Netherlands Enterprise Agency

Webinar MetOcean deskstudy and database for Hollandse Kust (noord) WFZ

Ir. F.C.W. (Frank) van Erp

Welcome

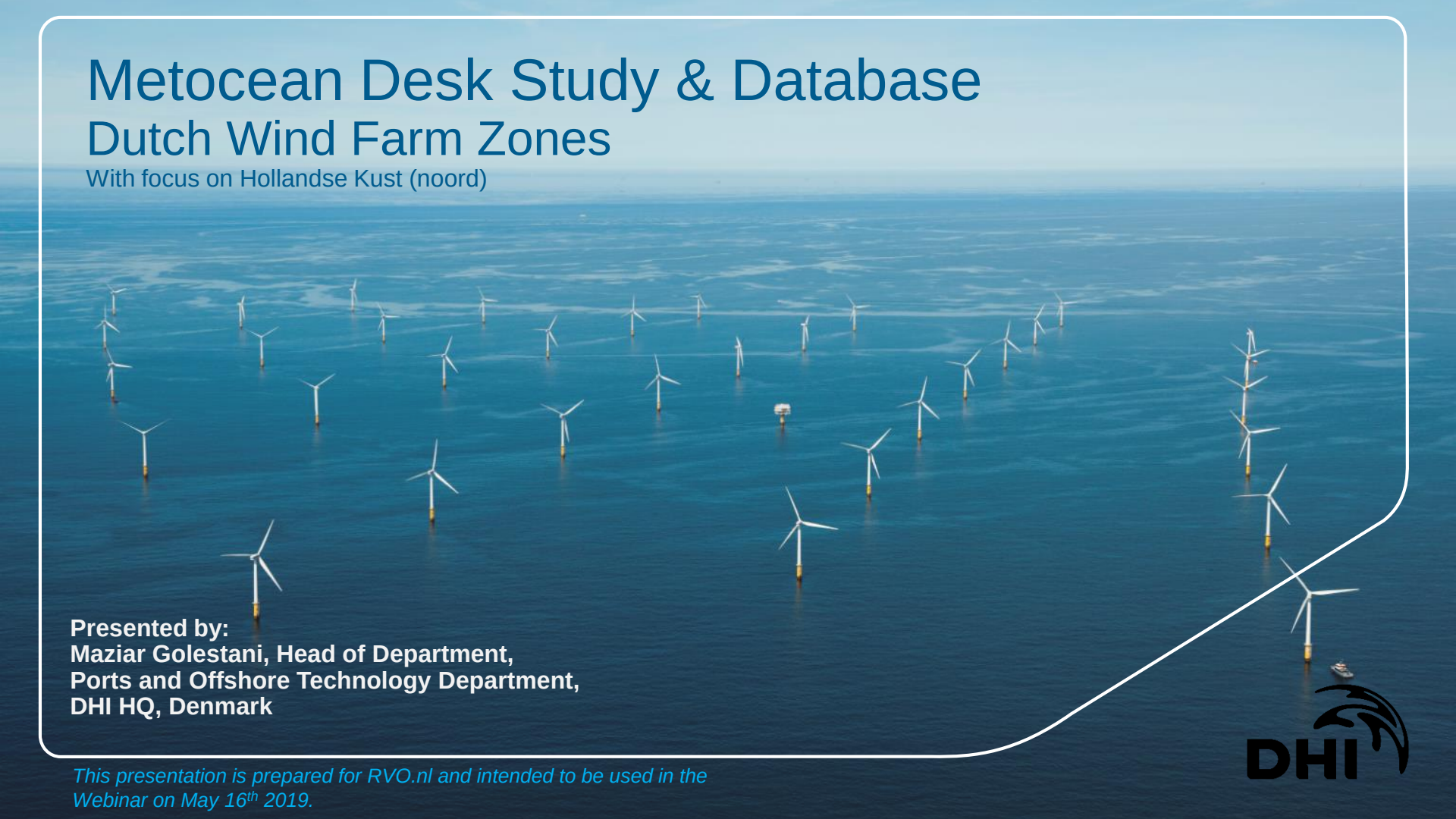
- Introduction speaker and panel
- Goal of this webinar
- Agenda

Have a successful meeting!

Metocean Desk Study & Database

Dutch Wind Farm Zones

With focus on Hollandse Kust (noord)



Presented by:
Maziar Golestani, Head of Department,
Ports and Offshore Technology Department,
DHI HQ, Denmark

This presentation is prepared for RVO.nl and intended to be used in the Webinar on May 16th 2019.

Objectives of this study

- Provide metocean condition to serve as input for design, installation and maintenance of OWF structures at Hollandse Kust (noord)
- Establish web-based database to include metocean data and analysis over Dutch Offshore Wind Farm area
- Analysis was based on advanced long-term numerical models
  - State-of-the-art methods
  - In accordance with offshore standards
- This study includes all design information and the wind resource assessment shall be used for yield analysis

Agenda

- Deliverables
- Establishment of MetOcean Data/Models
  - ❑ Wind
  - ❑ Water levels and Currents
  - ❑ Waves
- Normal and Extreme Conditions
- Database and it's user interface https://www.metocean-on-demand.com/

Project team – DHI Panel

Maziar Golestani, Senior MetOcean Specialist, Project Manager

Natacha Fery, MetOcean Specialist, Project Engineer

Hans Fabricius Hansen, Senior MetOcean Specialist, Quality Supervisor

Patrick Dich Grode, Senior MetOcean Specialist,

MOOD Project Manager

DHI who?

DHI & Offshore Renewables

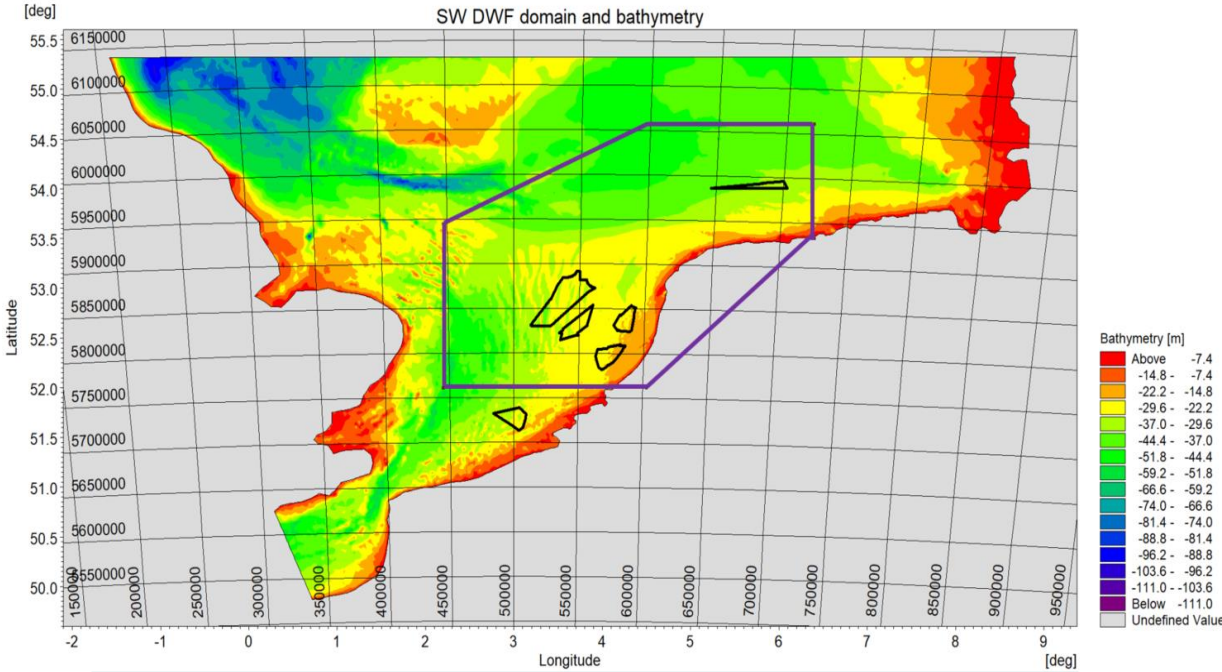
- We’re an independent, private and not-for-profit organisation
- Our knowledge represents 50+ years of dedicated research

  20% of our resources are allocated to R&D to enhance our knowledge and innovation

- Since 1991, world’s first offshore wind farm was constructed in Denmark
- DHI has contributed to more than 85% of the commissioned European offshore wind farms

Deliverables - Report

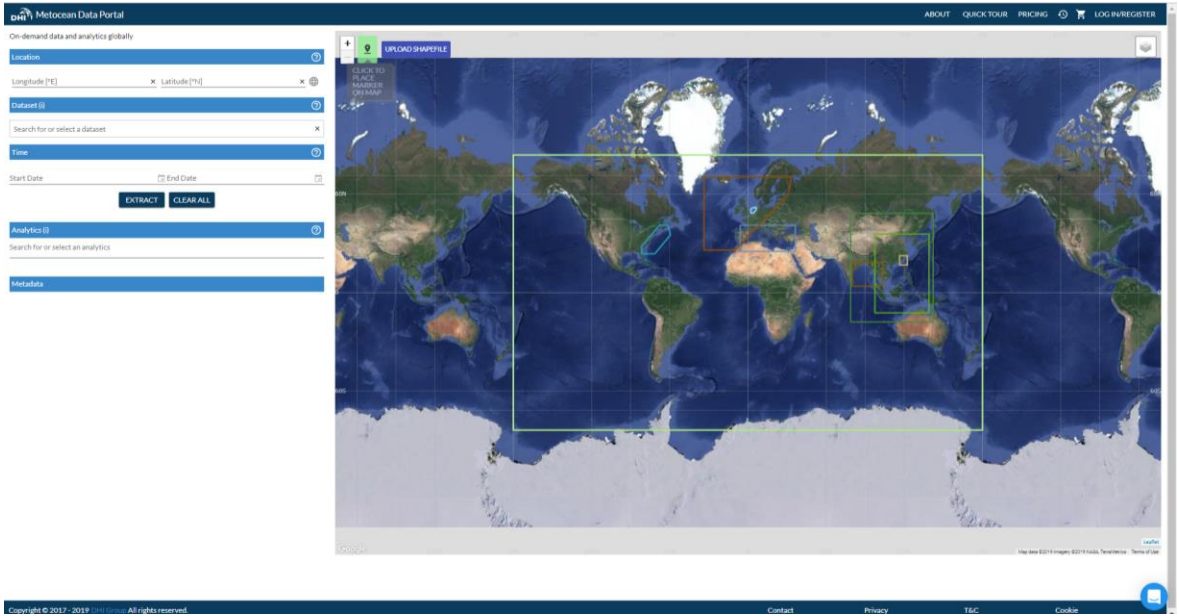
- MetOcean Report
  - ✓ Methodology and background data
  - ✓ Numerical models and their calibration/validation
  - ✓ Detailed analysis at one point per site (normal conditions)
  - ✓ Detailed analysis at five points per site (extreme conditions)



Map showing the area that is covered in the database (shown in purple) along with bathymetry (mMSL)

Deliverables – Web-based Database

- Web-based digital database
  - ✓ Access to time series and spectral data
  - ✓ Instant access to Extreme conditions and NSS tables
  - ✓ Map of normal and extreme conditions over the Dutch North Sea
  - ✓ On-the-fly analysis such as Weather-windows, scatter tables, altimeter comparison, rose plots etc.
  - ✓ Following GDPR regulations

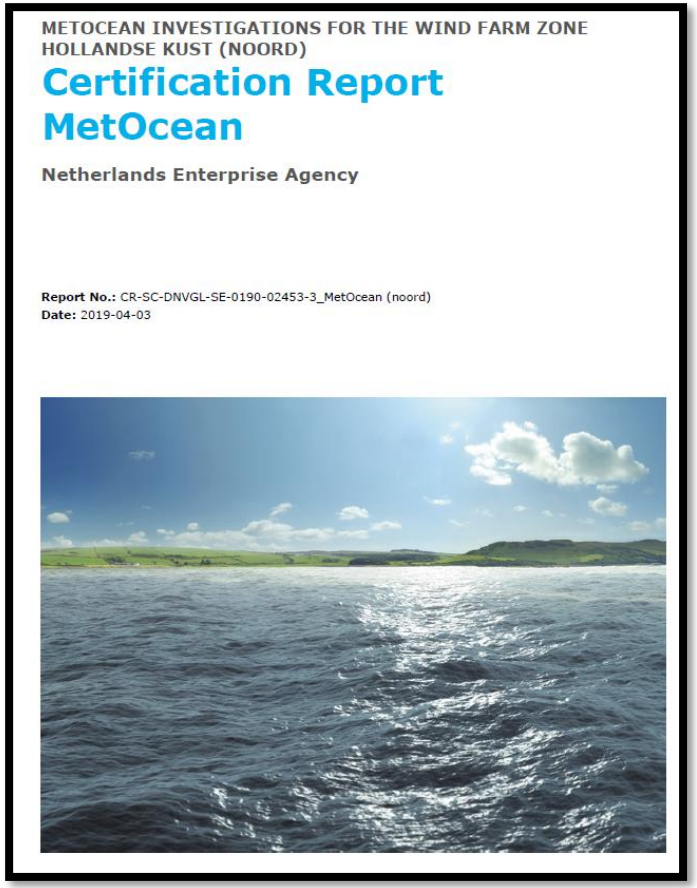


MetOcean-On-Demand Data Portal

https://www.metocean-on-demand.com

Quality Assurance of the project deliverables

- Extensive quality control procedure by DHI
- Reviewed and approved by RVO experts
- Review of the wind extreme value estimates by KNMI on behalf of RVO
- Certified by DNV-GL and distinguished as “state-of-the-art”
- Aligned with the WRA study performed by Oldbaum et al.


METOCEAN INVESTIGATIONS FOR THE WIND FARM ZONE HOLLANDSE KUST (NOORD)

Certification Report MetOcean

Netherlands Enterprise Agency

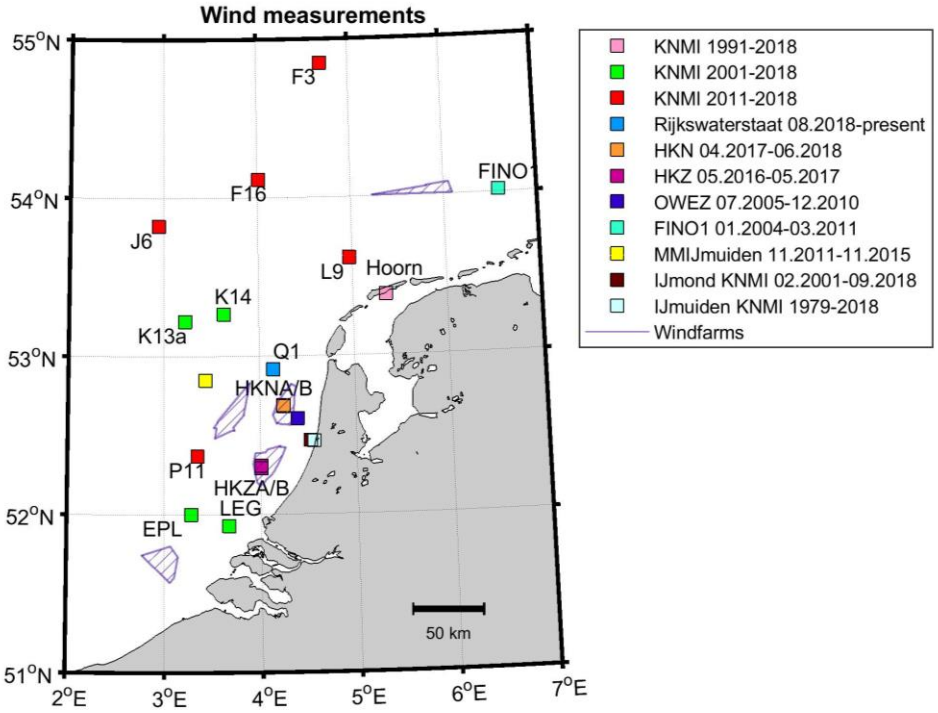
Report No.: CR-SC-DNVGL-SE-0190-02453-3_MetOcean (noord)
Date: 2019-04-03

Make a good foundation!

