The role of accurate nowcast data in ship efficiency analysis

Michael Haranen, NAPA Ltd., Helsinki/Finland, michael.haranen@napa.fi
Sami Myöhänen, NAPA Ltd., Helsinki/Finland, sami.myohanen@napa.fi
Dragos Sebastian Cristea, NAPA Ltd., /Finland, dragos.cristea@napa.fi

Abstract

This paper describes the results of statistical analysis of data collected from many vessels to discuss the problems which may occur during the data collection onboard, and the role of the nowcast data for technical performance evaluation. The research is focused on the quality of measurements of wind and speed through the water. The main goal of the research is to reveal the benefits of using nowcast data and its effect on the quality of statistical models which can be used for performance evaluation purposes. The results of the statistical analysis show that the nowcast data can be successfully used for validation of the on-board measurements and, in some cases, can substitute the onboard data without lack of analysis quality.

1 Introduction

An understanding of the factors that influence the ship resistance and their behavior is very important as they can be used for the technical performance evaluation. By technical performance, we understand here the relationship between the speed through the water and the corresponding energy consumption of the ship. This relationship may be described by using physical laws or can be estimated statistically by using machine learning and data mining techniques using sensor data collected onboard, *(Haranen 2016)*. The most important goal of the technical performance evaluation is to quantify possible deterioration of the hull condition due to hull or propeller fouling, paint problems, aging, etc. The performance evaluation can be done by data correction *(ISO 19030)*, or with the aid of statistical modeling.

Regardless of the methodological approach for the technical performance analysis and evaluation, it is important to assess and separate the effect of operational conditions and environmental factors. Therefore, it is extremely important to have accurate data for all variables which we use for the technical performance evaluation. Usually we use variables like propulsion power consumption, engine rpm, speed through the water, draft, trim, wind speed and direction, wave and swell height, water temperature, water depth, etc.

This paper mostly concerns about the quality of the wind data and measurements of the speed through the water. It is known that data collected onboard ship may be inaccurate and biased. Many publications describe problems with onboard measurements of the speed through the water or wind. Unfortunately, the problems described in the publications are usually case specific and thus cannot be generalized. In our research, we analyzed the data collected from many ships and tried to assess the scope of the problems with the onboard data for the wind and the speed through the water.

In the paper, we elaborate on the role of nowcast data from the technical performance analysis point of view. The term nowcasting is widely used in meteorology and is defined as the prediction for the present, near future and recent past weather conditions. Our research is focused on questions like:

- How can we use the nowcast data for validation of the data collected onboard?
- Can we prove that using the nowcast data will increase the accuracy and reliability of the analysis in general?
- Is it better to use wind measurements onboard or should we rely on nowcast data?
- Is it better to use speed log signals or should we calculate the ship speed through water from the speed over ground and nowcast ocean currents?

2 Data collection challenges

The main goal of this section is to discuss challenges related to data collection onboard ship and the role of the nowcast data, which is available from many independent weather providers. Nowadays, systems onboard the ship are capable to collect the environmental data for many sources. For example, it is common that every ship has an anemometer, thus collection of the wind speed and direction data seems to be a simple task. Echo sounders are standard devices on all ships, making it easy to collect information about water depth. With newest technology, it is also possible to measure and record the sea surface conditions, like wave and swell height and period. However, collection of the environmental data onboard the ship can be a challenging task and subject to errors.

While studying several scholars' research, we could identify plenty of issues that can appear for onboard weather and sea state related measurements. Referring to biased wind data, *Taylor et al. (1995)* emphasized that there are several possible sources of error for anemometer wind measurements. It is not known how well the deployed anemometers have been calibrated or what, if any, measures are taken to ensure that the instruments remain within calibration. In use, the anemometer is exposed to a turbulent flow, which fluctuates as the ship rolls and pitches and the anemometer may not be "vertical" with respect to the mean flow. The reported wind is an estimate of the average reading of a fluctuating analog dial made by the ship's officer and, thus, subject to errors. Errors are made also in converting to true wind velocity. According to *Moat et al. (2005)*, wind speed measurements obtained from ship-mounted anemometers are biased by the distortion of the airflow around the ship's hull and superstructure.

Depending on the ship type, location of the wind transducer, trim and wind direction, there can be big inaccuracies in certain wind directions in varying load conditions. For example, on a container ship with the deckhouse at the aft ship, the situation is very different depending on how high container stacks are in front of the deckhouse and when the relative wind is coming from the bow region. On the other hand, it is quite common for ferries and car carriers, that the wind is measured at the bow, but there is huge ship behind it. At the following wind, it is very difficult to measure wind in such a condition and then the wind driven wave data prediction fails as well.

As for the sea state measurements, in *Stredulinsky and Thornhill (2009)* the authors state that wave or swell height measurements can be performed through different methods, like using x-band radars, Doppler radars or wave buoys. Still, all these technologies present issues and challenges. With x-band Radar, there is no direct measurement of the wave elevation. The sensor captures backscattered intensities of the reflected Radar magnetic waves on the ocean surface. These intensity images must be converted into wave images by relying on 3D Fourier analysis. According to *Nielsen (2008)*, wave buoys do have several drawbacks. The first is that they require a suitable crane onboard the ship for deployment and recovery, which can be a difficult operation in high sea states. Trial operations must remain in relatively close proximity to the wave buoys for data to be useful. This limits the length of straight track runs before the vessel must return to the buoy. If several buoys are deployed, they can drift away from each other. This requires the ship to do manual adjustments. Buoy data may contain errors and its quality must be checked. In *Simos et al. (2010),* another method, used for wave measurements, is presented: an over-the-bow downward-looking Doppler radar. The radar gives the distance to the wave surface and, when combined with an accelerometer, can give the actual wave height. Many sea trials using this system have shown that it works reasonably well, but that there tends to be sensitivity in the wave height measurements to relative heading. It tends to work best in beam seas. Other drawbacks are that it does not give wave spectra (only wave height and characteristic encounter frequency are given), and it can be damaged in severe sea conditions.

On depth measurement issues, *Godin (1995)* states that sonars are complex and hard to calibrate. They include many sub-systems that possess their own configuration and calibration routines. There are several sources of error associated with depth measurements, and they must be detected and quantified by systematic testing procedures before being corrected or eliminated. For example, deep-water surveys (> 1000 m) involve much larger sonar footprints and thus, corresponding lower accuracy both in the positioning and in the depth measurements are usually acceptable. In addition, the accuracy requirements are much harder to meet in shallow waters (< 100m) where the calibration of the sounding systems becomes a critical issue, see *Hare and Tessier (1995)*.

