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Assessment of Coastal Altimetry Data in the South China Sea using Multiple Frequency Approaches

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Abstract. With a coastline length extending over 13,000 km, including the Malaysia region, the South China Sea presents a challenge to retrieve high quality data along the coastal area especially the sea level anomaly and significant wave height. Currently, coastal altimetry is still facing some issues especially when using the low frequency data such as data lacking near the coast, questionable data accuracy since the altimeter footprint contaminated with the land and less coverage of data from the installed ground truth data. This study aims to assess the coastal altimetry data of sea level and significant wave height in the South China Sea using low and high frequency approaches. This study involved deriving data from sea level anomaly (SLA) and significant wave height (SWH) through the use of Prototype for Expertise on AltiKa for Coastal, Hydrology and Ice (PEACHI) for high frequency and Radar Altimeter Database System (RADS) for low frequency of altimetry and ground truth station which is from tide gauge and Acoustic Wave and Current Profiler (AWAC). Comparison between altimetry and ground truth data has been made in order to validate the significant agreement between them. The validation of the data is to evaluate both types of frequencies with respect to the coastal distance. Consequently, the high frequency results for coastal results with a root mean square reliable ±0.14 metre level for the sea level anomaly (SLA) and ±0.18 metre level for significant wave height (SWH) are more reliable. PEACHI distance-to-coast data obtained a sufficient standard residual deviation ranging from 0 cm to 2.87 cm compared to RADS altimetry ranging from 0.08 cm to 14.20 cm. The findings of this study indicate that the coastal altimetry data benefit coastal development, coastal defence, monitoring and tourism by various related agencies.

1. Introduction
Coastal altimetry has become an essential tool for oceanography and studies supporting diverse applications, especially in the coastal zone, for instance, sea level anomaly and significant wave height. Satellite altimetry is a tool whose basic function is to observe, from space-based station, the signal released from altimeter to the surface of the earth and reflected back to the altimeter [1]. There are some advantages of the coastal altimetry, which is coastal area of a country can be developed based on the

data from the coastal altimeter as it provides parameters that can help the authorities. Coastal altimetry can be divided into two, low- and high-frequency data types, such as 1Hz and 40Hz, respectively [2].

The common practice used in Malaysia to obtain coastal altimetry data is to use low frequency through RADS system. However, this practice has limitations including the limitation of database and data handling because the data is too big. Therefore, the use of SARAL/AltiKa in this study may solve the problem as this satellite has data for both low and high frequencies, where RADS keeps low frequency and PEACHI keeps high frequency [2]. The use of RADS system leads to data inaccuracies when the low frequency has a footprint interval of 7km as stated by [3] and it is contaminated with the land features [4]. A study of sea level assessment of the SARAL/AltiKa mission has been conducted using data of low and high resolution in which higher root mean square error (RMSE) can be obtained using high frequency data [5]. The study used only two tide gauges for validation of sea level anomaly data and did not include assessment of East Malaysia, which consists of Sabah and Sarawak. This has led to incomplete overview of coastal altimetry data in Malaysia near the South China Sea. No study has been conducted to analyze wave height data using low and high frequency datasets.

The potential solution to this problem is to increase the number of tide gauge stations for anomaly assessment of the sea level and to further test the ocean parameter data. In this study, five tide gauge stations were used located at the Peninsular and Borneo of Malaysia near the South China Sea to analyze the sea level anomaly. This study contributes towards the coastal development in the Malaysia region; however, in situ data availability remains challenging as there is still lack of latest data.

Currently, significant wave height data can be collected using the Acoustic Wave and Current Profiler (AWAC) and Buoy. The problem is that both ground-based methods fail to provide good continuity and offer limited coverage of data. The possible solution for this problem is using the altimetry measurements to retrieve significant wave height data. Satellite altimetry is an instrument for viewing the Earth and the oceans from space. The higher interest in coastal area information and the need for precise and accurate determination of measurements in coastal altimetry study has led to the development of various measurement methods. This technology develops knowledge of sea information through sea level studies, ocean circulation and climate variability [6]. The basic concept of satellite is to calculate the two-way transit period of short pulses from the Earth's surface reflected as accurately as possible. This is based on the on-board radar altimeter that permanently transmits the specific energy of the microwave pulse to the sea surface, and the pulse transmits back to the altimeter sensor for precise measurements of the time taken from the signal between the satellite altimeter and the ocean surface. The measurement of the three-dimensional location of the satellite relative to a fixed earth coordinate system is by the use of independent tracking systems. The combination of these two measurements creates sea surface height profiles, or sea level, for the reference ellipsoid [7].

In the field, the situation is more complicated as the correction of altimeter range measurements such as orbital error (radial component) and instrumental effects such as offset antenna phase center, clock drift, electronic time delay, center of gravity, time delay of observations, Doppler shift error and others is accounted for by several factors [8]. Certain corrections, such as atmospheric correction due to troposphere (dry and humid conditions) and ionosphere error, also need to be made. Figure 1 displays the theory of satellite altimeter measurements.

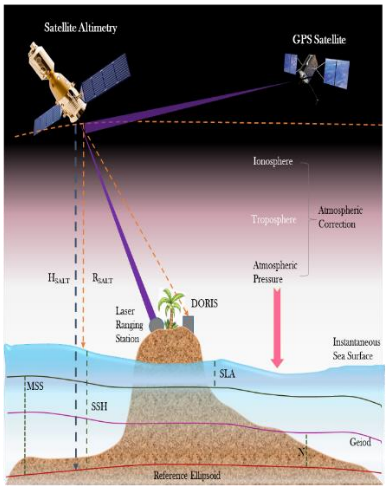


Figure 1. Principle measurements of satellite altimetry [9]

The calculation of altimeter range measurements as all the corrections have been taken into account can be said as corrected range $R_{corrected}$ which is related to the observed range $R_{(obs)}$;

$$R_{corrected}=R_{(obs)}-\Delta R_{dry}-\Delta R_{wet}-\Delta R_{iono}-\Delta R_{ssb} \quad \text{where,} \tag{1}$$

$R_{obs}= c\,t/2$ is the measured distance from the signal travel time, t and c is the speed of the echo pulse ignoring refraction.

ΔR_{dry} : Dry tropospheric correction
ΔR_{wet} : Wet tropospheric correction
ΔR_{iono} : Ionospheric correction
ΔR_{ssb} : Sea-state bias correction

The range measurement is then converted to the height, h of the sea surface relative to the reference ellipsoid and given as:

$$h = H - R_{corrected} = H - (R_{(obs)}-\Delta R_{dry}-\Delta R_{wet}-\Delta R_{iono}-\Delta R_{ssb}) \tag{2}$$

where,

H: Spacecraft height calculated by determining orbit.

