A NEW ALGORITHM FOR WIND SPEED AT LOW INCIDENCE ANGLES USING TRMM PRECIPITATION RADAR DATA

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1. INTRODUCTION

Two now-standard satellite active sensors for ocean wind estimation are the altimeter and the scatterometer. The former views the sea at nadir, whereas the latter views the sea at medium incidence angles (20º-60º). Altimeter and scatterometer data have been examined thoroughly to establish the relation between the Normalized Radar Cross Section, denoted as σ°, and surface wind (such as [1-2] and many others). However, the capability of spaceborne active radar observing surface wind at low incidence angles between 0~20º are rare owing to a lack of radar observation data at low incidence angles.

The successful operation of the Tropical Rainfall Mapping Mission (TRMM) has provided a unique, long-term, extensive dataset of accurate normalized radar cross section measured from the Ku-band Precipitation Radar (PR). Also, it is the first and only satellite system that provides such high angle-resolved scattering near nadir from 49 beams (0.1°~18.1°) measurements.

PR is not like altimeters which can measure the significant wave height and σ° simultaneously to improve altimeter wind speed measurements [3-4]. PR is not like scatterometer, which the backscatter is mainly due to ocean Bragg scattering. It is mainly by quasi-specular scattering at low incidence angles. Another difference between them is that scatterometer can acquire radar backscattering measurements from different viewing azimuth angles.

Several studies have developed empirical tabular model functions relating PR σ° to wind speed for incidence angles from nadir to 18º [5-7]. However, there is evidence that swell and sea maturity state affects the dependence of PR σ° on wind speed [6-7]. Therefore, those fully empirical functions cannot be used for retrieving wind speed from PR σ° measurement without considering more than one sea state parameter. Li *et al.* [8] take advantage of Ku-band scatterometer Geophysical Model Function model like SASS-2 to interpret PR σ° and make use of a maximum likelihood estimation technique to retrieve wind speed. While in this study, a new algorithm was developed for retrieving ocean surface winds using surface backscattering measurements from the TRMM PR without other auxiliary data. To our knowledge, this is the first time utilize the σ° - incidence angle profile to retrieve wind speed.

2. DATASETS

The PR operates at 13.8 GHz, horizontal polarization and the near-nadir incidence angle ranging from 0.1º to 18º [9]. The data product used herein is TRMM PR standard product 2A21 from the Goddard Distributed Active Archive Center. It contains information on ocean surface radar backscatter cross section, total path attenuation, and the presence of rain in the measurement cell, as well as standard quality flags, navigation and instrument geometry (e.g. incidence angle) information. Five years of data set (2004-2008) with PR surface cross-section measurements obtained under no-rain conditions are used for this study.

Wind speed data used for building and testing the model was obtained from the National Data Buoy Center (NDBC). Continuous winds data which contain information on wind vector in 10 minute interval are used.

The criteria used for the collocation between buoy measurements and PR observations are given as follows: spatial separation less than 0.15º (latitude and longitude), time separation within 5 minutes.

In order to illustrate the distribution of sea states after matching, buoy measured significant wave heights versus buoy wind speeds is showed in Fig. 1. It is shown that the sea states associated with buoy wind speed data covered almost all conditions, including developing wind waves, developed wind waves, swell and mixed sea.

3. METHOD AND RESULTS

At low incidence angles, the radar backscatter is mainly due to quasi-specular reflection of sea surface. For a Gaussian surface, the general expression for σ° near the nadir is given by [10]

$$\sigma^{0} = \frac{|R(0)|^2 \exp\left[-\dfrac{\tan^2\theta \cdot S_y^2}{2(S_x^2 S_y^2 - S_{xy}^2)}\right]}{2\cos^4\theta \cdot \sqrt{S_x^2 S_y^2 - S_{xy}^2}} \tag{1}$$

Where $|R(0)|^2$ is effective nadir reflection coefficient. S_x and S_y are the standard deviations of surface wave slope in x direction (ξ_x) and in y direction (ξ_y), and $S_{xy}^2 = \langle\xi_{xy}\rangle$ is their first joint moment. The x and y axes lie in the plane of the (mean) ocean surface, with the y axis perpendicular to the plane of incidence. For PR radar, S_x^2 is the slope variance in the antenna look direction. Those three parameters, S_x^2, S_y^2 and S_{xy}^2, are mainly related to wave directional spectrum and radar wavelength.

