THE PARIS OCEAN ALTIMETER IN-ORBIT DEMONSTRATOR

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1. ABSTRACT

Mesoscale ocean altimetry remains a challenge in satellite remote sensing. Conventional nadir looking radar altimeters can make observations only along the satellite ground track and many of them are needed to sample the sea surface at the required spatial and temporal resolutions. The Passive Reflectometry and Interferometry System (PARIS) using GNSS reflected signals was proposed back in 1993 as a means to perform ocean altimetry along several tracks simultaneously over a very wide swath. The bandwidth limitation of the GNSS signals and the large ionospheric delay at L-band are however issues which deserve careful attention in the design and performance of a PARIS ocean altimeter. This presentation describes such an instrument specially conceived to fully exploit the GNSS signals and to provide multi-frequency observations to correct for the ionospheric delay. Furthermore an in-orbit demonstration mission is proposed that would prove the expected altimetric accuracy suited for mesoscale ocean science.

2. INTRODUCTION

The concept of using GNSS reflected signals for ocean altimetry was proposed by ESA back in 1993, just when the American GPS and the Russian GLONASS constellations became operational. At that time only one single narrow band civilian signal was being transmitted by each of the two GNSS systems, and in the case of GPS, its performance was intentionally degraded by the selective availability.

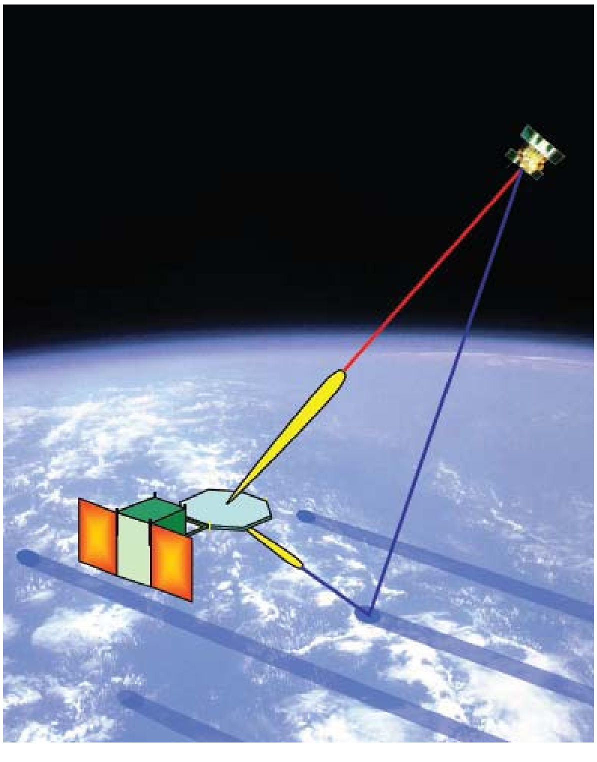
Since then, the GNSS constellation landscape has evolved –and will continue doing so– quite dramatically, with the appearance of new more powerful signals with more sophisticated code modulations and, above all, the development of three complete additional GNSS constellations: the European GALILEO, the Chinese COMPASS, and the Indian INSS). Assuming 33 satellites per constellation, and adding those from the Japanase regional QSZZ system as well as a few geostationary augmentation satellites per each constellation, the scenario in a decade from today may be one that will see over 180 navigation satellites illuminating the Earth surface, including the ocean, with their precise navigation signals.

If we now place a low Earth orbiting satellite capable of capturing the bouncing of these numerous signals off the ocean surface, then we will have managed to perform multiple observations over the ocean from a single satellite, and using a wide field of view passive instrument. Because the navigation signals are purposely designed for precise ranging, the first obvious application of such a system is ocean altimetry along simultaneous tracks, that is, mesoscale altimetry in the space domain. But also mesoscale altimetry in the temporal domain, as the system has inherently a wide field of view, and thus, a very short revisit time of less than 2 days. This concept is the one ESA proposed back in 1993 under the name of Passive Reflectometry and Interferometry System (PARIS) –see figure below.

