

Shipboard Measurements of Surface Flux and Near Surface Profiles and Surface Flux Parameterization

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LONG-TERM GOAL

The long-term goal of this project is to understand the effects of surface waves on the structure of the marine atmospheric surface layer and surface flux parameterizations under a broad range of wind-wave conditions.

OBJECTIVES

This project is part of the High Resolution Wave-Air-Sea Interaction research initiative (HiRes). The objectives of this project are to characterize low-level atmospheric wind and thermodynamic profiles and variations, to understand oceanic and atmospheric large scale forcing that affects boundary layer properties, and to understand the role of measured wave field in modifying atmospheric surface fluxes.

APPROACH

Our work within this project consists of three parts: measurements, the subsequent data analyses, and mesoscale model evaluation/improvements. The ship-based measurement efforts include high-rate sampling of the turbulent field for direct covariance flux measurements, continuous sampling of the low-level wind profiles by the ship-based acoustic Sodar, rawinsonde measurements of the troposphere, a suite of mean variables for quantifying the low-level thermodynamic and dynamic fields, downward radiation, and sea surface temperature measurements. The data analyses should focus on the low-level surface layer properties and surface flux parameterization involving sea state parameters. In addition to evaluating current COAMPS, we intend to experiment with sea-state dependant surface flux parameterization in COAMPS, possibly in coupled mode.

Qing Wang is responsible for the overall project. Mr. Richard J. Lind worked on instrument preparation, calibration, and data sampling. Dr. John Kalogiros, an external research associate from National Observatory of Athens, Greece, worked on the data analyses.

WORK COMPLETED

1. Continuous analyses of data from 2009 pilot experiment, focusing on identifying measurement issues.
2. Preparation of HiRes field measurements, including re-design of the NPS measurement system setup and testing and calibrating instruments.

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3. Participation in the shipboard HiRes experiment June 1- June 30, 2010 on board R/V Robert Gordon Sproul near Bodega Bay, CA. The full suite of NPS instruments used in the pilot experiment were deployed with an additional flux tower above the bow in order to measure the 'undisturbed' air. In particular, the mini-sodar was relocated to the rear of the ship to avoid interfering with the WAMosII radar antenna tower. This proved to be a success as the sodar measurements no longer had the low bias at the lower level and the sodar signal return are frequently seen below 100 m.
4. Initial evaluation of the dataset for data quality checking, initial calibration and correction of fast turbulence data for ship motion effects using GPS, compass and accelerometer data.
5. Identify time periods during which in-depth analyses will be made in connection with other HiRes measurements and models.
6. Detailed calibration of all ship-board measurements and processing of all measurements are needed and will be worked on in the follow-up project.

RESULTS

Rawinsonde measurements: Rawinsondes were released in frequent intervals from the ship in order to record the average vertical structure of the atmosphere. Figure 1 shows an example of interpolated time-height plots from the rawinsonde data on 21 June, 2010. These measurements captured the transition to a low level wind jet below 200 m, which was accompanied by a decrease of boundary layer depth (see potential temperature plot) and an increase of water vapor mixing ratio in the boundary layer.

