Wavemill: a new mission for high-resolution mapping of total ocean surface current vectors

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Abstract

Synoptic maps of total ocean surface currents from space are needed to improve parameterisations of oceanic sub-mesoscale dynamics and represent their impact on global ocean circulation, air-sea exchanges and the marine ecosystem. Wavemill is a hybrid interferometric SAR instrument that seeks to deliver high-resolution high-accuracy maps of ocean surface current vectors. It measures the total ocean surface current, including ageostrophic components, in one single-pass. Other secondary products include ocean wind vectors, swell, and some estimate of ocean surface topography. Proposed as an ESA Earth Explorer, the mission's prime objective is to deliver ocean surface current vector maps over two 100 km swaths with a resolution of 1 km or finer.

1 Science Drivers for High-Resolution Total ocean Surface Current Vectors

High-resolution satellite images of sea surface temperature and ocean colour reveal a multitude of highly dynamic small oceanic features that dominate the ocean variability at the mesoscale (10-100km) and sub-mesoscale (1-10km). Features such as eddies, fronts and filaments are ubiquitous and have been associated with energetic upper ocean dynamics and mixing processes. There is growing scientific evidence that these small oceanic scales play a major role for horizontal and vertical mixing, large-scale oceanic transport and ocean biology. For example, 50% of the vertical transport of ocean biogeochemical properties is thought to take place at scales smaller than 100km [1], while ageostrophic secondary circulation associated with eddies produce very large upwelling velocities of the order of 10 m/day [2]. Improved understanding of these processes is needed to develop improved parameterizations to represent these sub-mesoscale processes in models used for long-term climate predictions. Thus, with the response of the ocean biosphere to climate change remaining one of the greatest uncertainties in climate projections, there is a strong demand for synoptic observations of the ocean surface total current fields at these small scales.

Today, none of the available satellite techniques are able to provide direct measurements of these quantities with sufficient accuracy and resolution. Sequences of satellite sea surface temperature or ocean colour images can provide estimates of advection by tracking features from image to image using the Maximum Cross-Correlation method [3] but the method is affected by cloud and relies on the presence of strong trackable features in successive images. Satellite altimeters give all-weather day-and-night estimates of currents globally, based on differences in sea surface height from which the geostrophic component of the currents can be estimated. But the altimeters narrow swaths, large track-to-track separation and reliance on coarse geoid data mean that altimeters cannot resolve features below 70-100 km scales. This well-known limitation of altimetry is the prime motivation for the NASA/CNES Surface Water and Ocean Topography (SWOT) mission, which will rely on cross-track interferometry to deliver two-dimensional maps of sea surface height at 1km resolution [4].

Direct estimates of total surface currents can be obtained with satellite Synthetic Aperture Radar (SAR) by measuring the shift of the Doppler spectrum centroid in a method pioneered by [5]. More recently, significant advances in spaceborne measurements of currents were made possible thanks to along-track interferometric SAR experiments onboard TerraSAR-X [6]. However, even though these techniques do deliver total currents with useful spatial resolution and accuracy, they only provide one component of the current in the direction of the instrument line-of-sight.

2 Wavemill Instrument & Mission Concept

2.1 Instrument Concept

The Wavemill instrument concept was originally conceived by [7] to provide both along- and across-track interferometric baselines, thus enabling simultaneous Along Track (ATI) and Across Track (XTI) interferometry. Since then, the concept has undergone several iterations to result in the present configuration, which is optimised for ATI and offers certain advantages of implementation. In this configuration, the phase centres are aligned in the along-track direction, and there is no physical across-track baseline. XTI is achieved with squinted beams. This 'Javelin' in-line concept and the swath positions are shown in **Figure 1**.

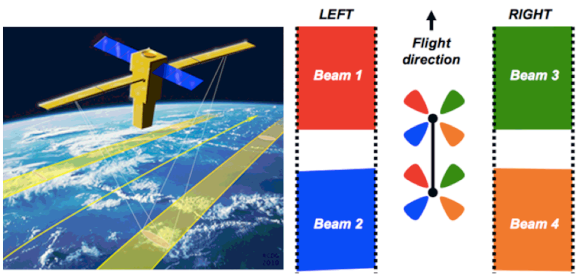

Figure 1: Artist impression of the Wavemill concept for the "Javelin" configuration based on squinted SAR showing the swaths and acquisition sequence