As we can see from the numerous examples, onboard data collection is a challenging task. At the same time the importance of accurate environmental data, which we use for the ship technical performance evaluation, is pointed out in many research papers. Here are some notable examples: a) determining how ship navigation is affected by extreme weather conditions, *Xia (2006)*; b) identifying algorithms and models for the prediction of ship speed and power for different weather states, *Chen (2013)*, *Soda et al. (2012)*; c) determining fuel savings algorithms, *Hellstrom (2003)*; d) researching new architectural ship designs, for example Flettner rotors design, *Traut et al. (2014)*; e) determining different ship routes based on weather and sea currents forecasts, *Padhy et al. (2008)*, *Tsujimoto et al. (2006)*, *Panigrahi et al. (2012)*, *Zhang, J., & Huang, L. (2017)*, *Cai, Y. (2014)*; f) analyzing characteristics of propulsion performance under various weather and sea conditions, *Sasaki (2009), Yokoi (2010), Tsujimoto (2000), Kayano (2013)*.

In this research, the accuracy of the wind data is under investigation. In the case of the ship's technical performance evaluation, the goal is to estimate the effect of wind speed/direction on ship performance. Usually, in slow winds, the ship will lose speed in headwinds and will gain speed in the case of following winds. If the wind speed is high, the speed will be reduced in both cases due to the increased wave actions and steering corrections. Having correct wind measures will highly increase the quality of the model and correspondingly will increase the quality of the research.

When we speak about technical performance evaluation there are two major sources of environmental data. We can collect data onboard, manually or by using sensors. On the other hand, there are numerous weather providers which make independent weather nowcast data available. We can identify two general benefits from the nowcast data. First, this data can be used for validation of the data that is collected onboard. Second, if for some reason we are not able to use the onboard sensor data or the data is erroneous, we can use the nowcast data instead.

2.1 Weather Interpolation Service

In Napa practice, nowcast data from several independent weather providers is used. They send data covering all important aspects related to sea conditions, like sea currents speed and direction, tidal currents speed and direction, air pressure, wave heights, wave direction, swell heights, water temperature, water salinity, wind speed, wind direction, ice concentration, salinity, etc.

The data files, containing environmental parameters, are built based on a grid with predefined resolution. In Figure 1 the example for of grid data for the oceanic currents is shown. To obtain exact environmental conditions for a certain ship, available weather nowcast data is interpolated according to the ship location and time. The important characteristic of the Napa platform is the ability to correctly approximate weather and sea conditions for specific coordinates in time (according to ship position and time of the measurement). Coordinate resolution can vary between providers or between parameters. As an example, sea current parameters are defined using a 0.25° resolution grid, while wind-related parameters are using a 0.5° resolution. For different providers/parameters the grid resolution can vary even more: 0.001°, 0.1°, 0.08°, 0.02°, 1.25°, etc. In this context, our interpolation functionality was developed to provide accurate weather data values for any reported ship position during the voyage of a ship.

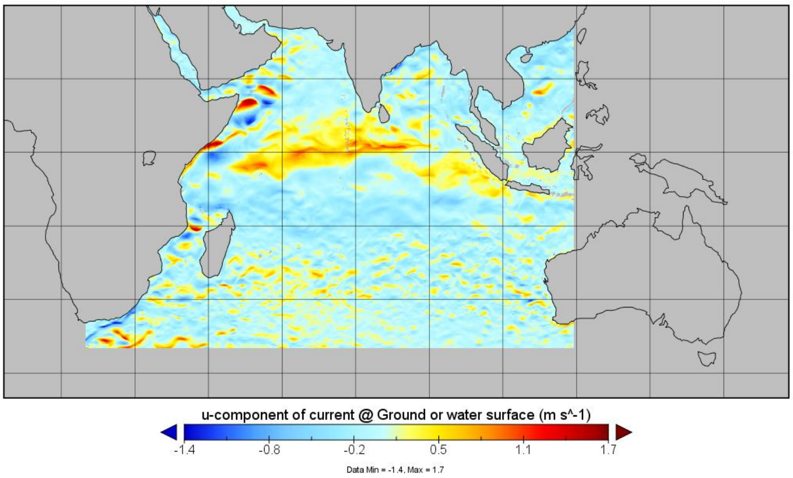

Figure 1. Current data for the Indian Ocean.

For interpolation, we use the bilinear and trilinear interpolation procedure, which is an extension of the linear interpolation. The main idea of the trilinear interpolation is shown in Figure 2. In order to fulfill the interpolation procedure, the weather files should contain data for the necessary dates and time, determined from the timestamps when the ship sailed over certain coordinates. In addition, it is mandatory for the ships to send both latitude and longitude for their position and the reference time of the measurement, see Figure 2.

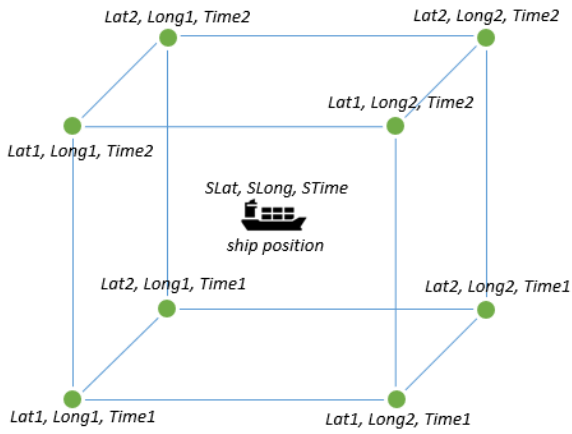

Figure 2: Ship position from the trilinear interpolation perspective.

3 On-board wind versus nowcast wind

This section is devoted to a comparison of the nowcast wind and wind measured onboard. First, we investigate how often the problems related to the wind measurement onboard the ship may be faced in general. Then, we present the results of the modeling test. The goal of the modeling test is to elaborate on the quality and goodness of the wind data from different sources.

Before data analysis and modeling, the onboard wind measurements need to be adjusted so that they correspond to the same height as the nowcast wind. Nowcast data usually contains the wind measurements reported at the height of 10 meters. Thus, the onboard measurements are adjusted to the same height by using the power law of the wind profile as follows:

$$V = V_m \left(\frac{h}{h_m}\right)^{1/7},$$

where V_m is the measured wind speed at the height h_m (depends on the anemometer location on-board), and $h = 10\ m$.

