Ocean Surface Current Airborne Radar (OSCAR): a new instrument to measure ocean surface dynamics at the sub-mesoscale

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Abstract – The ocean interacts with the atmosphere, land and ice on multiple spatial scales including fine sub-mesoscales that are often observed in high resolution optical images. Little is known about their dynamics however. SeaSTAR is an innovative satellite mission concept that proposes to address this gap by mapping ocean current and wind vectors at 1 km resolution. In this paper, we present the OSCAR instrument - an airborne demonstrator of the SeaSTAR concept - and the first results from a scientific campaign over the Iroise Sea in May 2022. The capabilities of OSCAR are demonstrated against ground truth data with very promising first results. These results open the door to using OSCAR as a scientific tool to provide unique 2D synoptic views of ocean and atmosphere dynamics at km-scales.

Keywords: Doppler Oceanography, Total Surface Current, Wind

1. INTRODUCTION

Monitoring ocean surface dynamics at high resolution in space and time is of paramount importance for understanding and modelling ocean-atmosphere interactions and other climate mechanisms, especially in coastal and polar areas. Measuring small-scale ocean currents and winds is critical to drive scientific understanding of the exchanges of gas, heat, and momentum between the atmosphere and the ocean, and to support the validation and development of improved forecasting models and climate projections.

SeaSTAR (Gommenginger et al., 2019) has been selected for Phase 0 study for the Earth Explorer 11 program of the European Space Agency (ESA). SeaSTAR aims to observe ocean submesoscale dynamics and small-scale atmosphere-ocean processes in coastal, shelf and polar seas by providing simultaneous measurements of current and wind vectors at 1 km resolution with accuracy of 0.1 m/s and 2 m/s respectively. If finally selected as EE11 mission, SeaSTAR would fly in the 2031 timeframe. OSCAR (Ocean Surface Current Airborne Radar) is the ESA airborne demonstrator of the SeaSTAR mission that was flown over the Iroise Sea (West of French Brittany) in May 2022. The OSCAR operations and products are representative of the spaceborne concept, with geophysical parameters and accuracies that directly relate those of the SeaSTAR satellite mission. In itself, OSCAR provides a new observing capability that will improve our understanding of ocean Doppler sensing thanks to its unique three-look Doppler capability, and can provide unique 2D synoptic view of ocean and atmosphere dynamics at km-scales to support and complement scientific investigations based on in situ, satellite and model data.

2. THE OSCAR INSTRUMENT

OSCAR is a Ku-band (13.5 GHz) Synthetic Aperture Radar (SAR) system with Along-Track Interferometric (ATI) and scatterometric capabilities in three azimuth directions. It has up to 150MHz bandwidth with 30W average power. In the baseline configuration, the instrument achieves a swath over 2 km wide for wind speeds of 3 m/s and greater. The Noise Equivalent Sigma Zero (NESZ) is between -30dB and -45dB and the radiometric resolution is better than 0.1dB.

The antenna system is stabilized using a 3-axes gimbal with a given accuracy of (0.3° see Speziali et al., 2018) and the antenna motion and attitude are recorded by an AP60 navigation unit and an Inertial Motion Unit (IMU), which are both rigidly mounted onto the antenna frame (Figure 1) with a residual error of 0.005° in yaw and 0.0025° in pitch and roll. Fully polarimetric observations are possible (up to 6 channels available). The instrument has been designed to be flexible in terms of operational parameters and configurations, including an adjustable length of the ATI baseline, to be fully representative of spaceborne scenarios (Figure 2).

OSCAR is tailored to measure 2D ocean surface current and wind vectors. The system features an ATI baseline for two fields of view squinted 45° fore and aft from the broadside direction. Interferometric measurements are obtained in two squinted line-of-sights angularly separated by 90 degrees. This ensures two independent measurements of the ocean surface motion in two lines of sight from which the ocean surface current vector can be derived.

Figure 1. OSCAR system inside the aircraft, showing the mounted gimbal, radio-frequency unit and analog-to-digital converter on the bottom right.

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Figure 2. OSCAR system mounted on the belly of the aircraft. The mounted antenna frame shows one single broadside antenna in the middle and two squinted antennas pairs on either side looking 45° fore and aft of the broadside direction.

After correcting the interferometric measurements for Doppler effects linked to navigation and geometry, the ocean surface motion sensed by the microwave radar in two lines-of-sight need to be corrected for a bias caused by ocean surface waves. Indeed, the ocean motion has two components: the total ocean surface current – consisting of all currents contributing to actual horizontal transport of water – and an unwanted measurement bias associated with wind-waves, known as wind-wave induced artifact surface velocity (WASV; see Martin et al., 2016). The WASV is understood to be mainly caused by the phase velocity of the surface scatterers responsible for the microwave backscatter (e.g. Bragg waves) modulated by the orbital motion of longer ocean waves. To first order, the WASV is a function of wind direction and wind speed.

