The MAEVA project

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Waves generated by extreme events & their impact on atolls and islands

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Ocean Waves in the South Pacific: Complementarity of SWIM and SAR Observations

L. Oruba, D. Hauser, E. Dormy, S. Planes

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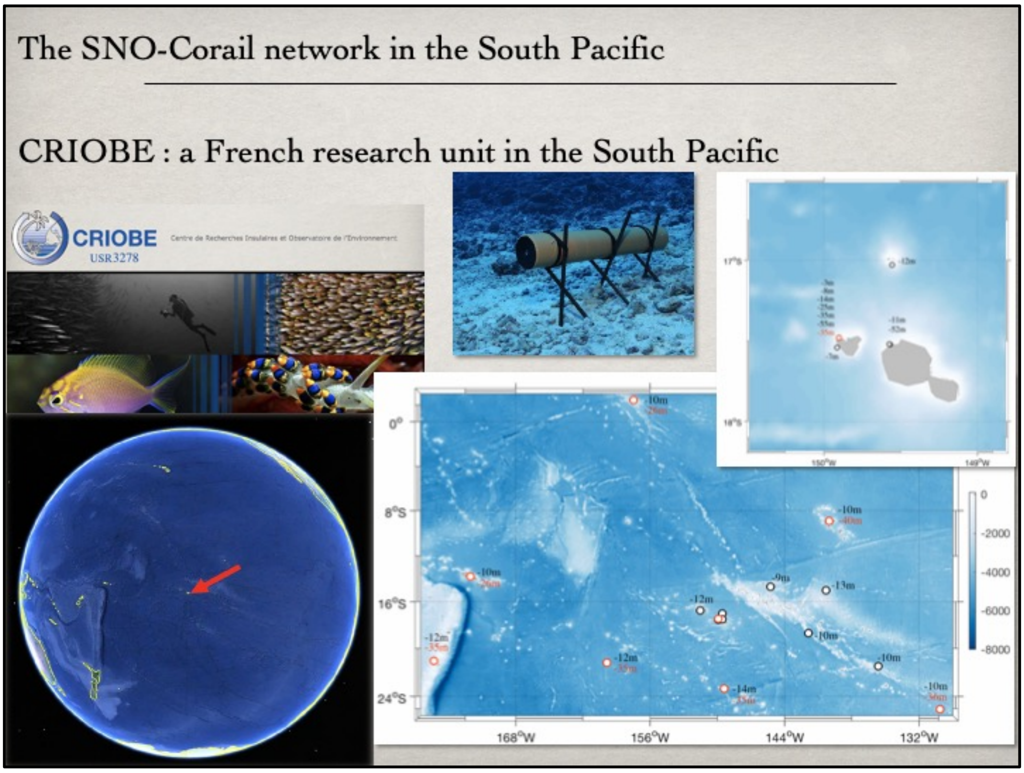
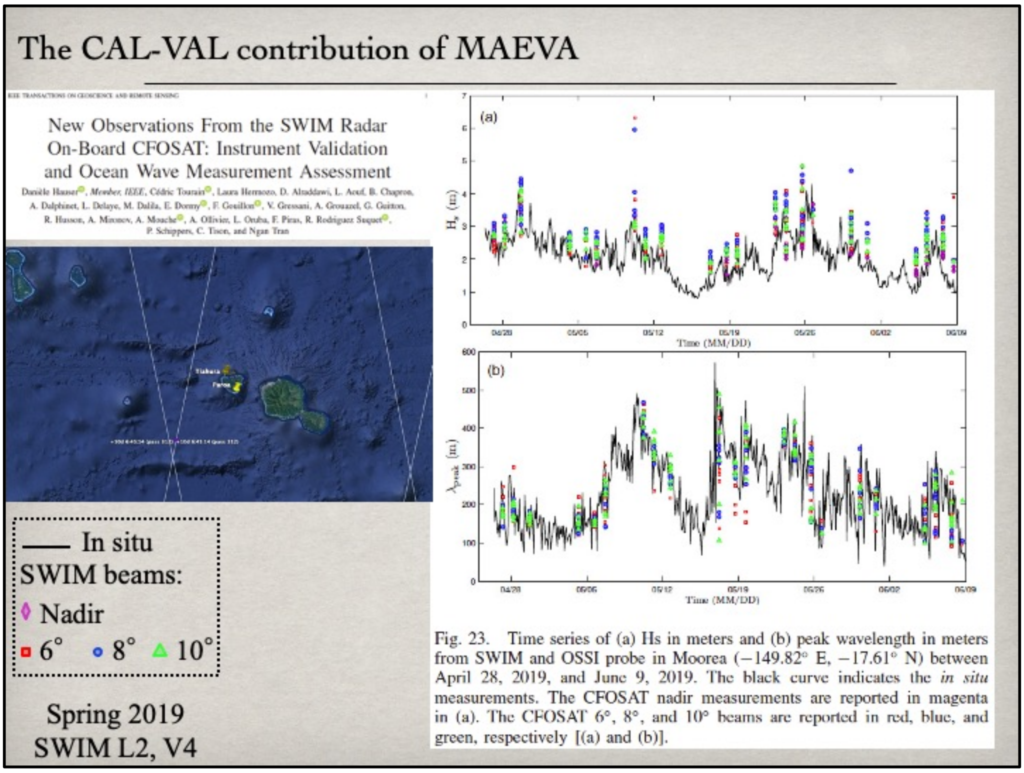
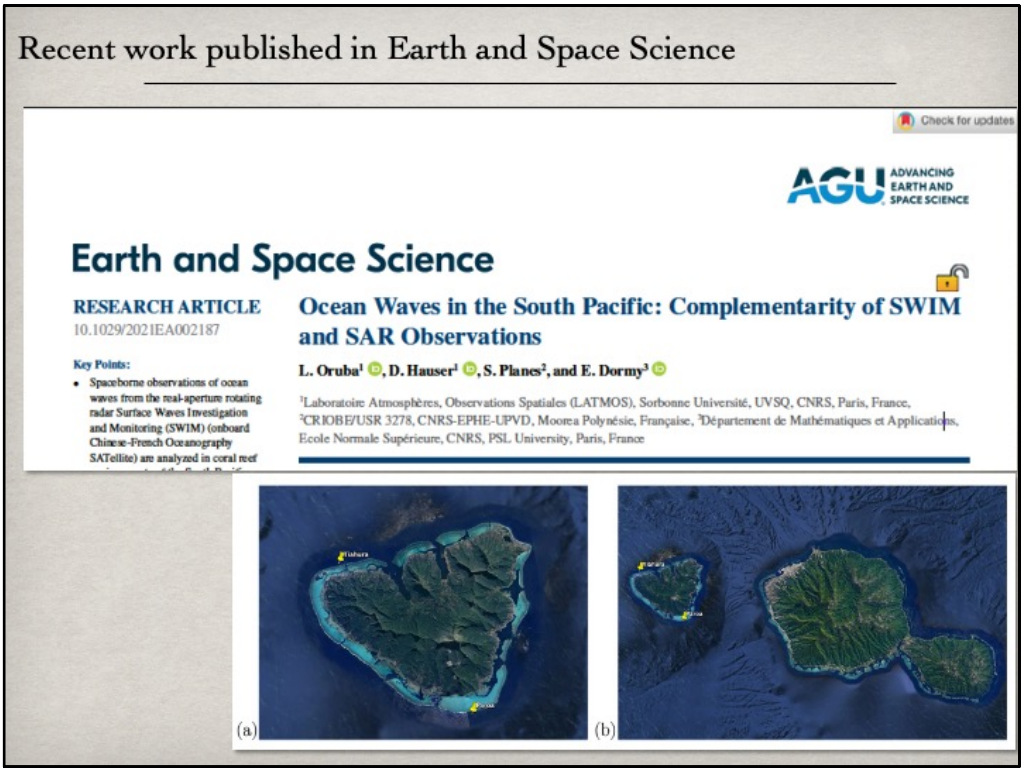


