

### 3. Application of the digital Intelligent operational network architecture to the SATH Technology

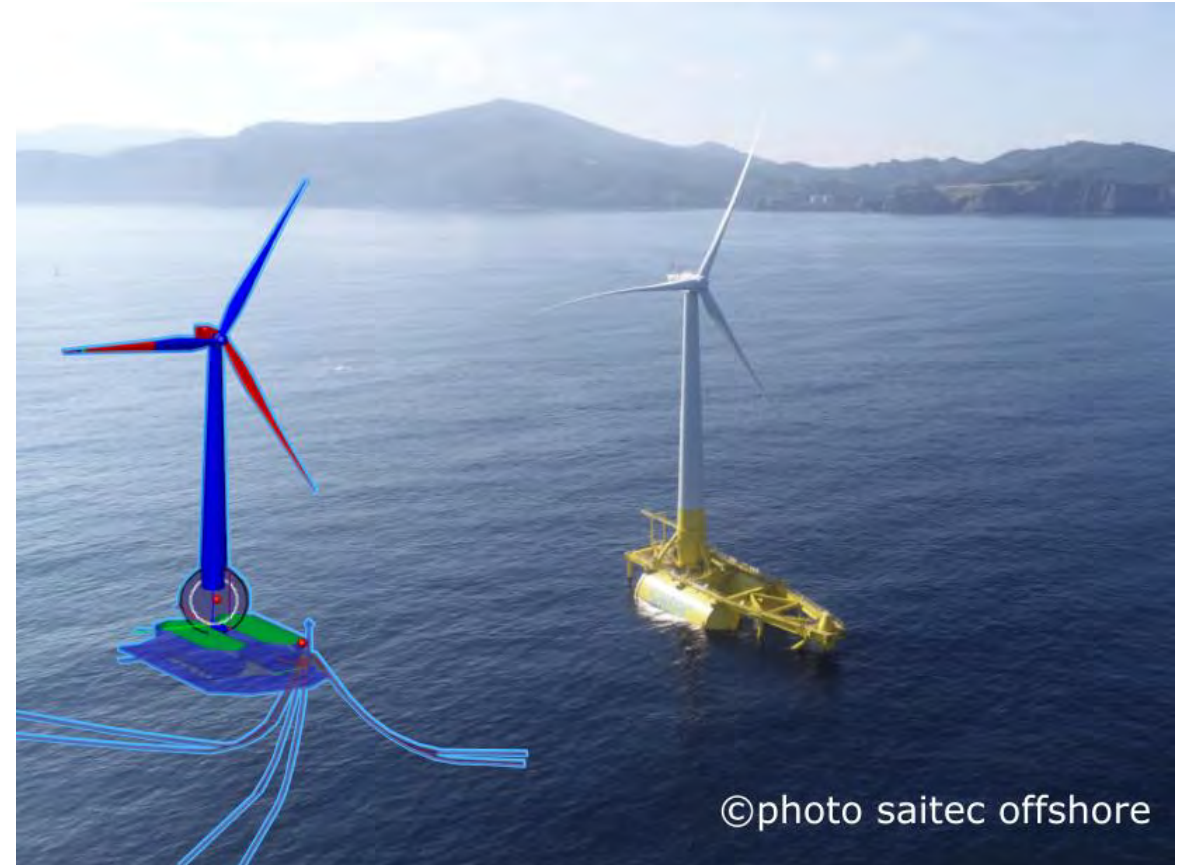
#### Part II – High-level description and model measure comparisons of digital twin technology



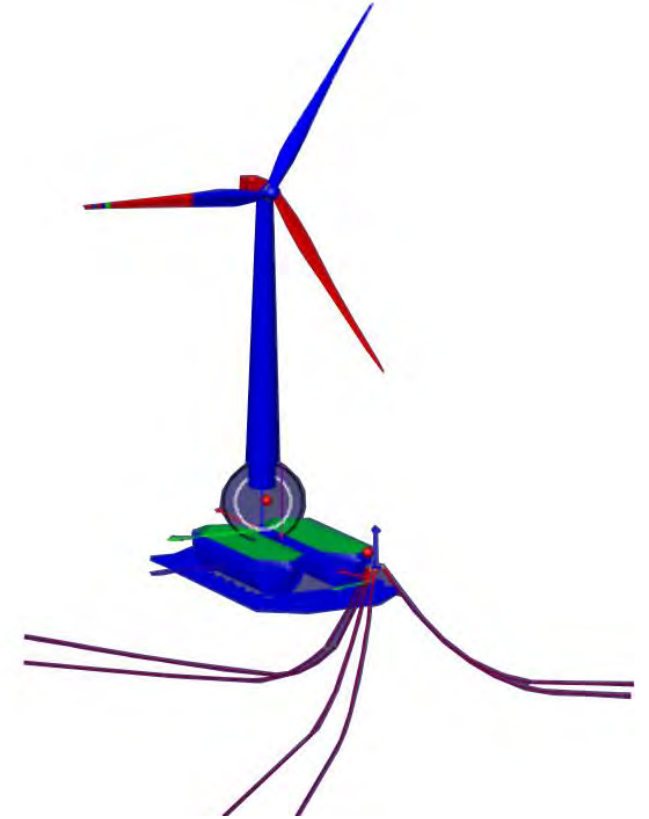
Romain Ribault, FRANCE ENERGIES  
MARINES



- Digital Twin tool applied to DemoSATH
- High level Digital Twin presentation
  - Based on previous work during DIONYSOS project
  - Adaptations for SIMA & other tools
- Model-measure comparisons in next presentation
  - With DemoSATH SCADA data
    - 20 channels provided by SAITEC
    - Over 400h of data at 1hz



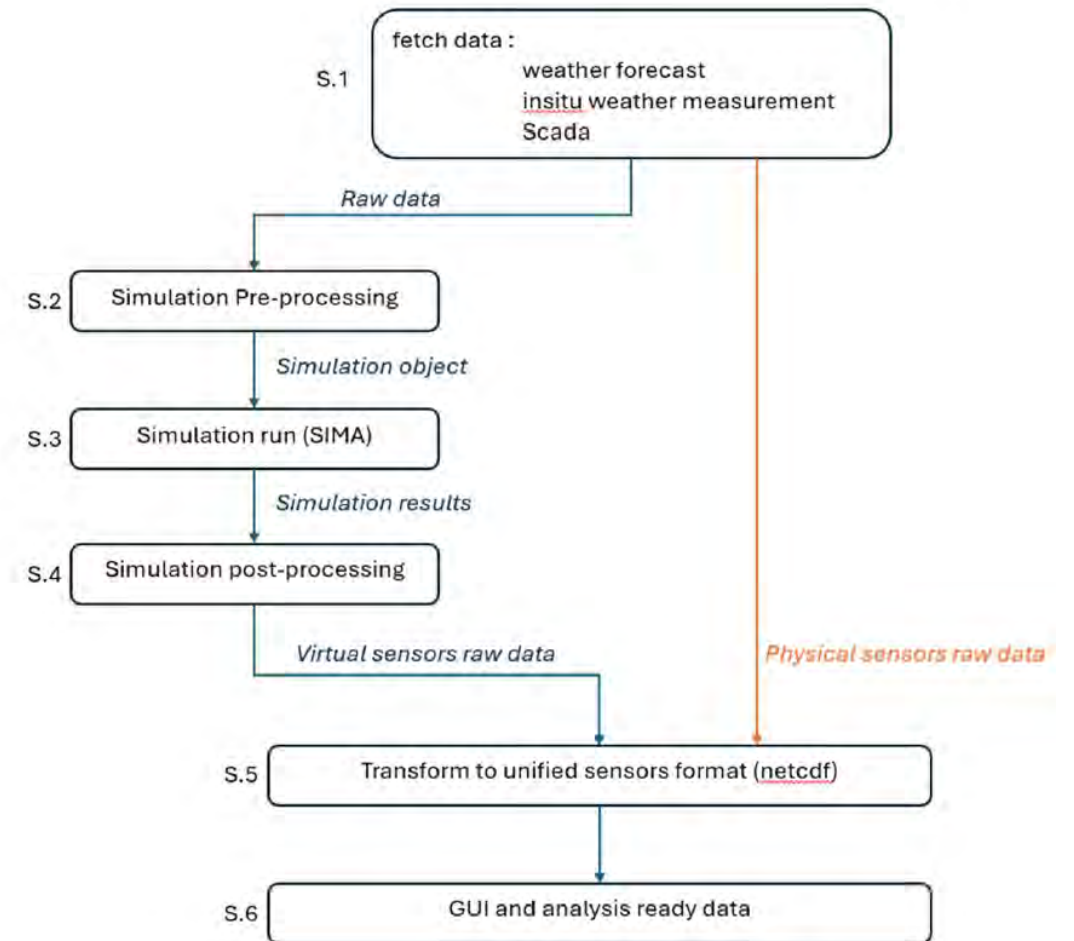
- SIMA fully coupled model
  - Mooring
  - Hydrodynamics
  - Structure
  - Aerodynamics
  - Controller
- Input parameters
  - Waves & current conditions
  - Turbsim input
  - Quadratic damping
  - ...
- Calibrated over years
  - Wave basin campaigns



