ForeCoast® Rail: Revolutionising Rail Safety in Wales with Advanced Wave Overtopping and Scour Risk Forecasting for Network Rail

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Motivation

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Forecas

FORECOAST SEA-STATE AND WEATHER FOR

Forecast issue: 24/02/2023 07:05

ABERTOFFD SEA WALL DJP 82.04

	High tide at	10:45 Fri 24th Feb 2023	23:05 Fri 24th Feb 2023	
RISK	Risk Forecast	No risk	No risk	N
	No risk	: NO ACTION FOR THIS TIDE		

AFON WEN SEA WALL DJP 127.09

	High tide at	10:50 Fri 24th Feb 2023	23:09 Fri 24th Feb 2023	
RISK	Risk Forecast	No risk	No risk	N
	No risk	: NO ACTION FOR THIS TIDE		

AFON WEN SEA WALL DJP 127.09

SEA-STATE AND WEATHER FORECAST

Forecast issue date: 24/02/2023

Forecast issue time: 07:05

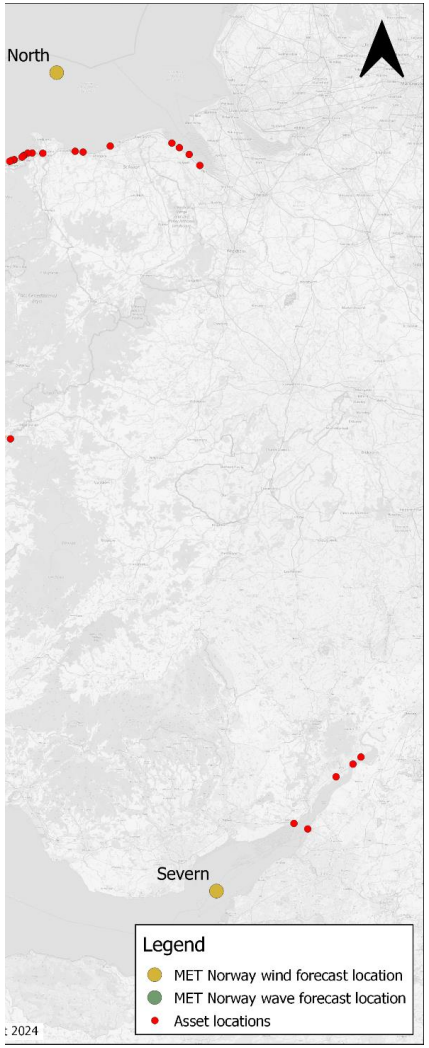
JBA ForeCoast Rail

	High tide at:	10:50 Fri 24th Feb 2023	23:09 Fri 24th Feb 2023	11:33 Sat 25th Feb 2023	23:52 Sat 25th Feb 2023	12:18 Sun 26th Feb 2023	00:39 Mon 27th Feb 2023	13:11 Mon 27th Feb 2023	01:37 Tue 28th Feb 2023	14:23 Tue 28th Feb 2023	03:01 Wed 1st Mar 2023
RISK	Risk Forecast	No risk	No risk	No risk	No risk	No risk	No risk	No risk	No risk	No risk	No risk
	No risk	NO ACTION FOR THIS TIDE									

FORECAST DATA

NEARSHORE	Wave height (m)	0	0	0	0	0	0.14	0	< 0.1	0	NA
	Overtopping (l/s/m)	0	0	0	0	0	0	0	0	0	NA
	Scour (m)	0	0	0	0	0	0	0	0	0	NA
SEA LEVEL	Tide (mAOD)	2.66	2.16	2.16	1.76	1.66	1.36	1.16	0.96	0.76	0.66
	Surge (m)	NA*	NA*	NA*	NA*	NA*	NA*	NA*	NA*	NA*	NA*
	Correction (m)	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
	Sea level (mAOD)	2.65	2.15	2.15	1.75	1.65	1.35	1.15	0.95	0.75	0.65
OFFSHORE	Wave height (m)	0.80	0.50	0.40	0.40	0.30	0.30	0.30	0.50	0.80	NA
	Wave direction	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	NA
	Wave period (s)	3	3	3	2	3	3	3	3	6	0
	Wind force	5	4	4	4	3	3	3	3	3	NA
	Wind direction	NNW	NE	NE	ENE	NE	NNE	E	NNE	NNE	NA

* A surge forecast is not yet available for this high tide. Therefore zero surge has been assumed when calculating the expected sea level. The surge and expected sea level for this high tide will be updated within the next forecast.



JBA consulting

NetworkRail

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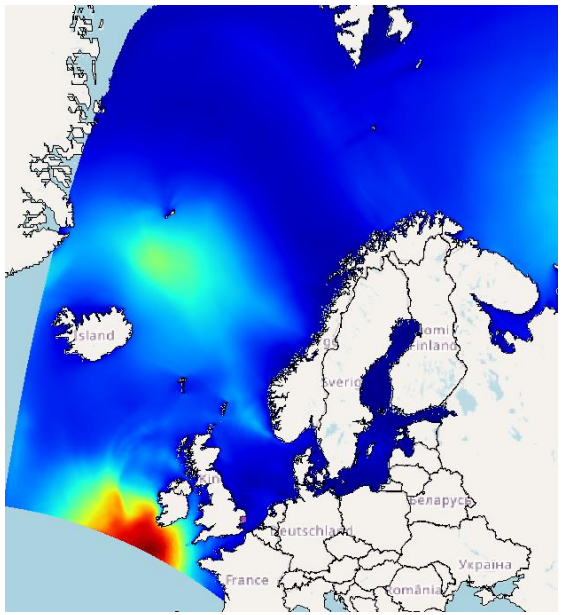
ForeCoast® Rail

Inputs

- wind & wave forecasts (Norwegian Meteorological Institute)
- Surge forecasts (Met Office)
- Astro tide from 12 gauges



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Forecasts

Run in real time:

- Equations: sea level and scour
- Machine learning emulators: wave conditions
- Neural Network: wave overtopping

Outputs

Three day forecast at each asset of:

- Sea level
- Nearshore wave conditions
- Wave overtopping
- Scour

Warnings and Alerts issued if assets at risk

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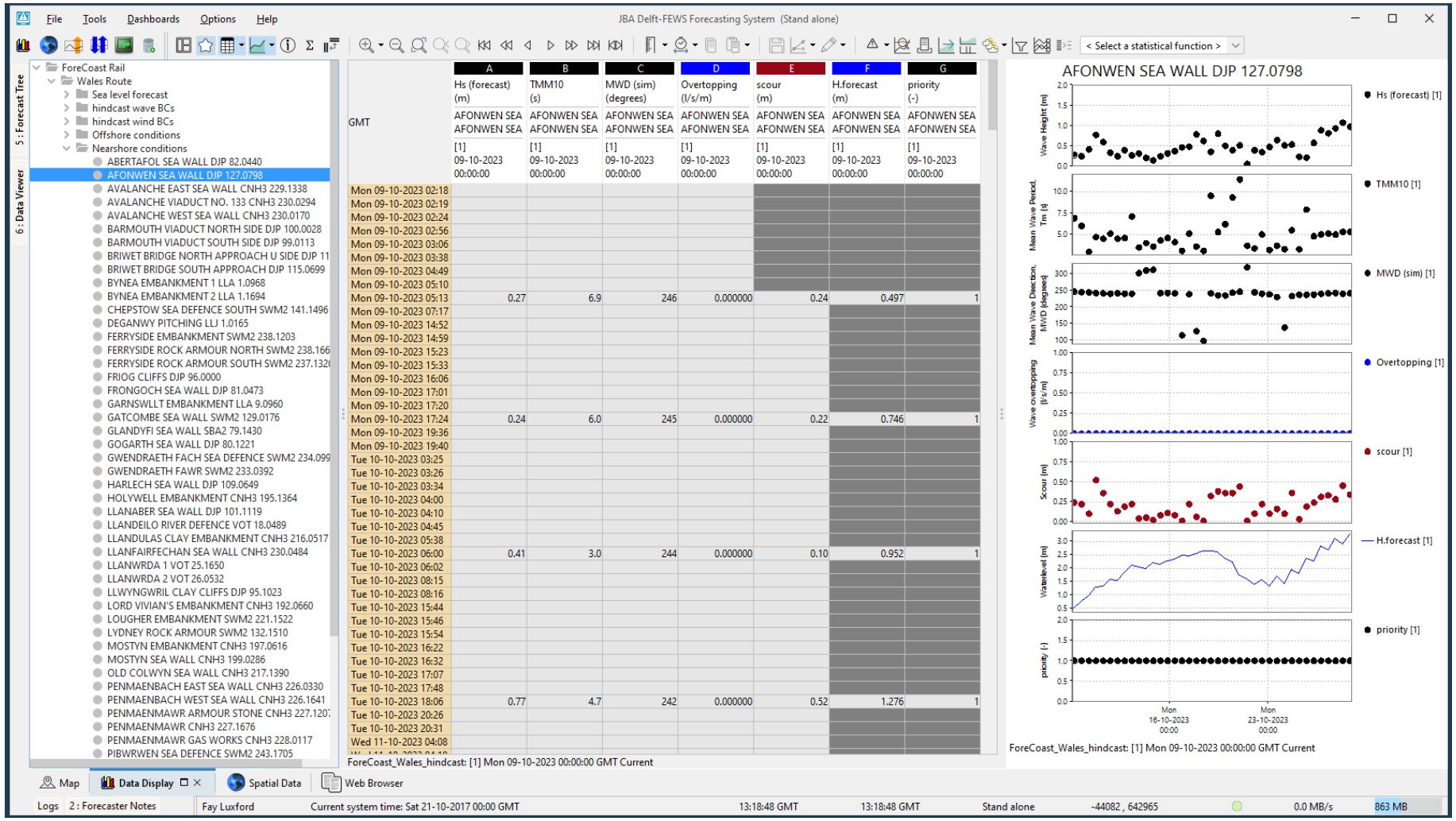

Forecasts run through Delft-FEWS software

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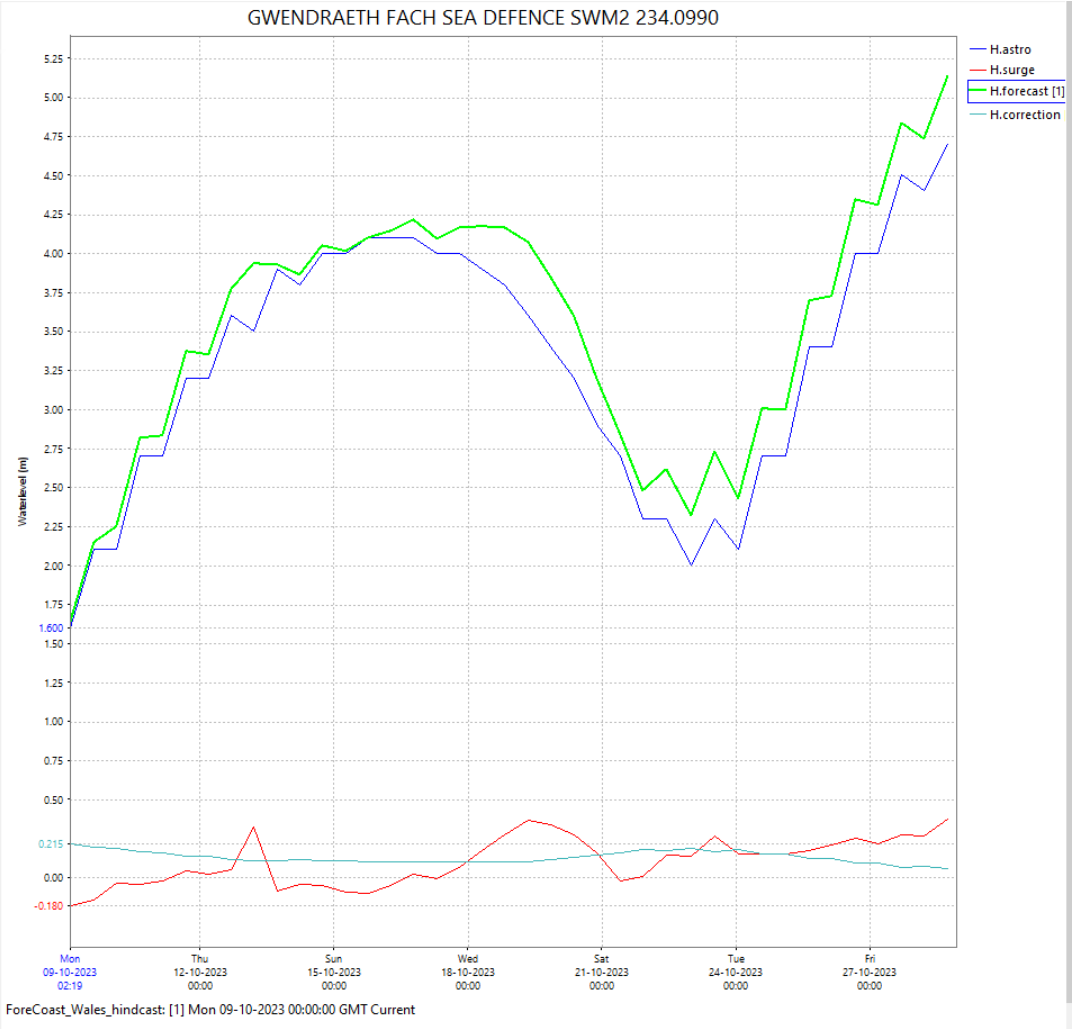
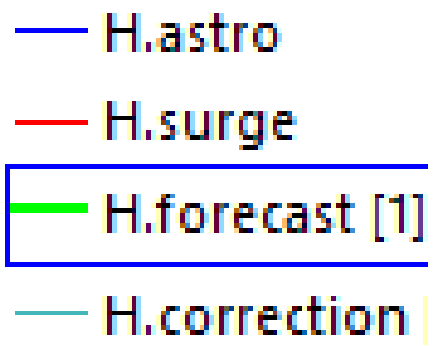
Sea level forecasts





