METOP SECOND GENERATION
RADIO OCCULTATION SOUNDING MISSION

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Abstract

ESA is currently running two parallel, competitive phase A/B1 studies for MetOp Second Generation (MetOp-SG). MetOp-SG is the space segment of EUMETSAT Polar System (EPS-SG) consisting of the satellites and instruments. The Phase A/B1 studies will be completed at the first quarter of 2013. The final implementation phases (B2/C/D) are planned to start in 2013.
ESA is responsible for instrument design of six missions, namely Microwave Sounding Mission (MWS), Scatterometer mission (SCA), Radio Occultation mission (RO), Microwave Imaging mission (MWI), Ice Cloud Imaging (ICI) mission, and Multi-viewing, Multi-channel, Multi-polarisation imaging mission (3MI).

This paper will present the instrument main design elements of the Radio Occultation sounding mission. This paper will present the expected performance of the instrument, focussing mainly on performance improvements compared to the current generation, i.e. the GRAS instrument on-board MetOp satellites.

INTRODUCTION

Since 2006, the European contribution to operational meteorological observations from polar orbit has been provided by the first generation of Meteorological Operational (MetOp) satellites. The MetOp Second Generation (MetOp-SG) series of satellites will provide continuity and enhancement of these observations in the timeframe of 2020 to 2040.
The MetOp-SG programme is being implemented in collaboration with EUMETSAT. ESA develops the prototype MetOp-SG satellites (including associated instruments) and procures, on behalf of EUMETSAT, the recurrent satellites (and associated instruments). EUMETSAT is responsible for the overall mission, funds the recurrent satellites, develops the ground segment, procures the launch and LEOP services and performs the satellites operations. The corresponding EUMETSAT Programme is termed the EUMETSAT Polar System – Second Generation or EPS-SG.
Within the whole MetOp-SG payload complement, ESA is responsible for the instrument design of six missions, namely the Microwave Sounding Mission (MWS), Scatterometer mission (SCA), Radio Occultation mission (RO), Microwave Imaging mission (MWI), Ice Cloud Imaging (ICI) mission, and Multi-viewing, Multi-channel, Multi-polarisation imaging mission (3MI).
Targeting an operational system of 21 years of operations, the current baseline foresees the implementation of the above payload complement in a two parallel series of satellites (designated as ‘Satellite A’ and ‘Satellite B’) in a three units per series (so-called “3+3” configuration). The currently on-going parallel Phase A/B1 studies will be completed in the first quarter of 2013, while the final implementation phases (B2/C/D) are planned to start in 2013.

This paper describes the main design features of the Radio Occultation mission instrument. In the following sections, the Radio Occultation measurement principle, the RO instrument architecture and the expected performance will be presented. A performance comparison with current generation, the GRAS instrument on board MetOp satellites, is also reported, as reference [1].

RADIO OCCULTATION MISSION OBJECTIVES AND MEASUREMENT CONCEPT

The main objective of the Radio Occultation sounding mission is to provide measurements of refractivity profiles in the troposphere and the lower stratosphere with a good vertical resolution and high accuracy. Refractivity profiles are then used for retrieving atmospheric temperature and humidity profiles as well information on surface pressure [2].
High quality and global observations of atmospheric temperature and humidity profiles are of great importance for real time assimilation on NWP (Numerical Weather Prediction) and climate monitoring.

A secondary objective of the RO mission is the retrieval of depth of the planetary boundary layer and the height (and structure) of the tropopause. Additionally, ionospheric total electron content (TEC) and electron density profiles can be retrieved.

The RO instrument is equivalently called the GNSS (Global Navigation Satellite System) RO instrument, since it exploits the L-band radio-navigation GNSS signals to extract the required information on the Earth atmosphere.
The RO instrument is a passive instrument measuring the time variation of the excess path length of GNSS signals as they are occulted by the atmosphere. As depicted in Figure 1, the excess path length is the path length difference between the straight line path (between the GNSS satellite and the RO sensor, light blue line in Figure 1) and the actual refracted path (red line in Figure 1) travelled by the signal when passing through the atmosphere (the path is refracted/bended due to vertical refractivity gradients of the atmosphere). Excess path length depends on the refractive index of the atmosphere which is a function of pressure, temperature and humidity. On board the RO sensor the excess path length is simply obtained by measuring the received GNSS signal carrier phase (equivalent to a signal Doppler shift).