Vittori, F., Azcona, J., Eguinoa, I., Pires, O., Rodríguez, A., Morató, Á., Garrido, C., & Desmond, C. (2022). Model tests of a 10 MW semi-submersible floating wind turbine under waves and wind using hybrid method to integrate the rotor thrust and moments. *Wind Energy Science*, 7(5), 2149–2161. <https://doi.org/10.5194/wes-7-2149-2022>

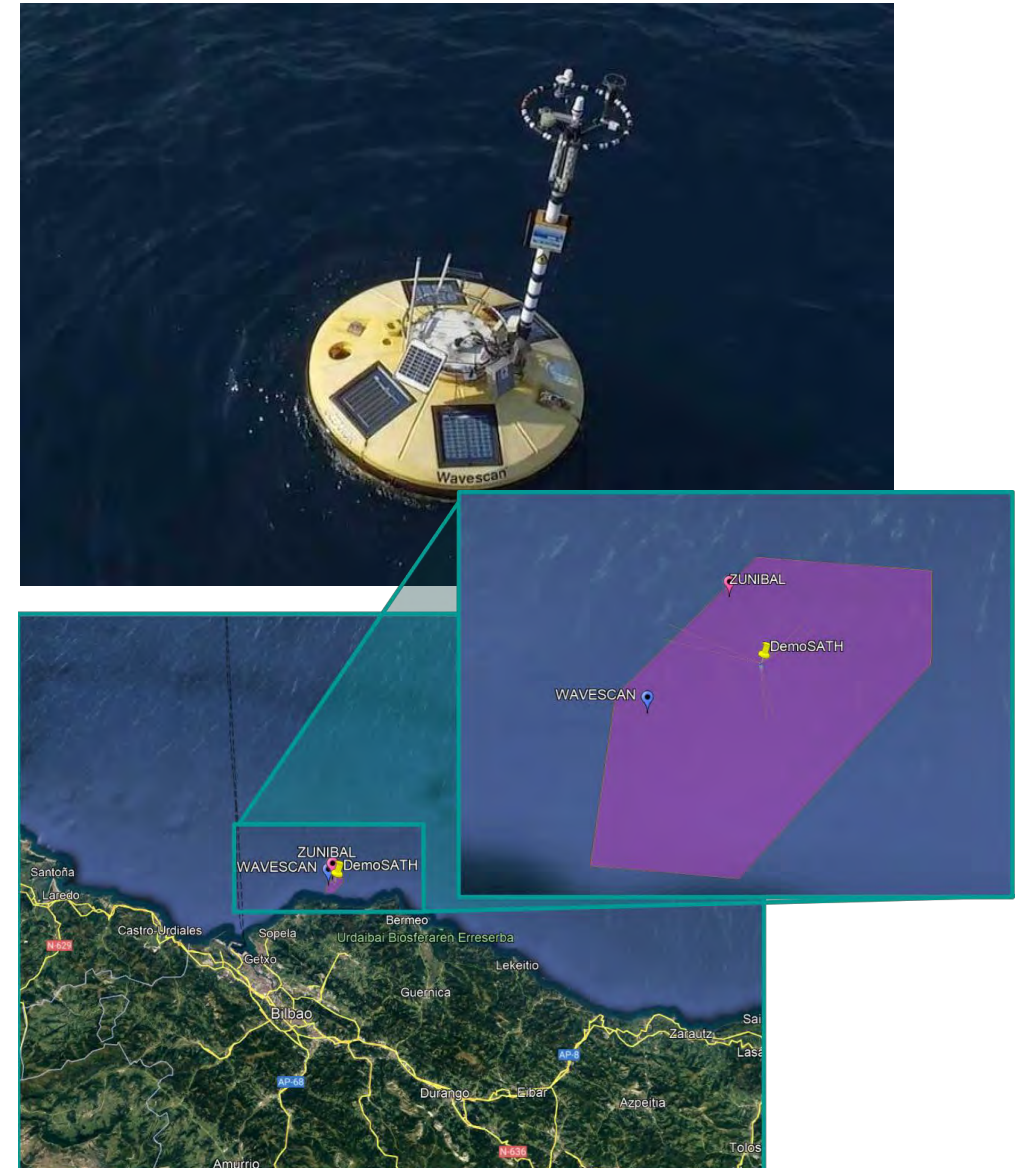
# Digital Twin global process overview

- Automated fetching & simu. Runs
  - Weather forecast
  - In-situ measurements
  - SCADA
- Simulation run
  - Pre-processing inputs
  - Run simulations
- Automated data post-processing
  - Units changes
  - Unified naming channels & reference frames
  - Automated cleaning
  - Merge data
- All data unified in a single database



# Digital Twin global process overview

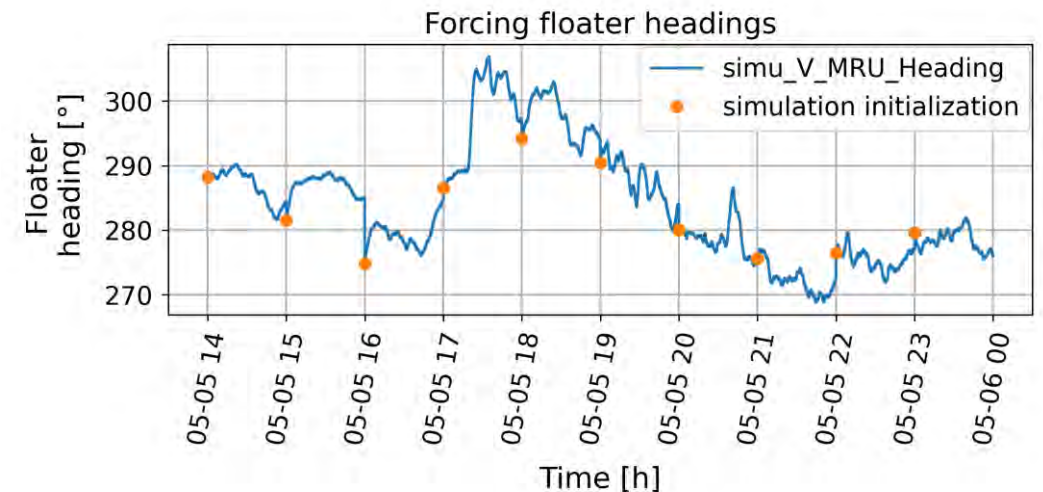
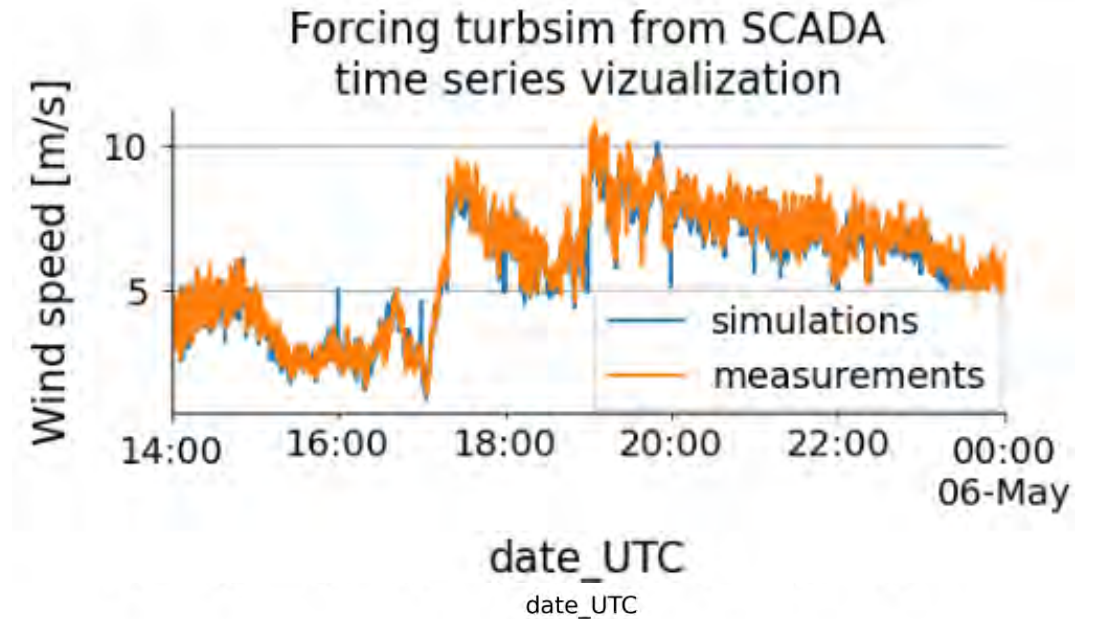
- Automated fetching & simu. Runs
  - Weather forecast
    - WAVEWATCH III
    - ARPEGE
    - MARS 2D
  - In-situ measurements
    - Wave buoy
    - Wind speed
    - Current
  - SCADA data
    - 20 channels provided by SAITEC
    - Punctual data transmission 400h at 1 Hz



