

THE ACCURACY OF MARINE SURFACE WINDS FROM SHIPS AND BUOYS

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1. INTRODUCTION

In this paper we will review the progress made in determining the accuracy of marine wind observations since the International COADS Winds Workshop, held in Kiel, Germany in 1994 (Diaz and Isemer, 1995). Accurate marine wind data are important because, as the sea surface roughness increases with wind speed, wind stress increases roughly as $(\text{wind speed})^{2.7}$ and mixed layer deepening with $(\text{wind speed})^4$. However, a major problem is that we do not have an error free source of wind data over the ocean. Whilst it might be expected that the best data sources would be anemometer measurements from research ships, ocean weather ships (OWSs) or meteorological buoys, we shall demonstrate in section 2 that there are potential biases in each of these data types. In section 3, we will discuss the methods of wind determination used by the Voluntary Observing ships (VOSs) and then consider random errors (section 4) and systematic errors (section 5). We will demonstrate that quantitative knowledge of the errors is vital in order, for example, to compare ship and satellite winds. We shall consider how future developments may improve the accuracy of VOS winds (section 7) before summarising our conclusions and providing some recommendations (section 8).

2. LACK OF AN ABSOLUTE STANDARD

2.1 RESEARCH SHIPS

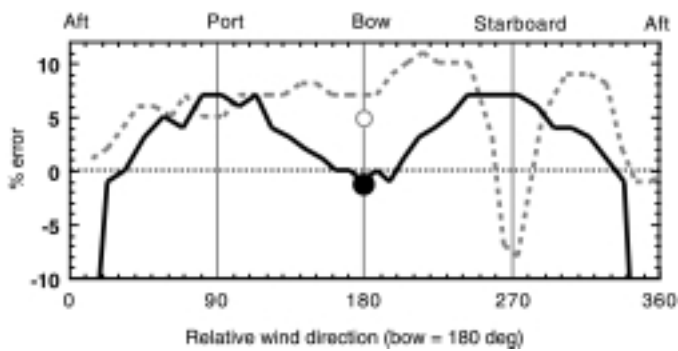
It should not be assumed that anemometer measurements on research ships are necessarily accurate. For example, before the World Ocean Circulation Experiment (WOCE), Taylor and Weller (1991) carefully specified the required underway meteorological measurements. Despite this, only one in five of the vessels recorded all the parameters needed to compute true wind, and for less than one ship in seven that calculation was applied correctly (Smith *et al.*, 1999). On ships like research ships, which are frequently moving slowly, possibly sideways or backwards, it is particularly important to log both the ship's head and the ship's course separately; this is not always appreciated.

Many research ships have a ship's anemometer which is permanently mounted, often over the wheelhouse, to give an indication of the meteorological conditions. Only for specific air-sea interaction experiments might they be equipped with accurately calibrated research anemometers, usually mounted on a special mast in the bow. Like all ships, research ships disturb the wind flow and the effect varies according to location. The results of a wind tunnel study using a model of a small research ship, CSS Dawson, are shown in Figure 1 (Thiebaut, 1990). At the ship's mainmast anemometer site the airflow is generally accelerated by 5 to 10 per cent except when the wind is from starboard (when it is in the wake of part of the mast) or from astern. Results from a computational fluid dynamics (CFD) study for bow on flow were in reasonable quantitative agreement and showed (Figure 2) that there is a large region of accelerated flow over the main accommodation block - this is typical of ships in general (section 5.3).

At the bow anemometer site the wind speed was close to the free stream value when the ship was pointed into the wind. However, for wind from either beam the wind would have been overestimated, and for winds from astern the anemometer was in the wake of the accommodation block. Had this anemometer

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Figure 1—Wind speed errors at the bow (solid lines) and main mast (dashed lines) anemometer sites as measured in wind tunnel studies of the CSS Dawson (Thiebaux, 1990). CFD model results are shown as a shaded circle for the bow anemometer site and an open circle for the main mast site. “Aft”, “Port”, “Bow”, “Stbd” indicates that the stern, port side, bow or starboard side of the ship is facing the wind (adapted from Yelland *et al.*, 1998b).



been mounted lower, it would have measured accelerated flow. On many ships the accommodation is nearer the bow and in such cases the bow anemometer would be in a region of decelerated flow.

Further examples of the computed flow around research ships are given by Yelland *et al.* (1998b). It is clear that obtaining accurate measurements of the mean wind requires considerable care, and that almost all ship wind data will be biased unless the airflow disturbance is taken into account.

2.2 OCEAN WEATHER SHIPS

Most OWSs were a similar size and shape to research ships. Typically they maintained their station by drifting beam on to the wind until the limit of their station ‘box’ was reached when they would steam back into the windward limit. In higher winds they would be ‘hove to’, i.e. heading into the wind at a speed just sufficient to maintain steerage way. These different operating modes would cause varying wind flow errors at the anemometer sites which were, in any case, not necessarily ideal. For example, the aft mast was used on the OWS Cumulus (which was studied by Taylor *et al.*, 1995 for the period 1987-1994 when the ship operated at 57°N 20°W). This was considered acceptable because the ship’s main purpose was to make weather observations for forecasting purposes (and now-casting and navigation for aviation) rather than to provide a climatological wind standard.

For the same reason, it is likely that corrections were not applied to the ship’s velocity through the water unless the ship was actually steaming. Taylor *et al.* (1995) used a sonic anemometer and GPS system on the OWS Cumulus to show that when the ship was drifting, the reported wind speed was too low and by slightly more than the expected amount - possibly due to flow distortion (Figure 3). When the ship was ‘hove to’ wind speeds were overestimated by approximately the expected amount. The difficulty of constructing a time series of weather ship data has been well illustrated by Isemer (1994); careful consideration of the history of observations at the OWS sites has resulted in a data set that is more consistent through time compared to VOS data (Isemer, 1995), but within which there are significant discontinuities at some sites.

