NON-SPACE APPLICATIONS OF GNSS-R: FROM RESEARCH TO OPERATIONAL SERVICES. EXAMPLES OF WATER AND LAND MONITORING SYSTEMS.

A. Egido(1) *[alejandro.egido@starlab.es], M. Delas*(2) *[matthieu.delas@star2earth.com], M. Garcia*(1) *[miquel.garcia@starlab.es], M. Caparrini*(1)*[marco.caparrini@starlab.es]*

(1)Starlab, (2)Star2Earth

1. INTRODUCTION

Earth Observation using navigation signals, after having been considered a sort of by-product of GNSS signals is finally gaining an autonomous status and is widely accepted as an alternative way, with its advantages and disadvantages, of remotely monitoring our planet.

The winning points that can be easily identified as the main reasons for the continuous growing interest in GNSS as a remote sensing tool are their global availability and the carrier frequencies used. In fact, L-band, in which all current and next-future Global Navigation Satellite Systems are emitting, is a portion of the electromagnetic spectrum that highly interacts with the natural medium and for this reason, the possible applications exploiting these signals are numerous.

Among the geophysical parameters to which navigation signals are sensitive to, one can mention topography, surface roughness, surface moisture, ionospheric electron content, tropospheric water vapour, water salinity, vegetation. Taking into account GNSS reflections, research in these fields has been developing for many years and the first pre-operational services are being put in place. In fact, while the scientific community is waiting for a dedicated GNSS-R space mission to confirm the theoretical predictions about the characteristics of these signals from space, ground based and airborne sensors have been developed and validated for various applications. Whereas the global and multistatic nature of GNSS-R allows global coverage and high time/space sampling rate for a GNSS-R space sensor, these two characteristics imply, for ground and air borne systems, the possibility of deploying instruments with the same performances all over the world (this will be completely true when also Galileo will be in place) and to take profit of multiple, simultaneous measurements. The GNSS-R research area which has been more thoroughly investigated concerns the reflection of navigation signals on water surfaces, provided the highly reflective nature of water at L-band. from water, the interest moved towards ice and land applications, more specifically to the detection of sea ice and the monitoring of soil moisture. Recently, GNSS-R have been (and are being) investigated as possible tool to monitor vegetation.

2. GNSS-R APPLICATIONS AT STARLAB

Starlab Barcelona has developed several GNSS-R applications that have reached over the last decade an operational maturity level on water-oriented services. Those include sea applications, such as sea state monitoring, and sea level monitoring, as well as inland water applications, namely water reservoir level monitoring. In addition, in the last years, an increasing interest has also been risen on soil applications, which lead to the establishment of new research lines on soil moisture monitoring. The four formerly mentioned applications are reviewed in the current paper.

Despite the fact the that final outcomes of the four applications presented above are significantly diverse, the basis for all of them is the comparison between the reflected and direct GNSS signals. In fact, while bouncing off the Earth surface, the GNSS signals undertake a scattering process which *impregnates* the reflected signal with valuable information about the surface geophysical parameters. In order to be able to extract such information out of GNSS signals, the received signals need to be cross-correlated with clean replicas of the pseudo-random noise codes that modulate the carrier. The outcomes of this process are the direct and reflected complex waveforms, which contain the essential information about the scattering surfaces and that are the starting point of the processing needed by the various GNSS-R applications.

For example, in the case of sea state monitoring, the significant wave height (SWH) is extracted from a parameter of the Interferometric Complex Field (ICF), defined as the time series resulting from the ratio of the direct and reflected waveforms peaks. Basically, the presence of waves produces a decorrelation of the sea surface, which turns into a decorrelation of the reflected signal. The parameter that measures the decorrelation level of the signal is the surface coherence time, being smaller the rougher the sea is, and vice versa. This parameter can be measured out of the autocorrelation function of the ICF, which is then linked to the SWH through a semi-empirical model. This application has reached an operational maturity level, which provides the possibility of serving quasi-real time sea state information through a web page interface. The results obtained by this operational service are presented in this paper.