In Napa practice, for the sake of simplicity, the wind speed and direction are transformed into headwind and crosswind components. In Figure 3, the example in which the time-series of the onboard and nowcast headwind are depicted demonstrating a good match between different sources for the wind data. Our onboard data represent 5-minute averages for the headwind. The nowcast wind is usually reported every 3 hours and it is interpolated to correspond the same time resolution. As one can notice from Figure 3, the values are close to each other. In this example case, the linear correlation between nowcast and onboard headwind is about 95.5%, which suggests that there is no major problem with the onboard measured wind.

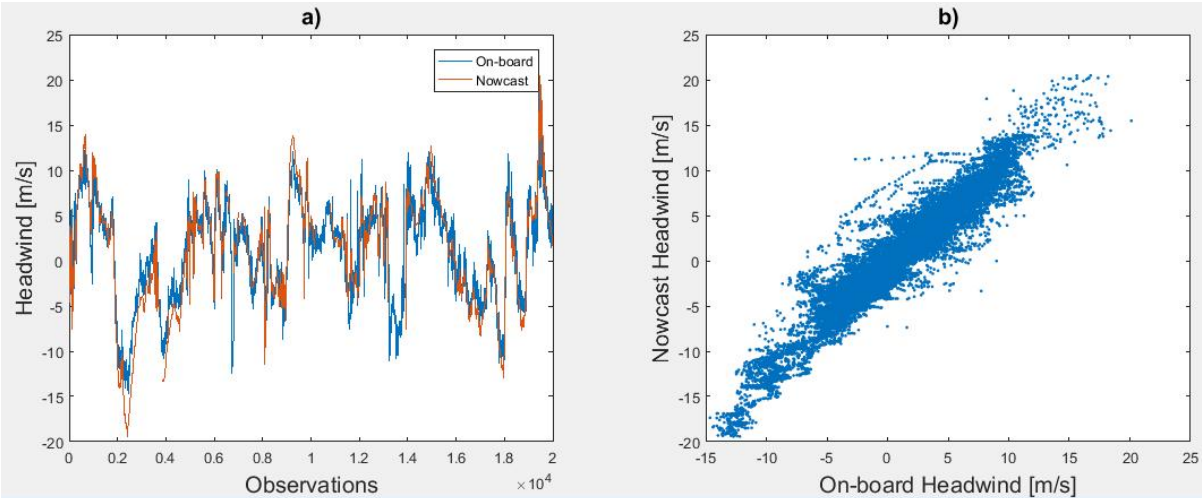

Figure 3. Nowcast vs. onboard headwind.

In Figure 4 and Table 1 the result of the wind comparison based on the data of 150 randomly selected ships. For each vessel, the linear correlation between wind components from two different sources, nowcast vs. onboard wind, were calculated. Figure 4 a) denotes the distribution of the correlation for the headwind, and b) stands for the crosswind component. Table 1 helps to understand the situation in general. As one can see, in about 20%-25% of all tested cases the linear correlation between wind components from two different sources is less than 80%. The results of this random test show that we may face some kind of problem with the wind measurements onboard for every fifth ship. This means that the wind data, which is measured onboard, should be always checked and validated against the nowcast data, which can be obtained from independent weather providers.

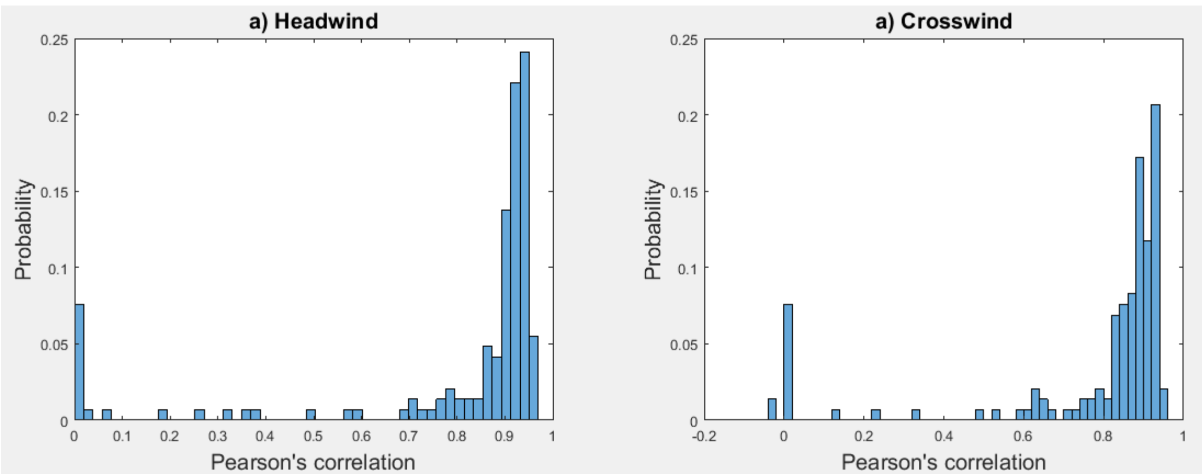

Figure 4. Distribution of the linear correlation between wind components from two different sources.

Table 1. Correlation vs. ship percentage.

Nowcast vs. on-board headwind correlation		Nowcast vs. on-board crosswind correlation	
Pearson's correlation	Percentage of vessels	Pearson's correlation	Percentage of vessels
< 80%	21%	< 80%	23%
80%-90%	17%	80%-90%	42%
90%-95%	56%	90%-95%	34%
>95%	6%	>95%	1%

3.1 Model-based comparison

Let us now examine the cases without any problems with the wind measurements onboard.
The most interesting questions are:

- What is the difference between the onboard and nowcast wind from the modeling point of view?
- Can we achieve better results by using onboard or nowcast data?
- Can we substitute erroneous onboard wind data with nowcast data without lack of accuracy of the analysis?

To find the answers to these questions we have implemented a modeling test. The main idea of the test is to compare predicting errors of the ship specific statistical models in which we use the wind from different sources. During the experiment, the model responses and all other model inputs except the wind remain unchanged. We assume that the smaller the model prediction errors are the better the wind components reflect the variation of the model response and the better the quality of the wind data is. For example, if the ship specific model uses the nowcast wind data and its prediction error is smaller than the error of the model, which uses the measurements onboard, then the nowcast data is adequate and has a better quality from the modeling point of view.

