DEVELOPMENT OF A NEW UAV-BASED LIDAR ALTIMETRY SOLUTION FOR IN-SITU WAVE SPECTRUM ESTIMATION

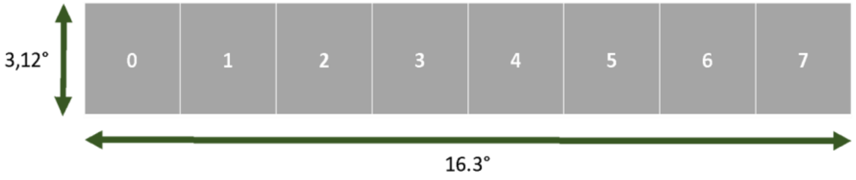
V.Fouqueau, JC.Poisson, G.Valladeau (vortex.io, France)
F.Boy, C.Tourain, C.Tison (CNES, France)

www.vortex-io.fr/

PRESENTATION OF THE ALTIMETER TECHNOLOGY

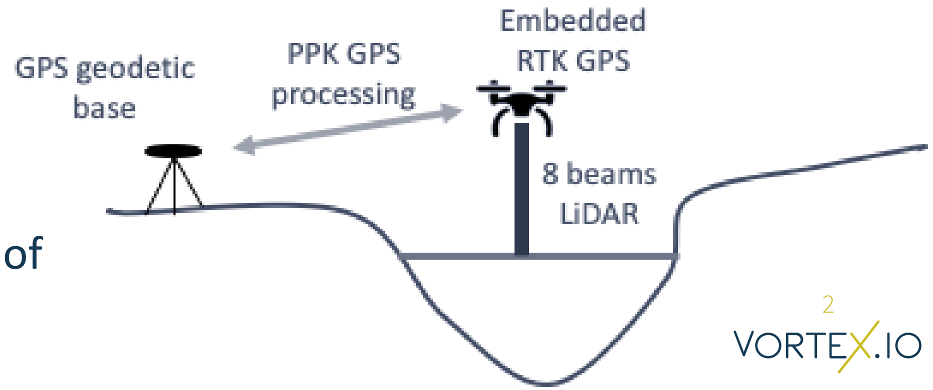
Altimeter characteristics

- **General**
  - Compatible with all drones capable of carrying 1kg
  - 900 gr / 3h of autonomy
- **LiDAR**
  - cm-level accuracy
  - from 50 cm to 90 meters range
  - 8 beams on a 16.3° swath
- **Camera**
  - 8 Megapixels
  - water masks
  - Orthophoto
  - Images of the water surface



Computation of the sea surface height :

- Computation of the **precise position** of the altimeter by PPK positioning
- Computation of the sea surface height by **correcting** the **precise position** of the altimeter by the **air drought** measured by the **LiDAR**



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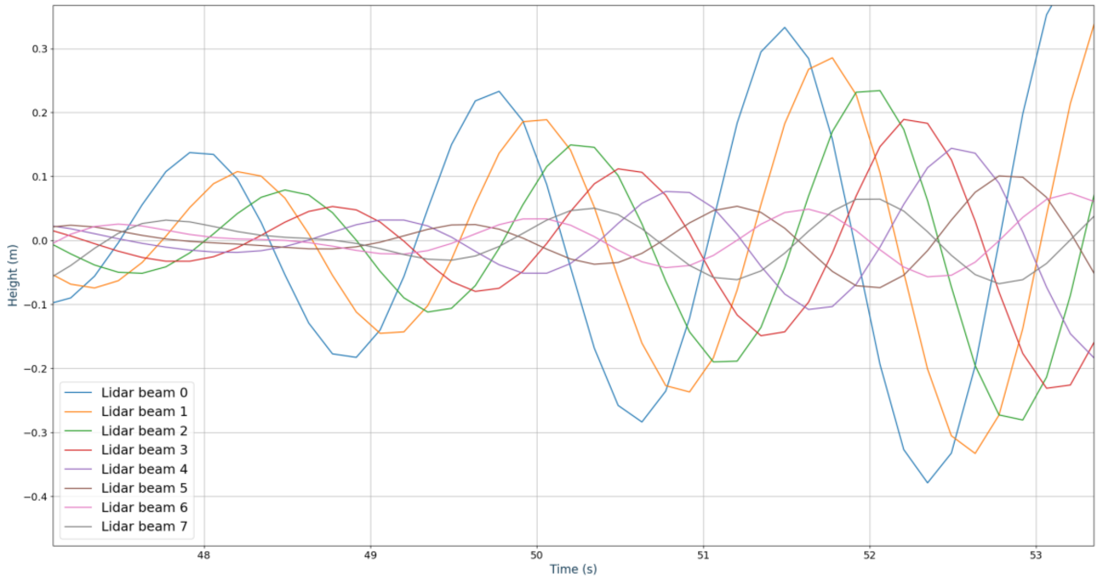
OBJECTIVES

