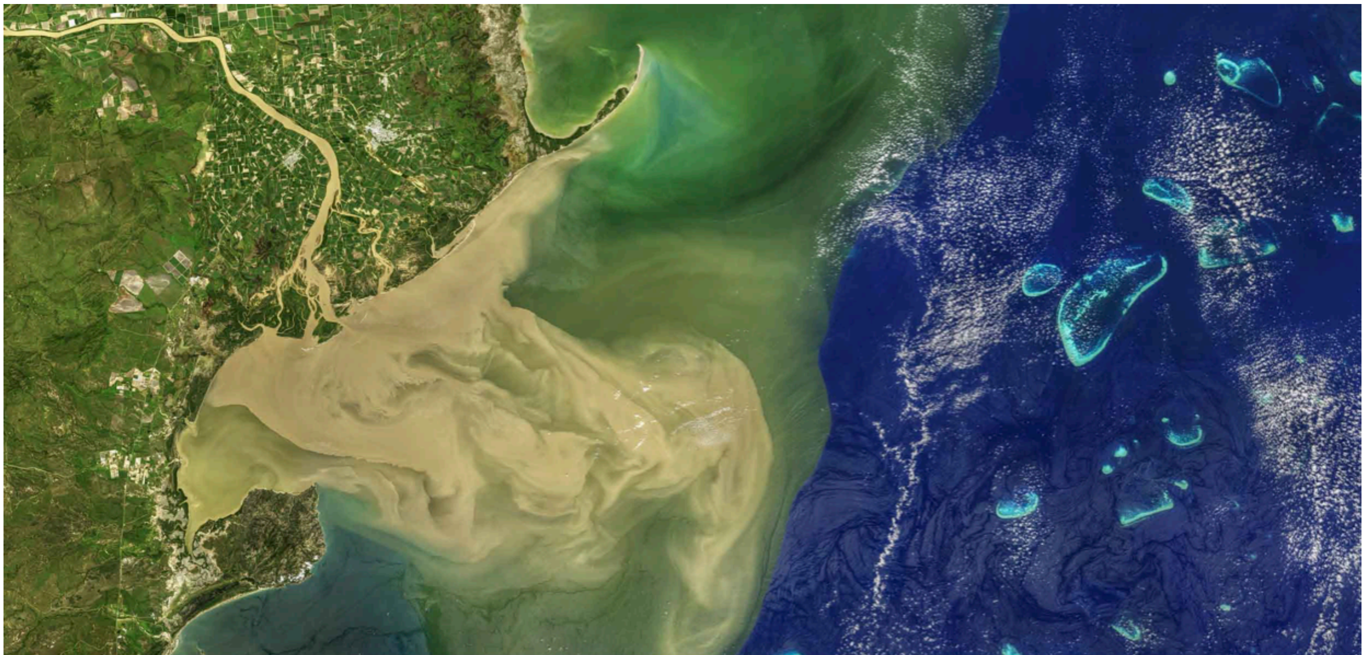
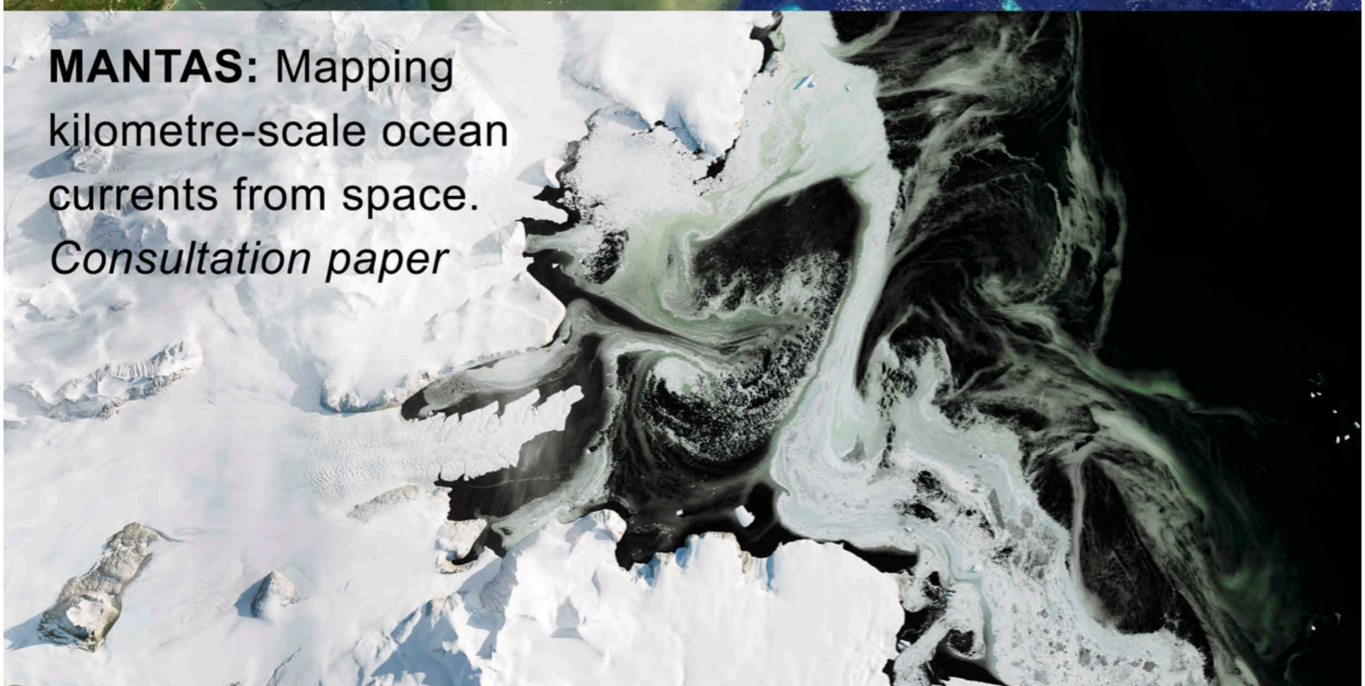
