A C-BAND CROSS POLARIZATION GEOPHYSICAL MODEL FUNCTION

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1. INTRODUCTION

Microwave backscattering from the ocean surface is closely related to the wind-generated ocean surface roughness. This property is used for obtaining global ocean surface vector winds. The deployed scatterometers so far do not use the cross-polarized sea return (VH , representing either vertical transmit horizontal receive or horizontal transmit vertical receive) because of its weak signal level. The copolarized returns (VV or HH), however, may saturate in high wind speeds especially for low incidence angles.

Recent analyses suggest that the saturation of C-band VH signal, if it exists, may occur at much higher wind velocities in comparison to the co-polarized signals (Hwang et al., 2010a, b; Vachon and Wolfe, 2011; Zhang et al., 2011). The result prompts the incorporation of VH channel in the next generation scatterometer designs for extending the retrieved wind speed range (Lin et al. 2012; Belmonte Rivas et al., 2014). In the meantime, much effort is devoted to developing cross polarization geophysical model functions (GMFs) for hurricane wind retrieval using polarimetric SAR imagery. Several of the GMFs assume a linear relationship between VH in dB and wind speed U_{10} (Zhang et al., 2014; van Zadelhoff et al., 2013, 2014). One

drawback of these GMFs is the lack of incidence angle (θ) dependence, at least for the high wind range ($U_{10} > 21$ m/s).

As illustrated in Fig. 1, recent analyses show that the dependence of VH in linear scale on U_{10} can be expressed in piecewise power-law functions (Hwang et al., 2014, 2015). Here, we present a C-band GMF using the piecewise power-law relationship. Presented in this study are three datasets (Zhang et al., 2014; van Zadelhoff et al., 2013, 2014) composed of R2 dual-polarization (VV and VH) NRCS and: (1) wind data from Buoy, stepped frequency microwave radiometer (SFMR) and H*Wind sources: BSH; (2) wind data from SFMR measurements: KNMI_S; and (3) wind data from ECMWF models: KNMI_E. The proposed GMF incorporates the incidence angle dependence for the full range of wind speed available in our datasets (up to 56 m/s).

2. THE GMF DESIGN

The proposed GMF is designed by representing the VH as power-law functions of wind speed in several wind speed groups (WSGs), with the proportionality coefficient and the exponent of the power-law function varying with the incidence angle. For the n -th WSG, this is written as

$$[\sigma_{0VH}(\theta)]_n = A_n(\theta) U_{10}^{a_n(\theta)}. \quad (1)$$

In order to adapt the better information in the future, easy modification of the GMF is an important consideration. For example, the number of WSGs and the parameterization in each WSG can be revised without major changes in the design structure as the database expands and knowledge of wind speed dependence in each WSG and incidence angle bin (IAB) becomes more refined.

Ideally, the coefficient A_n and exponent a_n can be derived from field data. Presently, only partial information is available or can be estimated due to a lack of comprehensive coverage in θ and U_{10} in our collected datasets. Some of the parameters can be computed with the requirement of continuity between neighboring WSGs of a given θ . In particular, if only the exponents a_n for all WSGs and a limited number of A_n can be specified, the remaining proportionality coefficients A_n can be obtained by matching

Fig. 1. Piecewise power law relationship between VH NRCS and wind speed illustrated by the BHS dataset: (a) assuming -30 dB average noise level, and (b). assuming -29 dB average noise level.

Table 1. C-Band VH GMF Parameters.

a. BSH & KNMI_S

θ	A_1	a_1	U_{t1}	a_2	U_{t2}	a_3	U_{t3}	a_4	U_{t4}	a_5
17.5	1.40E-04	0.90	10.00	2.00	21.00	1.10	25.00	0.75	30.00	-0.25
22.5	9.06E-05	1.10	11.00	2.25	21.00	1.10	25.00	0.75	33.00	-0.25
27.5	5.33E-05	1.30	12.00	2.35	21.00	1.50	32.00	0.75	35.00	-0.25
32.5	2.79E-05	1.50	14.00	2.50	21.00	1.50	34.00	1.00	35.00	-0.25
37.5	1.34E-05	1.70	15.00	2.70	21.00	2.00	34.00	1.50	35.00	-0.25
42.5	5.44E-06	1.90	15.00	3.00	21.00	2.60	28.00	1.00	40.00	-0.50
47.5	1.15E-06	2.10	15.00	3.60	21.00	3.50	28.00	3.00	50.00	1.50
52.5	8.00E-07	2.30	15.00	3.60	21.00	3.50	28.00	3.00	50.00	1.50

b. KNMI_E

17.5	1.40E-04	0.90	10.00	2.00	21.00	1.50	28.00	0.75	30.00	0.75
22.5	9.06E-05	1.10	11.00	2.25	21.00	1.50	32.00	1.00	33.00	1.00
27.5	5.33E-05	1.30	12.00	2.35	21.00	2.00	32.00	1.00	40.00	1.00
32.5	2.79E-05	1.50	14.00	2.50	21.00	2.00	34.00	1.00	40.00	1.00
37.5	1.34E-05	1.70	15.00	3.00	21.00	2.00	34.00	1.20	40.00	1.20
42.5	8.16E-06	1.90	15.00	3.00	21.00	2.00	28.00	1.20	40.00	1.20
47.5	3.45E-06	2.10	15.00	3.50	21.00	1.50	28.00	1.50	50.00	1.50
52.5	8.00E-07	2.30	15.00	3.20	21.00	1.50	28.00	1.50	50.00	1.50

the σ_{0VH} of neighboring WSGs at the corresponding transition wind speed U_t . This leads to a recursive equation

$$A_n(\theta) = A_{n-1}(\theta) U_{t(n-1)}^{a_{n-1}(\theta) - a_n(\theta)}, \quad (2)$$

where $U_{t(n-1)}$ is the transition velocity between $(n-1)$ -th and n -th WSGs. We can expect to have the most abundant observations in WSG1 for producing A_1 and a_1 in all θ bins. It becomes clear that only a reasonable knowledge of the wind speed exponents in higher wind speed groups is needed for completing the VH GMF formulation. The procedure is summarized in the following steps:

- Step 1: Divide data into some finite number of IABs.
- Step 2: For each i -th IAB determine the number of WSGs and estimate the appropriate $a_1(\theta)$, $U_{t1}(\theta)$, $a_2(\theta)$, $U_{t2}(\theta)$, $a_3(\theta)$, $U_{t3}(\theta)$, $a_4(\theta)$, ...
- Step 3: Use polynomial data fitting and obtain $A_1(\theta)$ for each i -th IAB in WSG1.
- Step 4: Compute $A_2(\theta)$, $A_3(\theta)$, ... using (2);
- Step 5: Interpolate $A_n(\theta)$ and $a_n(\theta)$ using the corresponding bin values $A_n(\theta_i)$ and $a_n(\theta_i)$.

Step 6: Compute $\sigma_{0VH}(\theta; U_{10})$ with (1) using the $A_n(\theta)$ and $a_n(\theta)$ determined in steps 1 to 5.

From examining the available data, it is judged that 5 WSGs can provide sufficient description of the available data with wind speed coverage up to 56 m/s. The recommended $A_1(\theta)$, $a_n(\theta)$ and $U_{tn}(\theta)$ are listed in Table 1a. To serve as a lookup table (LUT) for θ interpolation over the range between 20° and 50°, two additional entries are added for θ bins 15°-20° and 50°-55° by extrapolation. The KNMI_E dataset differs substantially from BSH and KNMI_S. Adjustments for the differences in $A_1(\theta)$, $U_{tn}(\theta)$ and $a_n(\theta)$ are listed in Table 1b.

Figure 2 shows a comparison of the proposed GMF with three recently published VH GMFs, referred to as vZ13_S, vZ13_E (van Zadelhoff et al., 2013, 2014) and Z14 (Zhang et al., 2014). In the same convention, the GMFs described in this paper are called H14_S and H14_E. To reduce clutter, we only show data in 3 θ bins: 22.5°±2.5°, 37.5°±2.5° and 47.5°±2.5°. The BSH (dark symbols) and KNMI_S (light symbols) data are combined in Fig. 2a and the KNMI_E data are shown in Fig. 2b.

Fig. 2. Comparison of various GMFs and datasets: (a) Combined BSH (dark symbols) and KNMI_S (light symbols) datasets and H14_S, Z14 and vZ13_S GMFs, and (b) KNMI_E dataset and H14_E, Z14, vZ13_S and vZ13_E GMFs.

Fig. 3. The wind speed inversion using 4 different GMFs (H14_S, Z14, vZ13_S and vZ13_E): (a) The pdf of δU_{10} , and (b) the scatter plot of measured and inverted U_{10} ; BSH dataset.

Figures 3, 4 and 5 show respectively the results of wind speed inversion for the BSH, KNMI_S and KNMI_E datasets using the various GMFs. For each figure, the pdf of the wind speed difference δU_{10} (inverted minus measured) is displayed in panel (a) and the scatter plot of inverted vs. measured U_{10} is shown in panel (b) with the color scheme identical to that used in (a). The better performance of the H14 algorithm is manifested in the narrower distribution of δU_{10} near 0 m/s (panel (a)) and more compact cluttering of data about the 1:1 diagonal line (panel (b)). The percentage of velocity difference for (H14_S, Z14, vZ13_S, vZ13_E) is (95, 95, 70, 90) within 5 m/s, (81, 78, 52, 74) within 3 m/s for the BSH dataset; (75, 69, 57, 69) within 5 m/s, (53, 52, 36, 49) within 3 m/s for the KNMI_S dataset; and (97, 91, 75, 94) within 5 m/s, (87, 72, 55, 84) within 3 m/s for the KNMI_E dataset.

More results and discussions are given in Hwang et al. (2015).

3. SUMMARY

In this paper, we present a framework to construct the C-band VH GMF. The method is built upon the piecewise

Fig. 4. The wind speed inversion using 4 different GMFs (H14_S, Z14, vZ13_S and vZ13_E): (a) The pdf of δU_{10} , and (b) the scatter plot of measured and inverted U_{10} ; KNMI_S dataset.

Fig. 5. The wind speed inversion using 4 different GMFs (H14_S, Z14, vZ13_S and vZ13_E): (a) The pdf of δU_{10} , and (b) the scatter plot of measured and inverted U_{10} ; KNMI_E dataset.

power-law relationship between $\sigma_{0VH}(\theta)$ and U_{10} . This is consistent with the property of piecewise power-law wind speed relationship of the short scale wind-generated waves serving as the Bragg resonance roughness elements of microwave scattering from the ocean surface (e.g., Hwang and Wang, 2004; Hwang et al., 2013).

Recognizing the difficulty of assembling sufficient collocated and simultaneous radar backscattering and wind velocity measurements to cover a broad range of wind speed and incidence angle, the GMF is designed to work with partial knowledge of the power-law function relating $\sigma_{0VH}(\theta)$ and U_{10} . In particular, the main input parameters are the exponents of the power-law functions in several IABs and WSGs, and the proportionality coefficient for the lowest WSG, of which the most abundant data is expected. It is also designed for easy refinement as new data becomes available or when datasets with different characteristics require special GMF variations.

4. REFERENCES

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