Get the right and fit-for-purpose data!

In-situ observations - Wind

- Measurements of wind speed/direction at various altitudes, water levels, currents and waves
- Ongoing measurements at HKNA & HKNB
- Used to calibrate/validate the numerical HD and SW models



Map showing the wind observations

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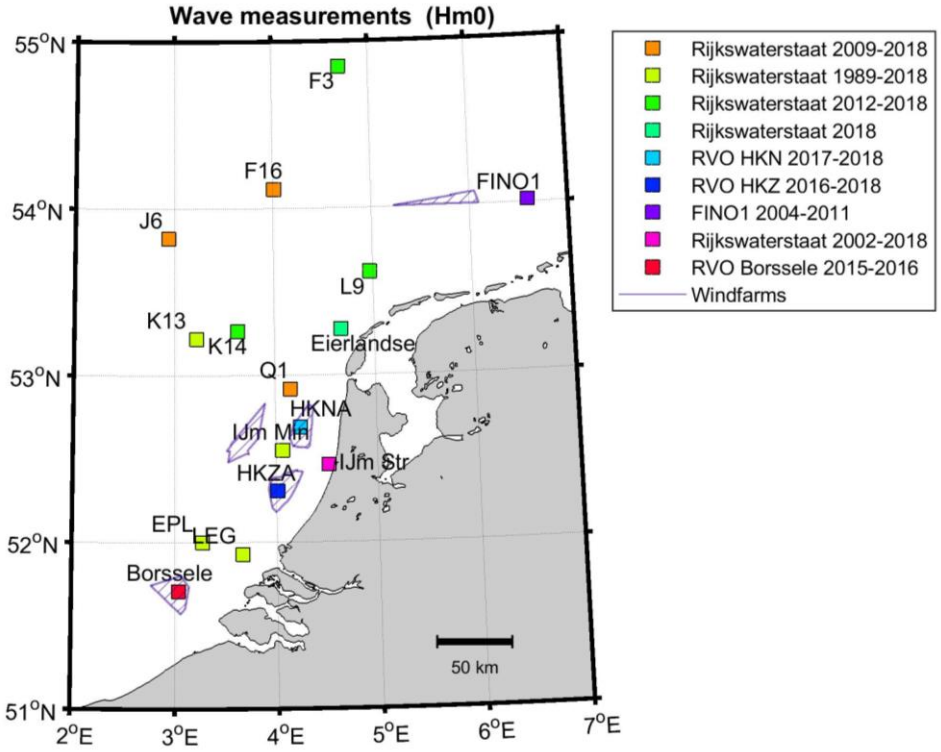
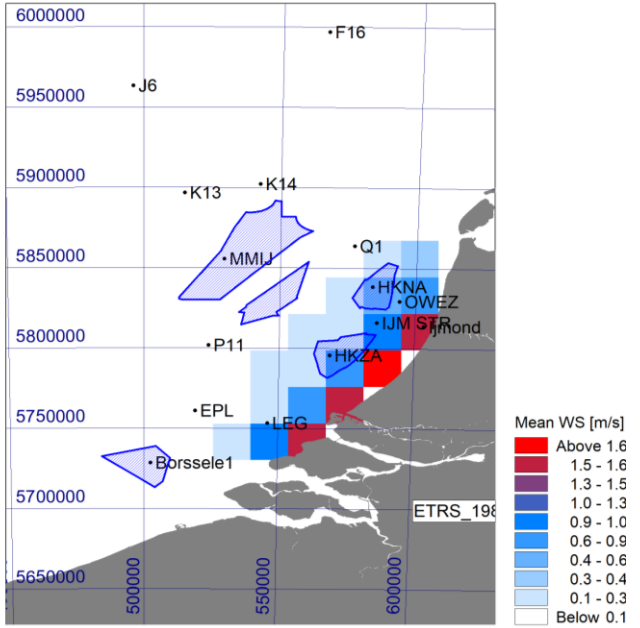


Map showing the wave observations

Wind Data Establishment

Climate Forecast System Reanalysis (CFSR)

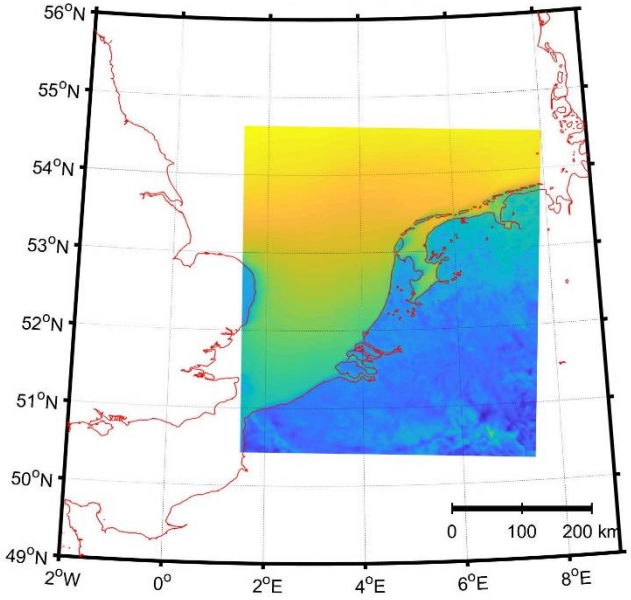
- Climate model 1979-2018, stability corrected
- Spatial resolution 0.3° (<2011) and 0.2° (>2011)
- Wind at 10mMSL
- Correction of **coastal (land) effects**
  - (1) Directional correction of wind speed based on observations at OWEZ
  - (2) Shift of grid cells from offshore to onshore (only in domain of interest)
- Validations at different altitudes
  - ✓ In-situ measurements (offshore + nearshore)
  - ✓ Satellite measurements (scatterometer)



Map showing the difference of wind speed between shifted-corrected and original CFSR (2017)

KNMI North Sea wind – KNW atlas (Harmonie)

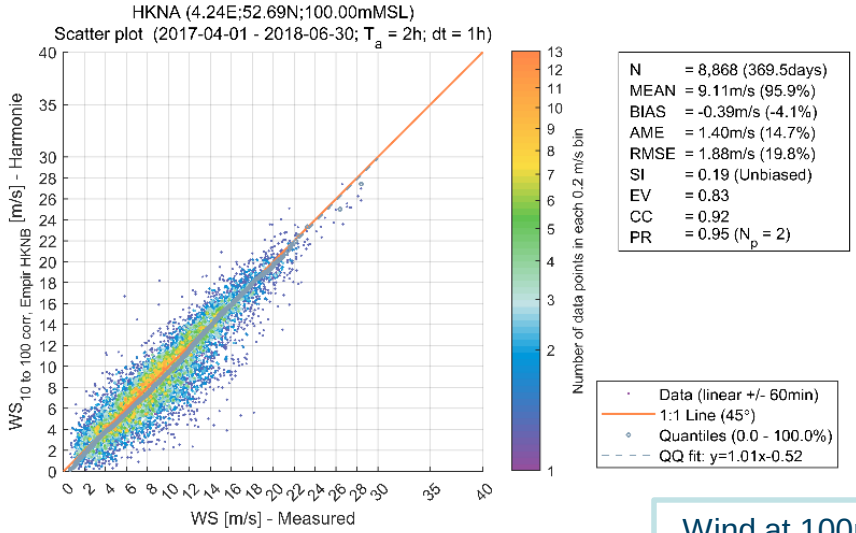
- Atmospheric model 1979-2018
- Spatial resolution 2.5km
- Wind at 10mMSL, 20mMSL, 40mMSL, 60mMSL, 80mMSL, 100mMSL, 150mMSL and 200mMSL

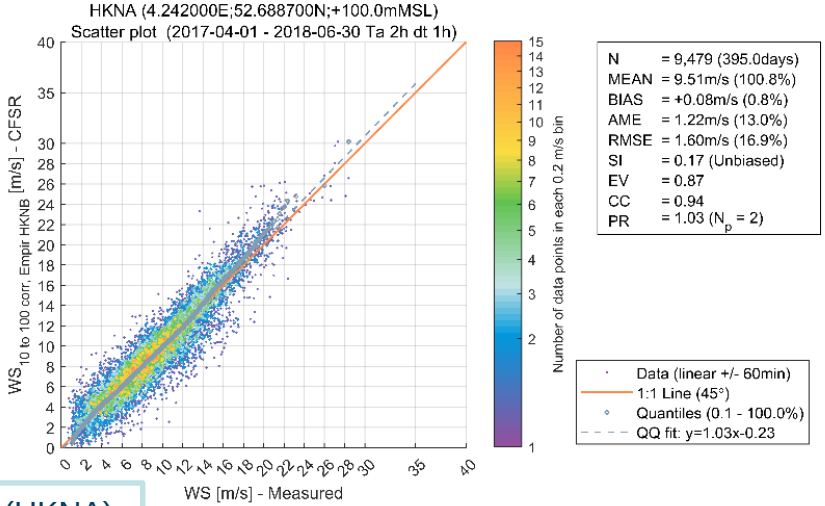


Map showing the domain of Harmonie

CFSR vs Harmonie

- Similar performance for offshore winds
- Harmonie wind better near the coast (lower bias and RMSE)
- Better reproduction of waves in MIKE with CFSR

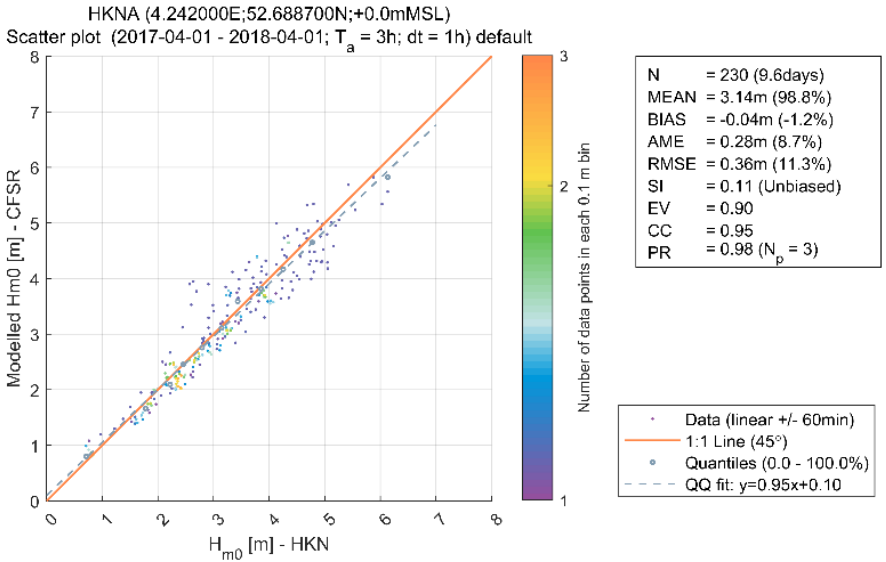




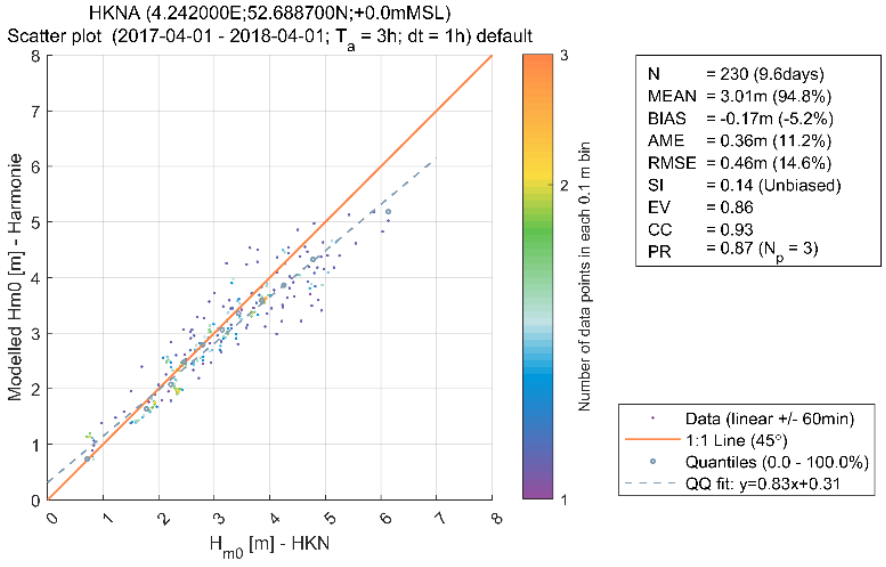
Wind at 100m (HKNA)

CFSR vs Harmonie

CFSR was selected to force the numerical models



Modelled waves (HKNA) using CFSR



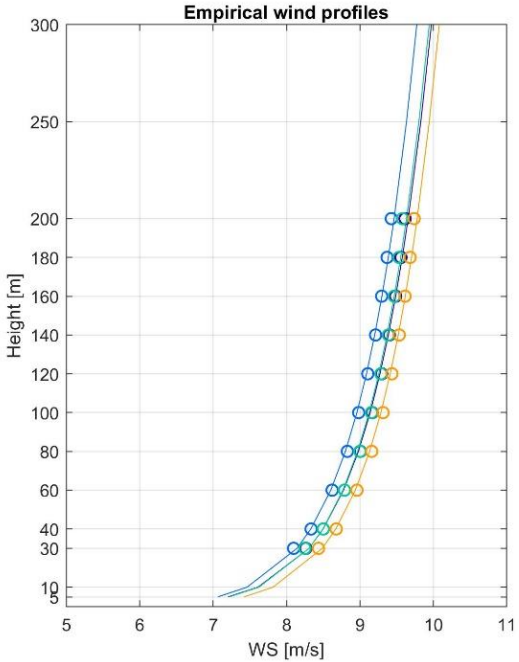
Modelled waves (HKNA) using Harmonie

Vertical wind speed profiles

- Based on LiDAR measurements at HKZ and HKN (30m to 200m height)
- Empirical profiles less conservative than Frøya profile (used in the HKZ study of 2017)

- Normal conditions => shear of 0.074 (HKNB)
- Extreme conditions => shear of 0.1 (ratio of 1.25 between 100m and 10m wind speed - from KNMI)

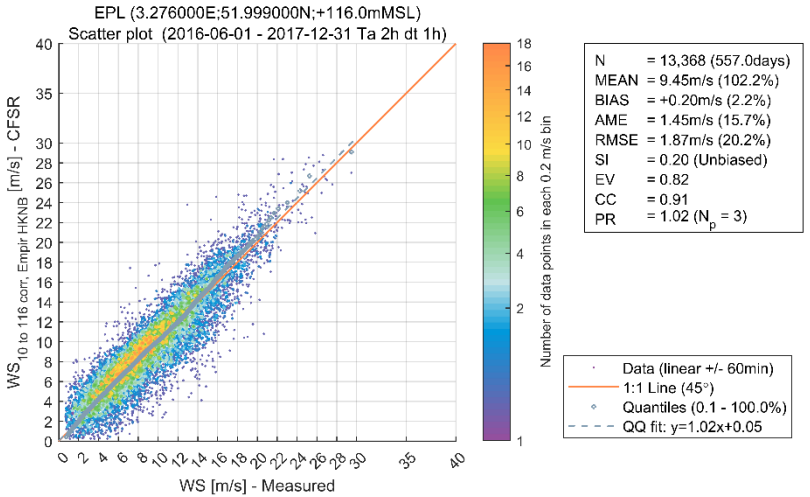
$$U_{z2} = {H_2}/{H_1}^{\alpha} U_{z1}$$