# Digital Twin global process overview

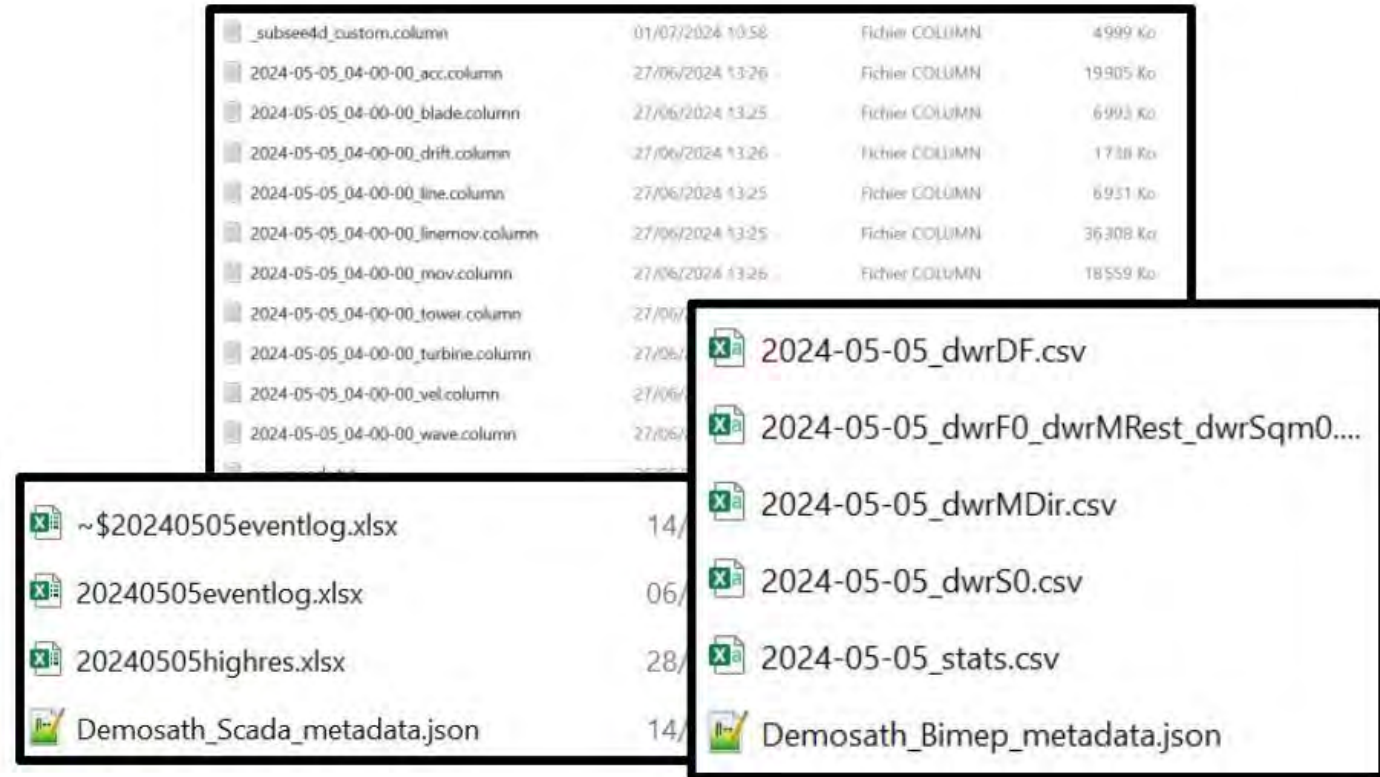
- Automated fetching & simu. Runs
  - Weather forecast
  - In-situ measurements
  - SCADA
- Cross-checking the different sources
  - Illustration with wind directions
- Forcings
  - wind time series with SCADA
  - Floater headings at simulation initialization

	Priority 1	Priority 2	Priority 3
<b>Wind</b>	1Hz time series from turbine anemometer	1h wind from weather buoy anemometer	1h mean wind speed & direction from ARPEGE
<b>Wave</b>	1h stats from buoy wave sensor	3h stats from WWIII forecast	
<b>Current</b>	1h stats from surface measurements of wave buoy	1h stats on surface velocity from MARS 2D	



# Data formatting & post-processing

- After simulation run we get
  - Numerous simulation files
  - SCADA files
  - In-situ measurement files
  - SIMA input file
  - Log files
  - ...
- This could include
  - Erroneous data
  - Missing values/ files
  - ...



_subseedd_custom.column	01/07/2024 10:58	Fichier COLUMN	4 989 Ko
2024-05-05_04-00-00_acc.column	27/06/2024 13:26	Fichier COLUMN	19 905 Ko
2024-05-05_04-00-00_blade.column	27/06/2024 13:25	Fichier COLUMN	6 993 Ko
2024-05-05_04-00-00_drift.column	27/06/2024 13:26	Fichier COLUMN	1 738 Ko
2024-05-05_04-00-00_line.column	27/06/2024 13:25	Fichier COLUMN	6 931 Ko
2024-05-05_04-00-00_linemov.column	27/06/2024 13:25	Fichier COLUMN	36 308 Ko
2024-05-05_04-00-00_mov.column	27/06/2024 13:26	Fichier COLUMN	18 559 Ko
2024-05-05_04-00-00_tower.column	27/06/2024 13:26	Fichier COLUMN	1 738 Ko
2024-05-05_04-00-00_turbine.column	27/06/2024 13:26	Fichier COLUMN	1 738 Ko
2024-05-05_04-00-00_vel.column	27/06/2024 13:26	Fichier COLUMN	1 738 Ko
2024-05-05_04-00-00_wave.column	27/06/2024 13:26	Fichier COLUMN	1 738 Ko

~\$20240505eventlog.xlsx	14/06/2024 10:58	Fichier EXCEL	14 000 Ko
20240505eventlog.xlsx	06/07/2024 10:58	Fichier EXCEL	14 000 Ko
20240505highres.xlsx	28/06/2024 10:58	Fichier EXCEL	28 000 Ko
Demosath_Scada_metadata.json	14/06/2024 10:58	Fichier JSON	14 000 Ko

2024-05-05_dwrDF.csv	14/06/2024 10:58	Fichier CSV	14 000 Ko
2024-05-05_dwrF0_dwrMRest_dwrSqm0....	06/07/2024 10:58	Fichier CSV	14 000 Ko
2024-05-05_dwrMDir.csv	28/06/2024 10:58	Fichier CSV	28 000 Ko
2024-05-05_dwrS0.csv	14/06/2024 10:58	Fichier CSV	14 000 Ko
2024-05-05_stats.csv	14/06/2024 10:58	Fichier CSV	14 000 Ko
Demosath_Bimep_metadata.json	14/06/2024 10:58	Fichier JSON	14 000 Ko

