Inversion and correction of wind speed at high sea state based on nadir data of SWIM on CFOSAT

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Abstract

In order to improve wind speed inversion accuracy, especially high wind speed accuracy, this paper proposes a new general wind speed correction method at medium and high sea conditions with taking into account those limitations and localizations of wind speed inversion mode. Firstly, analyzing and obtaining the functional relationship between the sea surface wind speed and the coverage rate of whitecaps (include bubble and droplets, foams) on the sea surface. Secondly, Establishing a multi-layer medium model with the air layer, the droplets layer, foams layer and seawater layer, and then calculating electromagnetic backscattering from the established model. And thus the backscattering coefficient of the rough sea surface covered with whitecaps can be obtained. At the same time the reduction of the backscattering from the sea surface due to whitecaps is also derived. Thirdly, comparing the calculated value of backscattering coefficient and the measured value from SWIM on CFOSAT to eliminate the whitecaps' effect so as to correct the wind speed. However, since the initial wind speed is still overestimated, the amount of the above correction is limited and the bias still exists. Therefore, this paper proposes a cyclic iterative correction method, which uses the corrected wind speed to calculate the coverage rate of whitecaps and backscattering coefficient from the sea surface once again, and compares the calculated values with SWIM's measured values once again to remove the influence of whitecaps on SWIM nadir point backscattering coefficient and re-correct the overestimated wind speed until the final correction value doesn't change.

Introduction

Under high sea conditions such as typhoon and hurricane, the sea surface waves break, generate foams, and spray droplets and bubbles, which are all called as whitecaps. Those whitecaps (including droplets and bubbles, foams) covering the rough sea surface will greatly absorb the electromagnetic pulses emitted by the satellite remote sensors such as Surface Ware Investigation and Monitoring (SWIM) on China France Oceanography Satellite(CFOSAT) and thus reduce the backscattering from the sea surface. This reduction of the sea surface backward electromagnetic scattering will affect the sea surface wind speed inversion and lead to wind speed overestimated. In general, the usual correction method is to correct the wind speed inversion function by taking into account the fact that the reflection coefficient of sea surface is attenuated to 0.2 or less from 0.61 due to whitecaps' absorption at 13.58GHz. It is obvious that sea surface wind speed inversion will be improved when the effect of whitecaps' absorption is eliminated. However the wind speed inversion model or function is empirical, local and regional, and perhaps is different for different satellites remote sensors. And thus it is a little difficult to practice the correction of whitecaps with a unified model for different microwave remote sensors and different sea areas. Therefore, many microwave remote sensors still have not applied or ignored the effect of whitecaps on wind speed inversion. As a result, the bias of the measured wind speed at normal sea conditions is kept at about 2m/s all the time, and will become much bigger under high sea conditions.