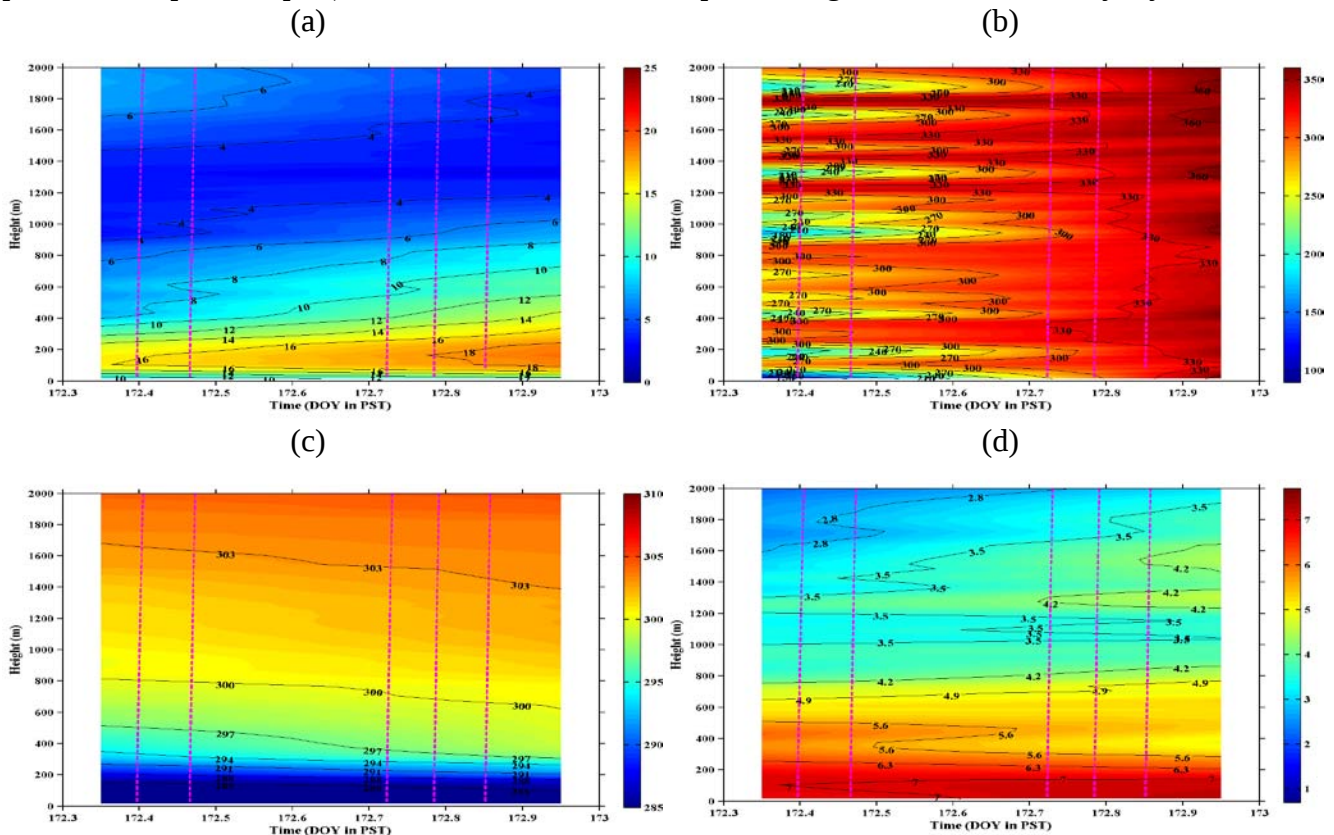


Figure 1. Time-height plots from interpolated rawinsonde measurements: (a) wind speed, (b) wind direction, (c) potential temperature, and (d) water vapor mixing ratio on 21 June, 2010.

In the following, we will show measurements from two experimental days. June 14, 2010 is characterized by low winds and June 21, 2010 by high winds. In this way we can see the effect of high winds and waves on ship measurements.

Ship and bow masts measurements: The aim of the comparison of the measurements from the two mast systems on the ship (named ship mast and bow mast systems) is to detect flow distortion effects on the ship mast measurements and of wave breaking effect on bow mast so that an optimal surface flux data can be obtained. A comparison of the time series (30 seconds average data) from both masts is shown in Fig. 2. Wind speed measurements from the two masts do not show an evident systematic

