Wave Observations across Tuamotu Archipelago from Wide Swath Radar Altimetry (SWOT)

Postec Taina[1], Dodet Guillaume[1], Ardhuin Fabrice[1]

[1]Laboratoire d'Océanographie Physique et Spatiale (LOPS), Univ. Brest, CNRS, IRD, Ifremer, IUEM, Brest, 29200, France

Motivation

- **Tuamotu Archipelago**
  - Located in **Pacific Ocean** : high frequency of fully developed storm swells
  - Mostly **unresolved atolls** : source of errors in wave models

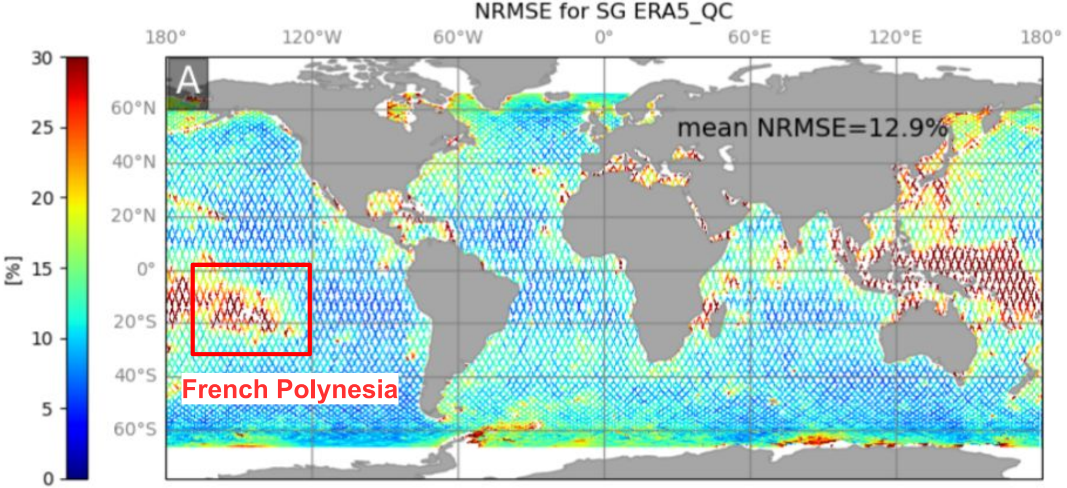

Figure 5.a. Normalized RMS error between Hm0 deduced from altimetry and simulated with a structured grid (0.5° resolution).
Gaffet et al. (2025). A new global high-resolution wave model for the tropical ocean using WAVEWATCH III version 7.14. Geoscientific Model Development

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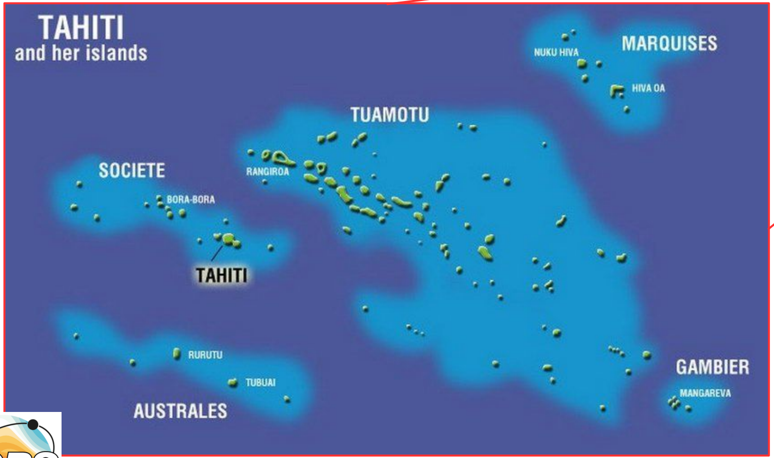

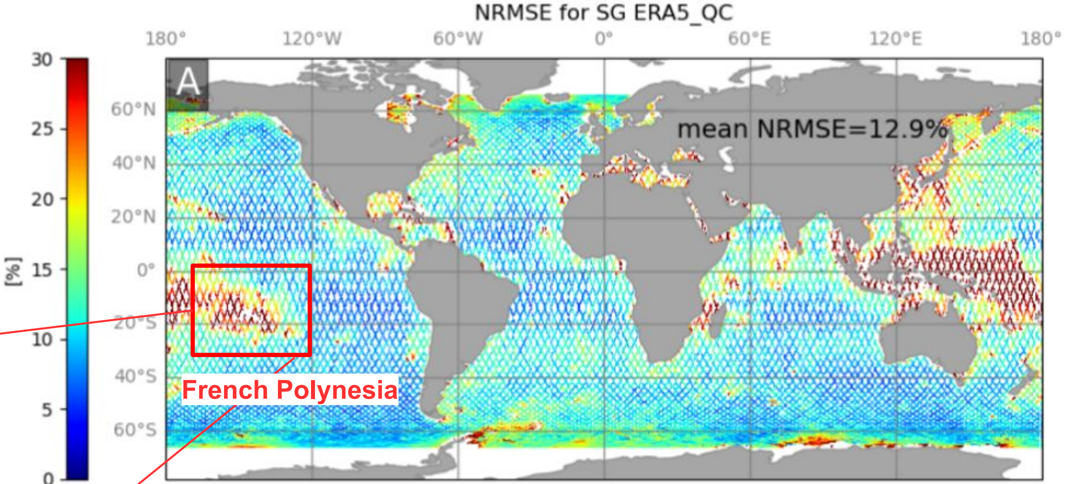

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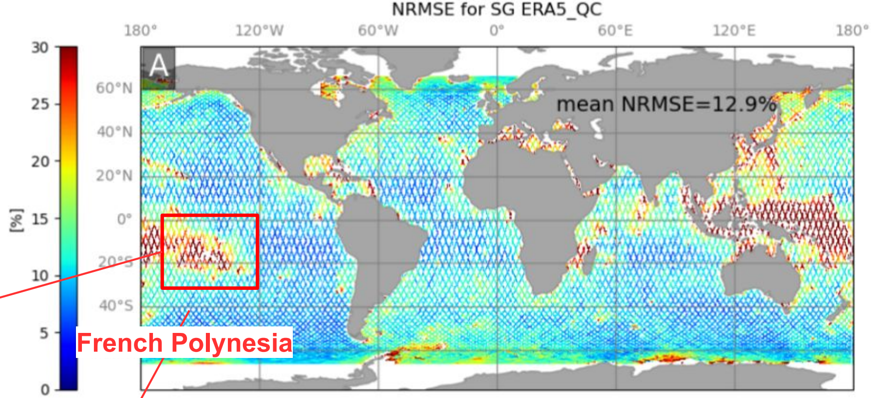
  - Very **effective in blocking swells**

→ **Ideal case to test island sheltering effect in wave models**



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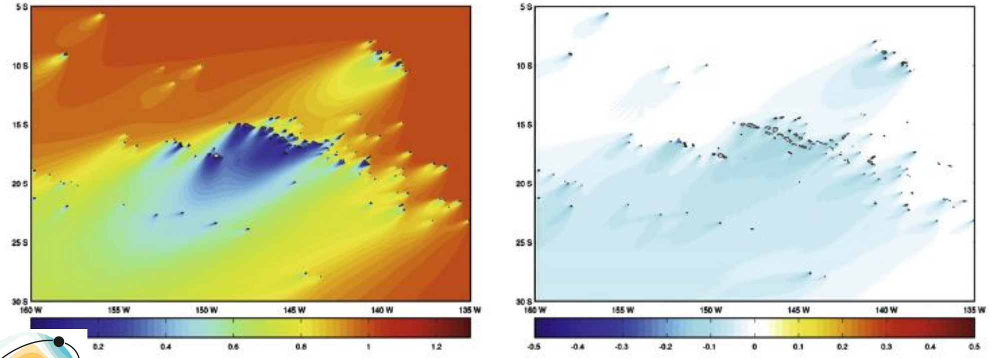

(a) Test OB-2 (b) OB-2 - NO-OB

Chawla, A., & Tolman, H. L. (2008). Obstruction grids for spectral wave models. Ocean Modelling, 22(1-2), 12-25.

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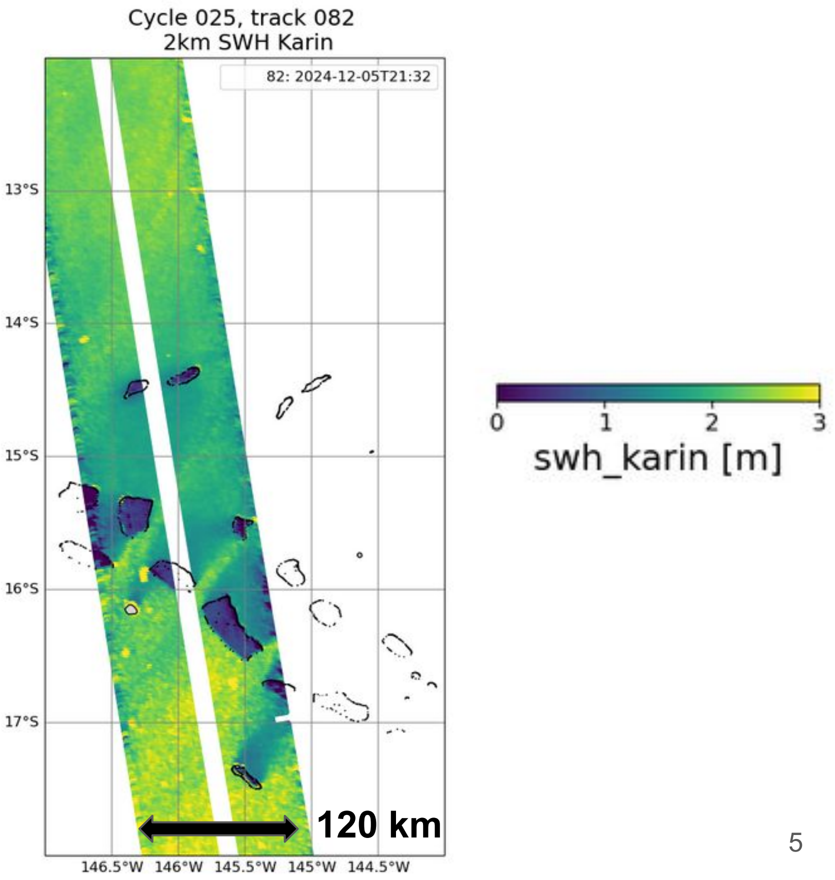
- **Wide Swath Radar Altimetry**
  - New insights of wave transformation, 2D view of wave fields thanks to Surface Water Ocean Topography (SWOT) satellite

