finalRAVEML
forecasting seastate

RAVE FORUM#2

- Sea state -

ML based approaches for spatial sea state prediction

04.11.2025

Thilo Grotebrune, Supreeth Hanumappa
Prof. Dr.-Ing. Torsten Schlurmann

Supported by:
Federal Ministry for Economic Affairs and Energy
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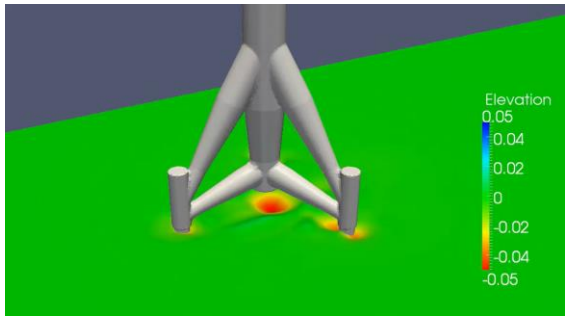
ptj
BSH BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE
Ludwig-Franzius-Institut für Wasserbau, Ästuar- und Küsteningenieurwesen
Fraunhofer IWES

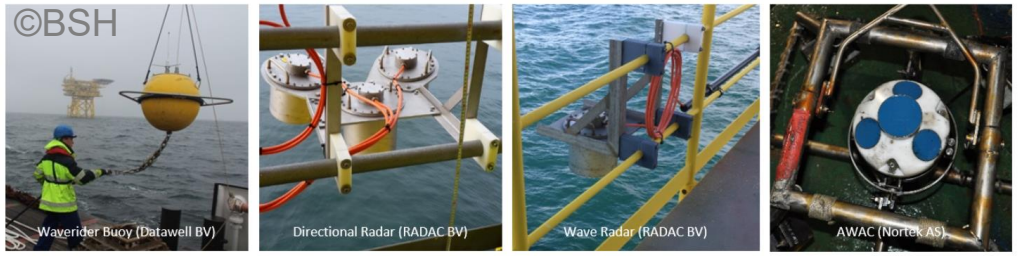
Who we are

- Ludwig-Franzius-Institute of Hydraulic, Estuarine and Coastal Engineering (LuFI)
- Our research activities cover a wide range of areas, including
  - coastal protection,
  - marine and offshore technology,
  - risk and vulnerability research in coastal zones, and
  - field measurements in Germany and abroad.

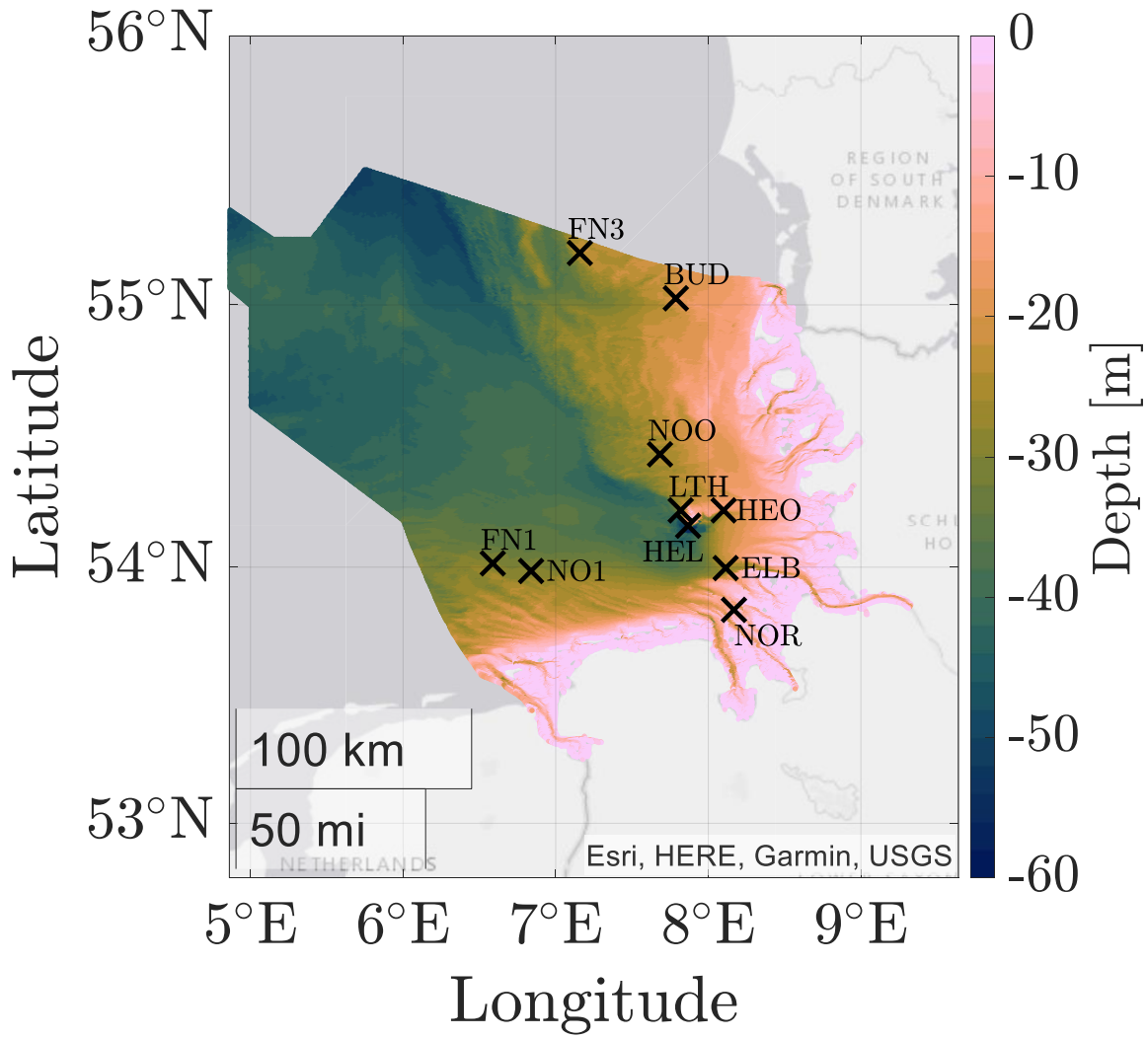


Database | Measurement Sites

- Multiple measuring sites in the German North Sea
- Seastate measurements via buoys, radar systems or ADCP



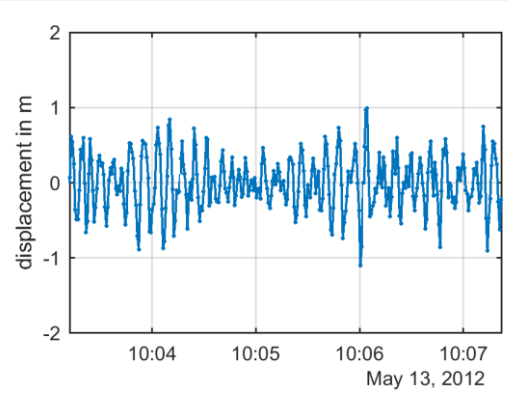
- Quality controlled and provided by the Federal Maritime and Hydrographic Agency



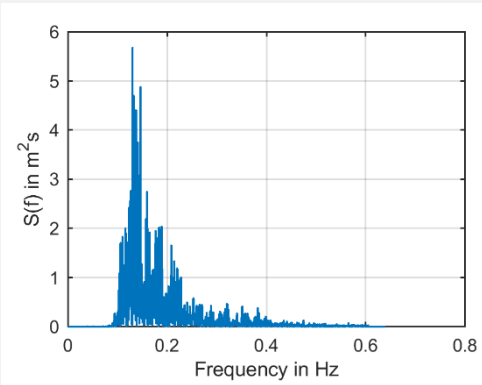
From Motion to Seastate | DWR MK-III

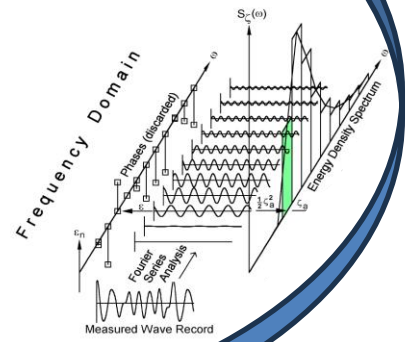
Datawell.nl [1]

@BSH

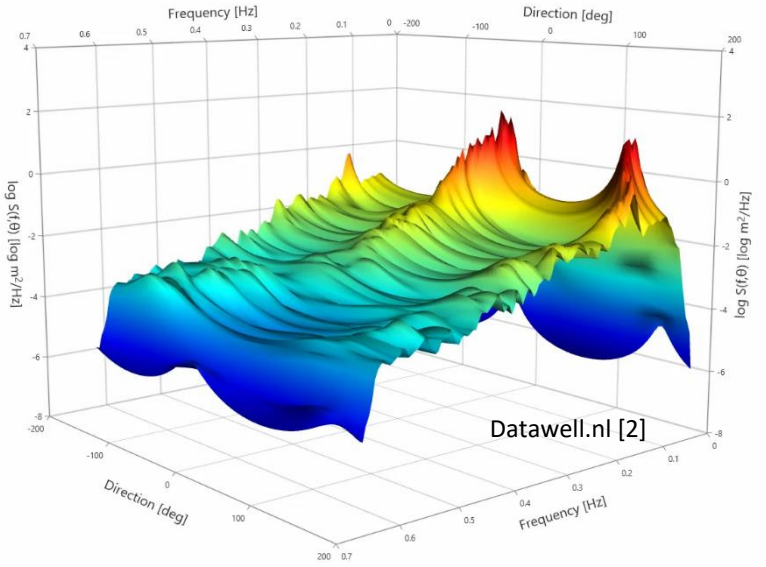


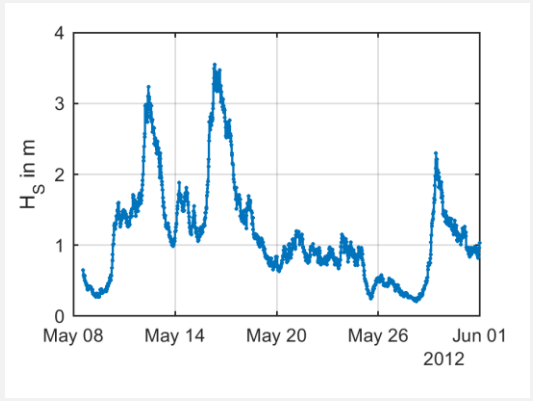
Buoy measures displacement at 2.56 Hz

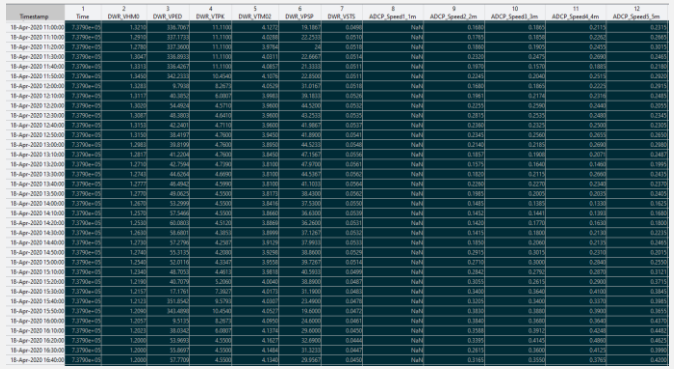




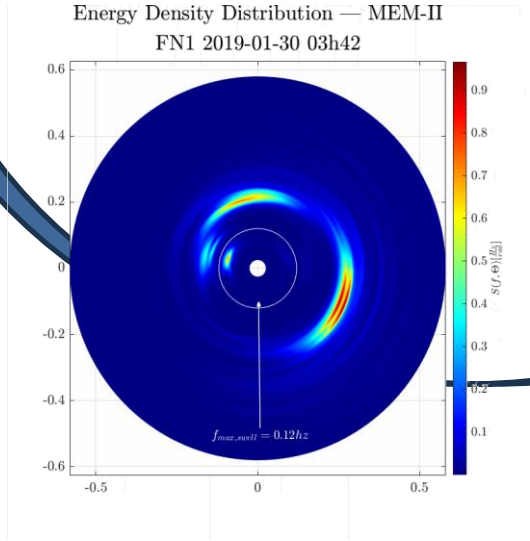
Spectral calculation for ~30min intervals.