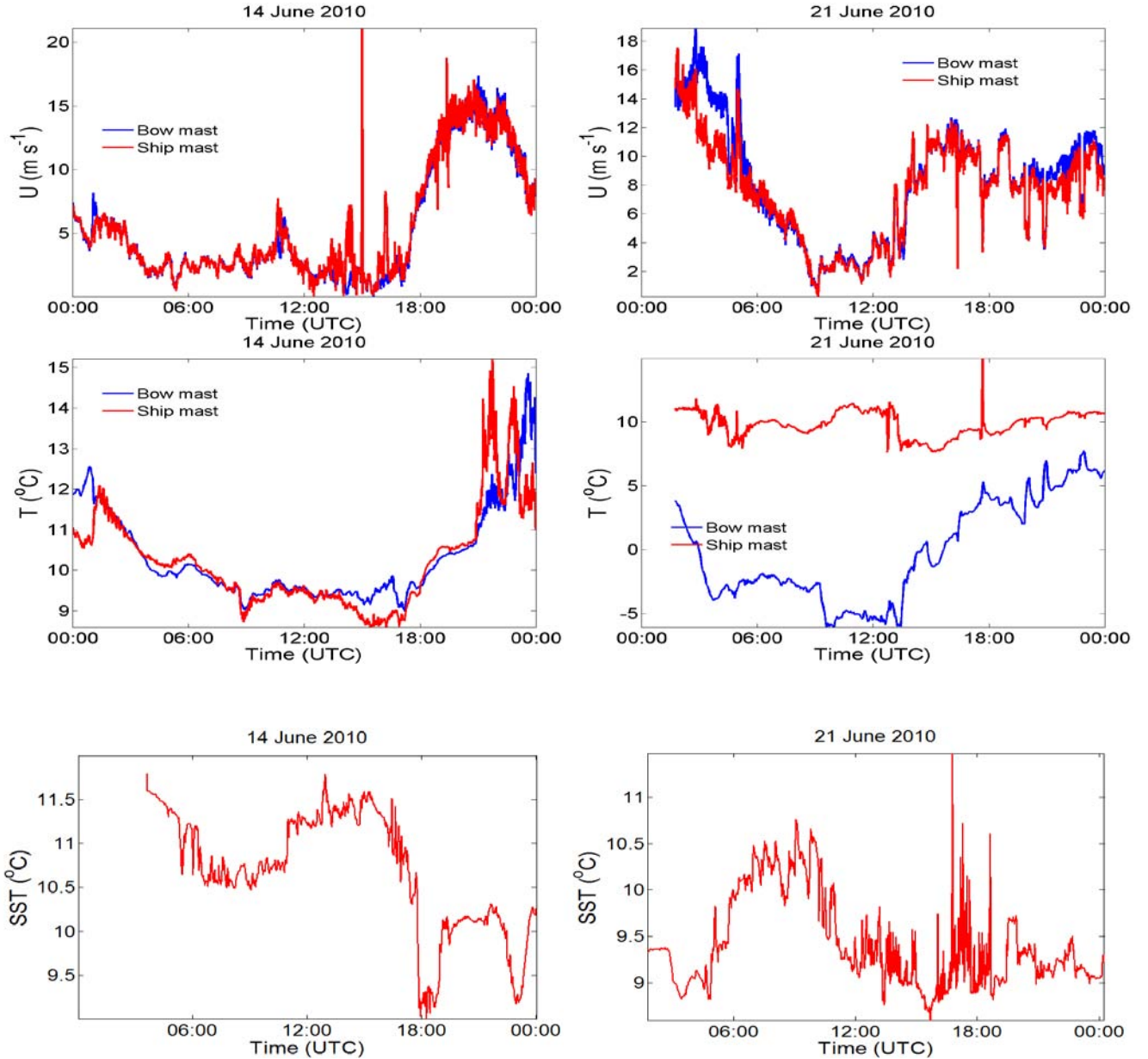


Figure 2. Time series of wind speed (U), air temperature (T) and sea surface temperature (SST) on the two experimental days.

difference with the exception of the high wind period 0000 to 0600 UTC on 21 of June. The wind direction shows a systematic difference, which were found to be caused by differences in the alignment of the sonic and attitude systems on the two masts. This will be corrected in the detailed analysis which will follow in the next months.

The air temperature measurements from the two systems show significant differences between the two masts, especially on the high-wind day (not shown). It is suspected that the bow measurements are affected by wave breaking that is similar to the problem in the Licor system. We also note that temperature spectra from the bow system showed systematically lower energy at all frequencies (not shown). The SST measurements shown in Fig. 2 are from a water bucket temperature sensor, which show that it can capture significant SST variations.

A first approach to quantify possible differences between ship and mast measurements is the scatter plot analysis shown in Fig. 3 for 30 seconds averages from five experimental days. The points out of the main clusters are due to sensors problems in some time periods on these days. The main clusters of points show no systematic difference for air temperature and water vapor. In the case of wind speed there may be higher wind speed for the ship mast than the bow mast (about 1 ms^{-1}) at wind speeds more than 10 ms^{-1} . A more detailed analysis will be carried in bins of the difference of wind direction from ship heading (i.e. coming direction to the ship) when a more accurate calibration and correction of wind measurements for ship motion will be carried out.