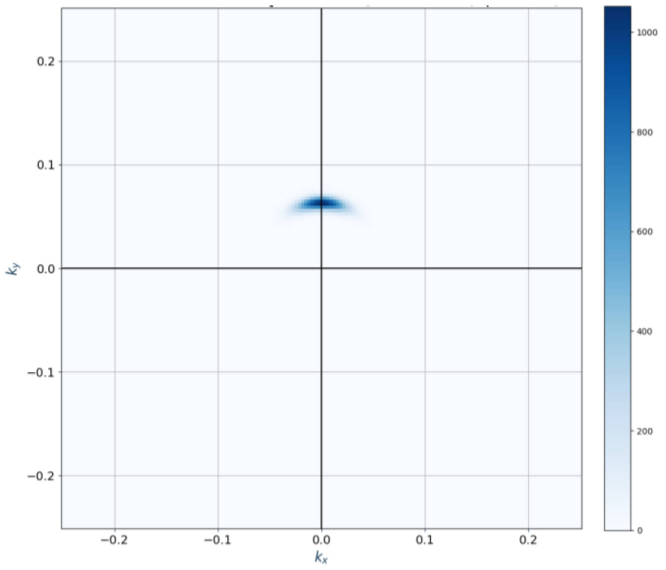
Can the vortex.io light-weight altimeter embedded on a UAV measure directional wave spectrum, to become a new Cal/Val system ?

VS



Sea surface height measurement

Computation of **directional wave spectrum** from the **SSH measurements**



Directional wave spectrum

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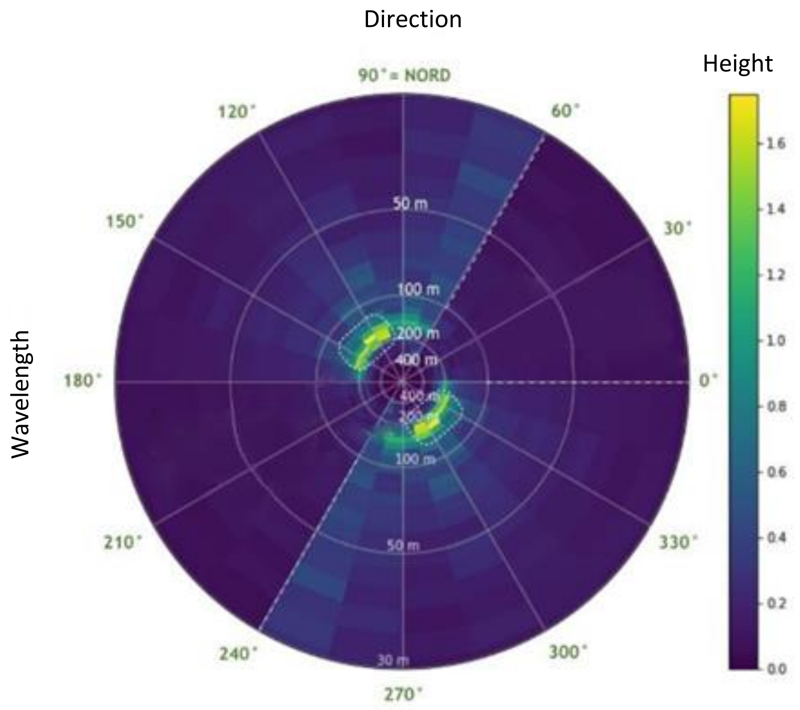
DIRECTIONAL WAVE SPECTRUM DEFINITION

