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Assessment of the Optimal Hydrodynamic Model for Malaysian Coastal Waters

by:

Nur Surayatul Atikah Alihan,

Assoc. Prof. Dr. Ami Hassan Md Din, Dr. Mohammad Hanif Hamden and Assoc. Prof. Dr. techn. Dudy Darmawan Wijaya

Email: nsatikah2@live.utm.my

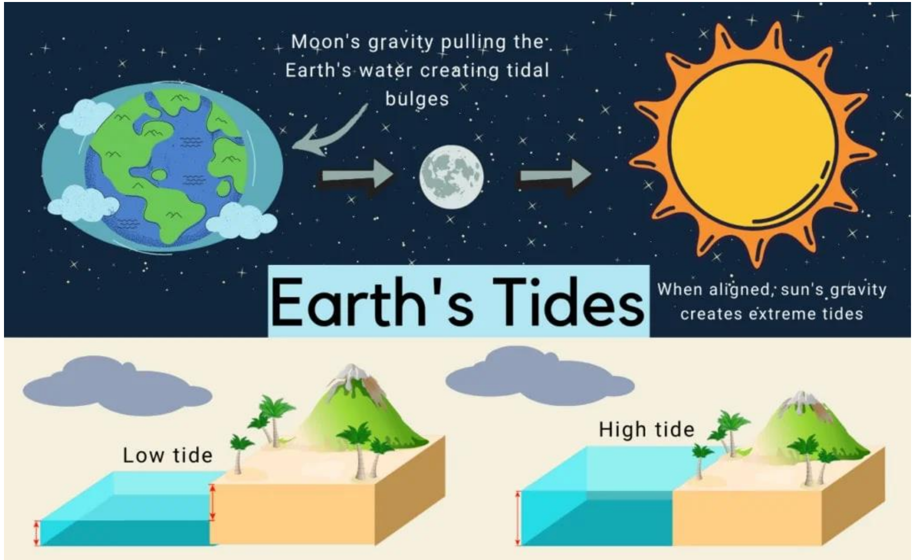
Geospatial Imaging and Information Research Group (GI2RG), Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Geodetic Science, Engineering and Innovation Research Group, Faculty of Earth Science and Technology, Institute of Technology Bandung, Bandung, Indonesia

CONTENTS

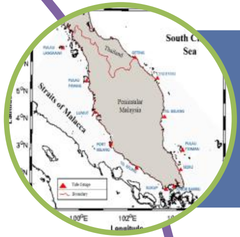
TIDES

- Tides, a periodic **rise and fall of the sea level** caused by the gravitational force of the Moon and Sun acting upon Earth's rotation (Pugh, 1996; Gan et al., 2021).
- Tides play a pivotal role in **influencing ocean variability** and have evolved into a significant focus within marine geodesy and hydrography.
- A comprehensive understanding of tides is essential for effective coastal management, disaster preparedness, environmental conservation, and various maritime activities.

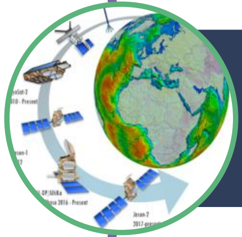


(Outforia, 2024)

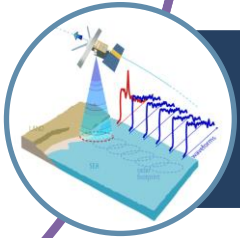
INTRODUCTION



The existence of the tidal station in Malaysia is still inadequate to provide the tidal information in Malaysian seas, particularly in open seas.



