Metocean Study

Hollandse Kust (zuid) & (noord) Wind Farm Zone

Presented by:
Maziar Golestani, MetOcean Specialist, Ports and Offshore Technology Department, DHI HQ, Denmark

This presentation is prepared for RVO.nl and intended to be used in the Webinar on January 17th 2017.

Objectives of this study

- Provide metocean condition to serve as input for design, installation and maintenance of OWF structures at Hollandse Kust (zuid) & (noord)

- Analysis was based on the best possible data sources
  - 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

- Short introduction to DHI
- Deliverables
- Establishment of MetOcean Data/Models
  - ✓ Wind
  - ✓ Water Levels and Current
  - ✓ Waves
- Normal and Extreme Conditions
- Database and it’s user interface (to be presented after this presentation)

Project team – Panel

Maziar Golestani, MetOcean Specialist, DHI HQ

Project Manager

Patrick Dich Grode, Senior MetOcean Specialist, DHI HQ

Quality Supervisor

Hans Fabricius Hansen, Senior MetOcean Specialist, DHI HQ

Quality Supervisor


DHI who?
- An ultra short introduction
DHI

DHI in short

We’re an independent, private and not-for-profit organisation

Our people are highly qualified

80% of our 1,150 employees hold an MSc or a PhD degree

Our knowledge represents 50+ years of dedicated research

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

We make this knowledge globally accessible

through our local teams and unique software

We are global

This ensures local relevance of our solutions

We're on a quest

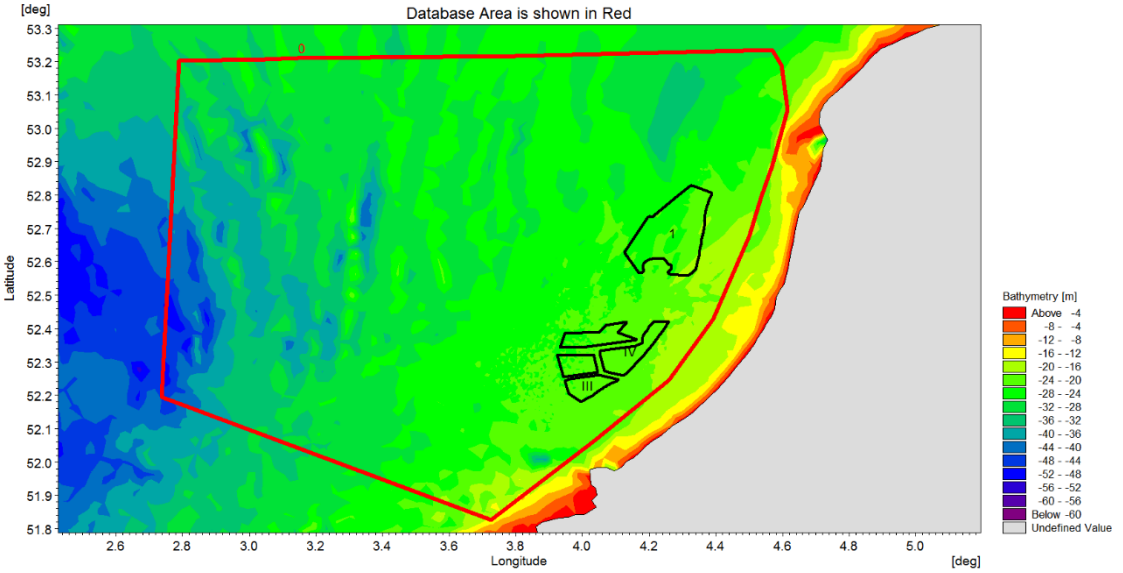
to help solve the world's toughest challenges in water environments


25+ years supporting offshore wind worldwide
85% of the commissioned European offshore wind farms have had a DHI added value

Deliverables

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

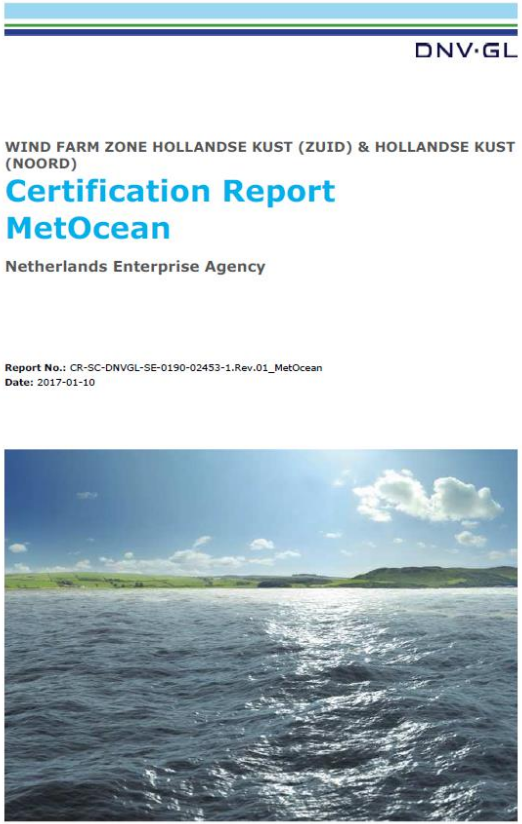
- Digital metocean Database
  - ✓ Access to different types of metocean analysis at any given point within the domain



Map showing the area that is covered in the database (shown in Red) along with Bathymetry (mMSL)

