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Cruise Report No. 33

OWS *Polarfront* Cruise P162

09 SEP – 04 OCT 2006

HiWASE mobilisation and shakedown cruise

Principal Scientists

M J Yelland & R W Pascal

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National Oceanography Centre, Southampton
University of Southampton Waterfront Campus
European Way
Southampton
Hants SO14 3ZH UK
Tel: +44 (0)023 8059 6406
Fax: +44 (0)023 8059 6204
Email: m.yelland@noc.soton.ac

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ABSTRACT

This report describes the mobilisation and shakedown cruise of the Norwegian weather ship *OWS Polarfront* in September 2006. The air-sea turbulent flux system "AutoFlux", a commercial wave measurement system "WAVEX" and a number of digital cameras were installed on the ship as part of the UK-SOLAS project "HiWASE" (High Wind Air-Sea Exchanges). These complemented the ship's mean meteorological sensors and a ship-borne wave recorder (SBWR) both run by the Norwegian Meteorological Institute (DNMI) and an underway pCO2 system run by the Bergen Centre for Climate Research (BCCR).

The *Polarfront* and its predecessors have occupied Station M (66 N, 2 E) for over 60 years. The ship is on station all year round, only leaving for an eight hour port call once every 4 weeks, and an annual refit for 5 days in September. The HiWASE instrumentation was installed in early September 2006, prior to the shakedown cruise P162. The various systems operated continuously from September 2006 until December 2009, when DNMI withdrew the ship from operation.

This cruise report describes the instrumentation installed on the ship, including that run by DNMI and BCCR as well as the HiWASE systems, and presents an initial analysis of the data quality from the various systems. Preliminary results are given for the air-sea fluxes of momentum, CO2 and sensible and latent heat. These fluxes were directly measured using the inertial dissipation and/or the eddy correlation (covariance) methods, from a suite of fast response sensors installed on the ship's foremast.

This report focuses on the systems as installed for the shakedown cruise. However, over the 3 year deployment period various changes were made: these are described in a separate metadata report (Moat et al., 2010).

KEYWORDS

Air-sea fluxes, air-sea interaction, inertial dissipation method, eddy correlation method, directional wave spectra, whitecaps, WAVES, SBWR, AutoFlux, OWS *Polarfront*, Station M, P162, HiWASE, SOLAS, DNMI, BCCR

ISSUING ORGANISATION

National Oceanography Centre, Southampton
University of Southampton, Waterfront Campus
European Way
Southampton SO14 3ZH UK
Tel: +44(0)23 80596116 Email: nol@noc.soton.ac.uk

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Personnel during cruise P162

Scientific Personnel

Margaret J. Yelland	NOCS
Robin W. Pascal	NOCS

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Jarle Nerhus	Master
Øyvind Synnevåg	1st Mate
Terje Nerhus	Chief Engineer
Gunvald Nerhus	Assistant Engineer
Kjell Skaret	Radiosonde Operator
Allan Nilsen	Radiosonde Operator
Odd Hanstvedt	Cook

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Development of the AutoFlux system was begun under MAST project MAS3-CT97-0108 and continued under two NOC Technology Innovation Fund projects. The "HiWASE" project is funded through the NERC thematic program "SOLAS" (grants NE/F007442/1, NE/C001826/1, NE/C001869/1, NE/C001834/1, NE/G000115/1, NE/G000123/1 and NE/G003696/1) and is also supported by NERC's Oceans 2025 program.

OWS *Polarfront* Cruise P162, 09th September to 04th October 2006. HiWASE mobilisation and shakedown cruise.

M. J. Yelland and R. W. Pascal

April 2010

1. Introduction

The "High Wind Air-Sea Exchanges" (HiWASE) experiment is funded under the NERC thematic project SOLAS ("Surface Ocean Lower Atmosphere Studies"). The overall aim of the project is to improve the parameterisation of air-sea turbulent fluxes of sensible and latent heat, momentum and CO_2 fluxes in terms of mean meteorological and sea-state variables. To do this entails making direct measurement of the fluxes themselves, as well as measuring the relevant mean meteorological (wind speed, air temperature etc) and sea-state (wind waves, swell, whitecapping etc) parameters, in a wide range of conditions particularly the poorly-understood high wind speed regime (15 m/s or more). To this end a number of sensors and systems were deployed on the ocean weather ship *Polarfront*. It is intended that all systems will operate continuously for at least two to three years.

The *Polarfront* is the world's last ocean weather ship and operates year-round in a region of large ΔpCO_2 and regular storms. The ship has occupied Station Mike (66 N, 2 E) since 1976 when it replaced the previous ships (*Polarfront I* and *Polarfront II*) which occupied the station in turn from 1948 to 1976. The ship is only off-station for a maximum of 3 days every month during its passage to and from the port of Alesund where it spends 8 hours once per month taking on stores and exchanging crew. Every year the ship spends one week of September in Maloy for maintenance etc. The *Polarfront* is owned by Misje Rederi AS, who operate the ship under contract to the Norwegian Meteorological Institute (DNMI)

The *Polarfront* was in Maloy from the 5th to the 9th September 2006 during which time four NOC staff (Yelland, Pascal, Moat and Harrison) mobilised the AutoFlux system and other instrumentation. During this time Miros staff installed the WAVEX wave radar system; staff from DNMI replaced the ship's scientific network; colleagues from Bergen University's Bjerknes Centre for Climate Research (BCCR) serviced their pCO_2 system and integrated the thermosalinograph (provided by HiWASE); and the ship's crew and owners were occupied with the ship's 30-year recertification.

The ship sailed at 14:30 on Friday 8th September (day 251) and spent a few hours at sea while the WAVEX system was commissioned. The ship then briefly returned to Maloy to put the Miros engineer ashore before departing at 16:00 for Station Mike. Two NOC staff (Pascal and Yelland) sailed with the ship for the initial shakedown cruise. The ship arrived at Station Mike at 02:30 on 10th September (day 253) for cruise number 162 I (the subsequent two cruises are numbered 163 II and 163 I, the numerals II and I denoting which of the two crews are on board). The ship left Station Mike at 00:01 on the 3rd October (day 276) and arrived at Alesund at 04:50 on the 4th October (day 277).

The behaviour of the *Polarfront* is described first (Section 2) since this influenced some of the decisions made with respect to the positioning of some of the instruments deployed. Section 3 describes the instrumentation used, both that deployed as part of the HiWASE project and also that belonging to DNMI and to BCCR where appropriate. Preliminary analysis of the data from the mean meteorological and waves systems are given in Section 4 along with suggested system modifications / improvements where necessary. Section 5 briefly describes the initial flux results. All times refer to GMT.

More information on the HiWASE project and near-real time data from the AutoFlux system can be found under http://www.noc.soton.ac.uk/ooc/CRUISES/HiWASE/index.php

This cruise report describes the setup of the equipment as it was during the shakedown cruise in September 2006. The systems remained on the ship until it was withdrawn from service by DNMI in December 2009. Various modifications to the systems were made during this 3 year deployment, and these are detailed in the metadata report by Moat et al. (2010). This cruise report should be read in conjunction with the metadata report.

2. *Polarfront* operations on Station Mike.

As described in the Introduction the *Polarfront* spends 25 days out of every 28 on Station Mike, with the other three days spent on passage to/from or in Alesund for an 8 hour port call. While on station the ship drifts beam-on to the weather with the main engines turned off to conserve fuel. Once the ship has drifted more than about 20 nm (0.3 degrees latitude) from 66 N 2 E it steams slowly (about 6 knots) upwind until it is back on station. In rough weather the ship can not drift beam-on but has to go hove-to, i.e. bow-on to the weather. The point at which this happens depends on the sea state as well as the wind speed, and usually occurs for wind speeds of between 15 and 20 m/s. In general, the ship drifts with the starboard beam upwind. However, when the wind is from the east or north the ship drifts with the port side upwind: prior to the cruise the reason given for this was poor inmarsat C reception when the ship's heading was to the north, but poor satellite television reception was also given as a reason during the cruise itself. Analysis of 6 months of ship heading and wind data provided by DNMI prior to the cruise indicated that the *Polarfront* operated port-side to the wind for up to 20% of the period examined. Since the HiWASE project needs good high wind speed data the instruments had to be well-exposed for bow-on winds. For this reason instruments were located to maximise exposure for winds blowing onto the bow and starboard beam. A request to the ship's crew to minimise the occurrence of winds on the port beam was acted on for the duration of the 3 year deployment.

