Calibration of SARAL/AltiKa Wind Speed

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***Abstract*—Satellite with ARgos and ALtiKa (SARAL)/AltiKa is the first oceanographic radar altimeter that operates in Ka-band which is very sensitive to the atmospheric factors like liquid water and water vapor. An empirical recipe is proposed to partially compensate for this impact for the purpose of ocean surface wind speed (SWS) evaluation. The results compare well with numerical prediction model fields and *in situ* measurements. SARAL SWS computed using the proposed recipe shows very low bias (below 0.4 m/s). The random error at a scale of 75 km is estimated at about 1.0 m/s, which is very close to that of the Ku-band altimeters.**

***Index Terms*—AltiKa, backscatter, Ka-band, radar altimeter (RA), Satellite with ARgos and ALtiKa (SARAL), wind speed.**

I. Introduction

INFORMATION about the surface wind speed (SWS) is very valuable for oceanic and atmospheric applications. SWS is one of the most important driving forces for ocean waves and circulation, and therefore, it is of special interest for the European Centre for Medium-Range Weather Forecasts (ECMWF). Radar altimeter (RA) SWS is used at ECMWF for monitoring the model 10-m wind speed parameter (which is equivalent to the SWS). It is also used as an independent tool to assess model changes as it is not assimilated by the model.

Ocean surface wind generates ripples on the water surface. The stronger the wind is, the steeper the ripples are. These ripples diffuse nadir-incident radar signal sent by the RA and therefore reduce the power of the signal echoed back to the RA antenna. Therefore, there is a strong (inverse) relation between the SWS and the radar backscatter. This relation is not exclusive and is not known precisely. Therefore, empirical algorithms have been used for this purpose so far (e.g., [1]).

Satellite with ARgos and ALtiKa (SARAL) is an Indo-French mission for the monitoring of the Earth environment developed and operated by the French Space Agency (CNES) and the Indian Space Research Organization. The satellite, which has a design lifetime of 3 years, was launched on February 25, 2013, and reached its final orbit on March 13, 2013. The satellite follows the sun-synchronous orbit that was occupied by the European Space Agency satellites of ERS-2 and ENVISAT during their nominal operations (altitude of about 800 km). The main payload of this mission is a Ka-band (35.75 GHz) altimeter called AltiKa which is the first space-borne oceanographic altimeter to operate at this radar frequency [2]. Radar signal at such short wavelength (about 1 cm) is able to measure the ocean surface topography with a finer resolution compared to other RAs operating at Ku-band (wavelength of about 2.2 cm) or other bands owing to the smaller Ka-band footprint and to the increased pulse reception frequency [3] compared to conventional altimeters. However, this comes at a cost of being sensitive to several atmospheric factors like liquid water and water vapor which are expected to adversely impact RA measurements [3].

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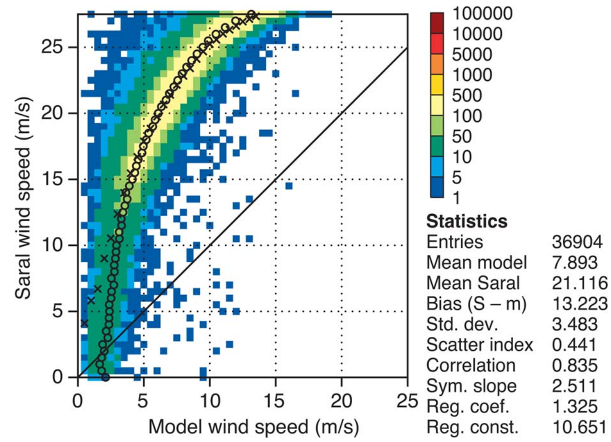

Fig. 1. Density scatter plot showing the comparison between the SARAL/AltiKa (using Jason-2 algorithm) and ECMWF model wind speeds for the period March 18–28, 2013. Crosses are the mean of y values for the given x values, while circles are vice versa. The number of entries in each box is in the legend.