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Nearshore wave forecast

For each wave model:

- Generated event set of extreme conditions
- Simulated in SWAN
- Used SWAN results to train emulators
- Emulators implemented into Delft-FEWS

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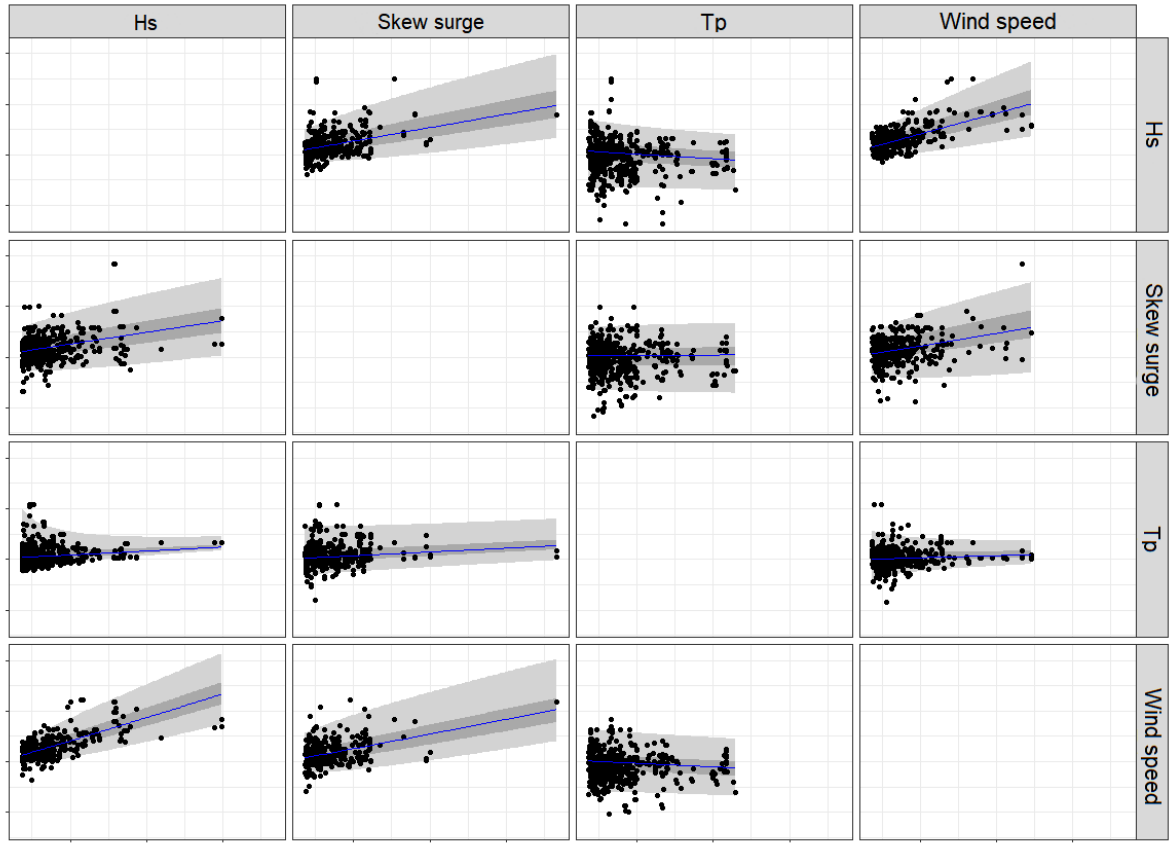
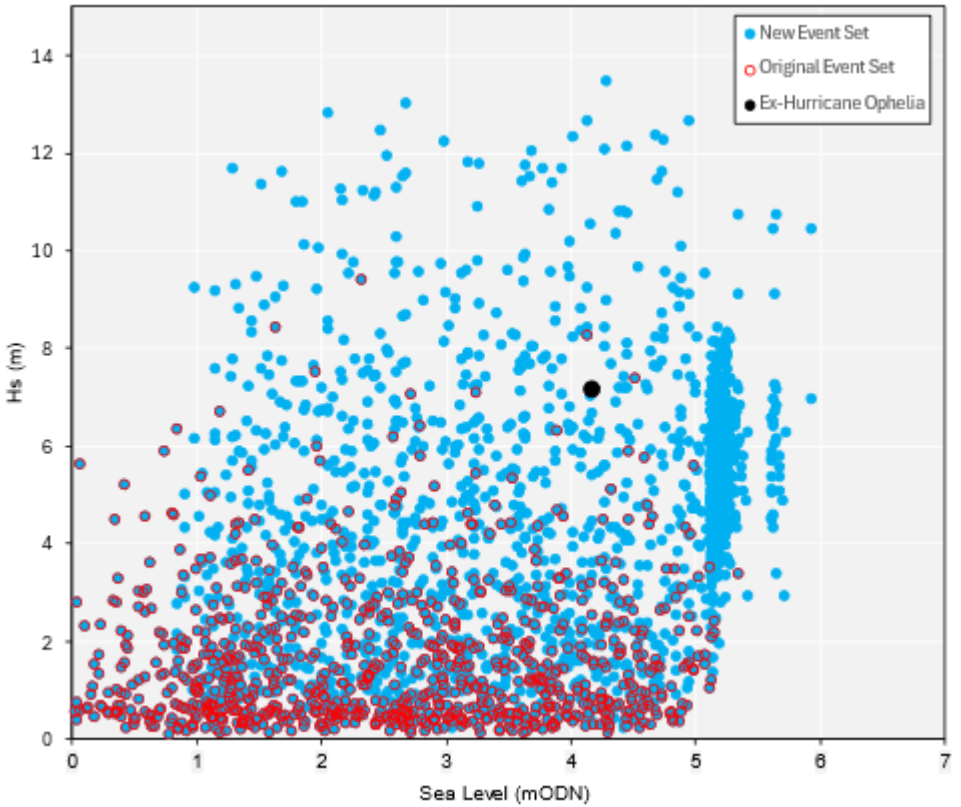
Nearshore wave forecast

