Geodetics Measurements within the Scope of Current and Future Perspectives of GNSS-Reflectometry and GNSS-Radio Occultation

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SUMMARY

Under the Global Navigation Satellite Systems (GNSS), Global Positioning System (GPS) is the one which almost fully covers the globe. So, GPS gives the opportunity to be used for GNSS-Reflectometry (GNSS-R) and GNSS-Radio Occultation's (GNSS-RO) experimental research. The GNSS-R is in an ascending way to obtain accurate results compare to the other Earth observation's techniques. The GNSS-R technology showed its ability for sensing land and soil moisture and the ocean and sea roughness including monitoring wind speed and wind-driven waves. Another approach of GNSS-R is to the Remote sensing application for monitoring the Earth's environmental traversing of snow thicknesses and ice altimetry, impacted by the global warming. Also one of the interesting integration of GPS signals in space applicative sectors is GNSS-RO for weather and climate forecasting. On the research way, GNSS-RO signals are used for observation atmospheric sounding which include water vapor, temperature and pressure. Due to the motion of both GPS transmitters and GPS receivers, GPS signal is bent and travels through different atmospherics layers which give instantaneous depictions of the weather conditions. For ionospheric sensing, occultation measurements have been proven also good and accurate results compare to the results given by number of meteorological centers around the world. Future research will be focused on the capabilities of those techniques in terrestrial's measurements and its benefits on possible replacement of present geodetic techniques of remote sensing. In the near future, GNSS-R and GNSS-RO are expected to flourish as an emerging application in the field of remote sensing obtaining fast and accurate results.

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1. INTRODUCTION

The Global Navigation Satellite System (GNSS) was innovated for positioning, navigation and timing. Nowadays the potential of reflected, refracted and scattered GNSS signal could be also successfully used in remote sensing application.

The space geodetic techniques and new mathematical approaches take benefit from the Global Geodetic Observing System to improve the accuracy of the measurements in remote sensing application using the GNSS-Reflectometry (GNSS-R) and GNSS-RadioOccultation (GNSS-RO) technology.

The paper will be presented the summary of existing research experiments from GNSS-R field and basic concept of GNSS-RO. It will be discussed about investigation of direct, reflected and bent MW GPS signals, implementation of GNSS-Reflected measurements in monitoring the current situation and future disasters prediction such as prediction of tsunami, monitoring ocean eddies, flooding and the other observations of the Earth.

2. GNSS-REFLECTOMETRY (GNSS-R)

This relatively new technique known as GNSS-Reflectometry, exploit scattered signals over the Earth surface and represents another approach of using satellite to monitor the Earth's environmental transition.

Further development of GNSS as a satellite microwave technique in L-band, more applications on this area are explored and utilized. The GNSS, including the Global Positioning System (GPS) of the United States, Russian GLONASS, the upcoming European GALILEO, and the Chinese COMPASS, can be characterized as highly precise and real-time microwave (L-band) technique with the signals through the Earth's atmosphere (Jin et al.,2010).

Global Navigation Satellite System-Reflectometry (GNSS-R) is a new but promising technology which comprises various remote sensing techniques. GNSS-Reflectometry measures reflected navigation satellite signal from water, ice or wet land surfaces. It works as bistatic radar in which transmitter and receiver are separated by a significant distance. The working principle is based on the collection of reflected GPS signal where the transmitter is the GNSS-Reflectometry L-band satellite and receiver is based on the ground, air or LEO orbit satellite (Gleason, 2006).

The receiver consists of two antennas positioned in the way that one is up-looking which collect the direct GNSS signal and the otherone is down-looking which gather the plenty of reflected signals. The delay between these two signals gives the possibility to calculate the surface state and height (Ignjatovic Stupar, 2013)

The main advantage of this technology is that, there is no need of an additional transmitter as a number of signal sources are available including GPS, Galileo, GLONASS, and COMPASS/beidou. We can use spread spectrum technology to enable the receiver to receiver weak signal. There is a broad range of uses for such things as sea water salinity detection, sea-wind retrieval, detection of moving targets and humidity measurement of land (Gleason, 2005).

