A NUMERICAL STUDY ON THE INFLUENCE OF OCEAN SURFACE WAVES ON GPS-REFLECTED SIGNALS

Maria Paola Clarizia[1,2], *Maurizio Di Bisceglie*[1], *Carmela Galdi*[1],
Christine Gommenginger[2] *and Meric Srokosz*[2]

[1] Università degli Studi del Sannio Piazza Roma 21, I-82100, Benevento, Italy
[2] National Oceanography Centre, Southampton, UK
Presenting author: Maria Paola Clarizia, email: marari@noc.soton.ac.uk

1. ABSTRACT

The ability to investigate properties of the sea surface by means of navigation signals has recently received growing interest from the remote sensing community. This innovative technique is known as Global Navigation Satellite System-Reflectometry (GNSS-R), and it relies on signals of opportunity transmitted from GNSS Constellations (e.g. GPS, Glonass, Galileo etc.), and reflected from the surface of the ocean, to look at a variety of ocean properties, primarily ocean surface roughness (scatterometry), but also sea surface height (altimetry). The retrieval of ocean roughness from GNSS-R data has now been demonstrated with a reasonable level of accuracy both from airborne [1] and spaceborne platforms [2]. GNSS-R signals are available globally, all the time and over the long term, and could potentially provide high-density global measurements of sea surface roughness, that are relevant for operational uses and scientific purposes, as well as to support climate Earth Observation missions such as SMOS.

Having shown in [2] that it is possible to retrieve the Directional Mean Square Slope of ocean height (DMSS) from UK-DMC Satellite Delay-Doppler Maps (DDMs) using the established theoretical scattering model by Zavorotny & Voronovich [3] (the Z-V model hereafter), we now focus on the implementation of an end-to-end simulator of the scattering of GPS signals from realistic sea surfaces. This approach was mainly motivated by the differences highlighted in [2] between the measured DDM and the DDM simulated using the Z-V theoretical model [3]. The Z-V model is sufficiently advanced to retrieve directional roughness information from GNSS-R data with reasonable accuracy, but it relies on a high-frequency limit approximation, the Geometric Optics (GO) for the scattering, and is able to describe the average sea surface scattering only. Our end-to-end simulation approach aims to address these limitations through the use of explicit realizations of the sea surface from which the scattering is computed, and through a more general scattering model, which accounts for the scattering from both large-scale and small-scale roughness components. Moreover, the vector formulation of the scattering here, as opposed to the scalar formulation used in [3], allows us to explore the effect of polarization, the importance of which has already been recognised and stressed from observations and modeling efforts as in [4] and [5].

In this work, the simulation of wind waves on the ocean surfaces is carried out by filtering a white Gaussian noise with the theoretical wave spectrum model described in [6], dependent only upon wind speed and direction. The resulting sea surface is linear, i.e. with Gaussian statistics of the sea surface height, and is made up of purely wind-generated waves. A low-pass filtered version of the theoretical spectrum is used to generate a realization of a sea surface with only the large-scale roughness components. Subsequently, additional swell components with specified amplitude, wavelengths and directions can be simulated and added to the wind wave surface, to represent a range of different sea surface conditions, in which a field of long-crested

low-amplitude swell waves travelling in a given direction is superimposed to waves of shorter wavelength, generated by local winds.

The scattering model used in this study to calculate the scattering explicitly from the large-scale roughness components of the sea surfaces is a facet-based implementation of the Kirchhoff Approximation (KA), or Physical Optics (PO). The KA is a scattering approximation, which represents the predominant scattering contribution around the specular direction. It requires the local radius of curvature to be much larger than the incident GPS wavelength (19 cm, L-Band), a condition which needs to be satisfied by the large-scale surface roughness components on the surfaces previously generated. The equation for the scattered field under the KA is [7]:

$$\mathbf{E}_s = K\,\widehat{n}_s \times \iint_S [\,\widehat{n} \times \mathbf{E} - \eta_s \widehat{n}_s \times (\widehat{n} \times \mathbf{H})\,]\, e^{jk_0 \widehat{n}_s \cdot \mathbf{r}} dS \tag{1}$$

where K is a constant dependent upon the incident wavenumber and the receiver range, $\widehat{n}_s$ is the unit scattering vector, $\widehat{n}$ is the local normal and $\mathbf{E}$ and $\mathbf{H}$ are the total electric and magnetic fields. The low-pass filtered surface is here modeled as an ensemble of n facets of dimension $[L_x, L_y]$, tilted and oriented in different directions. The Kirchhoff integral above is split into the sum of integrals for each facet, where the integral for a single facet is calculated in a closed-form. Thus,

