RAIN EFFECTS ON CFOSAT SCATTEROMETER: TOWARDS AN IMPROVED WIND QUALITY CONTROL

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ABSTRACT

Rain is known to be the most significant phenomenon in degrading the Ku-band scatterometer wind quality. After the decommission of the National Aeronautics and Space Administration scatterometer (NSCAT), little work has been done in characterizing the impact of rain on Ku-band fan beam scatterometer. In this paper, the rain impact on the backscatter measurements as well as the retrieved wind quality of the China-France Oceanography Satellite (CFOSAT) scatterometer (CSCAT) is investigated using the European Centre for Medium-range Weather Forecasts (ECMWF) winds and the Global Precipitation Measurement (GPM) mission's Microwave Imager (GMI) rain data as reference. The dependence of rain effects on the observing incidence angle is studied with the objective to optimize the configurations of wind inversion and quality control (QC). It is shown that the backscatter measurements at low incidence angles (~30°) are much less affected by rain than those at higher incidence angles. The operational CSCAT processing proves to be effective in screening rain-contaminated wind vectors but at the expense of many valuable winds. An adapted wind inversion scheme is proposed to further improve the CSCAT wind quality under rainy conditions.

Index Terms— CFOSAT, scatterometer, wind, quality control, rain

1. INTRODUCTION

The China-France Oceanography Satellite (CFOSAT) launched on 29 October 2018 carries two scientific payloads, namely the surface wave investigation and monitoring (SWIM) radar and the rotating fan-beam scatterometer (*abbr.* CSCAT) [1]. The latter is a real-aperture Ku-band radar with both vertically and horizontally polarized fan beams sweeping over Earth surface conically [2]. Similar to the other scatterometers, the non-wind geophysical phenomena, such as rain, confused sea state and local wind variability, could distort the backscatter signal associated with sea surface winds, and in turn, degrading the retrieved wind quality. In particular, rain is the most significant problem in affecting the Ku-band scatterometer wind quality [3]. On the one hand, rain could attenuate and scatter the microwave signal. As the rain rate increases, the radar gets less of backscatter signal from sea surface and more radiation scattered by the raindrops. On the other hand, rain splashing on sea surface could increase the surface roughness, resulting in an increased radar backscatters (σ^0). Overall, those effects not only lead to positive bias of the retrieved wind speed, but also degrade the quality of wind direction due to the loss of anisotropy in the backscatter signal. Moreover, heavy rain-induced wind variability generally increases the isotropy of radar backscatters within a certain wind vector cell (WVC), yielding lower quality winds as well [4].

Numerous studies have been carried out in the last twenty years to address the rain effects in Ku-band scatterometers. Most of them focus on the Ku-band pencil-beam scatterometers, such as filtering rain-contaminated winds [5][6], correcting for rain-induced backscatter signal [7][8], and/or modeling both rain- and wind-induced microwave scattering with the objective of retrieving both parameters simultaneously [9][10]. Nevertheless, little work on rain has been done for the Ku-band fan beam scatterometer. This paper intends to study the overall rain effects on the CSCAT backscatters at different incidence angles, in order to better understand how rain affects the retrieved wind quality of CSCAT, and to improve the quality control scheme for CSCAT Level 2 (L2) processing. Section 2 presents the data used in this study. Section 3 evaluates the rain effects on CSCAT backscatter measurements. In section 4, the wind quality of CSCAT is assessed under different rainy conditions. Finally, conclusions and outlooks are found in Section 5.

2. DATA

To study the effects of rain on CSCAT backscatter signal and retrieved winds, both the L2A and L2B products are collocated with the European Centre for Medium-range