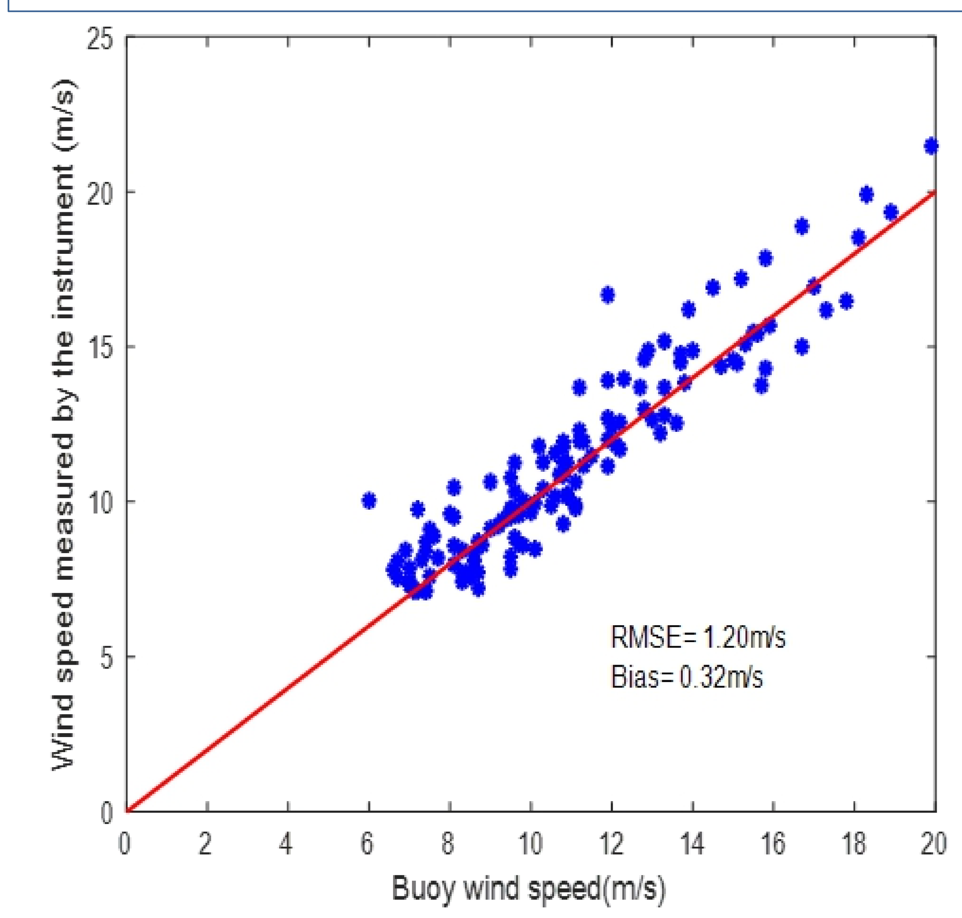

Figure 3 The Relationship between U_{10} and U_{true} before correcting U_{10}

Methods and Materials

In figure 1 a four-layer medium model is shown with a three-interface surface. the top surface z_1 separates free space (or the air) from a homogenous medium(spray droplets $\varepsilon_1,\mu_1=\mu_0$). The second surface z_2 separates spray droplets with a layer thickness d_1 from the another homogenous medium(foams $\varepsilon_2,\mu_2=\mu_0$). The bottom surface z_3 separated the medium of foams with a layer thickness d_2 from the bottom half space(sea water $\varepsilon_3,\mu_3=\mu_0$). Take an example for it, the sea surface is covered by spray droplets and foams at high sea states/conditions. At the same time $z_2=z_1+d_1$ and $z_3=z_2+d_2$ are valid approximately because spray droplets and foams float on the sea water. By the model the attenuation $\Delta\sigma^0(i)$ can be calculated.

(1)Choose the sea surface wind speed $U_{10}(0)$ measured by SWIM to obtain the coverage of whitecaps $C(i)$at the measured point.

$$C(i)=2.95\times10^{-6}U_{10}(0)^{3.52}$$

(2)From the coverage of whitecaps $C(i)$ the attenuation of $\Delta\sigma^0(i)$due to the whitecaps covering with the sea surface was calculated.

(3) The attenuation $\Delta\sigma^0(i)$ is added to the backscatter coefficient $\sigma^0(0)$ measured by SWIM to obtain the corrected backscatter coefficient $\sigma^0(i)$.

(4) Substitute the corrected backscatter coefficient $\sigma^0(i)$ and SWH measured by SWIM into the wind speed retrival mode to obtain the corrected wind speed $U_{10}(i)$.

(5) Bring the corrected new wind speed $U_{10}(i)$ back to step (1) to obtain the new coverage of whitecaps $C(i)$ once again.