→ **New ground truth for model validation and wave physics understanding**



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  - New in

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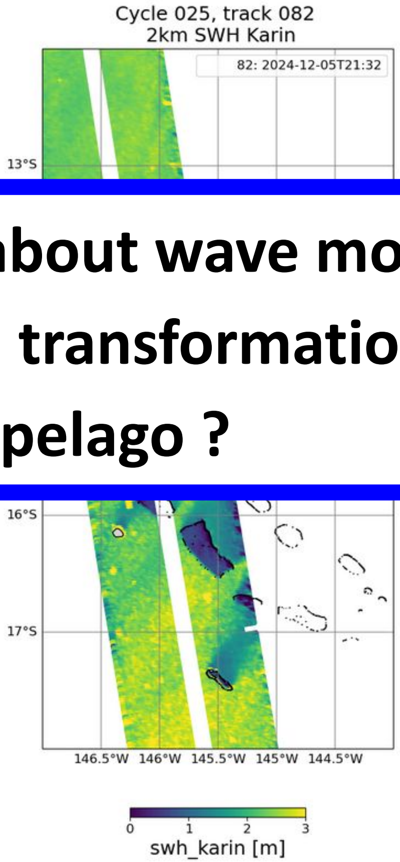
What can SWOT tell us about wave model performances and wave field transformation across Tuamotu Archipelago ?



Unresolved islands representation in wave models

Hardy et al (2001)	**Tolman et al (2003)**	Mentaschi et al (2018)
obstruction grid for each spectral directions	obstruction grid for x/y directions	source term approach

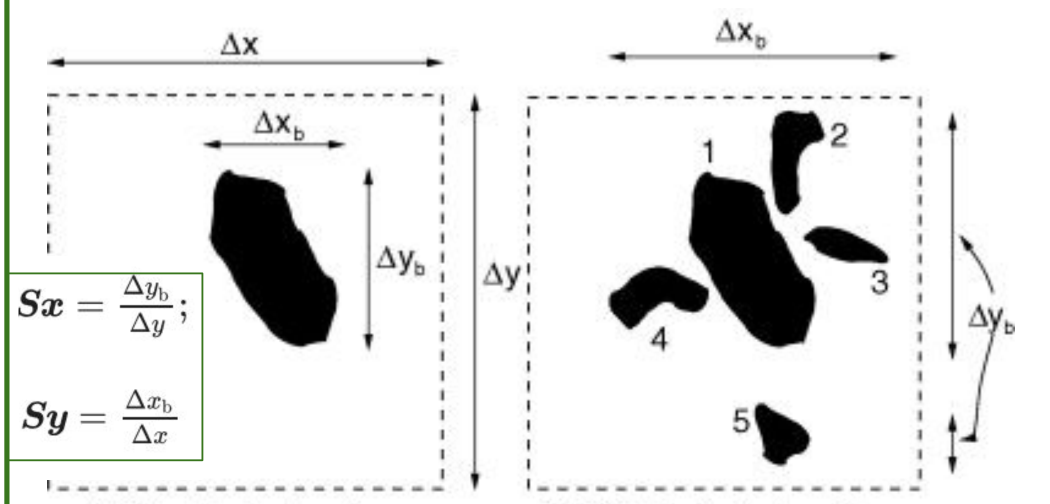
Unresolved islands representation in wave models

Hardy et al (2001) | **Tolman et al (2003)** | Mentaschi et al (2018)

Tolman et al (2003)

→ Use **coastlines + subgrid** to compute **obstruction coefficient S = Sx + Sy for each grid cells**

→ **Correction of energy fluxes** in the spatial propagation scheme, using transparency **coefficients** α **= 1 - S**



$$Sx = \frac{\Delta y_b}{\Delta y};$$

$$Sy = \frac{\Delta x_b}{\Delta x}$$

(a) Single obstruction (b) Multiple obstructions

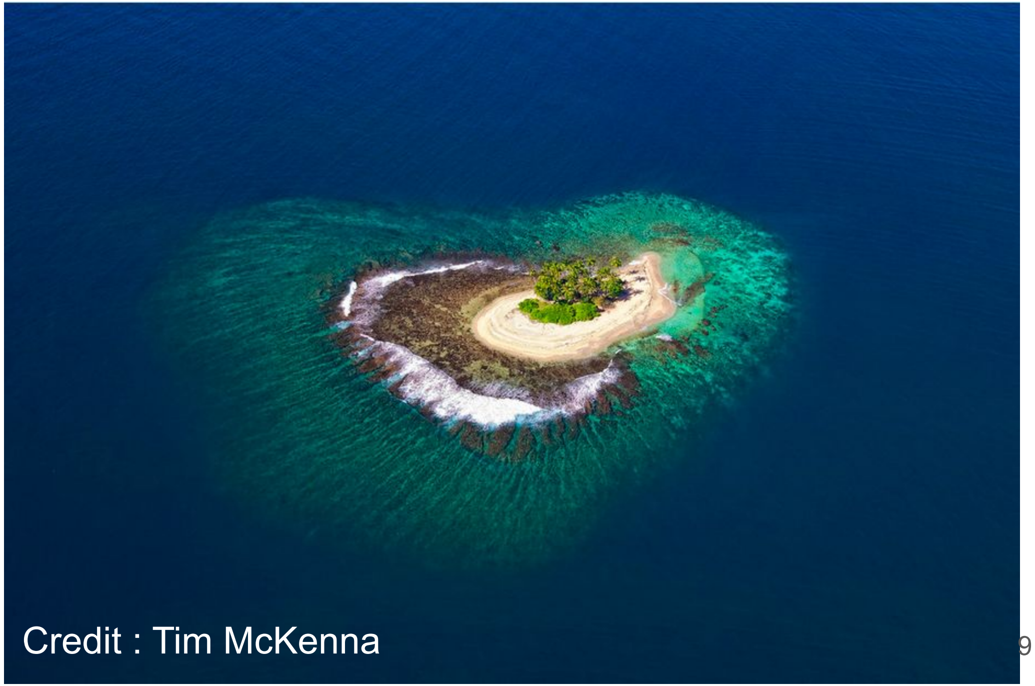
Unresolved islands representation in wave models

Hardy et al (2001) — **Tolman et al (2003)** — Mentaschi et al (2018)

Challenges of this method

→ **Properly take into account neighboring cells** effect

→ **Coastline information is not enough:** Islands / atolls might be composed of **inter-tidal areas, not represented in coastline data** → play a role in wave transformation



What can SWOT tell us about wave model performances and wave transformation across Tuamotu Archipelago ?

1) 2D view of wave Hs across Tuamotu

2) Spectral informations derived from SWOT sea level observations

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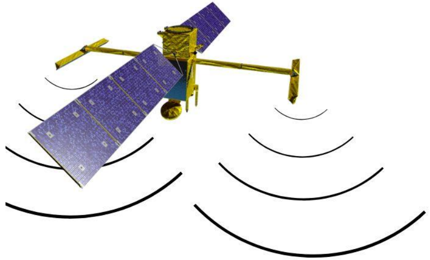
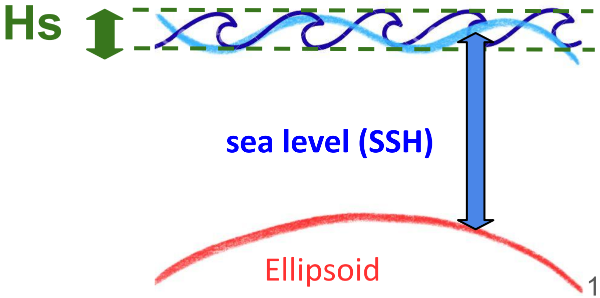