Multi-variate statistics



Event Set



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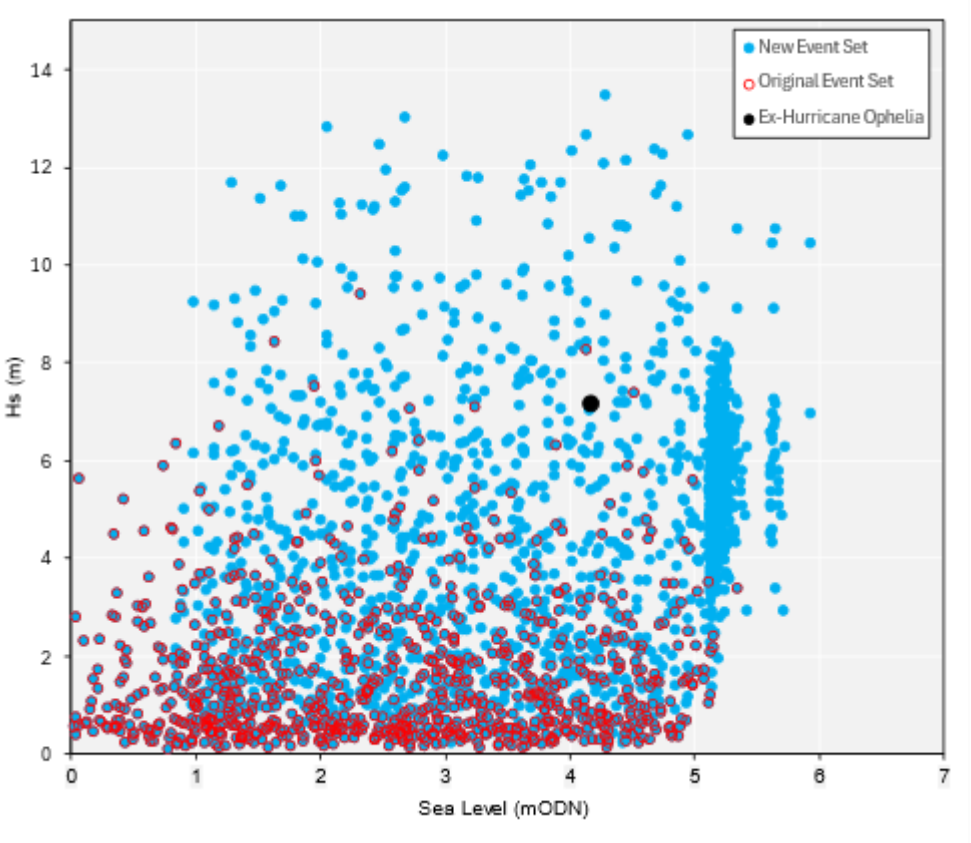
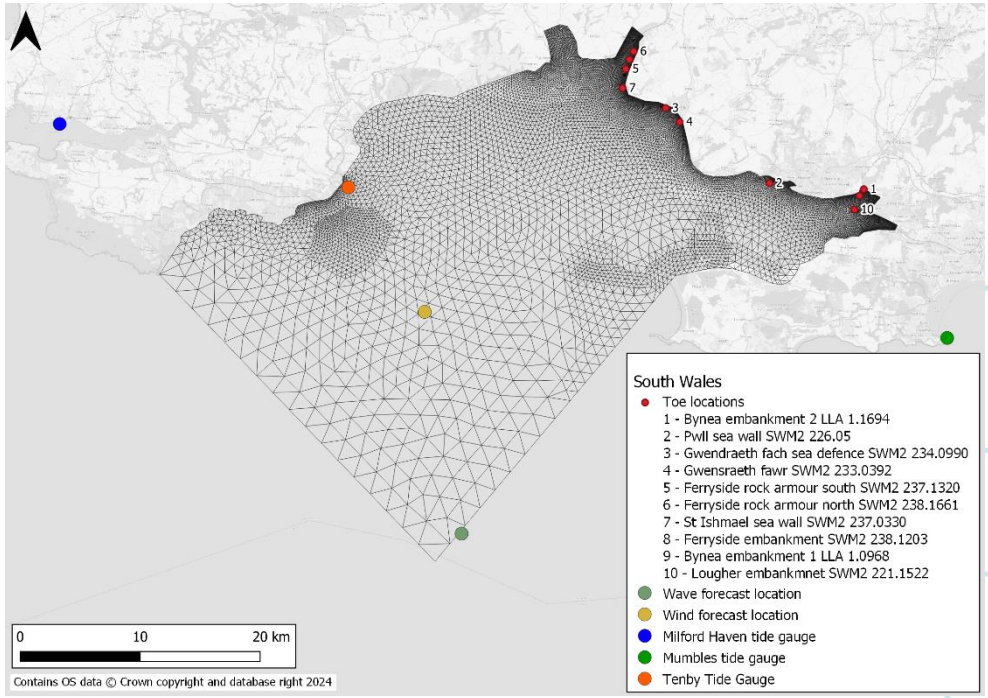
Nearshore wave forecast



