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Feasibility of maintaining satellite altimetry calibration site based on qianliyan islet at the Yellow Sea

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ABSTRACT

The calibration of the sea surface height (SSH) measured by satellite altimeters is essential to understand altimeter biases. Many factors affects the construction and maintenance of a permanent calibration site. In order to calibrate Chinese satellite altimetry missions, the feasibility of maintaining a calibration site based on the Qianliyan islet in Yellow Sea of China is taken into account. The related calibration facilities, such as the permanent tide gauge, GNSS reference station and meteorological station, were already operated by the Ministry of Natural Resources of China. The data could be fully used for satellite altimeter calibration with small fiscal expenditure. In addition, the location and marine environments of Qianliyan were discussed. Finally, we used the Jason-3 mission to check the possibility of calibration works. The result indicates that the brightness temperatures of three channels measured by microwave radiometer (MWR) and the derived wet tropospheric correction varies smoothly, which means the land contamination to MWR could be ignored. The high frequency waveforms at the Qianliyan site present no obvious difference from the normal waveforms received by satellite radar altimeter over the open ocean. In conclusion, the Qianliyan islet will not influence satellite altimetry observation. Following these analyses, a possible layout and mechanism of the Qianliyan calibration site are proposed.

1. Introduction

Accurate measurements of sea surface height (SSH) have been made available by altimeter missions since 1992. Altimeter measurements and the geophysical corrections used in the SSH computation are still subject to some degree of uncertainty. To assess the uncertainty of the satellite altimetry measurements, the calibration and validation are required in the entire system for each altimetry mission. Calibration aims to guarantee that the instrument's performance conforms to SI (International System of Units) or community accepted standards, and to each mission's specific requirements. Validation entails quantifying the precision of satellite-derived geophysical products. The two concepts are collectively referred to as “Cal/Val” [1].

The main object of calibration and validation is to evaluate the performance of the altimetry satellite system and provide early warnings of potential problems. The main approach of this work is to determine the bias of the altimetry system and its drift. Among the satellite altimetry missions of the recent 30 years, calibration is a necessary process to guarantee product quality. During the development of satellite altimetry, many problems were found through the work of Cal/Val. For example, the SSH bias of Jason-1 was estimated to be about 13 cm one year after the launch [2–4], and the SSH bias of Jason-2 at the Ku band is estimated to be about 16 cm initially [5–8]. After plenty of repeat checks, an instrumental error of 15.6 cm of Jason-2 was found and corrected [9]. Besides, the calibration of each altimetry satellite is a precondition in unifying several altimetry satellites' data.

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At present, there are mainly four permanent calibration sites, located at Harvest Oil Platform [5,10,11], Bass Strait [8,12,13], Corsica Island [14–16] and Gavdos Island [6,17–19], worked for more than ten years. Cross-comparisons are made possible by redundant results discovered by these Cal/Val sites using various methods, settings, and instruments. Additionally, when Cal/Val results are inconsistent between different sites, this suggests that further research regarding the identification and determination of the error sources is necessary. After the Chinese HY-2A satellite altimeter was launched in 2011, the vital requirement for building permanent calibration sites in China was raised. Recently, the Wanshan altimetry calibration site is constructed in the South China Sea, which has already worked to calibrate HY-2 series satellites (HY−2B/C/D) [20,21].

To raise the reliability of calibration, the construction of redundant calibration sites around China is necessary for the calibration of Chinese altimetry satellites, this paper analyzed the possibility of maintaining a permanent calibration site at the Qianliyan islet located in the Yellow Sea. Besides the Wanshan site, Qianliyan has also been chosen to calibrate the HY-2, Saral/AltiKa and Jason missions [22,23]. According to these works, the calibration results are consistent with those derived from other dedicated calibration sites. However, such works over the Qianliyan site were experimental, and this site was not fully operational for altimetry calibrations. This paper will discuss whether Qianliyan is fully qualified to serve as a permanent calibration site for Chinese satellite altimetry missions, which has not yet been determined.

2. Calibration methods

Sea surface height comparison-based altimetry calibration techniques can be broadly categorized into four types based on the work done in various calibration sites. These methods are known as the fixed platform method, the tide gauge method, the GNSS buoy method, and the oceanographic moorings method.