In Napa practice, we use a statistical modeling approach while analyzing the ship technical performance. During the analysis, we model the ship propulsion power and the speed through water using separate statistical models. Those models use many input variables, which reflect the variation of the operation and environmental conditions of the ship. The wind is one of the most important inputs for the statistical model and quality of the wind speed readings significantly affect the model quality.

The modeling test procedure is simple. For each ship dataset, we create models which explain the variation of the propulsion power consumption and the speed through the water. Two rounds of modeling procedure are completed. During the first round, we use the onboard wind data while modeling and, during the second round, the nowcast wind data is used. All other model inputs and response values remain the same during the experiment.

For the test the model structure is selected to be a generalized additive model, *Hastie (1986)*, whose structure is:

$$\hat{Y} = \alpha + f_1(X_1) + \cdots + f_n(X_n) + f_{n+1}(t),$$

where $\hat{Y}$ is the model response, X_i, $i = 1, \ldots, n$, is the set of the model inputs, like the engine rpm, draft, trim, wind speed and direction, swell, water temperature, etc., t is the time variable, which stands for the time related deterioration of the hull condition. The f_j are smooth functions, which are specified for each ship separately.

To compare the modeling results we use the statistical descriptors, like mean absolute percent error (MAPE) which is define as follows:

$$MAPE = \frac{\sum_1^m \left|\frac{\hat{Y}_i - Y_i}{Y_i}\right|}{m} 100\%,$$

where $\hat{Y}_i$, is the value estimated by the model, Y_i is the observed value of the response, i=1, … , m, is the number of all observations.

The experiment is done for 50 randomly selected ships with no observed problems in the wind measurements onboard. For each ship, we built the predictive models for the propulsion power and for the speed through the water. The main assumption is that the smaller the MAPE metric is the better the model is, the better the quality of the wind parameter source.

Additionally, we calculate the difference between the MAPE descriptors for each ship models. The MAPE difference for each ship is defined as:

$$MAPE_{difference} = MAPE_{nowcast} - MAPE_{onboard},$$

where $MAPE_{nowcast}$ is the mean absolute percent error of the model which uses the nowcast wind, and $MAPE_{onboard}$ is the error of the model which uses the onboard wind data.

The results of the statistical experiment are shown in Figures 5 and 6. In Figure 5, a) the distribution of the MAPE is shown for the power model which uses the onboard and nowcast wind data. The distributions are almost similar so it is hard to assess which source of the wind data is better. The median of all observed MAPE metrics is about 2.1%, which describes the general level of the quality of the model for the propulsion power. In Figure 5, b) the distribution of the pairwise differences between MAPE descriptors for each ship is shown. The median of the distribution is +0.08%, which suggests that in general, statistical models that use the nowcast data have slightly higher errors compared to the models that use the onboard wind data.

In Figure 6, a) and b) the same kind of results are shown for the speed model. Accordingly, the median of MAPE for all ship model is around 1.56% - see Figure 6, a). The distribution of the MAPE differences is shown in Figure 6, b). As in the case of the power model, the difference is positive, about +0.075%, suggesting that the models that use the nowcast wind measurements have slightly higher errors.

Although the models that use nowcast wind data have slightly higher prediction errors, we can claim that the decrease in the model accuracy is not dramatic at all. According to results of the modeling test, if we use the nowcast wind measurements instead of onboard wind data, the model mean absolute percent errors will increase just about 0.1% in average.

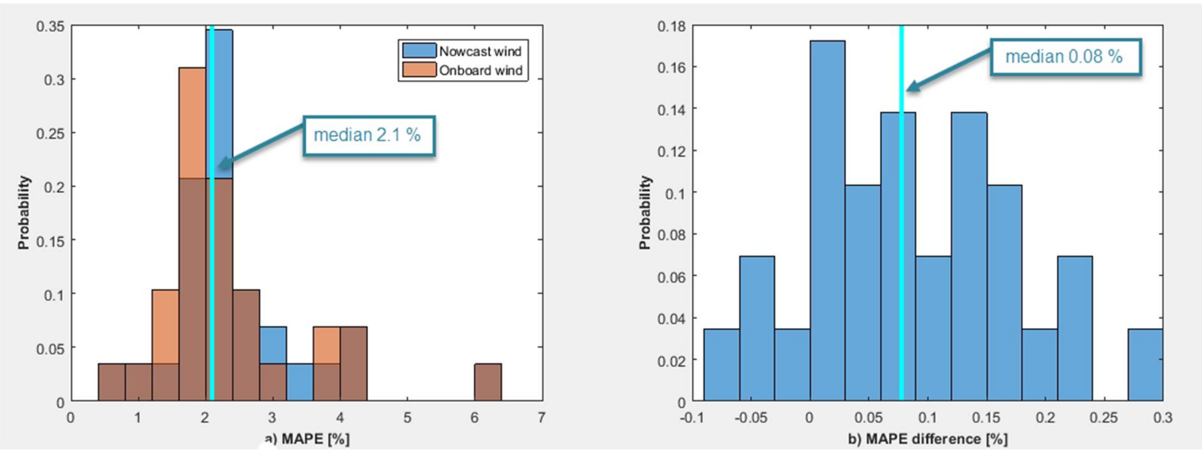

Figure 5. Comparison of errors for the power model; a) distribution of MAPE for models which use the nowcast and onboard wind, b) distribution of MAPE difference.

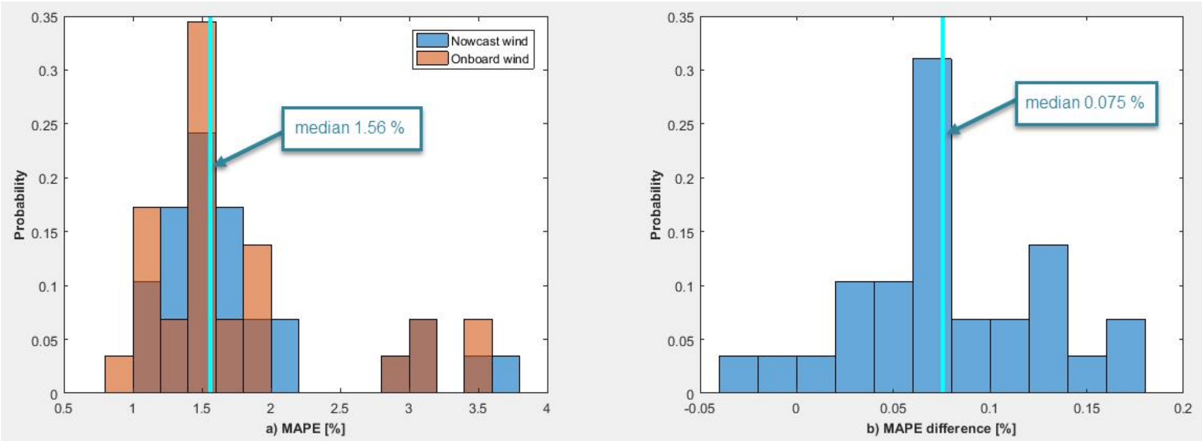

Figure 6. Comparison of errors for the speed model; a) distribution of MAPE for models which use the nowcast and onboard wind, b) distribution of MAPE difference.

