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Tidal of Malacca Straits From AIS Data

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ABSTRACT

This research focuses on investigating the correlation between ship coordinates and sea high-low levels in the Straits of Malacca, utilizing data obtained from the Automatic Identification System (AIS) through an AIS receiver strategically installed at the campus building. The raw data collected from ship traffic in the Malacca Straits undergoes meticulous processing to derive movement patterns and precise ship coordinates. By calculating the distances between these ship coordinates and referencing the AIS receiver, the research aims to identify the highest values of these distances within hourly and daily time frames, crucially indicating tidal patterns and sea high-low levels in the straits. The study proposes the application of a simple harmonic equation to estimate the tide's height based on the observed ship-sea correlation. The outcomes of this research hold significant potential for advancing our understanding of tidal and wave dynamics in the Straits of Malacca, benefiting the field of marine forecasting and navigation. Furthermore, the findings offer valuable insights for coastal management and disaster preparedness in the region, ultimately benefiting various maritime industries, environmental conservation efforts, and coastal communities. The comprehensive analysis presented in this thesis provides substantial contributions to the field of oceanography and offers practical implications for enhancing safety and sustainable practices in the straits and similar maritime regions.

1. Introduction.

The Automatic Identification System (AIS) serves as a valuable 'Big Data' source for marine traffic, providing crucial insights for risk assessment and navigation in congested waterways (Nieh et al., 2019). Introduced in 2003 to enhance maritime safety, AIS mandates certain tonnage ships, including cargo and passenger vessels, to be equipped with AIS systems. These transponders transmit and receive static and dynamic data to and from other vessels and terrestrial stations at regular intervals, making real-time and historical AIS data a vast information source. In-depth analysis of AIS data can simplify lookout and surveillance missions for watchkeeping personnel at sea and in ports.

Maritime traffic is an integral aspect of the shipping industry, encompassing various activities that directly impact security, safety, the environment, and socioeconomic factors (Kim et al., 2022). Traffic facilitates the movement of resources, thereby promoting globalization, spatial differentiation of social and economic activities, and the expansion of regional traffic networks. It plays a vital role in guiding, supporting, and ensuring regional and national development while reflecting spatial relations in trade.

The Malacca Strait, historically traversed for trade between India and the South China Sea and the Pacific Ocean, presents a complex hydrodynamic environment characterized by tidal convergence and seasonal monsoons (Abd Rahim et al., 2022). Further exploration in this domain holds substantial potential for enhancing maritime safety, navigation practices, and the comprehension of tidal dynamics in this region. The Straits of Malacca, a pivotal maritime conduit linking the Pacific Ocean and the Indian Ocean (Chai et al., 2017), experiences a sub-

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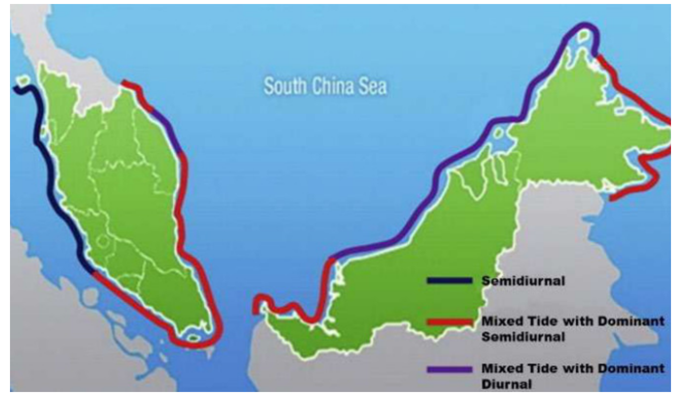
stantial influx of ships, resulting in the accumulation of extensive AIS data. Operational disruptions stemming from diverse factors are magnified by its distinction as one of the world's busiest waterways, necessitating meticulous data processing efforts. During periods of heightened traffic, an abundance of vessels can impede the system's data processing efficiency, potentially leading to delays or system malfunctions. Additionally, adverse weather conditions like rain or fog can hinder data collection and possibly compromise the effectiveness of radar systems (Qu et al., 2011)(Gonthier, 2007). Despite these challenges, the AIS system remains operative for the purpose of this study, albeit requiring an extended processing window for decoding raw data and presenting findings. Notably, despite the extensive prevalence of AIS studies, the relationship between ship movements and tides in the Malacca Strait remains relatively underexplored and will be expounded upon in this paper. This paper serves as an extension of prior research concerning the tidal characteristics derived from AIS data in the Malacca Straits (Mustaffa et al., 2023).