Sea Level Anomaly is an increase in water levels forced by non-storm-related meteorological and oceanographic processes [10]. The difference between actual sea surface height (SSH) and mean sea surface height (MSS) is defined as shown in Figure 2. sea level anomaly (SLA) is obtained relative to the reference period. A mean dynamic topography field can be used in order to retrieve the ADT. It shows the mean sea surface above the Geoid. ADT and SSH are time independent from the time reference period. The calculation of sea level anomaly (SLA) can be done using formula below:

$$SLA = SSH - MSS \tag{3}$$

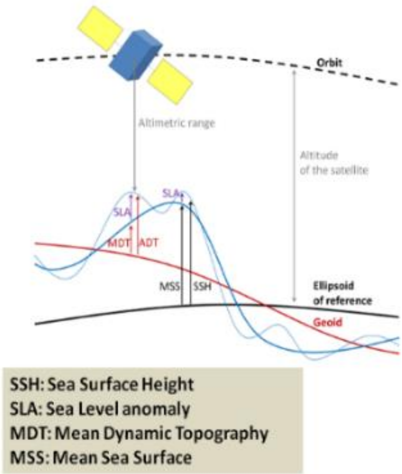


Figure 2. Difference between actual sea surface height (SSH) and the mean sea surface height (MSS) [11]

Significant wave height is historically defined as the mean wave height of the highest third wave (trough to crest) ($H_{1/3}$). significant wave height (SWH) is determined from the rate of increase of returned power of the radar altimeter pulse (the waveform slope) and requires no further correction other than some instrument parameters. significant wave height (SWH) can be determined as follows:

$$SWH^2 = \alpha^2 (\sigma^2_c - \sigma^2_p) \tag{4}$$

where σ_c is a measure of the waveform slope and σ_p is an instrument parameter, and α is a constant [12].

Because of the heterogeneous surface variations through altimeter footprints, coastal waveforms usually differ from open ocean waveforms and are therefore not clearly defined by the Brown model [13]. The two main sources of heterogeneous surface reflections are basically land surfaces and bright targets such as calm surface water [14]. Figure 3 shows the Brown model as analytical model which can describe the characteristics the ocean parameter echo waveform. Several parameters can be determined from the base waveform shape which are:

- Mid-height epoch reflects the time delay of the predicted return of the radar pulse (estimated by the tracker algorithm) and then the time taken for the radar pulse to travel the distance from the satellite surface and back again.
- The value P represents the backscatter coefficient (sigma0) given by the amplitude of the useful signal.
- The P0 is defined as thermal noise while the leading-edge slope represents the significant wave height (SWH).

This fundamental parameter obtained by means of the retraction waveform which is sea level, significant wave height and coefficient of backscattering is related to wind speed.

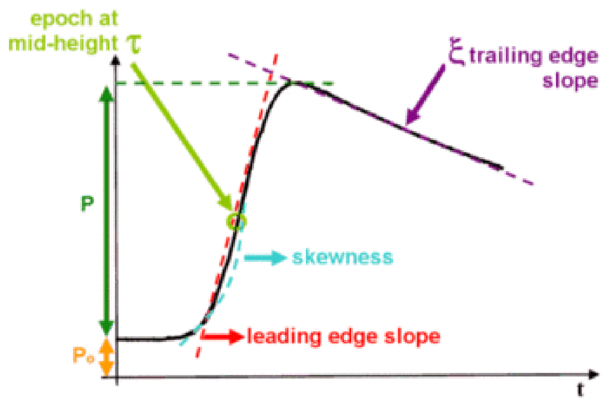


Figure 3. Brown model [13]

RADS and PEACHI (AVISO) system can give low and high frequency data which would be acknowledging assessment of the coastal area parameter. With the RADS system, for each footprint interval the common approach frequency as low as 1 Hz could be acquired at ~7 km. Meanwhile, the PEACHI (AVISO) system provides high frequency data (40 Hz) that was acquired at a footprint interval of ~250 m. Table 1 shows a multiple frequency comparison.

Table 1. Comparison between multiple frequency

No	Altimetry	Frequency	Frequency (Hz)	Footprint Interval (km)
1	RADS	Low	1	~7
2	PEACHI	High	40	~0.2

Hence, the aim of this study is to assess the coastal altimetry data of sea level and significant wave height from SARAL/AltiKa in the South China Sea using multiple frequency approaches. This paper would explain more specific research topics, for example, the derivation of sea level anomaly (SLA) and significant wave height (SWH) data using both frequencies. Comparison between altimetry data and ground truth data also performed in order to evaluate the distance to coast variation of satellite altimetry. It can be expected that the findings from this study beneficial to various agencies related to the coastal area such as for environment planning, coastal development, coastal defense, port terminal and facilities modification.

2. Data and Methods

2.1. Study area

The study region focuses on Peninsular Malaysia, Sabah and Sarawak facing the South China Sea, which is confined from 0° to 7° latitude and from 100° to 119° longitude as shown in Figure 4.

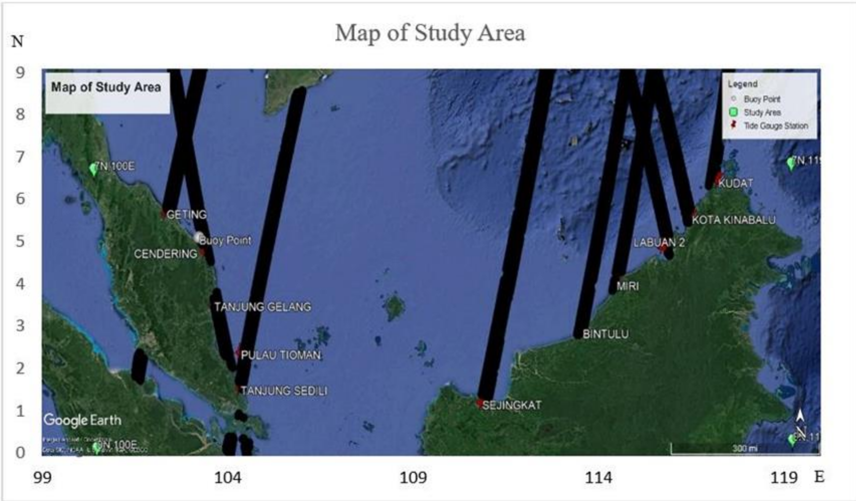


Figure 4. The map of study area of Malaysia for Altimeter track (Modified from Google Earth, 2020)

2.2. *Altimetry data sources*

SARAL/AltiKa for deriving the sea level anomaly and significant wave height data, one satellite altimeter mission is chosen in this study. The duration of this altimetry satellite data is three years, from 1 March 2013 to 31 December 2015. The selection of this time period is because the tidal station data from JUPEM is only available for the maximum period to end of 2015, whereas AWAC data provided by Universiti Malaysia Terengganu is only available from 2014 to the end of 2015.