$$\mathbf{E}_s = \sum_{i=1}^{n} \mathbf{E}_s^i = \sum_{i=1}^{n} K\sqrt{1+\alpha_i^2+\beta_i^2}\; e^{-j\mathbf{q}\cdot\mathbf{r}_i}\; L_x L_y \mathrm{sinc}\left[\,(q_x + q_z\alpha_i)\,\frac{L_x}{2}\right] \mathrm{sinc}\left[(q_y + q_z\beta_i)\,\frac{L_y}{2}\,\right] \widehat{n}_s \times \mathbf{p}_i \tag{2}$$

where $\mathbf{q} = k_0(\widehat{n}_s - \widehat{n}_i)$ is the scattering vector, $\widehat{n}_i$ is the unit incidence vector, $\mathbf{r}_i$ is the coordinate of the central point of the i–th facet, $\mathbf{p}_i$ is a polarization-dependent vector which represents the term in square brackets in (1), L_x and L_y are the sides of the facet along x and y, and α_i and β_i are the surface slopes along x and y at the central point of the i-th facet. Equation (2) represents each facet as a radiating antenna, with the width of its radiation lobe depending on the size of the facet. We compare this facet-based implementation of the KA scattering model with both the full integration of the Kirchhoff equation, and the GO limit used in [3] to show that the KA Facet approach is both computationally less expensive than the full Kirchhoff integration, and more accurate than GO. However, its performance clearly depends critically on choosing an appropriate size of the facets. This issue is examined carefully and chosen to comply with the specific KA approximation criteria relating the size of the facet to the incident wavelength, and to the ability of the facets to approximate the underlying sea surface.

The scattering from the large-scale roughness components of the simulated sea surfaces is analysed using an incident plane wave with the GPS wavelength, and the KA Facet approach. The scattering is computed for the whole surface, as a coherent integration of the contributions from all the facets, and its sensitivity with respect to different wind speeds and directions is investigated. An example of HH component of the Normalized Radar Cross Section (NRCS) and Polarization Ratio (HH) of the VV component over the HH component of NRCS for bistatic geometry, and for facets of 1 m^2 is shown in figures 1 and 2. In particular, the NRCS shows a good sensitivity with respect to wind speed, whereas the PR decreases for increasing scattering angles, but it is always lower than 1, meaning that the HH component is constantly stronger than the VV component.

Next, the influence of a swell superimposed over a wind wave sea is analyzed, particularly when parameters of the swell such as amplitude, wavelength and direction are changed.

After completing the computation of the scattering from the large-scale components, the contribution from the small-scale roughness is calculated statistically using the classical Small Perturbation Method (SPM) [7], and combined to the facet-based KA scattering model, to finally obtain a semi-deterministic Two-Scale Model (TSM) which takes into account the overall scattering from the large-scale and the small-scale roughness components of the sea surface. This semi-deterministic TSM is then employed to calculate the scattering, assuming the real Left-Hand Circularly Polarized (LHCP) GPS signal as the incident wave, whose transmitter is located at a typical GPS satellite altitude. An analysis of the sensitivity of the scattering is again carried out for different wind speeds and directions, and for different parameters of the superimposed swell. The influence of