Time series (.dat / .mat) of spectral parameters



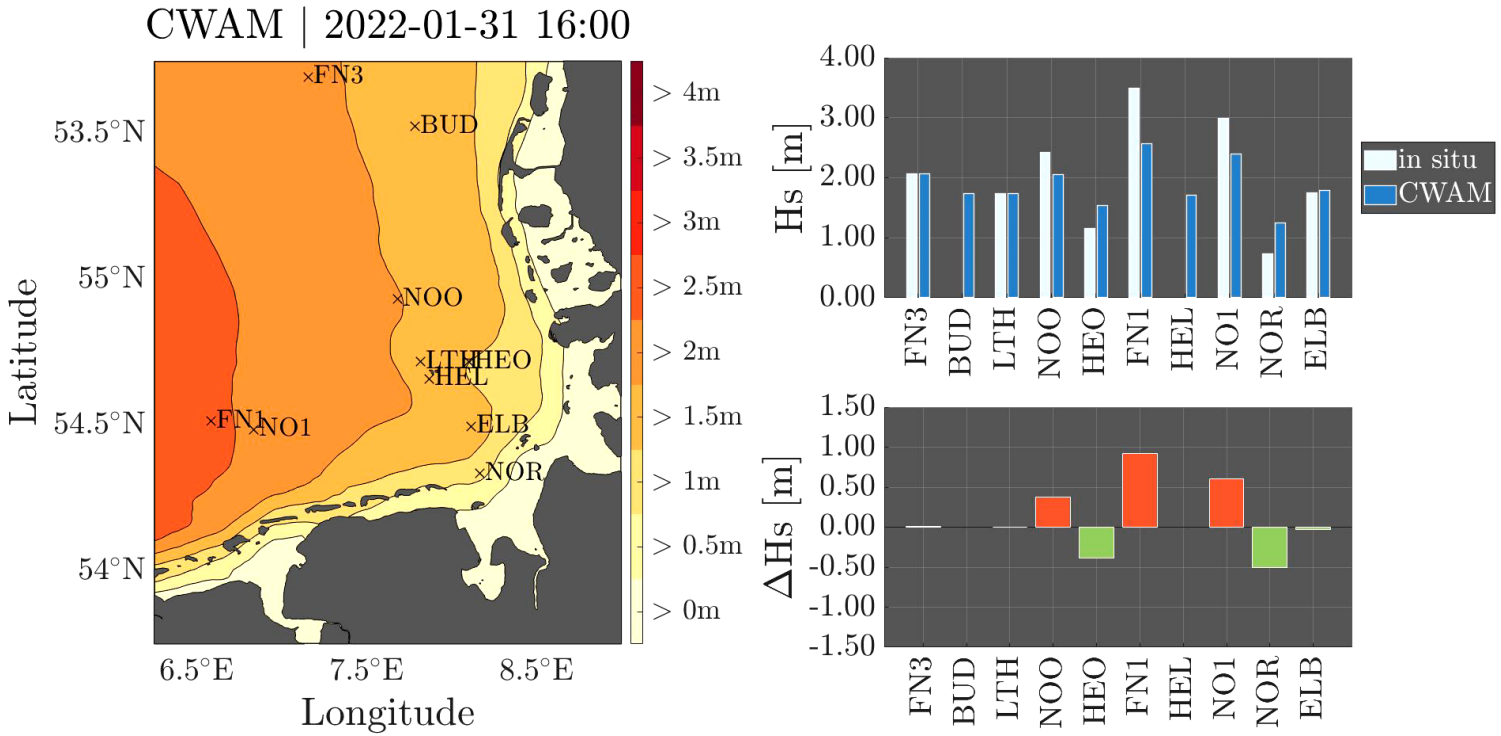
$$m_i = \int_0^\infty f^i \, S(f) \, \mathrm{d}f$$

Meaningful spectral parameters (Hs, Tp, Dir, …) are extracted by calculating spectral moments m_i.
→ Single Values for 30 min interval

German Coastal WAve Model (CWAM)

- Spectral wave model based on 3rd generation model WAM [2]
- Operated by German Weather Service (DWD)
- Driven by COSMO-EU wind input
- GWAM > EWAM > CWAM
  - Forecasts up to 72h
  - Temporal step 1h
  - Spatial resolution ~900m
- Consideration of currents and water level changes by coupling with HBM model

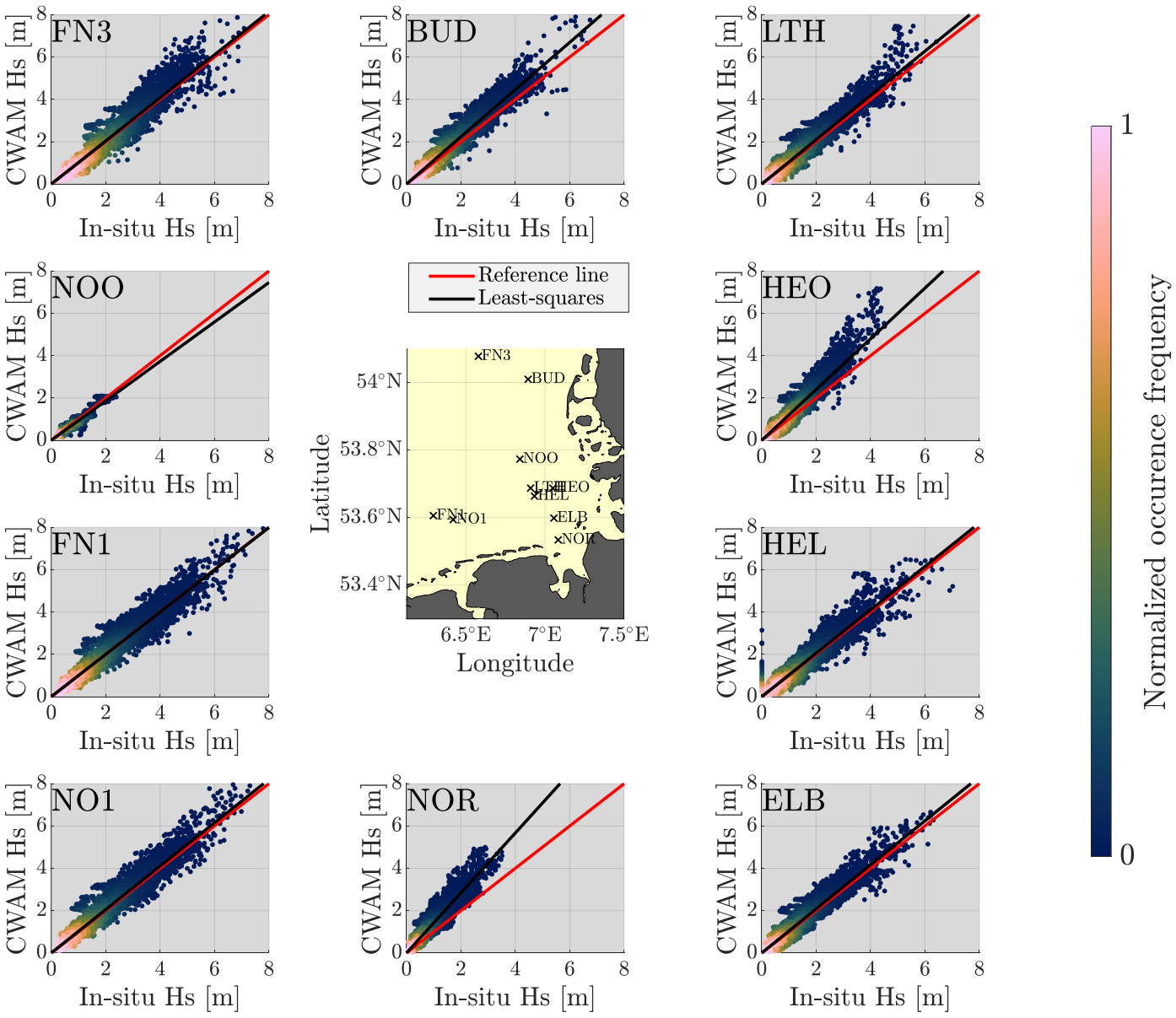
➢ Hs deviations > ±1m occur



[2] Hasselmann et al., 1988

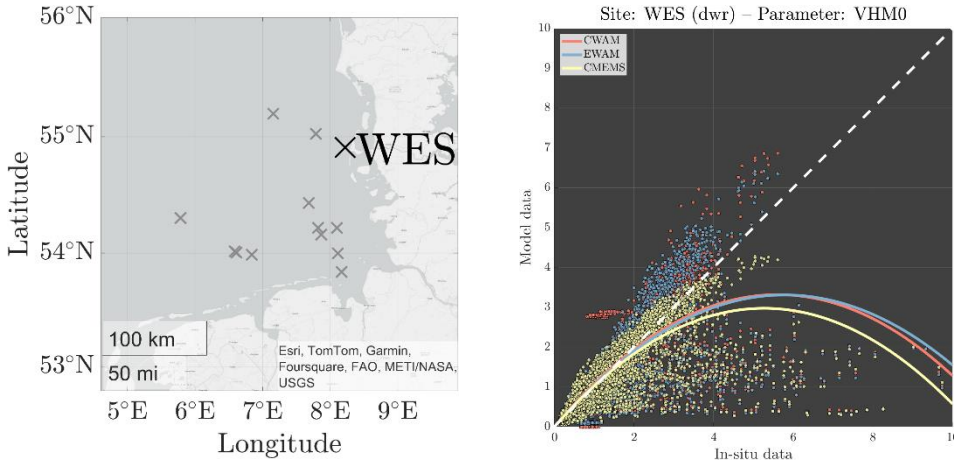
CWAM performance

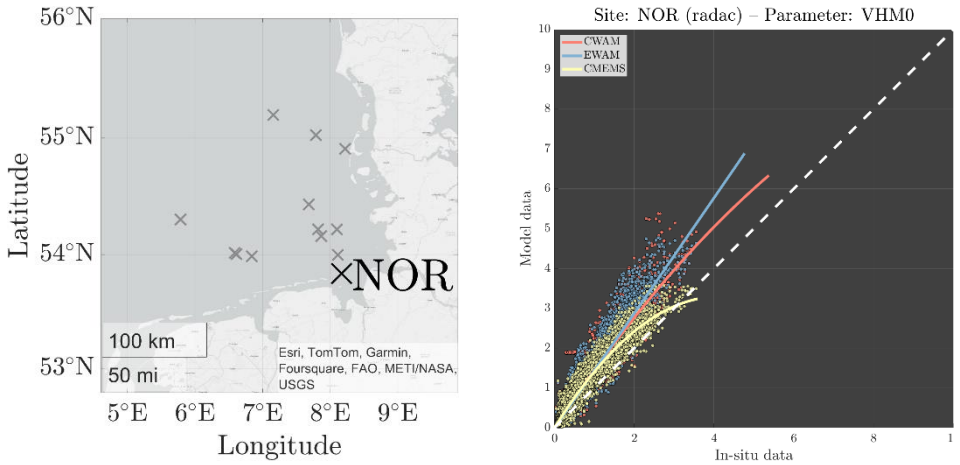
- Time period:
  2021/01/01 – 2022/08/31
- Up to ~29.000 valid data pairs per site
- Max occured Hs: ~8m