The Maeva project involves several French institutes. Among them, the CRIOBE is a French research unit in the south Pacific, which is interested in ecology, coral ecosystems and fishes. It is located in French Polynesia, in the middle of the South Pacific Ocean, with complex wave systems. Jointly with CRIOBE, we installed wave gauges to measure the temporal variation of pressure, at fixed depth. Thanks to these pressure measurements, we can reconstruct the surface waves height as a function of time. These wave gauges are located on the external slope of the coral reefs, between 10 and 30 meters depth.



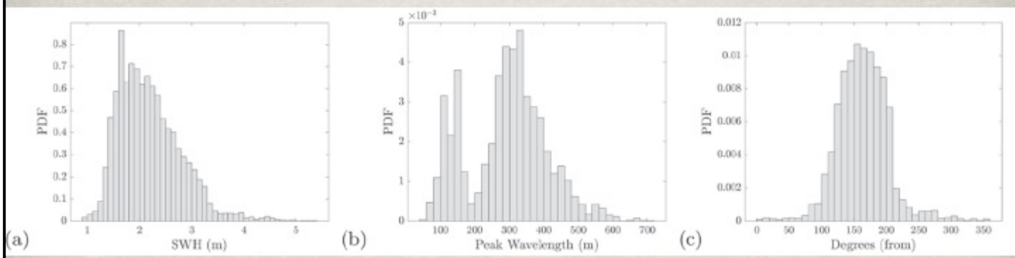
Our wave gauge deployed in Paroa (south of the Moorea Island) has been used for the SWIM cal-val.



The work presented here has been published in Earth and Space Science in May 2022.

It involves two Ocean Sensor System Inc (OSSI) wave gauges deployed in Tiahura and Paroa (north and south of Moorea Island).

Swells affecting the area of French Polynesia



Climatology of (a) the significant wave height
(b) the peak wave length
(c) the mean wave direction (“from” convention)
around the Iles du Vent archipelago.
Probability density function computed from Météo France WAve Model model data between April 2019 and April 2021.

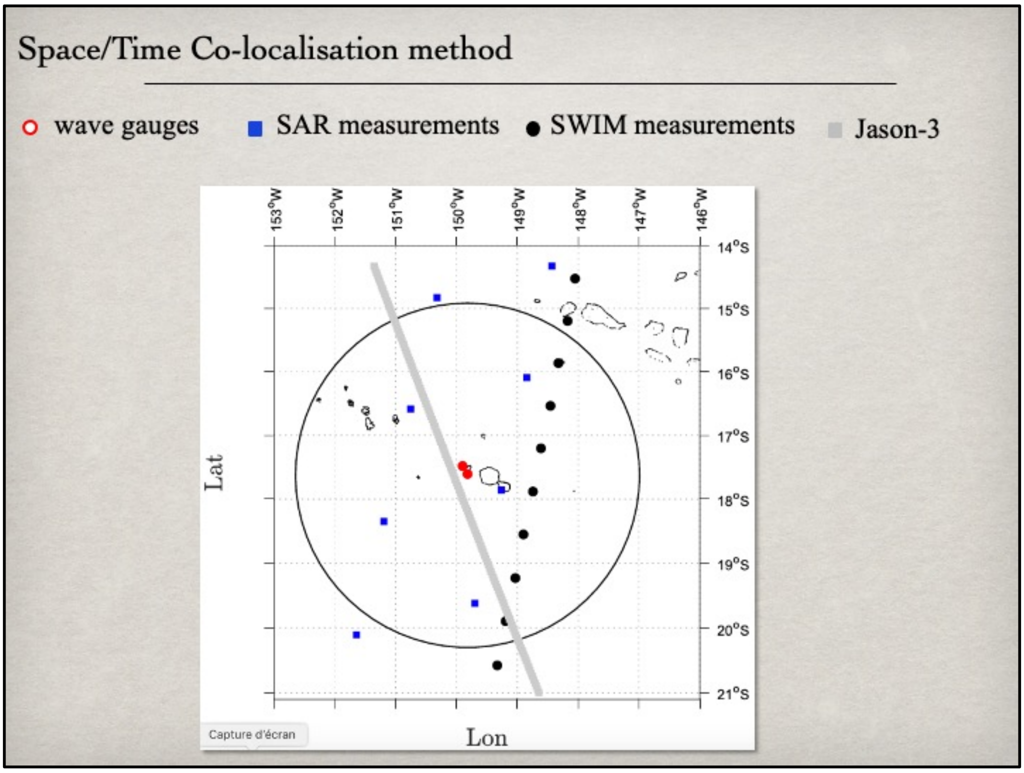
French Polynesia is affected by numerous swell episodes generated by atmospheric depressions, which have developed at higher latitudes in both the northern and the southern Pacific, and by trade winds. Most of ocean wave energy comes from South, with directions comprised between approximately 100 and 220 degrees.