Directional wave spectrum

- Describe the sea state
- Map the **energy** of the wave systems by their **frequency** and their **direction of propagation**

There are 2 types of wave systems :

- **The swell:** defined by $\boldsymbol{\lambda}$ **et** $\boldsymbol{\phi}$
- **The wind waves:** defined by $\boldsymbol{V}$ **et** $\boldsymbol{\phi_v}$



We can write the directional wave spectrum $\boldsymbol{S(f,\theta)}$ as :

$$\boldsymbol{S(f,\theta) = E(f)\,D(f,\theta)}$$

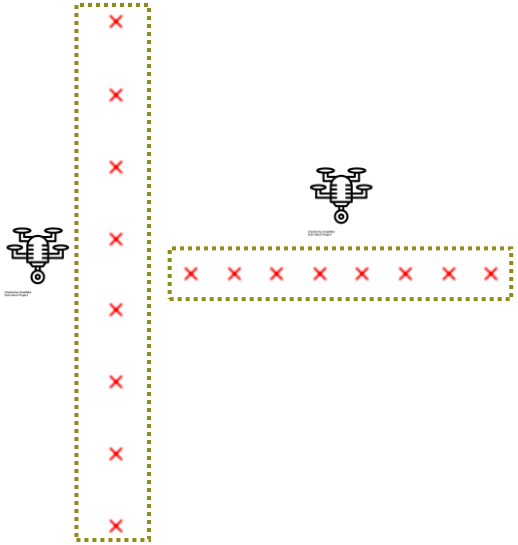
With $\boldsymbol{E(f)}$ the non-directional wave spectrum and $\boldsymbol{D(f,\theta)}$ the directional spreading function

We need to compute an estimation of $\boldsymbol{D(f,\theta)}$ and $\boldsymbol{E(f)}$ from the **sea surface height** measurement made by **vortex.io altimeter**

FLIGHT PLAN AND SIMULATIONS

Definition of the flight plan

Flight plan



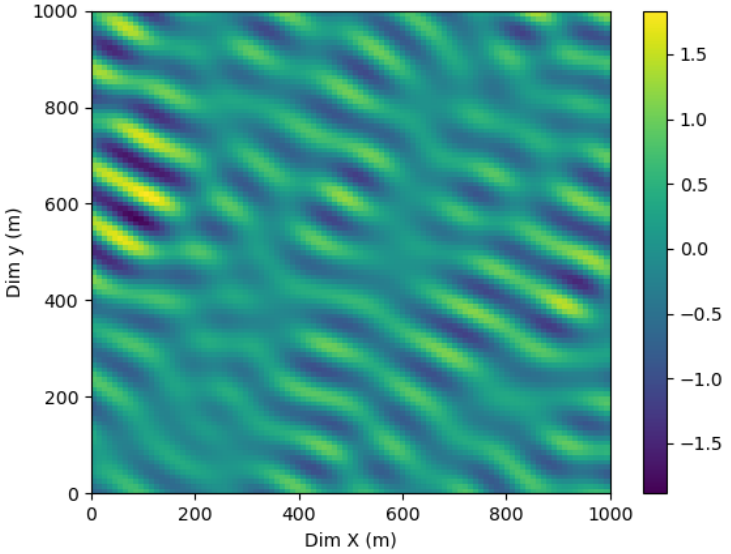
Red crosses correspond to the **LiDAR measurements**