Among these methods, except the tide gauge method, in situ SSH is directly measured by equipment deployed on the satellite ground track and away from the seashore. The equipment contain a tide gauge, GNSS buoy, GPS-zodiac system, or oceanographic moorings. These methods could be categorized as the direct method. In this method, SSH measured by altimetry satellite is compared with in situ SSH directly. In the standard tide gauge method, in situ SSH is measured by a tide gauge installed along the coast. In situ SSH should be extrapolated to a comparison point at open sea where satellite altimetry is valid. To reduce land contamination to the on-board microwave radiometer, the comparison point is always chosen to be approximately 20 km away from the tide gauge. Then, the tidal and geoid difference between tide gauge and the comparison points should be corrected.

Both direct and indirect methods were used by different calibration sites [5,6,8,10–19]. Since the precision of tidal and other models used in the compensation to differential sea surface height between comparison point and in situ measurements is constrained in indirect calibration methods, direct calibration methods are typically more frequently used than indirect calibration methods. Through the analysis of existing calibration sites, in all the conditions that a calibration site should satisfy, there are two necessary factors:

First, the SSH measured by altimetry satellite must be precise. There should be an appropriate comparison point which located on the ground track of the altimetry satellite. At this point, the waveforms of the altimeter should not be polluted by land or island, and meanwhile, the brightness temperatures measured by MWR should not be polluted as such. For instance, in the practice of the Bass Strait site, the compare point is set to about 15 km from the closest land in the beginning. Considering the influence of land on MWR, the comparison point is set to about 25 km from the closest land since the later 2000s [8].

Second, the in-situ SSH measured or extrapolated at the comparison point must be precise. If the in-situ SSH is measured directly at the comparison point, then the precision is relatively guaranteed but the problem is that the maintenance payout is great. If the in-situ SSH is extrapolated at the comparison point, then the precision of tidal and geoid models limits the calibration precision.

3. Environment of qianliyan and its influence on satellite altimetry measurement

As mentioned above the method should be carefully designed according to the marine environment around the calibration site to gain valid calibration results. This section introduces the geographical environment around Qianliyan is the influence of Qianliyan islet on satellite altimetry measurement.

3.1. Geographical environment

As shown in Fig. 1, Qianliyan is located in the center of the red cycle. This islet is about 45 km away from the nearest mainland, and its area is about 0.16 km^2. The mean water depth around the islet is about 30 m, which is very suitable for the deploying of oceanographic moorings to monitor the SSH. The satellite image [23] shows that the islet has the shape of a dumbbell, and the thinnest width is less than 100 m. Fig. 2 shows the variation of significant wave height (SWH) in this area derived from the first 200 cycles of Jason-3. The change of sea state is not too rough around the islet, which is beneficial for the calibration work.

On this islet, many facilities are relational to altimetry satellite calibration, including the permanent tide gauge, GNSS reference

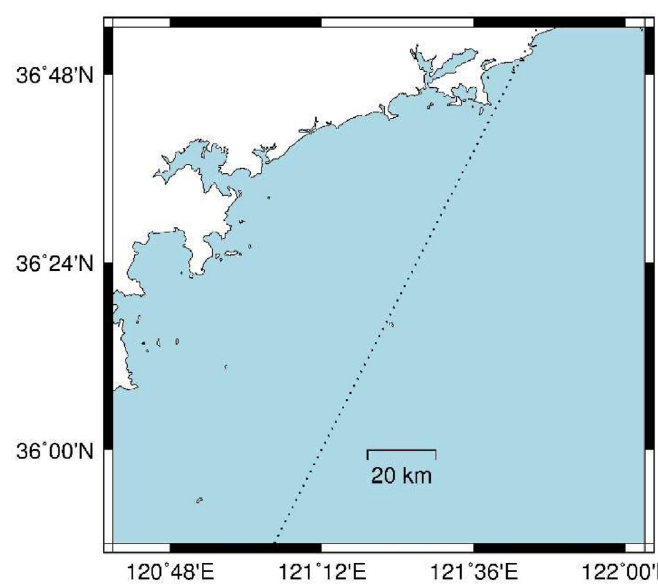

Fig. 1. The location of Qianliyan islet (the dashed line shows the ground track of Jason-3, pass No. 153).