Regarding altimetry applications, two techniques have been developed based on different characteristics of the direct and reflected signals. The first of these techniques is known as Phase Altimetry Algorithm. Being the ICF the quotient of the direct and reflected fields, the common parts of the direct and reflected signals are cancelled out, leaving only the contribution due to the scattering of the surface in the reflected signal, and the propagation delay which results from the geometrical difference between the paths of the direct and the reflected signals. Such path difference translates into the phase of the ICF which is the parameter used in the algorithm. After a phase unwrapping process and an ambiguity resolution method, the phase information is linked to the altimetry information through a geometrical relationship.

Even though the Phase Altimetry Algorithm is a very precise technique with demonstrated centimetric precision, it has some requirements that limit its usage to certain conditions: in order to be able to retrieve profitable phase information out of the reflected signal, the coherency of the signal needs to be preserved. This means, that the signal needs to be reflected from a moderately flat surface, otherwise, the scattering becomes a random process, that is, it destroys the phase information of the reflected signal. For this reason, the Phase Altimetry Algorithm is applied to in-land waters, such as lakes and water reservoirs, where the presence of waves is not remarkable, and the required precision is very high.

The second altimetry technique is known as the Code Altimetry Algorithm. In this case, instead of accounting for the phase of the ICF, the altimetric information is obtained from the displacement of the reflected waveforms with respect to the direct ones. Such displacement can be directly related to the direct and reflected signals delay, and is used, in a similar way as in the previous method, to extract the altimetry information of the water surface being monitored.

Despite the fact that the Code Altimetry Algorithm is not as precise as the Phase Altimetry Algorithm, it is not subjected to the coherency requirement for the reflected signal. Therefore it can be applied to rough surface such as the sea,.

Both altimetry algorithms, have reached a maturity level that allow the provision of operational services to customers. However, research efforts are also being invested in improving the precision and accuracy of the algorithms as well as in reducing their dependency on the number of available signals. Results of these various approaches to altimetry with GNSS-R in different campaigns will be presented.

Finally, regarding soil moisture applications, the parameter to be observed is the relative power of the reflected and the direct received signals. It is well known that the soil dielectric constant has a quadratic relationship with the volumetric soil moisture (VSM) content at L-band. In other words, an increase in VSM leads to an increase in the soil's dielectric constant, which in turn produces a higher soil reflectivity. On the other side, it can be demonstrated that the waveform peak depends on the signal carrier to noise ratio (CNR). In the case of the reflected signals, the CNR depends on the soil reflectivity, and for moderately rough soils, a simplified scattering model can be applied in order to extract soil reflectivity estimates out of the ratio of the direct and reflected waveform peaks. This soil reflectivity estimation is then used to obtain the VSM estimates. The results obtained with this method for VSM monitoring during airborne campaigns will be presented.

In addition to soil moisture estimation, the possibility of using GNSS-R signals for vegetation biomass monitoring is also being investigated. Despite the fact that the airborne experiments above mentioned show good correlation between soil moisture estimations and the ground-truth data, obtaining an operational service still remains a challenge, since there are coupled effects with the VSM, namely background temperature variation, vegetation canopy, and surface roughness, that lead to ambiguities in the determination of VSM. Other innovative techniques which are currently being investigated, such as polarimetric analysis of the signals, are believed to be very useful for precise soil moisture estimation.

3. CONCLUSIONS

Concluding, this paper wants to demonstrate the wide range of possible GNSS-R applications, both ground based and airborne. The level of maturity of such applications is not homogeneous but various of them have already reached an operational level. As final remark, it must be underlined that such applications, of an inherently local range and valuable as such, can be considered also as a path opener to similar applications to be obtained, on a global scale, by future GNSS-R payloads on board satellites.