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Research on Method to Detect Outlier Values of the Significant Wave Heights Derived from Sentinel-3a Satellite Altimetry Data in the East Sea

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Abstract: *The paper focuses on the research of detecting and removing outlier values in significant wave height data derived from satellite altimetry data over the East Sea. The significant wave heights, derived from data of two frequency bands: Ku band and C band, create a dual measurement set of the significant wave height. Based on the difference between these two significant wave height values, the limits of outlier values can be determined according to statistical probability theory. The candidate outliers are again verified by comparing with the values of neighboring points to decide whether to remove them from the dataset. The experiments were performed with significant wave heights derived from Sentinel-3A satellite altimetry data over the East Sea. The experimental results show that 10 out of 5177 points, accounting for 0.19%, have significant wave height values that are outliers and are removed from the dataset. These removed points are distributed in places with poor satellite altimetry measurement accuracy such as near islands or near the mainland. The method of this paper is useful to remove poor quality values from significant wave height datasets before putting them into use.*

Keywords: *Outlier value, Significant wave height, Satellite altimetry, East Sea*

1. Introduction

In recent years, satellite altimetry has advanced rapidly and has been effectively applied in a wide range of fields including geodesy, geophysics, oceanography, meteorology, and environmental studies. In geodesy, satellite altimetry data enable the determination of mean dynamic topography, marine geoid, marine gravity anomalies, and seafloor topography... In geophysics, these data allow for the investigation of the structure and composition of the Earth's crust beneath the ocean floor. Satellite altimetry has also been instrumental in generating the first global maps of sea ice and monitoring ice melt associated with global warming. Furthermore, satellite altimetry data are widely used for studying ocean currents and estimating significant wave height, among other applications.

To date, satellite altimetry remains the only technique capable of providing global ocean measurements with consistent accuracy, timeliness, and at relatively low cost (Fu and Cazenave, 2001). Numerous satellite altimetry missions have been launched, are currently operating, or are planned for the future, offering a rich source of data for marine research (Fig. 1).

One of the key applications of satellite altimetry is the estimation of significant wave height. Significant Wave Height (SWH) is defined as the average height of the highest one-third of the waves in a wave record. In the altimetry, SWH is the mean height of the highest one-third of waves, derived from the shape of the return radar waveform measured by the altimeter. The use of altimetry data to monitor ocean wave height and assess wave energy potential has been implemented effectively in several countries. For instance, in (Queffelec and Bentamy, 2007), the authors analyzed wave height variations in the Mediterranean Sea using data from 14 satellite altimetry missions. Their study proposed a methodology for analyzing wave height from satellite data, which can be applied to other geographical regions. Similarly, in (Wan et al., 2015) the authors evaluated wave energy resources in a study area using multi-satellite altimetry data. They produced wave energy maps and calculated wave energy indices, demonstrating the effectiveness and feasibility of using satellite altimetry for wave energy assessment. Korobkin and D'Sain assessed significant wave height in the Gulf of Mexico using Jason-1 data, reporting an accuracy of ± 0.17 m to ± 0.30 m when compared with buoy measurements (Korobkin and D'Sain, 2007). In 2015, Sepúlveda

Hector et al. compared wave height estimates from SARAL/AltiKa, Jason-2, and CryoSat-2 satellites, finding that SARAL/AltiKa data yielded more accurate results than Jason-2 (Sepúlveda Hector et al., 2015). In another study, in 2015, Jayaram et al. evaluated wave height and wind speed over the Indian Ocean using SARAL/AltiKa, achieving accuracies of ± 0.21 m for wave height and ± 0.01 m/s for wind speed (Jayaram et al., 2015).

In the Baltic Sea, Kudryavtseva and Soomere analyzed wave height measurements derived from multiple satellites including CRYOSAT-2, ERS-1/2, Jason-1/2, SARAL, ENVISAT, GEOSAT, and TOPEX. Their comparison with buoy data showed wave height accuracy ranging from ± 0.23 m to ± 0.37 m (Kudryavtseva and Soomere, 2016). Similarly, in Malaysian waters, scientists evaluated wave height using various satellite altimeters, reporting a wave height accuracy of ± 0.18 m when compared with buoy observations (Uti et al., 2018).

These studies consistently demonstrate that wave height derived from satellite altimetry is reasonably accurate, with typical errors ranging from ± 0.17 m to ± 0.37 m. Accuracy assessments based on comparisons with buoy data are generally reliable, but are often limited by the sparse availability of in-situ measurements. Consequently, outliers in the altimetry-derived wave height data may go undetected and unfiltered prior to analysis and application.

This paper focuses on developing a method for detecting and removing anomalous values in significant wave height data derived from satellite altimetry over the East Sea. The approach is based on analyzing the consistency of wave height values obtained from two radar frequency bands: Ku-band and C-band.