- We need to define **the flight plan** before generating the simulation
- **Static flights** of 20 minutes
- Measure located on a plan → **2 drones** at the same time flying in a **T-shape**
- Flight altitude → **50 meters**

Generation of the simulations

- Generated from **Elfouhaily** theoretical spectrum **(λ, ϕ)**
- Generated with RADARSPY from **CNES**
- We generated the measurements only on the **16 points** that corresponds to the **LiDAR beam location** on the surface

Simulated sea surface



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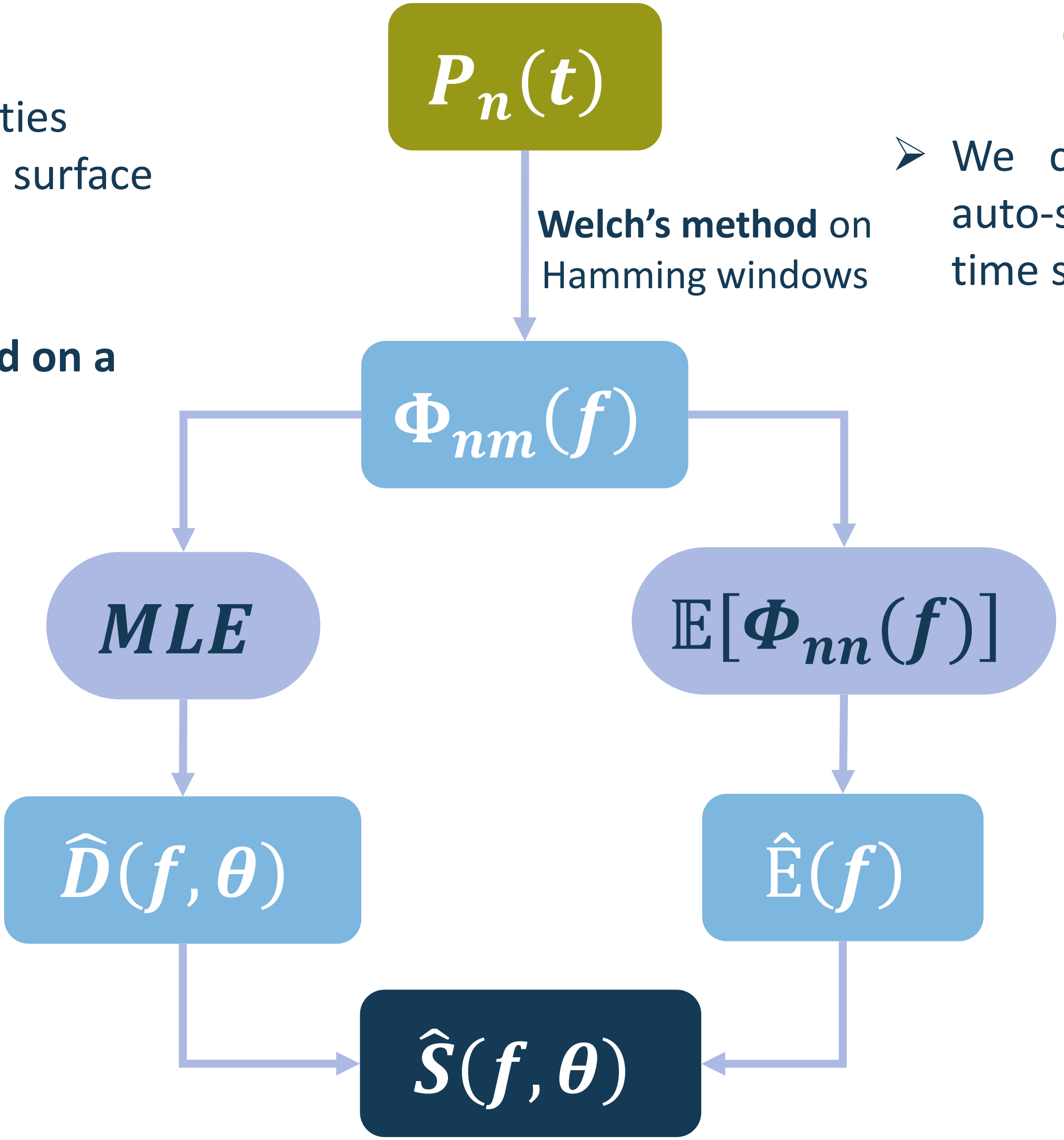
ESTIMATION METHOD

