

Study on satellite altimeter sea state bias estimation comprehensive model

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Abstract. The sea state bias (SSB) is one of the most prominent errors in satellite altimetry. The empirical model was mostly used in practical estimation of SSB, which includes the parametric model and nonparametric model. The estimation of SSB for the global area will result to large deviation with a single model, due to the different distribution of sea condition as well as the different accuracy of the two models. In this paper, two models were applied in regions of different latitude. The results of two models were statistical analyzed and evaluated. The analysis indicate that: the nonparametric model is more effective in the area further north than 30°N while the parametric model is more effective in other areas.

Introduction

The satellite altimeter can measure the global sea surface height (SSH) [1] quickly and accurately. Meanwhile, it can obtain important marine remote sensing information, such as significant wave height (SWH) and wind speed (U). The accuracy of altimeter has reached centimeter. At present, the orbit error has been greatly corrected by the development of precision orbit determination. SSB has been the largest source of error for satellite altimetry [2]. Although the value of SSB has reached decimeter, the correction residuals remain of centimeter scale. The empirical model used in practical application includes the parametric model [3] and nonparametric model [4]. When comes to a specialized altimetry mission for the global areas, only a single model was used to estimate the SSB. [5]. However, the two models for different latitude areas have their own advantage in accuracy and extension [6]. Because of the SSB are closely related to SWH and U [7]. The different climate and the sea state of the Northern and Southern Hemispheres account for the great difference of the sea state bias. Therefore, it is necessary to carried out research on the two models for regions of different latitude aiming at develop their respective advantages. A combined comprehensive model will improves the accuracy and extension of the SSB estimation on a global scale.

Global distribution of the sea state

The subpolar westerlies area is generally located between the latitude 30° ~60° in the Northern and Southern Hemispheres. The subpolar westerlies area mainly caused by subtropical high and low pressure belt and has perennial prevalence. Because of the westerlies, the SWH and U usually has larger range in that area. There are more land in the Northern Hemisphere, and most of the belt is irregular due to the influence of the terrain. However, the Southern Hemisphere has less land, the sea area is relatively vast. Thus, the less influenced subpolar westerlies accounts for the large wind speed and significant wave height.

The SWH and U information were extracted from the 106 cycle of Jason-2 altimeter data, and the global distribution map is shown in Fig.1.

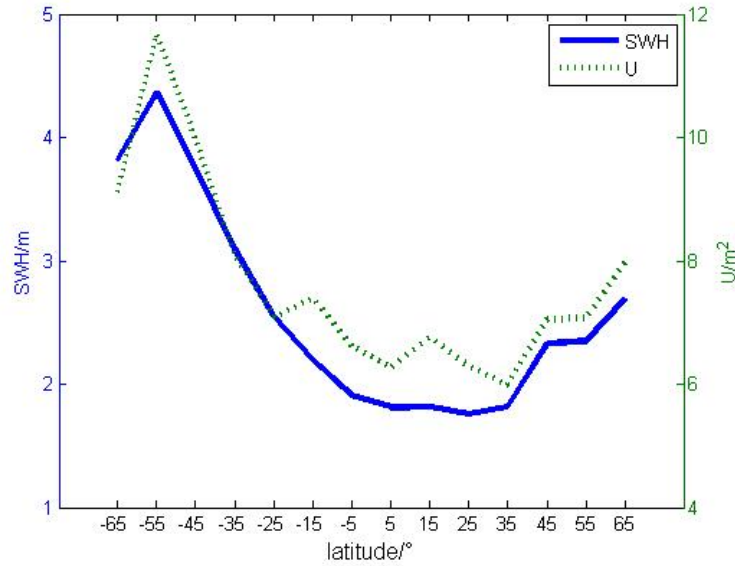


Fig.1. Global zonal distribution of \overline{SWH} and \overline{U}

From Figure 1 we can know the SWH and U began to increase from 30 degrees latitude of the Northern and Southern Hemisphere. The SWH or U value in the Southern Hemisphere is larger than the one that in Northern Hemisphere.

Model determination and result analysis

Model determination.

