain Thomson CPOD, Steve Smith, CPOS. Only Non-NMF SS was the PS, Robert Upstill-Goddard.

1) UNDERLYING POSSIBLE REASONS FOR OCCURRENCE

Two reasons come out of our meeting:

1) On inspection of the cable break, and by perusing the CLAM data sampled (attached), the reason for this break may not be down to events at the station it occurred, but may be down to events at a previous station, as no evidence of over tension is evident. 'Snatching' did occur before the break, not unduly violently.

2) POSSIBLE TRACTION WINCH failure - Extensive confidence building tests will have to be

carried out to see if the traction winch had anything to do with this and are being prepared at the writing of this report.

2) WHO INSPECTED THE REMAINS OF THE CABLE, THE HANGER DECK AND WINCH ROOM WIRE ROUTES AFTER THE INCIDENT

K. Jethwa (safety Officer) and Richard Warner (Asst Safety Officer).

They both noted that there was no evidence of cable jumping or seized sheaves anywhere.

3) ANY SPECIFIC ACTIONS OR INTENDED ACTIONS TAKEN BECAUSE OF THE INSPECTION

See attached for Pictures of break and CLAM data. The nature of the break indicates that it is a 'Clean' tension break which never reached its yield stress (see photograph attached). This is supported by the CLAM records (Attached). Also:
1) We can only look to advice from ashore for other avenues of investigation. To this end we are sending back 100 metres of CTD cable to George Batten.
2) Also there is the suspicion that the traction winch may have performed erratically and caused the break.. To this end we are setting up a test weight after re-terminating and to do repeated confidence building casts with the CTD winch system until (on consensus) we can safely rule out the Traction winch theory.

4) WHAT TRAINING HAS BEEN PROVIDED? IS THERE A NEED FOR FURTHER TRAINING?

None.

5) ARE THERE PLANS TO MONITOR FUTURE SIMILAR OPERATIONS?

Until we know definitely what caused this break, we cannot monitor exclusively, but only test the traction winch as mentioned above.

6) IS THE WINCH, WINCH DRUM AND REST OF THE CABLE IN GOOD ORDER

Apart from the assumed traction winch possible failure, the rest of the system is in good order and the status of the traction winch will remain until proved otherwise by repeatability tests. Guidance from ashore is appreciated in this matter.

7) ANY ADDITIONAL INFORMATION

1) Taking into account that the CLAM system only samples every 1 second, it is conceivable that a 'snatch' load could have escaped being recorded, but remember that the break was discovered a full I turn inside the traction winch sheave system.
2) If it is found to be the traction winch is at fault, then this report could have easily been a Near Miss Report or worse as the break could have happened when being lifted on deck or guided overside/inboard.

ADDED TO REPORT

1) Chris Barnard's Addition to this report – wire out/tension graphs from the CLAM data.
2) 5 Photographs showing the wire break, the traction winch and the tensioner and the position of the wire end in the traction winch.
3) Dan Comben's report
4) Mark Moore's report (winch driver at the time).

Cont…….

<table>
<tr><td colspan="2">RECOMMENDATIONS to prevent a repetition:

1) Professional scrutiny of the cable ashore (100 metres (including the broke end) will be sent to George Batten.
2) Consideration given to enabling a higher sampling rate on the CLAM tension.
3) Install digital recording cameras in winch room so that an event such as this could be replayed for all interested parties conducting an investigation.
4) The possibility of looking into the market for a reasonably sized clamp designed to arrest a ‘runaway’ cable, These are found in some ships, notably cable ships, and are hydraulic/gas powered operated by a monitor (someone in the winch cab?)</td></tr>
<tr><td><u>Completed By:</u>

Roger Chamberlain - Master</td><td>R.J. Chamberlain</td></tr>
</table>

Dan Comben’s Report:

At 07:04hrs on the 12-11-06 at position 56 29.93N 13 00 12W the CTD system has been lost just after deployment. The wire parted on the CTD Traction winch, the actual reason for this has not yet been established and is currently under investigation. The CLAM system dater has been analyzed and nothing untoward was found to suggest a reason for this failure.