2. Background.

Tides, governed by the cyclical motion of seawater due to celestial forces, manifest an array of temporal variations, spanning daily, fortnightly, monthly, annual, interannual, and long-term patterns. In addition to astronomical factors, other nonastronomical elements contribute to the diverse nature of tidal fluctuations across various locations. Tides wield significant physical impacts on coastal regions, shelf seas, and open oceans, influencing phenomena such as storm surges, coastal flooding, erosion, species distribution in intertidal ecosystems, and navigational dynamics for ports (Haigh et al., 2020). The tidal cycle entails two occurrences of high tide and low tide each day, generating a rhythm of two high tides and two low tides within a 24-hour and 50-minute span, a consequence of Earth's rotation that leads to the formation of dual tidal "bulges" throughout a lunar day. The gap between consecutive high tides approximates 12 hours and 25 minutes. The transition from high tide to low tide, or vice versa, unfolds over roughly six hours and 12.5 minutes along the shoreline (Read & Heaps, 2002). Utilizing harmonic analysis proves invaluable for quantifying tidal amplitudes in terms of water levels and volumetric flux, unveiling distinct propagation patterns for tidal flux compared to water level propagation within the strait. Comprehensive explorations into tidal amplitudes yield pivotal insights into the strait's region of tidal mixing (Walde & Hanus, 2020). Meanwhile, in the context of Malaysia, the west coast of Peninsular Malaysia experiences predominantly semi-diurnal and mixed tides, while the east coast, notably Terengganu, encounters mixed tides featuring a diurnal component (Ramadhan Basiddiq et al., 2022) as illustrated in Figure 1. Noteworthy is the fact that the tides within the Strait of Malacca are influenced by tidal propagation originating in the Indian Ocean, entering through the Andaman Sea. Tidal amplitude escalates from 80 cm in the north to 250 cm in the south, particularly as it approaches the narrowest channel of the Malacca Strait, influenced by bathymetric contours and tidal oscillations (Koropitan et al., 2021).

Figure 1: Types of tides as experienced in Malaysia.



Source: Ramadhan Basiddiq et al., 2022.

3. Methodology.

3.1. Data Collection.

In the process of collecting AIS data, a high-frequency (VHF) antenna captures frequency signals in wave format, which are subsequently detected and transformed into data by the AIS receiver originating from the transponder. The resulting data is visualized on a computer screen, and the subsequent graph provides a representation of the outcomes In this study, we will focusing collected data for 2019.

3.2. Data Analysis.

Initially, an analysis of the recorded data will focus on determining the volume of traffic. Subsequently, a month characterized by the highest traffic count will be selected. For the calculation of maximum ship distances, we will utilize latitude and longitude parameters. This study adopts the Euclidean equation, as previously employed in research (Hanyang et al., 2019; Zhang et al., 2017), in conjunction with AIS receiver coordinates from our laboratory as points of reference. To achieve this, the results will be visually presented through plotting, involving the creation of two distinct types of plots:

(i) Daily Maximum Distance: This plot will showcase the maximum distances observed on a daily basis for the selected month. By examining the fluctuations in distances over the course of the month, we aim to identify any recurring patterns or trends in relation to the tide variations.

(ii) Hourly Maximum Distance: For any specific chosen day, we will plot the maximum distances observed hourly. This plot will offer a more granular view, enabling us to investigate how the ship-sea distance changes throughout the day, and potentially reveal any short-term tide-related effects on ship coordinates.

All result will be compared with tide data from nearest hydrographic station (Port Klang) (Tide Times and Charts for Klang, Selangor and Weather Forecast for Fishing in Klang in 2023, 2023). By visualizing and analyzing these plots, we aim to gain valuable insights into the correlation between ship positions and sea tide levels in the Straits of Malacca. These findings could contribute to our understanding of tidal dynamics and their implications for maritime navigation in the region.

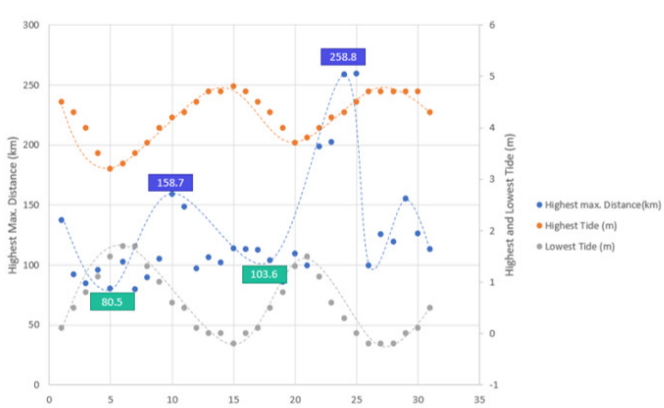
4. Result.

