New windows into air-sea interactions at atmospheric and oceanic sub/mesoscales using SWOT

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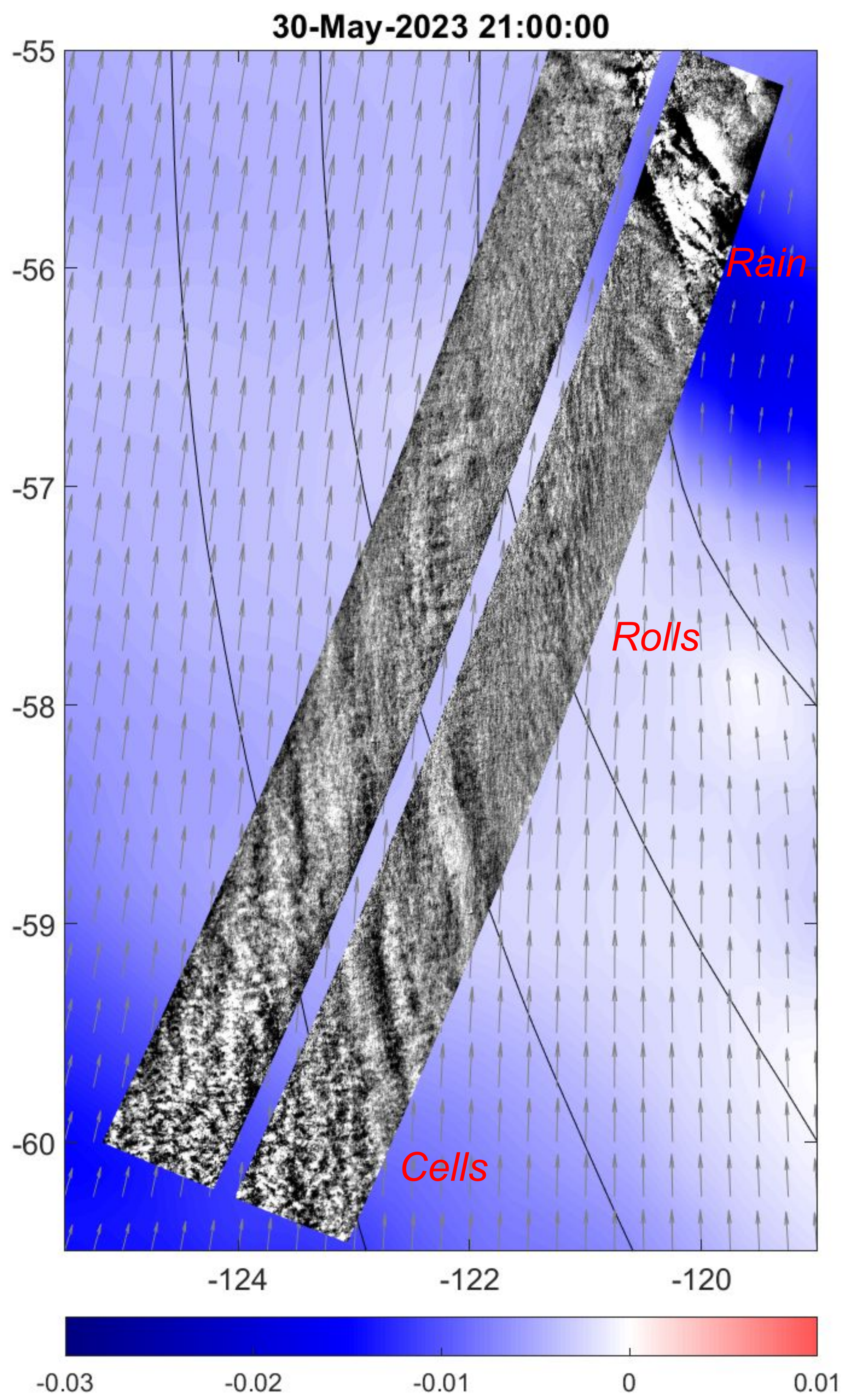
1) Science Questions

We postulate that SWOT sea surface roughness data presents a unique opportunity to devise new air-sea interaction remote sensing capabilities. Detecting atmospheric and oceanic signatures in SWOT backscatter will provide an entirely new view of the mesoscale and submesoscale phenomena and will be extremely valuable to air-sea interaction studies. The torrent of data demands that efficient methods be developed to take full benefit of the data. We propose to develop statistical image detection methods using the latest advances in machine learning techniques such as convolutional neural networks and contrastive models. The image classification output would be a new L2 product and this may likely apply to all SWOT products (e.g. quality flags). The image detection methods are transferable to other NASA missions (e.g. Aqua/MODIS, NiSAR). Considering the nexus between SWOT observational capabilities of 250-500 m pixels, continuous ~100-km swaths (left & right), and global non-sun-synchronous orbits, and where and how such data can contribute to the air-sea interaction research (e.g. refining parameterizations of energy and momentum exchange), we have formulated 3 science questions:



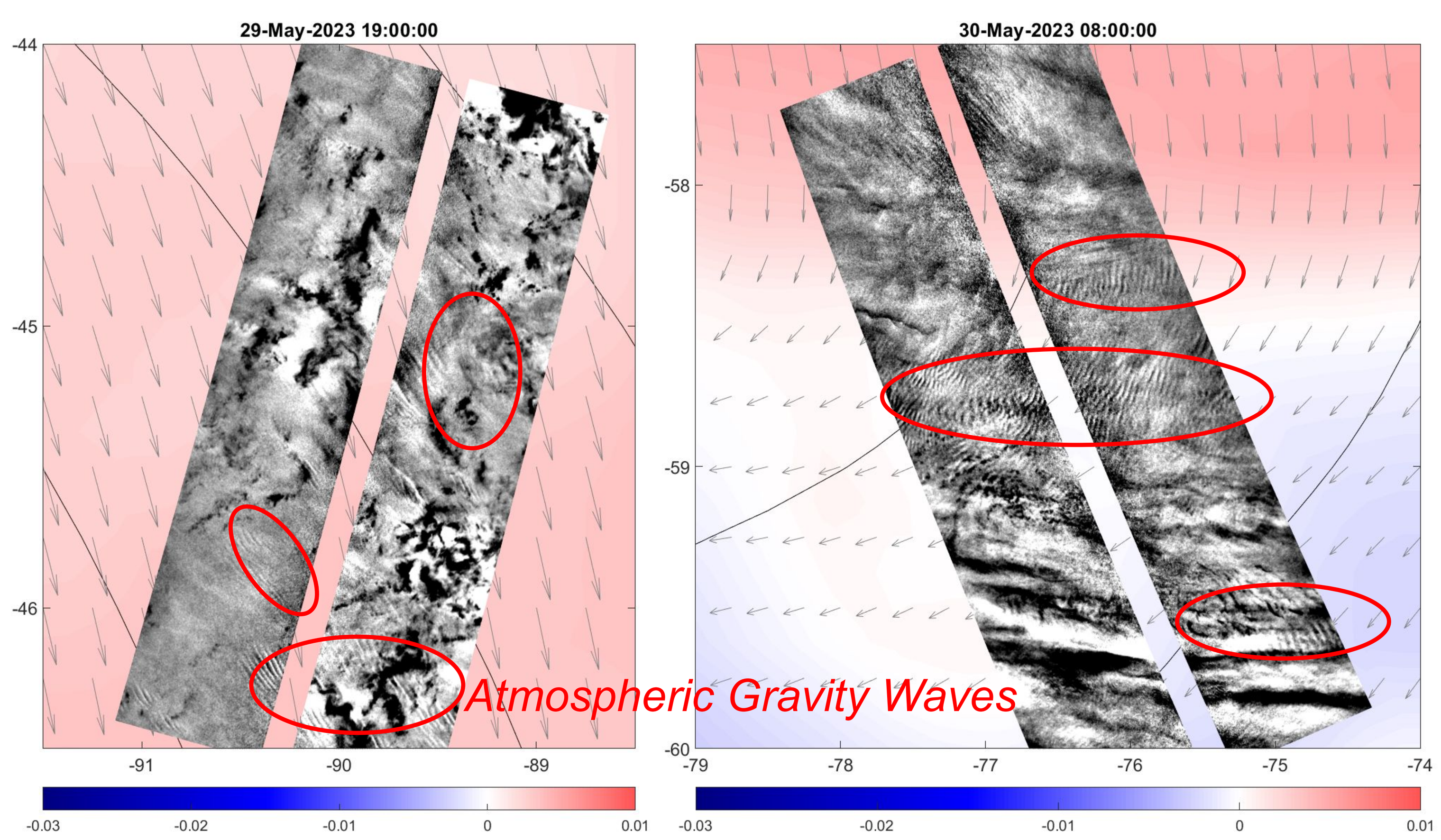
Question 1: Can SWOT provide the first quasi-weekly mapping of maritime boundary layer stratification states over the ocean?

Question 2: How frequently, under what conditions, and at what length scales do SWOT observe modifications of wind stress and the atmospheric boundary layer surrounding ocean fronts?

Question 3: How frequently and under what conditions are atmospheric internal waves spontaneously emitted in the marine atmospheric boundary layer (MABL) ahead of mid-latitude warm frontal zones? Do they modulate air-sea fluxes? Do they impact SWOT SSH estimates?