2.2.1. *Radar Altimetry Database System (RADS)*

RADS is used for processing and deriving sea level anomaly and significant wave height data. Uses Ubuntu (Linux) as its operating system for RADS processing. These satellite altimeter data for low frequency 1Hz are processed in RADS manually by using the rads2asc command. RADS data processing is started by creating a file called getraw.nml. Within this file the area of study or geographic region is defined with specific latitude and longitude. A single mission of satellite altimetry data processing is conducted by RADS using rads2asc script. In this part, a selection of single mission satellite altimeter is conducted by using a specific command in RADS as follows:

rads2asc sat=sa/a cycle=1,29 out=saa.asc sel=1,2,3,0, 17 -v -f &> saa.out &

where;

sat	= *sa/a* defined as satellite SARAL/AltiKa, Phase A
1	= time (s)
2	= latitude
3	= longitude
0	= sea level anomaly
17	= significant wave height

The key aspect of this processing is the analysis of the satellite altimeter track for both data and the analysis of the satellite altimeter's spatial coverage. In this analysis, the cycle and phase data collection for the satellite altimeter is based on the tidal and AWAC data duration from March 2013 to December 2015. The period of time also represented by cycle 1 till cycle 29 as stated in the command.

2.2.2. Prototype for Expertise on Altika for Coastal, Hydrology and Ice (PEACHI)

For high frequency data (PEACHI), the data is extracted from the AVISO+ system as shown in Figure 5. It is also used for extracting and processing sea level anomaly and significant wave height. In the AVISO system, there is an option to extract PEACHI data which is high frequency. Processing AVISO+ used products made from L2P. The L2P products are focused on the user along track products that contain period of time, sea level anomaly, significant wave height, data validity information, any corrections required to measure ocean parameters, and other parameters. AVISO+ allows users to determine the necessary corrections applied to their results. All such data extractions can be done online only. Users can visit http://aviso.altimetry.fr/index.php?id=3116 which users can freely define their specific parameter that users need.

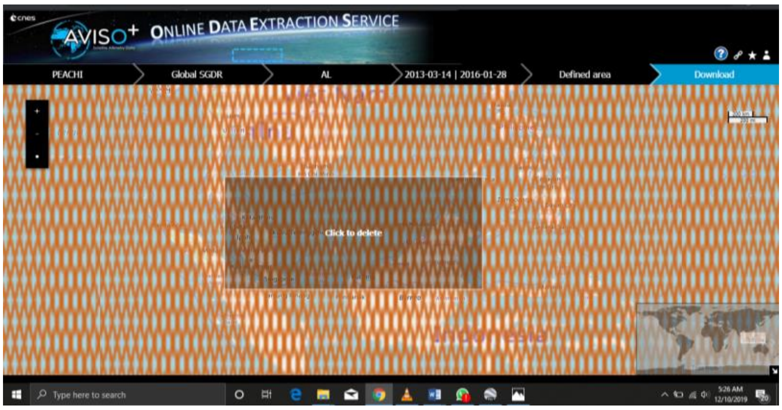


Figure 5. Data Extraction from Archiving, Validation and Interpretation [15]

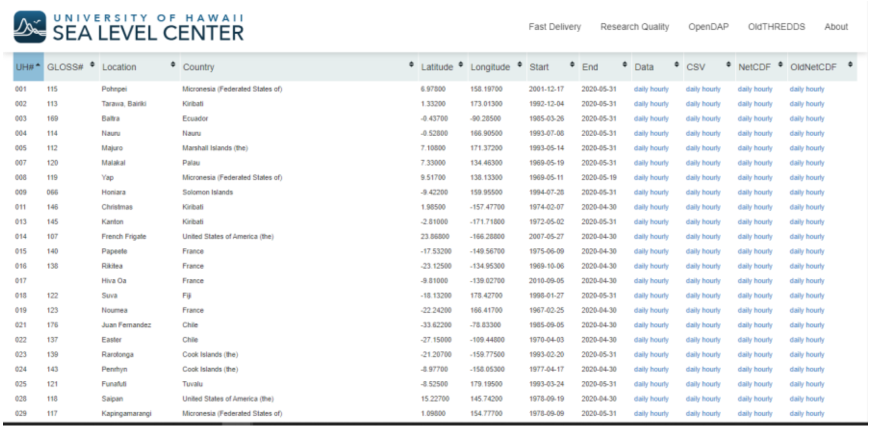
2.2.3. Tide gauge data

The University of Hawaii Sea Level Center (UHSLC) was in charge of gathering, transmitting, analyzing and interpreting sea level data from the worldwide tide gauge network. Thus, hourly tidal data are obtained from UHSLC in this study. Five tide stations are selected for validation purposes in this study. Sea level from the satellite altimeter is contrasted with tidal data by collecting sea level anomaly hourly at the locations of the tide gauge and the altimeter track closest to the tide gauge station. The data period extends from 1 March 2013 and 31 December 2015. However, to achieve a comparable result, the timeframe in each region must be the same, for example both must use UTC time. Hourly tidal data is collected from UHSLC via the http:/uhslc.soest.hawaii.edu / data/ website, as shown in Figure 6.

For validation process, five tide gauges were selected. Satellite altimeter sea level anomaly data are compared to tidal data by collecting hourly sea level anomaly (SLA) from the tide gauge station closest to the altimeter track. The extraction extended from March 2013 to December 2015. Sea level anomaly (SLA) pattern and relation between both measurements are then calculated and evaluated. Table 2 indicates the tide gauge station selected for this research.