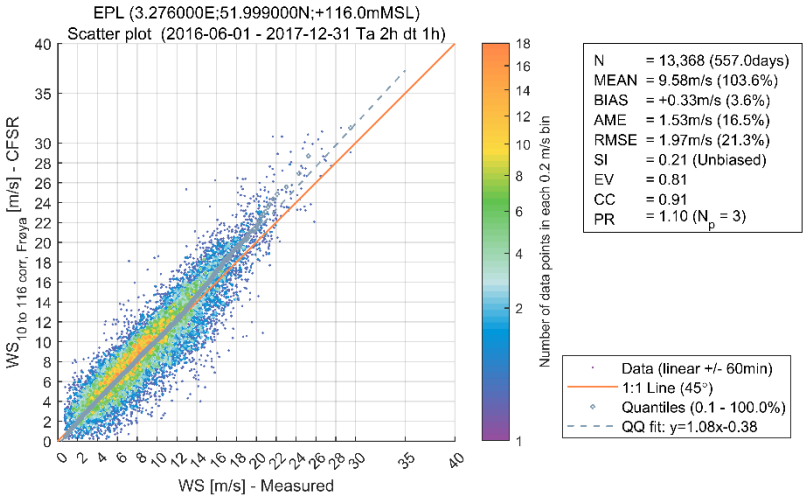
Empirical wind speed profiles at HKZA, HKZB, HKNA and HKNB

Empirical vs Frøya - Vertical wind speed profile

- Best performance with the empirical wind speed profile, mainly for high wind speeds



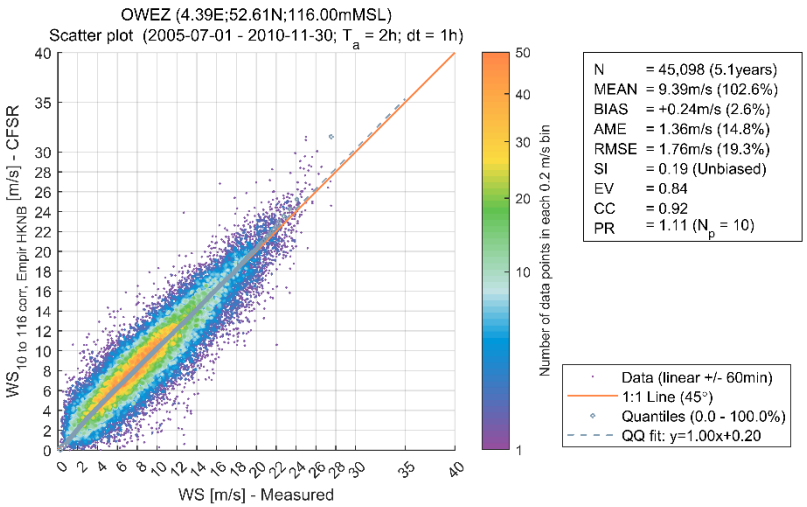
Empirical at EPL (116mMSL)

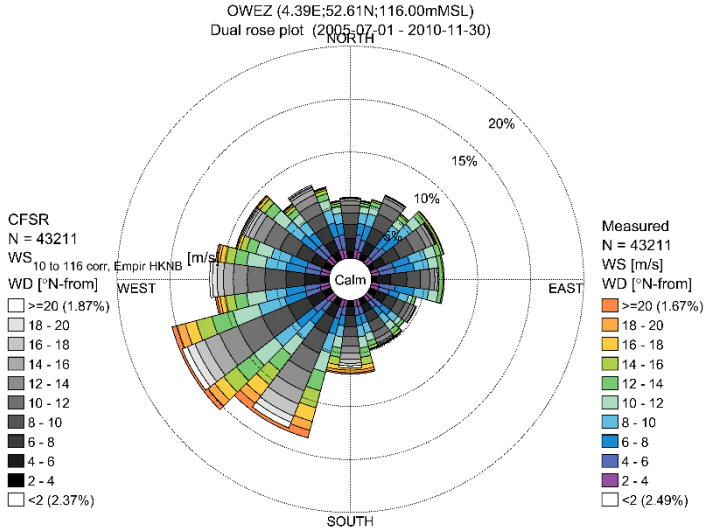


Frøya at EPL (116mMSL)

Validation of wind input with observations (1)

- CFSR vs observations

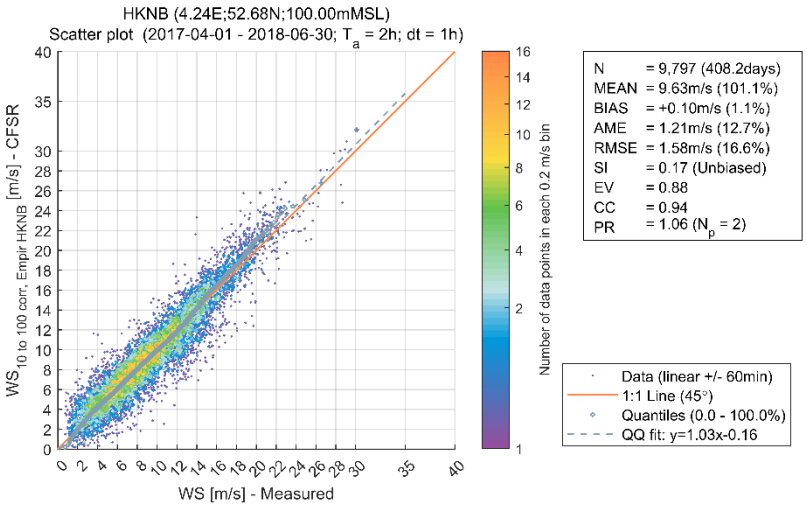


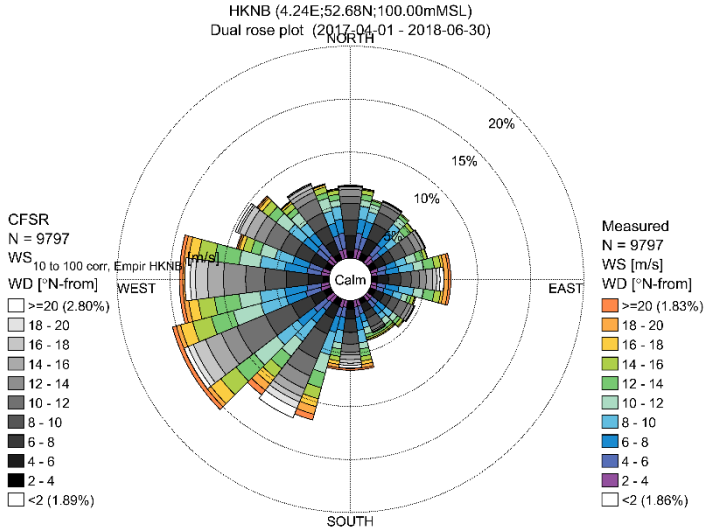


At OWEZ (116mMSL) 2005-2010

Validation of wind input with observations (2)

- CFSR vs observations

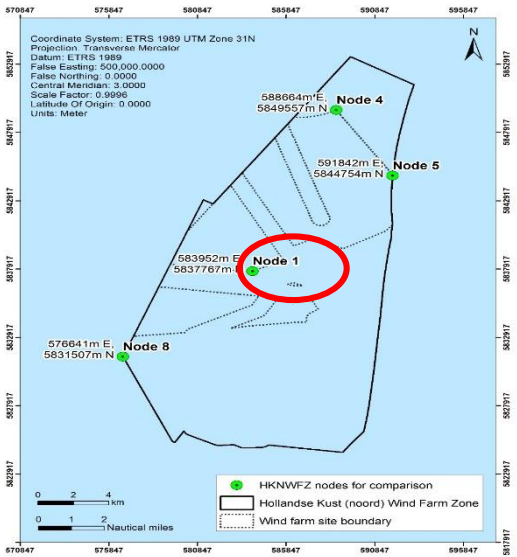


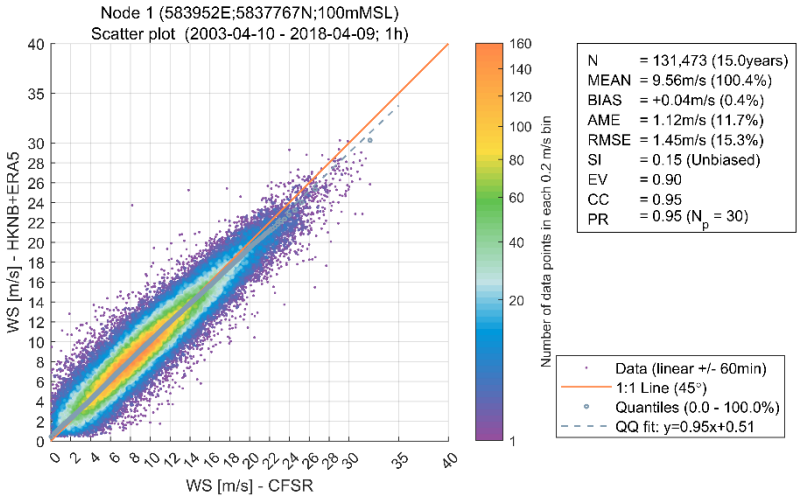


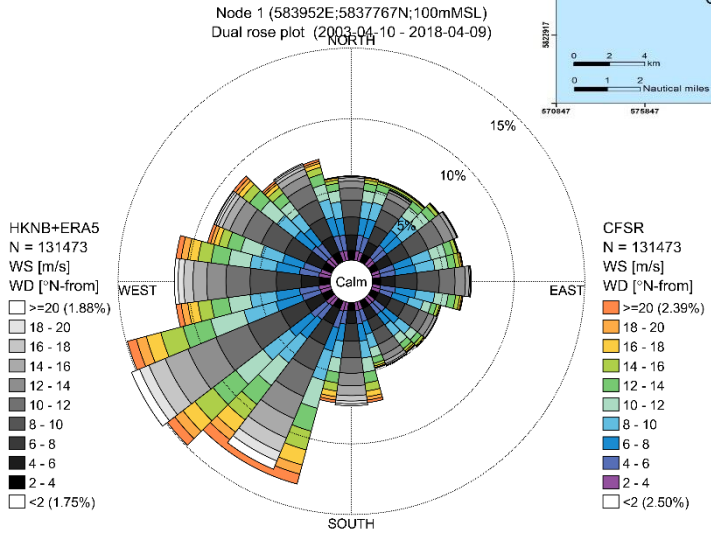
At HKNB (100mMSL) 2016-2017

Wind Resource Alignment

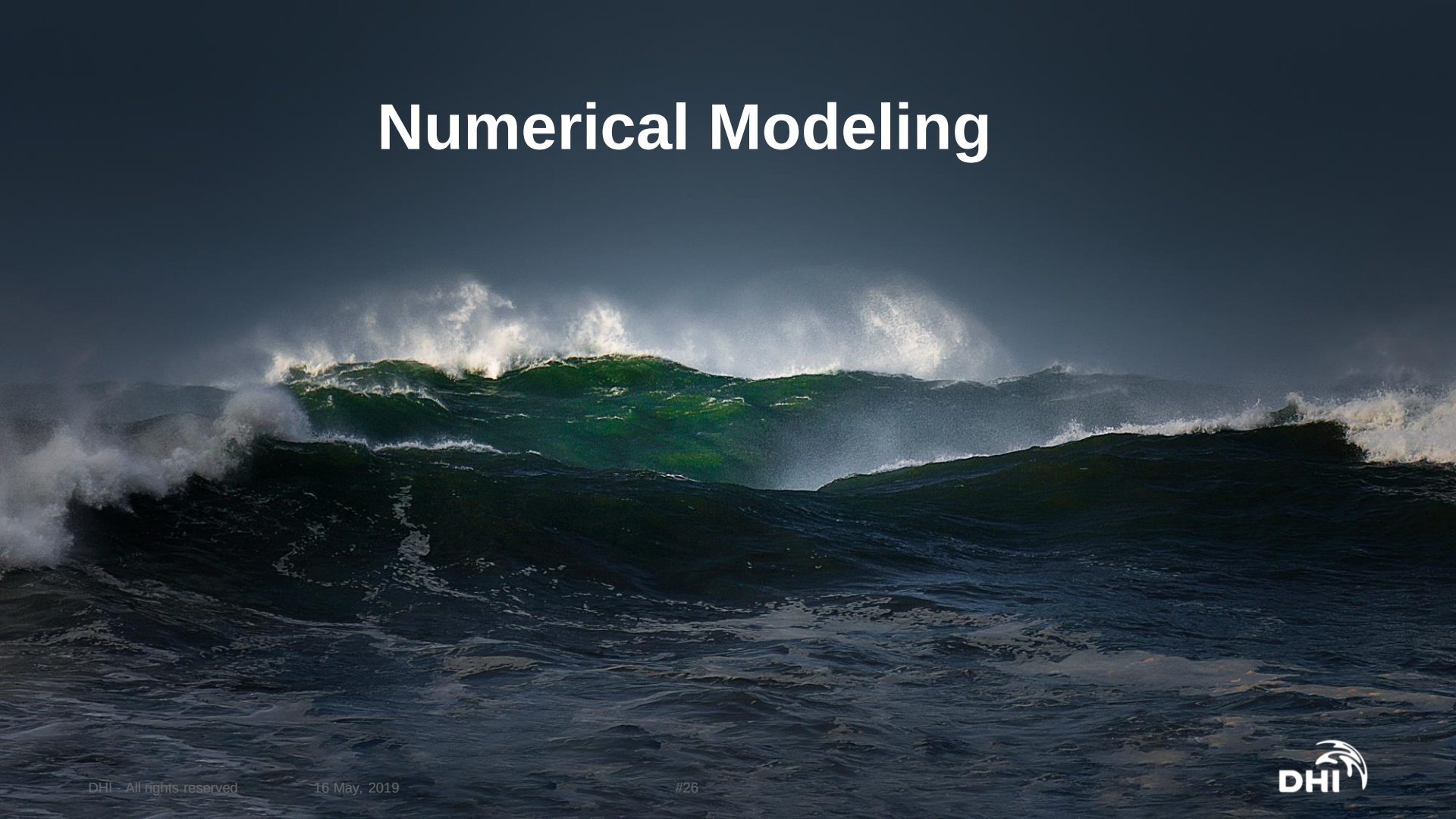
- Comparison of 100mMSL wind betwen CFSR corrected (DHI) and HKNB+ERA5 (Oldbaum consortium)
- 15 years comparison [2003-2018] at 4 nodes
- Mean wind speed 9.5m/s (**DHI**=> intended for wind farm design) and 9.6m/s (**Oldbaum**=> intended for wind farm modelling and yeild analysis)





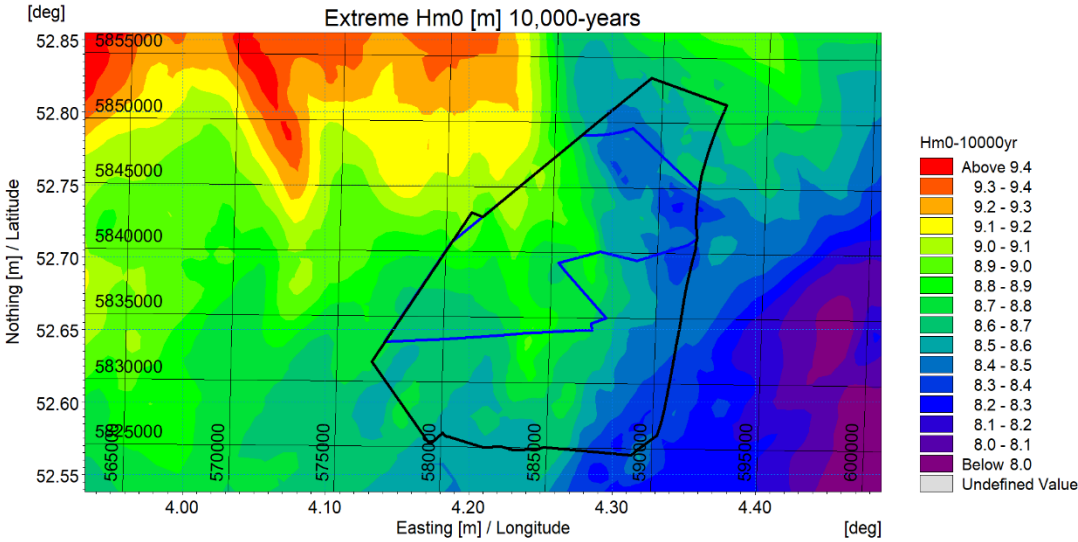


Numerical Modeling



Numerical Modelling Overview

- Simulation period covered the period 1979-01-01 to 2018-10-01
- Both Hydrodynamic and Wave models were forced with shifted-corrected CFSR wind
- The database provides data at all elements for the same period