Event set + everyday high tide conditions

SWAN simulations



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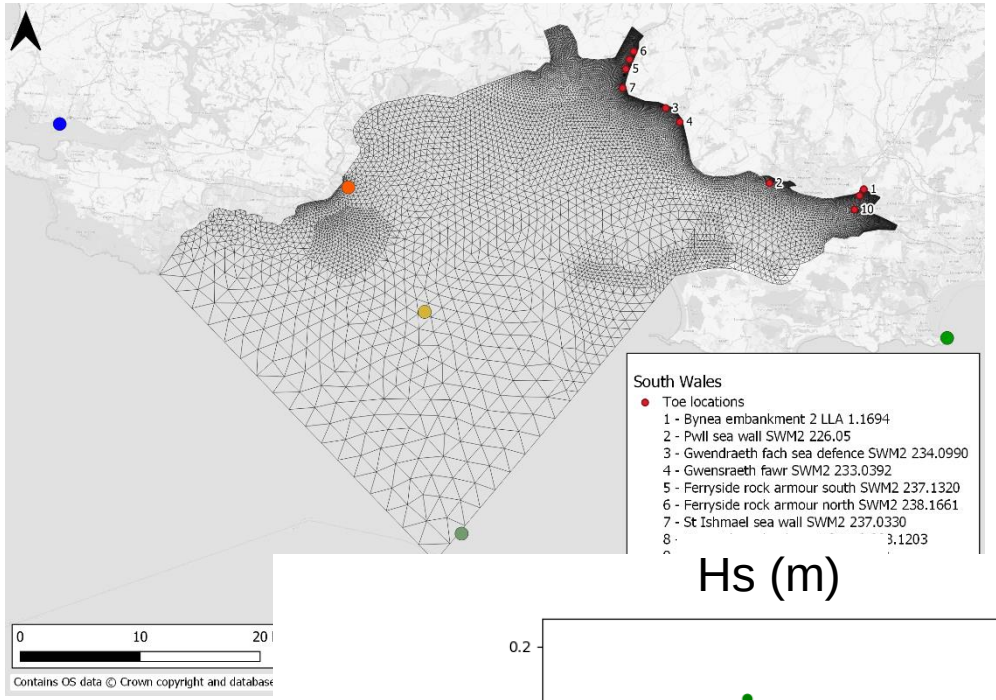
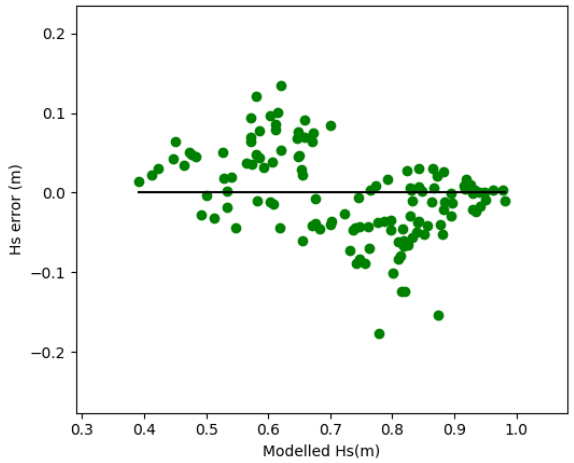
Nearshore wave forecast

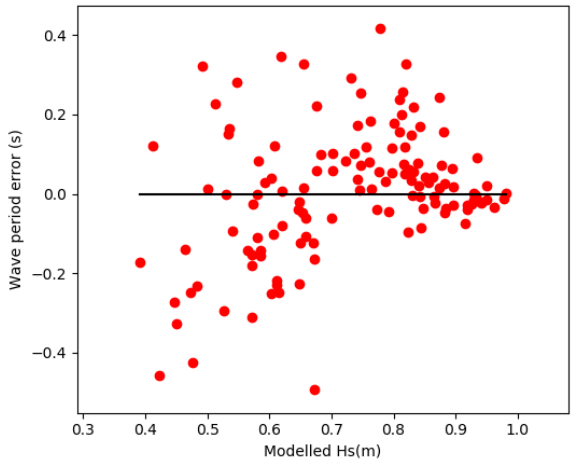


SWAN simulation results used to train emulators to predict nearshore wave conditions. Emulators are run in the forecasting system. Emulators shown to have a high level of accuracy.

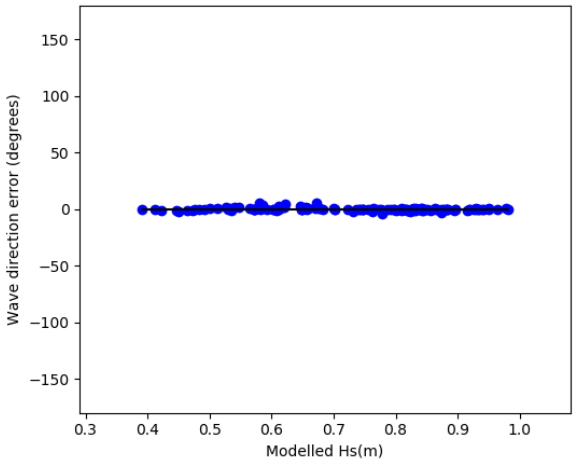
Hs (m)



Wave period (s)



Wave direction (º)



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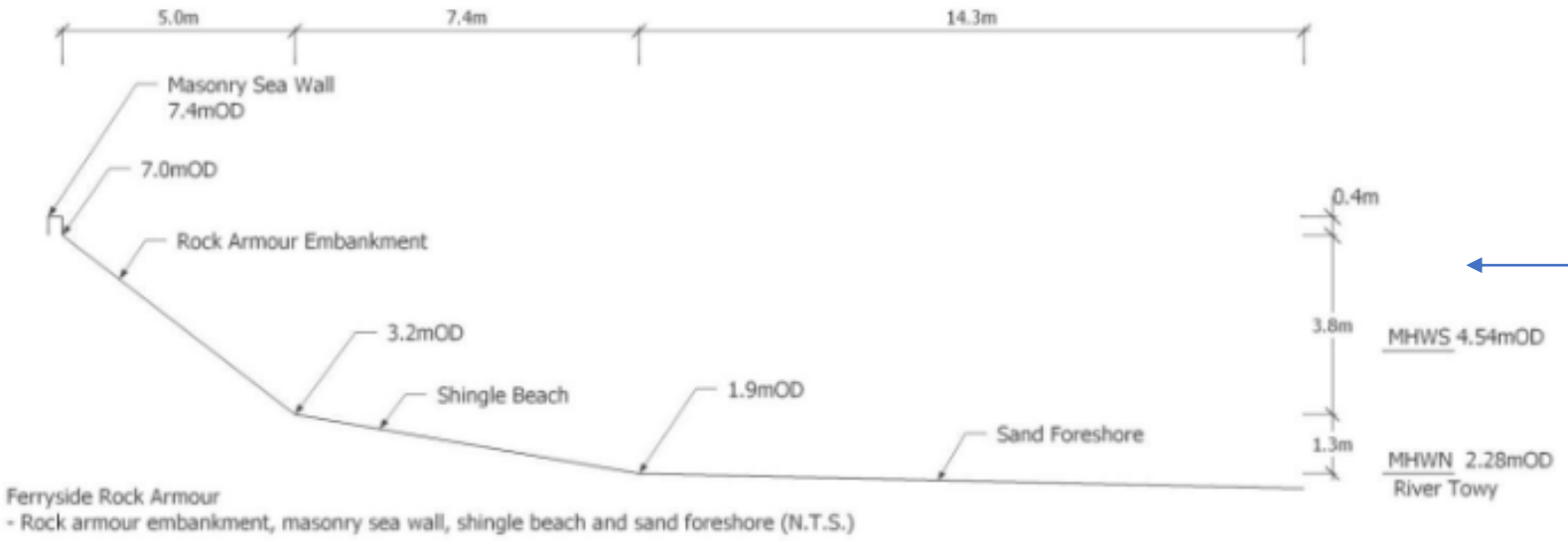
Wave overtopping forecasts