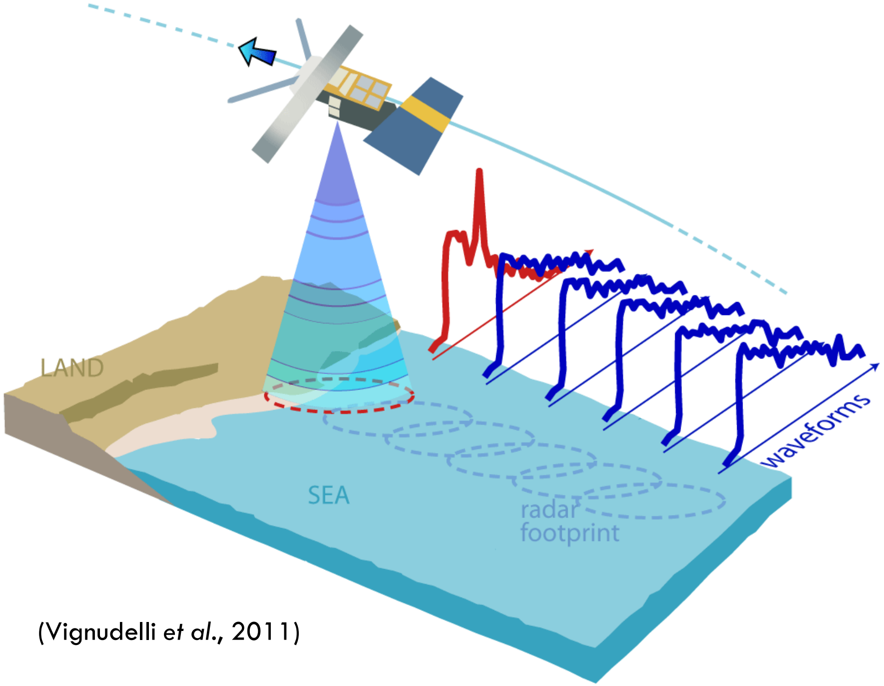
Satellite altimetry technique provide wide spatial data distributions all over the oceans where the availability of tide gauge station is scarce.



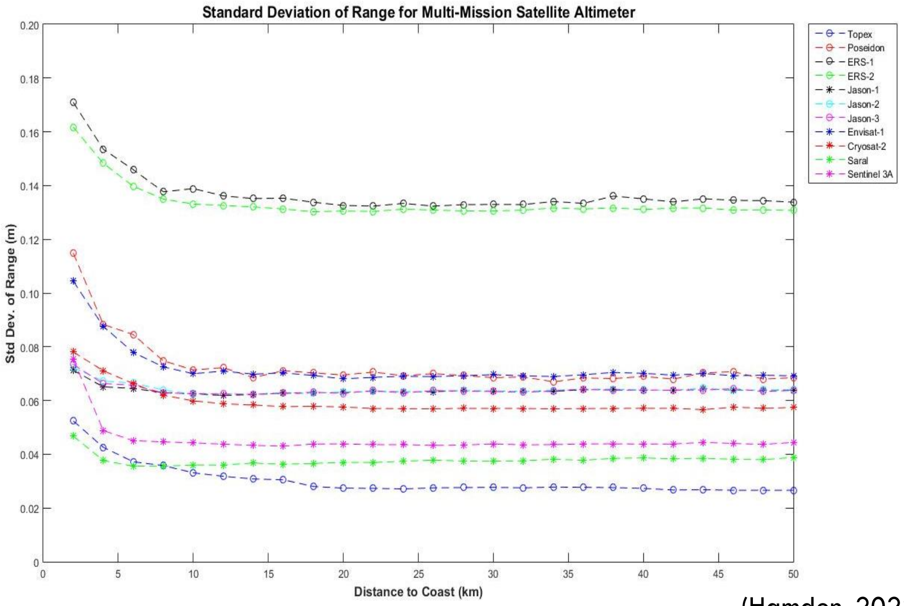
The accuracy of satellite altimeter degrades significantly in the coastal regions due to the complex tidal interaction from the hydrodynamic effect (Ainee, 2016; Abdullah, 2018).

INTRODUCTION

Challenges in Satellite Altimeter Approaches Coastal Areas



(Vignudelli *et al.*, 2011)



(Hamden, 2022)

The standard deviation of altimeter range based on the distance of altimeter footprint to the nearest coastline.

