A New Adaptive Re-tracking Algorithm of Retrieving and Computing SWH in the Coastal Waters for the Modern Computer and Communications

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Abstract. It is known that the echoes from offshore waters are affected by land echoes, the inversed ocean parameters such as sea surface height (SSH), significant wave height (SWH) and backscattering coefficient ($\sigma^0$) have relatively large errors and are even unreliable. And thus a large amount of offshore data is unusable. Firstly, this paper studied and analysed offshore waveforms' characteristics affected by land echoes. Secondly, the offshore echoes were simulated according to the electromagnetic scattering model and classified into five categories. Those characteristics of the contaminated echoes by land echoes were simulated to help retrieving oceanic parameters. Finally, a new adaptive weighted piecewise fitting algorithm (AWPFA) was presented to process offshore echoes of Jason-1/2 by an adaptive method of setting the adaptive weight coefficient according to the contamination degree of the echo waveforms. Compared with four kinds of offshore echo re-tracking algorithms, the new algorithm ignores the impacted components of echoes by land and mainly pays attention to the signal components of the ocean echoes. This new re-tracking algorithm can effectively improve the accuracy of ocean parameter inversion and reduce the unusable distance. It is an effective re-tracking method of processing offshore data for an altimeter.

Keywords: Oceanic remote sensing; Re-tracking algorithm; Offshore echo; Altimeter.

1. Introduction

The altimeter is a kind of microwave remote sensor for measuring oceanic dynamic parameters such as sea surface height (SSH), significant wave height (SWH), and wind speed etc. After decades of development, the traditional radar altimeter [1] has made remarkable progress, and the accuracy of the measured height has reached the centimeter level by all kinds of corrections such as the atmospheric, the rainfall [2] and son on, but a great quantity of offshore data surveyed by an altimeter is not all used effectively for retrieving oceanic parameters because those offshore data were contaminated by land or island echoes. For coastal echoes the original ocean model is hardly applicable, and is not suitable for retrieving oceanic dynamic parameters. Therefore, some efforts are mainly made in improving re-tracking algorithms to process offshore data [3-4] recently.

In the 1990s, Brooks and Lockwood [5-6] studied the impacts of islands on echo waveform of Geosat altimeter. It was found that the altimeter tended to track land echoes with strong backscattering, which led to abnormal SSH, SWH and $\sigma^0$. In 2002, Deng et al. [7] studied the influence of coastal land on the echoes of ERS2 and Poseidon altimeters in the sea area near Australia. The results showed that the data...
within 22 km offshore were not available for ocean model. In 2006, Deng et al.[8] improved the inversion accuracy of offshore parameters to a certain extent by a 5-parameter model and a multiple threshold method. In 2014, Passaro M et al[3-4] presented a multi-mission adaptive sub-waveform retracker for coastal altimetry, and improved SWH detection to a certain extent. In this paper, A new adaptive weighted piecewise fitting algorithm (AWPFA) is proposed to reconstruct these echo waveforms from the Chinese offshore data of Jason-1/2. The results show that AWPFA has stable and high precision parameter inversion performance, and is an effective algorithm of processing the offshore data and can effectively shorten the unusable distance.

2. Several Retracking Algorithms for Retrieving Oceanic Parameters

It is known that the oceanic model of MLE4[9] is suitable for re-tracking oceanic waveforms in figure 1 and not for land echoes. For coastal waters which include land and ocean surfaces, several algorithms can be applied as followings.

2.1. OCOG

OCOG algorithm[10] was presented by Wingham in 1986. Its basic idea is to determine the rectangular box so that the center of gravity(COG), retraction point $Lep$ and the amplitude $A$ can be defined. The waveform amplitude $A$ is defined as:

$$A = \sqrt{2 \times \sum_{k=1}^{n} \left(0.5 \times W(k)^2 \times W(k)^2\right)} \sum_{k=1}^{n} W(k)^2$$

(1)

where $W(k)$ is the return power at $k$th sampling point. The width of rectangle $Width$ is defined as:

$$Width = \left(\sum_{k=1}^{n} W(k)^3\right) / \sum_{k=1}^{n} W(k)^4$$

(2)

The COG of the center of gravity is defined as:

$$COG = \frac{\sum_{k=1}^{n} k \times W(k)^2}{\sum_{k=1}^{n} W(k)^2}$$

(3)

The re-tracking point $Lep$ is defined as:

$$Lep = COG - Width / 2$$

(4)

where those signs are defined in[10]. In some applications, the amplitude $A$, the center of gravity position $COG$ and the width $Width$ are often original input values of other re-tracking algorithms as shown in figure 2.