The GPS satellites are constantly broadcasting radio signals to the Earth and some of these signals are reflected back from the rough Earth's surface. These reflected signals are used to determine the surface characteristics of Earth. For example, the measurement of reflected GPS signal from the ocean surface could give us the information about ocean surface height, wind speed and direction, and even sea ice condition (Jin et al.,2010).

2.1 GNSS-Reflectometry measurement concept

The GNSS-Reflectometry analyzes the signals emitted by GNSS transmitters like GPS, GLONASS, GALILEO, and future COMPASS and retrieves the information from the Earth's surface. When the signal has rebounded off of the lakes, Oceans, Lands, or ice and Snow, it is captured by platforms. It has the characteristics of a bi-static radar and scatterometre (IEEC, nd).

There is cross-correlation between the signals and replicas (models) of GNSS and GNSS-R. The replica model will generate waveforms above the noise. Therefore, tuning the replicas to the right parameters permits to know the range and frequency changes in the range associated with a given satellite-receiver radio-link. There is an alternative approach to obtain GNSS-R waveforms and it has been done by cross correlating the reflected signals against the direct radio link. This technique has advantages of using the entire bandwidth of the transmitted signal which include the encrypted codes. The measurement of vertical distance between the surface level and the receiving platform can be done by comparing the ray-path lengths of the reflected and direct radio links (IEEC, nd).

This is the example of altimetric application, another example is consider some geophysical parameters that characterize the reflecting surface can be estimated when the distortion of the reflected signal is analyzed, such as its roughness and dielectric properties. The roughness spread the signal through the glistening zone; it reduces the peak power of the reflected waveform. “These longer delays are the result of signal ray-paths that have been reflected in areas of glistening zone further away from the specular - the link transmitter-specular-receiver has, by definition, the shortest ray-path (IEEC, nd).”

