

A green geometric shape consisting of a triangle and a parallelogram, pointing towards the top right.

Investigation of AI-Based Model Response for Early **Anomaly** Detection in Scale Wind Experimental Campaigns

A green geometric shape pointing towards the bottom right, containing silhouettes of wind turbines.

Presented by: Rudy Alkarem
EERA DeepWind
Trondheim, Norway

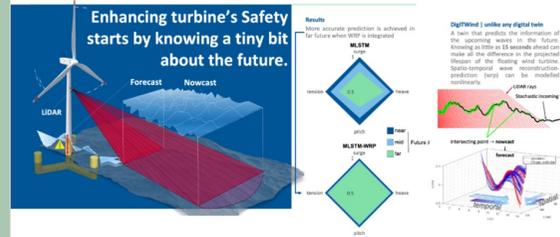
Layout

Introduction

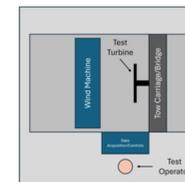
- Lab scale testing:
 - need: validation of new technologies (e.g., testing new control)
 - challenges:
 - delicate equipment: (e.g., performance-match thin airfoil blade sections)
 - no system redundancies due to tight mass constraints (especially for floating)
- Detecting early signs of anomalies can:
 - inform operators of their existence
 - automatically abort the test



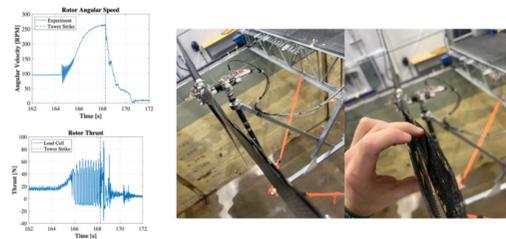
Multi-Fi DT incorporating wave prediction



Experimental Setup

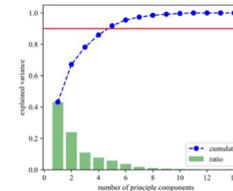
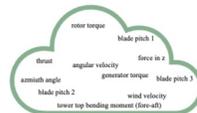


Failure incident at a high wind speed run



Principal components selection

Principal components:
IPC: retaining the first PC
MPC: retains **M** group of PCs that cumulatively explain 90% of the total variance



Results

Variation of anomaly detection criteria combination to the accuracy of the models

		T ⁺	F ⁺	T ⁻	Precision	Recall	F1 Score					
IPC	ΔE	AR	33	32	4	0.452	0.892	0.690				
	HR	0	8	0								
	$\Delta E \& E$	AR	32	15	5	0.681	0.865	0.762				
	HR	0	0	0								
MPC	$\Delta E \& E$	AR	19	0	18	1.000	0.514	0.679				
	HR	0	0	0								
	$\Delta E E$	AR	35	10	2	0.574	0.946	0.714				
	HR	0	16	0								

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Introduction

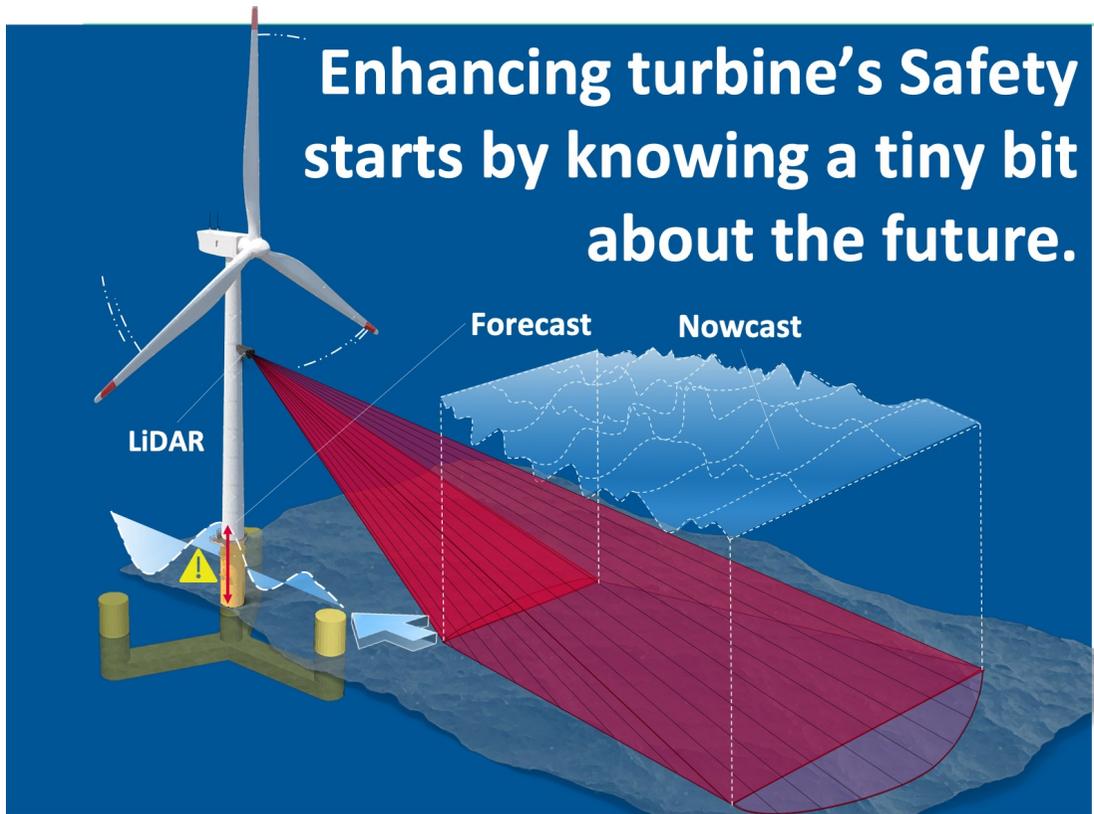
- Fault events:
 - operator error
 - erroneous control command
 - instrumentation malfunction
- Consequences of fault events:
 - costly damages
 - violation of laboraty safety standards
 - cause project delays