The routine meteorological and hydrographic operations of the ship are undertaken by the crew since scientists very rarely sail on the ship. Radiosondes are launched four times a day when the ship is at sea (either on station or on passage), at 0500, 1100, 1700 and 2300 GMT (ship time is GMT+1). The system uses Loran C to obtain wind speed from the sondes. For winds below about 10 m/s, the ship stays beam-on or the bow-thruster is used to bring the wind more on to the bow if necessary. For winds above 10 m/s the main engines are used to bring the ship bow-on to the wind. There is apparently no upper wind speed limit for radiosonde launches: in early January 2002 radiosondes were launched despite mean winds of 35 m/s.

CTDs are performed once a day on Mondays to Fridays (none at weekends). Four days a week the CTD is lowered to a depth of 1000 m. These CTDs are done wherever the ship is in relation to station Mike. Once a week, usually on Thursdays, the ship returns to exactly 66 N 2 E for a CTD to 2000 m (full depth) and obtains ten water bottle samples (at depths of 2000, 1500, 1200, 1000, 800, 600, 600, 400, 300 and surface). On the last Friday of each cruise an extra 2000 m dip is done and additional water samples from the top 200 m are taken to be analysed at BCCR for oxygen, nutrients and chlorophyll. The CTD itself is sent to BCCR at the end of each trip, as are the water samples. CTDs are usually begun at 1100 GMT: the 1000 m dip takes about an hour and the 2000 m dip two hours, during which time the bow thruster may be used to hold the ship with the wind on the stern. Depending on sea state, CTDs can only be done in winds of up to about 12 m/s. If bad weather prevents the deep CTD being carried out on a Thursday it is done if possible on the next day.

Air samples are obtained twice a week, using equipment carried to the upwind bridge wing. These samples are sent to the Carbon Cycle Group at NOAA in the US for analysis. Air sampling has no affect on ship operations.

The ship's officers also take full meteorological observations every hour.

3. The measurement systems.

This section describes the various instrumentation installed on the ship, both that installed as part of HiWASE and also that installed by BCCR and DNMI. Details of the instrument positions, serial numbers etc. are given in Moat et al. (2010) for the whole of the 3 year deployment.

3.1 The BCCR surface pCO_2 system and the TSG.

Colleagues from BCCR installed an underway CO_2 system in 2005. The system (Pierrot et al., 2008) is fully automated and is located in the forwards part of the hold, the deck of which is below the water line by about 1 m. The sea water intake for the system is the same as that used for the bow-thruster motor. The intake is located about 3 m below the water line i.e. about 2 m below the bow thruster motor. The seawater for the BCCR system is taken from a point near the motor and travels 2.7 m through a lagged metal pipe to a PRT100 sensor which is used as the intake temperature for the CO_2 system. The pump is located 1.3 m upstream of the PRT100 along a plastic pipe. The system obtains samples at about 3 minute intervals. Air samples are obtained about once every 3 hours and four gas standards are run about every 3 hours.

As part of HiWASE, NOC supplied a Seabird SBE45 MicroTSG (thermosalinograph) which BCCR colleagues integrated into their pCO_2 system. The TSG was located via a plastic pipe about 2 m from the pump, i.e. about 6 m from the water intake. The TSG outputs salinity and also water temperature as measured within the body of the TSG, generating data once every 3 seconds. The recommended flow rate for the TSG is between 0.6 and 1.8 litres/minute. On sailing the flow was set to 1.2 l/min but when checked a week later the flow had reduced to a trickle. It was checked and reset periodically from then on and although the flow was very variable it was always within the recommended limits. On day 266 the flow seemed to be constant at 1.6 l/min, perhaps helped by not turning the flow off and on at the main valve when checking the flow.

3.2 DNMI meteorological systems.

As may be expected of a weather ship, the *Polarfront* is well equipped with meteorological instrumentation. Prior to June 2006 the ship had **three anemometers** mounted on the foremast platform. On the port corner was a propeller vane instrument, 20 cm to starboard of the ship's centreline was a WindObserver denoted "Windldwr" and on the starboard corner was a second WindObserver denoted "Gill". During June 2006 the starboard sensor was replaced by an R3 Research sonic anemometer (also made by Gill Instruments Ltd) supplied by NOC. Figure 1 shows the layout of the instruments on the foremast platform as installed during the mobilisation period.

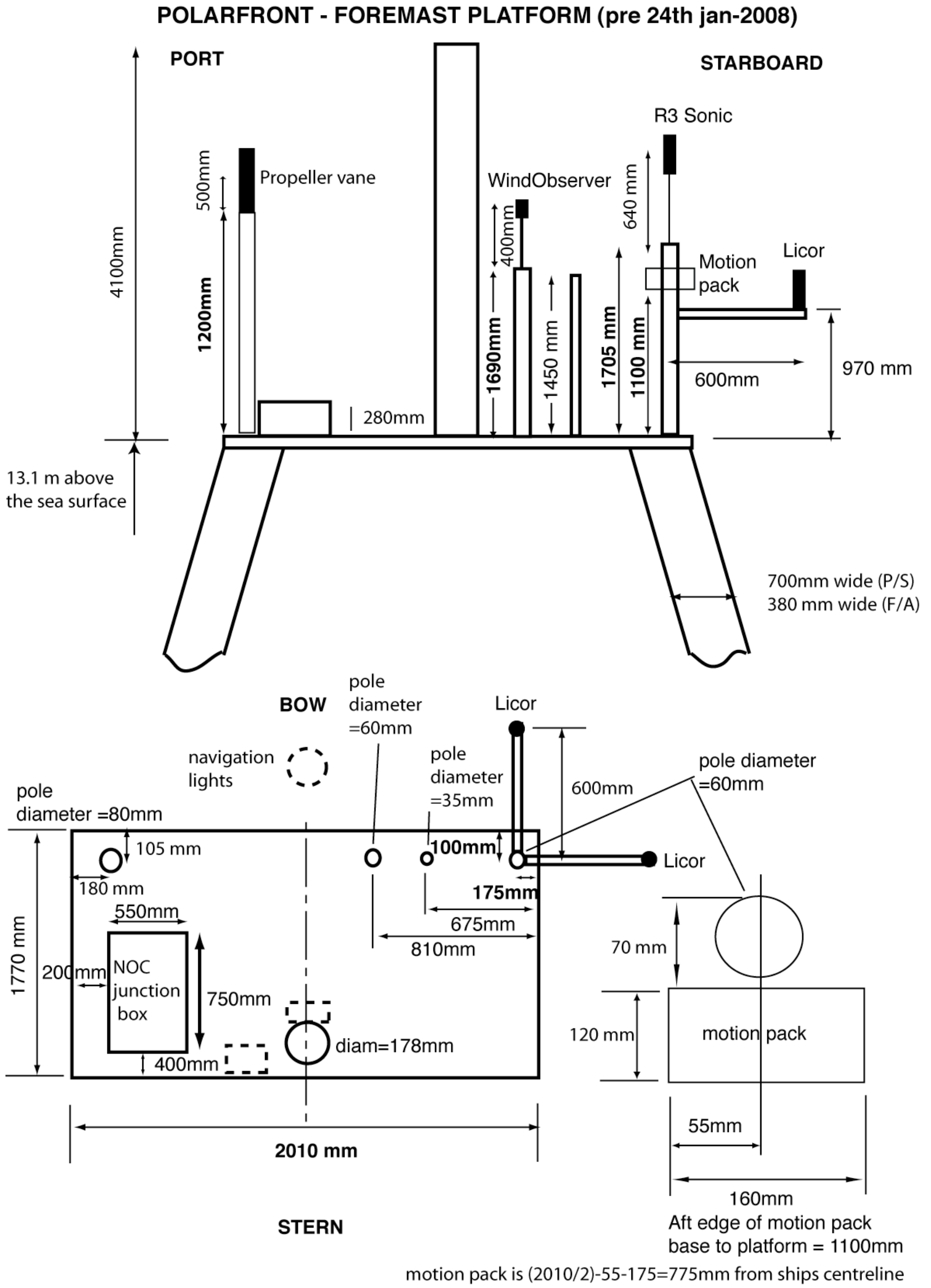

Figure 1. Layout of the foremast instrumentation from September 3rd 2006 to 24th January 2008. The top panel shows the view from the bridge looking forwards. The drawing on the bottom right shows the dimensions of the motion pack.