A study to assess the potential degradation level of various Ka-band products (specifically, range, significant wave height, and backscatter) was conducted before the launch [3], [4]. Numerical simulation combined with results from Jason mission estimated that the data loss due to rain can be between 5% and 10% [3]. Part of this loss is in tropical areas. The rain-related degradation also occurs during stormy conditions when RA measurements are highly needed.

With the exception of a few airborne Ka-band RA campaigns [5], there is no previous experience with Ka-band altimeters. Airborne Ka data suggest that there is a similar wind speed dependence on the backscatter (σ^0). Therefore, the operators decided to apply Jason-2 algorithm to evaluate the SWS with a proper disclaimer in the AltiKa handbook [2] until enough measurements are gathered and a proper calibration is done. Although this may be the best that can be done, it is clear that the resulted wind speed product is not correct, as can be seen in Fig. 1, which shows the global comparison between near real time (NRT) AltiKa and ECMWF model SWS for the period March 18–28, 2013. This is expected as the empirical relation between SWS and σ^0 is based on Jason-2 Ku-band σ^0 which is about 3 dB higher.

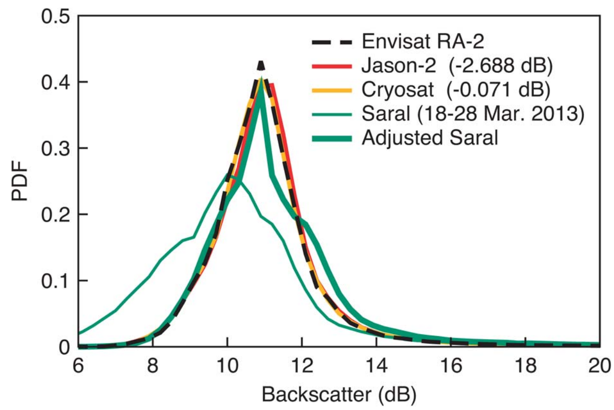

Fig. 2. Backscatter histograms of ENVISAT RA-2 (dash-dot), Jason-2 (long dashes), and CryoSat-2 LRM (short dashes) for all oceans during March 2012. The SARAL histogram during March 18–28, 2013, is shown before calibration (thin continuous line) and after calibration (thick continuous line).

A recipe to evaluate the SWS from the measured 1-Hz NRT AltiKa Operational Geophysical Data Record (OGDR) backscatter coefficient is outlined in Section II. The results of using the recipe are presented and discussed in Section III. Finally, the conclusion is given in Section IV.

II. Recipe for SWS Evaluation

Reference [1] presents a Ku-band wind speed algorithm that was specifically tailored for ENVISAT RA-2. This algorithm had been used operationally for RA-2 since October 2007. The same algorithm can be used successfully for ERS-2, Jason-1, and Jason-2 after applying fixed offsets to the backscatter coefficient values so that their probability density functions (pdf) or histograms become comparable with the corresponding ENVISAT histogram [1]. This is shown in Fig. 2 for ENVISAT, Jason-2, Jason-1, and CryoSat-2 low rate mode (LRM) data for the whole global oceans during the month of March 2012, which is the last full calendar month before the loss of ENVISAT in April 2012. It is clear that the concept is valid even for the LRM data of CryoSat-2 which has a different design, although it implements the same Ku-band as the other altimeters.

The 1-Hz NRT SARAL OGDR backscatter histogram for the global oceans during March 18–28, 2013, is also plotted (only the positive values of σ^0) in Fig. 2. It is clear that a simple offset cannot help SARAL histogram to match the histograms from Ku-band altimeters. Ka-band histogram is much flatter. This is mainly due to the higher sensitivity of Ka backscatter to the surface roughness in addition to the increased attenuation due to environmental factors like atmospheric temperature, liquid water (also called rain contamination), and water vapor.