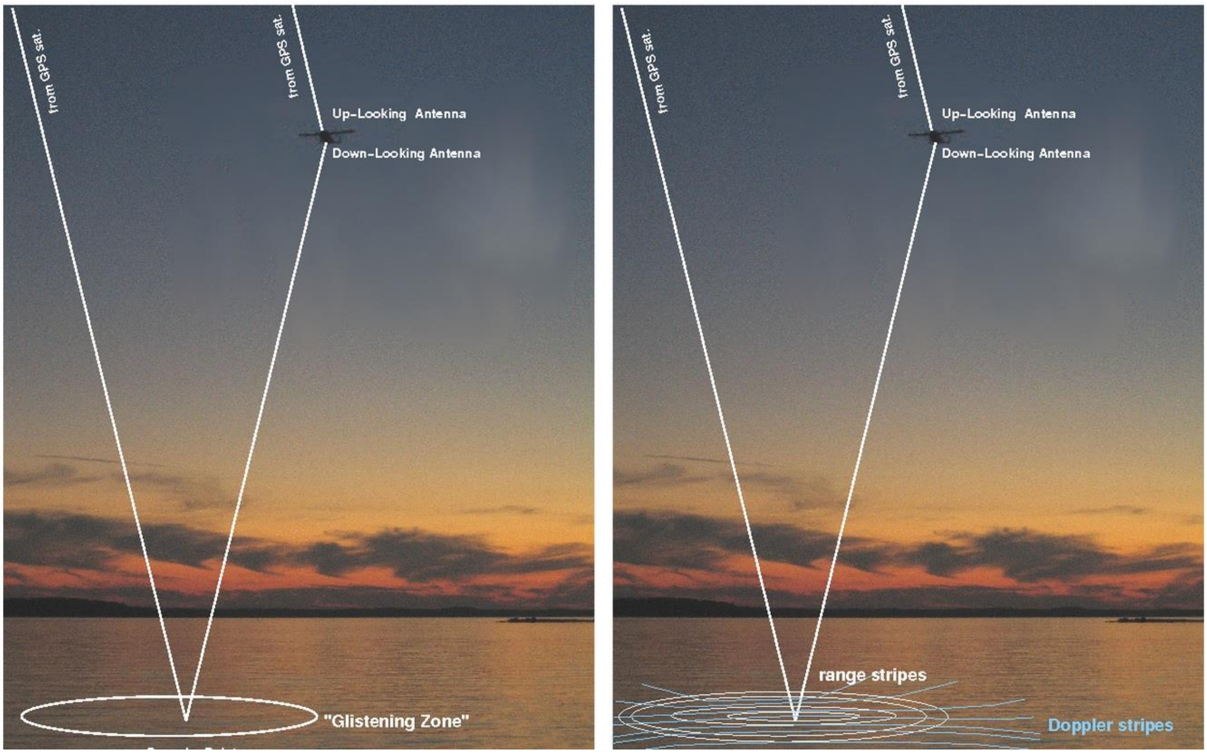

Fig 1: GNSS-R measurement concept (IEEC,2015)

From Figure 1, the left figure shows a GNSS satellite transmit the L-Band signals received directly by the elevated receiving platform and after the signal has rebounded off of the Earth surface. If the signal is smooth, the reflection will be secular otherwise; the signal scatters across the glistening area. In the right figure, the glistening area is wide.
Their reflection off patches arrives far away from the specular at the receiver with delays with regard to the specular.

2.2 GNSS-R involve in Earth's environmental observation

The ESA/ESTEC, Starlab-Spain, NASA, Institute of Electrical and Electronic Engineers-Geoscience and Remote Sensing Society, International Association of Geodesy, The Chinese Academy of Remote Sensing and the other agencies and institutions are currently work on development of GNSS-R technology and its implementation in monitoring the Earth's environmental phenomena. For those experiments were used different receptors such as Delay-Mapping Receiver (DMR) chips developed by NASA and GPS Open Loop Differential Real-Time Receiver (GOLD-RTR) by the study center space CSIS-IEEC, Spain and many others (Tay, 2013).

Specialized receivers were developed to acquire the reflected GNSS signals on a suitable surface. For different experiments the receptors were carried either by space platforms or by aircraft and stratospheric balloons or based on the ground (Ignjatovic Stupar, 2013).

2.2.1 Space-borne instruments

The usefulness of refracted and reflected signals from GPS to Earth's surface and scattered to the LEO spaceborne is the measurement of atmospheric phenomena. The GPS L-band signals are very sensitive to the atmospheric gas and plasma distribution over the ocean. Radar system for measurement of scattered signal can provide information about ionosphere and troposphere (Figure 2) (Ruffini et al., 2000).

Also, reflected signals from ocean roughness can be successfully received by the space borne receiver, offering day and night operation without the influence of different weather conditions.

However, the analysis of those signals remains difficult insofar as the reflections are disturbed by the movement of the ocean surface, the roughness and the maritime atmosphere and that those signals are a low level compared to noise. To overcome these difficulties, the processing of these signals requires the integration of multiple code sequences in a coherent and / or incoherent contribution (Tay, 2013).

To determine the position of the transmitter, receiver and Mean Sea surface height the delay measurements contain the errors such as:

- Ionospheric delay
- Clock errors in the transmitter and the receiver
- Neutral atmospheric delay

The present errors could be solved and eliminated from the measurements by using the dual GPS frequency for Ionospheric delay; clock errors by differencing; and for the neutral atmospheric delay by calibration to ~10 cm (Zuffada and Zavorotny, 2004).