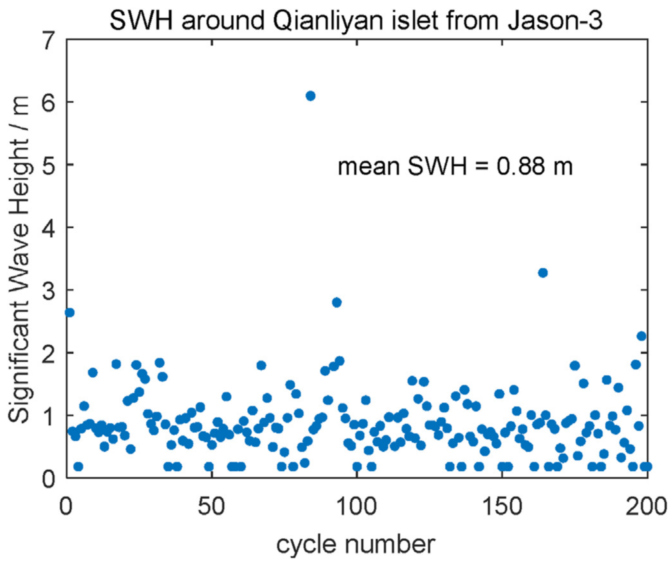

Fig. 2. SWH around Qianliyan islet from the first 200 cycles of Jason-3.

station and meteorological station [23]. These facilities all run in automatic mode, are hosted by the Ministry of Natural Resources of China. It is worth mentioning that the permanent tide gauge is standard well, which supplies accurate sea level measurements.

If the land of Qianliyan does not influence the measurement of the on-board altimeter and microwave radiometer, then this area could be well served for the calibration of altimetry satellite. The tide gauge could be worked as a permanent foundation that supplies high precision in situ SSH measurement without additional financial or workforce payout. The critical problem is whether the land is small enough. Fortunately, the Jason series altimetry satellites pass by this islet, and the geophysical data records supply an excellent opportunity to solve this question. The ground track of the first 200 cycles of Jason-3 passing by Qianliyan is shown in Fig. 3.

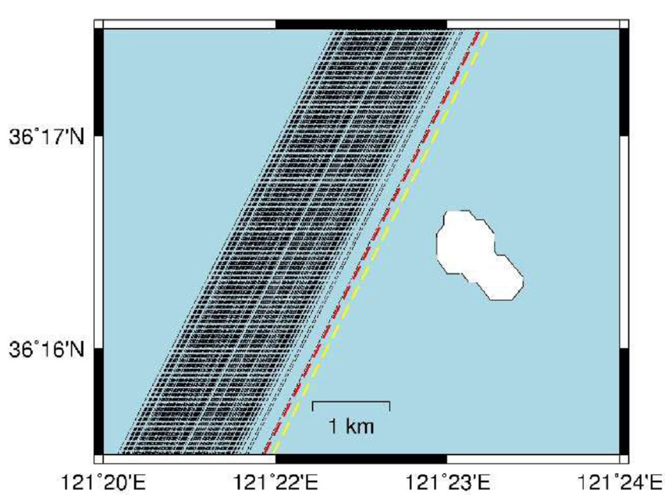

Fig. 3. Ground track of Jason-3 and location of Qianliyan islet. Among these cycles, the ground track of cycle No. 183 is the nearest one to Qianliyan (shown in yellow, the distance is less than 600 m), and the ground track of cycle No. 117 is beside cycle No. 183 (shown in red, the distance is less than 700 m).

3.2. Influence of qianliyan on microwave radiometer measurement

The area of Qianliyan is about 0.16 km^2, and typical brightness temperatures measured by the three channels of 18.7 GHz, 23.8 GHz and 34.0 GHz of microwave radiometer on Jason-3 is shown in Fig. 4. The time between TCA (time of closest approach) and land is about 12 s.

The change of brightness temperatures measured by Jason-3 before its ground track approaching land is shown in Fig. 4. In Fig. 4, 'tb_187' means the 18.7 GHz brightness temperature (tb) measurement, 'tb_238' and 'tb_340' means brightness temperature measurement of the other two channel. The red line means the coastline, where latitude is greater than the red line means land. The black dashed line means the position of the point of closest approach (PCA) to Qianliyan, and so PCA is the point on the ground track which refers to TCA.