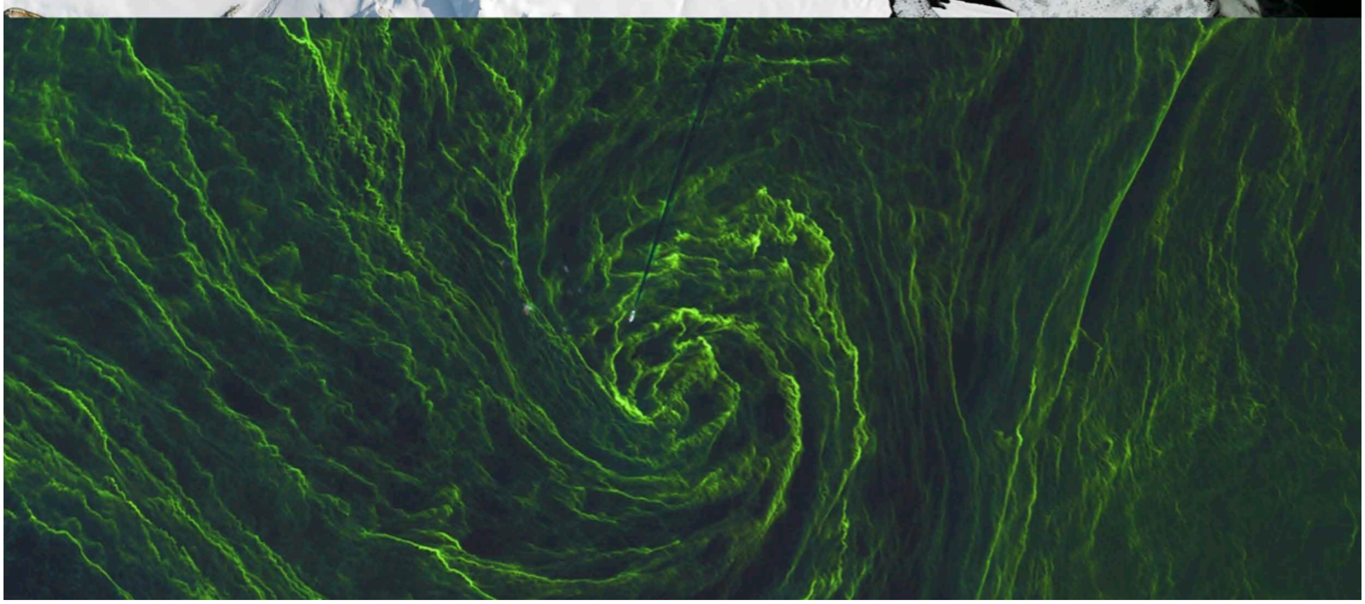