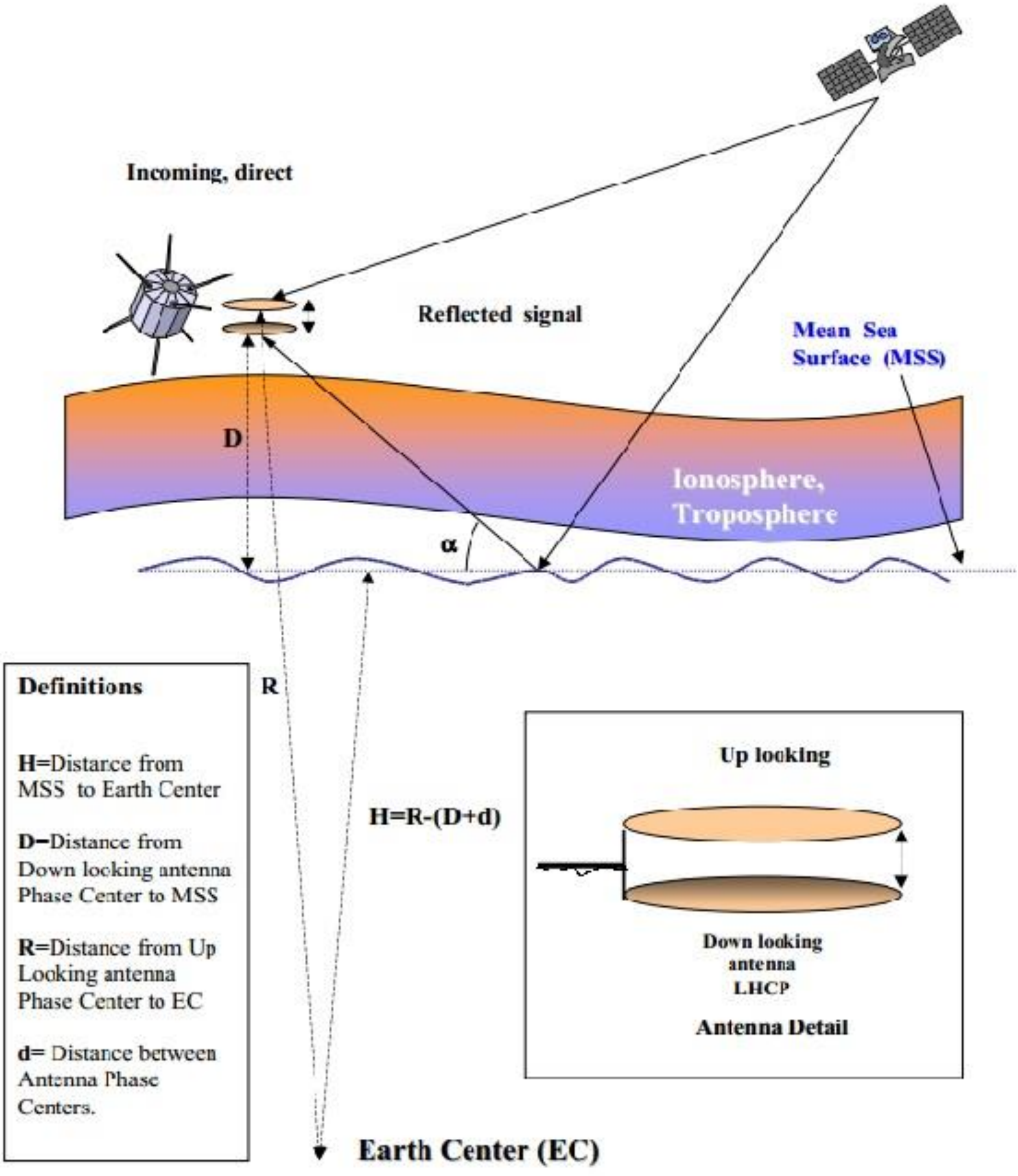

Fig 2: Measurement of scattered signal (Ruffini et al., 2000)

The LEO based satellite position is not stable over time, causing a change in the distance between the transmitter and the receiver over time, characterized by a Doppler effect. GNSS reflectometry theoretically not only allow altimetry, but also to mitigate the different characteristics of the reflected signals from different glistering zone. The roughness of each point of the surface has specific delays (different Doppler frequency offset) and the results of that leads to the production of maps or DDM (Delay Doppler Map). Hence, different Doppler waveform contains information about the reflected power along the ocean.