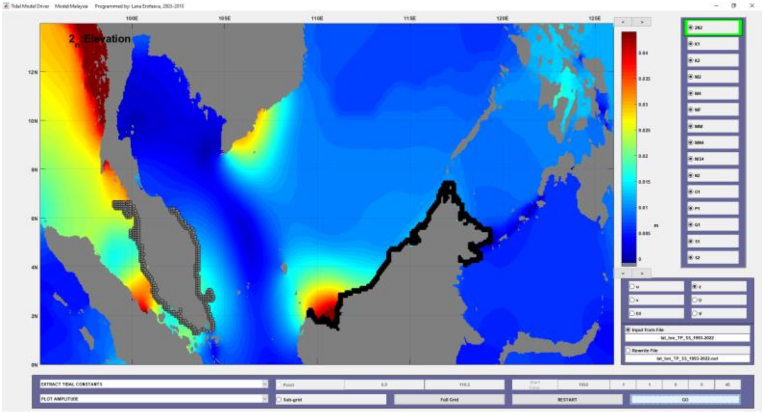
INTRODUCTION OF OCEAN TIDE MODEL

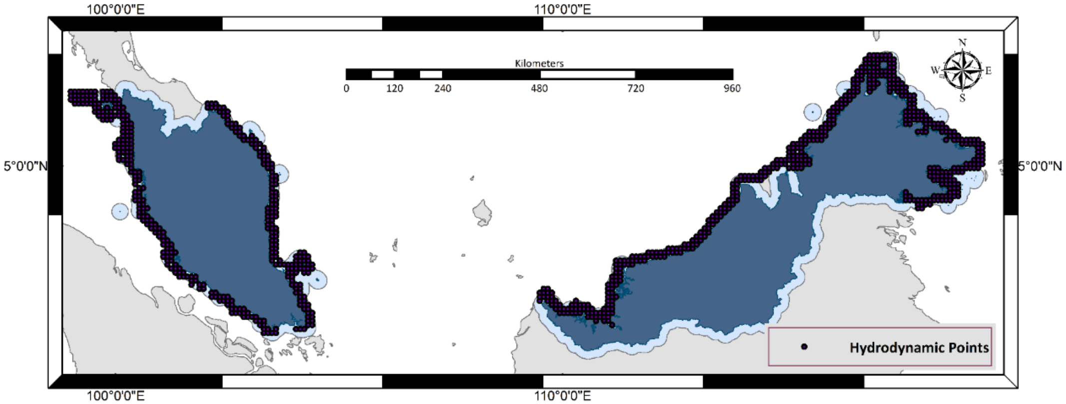
Hydrodynamic Model	Assimilation Model	Empirical Model
Derived by solving the LTE numerically, using bathymetry data as input of depths, and ocean tidal constants as the boundary conditions (or data constraints).	which is essentially the hydrodynamic approach, was proposed to **integrate altimetry data and/or tide gauge data into the hydrodynamic model**	**Requires sufficient altimetry data available only** for the ocean tide determination.

DATA AND METHODS

Hydrodynamic Model

- Three hydrodynamic models have been tested for derivation of tidal constituents along the coastal region with spanning period from 1993 to 2022; **Indian ocean model**, **TPXO9** model and **TPXO9-Atlas** model.
- A total of 377 hydrodynamic points are established in Peninsular Malaysia, complemented by 491 points in East Malaysia.
- The tidal information from the hydrodynamic model in this study is derived using **Tide Model Driver** version 2.5 (TMD).

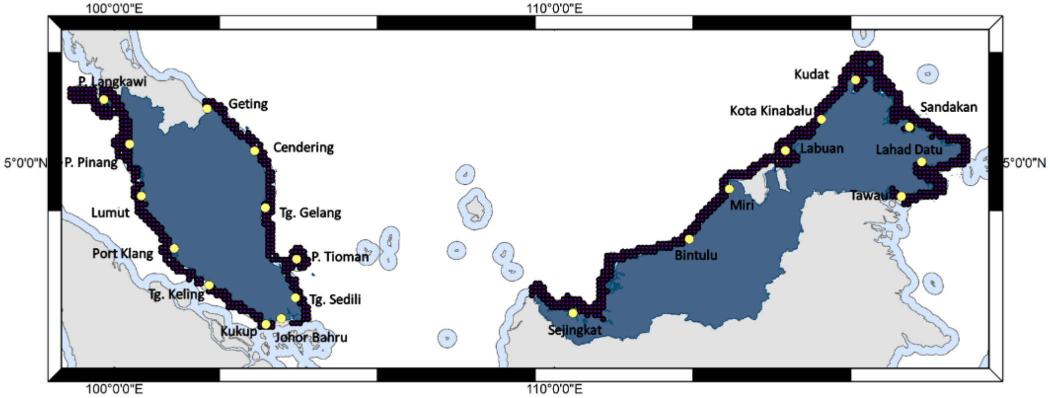




Model	Resolution	Type
Indian Ocean (IO)	1/12°	Regional
TPXO9	1/6°	Global
TPXO9-Atlas	1/30°	Global

