WAVEMILL: A NOVEL INSTRUMENT FOR OCEAN CIRCULATION MONITORING

José Márquez[1], *Giulio Ruffini*[1], *Dave Lancashire*[2], *Byron Richards*[2], *Christopher Buck*[3]

[1]Starlab Barcelona SL, Camí de l'Observatori s/n, 08035 Barcelona, Spain
[2]EADS Atrium Ltd., Anchorage Road, Portsmouth, Hampshire PO3 5PU, United Kingdom
[3]European Space Agency, Keplerlaan 1, 2201 AZ Noordwijk, The Netherlands

1. INTRODUCTION

The launch of the radar altimeters on-board the ERS and the TOPEX/Poseidon satellites has provided the means to monitor the ocean circulation in a global scale. However, the modelling of ocean flows and circulation models requires the proper spatio-temporal sampling of these phenomena while avoiding aliasing, a major risk due to the periodicity of tidal signals. The measurements derived from conventional altimetric data suffer from the fact that the altimeter coverage is restricted to a small swath (typically of a few kilometres) beneath the sub-satellite track. This fact results in large gaps, especially at temperate latitudes, and thus, interpolation in both space and time is required to identify small-scale features (with dimensions of 100 km or less) in the velocity field. Additionally, conventional altimeters are not able to deliver accurate measurements close to land due to ambiguous signals returns.

In the late nineties, a new measurement concept was presented to address the mesoscale sampling problem, the Wide Swath Ocean Altimeter (WSOA) [1], consisting of a wide-swath coherent interferometer (200 km swath) in combination with a nadir altimeter. This instrument is designed to provide very precise (a few centimetres) altimetric measurements of the ocean topography in open waters and coastal zones by ingeniously arranging two quasi nadir-looking interferometric antennas in cross-track direction (perpendicular to flight track). However, the system calibration, and more precisely the knowledge of the baseline attitude and length, became an important issue limiting the practical accuracy of the system.

The Wavemill concept, proposed in 2004 by Christopher Buck (ESA) [2], aims at retaining WSOA's benefits while solving its calibration limitations and, additionally, to measure directly 2D surface ocean currents and indirectly measure geostrophic currents. Moreover, Wavemill is able to provide collocated scattering information in time and space with the surface current measurements to estimate, e.g., wind speed over the oceans. This is achieved by modifying WSOA's antenna configuration: the two antennas are separated not only across-track but also in the along-track direction (parallel to the flight track). This configuration allows for direct measurement, in a single satellite pass, of 2D ocean surface currents by along-track interferometry (ATI) while retaining the ability of WSOA to measure ocean topography by cross-track interferometry (XTI). These remarkable features make

Wavemill an oceanographic radar unique in its class. Wavemill represents the most ambitious instrument to date regarding the study of the oceans.

The paper will describe the main results obtained in the framework of the ESA ITT Altimetric Measurements of 2D Ocean Surface Currents (AO/1-5571/07/NL/ST) with respect to system analysis, preliminary system performance, and baseline calibration performance.

2. SYSTEM CONCEPT

2.1. Wavemill Operation Mode

The Wavemill concept attempts to retain the WSOA benefits while solving its calibration limitations and additionally, to measure directly 2D surface ocean currents. These outstanding features can be obtained by separating the two antennas not only in the cross-track direction but also in the along-track one. This configuration allows direct measurement of 2D ocean surface currents by ATI while keeping the ability of WSOA to measure ocean geostrophic currents by XTI. The possibility of current measurements by combined ATI/XTI, also known as hybrid interferometry, has been successfully demonstrated in the past from airborne platform with repeated passes [3]. However, the proposed space instrument aims to 2D current measurements with a solely satellite single pass. The main features of Wavemill are:

- Interferometric side-looking synthetic aperture radar (SAR) operation.
- Right- and left-hand side-looking observation to acquire a total combined swath of 200 km. This configuration also allows for 2D ocean current observations and at the same time is required for the baseline calibration.
- Two beams squinted 25º fore (along-track direction) and aft (counter along-track direction) to measure 2D ocean surface currents. Although a 45º squinted geometry is optimum in terms of current estimation, it also requires a larger LOS swath, i.e. 141 km compared with the 111 km for the 25º case. The accommodation of a larger swath is problematic for the timing analysis and has been avoided.
- Incidence angle of 16º at mid swath to best trade sea surface height and currents off. Although 30º-45º is more appropriate for sea surface current estimation, a steeper incidence angle is better for sea surface height estimation, timing and signal-to-noise ratio (SNR), i.e. interferogram coherence.
- Two channels per observation: monostatic and bistatic. One antenna transmits and receives; a second one only receives.
- Four beams pulsed sequentially in a burst operation mode. This reduces the number of receivers from 8 to only 2 which are switched to each active beam. Additionally, the required power (launcher selection) and the processed data amount will be significantly reduced.

Figure 1 illustrates the Wavemill illumination geometry.