Based on the results of the experiment, we may conclude that in the cases without any problems with the onboard wind data it is preferable to use the onboard wind for the modeling and technical performance evaluation. If there are problems with the wind data collection or there is no data at all, we can substitute the wind data by the nowcast wind data without major decrease of the accuracy of the analysis.

4 Speed through water

The speed of the ship can be considered as one of the most important variables when we evaluate the technical performance of the ship. The most natural situation onboard is when the speed is measured in two different ways. The first way is to measure the speed through the water (STW) by using a speed log. The second way considers using the Global Positioning System (GPS) and obtains the speed over the ground (SOG). The speed over the ground measured by GPS is always considered to be the most accurate way for speed measuring. However, for ship technical performance evaluation, the speed through the water is what we need. Therefore, in a situation when the speed through the water is not available for some reason, it can be approximated by using the speed over the ground and the ocean currents. The ocean currents can be estimated by numerical modeling and the information about currents is usually a part of the nowcast data available from independent weather providers.

4.1 Quality of the speed measurements

It is a widely known fact that measurement of the speed through the water can be inaccurate. There are different types of devices for the ship speed measurement. Probably most widely used devices are based on the Doppler effect and electromagnetic property of water, *Babicz (2015).* Nowadays the speed log devices are claimed to be accurate or at least manufacturers advertise them to be accurate. However, there are many different publications which describe the problems related to the measurements of the speed through water; see for example *Bos (2016)*. In the last paper, the author describes the systematic and non-systematic errors related to the speed log.

Here are a couple of examples from Napa practice demonstrating problems which can be faced with the speed through water measurements. The time-series in Figure 7 describes the ratio between the speed over ground and the speed through the water for a RO-RO ship that operates in the Baltic Sea area. It is assumed that when the speed through the water is measured correctly, the ratio SOG/STW should follow the normal distribution with mean value equal to one. In Figure 7, we can clearly see the drift of the ratio, which appears a few months after the ship maintenance. At maximum, the ratio between SOG and STW achieves values about 1.3-1.4, which corresponds to a 30-40% average error in STW.

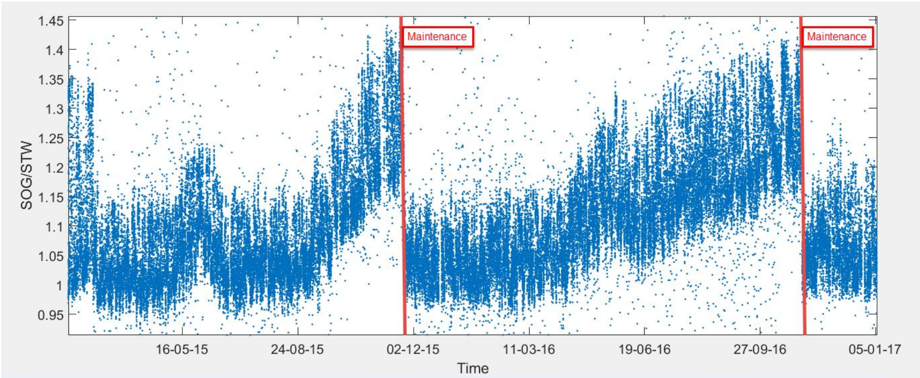

Figure 7. Ratio SOG/STW for RO-RO vessel indicating hard problems with STW measurements.

The ratio between the speed over ground and the speed through water for the second ship is depicted in Figure 8. In this example case, we can see not only the systematic bias, which is about 5%, but also a seasonal variation of the ratio, about +/- 2.5%, which seems to be related to the variation of the water temperature.

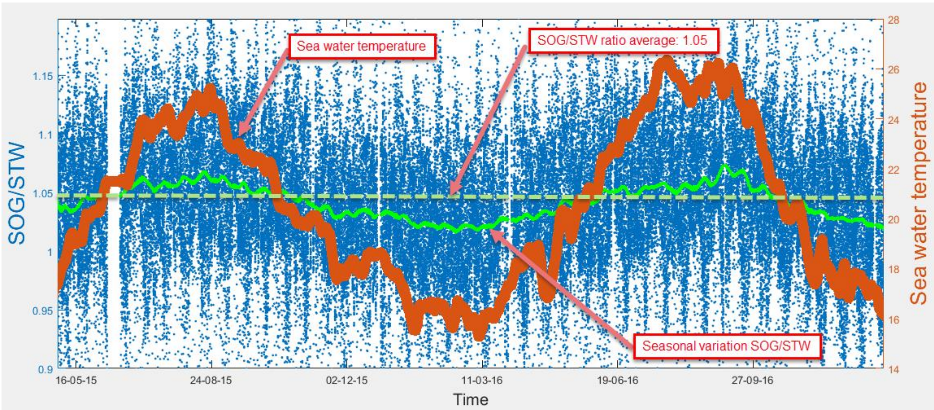

Figure 8. SOG/STW ratio for the RO-RO vessel indicating bias and seasonal variation in STW measurements.

Taking in account different publications and our own experience in Napa, we need to admit that the speed through the water must be always checked before doing any analysis concerning the ship technical performance. In our research, we tried to estimate statistically how often the problems with the speed log readings occur in general.

We have tested the speed log measurements from over 150 randomly selected ships. To describe the quality of the speed log measurements we are using statistical descriptor like the median of the absolute difference (*MAD*) between SOG and STW values, which is defined as follows:

$$MAD = median|V_i^{SOG} - V_i^{STW}|, i=1, \ldots, n,$$

where n is the number of all observation in the available data. This descriptor can be interpreted as the systematic bias of the speed log readings. We choose median instead of mean in order to avoid the outliers in the data, which may affect the mean value significantly.

