A Ku-band low incidence backscatter model for retrieving wind speeds

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Abstract: A new Ku-band low incidence backscatter model (KuLMOD) for retrieving wind speeds from Tropical Rainfall Mapping Mission (TRMM) precipitation radar (PR) data is proposed. The data set consisted of TRMM PR observations and collocated National Data Buoy Center (NDBC) and Tropical Ocean Global Atmosphere program (TOGA) buoy-measured wind and wave data. The TRMM PR data properties were analyzed with regard to their dependence on spatial resolution, wind speed, relative wind direction, and significant wave height. The KuLMOD model was developed using incidence angles (0.5–6.5°) and wind speeds (1.5–16.5 m/s) as inputs. The model coefficients were derived by fitting the collocated data. The KuLMOD-derived normalized radar cross section, σ_0, was compared with those obtained from the TRMM PR observations and a quasi-specular theoretical model and showed good agreement. With the KuLMOD, the wind speeds were retrieved from the TRMM PR data using the least squares method and validated with the buoy measurements, yielding a root mean square error of 1.45 m/s. The retrieval accuracies for the different incidence angles, wind speeds, and spatial resolutions were obtained.

Keywords: TRMM PR; Ku-band; low incidence; wind speed; retrieval

INTRODUCTION

A Ku-band low incidence wave spectrometer, called Surface Wave Investigation and Monitoring (SWIM) payload from the Chinese French Ocean SATellite (CFOSAT) mission, will be launched around 2018. Clearly, it is of great significance to simultaneously derive wind and wave data using SWIM data. Thus, in addition to wave retrieval, it is also reasonable to explore wind speed retrieval models using SWIM observations. In this paper, a new model for Ku-band radar measurements at low incidence angles is proposed based on matched TRMM PR and NDBC buoy data, with the model coefficients derived using a fitting method.

DATA SETS

The TRMM PR is a Ku-band pulsed radar operating at 13.8 GHz in a horizontal polarization.. The PR data product used was the TRMM PR standard product 2A21 (version 7) from the Goddard Distributed Active Archive Center, covering 15 years from 2000 to 2014. The collocated wind and wave data are obtained from the National Data Buoy Center (NDBC) and Tropical Ocean Global Atmosphere program (TOGA) buoy measurements.

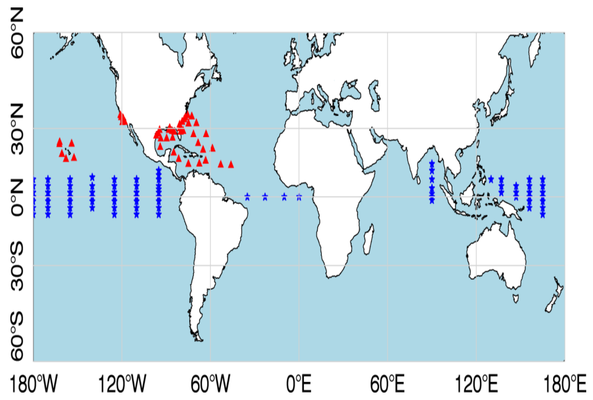


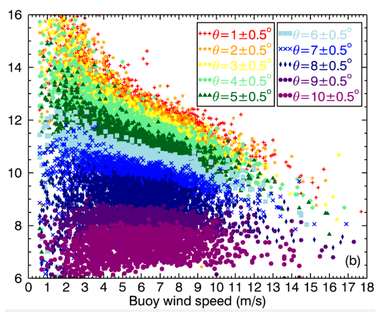
Figure 1. Locations of the 47 National Data Buoy Center (NDBC) and 104 Tropical Ocean Global Atmosphere program (TOGA) buoys used in the collocated data set. The periods of time covered by buoy data were not exactly the same. The red triangle symbols show the NDBC buoy stations, and the blue star symbols show the TOGA buoy stations.

MODEL

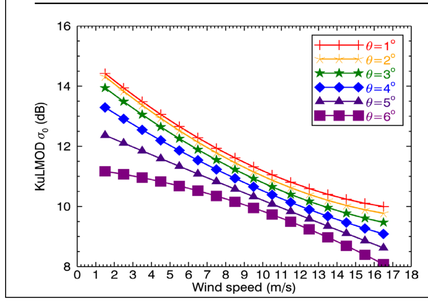
$$\sigma_0(\theta, U_{10}) = a(\theta) + b(\theta)U_{10} + c(\theta)U_{10}^2$$

with,

$$a(\theta) = a_0 + a_1\theta + a_2\theta^2$$
$$b(\theta) = b_0 + b_1\theta + b_2\theta^2$$
$$c(\theta) = c_0 + c_1\theta + c_2\theta^2$$