Other applications of this concept can also be envisaged, as sea state and significant wave height observations, for the effect of these geophysical parameters will be stamped in the amplitude and waveform of the returns.

And beyond the ocean, there is the land and the cryosphere, where there will also be a wealth of geophysical information about the surface contained, in one way or another, inside the GNSS reflected signals.

For this reason, ESA, in the frame of exploring the scientific applications of the European GALILEO global navigation system, has started the study of a in-orbit demonstration mission named the PARIS In-orbit Demonstrator, or PARIS IoD in short.

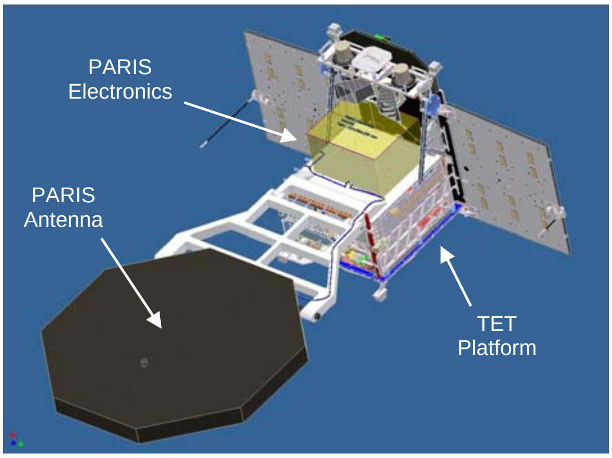


3. MISSION OBJECTIVE

The PARIS IoD aims at demonstrating that mesoscale ocean altimetry with an accuracy of the order of 5 cm is possible using GNSS reflected signals. The key factor to account for is the ionospheric delay, which is of several meters at L-band, the frequency band used by today's GNSS systems.
The altimetry performance of the demonstration mission, intentionally flying an antenna smaller than needed, would actually be not quite that much, but just some 15 cm.
Such objective of demonstrating accurate mesoscale altimetry using GNSS reflected signals should be possible thanks to the interferometric processing (or complex cross-correlation) with the corresponding direct signals, as well as accurate in-orbit delay and amplitude calibration techniques. As explained later, the interferometric processing is enabled by high-gain steerable beams pointed simultaneously towards the GNSS satellites and their reflection points.

4. PARIS IoD SATELLITE OVERVIEW

This demonstration mission comprises two elements: the German TET platform and the PARIS altimeter as single payload. TET is a platform developed within the German national space program for in-orbit demonstrations of technologies and techniques. Together with the platform is included the TET ground segment to receive science data and to perform satellite operations.
TET is a small platform with the shape of a prism and a maximum dimension of less than 80 cm. The 110 cm diameter PARIS antenna, requiring visibility on both sides, looks as shown in the figure below in its final configuration.



During launch, the antenna is folded with the array sitting flat on top of the platform. The required deployment is performed in two steps through two parallel hinge lines. The electronics of the PARIS altimeter are housed on top of the thermal interface plate provided by the TET platform (refer to figure – courtesy Kayser Threde, Germany). The harness between the antenna and the electronics comprises the radio-frequency signals, which are sent through optical fibres, some control lines and a power bus.
The PARIS IoD is proposed to be launched as secondary passenger thanks to its small size and compactness. One possible launcher is Rockot, where the demonstrator would be embarked inside the interface cone between the launcher and the main satellite passenger. This is following the example of PROBA-2, which is to be launched as a secondary satellite in a Rockot, with SMOS as main passenger. The PARIS IoD is slightly larger than PROBA-2 and a new larger interface cone will be required to allow such a double launch configuration.
Being a demonstration mission, PARIS IoD does not required a particular orbit. Nonetheless, the mission is being designed assuming a dawn-dusk sun-synchronous orbit, with a height around 800 km. Such a polar orbit will allow global coverage of the Earth in 3 days.
In measurement configuration the PARIS satellite flies Earth pointed, with the solar arrays pointing towards the sun. The deployed PARIS antenna have full clearance of direct and reflected signals within a full cone angle of more than 90 degrees. During amplitude calibration the satellite keeps an inertial attitude for about half an orbit to access the cold sky.
Scientific data are transmitted down to ground using a dedicated X-band link. Platform command and control is carried out through TET's low and high rate S-band links. An S-band high rate up-link is used to provide the payload with the ephemeris of the GPS and GALILEO satellites, needed for steering the antenna beams. Also required for beam steering are the time, position, velocity and attitude of the PARIS satellite, these being made available by the TET platform to the payload on the fly.
The thermal control of the payload electronics is done with a thermal interface plate, heat pipes and multi-layer insulating blankets.

