

Adjustment of the dual frequency altimeter low subsection backscatter coefficient statistical model

Abstract

The Ku band and C band backscatter coefficient statistical relationship plays an important role in dual frequency altimeter wind speed retrieval when it is rain. In order to improve the precision of wind speed retrieval, it is very important to put forward a proper statistical relationship. Jiang's relationship has higher precision than Quartly's and Yang's relationship between 12dB and 26dB. But if C band backscatter coefficient is 12dB, the wind speed is 27.3683m/s, so if the wind speed is larger than 27.3683m/s, Jiang's relationship can't work. High wind speed condition is one of the most important sea phenomena, so we eagerly need to build a new relationship that can apply to the entire sea phenomenon. This paper is based on the specular scattering theory, analyses the low backscatter coefficient subsection's relationship, put forward a method that if C band backscatter coefficient is between 12dB and 26dB, Jiang's relationship is used, if C band backscatter coefficient is smaller than 12dB, Yang's relationship is used. This relationship redounds to improve wind speed retrieval when it is rain.

Keywords: dual frequency altimeter, statistical model, backscatter coefficient, low subsection

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Introduction

NASA and French space agency launched Topex/Poseidon in 1992, and Topex is the first dual-frequency radar altimeter (Ku band 13.6GHz and C band 5.3GHz). The initial thought of the equipment of C band payload is to retrieve the total electron content. There is substantial progress for the altimeter sea surface wind speed error reduction caused by rain because the dual-frequency altimeter is available. Quartly et al.,¹ point out that the main influence of rain to radar altimeter echo is attenuating the signal; it is different between the attenuation of C band backscatter coefficient σ_C^0 and that of Ku band backscatter coefficient σ_{Ku}^0 in the rain. They established a statistical relationship model between σ_C^0 and σ_{Ku}^0 under the assumption of no rain, open sea, no sea ice and small signal deviation angle. The literature²⁻³ also established a statistical model and carried out relevant research of decrease rain influence. The precipitation capacity of 10 mm/h causes the signal attenuation of about 4.5dB for Ku band and about 0.26 for C band. If the backscatter error is 0.1dB, the retrieved wind speed error is about 0.3m/s in moderate wind, so the backscatter coefficient statistical model is very important for rain influence reduction. The amount of trial data is too small for the backscatter coefficient statistical model of the literature.¹ The statistical relationship model established in the literature⁵ is a piecewise linear function, which is disconnected at the link points. Jiang et al.,⁶ presented a new backscatter coefficient statistical model with 7 and a half years Jason-1 data by a polynomial fitting method to solve above problems, but the available range of C band backscatter coefficient is only 12 dB to 26 dB. C band backscatter coefficient of 12 dB corresponds to the sea surface wind speed of about 27m/s by calculation, which means that if the sea surface wind speed is higher than 27m/s, the model of literature⁵ lose effectiveness. However, high wind speed and severe sea situation often cause tremendous disasters,

so it is necessary to research low subsection backscatter coefficient statistical relationship.

In this paper, the low subsection backscatter coefficient statistical relationship of C band and Ku band is analyzed basing on the specular scattering theory in section 2, the accuracies of different methods are evaluated in section 3, and an adjusted method is put forward that if C band backscatter coefficient is in the range of 12 dB to 26 dB, the method of literature⁶ is available, and if C band backscatter coefficient is below 12 dB, the method of literature⁵ is available. The adjusted method can improve sea surface wind speed accuracy under rainfall conditions.

The basic theory of wind speed inversion of dual-frequency altimeter under rainfall condition

The influence of rainfall on the radar signal can be obtained by the function proposed by Marshall Palmer

$$k = aR^b$$

where k refers to the absorption coefficient, R is the precipitation capacity, a and b are coefficients determined by radar frequency.

The total attenuation of radar signal emission and reception follows the following relation,

$$A = 2kh = 2haR^b$$

where h is the height of rainfall.

Therefore, there is the following relationship between rainfall and the attenuation intensity caused by rainfall

$$R = \left(\frac{A}{2ha} \right)^{1/b} \quad (1)$$

$a = 34.6 \times 10^{-3}, b = 1.109$ for Ku band, $a = 1.06 \times 10^{-3}, b = 1.393$ for C band.