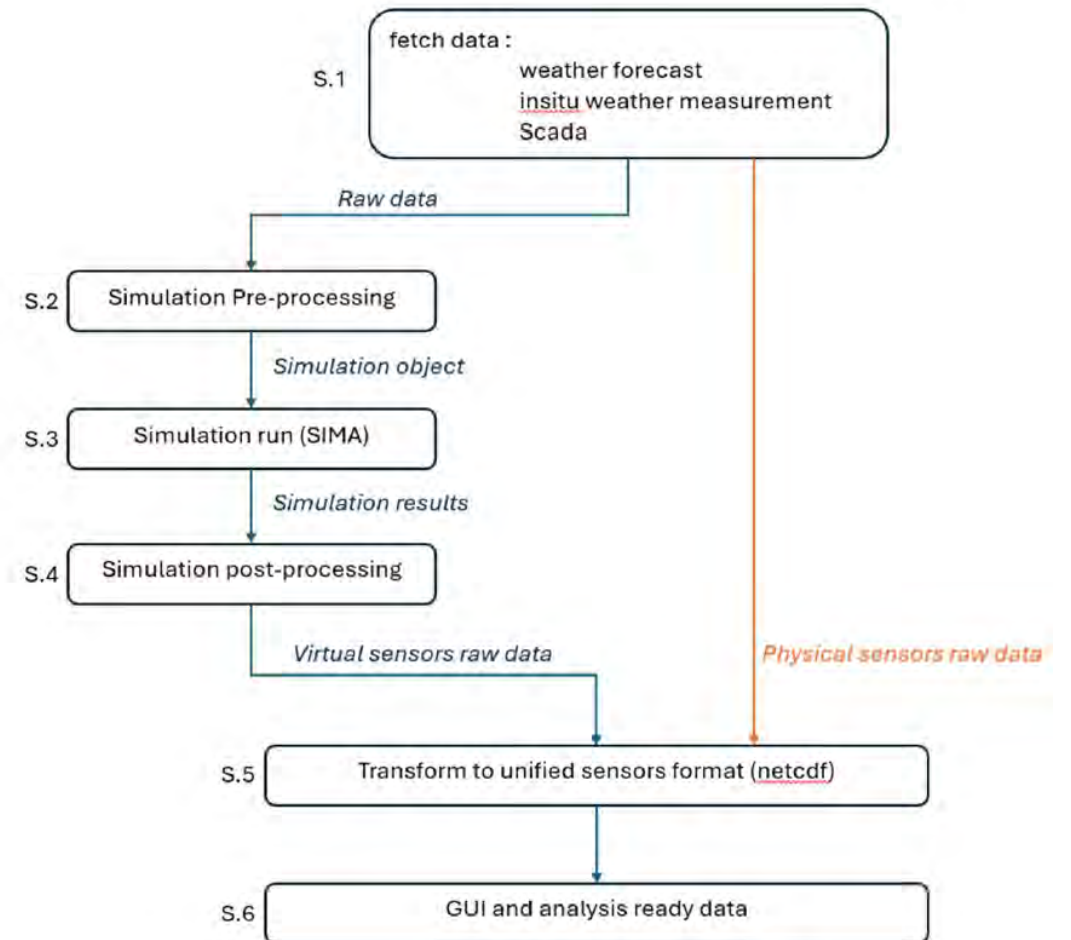
- Single file for all data sources: generic sensors
  - Unified naming scheme
  - Unified units & reference frames
  - All informations are condensed in one file
- Will include a first data cleaning
  - Interpolations
  - Out of range data cleaning
- Graphical User Interfaces
  - Tasks status
  - First visualizations
  - Erroneous inputs / outputs
- All data unified into one file

```
"AI_WindSpeed": {  
  "__type__":  
  "subsee4D:inputs:environment_sensors_catalogue:generic_sensors:channel",  
  "name": "AI_WindSpeed",  
  "description": "wind speed measurements by sonic anemometer",  
  "values": "values",  
  "Position": "ultrasonic anemometer above the nacelle, behind the blades",  
  "unit": "m/s",  
  "valid_min": 0,  
  "valid_max": 80.0,  
  "short_name": "AI_WindSpeed",  
  "allowable_interpolation_seconds": 1800,  
  "source": "Sima simulation",  
  "Channels": 1561889327,  
  "virtual_name": "WindSpeed"  
}
```

Status	Task name	Start time	End time
Success with errors	fetch_alloc_simu_results_SAITEC_PreProd	00h00	00h00
Success	Get_Weather_Forecasts_at_DEMOSATH	09h12	09h30
Success with Errors	datastream_none_SAITEC_PreProd_2024_04_11	09h30	09h30
Success	check_sea_state_reference_SAITEC_PreProd_2024_04_11	10h05	10h05
Success	run_newly_created_simulations_SIMA	10h10	11h41
Details			
Errors			
Children			
Success - Pre_Processing_24_simulations - 10h10 - 10h10			
Success - Run_Simulation_for_each_load_case - 10h10 - h			
Success with Errors	fetch_alloc_simu_results_SAITEC_PreProd	12h00	12h02
Details			
Errors			
Children			
Success with Errors - allocate_2024_04_11_00_00_simulation_results_data - 12h00 - h			
Errors			
Children			
Success with Errors - Allocate_Demosath_sensor_file - 12h00 - 12h00			
Success with Errors - 2024_04_11_00_00_Demosath_Scada_Create_Power_Spectral_Density - 12h00 - 12h00			
Errors			
Children			
Success with errors - PSD_for_2024_04_11_00_00 - 12h00 - h			
Errors			
ERROR CREATE_PSD - Cannot create PSD for 2024-04-11 00:00:00, no values for AI_WindSpeed			
ERROR CREATE_PSD - Cannot create PSD for 2024-04-11 00:00:00, no values for V_ST_TrueWindDir			
ERROR CREATE_PSD - Cannot create PSD for 2024-04-11 00:00:00, no values for V_RotorRpm			
ERROR CREATE_PSD - Cannot create PSD for 2024-04-11 00:00:00, no values for V_MRU_Longitude_ref			
ERROR CREATE_PSD - Cannot create PSD for 2024-04-11 00:00:00, no values for V_MRU_Latitude_ref			

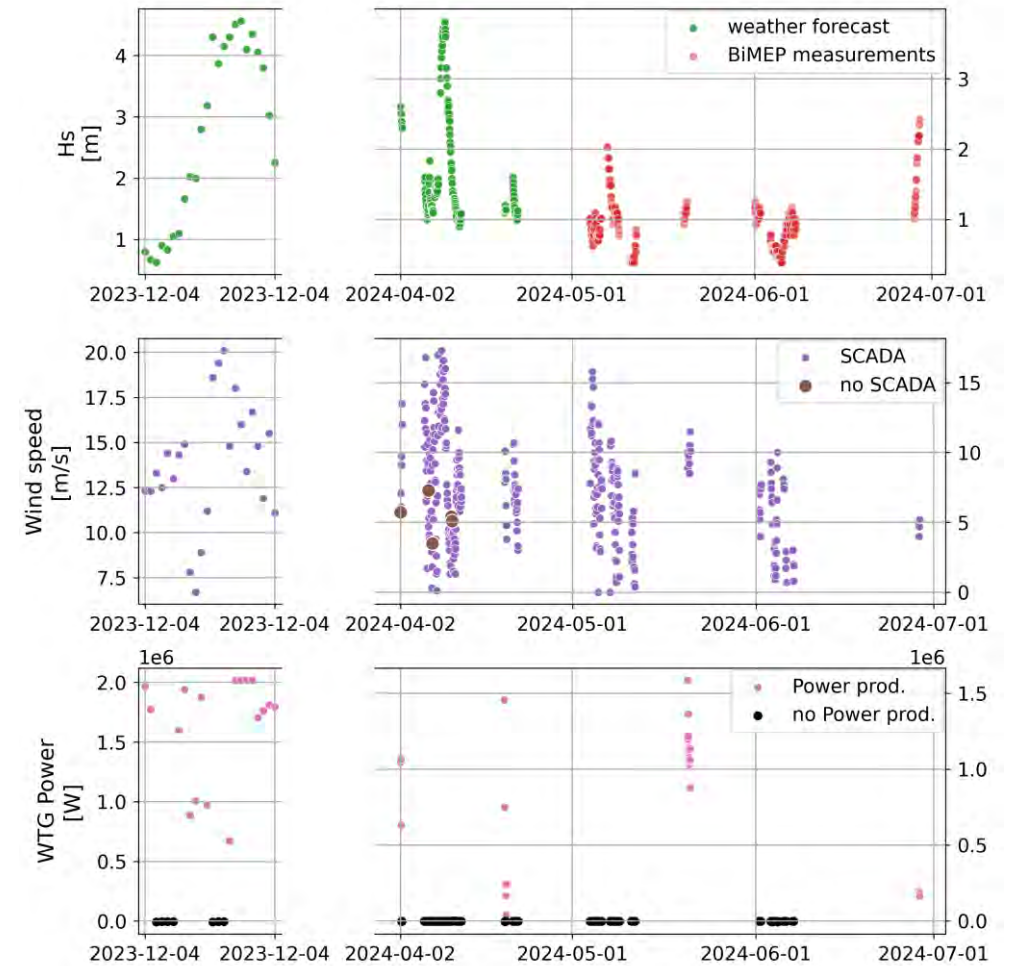
# Conclusions

- A global process: for a finished product
  - Data fetching
  - Simulation run
  - Post process
- i/o formatting for a software agnostic process
  - Takes all sources of inputs
  - Standard interface for simulation software swap



# Dataset presentation

- 486h dataset
- 287 hours with BiMEP in-situ environmental measurements
- 370h provided by SAITEC in hand picked conditions
  - Mostly May to end of June
  - Confident with turbine operation & measurements
  - End of project limited processing time
- DT operation
  - Has been running automatically generating a lot of points
  - Allows for subset selection & outlier identification
- An operational Digital Twin