The parametric model is based on the second order Taylor expansion of SWH and U and the extension is good. Parametric model can be applied to any SWH and U in normal range. The previous parametric model used the crossover differences of SSH, SWH, U to regress the model coefficient. The SSB is not real least squares fitting result. The error of the model coefficient reduces the accuracy of parametric model.

In this paper, an improved parametric model was applied. First the true value of SSB was obtained from direct estimation method [8]. Participating in modeling with the result will reduce the error of model and improve the accuracy of the model.

The final optimized improved parametric model is:

$$SSB = SWH[-0.0297624 + 0.003652763SWH - 0.00251436U - 0.0005458434SWH^2 - 0.00002327464U^2 + 0.000350866SWH \cdot U] \quad (1)$$

Nonparametric model is based on kernel smoothing estimation method to estimate the SSB. This model does not specify the form of a specific function. To construct weight matrix mass data is needed, and the accuracy of the results is relatively high. However, the modeling process is complex, needs huge computation with low efficiency and bad extension.

Nonparametric model select Gauss kernel function and $(h_U, h_{SWH}) = (2.1\text{m/s}, 0.92\text{m})$ as bandwidth value. First calculate the nonparametric SSBA value at crossover points of the rising orbit. Set the value of U and SWH interval 0.25m and 0.25m/s, respectively. SSB estimation is obtained from the difference between the SSBA and crossover points. The (SWH, U, SSB) query table is built and SSB arbitrary values can be obtained from the bilinear interpolation of the query table.

Model determination.

This paper uses 10 cycles of data provided by JASON-2 altimeter in 2014. The data covers the latitude between 66 degrees north latitude to 66 degrees south latitude. The parametric model and nonparametric model were both built by using the data set. Latitude interval 20° division grouping and get the results of the two models respectively in each groups. The result of parametric model is SSB_{PM} . The result of nonparametric model is SSB_{NP} . The density distribution of the difference

between the two results was shown in Fig.2 and Fig.3.