The current plan is to remove 100m from the wire, re-terminate and conduct tests to try and establish a reason for failure and subsequently build a level of confidence within the system. In the interim Dave Teare will assemble the spare CTD system, in the anticipation that the aforementioned level of confidence is reached.

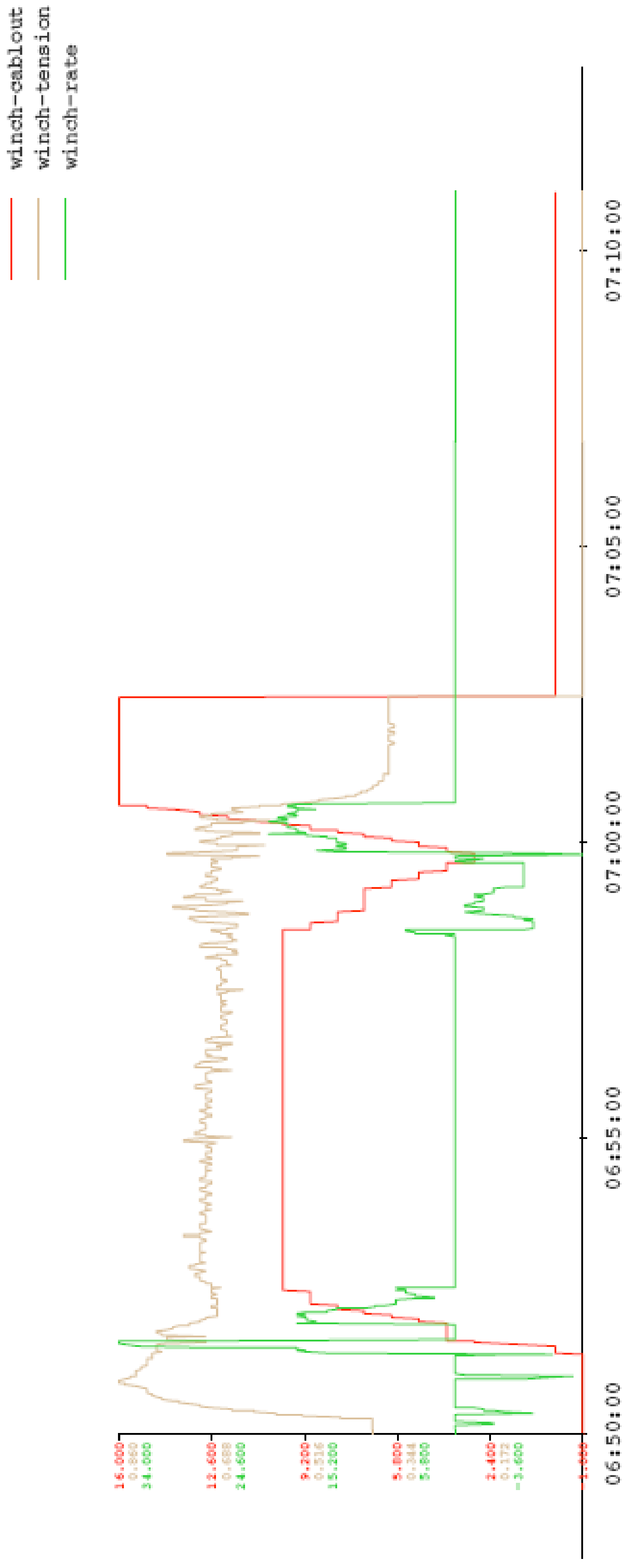
Mark Moore’s Report:

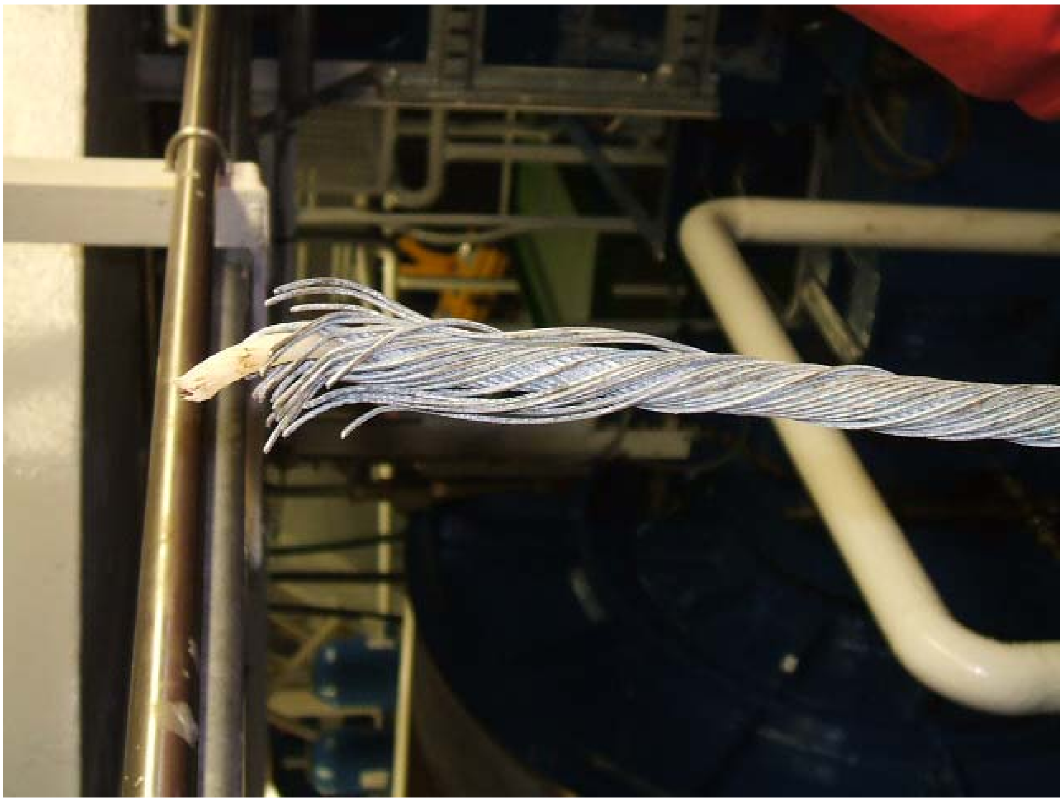
Mark Moore SG 1A
12 / 11/ 2006

Regarding parting of wire and loss of CTD

Before launching the CTD i did a pre check of the winch room and a pre check of the hanger deck all was ok
The bridge told me it was ok to launch the CTD. The CTD went over the ships side ok and down to 10 meters i was then told to bring the CTD back to the surface which i did to 3 meters below the surface . And was then told to take it down to 500 meters . At 18 meters Steve Smith (CPOS) told me to stop the winch as there was smoke or dust coming of the traction winch. I stopped the winch but by that time the wire had already left the winch room and gone over the side .
Taking the CTD with it

Wire out/tension graphs from the CLAM data.