Figure 2—CFD calculations for bow-on flow over the CSS Dawson. The shading indicates wind speed error, as a percentage of the undisturbed value, on a vertical fore-aft plane through the bow-mast anemometer position (shown by a cross). The numbers indicate the percentage error in each region.

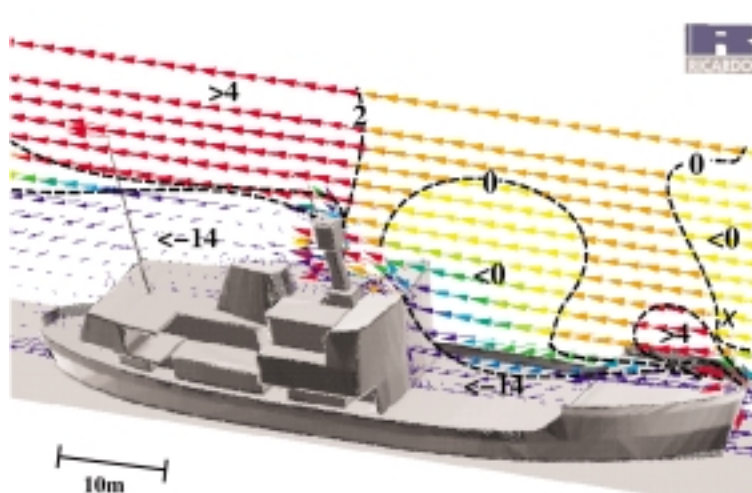
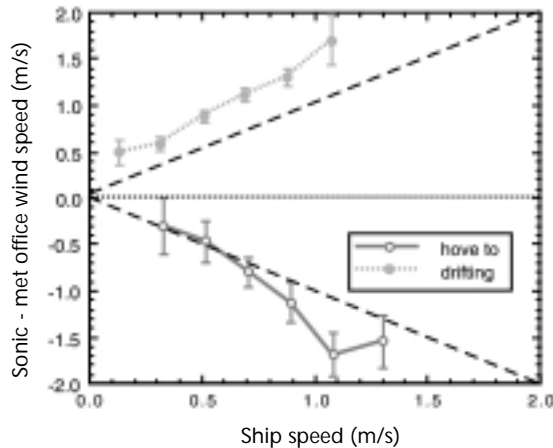


Figure 3—Average difference between wind speeds measured by research instrumentation (sonic anemometer plus GPS navigation package) and the standard WMO reports from the OWS Cumulus plotted against the ship speed from the navigation package. Cases where the ship was hove to or drifting are shown separately, the diagonal lines indicate agreement between the wind speed error and the ship's speed (from Taylor *et al.*, 1995).

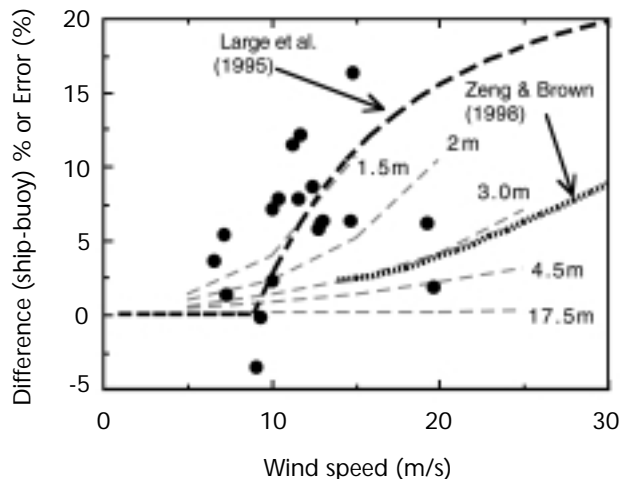


2.3 BUOY DATA

Wind speeds from meteorological buoys are believed to be biased low in strong winds (Large *et al.*, 1995; Weller and Taylor, 1998; Zeng and Brown, 1998). During the Storm Wind Study 2 experiment, SWS-2 (Dobson *et al.*, 1999; Taylor *et al.*, 1999), 10 m neutral equivalent winds were estimated using sonic anemometers on a buoy (at 4.5 m) and a nearby research ship (at 17.5 m). The comparison of the measured wind speed values is shown in Figure 4. The data are very scattered, but on average the buoy appears to underestimate the wind by about 5 per cent. There are two possible mechanisms. Firstly, assuming that the mean wind profile is logarithmic, an instrument being moved up and down vertically by the waves will measure an average wind which is less than the wind at the mean measurement height. Using the observed wave height to wind relationship for SWS-2, this effect has been crudely estimated for different anemometer heights (light dashed lines on Figure 4). Zeng and Brown (1998) noted that there were a lack of high wind speed data in buoy observations used for scatterometer calibration. They used surface air pressure data to infer a low bias for buoy winds at higher wind speeds. Their polynomial relationship (Figure 4) appears very similar to what might be expected due to the logarithmic averaging for a 3 m anemometer height - not an unreasonable mean anemometer height for the mix of buoy data that they used.