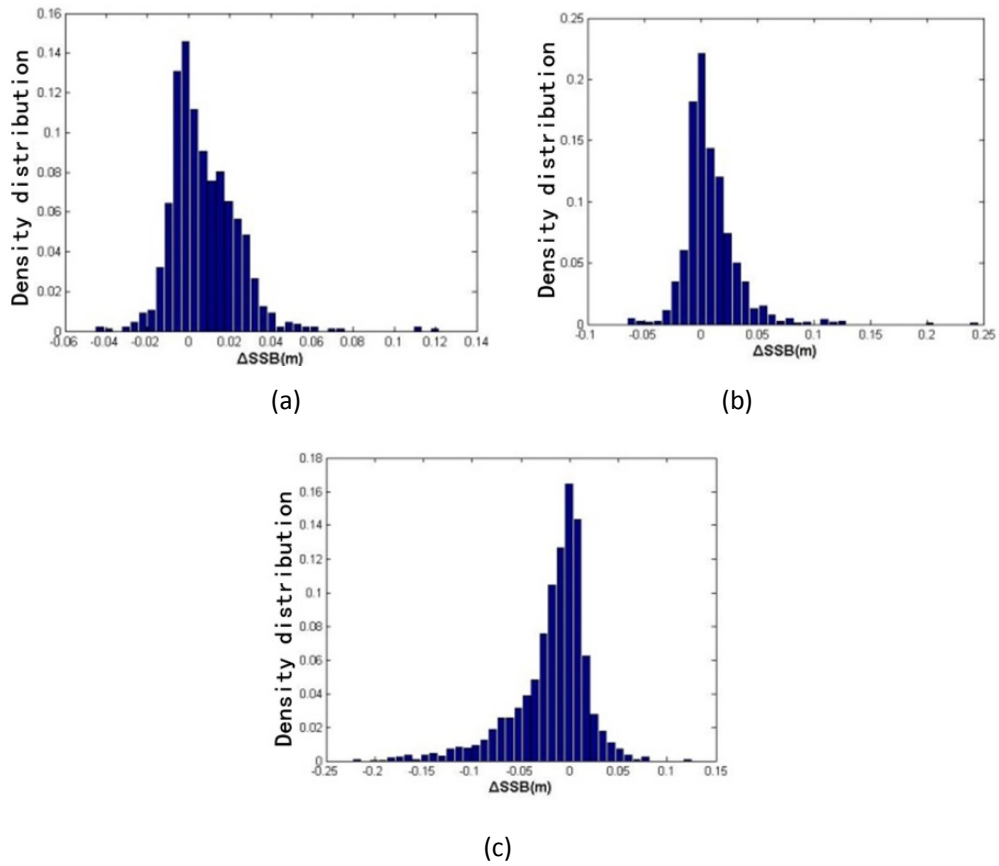


Fig.2. Density distribution of ΔSSB in the Northern Hemispheres
(a) ($0^\circ \sim 20^\circ$) (b) ($20^\circ \sim 40^\circ$) (c) ($40^\circ \sim 67^\circ$)

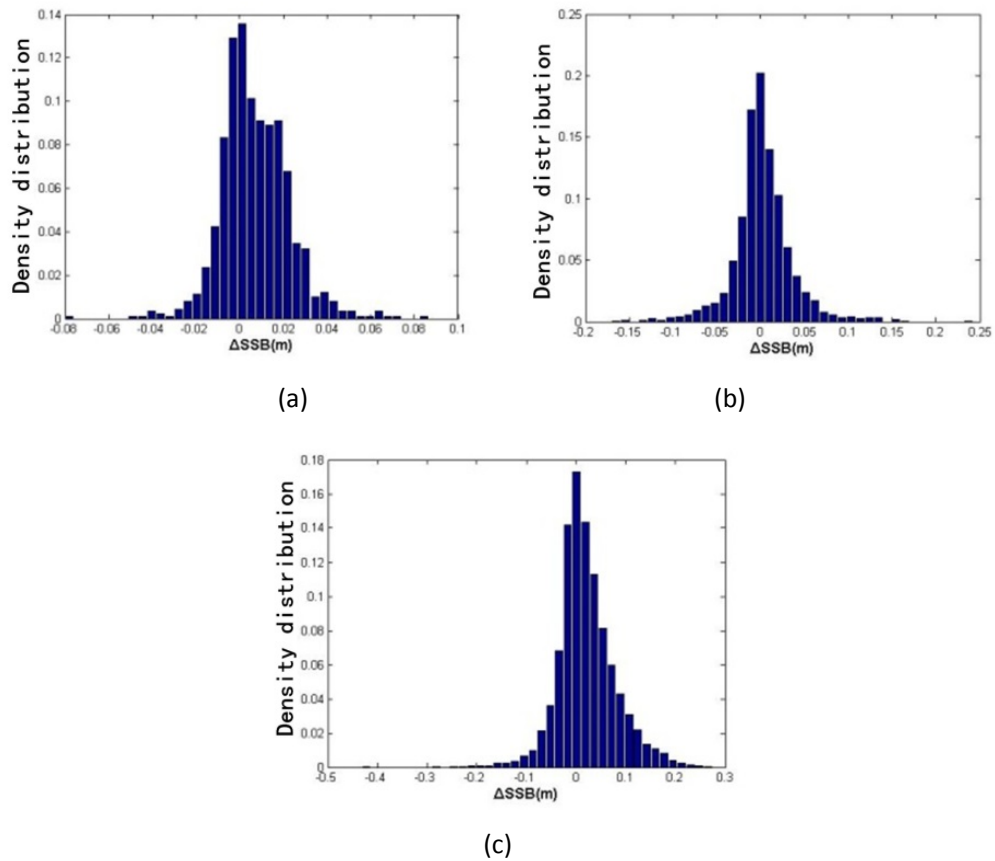


Fig.3. Density distribution of ΔSSB in southern hemispheres
(a) ($0^\circ \sim -20^\circ$) (b) ($-20^\circ \sim -40^\circ$) (c) ($-40^\circ \sim -67^\circ$)

From figure 2 can see that density distribution of ΔSSB in the northern region is not satisfied normal distribution and the mean is not 0. Most ΔSSB in low latitude area are positive and uniform in the middle latitude area while most ΔSSB in high latitude area are negative. From figure 3 we can see that density distribution in the southern region is also not satisfied normal distribution. Most ΔSSB in low and high latitude area are positive and uniform between 0 value in the middle latitude area. From figure 2 and figure 3, it can be concluded intuitively that the two results of parametric and nonparametric model are not equal in different area for both northern and southern region. The difference in the north and south latitude region is asymmetry.