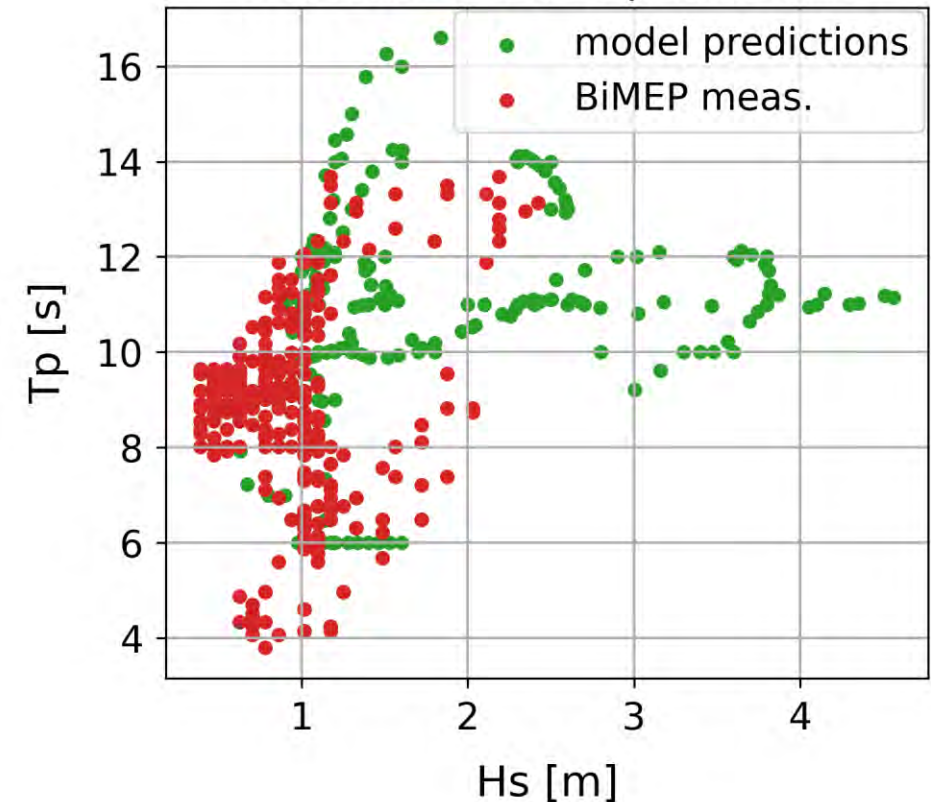


# Dataset presentation

- Operating the DT in best conditions only Priority 1 inputs
  
- Model – Measurements comparisons focus of a subset
  - With BiMEP waves and current measurements
  - With SCADA measurements
  - Milder conditions

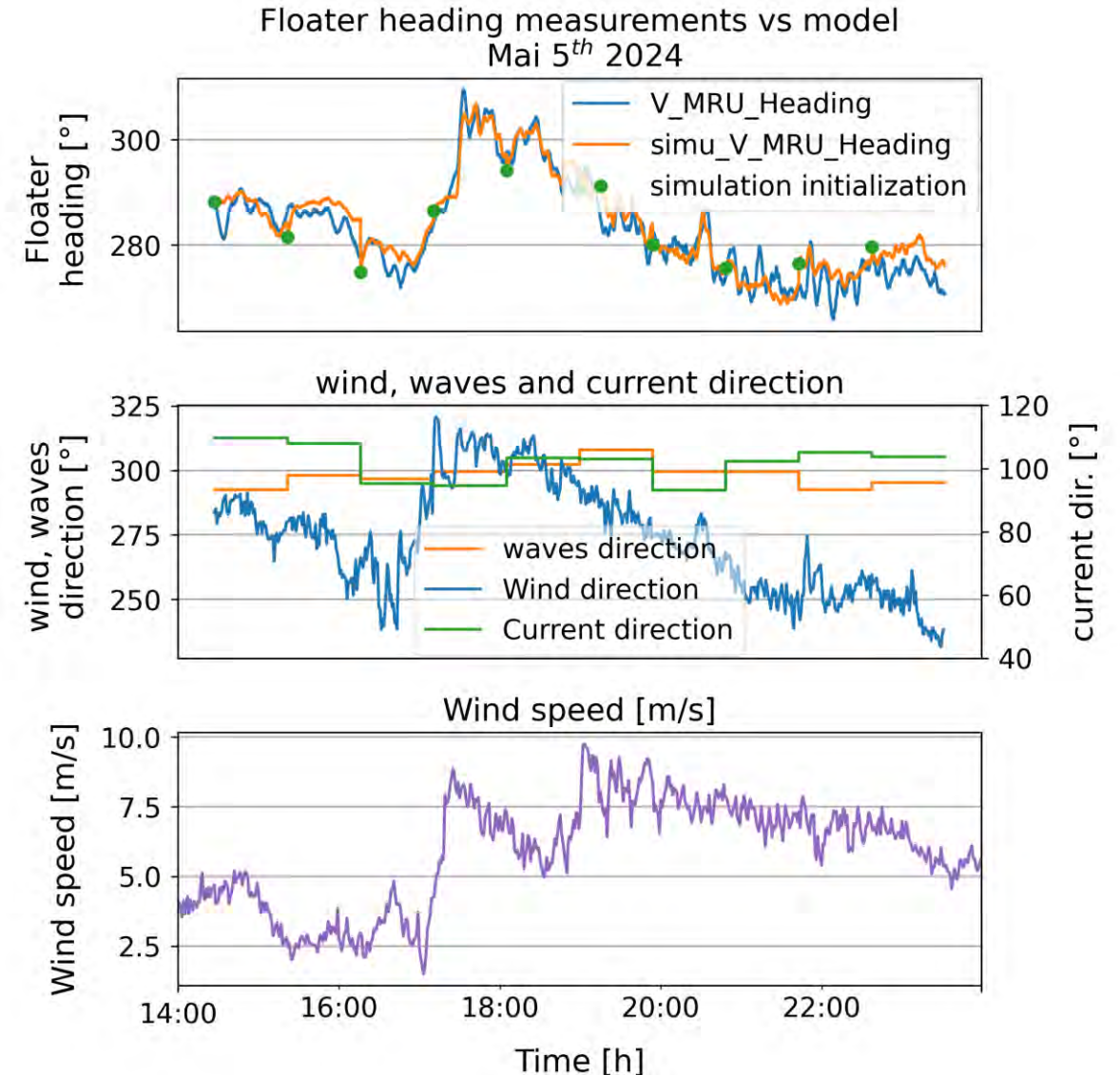
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Sea states included in the dataset measurements vs predictions



# SIMA model precision

- Illustration with a time-series
  - Selected for its strong wind direction variations
- Statistics on the subset (1Hz sampling)
  - Average error = 1.3°
  - Std error = 2.6°
  - Max error = 7.5°
- Key points
  - Initiating floater heading
  - Heading dynamics well captured
  - Finer resolution on current direction could help



# SIMA model precision

- Methodology: process a big dataset
  - Statistically representative waves conditions
- Statistical approach
  - Computed over 1 hour window (1 Hz sampling frequency)
  - Then aggregated over the dataset
  - Remove outliers defined as 5<sup>th</sup> and 95<sup>th</sup> percentile

## Several metrics selected here

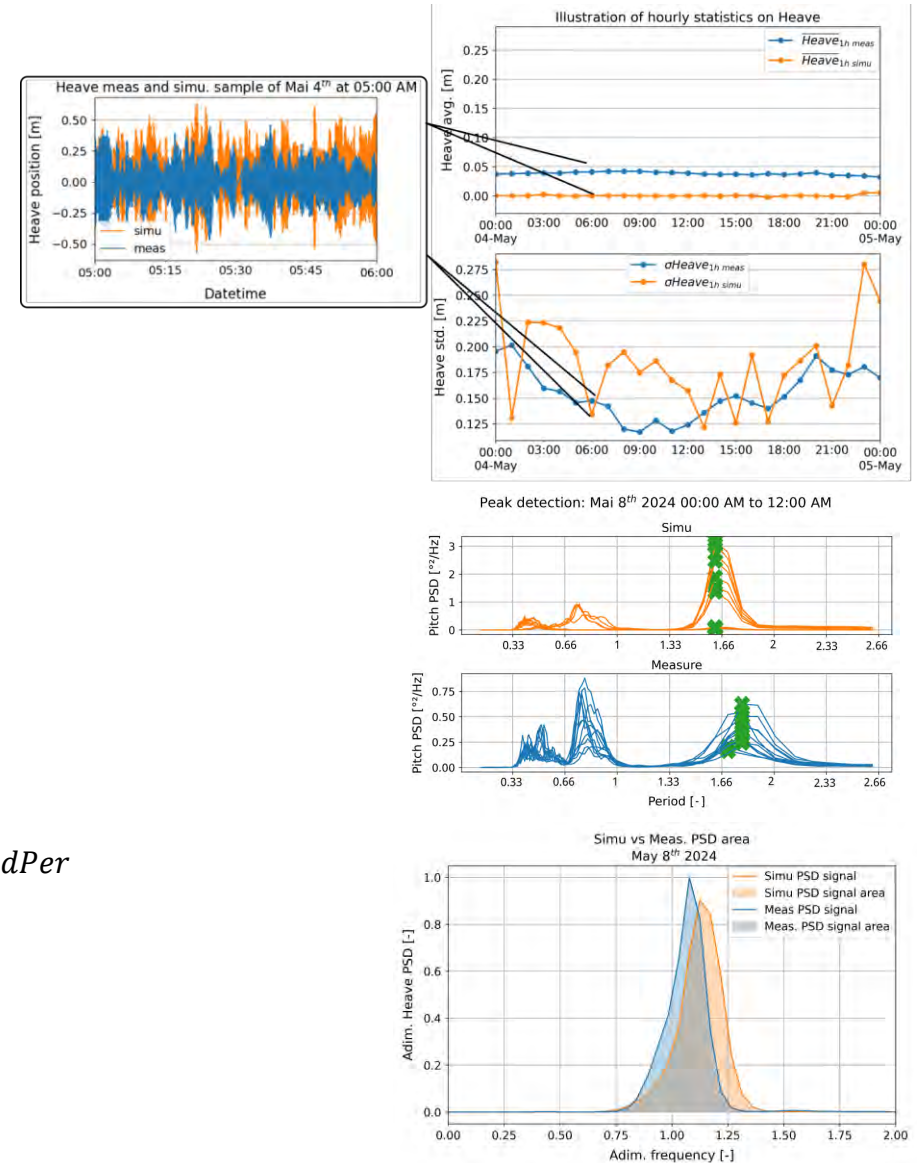
- average, std, min/max
- Natural frequencies
- PSD area
- Correlation