MANTAS: Mapping kilometre-scale ocean currents from space. *Consultation paper*





Cover images:

Top: Floodwaters from the Burdekin river form fine-scale plumes in the Great Barrier Reef after the Feb 2019 Queensland floods. Image: NASA

Middle: Sea ice in the Ross Sea, Antarctic. Image: NASA

Bottom: A toxic cyanobacteria bloom is concentrated into whorls by submesoscale currents in the Baltic Sea. Image: Copernicus Sentinel / ESA

The AUSWOT project is a partnership of:

AUSWOT
Australian Surface Water and Ocean Topography working group

Australian Government
Bureau of Meteorology

UNSW SYDNEY

Australian Institute of Marine Science

Royal Australian Navy

IMOS
Integrated Marine Observing System

MANTAS: An Australia-lead partnership to map kilometre-scale ocean dynamics from space

Executive Summary

In the coming decade, a constellation of new satellite missions will measure the upper ocean at a resolution that has not been possible before, providing critical information that is needed to track regional sea level change, monitor coastal processes, and observe "submesoscale" fronts and eddies with horizontal scales of 1-10 km. The first of these satellites, the Surface Water Ocean Topography (SWOT) mission[a], is scheduled for launch in September 2021.

The MANTAS (MApping oceaN Topography At Submesoscales) project is an Australian-lead partnership of researchers and stakeholders with the goal of utilising future satellite observations to **map and forecast kilometre-scale ocean dynamics in the Australasian region**. To achieve this goal, the MANTAS project will pursue the following ***Project Aims*****:**

- **A1:** develop national capability in the field of wide-swath satellite altimetry to capitalise on the next generation of Earth-observing satellites;
- **A2:** support the scientific goals of the SWOT mission through synergistic activities in Australia's diverse marine environments;
- **A3:** partner with Australian communities, government, and industry to deliver downstream data products that meet user needs, accelerate research and foster innovation;
- **A4:** engage in international and regional partnerships to promote and leverage capacity to extend the products and applications to the Indian, Pacific and Southern Ocean.

Wide-swath altimetry presents unparalleled opportunities for understanding, monitoring, and forecasting ocean currents in Australia's marine estate. However, the challenges posed by this new technology are beyond the scope of a single organization. The MANTAS project is a nationally coordinated effort to address these challenges. In doing so, this project will contribute to **strategic initiatives at the national level** through these ***National Benefits*****:**

- **B1:** develop national capability in critical space data gathering, analysis and services (Australian Civil Space Strategy 2019-2028);
- **B2:** secure Australia's role in the international Earth Observation community (Australian Earth Observation Community Plan 2026);
- **B3:** increase operational safety, reduce costs and improve planning decisions of marine industries through enhanced prediction of ocean currents, sea state, ocean health, and management of hazardous chemical spills (National Marine Science Plan 2025).

We seek partners in academia, industry, government and defence to participate in the MANTAS project. **Please send expressions of interest to s.keating@unsw.edu.au by 26 July.**

---

[a] https://swot.jpl.nasa.gov

Kilometre-scale ocean dynamics: a Grand Challenge

Ocean dynamics with horizontal scales of 1-10 km are found ubiquitously throughout the upper ocean. This regime of oceanic turbulence -- called the *submesoscale* -- plays a central role in ocean circulation, climate, and marine ecology[13]. Kilometre-scale ocean fronts act as "lungs" through which heat, carbon, and oxygen are exchanged between the atmosphere and the deep ocean[8,15,20]. Submesoscale eddies act as ecological niches for commercially important fish larvae[12,19] and strongly influence the entire trophic chain, from primary production by phytoplankton[10] to foraging behaviour by top predators[7].