Atmospheric attenuation and rain contamination are problems shared with the Ku-band RAs but with much reduced impact. Such problems are usually solved by making use of measurements of the radiometer accompanying the altimeter. An attenuation model and well-calibrated radiometer products will be used to sort out this problem (N. Picot; personal communications). For the time being, an empirical approach can be used to compensate for this impact.

First, the maximum acceptable standard deviation (SD) of the 40-Hz σ^0 is set to 5 dB. This eliminates severely affected measurements but allows for a certain level of variability at the same time. The value of σ^0 is increased to get a modified value σ^0_m as follows:

$$\sigma^0_m = \sigma^0 + nS \tag{1}$$

with S being the backscatter SD and n being a free parameter that was found by trial and error to be around 2. This treatment reduces significantly the impact of atmospheric attenuation.

To attain a comparable backscatter pdf to that of ENVISAT RA-2, σ^0_m in decibels is then scaled according to

$$\sigma^0_a = A + B\sigma^0_m \quad \text{if } \sigma^0_m < \sigma^0_t \tag{2}$$

$$\sigma^0_a = C + \sigma^0_m \quad \text{if } \sigma^0_m \geq \sigma^0_t \tag{3}$$

with A, B, C, and σ^0_t being the free fitting parameters that can be found by fitting both sides of the pdf to the corresponding RA-2 pdf. The parameters are then adjusted to ensure the continuity of (2) and (3) at σ^0_t to be

$$A = 4.0 \text{ dB} \quad B = 0.6765 \quad C = 0.7 \text{ dB} \quad \sigma^0_t = 10.2 \text{ dB}. \tag{4}$$

The final step is to apply a Ku-band wind speed algorithm. Specifically, the algorithm in [1] is used. This algorithm can be written as

$$U_m = \begin{cases} \alpha - \beta\sigma^0_a & \text{if } \sigma^0_a \leq \sigma_b \\ \gamma \exp\left(-\delta\sigma^0_a\right) & \text{if } \sigma^0_a > \sigma_b \end{cases} \tag{5}$$

SWS, U_{10}, is then computed from the first-guess U_m as

$$U_{10} = U_m + 1.4U_m^{0.096} \exp\left(-0.32U_m^{1.096}\right) \tag{6}$$

where α, β, γ, δ, and σ_b are the fitting parameters given by

$$\alpha = 46.5 \quad \beta = 3.6 \quad \gamma = 1690 \quad \delta = 0.5 \quad \sigma_b = 10.917 \text{ dB}. \tag{7}$$

III. Results and Discussion

Equations (1)–(4) result in adjusted SARAL backscatter coefficient values with a pdf very close to that of ENVISAT RA-2 as can be seen in Fig. 2 for the period March 18–28, 2013. Irrespective of the deviation in the adjusted SARAL pdf with respect to RA-2 around 12 dB, further fine tuning is not needed as the backscatter-wind speed relation is not very sensitive to small variations in σ^0 at that regime.

The recipe in Section II was used to evaluate the SWS from SARAL AltiKa OGDR backscatter for the period March 18 to May 30, 2013. The data then went through the quality control procedure described in [6] and [7]. Due to the scale difference between SARAL measurements (about 7 km) and the ECMWF Integrated Forecast System model (more than 70 km), the comparison is done at the model scale. Therefore, along-track averages of 11 SARAL measurements, called superobservations, are used in the comparison. This procedure has been in use at ECMWF for more than two decades (e.g., [6]–[8]).

Fig. 3 shows the comparison between the computed SARAL SWS superobservations and the ECMWF model 10-m wind

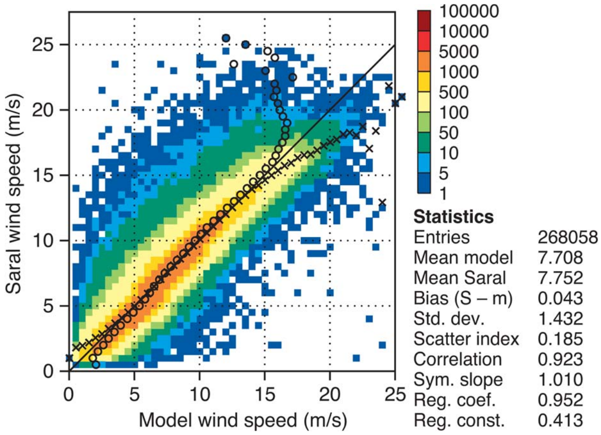

Fig. 3. Density scatter plot showing the comparison between the SARAL and ECMWF model wind speeds for the period March 18 to May 30, 2013. See Fig. 1 for crosses and circles.

