SEASTAR: a new mission for high-resolution imaging of ocean surface current and wind vectors from space

Christine Gommenginger, National Oceanography Centre, cg1@noc.ac.uk, United Kingdom
Bertrand Chapron, Ifremer, bertrand.chapron@ifremer.fr, France
Adrien Martin, National Oceanography Centre, admartin@noc.ac.uk, United Kingdom
Jose Marquez, Airbus Defence & Space, jose.marquez-martinez@airbus.com, United Kingdom
Christopher Brownsword, Centre for Earth Observation Instrumentation, CBROWNSWORD@qinetiq.com, United Kingdom
Christopher Buck, European Space Agency, Christopher.Buck@esa.int, The Netherlands

Abstract

SEASTAR is a new satellite mission concept being proposed to the European Space Agency through the Earth Explorer 10 call for mission ideas. The scientific objectives of SEASTAR are to support oceanographic research of mesoscale and submesoscale processes, upper ocean dynamics and air-sea interactions with the delivery of high-precision high-resolution two-dimensional maps of total ocean surface current vectors and wind vectors at a spatial resolution of 1 km. The focus of the mission is on the scientifically and societally important global coastal zone, shelf-seas and marginal ice zones. SEASTAR consists of a single satellite carrying a single Ku-band dual-polarisation instrument payload based on an ATI-based solution with two squinted look-directions. It will provide for the first time observations of the total ocean current vector field including ageostrophic components, with coincident measurements of wind vectors and waves. The satellite uses a sun-synchronous orbit (SSO) with fast-revisit orbital phases (1-2 day repeat) alternating with medium-revisit orbits (5-20 days repeat). While there is no dependence on data from other satellites, there are scientific benefits from synergy with Sentinel-1 and Sentinel-3.

1 Introduction

High-resolution satellite measurements of the ocean reveal that, far from being quiescent and uniform, the ocean is teeming with dynamic structures at different scales. In addition to the oceanic mesoscale (referring to currents and eddies on scales of the order of 10 to 100 km), the ocean is also characterised by intense variability at smaller scales between 100 metres and 10km, known as the submesoscale. Submesoscale features are clearly seen in high-resolution satellite infra-red sea surface temperature (SST) and ocean colour images and take the form of small eddies, fronts and filaments. These interact with the oceanic mesoscale and the atmosphere and play a significant role in upper ocean mixing, transport and air-sea exchanges, with impact on global and climatic scales. Although the submesoscale is frequently observed in satellite images, there is little data available at present, even with non-satellite methods, to provide information about ocean dynamics at these scales.

2 The need for new surface current observations

Obtaining the necessary observations to study submesoscale processes is very challenging with in situ methods. Insight has be gained using data from moorings, ships, floats and gliders as for example done by [1]. However, these observations tend to come from dedicated campaigns that are very expensive and typically localised and short-lived. In situ data also have limited opportunity to obtain the synoptic view of the two-dimensional horizontal field needed to support scientific interpretation.

Satellite images from high-resolution ocean colour and infrared SST sensors provide the best known evidence about the prevalence of mesoscale and submesoscale ocean features. Techniques have been developed to derive high-resolution ocean current vector fields from sequences of satellite images where SST serves as a passive tracer of the underlying circulation. Techniques such as Maximum Cross Correlation have found some success (e.g. [2]) but these do rely on the availability of relatively frequent cloud-free images with suitably traceable features, which limits their general applicability.

Satellite altimetry is the best-known and most-widely used source of global ocean current data. Through the Geostrophic Approximation, sea surface height gradients measured by altimeters along the satellite track are used to calculate the magnitude of the geostrophic current in the across-track direction. Two-dimensional fields of the geostrophic current are subsequently reconstructed by interpolating and combining data from the lattice of narrow altimeter tracks. Although altimeters provide measurements every 5-7 km along-track (1Hz), it has been shown that conventional altimetry (e.g. Jason-2) do not correctly resolve ocean features shorter than about 70 km [3]. This is not the case for SAR mode altimetry (e.g. Cryosat-2 and the Sentinel-3 Surface Topography Mission) which exploits Doppler information to achieve improved precision and finer spatial resolution. Nevertheless, as for all currents derived from sea surface height data, these are limited to representing the geostrophic component of the total current, at a resolution that remain relatively coarse (~ 1/3rd degree) mainly due to the separation between altimeter tracks.