We also estimate the possible linear drift in the speed log readings. This is done by fitting a linear model into the difference between SOG and STW, and estimating how much it is changed during the period of one year. Additionally, we calculate the standard deviation of the fitted linear model residuals, which describes the spread of the differences between SOG and STW.

In Figure 9, the main idea of the drift evaluation is described. In the example case we can see a small drift about 0.5 knots during the period of nine months. The standard deviation about 0.7 of the linear fit residuals indicates that there is no substantial problem with the speed log because the drift and deviation of the speed differences can be explained by the ocean currents.

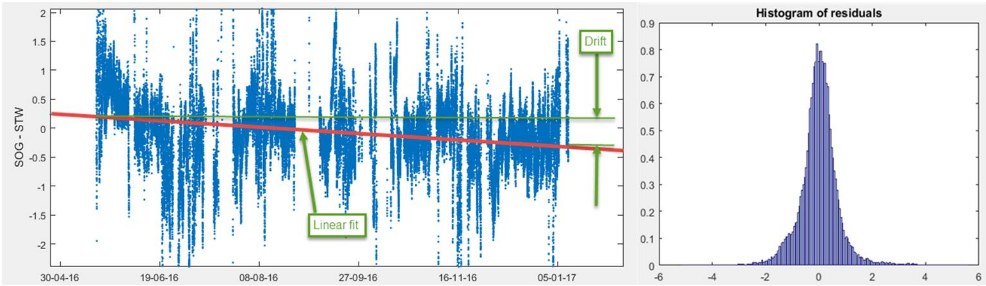

Figure 9. The linear model revealing the speed log drift about 0.5 knots during the period of 1 year, and the distribution of the model residuals with standard deviation about 0.7 knots.

In Figure 10 and Table 2, statistics calculated from 150 randomly selected ships are shown. They reflect the general situation with the speed log quality. According to the statistical distribution, the bias over 2 knots in the measurement of the speed through the water was found in 3% of all tested ships, and 89% of the ships have STW bias of less than 1 knot. Annual drift of less than 1 knot was found in 82% of the cases, and in 84% of the cases, the standard deviation of the difference between SOG and STW was less than 2 knots.

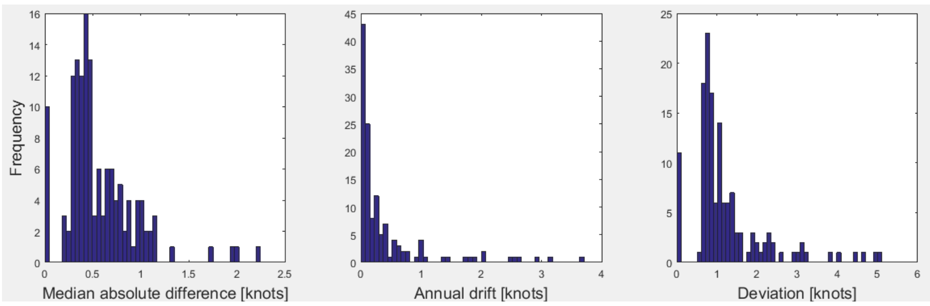

Figure 10. Distributions of statistics, which describe the quality of the speed, log reading.

Table 2. Percentage of statistics.

MAD [knots]		Annual drift [knots]		Deviation [knots]	
less than 0.5	57%	less than 1	82%	less than 1	53%
0.5-1	32%	1-2	5%	1-2	31%
1-2	8%	2-4	6%	2-4	12%
over 2	3%	over 4	7%	over 4	4%

The statistics presented in Figure 10 and Table 2 suggest that, in general, we may expect that in 10-15% of all cases we will have some problems with the measurements of the speed through the water.

In the cases with erroneous data, different strategies can be applied during the data analysis. The first strategy concerns possible correction of the STW readings. The systematic bias can be a result of faulty device calibration and can be corrected in some cases. In certain cases, we can also correct the drift in the STW readings afterward. The second strategy concerns using the nowcast data for the ocean currents. The main idea of this strategy is to calculate the speed through the water from the speed over ground and the sea currents. In the next section, we will discuss the difference between using the speed from different sources.

4.2 Model comparison test

The modeling test for the comparison of the speed through the water from different sources is similar to the test conducted for the comparison of the wind data. The modeling test is conducted for the ships' datasets, which have no problems with the speed log data. In this case we inspect the error statistics for the model which predicts the speed through the water. For each ship dataset, the set of the model inputs and the model structure is fixed, and only the source of the model response are changed.

In the test the model responses are:

- the speed measured by a speed log (STW),
- the speed which is combined from the speed over the ground and the nowcast ocean currents (SOG+currents),
- the speed over the ground (SOG).

We assumed that the model that uses as the response the speed over the ground should have a higher prediction error comparing to the model that uses the speed log readings as the response. This happens because the model loses some information because it does not take into account the effect of ocean currents. However, we built the model for SOG just to have a baseline for the comparison.

The goal of the modeling test is to investigate what happens to the predictive accuracy of the statistical model if we change the data source of the speed. How much do we lose or gain in the model accuracy if we, for example, substitute the speed log readings with the speed, which is combined from the speed over the ground and the ocean currents from nowcast data.

Figure 11 represents the results of the modeling test. In the figure, the normalized histograms of the mean absolute percent error (see definition of the MAPE in section 4.1) are shown for the models whose responses are taken from the different speed sources. The MAPE distribution of the SOG models has a median value about 3.25%. This is more than two times higher compared to the MAPE distribution of the STW models, which has a median of about 1.4%. This is the price of not taking in account the effect of the ocean currents. The MAPE distribution for the models, which use the speed through the water combined from SOG and the ocean currents nowcast, has the median about 2.9%. However, the improvement is not very dramatic comparing to the SOG models.