UK-DMC (UK- Disaster Monitoring Constellation) satellite or piggy-pack on satellite in general has low-cost and low-power instrument onboard which is ideally suited for deployment. In any given time, the 12 GPS satellites are in direct view of any point on the surface. This gives an opportunity to space-borne receiver to simultaneously detect multiple signals reflected of the surface (Gommenginger et al, 2012).

Scattering coefficient is capability of each specular point on the ocean (sea) surface to forward the incoming signal from transmitter to the receiver. But, it is necessary to underline that the signals reflected from different glistering zone have different relative delay.
By using a new space based passive microwave system it is possible too quickly detects a tsunami in the deep ocean. The best and accurate results for the tsunami prediction are obtained using the comparison method between current detection system and the new space-based system. It is one efficient tsunami system for the early-warning, especially to use in the near future.
After many tsunami catastrophes especially in the Indian Ocean, the governments worldwide insist to fully develop network of sensors for detection of tsunami around the globe.
The Passive Reflectometry and Interferometry System (PARIS) technique today is capable to detecting sea surface height with high accuracy with only few centimeters using very wide swath altimeter which is capable to reach 1000 km swath and more depending of orbital inclination. Constellations of 10 PARIS satellites with orbital inclination of 45° could cover the Earth form 45°S to 45°N with revisit time less than one hour and with resolution of 10-15 cm in height and 20-50 km in spatial resolution (Martin-Neira et al., 2005).

The waves are generated either by a deformation of the ocean floor (the water layer located above the fault then undergoes a displacement) or by underwater volcanic eruptions or by landslides. In the latter two cases the energy generated is much less than in the first for which the energy generated can cross oceans. The energy stored by the constraints is released during an earthquake rupture. The ocean is considered a thin layer by moving the whole of its

thickness. This deformation is considered instantaneous because the rupture velocity of the fault is ten times speed of wave propagation (Llovel et Zamuner, 2001).
Tsunami has large wavelength more than 100km and the speed (v) of shallow-water wave depends on gravity and water depth. In the shallow water tsunami travels slowly (10m/s) and in deep water much faster (100 km/h)(Equation 1) (Martin-Neira et al., 2005).

$$v = \sqrt{gD} \qquad (1)$$

For the early warning system to detect tsunami, the PARIS concept is very useful because of the large synoptic view of ocean in only 150 seconds for an area of 1000km x 1000km. Using 12 parallel tracks of reflection points with unintentional spacing between them, it is enough for PARIS constellation to detect a tsunami for less than 45 minutes. PARIS altimeters for the early detection of tsunami should be real driver to alert the coast area to prepare them for tsunami attack (Martin-Neira et al., 2005).
Detection of tsunami wave depends on the size of the footprint (A) and also of distance between swath(B) and glistering zone passes (S) over the tsunami area (Figure 3) (Stosius et al., 2011).

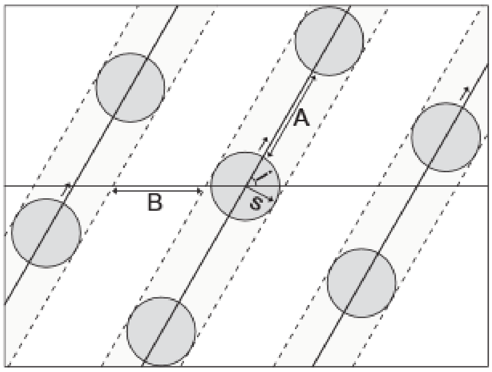

Fig 3 :Swath with a footprint (Stosius et al., 2011)

2.2.2 Air-borne instruments

Working on the same principle as space borne, air-borne instruments in general record the raw data on board the one aircraft and later post processed them in a laboratory. The composition of instruments on board:

- Zenith antenna signal
- Zenith, RHCP and LHCP horizontal and nadir signal

- Splitter for zenith and horizontal signals

This technique is most accurate than observation with conventional GNSS code. It is necessary to recording the corresponding carrier from required secularly reflected signal. In general this technique uses interferometric evaluation method for ocean altimetry observations. The collected and post processed data are compared with permanent Ocean topography model.

