STEPS TOWARDS THE PREPARATION OF A WAVEMILL MISSION

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ABSTRACT

Wavemill is a microwave instrument designed to retrieve ocean surface currents in two dimensions. After initial internal investigations and the successful results of a feasibility study, the European Space Agency (ESA) is pursuing a programme of steps aimed towards the development of a Wavemill-based mission. This includes a proof-of-concept campaign, scientific assessment of the product validity, end-to-end simulator development, mission (Phase 0) study and hardware risk retirement for the antenna and on-board processing sub-systems. This paper briefly covers all these activities and establishes a notional timeline for their completion. The end goal of a Wavemill mission is dependent not only on a successful conclusion to these activities but also on the interest and enthusiasm of the oceanographic community as well as the validity and applicability of the products such a mission could provide.

Index Terms — Wavemill, sea-surface currents, hybrid interferometry

1. INTRODUCTION

Accurate knowledge of spatial and temporal current variations in the open ocean and in coastal waters at high resolution (<5 km) is essential for a variety of applications, including maritime safety and risk management for coastal and off-shore structures, search and rescue operations, pollution fate tracking, monitoring of changes in coastal regions, coastal development and management, general ship operations, and a wealth of scientific studies on surface ocean current dynamics.

Extensive work has already been carried out in the area of ocean current mapping using coastal high frequency and satellite radar systems. Excellent results have been achieved using the Doppler anomaly of satellite SAR instruments but a significant limitation to the technique means that only currents in one direction can be estimated. Along-track SAR interferometry provides an alternative method but again, only one dimension can be estimated using conventional satellite SAR systems.

Wavemill attempts to retain many of the benefits of Wide Swath Ocean Altimetry (WSOA) concept, which is aimed at extending the resolution coverage of conventional ocean surface topography measurements (e.g. [1]). The Wavemill concept proposes simultaneous imaging of swaths to either side of the sub-satellite track allowing SAR interferometry of the ocean surface. The Wavemill antenna configuration basically consists of separating two antennas in both the across-track and along-track directions (i.e. parallel to the flight track), allowing the 2D ocean surface currents to be measured directly by means of along-track interferometry (ATI) while maintaining the ability of WSOA to measure ocean topography over swaths by means of across-track interferometry (XTI). The baselines required for the Ku-band (13.3GHz) system under study are around 3.5m across track and 12.5m along track. Despite these relatively modest dimensions, the system performance is predicted to be very good.

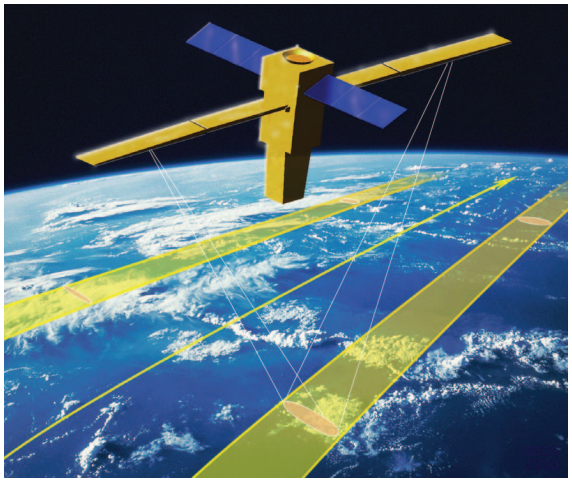

Figure 1: Impression of a Wavemill Mission. The antennas are 4.5m long and separated by a boom through the modular spacecraft.