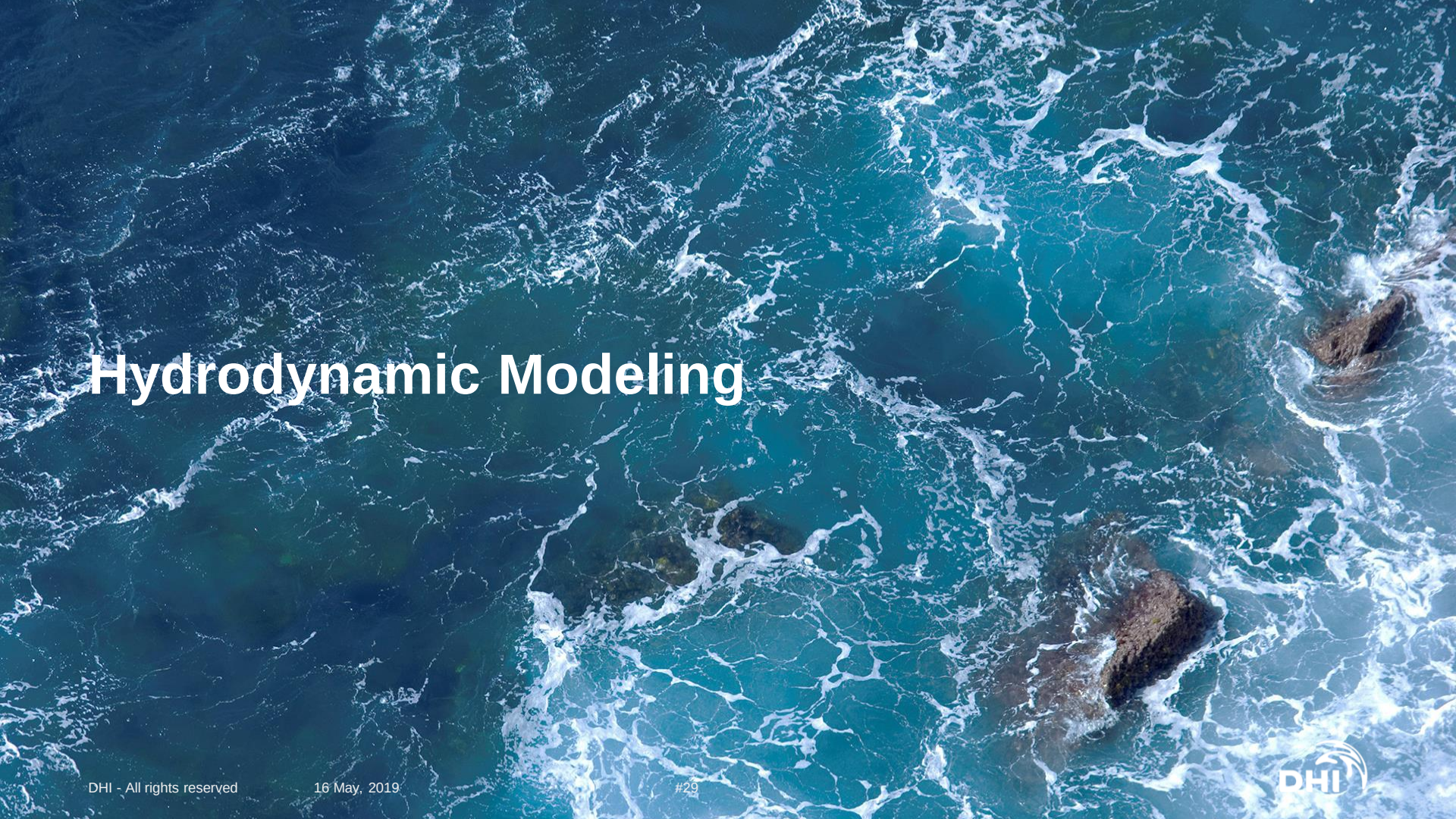
10,000-year Hm0 across the HKN area

Numerical Modelling Overview

For more than 25 years

MIKE Powered by DHI

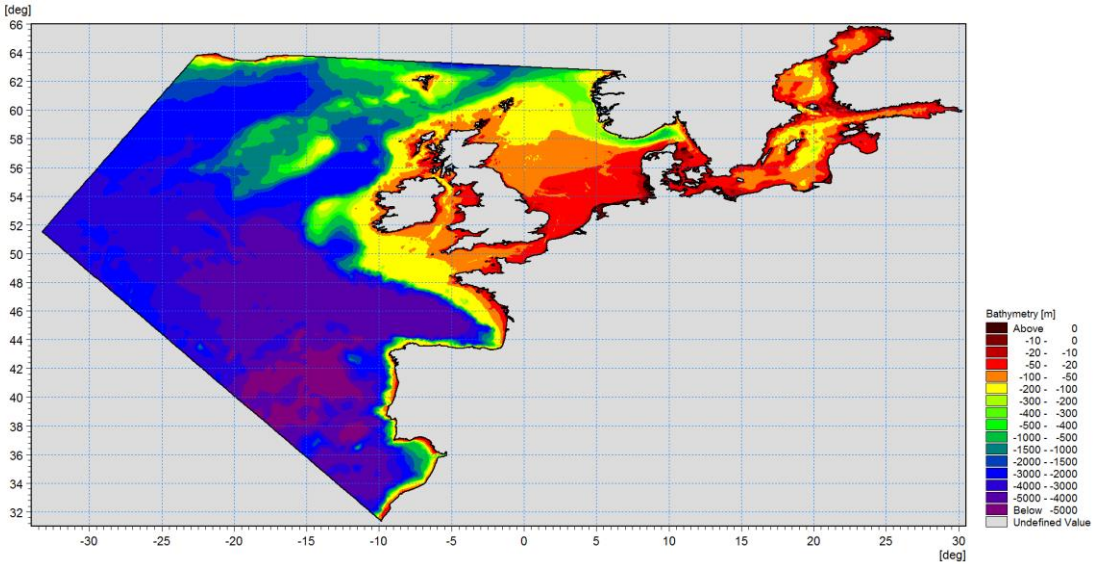
has been the preferred choice of water professionals around the world



Hydrodynamic Modeling

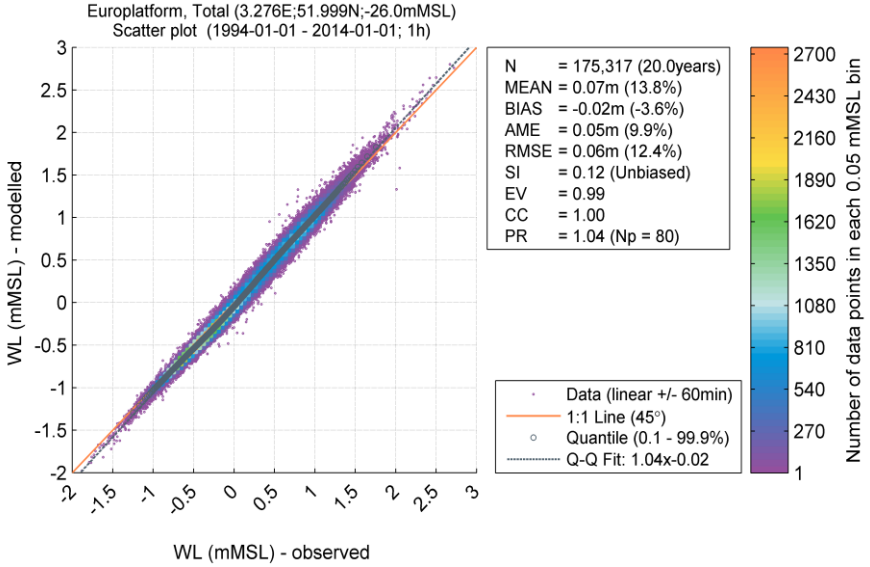
Water level and current modeling – Regional Model

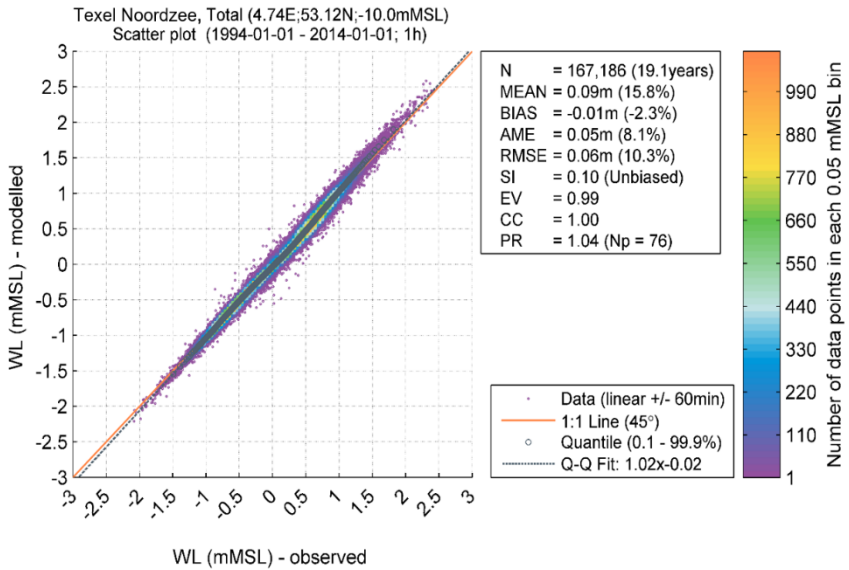
- DHI's dedicated North Atlantic Hydrodynamic Model (HD-DA,NA)
  - High Resolution
  - Excellent Quality
- Assimilation in the period 1994-2017
- Used as the boundary conditions for the local model
- Validated against multiple stations in the North Sea, English Channel and Baltic Sea and Inner Danish Waters



Regional Hydrodynamic Model Domain and bathymetry

Water level and current modeling – Regional Model



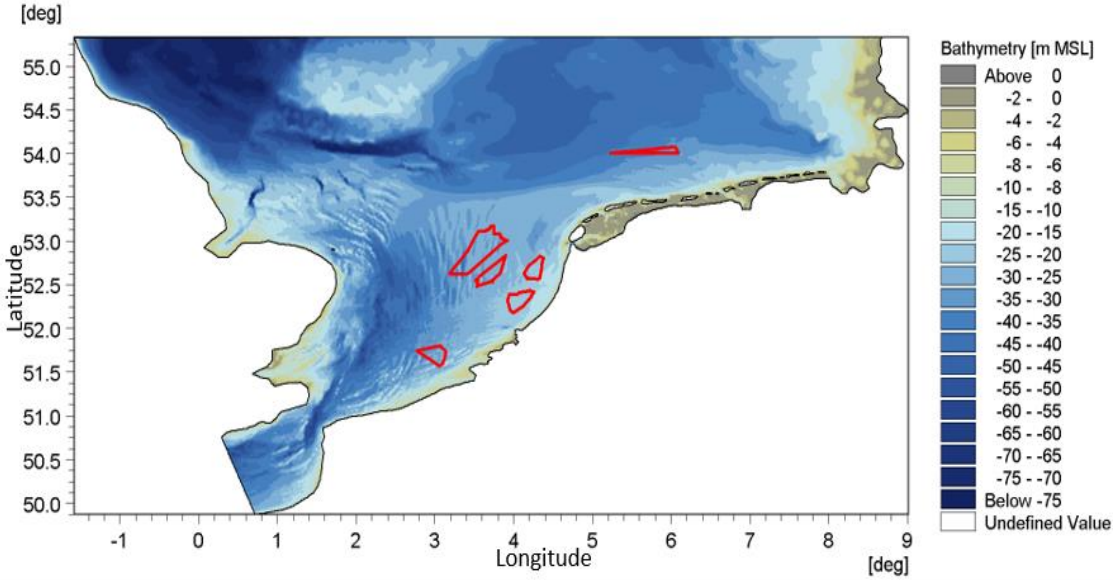


Validation at EPL (1994-2014)

Validation at Texel Noordzee (1994-2014)

Water level and current (HD) modeling – Local Model

- Local high-resolution hydrodynamic MIKE 21 FM HD (HD - DWF)
- Resolution varies from ~4-5km to ~200 meters
- Bathymetry
  - ✓RVO/Fugro
  - ✓Vaklodingen
  - ✓EMODnet
  - ✓Existence of sand dunes
- Takes the boundary from the Regional HD model (HD – DA, NA)
- Assimilation was not included in the local model



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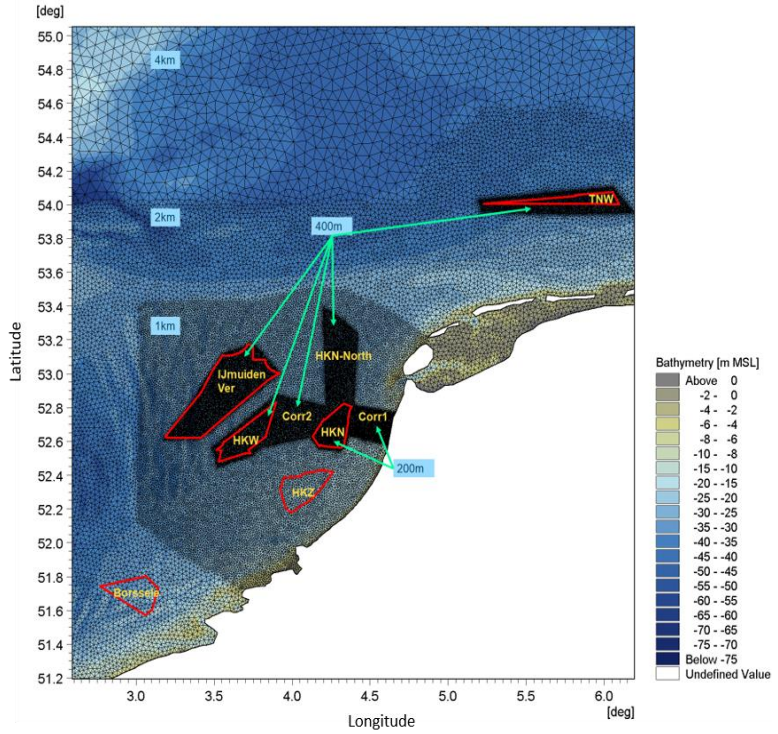
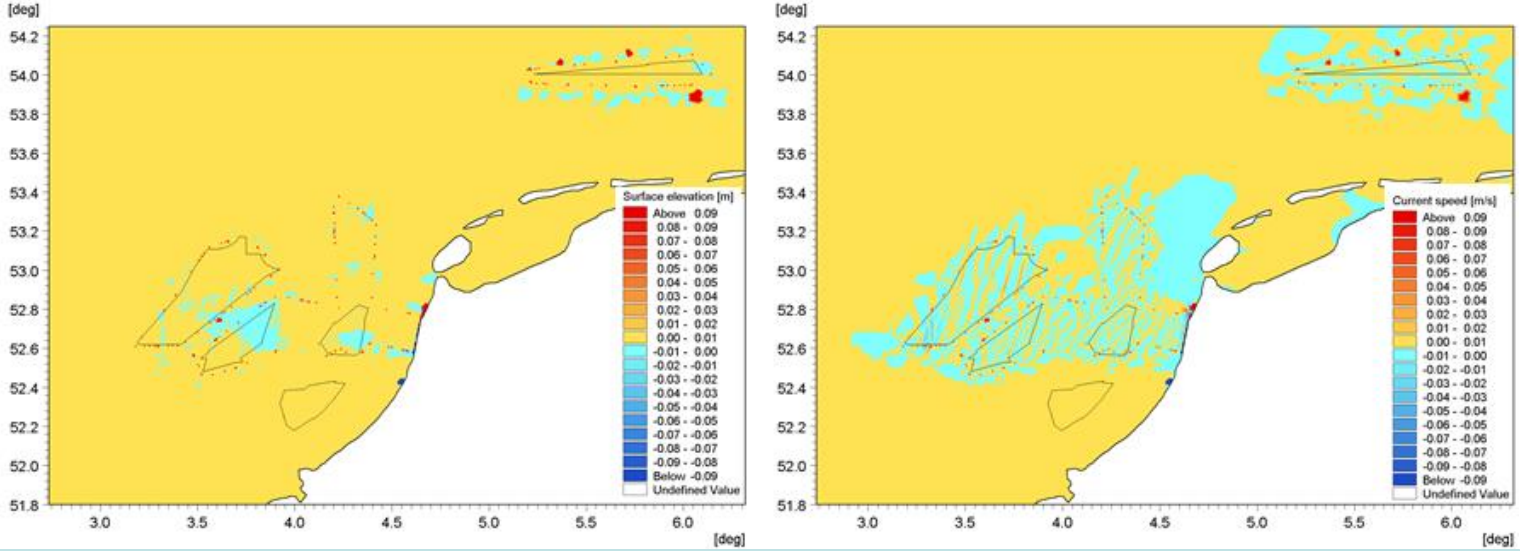