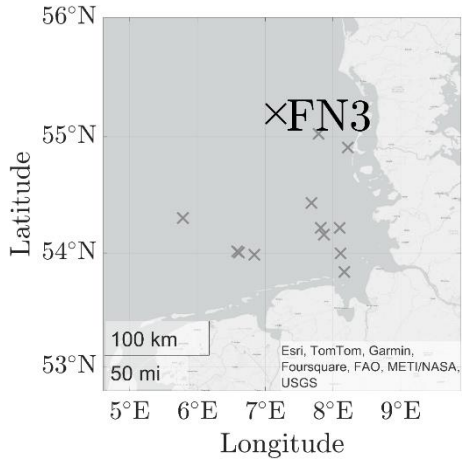
CWAM performance | Near- and Offshore

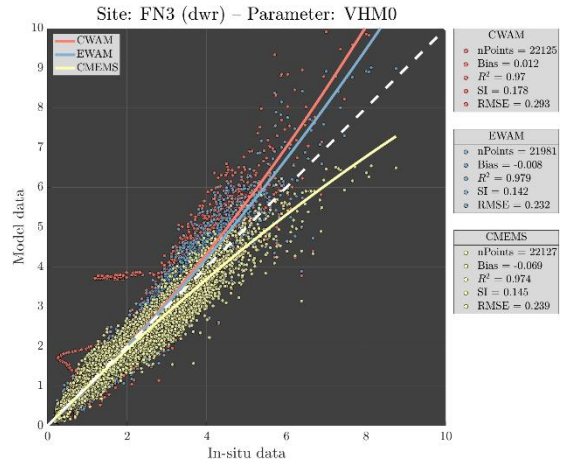
Nearshore

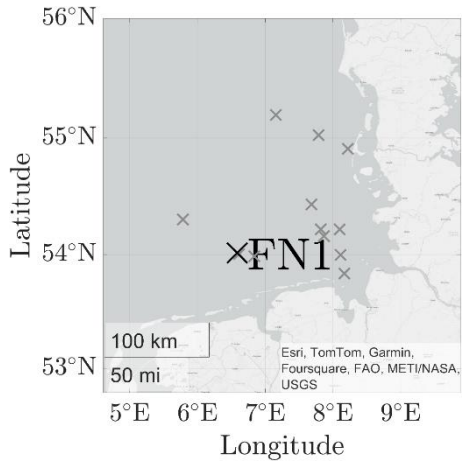


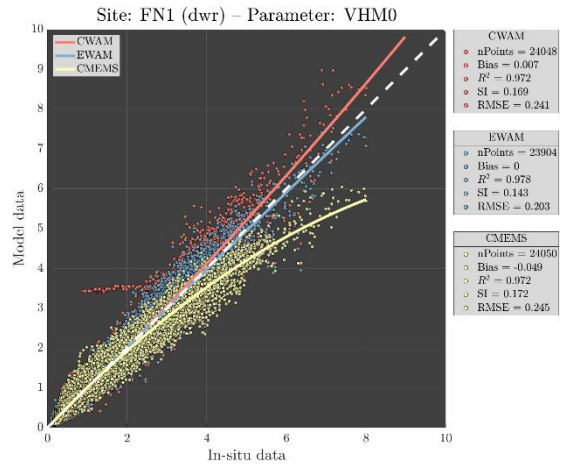


Offshore

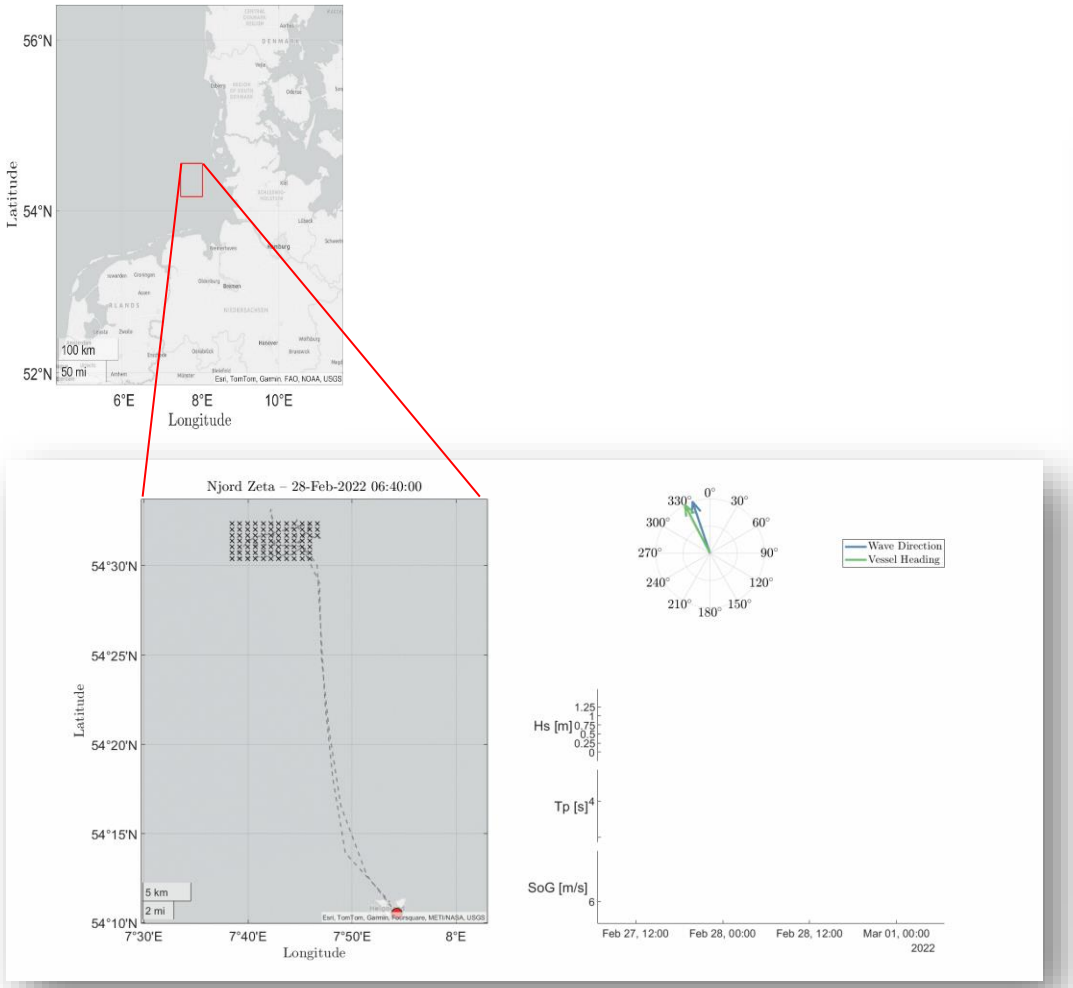


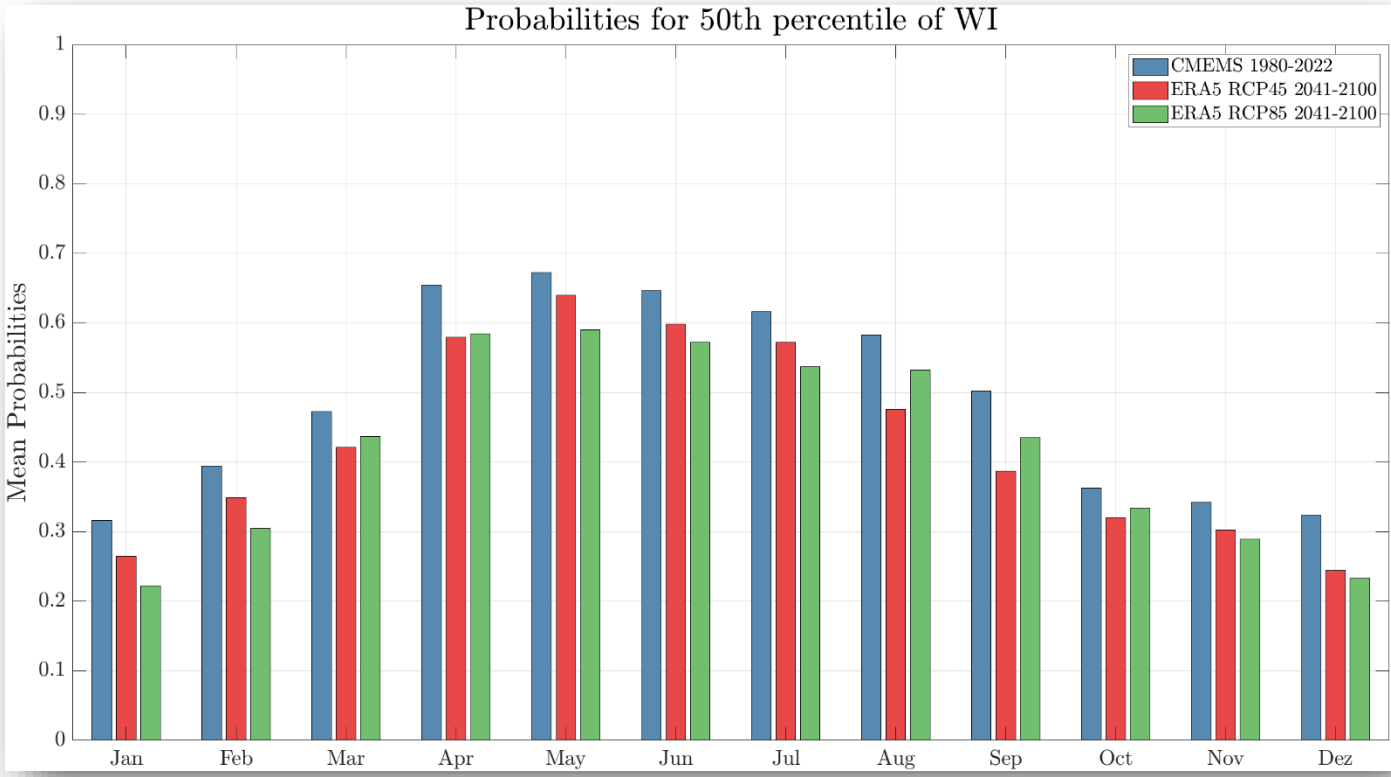




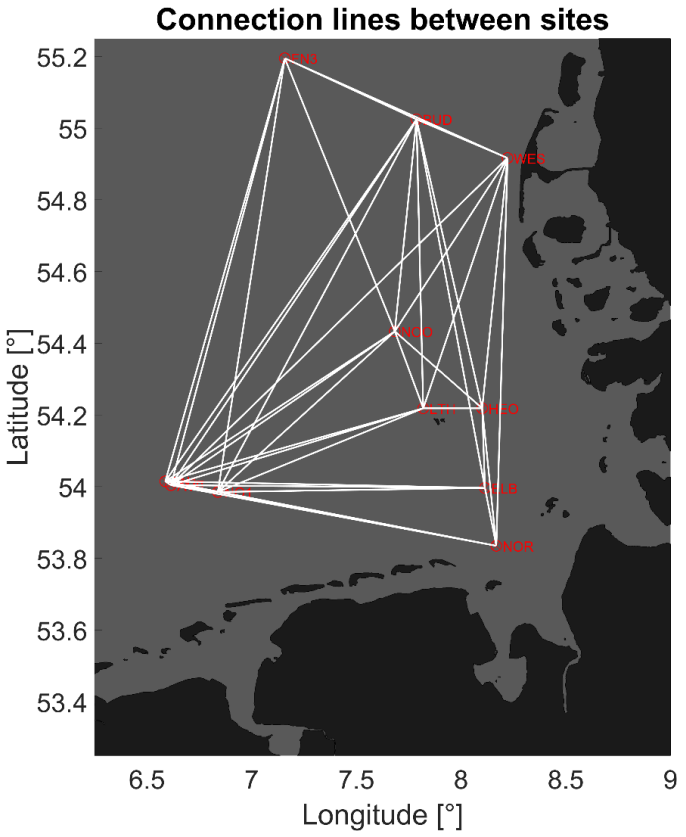


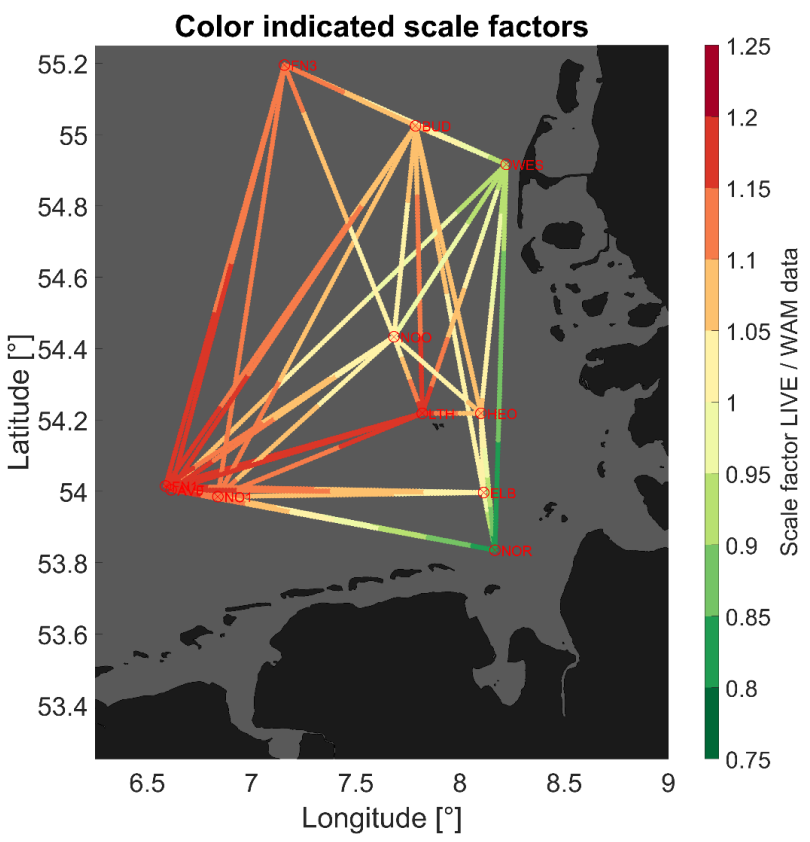