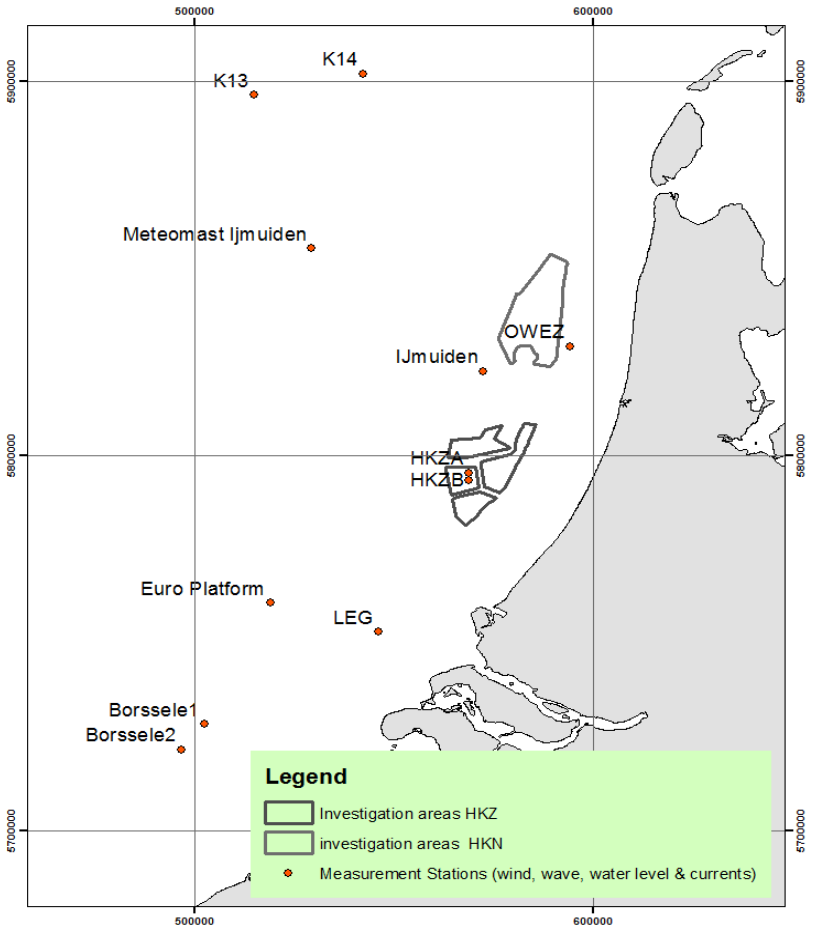
QA process of the project deliverables

- Extensive quality control procedure by DHI
- Reviewed and approved by RVO experts
- Review of the extreme value analysis by a statistical expert on behalf of RVO
- Certified by DNV-GL
- Aligned with the WRA study performed by Ecofys



In-situ observations

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



Make a good foundation!

Get the right and fit-for-purpose data!

Wind Data Establishment

The Climate Forecast System Reanalysis (CFSR) atmospheric model

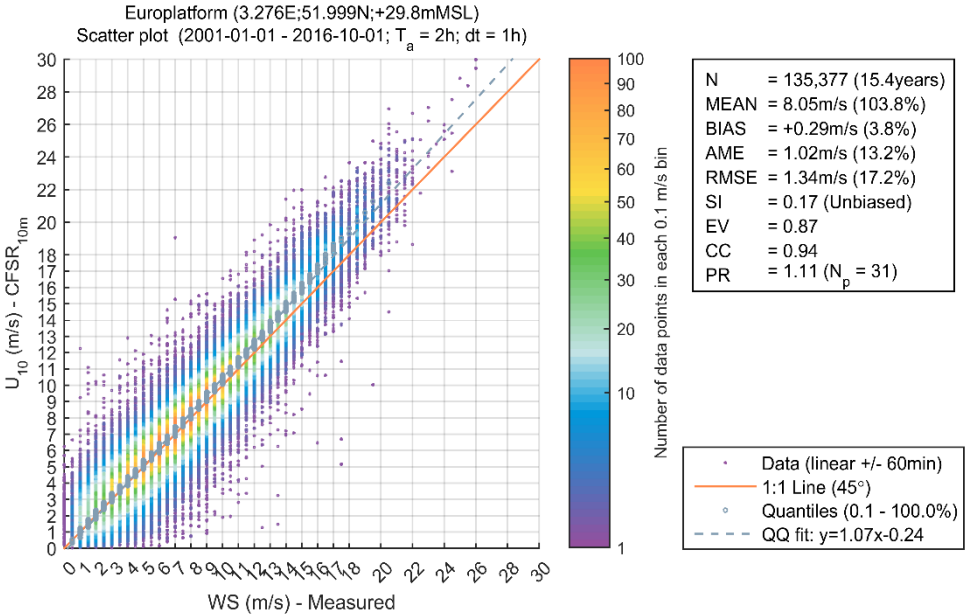
- CFSR (1979-2016) wind fields at 10mMSL & 100mMSL
- CFSR air and sea surface temperature, pressure and humidity

- Validations at different altitudes
  - ✓ In-situ measurements (offshore + nearshore)
  - ✓ Satellite measurements (scatterometer)

✓ CFSR at 10mMSL was used to derive wind speeds at higher altitudes + Frøya profile