As shown in Fig. 4, when the ground track passes by PCA, the brightness temperatures of three channels vary smoothly. That means the influence of Qianliyan on the brightness temperatures measured by onboard MWR is so tiny that it can be ignored.

The brightness temperature of land is much higher than the adjacent ocean. When the ground track approaches land, the brightness temperature increases, as shown in Fig. 4. If the brightness temperature is measured near land, then the measurement cannot reflect the accurate brightness temperature. In such circumstances, the observed brightness temperature is polluted by land.

As for comparison, while the ground track passes Saint-Pierre, France, at the coordinate about (21°20′31″ S, 55°28′40″ E), the measured wet tropospheric delay varies roughly, as shown in Fig. 5. In such circumstance, the observations of on-board MWR are seriously polluted by the land.

3.3. Influence of qianliyan on satellite altimeter measurement

The footprint of the on-board altimeter is much smaller than the microwave radiometer, and the waveform quality is more sensitive to the area of land in the footprint range. Utilizing those altimetry data that the ground track is nearest to the islet among different cycles, the influence of Qianliyan on the on-board altimeter could be estimated.

As shown in Fig. 3, in cycles No. 183 and No. 117, the ground track of pass No. 153 of Jason-3 approaches Qianliyan closest. From these two cycles, the influence of Qianliyan on on-board altimeter could be estimated clearly.

The waveform during the second of PCA received by the on-board altimeter for the above two cycles is shown in Fig. 6(a and b), and the waveform above the pure ocean is shown in Fig. 6(c) as a comparison. The thinner lines are waveforms in 20 Hz and the wide line is the averaged waveform in 1 s from 20 Hz waveforms.

Fig. 6 shows no obvious difference between the waveform of 20 Hz and averaged between the two cycles. The waveforms of these two cycles show to be the same as normal waveforms that the footprint is the pure ocean. To find out how many waveforms in 20 Hz are used to calculate the range of 1 Hz, the value of parameter "range_ocean_numval_1hz" of GDR-F data is checked out and the result is plotted in Fig. 7.

From Fig. 7, at the moment around TCA, there are about 17–20 observations of 20 Hz are used to calculate the 1 Hz range, that