The **DNMI air temperature and humidity sensors** are located in a Stevenson screen on top of the wheelhouse. The screen is located on the starboard side, near the forwards edge of the superstructure (Figure 2) . It can be seen that as well as being inside the screen the sensors are also enclosed in shields: it is thought that this may lead to problems with ventilation of the DNMI sensors. Air temperature, dew point temperature and relative humidity data are automatically processed by the DNMI acquisition system and 1 minute means along with maximum/minimum values are output onto the ship's data network.

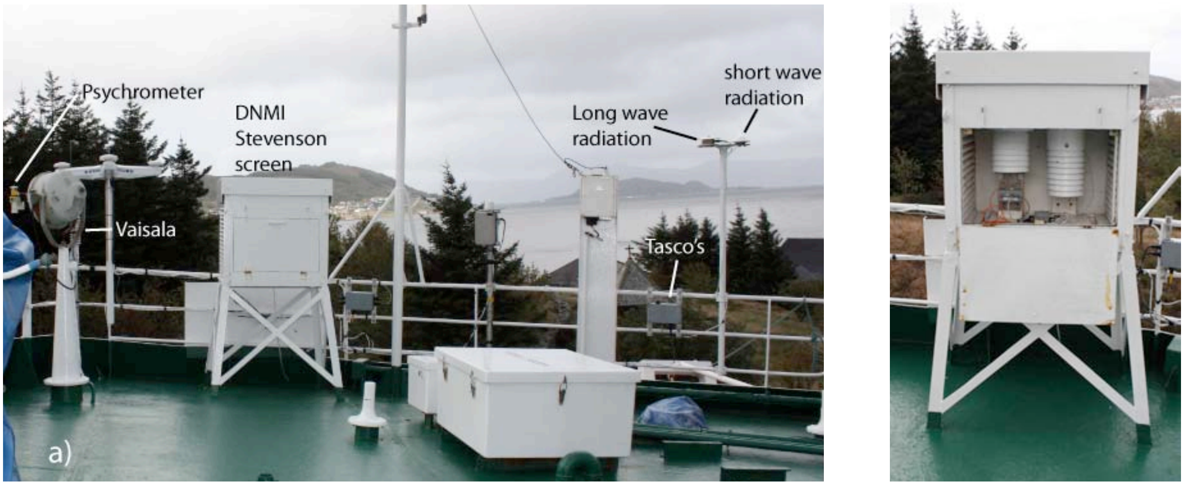

Figure 2. Left: view of the bridge top, looking towards the starboard side of the ship. Right: the opened Stevenson screen showing the shielding of the DNMI temperature sensors.

Within the meteorological laboratory there are three **air pressure sensors** mounted at a height of about 6.5 m above sea level. Again 1 minute average values are output to the ship's data network: variables P1 to P3 are uncorrected for height.

Two **PRT100 hull contact sea surface temperature (SST) sensors** are located in the engine room. The sensors are sited within the wells which contain the SBWR pressure sensors (Section 3.4) at a depth of about 1.4 m. The two SST sensors are located on either side of the ship. That denoted "TG1" is on the port side and "TG2" on the starboard. The wells are thoroughly insulated from the engine room space so should be relatively uncontaminated by the heat of the engine room. Prior to the cruise SST data from the two sensors had diverged to a difference of about 1 deg C. TG1 was replaced during mobilisation in Maloy.

3.3 Ship's navigation data.

Data from the ship's navigation systems is also made available via the ship's data network. These data are output at about 1 Hz. The ship has two navigation data streams. The two are very similar but the "old" data stream uses ship's heading from a gyro whereas the new one derives ship's heading from a Furuno satellite GPS compass. In addition to the ship's speed over the ground from the GPS data the ship is also equipped with an em-log (with transducers located amidships, well away from the bow thruster) which gives ship speed through the water. Data from the em-log are not available via the data network and are only displayed on the bridge. However, these data may be used to calculate true wind speed and direction as shown on the bridge display.

3.4 Ship Borne Wave Recorder.

As part of DNMI equipment, a SBWR was installed on the *Polarfront* in 1978. This system uses the motion of the ship itself to derive wave data from the ship's heave (from accelerometers) and roll (from pressure sensors at a depth of 1.4 m). In recent years it has been difficult to calibrate and maintain SBWR systems since the company (WS Oceans) which provided this service closed some time around 2001. However, NOC staff provided calibration equipment and recalibrated the SBWR while the ship was in Maloy. Calibration details are given in Moat et al. (2010).

The SBWR does not provide data on the direction of the waves, and its response is limited to waves of about 0.6 Hz or less. In addition, when the ship is steaming no allowance is made for ship speed on the calculated wave period. However, it does provide reliable data on the height of the longer wavelength waves and the resulting significant wave height (Hs) has been validated against directional wave buoys and satellite data (Yelland et al., 2007). DNMI set the SBWR to sample for a 30 minute period once every 45 minutes. The time stamp with the serial output refers to the end of the sample period.

It was noticed during the calibration process that noise in the system was causing the SBWR to register small amplitude (less than 0.5 m) waves of very long period (20 s or more) even though the ship was in dock. This is probably due to electrical noise in the system and may possibly be cured by replacing the cable.

3.5 NOC - WAVEX directional wave radar.

The HiWASE project provided funds for the purchase and installation of a directional wave radar system. A formal tendering procedure resulted in the selection of the Miros system "WAVEX". Wave radar systems use a standard marine x-band radar to obtain directional wave spectra. To do this, the radar must be operated in "short pulse" mode, a mode which is not usually used for navigational purposes. In principle the ship's existing radar could be used to provide input to the WAVEX data capture board and processing software, but this would require the ship's crew switching the ship's radar into short pulse mode when wave data were required. This option was not feasible for the long-term continuous deployment on the *Polarfront*. For this reason a separate x-band scanner was installed on the ships main mast at a height of 17 m above sea level.

Prior to leaving Maloy the ship steamed a few miles out to sea and the orientation of the scanner was checked by pointing the ship towards a small island. An offset of 5 degrees was determined and allowed for in the system configuration file. The WAVEX was set up to sample for a 2 minute period every five minutes. Spectra and mean parameters were recorded from every 5 minutes and raw data were recorded twice per hour. The WAVEX software allows up to eight mean parameters to be output over a serial link. These selected were recorded by the AutoFlux acquisition system and are described in Section 4.7.

3.6 NOC - digital cameras

Variables thought to affect the air-sea flux of CO_2 include wavebreaking and whitecap coverage. There is some evidence that spikes in the wave radar data can be related to these effects but another method of obtaining whitecap coverage is by digital imaging. Two digital cameras were installed in the port/forwards corner of the ship's bridge, one pointing forwards over the bow and the other to port. The starboard corner was the preferred location since the wind is most often on the starboard beam and it was thought that the ship would affect the waves to port. However, during mobilisation it was decided that the starboard corner was not possible since there was a) no mains power and b) no way to clean the outside of the windows. The port corner had both power and access to the outside. The cameras were set up at 90 degrees to each other, and both pointed down from the horizontal by about 10 degrees. Both were set to take pictures once every 30 minutes.

3.7 NOC - AutoFlux system.

3.7.1 The AutoFlux system

AutoFlux is an autonomous, stand-alone system which obtains direct measurements of the air-sea turbulent fluxes in addition to various mean meteorological parameters. The system automatically calculates momentum and latent heat flux values using the inertial dissipation (ID) method which 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 air flow 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. In order to correct for ship motion data from a MotionPak sensor is acquired via the six analogue input channels of the R3 anemometer. Once EC fluxes are calculated (currently done post-cruise) 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.

During the cruise the AutoFlux acquisition system was expanded to acquire data from all the instruments and systems on board (navigation, DNMI meteorological sensors, both wave systems, the underway pCO_2 and TSG system) except for the digital cameras. The acquisition system is based on a Sunfire V210 UNIX workstation running Solaris OS 9.