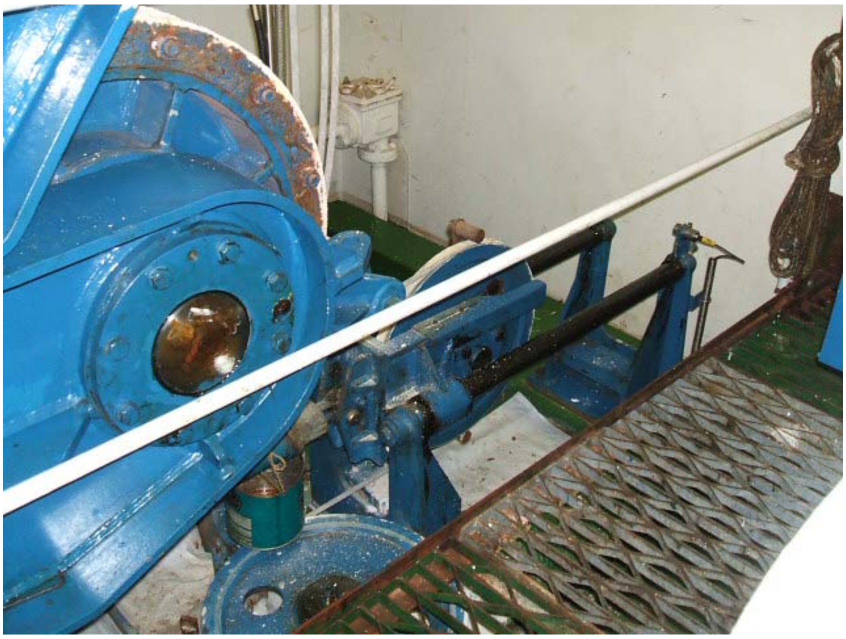




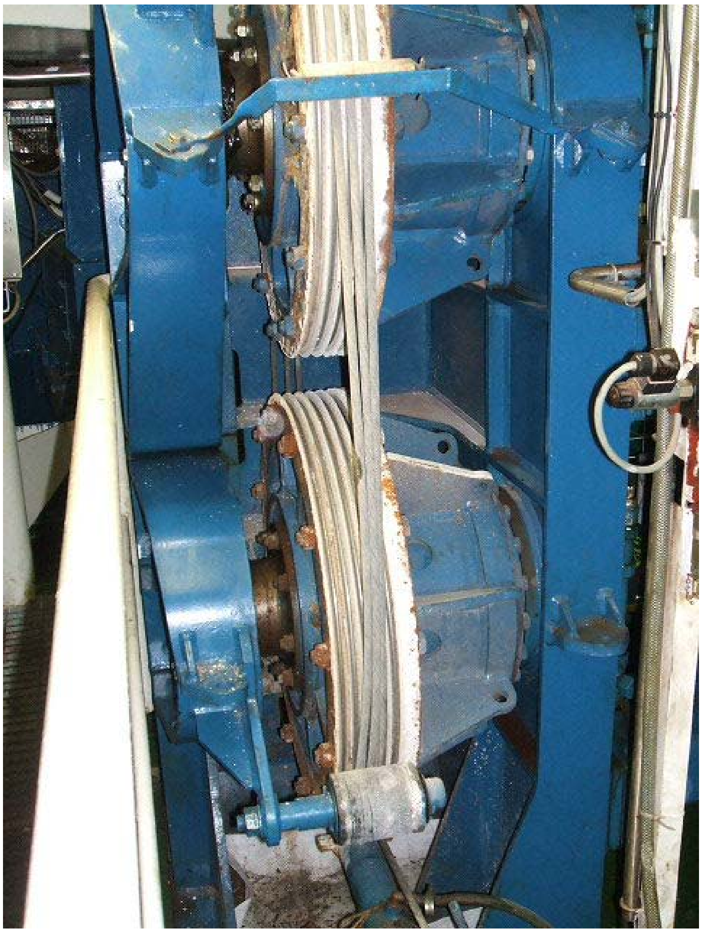
Cable break

Cable break, in situ

Detail of wire on drum



Wire tensioner



Traction wires in place

Appendix 3: Further reports on CTD loss by the Master and Chief Officer, as requested by onshore management

Observation Report on the loss of the CTD

The CTD was being prepared for launching and the vessel was head to wind 240 (G) and rolling. The rolling was marginal for deployment so I called the Captain to the bridge for a second opinion. It was decided and agreed that it was safe as long as we used the procedure of bringing the vessel head to swell for deployment and then back head to wind when fully deployed.

The ships head was brought around head to swell 300 (G) the CTD was deployed and then the head was then swung back around to 240 (G).
Not long after coming back to 240 (G) the vessel started to roll producing slack wire on a roll to starboard and taught wire when rolling to port. I was watching continuously from a position behind the chart table, that gave a good view of the hangar top, right throughout the deployment until the loss of the CTD occurred.
The Captain was in a position between the port radar and the helm position.