$$\overline{DoF_{error}} = \overline{DoF_{1h\ simu}} - \overline{DoF_{1h\ meas}}$$

$$\sigma_{error} = \sigma DoF_{1h\ simu} - \sigma DoF_{1h\ meas}$$

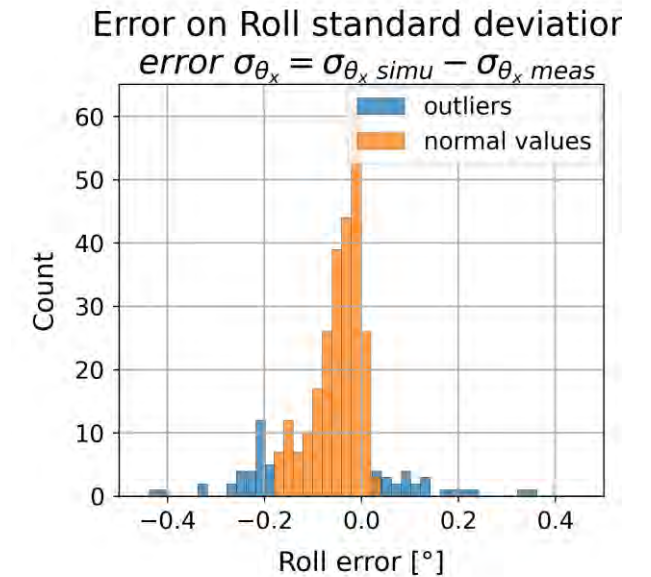
$$\Delta_{PSD} = \int_5^{40} PSD_{simu} \cdot dPer - \int_5^{40} PSD_{meas} \cdot dPer$$

$$r = \frac{Cov(x, y)}{\sigma_x \sigma_y}$$



- Statistics results
  - Heading is hard to capture.
  - Heave, Pitch, Roll well captured.

	Floater heading $\overline{heading}_{error} [^\circ]$	Floater Pitch $\sigma_{error} [^\circ]$	Floater Heave $\sigma_{error} [m]$	Floater Roll $\sigma_{error} [^\circ]$
Mean <sub>error</sub>	-1.9	0.032	0.024	-0.026
$\sigma_{error}$	13	0.093	0.125	0.062

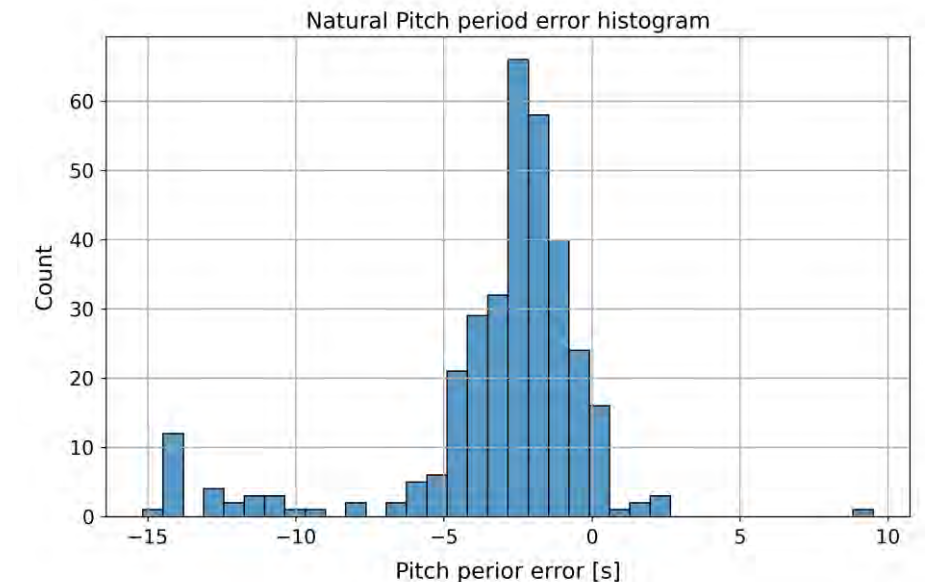
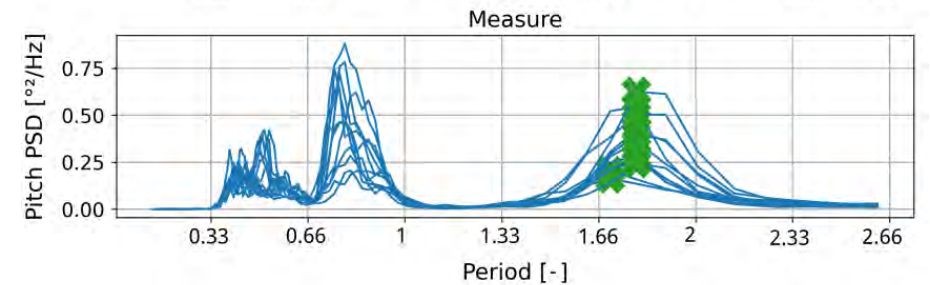
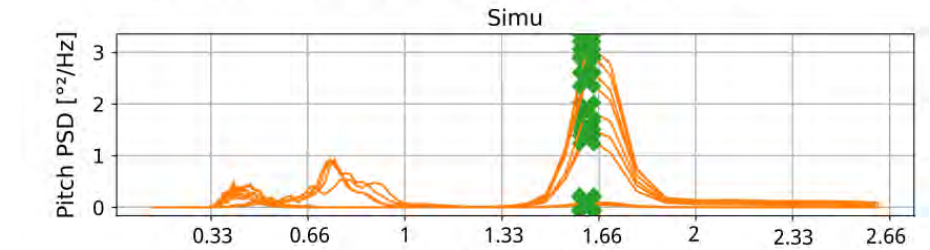


# SIMA model precision

- Statistics results
  - Heading is hard to capture.
  - Heave and Pitch well captured.
- Natural frequency
  - Good result for heave
  - Average Pitch & Roll result

	Floater Pitch [%]	Floater Heave [%]	Floater Roll [%]
Error [%]	-3,7%	-9.5%	-11.8%