Observations

- **N** time series of physical quantities noted $P_n(t)$ (can be elevation, surface speed, vertical acceleration …)
- Measurement point **distributed on a plan** or single point measuring **directional physical quantities**

Cross-spectrum matrix

- We compute the cross-spectrum and auto-spectrum matrix between the **N** time series observed



Spreading function

- We compute the estimation of $\hat{D}(f,\theta)$ with a maximum likelihood estimator

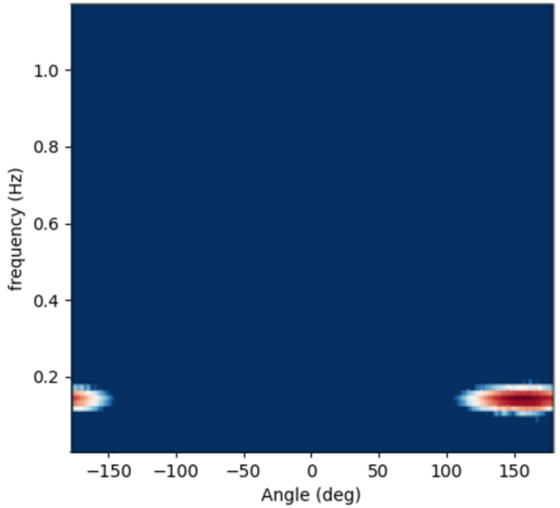
Non directional spectrum

- $\Phi_{nn}(f)$ correspond to the Fourier transform of the time series $P_n(t)$

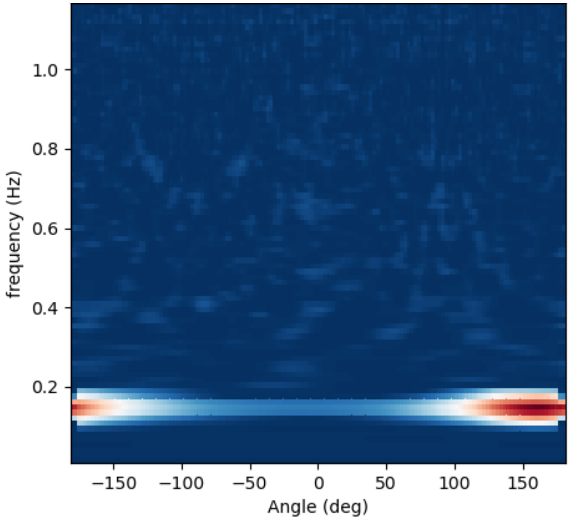
RESULTS ON SIMULATION

Simulation with **one swell system** and **gaussian noise** applied on the simulated measurements **(SNR 10 dB)** and **20% of missing measurements**