The second mechanism is that the instrument may enter regions where the vertical wind profile is distorted due to the sheltering effect of the waves. Large *et al.* (1995) suggested that the effect is to significantly bias buoy wind data for wind speeds above some threshold. Their predicted error for a 5 m anemometer height is also shown in Figure 4 and is much greater than that predicted by Zeng and Brown (1998). The preliminary SWS-2 results shown on Figure 4 appear to be of a similar order to the Large *et al.* (1995) prediction. However, the measured friction velocity values suggested that the wind error in the 20 to 25 m/s region

Figure 4—The difference (closed circles: (ship - buoy) per cent) between values of the 10 m neutral wind from buoy and ship data during the SWS-2 experiment for cases where the separation was less than 10 km (anemometer heights 4.5 m and 17.5 m respectively). Also shown are the calculated effects of vertical movement through logarithmic wind profiles for instruments at heights between 1.5 m and 17.5 m (light dashed lines); the mean error curve reported by Large *et al.* (1995) and the polynomial of Zeng and Brown (1998).



was 3 per cent to 5 per cent (similar to Zeng and Brown) rather than 15 per cent or more. The high frequency (2 Hz) data logged on the SWS-2 buoy became available just recently. These include buoy motions and wind velocities and will hopefully lead to a greater understanding of the problems related to wind measurements taken by buoys.

2.4
SATELLITE DATA

The physics of radar backscatter or microwave emission is not known well enough to allow an absolute calibration of satellite instruments so they are calibrated and verified against buoy data. Thus, if, as discussed above, the buoy data are biased, the satellite retrievals will also be biased (e.g. Zeng and Brown, 1998).

3.
METHOD OF
OBSERVATION FOR VOS
WINDS

VOS winds are either visually estimated or determined using an anemometer. In the Pacific most reports are anemometer-based (Table 1). The fraction of anemometer measurements has increased with time as has the average height of the anemometer. Because of the preference of some European meteorological agencies for visually estimated winds, the fraction of anemometer reports is significantly lower in the North Atlantic, and the anemometers are on average mounted lower. As might be expected, the anemometer height tends to be higher in the trans-oceanic shipping routes and lower in coastal regions (Kent and Taylor, 1997).

Table 1—Mean and standard deviation of the distribution of anemometer heights in January of each year indicated for the North Pacific and the North Atlantic. Also shown is the fraction of wind observations measured by anemometer (after Kent and Taylor, 1997).

Year	Mean Height (m)	Standard deviation (m)	Fraction (per cent)
<i>North Pacific (30° to 50°N, 180° to 150°W)</i>			
1980	28.7	5.9	69
1986	33.7	6.4	81
1990	35.2	8.4	82
<i>North Atlantic (30° to 50°N, 40° to 20°W)</i>			
1980	18.4	7.3	35
1986	21.5	8.9	44
1990	24.2	10.9	38

4.
RANDOM ERRORS IN VOS
WINDS

The random errors in VOS observations may be determined by the semivariogram technique which was described at this conference (Kent *et al.*, 1999b). Observations from pairs of ships are compared and the squared differences in the reported wind value are ranked according to the distance separating the ships. If enough observations are available, then the mean difference at zero separation may be determined by extrapolation. This represents twice the random error variance for a single ship observation.

4.1
METHOD OF DETERMINATION

4.2
TYPICAL ERROR VALUES

Kent *et al.*, (1999) analysed VOS observations from four months (January and July in 1980 and 1993) which they assumed to be typical of the period from 1980 to 1993 (the large computing resources needed for the calculations prevented more months from being examined). The results for wind speed are shown in Figures 5 and 6. A typical root mean square (RMS) error for a single wind speed observation was about 2.2 m/s. However, this was after instrumental observations had been corrected for the height of the anemometer above the sea surface (using the data from WMO-No. 47 and Kent *et al.*, 1999b) and visual observations corrected using the Lindau (1995) version of the Beaufort scale. For the observations as reported, the errors were about 15 per cent greater - about 2.5 m/s. This demonstrates that, despite the varying effects of air flow distortion around the ship, correcting the data for anemometer height does reduce the errors. The RMS wind speed errors appeared to be lower than average in tropical regions, however no significant dependence on wind speed was found.

Figure 5—Random observation errors for VOS wind speed reports. The upper figure is the number of report pairs used to make the estimate, the central figure is the rms error (m/s) for each 30° region, and the lower figure is the estimated uncertainty in the rms error estimate (from Kent *et al.*, 1999).

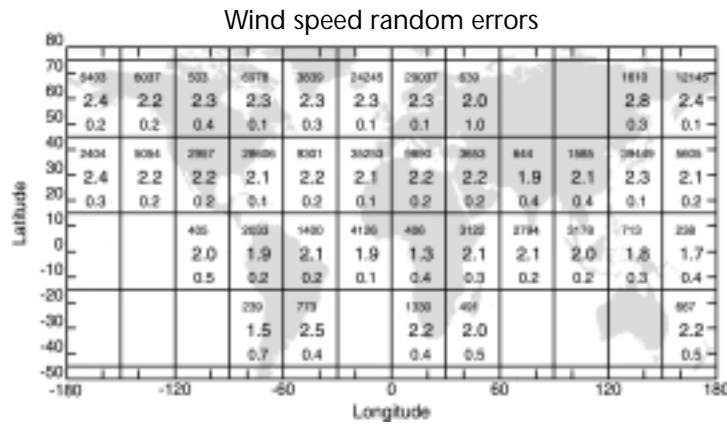
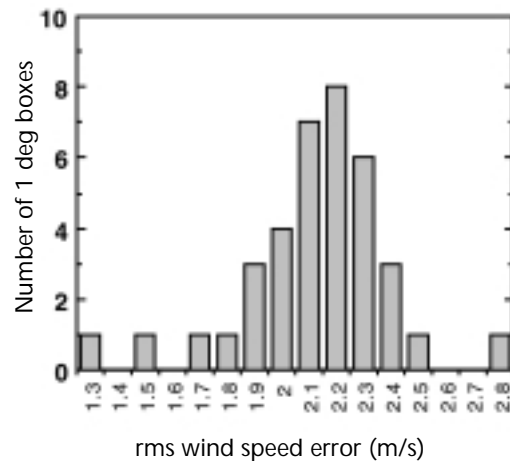


Figure 6—Histogram of the rms error estimates shown in Figure 5.