One of the interesting experimental measurements were doing over the lake in Germany used ZOIS (Zeppelin Occulation Interferometry Scatterometry), where zenith and horizontal antennas were at back engine and nadir antenna at cabin (Figure 4)(Stosius et al., 2011).

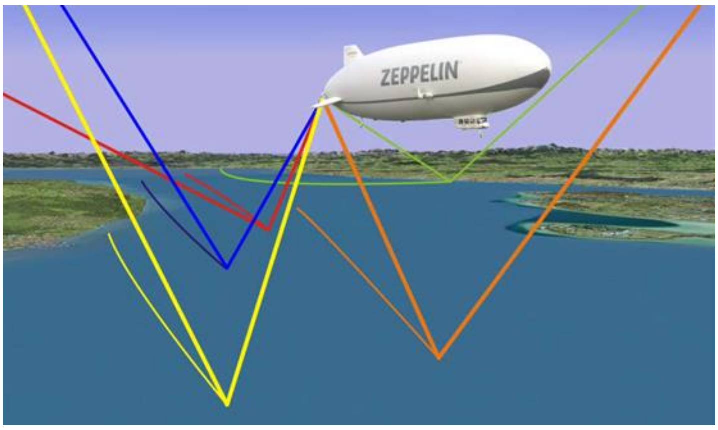

Fig 4: Zepplin Occulation Interferometry Scatterometry

2.2.3 Ground-borne instruments

Another type of application is coastal surveillance (e.g highlight salinity and tidal height) where the receiver is located a few meters above the surface of the ocean, sea, river, lake or any other wet surface. This type of receiver can provide more accurate information than space or air-borne based receivers. For local observation, many coastal experimental campaigns were done (example permanent station deployed at the Barcelona Port). The accuracy of given results are more than expected. That is the reason why this way of observation sea's conditions has become decisive method for the future research.

The main principle of those experiments is to accumulate and process measurement data for a long period continuously and compare with measurement in situ. The antenna system was developed by Star2Earth Spin-off Company of its Spanish parent company Starlab in Barcelona, Spain. The final product is Oceanpal® instrument and it is used for different the experiments in Europe United States and China (Figure 5) (Starlab, 2012). The Oceanpal antenna system is composed of tree subsystems:

- OAR (Oceanpal Antenna Rig) (Starlab, 2012) is measurement system with two antennas (one facing upwards and to the right polarized RHCP, and the second downward and left-polarized LHCP).
- ORFU (Oceanpal Radio Frequency Unit) subsystem connected to the OAR. These signals are first sampled before being correlated with known replica C / A code.
- ODMU (Oceanpal Data Management Unit) subsystem processing and recording data (Roussel 2012).

Fig 5: Oceanpal antenna

Classical oceanographic observation with buoys are much expensive than using Oceanpal instruments, reason is the costly infrastructures and maintenance. Oceanpal is installed out of water and maintenance of sensors and air bubblers are not necessary very often, which is a common problem with buoys.

One other approach og ground-based GNSS-R receivers is in the Arctic region. Applications of GNSS-R specially take a place in the observations for changes of sea ice level and snow classification (categories of ice age/thickness), the thermohaline circulation of fresh water realized by melting or iceberg calving, roughness of the sea and snow or ice, ocean wind speed etc. Unfortunately, the ionospheric effects in Arctic region increase electron precipitation on satellite signals. Also performance of GNSS is limited in the Arctic area compared to latitude (maximum elevation through a GPS reflection of 65 °). Using the GNSS-R in the Arctic, represent challenges for GPS, caused by low Globe coverage.

The sea-ice experiment named GPS-SIDS (Global positioning System –Sea Ice Dry Snow) was run on Greenland during the winter 2008/2009, which objective was to provide information of sea ice and dry snow thickness variations. The measurements based on the data analysis gathered from fixed ground platforms located on the coast (Eisen et al, 2008). It was used reflectometer named the Soil Moisture Interference pattern GNSS Observation at L-band (SMIGOL) which was 6 months autonomous instrument powered by solar panels and batteries. The developed retrieval algorithm is based on the position of notches.