Consequences at full scale?



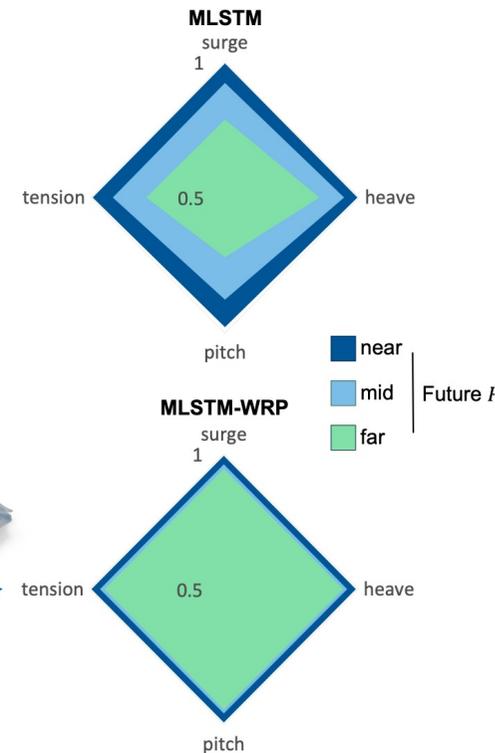
Multi-Fi DT incorporating wave prediction

Enhancing turbine's Safety starts by knowing a tiny bit about the future.