1) 2D view of wave Hs across Tuamotu

2) Spectral informations derived from SWOT sea level observations



2D view of wave Hs across Tuamotu

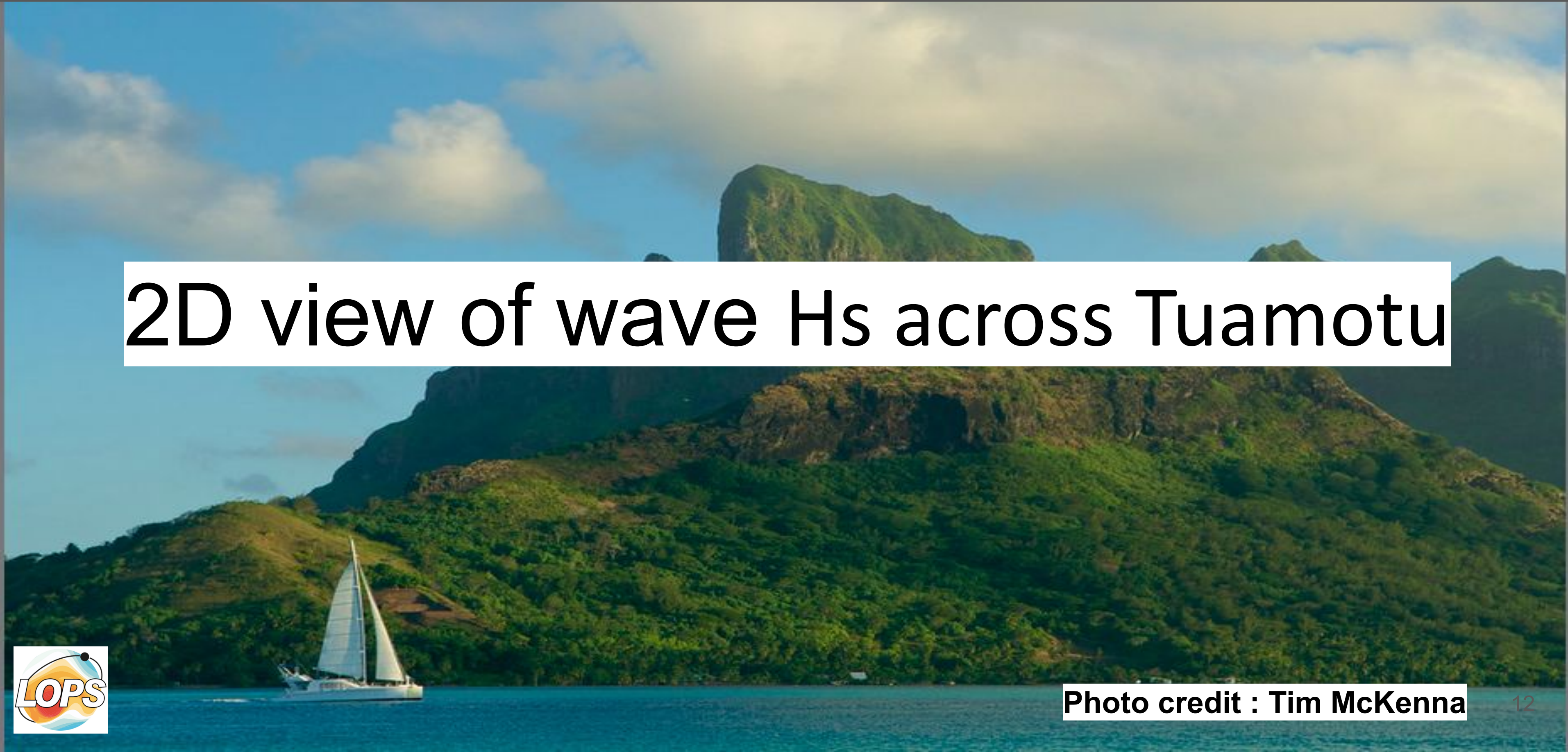
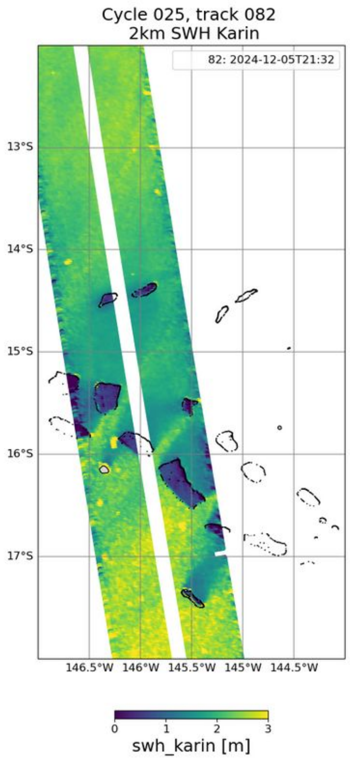


Photo credit : Tim McKenna

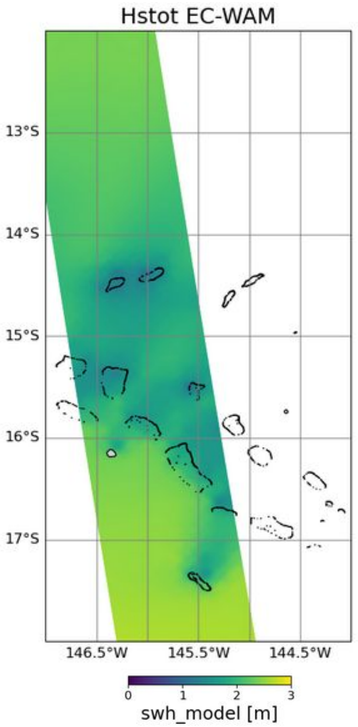
Observations : SWOT Hs
L2_LR_SSH_WindWave_…

- **Wide-swath** 2 x 50 km + 20-km blind zone
- Spatial resolution: **2-km gridded maps** of Hs in LR mode
- 21-day revisit period since July 2023



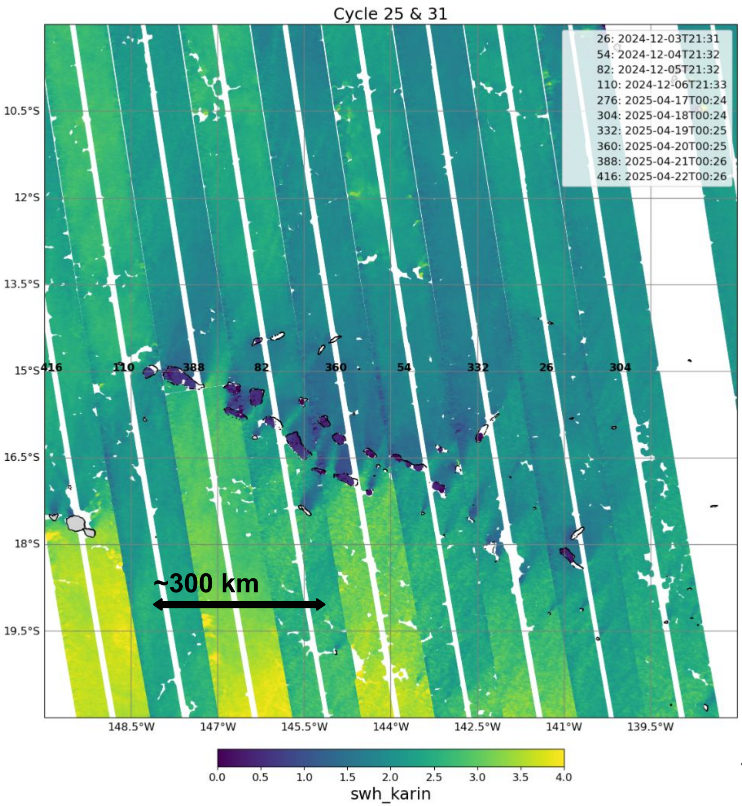
Wave model: EC-WAM Hs

- Native spatial resolution: 9km-gaussian grid
- **Linearly interpolated** on SWOT 2km-grid
- **Maximum delay** between SWOT and model : **3 hours** (linear interpolation)



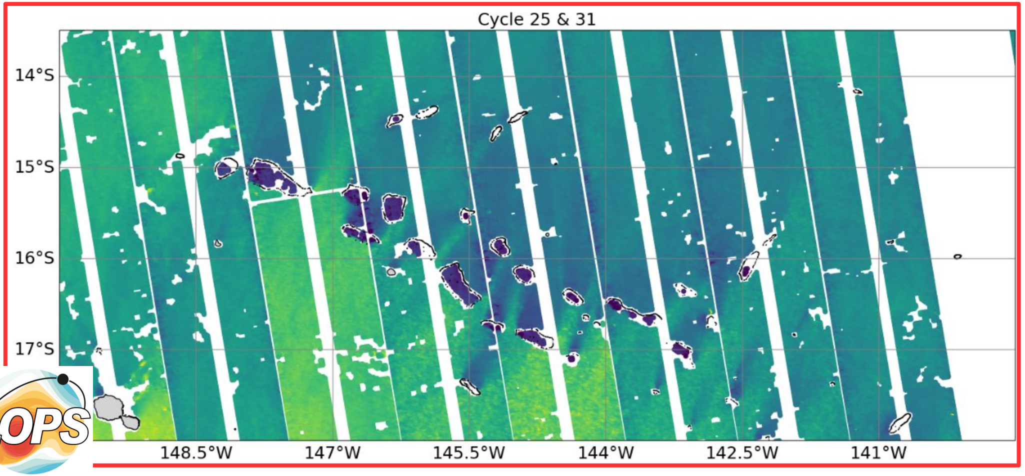
Composite SWOT Hs map

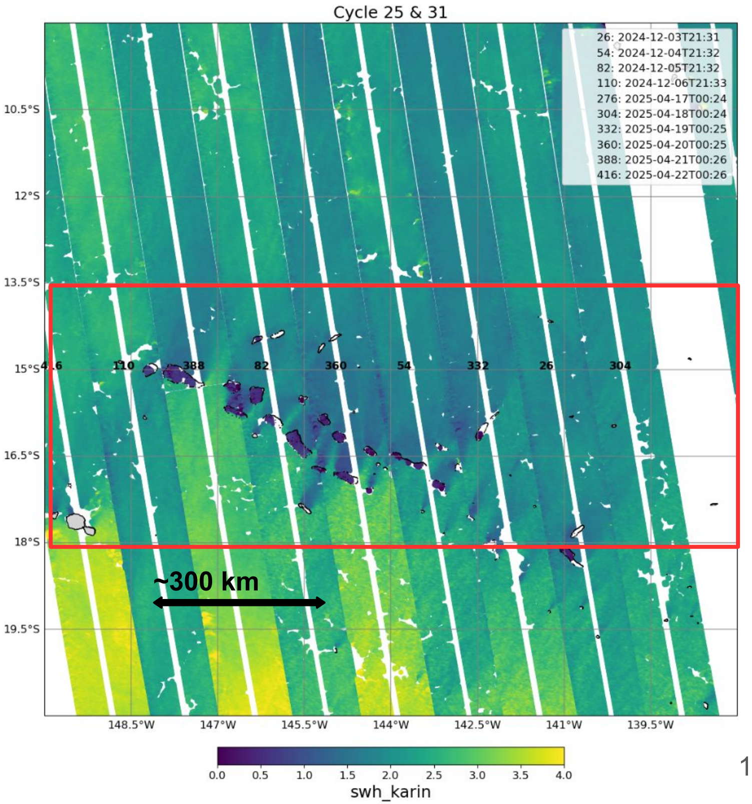
- Hs = swells + wind sea → **hard to see** archipelago's **regional sheltering effect**
- **Rain noise patterns** in SWOT data