2.2. Threshold Algorithm

Threshold algorithm[11] proposed by Davis in 1997 is a statistical algorithm. The algorithm is based on the amplitude calculated by the OCOG algorithm, and obtains the threshold corresponding to the threshold power according to the used threshold, and uses the linear interpolation threshold power and
the adjacent two echo power values to determine the front midpoint. Compared with the OCOG algorithm, the algorithm has high accuracy and simple implementation and the advantages of fast computing speed. The formulations are the following

\[ W_n = \frac{1}{5} \sum_{i=1}^{5} W(i) \]  

(5)

\[ T_k = W_n + q \times (A - W_n) \]  

(6)

\[ D_n = D_{k-1} + \frac{T_n - W_{k-1}}{W_k - W_{k-1}} \]  

(7)

Where \( A \) is the amplitude of the waveform based on the OCOG algorithm, \( W_n \) is the average value of the thermal noise area, \( W(i) \) represents the echo power value of the \( i \) sampling point, \( q \) stands for the threshold value which often is 50%; \( k \) is the sampling gate corresponding to the first excess \( T_n \) echo power, \( D_{k-1} \) is the \( k-1 \) sampling gate, \( D_n \) is the middle point of the rising edge.

2.3. 5/9-beta Algorithm

The multi-parameter fitting algorithm is a model algorithm[12]. For the simple waveforms of single peak, the 5-parameter model is used to fit the echo waveforms while the 9-parameter model is used for fitting the echoes with a double-peak, which is called as 9-beta algorithm. The 5-beta (5-\( \beta \)) linear algorithm was proposed by Martin et al. to process SeaSat altimeter data in 1983. The formulas are given as

\[ y(i) = \beta_1 + \beta_2 (1 + \beta_3 Q) P \left( \frac{n - \beta_4}{\beta_3} \right) \]  

(8)

\[ Q = \begin{cases} 0 & i < \beta_3 + 0.5 \beta_4 \\ i - (\beta_3 + 0.5 \beta_4) & i \geq \beta_3 + 0.5 \beta_4 \end{cases} \]  

(9)

\[ P(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-\frac{q^2}{2}} dq \]  

(10)

Where those signs were defined in [12].

2.4. An Adaptive Weighted Piecewise Fitting Algorithm

In this section, we will introduce a new adaptive weighted piecewise fitting waveform retracking algorithm. The basic idea of the algorithm is about fitting the echo waveform section-by-section on the basis of the least square method. The specific technology is to ignore the part of the echo waveform which is seriously polluted by land echoes (giving a smaller weight value or zero), and to focus on the sea echoes. Setting weighted values zero for echoes polluted by land or island echoes is different from the ordinary weighted fitting algorithm by getting rid of those polluted echoes and intercepting to obtain oceanic echoes according to the last echo and its received power. Here we finish retrieving oceanic parameters by setting the weight value \( W(i) \) of 0~1 such as 1 for oceanic surfaces and 0 for land surfaces. The weighted values vary adaptively with the characteristics of echoes. In this paper, Fit the measured echo waveform \( FFT(i) \) with the second order exponential echo model \( f_i(t_0, \sigma, A, \xi) \), and let

\[ F^2 = \sum_i W(i) \left( FFT(i) - f_i(t_0, \sigma, A, \xi) \right)^2 \]  

(11)

be minimum to derive those parameters \((t_0, \sigma, A, \xi)\) in the model. And thus we can obtain some marine information from these parameters. In this paper The second-order oceanic model is given as
\[ f(t) = A \exp\left(-v_1\right)(1 + \text{erf}(u_1)) - \frac{A}{2} \exp\left(-v_2\right)(1 + \text{erf}(u_2)) \]  

(12)

Where all signs were defined in [9].

3. Simulation and Classification of Echoes

In this section, several kinds of waveforms are simulated and analysed as followings.

3.1. Oceanic Echoes

The formation principle of the echo waveform received by altimeter at 0° incidence angle is shown in figure 3. The time delay is omitted, time \( t_0 \) is the starting point of the echo waveform. Time \( t_{1/2} \) is the half power point, \( t_1 \) is the maximum power point for retrieving \( \sigma^0 \). The segment from \( t_0 \) to \( t_1 \) is called as the leading or rising edge, from which slope significant wave height(SWH) can be derived. This curve or equation (three terms' convolution) in figure 3 is called as the ocean model which is satisfied with the echo waveform at open sea. When the footprint of altimeter is in the far sea area, the echo is ocean echo, which is not affected by Land Echoes. In figure 4(c) the measured waveform is the oceanic echo waveform from Jason-1. However, as the footprint of altimeter at nadir moves to the land gradually, the Ocean Echo is distorted and deformed by the land echo, and is no longer suitable for ocean model.

![Figure 3. The principle of the echo](image)

(a) Jason-1 from sea to Hong Kong island;(b)Some Echoes of pass 153;(c)an oceanic echo from Jason-1 satellite cycle 212 pass 153

3.2. Offshore Echoes

Figure 4(a or b) shows the waveform change diagram of JASON-1 satellite cycle 212 pass 153 near Hong Kong. There are three cases as followings.