In this section, we present the results of our analysis, emphasizing the maximum computed distances between ship coordinates and their linkage to tidal patterns on both hourly and daily scales. Through the utilization of a straightforward curve fitting approach, we aimed to predict tide timing and cycles. These discoveries possess considerable promise for enhancing our comprehension of tidal and wave dynamics within the Straits of Malacca, while concurrently carrying pragmatic implications for marine forecasting and navigation. We will focus our detailed analysis and discussion on the month of December 2019.

4.1. Daily Data.

Figure 2 illustrates two notable peaks in ship distances, measuring 158.7 km and 258.8 km, respectively, on December 10 and 24, alongside two corresponding troughs measuring 80.5 km and 103.6 km on December 5 and 18. Remarkably, these peaks consistently align with the harmonic cycle of tide timings, even across longer travel distances, showcasing a strong correlation between ship coordinates and local tidal patterns. This graph effectively portrays the interplay between ship movement and sea tide dynamics. Table 1 provides comprehensive tide cycle data for December 2019, presenting the largest distances (in km) observed during the first and second high and low tides. Specifically, December 10 recorded the highest distance of 158.7 km during its first high tide, while December 24 marked the second high tide with a maximum distance of 258.8 km. Conversely, the first low tide on December 5 registered the smallest distance of 80.5 km, while the second low tide on December 18 saw a slightly higher minimum distance of 103.6 km. This data effectively illustrates the relationship between tide occurrences and their corresponding maximum distances throughout December 2019.

Figure 2: Daily maximum distance and tide height for December 2019.



Source: Authors.

Table 1: Tide Day for December 2019.

Tide cycle	Max. distance (km)
1st high tide	158.7
2nd high tide	258.8
1st low tide	80.5
2nd low tide	103.6

Source: Authors.

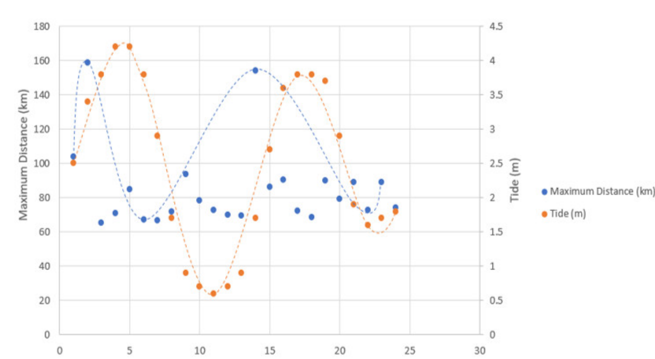
4.2. Hourly Data.

Examining the daily patterns illustrated in Figure 2, a more detailed understanding can be achieved by investigating ship distances and tidal behaviors at narrower time intervals for specific dates in December 2019, namely, December 10, December 24, December 5, and December 18. By segmenting the data into hourly intervals on these selected days, a closer examination of the alignment between ship coordinates and local tidal dynamics becomes possible, potentially revealing subtle variations and trends that might be obscured by broader daily averages. This hourly analysis has the potential to provide deeper insights into the intricate interplay between ship movements and tidal cycles, thereby enhancing our comprehensive comprehension of maritime dynamics during these particular days in December 2019.

4.3. Maximum Distance 10/12/2019.

Figure 3 depicts the hourly maximum distances (km) recorded on December 10th, 2019. The data reveals intriguing fluctuations in ship travel throughout the day, exhibiting distinct peaks and troughs that align with the observed tidal behavior during the same timeframe. Notably, the graph highlights two significant peaks at 2 a.m. and 2 p.m., registering maximum distances of 158.694 km and 154.315 km, respectively. These peaks correspond with elevated tide levels of 3.4 meters and 2.7 meters, underscoring the substantial impact of tides on maritime activities during these specific hours.

Figure 3: Hourly maximum distance on 10/12/2019.



Source: Authors.