Zoom of the final mesh used in the hindcast HDDWF modelling close to Hollandse Kust (noord), Hollandse Kust (west), IJmuiden Ver and Ten Noorden van de Waddeneilanden

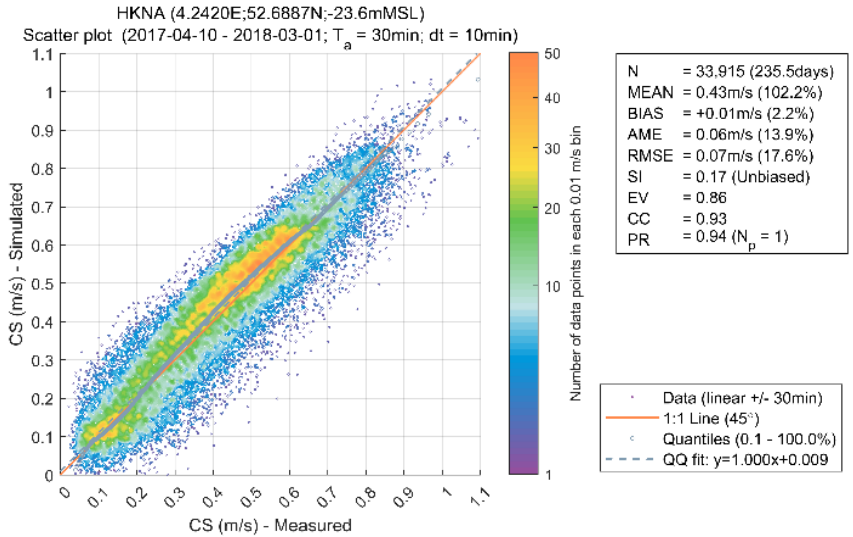
HD Modeling - Calibrations

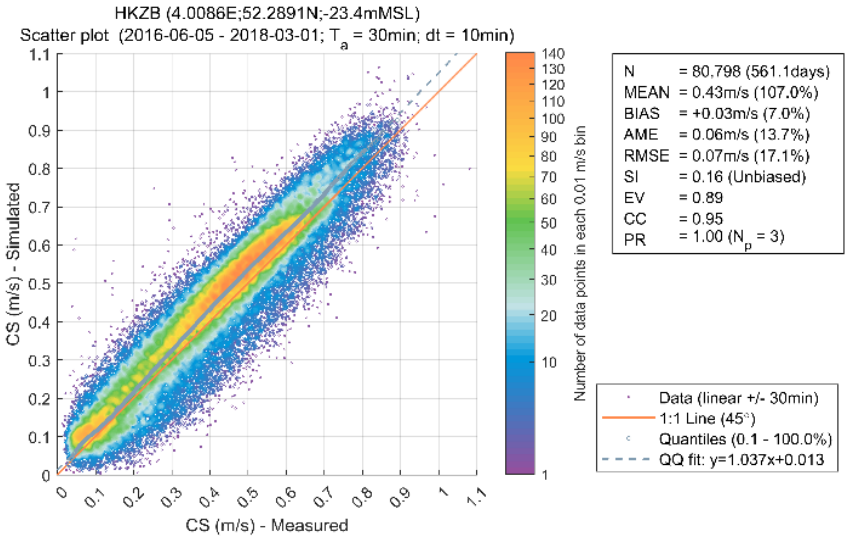
- Grid convergence (500m, 200m & 100m)
- Bed resistance
  - spatially-varying manning coefficient of 35$m^{1/3}$/s for water depth less than -25m otherwise 38$m^{1/3}$/s
- Wind friction



Maximum difference in water level (left) and current speed (right) between medium (200m) resolution versus fine resolution (100m)

HD modeling – Local Model Validation

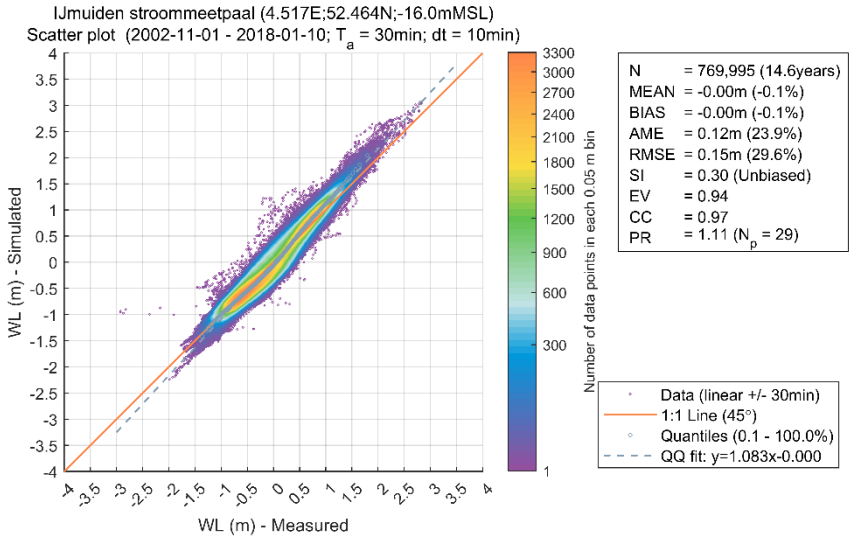


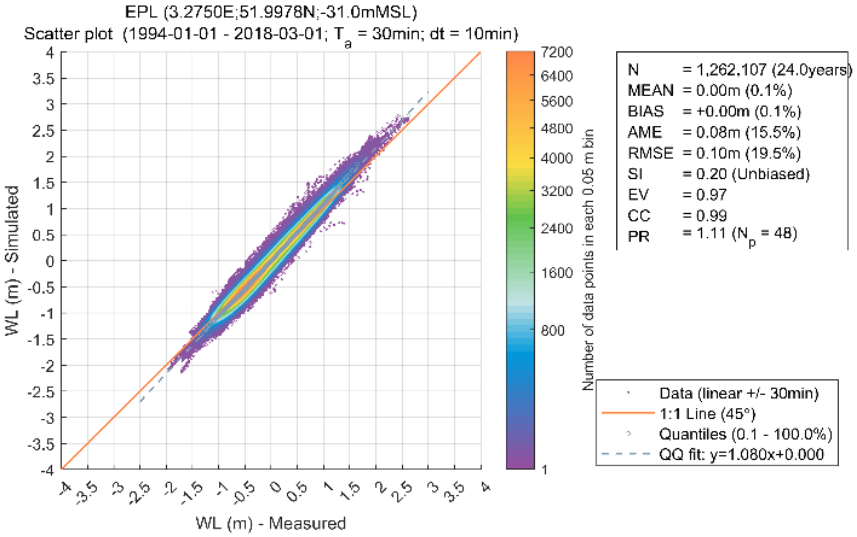


Validation at HKNA (2017-2018)

Validation at HKZB (2016-2018)

HD modeling – Local Model Validation

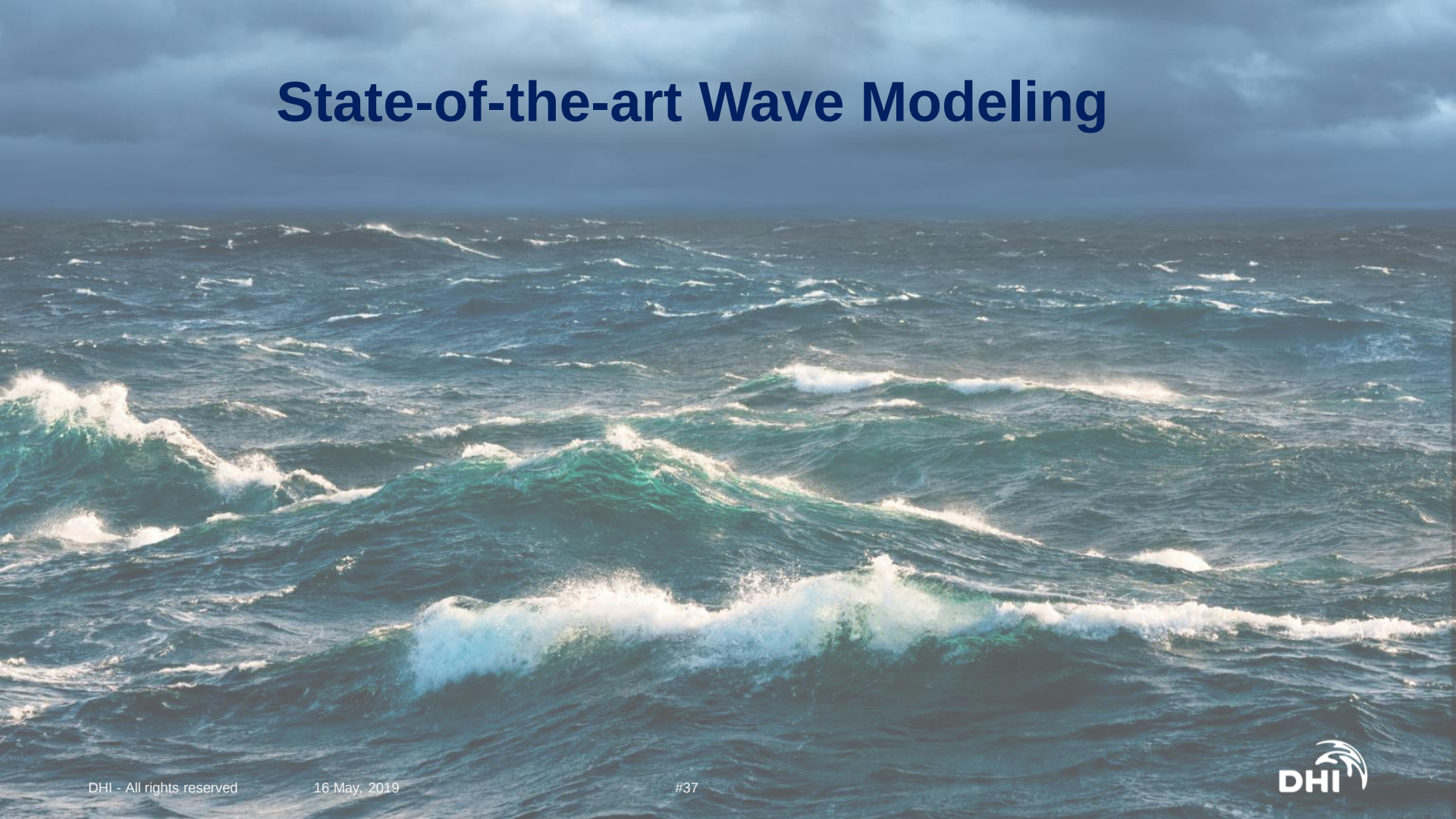




Validation at IJmuiden Stroommeetpaal (2002-2018)

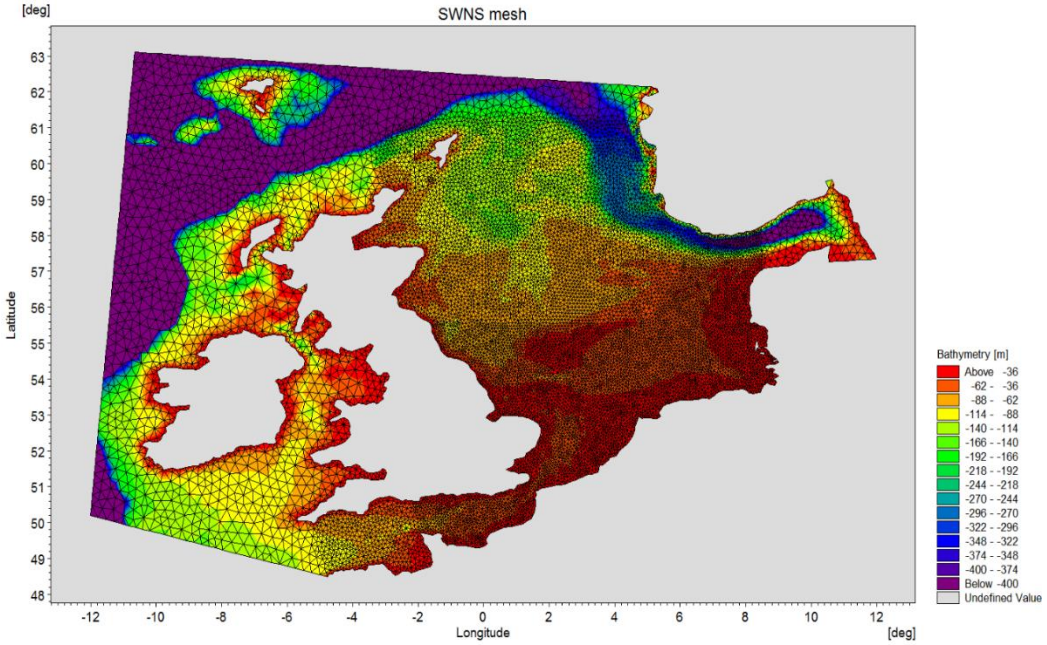
Validation at EPL (1994-2018)

State-of-the-art Wave Modeling



Wave Modeling- Regional North Sea Model

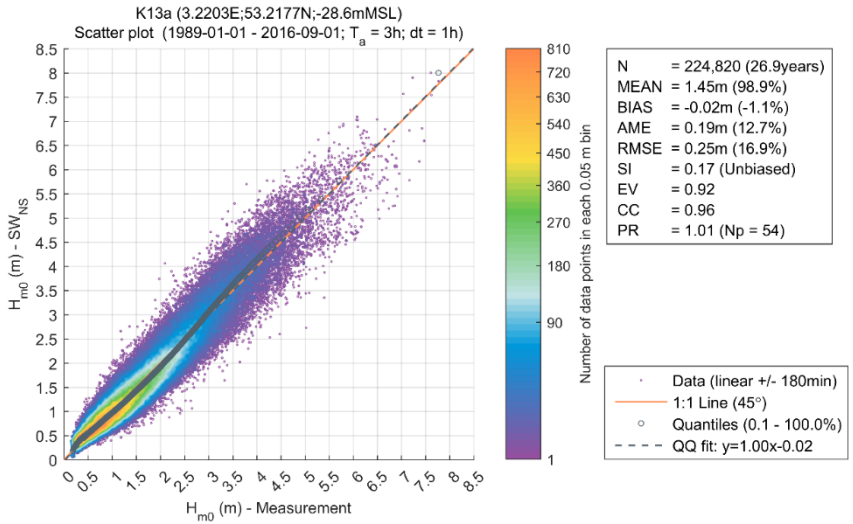
- Boundaries taken from DHI's Global Wave Model (GWM)
  - Spectral boundaries available on a 1500m resolution for this project
- ~16km resolution in North Atlantic down to ~5km resolution in the southern North Sea & English Channel
- 47 frequencies and 48 directions for spectral discretization
- Calibrated and Validated against several offshore measurements
- Validated against Altimeters