4.3 POSITION ERRORS

About 2 to 3 per cent of the VOS weather reports in the COADS (Woodruff *et al.*, 1993) collection of VOS weather reports can be identified as having incorrect position information. Typically the position is incorrect by 10° or is in the wrong quadrant. Often these data exist in COADS as duplicates, with one report having the correct position. Position errors are detected in operational forecast centres by tracking individual ships, but this is rarely done for climate studies. However, position errors are potentially very serious because the ship might be erroneously placed away from the shipping lanes in a data sparse region. Such a report may thus be given undue weight. For example, in January 1984, ship reports from near Iceland appeared as a group of erroneous duplicates in the COADS data set, positioned near Antarctica. Therefore, position errors may introduce significant errors into calculated wind fields (along with the fields of other variables).

5. SYSTEMATIC ERRORS IN VOS WINDS

5.1 METHOD OF DETERMINATION

Owing to the lack of an absolute standard, determining the systematic errors in VOS observations is difficult. The VSOP-NA (Voluntary Observing Ship Special Observing Programme - North Atlantic) project (Kent *et al.*, 1991, 1993) was designed to identify and, if possible, quantify systematic errors in the VOS data. A subset of 46 VOS was chosen, the instrumentation used on each of the participating ships documented (Kent and Taylor, 1991), and extra information was obtained with each report, for example, the relative wind at the time of the observation. The output from an atmospheric forecast model was used to compare one ship observation against another. The results were then analysed according to instrument type and exposure, ship size and nationality, and other factors.

5.2. ACCURACY OF ANEMOMETER WINDS

The VSOP-NA results showed that speed estimates from hand-held anemometers were very scattered at wind speeds above about 7m/s and that there was also a larger scatter in the direction estimates compared to other methods. The use of hand-held anemometers was therefore to be discouraged.

The VOSs in the VSOP-NA project reported the anemometer estimated relative wind speed in addition to the calculated true wind speed (only the latter is

transmitted in the standard ships weather observation). Kent *et al.* (1991) showed that a major cause of error was the calculation of the true wind speed. Only 50 per cent of the reported winds were within 1 m/s of the correct value and 30 per cent of the reports were more than 2.5 m/s incorrect (Figure 7). For wind direction, only 70 per cent were within $\pm 10^\circ$ of the correct direction and 13 percent were outside $\pm 50^\circ$. These are substantial needless errors which significantly degrade the quality of anemometer winds. A similar conclusion was reached by Gulev (1999). Results from a questionnaire distributed to 300 ships' officers showed that only 27 per cent of them used the correct method to compute true wind, 19 per cent did not know how to do the calculation, 21 per cent usually did not do the calculation and 33 per cent did it either episodically or approximately. This is perhaps not surprising given the problems in obtaining accurate true wind data from research ships (Smith *et al.*, 1999; see section 2.1 above).

Wind speed reports from VOSs are accompanied by a wind speed indicator flag which establishes whether the wind observations are a visual or anemometer report, and whether the units are knots or m/s. Any error in the indicator flag, for example resulting from miscoding or transmission, may lead to a large error in the accompanying wind report.

We have already noted (section 4.2) that correcting for the height of the anemometer above the sea demonstrably improved the data set. This correction should be done on a ship-by-ship basis since the average height of anemometers varies both geographically and with time (section 3).

For a 10 m/s wind and neutral stratification, an anemometer at 35 m will read about 10 per cent higher than one mounted at 20 m. For unstable conditions this ratio decreases. For very stable conditions one or both anemometers may be outside the near surface boundary layer, in which case the error would be indeterminate. Fortunately, very stable conditions are relatively rare over most of the ocean. For the VSOP-NA ships which used anemometers, the mean difference between the ship and model wind speed estimates increased with anemometer height even more than might have been expected due to the vertical wind profile (Figure 8).

Taylor *et al.* (1995) reanalysed the VSOP-NA results for wind speed. They found that having corrected OWS Cumulus data for ship motion and the VOS data for anemometer height, there appeared to be agreement between the OWS and VOS data for winds below 10 m/s. For higher wind speeds the VOS winds were biased high - by about 1.5 m/s to 2 m/s at 20 m/s wind speed. If this bias is real, the reasons might include misreading of the anemometer dial (gust values rather than mean winds being reported) and the air flow distortion caused by the ship.

5.3
CFD STUDIES OF AIRFLOW
DISTORTION FOR VOSs

We have noted above (section 2.1) that for ship mounted anemometers a major consideration is the air-flow disturbance caused by the ships' hull and superstructure. We have also shown that this may be determined using CFD simulation. The CFD results have been verified for wind speeds within 30° of the bow by comparisons with data from an array of anemometers on the research ships RRS Darwin and RRS Discovery. Both ships were instrumented with up to 10 anemometers located at various sites, including some regions of high flow distortion. These comparisons showed good agreement between the ships' data and the