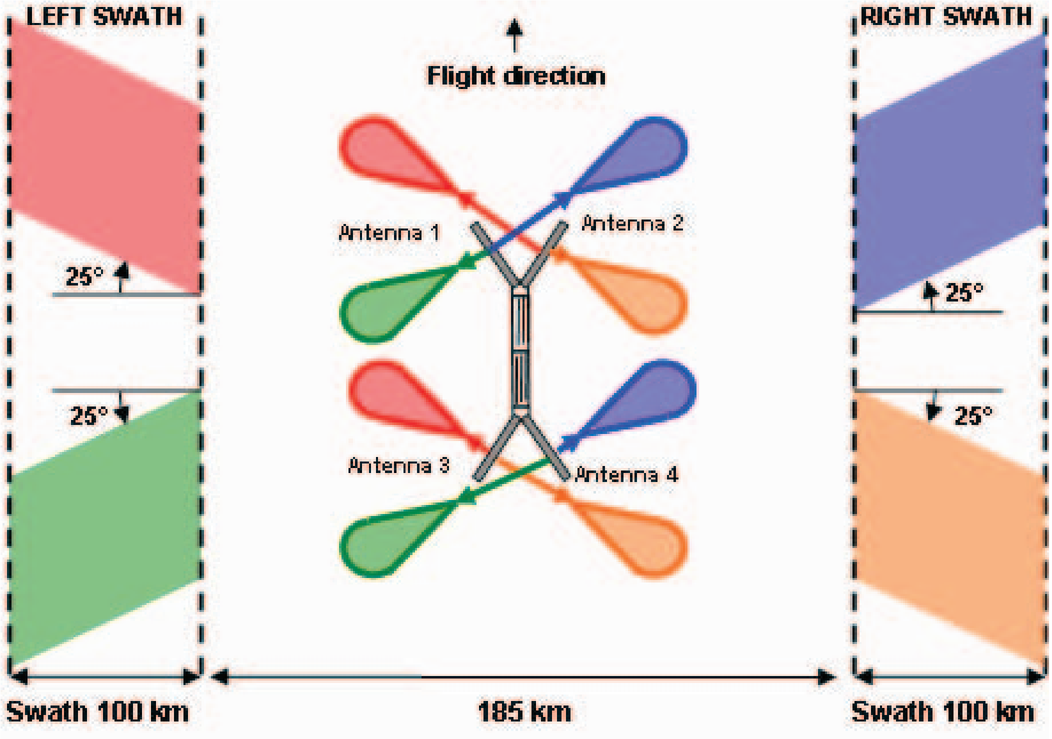

Figure 1: Wavemill Illumination Geometry.

2.2. Baseline Calibration Concept

The calibration of the baseline length and the baseline attitude is of paramount importance for the feasibility of the Wavemill concept since baseline uncertainties will compromise the accuracy and the hybrid phase separation in along-track and across-track terms. The calibration of the baseline errors has been described in [4] and it is based on the fact that the baseline impact on XTI phase for the Wavemill fore and aft beams can be estimated using interferometric images corresponding to the same topographic area (both in the right and left sections). Both baseline length and baseline attitude can then be estimated. Here, we only present the main concept ideas as a detailed concept analysis is currently been done and will be presented in the final paper.

The calibration concept is based on the use of co-time interferograms to the right- and left-hand side of the instrument. After phase flattening the interferograms, the height difference between fore, h_F, and aft, h_A, beams over the reference ellipsoid for one side of the instrument can be computed as

$$\begin{aligned} \Delta h = h_F - h_A = \\ = -\varphi_{\mathrm{F}}^{\mathrm{i}} \cdot s \cdot B^{-1} \cdot \left[\cos(\beta - \theta_s)\cos\alpha\cos\theta_0 + \sin\alpha\sin\theta_0\right]^{-1} + \\ + \varphi_{\mathrm{A}}^{\mathrm{i}} \cdot s \cdot B^{-1} \cdot \left[\cos(\beta + \theta_s)\cos\alpha\cos\theta_0 + \sin\alpha\sin\theta_0\right]^{-1} \end{aligned} \quad (1)$$

where B is the baseline length, β is the baseline azimuthal angle, α is the baseline elevation angle, θ_s is the observation squint angle, θ_0 is the reference incidence angle and $s=R_0 \sin \theta_0 / k$, where R_0 is the slant range for the reference height and k is the wavenumber. Assuming that the average height of the ocean (averaged over a large region, e.g. 1km x 1km) does not change in the time between imaging with the fore beams and the aft beams (which is of the order of minutes), the difference between these two topography maps should be ideally equal to zero. However, in case that there are some baseline length or orientation errors, the height difference between fore and aft beams will be non zero and thus, could be used to estimate the baseline length and attitude errors.

Equation (1) can be expanded to the first order error for each pixel of the generated height maps leading to a linear equation system relating the height measurement difference to the baseline deviations which can then be inverted. Provided that there are two families of equations: one for the right and one for the left sections; each family of equations will have linearly independent members for each imaged pixel (in range and if needed in azimuth). In a preliminary analysis, the system appears to be able to calibrate the aforementioned errors although a more detailed analysis is currently been done in order to set the bounds of the total error estimation. These results will be presented in the final paper.

11. REFERENCES

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