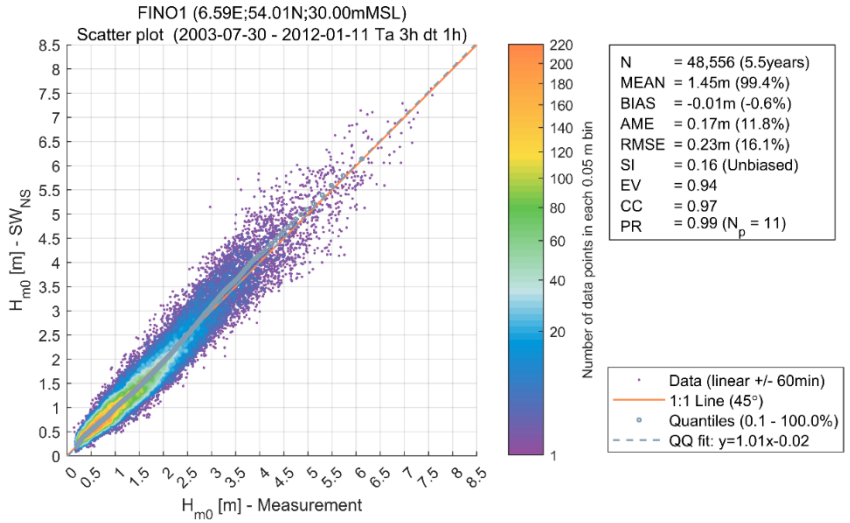
Regional Wave Model Domain and bathymetry

Wave Modeling- Regional North Sea Model

- Extra calibration phase with focus on largest storms
- Results proved that the SW-NS model provides high quality boundary conditions for the local model
- Atmospheric Stability effects, Air-Sea density ratio, Surface currents and CAP on friction velocity



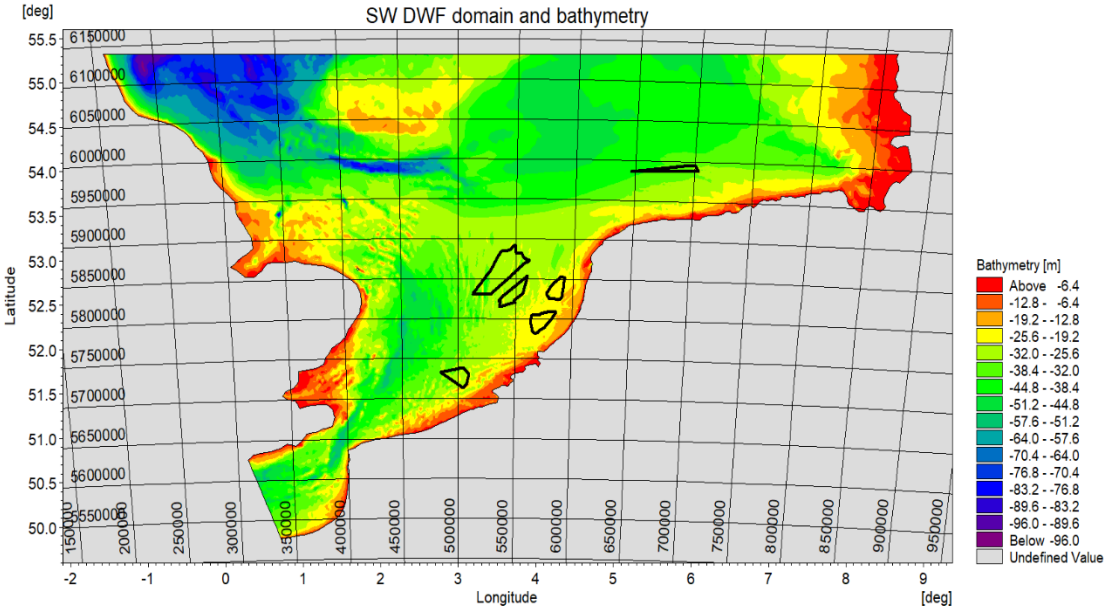
Validation at K13 (1989-2016)



Validation at FINO1 (2003-2012)

Wave Modeling- Local DWF model

- Takes the spectral boundaries from Regional North Sea model
- Same domain as the local HD model
- ~4km-400m resolution
- Varying in time and domain water level and currents from the local HD model
- Fully Spectral in-stationary
- 40 frequencies and 41 directions for spectral discretization
- Simulation Period: 1979-01-01 to 2018-10-01



Wave Model domain and bathymetry

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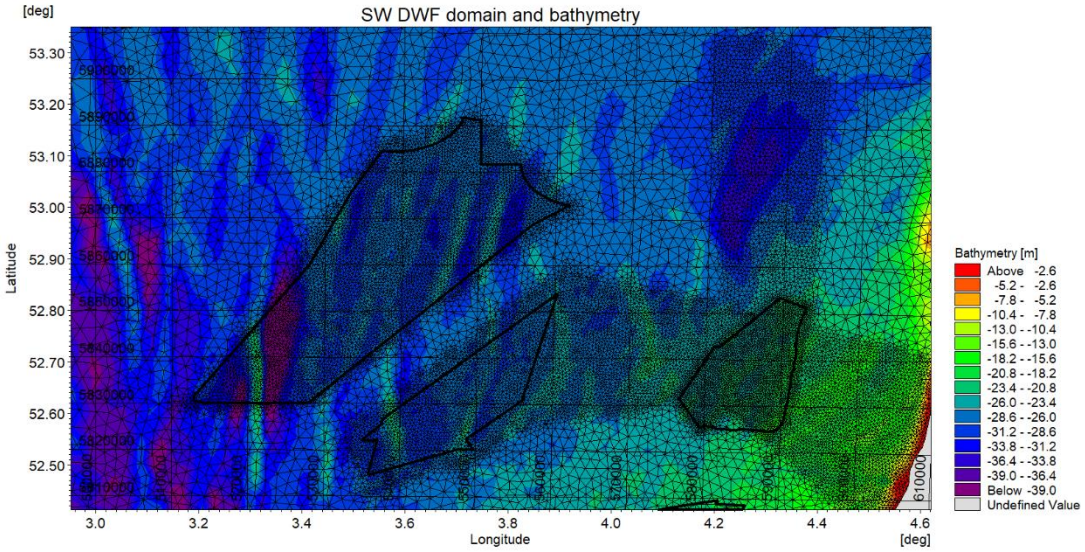
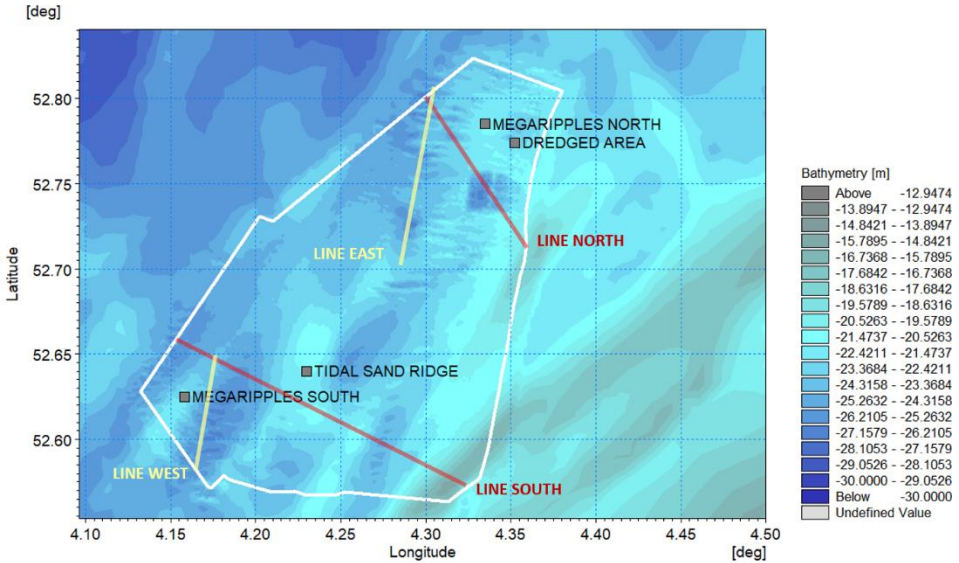
- 40 frequencies and 41 directions for spectral discretization
- Simulation Period: 1979-01-01 to 2018-10-01

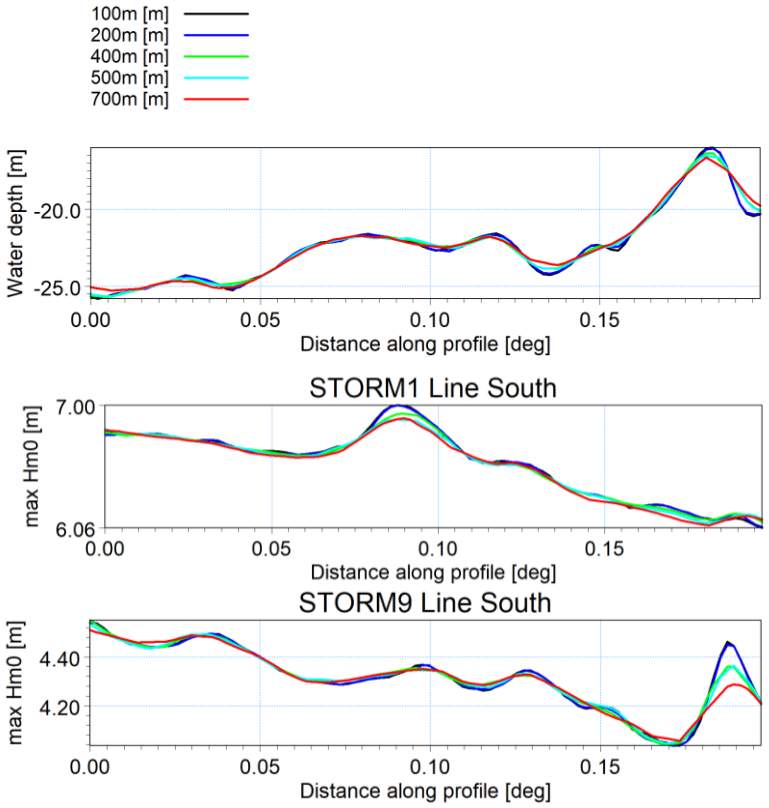


Zoom in to the wave model mesh at Hollandse Kust (noord), (west) and IJmuiden Ver (in addition to cable corridors)

Wave Modeling- Local DWF model – Mesh Convergence

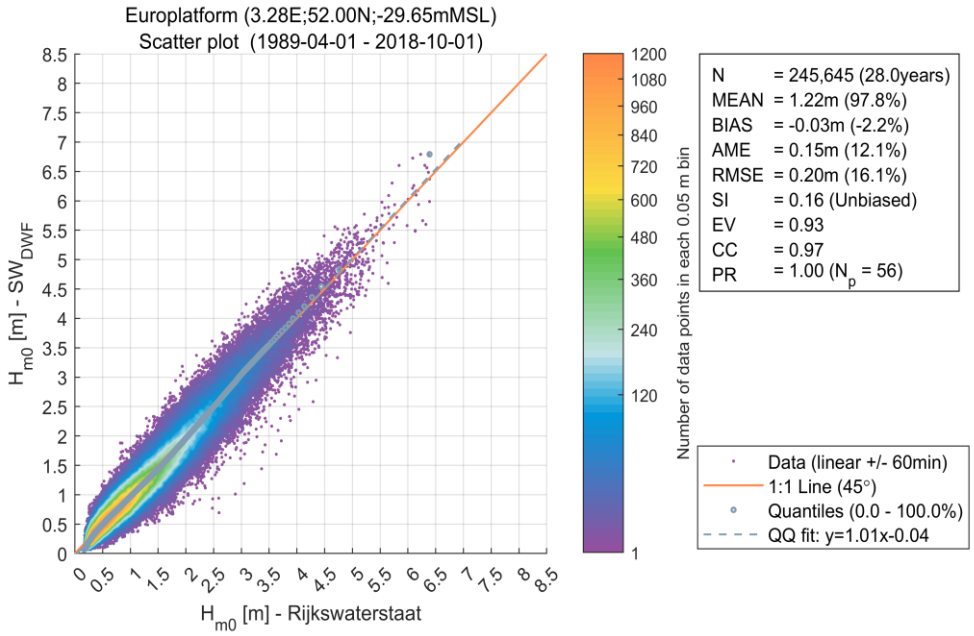
- Fully spectral modelling of largest storms coming from three main sectors (9 storms in total)
- 100m, 200m, 400m, 500m & 700m resolutions
- Time series and spatial comparisons (at points and along cross sections)





Wave Modeling- Local DWF model – Results

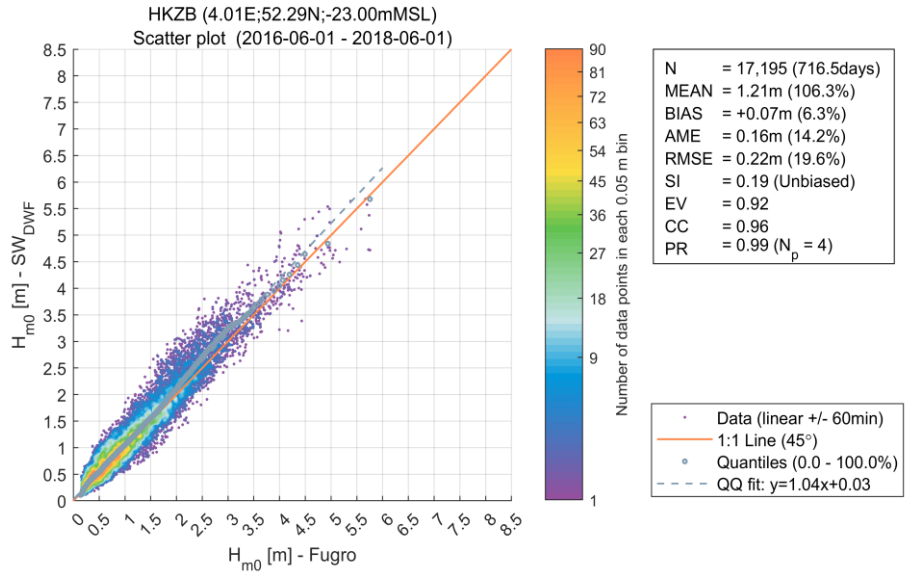
- Calibration was focused on:
  - the largest 53 storms (over the entire domain)
  - Winter 2016 & 2017 with measurements at HKN and HKZ
  - Largest 20 storms measured at HKN and HKZ
- Bottom friction and wind input were considered important
- Results showed excellent quality both for normal and extreme conditions at the site and areas nearby
- Result are considered an improvement over the previous DHI study at HKZ