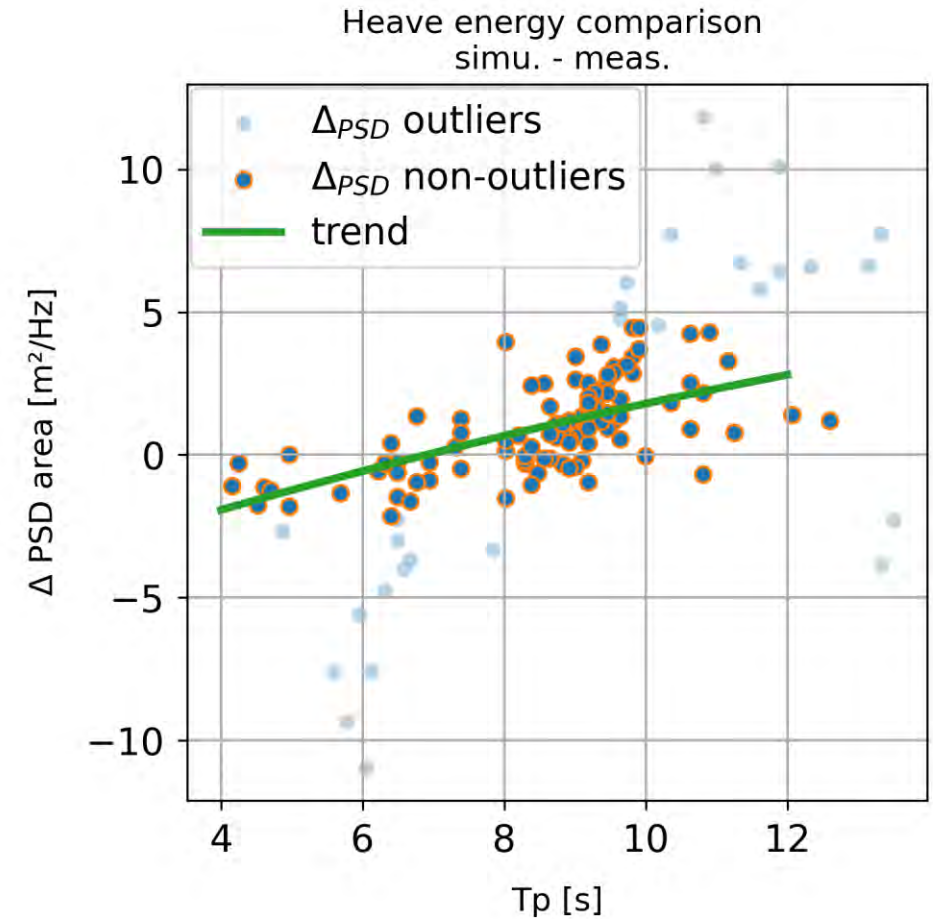
Peak detection: Mai 8<sup>th</sup> 2024 00:00 AM to 12:00 AM



# SIMA model precision

- Statistics results
- Natural frequency
- Influence of environmental conditions
  - Error increased for some DoF
  - Error decreased with others

	Hs	Tp	Wind speed	Wind dir.	Current speed
<b>Heading</b>	0.263	0.124	0.170	-0.144	0.098
<b>Heave</b>	0.44	0.43	0.39	-0.068	-0.04
<b>Pitch</b>	-0.126	-0.07	-0.004°	-0.133	0.090
<b>Roll</b>	0.210	-0.094	0.161	-0.166	0.113

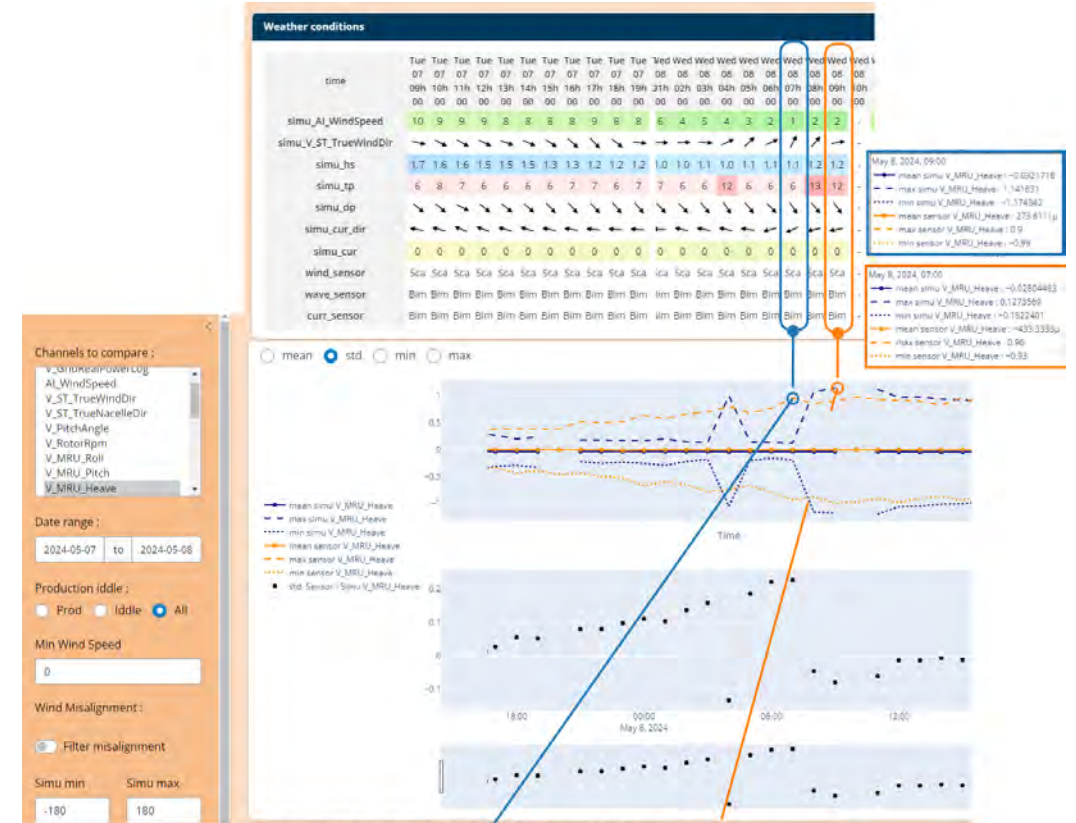


# Outlier identification & investigation

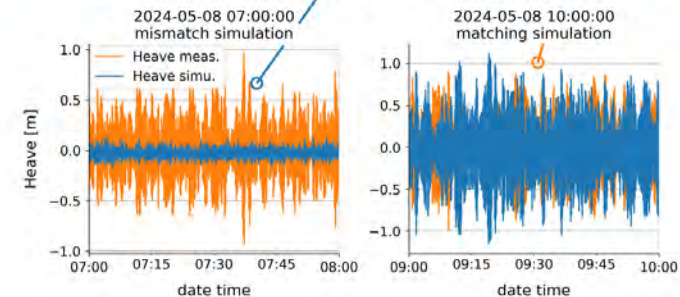
- Outliers study
  - Strange  $T_p$  variation on Mai 8<sup>th</sup>
  - $\sigma_{heave}$  diverging

	outlier simulation	matching simulation
$\sigma_{meas}$	0,27 m	0,31 m
$\sigma_{simu}$	0,04 m	0,39 m
error	85%	25%

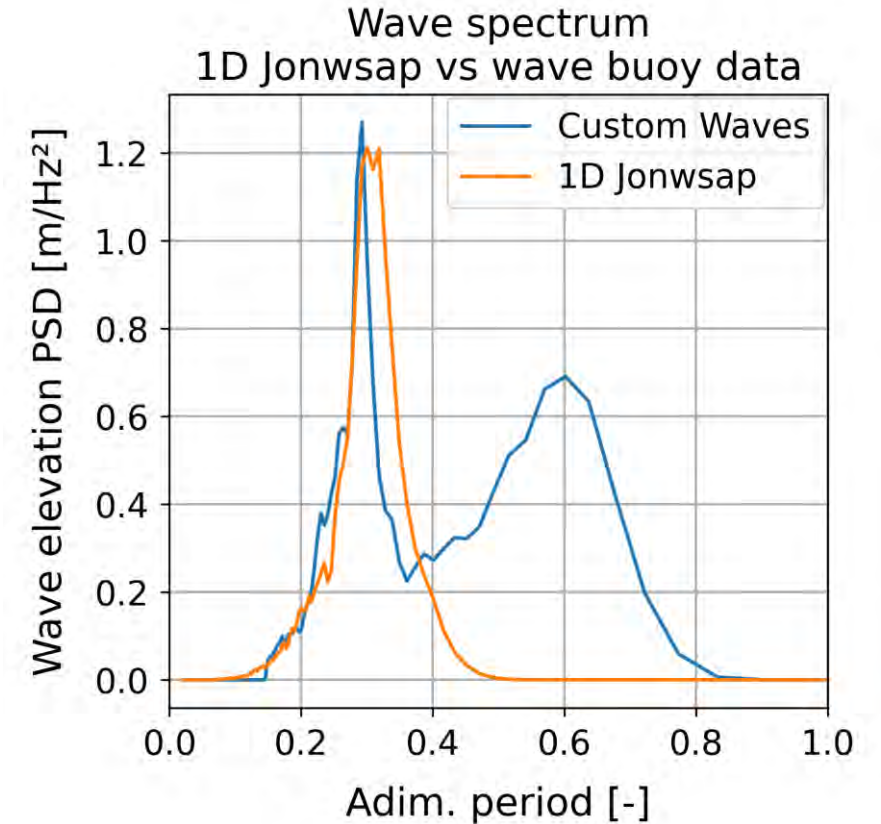
- Waves conditions modelled as 1-D Jonswap
  - Might be too strong of an assumption
  - Generates misreading of  $T_p$  in some conditions
    - Observed at 6 am
    - Influences the Heave motion