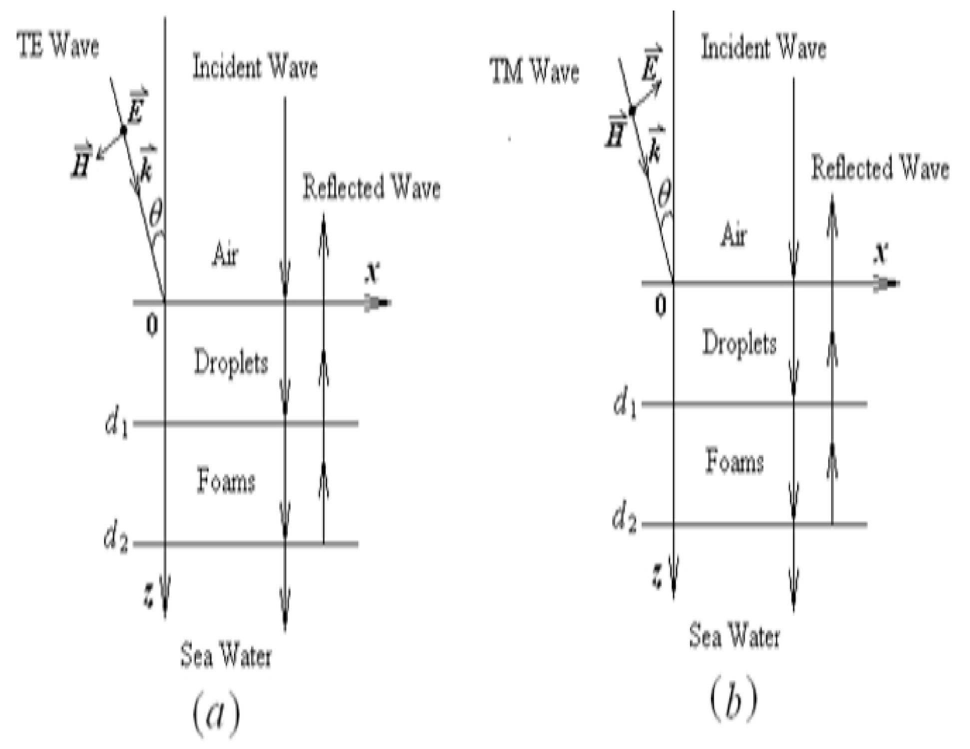

Figure 1 A four-layer medium model.

Results

The paper compared the corrected wind speed U_{10} with the buoy wind speed U_{true} as shown in figure 2. And then calculated RMSE of U_{10} corresponding to U_{true} which was reduced to 1.13m/s and the bias is reduced to 0.14m/s. The measured wind speed by SWIM is shown in figure 3.

It is obvious that those overestimated wind speed U_{10} at high wind speed (>12m/s) are corrected to be become smaller than the original values while those wind speed U_{10} at low or moderate wind speed (<12m/s) are not corrected at all and stay the same value. After having on the iterative correction of wind speed U_{10}, RMSE is reduced by 5.8% and the bias is reduced by 56% in comparison with the original values. In summary, the new cyclic iterative correction algorithm of wind speed proposed U_{10} in this paper can effectively improve the accuracy of wind speed inversion, especially high wind speed inversion.