✓ Directional corrections were made to CFSR based on the OWEZ measurements

CFSR vs. Europlatform measurements at 10mMSL



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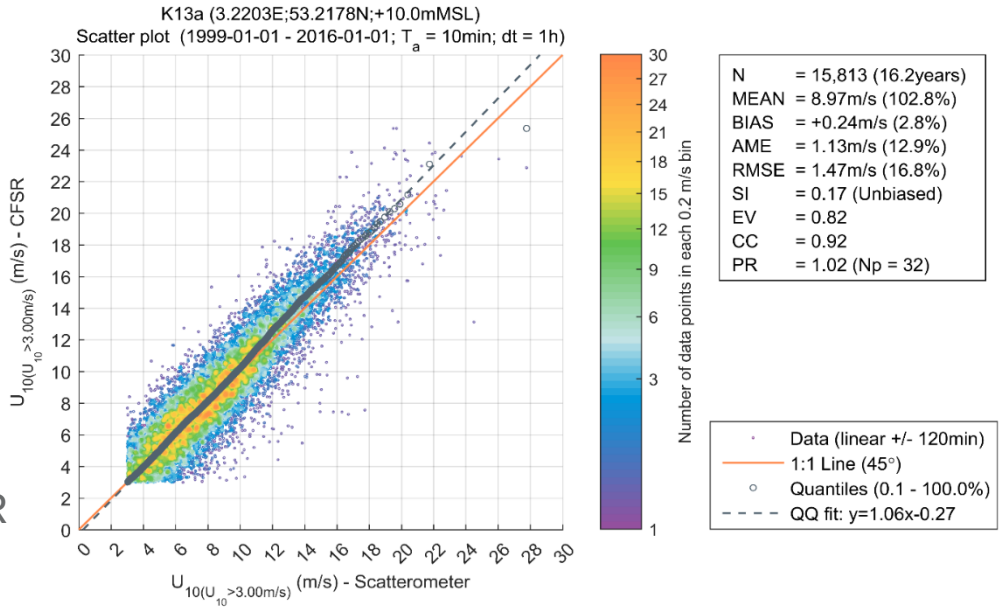
CFSR vs. Scattermeter at K13 at 10mMSL



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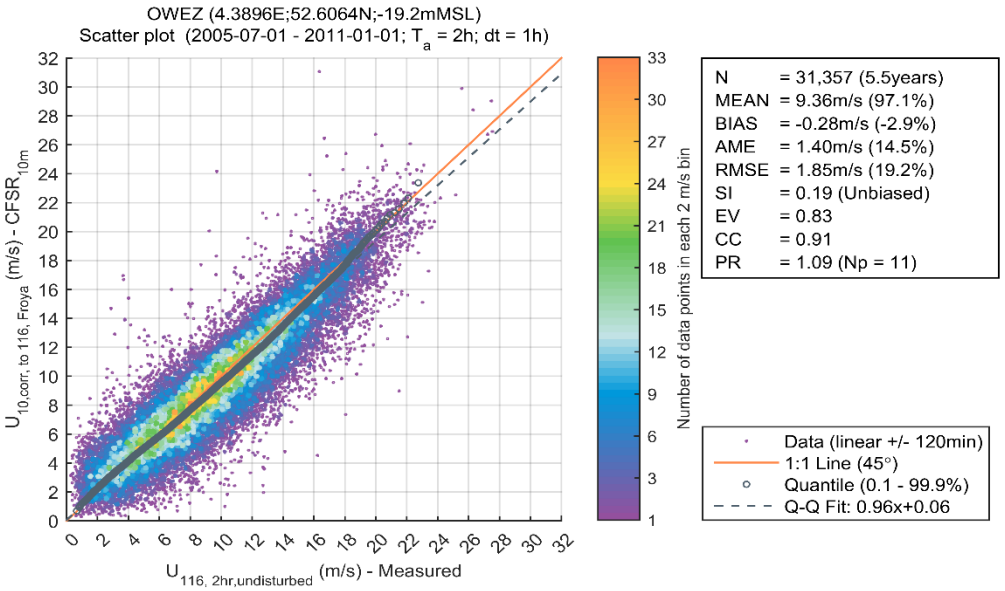
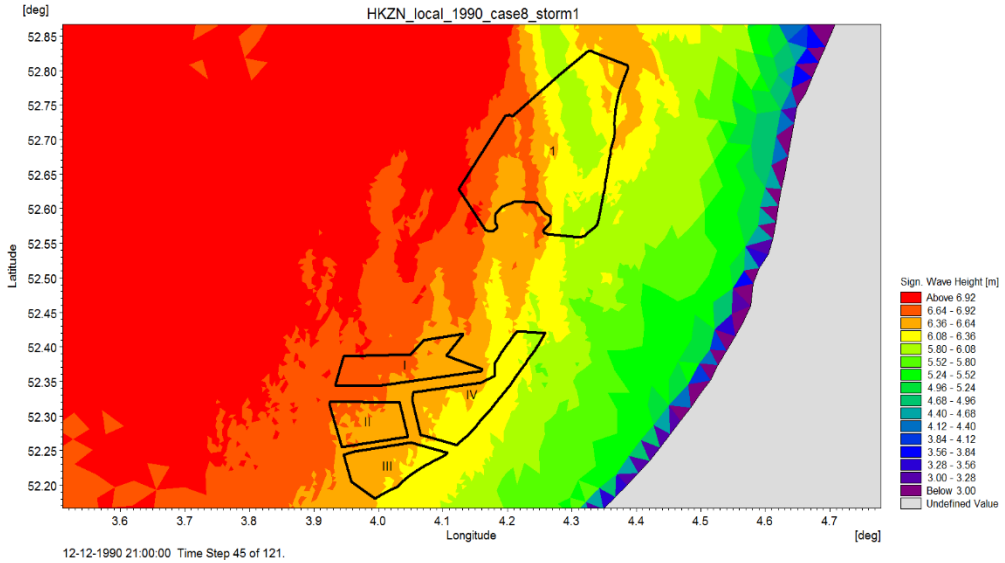
CFSR vs. OWEZ measurements at 116mMSL



Numerical Modeling

Numerical Modeling Overview

- Simulation period covered the period 1979-01-01 to 2016-09-01
- The models will be updated in summer 2017 to include the latest measurements
- Validation plots will be updated
- The database provides data for the period 1979-01-15 to 2016-01-01



Snapshot of the modelled significant wave height at the peak of the storm on 1990-12-12

Numerical Model Used (Hydrodynamic and Wave Model)