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 “mike”, the Sunfire workstation. Processing of all data and calculation of the ID fluxes was performed automatically 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. The workstation was powered via a UPS.

Housekeeping information, summary data from all systems and initial flux results are transmitted in a daily IRIDIUM message to NOC at about 0230 GMT each day. These data were displayed and made available on the project web site at http://www.noc.soton.ac.uk/ooc/CRUISES/HiWASE/OBS/data_intro.php . The IRIDIUM system also allows two-way communication with the AutoFlux systems, which provides a means to send commands to the system if required, for example stopping or re-starting an individual process or re-booting the UNIX workstation.

3.7.2 Mean meteorological sensors

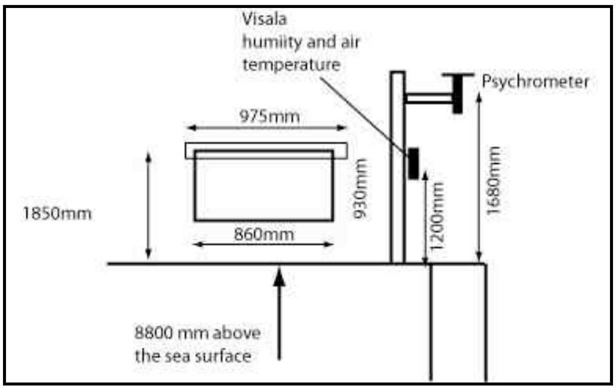

Figure 3. The layout of the Stevenson screen and the NOCS air temperature sensors on the wheelhouse top.

The NOCS mean meteorological sensors measured air temperature and humidity (from a Vaisala and a psychrommter), wind speed and direction, downwelling longwave (4-50 micron) and shortwave (310-2800 nm) radiation and infra-red (IR) sea surface and sky temperatures. The R3 anemometer was mounted on the foremast platform along with the other fast response sensors (see Figure 1 and Section 3.7.3) but the other mean meteorological sensors were all mounted on the starboard/forward area of the wheelhouse top (Figure 2 and Figure 3). Data from all sensors bar the R3 were logged once every 10 seconds.

3.7.3 Fast response sensors.

The air-sea fluxes of momentum and sensible heat were obtained from the R3 sonic anemometer and the fluxes of latent heat and CO_2 were obtained from two Licor 7500 H_2O/CO_2 sensors. All output data at 20 Hz. To obtain EC fluxes, ship motion data from a Systron-Donner "MotionPak" system has to be synchronised with those from the other fast response sensors. In order to achieve this the MotionPak output was logged via the analogue input channel of the R3 anemometer. In addition, a timer circuit was added in to the R3 sonic interface unit. This circuit generated an asymmetric square wave sync signal which was input to the analogue channel of both Licors and to the PRT input to the R3. Once allowance is made for the 0.185 second delay in the H_2O and CO_2 output from the Licors, this enables synchronisation of all fast response.

All of the fast response sensors were mounted on the ship's foremast (Figure 1) in order to obtain the best exposure for bow-on and starboard beam-on wind directions. The centre of the R3 sensor volume was 2.35m above the foremast platform. The R3 was oriented so that the "north" strut faced aft, i.e. a wind direction of 180 degrees represented a bow-on flow. The orientation of the anemometer was checked by measuring its distance from the ship's centreline and the standing at that distance on top of the bridge. The person on the bridge top could then view the alignment of the strut compared to the body of the R3 and inform the person on the foremast. The centre of the MotionPak was located 1.18 m below, 0.025m to starboard and 0.095m aft of the R3 volume. The location and orientation of the R3 and MotionPak were changed on a number of occasions during the 3 year deployment period. Details of all changes are given in the metadata report (Moat et al., 2010) along with information about the MotionPak and anemometer frames of reference.

Two Licors were located as near to the R3 as possible. However, to eliminate any risk of the Licors causing a disturbance of the air flow to the anemometers they were mounted at the same level as the rails around the foremast. Licor 1 was mounted 0.6 m directly forwards of the R3 pole and Licor 2 was mounted 0.6 m directly to starboard of the R3. Both sensors were at a height of 1.15 m above the platform. Both Licors were operated without shrouds for the entire cruise (although to protect them from shipyard dust both were shrouded until the ship left Maloy). After the cruise, the Licors were shrouded in turn for 4 weeks at a time, with the chip's crew swapping the shroud from one sensor to the other during port calls (see Moat et al., 2010 for details). The purpose of the shroud was to determine, and devise a correction for, the effect of head deformation on the measured fluxes (Yelland et al., 2009).

The draught of the ship was 11 feet (maximum load line of 12 feet) when the ship left Maloy. From the ship's GA plans this means the height of the above the water line was 13.1 m and the heights of the instruments above water were: sonic 13.1 + 2.35 = 15.45 m, Licors 13.1 + 1.15 = 14.25 m. On arrival in Aalesund the draught was 10 feet at the bow.

4. Initial analysis of the mean meteorological and wave parameters.

4.1 Air temperature and humidity

Air temperature and humidity data were available from the DNMI Vaisala sensors in the Stevenson screen, the NOC Vaisala sensor and the NOC psychrometer. The NOC sensors were both mounted close together on the forward starboard corner of the wheelhouse top. The Stevenson screen was on the starboard rail about 2 m aft of the NOC sensors. Figure 4 shows the difference between the air temperature measurements from the three sensors obtained during the shakedown cruise. Night-time data only were used to avoid any solar-heating effects. The data were averaged over 15 minutes. It can be seen that the NOC Vaisala sensor data are biased low by about 0.5 degrees compared to the psychrometer. On average, the DNMI Vaisala agrees reasonably well with the NOC psychrometer but the data are very scattered. Some of the scatter in the DNMI data may be due to the fact that the DNMI sensors are enclosed in a solar shield as well as being inside the Stevenson screen. This causes the DNMI data to lag behind the data from the NOC sensors. The cause of the scatter in the DNMI data is not presently understood. It has no simple relationship to wind speed or relative wind direction, but does seem to be related to humidity (Figure 5).

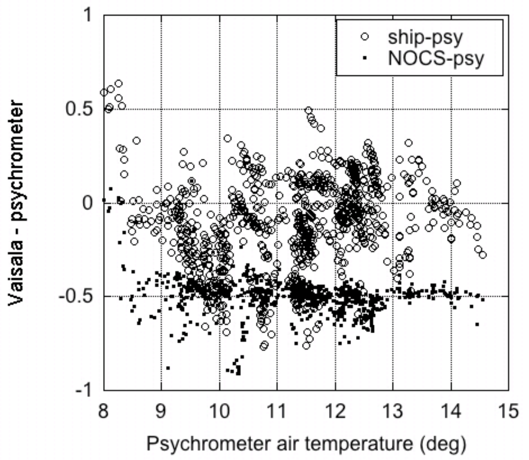

Figure 4. Air temperature differences (Vaisala - psychrometer) for the DNMI Vaisala sensor (open circles) and the NOC Vaisala sensor (dots) against the psychrometer temperature. Night time data only were used.

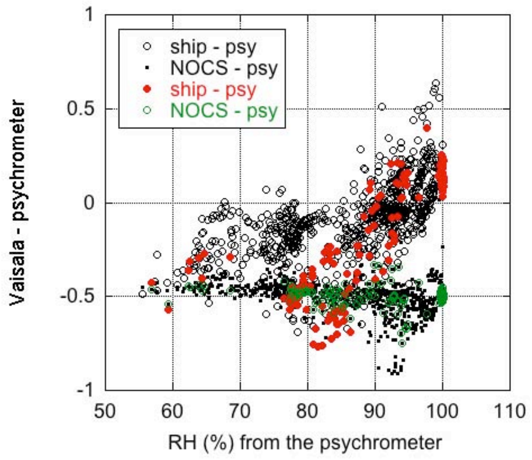

Figure 5. As Figure 4 but plotted against relative humidity. Points in black are for all wind speeds, whereas those in red or green indicate data obtained for relative wind speeds of less than 7 m/s.

A comparison the relative humidity is shown in Figure 6. Here it can be seen that the agreement between the NOC Vaisala and NOC psychrometer data is good for low humidities, but that at high humidities the Vaisala sensor under-reads: the Vaisala sensors never reports humidities over 95 % whereas the psychrometer regularly reported humidities of 100 %. Since mist and fog occurred regularly during the cruise values of 100% would seem reasonable. Similarly, the DNMI humidities never reported more than 95% but in this case the DNMI sensor over estimates the RH by more than 5% at the lower humidities.