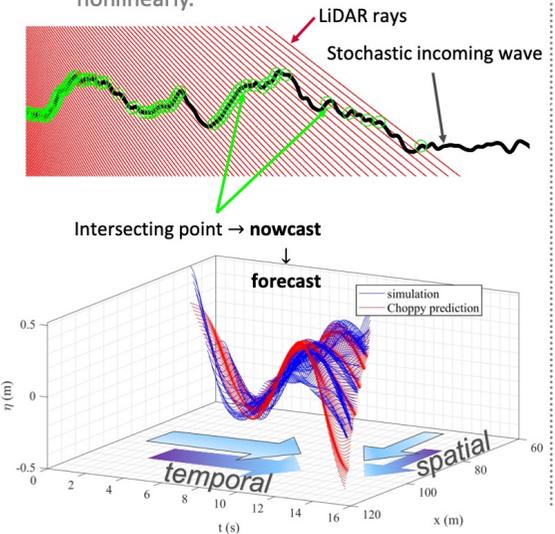
Results

More accurate prediction is achieved in far future when WRP is integrated

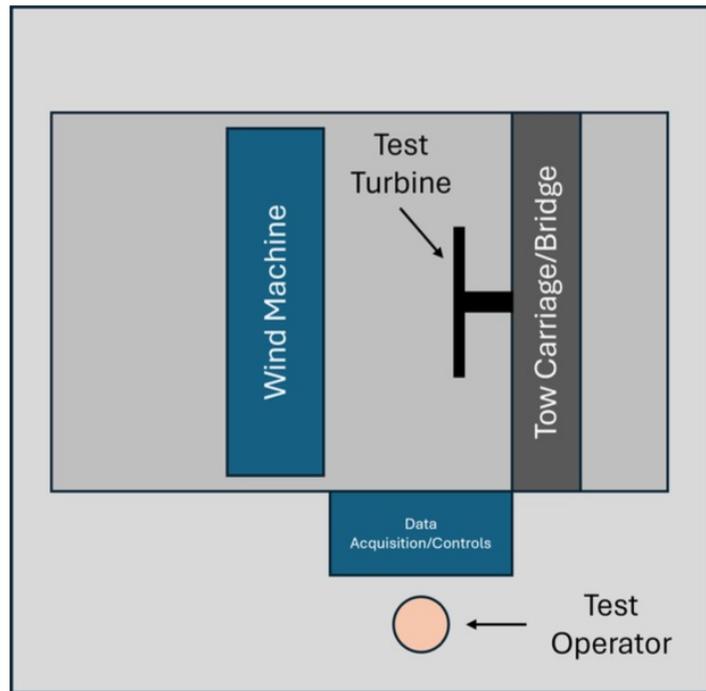


DigitWind | unlike any digital twin

A twin that predicts the information of the upcoming waves in the future. Knowing as little as 15 seconds ahead can make all the difference in the projected lifespan of the floating wind turbine. Spatio-temporal wave reconstruction-prediction (wrp) can be modelled nonlinearly.

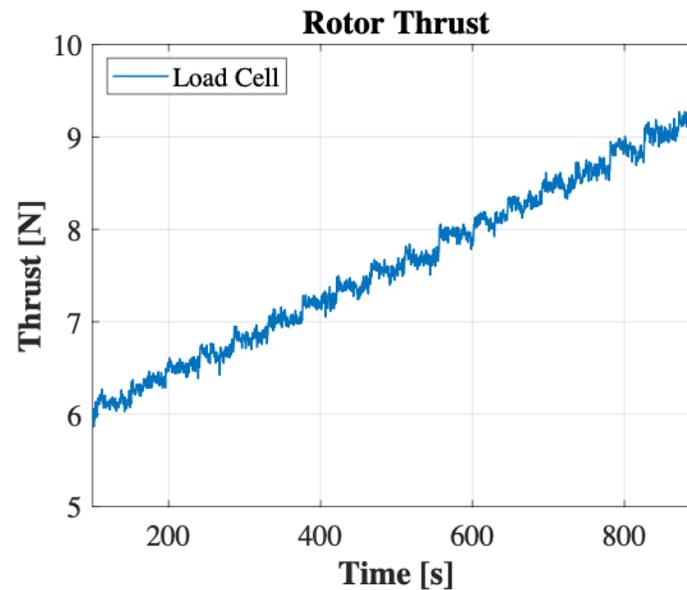
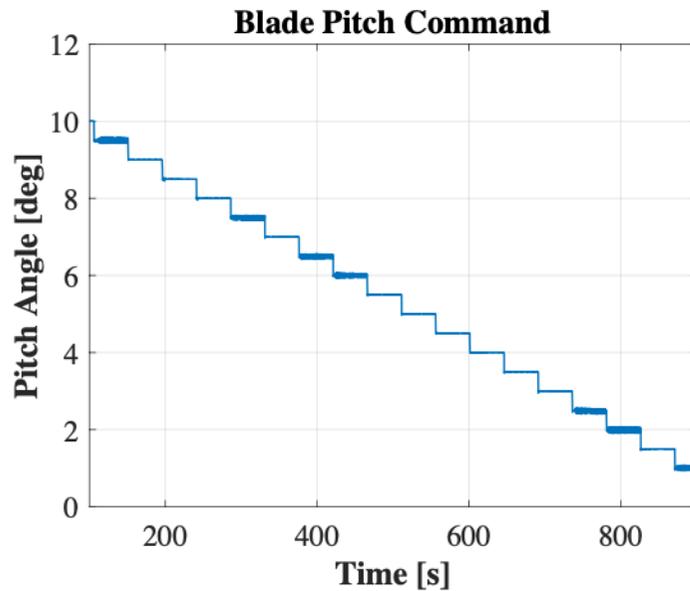
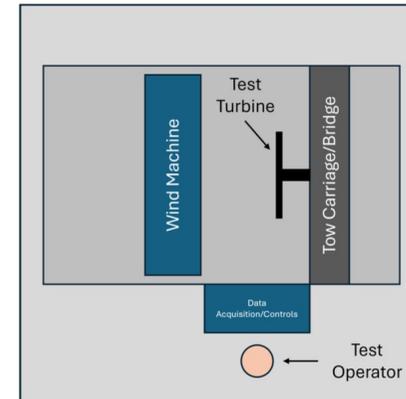