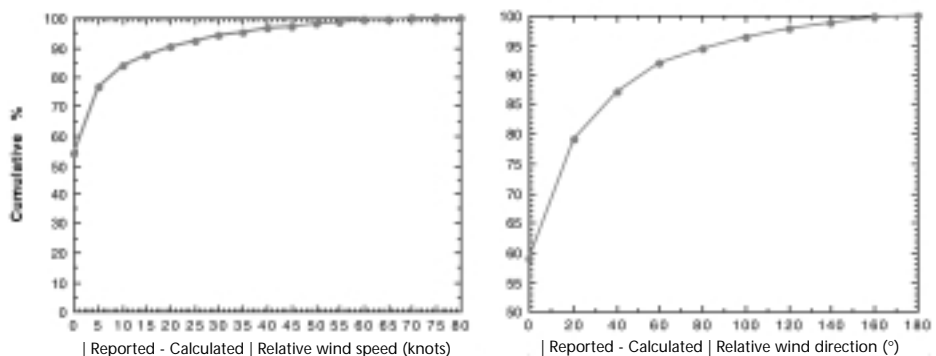
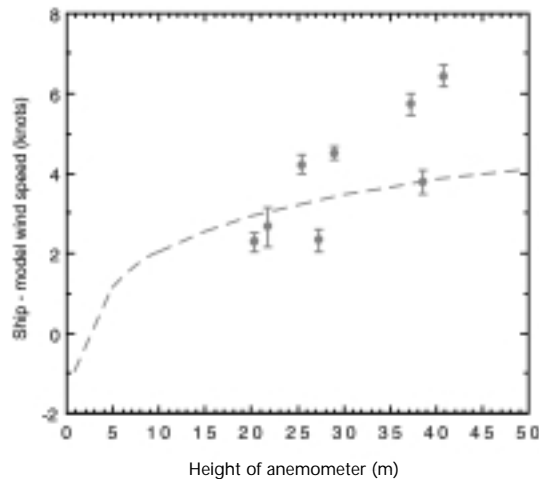


Figure 7—Cumulative histograms of the difference between the value calculated by the ship's officers and the correct value for true wind speed (right) and true wind direction (far right) (from Kent *et al.*, 1991).

Figure 8—Mean difference between the ship and model wind speed estimates for those VSOP-NA ships which used anemometers plotted against the anemometer height. Also shown is the expected variation of wind speed with height for a neutral boundary layer. This has been offset by the estimated mean error in the model winds (2 knots).



CFD results in all cases, except where the anemometers were in the wake of an upstream obstruction - a situation in which the CFD code is expected to perform poorly.

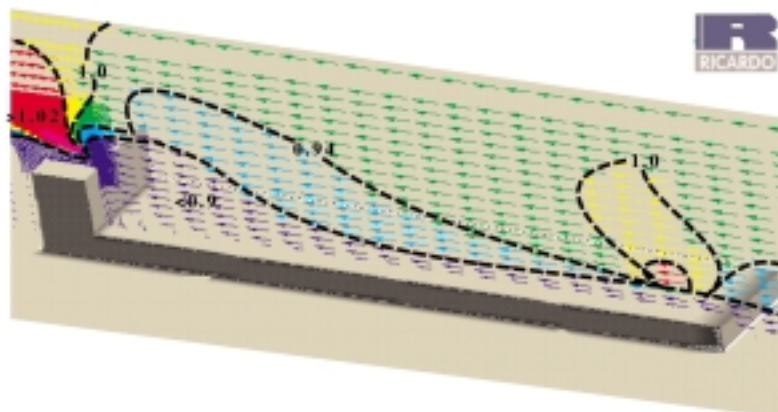
The obvious problem in applying CFD modelling to the VOS is the almost infinite variety of the size and shape of merchant ships. However, two ship types, container ships and tankers (the results of which may also be applicable to Oil Bulk Ore, or OBO ships), are believed to account for around 70 per cent of the deep-ocean merchant fleet. Since the effective shape and roughness for container ships will vary according to the degree of loading, we have chosen to study first of all the flow over tankers. Based on a sample of 36 tankers and 8 bulk carriers, three representative models were created (Table 2 and Figure 9). Tanker 1 was modelled with a close mesh to resolve the accelerated 'plume' region above the bridge; for tankers 2 and 3, a coarser mesh was used for computational efficiency.

Using the fluid dynamics analogy of flow past a rectangular block, we would expect the bridge-to-deck height (D) to be an important scaling factor. For example, the comparison between tanker 2 and tanker 3 showed a similar pattern of wind speed error for heights of less than around 8 m, but the magnitude of the decelerations differed by up to 20 per cent in profiles obtained near (i.e. within 5 m of) the front edge of the bridge. When distances were scaled by the bridge-to-deck height, these differences reduced to around 5 per cent. Indeed, all three models showed that at a height above the wheelhouse top of greater than $0.5D$ any anemometer site would give an

Table 2—Dimensions (metres) for the three tanker/bulk carrier models used in the CFD studies.

Tanker model number =	(1)	(2)	(3)
Length overall	170	250	330
Beam	27	42	62
Freeboard	6	8	10
Deck to Bridge top (D)	14	16	18
Bridge length	14	15	23

Figure 9—A three-dimensional view of a simple 'two block' tanker model. Model results of the wind speed error, expressed as the wind speed at a point divided by the free stream (undistorted) wind speed, are shown for a vertical plane intersecting the ship (Moat et al., 1998).



overestimate of the wind speed of up to 5 per cent (Figure 10). This held for all sites up to 10 m back from the front edge of the bridge (Figure 11) and would not vary with a moderate displacement to port or starboard of the centre line of the bridge.