It is thought that the DNMI sensors are Vaisala instruments similar to those used by NOC, i.e. a PT100 for air temperature and an HMP45 for humidity. However, the behaviour of the two is rather different: whereas the NOC Vaisala temperature and humidity data are measured separately and independently, this does not seem to be the case for the DNMI sensors, as indicated in Figure 7. Here the difference (Vaisala - psychrometer) air temperature data are plotted against the difference (Vaisala - psychrometer) relative humidity data. For the NOC Vaisala sensor the differences are un-related whereas the DNMI Vaisala differences correlate strongly. One explanation for the correlation would be heating of the air inside the Stevenson screen. This would cause an increase in the measured air temperature at the same time as a decrease in the relative humidity. If the DNMI Vaisala temperature was biased low by 0.5 degree compared to the psychrometer (as is the case for the NOC Vaisala) then the whole trend would be explained in this way. Note that the actual value of RH has bearing on the calculated bulk latent heat flux.

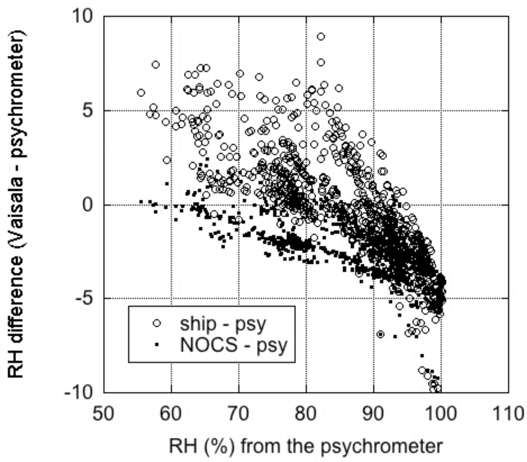

Figure 6. (Vaisala - psychrometer) differences for relative humidity plotted against RH from the psychrometer.

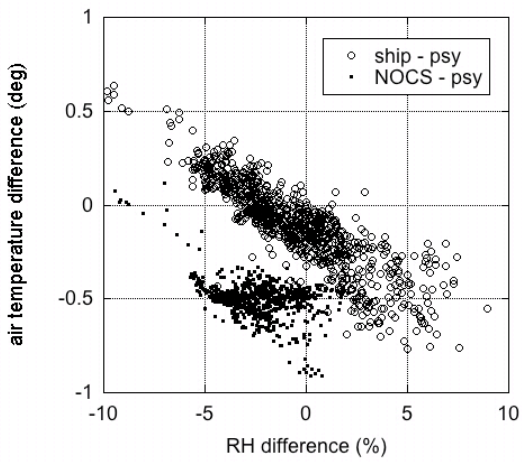

Figure 7. Air temperature difference (Vaisala - psychrometer) against the RH difference (Vaisala - psychrometer) for both the ship/DNMI Vaisala sensor and the NOCS Vaisala sensor.

4.2 Wind speed and direction.

As described in Section 3 there are three anemometers on the foremast platform. However, data from the propeller anemometer on the port side are not logged. The DNMI WindObserver "Windldwr" is mounted 0.2 m to starboard of the centreline and the NOC R3 is mounted in the starboard corner. The R3 anemometer replaced the second DNMI WindObserver denoted "Gill". Whereas the R3 anemometer measures all three components of the wind speed the WindObservers only measure the horizontal component. Figure 8 shows the measured (relative) wind speeds from "Windldwr" divided by those from the anemometers in the starboard corner, plotted against the measured relative wind direction from each sensor. A wind blowing onto the bow is at a direction of 180 degrees. The "Windldwr/Gill" values were obtained from data from previous cruises provided by DNMI, whereas the "Windllldwr/R3" data were obtained during the current cruise. In both cases it can be seen that for winds to port of bow-on the ratio is about 5 % smaller than for winds to starboard. Since this occurs in both cases it is clear that the cause lies with the data from the Windldwr sonic. It is not certain whether this is due to the effects of flow distortion or due to the instrument itself. However, the rapid change in the ratio as the wind direction moves through bow-on is unlikely to be due to flow distortion. In addition, at relative directions of 90, 180 and 270 degrees it can be seen that the ratio drops sharply. This is clearest in the comparison with the R3, and is due to the struts supporting the transducers of the WindObserver blocking the flow.

Figure 9 shows the difference in measured relative wind directions between the Windldwr and the two starboard anemometers. For bow-on winds the direction from the Windldwr is 5 degrees larger than that from the R3 and 7 degrees larger than that from the Gill. These differences decrease to 2 and 4 degrees respectively for beam-in winds. The offsets vary due to flow distortion deflecting the mean wind in the horizontal plane. The differences are due to the orientation of the instruments - it is very difficult to line an anemometer up exactly fore/aft. In order to check the alignments the anemometers were viewed through binoculars from the wheelhouse top. When standing at the same distance from the centreline that the anemometers were located it was possible to see any miss-alignment by comparing the position of the transducer supports (in the case of the WindObservers) or the struts (in the case of the R3). Figure 10 shows a close-up of photographs taken from the bridge. It can be seen that the Windldwr instruments was pointing slightly to port of bow-on and the original Gill slightly to starboard. When the Gill was replaced by the R3 the method was used to align the R3 as accurately as possible, probably to within 1 degree. The Windldwr was unchanged throughout. It is therefore thought that the wind directions from the Windldwr are biased high by 5 degrees for bow-on winds and those from the original Gill were biased low by 2 degrees. A complete analysis of instrument alignments is given for the whole 3 year deployment in Moat et al. (2010).

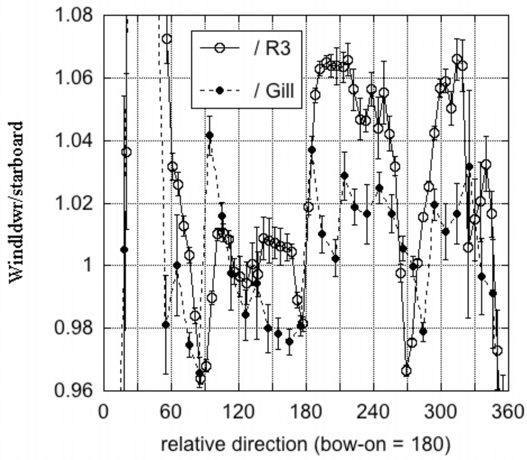

Figure 8. Ratio of relative wind speeds Windldwr / R3 (solid line) and Windldwr / Gill (dotted line) against relative wind direction.

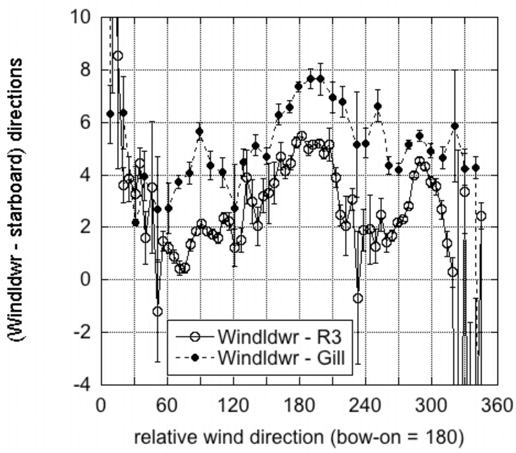

Figure 9. Differences in relative wind direction: Windldwr - R3 (solid line) and Windldwr - Gill (dotted)

Figure 10. The Windldwr (centre) and Gill (right) sonic anemometers taken from the bridge top.

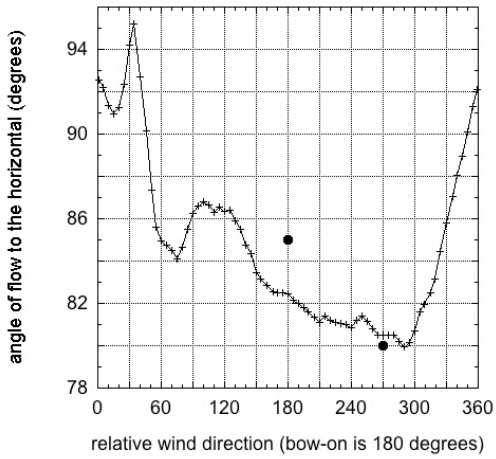

Figure 11. Angle of air flow from the R3 (line) and from the CFD models (solid circles).