For more than 25 years

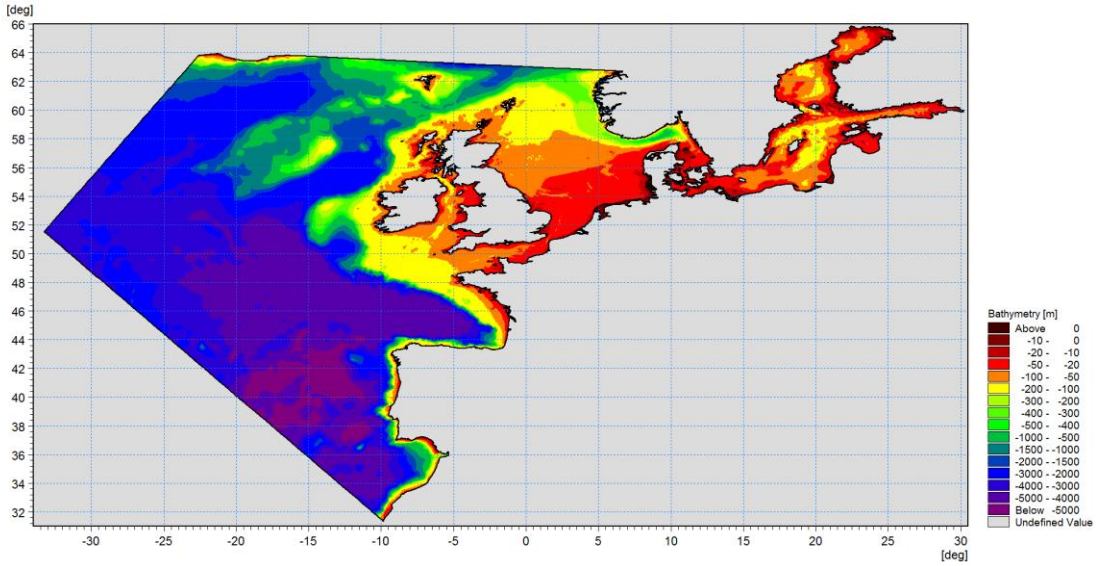
MIKE Powered by DHI

has been the preferred choice of water professionals around the world

Hydrodynamic Modeling

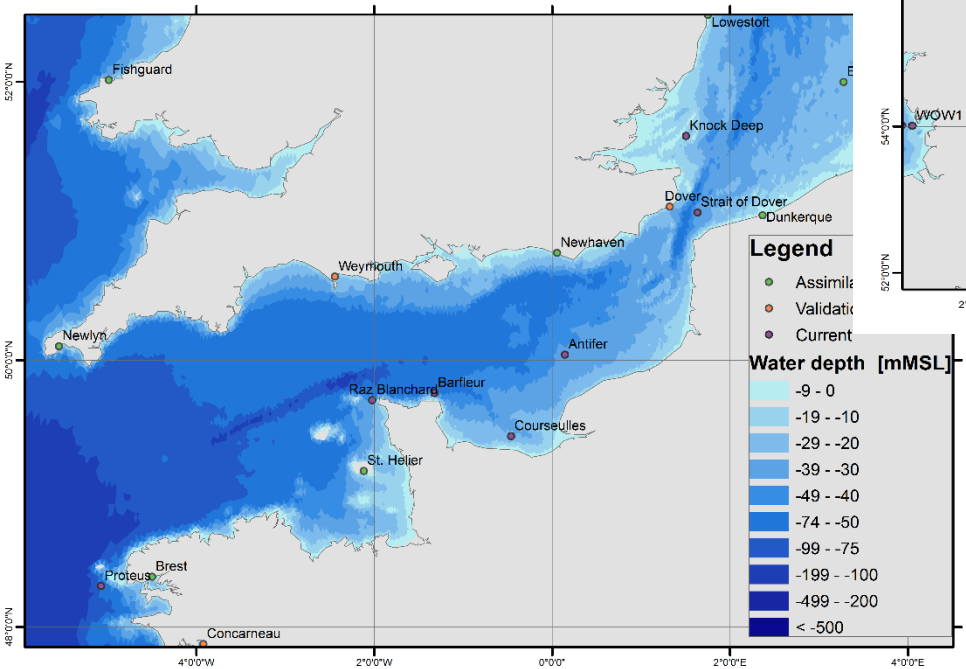
Water level and current modeling

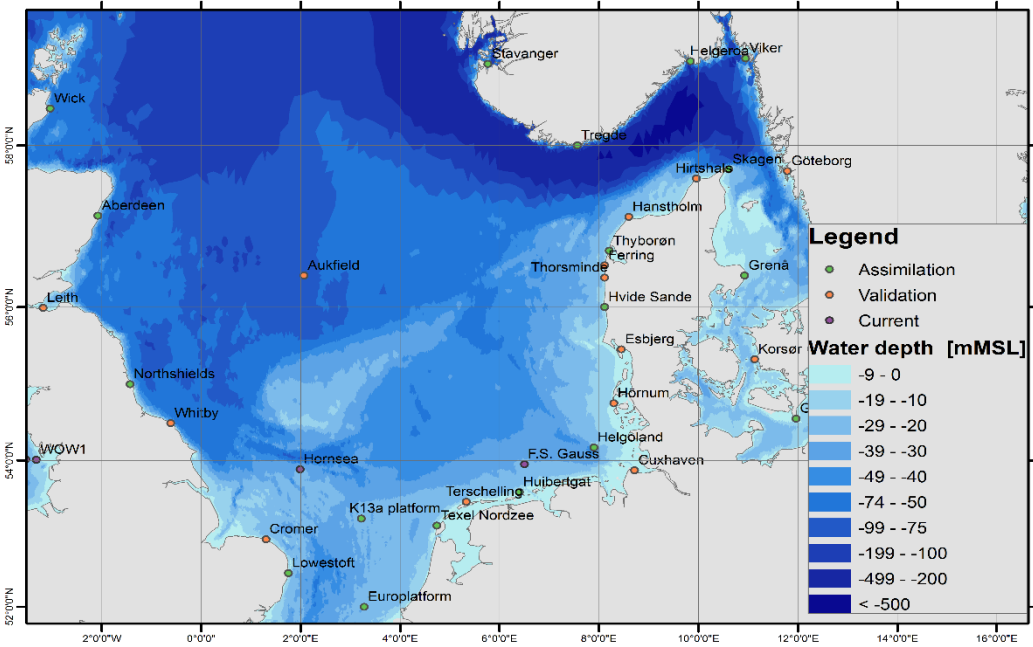
- DHI's dedicated North Atlantic Hydrodynamic Model (HD-DA,NA)
  - High Resolution
  - Excellent Quality
- Assimilation in the period 1994-2015
- Used as the boundary conditions for the local model