The basic iterative method^{2,7-10} for the inversion of wind speed by dual-frequency altimeter under rainfall condition is

First, estimate whether it is rain according to the backscatter coefficient statistical model of between σ_C^o and σ_{Ku}^o . If it is not rain, jump out of iteration;

If it is rain, $\sigma_{Ku}^{o'}$ is substituted into the statistical model to obtain the ideal backscatter coefficient of Ku band $\sigma_{Ku}^{o'}$, and then the signal attenuation of Ku band is obtained by comparing with it, $A_{Ku} = \sigma_{Ku}^{o'} - \sigma_{Ku}^o$;

Precipitation capacity R can be calculated by equation (1). R is independent of the radar signal, so the corresponding C band signal attenuation A_C can be calculated by equation (1). The signal attenuation of C band is $\sigma_C^o = \sigma_C^o + A_C$;

The new signal attenuation of Ku band A_{Ku}^o can be obtained by substituting $\sigma_{Ku}^{o'}$ and σ_{Ku}^o into the statistical relationship;

Judge whether $\sigma_{Ku}^{o'}$ is less than a certain threshold, if it is true, jump out of the iteration, and retrieve the sea surface wind speed by the corrected $\sigma_{Ku}^{o'}$. If it is false, go to 'c' and continue the iteration.

The precipitation capacity of 10 mm/h causes the signal attenuation of about 4.5dB for Ku band and about 0.26 for C band by equation (1). If the backscatter error is 0.1dB, the retrieved wind speed error is about 0.3m/s in the moderate wind from the Modified Chelton and Wentz Wind Speed Model Function (MCW), so the statistical model has important effects on wind speed retrieval.

Backscatter coefficient statistical model

There is a certain correlation between σ_{Ku}^o and σ_C^o physically, but this correlation cannot be deduced theoretically² which is usually based on empirical fitting.

Quartly et al.,¹ analyzed the influence of precipitation ideally on altimeter wind speed retrieval using Topex data. They suggested that the C band backscatter coefficient could be used to distinguish rain or not from the different influence on a different frequency. Forwardly, a piecewise statistical model fitting from Topex data from December 1992 to October 1993 (Cycle 11, 12, 21, 22, 29, 30, 39 and 40) is put

Table 1 Yang⁵ subsection coefficient of her standard relationship

σ_C^o range/dB	c_1	σ_C^o	σ_C^o range /dB	c_1	c_2
$16.2 \leq \sigma_C^o < 19.4$	1.202	-7.086	$16.2 \leq \sigma_C^o < 19.4$	0.894	-1.829
$13.0 \leq \sigma_C^o < 14.0$	1.471	-10.602	$19.4 \leq \sigma_C^o < 21.0$	0.916	-2.23
$14.0 \leq \sigma_C^o < 14.7$	1.527	-11.357	$21.0 \leq \sigma_C^o < 24.2$	1.026	-4.498
$14.7 \leq \sigma_C^o < 15.7$	1.099	-5.023	$24.2 \leq \sigma_C^o < 26.0$	0.849	-0.203
$15.7 \leq \sigma_C^o < 16.2$	0.914	-2.146	$26.2 \leq \sigma_C^o$	0.099	19.334

forward ignoring conditions that the liquid water content is less than 0.2mm.