Suddenly the sheaves on the hangar top appeared to go out of control, veer rapidly then stop suddenly, veer rapidly then stop suddenly, this certainly happened twice if not three times or more. As soon as I started to observe this apparent loss of control from the chart table, I called out to the Captain that the winch was going out of control and he came over to my position by the chart table. Both he and I saw the end of the CTD cable go over the side and the subsequent loss of the CTD. The Captain gave the order to stop the winch just after the wire went over the side and the winch was reported stopped.

That concludes my Observation.

Richard Warner
Chief Officer

In investigations such as this, I feel that what you 'thought you saw' is just as important as what you saw. When I was called over to the after end if the bridge from the forward console by Richard Warner to witness what was happening to the sheaves on the hangar top, I remember thinking how weird the sheave system was all moving (in my role as a regular observer and monitor of the hangar deck in these operations). There was something 'not right in the way it was moving- erratic and irregular' I gave the command to 'stop the winch' but it was too late. So I think I witnessed the last part of what Richard saw (all this in a few seconds).
Then the sheaves moved faster as they let the runaway cable out and I knew then that all was lost.

Roger Chamberlain
Master

Discovery 313 CTD Deployment System failure, Overview

After much consideration and close inspection of the CTD deployment System, taking into consideration the following factors.

1. **Wire condition (visual inspection)**
2. **Location of failure.**
3. **Sea Conditions.**
4. **CLAM data**
5. **Operational History.**

Wire Condition
The wire appears to be in good condition with minimal loss of its galvanized coating the inboard section of the wire that remained on the traction winch had no marks or indications to point to a pinch or snag of any type. There was some delaminating of the cable strands, which extends approximately 30cm down the cable. On closer inspection of the end section all evidence would point to a clean tensile brake. There was a slight bias or slant to the break, which is visible in the attached photographs. The actual Cable strand ends showed slight elongation and local necking.

Location of Failure
The position of the failure was in-between the two barrels of the traction winch on the last outboard turn. This would suggest that the wire would be protected from external induced snatch loading or internal back tension by sheave frictional losses.
The system has been carefully inspected for tell-tail marks that would give any indication to the cause of failure and nothing has been picked up. All the sheave blocks have subsequently been checked along with the drive motor couplings. The level wind system was also in good condition.

Sea Conditions
The conditions were marginal at the time of deployment but all parties agreed and still do that they were safe and within operational limits.
After the event it has come to light that a member of the catering staff witnessed the incident from outside the technicians' office on the forecastle Deck and has described it to coincide with a large ship roll that generated slack wire in the system, this could be coincidental but I thought I would add it as all information is important. It appears that the CLAM data concurs when you overlay pitch and roll. *See attached trace of tension, rate, pitch, course and roll.*

CLAM data
The CLAM data suggests no excessive loads where applied. A maximum load of 860kg was recorded throughout the operation. It has been muted that the one-second sampling rate of the CLAM system could have missed a large outboard load induced by ship movement. *See attached trace of cable out, tension and rate.*

Operational History
Taking into account the operational history of the CTD system and the Deep Tow Conducting System. It would seem that if a similar problem to the DT winch has been encountered then it would have taken a long time to materialize. There have been

problems with the CTD wire in the past with the system inducing torque into the cable and causing it to jump of sheaves but it is assumed that this is unrelated.
.

Conclusion
Due to the very nature and speed that the incident accrued and without any effective monitoring systems in place. It has been difficult to reach any objective view of what actually happened. A substandard cable can hopefully be eliminated or proved by the means of tensile testing. At the moment our main priority on board is to get this cruise back on track and facilitate some level of operational Science.

Appendix 4: Chief Engineers report on aft collision bulkhead

Subject:	Crack in Bulkhead
From:	"Discovery Master" <glne.master@sea.noc.soton.ac.uk>
Date:	Mon, November 13, 2006 11:12 am
To:	"PS" <glne.ps@discovery-comm.discovery>
Cc:	"TLO" <glne.tlo@discovery-comm.discovery>
Priority:	Normal
Options:	View Full Header | View Printable Version | Download this as a file

Dear Andy,
During routine inspections of the machinery spaces by the duty engineer around 2230 hrs last night, he noticed a wet patch on the aft collision bulkhead (frame No 9), near a beam knee on the longitudinal supporting girder, situated under the seismic compressor flat. Upon closer inspection he noticed a 6mm crack starting from the weld and 45 degrees. I was immediately summoned together with the second engineer. The crack had a small weep but nothing too alarming as to cause serious concern and it was decided to monitor overnight. I informed Roger of our findings and he also concurred to carry on monitoring.