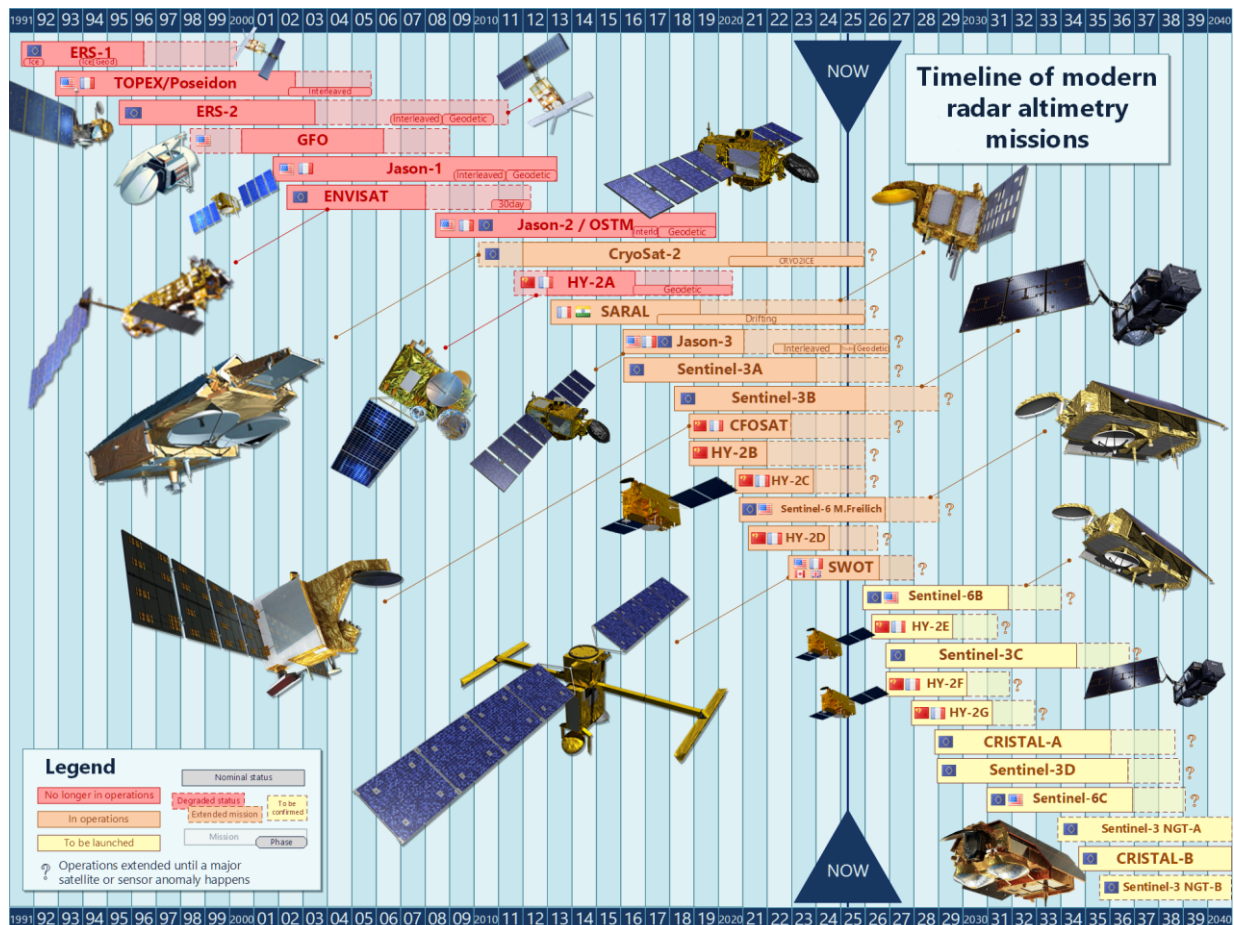


Fig. 1. Altimeter satellite missions (Aviso+, 2025)

2. Study Area and Data

2.1. Study Area

The study area covers the Vietnamese coastal waters and adjacent regions, bounded by latitudes 5.5°N to 25°N and longitudes 104.5°E to 117.5°E (Fig. 2). This region is characterized by complex oceanographic conditions, including highly variable tides, waves, and currents, all of which significantly influence the accuracy of corrections applied to satellite altimetry data.

There are multiple tidal regimes across the study area. In the northern part, the tide is characterized as regular diurnal. The central region experiences an irregular diurnal tide, while the southern region displays a more complex pattern, ranging from semidiurnal to diurnal tides with large tidal amplitudes (Ha, 2015).

Surface circulation in the East Sea exhibits strong seasonal variation, dominated by two large-scale gyres. During the northeast monsoon (winter), the surface current system is primarily driven by prevailing winds and partially influenced by thermohaline circulation resulting from spatial variations in seawater temperature and salinity. A distinctive feature of this period is the development of a large cyclonic gyre covering the entire basin (Rong, 1994). In contrast, the southwest monsoon (summer) generates a different current system, strongly shaped by the southwest wind field and the Intertropical Convergence Zone, which lies diagonally across the region from northwest to southeast. Additionally, the intensification of warm water inflow from the deep southeastern offshore area leads to the formation of anticyclonic gyres that counterbalance the winter gyres (Xu et al., 1980).

Significant wave height (SWH) in the region also exhibits considerable spatial variability. The lowest wave heights, generally below 3 meters, are found in the western Gulf of Thailand. In contrast, the highest wave heights – exceeding 12 meters – occur in the northeastern East Sea, a region frequently affected by tropical cyclones and strong northeasterly winds. In the central Gulf of Tonkin, wave heights can reach 9 – 10 meters, while in the central part of the East Sea, maximum wave heights are approximately 11 meters (Le, 2005).

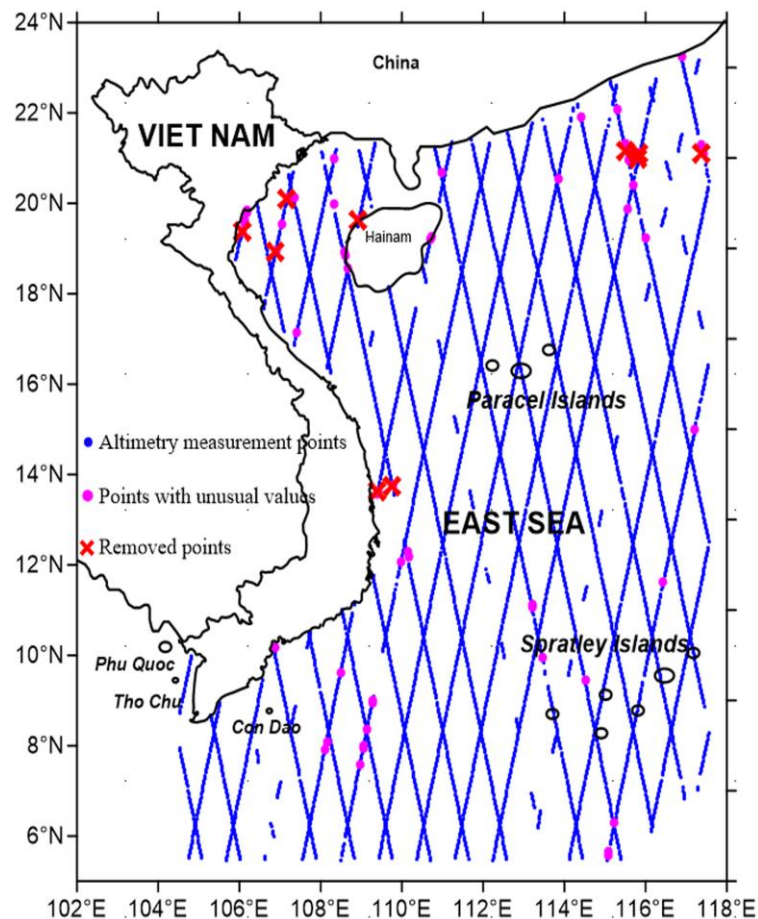


Fig. 2. Study Area and Data

2.2. Research Data

The dataset used in this study comprises significant wave height measurements derived from the SENTINEL-3A satellite during Cycle 2. A total of 5,177 data points were collected between 13 March 2016 and 8 April 2016. The wave height values were determined using data from both the Ku-band and C-band radar frequencies. All measurement locations are referenced in the WGS-84 coordinate system. The data were provided by the European Space Agency (ESA).

