GNSS reflectometry in experimental campaigns in support to the SMOS mission

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INTRODUCTION:

One of the goals of the European Soil Moisture and Ocean Salinity (SMOS) mission is to provide with accurate and precise sea surface salinity measurements (0.1 psu level), obtained from the emissivity detected by its L-band (~1.4 GHz) radiometer. The indirect measurement of the salinity requires knowledge of the sea surface roughness, to correct for its effects in the surface brightness. In particular, it needs information on the roughness scales sensitive to L-band radiation. Unlike Aquarius, the SMOS mission does not include a dedicated payload for such corrections, which will rely on ocean and atmospheric models. Models deal with standard meteorological and oceanographic parameters (wind vector, swell), and their suitability to reproduce the roughness scales to which L-band emissivity is sensitive is under investigation.

Global Navigation Satellite Systems reflectometry (GNSS-R, i.e. to gather the GNSS signals rebounded off the ocean, like a bi-static radar), work at L band. For instance, one of the carrier frequencies used by the Global Positioning System (GPS) is ~1.58 GHz, close to the SMOS one. The GPS bi-static reflectometry could thus capture a range of roughness scales similar to the range that affects the SMOS radiometric measurements. This can be useful for validation campaigns, and to open the possibility of including GNSS-R in future SMOS-like missions. Moreover, the relationship between bi-static scattering and emissivity can be used in air-borne campaigns to improve the understanding of both phenomena at L-band, enhancing the radiometric roughness correction models as well as the GNSS-R retrieval algorithms.

ESA has organized and conducted the CoSMOS series of air-borne experimental campaigns in support to the SMOS mission (2005 to 2007), as well as a Rehearsal Validation Campaign conducted in 2008. The GPS Open Loop Differential Real-Time Receiver (GOLD-RTR), designed and manufactured at the IEEC to perform GNSS reflectometry in hardware support (waveforms obtained in real-time), has been present in the ocean salinity CoSMOS campaigns (CoSMOS-OS 2006, CoSMOS-OS 2007), as well as the Rehearsal Campaign, 2008, when Soil Moisture measurements were also taken.

CAMPAIGNS AND EQUIPMENT:

IEEC's GOLD-RTR was used as GPS reflectometry instrument. This GNSS-R hardware receiver contains 640 complex correlators to obtain up to 10 simultaneous GPS satellites in the form of Delay Map or Delay-Doppler Maps, in both right- and left-hand circular polarization. The DTU's EMIRAD and TKK's HUT-2D radiometers were also aboard Skyvan, the TKK's aircraft used in all these flights.

CoSMOS-OS 2006, 12 flights over the North Sea, 3000 meter altitude.
CoSMOS-OS 2007, 3 flights over Baltic Sea (Finnish Bays), 300 meter altitude. Simultaneous collocated samples of water were taken in-situ to analyze their salinity.
SMOS Validation Rehearsal Campaign 2008, several flights from Finland to Spain, over Baltic and Mediterranean Seas, as well as continental mainland. Simultaneous in-situ Soil Moisture measurements were taken at several experimental sites.

Figure 1: GOLD-RTR, IEEC's GNSS-R hardware Receiver.

GNSS-R METHODOLOGY:

Sea Roughness MSS: The sea surface roughness has been inverted from Delay-Maps by analyzing the delay experienced by the peak of the waveform. Besides instrumental issues, the peak delay is related to (a) geometric delay of the specular point, and (b) scatterometric effects due to the roughness of the surface. Kirchhoff Geometric Optics (KGO) has been used as scattering forward model, and the inversion parameter is the mean square slopes (MSS), Figure 3.

Sea Roughness Slopes Probability Density Function (PDF): The delay-Doppler Maps have been used to extract the slopes' PDF at discrete slopes sampling (Figure 2). Non-Gaussian effects have been detected using this technique. KGO assumed.

Soil Moisture: The signal-to-noise level has been shown to correlate (qualitatively) with vegetation and soil moisture (Figure 4). Quantitative analysis is on-going.