Experimental Setup



Experimental Setup

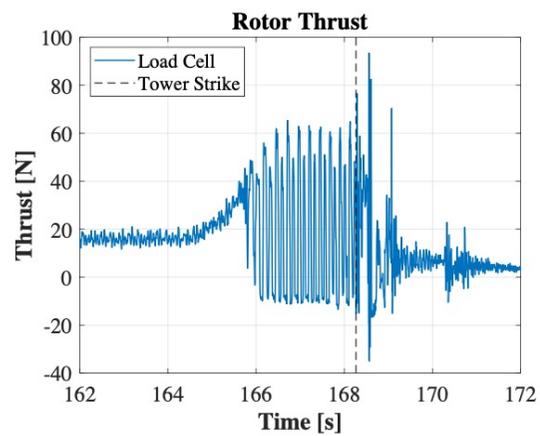
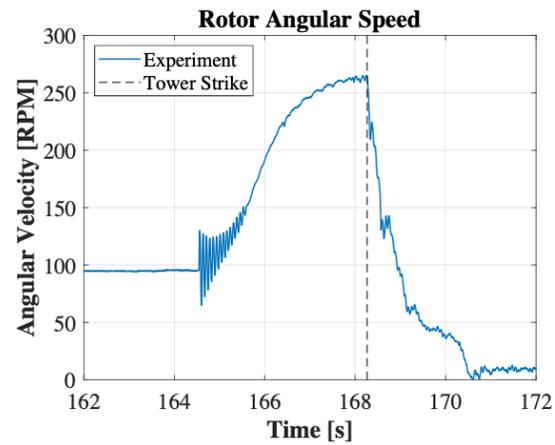
To characterize the rotor, experiments were performed at different wind speed/RPM pairs, cycling through blade pitch setpoints.



monitoring system:

Data acquisition system (DAQ)
using National Instruments cRIO

Failure incident at a high wind speed run

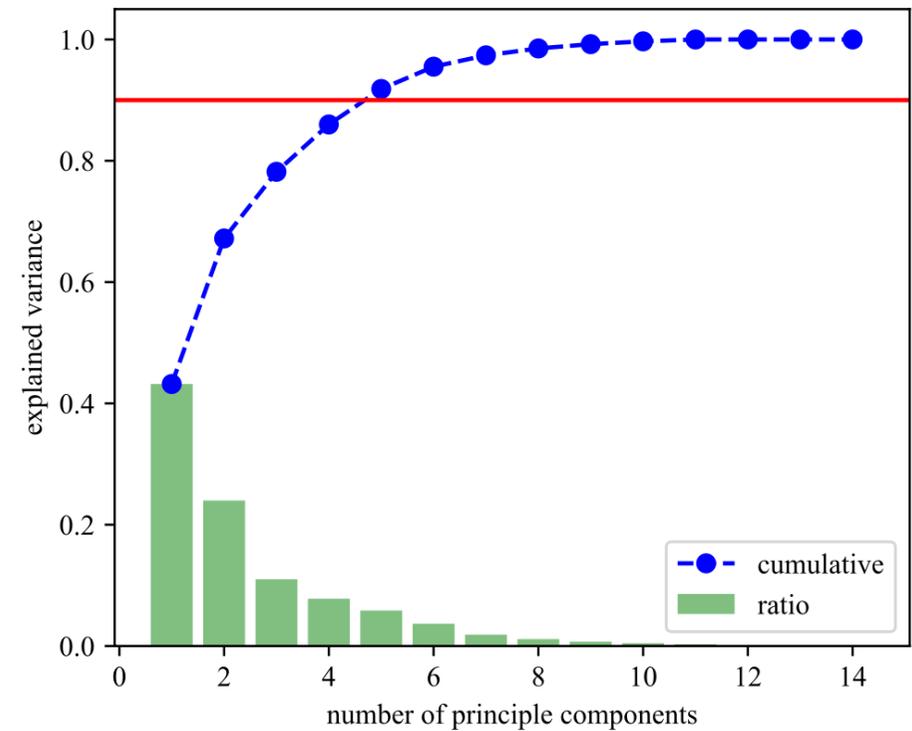
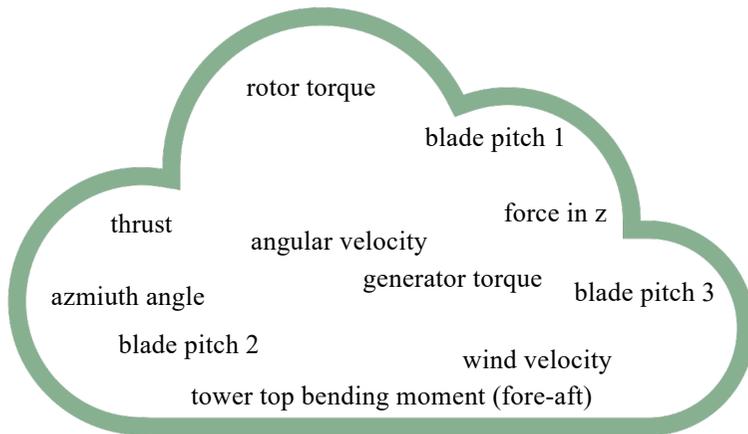


