Uncertainties in CO_2 transfer velocities due to bias in shipboard wind measurements caused by airflow distortion

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1. Introduction

Global ocean CO_2 uptake can be estimated from parameterizations of the gas transfer velocity (*k*) and globally mapped differences between the concentration of CO_2 in the ocean (pCO_{2sw}) and atmosphere (pCO_{2atm}). Global maps of the wind speed are also required since the transfer velocity is strongly dependent on wind speed.

In addition to possible uncertainties (e.g. surfactants, sea state, flux measurement errors etc.) in the estimates of *k*, mean wind speed measurements obtained from ships are subject to two major errors: (1) correction of relative wind measurements to fixed earth, and (2) correction of the wind speed for airflow distortion by the platform, which varies with the relative wind direction.

The first correction can be performed by standard ship parameters (heading, course and speed over ground). The second correction requires complex quantification of the mean wind speed biases with the relative wind directions, commonly obtained by computational fluid dynamics (CFD) modeling of the measurement platform (Yelland et al. 1998, 2002; Dupuis et al., 2003; Popinet et al., 2004).

2. Simulation

We created digital geometries of the research vessels Hakuho Maru (HK) and Mirai (MR) and computed the biases in mean wind speed at various anemometer locations using the large eddy simulation (LES) code GERRIS (http://gfs.sourceforge.net/). Wind directions from 0° to 360° are simulated in steps of 15°. Various wind speed monitoring locations (actual as well as potential locations) are defined in the simulation domain (see Fig. 1).

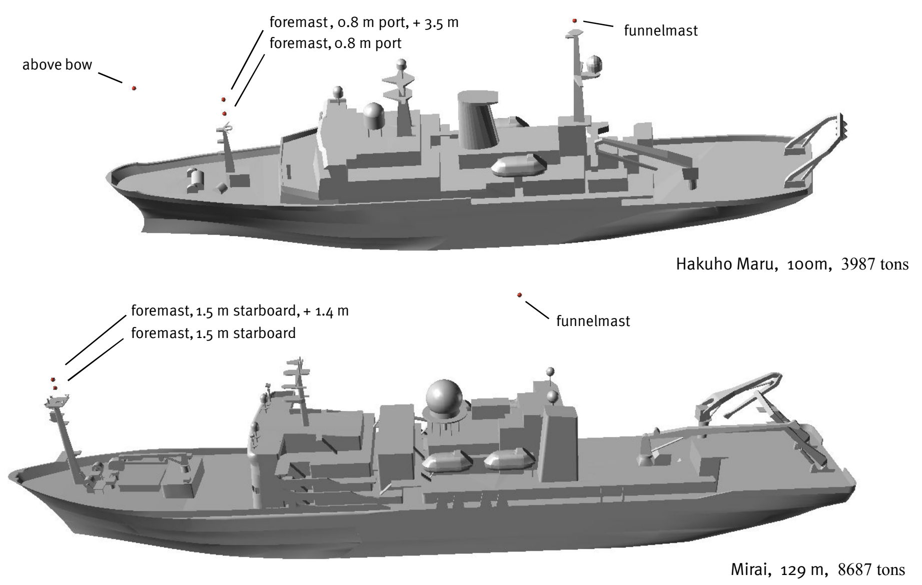

Fig. 1: Digital geometries of R/V Hakuho Maru [top] and R/V Mirai [bottom], red spheres indicating various anemometer locations

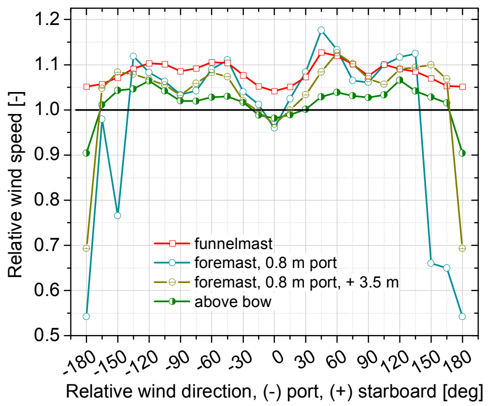

Fig. 2: R/V HAKUHO MARU: Relative wind speed (as a fraction of the undisturbed speed) against relative wind direction at various anemometer locations (see Fig. 1, top panel): [1] foremast (17 m asl), [2] foremast + 3.5 m (20.5 m asl), [3] funnel-mast (30.5 m asl), and [4] above bow (23 m asl)