Sentinel-3A is a satellite developed under the Copernicus Programme, jointly operated by the

European Space Agency and the European Commission (EC). It was launched into orbit on 16 February 2016. The satellite is equipped with multiple advanced Earth observation instruments, most notably the Synthetic Aperture Radar Altimeter (SRAL), which enables precise measurements of sea surface height, significant wave height, and ocean dynamics (ESA, 2016; Donlon et al., 2012).

3. Research Methodology

3.1. Calculation of Wave Height Differences from Ku-band and C-band Data and Detection of Outliers

Onboard the Sentinel-3A satellite, the Synthetic Aperture Radar Altimeter (SRAL) operates simultaneously at two radar frequency bands: the C-band and the Ku-band, in order to enhance the accuracy and reliability of surface measurements over both ocean and land. The Ku-band, operating at approximately 13.575 GHz, serves as the primary frequency for measuring sea surface height, significant wave height, and ocean surface currents. Due to its high sensitivity to sea surface roughness, the Ku-band provides data with high resolution and accuracy, making it particularly effective under rough sea conditions. The C-band, operating at approximately 5.41 GHz, has a longer wavelength and is less affected by atmospheric conditions such as water vapor or rain. Data from the C-band are primarily used to correct ionospheric and tropospheric errors that may affect Ku-band signals, thereby improving the overall measurement accuracy (ESA, 2016).

Both frequency bands provide independent estimates of significant wave height. By comparing the wave heights obtained from the Ku-band and C-band at the same measurement points, the wave height difference can be calculated. This difference is useful for assessing measurement accuracy and identifying anomalous or outlier values in the wave height dataset.

Let SWH_i^{Ku} and SWH_i^C denote the significant wave heights derived from the Ku-band and C-band, respectively, at the same observation point i . The secondary measurement, referred to as the wave height difference at point i , is defined as follows:

$$\Delta SWH_i = SWH_i^{Ku} - SWH_i^C \quad (1)$$

Thus, over the study area, a series of wave height differences can be defined as $(\Delta SWH_1, \Delta SWH_2, \dots, \Delta SWH_n)$. In the absence of measurement errors, the wave heights determined from the Ku-band and C-band at each point i would be equal, i.e., $SWH_i^{Ku} = SWH_i^C$ và $\Delta SWH_i = 0$. This implies that the true value of each difference is zero, and the observed value itself represents the measurement error.

Under this assumption, the root mean square error (RMSE) of the measurements can be estimated using the Gauss formula (Gauss, 1823; Hoang and Truong, 2003) as follows:

$$m_{\Delta SWH} = \pm \sqrt{\frac{[\Delta SWH \cdot \Delta SWH]}{n}} \quad (2)$$

According to the principle of equal influence, the variance of each individual measurement (i.e., from the Ku-band or C-band) contributes equally to the variance of the difference. Therefore, from Equation (1), the standard deviation of each band's measurement can be derived as:

$$m_{\Delta SWH}^2 = m_{Ku}^2 + m_C^2 = 2m_{SWH}^2 \quad (3)$$

Substituting into Equation (3), we obtain:

$$m_{SWH} = \frac{m_{\Delta SWH}}{\sqrt{2}} = \pm \sqrt{\frac{[\Delta SWH \cdot \Delta SWH]}{2n}} \quad (4)$$

According to the theory of probability and statistics, approximately 68.3% of random errors fall within the range of $(-\sigma, +\sigma)$, 95.5% within $(-2\sigma, +2\sigma)$, and 99.7% within $(-3\sigma, +3\sigma)$, where σ denotes the root mean square error (Phan Van Hien et al., 2017). Applying this principle to the dataset of wave height differences ΔSWH_i , we can assume that approximately 99.7% of the values should lie within the range $(-3 \times m_{\Delta SWH}, +3 \times m_{\Delta SWH})$, where $m_{\Delta SWH}$ is the root mean square error of the wave height differences. This implies that values of ΔSWH_i falling within the range $(-3 \times m_{\Delta SWH}, +3 \times m_{\Delta SWH})$ are consistent with the statistical distribution of measurement errors, whereas those falling outside this interval are considered statistically anomalous and may indicate abnormal observations.

In addition, correlation analysis and the construction of a scatter plot between the two types of significant wave height (derived from the Ku-band and C-band) provide valuable insights into their consistency and potential differences. The correlation coefficient R serves as a statistical measure of the strength and direction of the linear relationship between the two datasets. The value of R ranges from -1 to +1: $R = 1$ indicates a perfect positive linear correlation, $R = -1$ indicates a perfect negative linear correlation, $R = 0$ indicates no linear correlation. Thus, if the wave heights derived from the Ku-band are consistent with those from the C-band, the correlation coefficient between them should be approximately equal to 1. The Pearson correlation coefficient R is calculated using the following formula (McKean and Sheather, 2003):

$$R = \frac{\sum_{i=1}^n (SWH_i^{Ku} - SWH_{ave}^{Ku}) \cdot (SWH_i^C - SWH_{ave}^C)}{\sqrt{\sum_{i=1}^n (SWH_i^{Ku} - SWH_{ave}^{Ku})^2 \cdot \sum_{i=1}^m (SWH_i^C - SWH_{ave}^C)^2}} \quad (5)$$

Where SWH_{ave}^{Ku} và SWH_{ave}^C denote the mean significant wave heights derived from the Ku-band and C-band, respectively.

The correlation between the two types of significant wave height can also be visualized using a scatter plot, in which each axis (the x-axis and y-axis) represents the values of one wave height dataset (Fig. 4). If the two datasets are highly consistent, the data points will be concentrated along the identity line $y=x$. Conversely, if there are discrepancies between them, the points will deviate from this line and appear more dispersed.

3.2. Comparison of significant wave heights at potential outliers with neighboring observations

Anomalies in the wave height difference values may result from errors in the Ku-band measurement, the C-band measurement, or both. Since the officially adopted significant wave height values are derived from the Ku-band, any error in the Ku-band data renders that measurement invalid and necessitates its removal from the dataset. However, if the error originates solely from the C-band while the Ku-band measurement remains accurate, the Ku-band value can still be retained and used in further analysis.

