COMBINED ANALYSIS OF NEAR-NADIR MICROWAVE DUAL-FREQUENCY MEASUREMENT OVER THE OCEAN. APPLICATION TO THE KA-KU DPR DATA OF GPM.

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1. ABSTRACT

In this work we use a global colocalized ocean surface observations in near nadir Ka and Ku band microwave measurements to comment on their discrepancies and the different physical multi-scale processes involved in both bands. The latter are from The Dual Frequency Precipitation Radar (DPR) onboard the Global Precipitation Measurement (GPM) platform and are colocalized with the wave model Wave Watch III giving access to local wave and wind conditions. Sensitivity of the radar cross section ($\sigma^0$) with wind speed ($U_{10}$) and significant wave height (SWH) are compared and analysed in term of physical processes involved in the scattering phenomenon.  We focus on the relationship between Ka and Ku cross sections fall-off with incidence to provide a valuable insight on the roughness structure (slope and curvature) of the ocean surface. Future spatial missions can take benefit of this work for possible inter-validation/comparison in this frequency regime and range of incidence (SWOT, CFOSAT, ...)

2. INTRODUCTION

This work is primarily focused on issues pertaining to the inference of ocean surface slope and curvature statistics using satellite radar observations that rely upon the quasi-specular reflection mechanism. By providing normalized radar cross section ($\sigma^0$) measurements in both Ku and Ka-Band, the dual-frequency precipitation radar (DPR) onboard the Global Precipitation Measurement (GPM) mission opens an opportunity to refine our present understanding of the physical processes involved in the scattering by the ocean in the high-frequency micro-wave regime.

With exactly matching ocean cells at and around nadir incidence angles, the Ka and Ku PR enable systematic and colocalized analysis of the differing ocean scattering characteristics for both bands. As shown in this letter, the bi-frequency analysis can provide direct means to possibly separate surface slope and curvature effects. This can lead to a better estimation of the fine scales present at the surface which can then be related to physical air-sea processes, such as the local wind stress and the rate of gas exchange across the sea surface.

The DPR onboard GPM provides large co-localized Ka- and Ku-band data sets, for the same range of incidence angles (0° – 9°). Similarly to [1, 2], the bi-frequency analysis of the $\sigma^0$ angular fall-off to derive surface parameters can relax the constrain of having intercalibrated measurements. We present an overview of the Ka and Ku $\sigma^0$ measurements and global comparisons with numerical wind and wave parameter estimates. Using an extended Physical Optics (PO) approach the interpretation of the differing Ka/Ku $\sigma^0$ fall-off sensitivity is discussed and further related to the well known Cox & Munk measurements [3]. As anticipated and demonstrated, the combined bi-frequency analysis can be efficiently used to separate long and short scale roughness elements to further infer total sea surface mean squared slope and curvature parameters.
The GPM platform carries the first space-borne Ku/Ka-band Dual-frequency Precipitation Radar (DPR). In particular, the KaPR operates at 35.5 GHz and the KuPR at 13.6 GHz with nadir oriented antennas. As designed, KuPR and KaPR have 25 matched beams to provide perfectly co-localized Ku/Ka measurements. For this study, selected data correspond to the Nominal Swath (NS) of the KuPR and the co-localized Matched Swath (MS) of the KaPR. For all selected points, outputs of the Wave Watch III (WW3) wave model were collected to provide sea state information, wind speed and significant wave height, correspondingly. The WW3 model was processed with a 0.5 degree / 1h spatio-temporal resolution. For example, figure 1 shows near-nadir, 0.7 degree, Ka-band $\sigma^0$ versus model significant wave height, SWH, for different wind speeds. Ku and Ka-band $\sigma^0$ measurements are sensitive to both wind speed and sea state degree of development, i.e. SWH. The latter sensitivity of $\sigma^0$ to SWH decreases with increasing wind speed, and also for higher incidences (up to 9 degrees).

4. FALL-OFF ANALYSIS

The Geometrical Optics (GO) approximation for electromagnetic (EM) scattering from rough sea surfaces is widely used to interpret nadir and near-nadir microwave radar measurements ([4]). Under isotropic Gaussian assumption of the slope statistical distribution, it simply writes:

$$\sigma^0 = \frac{|R|^2 \sec^4(\theta)}{\text{mss}_T} \exp\left(-\frac{\tan^2(\theta)}{\text{mss}_T}\right) \quad (1)$$

where $\theta$ is the radar incidence angle, $\text{mss}_T$ the total mean square slope and $|R|$ the Fresnel coefficient at normal incidence. This form (1) explains the popular and robust Gaussian regression to analyze $\sigma^0$, leading to the evaluation of an unique effective shape parameter: $\text{mss}_s$. Based on the Physical Optics (PO) formulation, a first order correction to the GO model can, in the isotropic case, be written as:

$$\sigma^0 = \frac{|R|^2 \sec^4(\theta)}{\text{mss}_T} \exp\left(-\frac{\tan^2(\theta)}{\text{mss}_T}\right) \times \left[1 + \frac{\alpha}{4} \left(\frac{\tan^4(\theta)}{\text{mss}_T^2} - 4\frac{\tan^2(\theta)}{\text{mss}_T} + 2\right)\right] \quad (2)$$
Fig. 2. Mss shape versus wind speed for different significant wave height. Colored curves are derived from the regression of the Ku/Ka DPR incidence variations. Solid lines stand for the Ku band and dashed lines for Ka band. Blue points are C&M 54 reference points. Grey stars are C&M points without kurtosis correction.

where

\[
\alpha = \frac{2 \lambda_4}{3} + \frac{\text{msc}}{Q_2^2 \text{mss}^2} \tag{3}
\]

with \(\lambda_4\), a kurtosis coefficient that can be related to the \(c_{04}\) and \(c_{40}\) fourth order statistical parameters introduced by [3] \((\lambda_4 = c_4/\text{mss}^2)\), and msc is a parameter directly linked to the sea surface mean squared curvature. Note that the isotropic assumption cancels out the skewness coefficient introduced by [3].

Assuming this model correction sufficiently small, and considering small incidence angles, a direct identification of the \(\tan^2(\theta)\) factor in equation (2) leads to define:

\[
\text{mss}_s \simeq \text{mss}_T \times (1 - \alpha) \tag{4}
\]

\(\sigma^0\) dependence to the incidence angle stays very close to the gaussian shape for both Ka and Ku bands and for a wide range of wind speeds \((0 < U_{10} < 18 \text{ m.s}^{-1})\) and significant wave heights \((0 < \text{SWH} < 6.5 \text{ m})\). The deviation from the normal law is visually noticeable for very low sea state or sufficiently large angles. Using equation (1) to characterize the incidence fall-off of \(\sigma^0\), the most simple approach is to infer the shape parameter \(\text{mss}_\text{shape}\) from a basic regression. The slope coefficient of a linear regression in the \((\log(\sigma^0), \tan^2(\theta))\) coordinates directly provides the inverse of the shape parameter.

Figure 2 gives the inferred \(\text{mss}_\text{shape}\) as a function of wind speed and sea state for the Ku and Ka bands. It illustrates the large variability of the shape parameter with the SWH for low wind speed in both bands.

5. REFERENCES