PR data analysis shows, from nadir to 10°, the σ° measurements in each matched cell as a function of incidence angles are quite close to formula (1). In near nadir, σ° shows a large variance. That's another reason why PR nadir σ° is not suitable for wind speed retrieval using altimeter algorithm. Meanwhile, the wind direction modulation is small. For example, the directional peak-to-peak modulation is about 0.8dB at 10° incidence at a

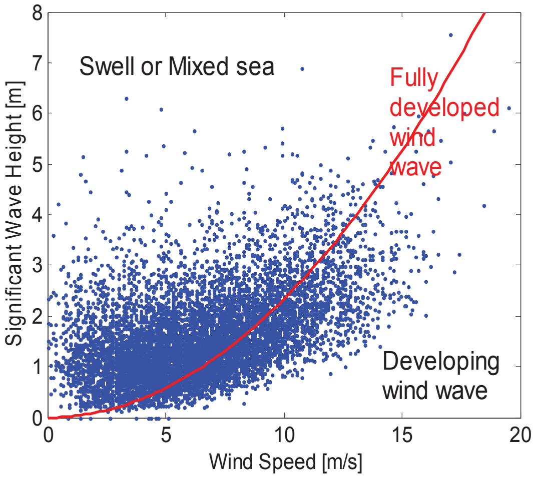

Fig. 1. Buoy measured significant wave height versus buoy wind speed. A fully developed wind wave, calculated from the JONSWAP spectrum, is showed by the red line. The blue dots show the buoy data.

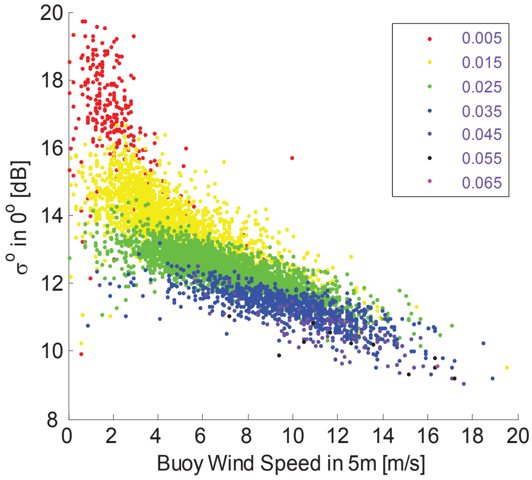

Fig. 2. Retrieved nadir σ° as a function of buoy wind speed for different slop variance parameters varying from 0.005 to 0.065.

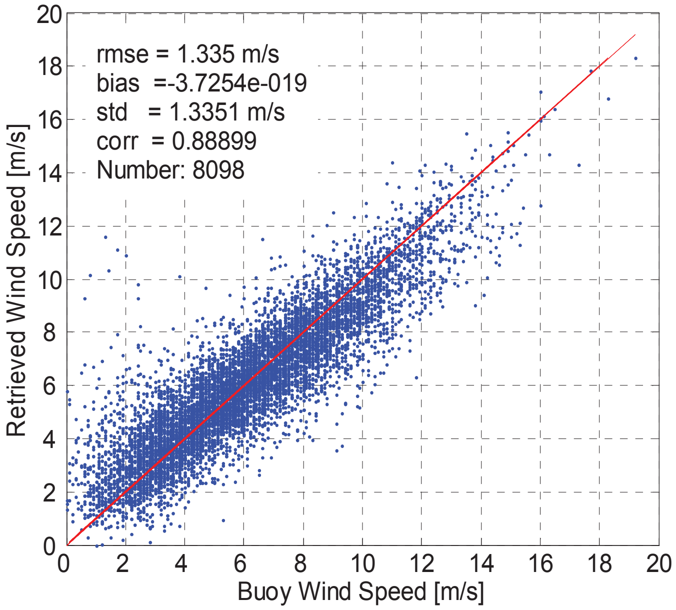

Fig. 3. Comparison of the ocean surface winds retrieved from the TRMM PR and observed by NDBC buoys. 8098 matched cases, both the 5m wind speed and 10m wind speed, are showed here.

15-m/s wind. This modulation is increases with wind speed and incidence angle. Above 10°, the Bragg scattering cannot be neglect and the modulation caused by wind direction is not weak any more. In this study, only the data measured below 10° are used for wind speed retrieval only. In each matching cell, firstly, the 'averaged' nadir σ°=

$\frac{1}{2}|R(0)|^2 \Big/ \sqrt{S_x^2 S_y^2 - S_{xy}^2}$ (hereafter denoted σ_0^o) and Slop Variance Parameter $2(S_x^2 S_y^2 - S_{xy}^2)/S_y^2$ (hereafter called SVP) are calculated. The results show that SVP influence the σ_0^o dependence on wind speed (Fig. 2).

Based on the fact showed in Fig. 2, new models are then constructed relating wind speed as a function of σ_0^o and SVP. The anemometer height for NDBC buoys in general equaling 5m or 10m. Here, buoy winds are not normalized to an equivalent anemometer height. Instead, two models are built for two height wind speed.

The validation of model results is showed in Fig. 3. It is shown that the REMS of the PR retrieved wind speed with respect to the buoy wind speed are about 1.34m/s and a bias nearly zero. The new algorithm is shown to perform better than the previous algorithm performed by Li *et al.* [8] which with REMS of 1.73m/s and a bias of 0.06m/s. Additional comparisons will be performed using Altimeter and QuickSCAT measurements.

4. REFERENCES

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