3.2.1. The distorted noise area. When the satellite is close to the mainland, the high mountain peaks, buildings or artificial structures on the land protrude from the surface of the ocean to a great extent. Before the electromagnetic waves reach the sea surface, the electromagnetic waves are first projected
onto these peaks or artificial buildings and then are reflected back to the satellite, a spike is formed in the noise region of the echo waveform. This case is that the noise area is distorted or contaminated, as shown in Figure 5(a or b). The case can be simulated by the electromagnetic scattering model, as shown in Figure 6. For simplify, the electromagnetic scattering model is shown in Figure 6(a). The area of island is very small and backscattering coefficient is not enough large so that the peak in noise area in Figure 6(c) is not more than the oceanic echoes. In Figure 6(b) the backscattering coefficients (or RCS) of sea surfaces are computed by

$$\sigma_\beta = \frac{|\hat{g}(0)|^2}{s^2} \sec^2 \theta \cdot \exp\left(-\frac{\tan^2 \theta}{s^2}\right)$$

(13)

where $\theta$ is local incidence angle, $s^2$ is the mean square slope of the rough surface, and can be expressed as

$$s^2 = 3.66 \times 10^3 U_{19.5}$$

(14)

3.2.2. The distorted/polluted failing edge. In this case, the land is far from the nadir of altimeter, and the land echo only affects the failing edge of the oceanic waveform, as shown in figure 7. it is obvious that the failing edge all the way down is disturbed when the land echoes enter into the receiver of altimeter. The land can be regarded as quasi mirror reflection, and the echo power is stronger than the sea echo, as causes the failing edge to be raised. With the altimeter's footprint closing to the land, the raised segment of the failing edge gradually move forward until the leading edge is reached, as shown in figure
7 (No.1 or No.2). The case can also be simulated by a physical model in Figure 8. In Figure 8(a) a piece of land is far from the nadir of altimeter, and land is nearer the nadir of altimeter in Figure 8(b). It is obvious that the strong reflection signal from the land gradually moves to the front of the echo waveform, as shown in figure 8(c/d).

![Figure 7. The trailing/failing edge is polluted by lands](image)

![Figure 8. The simulated echo polluted by the land echo(c/d) is nearer from the nadir of altimeter than (a/b)](image)

3.2.3. The distorted leading/rising edge. This case is that there exists lands or islands at nadir or its nearby, which causes the leading edge to be contaminated by land echoes. The most typical sea surface condition is that some islands or lands are surrounded by sea water, or the nadir of satellite is near the land. For simplify, some regular geometry stands for islands or lands (eg. rectangular or circle) in figure 9. For this sea-island/land surfaces. For this type of waveform, we can fit the measured date with the sea model by setting weighted value 0 at the polluted segment of the leading edge and 1 at the failing edge. If all segments of the leading edge are contaminated by islands or lands, the errors of retrieving SWH and SSH are so large that the retrievals are not credible. So long as the whole or part of the leading edge is not contaminated by islands and lands, SWH and SSH correction can be extracted from echoes by AWPFA.

![Figure 9. Simulation of the contaminated leading edge of the echo waveform](image)
3.2.4. The land echoes. The land echoes are generally peak waveforms, as shown in figure 10. No information of oceanic parameters is extracted. This kind of waveforms will not be processed in this paper.

4. Results

In this section, the measurements of Jason-2 are selected near offshore waters, as shown in figure 11. The Adaptive Weighted Piecewise Fitting Algorithm (AWPFA) is applied to the offshore data for extracting oceanic information. Firstly, in order to get rid of the land effects, an oceanic waveform is constructed in terms of the leading edge or its segments and its last waveform parameters such as the mis-pointing. Secondly, extracting oceanic parameters by AWPFA can avoid interference of land echoes and improve the accuracy of parameter inversion. In figure 11 an oceanic waveform shown in dash lines is constructed in terms of received power and mis-pointing, it is obvious that the land effects of six waveforms are removed. These six waveforms were re-tracked by OCOG, Threshold, 5-β, Oceanic model and WPFA, SSH corrections were obtained by these algorithms. The results are shown in figure 11--figure 14. From figure 12- figure 14 it is obvious that SSH corrections by AWPFA are always relatively stable, with little fluctuation, while the data by other algorithms and satellite measurements show great fluctuation when the nadir of altimeter is getting closer to land. AWPFA with constructing an oceanic model to get rid of land effects and varying the weighted values according to the polluted degree by land echoes has higher accuracy for re-tracking echo waveforms in offshore area and can effectively shorten the unusable distance.
5. Conclusion
According to the electromagnetic scattering model, the influence of island and land on the ocean echo received by altimeter is simulated and analyzed, and the physical mechanism of island and land influence on the ocean echo is studied. According to the different parts of the echo contaminated by land or island, the offshore echo waveforms are classified and analyzed. In order to reduce the impact of land echo on ocean echo, this paper proposes a method of constructing ocean echo with considering about the received power, some parameters of the last received echo and varying the weighted values according to the polluted degree by land echoes. Compared with other traditional tracking algorithms, this algorithm can effectively fit those echoes whose leading or rising edges are contaminated partly by land echoes, and improve the accuracy of retrieving oceanic parameters.

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