Database constructed for our investigation

- SWIM 2D spectra (since 26 April 2019): Aviso, 5.1.2
  We use the beams 6°, 8°, 10° and their combination.
- SAR Sentinel 2D spectra (since December 2019)
- Jason-3 SWH
- 2 OSSI wave gauges providing omni-directional spectra reconstructed from continuous 1Hz pressure recording (since March 2018):

Tiahura -30m

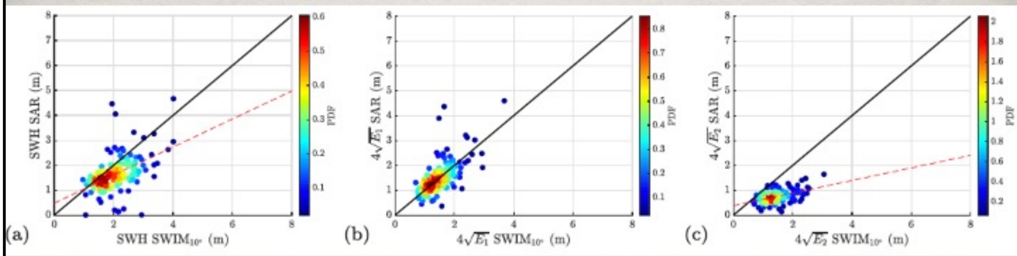
Paroa -30m



Co-localisation in space: we selected the CFOSAT tracks at less than 300km from Moorea island, and the SAR imagettes located less than 5° far from Moorea island.

Co-localisation in time: less than 1h difference

Statistical Study of the Significant Wave Height

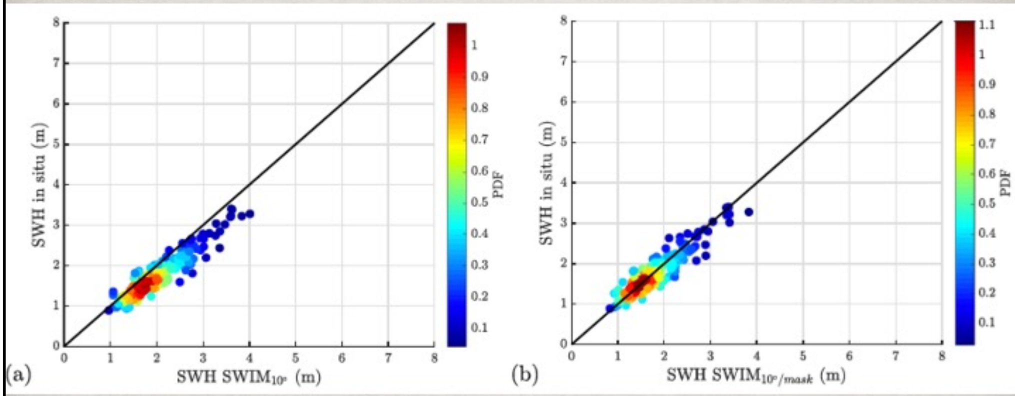


Scatterplot and probability density function (in colors) associated to 159 collocated wave measurements by **SAR (in ordinate)** and **SWIM 10° (in abscissa)**.

(a) Significant wave height
(b) $4\sqrt{E_1}$
(c) $4\sqrt{E_2}$
where E_1 (resp. E_2) is the spectrum energy restricted to $k < 0.04$ m^{-1} (resp. $k > 0.04$ m^{-1}).

(a) The SAR detects less energy than SWIM, and the difference increases with SWH. To investigate such a difference, we constructed two partitions: the first one (energy E_1) corresponds to the energy associated to wave numbers smaller than $k^* = 0.04$, whereas the second one (energy E_2) corresponds to the remaining spectrum. (b) and (c) These two graphs show that the underestimation of the SWH by the SAR originates from wavenumbers larger than 0.04 m^{-1}: the SAR underestimates the energy of wavelengths smaller than about 150 m. This is the signature of the azimuth cut-off inherent to SAR which limits wind-sea measurements.