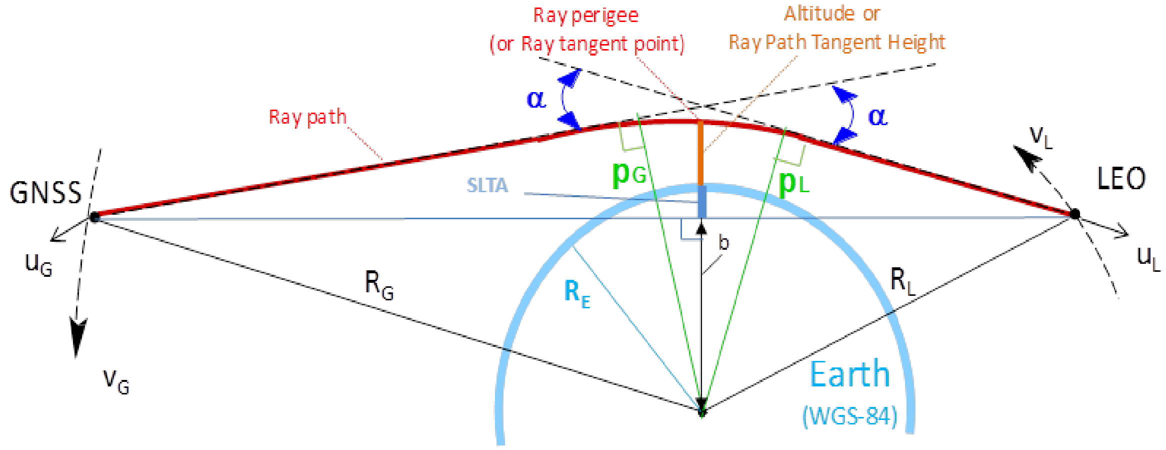

Figure 1: Radio occultation geometry; shown are the bending angle (α) , the GNSS and LEO side impact parameters (pG and pL), the GNSS and LEO coordinate vectors (RG , RL), the ray path (solid red line), the Straight Line Tangent Altitude (SLTA), Altitude or Ray Path Tangent Height (in orange) and the satellite side asymptotes of the ray path (dashed).

The RO Level 1b product, starting point for the derivation of instrument requirements, is defined as the geolocated, time-tagged neutral bending angle as a function of impact parameter, available for each occultation.

Main RO instrument requirements are listed in the following [2],[3]:

- Number of Occultations per SAT: > 1300/day,
- Bending Angle Accuracy: < 0.5μrad @ 35km (1sigma),
- Minimum SLTA: < -300km,
- Carrier and Code Open-Loop in Dual Frequency,
- Open-Loop and Closed-Loop parallel processing,
- Altitude Range: 0-80km for atmosphere, 80km- 500km for ionosphere,
- Tracking of GNSS constellations: GPS, Galileo, and optionally GLONASS, BeiDou.

A detailed overview of GNSS systems, centre-frequencies and signal components to be tracked by the RO instrument is reported in Table 1 [4]-[9].

System	Signal	Carrier Frequency [MHz]
GPS	L1 C/A	1575.42
GPS	L1C	1575.42
GPS	L5	1176.45
Galileo	E1-B/C	1575.42
Galileo	E5a	1176.45
GLONASS	L1 OC	1575.42*
GLONASS	L5 OC	1176.45*
Compass-BeiDou	B1	1575.42*
Compass-BeiDou	B2a	1175.00*

Table 1: GNSS CDMA Open-Access signals for RO mission

INSTRUMENT DESCRIPTION

The RO instrument is mainly composed of 3 antennas (zenith, velocity and anti-velocity antennas), of a central electronics unit, and, if needed, depending on satellite configuration, by external LNA/filtering units for system noise figure minimization. The velocity and anti-velocity antennas are respectively looking in the velocity and anti-velocity satellite directions for tracking of rising and setting occultations. The central electronic unit is the core of the instrument. It performs signal filtering, down-conversion, signal processing, storage and instrument control tasks. The electronic unit is able to track new high-rate GPS, Galileo, GLONASS and Beidou signals as well as pilot signals. The signals are tracked by means of classical closed-loops, but also, in parallel, by carrier and code open-loops in order to deal with multipath conditions occurring in the lower troposphere. Tracking parameters such as sampling rate, integration time, loops bandwidth, are configurable anytime during the mission in order to guarantee maximum signal processing flexibility. The instrument operates both at L1 and L5 GNSS centre frequencies in order to support the on-ground processing for correction of frequency-dependent ionospheric effects.

