Innovative radar altimeter concepts

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Abstract — In the frame of the study "Innovative Radar Altimeter Concepts", founded by the European Space Agency (ESA), the authors analyzed potential advanced measurement concepts for radar altimeters of future generation, studied the feasibility of the identified techniques and proposed a design for an instrument based on the most promising system concept. This paper summarizes the major results of the study.

Keywords: altimetry, synthetic aperture radar, interferometry, satellite constellation.

I. INTRODUCTION

Altimeter observations are recognized by the science community as a fundamental component of the integrated observing strategy for the World Ocean Circulation Experiment (WOCE). In the last decades, satellite radar altimeters have been successfully exploited to monitor the ocean surface on a global scale, and by now measurements performed by radar altimeters are fundamental for understanding key climate mechanisms, for studying ice dynamics, for monitoring tides, for investigating interactions between ocean and atmosphere in climate perturbations.

In the short term, availability of altimeter measurements is guaranteed thanks to ENVISAT and JASON missions, and, approximately in the same time frame, the CRYOSAT mission will provide also high resolution maps of ice topography. Nevertheless, continuity in observations shall be guaranteed also in the post ENVISAT era, and the challenge for continuity shall be combined with the additional users' need for global, near real time, high accuracy and high resolution measurements.

Fig. 1 shows a diagram of the space-time scales of major processes determining the ocean and ice dynamics [1]. It is evident that there are many processes that occur on the temporal and spatial scales that are not resolved by present radar altimeters yet. Up to now, the repeat cycles of altimeter missions have allowed to measure large scale sea surface height fields, for studies of ocean variability on monthly and longer time scales, with space scales of few hundred of kilometers. Poor information is available on processes at shorter space and time scales, such as large scale barotropic signals and coastal processes, but also extracting information about mesoscale is problematic. On the other hand, a large fraction of the eddy kinetic energy of the ocean is concentrated just in eddies and currents with spatial scales shorter than the ones resolved, thus providing high resolution measurements should be the key requirement for future radar altimeters.

Classical altimeter measurements inevitably involve a trade-off between spatial and temporal resolution. The two parameters can not be optimized together and improvement of spatial resolution implies degradation for temporal sampling, with obvious consequences for the data usefulness. In order to resolve this constraint, either the typical mission configuration based on a single satellite must be changed in favor of a constellations of altimeters, or the classical system concept exploited to achieve the height measurement must be substituted by innovative solutions.
In the following, some candidate system concepts are considered and a possible instrument architecture for the most promising technique is presented.

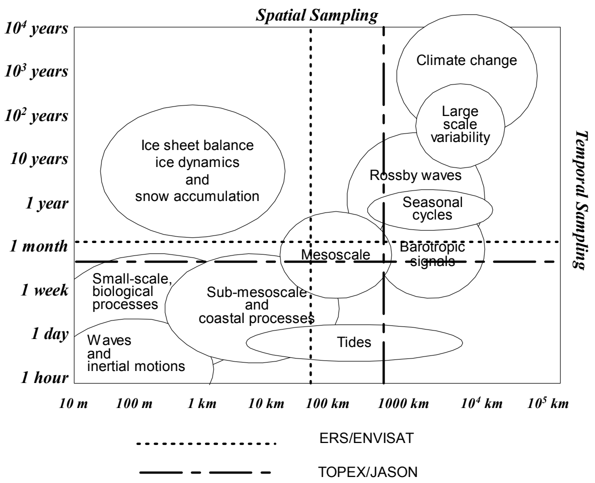

Figure 1. Schematic view of the approximated space-time scales of the major processes determining ocean and ice dynamics.

II. SYSTEM CONCEPTS

The authors studied applications and products from past and current altimeter missions and defined a set of user requirements for a hypothetical radar altimeter. Then these requirements were translated into engineering parameters and possible measurements concepts suited to meet the requested performance were analyzed. The following techniques were considered: constellation based techniques, off-nadir multibeam technique, two-dish interferometry, bistatic altimetry, techniques based on opportunity signals provided by Global Navigation Satellite Systems (GNSS), techniques based on Synthetic Aperture Radar (SAR) and SAR Interferometry (SARIn).