Submesoscale currents critically impact Australia's $70B blue economy, including coastal industries, fisheries, offshore oil and gas, and marine safety. Kilometre-scale ocean turbulence disperse ocean-borne material, such as radioactive plumes[18] and debris from the MH370 disaster[4], over large distances. Surface convergence and down-welling near submesoscale fronts concentrate harmful algal blooms[1] and marine pollutants like plastics[11] and oil from the 2010 *Deepwater Horizon* spill[17,6].

In spite of their importance, our understanding of ocean submesoscales is limited by the difficulty of observing the ocean at these scales. Measurements of submesoscale features using ship-board instruments[19,3], GPS-tracked drifters[23], and coastal radar[12,21] are costly and limited in both space and time. Extant satellite observations provide global coverage but are likewise limited by sensor resolution, orbital characteristics, and clouds.

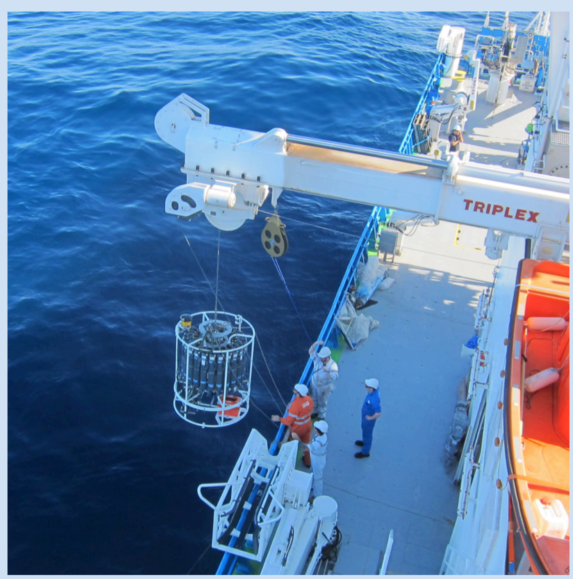
Submesoscales: a regime of ocean variability with typical horizontal scales of 100m-10km, depths of 10-1000m, and timescales of hours to days.

Wide-swath altimetry: pioneering remote sensing technology that will retrieve 2D maps of sea level with 10 times the spatial resolution of contemporary satellites.

Data assimilation: a mathematical method to estimate the state of a real-world system (e.g. the ocean) by combining observations with a numerical model. Data Assimilation is the basis for modern weather predication and ocean forecasting.

Case study: Frontal eddies in the East Australian Current

Frontal eddies are submesoscale ocean vortices that frequently form in western boundary currents like the East Australian Current (EAC). In June 2015, a team of UNSW researchers aboard the R/V *Investigator* made the first detailed bio-physical measurements of an EAC frontal eddy. They found that the eddy had very high concentrations of nutrients, chlorophyll, and coastal fish larvae. These findings indicate that frontal eddies act as "incubators" for commercially important fish species, supporting local primary productivity[19]. The ability to monitor these eddies will be of great value to fisheries managers along the southeastern coast of New South Wales. (Image: Shane Keating)



Merging observations with ocean models ("data assimilation") -- a key component of ocean forecasting efforts -- presents additional practical challenges: submesoscale dynamics are inherently non-linear, rapidly evolving, and difficult to predict[9]. As a result, monitoring submesoscale ocean currents is "a Grand Challenge for ocean remote sensing", in the words of NASA oceanographer Dr. Lee-Leung Fu, Lead Scientist for the SWOT Mission.