The presence of the ship deflects the mean wind in the vertical as well as the horizontal. Figure 11 shows the angle of the mean wind to the horizontal as measured by the R3 anemometer (these data are not available from the WindObservers since they do not measure the vertical component of the wind speed). Also shown on the plot are the predicted angles as estimated from a CFD model of the airflow over the ship (Moat and Yelland, 2009). Winds from the port beam were not modelled due to the presence of the other anemometers upwind of the R3. The angle of the R3 anemometer to the vertical was measured in Maloy and in subsequent ship visits: the R3 tended to lean to aft by a degree or two and there was no consistent tilt in the port starboard direction. Given the tilt to aft of the R3, the measured angle of the mean wind agrees very well indeed with the results from the CFD model. A complete history of instrument tilts is given for the whole 3 year deployment in Moat et al. (2010).

4.3 Sea surface temperature.

Sea surface temperature (SST) data were obtained from: two DNMI hull contact PRT100 sensors (TG1 and TG2) located in the port and starboard SBWR wells at a depth of 1.4 m; the BCCR intake temperature (Tin) 2.7 m along the lagged metal pipe leading from the bow-thruster motor at a depth of 3m; the TSG temperature measured 2.8 m further downstream of Tin; and two Tasco infrared radiation (IR) sensors mounted on the wheelhouse top, both pointing down from the horizontal by 45 to 60 degrees. At the end of the cruise the uppermost Tasco (Tsky) was pointed about 45 to 60 degrees upwards to the sky.

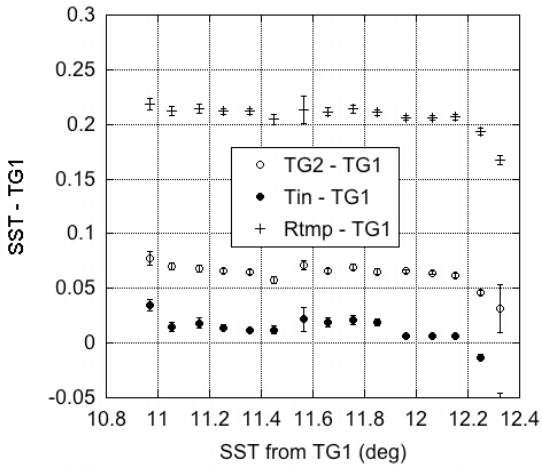

Figure 12. Difference in SST from the various sensors as indicated in the key.

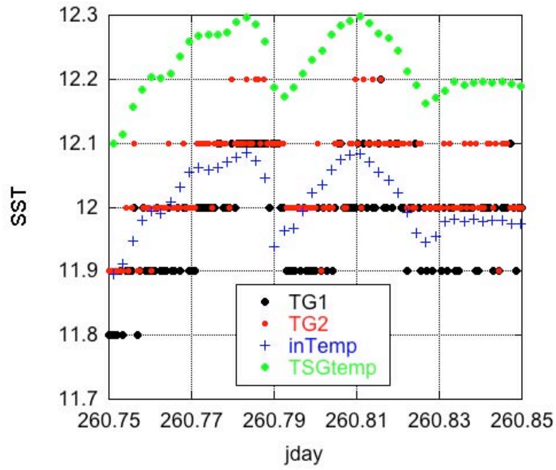

Figure 13. Short time series of SST from the various SST sensors as indicated in the key.

Figure 12 shows a comparison of all SST data except those from the Tasco IR sensors. The difference (SST-TG1) are shown for the other hull contact sensor (TG2) the CO_2 intake (Tin) and the TSG (Rtmp). Tin agrees to within about 0.02 with TG1, and TG2 agrees to within 0.07. Data from the TSG are biased high by more than 0.2 degrees, probably since the sensor is a few meters further downstream of the other intake sensors, and the plastic pipe between the two is not lagged. The increases/decreases in the differences at low/high temperatures seen for all sensors is an artefact of the binning process. At the start of the cruise data from TG1 was selected to be used in the flux calculations, since this sensor was the most recently replaced and calibrated. However, the data from the hull contact sensors are only output to one decimal place. Figure 13 shows 2 hours and 24 minutes of data from the CO_2/TSG system and the hull contact sensors. It can be seen that there is structure in the SST data that is lost by the hull contact sensors.

4.4 Surface Salinity

Sea surface salinity (SSS) was obtained continuously from the NOCS TSG. SSS data were also obtained from the CTD dips, and bottle samples were obtained periodically from the intake pipe (3 m depth) and from the CTD Nansen bottles ("at surface"): these three sources of data agreed well and were used together as a calibration data set for the salinity from the TSG. A comparison of these data for the whole 3 year deployment (Moat, 2010) showed that the TSG tended to drift over time and tended to under-read by between 0 and 1 psu depending on when the instrument had last been cleaned. The TSG salinity data had time-dependent corrections applied before being sent to BODC. The corrected TSG salinities showed residual differences from the calibration data of less than 0.1 psu except for 2 months in mid-summer when the mean salinities tended to decrease by 1 psu and become noisy: for these two months residual differences were generally less than ±0.2 psu. See Moat (2010) for full details.

4.5. Downwelling radiation and atmospheric pressure.

The three atmospheric pressure sensors located in the laboratory agree very well. The mean difference between the 1 minute averaged P2 - P1 is 0.08 mb (s.d. 0.06, maximum 0.3). For P3 - P1 the mean difference is 0.3mb (s.d. 0.05, maximum 0.5).

Only one downwelling short-wave and one downwelling long-wave radiation sensor were installed so no intercomparison is possible. However, the LW sensor used was one that had proved reliable and accurate to about 5 W/m^2 on recent cruises. The SW sensor was installed at the start of the cruise but the long wave sensor was not deployed until the evening of day 268.

4.6. Navigation data.

As described in Section 3.3 two navigation data streams are available, and both were logged during the cruise. The “old” data obtains ship’s heading from the gyro whereas the new data “Nav2” obtains heading from GPS data: the latter is reputed to be more accurate. Otherwise both data streams are very similar, except that parameters “number of satellites", “quality” and "HDOP” are present in the old data but not in the new. In addition, the old data stream may output rate of change of heading but this seems to be turned off when the bridge swapped from old to new systems once well away from land.

Both data streams output data at 1 Hz. Teething problems with the TCP acquisition programs meant there was significant data loss for the first nine or ten days of the cruise, but from about day 261 the 1 Hz data were acquired with minimal losses. The “old” data were processed and used in the flux calculations.

4.7 Wave systems.

As described above, the *Polarfront* has been equipped with a SBWR since 1978. As part of the HiWASE project a directional wave radar “WAVEX” was also installed. The SBWR provides reliable wave height data but no directional information. In contrast, wave radars are known to give reliable directional information, but wave heights from such systems are relatively unproven. Since the backscatter from the wave radar does not provide direct height information it must be inferred using a commercially-confidential algorithm.

Raw data from both systems were not examined during the cruise but were recorded for post cruise analysis. However, summary parameters from both system were available via serial outputs and were logged via the AutoFlux system. These data are included in the daily iridium messages. The parameters output from the SBWR are fixed but for the WAVEX there is a choice of 8 out of 44 parameters. Table 1 lists the parameters from both systems. For the WAVEX system, the 4^{th} order spectral moment was initially selected since this is related to wavebreaking. However, the serial data are only given to one decimal place so m4 was always zero (this would also apply to most of the other moments too). Since it was not possible to change the format, SPRt was selected instead on day 272.

SBWR parameters		WAVEX parameters (code)	
Hmax	Max peak-to trough	Hm0 (003)	= 4 * m0**1/2
Hs	= 4 * m0**1/2	Tm02 (012)	= (m0/m2)**1/2
Te	= m-1/m0	Tp1 (006)	= 1/Fp1
m-2		Dp1_t (017)	
m-1		m4 (030) then SPRt (022)	Changed day 272 1645 GMT
m0		Tp2 (007)	= 1/Fp2
m1		Dp2_t (036)	
m2		Dpt_t (020)	
8xflags	Last four are wrong.		