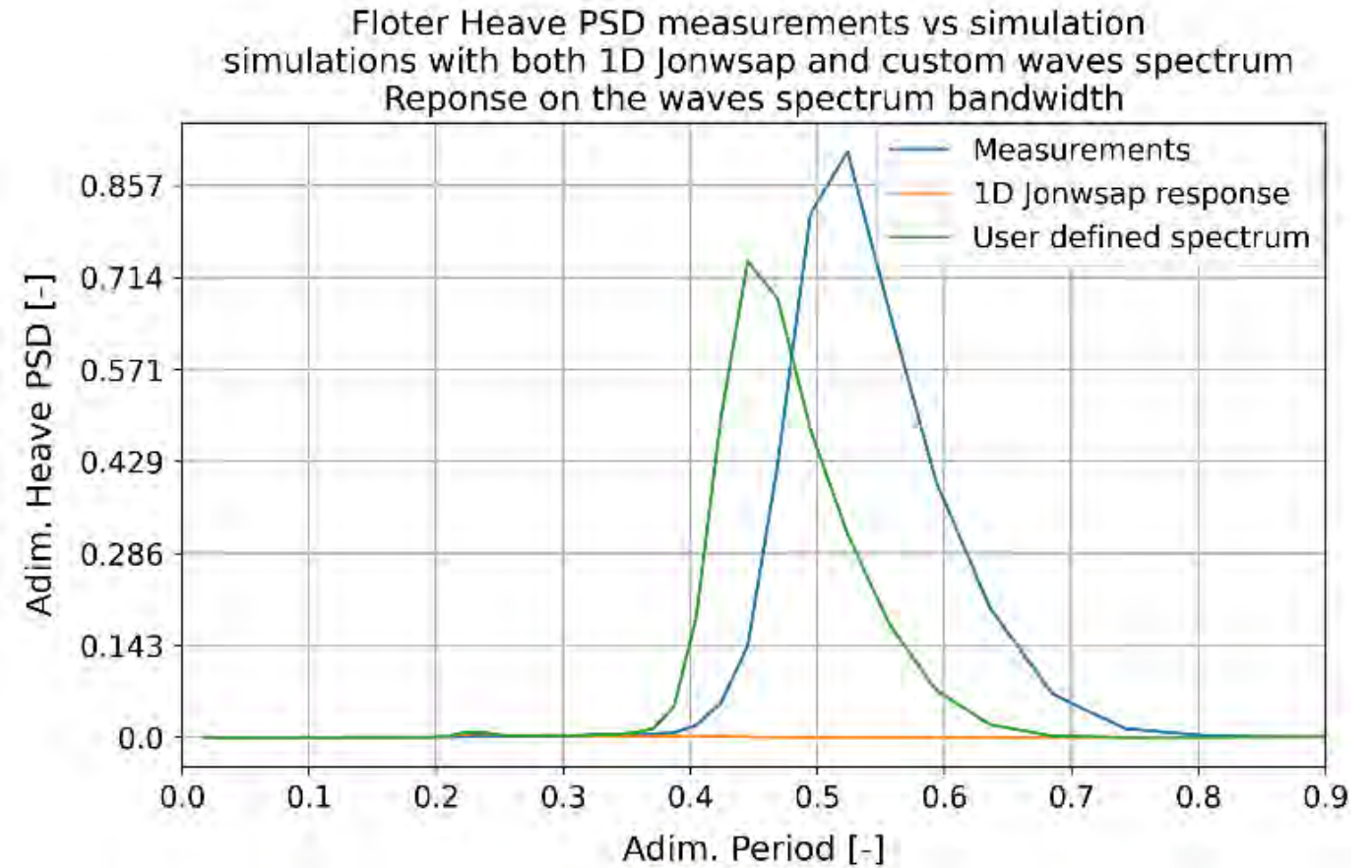
Identification of matching and mismatching simulations



- Refined waves model for SIMA:
  - Before : 1D Jonswap
  - After : 24 dir measured - custom spectra
- Warning - methodology issue for viscous damping:
  - Model with Morison elements not well suited for double peak



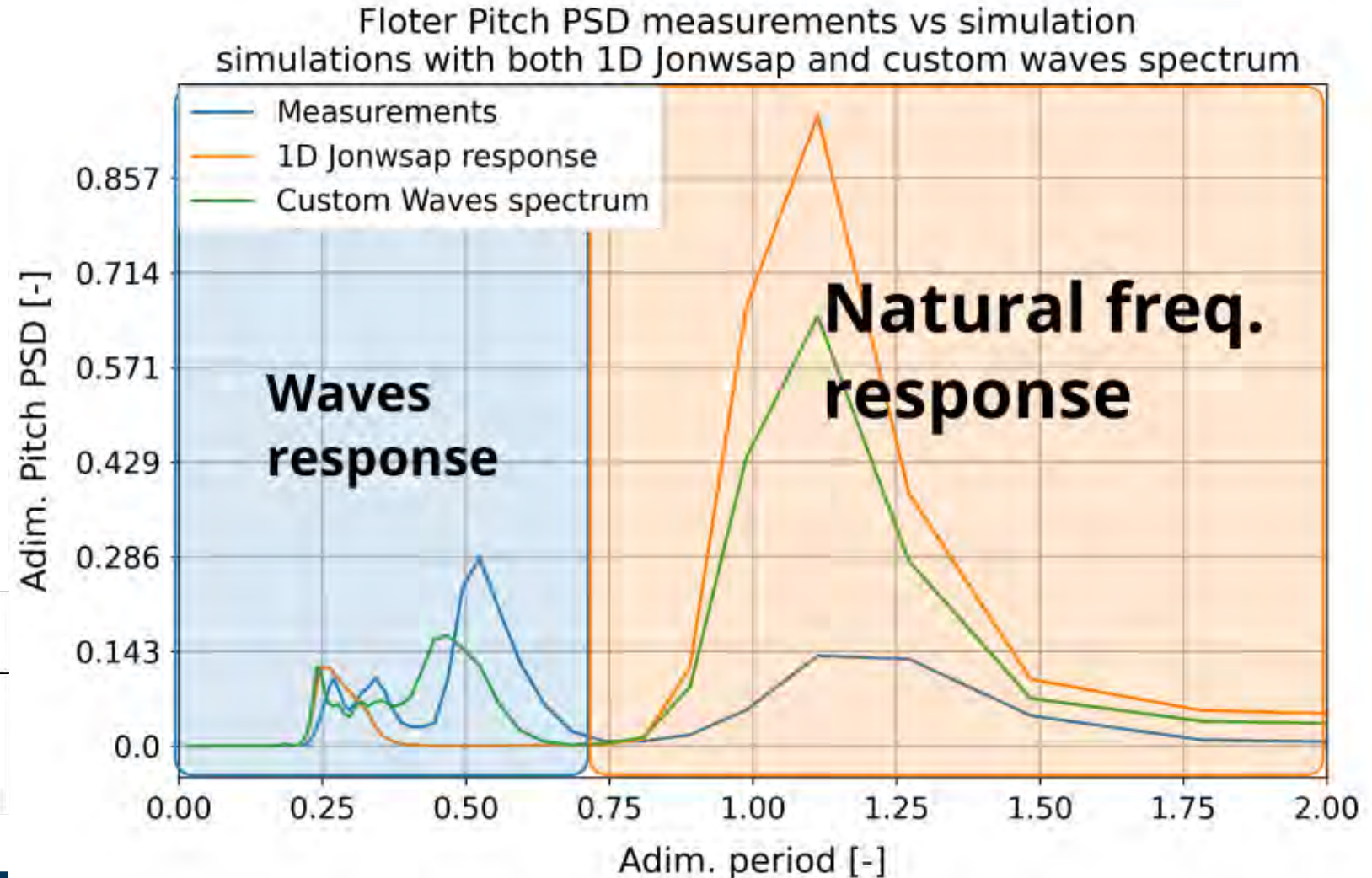
- Enhanced Heave modelling :
  - Now capture Heave response
  - Slight shift & amplitude mismatch



# Improved model with enhanced wave modelling

- Enhanced Heave modelling
  - Now capture Heave response
  - Slight shift & amplitude mismatch
- Enhanced pitch modelling
  - Good wave response .
  - Improved pitch n.f. Response.

	Waves response	natural freq. Response
Meas.	3.91	0.72
1D JONSWAP	2.12 (46%)	4.29 (496%)
Custom	3.64 (7%)	2.96 (311%)



# Conclusions

- The Digital Twin is operating on a big Dataset
  - Automated process with redundant inputs
  - Model anomaly detection tool
  - Allows for investigations with design teams
- Model validation
  - Good fidelity of the model
  - Enhancement points observed
- Openings and future developments
  - Investigate other outliers
  - Implement refined waves modelling
  - Virtual sensors applications
  - ...