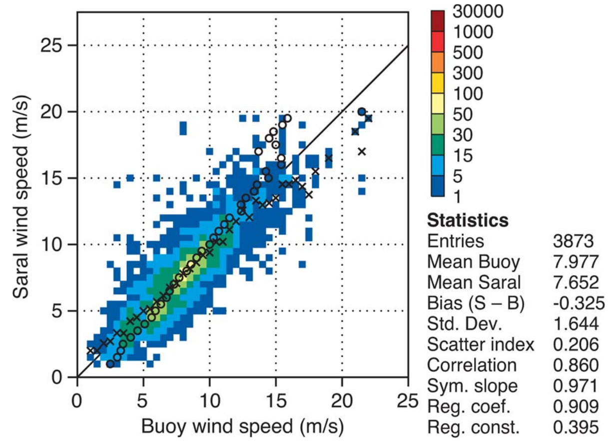

Fig. 4. Same as in Fig. 3, but the comparison is done against available buoys. See Fig. 1 for crosses and circles.

speed over global oceans and for the period March 18 to May 30, 2013, as a density scatter plot similar to Fig. 1. It is clear that the agreement is quite good. The computed SARAL wind speed is virtually unbiased compared to the model. The SD of the difference (SDD) between the computed SARAL winds and the model is 1.43 m/s (or 18.5% with respect to the mean). This is slightly higher than those from Ku-band RAs which have typical values around 1.2 m/s (e.g., [1] and [8]). Assuming that the model wind speed absolute random error (in SD sense) to be about 1.0 m/s [8], it is possible to estimate the SARAL SWS to be around 1.0 m/s at the superobservation scale (75 km). This figure is within the requirements [2] even after adjusting for the scale impact.

Furthermore, SARAL wind speed was compared against available *in situ* (also referred to them as buoy) measurements from offshore buoys and platforms as received routinely through the World Meteorological Organization Global Telecommunication System. Those are generally 1-h data received in NRT and mainly collected off the coasts of North America and Europe. Details about this type of data with their preprocessing can be found in [9]. For this comparison, the same scale (75 km) and the same period (March 17 to May 30, 2013) are selected. The criteria suggested by [8] to accept the collocations are used. The comparison between the computed SARAL wind speed and the buoys is shown in Fig. 4. SARAL SWS is lower by 0.33 m/s. The SDD is 1.65 m/s. The collocation error, estimated at about 0.2 m/s [8], contributes to this higher SDD value. It is also possible to estimate the random error of SARAL SWS to be around 1.0 m/s if the buoy error of about 1.0 m/s is used and the additional collocation error is accounted for [8].

IV. Conclusion

SARAL/AltiKa uses Ka-band which enables the altimeter to make finer measurements at a cost of high sensitivity to the atmospheric liquid water (e.g., rain) and water vapor. Ku-band wind speed algorithm cannot be used directly for SARAL. An empirical recipe has been proposed to partially compensate for the impact of atmospheric factors. Compared to the ECMWF model and *in situ* measurements, the SARAL SWS computed using the proposed recipe has a very low bias (less than ∼0.4 m/s) and an SDD that is slightly higher than Ku-band altimeters (∼1.5 m/s compared to ∼1.2 m/s at 75-km scale). It is highly recommended to use a model that can account for the atmospheric attenuation and to fit (4) for corrected Ka-band backscatter. In the meantime, the presented recipe can be used to evaluate SARAL wind speed.

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