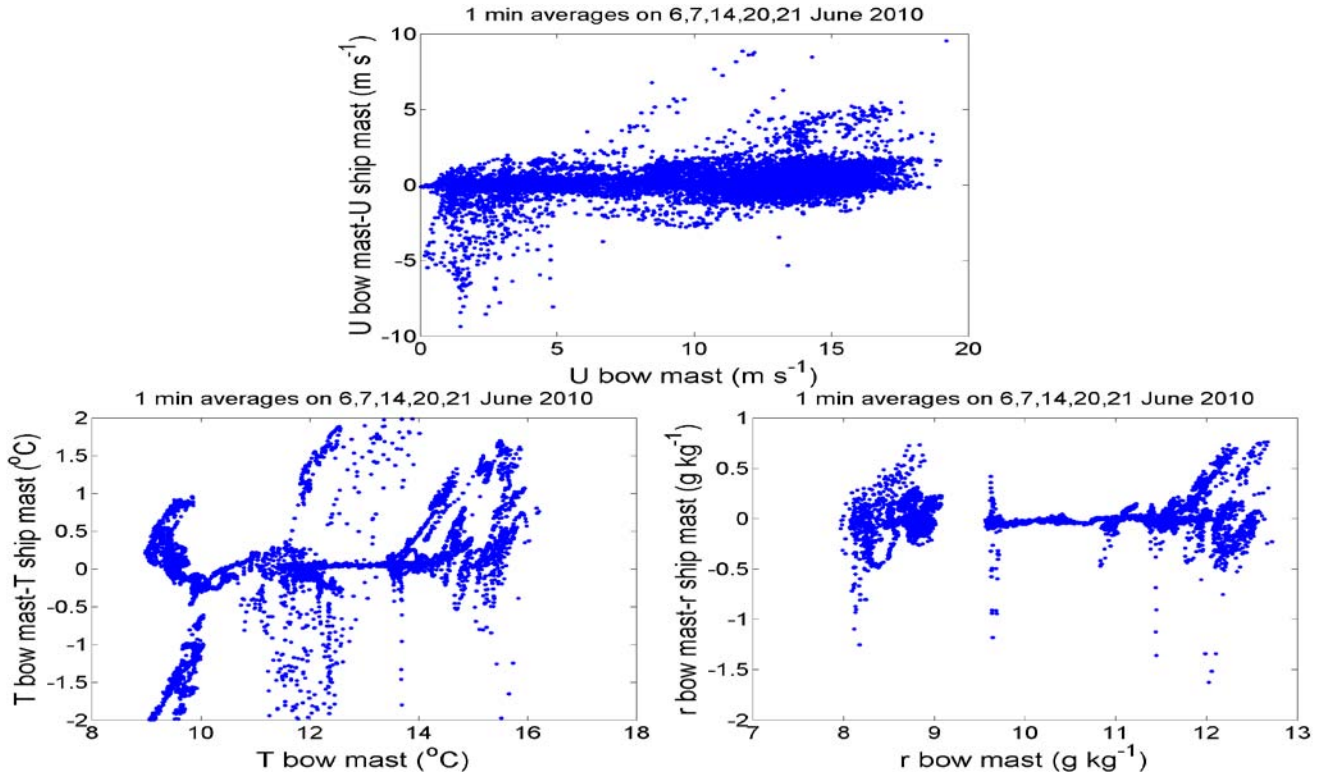


Figure 3. Scatter plots of the difference of ship and bow mast measurements: wind speed (U), air temperature (T), and water vapor mixing ratio (r), for five experimental days.

Flux measurements are not shown here because the accurate calibration and correction of data is needed in order to be able to get accurate results and evaluate turbulent flux parameterizations.

Sodar profile measurements: The measurements with the high resolution sodar intended to obtain the vertical structure of turbulence near the sea surface. Figure 4 shows wind speed and direction time-height plots (facsimile type) of the sodar measurements on the two experimental days. We also examined the signal to noise ratio and the backscatter intensity that are indicative of the quality of the received signal from the three acoustic beams (not shown). Under low wind conditions, the quality of the signal can be satisfactory up to 200 m above sea surface depending on the existence of turbulence at that height. Under high winds this height range may be limited to 50 m.