Regional Hydrodynamic Model Domain and bathymetry

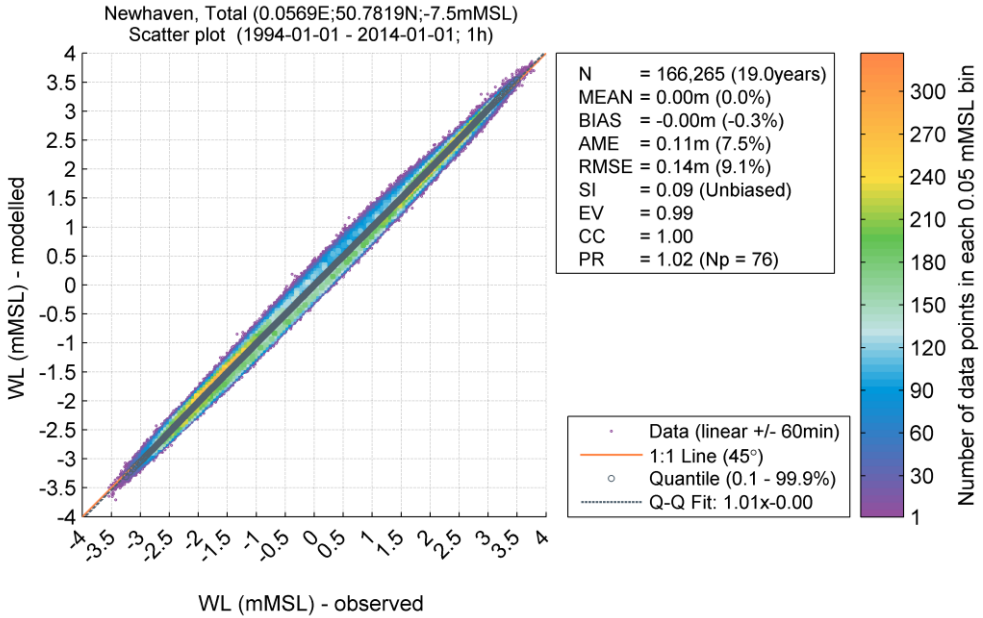
Validation/Assimilation stations used in the HD modeling





Water level and current modeling – Regional Model

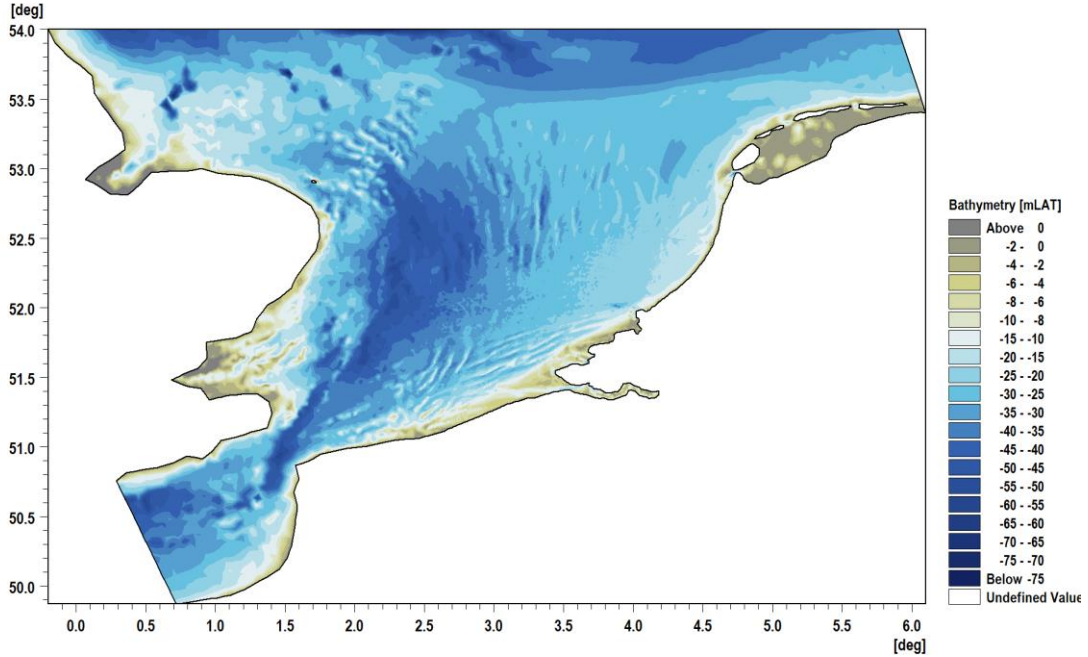
- Boundaries taken from DHI's dedicated North Atlantic Hydrodynamic Model (HD-DA,NA)
  - High Resolution
  - Excellent Quality
- Assimilation in the period 1994-2015
- Validated against multiple stations in the North Sea, English Channel and Baltic Sea and Inner Danish Waters



Modelled vs. Measured water levels at Newhaven (1994-2014)

Water level and current modeling – Local Model

- Local high-resolution hydrodynamic MIKE 21 FM HD (HD - HKZN)
- Resolution varies from ~5km to ~200 meters
  - ~200m at the HKZN area
  - ~200m at the Borssele WFZ
- Bathymetry
  - ✓RVO/Fugro
  - ✓EMODnet
  - ✓Existence of sand dunes