The measurement acquisition consists of four regions illuminated in sequence, two forward left and right and two backward left and right, for each antenna, making a total of eight beams. Simultaneous returns from two antennas are combined to form interferograms for which the two phase centres are separated in the look direction (XTI), for which height differences will result in interferometric phase shifts which provide information on ocean surface topography. Since both antennas see the surface at the same time, no surface motion is registered in the phase. Combining returns from two looks taken at slightly different times forms interferograms, which register surface motion-induced phase shifts (ATI) that provide measurements of ocean surface displacement in the line of sight direction. By repeating this process in the fore and aft directions, it is possible to retrieve two components of surface displacement, from which current direction is derived. The present configuration provides baselines between phase centres, which are pure along track (ATI), pure across track (XTI) and also hybrid baselines (HTI), which contain both co-time (XTI) and co-located (ATI) information.

The present configuration leads to two swaths, one left and one right of the ground track, each 100 km wide, separated by about 100km. Theoretical modelling of microwave backscatter indicate that higher incidence angles would ensure better current retrieval performance, thus trade-offs are necessary between incidence angle, swath width and PRF. The present antenna design is based on planar leaky waveguide slotted arrays, approximately 4.5 meters in length. The orientation of the antenna face towards nadir ensures that all antennas experience the same solar flux, thus minimising thermo-elastic distortion.

2.2 Mission Concept

It is a requirement of the mission that the spacecraft should be compatible with a Vega launcher, which imposes strict constraints on the surface area available for dissipation of the heat generated by the high power amplifier sub-system. The expected orbit will be sun-synchronous with an altitude in the range 400 – 600 km. Complementarity with other missions such as Sentinel-3, the Surface Water and Ocean Topography, MetOP-SG and Jason-CS satellites will be important considerations in mission planning, driven by strong scientific requirements for the Wavemill data to be exploited in synergy with sea surface temperature, ocean colour, sea surface height and ocean wind data from other satellites. The in-line design and the system observation concept are shown in **Figure 2**.

It is intended that Wavemill will operate continuously around the orbit and the dual swaths will ensure full global coverage with a 2 – 10 day revisit. Data reduction techniques will allow the provision of single look complex (SLC) data to ground for a high percentage of each orbit with the option of on-board processed products for short periods.

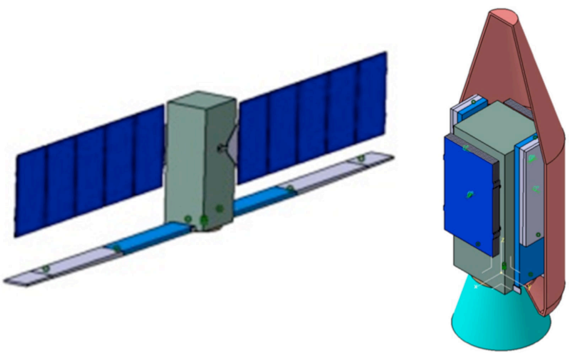

Figure 2: Wavemill 'Javelin' concept and accommodation in Vega

3 Experimental & Theoretical basis

3.1 Wavemill airborne proof-of-concept experiment

A Wavemill airborne proof-of-concept experiment took place on 25 and 26 October 2011 with flights over various sites in the Irish Sea, Liverpool Bay and Anglesey areas off the west coast of the United Kingdom. Data was acquired with the Wavemill airborne demonstrator developed by Astrium Ltd, deployed onboard a Douglas DC-3 aircraft. Acquisitions were carried out in single-pass mode using two pairs of antennas: two looking fore and two looking aft of the aircraft. One antenna operated in transmit/receive mode (monostatic channel), while the second operated in receive mode only (bistatic channel). The campaign resulted in the flights shown in **Figure 3**.

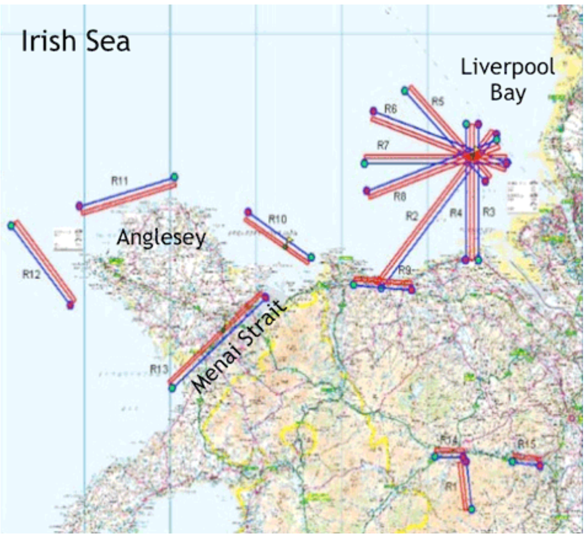

Figure 3: Location of Wavemill airborne proof-of-concept flights over the Irish Sea/Liverpool Bay/Anglesey area off the west coast of the UK.