Assessing the offshore operability → RAVE Workshop 2024 by L. Fröhling

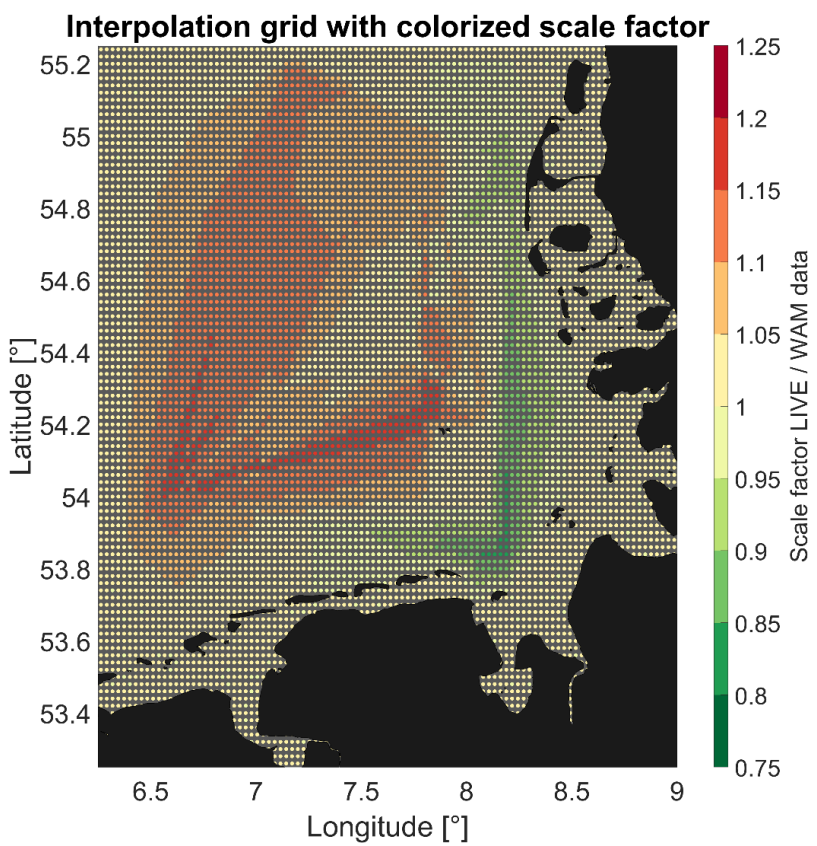




➢ Correct the NWP with Measurements





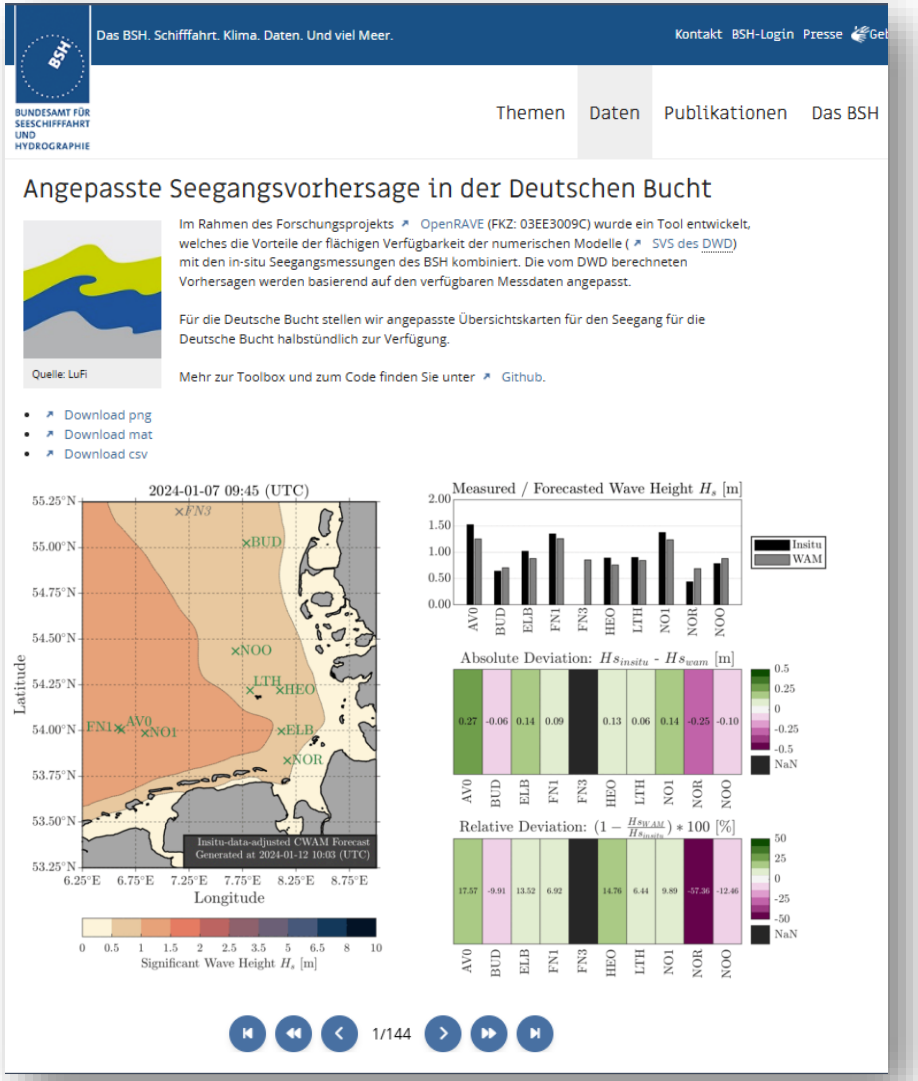


„Seegangsmodul“

- Assimilation of in-situ data into numerical xWAM: „in-situ data adjusted xWAM *forecast* of the sign. wave height in the German Bight“

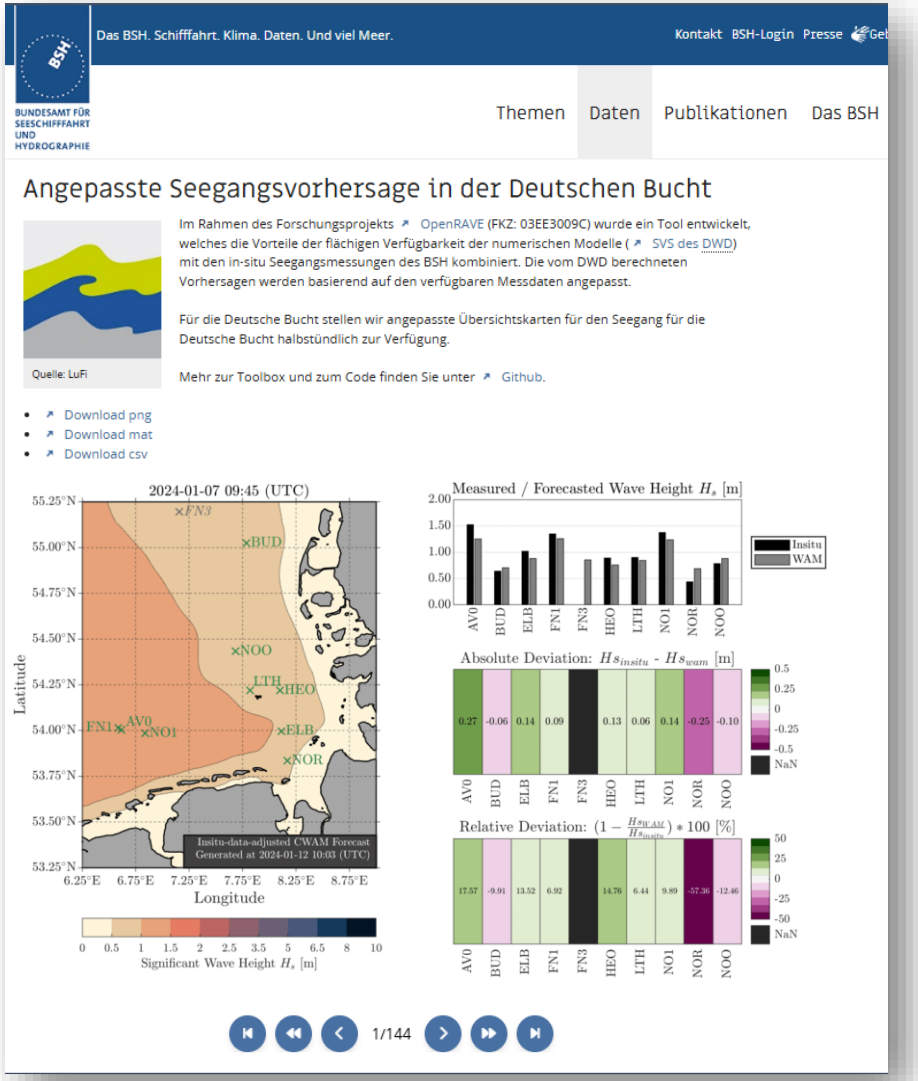
- Data and figures are provided via BSH website:

https://www.bsh.de/DE/DATEN/Klima-und-Meer/Seegang/seegang_node.html



Limitations

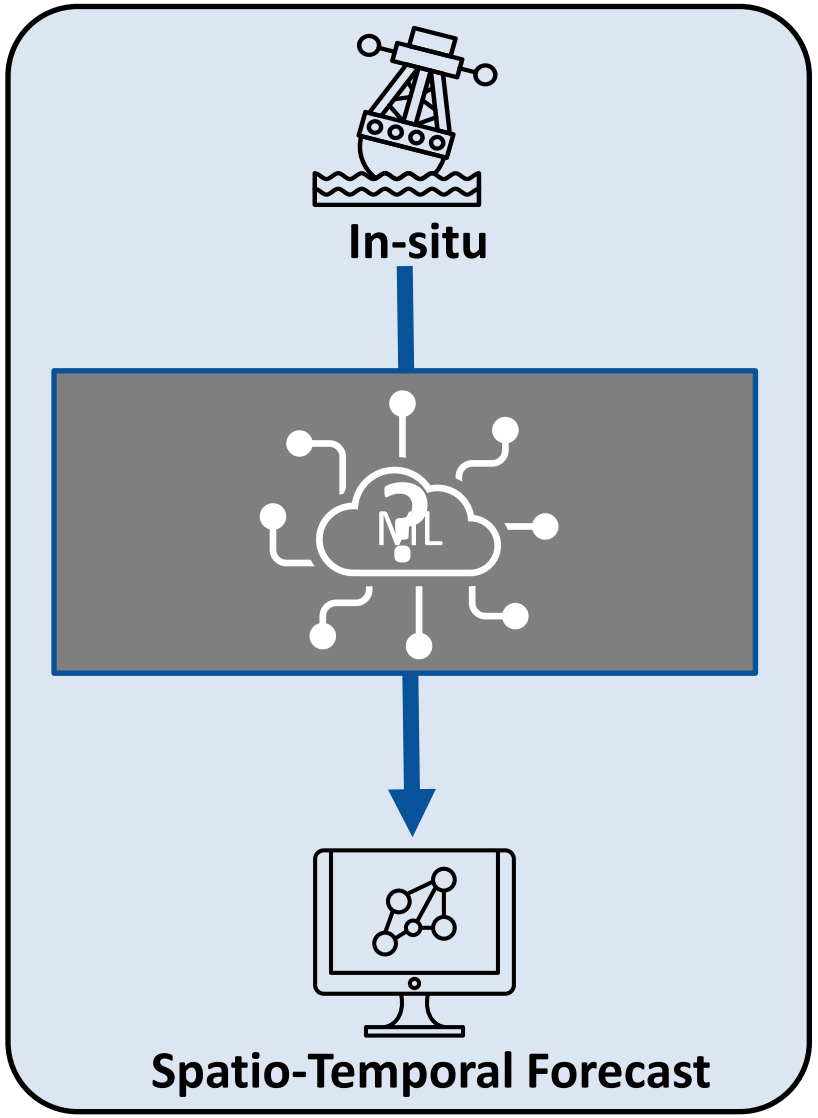
- „Realtime“
- Dependent on NWP data
- Based on bi-linear interpolation method
- Data availability crucial for tool performance



Framework Approach

Objective:
Develop a framework capable of generating spatio-temporal sea state forecasts in the German Bight using only in-situ measurement data

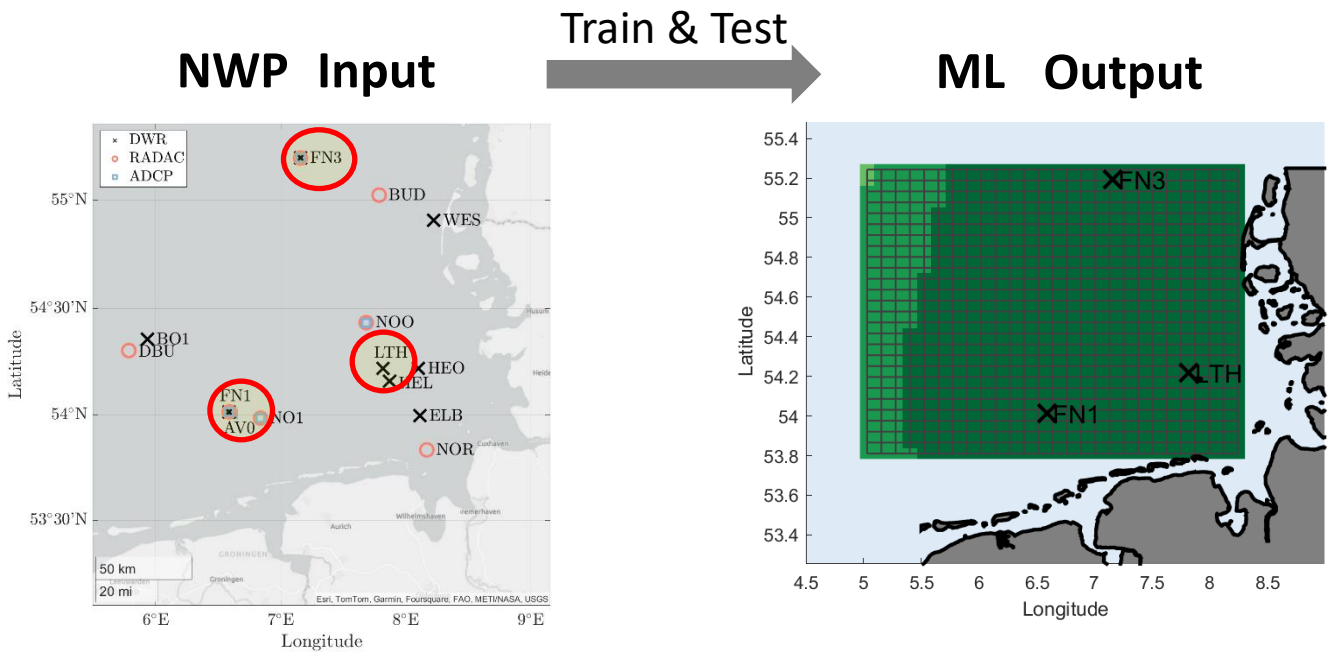
Goal:
More computationally efficient and potentially more accurate than traditional numerical models.



Spatial Model

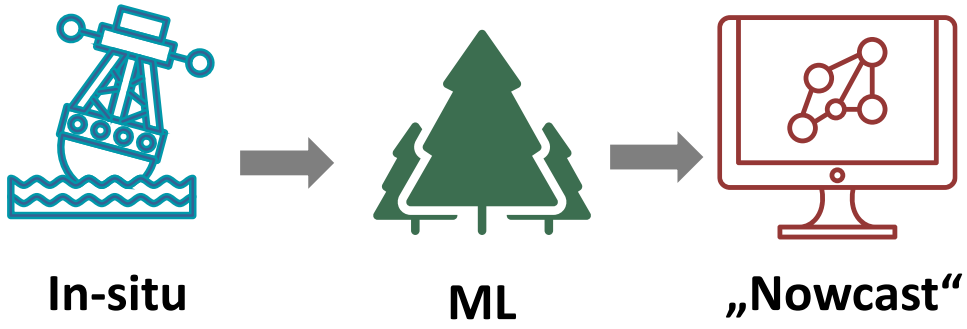
- Numerical Weather Prediction (NWP) model data used to train maschine learning model

- Model trained to predict mesh grid data using *single-site inputs*



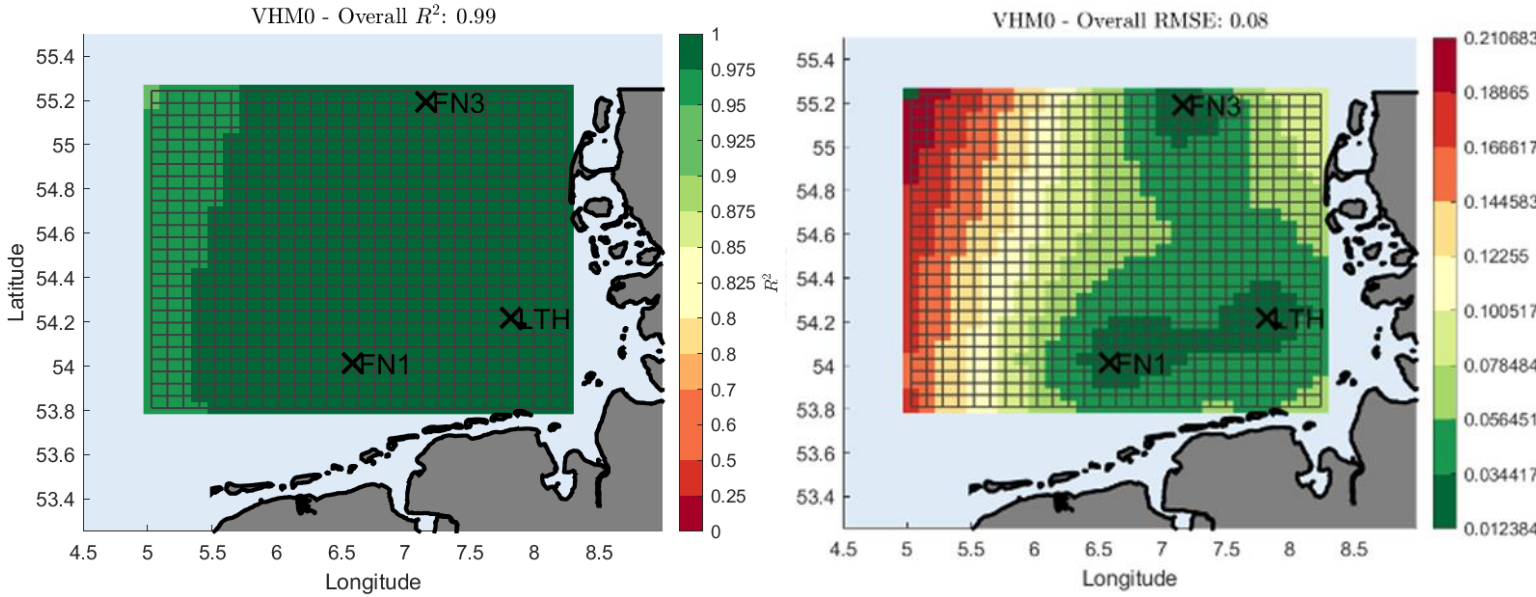
Spatial Model

- In-situ measurements used as input for trained ml model
- Model generates a „nowcast“ of sea state in German Bight
- No influence from preceding/following time steps on the result
- Fully independent of NWP data



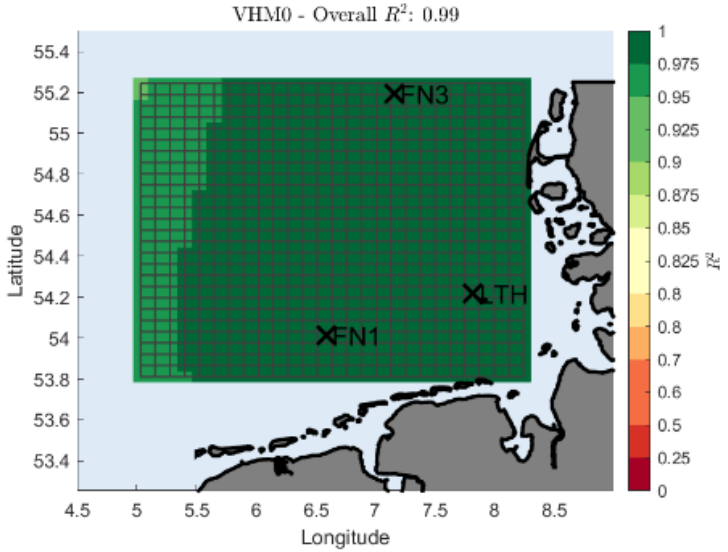
Prelimenary results…

- 25 years AWPR data for training, 8 years for testing
- Cropped area to avoid NaN values in data, dimension reduction to 27x27
- Determine R^2 & RSME (total and for each cell) to assess model performance
- Cell-averaged model performance *$R^2$and RMSE* visualized for *VHM0*