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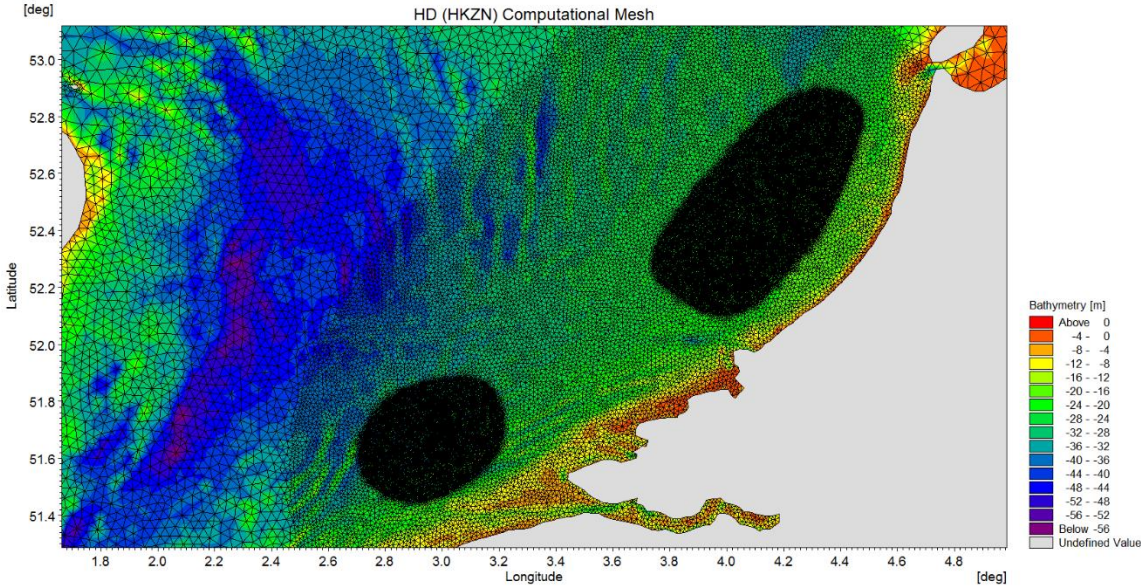
- Resolution varies from ~5km to ~200 meters
  - ~200m at the HKZN area
  - ~200m at the Borssele WFZ
- Bathymetry
  - ✓ RVO/Fugro
  - ✓ EMODnet
- Takes the boundary from the Regional HD model (HD – DA, NA)
- Assimilation was not included in the local model

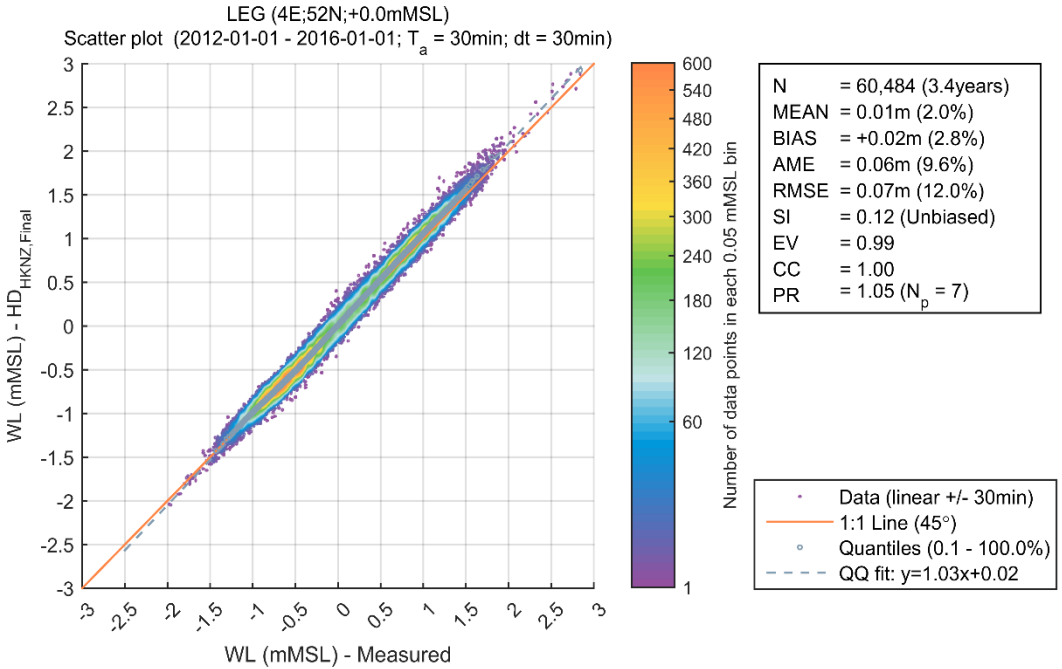


Local Hydrodynamic Model Mesh and bathymetry- Zoom in to the HKZN area

Water level and current modeling – Local Model Validation

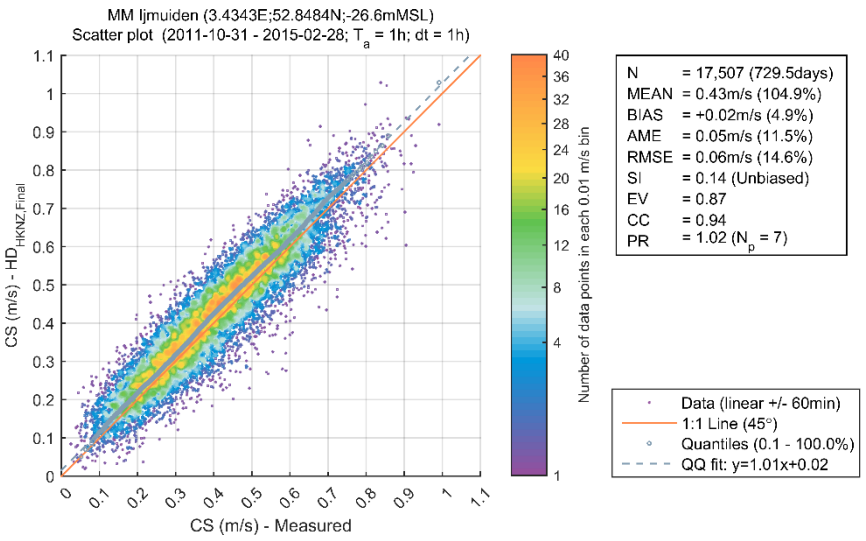
- Validated against available measurements

