Optimization the navigation route from Singapore to Santos by using the ship`s software and processing the hydrometeorological parameters received in real time

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Abstract. The subject of this paper is to analyze the hydrometeorological parameters received on board during on route from Singapore to Santos (Brazil) between July 15th and August 4th, 2018 to optimize fuel consumption on board. The information was obtained daily, in real time, using on-board measurement tools and SPOS 8 Software provided by MeteoGroup, and those related to fuel consumption in the EcoVoyage program. General analyzes of hydrometeorological parameters were introduced as graphs, with more detailed values extracted from MSPS (Maersk Ship Performance System).

Keywords: hydrometeorological parameters, maritime routes, voyage optimization, SPOS, EcoVoyage

1. Introduction
The International Maritime Organization issued a study on energy optimization in 2016 as part of the implementation of the Ship Energy Efficiency Management Plan (SEEMP) [1], which specifies that best practices in performance chapters specific hardware and technical measures to improve energy efficiency, weather forecast optimization programs, and simulation software.

Also, the latest IMO regulatory requirements for the control of toxic gas emissions from ships have a sparked interest in whether ships are adequately equipped to operate safely in adverse weather conditions where compliance is achieved simply by reducing power [2]. Therefore, a number of companies "Weathernews Int.", "AMI", "C-Map", "SMHI", "SPOS", "Seaware", "Weather Routing
Inc. " have been adapted to IMO requirements and offer day-to-day daily assistance to optimized routes [3]. This paper focuses on receiving hydrometeorological parameters on board ship from different sources and detailed analysis of route planning (SINGAPORE - SANTOS). The values of hydrometeorological parameters were processed in real-time on-board ship, framed in tables or graphs for ease of comprehension and then analyzed by means of bibliographic sources and experience practical on board.

2. Methods used to assess the voyage

For the real-time determination of hydrometeorological parameters, we use on-board instruments (thermometer, barometer) and also software (for example, SPOS 8 for the determination and characterization of the weather forecast, EcoVoyage for the determination of travel efficiency and economy and MSPS to send these hydrometeorological reports to the company). One of Meteogroup's most important products is the Ship Performance Optimization System (SPOS), which has proved to be the most precise and reliable monitoring system of weather on the world on board ships. MeteoGroup developed the last version SPOS9 (Ship Performance Optimization System) to address Route planning and optimization involves juggling safety, efficiency, navigation, costs, port rotation, ETAs, speed ranges and additional constraints such as trim and seakeeping. [4] Therefore, the master and crew are allowed to adjust route calculations based on meteorological information provided and specific characteristics of the ship. In this way, the commander can sketch the optimal route, both in safety and efficiency, for his ship.

Route planning consisted of the following steps: gathering information on the maritime areas to be transited, planning in detail the route to be traveled by ship, the voyage and monitoring the way it is going. The Singapore - Santos route was planned in ECDIS, taking into account good sailor practice and company procedures. To achieve it, were used oceanic, general, coastal and special coastal maps, as well as plans containing detailed information about lakes and ports. Once the route is ready, it is imported into the Eco Voyage program to analyze intermediate routing points, determine port overhead information, and create a folder to be downloaded to the printer and provide all the information on the scheduled route. This plan is presented to the master and signed by him and each order officer on request. To provide hydrometeorological data, the route is then entered into the SPOS 8 program as shown in figure1.

![Figure 1 Synoptic map with route planning using SPOS 8 [4]](image-url)
The SPOS system have two sources of meteorological information that are required for its on-board functionality: a predicted database that is updated by MeteoGroup emails and a climatological database [5] [6]. For route calculations, the data contained in weather warnings are used as long as the simulated voyage is within the limits of the areas for which the warnings are drawn. Otherwise, climatological data is used when the warnings are over.

The dedicated climatological database, similar to the pilot maps, contains monthly average values for surface pressure, wind, waves, swell and ocean currents. The area covered by this climatological database ranged from 75 °N-60 °S to 180 °W-180 °E with a resolution of 2.5 degrees.

The predicted data was available four times per day across the globe from 90 °N to 90 °S. The forecast is divided into oceanic regions, such as the North Atlantic Ocean and the South Pacific Ocean, with a resolution of 2.5 degrees, and smaller areas such as the South China Sea or the Mediterranean Sea for coastal waters with a 1-degree resolution.