3 The relevance of SAR for ocean currents

Direct estimates of the total ocean surface current can already be obtained from microwave imaging radars by measuring the small Doppler shift induced by the ocean surface motion in reflected microwave signals. This has been demonstrated successfully with Synthetic Aperture Radar (SAR) systems using the Doppler Centroid Anomaly (DCA) method (e.g. [4]) as well as with Along-Track Interferometry (ATI) systems ([5]). These systems measure Doppler signals in one direction broadside of the satellite track from which the component of the current in the line-of-sight direction can be determined.

Extension of this technique to measure two vectorial components of the surface current have so far been explored only with airborne systems. [6] suggested ways of measuring the Doppler signals with one system in several directions, either by using data from two quasi-simultaneous orthogonal flights or by using systems with antennas pointing in two different azimuth directions. A few studies have used orthogonal flights (e.g. [7]) to derive current vectors, and excellent results have been obtained to measure current vectors in a single aircraft pass with the airborne Dual Beam along-track Interferometer (DBI; [8], [9]). The DBI uses two pairs of antennas, one pair squinting forward and the other backward with respect to the aircraft broadside. In [9], the system uses a squint angle of 20° and very high incidence angles above 60° resulting in high sensitivity to surface currents and excellent mapping capability. The high incidence angle range of the DBI does however make it difficult to implement as a satellite mission due to instrument power considerations. SEASTAR uses the same measuring principles as DBI with notable differences in the choice of squint and incidence angle which make SEASTAR compatible with spaceborne implementation.

4 SEASTAR observation principles

SEASTAR is an active microwave system using squinted along-track SAR interferometry. It derives from the Wavemill mission concept conceived by [10], which featured interferometric baselines both along-track and across-track to simultaneously map sea surface height and ocean surface velocity fields over two swaths with a single spaceborne system. SEASTAR is an evolution of the Wavemill concept where instrument and mission parameters have been optimised to prioritise the delivery of ocean surface current and wind vectors with high-resolution and high-accuracy.

The basic measuring principle of SEASTAR relies on estimating the Doppler frequency shift observed by two successive SAR images acquired within a very short time interval from a single satellite overpass. The frequency shift is directly related to the displacement of the ocean surface in the line-of-sight of the instrument during the time interval between the two acquisitions. The ATI principle has been established and demonstrated extensively with airborne systems e.g. [7] and more recently with spaceborne data from TerraSAR-X and TanDEM-X [5]. Conventional ATI will only sense the component of the ocean surface motion in the instrument broadside direction however.

The innovative aspects of SEASTAR are to apply the principle of ATI in two squinted directions fore and aft of the instrument broadside to retrieve the two components of ocean surface current vectors. The measuring principle is illustrated in **Figure 1**.

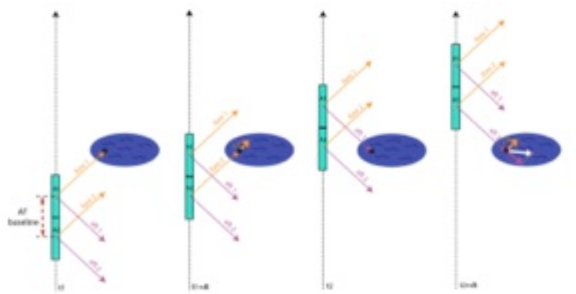

Figure 1: SEASTAR squinted ATI measurement principles.

5 Observation requirements

The observational requirements for SEASTAR ocean surface current vectors that derive from the mission scientific objectives are summarised in **Table 1**.