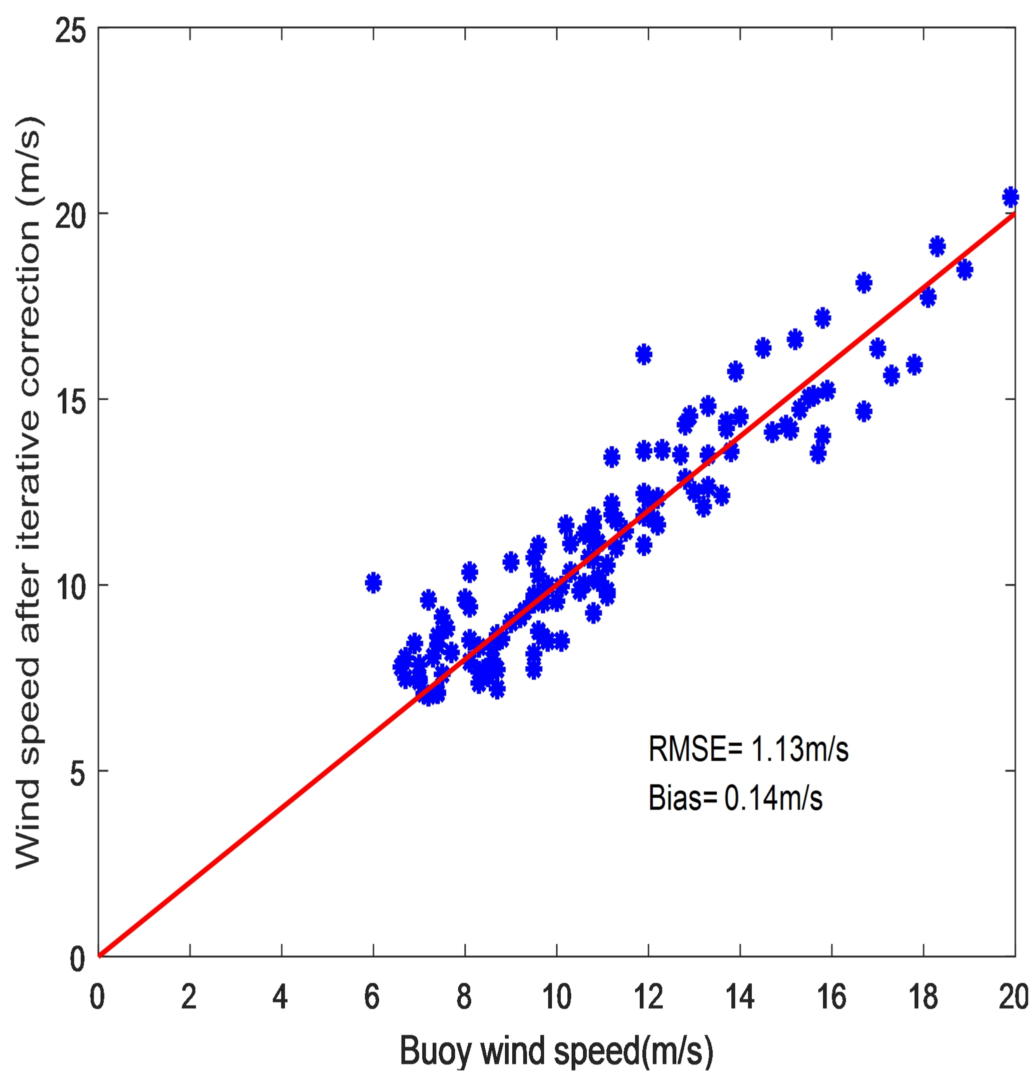

Figure 2 The Relationship between U_{10} and U_{true} after correcting U_{10} .

Discussion

Under the condition that the incident angle is 0^0 there exists only the foam layer, the reflectivity of the sea surface gradually decreases to about 0.0445 from 0.608 and the thickness of the foam layer increases to 5cm when the sea surface wind speed is 45m/s or so. These foams can cause the sea surface backscattering coefficient σ^0 to decrease about 11.4dB, resulting in blind spots for a radar at high sea conditions. when the sea surface wind speed is 7m/s or more than 7m/s the thickness of the spray droplets layer arrives at 36.75cm and the reflectivity of the sea surface will rapidly decay to 0.238 or so. And thus the sea surface backscattering coefficient σ^0 will decrease about 4.07dB. All in all, when the sea surface wind speed arrives at 7m/s or more than the reflectivity of the sea surface begins to decay rapidly to 0.2336 from 0.608 and the sea surface backscattering coefficient σ^0 will also decrease about 4.1543dB. Therefore the effection of whitecaps should not be neglected when the sea surface wind speed arrives at 7m/s.

Conclusions

The new algorithm can improve the accuracy of the sea surface wind speed from RMSE 1.20m/s to 1.13m/s and their bias 0.32m/s to 0.14m/s by comparing the corrected results with the buoy data provided by NDBC. At the same time, for high wind speed(>12m/s) the correction effect the new proposed algorithm is significant, for low or medium wind speed(<12m/s) the correction amount is small or almost no correction. This is also in a good accord with practical experience and law because the coverage and thickness of whitecaps at low or medium wind speed are so small that the effection of whitecaps on the sea surface backscattering coefficient σ^0 can be ignored. the new algorithm can remove the influence of whitecaps on the wind speed inversion, especially for high wind speed, and can effectively improve the accuracy of wind speed inversion.

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