At this mornings inspection it was found that the original crack had progressed from 6 mm to around 50 mm. Also another crack has now appeared running 135 degrees from the weld. The area concerned is directly above the stern tube seal and is highlighted in the attached images. It is causing us some concern due to the appearance of the second crack overnight. Also to bear in mind that there is a lot of vibration in the vicinity, under seaway and the inclement weather is pulsing the area around the stern tube. Please also refer to the General Arrangement plan sheet 1(Des 28851) - Frame No 9. However this plan does not show the longitudinal girder under the seismic compressor flat. Also to note, as this is a collision bulkhead, it is affected by class (Lloyd's)

Best Regards
Jet


CRACK
CRACK
2300 →
0600
EM
EX


CRACK
2300 →
0600
E


EMERGENCY
EXIT
84
84


LEAK
CRACK
CRACK
2300 →
0600
EME
EXIT

Appendix 5: Near miss and investigation report: Power loss

RRS DISCOVERY NEAR MISS & INVESTIGATION REPORT

NEAR MISS Report No: 056

Type: Total Loss of Power	**Date:** 02/12/06	**Time:** 0212-18 (UT)
Geographical Position: 57 04.64N 006 17.03W	**Geographical Location:** 1.5 Miles NE of Rhum Island, Inner Hebrides	
Location on Ship: Wheelhouse & Engine Room		
Weather: Wind 230 x 35-45 knots – causing a drift of 1.5 knots. Sea sheltered.	**Course:** Hove To	**Speed:** 0.5 knots
Activity: Sheltering from the effects of the Storm Force SW'ly winds – a sea break. Bridge OOW – Malcolm Graves 2nd Officer		
NATURE OF INCIDENT: Total Loss of power – a 'blackout'		

Investigative Preamble:

8) UNDERLYING REASONS FOR OCCURRENCE

Unfortunately, the lights that indicate the number and sequence of Generators running, on the forward Bridge Console were not fully functional. If this visual information had been available at the time preceding the blackout, it is likely the OOW would have reacted positively and in time to have prevented the Power Systems Failure by informing the Duty Engineer that (referring to the engine room log printout) No 3 ESL had shut itself down (at 0040 hrs). There were no alarms initiated to warn the duty engineer or the OOW of this happening. Thus the vessel had only No 2 ESL on line. Both ESL's were in manual mode.

Events preceding the blackout:

29 November 2006: The No 3 generator has had a long history of giving an under voltage alarm for no apparent reason. To try and rectify this problem it was decided to fit the spare AC module (this had previously failed due to smoothing capacitors C401 and C402 in the +160V/-160V supply circuits) These had been repaired on board but the module had not been proved in circuit. It was not known why these capacitors had initially failed.

Once the spare module was fitted the generator was run up and put on the board. It ran normally taking load for about 5 minutes the breaker for No 2 generator tripped out and No 2 engine stopped. Shortly after this the breaker for No 3 tripped out.

The spare AC module was removed and the original re-fitted. Again the generator was run up and put on the board. Within 10 minutes the same thing happened again, No2 breaker tripped and No 2 engine shut down followed quickly by No 3 breaker tripping.

Although No 3 engine did not shut down it was noted that the output voltage had fallen to 220 volts and the frequency was off the scale. Inside the control cabinet of No 3 breaker F11 had tripped and resetting this restored the output voltage to 415V.