3. AIRBORNE CAMPAIGN PRELIMINARY RESULTS

The airborne campaign in French Brittany consisted of four flights on the 17, 22, 25 and 27 May 2022. The first three flights focused over the Iroise Sea, west of Brest (France), where the site is well instrumented. Ground truth measurements of total ocean surface current vector (TSCV) were obtained from a WERA HF radar, supported by data from an X-band marine radar, stereo-video and a down-looking ADCP. For each flight, the aircraft flight path described a star pattern to sample different azimuth directions over an area of homogeneous currents, with additional acquisitions close to Ouessant Island characterized by strong current gradients. Preliminary results focus on this specific area.

Figure 3 presents first results from OSCAR for the ATI antenna pairs squinted fore (left panel) and aft (right panel). The aircraft is heading North with the antennas looking on the left side. Colors from green to brown represents the OSCAR radial velocity for each fore and aft direction (without WASV correction). The middle panel in Figure 3 shows the total velocity (color) and direction (black arrows) measured by the X-band marine radar. The figure shows a general pattern of current flowing to the North-West. The black arrows from the X-band marine radar have been superimposed over the OSCAR data. The fore antenna pair (Fig. 3 left) is aligned with the current and senses strong patterns and gradients (brown to green), which agree well with gradients observed by the X-band marine radar. The aft antenna pair (Fig. 3 right) look perpendicular to the main current, and do not sense any strong gradients (uniform field in brown). These first results are very promising for this long-awaited instrument.

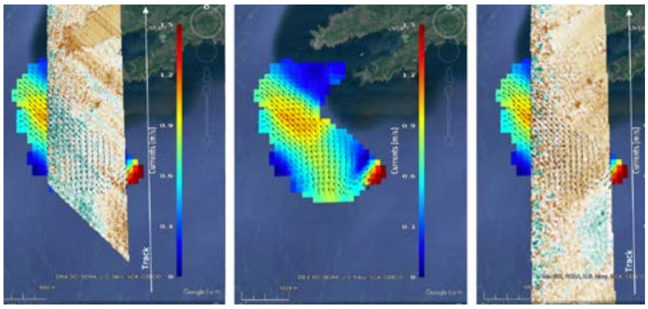

Figure 3. Preliminary OSCAR results for 17 May 2022 over la Jument lighthouse on Ouessant Island. (left) OSCAR 45° squint fore; (right) OSCAR 45° squint aft; (middle) X-band ground-based marine radar.

4. OUTLOOK

OSCAR is a new airborne instrument that offers new high-resolution imaging of current and wind vectors at ~100 meters resolution with high-accuracy (0.10 m/s for current) over a swath 2 to 3 km wide. With a ground speed of ~80 m/s and an autonomy of 5 hours, OSCAR is well suited to supporting process and modelling studies. Bringing unique 2D synoptic views of ocean and atmosphere dynamic properties at km-scale, OSCAR can complement in-situ observations and models to help better understand processes and horizontal and vertical exchanges in the upper ocean and the atmospheric boundary layer.

OSCAR will also improve our understanding of ocean Doppler remote sensing thanks to its distinctive ability to acquire high-resolution backscatter and Doppler data in multiple azimuth directions for the same environmental conditions over well instrumented sites. The knowledge derived from OSCAR will benefit existing Sentinel-1 Doppler and Radial velocity data (Martin et al., 2022), the forthcoming ESA Earth Explorer 10 Harmony mission and the ESA Earth Explorer 11 SeaSTAR mission candidate.

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REFERENCES

C. Gommenginger, and the SeaSTAR international Team, "SEASTAR: A Mission to Study Ocean Submesoscale Dynamics and Small-Scale Atmosphere-Ocean Processes in Coastal, Shelf and Polar Seas", Frontiers in Marine Science , 2019 https://doi.org/10.3389/fmars.2019.00457.

A. C. H. Martin, C. Gommenginger, J. Marquez, S. Doody, V. Navarro, and C. Buck, "Wind-Wave induced velocity in ATI SAR Ocean Surface Currents: First experimental evidence from an airborne campaign", Journal of Geophysical Research: Oceans , 2016, http://dx.doi.org/10.1002/2015JC011459.

A. C. H. Martin, C. P. Gommenginger, B. Jacob, and J. Staneva, "First multi-year assessment of Sentinel-1 radial velocity products using HF radar currents in a coastal environment", Remote Sensing of Environment , 2022, https://doi.org/10.1016/j.rse.2021.112758.

F. Speziali, V. Navarro, and S. Placidi, "Ocean Surface Current Airborne Radar Demonstrator (OSCAR) Instrument Performance Report [DD-3]" , 2018. ESA/ESTEC Contract No. 4000116410/16/NL/BJ.