Wavemill not only provides a system capable of direct retrieval of ocean surface currents through along-track interferometry: it can also map the surface topography of the ocean. At the same time, the Wavemill antenna configuration offers a solution for the baseline calibration limitations inherent in such interferometric wide swath systems. The possibility of measuring surface currents together with surface topography by combined ATI/XTI, also known as hybrid interferometry, has been successfully

demonstrated in the past from airborne platforms e.g. Siegmund et al [2] as well as from space as in the SRTM mission [3]. The difference with the Wavemill instrument is that it aims to provide 2D ocean current measurements with a single satellite pass while at the same time determining the ocean surface topography over a wide swath. It is easy to see that such a system lends itself to a number of additional applications including the potential for surface wind speed retrieval over the ocean, measurements of sea ice dynamics, large river flows and lake surface currents, significant wave heights and swell wave characteristics. Furthermore, a Ku-band SAR system is potentially capable of measuring a variety of geophysical parameters (e.g. snow water equivalent, icebergs and ice dynamics).

Under ESA contract, Starlab (E) and Astrium (UK) have conducted a feasibility study on Wavemill and the conclusions are promising both in terms of performance and instrument design. Results suggest that currents of less than 10cm/s are measurable and the directional accuracy, although dependent on the strength of the current, is of the order of 10° for currents of 40cm/s dropping to a few degrees for fast currents of around 1m/s. Due to the geometry and antenna patterns, ambiguous energy from land will not be a serious issue making Wavemill very useful for the monitoring of coastal currents.

Following the positive outcome of the feasibility study, the Agency has started to initiate a number of steps towards the establishment of a full science, instrument and mission concept for the retrieval of ocean currents. These steps are set out as follows:

- A proof-of-concept campaign with squinted interferometric SAR capability
- Development of an end-to-end simulator towards the end of which there will be a workshop to present the findings to the scientific community
- A scientific product assessment study
- Potentially an internal Concurrent Design Facility study to help focus the system study
- A system study
- Risk retirement in the form of:
    - Antenna breadboard
    - On-board processor breadboard

The suggested timing for all of these activities is presented in figure 2.

2. PROOF-OF-CONCEPT CAMPAIGN

The main precepts of the Wavemill instrument (i.e. squinted hybrid interferometry) and the specific processing required have yet to be proven conclusively but if this is achieved then Wavemill represents an extremely innovative and significant instrument regarding the study of the oceans. Proving the Wavemill measurement concept is the purpose of the Wavemill Proof-of-Concept Campaign. The current plan is to fly Astrium's X-SAR instrument in Wavemill configuration over a test site with "ground truth" provided by HF radar, buoys and acoustic Doppler current profilers. Ideally this will take place under a variety of wind and tide conditions.

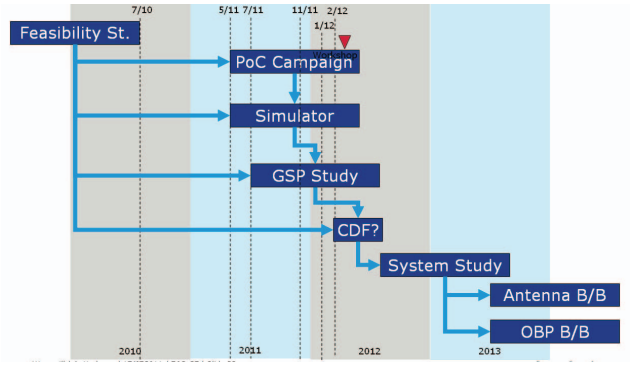

Figure 2: Timing for Wavemill Mission Preparatory Steps

The findings of the WPCC campaign will be an important step in understanding the true potential of Wavemill for oceanography and this is to be achieved by flying an interferometric SAR instrument with squinted beams in order to demonstrate the feasibility of the Wavemill concept and to obtain a better understanding of the products that could be derived form a Wavemill instrument.