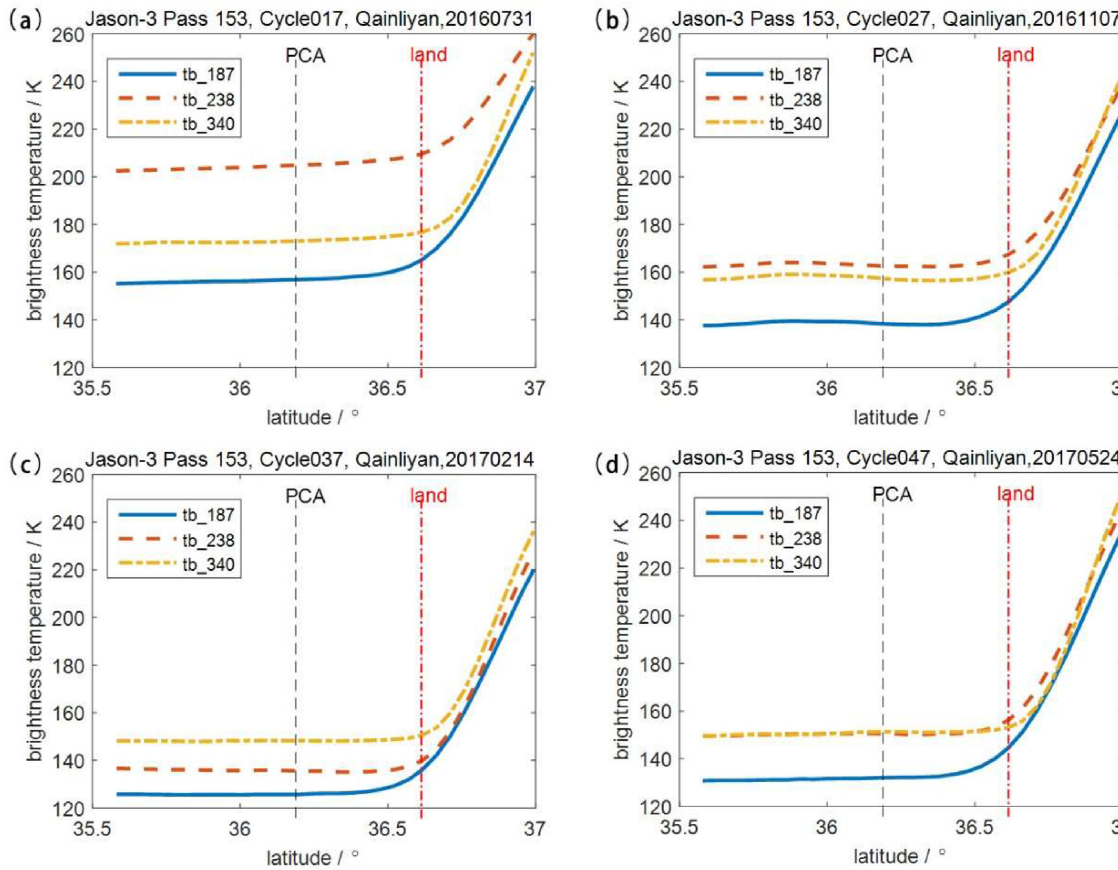

Fig. 4. The measurements of brightness temperatures of Jason-3 microwave radiometer.

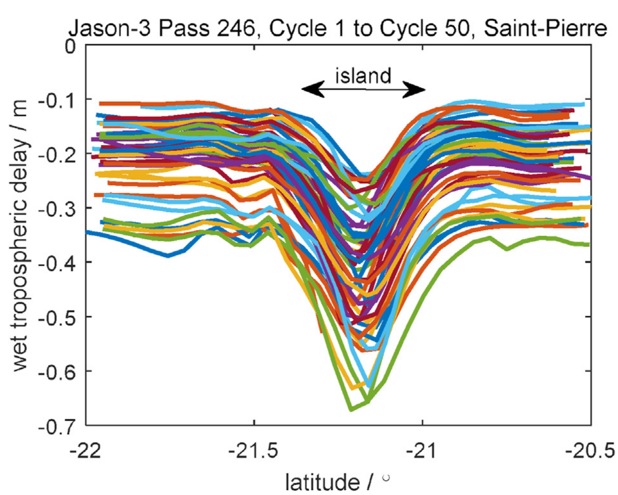

Fig. 5. The wet tropospheric correction derived by MWR passing by Saint-Pierre, France, from cycle No. 001 to cycle No. 050 of Jason-3.

means even when the ground track is only about 600 m far from Qianliyan in the nearest, the range observed by altimeter is with high quality.

Automatic Gain Control (AGC) reflects the stability of received waveforms. The change of 1 Hz AGC at the Ku band from cycle No. 179 to cycle No. 184 is plotted in Fig. 8, and the interval between two points on each line is 1 s. From Fig. 8, the AGC varies smoothly around PCA. At cycle No. 179 and 181, the minor change of AGC shows that the land of the Qianliyan islet does not obviously influence the returned waveforms. Even though the AGC changes at other cycles, it is believed that such change is caused by the variation of the sea surface state but not the islet.

From the 1-s averaged waveform shown in Fig. 9, the shape of the waveform around TCA is not different from normal ones.

From the range measured by the altimeter shown in Fig. 10, the range measured at TCA is along with those measured before and after TCA. This shows that the range measured by the satellite altimeter is continuous, and the range measurement is not influenced by the islet.

The above analysis shows that the Qianliyan has no visible contamination to altimeter waveform while the ground track is 600 m away from the islet. This implies that the Qianliyan is very suitable for the calibration of altimetry satellite, considering that many permanent facilities, such as tide gauge and GNSS reference station that could be utilized in the calibration work.