Table 2. Selected tide gauge

Tide Gauge Station	Latitude (°)	Longitude (°)
1. Geting	6.226	102.107
2. Cendering	5.265	103.187
3. Tanjung Sedili	1.932	104.115
4. Bintulu	3.262	113.064
5. Kota Kinabalu	5.983	116.067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UH#	GLOSS#	Location	Country	Latitude	Longitude	Start	End	Data	CSV	NetCDF	OldNetCDF
001	115	Pohnpei	Micronesia (Federated States of)	6.97800	158.19700	2001-12-17	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
002	113	Tarawa, Bairiki	Kiribati	1.33200	173.01300	1992-12-04	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
003	169	Baltra	Ecuador	-0.43700	-90.28500	1985-03-26	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
004	114	Nauru	Nauru	-0.52800	166.90500	1993-07-08	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
005	112	Majuro	Marshall Islands (the)	7.10800	171.37200	1993-05-14	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
007	120	Malakal	Palau	7.33000	134.46300	1969-05-19	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
008	119	Yap	Micronesia (Federated States of)	9.51700	138.13300	1969-05-11	2020-05-19	daily hourly	daily hourly	daily hourly	daily hourly
009	066	Honiara	Solomon Islands	-9.42200	159.95500	1994-07-28	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
011	146	Christmas	Kiribati	1.98500	-157.47700	1974-02-07	2020-04-30	daily hourly	daily hourly	daily hourly	daily hourly
013	145	Kanton	Kiribati	-2.81000	-171.71800	1972-05-02	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
014	107	French Frigate	United States of America (the)	23.86800	-166.28800	2007-05-27	2020-04-30	daily hourly	daily hourly	daily hourly	daily hourly
015	140	Papeete	France	-17.53200	-149.56700	1975-06-09	2020-04-30	daily hourly	daily hourly	daily hourly	daily hourly
016	138	Rikitea	France	-23.12500	-134.95300	1969-10-06	2020-04-30	daily hourly	daily hourly	daily hourly	daily hourly
017		Hiva Oa	France	-9.81000	-139.02700	2010-09-05	2020-04-30	daily hourly	daily hourly	daily hourly	daily hourly
018	122	Suva	Fiji	-18.13200	178.42700	1998-01-27	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
019	123	Noumea	France	-22.24200	166.41700	1967-02-25	2020-04-30	daily hourly	daily hourly	daily hourly	daily hourly
021	176	Juan Fernandez	Chile	-33.62200	-78.83300	1985-09-05	2020-04-30	daily hourly	daily hourly	daily hourly	daily hourly
022	137	Easter	Chile	-27.15000	-109.44800	1970-04-03	2020-04-30	daily hourly	daily hourly	daily hourly	daily hourly
023	139	Rarotonga	Cook Islands (the)	-21.20700	-159.77500	1993-02-20	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
024	143	Penrhyn	Cook Islands (the)	-8.97700	-158.05300	1977-04-17	2020-04-30	daily hourly	daily hourly	daily hourly	daily hourly
025	121	Funafuti	Tuvalu	-8.52500	179.19500	1993-03-24	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly
028	118	Saipan	United States of America (the)	15.22700	145.74200	1978-09-19	2020-04-30	daily hourly	daily hourly	daily hourly	daily hourly
029	117	Kapingamarangi	Micronesia (Federated States of)	1.09800	154.77700	1978-09-09	2020-05-31	daily hourly	daily hourly	daily hourly	daily hourly

Figure 6. Permanent Service for Mean Sea Level [16]

2.2.4. Acoustic wave and current profiler

AWAC is a device that uses the specific surface tracking function owned by Universiti Malaysia Terengganu (UMT), to measure wave height, wave direction and maximum current profile**.** The raw data for the point consists of several marine parameters such as significant wave height, current direction. Table 3 shows the example of AWAC data that has been acquired from March 2013 to December 2015. Then, relationship between altimetry and ground truth station are calculated and assessed. Table 4 shows the location selected AWAC in this study.

Table 3. An example of data acquired from AWAC station

No	Date and Time	Significant Wave Height (H_{MAX})
1	4/21/2013 16:01	0.38m
2	4/21/2013 16:21	0.50m
3	4/21/2013 16:41	0.41m
4	4/21/2013 17:01	0.45m

Table 4. Location of Selected AWAC Station

Ground Station	Latitude	Longitude
AWAC	5.44277778N	103.16055556E

2.3. Data validation: Ground-truth versus Satellite Altimetry

Satellite altimeter data are validated with i) tide gauge ii) AWAC measurement. The sea level anomaly is validated with tidal data while significant wave height is validated with the AWAC measurements. The validation of sea level anomaly (SLA) with the tide measurements is set to hourly and the location must be consistent near to tide gauge station locations. The validation of significant wave height is by using collocation method to assess the reliability of satellite altimeter. Table 5 shows the validation to be performed.

Table 5. Validation process to be performed

No	Ocean Parameter	Validation
1	Sea Level Anomaly	Altimetry vs Tide Gauge
2	Significant Wave Height	Altimetry vs AWAC

The data verification is performed by making three types of analysis; the correlation analysis between two sets of data, root mean square error (RMSE), trend and magnitude of these two data sets by plotting a graph at the selected point. Root mean square error (RMSE) is a method to measure the standard deviation of the residuals (prediction errors) by using formula as follows:

$$RMSE = \sqrt{\frac{\sum_{=1}^{n}(p_i - a_i)^2}{n}} \tag{5}$$

where;

p_i = Satellite altimeter data
a_i = Tidal data from tide gauge or AWAC measurements
n = Total no. of data
i = No. of data

2.4. Coastal altimetry data evaluation

In this part, data evaluation has been implemented. The high and low frequency data of sea level anomaly and significant wave height is evaluated with respect to the coastal area within less than 50 km using the calculation standard deviation of residual. In addition to a small value of root mean square deviation, a good correlation must be shown to ensure the sea level anomaly (SLA) and significant wave height (SWH) precision from satellite altimeter. The residual of standard deviation is only the standard deviation of the remaining qualities, or the distinction between a lot of measured and predicted values. The standard deviation of the residuals ascertains how much the information focuses spread around the regression line. In this study, this data evaluation was performed to see how far the data from altimeter for sea level anomaly and significant wave height fit with the actual model.

3. Results and Discussion

This section analyses and discusses two types of parameters, which is sea level anomaly and significant wave height from satellite altimetry with tide gauge and AWAC station, respectively. This is classified into sea level anomaly and significant wave height, sea level and significant wave height in relation to distance to coast.

3.1. Verification: Altimeter versus tide gauge

Using the time series trend and the correlation study of sea level anomalies, data verification from altimetry and ground truth data is carried out. Evaluation process by analysing the trend and correlation between March 2013 and December 31, 2015 for both measurements are carried out. As shown in Figure 7, majority of the graph trends indicate a good association and correlation between satellite altimeter and tide gauge for sea level anomaly. It is notable that there is a gap within few months in tide gauge time series as shown in the figure (orange line) due to invalid data obtained from UHSLC source. The absence of tide gauge data has caused the quality in making the analysis to be low. This is because the tide gauge data that should be used to make comparisons with altimeter data accurately cannot be done and at the same time affect the quality of analysis Also, Figure 8 illustrates 29 cycles of altimetry sea level anomaly (SLA) data from RADS and PEACHI at all station were used to compare with tidal sea level anomaly (SLA). The findings show that in comparison to the tidal data, altimetry data achieve a satisfactory root mean square error (RMSE) ranging from 0.02m to 0.21m.