Table 1: SWOT Mission characteristics

Mission budget: US $1B (AU $1.5B)
Target launch date: Sept 2021. **Launch vehicle:** SpaceX Falcon 9 rocket
Instruments: Ka-band interferometer, Nadir altimeter, Microwave radiometer
Sampling pattern: 120 km swath with 2 km grid (effective resolution ~7 km)
Fast sampling orbit (0-3 months): 1-day orbit at 857 km and 78° inclination
Science orbit (3-36 months+): 21-day orbit at 891 km and 78° inclination

Intellectual infrastructure for Australia's blue economy

The imperative for improved understanding of submesoscale variability on regional and seasonal scales is widely acknowledged in the international oceanographic community[8]. To meet this need, the US, French, Canadian and United Kingdom governments have committed US $1B (AU $1.5B) towards the Surface Water Ocean Topography mission. The SWOT mission will deploy pioneering wide-swath radar interferometry to measure sea-surface height over a 120 km swath of ocean with a resolution ten times that of current technologies[22] (Table 1). SWOT promises to revolutionize our understanding of ocean dynamics and will be a powerhouse for monitoring Earth's oceans and their role in a changing climate.

The Australian goverment is investing $2.3M (with a planned $4.0M in co-investment) to provide essential support for SWOT through enhancements to Australia's observing infrastructure. These include the Integrated Marine Observing System (IMOS) altimeter calibration and validation (cal/val) subfacility in the Bass Strait -- the sole southern hemisphere calibration stream for the SWOT mission -- as well as the IMOS SOFS mooring in the Southern Ocean and the Yongala NRS site in the Great Barrier Reef (Table 2).

The SWOT mission presents unparalleled opportunities for understanding and monitoring Australia's marine estate. Given the broad national interest in this platform, the Australian marine science and remote sensing community established the Australian Surface Water Ocean Topography (AUSWOT) working group[b] to coordinate investment nationally, avoid duplication of effort, and accelerate the path to societal benefit. AUSWOT is a regional partnership of researchers and stakeholders in the University sector, industry, government, and defence with the goal of **building the "intellectual infrastructure" required to ensure that the economic benefits of the SWOT mission flow through to Australian marine industries.**

[b] https://auswot.org/

This intellectual infrastructure will include (i) new domestic capacity in wide-swath altimetric observations, (ii) data assimilation and forecasting of ocean submesoscales, (iii) downstream data products for end-users in fisheries management, marine safety, defence, and oil and gas, and (iv) training skilled professionals for the rapidly growing Earth Observation sector, which is projected to generate 15,000 jobs in Australia by 2025[4].

SWOT is a path-finding mission -- the first of its kind, but by no means the last. Several future missions are planned for launch in the next decade, including the European Space Agency's SKIM satellite. The intellectual infrastructure developed through the MANTAS project will have a legacy well beyond the planned lifetime of the SWOT mission (see Implementation plan).

Implementation plan 2019-2023+

Phase 1: Engaging partners (2019-2020)

- Consult with Australian marine science and surface water research community
- Build partnerships with government, industry, and defence
- Secure external funding support from state and federal agencies and industry partners

Phase 2: Building Capacity (2020-2021)

- Develop a suite of regional submesoscale-resolving numerical models for target sites
- Assess observation impact through observation system simulation experiments (OSSEs)
- Develop data assimilation and forecasting capacity

Phase 3: Expanding Knowledge (2021-2022)

- Calibration and validation of SWOT wide-swath altimetry data
- Synergistic field campaigns during SWOT fast-sampling phase
- Fine-scale process studies of upper ocean dynamics, wave-current interactions, reef dynamics, internal gravity waves, and sea-ice

Phase 4: Enabling Innovation (2022-2023+)

