Going with the flow: state of the art marine meteorological measurements on the new NERC research vessel

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Research ships obtain high-quality meteorological measurements above the ocean surface. These measurements include wind speed and direction, air and sea surface temperature, and atmospheric humidity. Although the sensors are usually well maintained and located in well-exposed sites, such as on a foremast in the bows of the ship, errors can still occur in the measurements. For example, the wind speed measurements will be biased by the distortion of the flow of air to the anemometer caused by the presence of the ship itself. Depending on the ship's orientation to the wind, the airflow may be raised substantially as it flows over the ship, accelerated or decelerated and become highly turbulent downwind of masts and funnels. Improving the accuracy of the wind speed measurements from research ships is important for research studies of the physical and chemical interactions between the atmosphere and the ocean; for example, studies which examine the rate at which heat, momentum and carbon dioxide are exchanged between the atmosphere and the surface waters. Understanding these exchanges will contribute to a better understanding of the world's climate. For this reason, airflow distortion effects were taken into account in the design of the UK's new research vessel, the RRS *James Cook*.

The RRS *James Cook* (Figure 1) was delivered to the UK's Natural Environment Research Council (NERC) in the summer of 2006, and replaced NERC's RRS *Charles Darwin* which was decommissioned in June 2006. The RRS *James Cook* is 90 m in length and operates worldwide from the tropics to the edge of the ice sheets. The ship's design enables it to work in higher sea-states and stronger winds than the NERC's other research vessel, the RRS *Discovery*. The RRS *James Cook* can carry 54 scientists and crew and spend up to 50 days at sea before needing to refuel. During the design stage of this vessel, scientists from the National Oceanography Centre, Southampton, (NOCS) made a number of recommendations to the naval architects to guide the production of a ship capable of obtaining the most accurate wind speed measurements possible. NOCS staff advised that the new ship should have a raked, or streamlined, superstructure to minimize the effects of airflow distortion, and that the mast in the bows (where the anemometers are located) be as tall and as far forward as possible.

Once the ship was designed, the numerical model VECTIS (Ricardo, 2001) was used to simulate the airflow over the RRS *James Cook* for wind directions blowing within 30 degrees of bow-on. This range of wind directions was chosen since it is the most commonly encountered (especially when the ship is on passage or on station) and it is also the same range that is used for many research studies of atmosphere-ocean interaction. The model simulations were three-dimensional and were solved using computational grids of up to 3 million cells. Each wind direction took about a week to complete. The number of cells used was higher in regions of interest (e.g. the foremast) and lower in other areas. Figure 2 shows the numerical model of the ship along with a single slice of wind speed data for a bow-on wind direction. When well away from the influence of the ship the wind speed has a logarithmic vertical profile, i.e. the wind speed near the sea surface is close to zero and the speed increases with height. When the wind approaches the ship, it begins to distort. Figure 2 shows that the flow of air is severely decelerated in some regions (shown by the blue arrows), particularly

Figure 1. The RRS James Cook. (© NERC.)

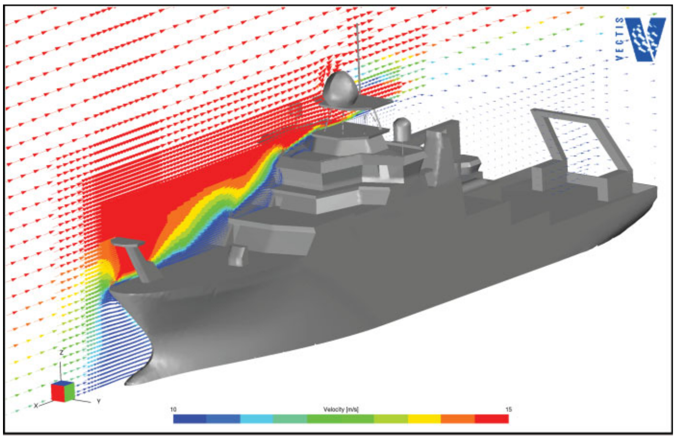

Figure 2. An image of the airflow over the bow of the RRS James Cook. *The arrows represent the direction and speed of the wind and the colour represents the total wind speed at each point. Blue represents a low wind speed (10 m/s or less) and red a high wind speed (15 m/s or more).*