- Running a wave overtopping Neural Network in Delft-FEWS



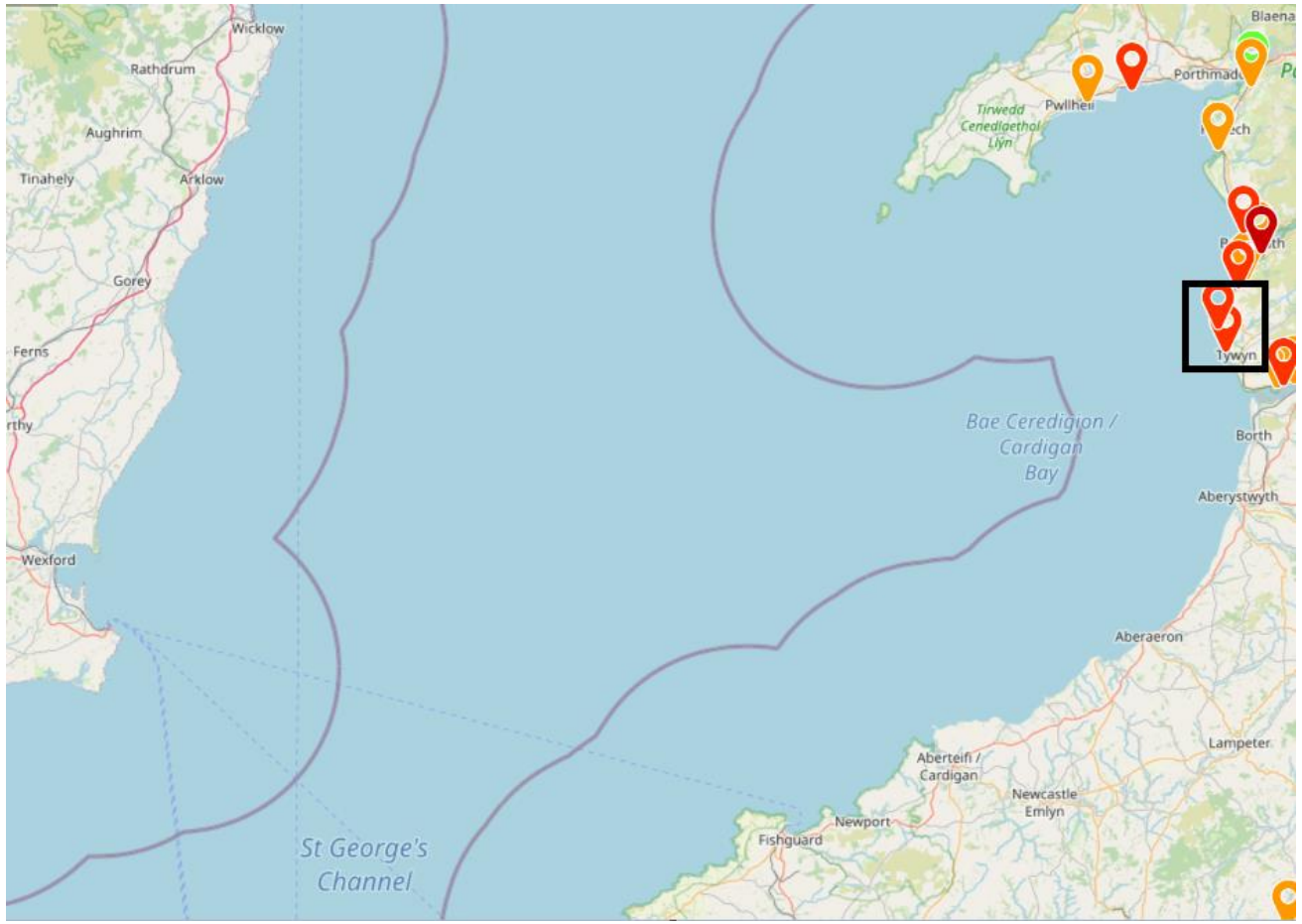
Inputs

- Sea level
- Nearshore wave direction
- Nearshore H_s
- Nearshore T_{m-10}

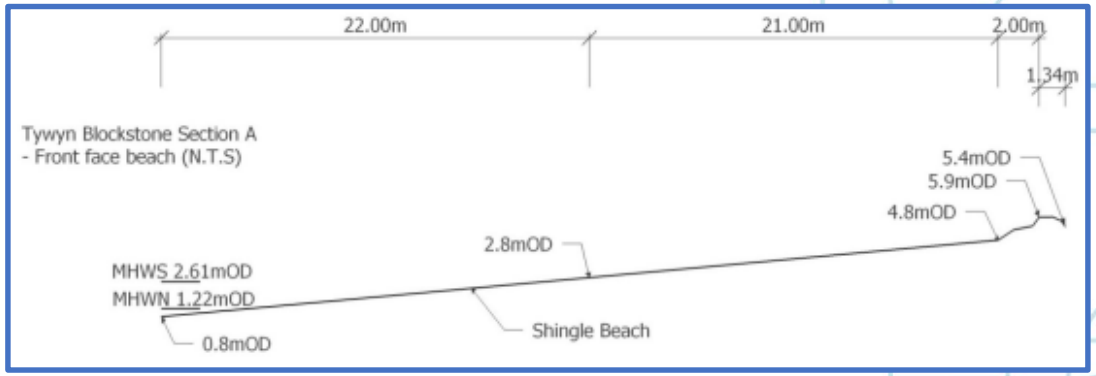
Scour forecasts

Currently a simple scour equation, based on forecasted depth of water at the defence toe, wave height and wave period

Infra-gravity waves



EurOtop II recommends an alternative overtopping method for extremely/very shallow foreshore conditions, which involves **increasing the wave period $T_{m-1,0}$ from a phase averaged model** like SWAN due the presence of infragravity waves and using the **empirical formula of Altomare et al. (2016)** to calculate wave overtopping. Since EurOtop II was published, Lashley et al (2020) proposed that wave overtopping calculations where infragravity waves play a part could further be improved by also **increasing the wave height H_{m0}**.