Figure 1 (left) SWOT backscatter in the cold sector of a typical SH baroclinic storm provides a synopsis of the major project goal: Produce the first-ever continuous dataset of marine atmospheric boundary layer (MABL) stratification and classification of crucial oceanic and atmospheric phenomena necessary for advancing air-sea interaction process studies at mesoscales and submesoscales. SWOT captures the transition from a convectively-driven MABL in the southwest into a shear-driven MABL between ~59°S and ~55.5°S. The transitions are marked by transformations in coherent structures that leave an imprint on ocean surface waves and modulate SWOT backscatter. Convective cells in the south give way to shear-generated rolls as the stratification changes from unstable to near-neutral. Rain signatures are seen in the northernmost part of the right (as plotted) swath. Shading is ERA5 air-sea stratification through a Richardson Number (Ri) at the overpass time. Its overall agreement with SWOT supports the geophysical interpretation. However, the subtle discrepancies indicate that even sophisticated surface analyses have significant room for improvement at mesoscale and submesoscales, which indicates one of the broader impacts of the proposed research.

2) New remote sensing capability - routine atmospheric gravity wave observations



Observations of gravity waves associated with fronts are a new observation in the open ocean. The fundamental steps will be to characterize their relationship to the atmospheric frontal zones, wavelengths, and orientation of the wave crests relative to the frontal orientation. It is desirable to characterize relative to the wind direction, but fronts are regions of sharp changes in wind direction. Various ocean vector wind products (ASCAT, COWVR, etc.) will be of value. Of particular interest is the coupling between gravity waves and MABL rolls.

Figure 2 (above): Examples of atmospheric gravity waves observed by SWOT in the warm sector of a baroclinic storm. ERA5 surface analyses provide closest-in-time wind surface wind vectors and air-sea Richardson Number (shading). The left panel shows gravity waves generated by convective clouds. The right panel shows a large region of gravity waves associated with the weak frontal zone indicated by the wind direction shift. Since gravity waves require stable stratification, the evident misregistration of SWOT-observed atmospheric waves and ERA5 stable Richardson Number illustrates the meridional error in the surface reanalysis that is likely due to relatively small errors in the location and extent of the storm features.