The lowest difference in root mean square error (RMSE) obtained is at Tg Sedili station, at 0.02 m, and the highest difference in is at Bintulu station, at 0.21 m. Both tide gauge stations display the correlation study, varying from -0.3426 to 0.6904 for the R^2 value. The correlation analysis using RADS data is better than PEACHI. In contrast, the RMSE between PEACHI and tide gauge data shows a promising finding with less than 0.14m for all five tide gauge stations. Table 6 shows the summary of correlation analysis, R^2 and RMSE for each station.

The originality of these studies is the greater number of tide gauges used compared with previous studies in the Malaysian region. For example, studies conducted by [5] concentrate only on two tide gauge stations located in Peninsular Malaysia to validate altimeter data near the Malaysian Peninsula. This result offers a better view of the coastal altimetry in the Malaysia region since it also analysed Borneo region which is located at East of Malaysia. The result shows good agreement between altimetry data and tide gauge data in the coastal areas as proved by studies conducted by [17]. The correlation analysis between RADS and tide gauge data is acceptable as discussed by [12]. Nevertheless, poor correlation analysis between PEACHI and tide gauge data may be found because altimetry track is too close to tide gauge (~200 m) and may have contaminated with land as mentioned by [18].

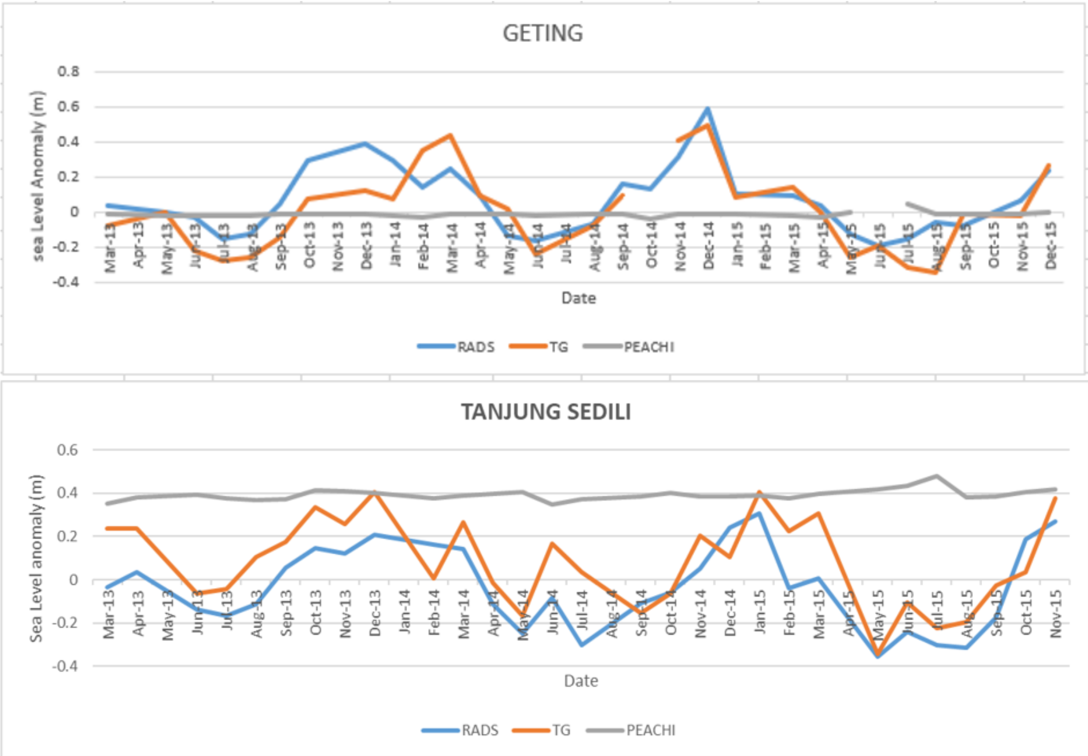
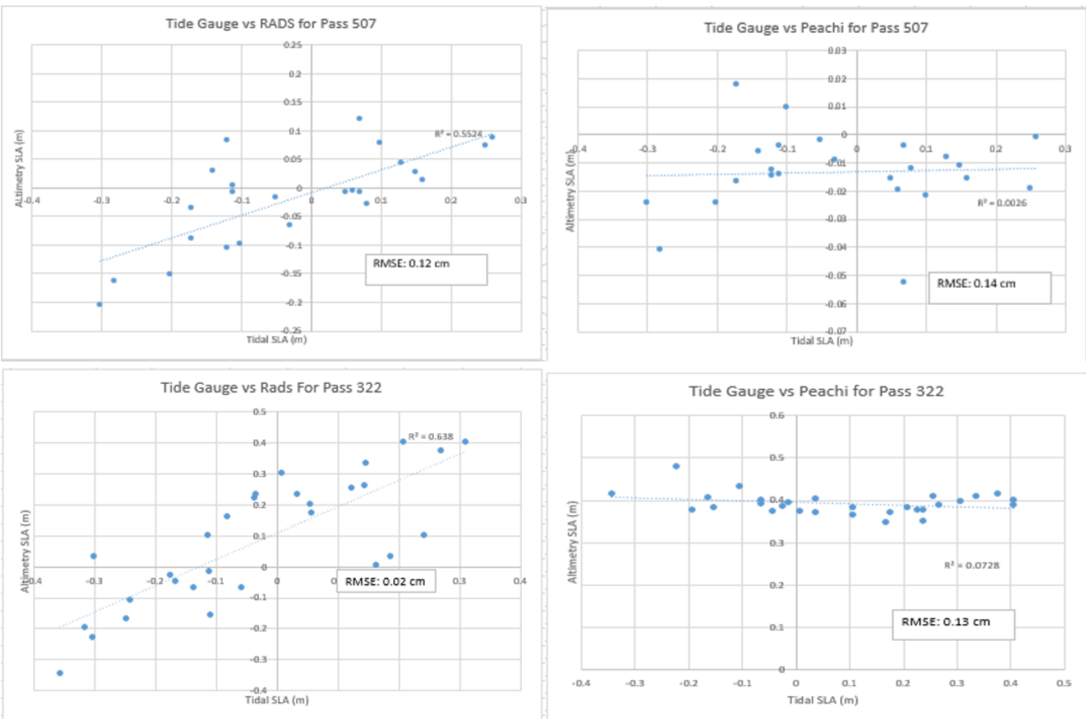


Figure 7. Comparison of time series trend from Tide Gauge (orange) with hourly sea level anomaly (SLA), RADS (blue) and PEACHI (grey) at the selected tide gauge station. Units are meter.