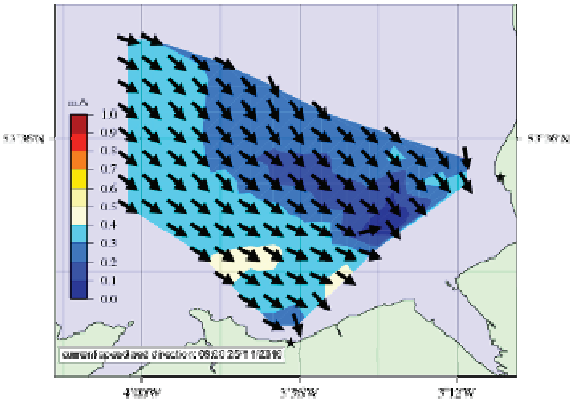

Figure 3: Liverpool Bay area site for the Wavemill proof-of-concept campaign

3. END-TO-END SIMULATOR

An end-to-end simulator is required to enable system parameters to be varied in a controlled way and thus facilitate the development of a practical, spaceborne Wavemill instrument. The objective of this activity is to develop an end-to-end simulator for assessing different configurations of Wavemill instrument, their sensitivity to baseline errors and sea-surface conditions, by re-constructing sea surface topography and current maps under varying conditions.

The RFQ (request for quotation) has already been issued for this activity and it is expected to start in June 2011.

4. MISSION STUDY

A mission study is to be performed to characterize and demonstrate the system-level feasibility of a mission making use of the Wavemill instrument concept. This shall be split into two studies, one on the scientific products – the product assessment study – and the other devoted to the preliminary design of a mission – the system study.

4.1. Mission Requirements

Wavemill scientific objectives for the mission are directly linked to specific challenges in ESA's Living Planet Programme [6]. Indicated in table 1 are primary objectives, which will receive principal focus in the mission, and secondary objectives, which are opportunities for the mission to help address important questions and challenges.

Table 1: Main scientific mission requirements

Wavemill Scientific Objectives	**Primary or Secondary Objective**	**ESA's Living Planet Programme Challenges Addressed**
1. Quantify and map (sub)-mesoscale (<0.1 – 10 km) ocean surface current vectors and their variability	P	Ocean Challenges 1, 2, 3, 4 and 5
2. Quantify and map (sub)-mesoscale sea surface height and its variability	P	Ocean Challenges 1, 2, 3, 4 and 5
3. Evaluate and reduce the uncertainty of (sub)-mesoscale ocean surface current variability measurements at regional and global scales	P	Ocean Challenge 1
4. Quantify and map ocean swell and waves at regional and global scales	P	Ocean Challenges 1, 2, 3, 4 and 5
4. Quantify and map the variability of sea ice, sea ice thickness and velocity	P	Cryosphere Challenges 1, 2 and 4
5. Quantify and map the size, velocity and the variability of icebergs	S	Cryosphere Challenges 1, 2 and 4
6. Quantify and map river flows and river flow variability	S	Land Challenges 1 and 3
7. Improve and validate numerical ocean circulation model and data-based assessment and prediction of ocean circulation	P	Ocean Challenges 1 and 5
8. Improve and validate hydrological models through data assimilation and improve freshwater inflow into the ocean.	P	Land Challenges 1 and 3

4.2. Product Assessment Study

The purpose of this study is to determine the scientific validity of the data products as derived from measurements taken by a spaceborne Wavemill instrument and to ascertain if, from a scientific point of view, the usefulness of these products can be significantly enhanced through additional processing of the instrument data and/or by the inclusion of data from a second, complementary instrument. The particular areas to be covered under the study are:

- A review of the state-of-the-art of along-track interferometry for ocean current retrieval
- The validity of the scientific products produced by a Wavemill instrument
- Scatterometric processing of the Wavemill data to retrieve the wind speed and its impact on surface current retrieval
- Potential additional products such as inland water height, river flow rate, sea-ice freeboard and age
- Complementary instrument data e.g. thermal imagery, conventional altimetry, microwave radiometry etc.

It is intended that the product assessment study shall result in a further detailed Mission Requirements Document to feed into the Wavemill system study in order to arrive at a complete basic mission design.

4.3. System Study

The purpose of the system study is to provide a preliminary design for a mission based on the Wavemill concept. This preliminary design shall demonstrate system feasibility. The system under consideration in the study shall cover all the elements (both space and ground) necessary to provide Level 2 products.