3) Atmospheric and Oceanic Phenomena Observed in SWOT

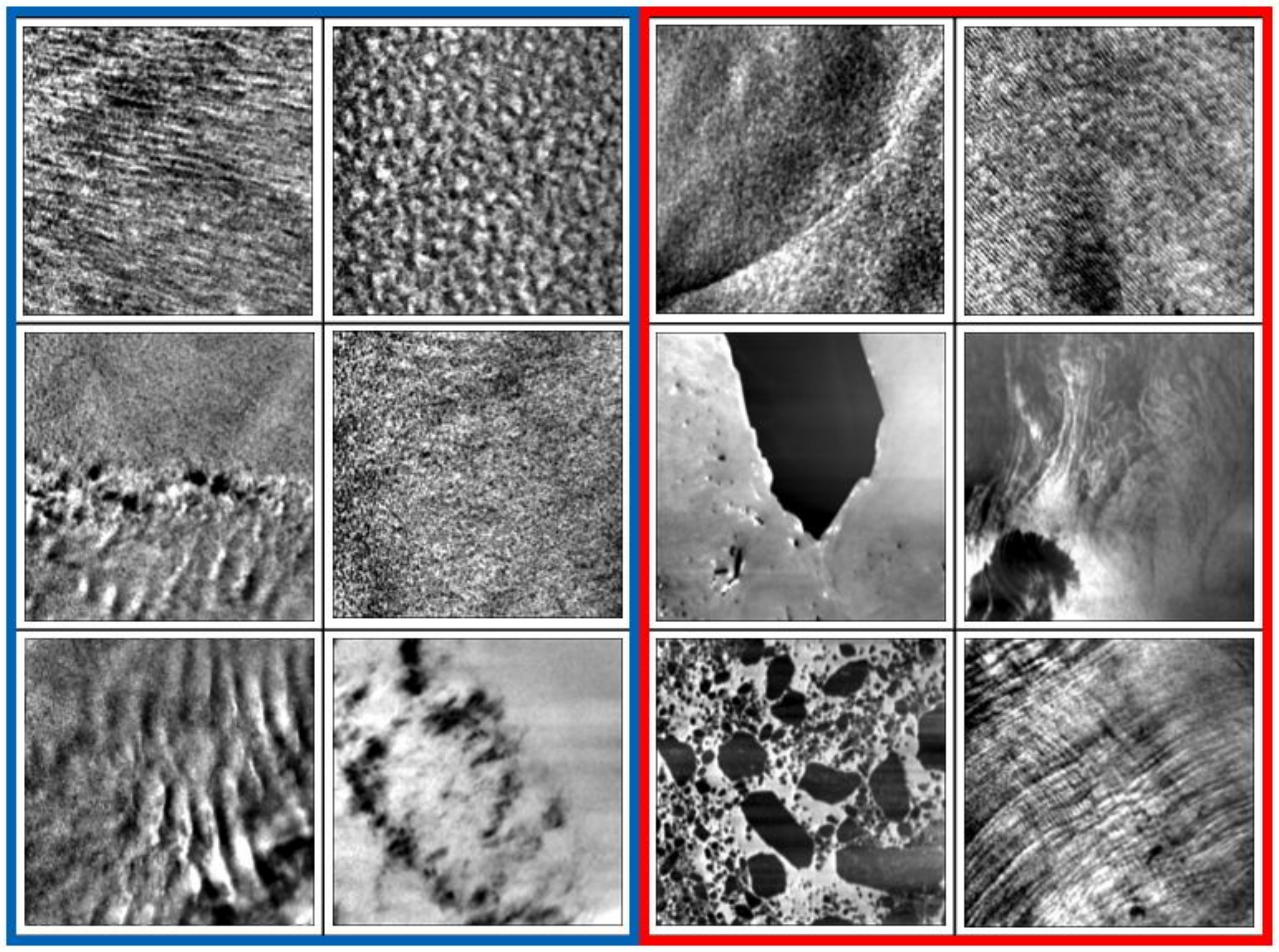


Figure 3 (above) Example SWOT backscatter ocean scenes (50x50 km) from the low rate L2 unsmoothed product. In blue are distinct atmospheric wind perturbations (clockwise from the top left): wind streaks (rolls), microscale convection (cells), no atmospheric signature, rain, atmospheric gravity waves, and an atmospheric warm front with associated gravity waves and rain clouds. In red are observed ocean and ice features including ocean front, swell, biological slicks, internal waves, sea ice, and icebergs. Automated scene machine learning classification will follow from previous efforts using Sentinel-1 SAR.

4) Objectives

Technical Objectives

►**Labeled archive of SWOT imagery** - Develop an archive of multi-tagged SWOT images of the 12 (13 including cold pools) dominant classes shown in Figure 3. Each scene will tag every feature since concurrent phenomena are common such as rain and rolls. First we will define an unambiguous set of rules to label the imagery. We target labeling O(10,000) images as we have had success using this order of magnitude to build subsequent image classification models.

►**SWOT image detection machine learning model** - build image detection models for SWOT imagery using the tagged archive. We will compare output to complementary remote sensing technologies (e.g. rain rates from GPM to the occurrence of rain probabilities using the SWOT classification model).

►**SWOT L2 swath product of phenomena probabilities** - produce phenomena probabilities for every swath pixel (~1-10 km) and delivered as a L2 product. Independent quality flags could be developed for all ≥L2 SWOT products.

Scientific Endeavors

►**Oceanic Front detection** - ocean fronts with concurrent MABL rolls/cells detection - new capability

- ►**MABL organized turbulence near ocean fronts** - statistical approach of joint roll/cell and ocean fronts probabilities
- ►**Wind stress and heat flux variability across ocean fronts** - Can SWOT surface roughness data quantify the extent of coupling between ocean current shear and SST changes? And at what scales is this observed?

►**Atmospheric Gravity Wave detection** - new capability in open ocean

- ►Focus on gravity waves associated with warm frontal zone dynamics since they are not observe with other technologies. Goal is to characterize their relationship to the frontal zones, wavelengths, and orientation of the wave crests relative to the frontal orientation. Emphasis will be placed on the coupling between gravity waves and boundary layer rolls as well as examining the SWOT SSHs in the regions in and surrounding the observed waves, including convectively generated ones.

5) References

Stopa, J.E., Wang, C., Vandemark, V. Foster, R. C., Mouche, A., Chapron, B., (2022). Automated global classification of surface layer stratification using high-resolution sea surface roughness measurements by satellite synthetic aperture radar, Geophysical Research Letters, 49, e2022GL098686. doi:10.1029/2022GL098686

Wang, C., Tandeo, P., Mouche, A., Stopa, J. E., Gressani, V., Longepe, N., . . . Chapron, B. (2019b, dec). Classification of the global sentinel-1 SAR vignettes for ocean surface process studies. Remote Sensing of Environment, 234, 111457. doi: 10.1016/j.rse.2019.111457

Wang, C., Vandemark, D., Mouche, A., Chapron, B., Li, H., & Foster, R. C. (2020). An assessment of marine atmospheric boundary layer roll detection using Sentinel-1 SAR data. Remote Sensing of Environment, 250, 112031. doi:10.1016/j.rse.2020.112031

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