Table 2 presents the hourly maximum distances (km) along with the corresponding tide heights (m) for the 1st and 2nd high tides observed on December 10th, 2019. The data reveals that the 1st high tide occurred at 2 a.m., coinciding with the highest travel distance achieved at 4 a.m. In contrast, the 2nd high tide occurred at 2 p.m., with the peak distance attained and recorded at 5 p.m.

Table 2: Hourly maximum distance and tides on 10/12/2019.

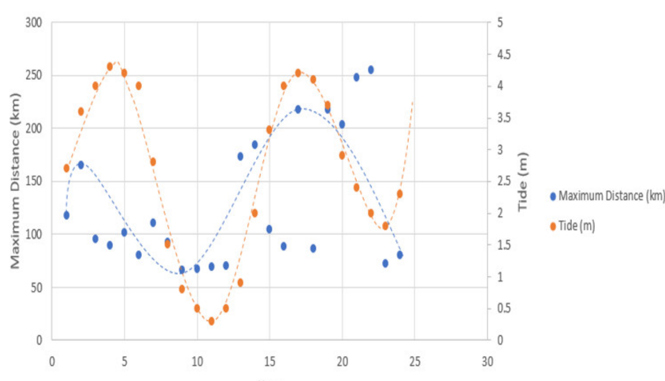
Tide cycle	Max. distance (km)	Tide (m) (m)
1st high tide	2 a.m	4 a.m
2nd high tide	2 p.m	5 p.m

Source: Authors.

4.3.1. Maximum Distance 10/12/2019.

The graph presented in Figure 4 illustrates the hourly maximum distances (measured in kilometers) recorded on December 24th, 2019. The data reveals intriguing patterns in ship travel throughout the day, directly corresponding to the observed tidal behavior during the same period. Notably, the graph exhibits two distinct peaks in ship distances at 2 a.m. and 5 p.m., with recorded maximum distances of 164.877 km and 217.948 km, respectively. Importantly, these peaks align precisely with high tide events, during which the tide levels reached 3.6 meters at 2 a.m. and 4.2 meters at 5 p.m. The strong correlation between the maximum distances and high tide levels suggests that favorable tidal conditions contributed to longer ship travel during these specific hours.

Figure 4: Hourly maximum distance on 24/12/2019.



Source: Authors.

Table 3 offers an overview of the hourly maximum distances (in kilometers) and their corresponding tide levels (in meters) for the 1st and 2nd high tides recorded on December 24th, 2019. The data highlights that the initial high tide occurred at 2 a.m., synchronizing with the maximum distance traveled within the same hour. Likewise, the second high tide transpired at 5 p.m., precisely matching the peak distance achieved during that specific hour.

Table 3: Hourly maximum distance and tides on 24/12/2019.

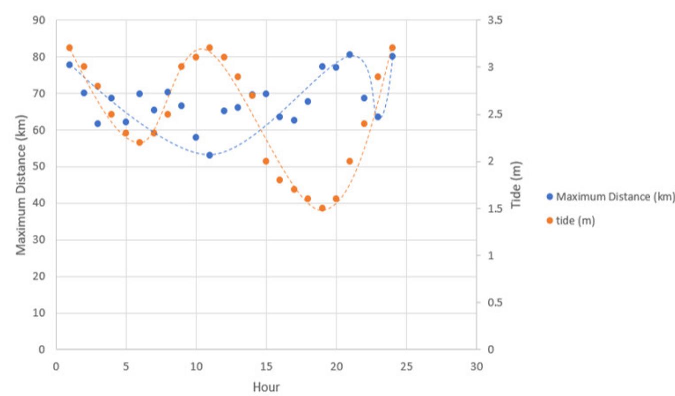
Tide cycle	Max. distance (km)	Tide (m) (m)
1st high tide	2 a.m	4 a.m
2nd high tide	5 p.m	5 p.m

Source: Authors.

4.3.2. Maximum Distance 5/12/2019.

The graph depicted in Figure 5 illustrates the maximum hourly distances (measured in kilometers) documented on December 5, 2019. The data unveils intriguing patterns in ship movements throughout the day, directly corresponding to the observed tidal behavior during the same period. Notably, the graph showcases two distinct peaks in ship distances at 1 a.m. and 9 p.m., where the recorded maximum distances were 77.779 km and 80.521 km, respectively. Interestingly, these peaks align precisely with high tide events occurring at 12 a.m. and 11 a.m., with tide levels reaching 3.2 meters for both occurrences. The strong correlation between the maximum distances and high tide levels implies that favorable tidal conditions facilitated extended ship travel during these specific hours.