The correlation values of the measurements with the ground – truth in different points of the surface show explain that the Interference Pattern Technique (IPT) is able to monitor the changes in the snow thickness variation. As a final result of collected data it was map of snow thickness retrieved from the same receiver and correlation of the retrievals with the ground-truth. The retrieval algorithm developed for it is based on the position of notches (Figure 6) (Rodriguez et al, 2011).

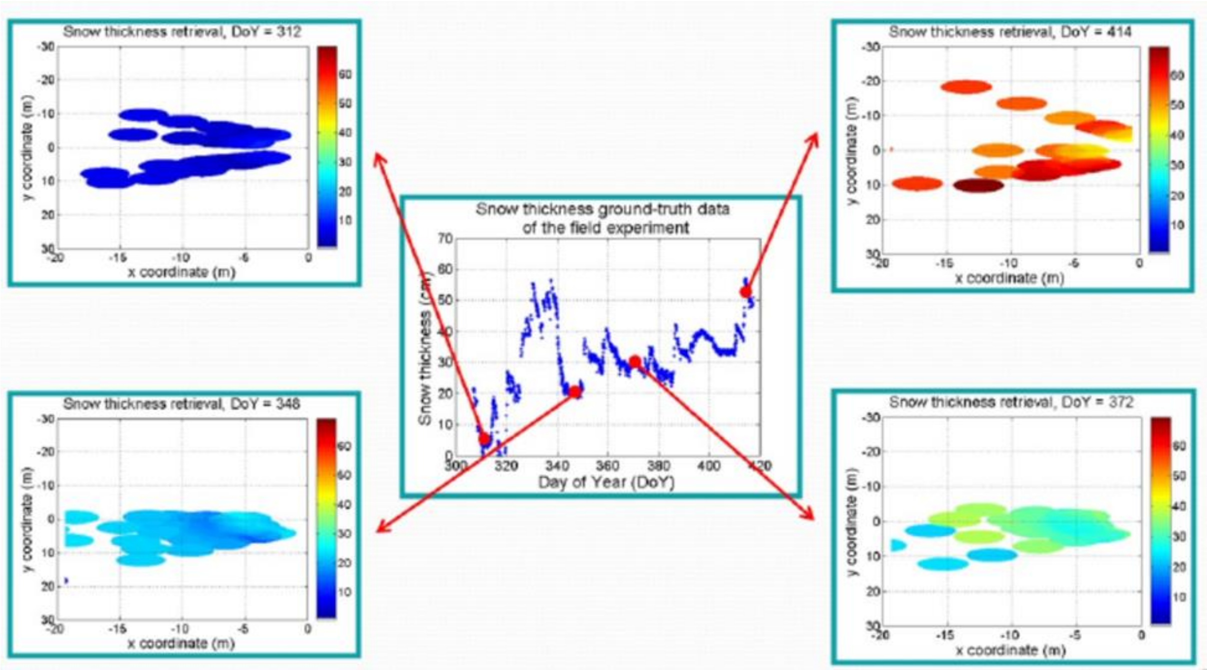

Fig. 6: Snow thickness maps retrieved (Rodriguez et al, 2011)

The power of reflectometry depends on the wavelength of GPS, angle of the reflection, the gain antenna and on the reflected surface.

3. GNSS-RADIO OCCULATATION (GNSS-RO)

One of the new contributions of GNSS signals is the Radio Occultation (RO) technique used for atmospheric sounding, weather analyses and monitoring of climate change. A main advantage of this information is to augment current weather data sets to produce accurate weather results which consist of density profiles and temperature in different atmospheric layers like troposphere and stratosphere. Also most important measure is the ionospheric total electron content (TEC) which is involve in calculation of carrier phase delays of transmitted radio signals from satellites.
The principle of GNSS Radio Occultation (GNSS-RO) consist of constant measurement of the received setting/rising radio signals from GNSS satellites by receiver based on a LEO orbiting

satellite. Generally speaking the GNSS signal bends due to the atmosphere of the Earth before it arrives to the receiver (Figure 7). The amount of signal deflection is proportional to atmospheric conditions.