3. Results

3.1. Processing statistical data for wind direction and speed

Due to the increase of solar radiation there is an increase of air temperature at the surface of the ocean when the winds are rare or their speed is very low [7].

The wind power disposed in the kinetic energy equation [8] can be written as follows:

$$\theta = \oint_{z=0} \theta \times \tau_s dS = \oint_{z=0} (u \tau_s^x + \theta \tau_s^y) dS$$

(3.1)

$v = (u,v)$ – the velocity

$\tau_s$ - surface wind tension

Where the double integral represents a surface integral evaluated at the ocean surface.

The zonal component of wind power $\theta = \oint_{z=0} (u \tau_s^x) dS$ represent the dominant source of fluctuations in wind power from the kinetic energy equation.

On July 24th, the ship approaches to the South African coast, traverse the Madagascar. In fig. 2 and fig. 3 is observed the direction of the winds along the entire route on this date. Near the Equator, in the northern Indian Ocean, can see how the winds change their orientation direction under the action of the Coriolis force, clockwise in the north and trigonometric sense south of the Equator. At the point of the ship, the winds are lower in intensity, reaching maximum speeds between 15 and 20 knots.
Due to the low pressure areas in the southern African continent, it is noticeable how the winds change their direction and increase the speed by being attracted by two great depressions in the South Indian Ocean and the Atlantic Ocean respectively. Movement of air masses in depression areas is clockwise (Figure 4).

Using on board information from past observation from EcoVoyage by officers, continuously updated information from SPOS 8, as well as information on wind speeds over several days of a day, depending on how often these were sent to MSPS (Maersk Ship Performance System), we obtained the variation diagrams related to the wind and the actual wind on the Beaufort scale (Figure 5), as well as the diagram of the height and waves and swell period from July 15 to August 4, 2018 (Figure 6).
It can be seen in both figure, Fig. 5, and Fig. 6, an inequality between the number of observations on different days as they appear on the abscissa due to the frequency of transmission of the number of observations, and that the true wind speed is generally lower than that of the apparent wind (relative position of the ship's path towards the direction real wind). Crossing the Indian Ocean, it is noticed that until July 26, 2018, when the ship is at Cape of Good Hope, the values begin to decrease rapidly, and then return to the initial values when the ship is moving to the South Atlantic. In the last part of the voyage the ship encounters strong winds, due to the unstable weather in the winter near the Brazilian coast. After August 3, the values increase significantly, the waves are getting taller and the ship is very difficult to handle.

The figure 6 shows the values of the swell period and the wave produced in seconds and the height of the swell and the wave is expressed in meters. It is obvious that the period of the swell is higher than the wave period, aproximately with 5 seconds bigger. The height of the swell remains mostly constant throughout the voyage, being minimal in the Indian Ocean during the summer monsoon and having the highest values near Brazil. In marine practice, the high height of the swell made it difficult for ships to get on board and landed in Brazilian ports. The waves have a lower intensity and, like wind values, they grow along with the South American coast and reach the height of 6 meters in the wind with a value
of 8 on the Beaufort scale. We can see, therefore, the close connection between the winds and the waves in the next diagrams:

The diagram in Fig. 7 outlines the directions of the wind during the voyage. Starting from the left of the chart, from the beginning of the voyage, can see how the direction of the waves is in line with the direction of the true wind, and the apparent wind obviously maintains different directions depending on the ship's way.

![Wind direction, wave and swell chart from July 15 to August 4, 2018](image1)

Figure 7 Wind direction, wave and swell chart from July 15 to August 4, 2018

### 3.2 Processing of statistical data for temperature

Comparing the temperature values in the first days of the voyage with those of the last days and taking into account the similarities and differences in Fig. 8 and Fig. 9, it is noted that ocean surface air temperatures remained approximately constant throughout the voyage in each studied region.