30 November: investigated the input and output voltages of T3, these were recorded and compared with readings taken from No4 generator. Nothing untoward noted. Commenced voltage and waveform checks on No 3 AC module. Due to the adverse weather conditions at the

time it was decided not to try and put No 3 back on the board so it was only possible to record voltages and waveforms with the generator running off load. We waited patiently for the weather to ameliorate so that No. 3 could be put back on the board and observed.
01 December: No 3 was at last put on the board under load and observed for a few hours. At this time the remaining voltage and waveform tests were completed as per the manual on board and the results obtained were more or less the same as those quoted in the manual.
No 3 generator was running normally and load sharing with the other three generators all of which were running in manual.
After 6-8 hours of testing, we decided that some confidence had been restored and that we were going to 'give it a go' as far as venturing out to Rockall was concerned.
Whilst we were on our way the weather deteriorated to such an extent that a decision was made to re-shelter the vessel, more so because of forecasts of Storm force winds and associated waves and although we had gained *some* confidence, I did not want to push it this far yet, as the journey back to shelter would be a testing ride in itself.
02 December – 0212 UT: total blackout. Stornoway Coastguard was fully informed right from the start as I did not know how long it would be for power to be restored and we had only 2 hours max of drift time in the high winds. Partial power / propulsion restored at 0218 hrs, on No's 1 & 4 ESL's (power / 50 RPM on propeller / Bow Thrust). This was just enough to scotch our downwind drift of 1.5-2knots towards the Isle of Skye, only 3 miles away. Full maximum power was available at 0228 UT on No's 1, 2 & 4 ESL's.
Also, to note here is that as the blackout occurred, the emergency generator started but had not gone on the board. A worrying experience for all non NMF SS personnel on board.

9) <u>WHO WERE INVOLVED WITH THE GENERATOR PROBLEMS AND THEIR INVESTIGATION / TESTING</u>

The Engineering Department aboard and the Master as part of the Probe and a full understanding of the problem. They were assisted by Siemens over the phone, as directed by the Technical Manager ashore.

10) <u>ANY SPECIFIC ACTION TAKEN AS A RESULT OF THE PROBLEM / INVESTIGATION / TESTING</u>

<u>Before the blackout</u>
A 6-8 hour period of confidence building as we steamed toward Barra. The serious nature of the weather forecast enabled the Master to 'take care' as he knew that a run toward shelter would not only test her further in the worsening conditions and enhance confidence, but also bring her near safety if things went wrong. Ultimately things went wrong whilst at shelter, not on the journey to it.
<u>Since the blackout</u>
The engine room are now on watches.
The ETO is investigating the dysfunctional nature of the lights that indicate the number and sequence of Generators running, on the forward Bridge Console.
An investigation is also underway regarding the Emergency Alternator and why it did not go on the board.
The vessel has taken a sheltered route to a safe anchorage or area in the Sound of Mull to await a weather window so she may go on to Glasgow to berth for further investigations.
Top Management ashore are supporting the Master and his Top Management aboard (including the PS) in his decision to stop workings out at Rockall until the problems are dealt with (which is planned once the vessel is berthed in Glasgow).

11) <u>WHAT TRAINING HAS BEEN PROVIDED? IS THERE A NEED FOR FURTHER TRAINING?</u>
None, Certain problems are considered tasks over and beyond the abilities of the Engineers aboard.

12) ARE THERE PLANS TO MONITOR FUTURE SIMILAR OPERATIONS?
Yes, watches being kept by the engine room are enabling constant monitoring.

13) IS THE PROPULSION IN GOOD ORDER AND SAFE AFTER THE EVENT

Yes – as long as watches are kept and monitoring continues

14) ANY ADDITIONAL INFORMATION
See Chief Engineer's reports
2nd Officer Malcolm Graves report attached (OOW at the time of the 'blackout').

RECOMMENDATIONS to prevent a repetition:

To await the chance to round the Mull of Kintyre into the Firth of Clyde to arrive Glasgow as soon as is practicable so that further, deeper investigation, and fault finding can take place. The vessel is currently at anchor in the Sound of Mull sheltering from severe SW'ly gales, and will not attempt to round the Mull of Kintyre until the weather ameliorates sufficiently. This is because the confidence to do this in severe weather conditions has diminished somewhat.
The ETO is investigating the dysfunctional nature of the lights that indicate the number and sequence of Generators running, on the forward Bridge Console.
Engine Control Indicator lamps on bridge console: A DMS Document change has been made to the familiarisation of Deck officers SMM 3106.4 and also to the Bridge sailing checklist SMM 3108.7.
Chief Engineers report on problems needed to be addressed dated 3rd December 2006;
This is attached to this report and lists problematic areas that need to be addressed.