Theoretical spectrum

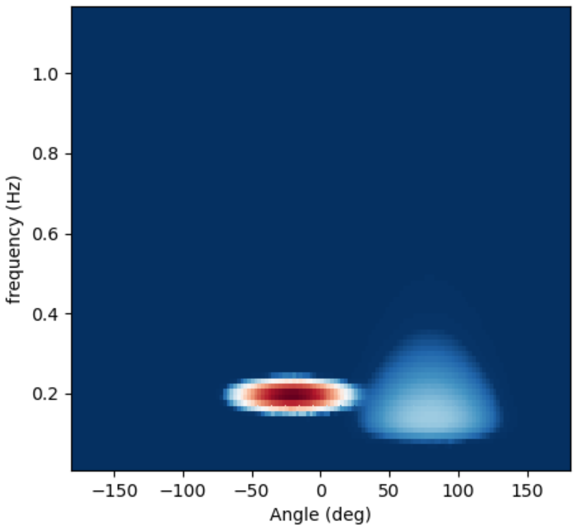


Estimated spectrum

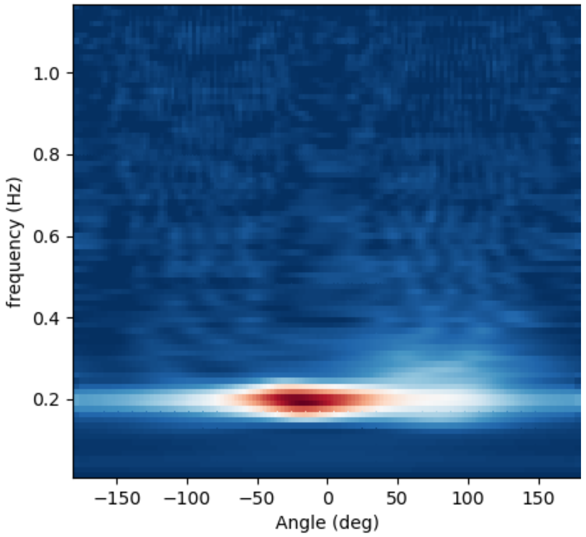


Simulation with **one swell system,** a **wind wave system** and **gaussian noise** applied on the simulated measurements **(SNR 10 dB)** and **20% of missing measurements**

Theoretical spectrum

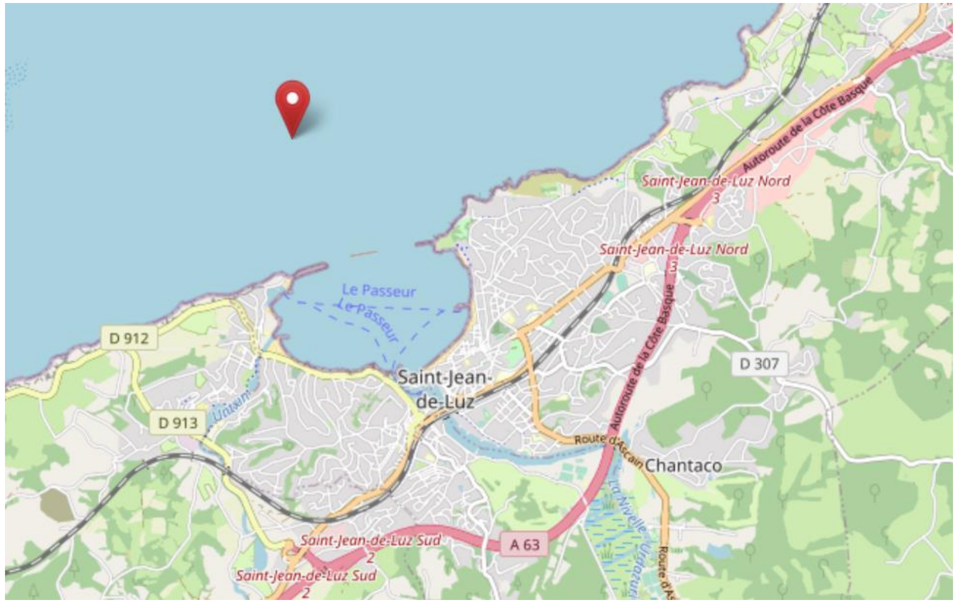


Estimated spectrum



- The estimation method **works very well** on all kind of simulations with **different sea states** (Multiple swell systems, wind waves) with different amplitude and direction
- The angular spreading is due to the **missing measurements** and increased by the **gaussian noise**
- The method **works on simulation**, we can test it on **real data**

PRESENTATION OF THE FIELD CAMPAIGN



The field deployment was performed the 1st October 2021 just outside of Saint-Jean-de-Luz bay:

- Measurement made next to a **buoy** from the French **CANDHIS** network
- Take-off from a boat
- Issue with one drone, campaign performed with one altimeter

Sea state observed :

- Very **low wind**
- Monochromatic swell with a **8-10 seconds period**
- **Low swell amplitude** around 50 – 70 cm

The sea state is **smoother** than expected

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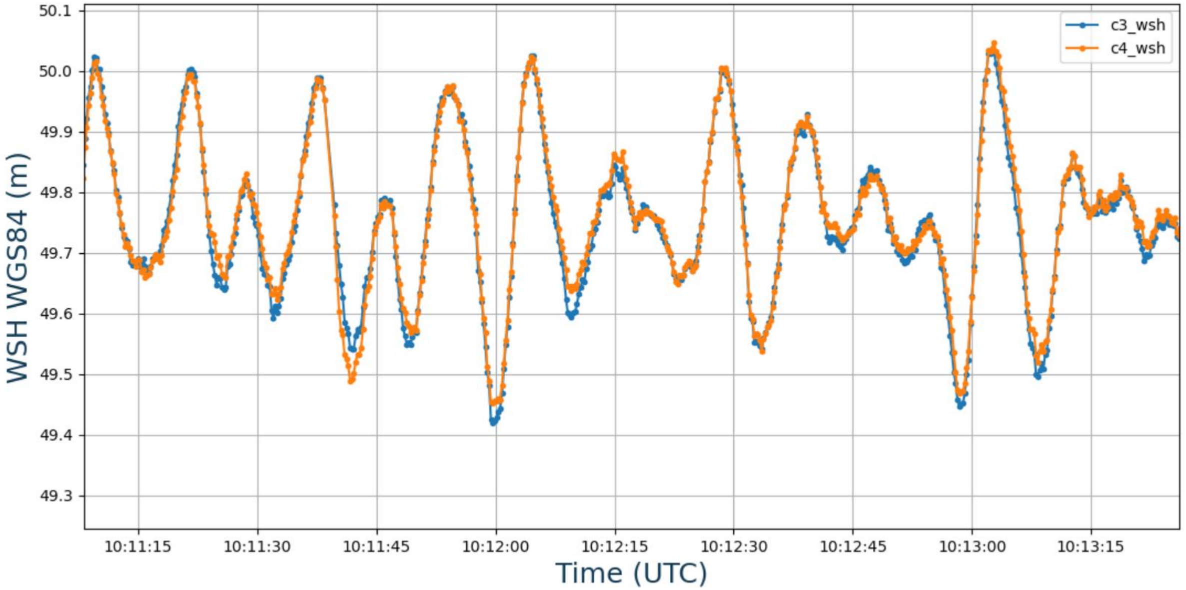
RESULTS ON THE FIELD CAMPAIGN → SSH

Sea surface observed by vortex.io altimeter

Camera

LiDAR



- The camera records **the sea surface movements**, we can observe precisely the wave system
- We observe precisely **the swell** with the LiDAR, it is a excellent measurement of **sea surface height**
- Only 2 beams are represented here for the sake of clarity, but **we have measurement on the 8 beams**