Principal components selection

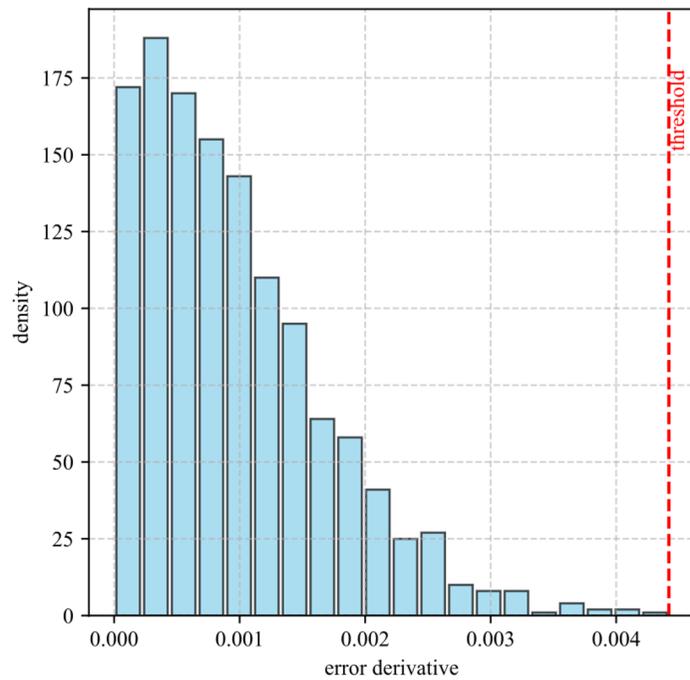
Principal components:

1PC: retaining the first PC

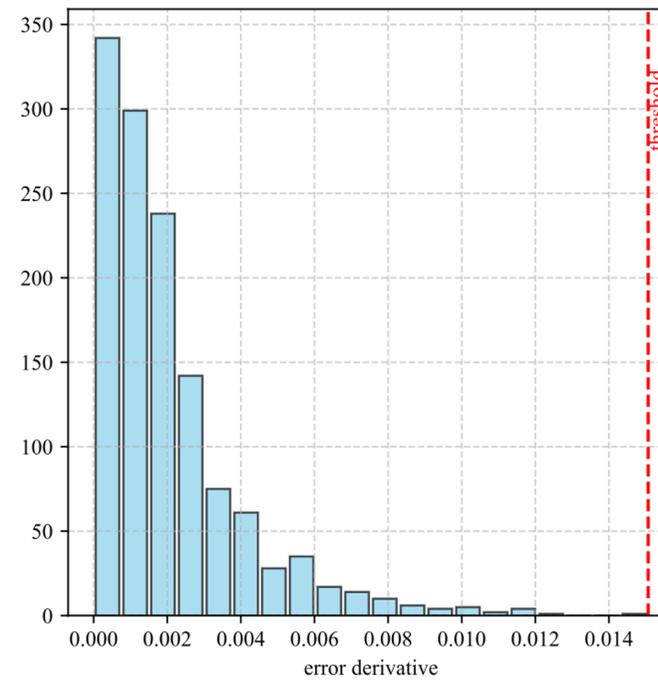
MPC: retains **M** group of PCs that cumulatively explain 90% of the total variance



Anomaly threshold



(c) Error derivative histogram in 1PC model.

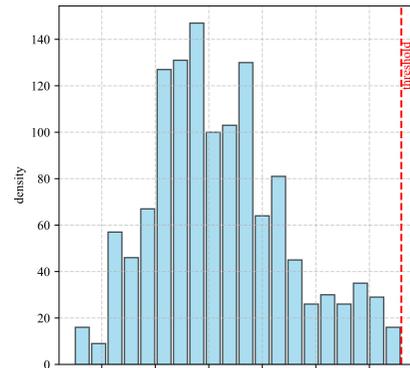


(d) Error derivative histogram in MPC model.