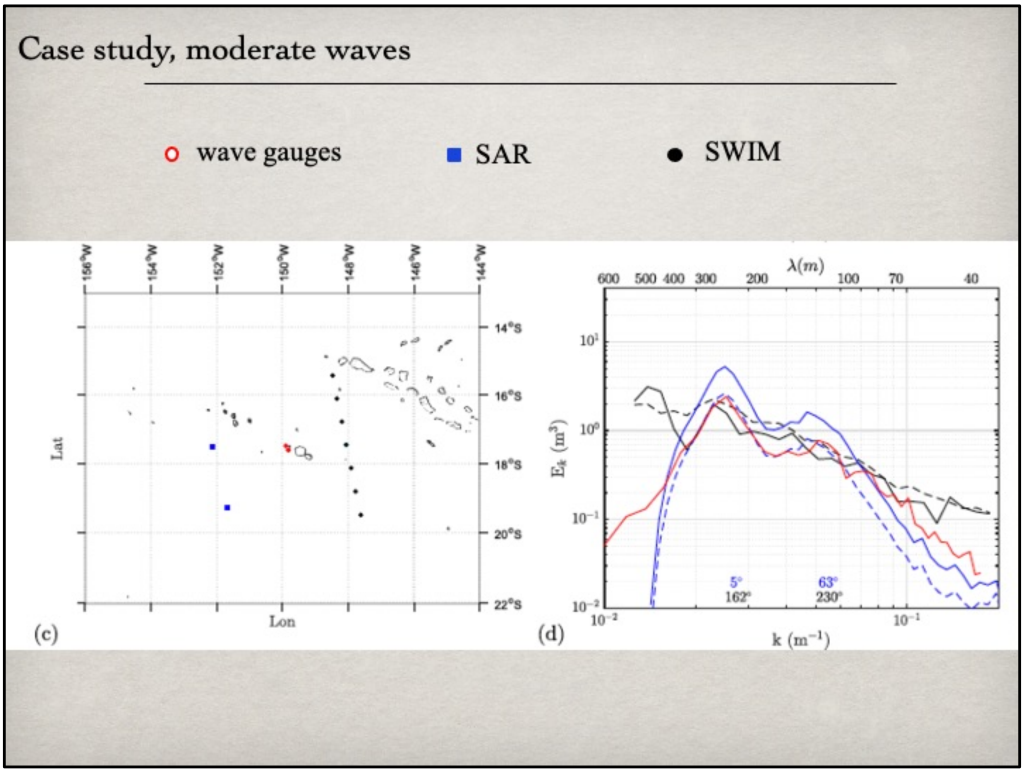
Statistical Study of the Significant Wave Height



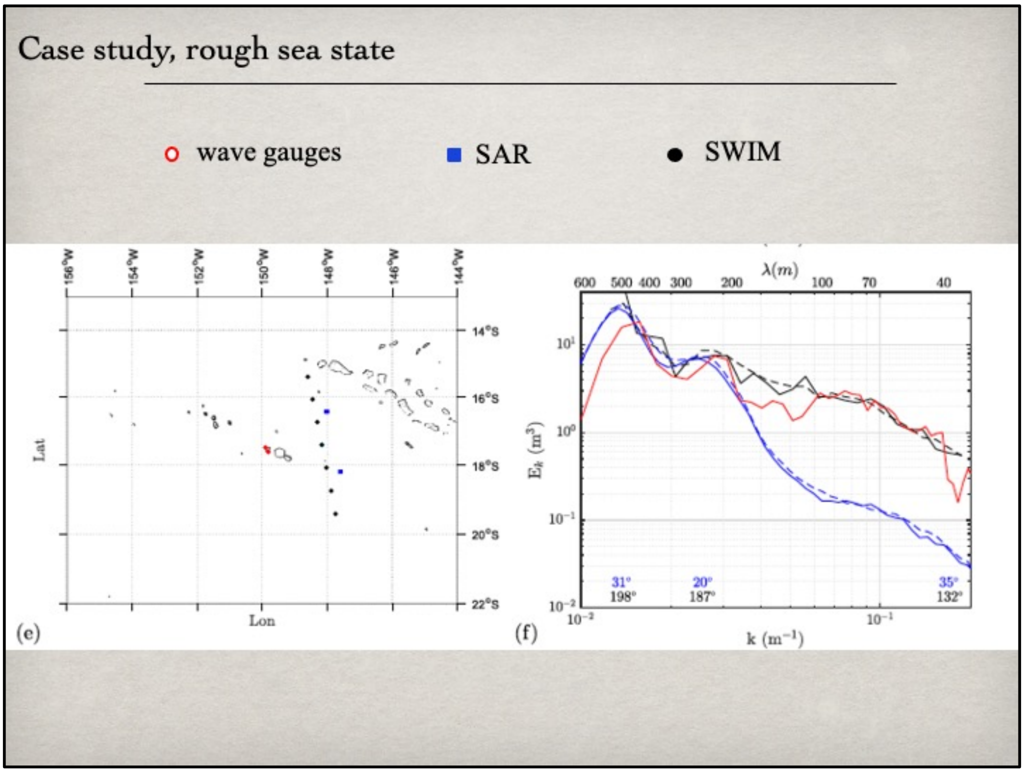
(a) Significant wave height (SWH) as measured by **wave gauges (in ordinate)** and by **SWIM 10°**