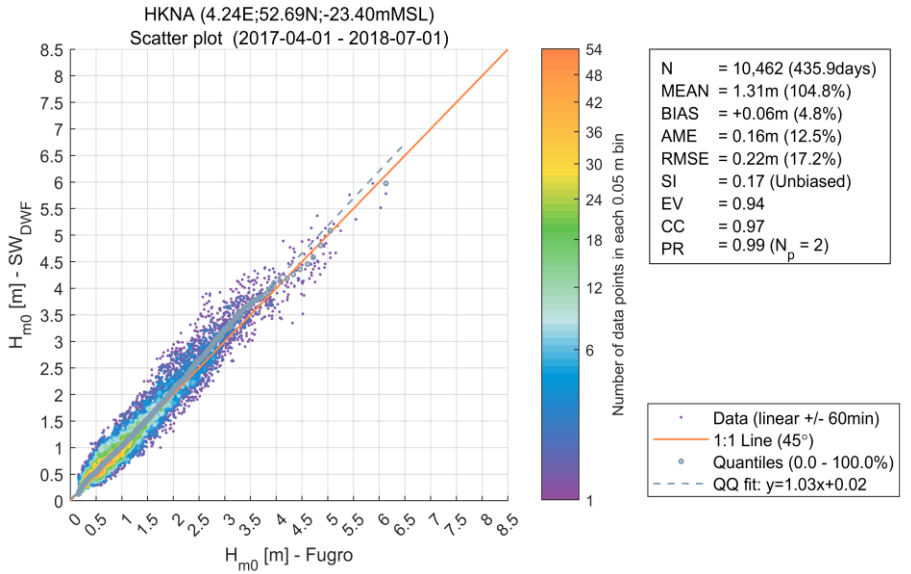
Validation at Europlatform (1989-2018)

Wave Modeling- Local DWF model – Results

- Results showed excellent quality both for normal and extreme conditions at Hollandse Kust (noord) and other areas within the Dutch Wind Farm zones



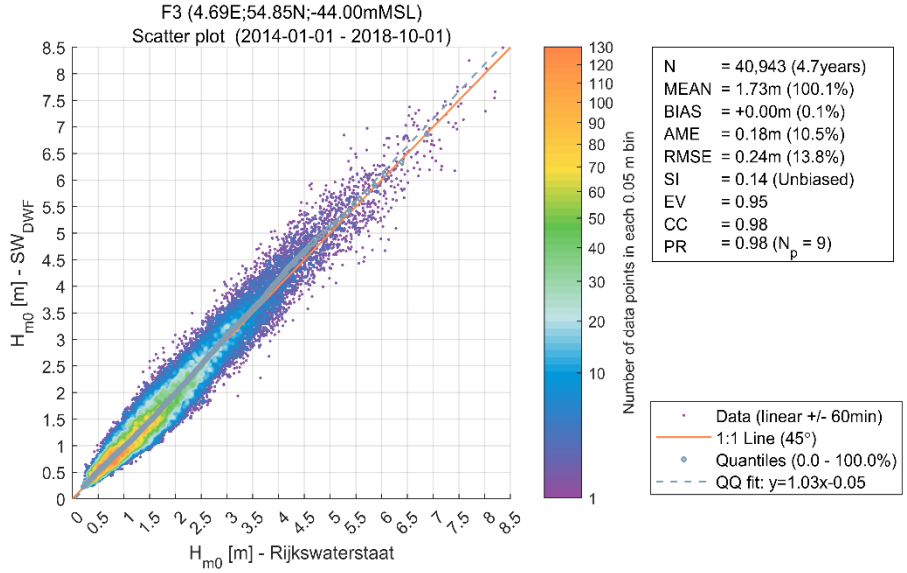
Validation at HKZB (2016-2018)



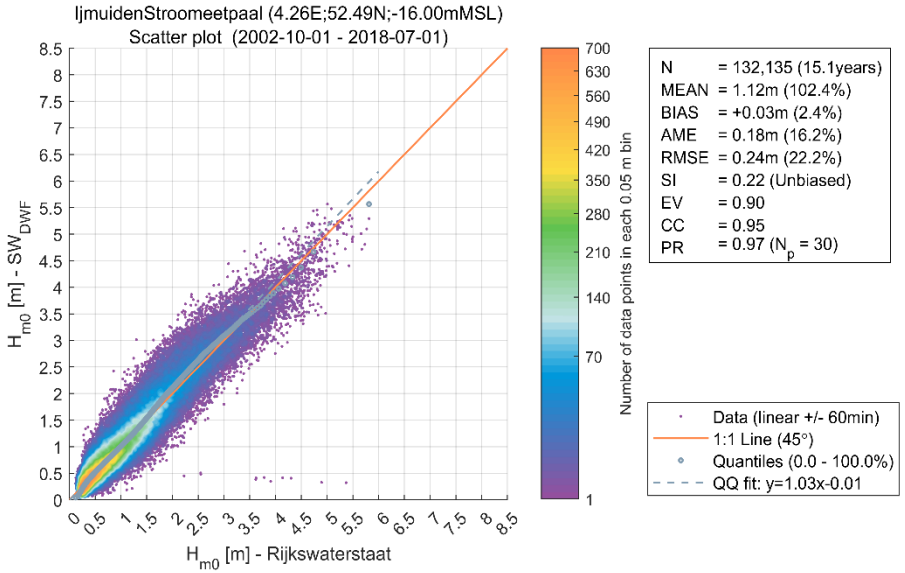
Validation at HKNA (2017-2018)

Wave Modeling- Local DWF model – Results

- Results showed excellent quality both for normal and extreme conditions at Hollandse Kust (noord) and other areas within the Dutch Wind Farm zones



Validation at F3 (2014-2018)

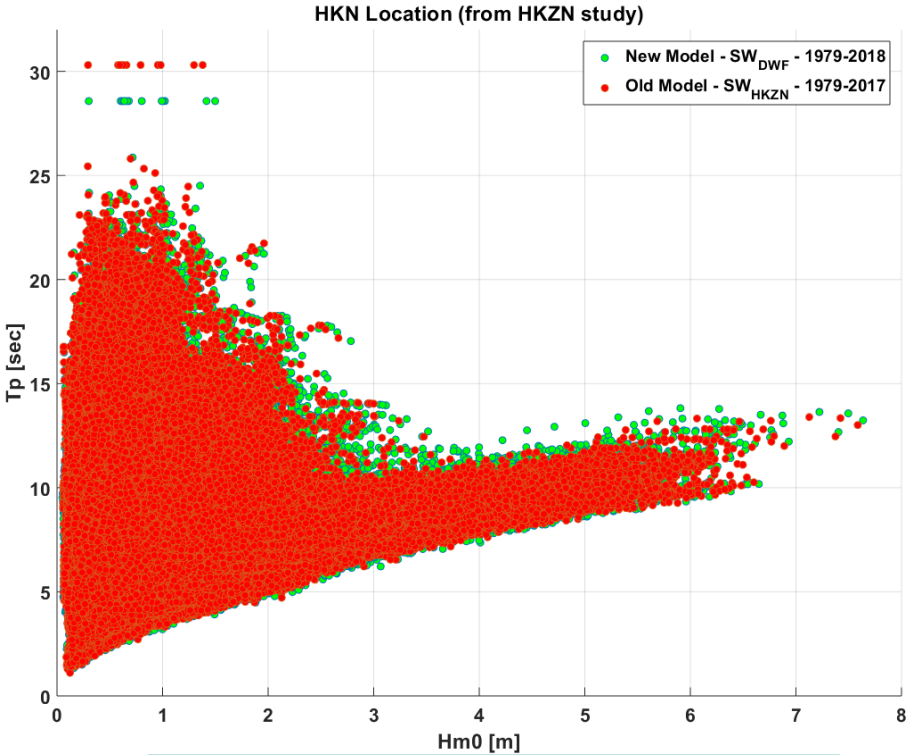


Validation at Ijmuiden Stroomeetpaal (2002-2018)

Comparison with DHI's 2016 study (HKZN)

- SW_{DWF} uses local bathymetry data and higher resolution of ~400m at Hollandse Kust (noord) compared to ~600m in SW_{HKZN}
- SW_{DWF} uses corrected/shifted CFSR
- SW_{DWF} is more comprehensively calibrated against the local measurements at Hollandse Kust (noord) and (zuid)

- Both models show very similar results

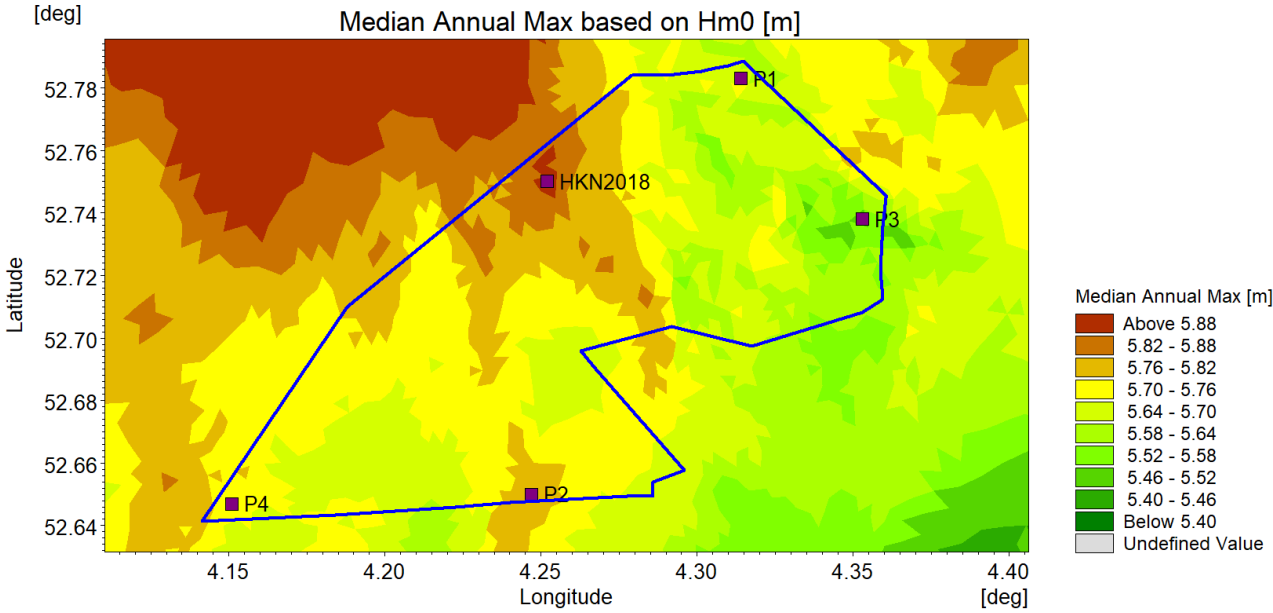


Scatter comparison of Hm0 vs. Tp between SW_{DWF} (green) and SW_{HKZN}

Normal and Extreme Conditions at Hollandse Kust (noord)

Analysis Points

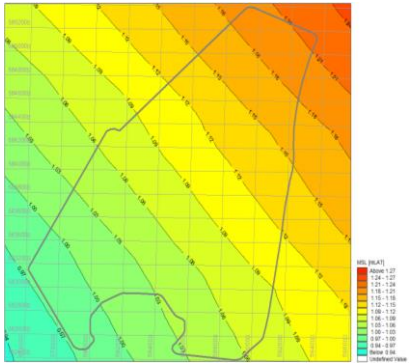
- Detailed Normal conditions are presented at one point in the report
- Detailed Extreme conditions are discussed at 5 points in the report
- Based on median of the annual max Hm0
- Spectral point was extracted from the 1km grid



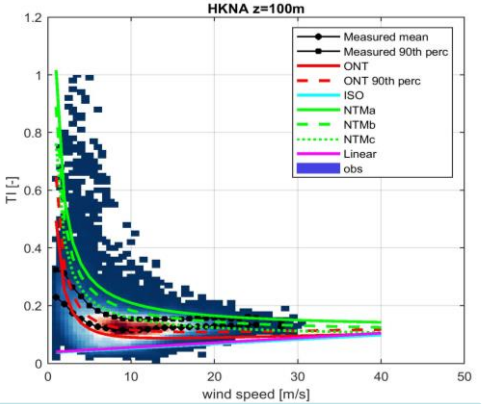
Location of the points selected for the analysis of extreme and normal conditions and annual median maximum H_{m0}

Normal Conditions

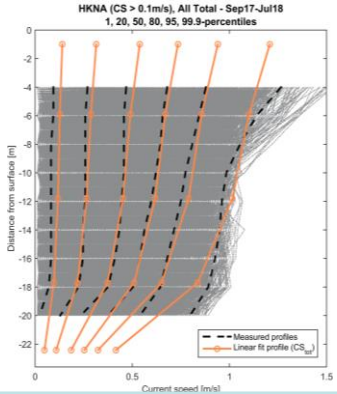
Common Parameters:
Time series
Rose plots
Scatter diagrams
Persistence (weather-windows)
Misalignment
Astronomical tide
Weibull parameters
Wind and wave spectra
Surface maps
Wind turbulence intensity
Fatigue
NSS tables
Vertical current profile



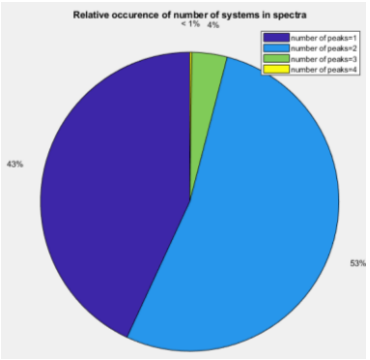
Surface map of MSL (mLAT)



Turbulence intensity



Current vertical profiles

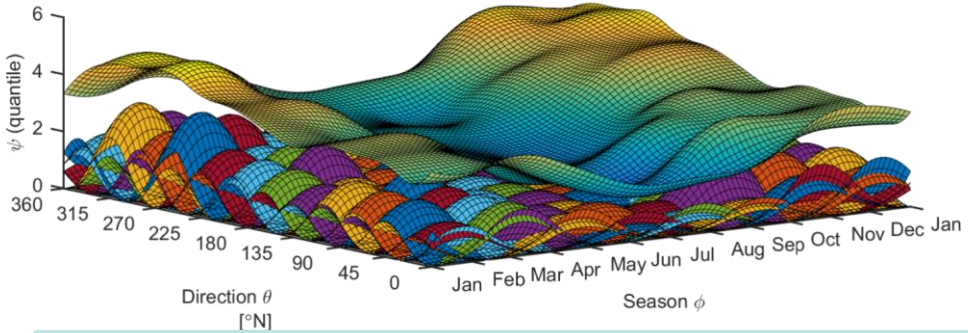


Sea/swell contribution

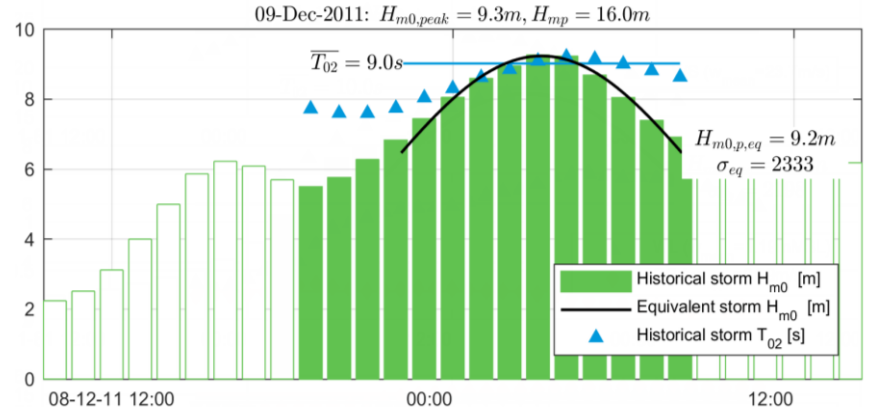
Extreme Conditions

- J-EVA Statistical + Storm model
- Marginal and conditional distributions dependent on co-variates
  - Wind, wave and current directions
  - Seasons
- J-EVA simulations
  - In order of 10,000 to 50,000 years
  - For 10,000 year extremes, simulation are in order of 1-4 million years long