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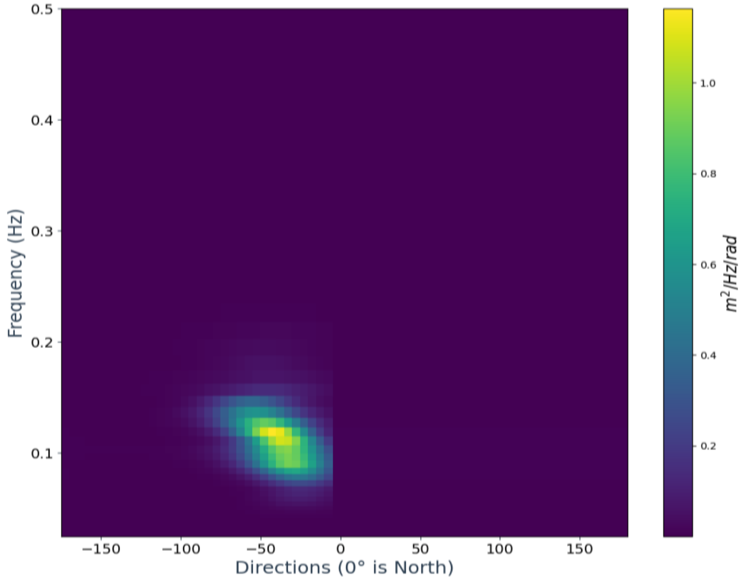
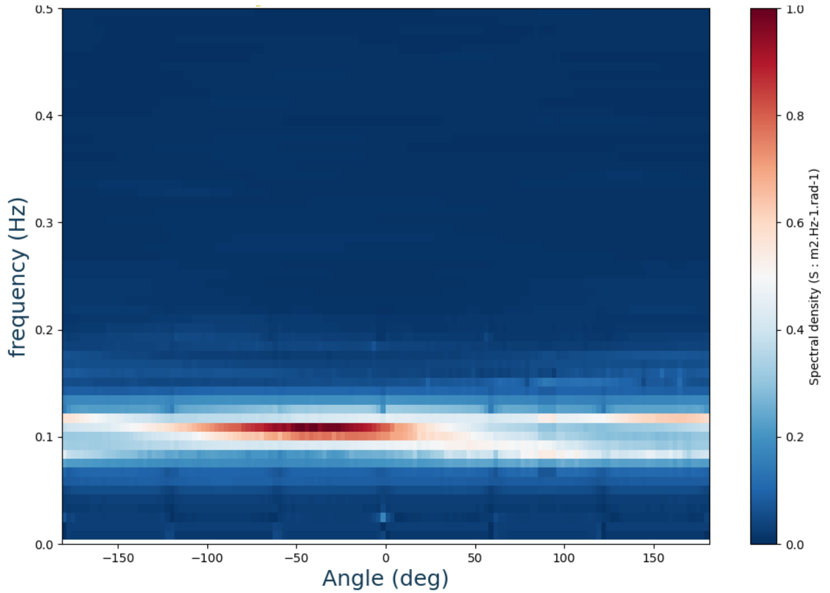
RESULTS ON THE FIELD CAMPAIGN → SPECTRUM

Directional wave spectrum measured in Saint-Jean-de-Luz

CANDHIS buoy



Vortex.io altimeter



- The directional wave spectrum measured by vortex.io altimeter **is similar to the one measured** by the CANDHIS buoy
- **The accuracy is excellent** for the frequency and good for the direction with an angular spreading
- It is a first raw POC: **no post-processing or editing** has been applied to the vortex.io spectrum

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CONCLUSION OF THE PROJECT

- The method **works perfectly on the simulations**, we obtained excellent results on all the **different sea states** with perturbations
- The **results** of the campaign are **very good**, even with an almost **calm sea surface** and only one drone
- The comparison with the **CANDHIS buoy** tells us that our **method is accurate**
- This project was only a proof of concept, **the results exceed our expectations**

Vortex.io altimeter is a valid method to measure sea swell spectrum

NEXT STEPS

ONGOING

1. Development of a **second estimation method** based on the **LiDAR and camera** to increase the accuracy

2. **Improvement** of the estimation method (Filtering, post processing, drop of hamming windows with missing data …)

3. Definition of the **best flight plan** and performance analysis

POSSIBLE / SOON

4. Development of a **new altimeter** with a **grid LiDAR** to perform the measurement with **only one altimeter**

FINAL GOAL

5. Miniaturization of the altimeter to embed it with under an **autonomous drone**

6. Development of an **automatic product** that measure **sea state** (SSH and wave spectrum) from the coast based on **autonomous drone**

2023


Thank you for your attention
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