PREDICTED PERFORMANCE

The upcoming deployment of new GNSS constellations (i.e. Galileo, Beidou-Compass) and the improvement of associated signal characteristics make the MetOp-SG Radio Occultation sounding mission very attractive, considering the success of the current mission on board MetOp.
As an example, the coverage will improve up to three times thanks to the exploitation of Galileo and GLONASS (or Beidou/Compass) systems. With a single satellite it will be possible to achieve more than 1300 occultations per day.
In addition, the characteristics of novel signals such as the pilot signals, will guarantee higher quality observations on the lower troposphere regions. Novel design of open-loop acquisition schemes will also improve the quality and robustness of observations on the low troposphere. Other improvements come from the use of dual frequency channels with wide separation (i.e. L1 and L5), leading to better correction of the ionosphere.

Figure 2 shows the expected evolution of GNSS systems deployment, according to latest available public information [4]-[9].

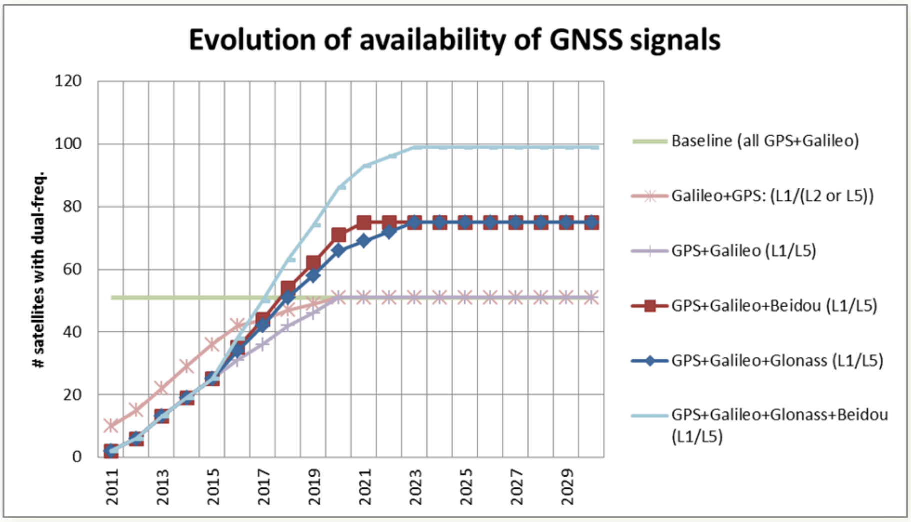

Figure 2: Expected time-evolution of GNSS satellites (GPS, Galileo, Compass, GLONASS)

All these features will be such that the radio occultation instrument will almost double the bending angle accuracy performance with respect first generation and will provide up to three times better Earth spatial-temporal sampling.

Instrument predicted performance are reported in Table 2. GRAS performance is reported as well as reference.

Parameter	MetOp GRAS	MetOp-SG
Bending Angle Accuracy	<0.8 µrad @ 35km	<0.5 µrad @ 35km
Number of observations per satellite	~ 650 occ/day	~ 1300 occ/day (GPS, Gal) ~2600 occ/day (GPS, Gal, GLO, Comp)
GNSS constellations	GPS only	GPS, Galileo, GLONASS, Compass
Closed Loop	Yes, @ L1 and L2	Yes, @ L1 and L5
Open Loop for low altitudes tracking	Open Loop @ L1, Carrier Open-Loop with Doppler Model	Open Loop @ L1 and L5, Open Loop in Code and Carrier
Use of Pilot Signals	No	Yes, yields to better performance in closed loop
Minimum SLTA	-140km, extendible	-300km

Table 2: Radio Occultation Instrument Performance Summary and comparison with GRAS

CONCLUSIONS

The Radio Occultation Sounding mission will form part of the MetOp-SG programme being implemented in collaboration with EUMETSAT and targeting an operational system of 21 years of operations. The Radio Occultation instrument will provide measurements of refractivity profiles in the troposphere and the lower stratosphere with very high accuracy and number of observations taken by a single satellite. This paper has presented the main performance and design characteristics of the instrument as it is currently defined within the on-going Phase A/B1 feasibility studies.

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