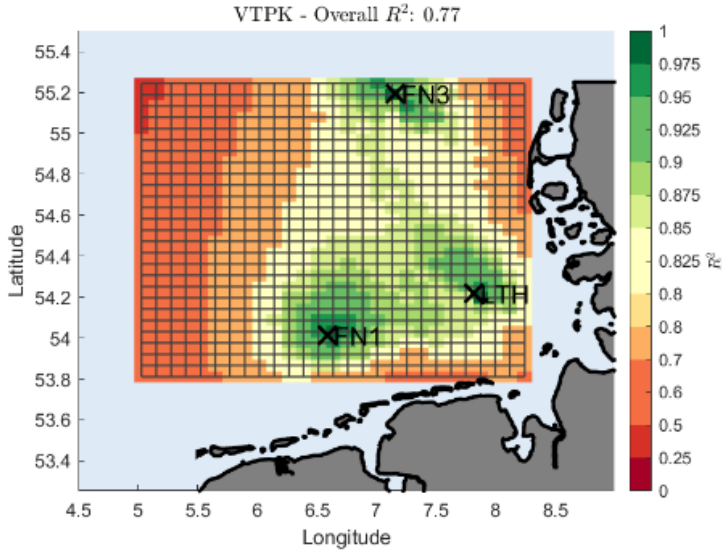


Cell-averaged model performance: 2016/01/01 - 2023/12/31

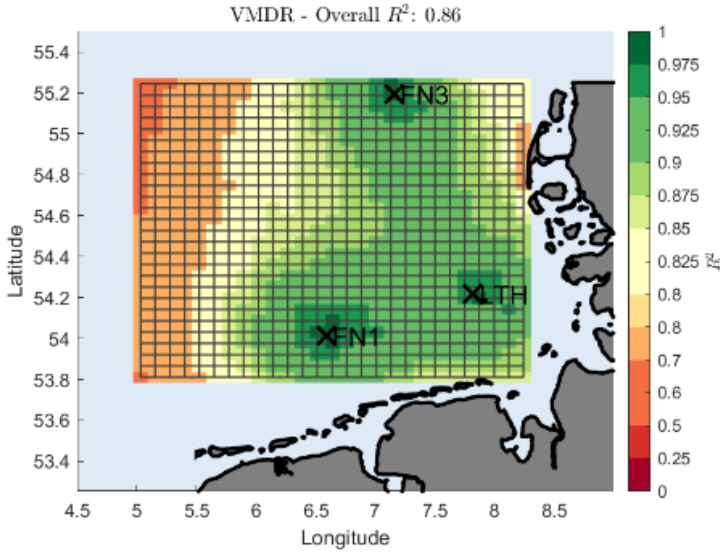
H_{m0}



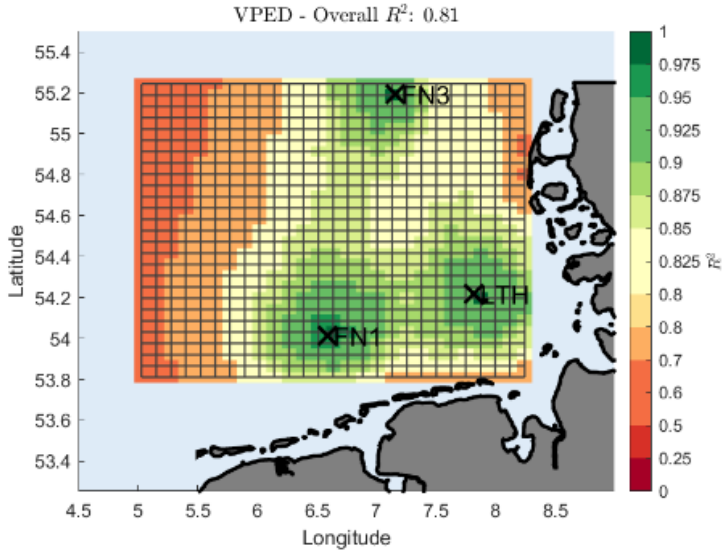
T_p



Dir_{mean}



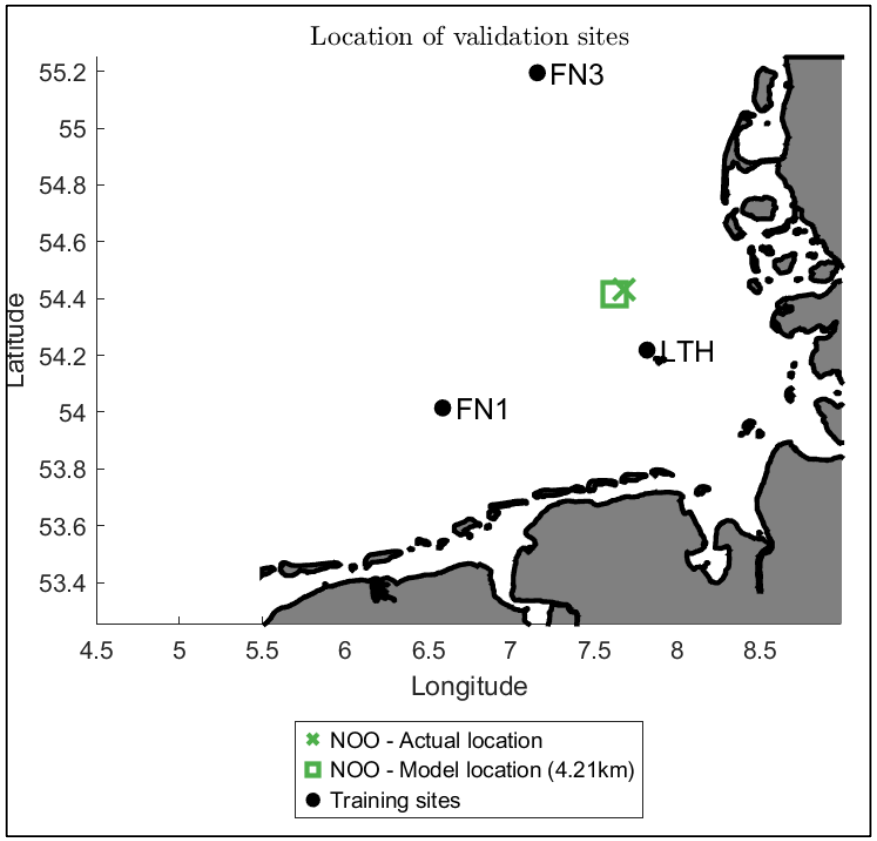
Dir_{peak}

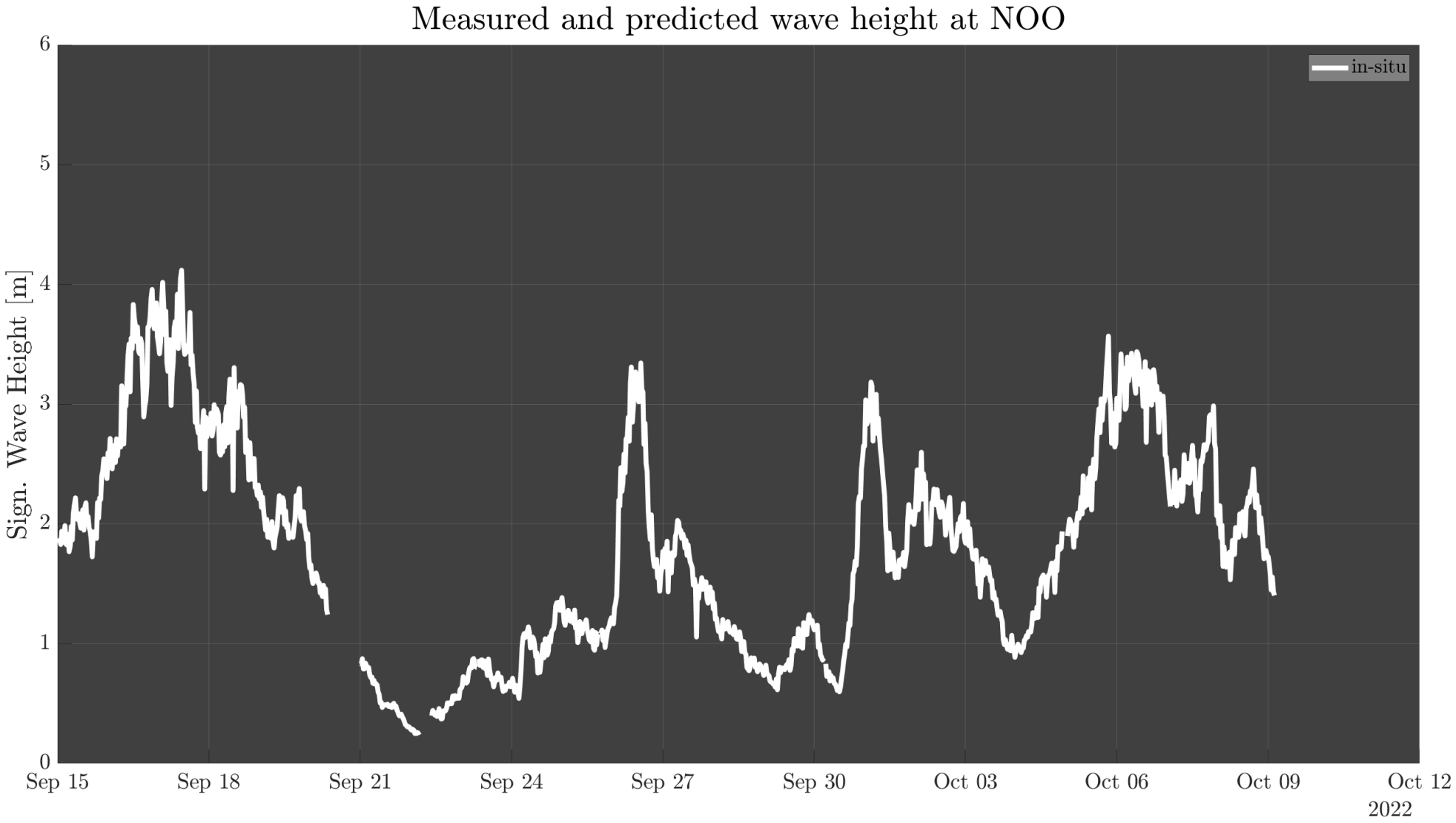


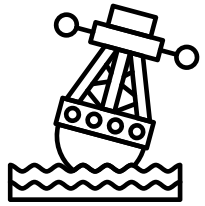
Validation at NOO

- ML model trained with input locations FN1, FN3, LTH

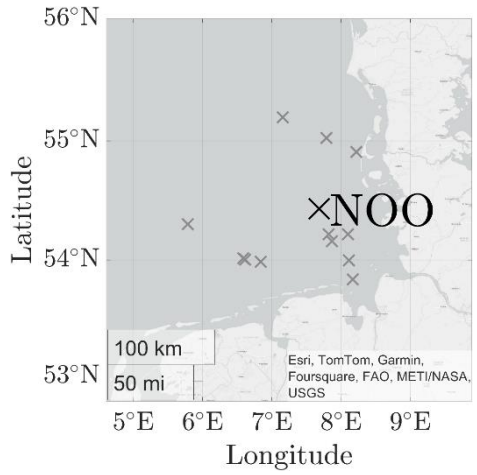
- Validation at NOO location for time period 2022/09/15 – 2022/10/15
  - In-situ measurements
  - EWAM forecast
  - Seastate module
  - ML model with EWAM input
  - ML model with in-situ input