This alternative method is applied when the foreshore is considered as extremely/very shallow

$$\frac{water\ depth_{toe}}{H_{m0,deep\ water}} < 1$$

Altomare, C., Suzuki, T., Chen, X., Verwaest, T. and Kortenhaus, A., 2016. Wave overtopping of sea dikes with very shallow foreshores. Coastal Engineering, 116, pp.236-257, doi: doi.org/10.1016/j.coastaleng.2016.07.002

Lashley, C.H., Zanuttigh, B., Bricker, J.D., Van der Meer, J., Altomare, C., Suzuki, T., Roeber, V. and Oosterlo, P., 2020. Benchmarking of numerical models for wave overtopping at dikes with shallow mildly sloping foreshores: Accuracy versus speed. Environmental Modelling & Software, 130, p.104740

Warning & Alert Thresholds

Still water level and wave overtopping

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Validation - hindcast

- Hindcast of system run from 2016 to 2023
- Preliminary results
- Matched client expectations in terms of assets where there is a known issue and relative frequency
- Preliminary results show some thresholds need updating

	Alerts	Warnings
AFONWEN SEA WALL DJP 127.0798	2	126
AVALANCHE EAST SEA WALL CNH3 229.1338	4	0
AVALANCHE VIADUCT NO. 133 CNH3 230.0294	4	0
BARMOUTH VIADUCT NORTH SIDE DJP 100.0028	1	1
BARMOUTH VIADUCT SOUTH SIDE DJP 99.0113	2	1
DEGANWY PITCHING LLJ 1.0165	2	0
FERRYSIDE ROCK ARMOUR SOUTH SWM2 237.1320	1	3
FRONGOCH SEA WALL DJP 81.0473	0	1
GATCOMBE SEA WALL SWM2 129.0176	11	22
GWENDRAETH FACH SEA DEFENCE SWM2 234.0990	3	21
GWENDRAETH FAWR SWM2 233.0392	6	14
LLANABER SEA WALL DJP 101.1119	0	134
PENMAENMAWR GAS WORKS CNH3 228.0117	4	0
PWLL SEA WALL SWM2 226.0473	5	64
St. ISHMAEL SEA WALL SWM2 237.0330	6	0
TYWYN BLOCKSTONE DJP 89.0722	115	325

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Validation – Afonwen Sea Wall

- Originally provided only with flood history for Storm Brian

MHWS = 2.56mAODN

HAT = 3.36mAODN

Top 10 overtopping events in hindcast

Date	Hs (m)	OT (l/s/m)	Scour (m)	Sea level (mAOD)	Surge	Astro	Rank	Named Storm
21/10/2017 08:50	1.64	1.64	1.39	3.03	0.68	2.36	-	Storm Brian
02/01/2018 20:17	1.73	5.41	0.82	3.72	0.77	2.96	3	Storm Eleanor
03/01/2018 08:38	1.54	3.38	1.25	3.45	0.40	3.06	9	
17/04/2018 08:43	1.7	4.19	1.24	3.41	0.46	2.96	5	NA
13/01/2020 21:59	1.63	3.74	1.41	3.25	0.60	2.66	7	Storm Brendan
09/02/2020 07:56	1.93	10.18	1.39	3.47	0.82	2.66	1	Storm Ciara
09/02/2020 20:19	1.64	4.47	1.42	3.28	0.53	2.76	4	
21/08/2020 09:21	1.79	6.78	1.31	3.4	0.55	2.86	2	Storm Ellen
15/11/2020 07:44	1.65	2.93	1.04	3.46	0.52	2.96	10	NA
15/11/2020 20:05	1.42	4.15	1.28	3.34	0.19	3.16	6	NA
24/11/2022 20:11	1.73	3.6	1.1	3.53	0.68	2.86	8	NA

- Storm Ciara client feedback – found paperwork showing the defence had been repaired following this event

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What’s next?

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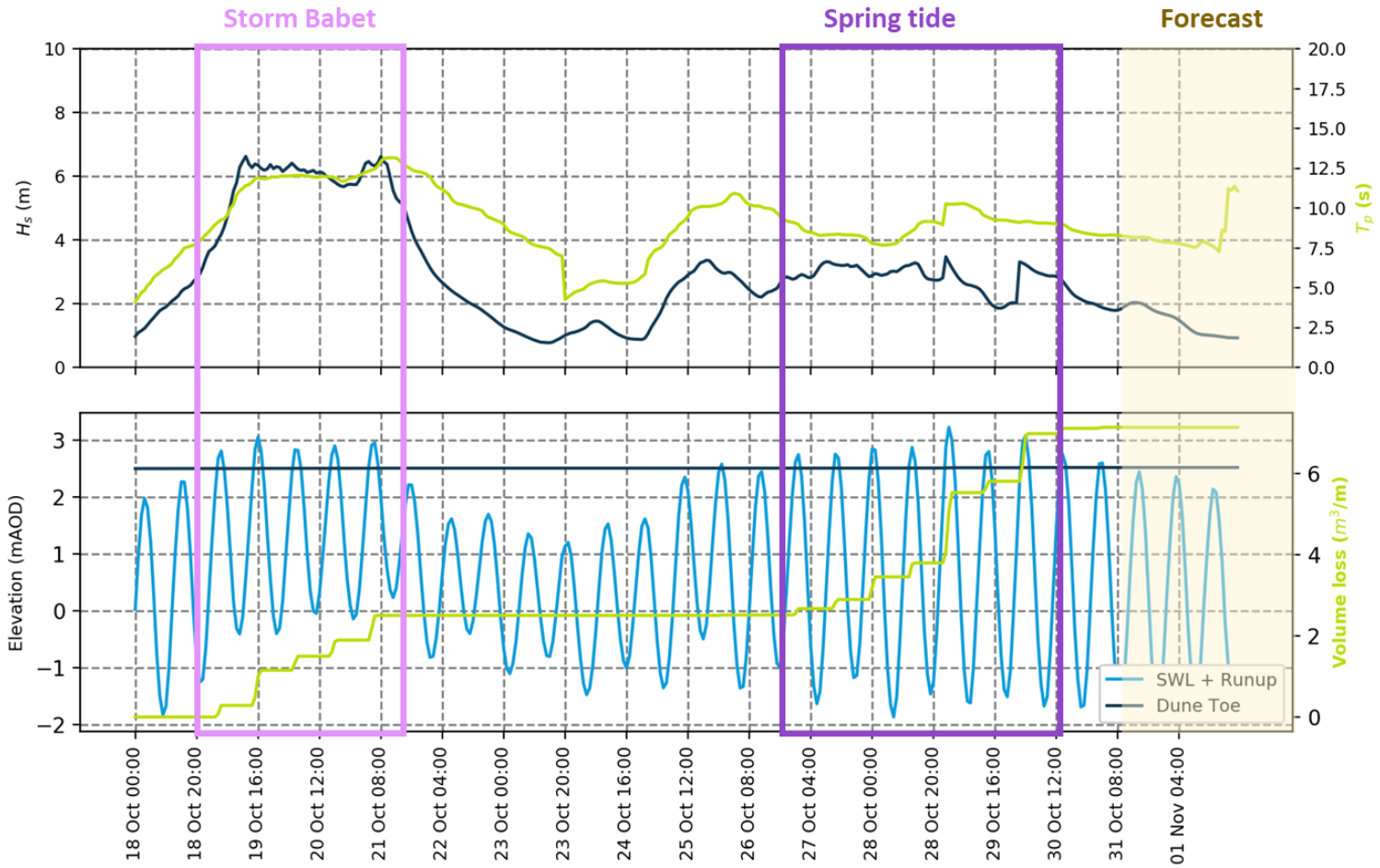
Erosion modelling improvements