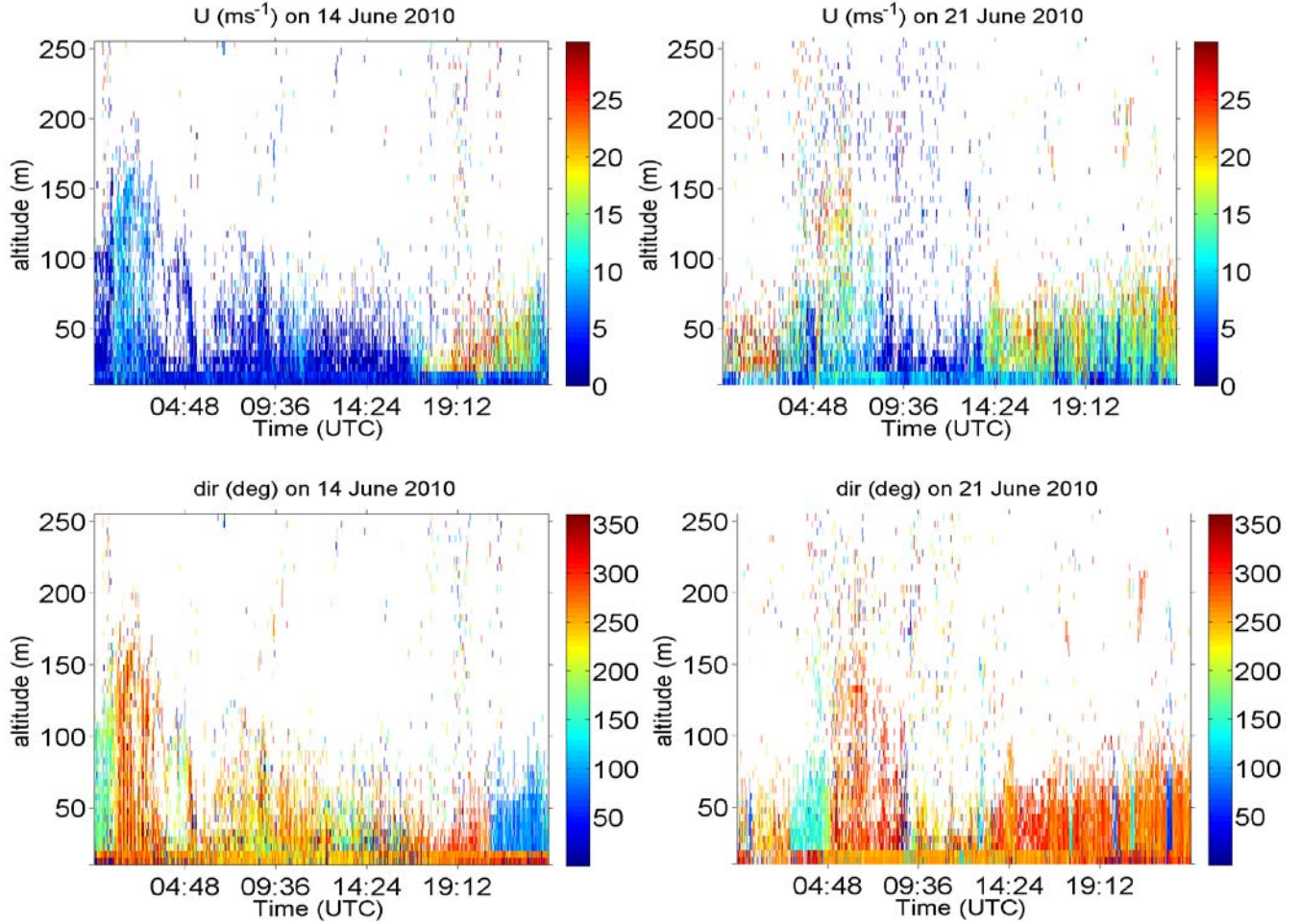


Figure 4. Same as Fig. 7 but for wind speed and direction

Sodar measurements of wind speed in Fin. 4 captured the increase of wind speed after 1800 on 14 June and the decrease of wind speed on 21 of June around 0900 UTC, consistent with the mast measurements (Fig. 2). The comparison of wind direction variations is not too successful because more accurate calibration of attitude sensors are needed, which will be made using a third set of such sensors installed on the sodar system in addition to the two masts.