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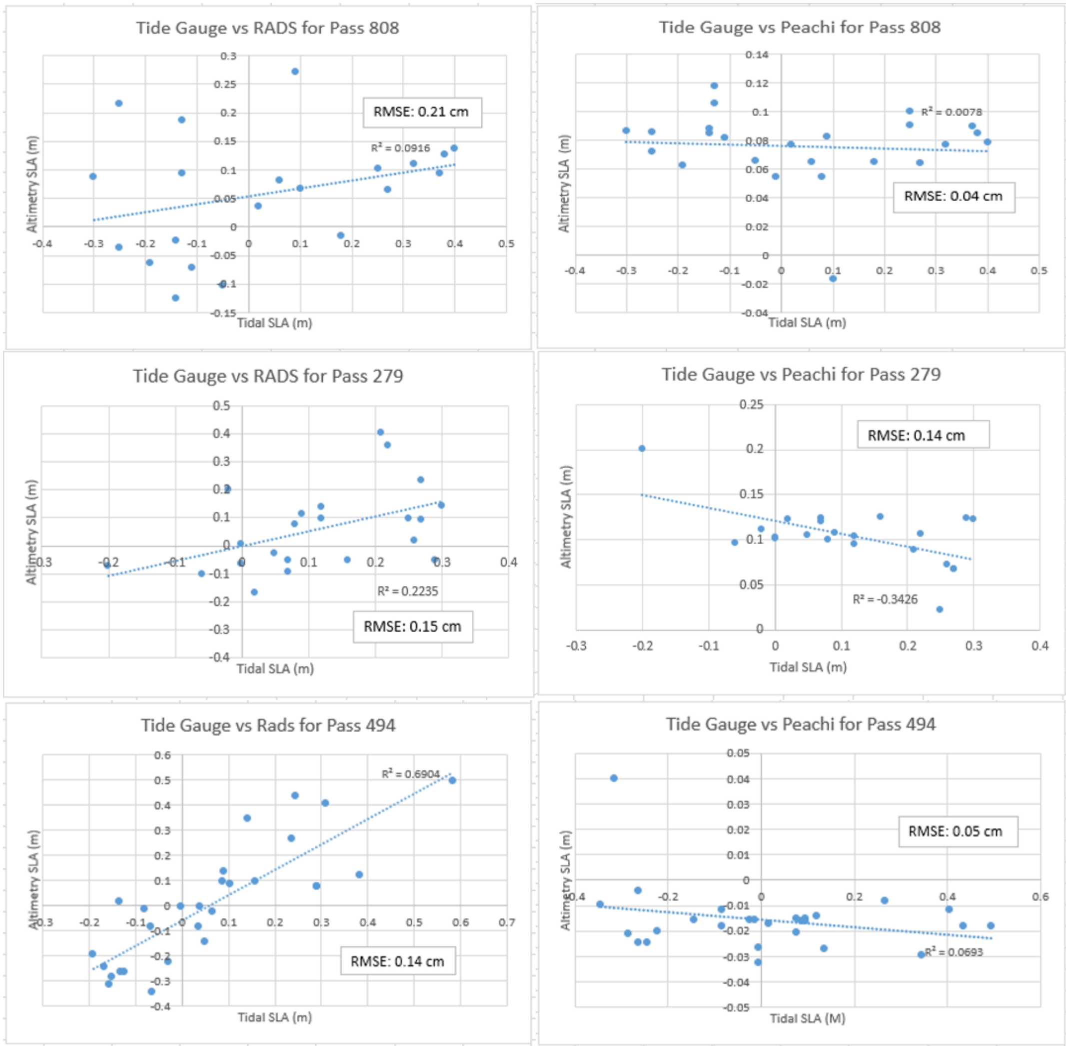

Figure 8. Correlation analysis, R^2 and RMSE comparison with sea level anomaly (SLA) from tide gauge versus RADS (left) and tide gauge versus PEACHI (right) at the selected tide gauge station.

Table 6. Summary of correlation, R^2 and RMSE for RADS and PEACHI altimeter at tide gauge station

Altimetry	Tide Gauge	Cycle	Pass	Correlation (R^2)	RMSE (m)
RADS	Bintulu	1-29	808	0.0916	0.21
	Cendering		279	0.2235	0.15
	Geting		494	0.6904	0.14
	Kota Kinabalu		507	0.5524	0.12
	Tg Sedili		322	0.5380	0.02
PEACHI	Bintulu	1-29	808	0.0078	0.04
	Cendering		279	-0.3426	0.14
	Geting		494	0.0693	0.05
	Kota Kinabalu		507	0.0026	0.14
	Tg Sedili		322	0.0728	0.13

3.2. *Verification: Altimetry versus AWAC*

Hourly altimetry and AWAC station data verification is conducted using time series pattern and the significant wave height correlation analysis**.** Both measurements were evaluated from March 2013 to 31 December 2013 by examining trend and correlation over the same period. The graph patterns show a bad correlation and agreement between the significant wave height from the satellite altimeter and the AWAC results, based on Figure 9 and 10 due to unavailability of ground truth data. It is notable that there is a gap within month of April and June in AWAC time series as shown in Figure 9 due to invalid data obtained from Universiti Malaysia Terengganu sources. Also, Figure 10 illustrates 10 cycles of altimetry significant wave height (SWH) data from RADS and PEACHI were used to compare with AWAC data. The results show a reasonable root mean square error (RMSE) with altimetry data varying from 0.18 m to 0.26 m relative to the ground truth data, which is AWAC data.