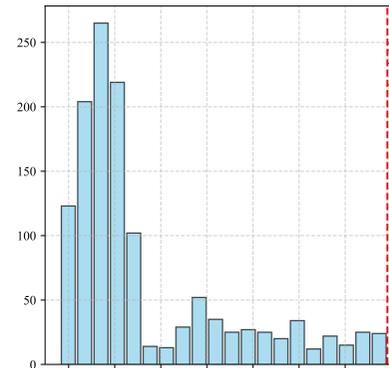
Anomaly threshold

E

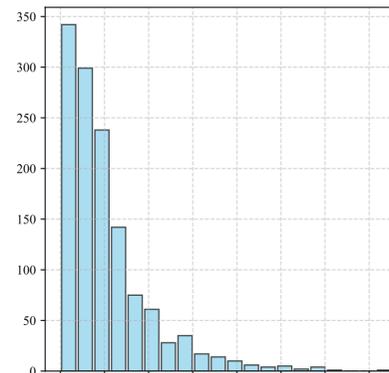
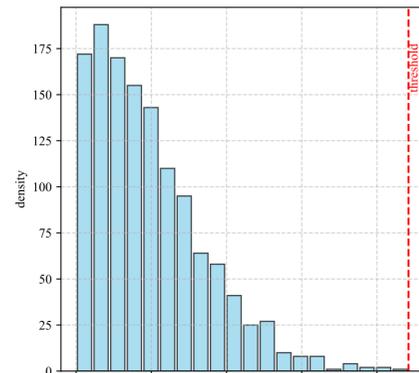
1PC



MPC



ΔE



Performance Metrics

		T/F: Anomaly or not
	+/-: detected by the model or not	

True negative (undetected true anomaly)	True positive (detected anomaly is true)
False negative (undetected false anomaly)	False positive (detected anomaly is false)

Performance Metrics

T^-	T^+
F^-	F^+

ratio of true positives to all detected: Precision (P)

$$P = \frac{T^+}{T^+ + F^+}$$

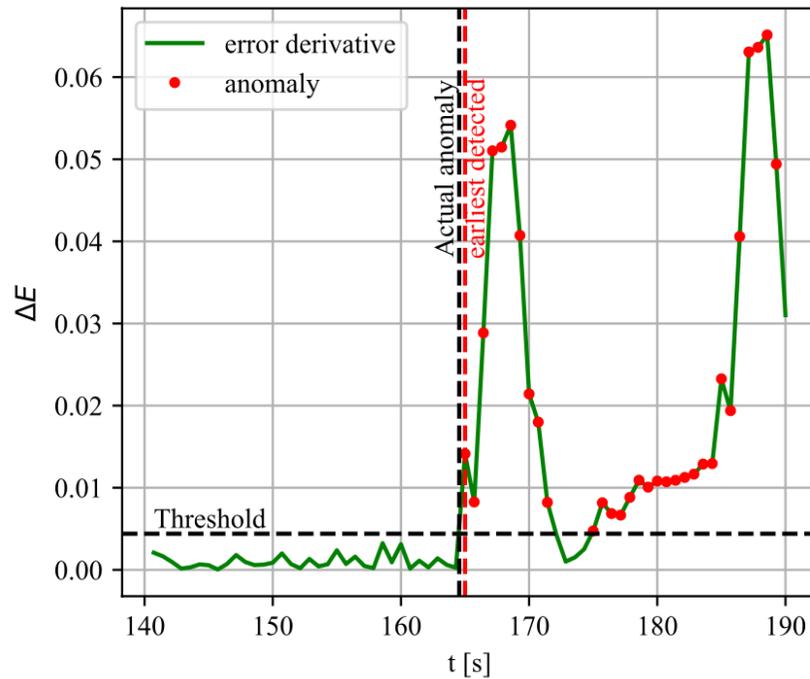
ratio of true positives to all true anomalies: Recall (R)