Composite SWOT Hs map

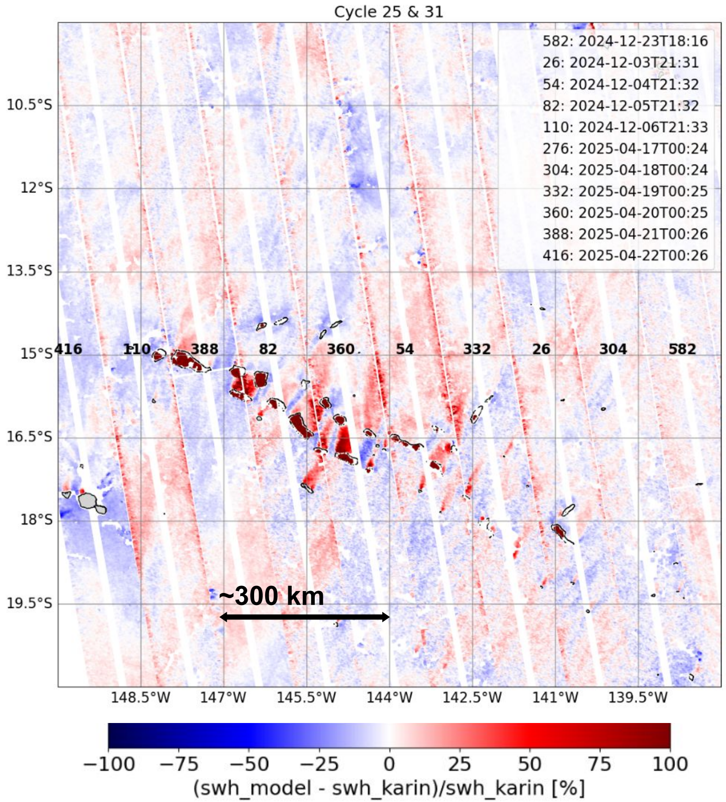
- Hs = swells + wind sea → **hard to see** archipelago's **regional sheltering effect**
- **Rain noise patterns** in SWOT data
- **Local island sheltering** effect on incoming swells
- **Swell energy crossing** the archipelago between atolls





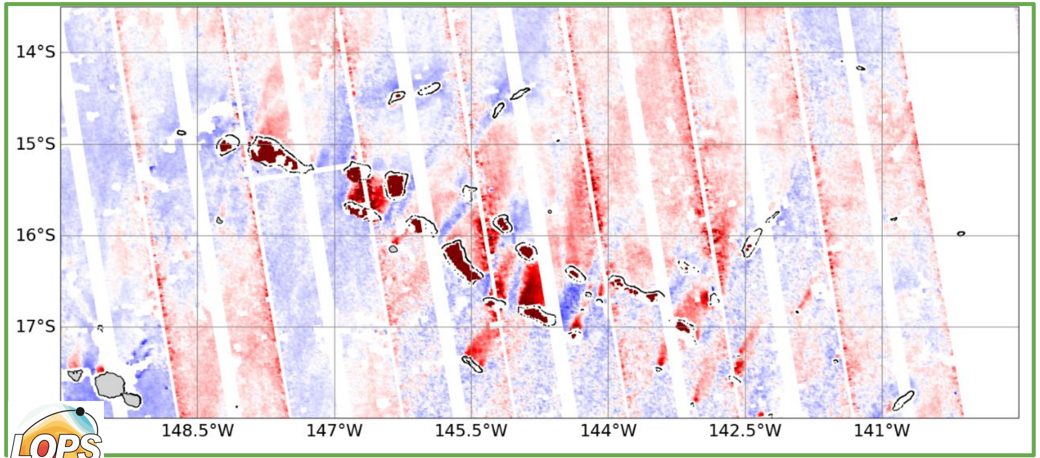
NBIAS between SWOT SWH (ref) and EC-WAM (model)

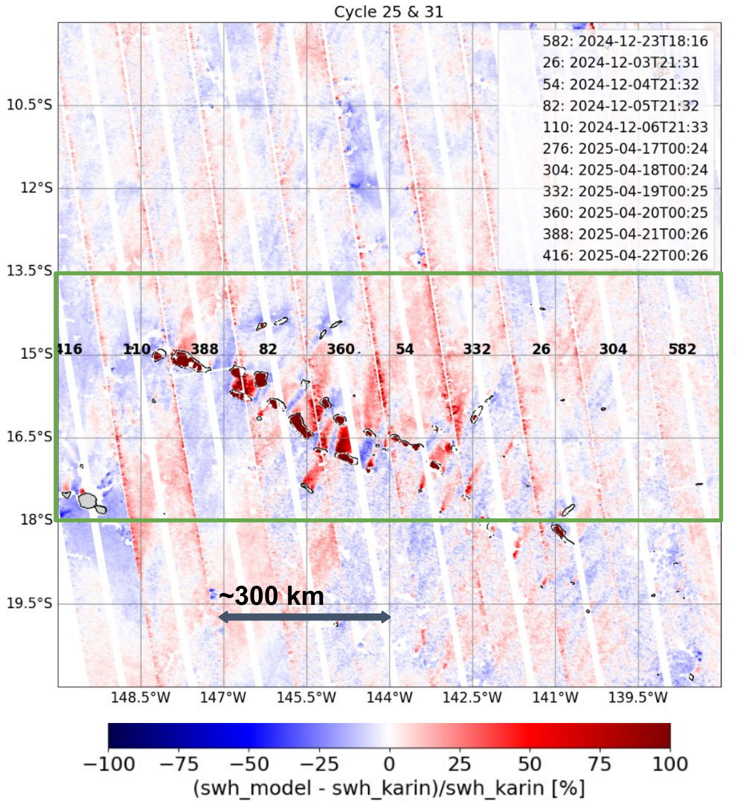
- Regional scale : **no clear NBIAS trend**



NBIAS between SWOT SWH (ref) and EC-WAM (model)

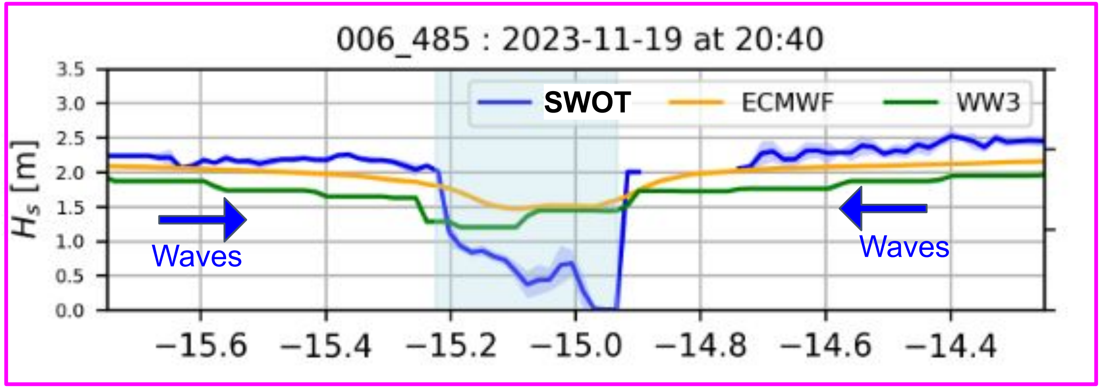
- Regional scale : **no clear NBIAS trend**
- **Underestimation of island sheltering** effect
- **Underestimation** of wave **energy crossing** the archipelago
- Wave **overestimation in atolls inner lagoons**

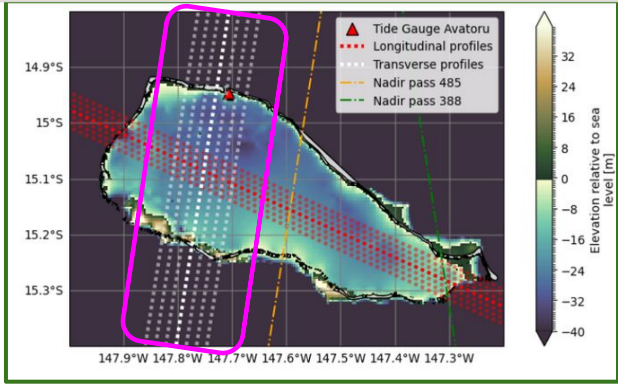


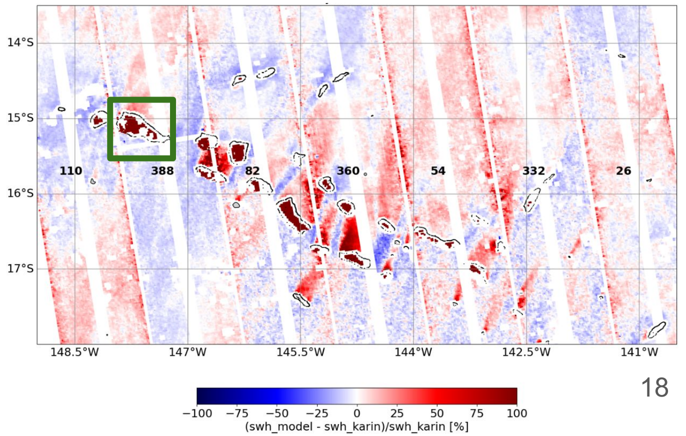


Wave attenuation in Rangiroa lagoon

- Strong **swell attenuation** induced by breaking over reef top
- **Hs up to 1m** observed in the lagoon (low wind)
- **Lagoon Hs overestimated** by wave models