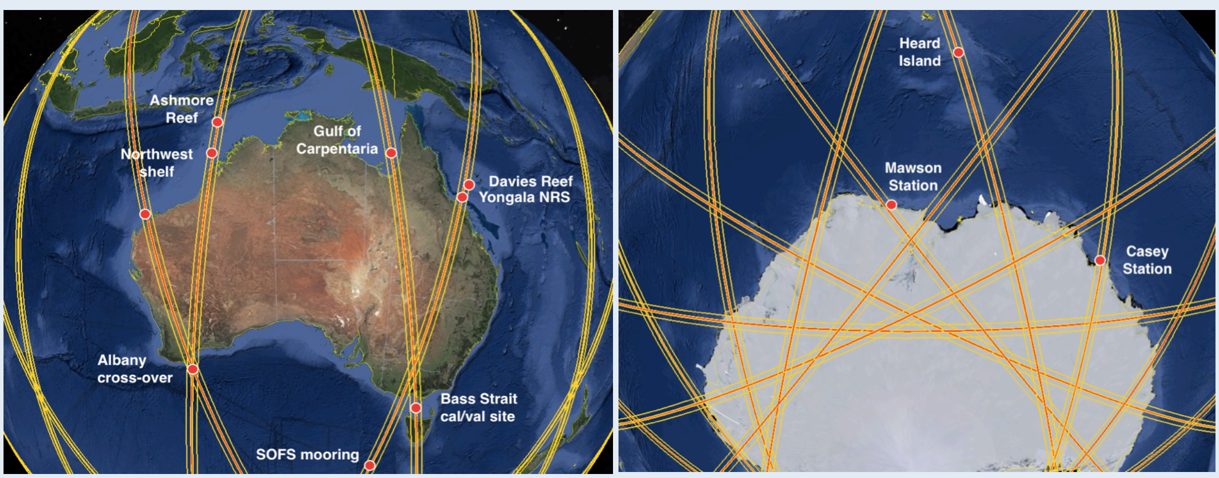
- Data assimilation and forecasting of ocean submesoscales
- Downstream data products for end-users in fisheries management, marine safety, defence, and oil and gas
- Training skilled professionals for the Earth Observation sector in Australia

A once-in-a-generation opportunity for Australian marine science

The SWOT mission is a once-in-a-generation opportunity to advance our understanding of upper ocean dynamics in Australia's marine environment. For the first 90 days of its mission, SWOT will operate in a "fast sampling mode", revisiting specific locations around the globe daily. The SWOT Science Team has invited the international ocean science community to participate in a global series of field campaigns in regions covered by SWOT's unique fast-sampling phase[14]. Preliminary mission data will be made available to these groups to carry out ground-breaking studies of fine-scale ocean processes that have never been possible before.

Australia's marine science community is ideally positioned to capitalize on this opportunity. With the world's third largest exclusive economic zone (EEZ), Australia has a lion's share of potential field sites of high oceanographic and economic significance in the footprint of the fast-sampling orbit. Several of these are already instrumented and/or readily accessible by small vessel. Following consultations with the oceanographic community, the AUSWOT working group has identified a number of high-priority target sites for synergistic research activities during SWOT's fast-sampling phase (Table 2). **We are currently engaging partners in academia, government, industry, and defence to develop investigation plans for these sites.**

Table 2: Target field sites during SWOT fast-sampling sites



Currently supported through IMOS	***Research activities***
Bass Strait altimetry cal/val site	Calibration and validation
SOFS Mooring	Calibration and validation
Yongala NRS	Calibration and validation
Seeking cash support from partners	
Albany cross-over	Wave-current interactions
Northwest shelf	Internal gravity waves
Davies Reef (GBR)	Reef/current dynamics
Seeking in-kind support from partners	
Ashmore Reef	Indonesian throughflow
Gulf of Carpentaria	Tidal dynamics, larval transport
Heard Island	Phytoplankton bloom dynamics
Mawson Station, Casey Station	Sea-ice/free-board monitoring