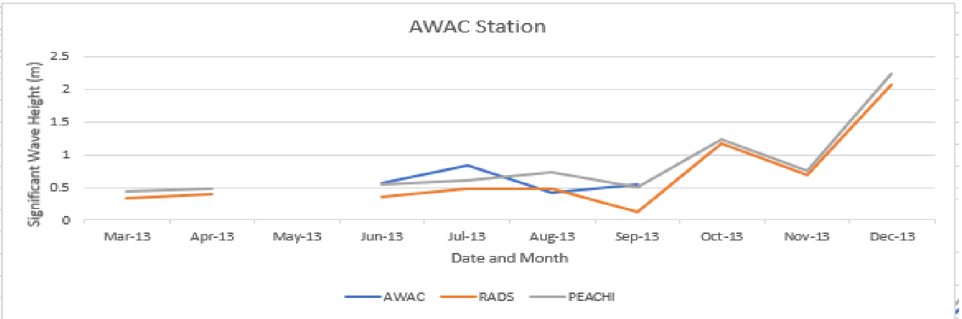

Figure 9. Comparison of time series trend from AWAC (orange) with hourly significant wave height (SWH), RADS (blue) and PEACHI (grey) at AWAC station (Peninsular Malaysia) using Pass 494 of altimeter track. Units are meter.

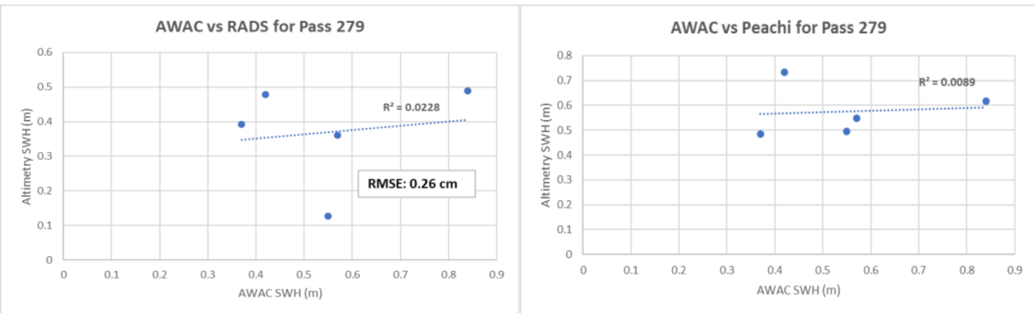

Figure 10. Correlation analysis, R^2 and RMSE comparison with hourly significant wave height (SWH) from AWAC versus RADS (left) and tide AWAC versus PEACHI (right) at AWAC station (Peninsular Malaysia).

The highest difference obtained in root mean square error (RMSE) is from RADS, which is at 0.18m, and the lowest difference obtained is from PEACHI, which is at 0.26m. The AWAC station show the correlation analysis, R^2 value below 0.02. The correlation analysis using RADS data is better than PEACHI. It can be said that the correlation analysis using RADS and PEACHI is acceptable. The relative error between ground truth station and satellite altimetry as mentioned by [19] is fairly equal. Satellite altimeter can now accomplish a consistent and accurate wave height in a large coverage area. With the ground truth measurements, altimeter measurements have shown a good significant accuracy [20]. Table 7 shows the correlation analysis, R^2 and root mean square error (RMSE) summaries for each station.

Table 7. R^2 and RMSE summaries at AWAC station with altimetry for RADS and PEACHI

Altimetry	Ground Station	Cycle	Pass	Correlation (R^2)	RMSE (m)
RADS	AWAC	1-8	494	0.0228	0.26
PEACHI	AWAC	1-8	494	0.0089	0.18

3.3. Variation of sea level anomaly in relating to distance to coast

Next, distance to coastal analysis is performed to extend the assessment of sea level anomaly data from RADS and PEACHI. The data span used for this analysis is from 1st March 2013 and up to 31st December 2015 as shown in Figure 11.

The area of interest for the analysis of distance to coast is shown in Figure 11 by using Passes 279, 322, 507, 494 and 808 of altimeter track. All datasets from low frequency (RADS) and high frequency (PEACHI) are evaluated in relating to the distance to coast by computing the standard deviation of residual for sea level anomaly. Referring to Figure 11, the results show that the standard deviation of residual from distance to coast for PEACHI using Pass 279 achieves a satisfactory result ranged between 0.014cm to 1.5cm. Meanwhile, standard deviation of residual for RADS data shows a higher variation ranged between 3.02cm to 4.80cm. The finding provides a similar result to Pass 322 with RADS data having a higher variation compared to PEACHI data. The standard deviation of residual for RADS is ranged at 0 cm to 14.20cm and PEACHI at 0cm to 2.87cm, respectively.

Similar to other stations, RADS data shows higher variation compared to PEACHI for the standard deviation of residual. Figure 11 also shows that using Pass 494, RADS data have higher variation, ranging between 0.79cm to 4.73cm, while PEACHI only have variation ranging between 0cm to 0.81cm. With Pass 808 at Bintulu, ranged between 1.9cm to 4.7cm using RADS while 0cm to 1.3cm when using Peachi datasets. Only for Pass 507 does the variation between RADS and PEACHI show almost similar variation, which is 0.19cm to 1.27cm for RADS and 0.07cm to 1.52cm for PEACHI. This may be because the track of both altimetry data is almost the same. These results may relate to the altimeter footprint with PEACHI data having smaller footprint at ~200m interval compared to RADS data with footprint at ~7km interval as discussed also by [3].

3.4. Variation of significant wave height in relating to distance to coast

Distance to coast analysis has been performed to extend the assessment of significant wave height data from RADS and PEACHI. The data span used for this analysis is from 1st March 2013 to 31st December 2015 as shown in Figure 12. The region of interest for the analysis of distance to coast is shown in figures below by utilizing Passes 279 of altimeter track. All datasets from low frequency (RADS) and high frequency (PEACHI) are assessed in identifying the distance to coast by registering the standard deviation of significant wave height. Referring to Figure 12, the outcome shows that the distance to coast for RADS in terms of standard deviation of residual utilizing Pass 279 accomplishes a good outcome with range at 5.82cm to 6.65cm. Result in this study for both measurements appear to be equal after five kilometres from the coast to a distance of 50km, which is ranging below 1 meter. Only at an early distance does the standard deviation of the residual show a poor decision. This may be because the altimeter track is contaminated with the land [4].