$$\left. \begin{aligned} \sigma_{Ku}^o &= 8.99 + 1.19(\sigma_C^o - 13.0), \sigma_C^o < 13.0dB; \\ \sigma_{Ku}^o &= 8.99 + 1.52(\sigma_C^o - 13.0), \sigma_C^o \in [13.0dB, 14.0dB); \\ \sigma_{Ku}^o &= 10.51 + 1.21(\sigma_C^o - 14.0), \sigma_C^o \in [14.0dB, 14.7dB); \\ \sigma_{Ku}^o &= 11.36 + 0.89(\sigma_C^o - 14.7), \sigma_C^o \in [14.7dB, 15.7dB); \\ \sigma_{Ku}^o &= 12.25 + 0.72(\sigma_C^o - 15.7), \sigma_C^o \in [15.7dB, 16.2dB); \\ \sigma_{Ku}^o &= 12.61 + 0.86(\sigma_C^o - 16.2), \sigma_C^o \in [16.2dB, 19.4dB); \\ \sigma_{Ku}^o &= 15.36 + 0.96(\sigma_C^o - 19.4), \sigma_C^o \in [19.4dB, 21.0dB); \\ \sigma_{Ku}^o &= 16.90 + 1.07(\sigma_C^o - 21.0), \sigma_C^o \in [21.0dB, 24.2dB); \\ \sigma_{Ku}^o &= 20.31 + 1.11(\sigma_C^o - 24.2), \sigma_C^o \in [24.2dB, 26.0dB); \\ \sigma_{Ku}^o &= \text{undefined}, \sigma_C^o \geq 26.2dB. \end{aligned} \right\} \quad (2)$$

Yang⁵ suggested a piecewise statistical model using piecewise linear fitting by Jason-1 data from March 2006 to February 2007 (Cycle 155, 157, 159, 163, 167, 169, 172, 174, 176, 180, 184 and 188) (Table 1). Its expression is

$$\sigma_{Ku}^o = f[\sigma_C^o] = c_1 \times \sigma_C^o + c_2 \quad (3)$$

Quartly et al.,¹ and Yang⁵ fitted the statistical model by 80 days and 120 days data respectively, the amount of data is small and unrepresentative. The piecewise linear function link points of Yang⁵ are disconnected.

Jiang et al.,⁶ presented a new backscatter coefficient statistical model with 7 and a half years no rain, open sea, no sea ice and small signal deviation angle Jason-1 data by polynomial fitting method to solve above problems, but the available range of C band backscatter coefficient is only 12 dB to 26 dB (Equation 4). The fitting coefficients are listed in Table 2.

$$\sigma_{Ku}^o = f(\sigma_C^o) = a(\sigma_C^o)^6 + b(\sigma_C^o)^5 + c(\sigma_C^o)^4 + d(\sigma_C^o)^3 + e(\sigma_C^o)^2 + f(\sigma_C^o) + g \quad (4)$$

The above three statistical model standard deviations are listed in Table 3. Jiang et al.,⁶ standard deviations are significantly better between 12 dB to 26 dB than the standard deviation of Quartly et al.,¹ and Yang.⁵ Only in the range of 12 dB to 15 dB, the accuracy of Yang⁵ is higher than Jiang et al.,⁶ the accuracy of Jiang et al.,⁶ are very high in the rest of the range.

Table 2 Jiang et al.,⁶ coefficients

coefficients	value
<i>a</i>	23.7591600170160e-006
<i>b</i>	-2.76710569836364e-003
<i>c</i>	132.238924476659e-003
<i>e</i>	-3.31438816243354
<i>e</i>	45.8713603676501
<i>f</i>	-330.723722504547
<i>g</i>	975.195895449145

Table 3 Standard deviation of the three standard relationships

standard deviation	$\sigma_C^o \in [12, 26] / \text{dB}$	$\sigma_C^o \in [12, 15] / \text{dB}$	$\sigma_C^o \in [15, 20] / \text{dB}$	$\sigma_C^o \in [20, 23] / \text{dB}$
Jiang et al., ⁶	0.0543	0.0606	0.0602	0.0384
Yang ⁵	0.1896	0.0273	0.086	0.2634
Quarty et al., ¹	0.3124	0.439	0.1827	0.3843

Adjustment of the backscatter coefficient statistical model

This section will discuss the shortcomings of the statistical relationship in Jiang et al.,⁶ and advance the adjusted methods.

The statistical scatter diagram of Jason-1 radar altimeter from cycle 1 to cycle 279 is shown in Figure 1. The samples selected criterion is no rain, open sea, no sea ice and small signal deviation angle. Because the accuracy of backscatter coefficient values of Jason-1’s GDR (Geophysical Data Records) is 0.01dB, the scatter points are drawn every 0.01dB during statistics.