Exploiting a constellation of satellites equipped with nadir-looking radar altimeters is the most intuitive solution to overcome the sampling limitations of a single satellite system [2]. Nevertheless, the major drawback of this approach is represented by the number of satellites necessary to achieve the sampling performance required to resolve at least mesoscale dynamics.

In multibeam techniques the conventional pulse-limited radar altimeter concept is modified by extending the limited, although high performing, nadir looking measurement capability with the inclusion of measurements taken by additional antenna beams pointed off-nadir [3]. The separation between two adjacent beams determines the achievable spatial sampling; whereas the beam footprint dimensions fix the spatial resolution.

The technique known as two-dish amplitude interferometry represents an alternative solution for synthesizing multiple beams [3]. This concept is based on a monopulse system widely exploited in radio astronomy, where interferometry is used for receiving radiation from celestial radio objects as they drift across the sky through the antenna pattern.

The distinguishing feature of a bistatic radar is represented by separated antennae for transmission and reception. The application of the bistatic concept to radar altimetry appears as an attractive solution, since a couple of satellites provides the capability to acquire three measure tracks (the two sub-satellite tracks and the track in the middle), thus improving the sampling performance of the system [4].

The use of GNSS signals for ocean altimetry has been increasingly considered in the last years [5]. The opportunity signals incoming from the navigation systems cross the atmosphere, arrive at the ocean surface and are bounced back to the atmosphere, with a signal power dependent on surface roughness and angle of incidence. A user satellite provided with the adequate GNSS equipment can receive and track the reflected signals, process them and retrieve the height of the user platform over the water surface.

Some authors thought to apply the SAR and SARIn concepts to radar altimetry [6]. These techniques allow to achieve high spatial resolution with the simultaneous accessibility of wide ocean regions, thus meeting both the temporal and spatial sampling capabilities required to the radar altimeters of future generation. In particular, SARIn appears as the natural solution to exploit SAR at the aim of measuring height. This technique allows to retrieve topographic maps from the differential phase measured by two radar antennae, looking at the same portion of surface. Resolutions comparable with the ones attainable by SAR sensors are absolutely not necessary, thus the required data processing can be simplified and the multi-look technique can be effectively employed to minimize the phase noise corrupting the accuracy of height measurements.

III. INSTRUMENT DEFINITION

The candidate techniques were evaluated in terms of pros and cons and, at the end of a selection process, a system concept based on SARIn was recognized as the most attractive solution. This technique, better known as Wide Swath Ocean Altimeter (WSOA) [7], was assumed as reference for the instrument definition. Fig. 2 shows a pictorial representation of the concept.

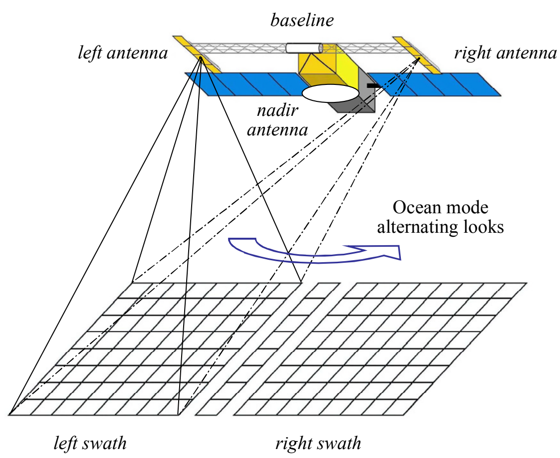

Figure 2. Wide Swath Ocean Altimeter

Two planar antennae, placed at the tips of a mast (baseline) implements the interferometric couple, whereas the central antenna is devoted to classical, nadir measurements.