Statistical t test prove that there is significant differences in quantitative evaluation or not in each group. The confidence level is 95%, and the critical value of t test was 1.96. T absolute values obtained by block segmentation was shown in Table 1.

Table 1. T absolute values of each group

	Northern hemispheres			Southern hemispheres		
Latitude(°)	0~20	20~40	40~67	0~-20	-20~-40	-40~-67
T value	4.3927	4.4991	10.7783	4.8119	2.0016	23.0916

It can be seen that every t absolute value is larger than the critical value 1.96. It is further demonstrated that there are significant differences between the two models of different latitude areas.

Evaluation and comprehensive application.

Adopt the coefficient of decision R_a^2 to evaluate model validity.

$$R_a^2 = 1 - \frac{n-1}{n-m-1} (1 - R^2) \quad (2)$$

$$R^2 = SSR / SST \quad (3)$$

N is the sample number, m is the variable number, SSR is regression sum of squares and SST is total variation. The goodness of fit to the sample observation value of the regression model can be evaluated by R_a^2 . The part of SST can be explained the model results is larger when the R_a^2 is larger. The two model's goodness of fit is better. R_a^2 values of each group are shown in table 2, and the distribution curve is shown in figure 4 (PM and NP are short for parametric and nonparametric):

Table 2 R_a^2 values of each group

	Northern Hemispheres			Southern Hemispheres		
Latitude(°)	0~20	20~40	40~67	0~-20	-20~-40	-40~-67
R_a^2 (PM)	0.3096	0.3075	0.3229	0.2917	0.3140	0.3645
R_a^2 (NP)	0.2473	0.3379	0.3503	0.2521	0.3091	0.3664

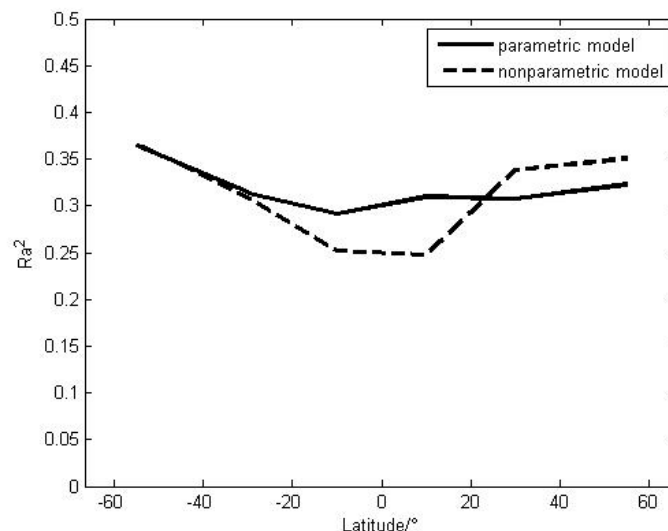


Fig.4. The distribution curve of R_a^2

From table 2 and figure 4 can be seen, above 30° north latitude the nonparametric model result is larger than parametric model results. The nonparametric model is more effective in this area while parametric model is more effective in other areas.

Conclusion

This paper that divided the data into each bin interval is 20° latitude areas, then estimate the SSB by the improved parametric model and nonparametric model in different areas respectively. Analysis show that there are significant differences between the two results of different models are different from t test and the density distribution of ΔSSB . Through goodness of fit test and compute the coefficient of decision of different model results in different areas. And then make quantitative evaluation of the validity of the model give the conclusion: The nonparametric model is more effective in the area above 30° north latitude and the parametric model is effective and efficiency in the other areas. The comprehensive application of two kinds of empirical models in the whole latitude region is realized.

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