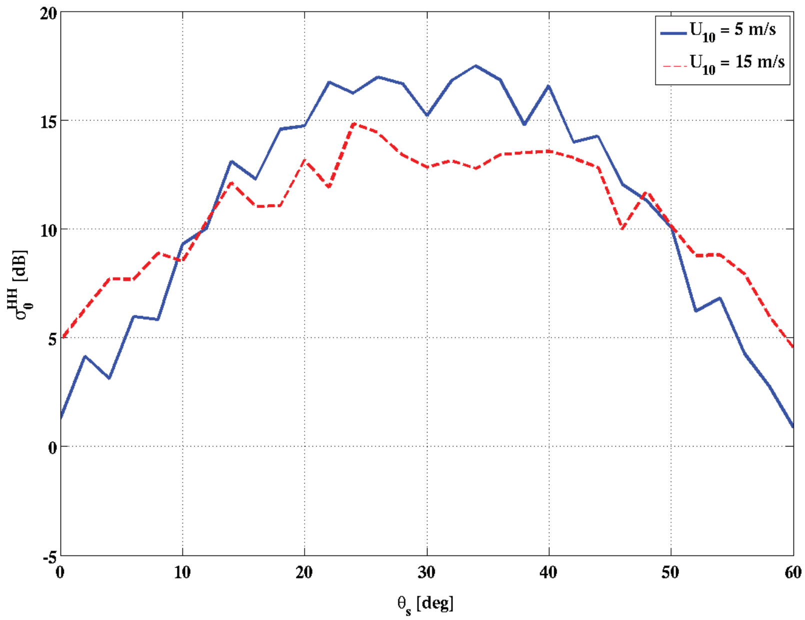

Fig. 1. HH component of the NRCS in dB, for a bistatic geometry with varying θ_s (scattering angle) and fixed $\theta_i = 30^o$ (incident angle), averaged over 20 realizations of the sea surface. The incident and scattering angles are respectively the angles that the transmitter and receiver form with the normal to the mean sea surface. The two NRCS are for a wind speed of 5 m/s (blue) and of 15 m/s (red).

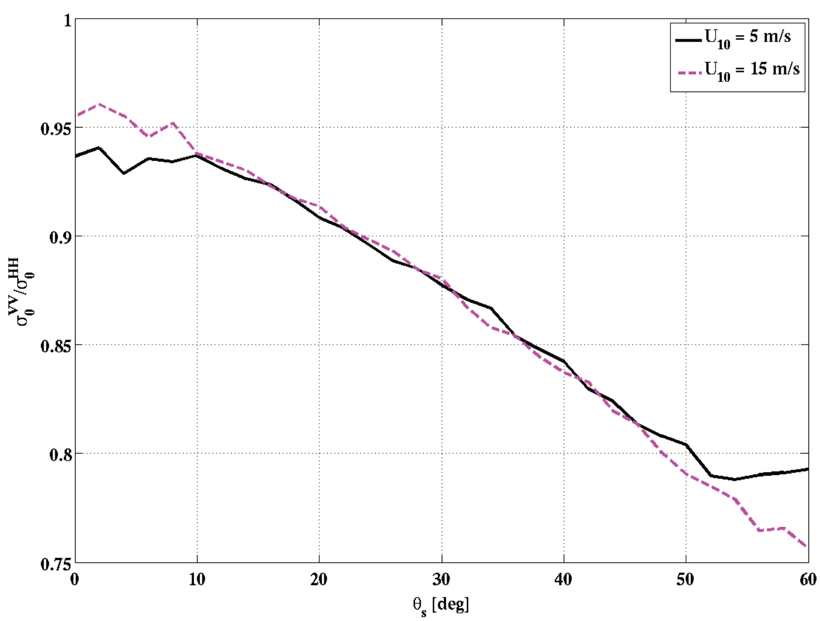

Fig. 2. Polarization Ratios for wind speeds of 5 m/s (black) and 15 m/s (magenta).

different sea surface wave components and geophysical parameters is investigated. Diversities in trend and behavior of the two circular polarizations are highlighted and discussed.

2. REFERENCES

[1] O. Germain, G. Ruffini, F. Soulat, M. Caparrini, B. Chapron, and P. Silvestrin, “The GNSS-R eddy experiment II: L-band and optical speculometry for directional sea-roughness retrieval from low altitude aircraft,” *Geophys. Res. Lett.*, vol. 31, 2003.

[2] Clarizia M. P., C. P. Gommenginger, S. T. Gleason, M. A. Srokosz, C. Galdi, and M. Di Bisceglie, “Analysis of GNSS-R delay-doppler maps from the UK-DMC satellite over the ocean,” *Geophys. Res. Lett.*, vol. 36, L02608, 2009.

[3] V. U. Zavorotny and A. G. Voronovich, “Scattering of GPS signals from the ocean with wind remote sensing application,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 38, pp. 951–964, March 2000.

[4] C. Zuffada, A. Fung, J. Parker, M. Okolicanyi, and E. Huang, “Polarization properties of the GPS signal scattered off a wind-driven ocean,” *Antennas and Propagation, IEEE Transactions on*, vol. 52, no. 1, pp. 172–188, Jan. 2004.

[5] D.R. Thompson, T.M. Elfouhaily, and J.L. Garrison, “An improved geometrical optics model for bistatic GPS scattering from the ocean surface,” *Geoscience and Remote Sensing, IEEE Transactions on*, vol. 43, no. 12, pp. 2810–2821, Dec. 2005.

[6] Elfouhaily, T. B. Chapron, K. Katsaros, and D. Vandemark, “A unified directional spectrum for long and short wind-driven waves,” *J. Geophys*, vol. 102(C7), 15, pp. 781–796, 1997.

[7] F. T. Ulaby, R. K. Moore, and A. K. Fung, *Microwave Remote Sensing: Active and Passive*, vol. 2, Artech House, 1986.