Below a height above the wheelhouse top of 0.5D the results vary according to both anemometer position and the mesh density used in the model. The tanker 1 model (fine mesh) shows a ‘plume’ of accelerated flow, with a maximum acceleration of around 13 per cent at a height of about 4 m above the bridge (and about 4 m from the bridge front) and large decelerations below this height (Figures 11 and 12). The other two tankers do not resolve the plume and both show decelerations at heights of less than 5 or 6 m. Here we have used dimensions in metres to emphasize that an anemometer mounted above the wheelhouse may be below, in, or above the plume maximum depending on how high and how far aft it is mounted. Below the plume the wind will be significantly underestimated, above the plume an overestimate will occur. If the anemometer is in the plume the overestimate may be significant and vary rapidly with relative wind direction.

5.4 ACCURACY OF VISUAL WIND ESTIMATES

Kent and Taylor (1997) reviewed the various Beaufort equivalent scales and found that the Lindau scale (1995) was the most effective at giving similar wind speed distributions for both anemometer estimated and visual monthly mean wind data. They also confirmed Lindau’s suggestion that the characteristic biases of the earlier Beaufort scales could be explained by the statistical method by which they were derived. The ‘UWM’ scale (developed by da Silva *et al.*, 1995 at the University of Wisconsin, Milwaukee), which is similar to the Lindau scale, also performed well. It should be noted that the Lindau scale is more similar to the WMO code 1100 scale used for the observations than the so-called ‘scientific scale’ recommended by CMM-IV (see WMO, 1970).

Figure 10—The fractional wind speed error for each of the three tanker models at a distance (x) from the front of the wheelhouse where $x/D = 0.6$. The vertical scale is z/D where z is the height of the anemometer above the wheelhouse and D is the height of the bridge top above the deck.

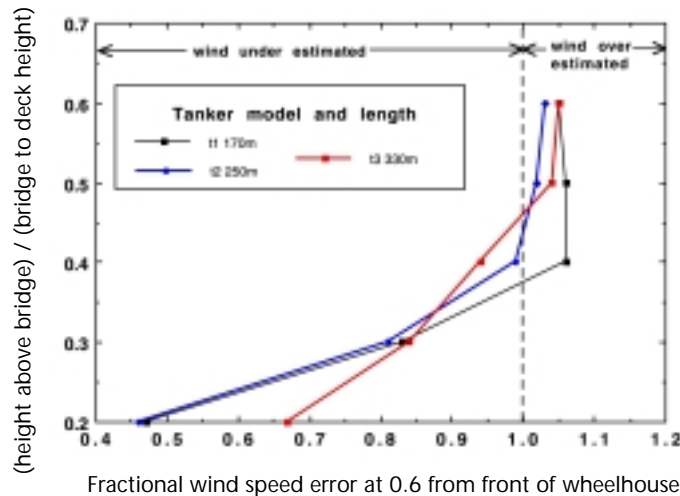
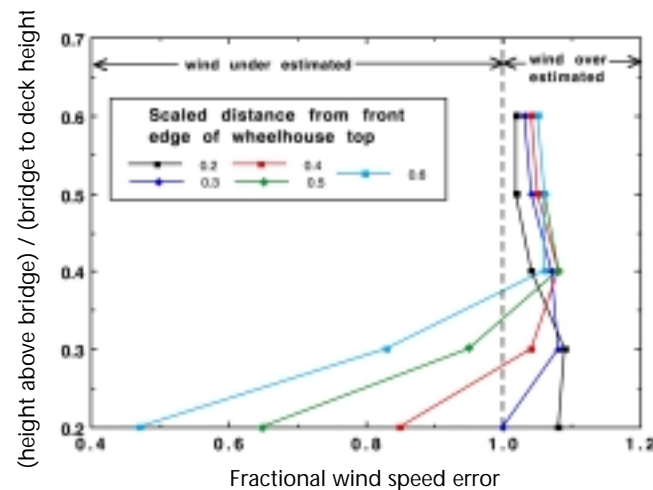


Figure 11—As Figure 10, but for tanker (1) at different scaled distances from the front of the wheelhouse (x/D).



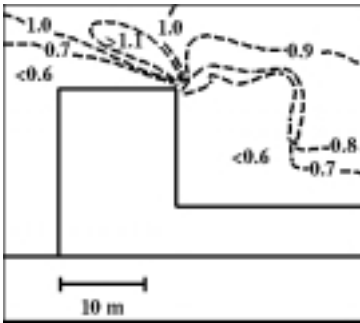


Figure 12—Detailed view showing airflow distortion over the stern section of a typical tanker as determined by CFD modelling (after Yelland *et al.*, 1998a). The wind is blowing from right to left.

6 COMPARISON WITH SATELLITE DATA

6.1 IMPORTANCE OF CORRECT ERROR TREATMENT

However, Gulev (1999) showed that the use of the Lindau scale degrades the agreement between VOS winds and a data set of Russian research ship winds. The reason for this is that the Lindau and UWM scales are calculated to bring VOS visual and VOS anemometer winds into agreement. The anemometer winds from the Russian research ships used by Gulev were similar in magnitude to unadjusted VOS visual winds and significantly higher in magnitude compared to VOS anemometer reports. Thus, converting the VOS winds to the Lindau scale decreased the stronger wind values, thereby improving the comparison with the VOS anemometer data as expected, but degrading the agreement with the research ship data.

If Gulev's research vessel data are correct, the implication is that VOS winds are on average underestimated. However, Isemer (1994) noted that when weather station C began to be manned by ships which provided Gulev's data set, there appeared to be an increase in the measured winds. This does not prove that the Russian winds are necessarily too high; we repeat that, in our view, there is not an absolute standard for wind measurement.

Finally, in discussing visual winds, we would stress that it is important that the ships' officers do not change from the present WMO code 1100 scale. Any adjustment should be left to those preparing climatological data sets.