Table 1. Parameters output from the wave systems via serial link for real-time monitoring.

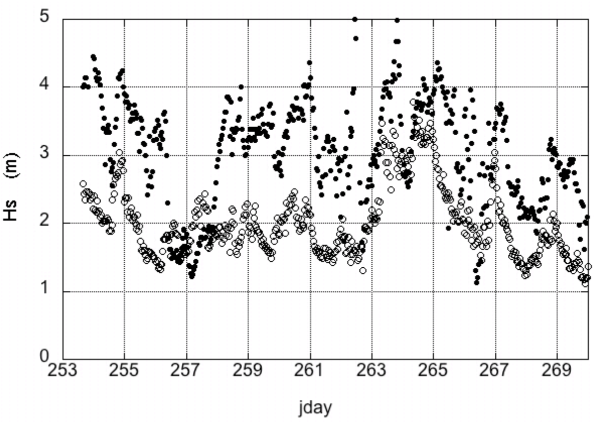

Figure 14. Significant wave height from the SBWR (open circles) and the WAVEX (dots).

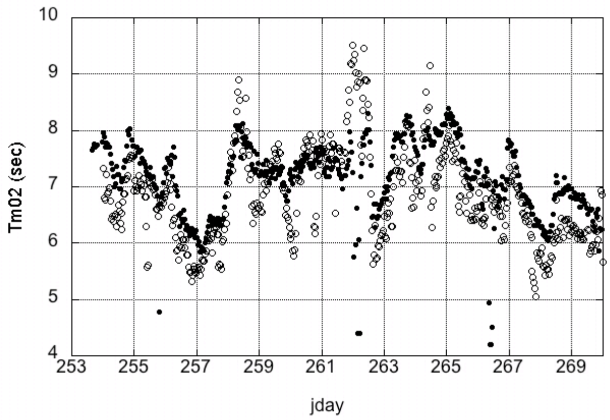

Figure 15. Zero up-crossing period from the SBWR (open circles) and the WAVEX (dots).

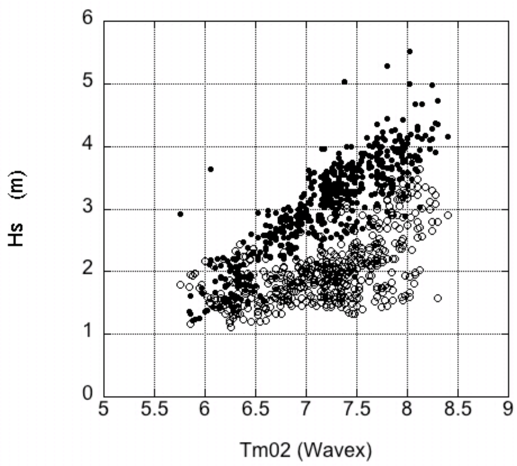

Figure 16. Hs from the SBWR (open circles) and the WAVEX (dots) against Tm02 period from the WAVEX.

It was only possible to make direct comparisons between the two systems for the significant wave height (Hs) and for the mean zero up-crossing period (Tm02). These are shown in Figures 14 and 15 respectively. It can be seen that the two systems agree well for wave period. Large differences in period only occur when the ship is steaming since the SBWR does not take ship speed into account. In contrast the two systems differ quite dramatically in their estimates of Hs, with the WAVEX data overestimating the SBWR values by almost 100% on occasion.

Preliminary results suggest that the two only agree in the absence of swell waves. Figure 16 shows the Hs values from the two systems against the period Tm02 from the WAVEX data. Whereas there is no clear relationship between Hs and period from the SBWR there is a roughly linear relationship for the WAVEX data. This relationship is much less clearer for Tp1 or Tp2.

Post cruise analysis of 12 months of wave data from the two systems showed that the WAVEX algorithm seems to identify a dominant wave system and then assume that it is fully-developed when inferring the wave height associated with that wave system. This works reasonably well most of the time, but when conditions are swell dominated and the winds are light, this results in Hs values which are too large by a factor of 2 or 3. See Yelland et al. (2007) for details.

4.8 Digital cameras.

The aim of the cameras was to obtain digital images for analysis of whitecap coverage. Both were set up to use their internal interval timers to take pictures once every 30 minutes: between pictures the cameras went in to sleep or standby mode. Problems occurred with both cameras hanging after they had turned themselves on, but before they had taken a picture. Once hung in the "on" mode they did not respond to any buttons, and could only be re-activated by turning off the mains power of and removing the internal batteries. Once the cameras had returned to the interval mode the picture button had to be pressed once to initiate image capture. This problem of the cameras hanging will be resolved for the coming cruises by powering the cameras using mains power only (no batteries) via mains timer. The timer will be set to turn off at night and on in the morning (which also avoids taking pictures at night). In addition, clamps have been made which will keep the picture button down permanently which obviates anyone having to manually initiate image capture: when the cameras are powered up into the (default) interval mode pictures will be taken every 30 minutes as before. Pictures are time-stamped within their metadata.

4.9 Hourly Meteorological Observations.

The ship's crew perform full WMO meteorological observations every hour. Since the SBWR PC is on the bridge it is thought that this has long been used as an aid to the visual wave observations. The WAVEX display is located in the "plot" just aft of the bridge and now may also influence the observations, particularly in the detection of different swell directions.

Similarly, on the bridge next to the SBWR display and just above the area used to record the WMO reports, there is a true wind speed and direction display. The true wind speed here is derived from the Gill Windldwr anemometer and ship speed through the water from an EM-log, rather than ship speed over the ground from the GPS. Colleagues from DNMI had expressed concern that this true wind speed was biased low, possibly due to a problem with the EM-log data. To check these true winds, the ship's crew made hourly written notes of the readings from the display. These were compared with the true winds calculated from the NOC R3 anemometer and the GPS: the true wind speeds from the bridge display were seen to be biased low by about 9% on average. However, there was not enough data to confirm whether this was due to the EM-log, particularly since the ship was drifting for most of the data and the ship speeds were very small. It was suggested to DNMI that the crew be asked to make regular notes on the EM-log speed itself (since these data are not logged anywhere).

The ship's WMO reports of cloud coverage, type and height will be used to improve the parameterisation of downwelling long-wave radiation in terms of cloud cover and type (Pascal and Josey, 2000; Josey et al, 2003). The parameterisation will allow calculation of the LW radiation to be made from the visual observations routinely obtained by the 7000-strong Voluntary Observing Ship fleet, thus ultimately improving the accuracy of weather forecast models.

5 The fast response sensors and the air-sea fluxes.

The AutoFlux system calculates fluxes in near-real time using the inertial dissipation (ID) method. This method can be used for the momentum flux and the latent heat flux. The sensible heat and CO_2 fluxes can not be calculated in this way since the sensors do not have the required high frequency response. All the fluxes are calculated using the eddy correlation (EC) method post cruise. Initial results will be discussed briefly here, since they are described in more detail in the references given.

5.1 ID momentum flux from the R3 anemometer.

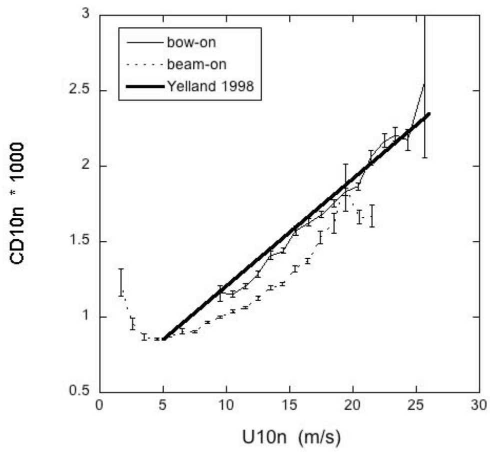

Figure 17. The drag coefficient for the momentum flux (ID method) plotted against wind speed, separated into bow-on flows (±30 degrees) and flows on to the starboard beam (±30 degrees), along with the results of Yelland et al. (1998).