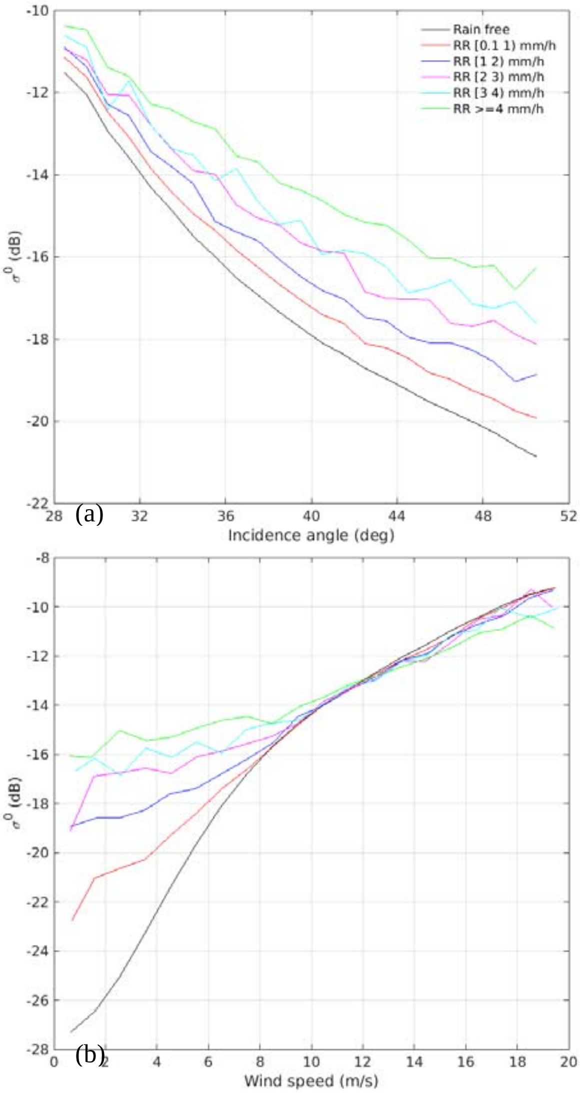

Fig. 1 The averaged CSCAT σ^0 (VV beam) as a function of (a) incidence angle for 6 m/s < wind speed < 7 m/s; and (b) ECMWF wind speed for the incidence angle of 40°. Color indicates different rain rates.

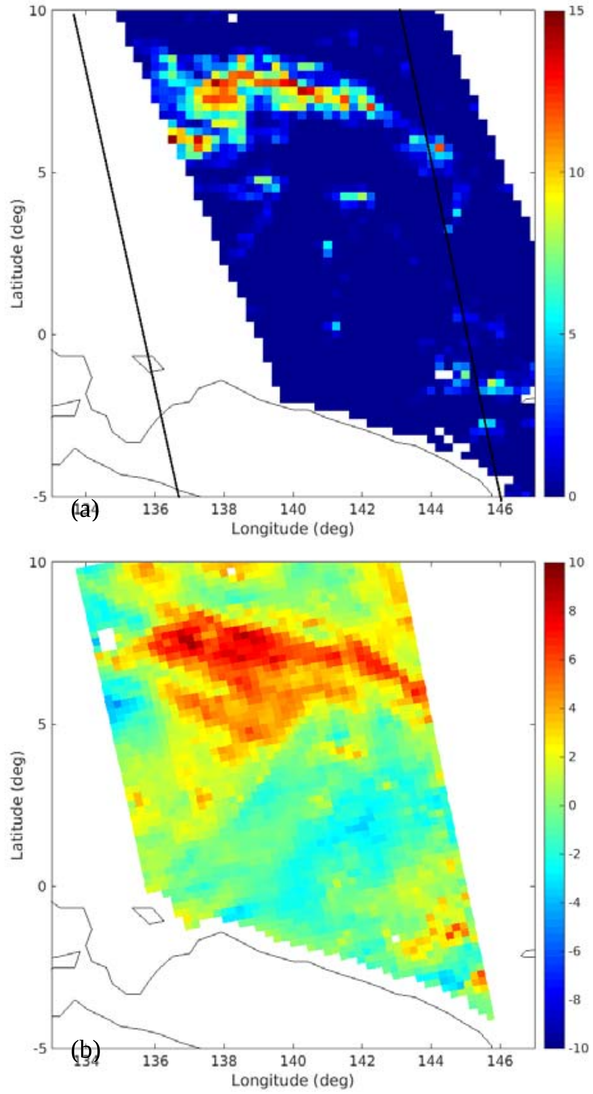

Fig. 2 (a) GMI rain rate collocated with the CSCAT observation, colorbar indicates the rain rate in mm/h; (b) CSCAT wind speed bias w.r.t. the ECMWF reference winds, colorbar indicates the bias in m/s.