Completed By: Roger Chamberlain - Master	R.J. Chamberlain

Appendix 6: Letter from Chief Engineer to NERC RSU Technical Manager re power loss

R.R.S. Discovery

At sea
Saturday 02/12/06

Mr. T. Lee
Technical Manager
NERC Research Ship Unit
National Oceanography Centre
Empress Dock
Southampton
SO14 3ZH

<u>Blackout Report</u>

Dear Tim,
Please be advised that we experienced a total blackout at 0212 hrs and power / propulsion restored at 0218 hrs, on No's 1 & 4 ESL's. This was a partial restoration (power / 50 RPM on propeller / Bow Thrust) and full maximum power was available at 0228 hrs on No's 1, 2 & 4 ESL's.
Also, to note here is that as the blackout occurred, the emergency generator started but had not gone on the board. However, this was load tested only last Saturday during weekly routines with no abnormalities.

Last night, Friday the 1st of December, the duty engineer carried out his usual rounds and nothing seemed to be amiss. Also, at that time No 2, 3 & 4 ESL's were on line. As the vessel was in sheltered area it was decided with the confirmation from the bridge to move down to two ESL's, namely No's 2 & 3. The loading at the time was around 45 percent, with these two engines. This includes the normal ships loading, propulsion and bow thrust.

Referring to the engine room log printout, No 3 ESL had shut itself down at 0040 hrs. There were no alarms initiated to warn the duty engineer of this happening. Thus the vessel had only No 2 ESL on line. Both ESL's were in manual mode. (Note: PMS – Power Management System is not utilised any more due to it's erratic performance and unreliability).

The blackout occurred whilst the vessel was being manoeuvred to maintain head into wind. That is, No 2 ESL was overloaded, which tripped its breaker and shut itself down. Again there were no alarms to indicate overloading taking place to alert the duty engineer, other than the illuminated indicator on the bridge.
However, it is now clear that No 3 ESL had shut itself down due to failure of it's AC Module. The problems associated with this unit were relayed to yourself on Wednesday the 29th. With consultation from Siemens the AC Module was tested to find nothing amiss and was load tested yesterday morning, before bring No 3 ESL

into service and was monitored closely for well over 6 hrs. Nothing was found amiss when control voltages and wave forms (using oscilloscope) were checked against the AC Module manual.

Again, as the situation stands, it would be very unwise for this vessel to continue until the problems with the AC Modules are addressed fully, as with 3 engines, there is no redundancy available.

Yours Faithfully

____

K G Jethwa
Chief Engineer
RRS Discovery

COMMENTS FROM THE MASTER

A Full report from me will be forthcoming shortly.
After the AC Module problems on the 29th November and the subsequent 6-8 hours of testing, we decided that some confidence had been restored and that we were going to 'give it a go' as far as venturing out to Rockall was concerned.
Whilst we were on our way the weather deteriorated to such an extent that a decision was made to re-shelter the vessel, more so because of forecasts of Storm force winds and associated waves.
As far as I am concerned that decision was, in retrospect, a good one. The event of the above blackout could have been catastrophic out there in the storm. It was perilous enough in shelter as the strong winds can 'sail' the Discovery up to 1.5 – 2 knots, so in a relatively short time the danger of grounding is real.
Stornoway Coastguard was fully informed right from the start as I did not know how long it would be for power to be restored and we had only 2 hours max of drift time. Even the provision of enough power for 50 revs and the bowthrust, only just scotches any drift in those winds.
Needless to say, these events have drained any confidence we have in venturing out to Rockall and all management aboard (including the PS) concur.
We therefore have liaised with Top Management ashore and agreed for the vessel to continue sheltering until we have the weather for us to confidently tackle the Mull of Kintyre for a passage to the Clyde for berthing, where we await further investigation.

Yours

Roger Chamberlain
Master