Observational requirements for SEASTAR products			
Requirement	**Goal**	**Baseline**	**Threshold**
Level 2 Total Ocean Surface Current Vector (L2-TOSCV)			
Horizontal spatial resolution	300m	1km	
Swath width	2 x 200km	1 x 200km or 2 x 120km	1 x 150km or 2 x 90km
Revisit (fast-repeat orbit)		1-2 days	
Revisit (drifting orbit)		30 days	
Coverage	Global coastal + shelf seas + sea ice margins		
Accuracy on current speed	5 cm/s	10 cm/s	20 cm/s
Accuracy on current direction	5°	10°	10°
Level 2 Ocean Surface Wind vector			
Spatial resolution, swath width, revisit and coverage		same as L2-TOSCV	
Accuracy on wind speed	2 m/s	2 m/s	2 m/s
Accuracy on wind direction	10°	20°	20°

Table 1: Observational requirements for SEASTAR ocean surface current vector product

6 Proposed Mission Architecture

Here we provide but a brief overview of some of the key features of the SEASTAR mission concept.

6.1 Space Segment: Payload

6.1.1 Instrument configuration

To simplify the mechanical design of the spacecraft and instrument, an in-line configuration referred to as “Javelin” has been selected for the payload design. In this configuration, the phase centres of the antennas are aligned in the along-track direction, and there is no physical across-track baseline. This ‘Javelin’ in-line concept allows the squinted observations and the widest swath to be acquired for the data rate and geometry selected.

6.1.2 Carrier Frequency

The baseline frequency is Ku-band. This is best in terms of performance (greater electrical length, baseline and directivity due to the short wavelength) and preferred by oceanographers since Ku-band is already available and widely used. It also means the mission can take advantage of the development in Wavemill/OSCM projects and existing bread-boarding activities.

6.1.3 Polarisation

Both V and H polarisations are required to support simultaneous retrieval of current and wind vectors and to provided added information on contributions by wave breaking at small scales. Dual-polarisation is the baseline as this also provides the flexibility to include cross-polar V (TX) / H (RX) through suitable switch selection, which may be desirable for investigating the depolarised scattering effects of the ocean surface.

6.1.4 Instrument & Payload architecture

The instrument contains the following elements:

- Front-end
- Couplers
- Limiters
  - Low Noise Amplifiers (LNAs)
  - Circulators
  - Radiating subarray
  - Beamforming network
  - Support structure
  - Payload Electronics:
    - High Power Amplifier
    - Transmit Mission Dependant Filter Equipment (Tx MDFE)
    - Receive Mission Dependant Filter Equipment (Rx MDFE)
    - Integrated Central Electronics, including:
  - Transmit Modules (TxM)
  - Receive Modules (RxM)
  - Instrument Control Modules (ICM)
  - Timing Control Modules (TCM)
  - Power Conditioning Modules (PCM)
  - Metrology system

The payload architecture is presented in **Figure 2**.

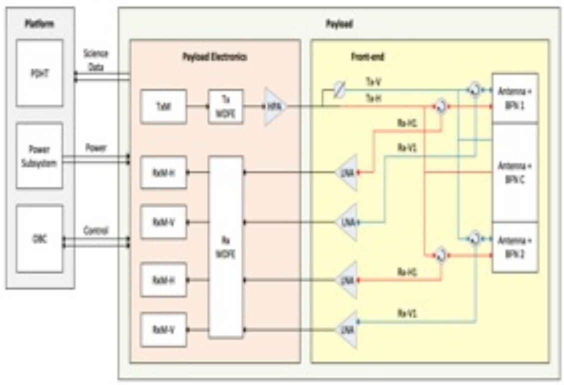

Figure 2: ATI payload architecture

6.1.5 Antenna Type

To ensure a low cost implementation the antenna should be passive (that means a centralised power architecture with single power source feeding the antenna rather than a distributed power architecture with TRMs distributed across the antenna). The options considered for this are:

- Leaky waveguide: offers true H/V polarisation at the surface but has poorer antenna performance compared to the resonant slot (gain is reduced and the azimuth sidelobes are less well defined).
- Resonant slot waveguide: similar to waveguide technology used on broadside looking radar satellites but with a different slot spacing to allow for electrical steering. It offers an improved antenna performance compared to the leaky waveguide technology but results in +/- 45° tilted polarisations at the surface.