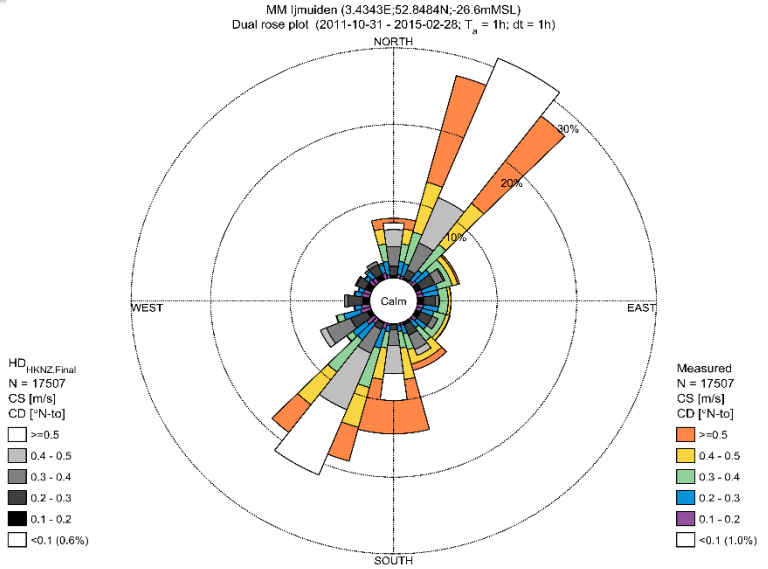
Modelled vs. Measured water levels at LEG (2012-2016)



Water level and current modeling – Local Model Validation

Modelled vs. Measured Currents at MM Ijmuiden (2011-2015)

