SIMULATION OF GNSS RETURNS FOR DELAY–DOPPLER ANALYSIS OF THE OCEAN SURFACE

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

[1]Università degli Studi del Sannio, Piazza Roma 21, I-82100, Benevento, Italy
[2]National Oceanography Centre, Southampton, UK

1. ABSTRACT

GNSS-Reflectometry is a revolutionary approach to Earth Observation and is recently undergoing rapid advances, especially because the signals of opportunity scattered worldwide from the ocean surface can be used to investigate many important geophysical properties in a near-real time. Global sampling and high temporal resolution of GNSS-R signals encourage application in both ocean surface scatterometry (sea roughness, wind speed and direction) and ocean altimetry (sea surface height and mean sea level).

Recent studies on scatterometry using GNSS-R have shown the possibility to retrieve the sea surface roughness, with airborne [1] and spaceborne [2] GPS-R receivers using a 2-D representation of the scattered signal power in the delay and Doppler domain, known as delay-Doppler map (DDM). The typical approach is to perform a least square fitting of measured DDMs with simulated DDMs using the theoretical Zavorotny-Voronovich (Z-V) model [3], to retrieve the optimal directional Mean Square Slopes (MSS), representative of the surface roughness. The Z-V model gives an expression of the average scattered power, in the Geometric Optics (GO) limit, through a bistatic radar equation, adapted to the GNSS case. Some new analysis and results presented in [2] show how GNSS-R can be used to retrieve wave properties from satellite data, but at the same time highlight some important differences between DDMs derived from GPS-R data and simulated DDMs from the theoretical model. These differences are probably due to some scattering mechanisms that are not properly considered in the GO-based model.

As opposed to [1] and [2], we use here a different approach, in that we simulate the whole end-to-end microwave scattering of GNSS signals from the sea surface. Our approach stems from the idea that accurate retrievals of sea surface height and sea roughness require a better description of the microwave/ocean interaction and scattering mechanisms, as well as a more realistic representation of the ocean surface. The GNSS-R simulator performs the generation of the transmitted GPS signal, the scattering by a realistic ocean surface, and the signal reception and processing in the delay-Doppler domain to produce a DDM as the final output. The fundamental steps to be implemented are: a) The simulation of a realistic sea surface, with specific statistical and spectral properties; b) the selection of a realistic scattering model; c) the implementation of GNSS-R processing to produce the final scattered power in the delay-Doppler domain (DDM).

To generate the sea surface, we filter a white Gaussian process with the sea surface spectrum described by Elfouhaily et al. [4]. This ensures the twofold advantage of preserving the Gaussian statistics of the sea surface heights (a realistic assumption) and imposing the desired spectral properties to the sea surface. The output of the filter is a snapshot of a sea surface, which can be modelled as an ensemble of facets, tilted and oriented in arbitrary directions, and whose size is chosen according to the spectral requirements and criteria induced by the scattering parameters.

The scattering model that we adopt to effectively represent the GPS scattering from the sea surface is a semi-deterministic two-scale model. The two-scale model assumes that the sea surface shape is made by a larger (gravity) roughness scale, and a smaller (capillary) scale, and therefore accounts for the two complementary scattering mechanisms. The scattering from the large-scale roughness is usually described using the Kirchhoff Approximation (KA) or Physical Optics (PO) [5]. The KA is based on the assumption that the radius of curvature of the waves is much larger than the electromagnetic wavelength (19 cm in the case of GPS), such that the surface can be locally approximated by its tangent plane. According to the KA, the scattered power from each facet, in the quasi-specular regime, is concentrated within a narrow cone around the specular direction. The KA in the high frequency limit reduces to the Geometric Optics (GO), where the scattering occurs in the specular direction only.

The scattering from the small-scale capillary waves can be usefully described using the first order Small Perturbation Method (SPM), which assumes small roughness (compared to the incident wavelength), and gently varying surface [6]. The SPM is based on a series expansion to the first order of the surface height and of the scattered field. The scattered field is given by a predominant coherent component, due to waves resonant with the incident radiation (Bragg scattering), plus an incoherent diffuse component. Indeed, the KA works well in the specular zone only, as it does not account for the Bragg component occurring for higher scattering angles, whereas the SPM tends to underestimate the quasi-specular contribution. The two-scale model accounts for both scattering phenomena, and the final average Bistatic Radar Cross Section (BRCS) σ_0 is evaluated by properly combining the average cross sections given by the KA and the SPM [7]. This brings to the delicate issue of choosing a wavenumber cutoff, to separate the large-scale and small-scale components in the sea spectrum.
To associate a simulation stage with a specific observation of the sea surface we have considered a semi-deterministic approach where we combine a deterministic instantaneous configuration of the large-scale sea facets (and its scattering cross section from the KA model) with an average cross section from the SPM. Once a sea surface is generated and the two-scale scattering cross sections are evaluated for each facet, the scattered power can be computed using the polarimetric radar equation for the bistatic case [8]. The received signal is finally processed using the classical 2-D coherent correlation in the delay-Doppler domain, and subsequent incoherent accumulation, to obtain a synthetic DDM. An analysis is carried out on DDMs obtained by varying some important parameters of the simulator, primarily the wavenumber cutoff and the facet size. The synthetic DDMs are then compared to the measured DDM from UK-DMC data (using the same coherent and incoherent integration times) as well as to simulated DDMs using the simple GO-based Z-V model. Similarities and differences are investigated and discussed.

2. REFERENCES

[1] O. Germain, G. Ruffini, F. Soulat, M. Caparrini, B. Chapron, and P. Silvestrin, "The eddy experiment: Gnss-r speculometry for directional sea-roughness retrieval from low altitude aircraft," *Geophys. Res. Letters*, vol. 31, no. L12306, doi:10.1029/2004GL019994, November 2004.

[2] M. P. Clarizia, C. Gommenginger, S. Gleason, C. Galdi, and M. Unwin, "Global navigation satellite system-reflectometry (gnss-r) from the uk-dmc satellite for remote sensing of the ocean surface," *Proceedings of IGARSS 08*, July 2008.

[3] V. U. Zavorotny and A. G. Voronovich, "Scattering of gps signals from the ocean with wind remote sensing applications," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 38, no. 2, pp. 951–964, March 2000.

[4] T. Elfouhaily, B. Chapron, K. Katsaros, and D. Vandemark, "A unified directional spectrum for long and short wind-driven waves," *Journal of Geophysical Research*, vol. 102, no. C7, pp. 15,781–15,796, July 1997.

[5] P. Beckmann and A. Spizzichino, *The Scattering of Electromagnetic Waves from Rough Surfaces*, Macmillan, New York, 1963.

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

[7] G. E. Ruffini, Cardellach, A. Rius, and J. M. Aparicio, "Remote sensing of the ocean by bistatic radar observations: a review," *IEEC Report*, October 1999.

[8] A. Arnold-Bos, A. Khenchaf, and A. Martin, "Bistatic radar imaging of the marine environment- part i: Theoretical background," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 45, no. 11, pp. 3372–3383, November 2007.