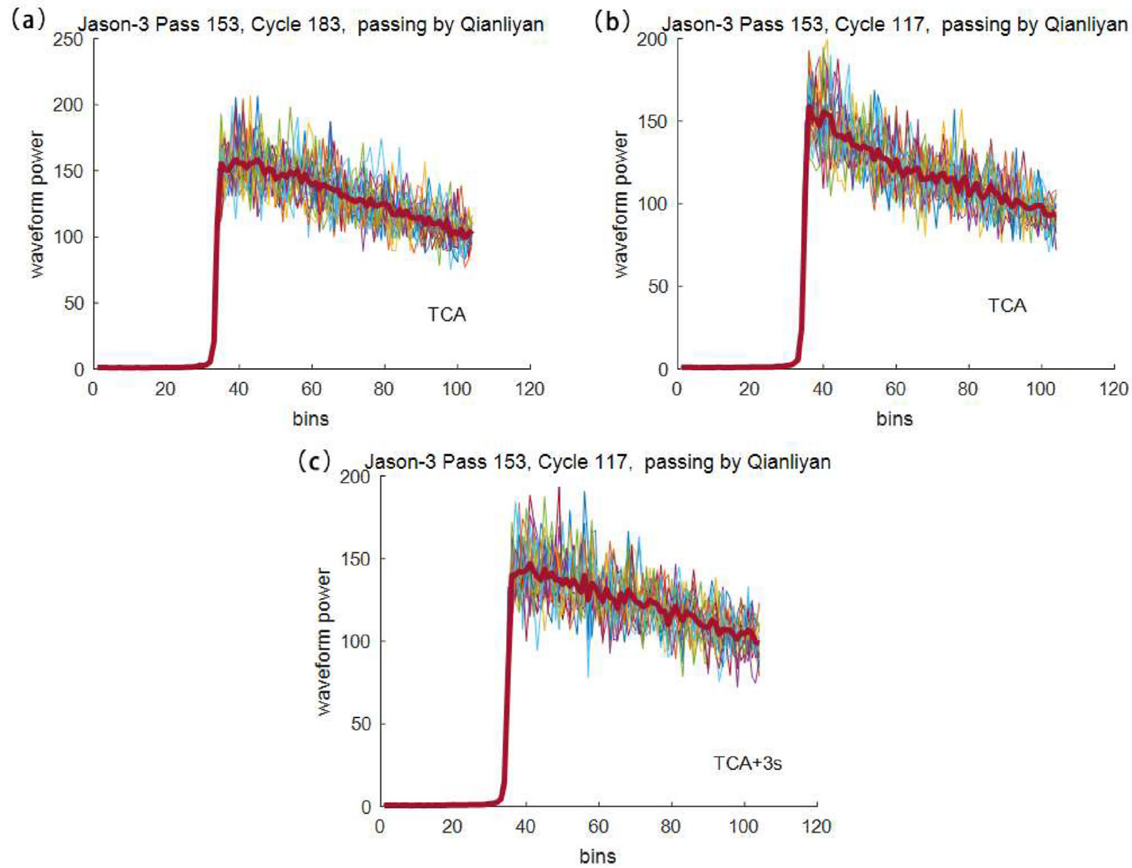

Fig. 6. The waveforms of cycle No. 183 and No. 117, pass No. 153 of Jason-3 around TCA. The waveform above the pure ocean is shown in (c) and the time is 3 s after the time in (b).

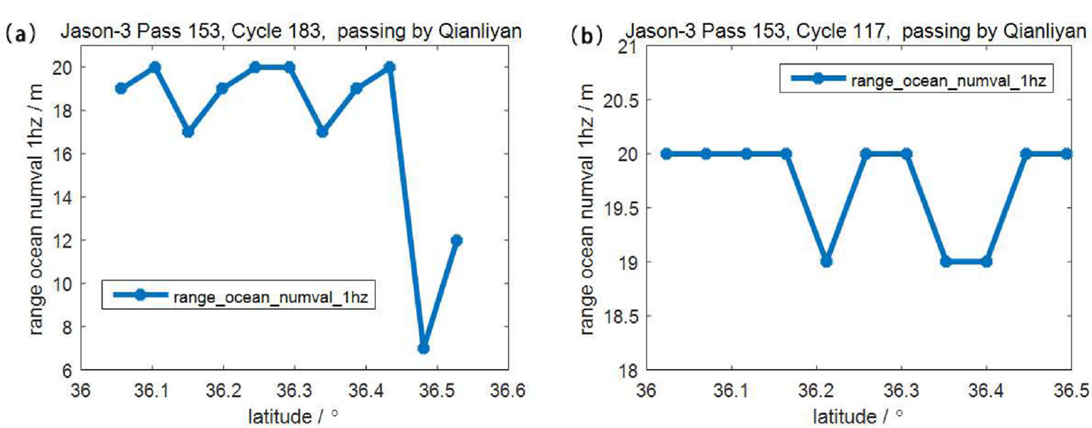

Fig. 7. The “range_ocean_numval_1hz” of cycle No. 183(a) and No. 117(b), pass No. 153 of Jason-3 around TCA.