LOPS

Spectral informations derived from SWOT sea level observations

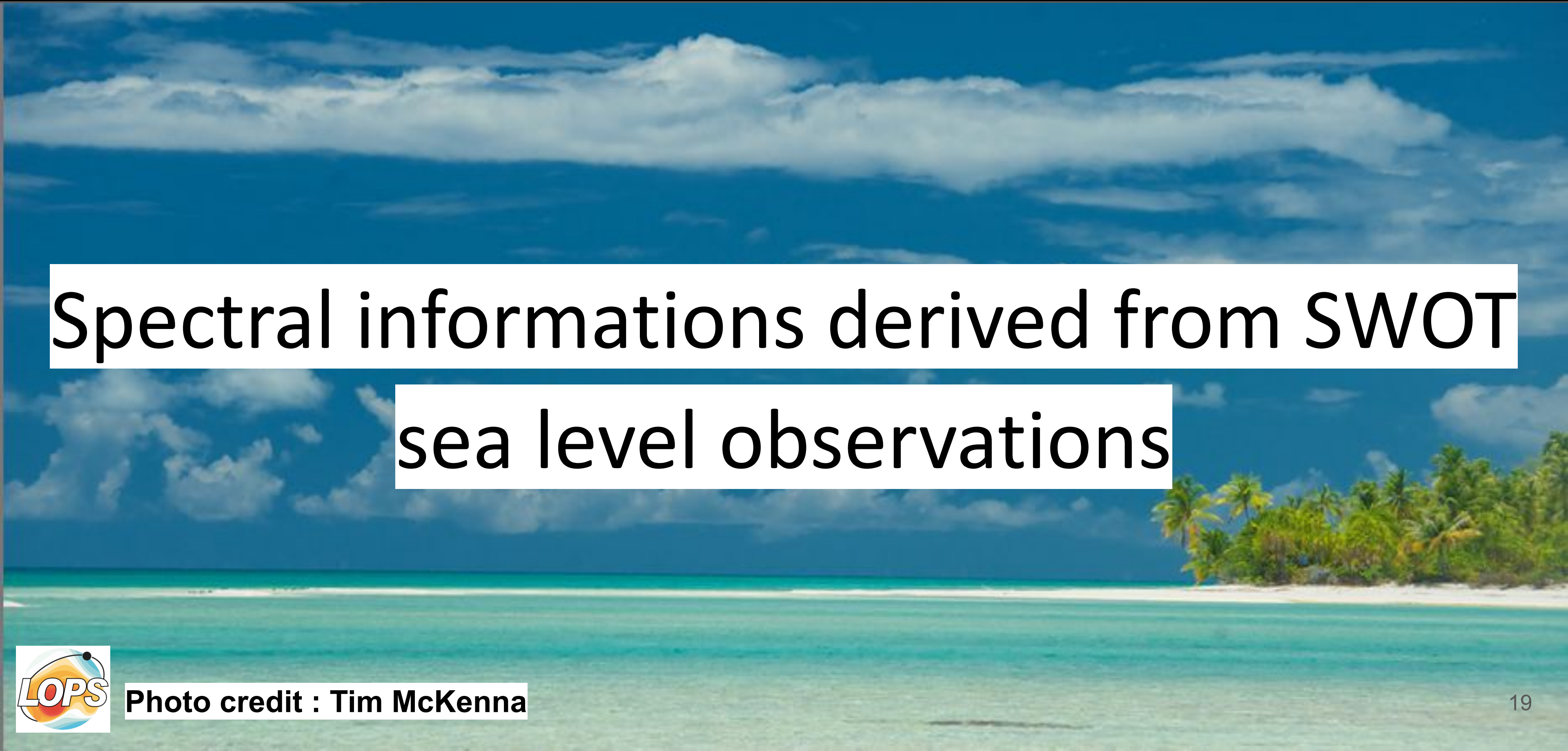
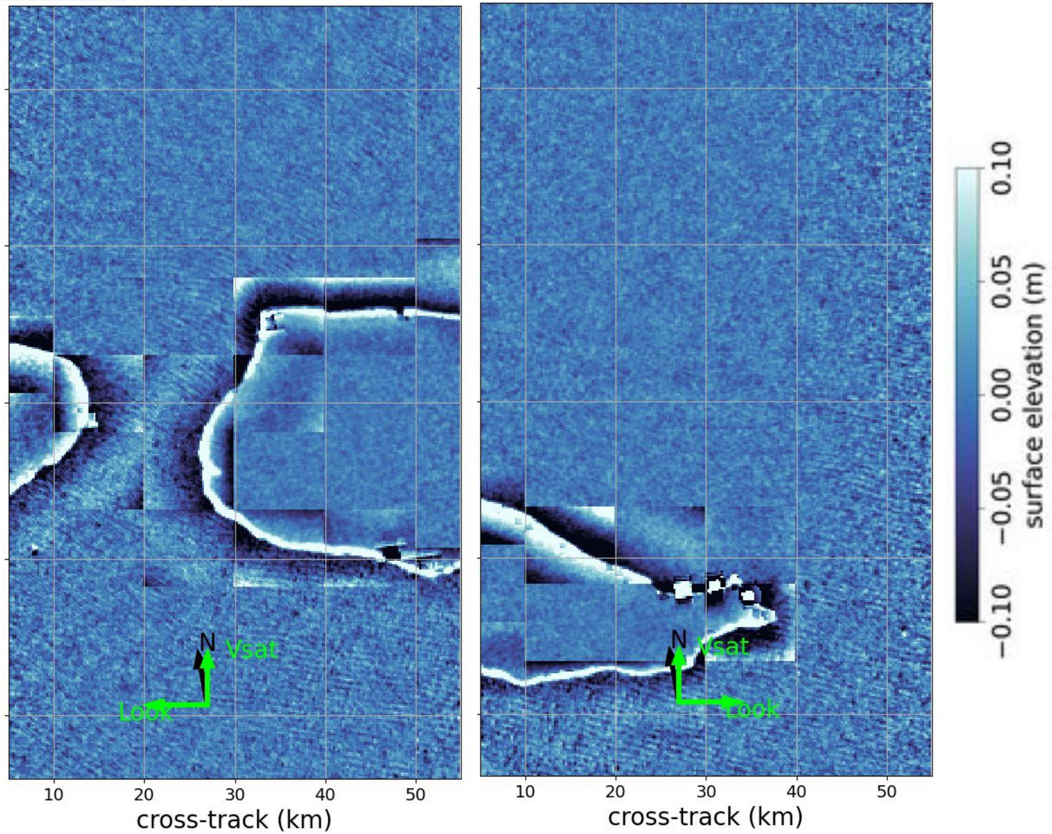


Photo credit : Tim McKenna

Observations : 250m - gridded SWOT SSH
*L3_LR_SSH_Unsmoothed_*
…
→ Only swells with λ > 500m (T > 18s) are resolved

Detrend SSH to obtain SSHA



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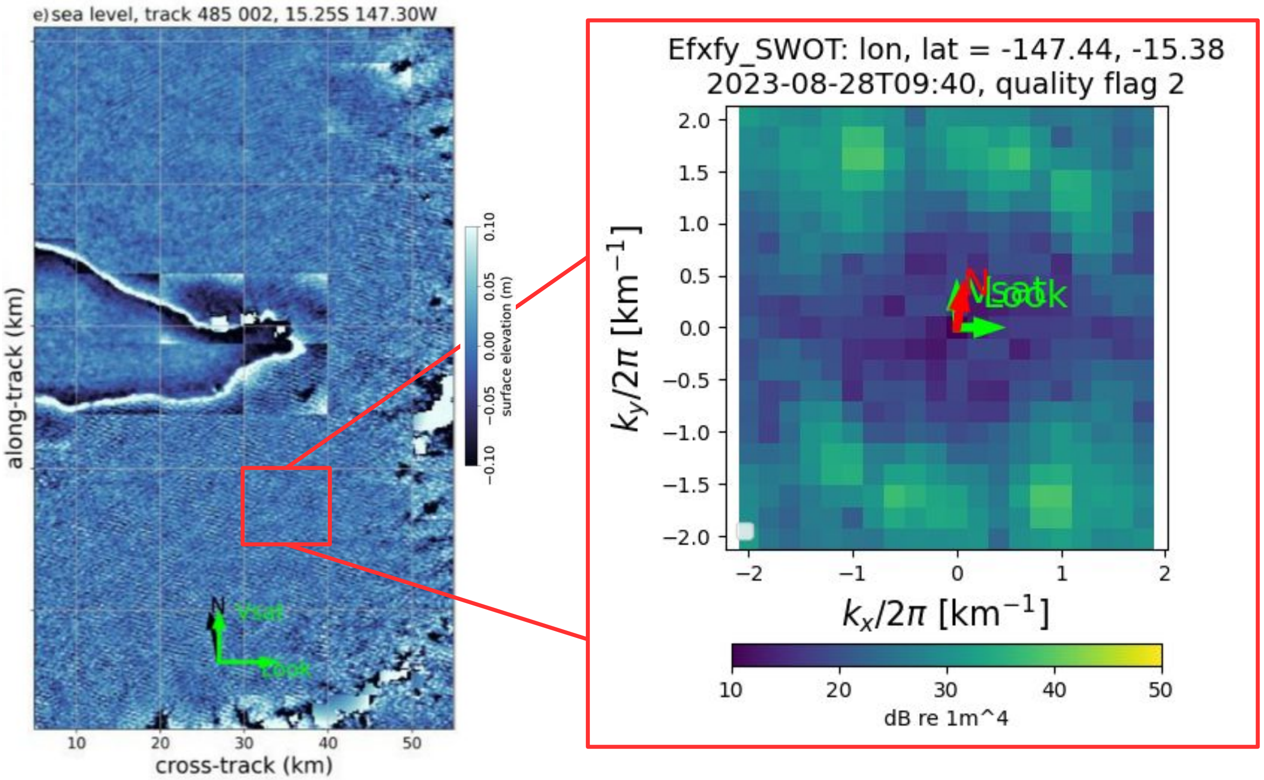