(b) Same as (a) except that an angular mask between 75° and 135° was applied to SWIM 2D spectra before computing the SWH.

The comparison between SWIM and the in situ wave gauges was performed using 209 collocated data. (a) Shows the SWH measured by the SWIM beam 10° and the SWH reconstructed from the in situ measurements by both wave gauges. The SWH measured by the SWIM beam 10° is slightly larger than the SWH reconstructed from the in situ measurements by both wave gauges. In other words SWIM detects more energy than the wave gauges. This bias may be due to the masking by the island of Tahiti, which prevents the wave gauges from measuring the wave energy coming from the angular sector [70°,130°]. To overcome this bias, an angular mask was applied to SWIM 2D spectra dropping the energy in the 4 bins between 75° and 135°. The SWH obtained after this masking of the SWIM 2D spectra is shown in (b) : this modified quantity appears fully consistent with the SWH measured by wave gauges.



This case (13 April 2020) corresponds to moderate waves, the SWH being smaller than 1.5 m. The most striking point is that the SWIM spectra (black) are quite flat compared to the spectra provided by the SAR (blue) and the wave gauges (red), which both exhibit more marked variations. The performance of SWIM in characterizing moderate sea states is not as good as that of the SAR. This is probably due to the limitation of SWIM measurements in low sea-state conditions, where speckle noise is not perfectly eliminated and may induce a parasitic peak at small wavenumbers and an increase in the noise floor at large wave numbers (Hauser et al., 2021).



This case (22 May 2020) corresponds to rough sea states with a SWH of 3 m. The spectra shown here exhibit two peaks corresponding to southern swells of 200 and 400 m. These peaks are captured by the wave gauges, the SAR and SWIM. The wave gauges and SWIM detect more energy for $k > 0.04$ m^{-1} in that case than in the previous one. This is however not the case for the SAR whose spectra decrease much more rapidly with k than the in situ and SWIM spectra. This is due to the azimuth cut-off. Indeed, the dominant swell, generally comes from the South in this area, that is, is close to the azimuth direction. This is the case for this example. The directions of each partition modeled by MFWAM are indicated above the horizontal axis (in black), as well as the angle $\Delta\theta$ (in blue) which measures the difference between the waves propagation direction and the azimuth. This highlights that the drops in SAR spectra correspond to small values of $\Delta\theta$ (35˚ in that case), whereas situations corresponding to a larger value of $\Delta\theta$ (63˚ in the previous case) do not yield such a bias.

Summary

- Comparing in situ and satellite measurements around the Moorea Island, we have shown that in rough sea states, SWIM wave measurements offer a chance to measure the wind-sea, corresponding to wavelengths smaller than about 150 m, whereas the SAR is limited by the azimuth cut-off, which prevents measurements of the wind sea waves or short swell. This limitation is particularly important in this region where most of the wave energy comes from the South and propagates in directions close to the SAR azimuth direction. These wavelengths have been shown to be important to properly estimate the SWH from SAR spectra under strong wind conditions, a decisive point to investigate the impact of extreme weather conditions on tropical islands.

- It should however be noted that for low to moderate sea states, the SAR appears to provide more reliable measurements than SWIM, due to remaining speckle contamination in the SWIM spectra.

- Hence, the complementarity of the SWIM and SAR measurements in the South Pacific strongly depends on the wavelength, the SWH and the direction of propagation. In this region, and for moderate to high sea-state conditions, the real-aperture radar technology appears to open the possibility of a finer estimate of waves impact and potential damages.

For further information:

Oruba, Hauser, Planes & Dormy (2022), ***Earth and Space Science*****,** ***9*****, e2021EA002187.**