P1.4 SHIP BASED TURBULENCE MEASUREMENTS UNDER HEAVY SEAS : MEASUREMENT, MOTION CORRECTION, AND INTERPRETATION

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1. INTRODUCTION

Parameterizations of air-sea fluxes are most uncertain under high wind conditions where measurements are sparse, difficult to obtain, and potentially subject to large sources of contamination due to platform motion. The SEASAW field campaign (Brooks et al. 2007) set out to measure CO_2 gas fluxes and sea salt aerosol fluxes under condition of high winds. During the course of two research cruises – D313, November 7 to December 2 2006 and D317, March 21 to April 12 2007 – we sampled mean wind speeds up to 20 m/s, and significant wave heights of up to 8.9 m with individual waves of up to 17 m (crest to peak). At the higher end of our wind speed and wave height regimes, ship based turbulence measurements become extremely challenging: the platform motion is substantial and the orientation of instrumentation relative to the mean flow and its height above the surface changes significantly with the ship's pitch, roll, and position on the waves.

Here we examine some of the data from two different turbulence systems operated during SEASAW, the corrections required for platform orientation and motion, and the interpretation of the measurements under the most extreme conditions.

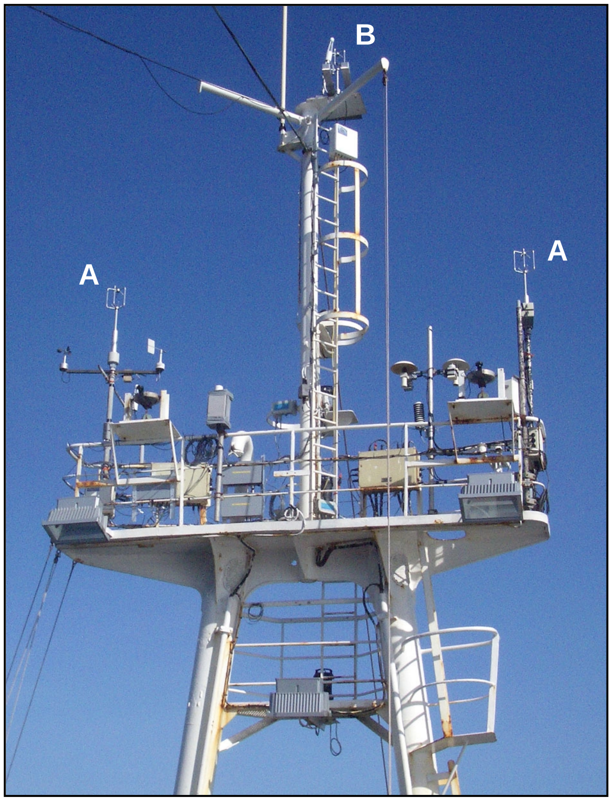

Figure 1. Foremast of the RRS Discovery. The NOC Autoflux sonic anemometers can be seen at either side of the platform (A), the Leeds sonic (B) is just visible with a LiCOR-7500 gas analyzer situated just behind it on the top of the mast.

2. TURBULENCE MEASUREMENT SYSTEMS

Two turbulence measurement systems were installed on the RRS Discovery for the SEASAW cruises (Figures 1 and 2). Both are based around Gill R3A sonic anemometers and installed on the foremast. The instrument site on the foremast platform of the *RRS Discovery* suffers relatively little from flow distortion compared to other research ships since the mast is well forward of a reasonably streamlined superstructure. For example, Yelland et al. (1998) showed that the mean bias in the inertial dissipation drag coefficient obtained from instruments on the Discovery is only 6% (bow-on flow). The AutoFlux system (Pascal and Yelland 2004) installed by the National Oceanography Centre, Southampton consisted of twin sonic anemometers mounted at the forward corners of the meteorological platform on the foremast, at a heights of 17.9 m (starboard) and 18.6 m (port) above the surface. A Systron Donner MotionPak was mounted at the base of the starboard sonic anemometer, and LiCOR-7500 sensors were located about 80 cm below, and 80 cm forwards of each sonic anemometer. The signals output from the MotionPak were logged via the analogue input channels to the anemometer. The MotionPak uses three orthogonally mounted solid-state quartz angular rate sensors (resolution < 0.004 °/sec), and three linear servo accelerometers (resolution < 10 µg) and has been successfully used for ship motion corrections to EC flux measurements for a number of years (e.g. Edson et. Al 1998). An electronic synchronization signal was input to the analogue channels of the LiCORs and sonic anemometers so that the data streams could be accurately aligned. The ship's navigation data (1 Hz) was logged in real time to the same workstation..