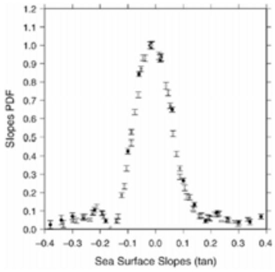

Figure 2: Example of sea surface slopes' PDF inverted from GNSS-R Delay-Doppler Maps, non-Gaussian effects detected. (PRN 19, April 15 2006)

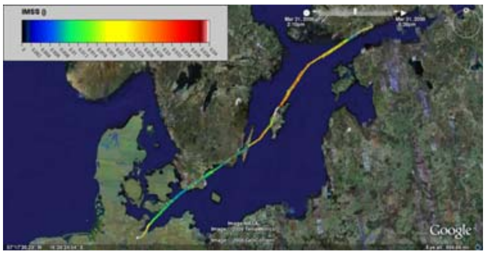

Figure 3: MSS over the Baltic Sea as extracted by the GNSS-R observations, Rehearsal Campaign 31 March 2008. Sheltered areas presented low MSS whereas open sea roughness had higher MSS (color scale from 0 to 0.040).

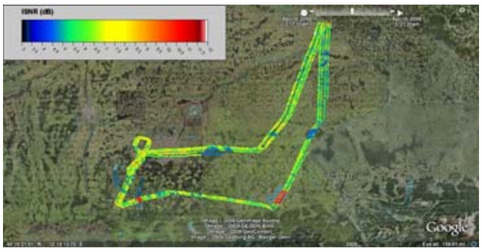

Figure 4: Signal-to-noise level of the GNSS-Reflections over the Munich in-situ observation site. The SNR qualitatively correlates with vegetation and soil-moisture. Quantitative analysis is on-going.

SEA SURFACE Bi-STATIC SCATTERING MODELS MOST SUITABLE AT L-BAND:

Most of the GNSS-R work conducted so far has assumed KGO as scattering model in spite of dealing with L-band signals, of relatively large electromagnetic wavelength. The analysis of this large data set as based on KGO has shown some difficulties to be fully consistent, especially at low elevation angles (Figure 5). We are currently investigating whether this is a consequence of the scattering model. Preliminary results seem to indicate that some inconsistencies could be solved by applying more realistic scattering models, such as Kirchhoff Approximation (KA) or the Small Slope Approximation (SSA) (Figure 6).

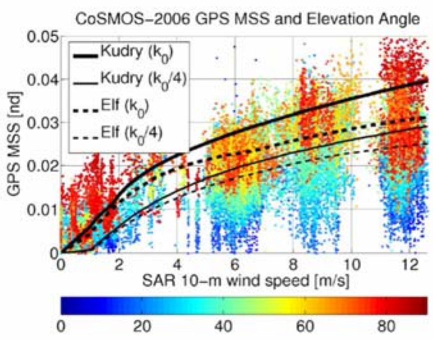

Figure 5: MSS estimates in CoSMOS-OS 2006, as obtained using the KGO scattering model, and compared to the ENVISAT SAR collocated simultaneous wind measurements. The color code is for elevation angle (90 deg - incidence angle). The KGO-based roughness retrievals tend to under-estimate the MSS at low elevation angles of observation.

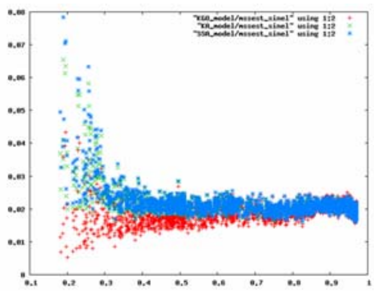

Figure 6: MSS estimates (y-axis) for data taken in April 15 2006, as function of the sinus of the elevation angle (x-axis). Preliminary estimates based on KA, SSA, and KGO forward models plotted in green, blue, and red respectively. KA and SSA result in consistent estimates whereas KGO tends to under-estimate the MSS as elevation decreases. All the models fail at very low elevation angles (it might be related to the data quality).