To determine the source of anomalies, at locations where the wave height difference is flagged as abnormal, the Ku-band-derived wave height is compared with those of its neighboring points along the satellite track. The deviation from neighboring values is calculated as follows:

$$\delta_{SWH} = SWH_i - (SWH_{i-1} + SWH_{i+1})/2 \quad (6)$$

If the absolute value of the deviation $|\delta_{SWH}|$ is less than three times the standard deviation of significant wave height measurements (i.e., $3 \times m_{SWH}$), the wave height at that point is considered consistent with its surroundings and is retained. Otherwise, it is regarded as an outlier and excluded from the dataset. To increase the reliability of the filtering process, a stricter threshold (such as $2 \times m_{SWH}$) may be applied.

4. Results and discussion

4.1. Results of Anomaly Detection in Significant Wave Height Values

Based on the methodology described above, the statistics of the wave height differences between Ku-band and C-band measurements are summarized in Table 1.

Tab. 1. Statistics of Significant Wave Height Differences

Statistics type	$\Delta WSH_{\max}$ (m)	$\Delta WSH_{\min}$ (m)	$m_{\Delta WSH}$ (m)	R	m_{WSH} (m)
Before removing	2.237	-6.453	± 0.571	0.69077	± 0.405
After removing	1.655	-1.666	± 0.451	0.78043	± 0.320

As shown in Table 1, the discrepancy between significant wave heights derived from the Ku-band and C-band is relatively large, with the maximum absolute difference reaching up to 6.453 meters. The root mean square error of the wave height differences is ± 0.571 meters.

The frequency distribution of wave height differences is shown in Figure 3a. As illustrated, the differences generally follow a normal distribution. However, several values exceed the threshold of three times the standard deviation. These outliers are more frequently distributed on the left side of the histogram than on the right.

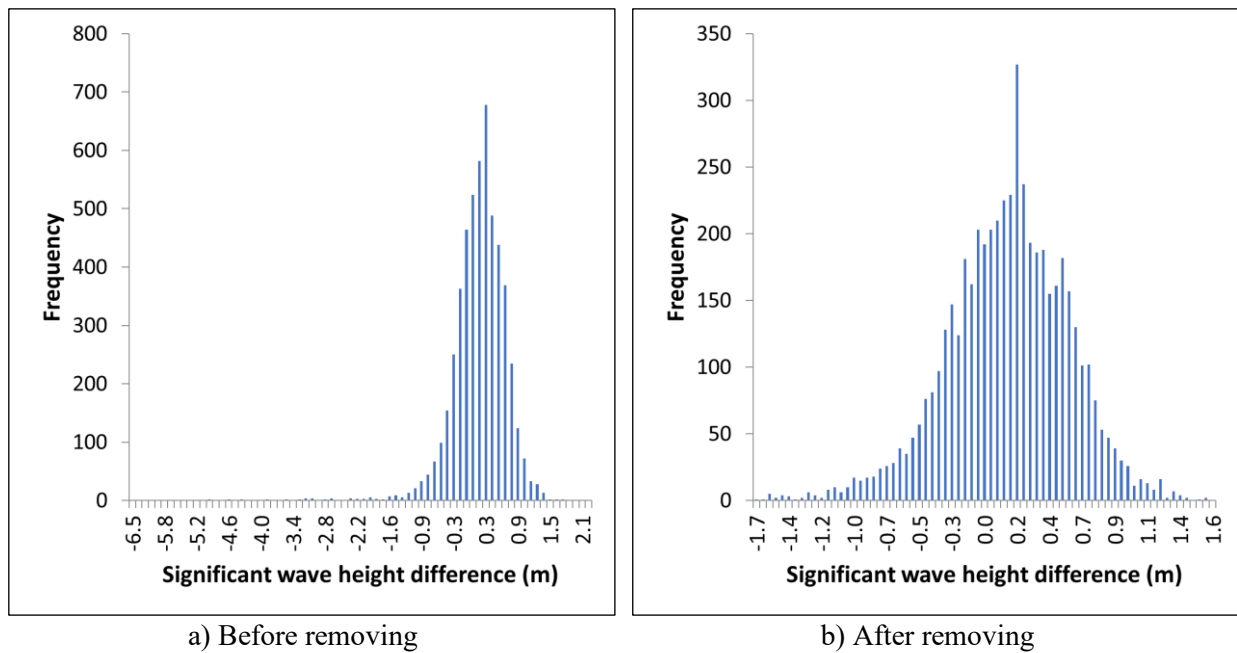


Fig. 3. Histogram of significant wave height differences

The scatter plot illustrating the correlation between significant wave heights derived from the Ku-band and the C-band is presented in Figure 4. As shown in Figure 4a, several data points exhibit substantial discrepancies between the Ku-band and C-band measurements. The correlation coefficient is relatively low, with a value of $R = 0.69077$, indicating only a moderate linear relationship between the two datasets.

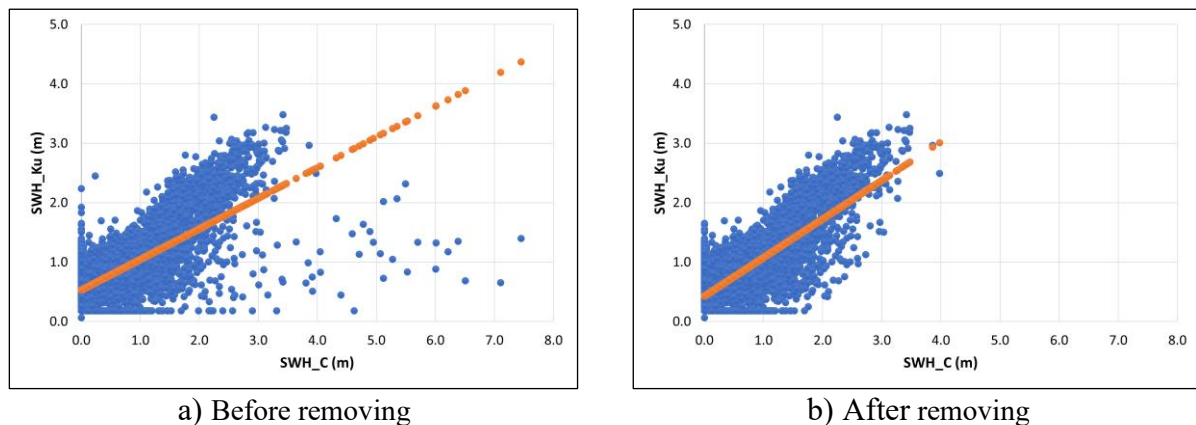


Fig. 4. Correlation plot between significant wave heights derived from Ku-band and C-band measurements

The calculation results indicate that a total of 58 points lie outside the interval $(-3 \times m\Delta SWH, +3 \times m\Delta SWH)$. These potential outliers are depicted as pink circles in Figure 2. They are primarily located near coastlines or around islands, where satellite altimetry typically exhibits reduced measurement accuracy.