Example forecasted dune volume loss in Montrose (Scotland)

Risk at lots of sites is the cumulative effect of multiple storms. Currently working on forecasting systems that can use updated nearshore bathymetry either from observations or modelling as input to subsequent forecasts.

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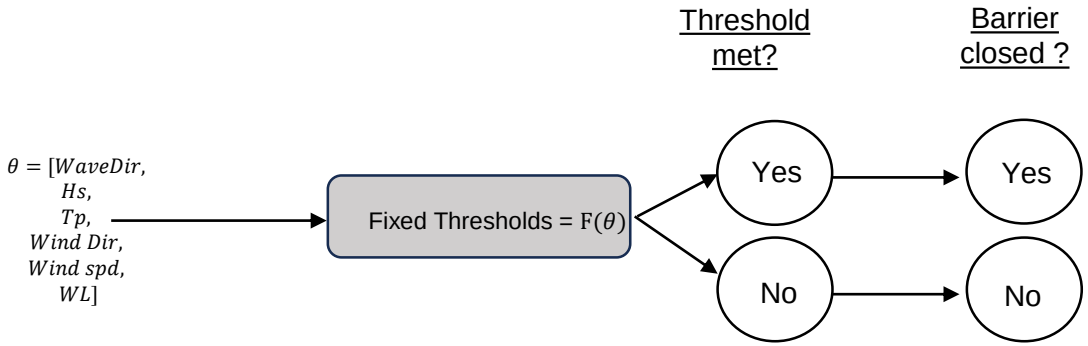
Machine learning for Coastal Hazard Forecasting

Churchill Barriers

1. Barriers are critical infrastructure in Orkney
2. Understanding, how, when and for how long they may close in storms is key for emergency planning

Traditional setup

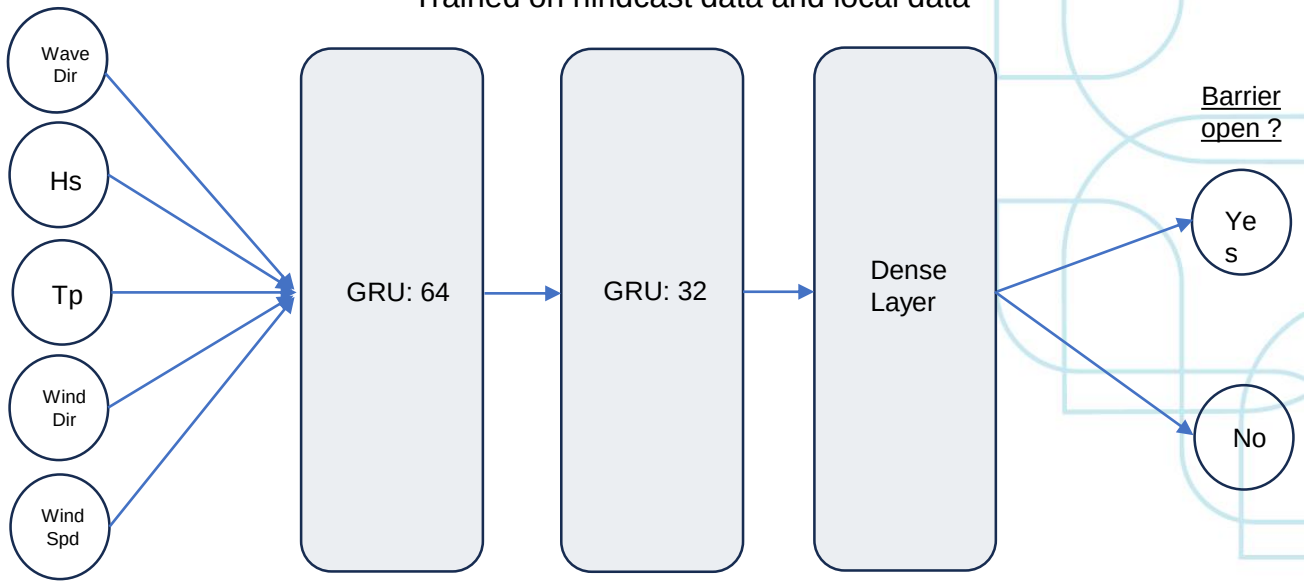
- Traditional forecasting system built upon fixed thresholding which produces conservative forecasts
- Generated from hindcast and lookup tables



Deterministic threshold modelling

Machine learning setup

- Machine learning setup allows for flexible forecasting and can take into local effects
- Able to take into account real-time wind and wave data
- Trained on hindcast data and local data



Neural Network for Anomaly Detection

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