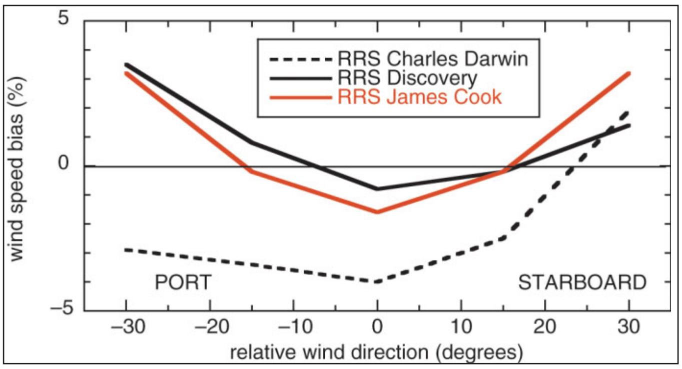

Figure 3. The wind speed bias at typical foremast anemometer locations. A relative wind direction of 0 degrees indicates a flow directly on to the bow.

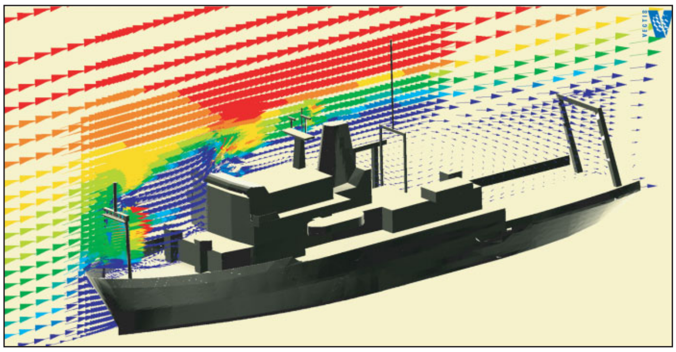

Figure 4. As in Figure 2, but for the airflow over the bow of the RRS Charles Darwin *(from Moat et al. 2005b). The large deceleration of the airflow (blue arrows) between the foremast and the superstructure is clearly seen.*

directly upwind of an obstacle. In other areas, such as above an abrupt edge, the flow is significantly accelerated.

The results of this study are compared to previous airflow studies of the RRS *Discovery* and RRS *Charles Darwin* in Figure 3. Previous model simulations have been tested using in-situ data; with the exception of anemometers located within the wake of an upwind obstruction the simulations and the in-situ wind speed measurements typically agreed to within 2% (Yelland *et al*., 2002). For a bow-on flow, the measured wind speeds are biased low by about 2% compared to the free stream (or undisturbed) wind speed for anemometers located on the mast in the bows of the RRS *James Cook*. For a wind at 30 degrees to the bow, the bias becomes 4% high. For wind directions greater than 30 degrees off the bow, the errors are likely to be larger. The results are similar to the wind speed errors at anemometer locations on the RRS *Discovery* (Yelland *et al*., 1998, 2002), which also has a streamlined superstructure. The results for the RRS *Discovery* shown in Figure 3 are not symmetrical since the anemometer was located to one side of the foremast, rather than in the centre as is the case for the RRS *James Cook*. In contrast, similar anemometer locations on the decommissioned RRS *Charles Darwin* produced much larger biases since this ship had a large square superstructure (Figure 4) which blocked the airflow to the foremast. This is the reason for preferring a streamlined superstructure during the design of the RRS *James Cook*.

The number of research ships is small and therefore the proportion of the ocean that they can cover is very limited. In contrast, there are several thousand merchant ships participating in the World Meteorological Organization's Voluntary Observing Ships (VOS) programme. These ships routinely report meteorological parameters at the ocean surface and the reports are used in weather forecasts as well as for climate studies. It is difficult to quantify the effects of airflow distortion at anemometer locations on VOS because it is impossible to study each VOS individually. Therefore Moat *et al*., (2006) modelled the airflow over a 'typical' VOS using VECTIS and developed a method to estimate the wind speed bias depending on ship size, ship type and anemometer location. For many VOS the anemometer location was not known, but this information is now collected routinely.

More information on the flow distortion caused by ship structure and its implications for meteorological measurements can be obtained from Moat *et al*., (2005a), and from the project websites;

Airflow study: http://www.noc.soton.ac.uk/ooc/CFD/cfd_jcook.php

RRS *James Cook*: http://www.nerc.ac.uk/research/sites/facilities/marine/jamescook.asp

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