The International Beacon Satellite Symposium *BSS2010*
P. Doherty, M. Hernández-Pajares, J.M. Juan, J. Sanz and A. Aragon-Angel (Eds)
Campus Nord UPC, Barcelona, 2010

TROPOSPHERIC INFORMATION CONTENT EMBEDDED IN GNSS RO REFLECTED SIGNALS

Estel Cardellach*, Santiago Oliveras* and Antonio Rius*

* Institute for Space Science (ICE-CSIC/IEEC) Universitat Autonoma de Barcelona
Fac. Ciencies Torre C5-par, 08193 Bellaterra, Barcelona, Spain
e-mail: estel@ieec.uab.es
Web page: http://www.ice.csic.es

Key words: GNSS, GPS, Radio-Occultations, GNSS-R, Troposphere.

Summary: This work presents the studies being conducted on the retrieval of tropospheric information from GNSS Radio-Occultation signals reflected off of the Earth's surface.

1 INTRODUCTION

[1] proved that some signatures detected in radio-holographic images of the Global Navigation Satellite System (GNSS) Radio-Occultations (RO) corresponded to the interference with signal of the same GNSS satellite that rebound off of the surface of the Earth, in a very slant geometry. The reflected signals found in CHAMP RO data were processed in[2] to perform phase-delay altimetry of Polar Ice, with formal precision of ~0.7 m. Further investigations on the potential use of these reflected signals required an automatic way to detect and flag the RO according to the presence of reflections. This was achieved and presented in[3,4]. In particular, two major conclusions were obtained: (a) simulation work shown that current standard techniques applied in the RO inversion are not affected by the interference with the reflected signal, meaning that reflected signals do not disturb canonical-transform or full spectrum inversion retrievals; (b) moreover, empirical work shown that the comparison between GPS-inverted and ECMWF post-processed refractivity profiles yield better results when reflected signals are present. A possible explanation to these results is being investigated under the EUMETSAT's GRAS SAF project. The correlation between the goodness of the data and the presence of reflected signals might have operational applications, such as a quality flag for properly weighted assimilation of the RO data into Numerical Weather Prediction Models (NWPM). On the other hand, the

geographical and seasonal patterns and statistics might help identifying the conditions under which reflections are captured by the receiver, which in turn can help identifying potential applications of the reflected-RO for geophysical studies.

A Support Vector Machine (SVM) algorithm has been implemented to identify the RO events with presence of reflected signals. The details of the process are compiled in[4].
The output of the SVM is a scalar value which relates to the certainty of presence/lack of signal. Positive values of the SVM flag indicate likely-reflection, whereas negative values the lack of it. The flag is normalized to provide values beyond ±1 when the algorithm has large confidence, and between -1 and +1 when the system is not as confident of the result. A validation processes was performed on 3350 RO events of February 2007 and 2257 RO events of November 2008 visually inspected and manually flagged. The validation determined that the percentage error of the SVM flag is acceptable for values greater than 0.25 (97.81% success for February 2007 sub-set, 99.47% for November 2008).

2 REFLECTION STATISTICS

A set of two months of COSMIC data, November and December 2008, has been used to look at the statistics of the reflection events. This represents 128860 COSMIC radio-occultations globally distributed. Defining a RO with reflection when the SVM flag is >0.25, the percentage of RO with reflections sum up to 36%. 45% of the setting occultation do present reflected signals, against 24% of the rising RO. If we focus on ROs over the Oceans, 44% of them present reflected signatures.

The statistics present a clear dependence on the latitude: the percentage of reflections increase with the latitude (Table 1)

Latitudes (deg)	Percentage Reflections		
	OCEAN+LAND	OCEAN	LAND
$\lvert lat\rvert \le 20^{\circ}$	22	32	8
$20^{\circ} < \lvert lat\rvert \le 50^{\circ}$	41	51	12
$50^{\circ} < \lvert lat\rvert \le 70^{\circ}$	53	75	14
$70^{\circ} < \lvert lat\rvert \le 90^{\circ}$	72	80	64

Table 1: Percentage of reflected signals within different latitudinal belts, and reflecting surfaces.

According to these results, reflections might occur at any sort of surface (ocean, ice, land), however, land-reflections are spare (and concentrate in smooth areas, free of vegetation, or continental ice). This opens the question about the reasons why not all the ocean RO contain reflected signals, and in particular, why the Ocean reflections depend on the latitude.

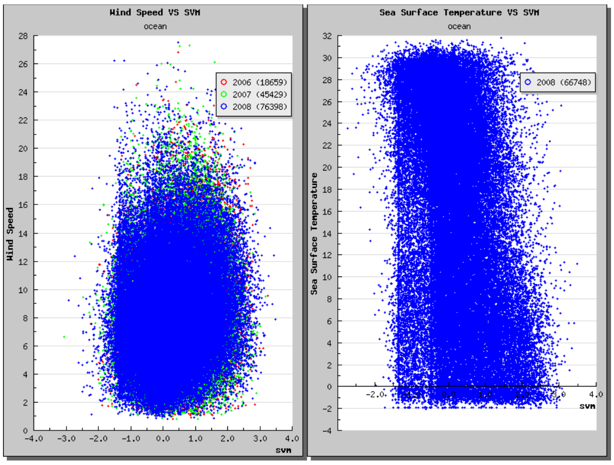

Figure 1: (left) Correlation between the SVM-flag (positive for clear reflection, negative for clear no-reflection) and QuikSCAT sea surface winds. (right) Correlation between the SVM-flag and sea surface temperature.