$$R = \frac{T^+}{T^+ + T^-}$$

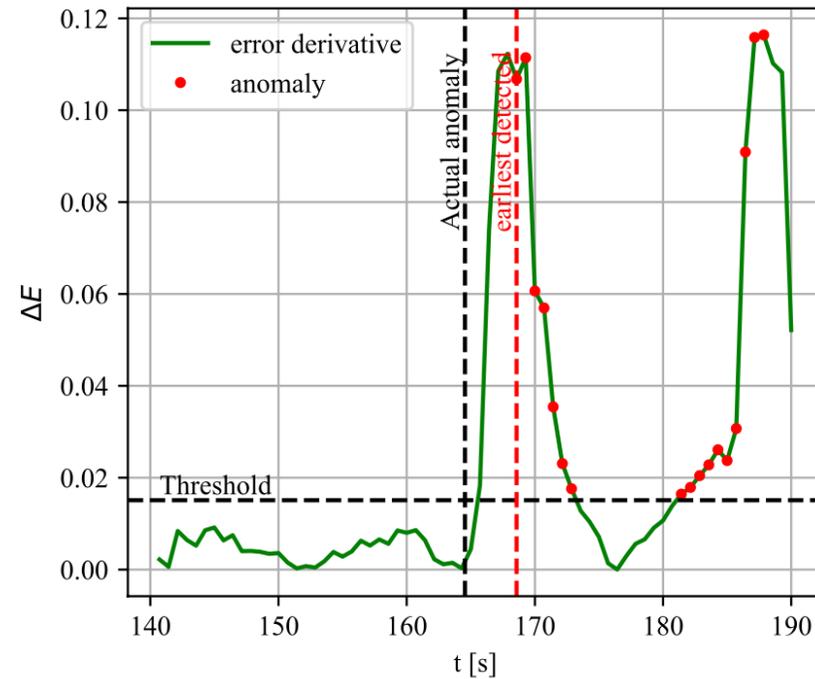
$$0 < FI = 2 \times \frac{P \times R}{P + R} < 1$$

Results

Pre-strike anomaly detection



(a) 1PC anomaly detection



(b) MPC anomaly detection

Results

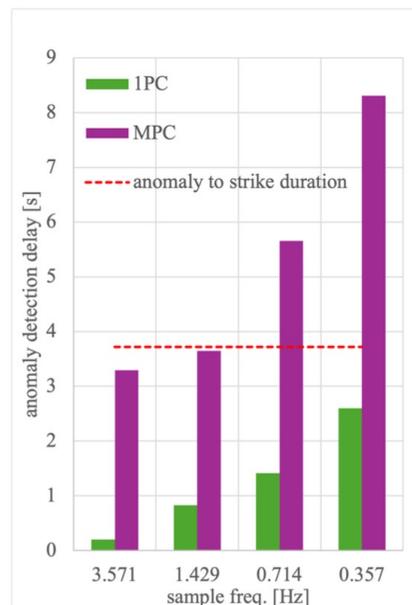
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1PC	ΔE	AR	33	32	4	0.452	0.892	0.600
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	$\Delta E \& E$	AR	32	15	5	0.681	0.865	0.762
		HR	0	0	0			
	$\Delta E E$	AR	37	149	0	0.188	1.000	0.316
		HR	0	11	0			

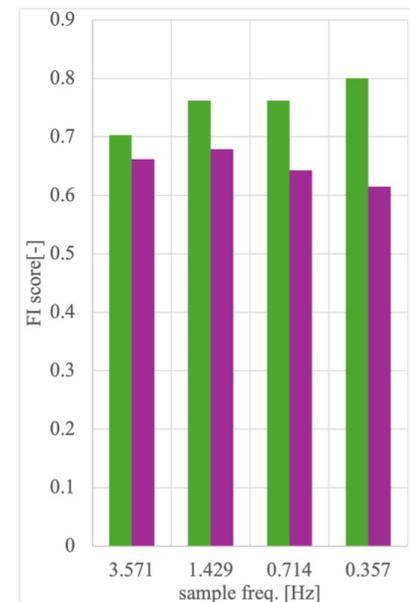
			T ⁺	F ⁺	T ⁻	Precision	Recall	FI Score
MPC	ΔE	AR	25	10	12	0.510	0.676	0.581
		HR	0	14	0			
	$\Delta E \& E$	AR	19	0	18	1.000	0.514	0.679
		HR	0	0	0			
	$\Delta E E$	AR	35	10	2	0.574	0.946	0.714
		HR	0	16	0			