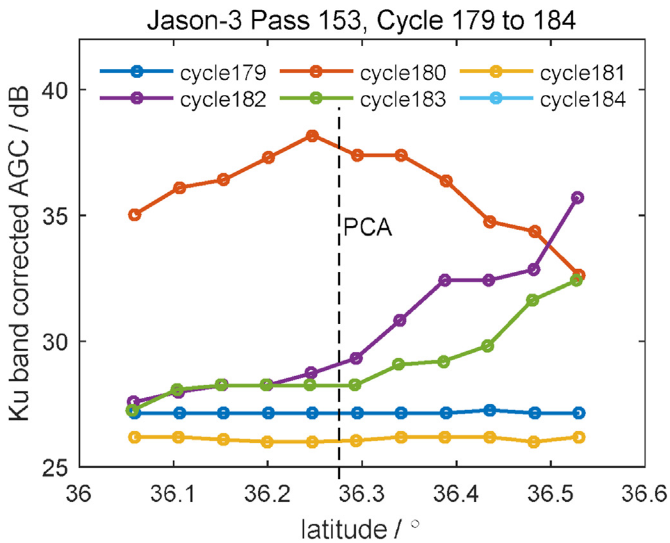

Fig. 8. AGC at Ku band from cycle No. 179 to No. 184, pass No. 153 of Jason-3 around PCA.

4. Scheme of qianliyan calibration site for Chinese satellite altimetry mission

The orbit of the altimetry satellite and the position of its calibration site should be considered together in the orbit demonstration. For the new altimetry satellite, its orbit could be settled to be consistent with the location of the calibration site. As so, the possible layout of Qianliyan calibration site could be proposed as follow. Suppose the orbit angle of altimetry satellite is 105°. Then the position relationship between the ground track and fixed facilities could be arranged as shown in Fig. 11.

By applying the existing tide gauge and GNSS station, the ground track could be set as the black line shown in Fig. 11. The green cycle in Fig. 11 is the position of comparison point in this scenario, moorings or GNSS buoys could be deployed at this point.

The deployment of moorings or GNSS buoys is optional. Without these deployments, the automatic tide gauge and GNSS station could accomplish the calibration work. In such circumstances, for the comparison point is only 1 km away from the tide gauge, the differential tide between these two points could be neglected and the influence could be reduced after many times of calibrations.

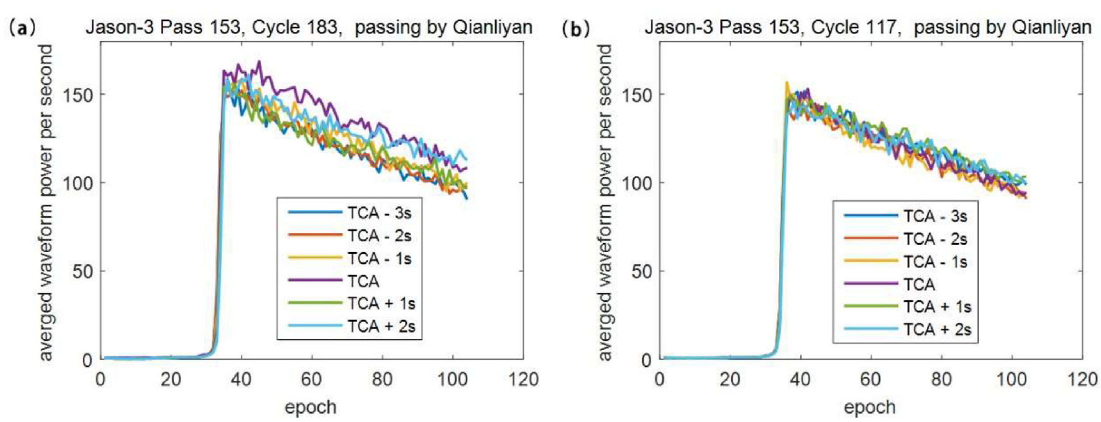

Fig. 9. The waveform averaged per second of cycle No. 183 and No. 117, pass No. 153 of Jason-3 around TCA.