The second turbulence system, installed by the University of Leeds, consisted of a single sonic anemometer mounted at the top of the foremast, 21.3 m above the surface. Twin custom built motion packs were mounted on arms extended back from the plate on

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Figure 2. The RRS Discovery in port in Stornoway, showing the foremast with turbulence instrument installations.

which the sonic was mounted. This mounting arrangement was required to remove the magnetic compasses within the motion packs from the immediate distorting effects of the steel mast and mounting plate. The motion packs consisted of a pitch, roll, and electronic compass module (model TCM2 from PNI Corporation), coupled to a control and communications board incorporating a set of 3-axis accelerometers with a resolution of 1 milli-g, designed and built at Leeds. The TCM2 modules have an internal calibration routine that allows compensation for fixed sources of distortion to the local magnetic field, such as that of the ship's superstructure, as well as automatic compensation for the effects of tilt on the compass heading. Two motion packs were used in part to provide redundancy, and in part to avoid having to trade off resolution against range on the pitch and roll data. The two units incorporated slightly different models of TCM2 modules, one having a tilt range of just ±22º and a resolution of 0.1º, the other having a greater range of ±50º but a lower resolution of 0.2º. The motion packs both provided pitch, roll, heading, and linear accelerations along the x, y, and z axes at 20 Hz.

The pitch and roll angles are derived from a fluid-filled tilt sensor; if subject to a sideways acceleration, the fluid will 'slosh' against the side its cell and indicate an erroneous tilt. At the same time, the accelerometers measure a component of gravity as well as their inertial acceleration. An iterative procedure is used to correct both the accelerometers and tilt sensors for these contaminations. We first assume that the tilt sensor is providing an accurate tilt and correct the acceleration by removing the component of gravity it should measure due to this tilt; we then take the corrected acceleration and correct the tilt angle. The process is iterated until all values converge to within the limits of the instrument resolutions. Since the fluid filled cell is slightly damped the iteration converges rapidly – typically within 6-8 iterations. The vector offset between accelerometers and anemometer measurement volume means that rotational motions about the accelerometers will produce additional linear motions at the anemometer head.

Given measurements of the pitch, roll, and heading angles, it is a straightforward matter to rotate both the sonic anemometer turbulent wind components and the linear accelerations into a geodetic reference frame. A running integral of the accelerations then provides linear velocities which can be added to the turbulent wind components to correct for the ship motion. As is usual with such systems small residual DC offsets or drifts in the accelerometers results in spurious velocities over long periods (Edson et al. 1998; Schulze et al. 2005). These effects are avoided by high-pass filtering the accelerations before integration, and then again high-pass filtering the resultant velocities. Any low frequency, or constant motion of the ship – for example when measurements are obtained while under way – are compensated for by low-pass filtering the platform velocities derived from the ship's navigation system to complement the frequency range covered by the motion packs, and adding these velocities to the turbulent wind measurements also. Filtering is performed in frequency space by first obtaining the Fourier transform of the time series, then setting the Fourier coefficients in the stop-band to zero, and applying a cosine roll-off to those between the pass-band and stop-band, and finally applying the inverse Fourier transform to obtain the filtered time series.

A preliminary analysis of the motion correction and comparison of the two systems will be presents, along with measurements of the turbulent wind field under high wave conditions.

***ACKNOWLEDGEMENTS*:** SEASAW was funded by the UK Natural Environment Research Council, grant number NE/C001842/1.

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