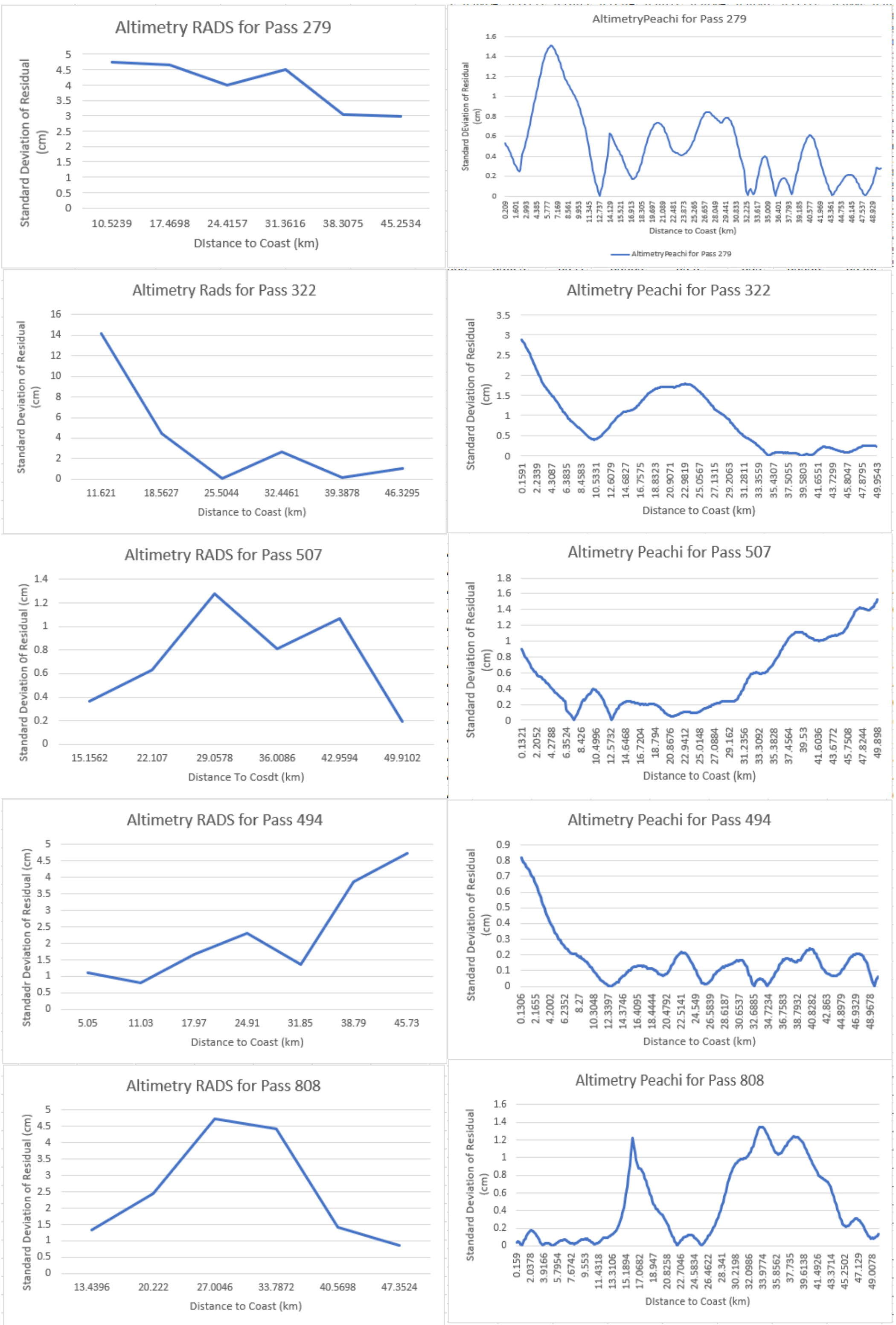

Figure 11. Comparison of standard residual deviation between RADS (1Hz) and PEACHI (40Hz) from distance to coast for all passes involved.

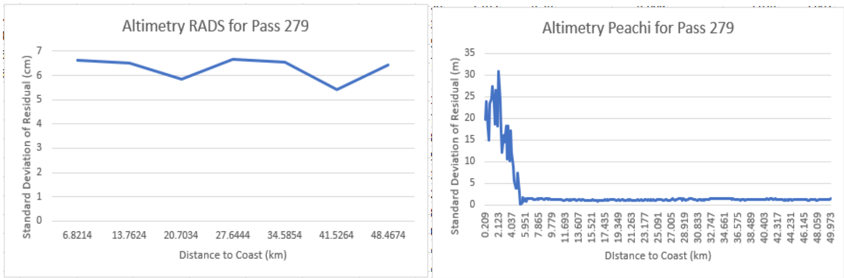

Figure 12. Comparison of standard residual deviation from distance to coast between RADS (1Hz) and PEACHI (40Hz) for Pass 494.

3.5. Coastal Altimetry data in the South China Sea
Based on the results, the assessment of coastal altimetry data near the region of Malaysia shows promising findings, which is that all tide stations show good correlation with the altimeter data, especially for the Geting, Kota Kinabalu and Tg Sedili station. It shows the previous approach by using RADS is good for the correlation between altimeter and tidal data. However, the correlation between both data shows poor correlations, which is less than 0.07cm when it comes to the high frequency data, which may due to the proximity of altimeter track with the tide stations. Moreover, the footprint interval is only approximately 200m each as the footprint of the altimeter is contaminated with the land near the coast as discussed by [4]. For the correlation analysis, it can be assessed that the low frequency is better than the high frequency as previous approach is using the low frequency. Instead of using high frequency that shows poor correlation, it shows inverted results in which all tide stations display high root mean square error (RMSE) difference rather than low frequency data.

For the significant wave height, it is difficult to see the overall correlation at Malaysia region due to the unavailability of data. Data is only available every three months, thus it is hard to say whether the high or low frequency is better. For example, the result of correlation between high and low frequency with the AWAC data is almost the same as shown in Figure 10 and same also with the root mean square error (RMSE) difference. It can be seen the agreement of AWAC and altimeter when more AWAC or Buoy stations are assessed. Overall, the least difference between both measurements still show that the low frequency is better that high frequency for assess the significant wave height (SWH) in terms of standard deviation of residual.

The verification of sea level anomaly and significant wave height data using a time series graph and statistical analysis has shown the reliability of sea level anomaly and significant wave height data form satellite altimeter. In addition, the assessment of coastal altimetry data from satellite altimeter gives a good opportunity to highlight the benefit of this study, which is the development of coastal area by various agencies.

4. Conclusions
The assessment of coastal altimetry data in the South China Sea using multiple frequency approaches have been performed and several significant findings has been taken into account. Coastal altimetry is a preferred tool for measuring greater coverage of sea level anomaly data in Malaysia, including Sabah and Sarawak, where the number of tide gauge stations is still limited in number and geographical range. For the significant wave height, satellite altimetry is also believed to be the alternative to the ground truth station in measuring larger coverage of area where the number of stations is also limited in number.

In conclusion, RADS and PEACHI are extremely useful in research and education as well as in the operational and industrial use of radar altimeter data products. However, more study and analysis, particularly for high frequency of altimetry data, is highly recommended as it is expected that this type of data would be of major benefit particularly for coastal applications in future.

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