Figure 5: Hourly maximum distance on 5/12/2019.



Source: Authors.

Table 4 provides a summary of the tidal patterns and hourly maximum distances for December 5, 2019, in the Straits of Malacca. Two high tide cycles are noted, with the first occurring at 1 a.m. and the second at 9 p.m. The corresponding tidal levels are listed as 12 a.m. and 11 a.m., respectively.

Table 4: Hourly maximum distance and tides on 5/12/2019.

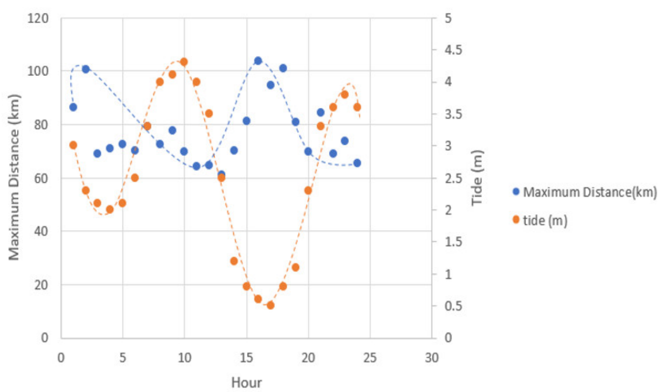
Tide cycle	Max. distance (km)	Tide (m)(m)
1st high tide	1 a.m	12 a.m
2nd high tide	9 p.m	11 p.m

Source: Authors.

4.3.3. Maximum Distance 18/12/2019.

Figure 6 presents the hourly maximum distances (in kilometers) attained on December 18, 2019. The data reveals compelling trends in ship movement that are directly influenced by concurrent tidal dynamics. Interestingly, the graph displays two distinct peaks in ship distances occurring at 2 a.m. and 4 p.m., with recorded maximum distances of 100.35 km and 103.562 km, respectively. Notably, these peaks align precisely with the highest tide levels observed on that day, measuring 4.3 meters at 10 a.m. and 3.8 meters at 11 p.m. The strong correlation between maximum distances and high tide levels suggests favorable tidal conditions during these specific time frames, contributing to extended ship travel durations.

Figure 6: Hourly maximum distance on 18/12/2019.



Source: Authors.

Table 5 outlines the hourly maximum distances (in kilometers) and the corresponding tide levels (in meters) for December 18th, 2019. The data distinctly highlights two instances of high tide occurring on this day, precisely at 2 a.m. and 4 p.m., respectively. Importantly, the peak ship movements were observed during the hours immediately following each high tide occurrence, specifically at 10 a.m. following the first high tide and at 11 p.m. following the second-high tide.

Table 5: Hourly maximum distance and tides on 18/12/2019.

Tide cycle	Max. distance (km)	Tide (m) (m)
1st high tide	2a.m	10a.m
2nd high tide	4p.m	11p.m

Source: Authors.

Conclusion and Recommendation.

The results of the study demonstrate a significant relationship between ship coordinates and tidal timing in the Straits of Malacca, emphasizing the dependability of Automatic Identification System (AIS) data as a valuable tool for forecasting tidal times. The effectiveness of this method in understanding tidal dynamics is evident in its accurate determination of the peak and trough high tide hours through analysis of AIS data. This achievement can be attributed to the harmonized alignment of tidal occurrences with ship coordinates, a consequence of the ocean's resonant motion influenced by the gravitational forces of the moon and sun (Balasubramanian, 2015).

Based on these findings, the study advocates for a deeper investigation into the practicality of utilizing AIS data for the prediction of sea levels during tidal occurrences. By harnessing AIS data for forecasting sea levels, valuable insights can be gained to fortify coastal management strategies and enhance disaster preparedness within the region. This predictive capacity holds the potential to significantly enhance safety measures and readiness against possible coastal threats, as it enables the anticipation of tidal surges and fluctuations. Consequently, this research validates the precision of AIS data in estimating tidal levels within the Straits of Malacca, thereby making a substantial contribution to our understanding of tidal and wave dynamics. Furthermore, it opens doors for future advancements in the realm of coastal management and marine forecasting methodologies. The observed correlation between ship coordinates and sea high-low levels underscores the utility of AIS data mining as an invaluable tool for a range of maritime applications, navigation purposes, and environmental conservation efforts, both within the specified area and beyond.

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