For this study the system will be divided into three segments: the space segment, the mission operations ground segment and the payload data ground segment. The space segment will be subdivided into the instrument and the satellite platform with its sub-systems. The study will be organized in two parts; the architectural definition and the system definition.

In the first part the Wavemill concept will be assessed under the double light of the fulfilment of user needs and affordability. The second part will provide a definition of the end-to-end system with special emphasis on the definition of

the instrument, the configuration, the mechanisms and the AOCS of the satellite, which are the most challenging elements of the new system.

5. RISK RETIREMENT

5.1. Antenna Breadboard

This activity covers the development of a prototype Wavemill antenna. The feasibility study, demonstrated the value of the "javelin" concept since it can provide the required along- and across-track baselines despite a compact spacecraft at launch and one which is nearly optimal for AOCS (long and thin in the flight direction). However, this design calls for an antenna capable of producing up to four squinted beams with a swath width of around 100km at an incidence angle of 25-45°. This key component needs to be addressed and realized in a breadboard to bring the whole Wavemill concept together.

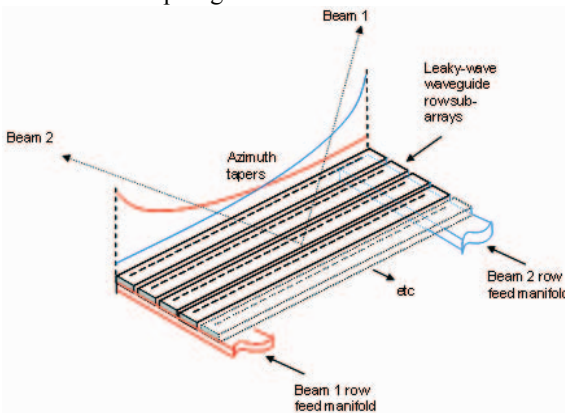

Figure 4: Slotted waveguide antenna proposed for Wavemill

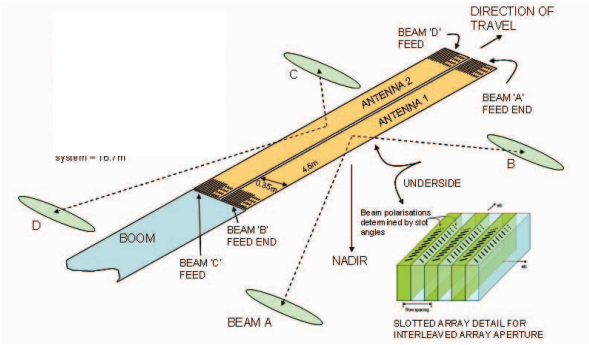

Figure 5: Proposed antenna assembly

From the feasibility study it seems that a specific type of slotted waveguide antenna known as a 'leaky wave' antenna should be able to produce the required beams since it has the property of naturally squinting to 45° with swaths on the ground orthogonal to the sub-satellite track. This will save power and data rate. A breadboard of such an antenna operating in Ku-band with >100MHz bandwidth shall be designed, manufactured and tested in this activity.

5.2. On-board Processor Breadboard

This activity covers the development of a prototype on-board processor for Wavemill. With its four interferometric pairs of SAR images Wavemill produces an enormous amount of data at a very high data rate. Fortunately, due to the fact that signal (phase) quality is required rather spatial resolution a very high amount of multi-looking can be performed on the images on board, drastically reducing the quantity of data to be downlinked.

The activity is to cover the full on-board processing steps for Wavemill, which include:

- SAR processing
- Image registration
- Co-time interferogram generation
- Multi-looking
- Flat earth correction
- Hybrid interferogram generation
- Hybrid phase separation

The design shall be based on FFT and processing chipsets (e.g. PowerFFT and Leon II) which are functionally representative of space-qualified components.

6. REFERENCES

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