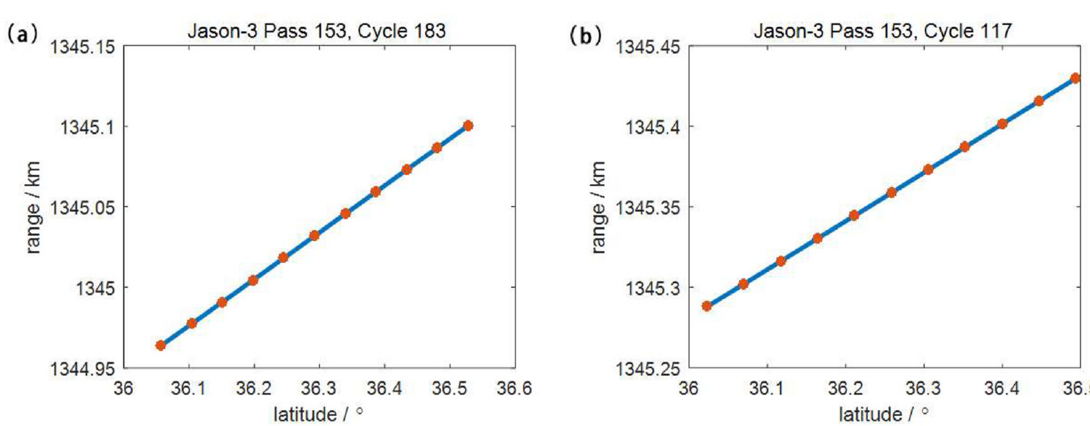

Fig. 10. The measurement of the range of cycle No. 183 and No. 117, pass No. 153 of Jason-3 around TCA.

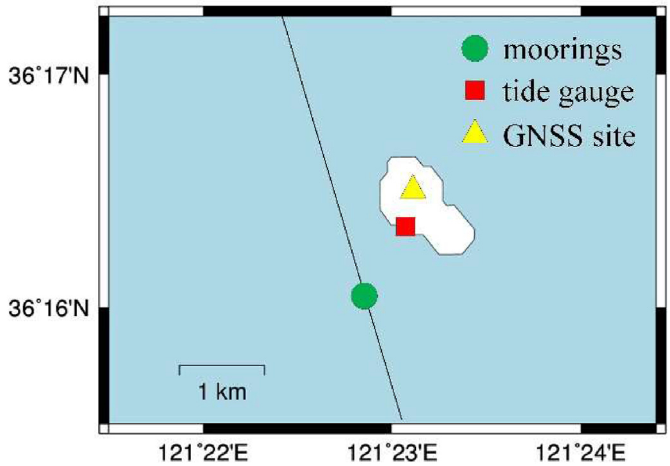

Fig. 11. The proposed layout of Qianliyan calibration site.

If moorings or GNSS buoys are settled, the calibration results from the moorings or GNSS buoys and the results derived from the tide gauge can be compared. Considering the geoid difference between the tide gauge and the comparison point, moorings or GNSS buoys should be best settled at the comparison point. Even using the tide gauge data, the calibration results could be accomplished in a persistent way.

5. Conclusions

The Qianliyan islet at the Yellow Sea is an ideal location to build a permanent calibration site for altimetry satellites. The facilities on Qianliyan could be used without additional financial or workforce investment, and the fixed tide gauge on the islet could provide consistent in situ sea surface height, similar to the work of the Harvest site. As a result, the altimetry satellite could be calibrated using direct SSH measurements, and the compare point could be set close to the islet.

If the compare point could not be placed too close to the islet, it could be placed about 500 m away from the islet, where the islet will not interfere with the waveforms of the on-board altimeter or the brightness temperatures measured by MWRs. The tidal difference between the compare point and the tide gauge could also be disregarded.

There are still many tasks to complete to build a high-precision absolute altimetry calibration site, even though many conveniences could be achieved using the current permanent facilities in Qianliyan. First, the regional geoid model should be carefully surveyed to ensure that the calibration precision is achieved using tide gauge observations. Second, high-precision moorings and GNSS buoys should be manufactured to construct an integral calibration system.

Conflicts of interest

The authors declare that there is no conflicts of interest.

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