After removing these 58 outlier points, the updated wave height statistics are presented in row 3 of Table 1. The revised frequency distribution of wave height differences is shown in Figure 3b, while the updated correlation plot is provided in Figure 4b.

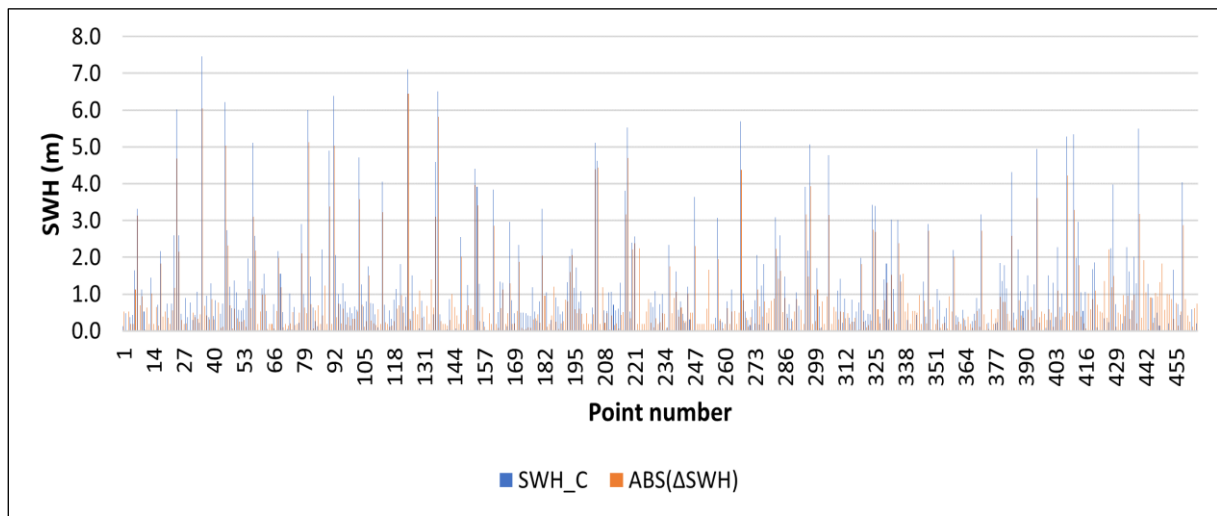
These results demonstrate that, after outlier removal, the wave height measurement accuracy improves to ± 0.320 meters. The distribution of wave height differences more closely follows a random (normal) distribution, and the correlation between Ku-band and C-band wave heights increases significantly, with the correlation coefficient rising to $R=0.78043$.

4.2. Comparison of Wave Heights at Potential outliers with Neighboring Points

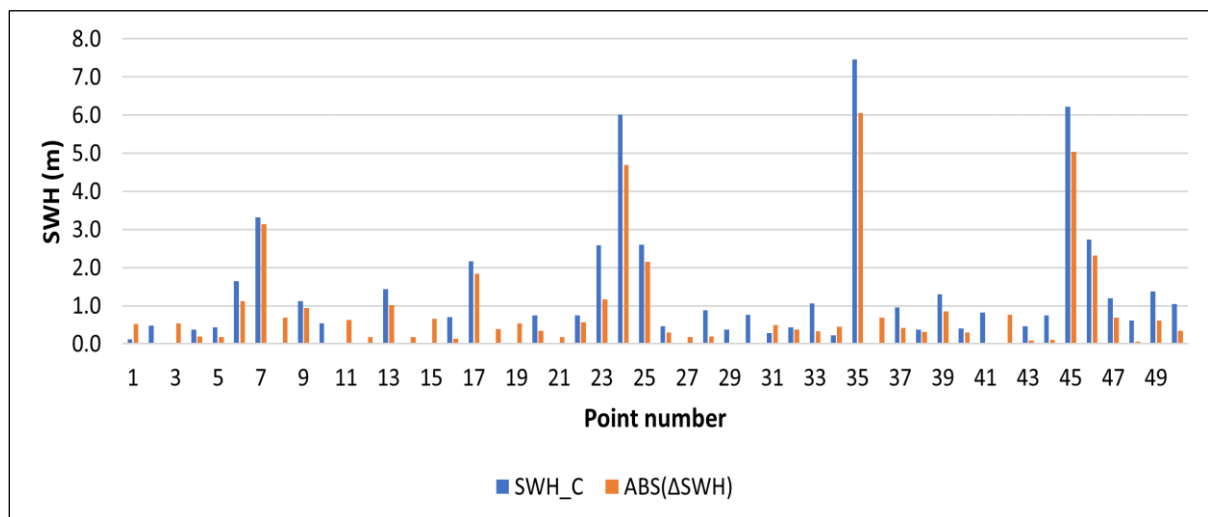
As shown in Section 4.1, removing potential outliers results in a dataset with improved statistical characteristics. However, excluding all these points may be wasteful, especially when the wave height derived from the Ku-band remains accurate. In this section, we investigate and analyze the potential causes

of the wave height anomalies.