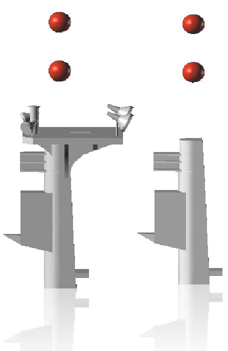

Fig. 3: R/V MIRAI, detail of top of foremast: [left] foremast with pedestal, [right] foremast without pedestal. Anemometer locations at 1.5 m starboard are indicated by red spheres: [bottom] 'foremast', [top] 'foremast, + 1.4 m' (see Fig. 4)

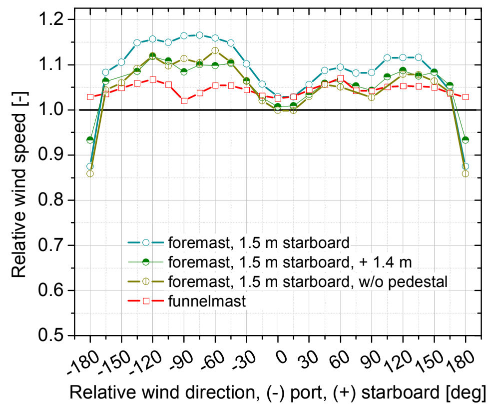

Fig. 4: R/V MIRAI: Relative wind speed (as a fraction of the undisturbed speed) against relative wind direction at various anemometer locations (see Fig. 1, bottom panel): [1] foremast (23.5 m asl), [2] foremast +1.4 m (24.9 m asl), [3] foremast w/o pedestal (23.5 m asl), [4] funnel-mast (30.5 m asl)

3. Results

Simulation results of mean wind speed (see Fig. 2 and 4) at the ship anemometer locations (foremast) show the lowest biases during on-bow wind conditions (HK +4%/ MR +2.5%), whereas, the typically highest biases are for off bow flows (+17.5%/+16.5%) and during aft-wind conditions (-46%/ -13%).

At both vessels the ship anemometers are located at the top of the foremast, close to the ship's centerline, HK 0.8 m to port, and MR 1.5 m to starboard, which results in asymmetric bias caused by the different distance from anemometer location to the ship's side. For instance in case of R/V Mirai, the biases at port-wind conditions are higher than during starboard-side conditions, as the anemometer is located starboard of the ship's centerline.

Besides this global flow distortion effects, local geometry features can bias the wind speed as well, e.g. the pedestal (3 m x 2.7 m) at the top of Mirai's foremast (see Fig. 3 for geometry details). The bias of the mean wind speed without the pedestal is up to 5% lower than with the pedestal (see Fig. 4, graph 'foremast, w/o pedestal'), the same bias reduction can be achieved by lifting the anemometer up by 1.4 m (see Fig. 4, graph 'foremast, + 1.4 m').

An obvious method to improve the wind measurement quality without having the computed biases is to limit the measurements to on-bow flow sectors from ± 30° to up to ± 90°. This approach would avoid the highest errors; however, for flows within ±45 degrees of the bow the bias in the mean wind speeds for both ships are up to 17 %.

Taking the error propagation into account, the errors for transfer velocities due to bias in wind speed measurements are a factor of 2 or 3 higher when employing commonly used quadratic or cubical relationships of wind speed and transfer velocity, (see Fig. 5).

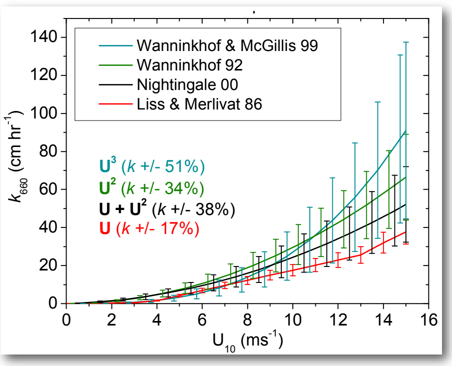

Fig. 5: Various transfer velocities (*k*) from previous studies with error bars representing a mean wind speed measurement which is biased by ±17%

4. Conclusions

- Bias in wind speed is the result of global (ship's body) and local geometry (e.g. pedestal) features.
- Limiting the wind-sector to on-bow wind can incorporate significantly high biases in wind speed, in this study, up to 17%
- Errors in *k* due to biased wind speed are a factor of 2 or 3 higher when employing commonly used quadratic or cubical models of transfer velocities, in this study up to 51%.
- The bias in wind speed due to flow distortion can explain a part of the uncertainties in transfer velocities, especially at high wind speeds

Acknowledgements

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