Weather Forecasts (ECMWF) winds and the Global Precipitation Measurement (GPM) mission's Microwave Imager (GMI) rain data. The collocations consist of four months of measurements during January – April 2019. Note that ECMWF three-hourly forecast winds are interpolated spatially and temporally to the CSCAT data acquisition location and time. The collocation criteria for GMI rain data are less than 30 minutes and 0.25° spatial distance from the CSCAT measurements. The total amount of collocations is about 1.7 million.

A numerical ocean calibration (NOC), based on comparing the probability density function of the measured backscatter data with the simulated backscatter data from the European Centre for Medium-Range Weather Forecasts (ECMWF) winds, is used to eliminate the systematic biases of the averaged backscatter values [11]. The NOC coefficients are calculated offline using the data from December 19 2018 to January 3 2019, and then applied to the whole period of L2 processing.

3. RAIN IMPACT ON CSCAT σ^0

Figure 1 shows the averaged σ^0 of CSCAT VV beam as a function of incidence angle (Fig. 1a) and wind speed (Fig. 1b), respectively. Similar results are found for the HH beam (not shown). In accordance with the past researches as mentioned in Section 1, rain generally increases the radar backscatter, except for the case at high wind and large rain rate conditions (see the green curve in Fig. 1b). Due to lack of collocations, the slight σ^0 depression at high winds is not

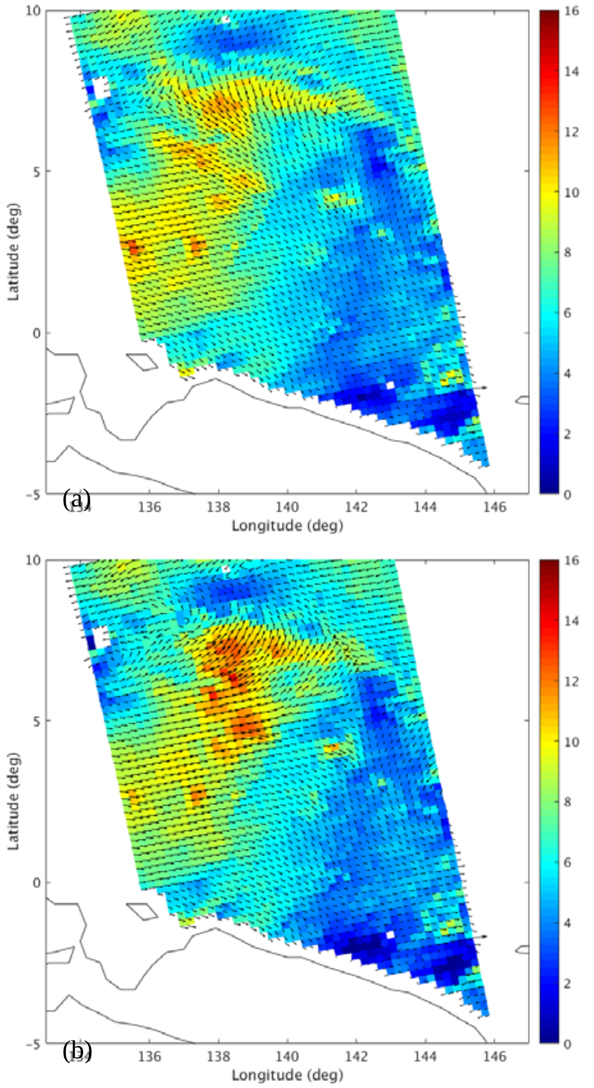

Fig. 3 CSCAT retrieved wind field using (a) all the available observations; (b) four views of the lowest incidence angles. Colorbar indicates the wind speed.

statistical significant, more data will be used to further investigate this problem.

Specifically, the rain effects on CSCAT σ^0 increase as the rain rate, but decrease as the incidence angle or the wind speed. This is probably due to that the resonance Bragg wavelength becomes larger as the incidence angle decreases for a given radar signal wavelength. While the modification of sea surface roughness by impinging raindrops decreases as the wavelength of water waves increases.