In order to achieve high performance both over ocean and ice, two dedicated operational modes were envisaged: Ocean mode and Ice mode [1]. When operated in Ocean mode, the wide swath altimeter covers two swaths, by alternating looks on the left and on the right side of the sub-satellite track. The system covers a total area of 180 kilometers, with resolution cells of 10 kilometers. The coverage gap between the two side swaths is fulfilled thanks to the measure of a nadir-looking altimeter (Ku-band), which, furthermore, is mounted on-board for providing the ionosphere correction (S-band). The use of nadir-looking altimeter and wide swath altimeter is not contemporaneous, but operations are interrupted at a proper rate for nadir-looking measurements and for calibration. In Ice mode, the altimeter covers a single swath at enhanced resolution (300 meters). Furthermore, the system implements a ping-pong technique, alternating transmission from left and right antenna to double the effective baseline, and doubles the duty-cycle to cope with the weaker scattering from sea ice.

A block diagram of the proposed instrument is reported in Figure 3. The main blocks are:

- Digital Subsystem (Digital S/S): the Digital Chirp Generator (DCG) computes and generates the samples of the signals to be transmitted; the block named Baseband Conversion, Analog to Digital Converter (ADC) and Formatter includes phase detectors for the baseband conversion of the signal, and implements all the functions which are necessary for acquisition, processing and signal formatting; the Controller is in charge of the overall control function.

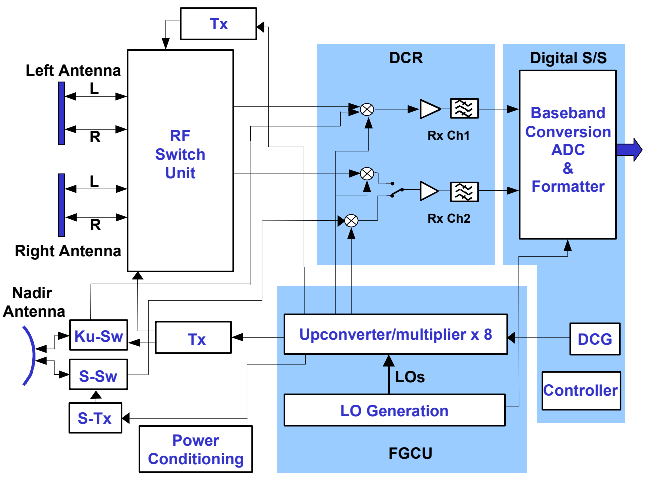

Figure 3. Instrument architecture

- Radio Frequency Subsystem (RF S/S): the Frequency Generation and Conversion Unit (FGCU) provides the local oscillators (Los) and performs up-conversion of the chirp signal; the Ku-band transmitters (Tx) feed both the wide swath and the nadir looking altimeter; the S-band transmitter (S-Tx) and the Ku/S-band switches (Ku-SW and S-SW) are associated with the nadir-pointing antenna; the RF Switch Unit provides switching between Tx/Rx and between the different beams of the antennae; the Dual Channel Receiver (DCR) completes the RF S/S.

- The wide swath antennae (left and right, with separate I/O ports for left and right beam) and the nadir-pointing antenna (dual-band).

IV. CONCLUSIONS

The authors analyzed innovative system concepts which promise to overcome the limitations of present altimeters and selected the WSOA as the most attractive solution.

The WSOA technique overcomes the traditional concept of radar altimeters, intended as instruments devoted to the acquisition of height profiles, and transforms radar altimeters into imagery sensors in the proper sense of the word. The considered approach increases the resolution of the system and its coverage capability, so that a single satellite mission capable of resolving mesoscale phenomena becomes viable. In addition, SAR processing allows to achieve, in the frame of the same instrument, also the higher resolutions requested by the study of ice.

The authors studied the feasibility of the WSOA system concept and identified both the advantages and the critical aspects of the technique (e.g. ensuring the height accuracy of present altimeters even at the boarder of the swath is not so simple). In the end, it was demonstrated that the WSOA is something more than a mere appealing concept and has the potentials to be translated into a successful operational instrument.

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