Coefficient	Fitted value	Coefficient	Fitted value
a_0	15.021540	b_2	0.024089
a_1	0.381658	c_0	0.019823
a_2	−0.166157	c_1	0.002698
b_0	−0.581659	c_2	−0.001108
b_1	−0.067949		



Based on the data properties (shown in Figure 2), a new Ku-band low incidence wind speed model (KuLMOD) was proposed. The model was designed as a simple linear second-order polynomial function of the incidence angle and wind speed as:

Figure 2. Tropical Rainfall Mapping Mission precipitation radar (TRMM PR) normalized radar cross section σ_0 dependence on the wind speed, with σ_0 averaged using a 5x5 pixel boxcar. The symbols show 10 different incidence angle bins between 1 and 10°

Model parameters are derived by fitting the Tropical Rainfall Mapping Mission precipitation radar (TRMM PR) normalized radar cross section σ_0 to the collocated wind speed. Figure 3 plots the KuLMOD-derived σ_0 for different wind speeds and incidence angles. The σ_0 decreased with increasing wind speed, which is consistent with the TRMM PR data properties.

Figure 3. Ku-band low incidence model (KuLMOD)-derived normalized radar cross section σ_0 as a function of the wind speed for different incidence angles. The symbols show six different incidence angles

RESULTS and ANALYSES

Using the KuLMOD, the wind speeds were retrieved from the TRMM PR data by the least squares method and compared with the buoy-measured wind speeds The retrieved wind speeds were compared with the buoy-measured wind speeds (Figure 4) and showed good correlation with a CORR of 0.83, essentially no bias (0.03 m/s),and an RMS error of 1.45 m/s. Therefore, the retrieved wind speeds agreed well with the buoy-measured wind speeds. However, there were minor inconsistencies between the retrievals and the buoy measurements, with higher retrievals for buoy wind speeds above 12 m/s.

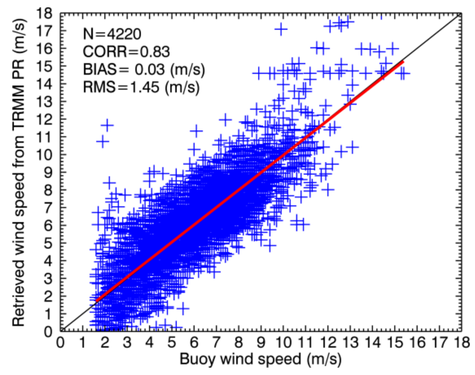


Figure 4. Comparison between the wind speeds measured by the buoys and retrieved from the Tropical Rainfall Mapping Mission precipitation radar (TRMM PR) using the Ku-band low incidence model (KuLMOD). The red line shows the one-order polynomial fitted line and the red line is for reference

Figure 5 shows the RMS errors of the wind speed retrievals as a function of the incidence angle and wind speed bins. The retrievals for the 2–5° bins were better than those for the other bins (Figure 14a), yielding an average RMS error of about 1.37 m/s. The retrievals for the 4–9 m/s bins had better accuracies than those for the other wind speeds (Figure 14b), with an averaged RMS error of about 1.39 m/s.

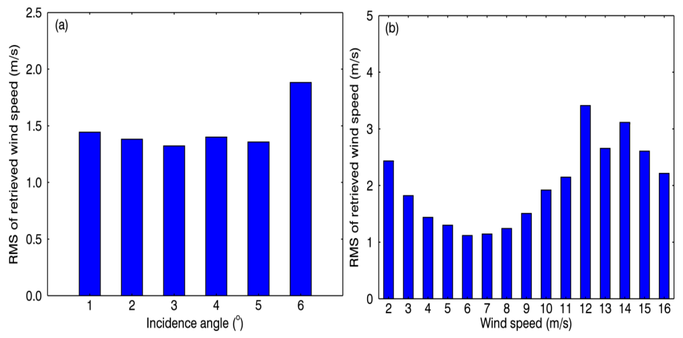


Figure 5 Root mean square (RMS) error of the Tropical Rainfall Mapping Mission precipitation radar (TRMM PR) wind speed retrievals as a function of the (**a**)incidence angle bins and (**b**) wind speed bins.

CONCLUSIONS

A new model was proposed to retrieve wind speeds from Ku-band TRMM PR data obtained at low incidence angles. The matched data set consisted of TRMM PR observations and NDBC buoy-measured wind and wave data. TRMM PR data were analyzed as a function of the wind speed. The σ_0 clearly decreased with the wind speed. The model assumed a simple linear second-order polynomial function, with the coefficients derived by fitting the collocation data set.

With the KuLMOD, the wind speeds were retrieved from the TRMM PR σ_0 by the least squares method and validated with the collocated buoy wind speeds, showing an RMS error of 1.45 m/s. The retrieval accuracy was further analyzed as a function of the incidence angle and wind speed, with better accuracies obtained for the 2–5° incidence angles and 4–9 m/s wind speeds.

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