Kent *et al.* (1998; henceforth K98) compared VOS winds with those measured by the scatterometer on ERS-1. The VOS winds had been quality controlled and corrected for anemometer height, or adjusted to the Lindau scale, as appropriate. The study demonstrated very clearly the importance of properly accounting for the observation errors in each of the data sets which are compared. Thus, Figure 13 shows the results of different comparison strategies. If the (satellite-ship) differences were averaged as a function of the ship winds it appeared that, compared to the ships, the scatterometer was biased high at low wind speeds and high at high wind speeds. Similar plots showing similar apparent bias can often be found in the literature (e.g. Liu, 1984; Offiler, 1994; Boutin and Etcheto, 1996).

However, if the same differences were binned using the satellite data as the independent variable then the conclusions appeared different. The satellite data were apparently low at lower winds but in agreement with the ship data over much of the wind speed range. K98 demonstrated that this was due to the different variance for the two data sets; a problem that has been recently discussed by Tolman (1998; see also Kent & Taylor, 1999).

To simulate the effect, K98 used a single wind speed data set obtained from a moored buoy. The simulated data sets were calculated by adding to the buoy wind data random errors, normally distributed with an rms of 2.0 m/s to represent the ship winds and 0.5 m/s to represent the scatterometer winds. These rms values had previously been obtained by semivariogram analysis. The two simulated data sets were then analysed in a similar manner to the actual data sets. Apart from a small offset when using the simulated satellite data as the independent variable, the results of the simulation (also shown in Figure 13) showed

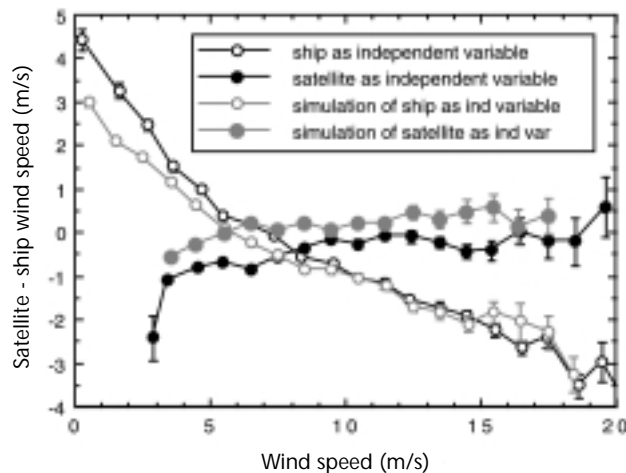


Figure 13—Comparison of the ERS-1 scatterometer with ship wind speeds showing different results depending on which data set is used as the independent variable. Also shown (lighter lines) are the results of the simulated comparison described in the text (from Kent *et al.*, 1998).

the same behaviour as the real data. K98 proceeded to demonstrate that the same effect could result in a stability dependent bias being erroneously ascribed to the scatterometer data.

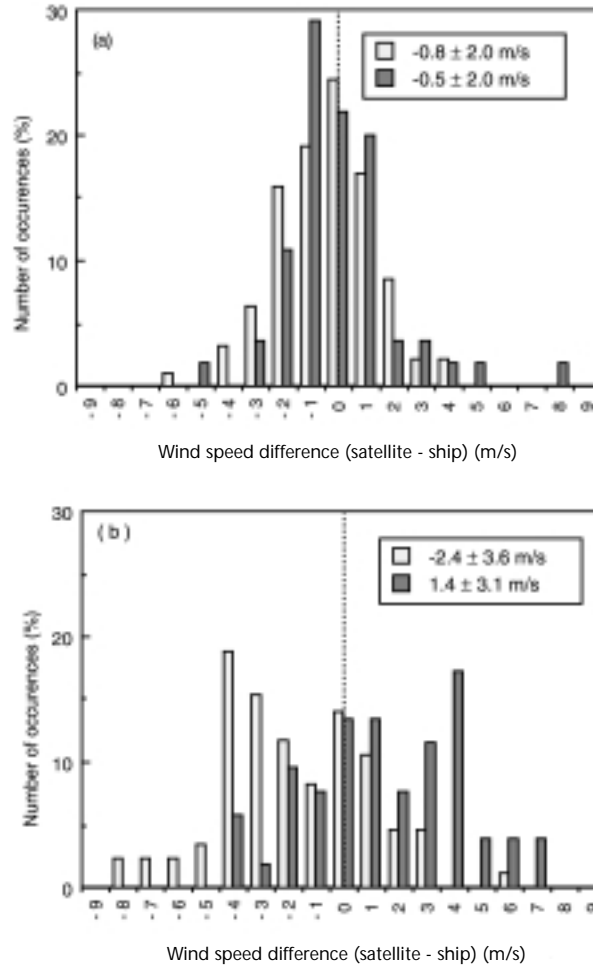
Using a regression method which correctly allows for the different error characteristics for each regression variable (e.g. Graybill, 1961), K98 showed that the ship winds were slightly higher than those from the scatterometer:

$$U_{10m}(ship) = 1.025U_{10m}(scat) + 0.255 \quad (1)$$

A very different result would be obtained by regressing the satellite winds on ship winds without considering the errors. The ship values are around 0.5 m/s higher at 10 m/s and 1 m/s higher at 30 m/s. This could be due to the buoy measured winds, used to develop the scatterometer algorithm, underestimating the wind speed; it may be due to airflow disturbance biasing the ship winds; we do not know if either is correct.