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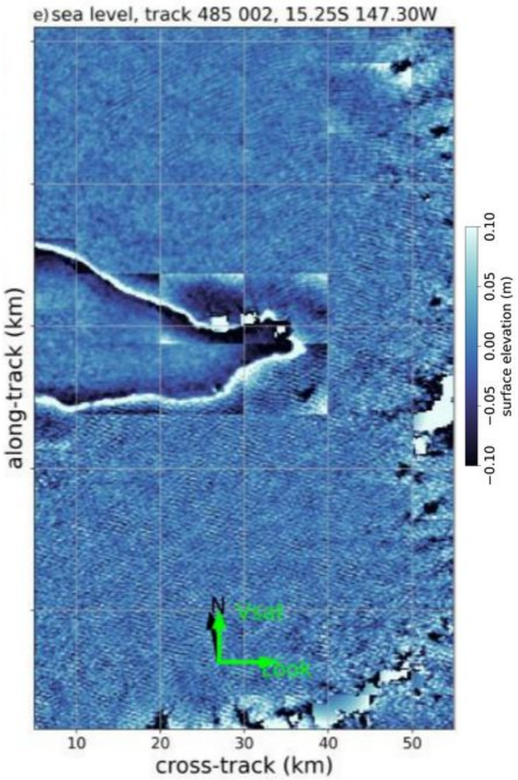
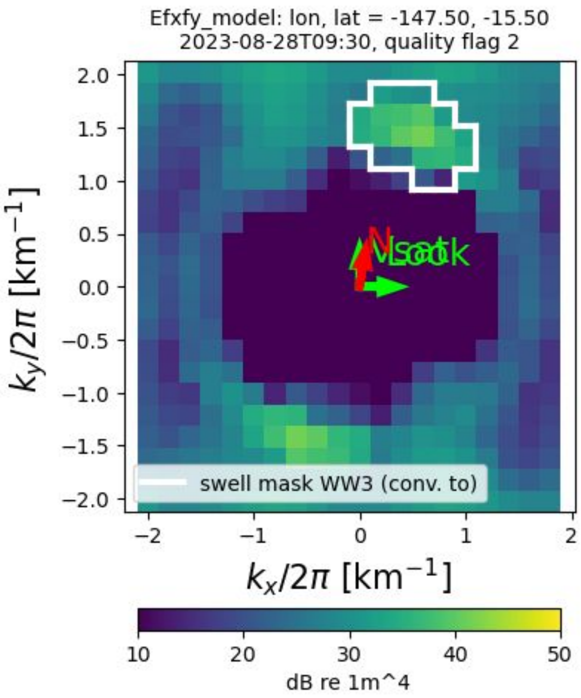
Colocate WW3 model spectra and deduce a swell mask (preliminary version)

Compute integrated wave parameters using swell mask : H18, L18, phi18





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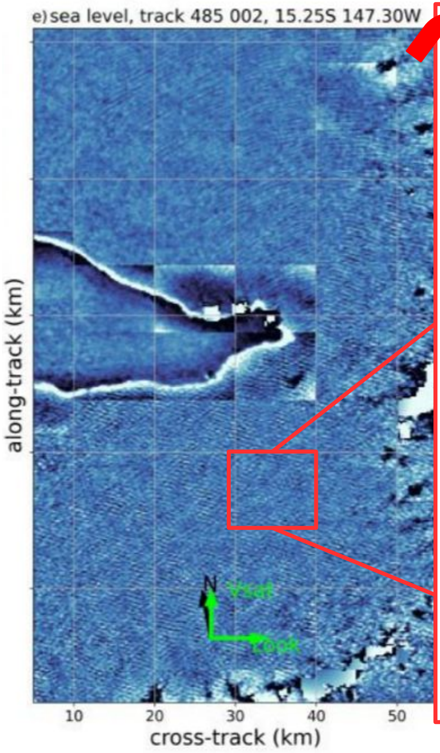
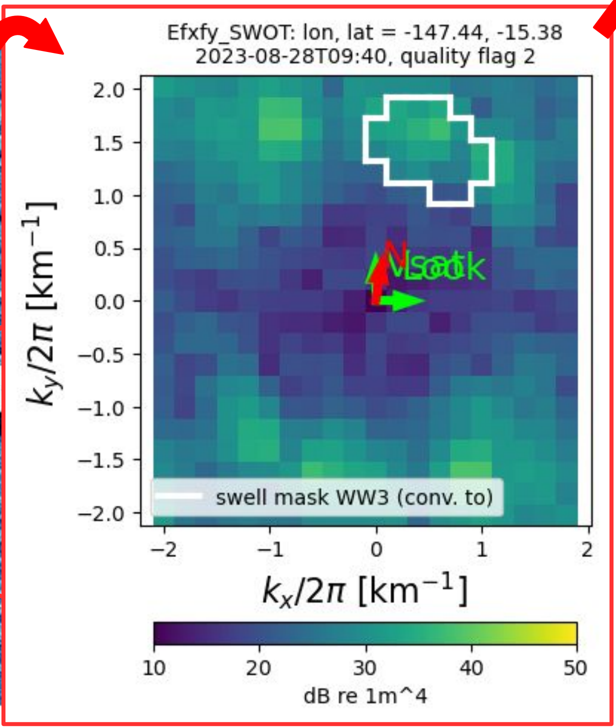
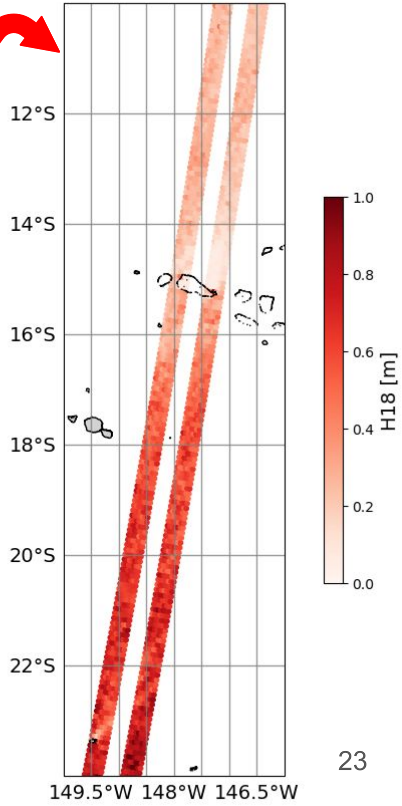
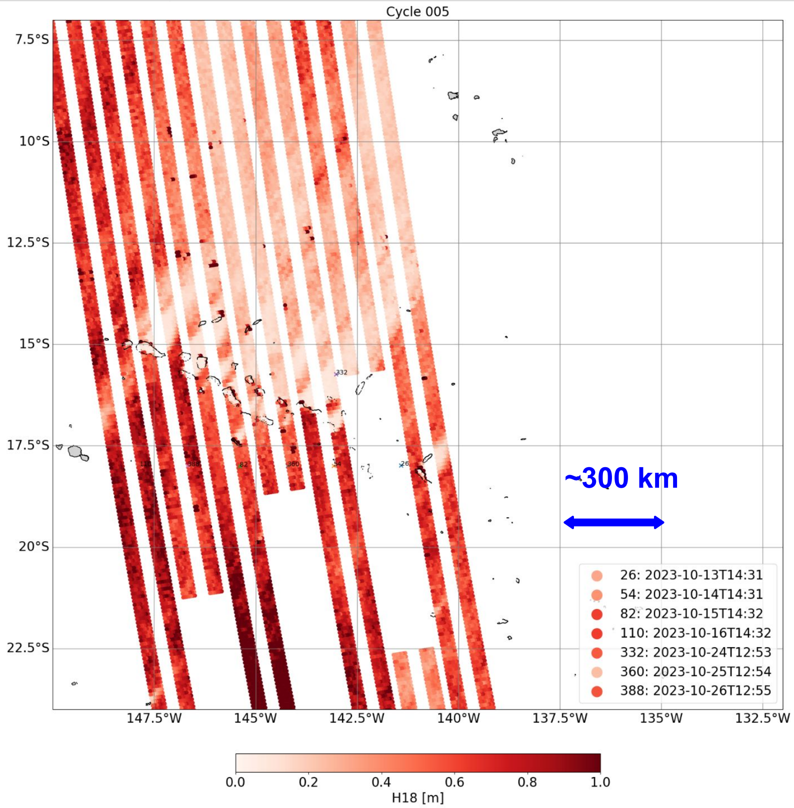






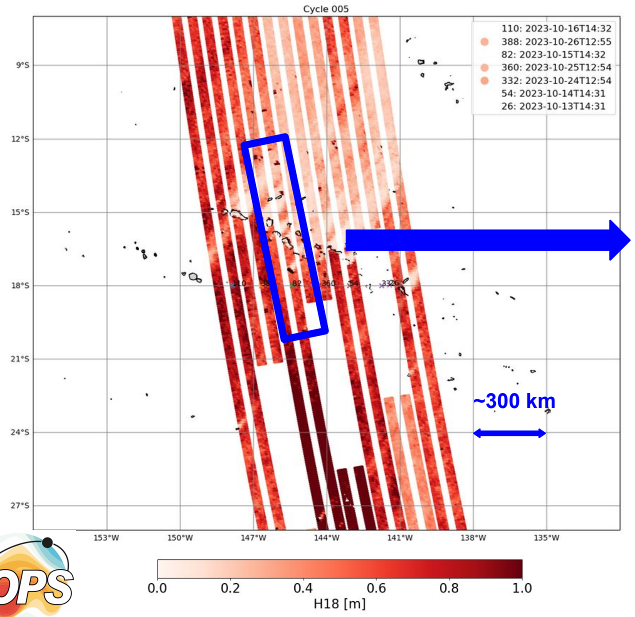
Integrated H18 maps computed on SSHA spectra **using swell mask deduced from WW3 spectra**