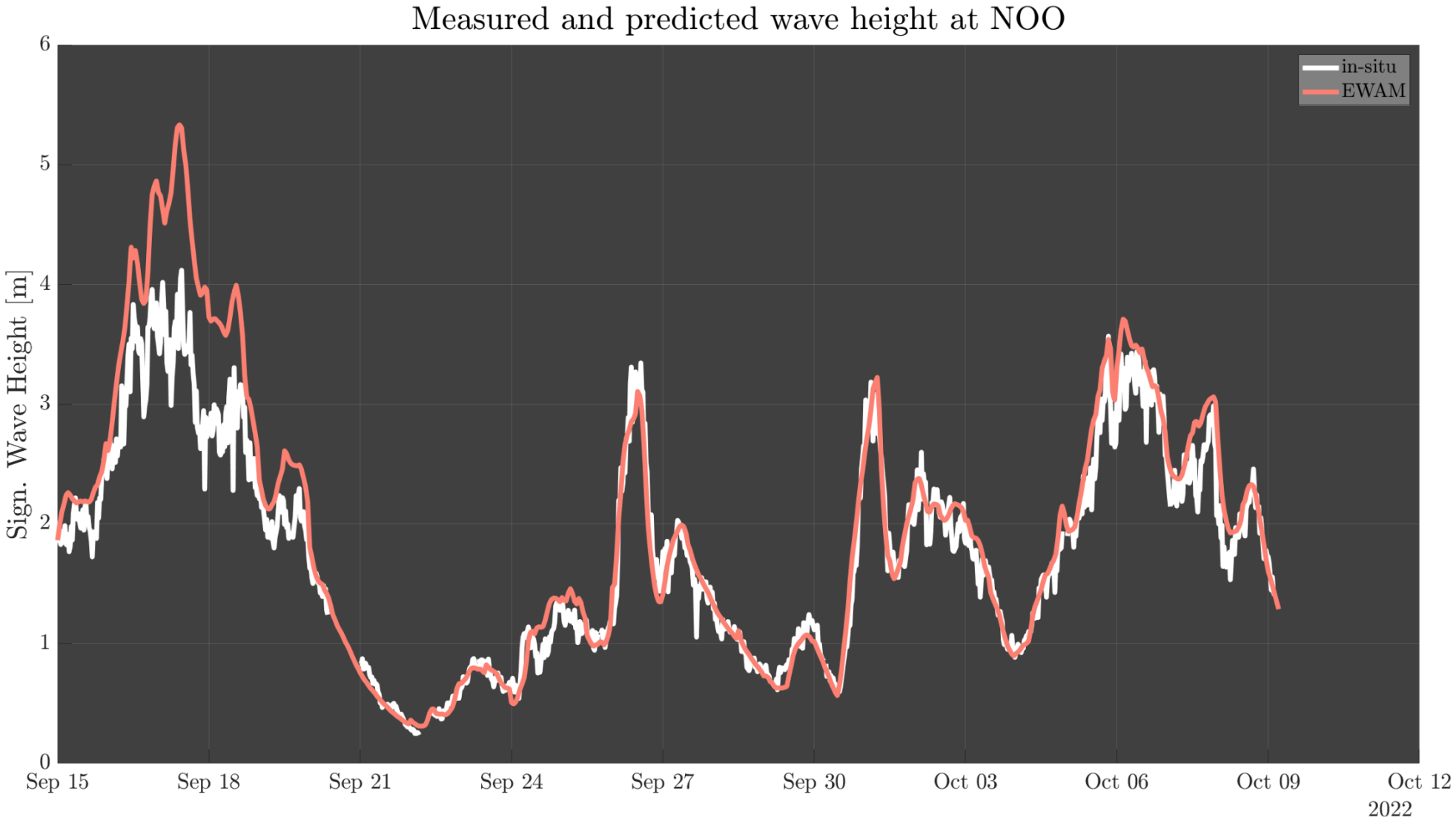



Measured and predicted wave height at NOO
in-situ
Sign. Wave Height [m]
0
1
2
3
4
5
6
Sep 15
Sep 18
Sep 21
Sep 24
Sep 27
Sep 30
Oct 03
Oct 06
Oct 09
Oct 12
2022



In-situ


56°N
55°N
54°N
53°N
Latitude
NOO
100 km
50 mi
Esri, TomTom, Garmin, Foursquare, FAO, METI/NASA, USGS
5°E
6°E
7°E
8°E
9°E
Longitude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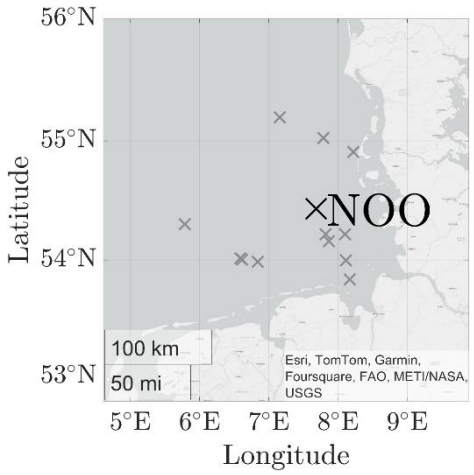
EWAM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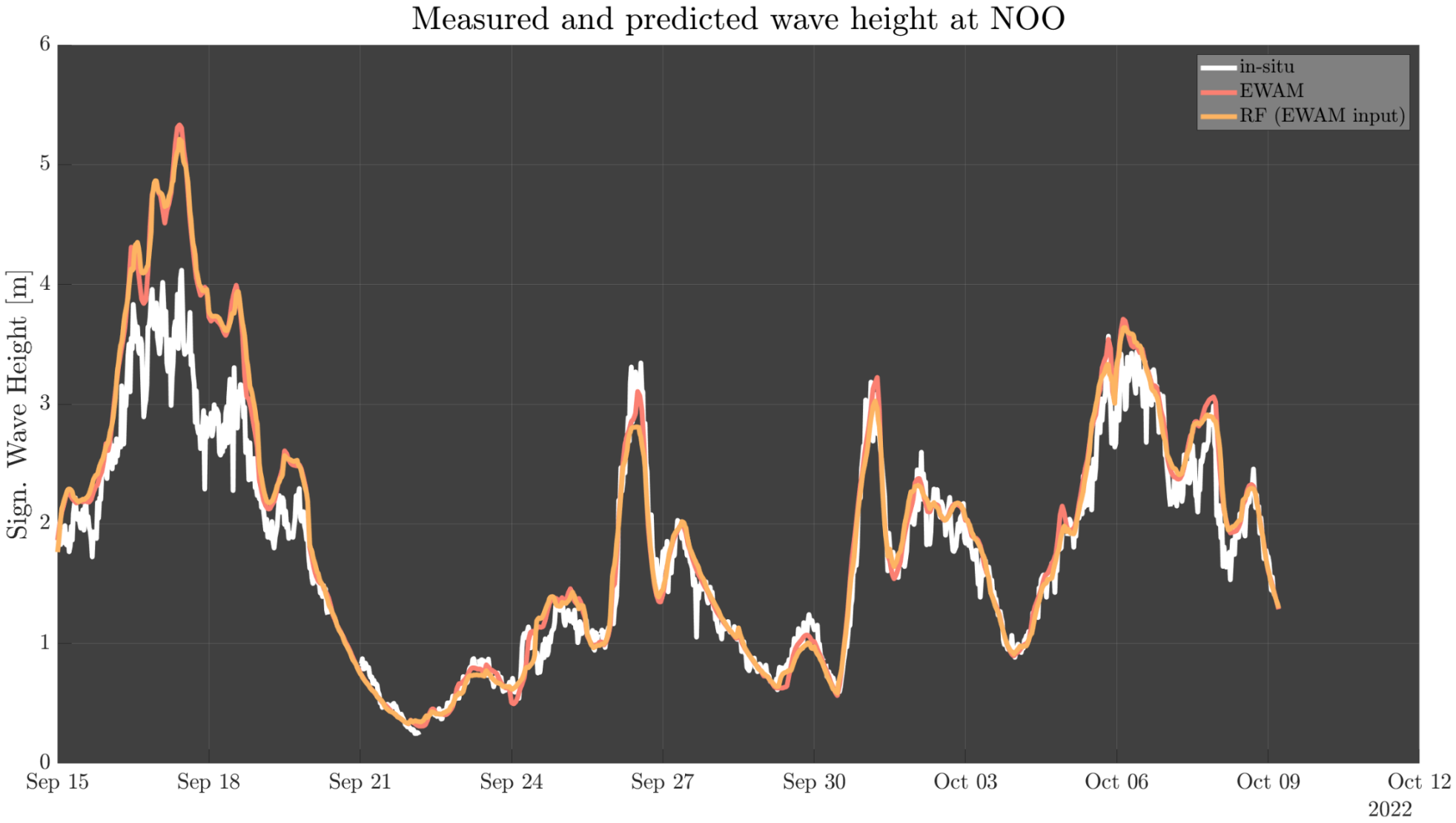
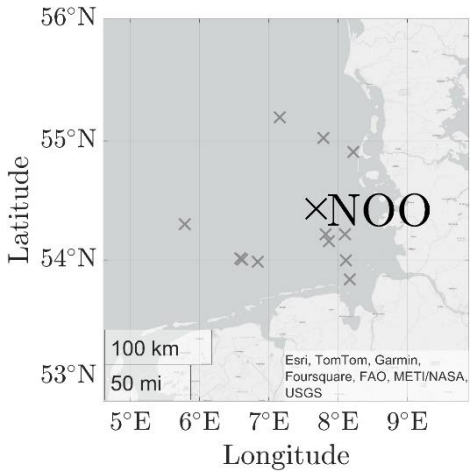
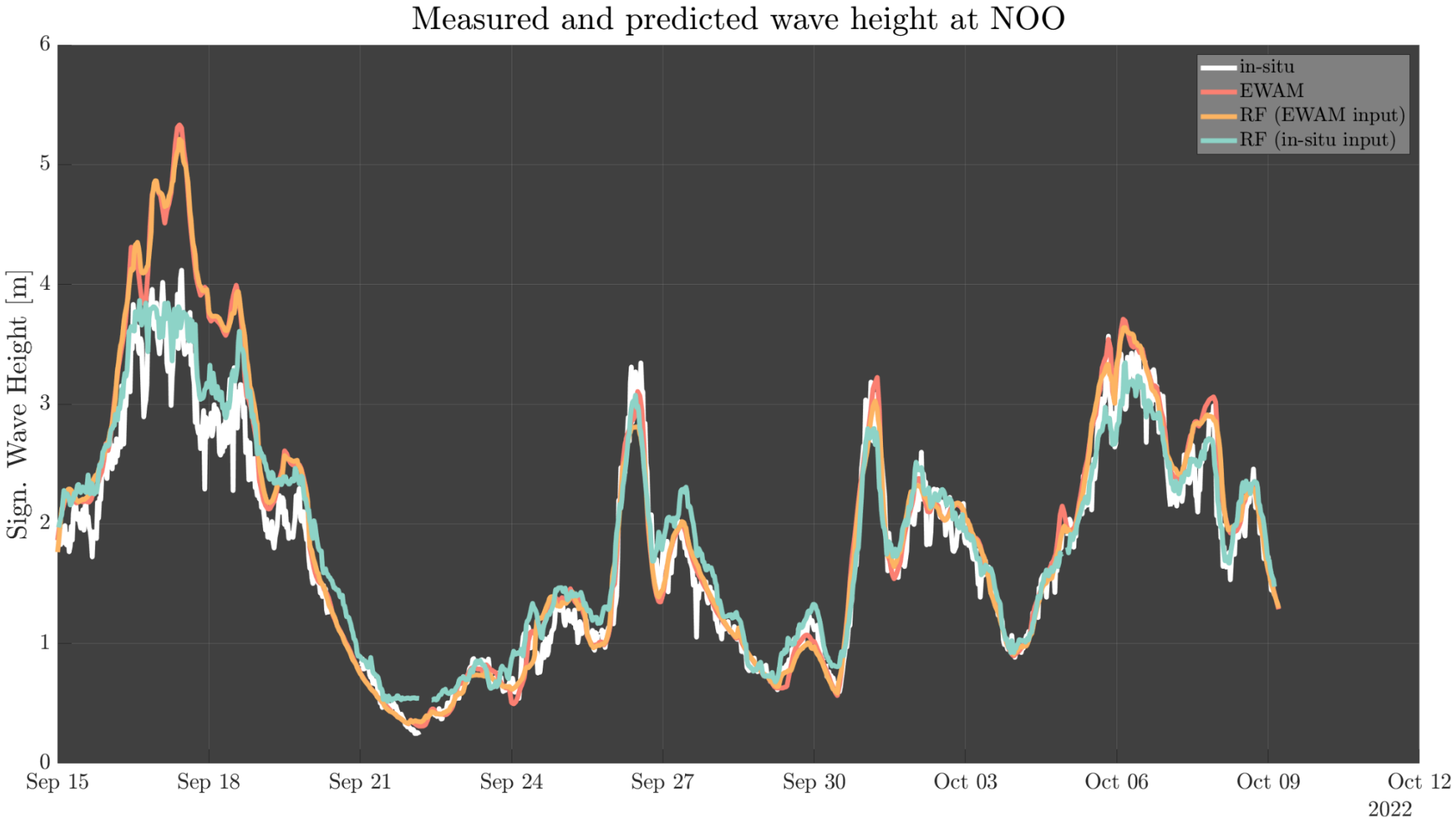
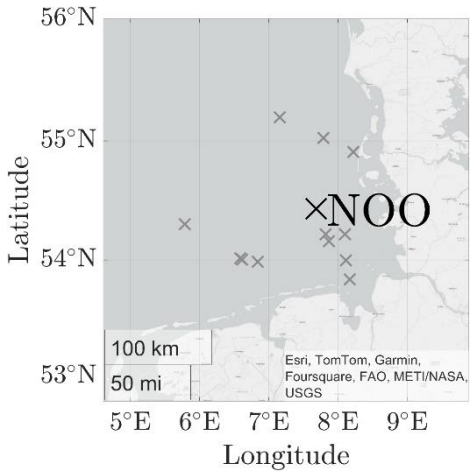