Ocean wave effects and turbulence data quality: Ocean waves has a significant effect on fast wind measurements onboard ship platforms. This depends on waves frequency as well as the ship response to waves. The success of wave effect correction can be evaluated using power spectra of the

corresponding quantities. Figure 5 shows spectra of attitude angles (pitch and roll) on the two experimental days from both the ship mast and the bow mast.

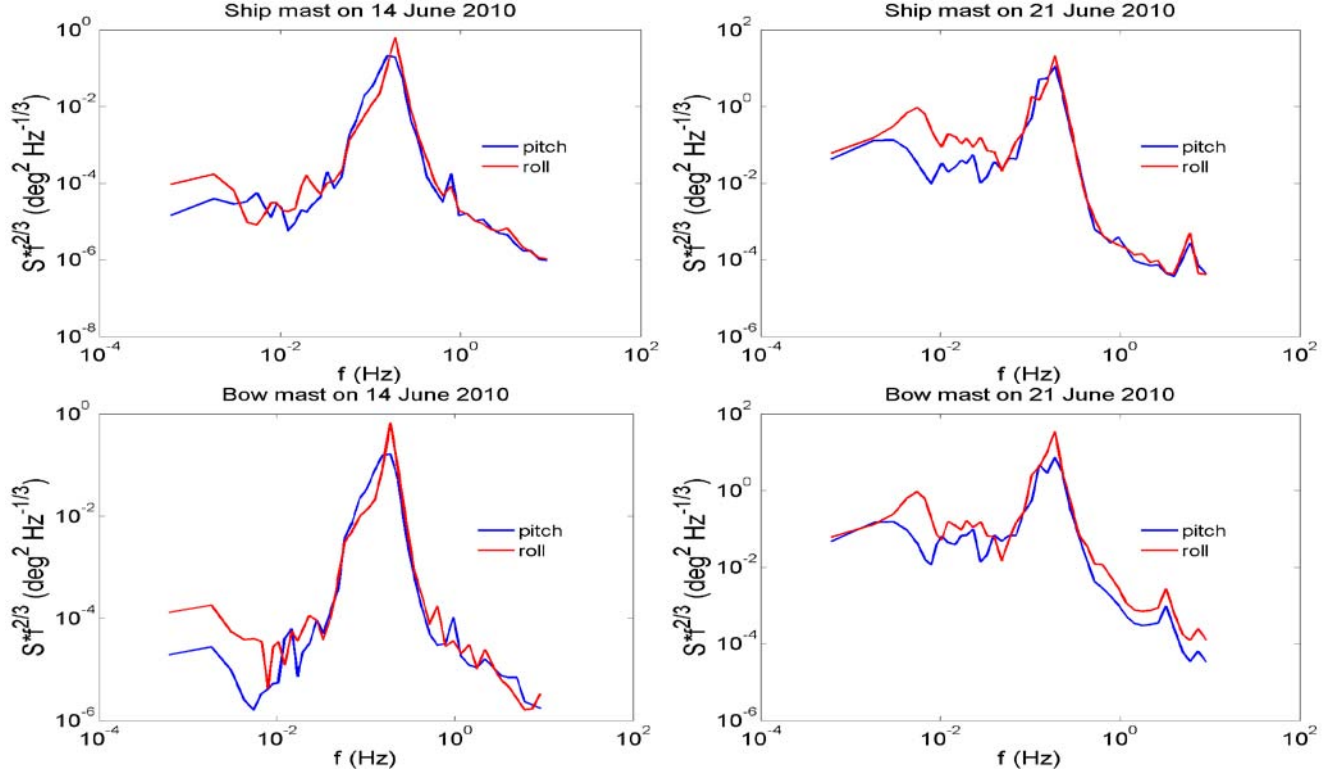


Figure 5. Power spectra of attitude angles from similar sensors on both masts at a low wind (14 of June) and a high wind (21 of June) time period of 15 minutes.

The time periods of these spectra are 14 minutes starting at 1200 and 0241 UTC on 14 and 21 of June, respectively. These time periods correspond to very low winds on the first day (about 2 ms^{-1}) and high winds on the second day (about 15 ms^{-1}). In both cases the peak frequency response to ocean surface waves is at about 0.19 Hz, with higher intensity on the high winds period. Even though the sensors of attitude angles were similar there are minor differences in power spectra from the two masts at low and high frequencies, which implies that the attitude systems had a little different response.