First application of such advanced statistical methods in Offshore Wind industry



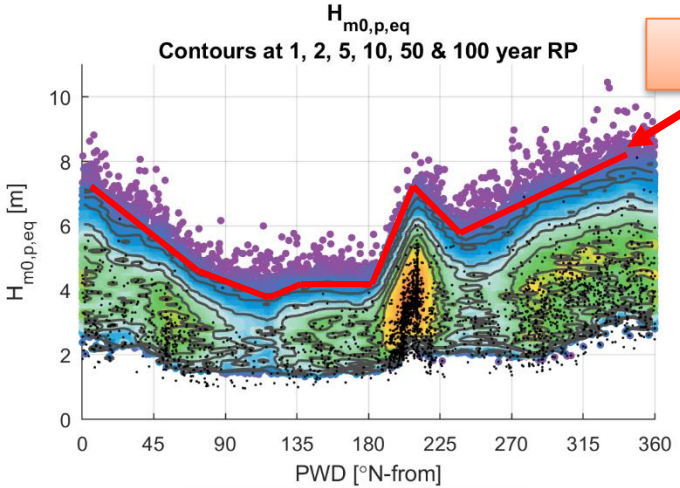
Bayesian P-splines for 2-dimensional description of model parameters



Examples of hindcast storms and storm model parameterization

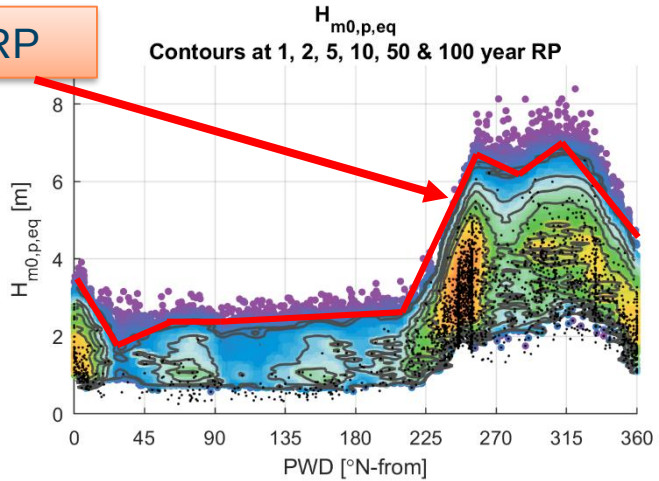
J-EVA tool

- Bayesian non-stationary extreme value analysis method applied (J-EVA)
  - Based on EVA methods developed at University of Lancaster (https://www.maths.lancs.ac.uk/~tawn/)
  - Matured in Oil&Gas industry over the last decade (http://www.lancs.ac.uk/~jonathan/)
  - Methods implemented and further developed by DHI for major Oil&Gas operator*
  - Methods applied and 3rd party verified in re-assessement of structural integrety



Nearshore point

100-year RP



Offshore point

J-EVA simulation of storm events based on 25,000 years

* Hans Fabricius Hansen, David Randell, Allan Rod Zeeberg, Philip Jonathan, (2019), Directional-seasonal extreme value analysis of North Sea storm conditions, to be submitted for review

Comparison with HKZN study

- More accurate and reliable results, particularly at Hollandse Kust (noord)
- Less conservatism in extreme values
- Better representation of directional and seasonal variability

	Extreme Hmax [m] - T_R [years]							
	1	2	5	10	50	100	1000	10000
Omni - HKZN Study	10.7	11.5	12.5	13.2	14.6	15.2	17.3	19.9
Omni - New Study	10.4	11.1	12.0	12.6	13.9	14.6	16.2	18.1
Difference	-0.4	-0.4	-0.5	-0.6	-0.7	-0.5	-1.1	-1.8

	Extreme Cmax [mSWL] - T_R [years]							
	1	2	5	10	50	100	1000	10000
Omni - HKZN Study	6.8	7.4	8.1	8.6	9.6	10.0	11.5	13.5
Omni - New Study	6.6	7.2	7.8	8.3	9.3	9.8	11.1	12.7
Difference	-0.2	-0.2	-0.3	-0.3	-0.3	-0.2	-0.5	-0.8

Differences between HKZN study and this study (New Study) for extreme Hmax [m] and Cmax [mSWL] values at HKN for different return periods

Comparison with HKZN study

- More accurate and reliable results, particularly at Hollandse Kust (noord)
- Less conservatism in extreme values
  - Verification performed by KNMI (U10=30m/s, U100=37m/s)
- Better representation of directional and seasonal variability

Differences between HKZN study and this study (New Study) for extreme 1hr wind speed at 10mMSL (top) and 100mMSL (middle) and 10-minute wind speed at 100mMSL (bottom) at HKN for different return periods

	Extreme 1hr Wind Speed @ 10mMSL [m/s] - T_R [years]					
	1	2	5	10	50	100
Omni - HKZN Study	24.7	25.4	27.5	28.7	31.4	32.5
Omni - New Study	24.9	26.2	27.6	28.6	30.8	31.7
Difference	0.2	0.8	0.1	-0.1	-0.6	-0.8

	Extreme 1hr Wind Speed @ 100mMSL [m/s] - T_R [years]					
	1	2	5	10	50	100
Omni - HKZN Study	31.7	32.7	35.6	37.4	41.2	42.8
Omni - New Study	31.0	32.5	34.4	35.5	38.2	39.4
Difference	-0.7	-0.2	-1.2	-1.9	-3.0	-3.4

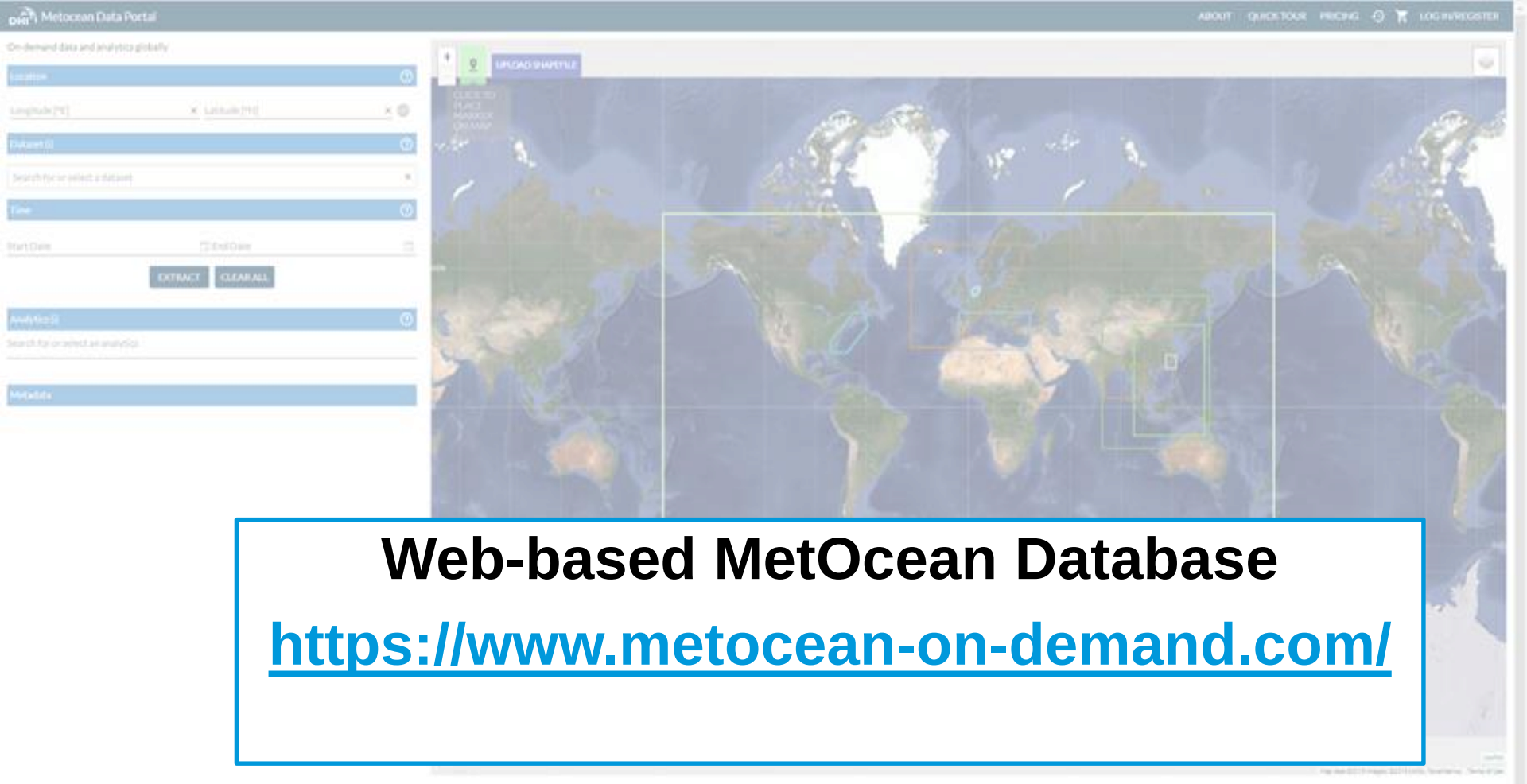
	Extreme 10-minute Wind Speed @ 100mMSL [m/s] - T_R [years]					
	1	2	5	10	50	100
Omni - HKZN Study	33.5	34.6	37.7	39.7	43.8	45.5
Omni - New Study	33.0	34.6	36.6	37.9	40.9	42.2
Difference	-0.5	0.1	-1.0	-1.7	-2.9	-3.3

Report (https://offshorewind.rvo.nl/windwaternh)

- Data basis
- Modelling (setup, calibration & validation)
- Normal & Extreme Conditions
- Joint Metocean conditions
- Snow, ice accretion and sea ice conditions
- Air temperature, humidity, pressure & density (at various heights)
- Seawater temperature, salinity and density
- Visibility
- Lightning
- Marine Growth

Variable	Extreme values (omni) - Return Period [Year]					
	1	2	5	10	50	100
Wind speed, 100mMSL, 10-min [m/s]	33.1	34.8	36.7	38.1	41.0	42.1
Water level, Total, High [mLAT]	3.2	3.4	3.5	3.7	4.0	4.1
Water level, Total, Low [mLAT]	-0.5	-0.6	-0.7	-0.8	-1.0	-1.1
Water level, Residual, High [m]	1.6	1.8	2.0	2.2	2.5	2.6
Water level, Residual, Low [m]	-1.0	-1.1	-1.3	-1.3	-1.5	-1.6
Current Speed, Total, Depth-averaged [m/s]	1.0	1.0	1.1	1.1	1.1	1.2
Current Speed, Residual, Depth-averaged [m/s]	0.6	0.6	0.7	0.8	0.9	1.0
Significant wave height, $H_{m0,\,3h}$ [m]	5.6	5.9	6.4	6.7	7.3	7.6
Peak wave period, T_p, ass. with $H_{m0,\,3h}$ [s]	10.0	10.5	10.9	11.1	11.5	11.8
Maximum wave height, H_{max} [m]	10.4	11.1	12.0	12.6	14.0	14.5
Wave period, T, ass. with H_{max} [s]	9.0	9.0	9.4	9.7	10.0	10.2
Maximum crest level, C_{max}, SWL [mSWL]	6.6	7.1	7.7	8.2	9.2	9.6
Maximum crest level, C_{max}, MSL [mMSL]	8.0	8.7	9.4	10.0	11.2	11.6
Maximum crest level, C_{max}, LAT [mLAT]	9.1	9.8	10.5	11.1	12.3	12.7

Summary of extreme values at HKN2018

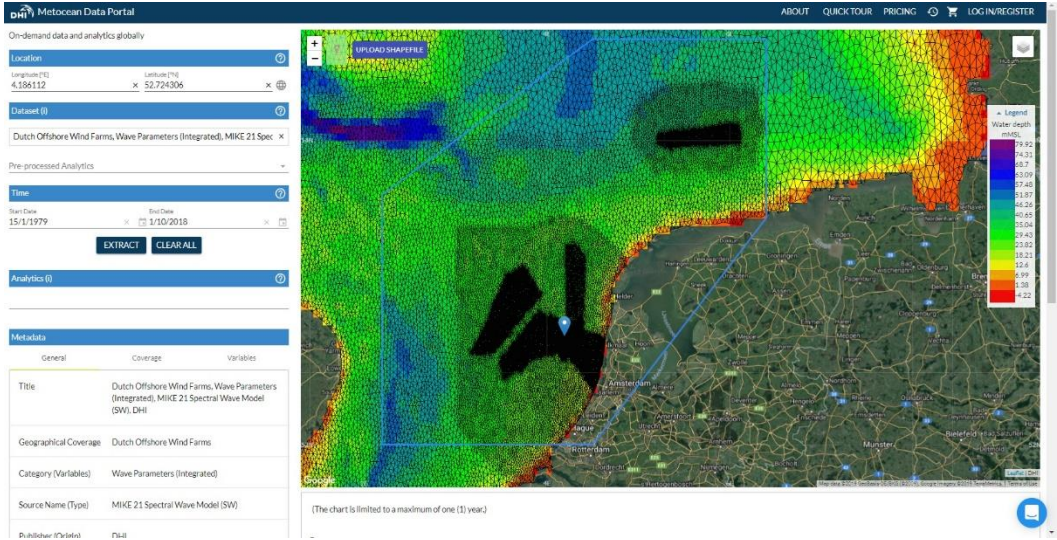


Web-based MetOcean Database

https://www.metocean-on-demand.com/

Metocean Database Features

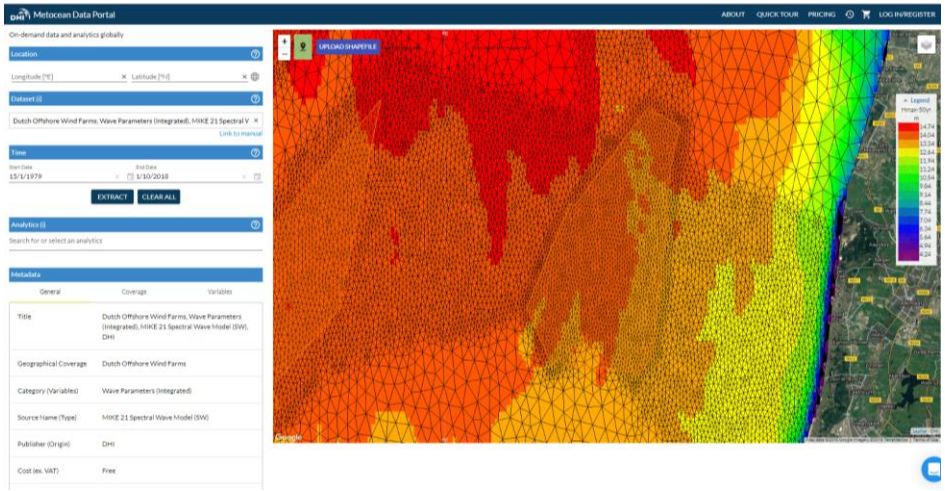
- World's first certified web-based metocean database
- Access to 40 years of time series at all elements
- Access to 40 years of spectral data within 1km grid (offshore wind farms) and 5km grid (offshore areas and cable corridors)
- Instant access to extreme conditions and NSS tables at all elements
- Map of normal and extreme conditions over the Dutch North Sea
- On-the-fly analysis such as weather-windows, scatter tables, altimeter comparison, rose plots etc.
- Following the EU General Data Protection Regulation (GDPR)



Metocean database covering the Dutch Offshore Wind Farm areas

Metocean Database Application

- Certified data only at Hollandse Kust (noord) to be used for design
- Feasibility level data at Hollandse Kust (west), IJmuiden Ver, Ten Noorden van den Waddeneilanden and cable corridors
- Extreme values, NSS tables, Weather-windows (workability), scatter tables etc. available at all elements
- Possibility to add user defined shapefiles
- Possibility to input UTM and Long/Lat coordinates



Map of 50-year Hmax [m] values around Hollandse Kust (noord)

Closing

- Questionnaire
- Lessons learned
- Availability panel
- Communications
  - https://offshorewind.rvo.nl
  - woz@rvo.nl

Thank you very much!