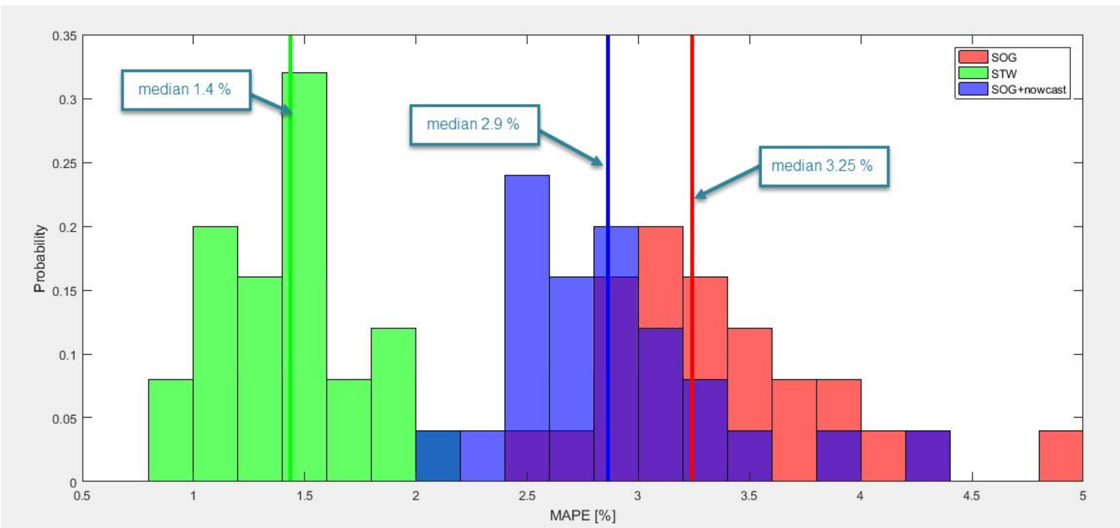

Figure 11. Distribution of MAPE for models with different responses.

The results of the modeling test suggest that in the cases with no observed problems with the speed log readings we should always utilize the STW measured onboard in order to have the best model accuracy. However, in cases with erroneous speed log data we can substitute it by the speed through the water values, which are combined from the speed over the ground and the nowcast ocean currents.

In Figure 12, we present the example of the analysis case for technical performance evaluation. In the figure, the speed drop due to the decreased hull condition is visualized for the period of more than three years. A negative speed drop indicates a decrease of the speed, a positive, in contrary, increase of the speed, for example after the ship maintenance. In the analysis we have used two different sources for the ship speed, the speed through the water that was measured by a speed log, and the speed that is combined from the speed over the ground and the nowcast ocean currents. The estimated speed drop is denoted in knots. As we can see from the figure, the difference between the speed drop that is estimated with different speed is small.

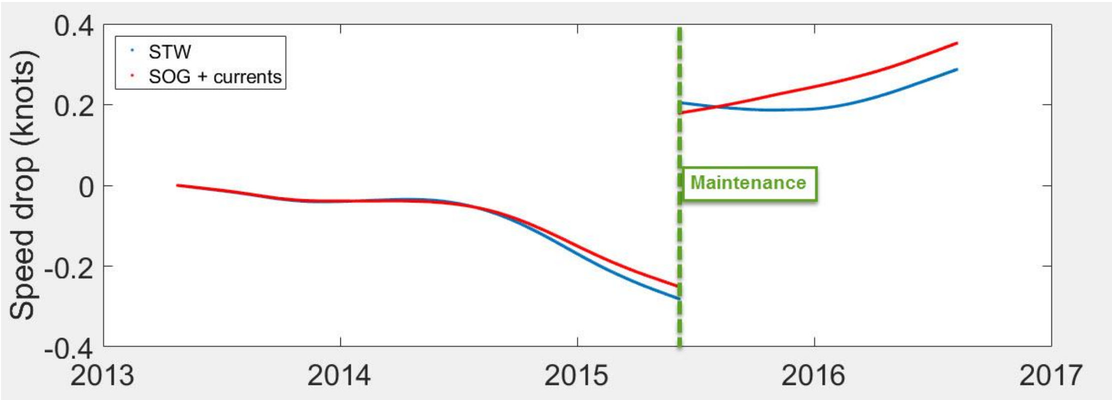

Figure 12. Speed drop estimated from the STW (blue curve) and speed that is combined from SOG and nowcast ocean currents (red curve).

In Figure 13, we visualize the result of comparison of the speed drop that was evaluated by the statistical models from different speed sources. For each ship data set the speed drop was estimated from the three different responses: STW, SOG and SOG combined with the nowcast ocean currents. For each ship we calculated the mean absolute error between the speed drop estimations done with different responses as follows:

$$MAE = \frac{|V_i^1 - V_i^2|}{n}, \; i=1, \ldots, n,$$

where V_i^1 is the speed drop estimated by the model 1, V_i^2 is the speed drop estimated by the model 2, and n is the number of observations. The MAE is calculated for two pairs of models: STW vs. SOG, and STW vs. SOG+currents.

The box-plots in Figure 13 describe the distribution of the mean absolute errors over all ships' datasets. As we can see, that difference between the speed drop that is estimated by the statistical models, which are built from difference sources, is small. The median difference between the speed drop for the pair STW versus SOG+currents is about 0.06 knots, and for the pair STW versus SOG is 0.08 knots.

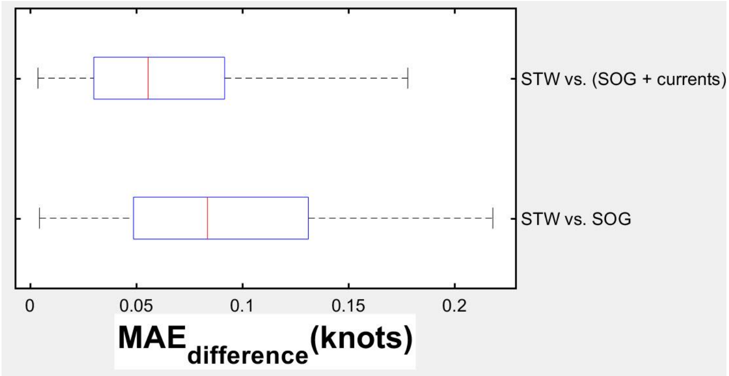

Figure 13. Distributions describing difference between the speed drop: STW vs SOG, and STW vs. SOG+currents.

5 Conclusions

The accuracy and quality of the ship data, which we use for the technical performance evaluation, is essential. At the same time, data collection onboard the ship may be difficult and subject to errors. Therefore, the role of the independent nowcast data cannot be underestimated. We can use the nowcast data for validation of the onboard sensor data. We can also substitute the onboard data with the nowcast data in the case when we have some problems with the data collection onboard.