References

1. Advancing Space: Australian Civil Space Strategy 2019-2028. https://www.industry.gov.au/data-and-publications/australian-civil-space-strategy-2019-2028 (2019).
2. Anderson, D.M., A.D. Cembella, and G.M. Hallegraeff. Progress in understanding harmful algal blooms (HABs): Paradigm shifts and new technologies for research, monitoring and management. *Ann. Rev. Mar. Sci.* 4: 143-176 (2012).
3. Archer, M., A. Schaeffer, S.R. Keating, M. Roughan, R. Holmes and L. Siegelman. Observations of submesoscale instability and frontal subduction within the mesoscale eddy field of the Tasman Sea. *Submitted to J. Phys. Oceanogr.* (2019).
4. Australian Earth Observation Community Plan 2026: Delivering essential information and services for Australia's future. https://www.eoa.org.au/aeocp-the-plan (2016).
5. Carrado, R., G. Lacorata, L. Palatella, R. Santoleri, E. Zambianchi. General characteristics of relative dispersion in the ocean. *Scientific Reports* 7: 46291 (2017).
6. d'Asaro, E.A. and others. Ocean convergence and dispersion of flotsam. *Proc. Natl. Acad. Sci. USA* 115(6): 1162-1167 (2018).
7. Della Penna, A., S. De Monte, E. Kestenare, C. Guinet and F. d'Ovidio. Quasi-planktonic behavior of foraging top marine predators. *Sci. Rep.* **5**, 18063 (2015).
8. Ferrari, R. A frontal challenge for climate models. Science 332: 316 (2011).
9. Keating , S.R., A.J. Majda and K.S. Smith . New methods for estimating ocean eddy heat transport using satellite altimetry. Mon. Weather Rev. 140(5): 1703 (2012).
10. Lévy, M. R. Ferrari, P. Franks, A. Martin and P. Rivière. Bringing physics to life at the submesoscale. *Geophys. Res. Lett.* 39: L14602 (2012).
11. Maes, C. and B. Blanke. Tracking the origins of plastic debris across the Coral Sea: A case study from the Ouvéa Island, New Caledonia. *Mar. Pollut. Bull.* 97(1-2): 160-168 (2015).
12. Mantovanelli, A., S.R. Keating , L.R. Wyatt, M. Roughan and A. Schaeffer. Eulerian and Lagrangian characterization of two counter-rotating submesoscale eddies in a western boundary current. *J. Geophys. Res.* 122 (6): 4902-4921 (2017).
13. McWilliams, J.C. Submesoscale currents in the ocean. *Proc. Roy. Soc. A* 472: 20160117 (2016)
14. Morrow, R., L.-L. Fu, F. D'Ovidio, and J. T. Farrar. Scientists invited to collaborate in satellite mission's debut, *Eos, 100,* DOI 10.1029/2019EO110423 (2019),
15. National Marine Science Plan 2015-2025: Driving the development of Australia's blue economy. https://www.marinescience.net.au/nationalmarinescienceplan (2015).
16. Omand, M., E. D'Asaro, C. Lee, M. Perry, N. Briggs, I. Cetinić and A. Mahadevan. Eddy-driven subduction exports particulate organic carbon from the spring bloom. *Science* 346: p222 (2015).
17. Poje, A. et al. Submesoscale dispersion in the vicinity of the Deepwater Horizon spill. *Proc. Nat. Acad. Sci. USA* 111(35): 12693 (2014).
18. Rossi, V., E. van Sebille, A. Sen Gupta, V. Garçon and M.H. England. Multi-decadal projections of surface and interior pathways of the Fukushima Cesium-137 radioactive plume. *Deep-Sea Res.* 80: 37-46 (2013).
19. Roughan, M., S.R. Keating , A. Schaeffer, P. Cetina Heredia, D. Griffin, R. Robertson, C. Rocha, I.M. Suthers. A tale of two eddies: The bio-physical characteristics of two contrasting cyclonic eddies in the East Australian Current. *J. Geophys. Res.* 122 (3): 2494–2518 (2017).
20. Sasaki, H. P. Klein , B. Qiu and Y. Sasai. Impact of oceanic-scale interactions on the seasonal modulation of ocean dynamics by the atmosphere. *Nature Communications* 5: p5636 (2014).
21. Schaeffer, A., A. Gramoulle, M. Roughan and A. Mantovanelli. Characterizing frontal eddies along the East Australian Current from HF radar observations. *J. Geophys. Res. Oceans* 122(5): 3964-3980.
22. Surface Water and Ocean Topography Mission (SWOT) Project: Science Requirements Document. https://swot.jpl.nasa.gov/documents.htm (2018).
23. van Sebille, E., S. Waterman, A. Barthel, R. Lumpkin, S.R. Keating, C. Fogwill and C. Turney. Pairwise surface drifter separation in the western Pacific sector of the Southern Ocean. *J. Geophys. Res. Oceans* 120(10): 6768-6781 (2015).