5. PAYLOAD DESCRIPTION

The PARIS altimeter consists of two distinct elements: the antenna and the electronics unit. The antenna is deployable while the electronics unit sits on the TET platform.
The antenna is an active double-faced array, each face comprising 31 small two-frequency (GPS L1 and L5) radiating elements arranged in an hexagonal 1-6-12-12 grid. Both up and down-looking arrays are identical, except for the polarisations, which are circular right and left-hand respectively.
Each up-looking antenna element is paired with its opposite down-looking element. This pairing is implemented through a calibration switch which allows swapping the antennas and the receivers for accurate

removal of any instrumental delays. The calibration switch also allows connecting a reference load to all receivers, this providing a warm input reference level that, together with the cold sky, forms the basis of the amplitude calibration strategy.

The 62 radio-frequency switch outputs are low noise amplified and converted into optical signals. Through fibre links attached to the yoke these signals are routed from the antenna into the electronics unit. Following an optical-to-electrical conversion, the two frequency bands received by each antenna element, GPS L1 (same as GALILEO E1) and GPS L5 (also covering GALILEO E5) are demultiplexed, each band feeding a separate beamformer. In the beamformers each signal is first split into 4 branches and then phase shifted and amplitude weighted to steer the four beams towards the GNSS satellites or their reflection points. All signals from the same branch are finally combined to form one beam. In total there are 16 beams: 4 up-looking and 4 down-looking beams for each of the two frequency bands, GPS L1 and L5.

The beam signals are down-converted and the up and down-looking beams corresponding to the same GNSS satellite are further Doppler shifted with respect to each other so that their final intermediate frequencies coincide. The down-converted Doppler-shifted beam signals are digitised to 1 bit before being made available at the output of the beamformers.

The beamformer outputs are passed onto the correlator unit which performs a straight complex cross-correlation between each pair of beams corresponding to the same GNSS satellite. Prior to the cross-correlation the direct signal is delayed to compensate for the difference in travel time between the reflected and direct signals. The cross-correlation is calculated over the so called coherent integration time.

The phase values of the phase shifters are computed based on the GNSS ephemeris, uplinked from ground, and the platform time, position, velocity and attitude, provided by the platform. The refresh rate of the GNSS ephemeris is faster than 5 hours, which is nominally the maximum time in between contacts with the TET’s ground stations.

The amplitude of the cross-correlations over the coherent integration time fluctuates strongly due to speckle. A further incoherent average is taken on-board to reduce data rate and to mitigate the amplitude fluctuations of the waveforms. The incoherently averaged waveforms are stored in the on-board memory and sent to ground through the X-band link at a moderate speed of less than 10 Mbit/s at each pass over a ground station.

On ground a retracking processing is performed from which the geophysical information of altimetry is retrieved, possibly together with other type of information as sea state and significant wave height. The ionospheric delay is corrected through the observations in the two frequencies.

6. CONCLUSIONS

GNSS systems illuminate the whole global, including the ocean, with sophisticated signals purposely design for ranging. They will very likely keep growing and improving for the next decades to come. A low Earth platform could collect their reflections off the ocean surface to retrieve mesoscale topography as well as other useful ocean geophysical information. In doing so the large ionospheric delay needs to be accounted for by performing observations at two frequencies.

A demonstration mission has been presented which is being considered at ESA and which could prove the feasibility of GNSS reflected signals for accurate mesoscale altimetry. This should be possible thanks to the direct correlation between up and down-looking signals, and accurate delay and amplitude calibration techniques.