Future nanosatellite constellation for radio occultation measurements: preliminary design studies

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Foreword

**A study performed by CNES with some collaborations**

Thanks to the co-authors:

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CNES : French national centre for space research
MÉTÉO-FRANCE/CNRM : French national meteorological research centre
IPSL/LATMOS : Atmosphere and Spatial Observation Lab
IPGP : Earth physics institute
Outline

1. Motivation for the mission
2. Objectives of the mission
3. Mission requirements
4. Main technical specifications
5. Conclusion and prospect
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Motivation for the mission

Impact of GNSS-RO data on NWP at Météo-France

Percentage of observation types assimilated in Météo-France global model ARPEGE (January 2015) together with the corresponding FSO impact.
Motivation for the mission

Stagnation to decrease of the number of available occultations

Current GNSS-RO measurements available for NWP

- Currently 3000 occultations per day
- Tendency to decrease of the number of available occultations (ending COSMIC-1)

Evolution of the number of GNSS-RO observations in the Météo-France database
Outline

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2 Objectives of the mission

3 Mission requirements

4 Main technical specifications

5 Conclusion and prospect
Objective: increase the volume of GNSS-RO

Targeted number of occultations

- Refering to Harnisch et al (2013), no saturation effect in the impact of the number of occultations per day assimilated by numerical weather prediction models.
- Objective of the mission: **10,000 occultations** per day beyond 2025 in addition to the planned operational programs (EPS-SG (METOP-SG), post COSMIC-2).
  - A total of **16,000 occultations** per day beyond 2020-2025.
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Scientific interest in GNSS-RO

RO measurements to observe the atmosphere

Interests for numerical weather prediction, climatic trends, space weather

RO measurements provide:
- tropospheric and stratospheric temperature up to 50-60 km
- water vapor content
- surface pressure
- Total Electron Content (TEC) and electron density over the ionosphere
- phase and amplitude of ionospheric scintillations
### Mission requirements

**Analysis of the end user needs**

#### Requirements for NWP, climate and space weather

- The requirements have to cope with the end user needs while remaining in a low cost framework.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Community NWP</th>
<th>Community Climate</th>
<th>Community Space Weather</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vertical resolution</strong></td>
<td>1 km</td>
<td>500 m</td>
<td>layer E : 1km above layer F2 : 10 km</td>
</tr>
<tr>
<td>50 to 80 km</td>
<td>1 km</td>
<td></td>
<td>above layer F2 : 10 km</td>
</tr>
<tr>
<td>25 to 50 km</td>
<td>500 m</td>
<td>1 km</td>
<td>above layer F2 : 10 km</td>
</tr>
<tr>
<td>0 to 25 km</td>
<td>200 m</td>
<td></td>
<td>above layer F2 : 10 km</td>
</tr>
<tr>
<td><strong>Horizontal resolution</strong></td>
<td>100 to 200 km</td>
<td>100 to 200 km</td>
<td>100 to 200 km</td>
</tr>
<tr>
<td><strong>Bending angle precision</strong></td>
<td>3 µrad</td>
<td>3 µrad</td>
<td>Accuracy &lt; 3TECU</td>
</tr>
<tr>
<td>35 to 80 km</td>
<td>0.8%</td>
<td>0.8%</td>
<td></td>
</tr>
<tr>
<td>10 to 35 km</td>
<td>0.8 to 5%</td>
<td>0.8 to 5%</td>
<td></td>
</tr>
<tr>
<td>0 to 10 km</td>
<td>0.8 to 5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Data latency</strong></td>
<td>1 to 3 hours</td>
<td>~ 1 month</td>
<td>10 to 60 min</td>
</tr>
</tbody>
</table>
A nanosatellite constellation

Small size, low energy, low cost satellites

- analysis of the existing preliminary studies based on small satellites (*MicroGEM*, *PlanetiQ*, *Spire*, *GeoOptics*)
- targets for sizing: use of small GNSS-RO receivers, mass of the instrument 1.5 kg using a minimalist instrumentation
- consumption of 24 Watts
Number of satellites for a worldwide and uniform coverage

- Depends on the altitude of the LEO, number and coverage of antennas, number of constellations used

- 2 options to cope with the 10,000 per day required occultations:
  - Using only GPS constellation and 2 antennas, need for 12 LEO satellites spread over 3 plans, altitude 600 km, antenna coverage 50 degrees
  - Using GPS+Galileo constellations and 2 antennas, need for 8 LEO satellites spread over 2 plans, altitude 600 km, antenna coverage 50 degrees
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![Graph showing theoretical number of rising occultations per day vs LEO altitude](image)

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Ground station network

- Maximum data latency with 1 (Northern hemisphere) and 2 polar stations (Northern and Southern hemisphere):

  - Maximum time (minutes)
    - 1 ground station
    - 2 ground stations

- Data latency compatible with the requirements for NWP and space weather (mean latency of 20 min for the tropical band) with 2 ground stations.
### Adjustment of the receiver parameters

- Study of 55 occultation profiles for different atmospheric conditions (EUMETSAT/ECMWF)
- Analysis of $C/N\_O$ during a particular descending occultation
Choice of the GNSS frequencies

- Impact of the different GNSS frequencies on the instrumental performances:
  - The more tracking availability and the lowest tracking loss (not shown) for L5
  - The more precise phase measurement for E1
  - Main option: receiver bi-frequencies (E1 and L5) and bi-GNSS constellation (GPS and Galileo)
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Antenna

Main technical specifications

- 2 directive antennas: on the side of satellite velocity vector and the anti-speed side
- Array antenna (favorite option): patch antenna (good RF performance, low mass)
- Small-size antenna: for 3 unit elements, 390 mm by 130 mm
- Antenna coverage: +/- 50 degrees around the speed and anti-speed vectors.
- Gain of antenna: at least 8 dBi (result of the analysis of the impact of the antenna gain on the instrumental performances)
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The choice of the sampling frequency of the measurements linked to the vertical resolution targeted performances

- Frequency of **50 Hz** to satisfy the requirements of vertical resolution (200 m)
Conclusion and prospect

Progress of the mission

CNES has performed the preliminary design studies of a mission for a future nanosatellite constellation of GNSS-RO receivers:

- Targeted number of occultations: 10,000 per day
- Main identified technical specifications to meet the end user requirements and comply with the low cost constraint:
  - Small size and small mass (< 50 kg) with a minimalist instrumentation to remain a low cost system
  - Main planned option for the constellation: 8 LEO satellites, altitude of 600 km
  - Receiver bi-frequencies (E1 and L5) and bi-GNSS constellation (GPS+Galileo)
  - 2 polar ground stations
  - Array antenna with at least 8 dB gain, 50 degree coverage

- Further underway studies for the different technical options, for open loop, adaptative loop . . .
- Ending of these preliminary design studies by the end of the year.
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Thank you for your attention!

Any questions?

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