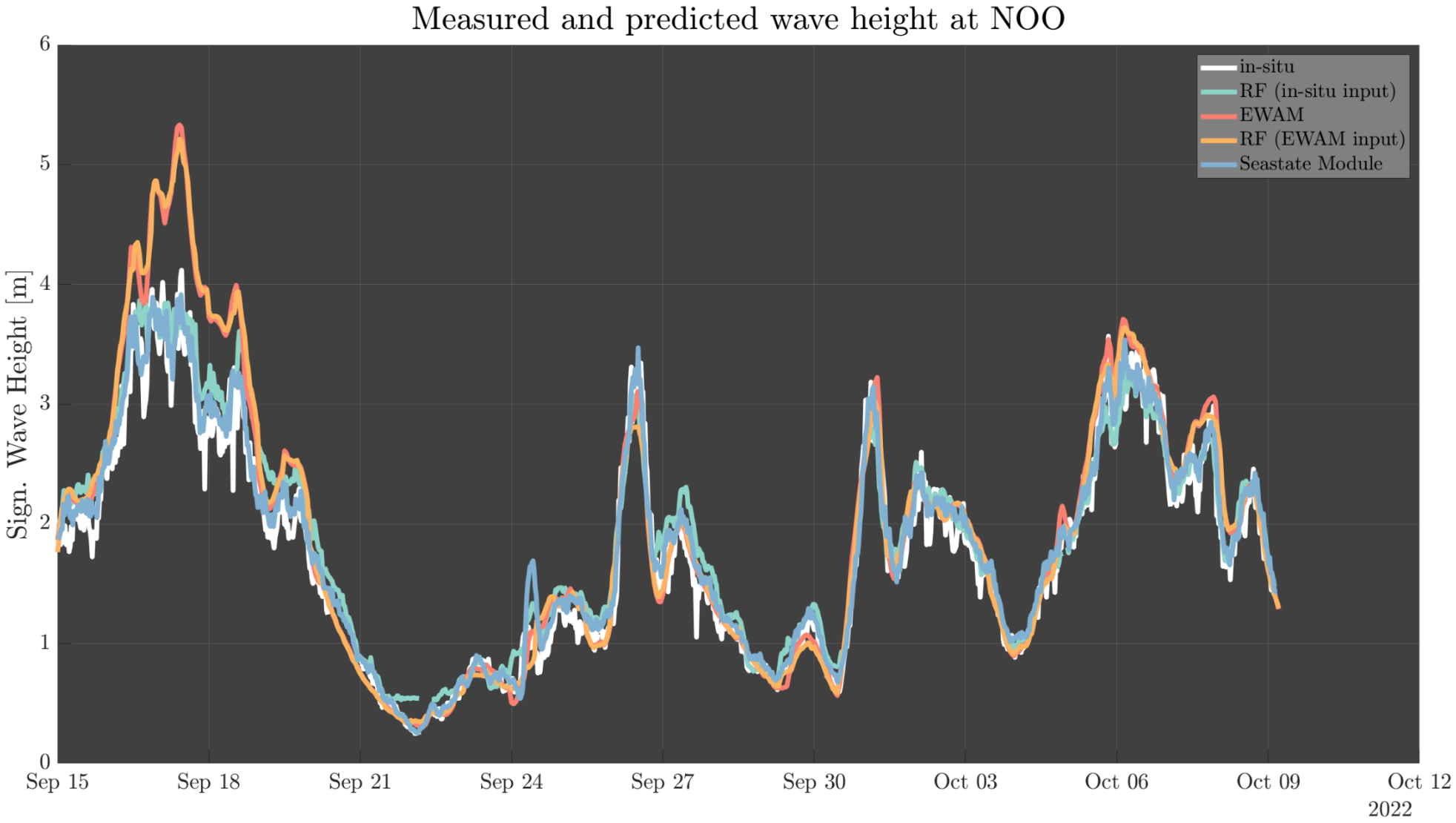
Random Forest (EWAM input)





ML Model
(in-situ input)

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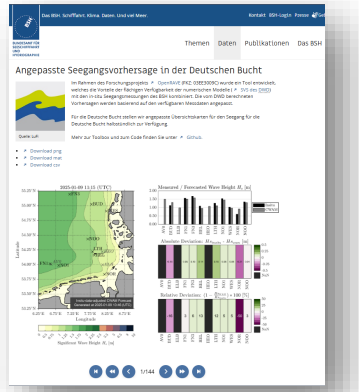
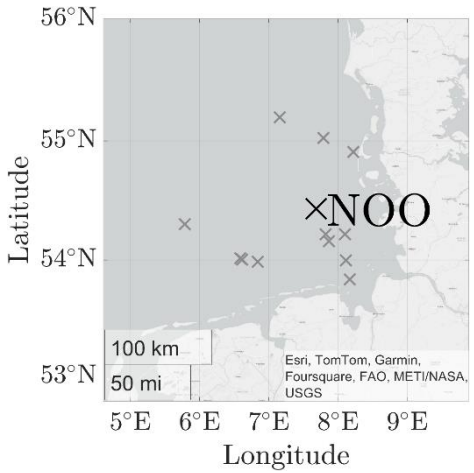
Sep 27
Sep 30
Oct 03
Oct 06
Oct 09
Oct 12
2022
in-situ
RF (in-situ input)
EWAM
RF (EWAM input)
Seastate Module


Angepasste Seegangsvorhersage in der Deutschen Bucht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Latitude
NOO
100 km
50 mi
Esri, TomTom, Garmin, Foursquare, FAO, METI/NASA, USGS
5°E
6°E
7°E
8°E
9°E
Longitude

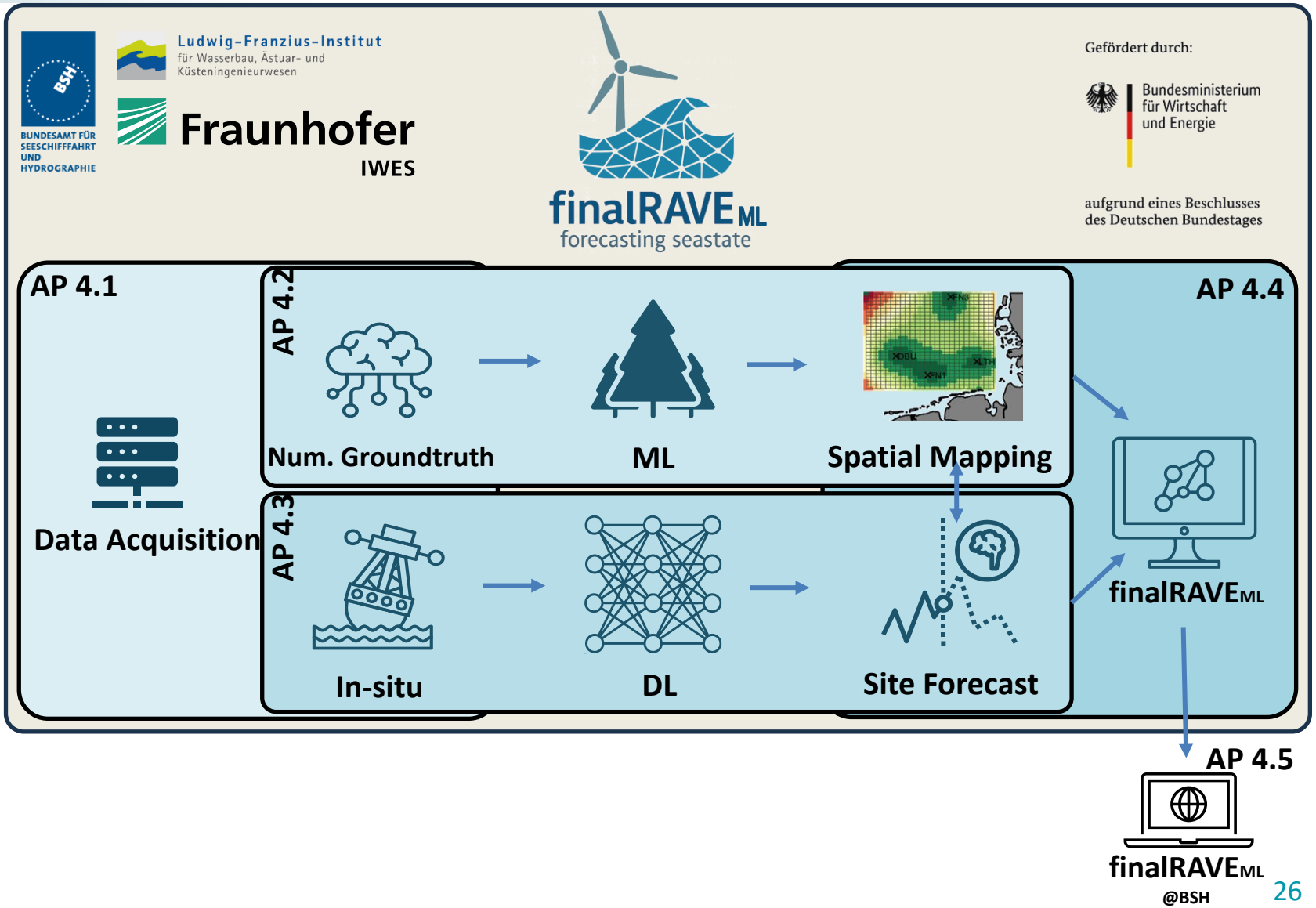
Spatial Model | Influencing factors

- The NWP chosen for training
- Amount and location of input sites
- Features chosen for training / prediction
- Hyperparameter tuning
- Alternative ML/DL approaches

finalRAVE

- Development of a data driven spatio-temporal framework in **finalRAVE**

- Increase of feature space to spectral information
- Deriving sea state information from moments



Thank you!

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für Wasserbau, Ästuar- und Küsteningenieurwesen

Fraunhofer IWES

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Thilo Grotebrune
Research associate
grotebrune@lufi.uni-hannover.de

Supreeth Hanumappa
Research associate
hanumappa@lufi.uni-hannover.de

M.Sc., Lukas Fröhling
Blue C Engineering GmbH
l.froehling@bluec.engineering

Sources

Images:
[1&2] https://datawell.nl/wp-content/uploads/2022/08/bannerhomeproduct-475x1024.png, Accessed: 04.11.2025

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