To achieve the polarisation requirements, a leaky waveguide is taken as the baseline.

6.1.6 Antenna Configuration

The antenna for the dual-sided configuration achieves the swaths by having a triangular 'rooftop' style antenna structure that physically points the beam from the face of the antenna surface. For the single-sided configuration, the single planar array points the beam to the surface electronically. The baseline configuration is for dual-sided operation.

6.2 Space Segment: Platform

The design solution that best fits the SEASTAR mission in terms of cost, heritage and flexibility is to combine the core avionics and main componentry of the Astrobus-L line with a customised structure that can be designed to fit into the VEGA-class fairing, while providing the correct payload volume.

6.3 Ground Segment: Data downlink

The squinted ATI technique generates high volumes of data that call for a high-performance downlinking solution to transmit the data to the ground without compromising the scientific objectives or using multiple and changing ground stations. For the dual-sided 2 x 100km swath mission configuration, the RAW data rate is 487 Mbps and 292 Mbps with 6-bit BAW compression.

A conventional X-band link will typically allow data download rates of around 0.5Gbits/s, thus the use of conventional data downlink technology is not appropriate. It is expected that a high rate telemetry system in K-band will become operational in the foreseeable future. As these are still under development, the achievable data rates of the system is not yet known, but it is assumed that the final rate will be around 4-10 Gbits/s. With this system, the data volumes generated by SEASTAR come within feasible limits of downlinking.

6.4 Ground Segment: Ground station

The ground station selection for SEASTAR is based upon a single ground station system. This is to ensure the mission remains appealing in terms of future operational costs for ESA. The baseline solution is to use the ESA core ground station at Kiruna, with Svalbard as the second choice for the increased access times it provides.

References

[1] Shcherbina, A. Y. et al. (2015), The LatMix summer campaign: submesoscale stirring in the upper ocean, Bulletin Am. Met. Society, 96(8), 1257-1279.

[2] Emery, W. J. et al., (1986), An objective method for computing advective surface velocities from sequential infrared satellite images, J. Geophys. Res., 91(C11), 12865-12878.

[3] Dibarboure, G. et al. (2014), Investigating short-wavelength correlated errors on low-resolution mode altimetry, J. Atm. Ocean. Tech., 31(6), 1337-1362.

[4] Shuchman, R. & G. Meadows (1980), Airborne synthetic aperture radar observation of surf zone conditions, Geophys. Res. Lett., 7(11), 857-860.

[5] Romeiser, R. et al. (2014), Quality assessment of surface current fields from TerraSAR-X and TanDEM-X along-track interferometry and Doppler centroid analysis, IEEE Trans. Geosc. Rem. Sensing, 52(5), 2759-2772.

[6] Lyzenga, D. et al. (1982), Synthetic aperture radar measurements of ocean surface currents, Geophys. Res. Lett., 9(7), 747-750.

[7] Graber, H. C. et a;. (1996), Ocean surface features and currents measured with synthetic aperture radar interferometry and HF radar, J. Geophys. Res., 101(C11), 25813-25832.

[8] Frasier, S. J. & A. J. Camps (2001), Dual-beam interferometry for ocean surface current vector mapping, IEEE Trans. Geosc. Rem. Sensing, 39(2), 401-414.

[9] Toporkov, J. V. et al. (2005), Sea surface velocity vector retrieval using dual-beam interferometry: First demonstration, IEEE transactions on geoscience and remote sensing, 43(11), 2494-2502.

[10] Buck, C. (2005), An extension to the wide swath ocean altimeter concept, paper presented at Geoscience and Remote Sensing Symposium, 2005. IGARSS'05. Proceedings. 2005 IEEE International, IEEE.