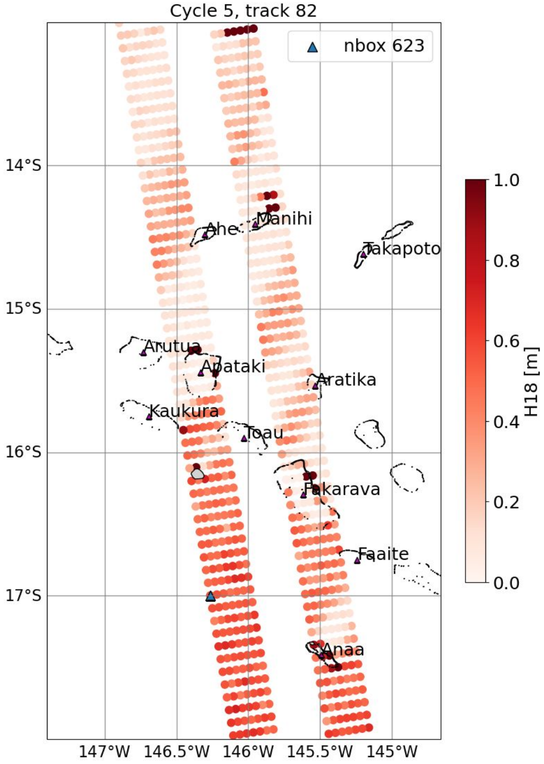
- Separate swells from wind seas (**λ > 500m eq T > 18s**)
- Regional island shadowing effect
- Strong small islands shadows
- V1 dataset available at CNES aviso ftp



Zoom on track 82, cycle 5

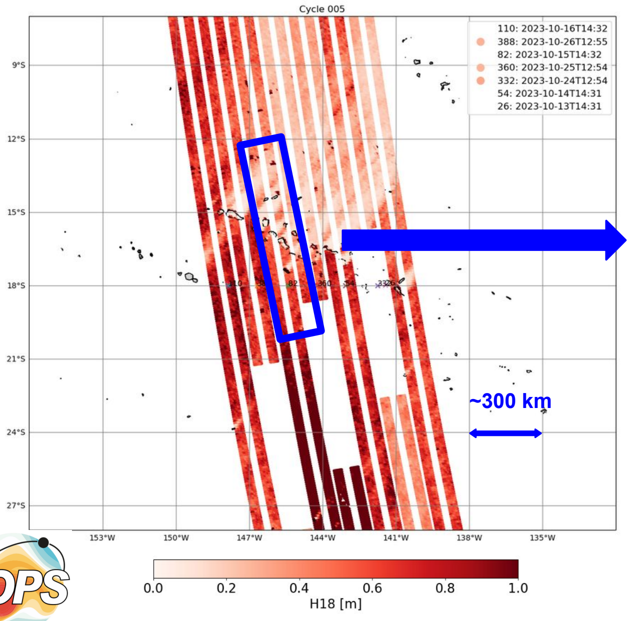
→ Informations on wave transformation at local scale : **attenuation**

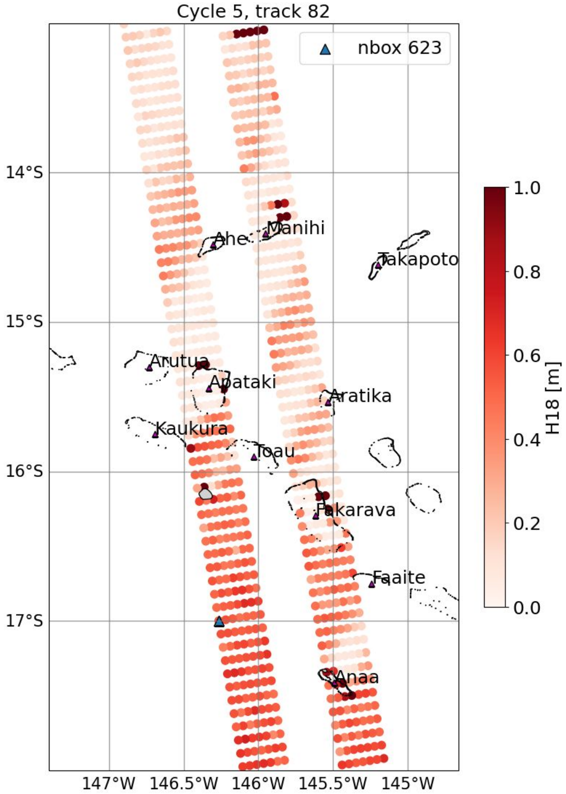


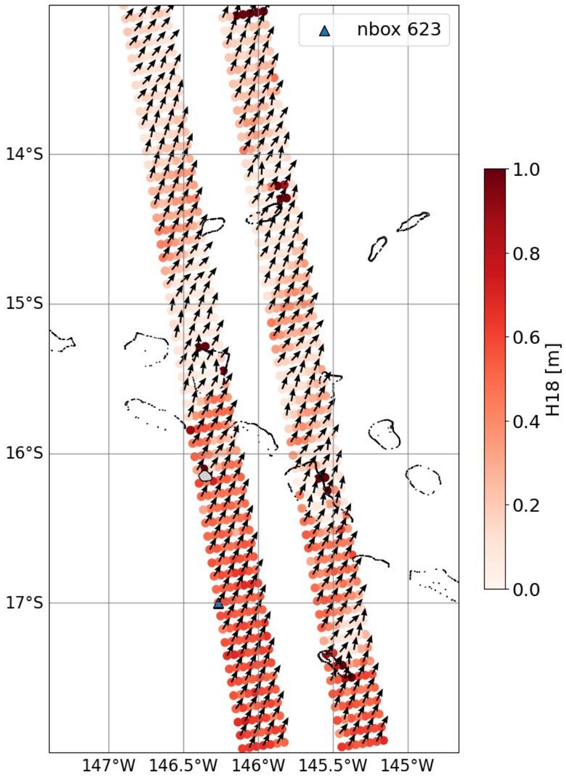


Zoom on track 82, cycle 5

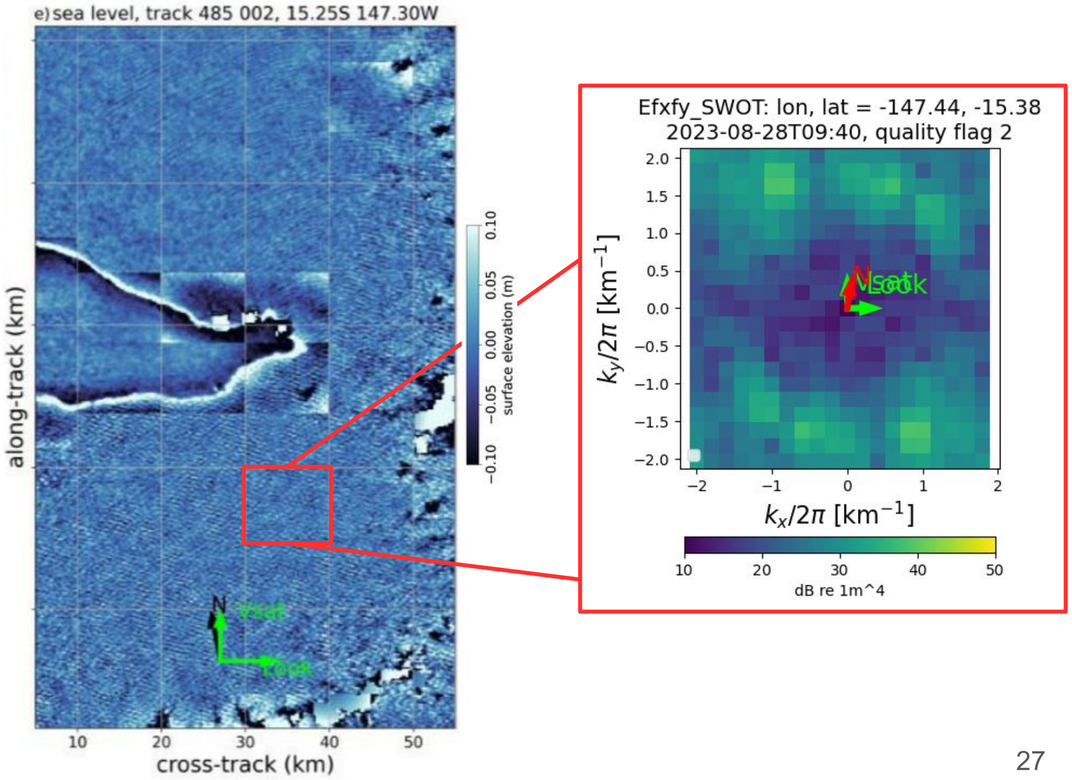
→ Informations on wave transformation at local scale : **attenuation & rotation**