Results

Sensitivity study of sampling frequency to anomaly detection delay, and accuracy



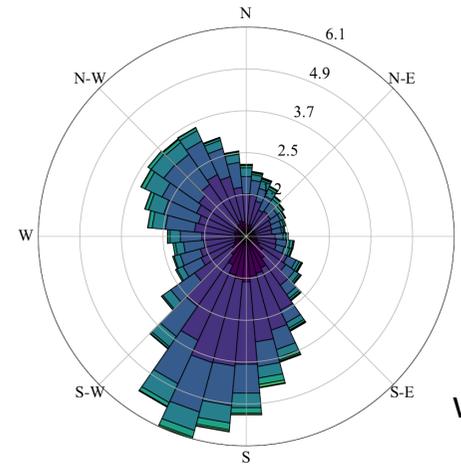
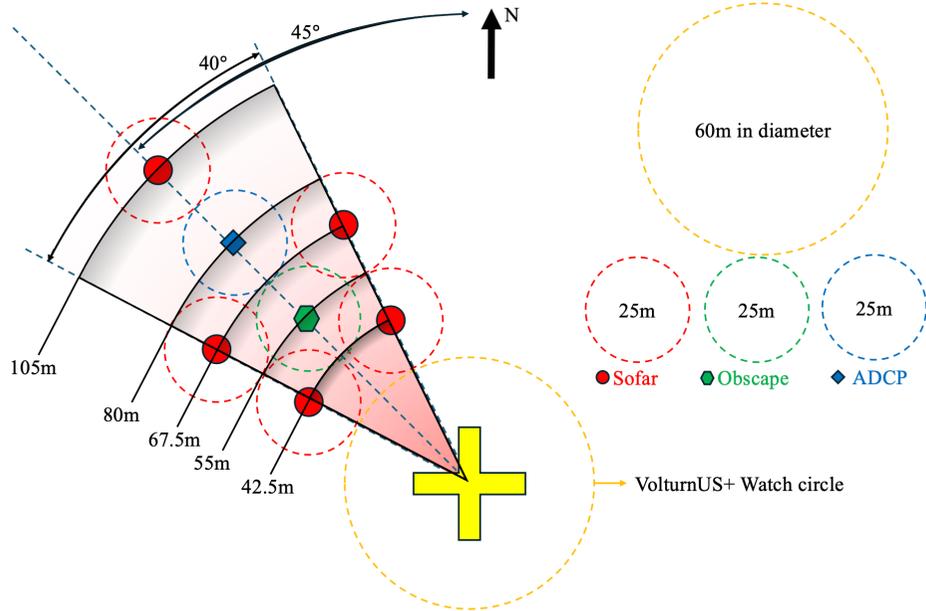
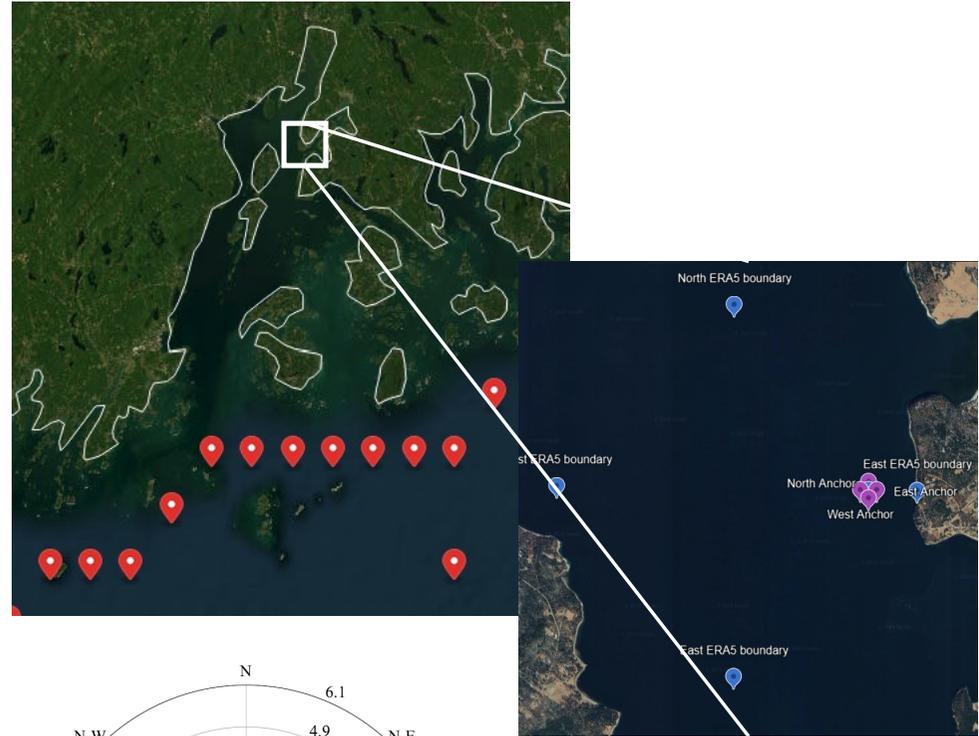
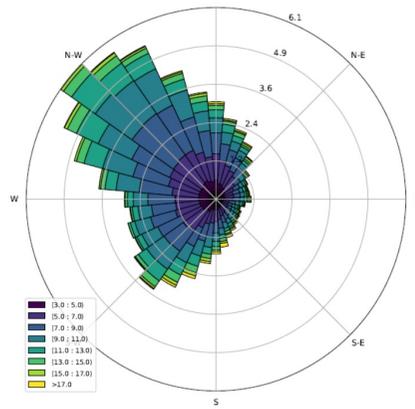
(a) detection delay



(b) FI score

Next step

100m height wind directionality



wave directionality



Thank you

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