To do this, we present the absolute values of the wave height differences at potential outliers, along with the C-band-derived wave heights of several neighboring points, in Figure 5. Figure 5a shows the complete plot, while a magnified portion of Figure 5a is displayed in Figure 5b for better visualization.



a) Full view

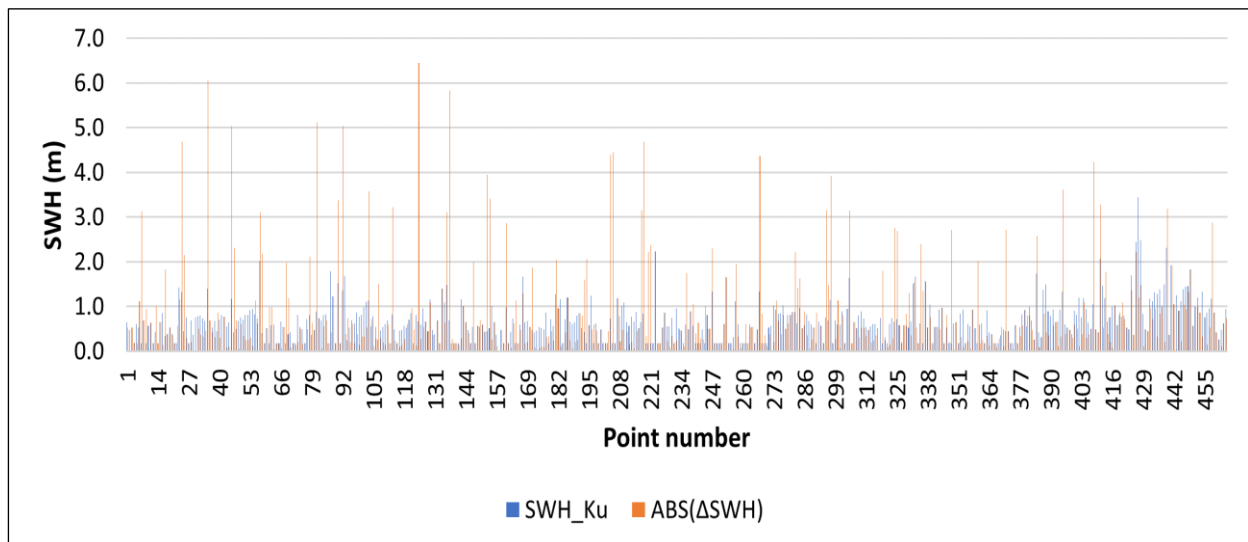


b) Zoomed-in section

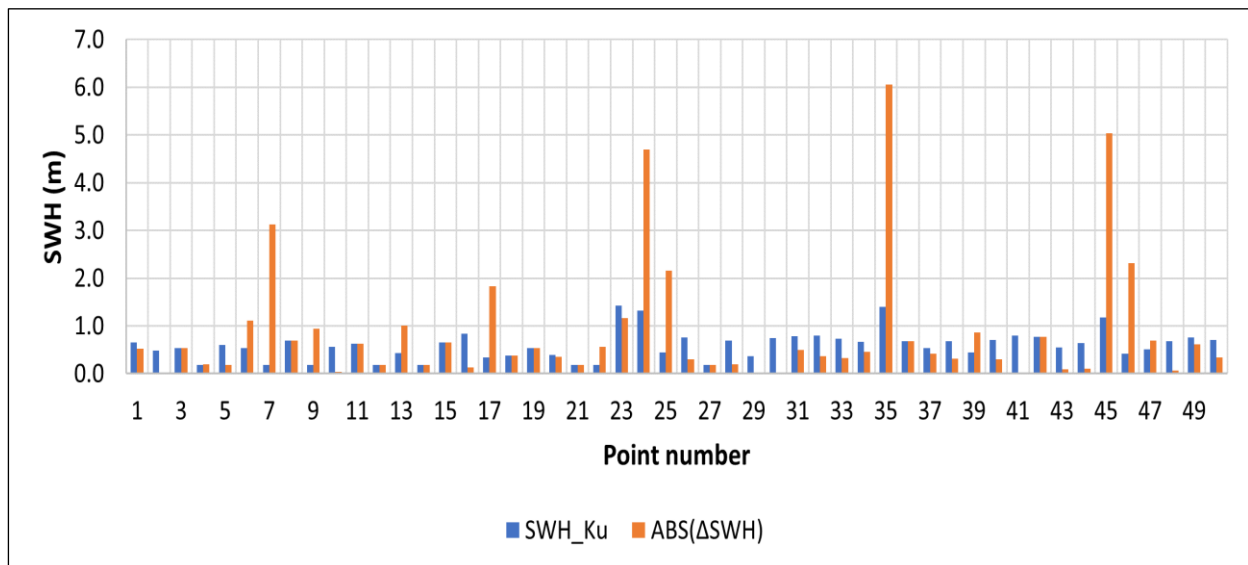
Fig. 5. Plot of the absolute values of wave height differences at potential outliers and the corresponding C-band-derived wave heights at those points and their neighboring locations

From Figure 5, it can be observed that, at points with large absolute values of wave height differences, the C-band-derived wave heights (SWH_C) also tend to be significantly large and differ markedly from those of neighboring points.

Similarly, we plot the absolute values of wave height differences at potential outliers alongside the Ku-band-derived wave heights at those points and their surrounding locations in Figure 6. Figure 6a presents the full plot, while a magnified portion is shown in Figure 6b for better clarity.



a) Full view



b) Zoomed-in section

Fig. 6. Plot of the absolute values of wave height differences at potential outliers and the corresponding Ku-band-derived wave heights at those points and their neighboring locations.

From Figure 6, it can be observed that, at points with large absolute values of wave height differences, the Ku-band-derived wave heights (SWH_Ku) generally do not show significant deviations from neighboring values. This suggests that the primary cause of the discrepancies between wave heights derived from the Ku and C bands is likely due to errors in the C-band measurements rather than the Ku-band. This observation is consistent with the theoretical understanding that Ku-band-derived wave heights are generally more accurate (ESA, 2016).

4.3. Results of Wave Height Deviation Analysis Relative to Neighboring Values

At the potential outliers, the deviations of wave heights derived from the Ku and C bands relative to their neighboring points along the satellite track were calculated using Equation (6). The results are shown in Figure 7. This figure indicates that, at the potential outliers, the deviations of the Ku-band-derived wave heights are significantly smaller than those of the C-band, further supporting the conclusion that the anomalies are primarily due to errors in the C-band measurements.