DATA AND METHODS

Statistical Assessment



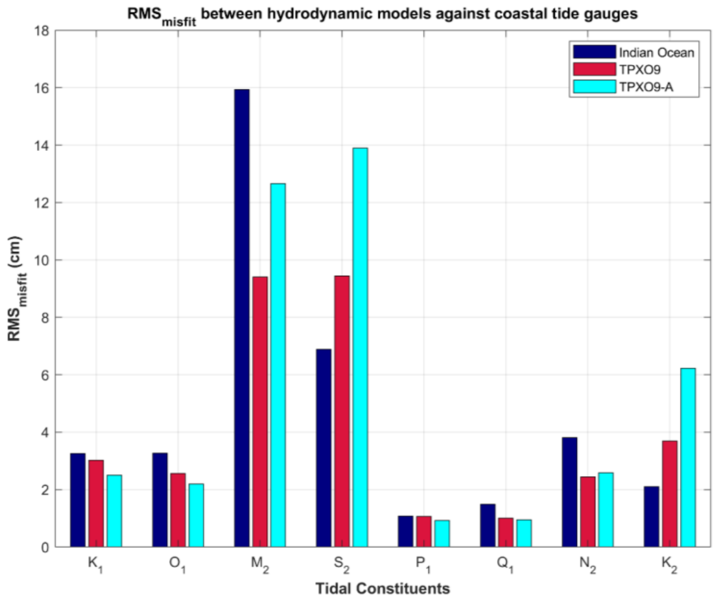
$$RMS_{misfit} = \left\{ \frac{1}{2M} \sum_{k=1}^{M} [(A_c \cos\theta_c - A_i \cos\theta_i)^2 + (A_c \sin\theta_c - A_i \sin\theta_i)^2] \right\}^{\frac{1}{2}}$$

$$RSS = \left(\sum_{a=1}^{TC} RMS_a^2 \right)^{\frac{1}{2}}$$

Station	Marker Name	Latitude	Longitude	Nearest Distance (km)
Bintulu	BINT	3° 15' 44.00" N	113° 03' 50.00" E	7.52
Cendering	CEND	5° 15' 54.00" N	103° 11' 12.00" E	6.94
Geting	GETI	6° 13' 35.00" N	102° 06' 24.00" E	9.47
Johor Bahru	JHBR	1° 27' 43.20" N	103° 47' 31.20" E	30.25
Kota Kinabalu	KINA	5° 58' 59.99" N	116° 04' 00.00" E	5.25
Kudat	KUDA	6° 52' 44.40" N	116° 50' 38.40" E	5.18
Kukup	KUKU	1° 19' 31.00" N	103° 26' 34.00" E	4.60
Labuan	LABU	5° 16' 22.80" N	115° 15' 00.00" E	5.86
Lahad Datu	DATU	5° 1' 8.40" N	118° 20' 45.60" E	8.61
Pulau Langkawi	LGKW	6° 25' 51.00" N	99° 45' 51.00" E	7.28
Lumut	LUMU	4° 14' 24.00" N	100° 36' 47.99" E	1.35
Miri	MIRI	4° 24' 04.00" N	113° 58' 27.99" E	8.27
Pulau Pinang	PINA	5° 25' 18.00" N	100° 28' 00.03" E	2.46
Port Klang	KELA	3° 02' 60.00" N	101° 21' 29.99" E	2.29
Sandakan	SAND	5° 48' 36.00" N	118° 04' 02.00" E	8.26
Sejingkat	SJKT	1° 34' 58.80" N	110° 25' 19.20" E	16.97
Tawau	TAWA	4° 13' 58.80" N	117° 52' 58.80" E	2.57
Tanjung Gelang	GELA	3° 58' 30.00" N	103° 25' 48.00" E	2.77
Tanjung Keling	KELI	2° 12' 54.00" N	102° 09' 11.99" E	6.09
Tanjung Sedili	SEDI	1° 55' 54.00" N	104° 06' 54.00" E	4.93
Pulau Tioman	TIOM	2° 48' 26.00" N	104° 08' 24.00" E	8.15

RESULTS AND DISCUSSION

- The findings reveal that the TPXO9-Atlas model generally performs better in representing diurnal constituents, while the TPXO9 model excels in representing semi-diurnal constituents.
- **TPXO9** exhibits the lowest RSS values, indicating **the best overall fit** for Malaysian coastal region.
- Despite the strong performance of **TPXO9-Atlas** in diurnal components, it has a slightly **higher RSS**, which is **less optimal**.