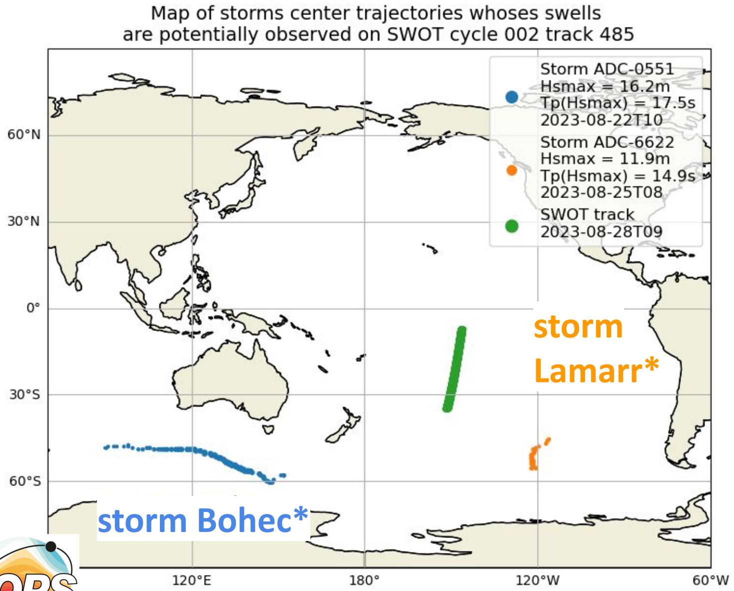


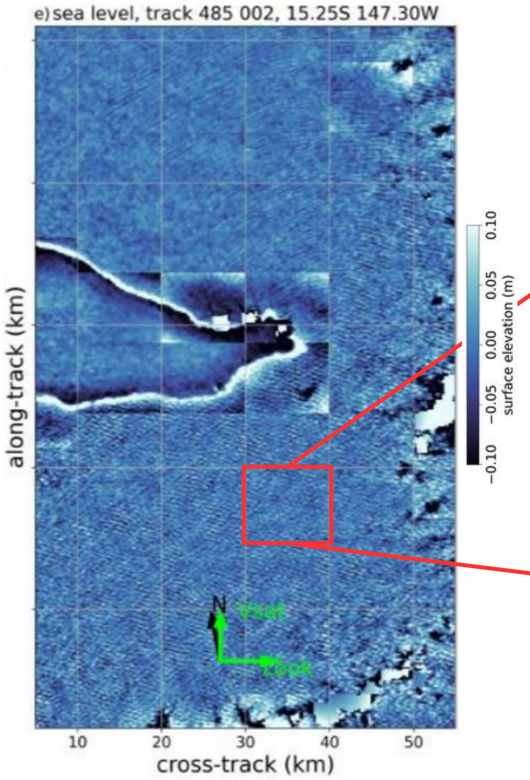


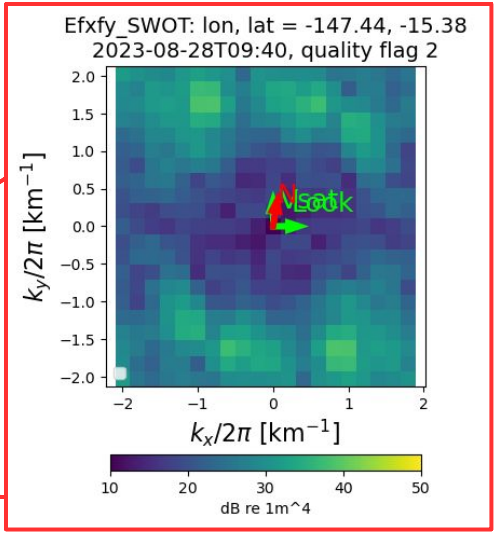
Come back on track 485, cycle 2, over passing Rangiroa
→ **2 swells** arriving on Rangiroa atoll



Come back on track 485, cycle 2, over passing Rangiroa
→ **Sharpen swell mask precision** using theoretical storm center position







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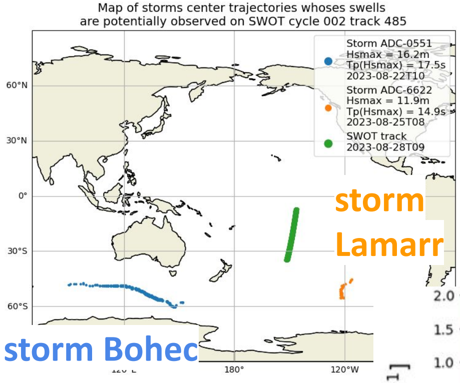
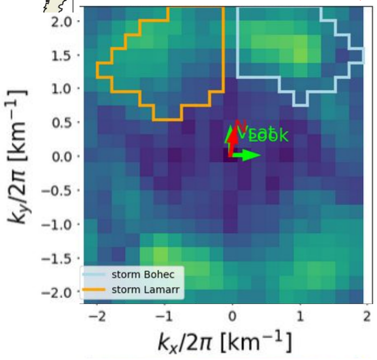
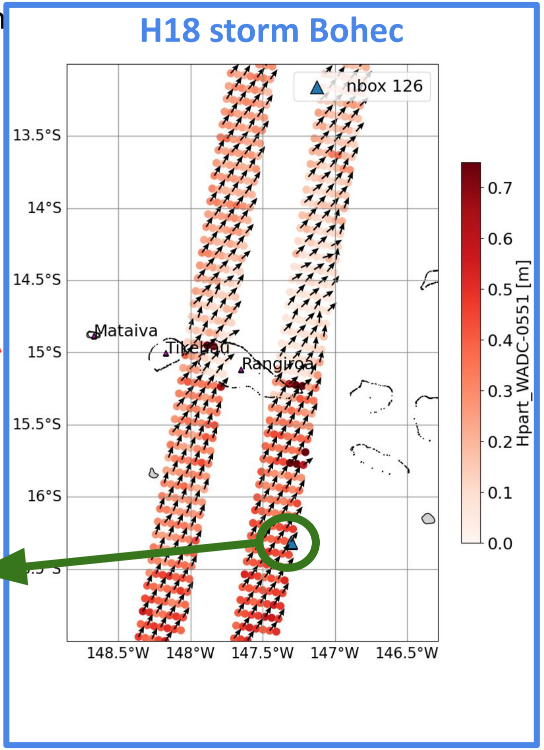
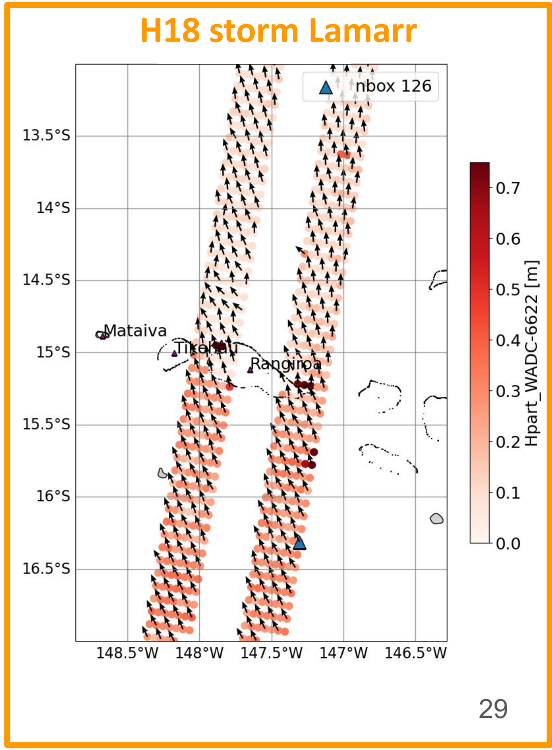








Conclusion

Photo credit : Tim McKenna

What can SWOT tell us about wave model performances and wave transformation across Tuamotu Archipelago ?

- **Realistic 2D view of wave field transformation**, both near the atolls and in lagoons
- Promising **data for model validation** in geomorphologically complex areas
- SWOT sea level observations offer **spectral informations on long swells** (λ > 400m)
- Unfold **wave transformation quantification** possibilities (obstruction grids, model forcings, wave refraction, reflection..)
- SWOT data is new → **understanding still in progress** (instrumental noise, surface wave effects on sea level measurements etc ..)

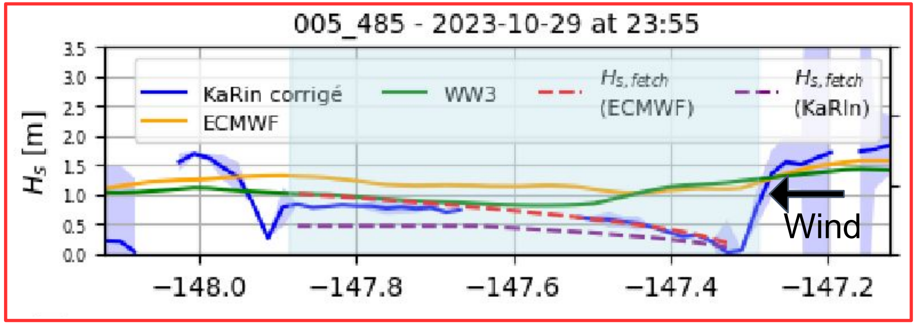
Back up slides

Access to SWOT spectral informations derived from sea level measurements : https://swot-community.github.io/SWOT-galleries/SWOT-Oceanography/ex_swot_l3_lr_ww_startup.html

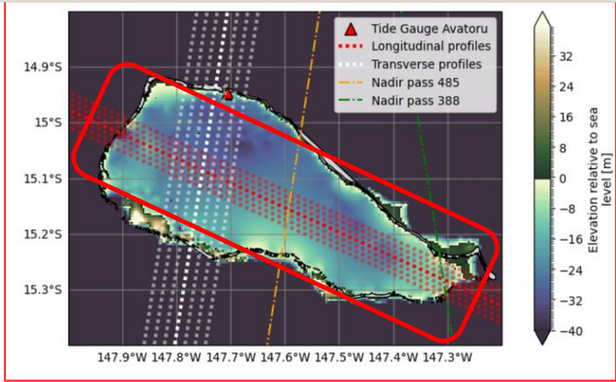
Access to SWOT Hs data : https://swot-community.github.io/SWOT-galleries/SWOT-Oceanography/ex_swot_l2_basic_startup_aviso_ftp.html

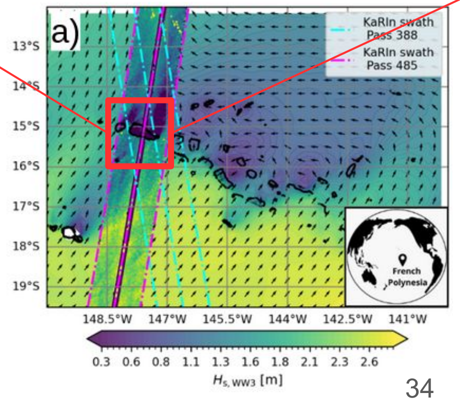
Wave attenuation in Rangiroa lagoon

- Strong swell attenuation induced by breaking over reef top
- Lagoon Hs overestimated by wave models
- Hs up to 1m observed in the lagoon (low wind)
- Wave growth in the lagoon partially explained using fetch law (Windspeed ~ 5m/s)



Waves (ESE)





Fetch law (eq 37 Elfouhaily et al. ('1997):):

$$H_s \approx 0.26 \frac{U_{10}^2}{g} \left(\min \left\{ \frac{X^*}{X_0^*}, 1 \right\} \right)^{0.5}$$