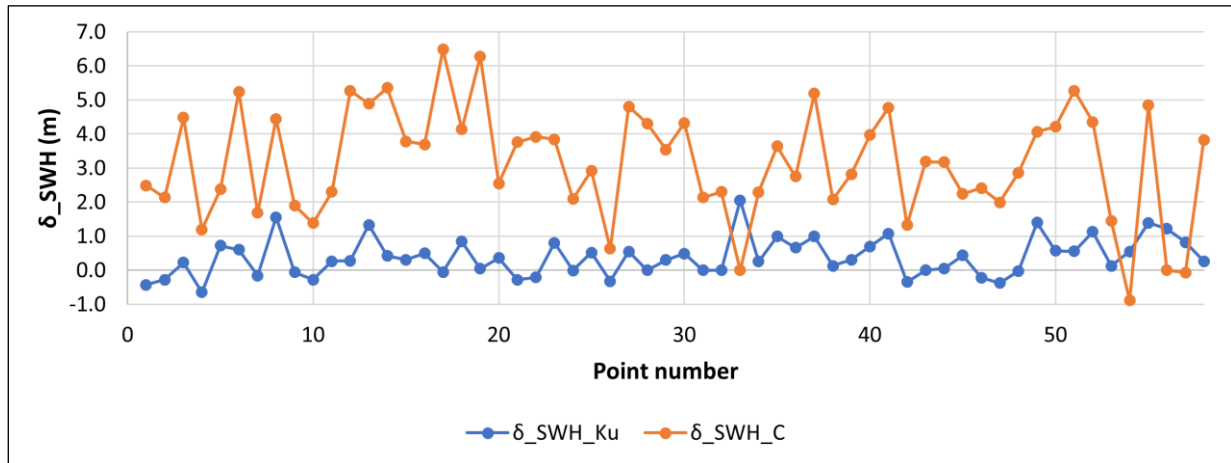


Fig. 7. Deviation of wave heights derived from Ku- and C-band measurements relative to neighboring points along the satellite track

The relationship between the absolute values of the significant wave height differences and their deviations from neighboring point-derived values is presented in Figure 8. Figure 8 reveals that, at potential outliers characterized by large absolute wave height differences ($|\Delta SWH|$), the majority exhibit significant deviations in wave height measurements obtained from the C-band relative to neighboring points ($|\delta_{SWH_C}|$), whereas only a small number of cases show substantial deviations in the Ku-band wave height values ($|\delta_{SWH_Ku}|$).

This finding further reinforces the conclusion that wave height measurements derived from the Ku-band are generally more reliable than those from the C-band. Consequently, the observed anomalies in wave height differences are primarily attributable to errors associated with the C-band measurements.

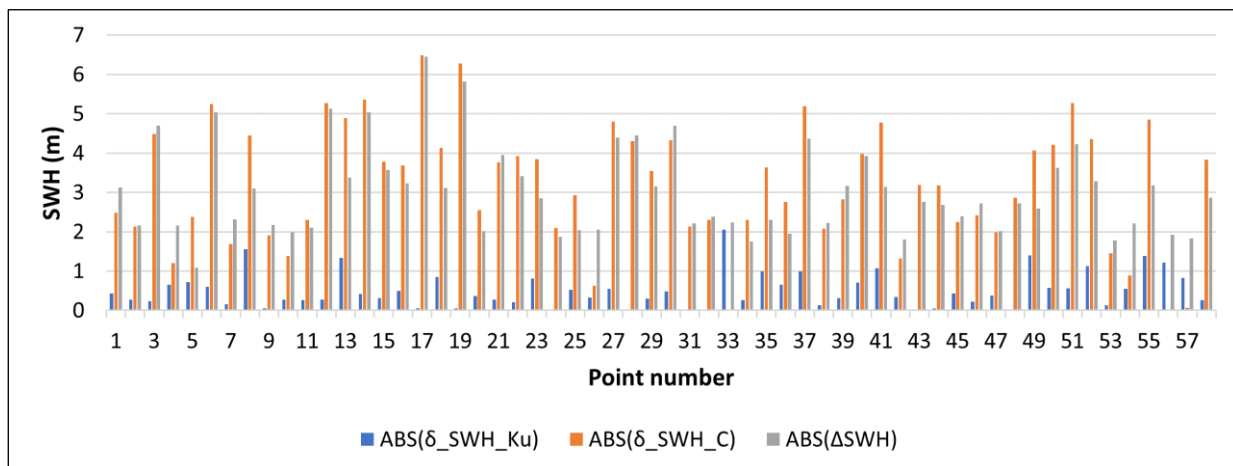


Fig. 8. Relationship between the absolute value of the significant wave height difference and the deviation from values derived from neighboring points

Based on the comparison of wave height deviations derived from the Ku-band with neighboring points using a threshold of two times the root mean square error of wave height ($2 \times m_{SWH}$), we identified 10 points where $|\delta_{SWH_Ku}| > |2 \times m_{SWH}|$. These points are marked with red "X" symbols on Figure 2. As shown in Figure 2, all of these points are located near coastlines or islands - areas where satellite altimetry measurements are often affected by various error sources. These points not only exhibit large wave height differences between Ku-band and C-band measurements, but also display significant deviations in Ku-band-derived wave heights relative to their neighboring values. Therefore, these points were excluded from the significant wave height dataset.

Table 2 lists 58 points with anomalous significant wave height differences, among which 10 points were excluded (highlighted in red). These excluded points exhibit large SWH differences between Ku-band and C-band estimates, as well as large deviations in wave height relative to neighboring points, computed

for both Ku-band and C-band data. The remaining 48 points, although showing large SWH differences and large deviations in C-band-derived wave heights compared to neighboring values, have small deviations in Ku-band-derived wave heights. Therefore, these points are still considered reliable and were retained in the wave height dataset.