The continuously radio signals are broadcast until the GNSS signals set below the Earth's atmosphere (go down below the surface). The signals that have passed through the Earth's atmosphere scan layers of the atmosphere and simultaneously determine the vertical profiles of the refractive atmospheric index. (Jin et al. 2014).

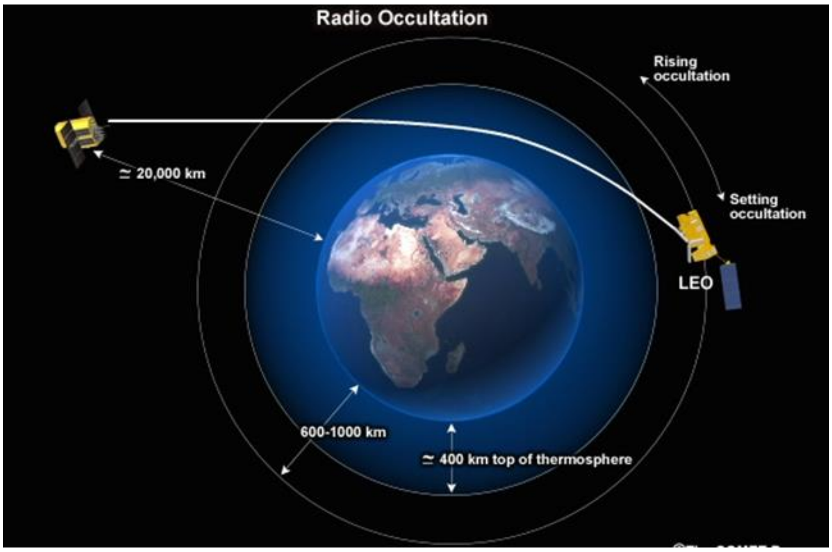

Fig 7: GNSS-RO principles and geometry (EUMETSAT)

4. CONCLUSIONS

Looking through GNSS-R and GNSS-RO experiments which were already done it is possible to conclude which kind of advantages and disadvantages both techniques may propose. The advantages of the GNSS-R compared to using scatterometry and radar altimetry will be pointed several important issues such as wide range of uses (detection of sea salinity, sea roughness, wind speed, ionospheric sensing, soil moisture measurements, ice and snow observation),it is not necessary to have an additional transmitter, 4 to 12 GNSS satellite signals can be collected simultaneously, the receiver collect weak signals using the spread-spectrum communication technology and not the influence of different weather. Not too many disadvantages but at least most technically and economically impacted in investigation of both techniques (e.g. high cost of experiments, no implacable in the urban areas and still not fully coverage of Galileo, GLONAS and others navigation systems.

Development of GNSS-R technique has versatile potential for using GNSS signals for producing the images of the Earth's surface in the near- real time remote sensing, in continuity and with high accuracy. Combined data from refracted and reflected signals from GPS satellites with ground GNSS observations can provide high resolution of weather condition as temperature and pressure, tropospheric water vapour and ionospheric total electron content (TEC) with electron density profile as well.

If we talk about comparison between geodetics measurements with GNSS-R and GNSS-RO we are still far a way to obtain equal accuracy of measurements. The geophysical measurement will benefit from the availability of GNNS signals and their stability, accuracy and precision will be enhanced. It is important to understand that both techniques GNSS-R and GNSS-RO will be involved in future remote sensing application only under condition when GNSS system become fully operated with all navigation systems.

In addition, there are always several satellite transmitters visible from any point on Earth providing views with different geometries and high resolution, thus reinforcing the power extraction measurements of land (land or sea).

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BIOGRAPHICAL NOTES

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