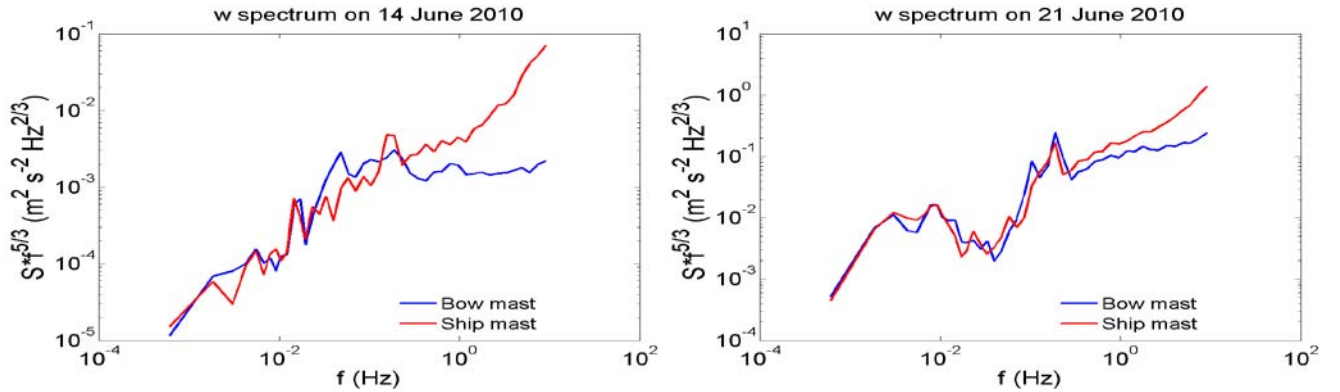


Figure 6. Same as Fig. 1 but for the vertical air velocity from the sonic anemometers.

Figure 6 shows spectra of vertical air velocity for the same time periods as in Fig. 5. For the low wind case the wave peak cannot be seen, suggesting clean removal of ship motion in the wind retrieval in this case. In the high wind case, the peak associated with surface waves can be identified from the spectra, indicating that a more accurate correction method is needed to completely remove the ship motion effect under these conditions. Similar conclusion can be drawn for the spectra of horizontal wind and temperature (estimated from the sonic temperature). In addition, we note the higher energy at high frequencies of vertical air velocity and wind from the ship mast systems compared to the bow measurements. The bow system seems to follow the inertial subrange law of $f^{5/3}$, suggesting that the higher energy of ship mast systems is likely due to higher electronic noise at high frequencies. The aliasing effect of energy at higher than Nyquist frequency (10 Hz i.e. half of the sampling frequency) which is folded back to the frequency range of measurements is small as indicated by the bow mast spectra. On the other hand the temperature spectra of both systems show this probable noise problem, with the ship mast showing consistently more energy at all frequencies than bow mast. A more detailed analysis is needed in order to identify the reason of low energy in temperature fluctuations from the bow mast system.

We note that the high frequency noise does not mean that fluxes (i.e. covariance of vertical velocity and wind speed components (momentum flux case), potential temperature (sensible heat flux) or water vapor mixing ratio (latent heat flux) will have the same problem. Most of this random noise should cancel out in the covariance calculation because it is uncorrelated between different sensors. We also note that the fast water vapor mixing ratio measurements with the same Licor systems on the two masts (not shown here) had significant differences and frequent problems, which is probable due to the sensitivity of Licor sensor to the sprays from the breaking waves, especially the system on the bow mast. More careful analyses are needed for the flux measurement systems, especially in high wind conditions.

IMPACT/APPLICATIONS

The measurements from the HiRes ship-based systems is a very useful dataset for the understanding of the behavior of the atmospheric boundary layer near sea surface under different wind and sea wave conditions. Wave data will be obtained from others researchers in the project.

TRANSITIONS

The results of this project will potentially help to evaluate and improve the turbulence parameterizations of near sea surface atmospheric boundary layer in mesoscale models.

RELATED PROJECTS

Related project is the ONR High Resolution Wave Air-Sea Interaction DRI.