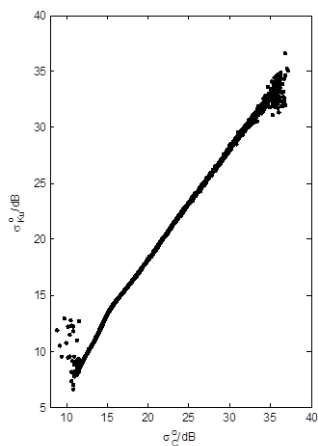


Figure 1 The σ_C^o and σ_{Ku}^o statistical scatter diagram of Jason-1 radar altimeter from cycle 1 to cycle 279.

The scatter points are relatively concentrated when $\sigma_C^o \in [12, 26]$, and the correlation of Ku band and C band backscatter coefficient is obvious. But the scatter points are relatively divergent when $\sigma_C^o < 12$ dB and $\sigma_C^o > 26$ dB, this is the reason that Jiang et al.,⁶ adopted the range of $\sigma_C^o \in [12, 26]$.

Some samples of sea surface wind speed value corresponding to Ku band backscatter coefficients using the method of Jiang et al.,¹¹ are listed in Table 4.

When the significant wave height is 1m and $\sigma_C^o = 23.3\text{dB}$, the calculated wind speed value is 0.0084 m/s. Since the higher the backscatter coefficient of radar altimeter is, the smaller the corresponding wind speed value is, so the condition of $\sigma_C^o > 26$ dB will not be considered. According to equation (4), when $\sigma_C^o = 12\text{dB}$, $\sigma_{Ku}^o = 9.0800\text{dB}$, the corresponding wind speed value is 27.3683m/s, that is to say, when the wind speed calculated by radar altimeter is greater than 27.3683m/s, σ_C^o should be less than 12dB. High wind speed and severe sea situation often cause tremendous disasters, so it is necessary to research the statistical model when $\sigma_C^o < 12$ dB. The Ku band and C band statistical model of equation (4) in the range of $\sigma_C^o \in [8, 32]$ is shown in Figure 2. When $\sigma_C^o \in [8, 12]$, it means that σ_C^o decreases if σ_C^o increases which violates the specular scattering theory of radar altimeter. This paper adopts the statistical model of Yang⁵ in the range of $\sigma_C^o \in [8, 12]$ (The dotted line in figure 2). The reason is that the accuracy of Yang⁵ is the highest when $\sigma_C^o \in [8, 12]$ in Table 3 which meets the specular scattering theory.

That is, Yang⁵ is adopted when $\sigma_C^0 \in [8,12)$, while Jiang et al.,⁶ is adopted when $\sigma_C^0 \in [12,26)$.

Table 4 The correspondence of sea surface wind speed and significant wave height with σ_{Ku}^0

σ_{Ku}^0 /dB	Wind speed/ $m \cdot s^{-1}$	Significant wave height /m
23.300	0.0084	1
10.2313	20	—
9.0800	27.3683	—
8.6688	30	—
7.1063	40	—
5.5438	50	—

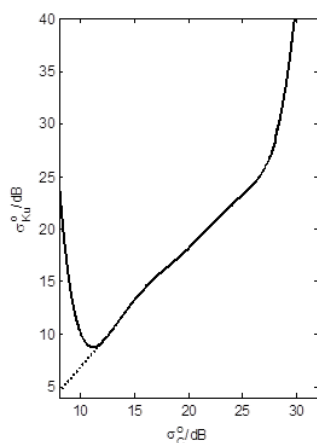


Figure 2 The backscatter coefficient statistical model in the range of $\sigma_C^0 \in [8,32)$.

Conclusions

The backscatter coefficient statistical model plays an important role in the sea surface wind speed retrieval using dual frequency altimeter. This paper suggests an adjustment of low subsection backscatter coefficient statistical relationship, that is, Yang⁵ is adopted when $\sigma_C^0 \in [8,15)$, while Jiang et al.,⁶ is adopted when $\sigma_C^0 \in [15,26)$. The adjustment will improve the accuracy of the statistical model, and have a positive affect for high wind speed retrieval. Work in this paper and Jiang et al.,⁶ only consider the statistical relationship between σ_C^0 and σ_{Ku}^0 without any physical mechanism research, and is short of in situ data verification. Further work will consider these aspects.

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Conflicts of interest

Authors declare that there is no conflict of interest.

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