Hydrodynamic Model	RMS_{misfit} (cm)								RSS (cm)
	K_1	O_1	M_2	S_2	P_1	Q_1	N_2	K_2	
Indian Ocean	3.26	3.27	15.93	6.88	1.08	1.49	3.81	2.10	18.57
TPXO9	3.02	2.56	9.41	9.44	1.07	1.01	2.44	3.69	**14.67**
TPXO9-Atlas	2.50	2.20	12.66	13.90	0.92	0.95	2.58	6.22	20.29

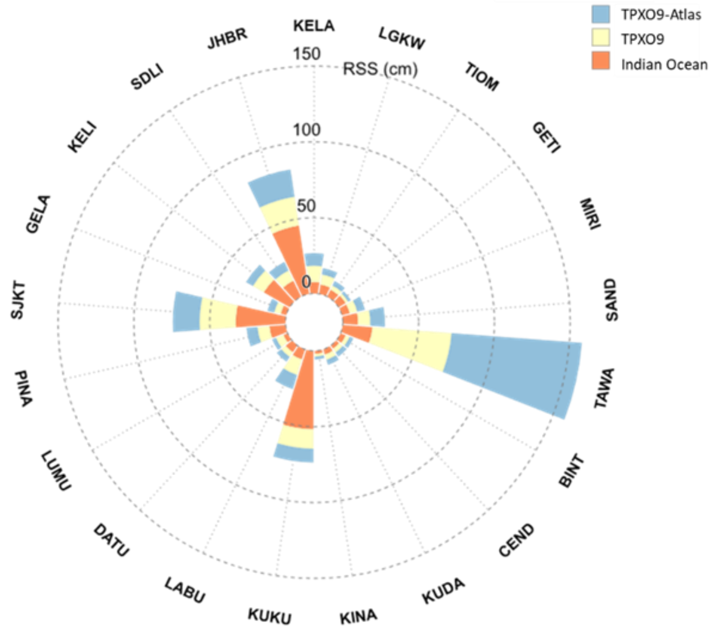
RESULTS AND DISCUSSION

- According to Fu et al. (2020), **the tidal variability of the study region** influences the misfits between the hydrodynamic model and the observed tidal data.

- The **Indian Ocean model**, represented in orange, generally exhibits **larger RSS** values, particularly at Tawau (TAWA), Kukup (KUKU), Sejingkat (SJKT) and Johor Bahru (JHBR) stations with errors reaching up 52 cm.

- The **TPXO9-Atlas** represented in blue is produced smaller RSS errors overall but still presents **notable discrepancies** at Tawau station with errors up to 86 cm.

- The **TPXO9 model** represented in yellow, indicating the **best overall fit** for Malaysian coastal region, shows marginally smaller errors, but significant discrepancies remain at the same stations, notably at Tawau and Sejingkat stations.



RESULTS AND DISCUSSION

- A **common feature** across all three hydrodynamic models is the **heightened discrepancies** at certain stations, particularly **Tawau, Kukup, Sejingkat and Johor Bahru stations**, which display the **largest RSS** errors.
- This discrepancy could be attributed to the **complex dynamics of the geographical locations** of these tide gauges stations, potentially **impacting the accuracy** of the hydrodynamic model.
- These regions often have **limited satellite altimetry coverage,** which restricts the data available to improve the model (Chen et al., 2005; Fu et al., 2020). The altimetry data is particularly sparse in such coastal environments, where the models rely on high resolution inputs to accurately simulate tidal patterns.

CONCLUDING REMARKS

- This study has provided valuable insights into the **accuracy assessment of the hydrodynamic model along the coastal areas of Malaysian waters.** The performance of these models is identified through the analysis of eight major tidal constituents extracted from the TMD and compared against derived tidal constituents from Malaysian tide gauges.
- The statistical assessment using RMSmisfit and RSS has revealed varying degrees of accuracy across different tidal constituents. Notably, **TPXO9 emerged as the model with the best overall accuracy** compared to the other models.
- The findings highlight the importance of incorporating factors such as **data assimilation methods** in enhancing the accuracy of the tidal model in complex geographical areas, underscoring the need for further research and refinement in modelling methodologies to achieve greater precision in such regions.
- Overall, this study represents a **key step** in the development of more accurate and reliable regional tidal models, significantly contributing to ongoing efforts to enhance tidal model precision for better coastal management and more informed decision-making.

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