- 6.2 QUALITY CONTROL OF VOS DATA K98 also showed that the scatterometer data could be used to identify ships whose wind reports showed large biases or error variability. Thus, Figure 14(a) shows the distribution of satellite-ship comparisons for two ships reporting reliable winds. The rms scatter is typical of the overall data set from the ships, and the mean bias is similar to that predicted by (1). In contrast, Figure 14(b) shows the distribution for two ships whose wind estimates were less reliable. Although both histograms showed a number of observations close to the scatterometer values, secondary peaks occurred at about 4 m/s difference. Since these ships were reporting visual winds, correction to true wind should not have been a problem. Rather, it suggests that a Beaufort force two intervals away from the true value was sometimes chosen.
7. FUTURE DEVELOPMENTS
- 7.1 AUTOMATIC CODING The use of automatic coding of ships' weather messages using a personal computer system and form filling techniques is becoming more common. A popular system is TurboWin developed at KNMI in the Netherlands. Such a system should ensure that position is correctly coded (and compatible with the last reported position) and remove a major source of error by automatically computing true wind.
- 7.2 AUTOMATIC DATA ACQUISITION Computer-based systems can also be used to automate data acquisition. For example, the Improved Meteorological System (IMET) has been installed on a number of US Research Vessels and is now being placed on US VOS (Weller and Taylor, 1998). IMET uses sensors chosen (based on laboratory and field studies) for accuracy, reliability, low power consumption and their ability to stay in calibration during unattended operation. The sensors are combined with front end digital electronics to make a module which is digitally addressable (RS-232 or RS-485), stores its calibration information and provides either raw data or data in meteorological units. The present set of IMET modules includes wind velocity and most other meteorological variables.
- 7.3 AIR-SEA FLUX DETERMINATION Using European Union funding under the MAST programme, the AutoFlux Group (1997) is developing an autonomous system for monitoring air-sea fluxes using the inertial dissipation method and ship-mounted instrumentation. It aims to develop and test a prototype system, called AutoFlux, which will measure surface stress, sensible and latent heat flux, and also carbon dioxide flux. The system is aimed primarily at unattended use on VOSs and on unmanned buoys. The fluxes are derived from the turbulence spectra using the 'inertial dissipation' method. This technique minimizes the effects of flow distortion and platform motion. The system software will manage data conversion, storage and transmission, including the necessary navigational information. The present project should be regarded as 'proof of concept', but, if successful, AutoFlux-type systems might be installed on selected VOSs in a few years time. Transmitting flux data over the GTS will require a new code format.

Figure 14—Comparison of satellite-ship wind speed differences for individual ships: (a) two ‘good’ ships (one anemometer, one visual); (b) two ‘bad’ ships (both visual).



7.4 SATELLITE TRANSMISSION

The recent introduction of relatively inexpensive global data transmission systems via satellites suggests the possibility of transmitting a more comprehensive weather observation message that includes information such as the method of SST measurement, the relative wind observation, etc. The full message could be archived for use in climate studies with the standard GTS message being extracted and transmitted by the land station for weather prediction purposes.

7.5 AN IMPROVED SUBSET OF THE VOSS

While these various improvements to VOS observations are highly desirable, systems such as IMET or AutoFlux are much more expensive and require more shore-side support compared to the instrumentation typically provided to the VOSSs. It will not be practicable to supply such instrumentation to a substantial fraction of the VOS fleet. However, the establishment of an improved subset of VOSSs would provide a verification standard which would allow the biases in the standard VOS data to be quantified. As a result, all VOS observations would be improved in value. A subset of about 100 to 300 selected VOSSs could provide a significant contribution (e.g. Taylor, 1984).

8. SUMMARY

We have emphasised the lack of an absolute calibration standard for marine wind measurements. Wind data obtained from ships are affected by the air flow distortion around the ship. This is true for all practicable anemometer sites. Positions can be found where for some relative wind directions the disturbed wind speed matches the free stream wind speed, but this is unlikely to hold for all wind directions. We have demonstrated success in correcting these errors using CFD or wind tunnel data but there are very few data sets for which this has been done. Data from buoys are suspect at higher wind speeds because of the sheltering effect of waves. The error in buoy winds may have also caused bias in scatterometer data.

The fraction of anemometer-based winds has increased with time, particularly in the Pacific. The average height of anemometers is higher in the Pacific compared to the Atlantic. Correcting for anemometer height (on a ship-by-ship basis) and adjusting winds to the Lindau scale reduces the rms scatter in the wind speed data set by about 15 per cent.

A major source of error in anemometer-derived winds is the calculation of true wind speed and direction from the measured wind speed; an automatic method of calculation is required. CFD studies on the airflow over simple generic tanker models show that it is important that the anemometer be mounted above the plume of accelerated air which occurs over the wheelhouse top.

In comparing ship and scatterometer data we have emphasised the importance of taking the different error characteristics into account. When this is done, it appears that the ships are biased high compared to the scatterometer by around 4 per cent; we do not know which is the most correct. The scatterometer data can be used to identify ships whose wind reports are less reliable.

In the future it is expected that VOS meteorological reports will be increasingly automated, thereby removing errors in calculating true winds or in coding the ship's position. An improved subset of the VOSs would be valuable as a standard for improving the VOS data set as a whole.

Finally we make the following recommendations:

- For ships reporting anemometer winds, the ship's officers should be provided with an automated method of calculating the true wind.
- Anemometer read-outs should automatically average the winds.
- Hand-held wind sensors should not be used.
- The position of the anemometer must be documented. This must include height above sea level and also measurements indicating the location of the anemometer in relation to the overall shape of the ship. In future this will allow average CFD corrections to be calculated for typical VOSs.
- Visual wind observations should continue to be based on the WMO code 1100 scale. For scientific analysis the Lindau scale is to be preferred over other versions (such as that recommended by CMM-IV).
- That a high quality subset of the VOSs be developed and used to verify the data from the VOS fleet as a whole.

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