Tab. 2. Points with Anomalous Significant Wave Height Differences

STT	B (°)	L (°)	SWH ^{Ku} (m)	SWH ^C (m)	Δ SWH ^(Ku-C) (m)	δ_{SWH}^{Ku} (m)	δ_{SWH}^C (m)
1	10.164924	106.821752	0.181	3.312	-3.131	-0.430	2.488
2	9.932245	113.419916	0.335	2.488	-2.153	-0.277	2.135
3	11.054819	113.165624	1.322	6.011	-4.689	0.229	4.487
4	11.113898	113.152204	0.445	2.602	-2.157	-0.648	1.200
5	20.676730	110.912537	1.398	2.488	-1.090	0.721	2.380
6	19.239088	110.673217	1.175	6.216	-5.041	0.602	5.247
7	19.180097	110.659063	0.415	2.733	-2.318	-0.159	1.686
8	13.631571	109.356521	2.017	5.120	-3.103	1.560	4.445
9	13.572512	109.342922	0.401	2.578	-2.177	-0.057	1.903
10	9.614478	108.441317	0.181	2.163	-1.982	-0.278	1.385
11	8.078048	108.095651	0.803	2.909	-2.106	0.264	2.301
12	7.900755	108.055888	0.884	6.006	-5.122	0.277	5.271
13	21.093277	117.356390	1.513	4.892	-3.379	1.332	4.892
14	21.270153	117.313165	1.352	6.386	-5.034	0.420	5.358
15	23.215179	116.832667	1.133	4.707	-3.574	0.308	3.786
16	9.438557	114.464418	0.827	4.051	-3.224	0.496	3.694
17	12.068148	109.932960	0.654	7.107	-6.453	-0.048	6.482
18	8.995886	109.236445	1.479	4.589	-3.110	0.803	4.137
19	8.936794	109.223138	0.685	6.508	-5.823	0.049	6.281
20	8.345859	109.090234	0.541	2.548	-2.007	0.360	2.548
21	7.991284	109.010625	0.447	4.402	-3.955	-0.276	3.763
22	7.932187	108.997366	0.510	3.919	-3.409	-0.213	3.919
23	7.577601	108.917867	0.986	3.843	-2.857	0.805	3.843
24	14.974164	117.146778	0.470	2.340	-1.870	-0.006	2.093
25	11.607689	116.372539	1.283	3.321	-2.038	0.520	2.923
26	6.289398	115.174447	0.181	2.234	-2.053	-0.326	0.632
27	5.639239	115.029447	0.729	5.120	-4.391	0.548	4.804
28	5.580133	115.016277	0.181	4.625	-4.444	0.004	4.309
29	19.840096	106.142066	0.650	3.807	-3.157	0.302	3.547
30	19.781116	106.127833	0.835	5.526	-4.691	0.487	4.328
31	19.604170	106.085178	0.181	2.397	-2.216	0.010	2.137
32	19.545187	106.070975	0.181	2.561	-2.380	0.008	2.301
33	19.368231	106.028407	2.237	0.000	2.237	2.056	0.000
34	20.105359	107.307136	0.587	2.339	-1.752	0.257	2.298

STT	B (°)	L (°)	SWH ^{Ku} (m)	SWH ^C (m)	$\Delta\text{SWH}^{(\text{Ku}-\text{C})}$ (m)	$\delta_{\text{SWH}}^{\text{Ku}}$ (m)	$\delta_{\text{SWH}}^{\text{C}}$ (m)
35	20.110788	107.142059	1.338	3.642	-2.304	0.997	3.642
36	19.520984	106.999730	1.119	3.072	-1.953	0.660	2.754
37	18.931091	106.858126	1.332	5.701	-4.369	0.996	5.194
38	20.527349	113.788411	0.872	3.093	-2.221	0.126	2.076
39	12.167341	110.104010	0.750	3.913	-3.163	0.313	2.825
40	12.285475	110.077011	1.141	5.065	-3.924	0.704	3.977
41	13.761984	109.738065	1.634	4.778	-3.144	1.074	4.778
42	18.543155	108.617592	0.181	1.988	-1.807	-0.344	1.326
43	18.838127	108.547111	0.663	3.419	-2.756	0.003	3.192
44	18.897119	108.532994	0.713	3.399	-2.686	0.053	3.172
45	19.958823	108.277672	0.617	3.004	-2.387	0.436	2.243
46	20.964804	108.284904	0.181	2.900	-2.719	-0.218	2.414
47	17.130338	107.365511	0.181	2.196	-2.015	-0.372	1.991
48	21.902571	114.349085	0.445	3.163	-2.718	-0.019	2.865
49	19.630783	108.896347	1.734	4.319	-2.585	1.399	4.069
50	19.227884	115.934620	1.333	4.949	-3.616	0.569	4.213
51	20.938113	115.520884	1.045	5.275	-4.230	0.559	5.275
52	21.173944	115.463307	2.065	5.350	-3.285	1.126	4.358
53	21.291854	115.434470	1.190	2.971	-1.781	0.126	1.456
54	22.058167	115.246223	2.449	0.237	2.212	0.550	-0.886
55	21.106341	115.799378	2.316	5.495	-3.179	1.392	4.852
56	20.988416	115.770591	1.925	0.000	1.925	1.220	0.000
57	20.398730	115.627127	1.831	0.000	1.831	0.804	-0.068
58	19.867931	115.498669	1.176	4.046	-2.870	0.267	3.830

4.4. Method for Detecting and Removing Unreliable Significant Wave Height Data

Based on theoretical analysis and empirical results, we propose a systematic procedure for detecting anomalous values and eliminating unreliable satellite altimetry-derived significant wave height data. The approach is outlined as follows:

Step 1. Calculate the difference in SWH derived from Ku-band and C-band measurements for each observation point ($\Delta\text{SWH}^{\text{Ku}-\text{C}}$)

Step 2. Compute the root mean square error of the SWH differences, $m_{\Delta\text{SWH}}$, and the root mean square error of the SWH, m_{SWH} ;

Step 3. Retain the points where the SWH difference ($\Delta\text{SWH}^{\text{Ku}-\text{C}}$) falls within the interval $(-3 \times m_{\Delta\text{SWH}}, 3 \times m_{\Delta\text{SWH}})$;

Step 4. For points where ΔSWH falls outside the interval $(-3 \times m_{\Delta\text{SWH}}, 3 \times m_{\Delta\text{SWH}})$, compute the deviation of Ku-band SWH compared to neighboring points ($\delta_{\text{SWH}}^{\text{Ku}}$);

Step 5. Retain the points where ($\delta_{\text{SWH}}^{\text{Ku}}$) falls within the interval $(-2 \times m_{\text{SWH}}, 2 \times m_{\text{SWH}})$;

Step 6. Eliminate the points where ($\delta_{\text{SWH}}^{\text{Ku}}$) falls outside the interval $(-2 \times m_{\text{SWH}}, 2 \times m_{\text{SWH}})$.

5. Conclusion

This study investigated and proposed a method for detecting anomalous values and identifying unreliable measurements in satellite altimetry-derived significant wave height datasets. The proposed approach is essential for filtering out erroneous data before utilizing the SWH dataset in applications.

By calculating the difference in SWH derived from Ku-band and C-band observations, the root mean square error of this differential indicator was computed. Points exhibiting absolute differences greater than three times the standard deviation were flagged as potentially anomalous.

While some of these anomalies may stem from errors in Ku-band estimates, analysis shows that the majority are due to inaccuracies in the C-band measurements. Consequently, the deviation of Ku-band SWH values relative to their neighboring points was used as a criterion to determine whether a measurement should be retained or discarded.

Experimental results using a dataset of 5,177 SWH observations from the Sentinel-3A satellite over the East Sea revealed 58 potential outliers based on Ku–C band differences. Among them, 10 points (accounting for 0.19% of the total) were identified as unreliable and removed. These discarded points are primarily located near coastlines or islands, where satellite altimetry accuracy tends to degrade due to complex surface conditions.

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