The dependence of rain effects on the observing incidence angle opens up opportunities to improve the CSCAT wind retrieval as well as the wind quality control under rainy conditions, particularly for the inner-swath WVCs with observations of both low and high incidence angles.

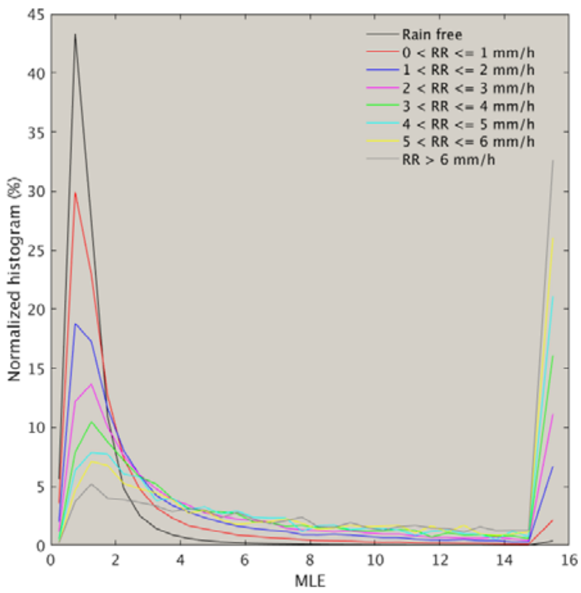

Fig. 3 MLE histogram for different RR intervals (see the legend)

4. RAIN IMPACT ON CSCAT WINDS

The nominal CSCAT L2 winds, which are derived using all the available backscatter measurements, are assessed in this section. Figure 2 illustrates the GMI rain rate collocated with CSCAT observation on December 20th 2019, and the retrieved wind speed bias (operational product) w.r.t. the ECMWF reference winds, respectively. The ECMWF wind speed is generally below 10 m/s in this case (not shown). As expected, the rain-induced bias is positive and remarkable. The nominal CSCAT wind field is shown in Fig. 3(a), and the one retrieved using only four views of the lowest incidence angles is illustrated in Fig. 3(b). Obviously, different combinations of σ^0s used in the inversion could lead to different retrieved winds, particularly over the rainy areas. For instance, a strong convergent front is presented in Fig. 3(b) but absent in Fig. 3(a). Since ECMWF wind errors also increase over rainy areas, an independent wind reference, such as winds derived from C-band scatterometer, is needed to validate the two different wind retrievals in Fig. 3.

The rain impact on CSCAT inversion residual, namely Maximum Likelihood Estimator (MLE) value, is shown in Fig. 3. There is a clear bias of MLE distribution toward large MLE values as rain rate increases. Conventionally, a MLE threshold (such as the dashed curve) is set to discriminate good-quality WVCs from poor-quality WVCs. Note also that, although MLE increases with RR, it is clear that there are many WVVs with low MLE values even at heavy rain conditions. One can further constrain the QC by reducing the MLE threshold, but a an expense of filtering a significant amount of rain-free good quality data.

5. CONCLUSIONS

This paper shows the preliminary results of rain effects on Ku-band fan beam scatterometer. In line with the previous studies, the Ku-band radar backscatter signal over sea surface is generally increased by rain, i.e., the rain effects on CSCAT σ^0 increase as the rain rate, but decrease as the incidence angle or the wind speed. Overall, the retrieved wind speed of CSCAT is significantly overestimated under rainy conditions. The inversion residual or MLE is very sensitive to rain, such that it can be used in discriminating good-wind-quality WVCs from poor-wind-quality WVCs. However, the MLE-based QC does not effectively screen rain.

An adapted wind inversion scheme that uses backscatter measurements of low incidence angles rather than all of the observations is proposed to improve the CSCAT wind retrieval and quality control under rainy conditions. Though independent wind reference is needed to further validate the new inversion scheme, preliminary test shows that more wind variability over rainy areas is acquired by excluding the σ^0s at high incidence angles in the wind retrieval. A comprehensive verification will be carried out soon.

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