The current research was focused on the quality of the wind data and the data of the speed through the water. According to the statistical analysis and modeling tests, we may claim that:

- In 20% - 25% of all cases, we may face problems with the wind measurements onboard ship.
- We should always validate the quality of the onboard wind data by using the nowcast data from independent weather providers.
- In the case of the erroneous onboard wind data, it can be substituted by the nowcast wind data without major decrease of the accuracy of the analysis.
- In 10% - 15% of all cases, we may face problems with the measurements of the speed through water onboard the ship.
- The onboard data for the speed through the water should be always checked and validated before the technical analysis.
- In the case of the erroneous data for the speed through the water, we can replace it by the speed, which is combined from the speed over the ground and the nowcast ocean currents data.

References

BABICZ, J., (2015), *Encyclopedia of Ship Technology*, Wärtsilä Corporation, second edition, ISBN 978-952-93-5536-5.

BOS, M. (2016), *How MetOcean Data Can Improve Accuracy and Reliability of Vessel Performance Estimates*, 1th Hull Performance & Insight Conference proceedings, pp. 106-114.

CAI, Y., WEN, Y., WU, L., (2014), *Ship Route Design for Avoiding Heavy Weather and Sea Conditions*, The international journal on marine navigation and safety of sea transportation, Vol.8, No.4.

CHEN, C., SHIGEAKI, S., KENJI, S., (2013), *Numerical ship navigation based on weather and ocean simulation*, Ocean Engineering 69, 44–53.

GODIN, A., (1996), *The Calibration of Shallow Water Multibeam Echo Sounding Systems*, Proceedings of the Canadian Hydrographic Conference, June 3-5 1996, Halifax, N.S., pp. 25-31.

HARANEN, M; PAKKANEN, P.; KARIRANTA, R.; SALO, J., (2016), *White, Grey and Black-Box Modeling in Ship Performance Evaluation,* 1th Hull Performance & Insight Conference proceedings, page 115-127.

HARE, R., TESSIER, B., (1995), *Water level accuracy estimation for real-time navigation in the St. Lawrence River*, Department of Fisheries and Oceans, Canadian Hydrographic Service internal report, Laurentian region, 147 p.

HASTIE, T.; TIBSHIRANI, R. (1986), *Generalized additive models*, Statistical Science 1/3, pp.297-318

HASTIE, T.; TIBSHIRANI, R.; FRIEDMAN, J. (2003), *The Elements of Statistical Learning*, Springer, ISBN: 9780387952840

HELLSTROM, T., (2003), *Three Levels of Fuel Optimization at Sea*, Proceedings of the 2nd International Conference on Computer Applications and Information Technology in the Marine Industries (COMPIT2003) Hamburg.

ISO 15016, *Ships and marine technology - Guidelines for the assessment of speed and power performance by analysis of speed trial data*

ISO/CD 19030-1, *Ship and marine technology - Measurements of changes in hull and propeller performance, Part 1: General Principles* (2015)

ISO/CD 19030-2, *Ship and marine technology - Measurements of changes in hull and propeller performance, Part 2: Default method* (2015)

ITTC (2005) – *Recommended Procedures and Guidelines, Full-Scale Measurements Speed and Power Trials*

KAYANO, J., YABUKI, H., SASAKI, N., HIWATASHI, R., (2013), *A Study on the Propulsion Performance in the Actual Sea by means of Full-scale Experiments*, International Journal on Marine Navigation and Safety of Sea Transportation, Volume 7, Number 4

MOAT, B., YELLAND, M., MOLLAND, A., (2005), *Quantifying the airflow distortion over merchant ships: part II: application of model results*, submitted to the J. of Atmos. and Ocean. Tech.

MOLLAND, A.F.; TURNOCK, S.R; HUDSON, D.A., (2011), *Ship Resistance and Propulsion*, Cambridge University Press, ISBN 978-0-521-76052-2.

NIELSEN, U.D., (2008b), *The wave buoy analogy – Estimating high-frequency wave excitations*, Applied Ocean Research, Vol. 30, pp. 100-106.

PADHY, C. P., SEN, D., BHASKARAN, P. K., (2008), *Application of wave model for weather routing of ships in the North Indian Ocean*, Natural Hazards, 44(3), 373- 385.

PANIGRAHI, J. K., PADHY, C. P., SEN, D., SWAIN, J., & LARSEN, O., (2012), *Optimal ship tracking on a navigation route between two ports: a hydrodynamics approach*, Journal of marine science and technology, 17(1), 59-67.

SASAKI, N., (2009), *Development of ship performance index (10 modes at sea)*, Report of National Maritime Research Institute, Vol.9 No.4; 1-46

SIMOS, A.N., TANNURI, E.A., SPARANO, J.V. and MATOS, V.L.F., (2010), *Estimating wave spectra from the motions of moored vessels: Experimental validation*, Applied Ocean Research, Vol. 32, pp. 191-208.

SODA, T., SHIOTANI, S., et al., (2012), *Research on ship navigation in numerical simulation of weather and ocean in a bay*, International Journal on Marine Navigation and Safety of Sea Transportation 6 (1), 19–25

STREDULINSKY, D.C., THORNHILL, E.M., (2009), *Shipboard Wave Measurement through Fusion of Wave Radar and Ship Motion Data*, Defence R&D Canada – Atlantic, TM, 2009.

TRAUT, M., GILBERT, P., WALSH, C., BOWS, A., FILIPPONE, A., STANSBY, P., WOOD, R., (2014), *Propulsive power contribution of a kite and a Flettner rotor on selected shipping routes*, Applied Energy, 113 (2014) 362–372.

TSUJIMOTO, M., TANIZAWA, K., (2006), *Development of a weather adaptive navigation system considering ship performance in actual seas*, 25'th international conference on offshore mechanics and arctic engineering, Hamburg, Germany, 4-9.

XIA, H., SHIOTANI, S., et al., (2006a), *A study of weather routing considering real-time data of weather and ocean for sailing ship in coastal area–basic simulation of ship positioning by ship maneuvering and experiment by a real ship*, Journal of the Kansai Society of Naval Architects, Japan 234, 159–166.

XIA, H., SHIOTANI, S., et al., (2006b), *Estimation of ship's course for sailing on route by navigation simulation in coastal water*, Journal of Japan Institute of Navigation 115, 51–57.

YOKOI, T., (2010), *A mechanism on parallel processing to numerical weather prediction for weather routing – Accuracy evaluation and performance benchmark of the sea surface wind prediction*, Proceeding of Asia Navigation Conference 2010; 33-40

ZHANG, J., & HUANG, L., (2007), *Optimal Ship Weather Routing Using Isochrone Method on the Basis of Weather Changes*, International Conference on Transportation Engineering 2007 (pp. 2650-2655). ASCE.