![Air temperature distribution on July 15, 2018 (SPOS 8 Screen Capture)](image2)

Figure 8 Air temperature distribution on July 15, 2018 (SPOS 8 Screen Capture) [4]
Take into consideration the strong correlation between temperature and pressure distribution, in Figure 10 it can be seen the relationship between the air and water temperature, respectively, between the average temperature and the average atmospheric pressure during the entire voyage period. It can be noticed how the water temperature remains above the air temperature due to the fact that the water retains the heat for a longer time. If the atmospheric pressure is lower, reaching minimum values of 1000-1005 mb in Indian Ocean, the temperature reach highest value, up to 32 °C. When the ship travels southwest, pressures start to rise and temperatures are suddenly falling due to the appearance of cold air in the polar areas near South Africa. Temperatures remain low due to Brazilian winter, but pressures increase slightly as the ship approaches the destination.

Figure 10 Diagram of surface air temperature, water and atmospheric pressure during July, 15 – August, 4 2018

3.3. Processing of current speed data
The current information is presented statistically in Fig. 11, the value being compared to those recorded in the pilot cards of the areas crossed for this period of the year.
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Figure 11 Speed and current direction diagram from July 15 to August 4, 2018

The currents values (direction and speed) are defining elements both in the calculation of wind and current, as well as in the ship's resistance, thus optimizing fuel consumption onboard and optimizing the route.

4. Assessment of the evolution of hydrometeorological parameters on the ship's route and the distances covered, as well as on the ship's consumption during the voyage

This study analyzes the influence of hydrometeorological parameters on the ship's route and the distances covered, as well as on the ship's consumption during the voyage [9, 10].

The data was retrieved from EcoVoyage in real time. ECO Voyages is an instrument designed to provide the commander with optimal speed information at every point in the voyage so that propulsion power remains as constant as possible and thus obtain the lowest fuel consumption. Based on the ship's particularities and detailed and up-to-date information about currents, winds, waves, and depth restrictions on the planned route, the optimal route can be chosen to avoid unwanted ship oscillations while maintaining a fixed time arrival at destination.

Up-to-date current information is received from other ships on the same route through a central server. In addition, general wind, wave and current information is anticipated with SPOS. During the voyage, the number of rotation of the propeller per minute remained constant, thus providing a steady economic speed. The ship used the automatic pilot on Economic mode to save fuel consumption. In Fig. 12 it can be seen how fuel consumption is directly proportional to the power of the turbine generator.

Figure 12 Diagram of engine power and fuel consumption values
The engine power is directly proportional to the number of turns routed to the propeller. In the last part of the voyage there is an increase in power, due to strong winds and large swell near the Brazilian coast. Thus, throughout the voyage, the ship used the Constant Propulsion Plan suggested by EcoVoyage and determined by specific calculations within the program. In fig. 13 are compared the speed observed at GPS with that calculated at the loch. It can be seen that the two speeds were constant in most of the voyage, fluctuating only in areas with strong currents that influence the speed over ground and the speed through water.

The values of the distances were reintroduced at each observation, and for this reason were observed big differences between the measured distances. The total distance calculated by GPS at the end of the voyage with these values was 9898.7 Nm, and the total loch distance was 9864.7 Nm, with an error margin of approximately 0.4 %.

In figure 14 is observed the relationship between the remaining budget for the voyage expressed in dollars and the fuel remaining on board, the two being directly proportional. Propulsion power remains constant, and as the ship advances, the budget, the remaining fuel and the distance to the destination are decreasing. The amount of fuel required to navigate a nautical mile is represented by yellow and appears as a straight line because its values are much lower than other parameters. However, it remains constant at around 200 tonnes.
5. Conclusions
On July 15th, 2018, the ship left Singapore's port with 1,992 tons of fuel on board and a budget of $774,887 for fuel consumption. At the end of the voyage, the remaining budget was $ 50,192, and the amount of fuel saved on board reached 140 tons. Thus, using weather warnings from SPOS 8 and using EcoVoyage's suggested navigation optimization plans, the ship saves about 7.03 % of fuel consumption and 6.48 % of the fuel budget.

Optimizing a sailing route is a complex task, as it depends on the following:
- the optimization base is the weather forecast. As the weather forecast probability decreases over time, the optimization method should not be used for the final parts of the voyage as this should not affect the initial decision too much.
- there are many ship-to-ship combinations and engine settings from the port of departure to the port of arrival, leading to a huge amount of time and a great memory storage and processing capability.
- the optimization objectives need to be clarified from the outset. By comparison, in some situations, it will be "just in time", another will want to get "shortest time" with high fuel consumption, and others will have different reasons (low fuel consumption, avoiding rough sea, etc.).

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