Ocean surface roughness conditions do not drive the presence/lack of reflected signals. This has been analyzed by correlating the QuikSCAT scatterometer surface wind at the location/time of the RO event (daily means at 0.5º spatial resolution) and the SVM reflection flag (Figure 1-left).

However, the sea surface temperature (daily observations as provided by ODYSSEA-analysis at 0.1º spatial resolution[5]) does anti-correlates with the SVM-flagging: high temperatures relate to more negative SVM values (lack of reflections), as shown in Figure 1-right.

One might think that the temperature affects the reflectivity of the surface. This is in general true, but the Fresnel reflection coefficients for the co-polar component of circular polarized signals do not change significantly with temperature (much less than 0.1% variation between temperatures 1º to 20º C, at incidence angles greater than80º).

A possible answer to this contradiction can be the characteristics of the air over masses of warm water. This would link the lack of reflected signals with some special tropospheric conditions.

Several atmospheric parameters extracted from the same RO-profiles have been checked for correlation with the SVM flag. Although in general those are not correlated, most of them do present different behaviors depending on the reflection flag value (correlation of the envelope). The average wet-temperature does anti-correlate with the SVM-flag (Figure 2-right).

3 CONCLUSIONS

- Except for Land-RO events, reflection occurs independently of the surface conditions, but a latitudinal pattern is observed.
- Correlations have been found between the reflection-flag and atmospheric conditions.
- Further work is being conducted to extract the tropospheric information content out of the reflected signals.

ACKNOWLEDGEMENTS

Project under the EUMETSAT GRAS-SAF CDOP contract, in collaboration with the NASA/ROSES project Ocean, Ice, Land and Atmosphere GNSS-R Remote Sensing Using CHAMP, SAC-C and COSMIC. E.C. has a Ramon y Cajal Award contract of the Spanish Ministry of Science and Education.

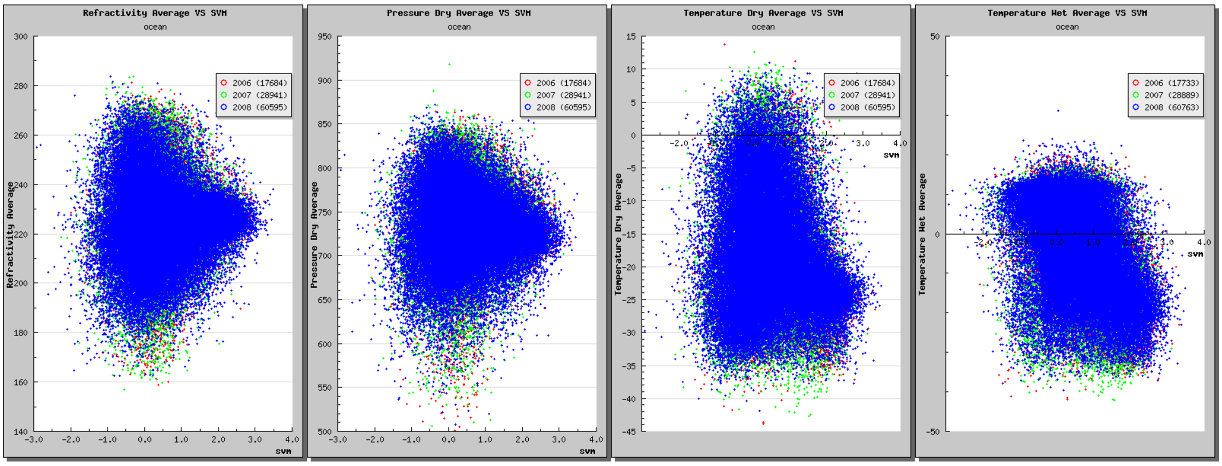

Figure 2: Correlation between the reflection flag (Ocean events) and atmospheric parameters extracted from the post-processed RO profiles (averaged at the bottom 5-km). Left-to-right: refractivity; dry pressure; dry temperature; wet temperature.

REFERENCES

[1] Beyerle, G., K. Hocke, J. Wickert et al. (2002), GPS radio occultation with CHAMP: A radio holographic analysis of GPS signal propagation in the troposphere and surface reflections, J. Geophys. Res., 107(D24), 4802, doi:10.1029/2001JD001402.

[2] Cardellach, E., C.O. Ao, M. de la Torre-Juárez, and G.A. Hajj (2004), Carrier phase delay altimetry with GPS-reflection/occultation interferometry from low Earth orbiters, Geophs. Res. Letters, 31, L10402, doi:10.1029/2004GL019775.

[3] Cardellach, E., S. Oliveras, and A. Rius (2008), Applications of the Reflected Signals Found in GNSS Radio Occultation Events, Proceedings of GRAS SAF Workshop on Applications of GPS radio occultation measurements, ECMWF, Reading, UK 16-18 June 2008. http://www.ecmwf.int/publications/

[4] Cardellach, E., S. Oliveras, and A. Rius, GNSS Signal Interference Classified by means of a Supervised Learning Method Applied in the Time-Frequency Domain, IEEE Proceedings of 2009 2nd International Congress on Image and Signal Process- ing, Tijuan, China, 17-21 October 2009, published by Institute of Electrical and Electronic Engineers, ISBN 13: 978-1-4244-4130-3.

[5] Piolle,J.F., and E. Autret, ERSEA-WP02-IFR-STR-001-1A, http://www.mersea.eu.org/Satellite/MERSEA-WP02-IFR-STR-001-1A.doc