3.2 Processing and inversion approach

The data from the Wavemill proof-of-concept (POC) flights obtained over water were processed to retrieve surface motion measurements. After careful correction for aircraft attitude variations and phase calibration, the data is pre-processed into equi-spaced range compressed data along a straight line. Subsequent processing consists of three main steps: SAR processing, Interferometric Processing and Sea Surface Currents retrieval (**Figure 4**).

Radial velocities estimated for the fore and aft observations are projected on the sea surface to produce two-dimensional maps of surface motion vectors, such as shown in **Figure 5**. The vectors represents the total displacement velocity of the surface over a 100 meter grid and a 1.5 km wide swath, uncorrected for wind and wave effects.

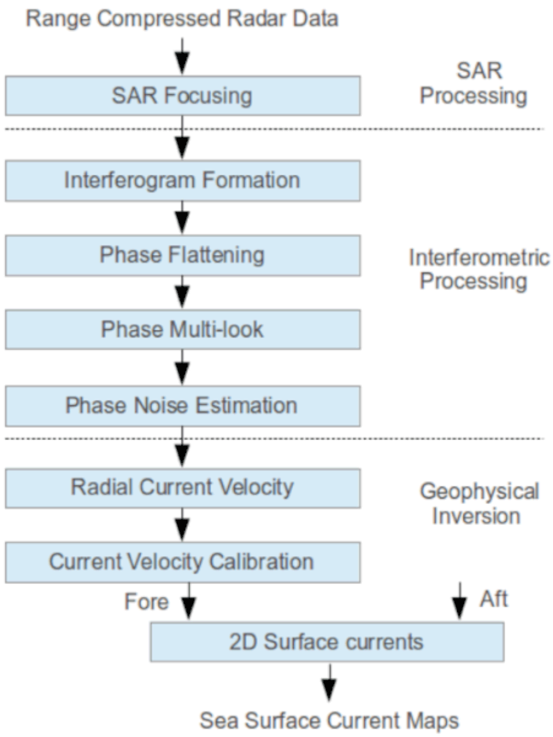

Figure 4: Overview of the Wavemill POC processing.

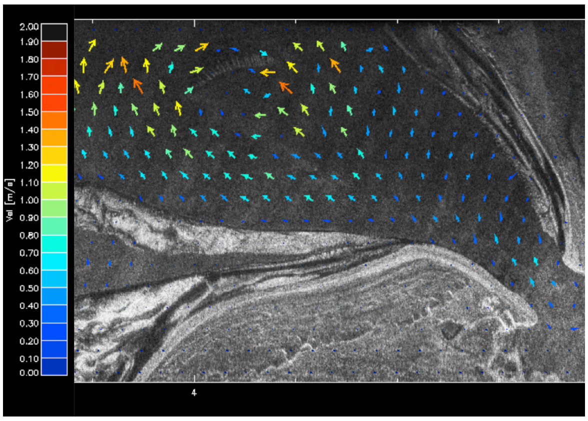

Figure 5: Two-dimensional map of sea surface motion vectors from Wavemill POC flight over Menai Strait.

4 Validation and Geophysical interpretation

The Wavemill POC flights were timed to coincide with maximum ebbing tidal flow, resulting in south-westerly currents of the order of 0.8m/s. Environmental conditions during the flights corresponded to light winds (5-6 m/s) and low sea state (0.5 m significant wave height). Independent validation data was available for sixteen flights, including surface current data from HF radar and ADCP, and wind and wave measurements from a local meteorological station and a wave buoy within the scenes.

Comparisons with the validation data are still on-going but show encouraging results, even though the Wavemill currents clearly show sensitivity to wind and wave direction. Further work is underway to devise optimal mitigation and retrieval strategies to obtain high-accuracy measurements of the total ocean surface current vectors, wind vector and wave conditions.

References

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