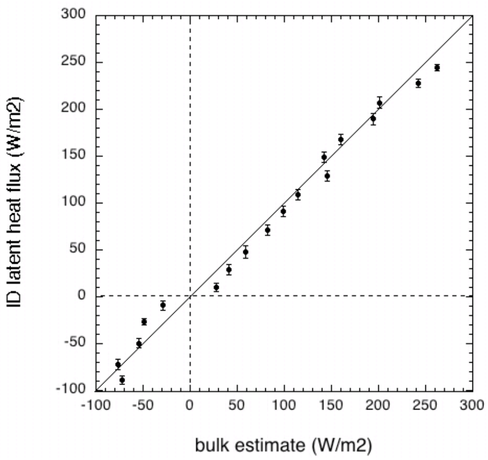

Figure 18. Inertial dissipation estimates of the latent heat flux averaged against those from a bulk formula (Smith, 1988). The line indicates 1:1 agreement.

Figure 17 shows the ID momentum flux for bow-on and beam on winds separately, from about 12 months of data (Brooks et al., 2009). The CFD study of the flow over the ship (Moat and Yelland, 2009) showed that for bow-on winds, the wind is decelerated by about 1% (less than 0.5% if displacement is accounted for) and the flow is displaced upwards by 1.25 m, i.e. the effective anemometer height is 14.25 m (actual height of 15.5 m minus the 1.25 m displacement). In the ID calculation the effective anemometer height was 14 m, rather than 14.25: this would reduce the calculated drag coefficient slightly. However, no deceleration was allowed for in the calculation, which would mean that the calculated drag coefficient is slightly overestimated. In short, the calculated drag coefficient is in good agreement with that found from previous studies. The beam-on drag coefficients were calculated in exactly the same way and the results are biased low by a significant amount, since for beam on flows the flow has been accelerated by 5% (allowing for this would have increased the drag coefficient significantly) and displaced vertically by about 4 m (allowing for this would also increase the drag coefficient).

5.2 ID Latent heat fluxes from the Licor H_2O/CO_2 sensors.

Yelland et al., (2009) showed preliminary comparison of the ID latent heat fluxes with those from a bulk formula. Figure 18 shows a comparison of the latent heat flux calculated from the ID method binned against the flux calculated from the bulk formula of Smith (1988). It can be seen that on average the latent heat flux from the ID method is in good agreement with that from the bulk formula, suggesting that the ID scalar fluxes are not biased very significantly by flow distortion.

5.3 The EC fluxes.

Figure 19 shows the latent heat flux calculated via the eddy correlation method averaged against the bulk formula estimates, from about 80 days of data from Licor 1 in 2007, after corrections for head deformation have been applied (Yelland et al., 2009).

Figure 20 shows a similar plot for the EC sensible heat fluxes from about 160 days of data in 2007 (there is less latent heat flux than sensible heat flux data since Licor 1 was shrouded for at least half the time). Both figures show that for bow-on winds, when flow distortion effects are smallest, the EC fluxes underestimate significantly. For beam-on winds the agreement with the bulk estimate is better in both cases.

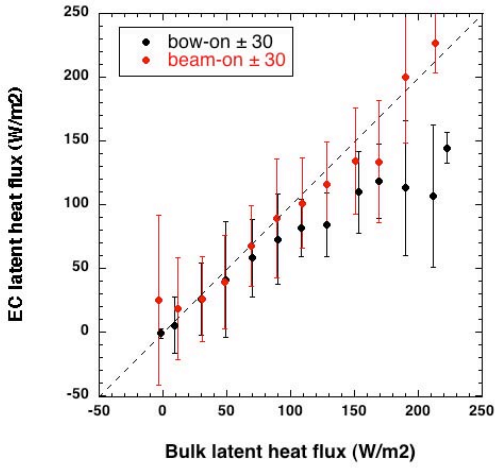

Figure 19. Latent heat fluxes calculated from the eddy correlation method against bulk formula estimates, separated by relative wind direction as shown in the key.

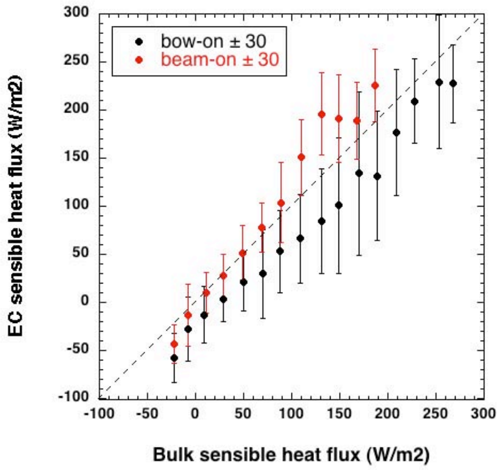

Figure 20. Sensible heat fluxes calculated from the eddy correlation method against bulk formula estimates, separated by relative wind direction as shown in the key

Figure 21 shows the friction velocity (i.e. the square root of the kinematic momentum flux) from both the ID and EC methods plotted against wind speed, and separated into bow-on and beam-on winds. As expected from the drag coefficient results (Figure 17), the bow-on ID results are in good agreement with previous results, and the ID beam-on data are biased low due to the effects of flow distortion. The EC results again show lower friction velocities for beam-on winds compared to bow-on winds, but the results for both wind directions are biased significantly high compared to the ID and previous results, again due most probably to the effects of flow distortion. Figure 22 shows preliminary gas transfer velocity estimates determined from the CO_2 flux data (EC method only) and the underway delta pCO_2 data from the BCCR system. This figure is reproduced from Prytherch et al. (2010) who describe a novel method for calculating the CO_2 flux from the open-path Licor data.

The influence of flow distortion on all the fluxes is the subject of future work.

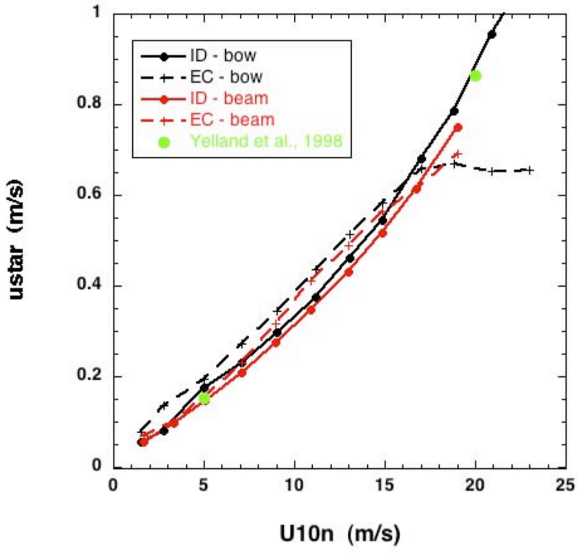

Figure 21. EC and ID friction velocities against wind speeds, split by relative wind direction as shown in the key.

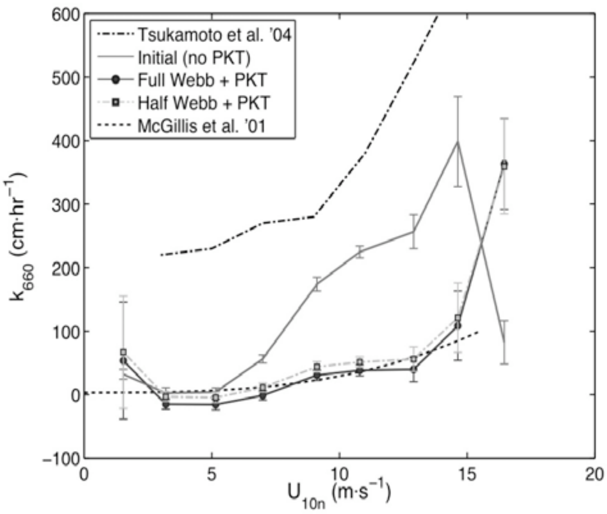

Figure 22. Gas transfer velocity (k) against wind speed. Previous relationships, initial results from HiWASE and HiWASE data after applying the correction of Prytherch et al. (2010) as shown in the key.

6 Summary

This report describes the initial installation of the air-sea flux, surface waves and whitecapping systems installed on the OWS *Polarfront* in September 2006 as part of the High Wind Air-Sea Exchange project, part of the UK's contribution to the international SOLAS program. The instrumentation operated continuously until December 2009 when the ship was withdrawn from service by DNMI. This report should be read in conjunction with a separate document which details the metadata for the whole 3 year deployment (Moat et al., 2010).

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