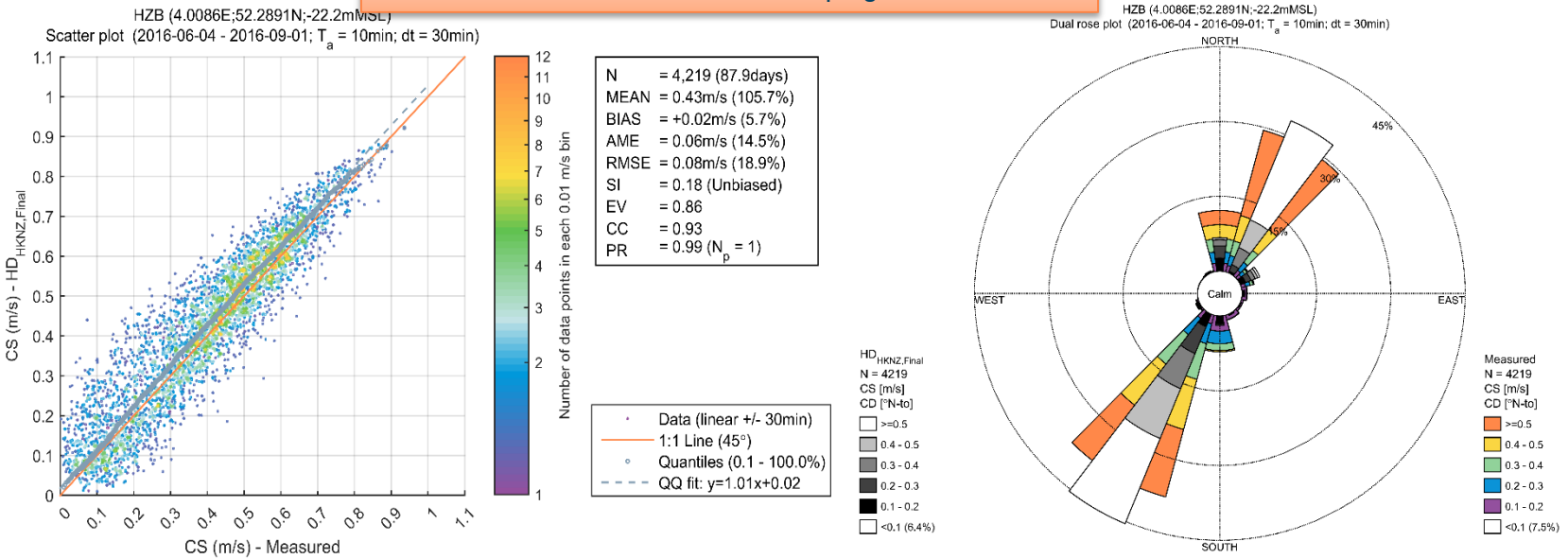




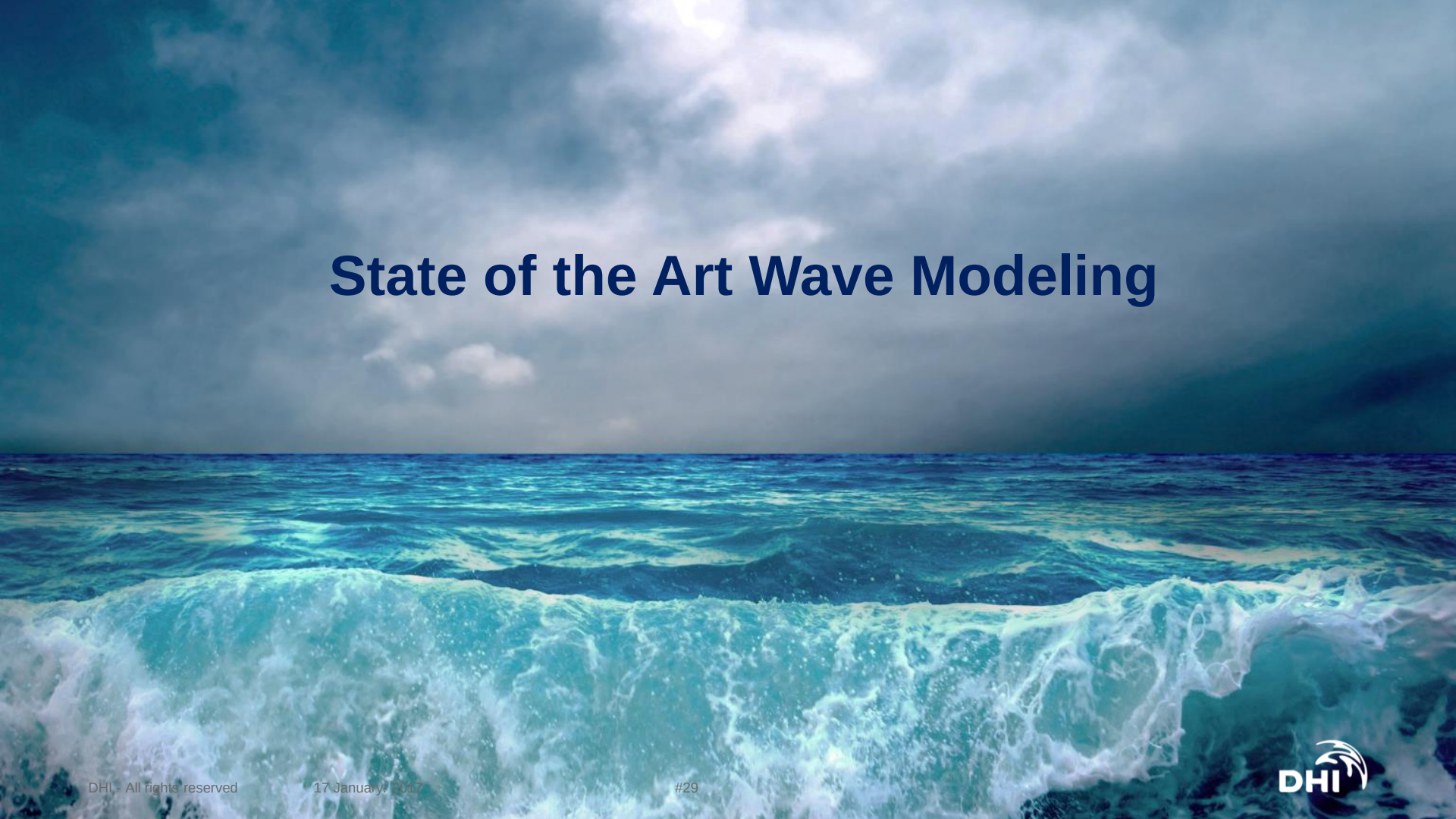
Water level and current modeling – Local Model Validation

Modelled vs. Measured Currents at HKZB(2016)

No Assimilation in 2016- To be updated after completion of measurement campaign



State of the Art Wave Modeling



Improvements in Wave Modeling Methods…

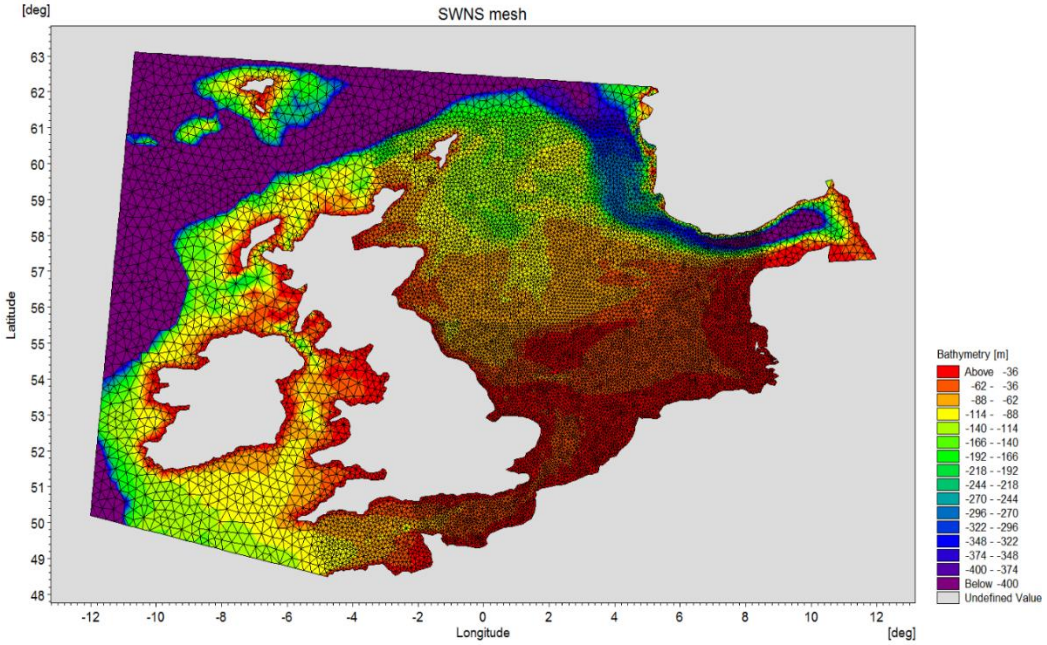
- Taking the atmospheric stability effects into account
- Applying varying in time and domain Air-Sea density ratio
- Including the influence of surface currents into wave growth (wave-current interaction)
- Applying a CAP to the friction velocity for large wind speeds

Golestani, M., Jensen, P. M., & Kofoed-Hansen, H. (2015). *On the influence of atmospheric stability on the wave climate in a warm and saline water body*. St. John's, Newfoundland, Canada: OMAE

Bolaños, R. X.-H. (2014). *Coupling atmosphere and waves for coastal wind turbine design*. Seoul: 34th International Conference On Coastal Engineering

Wave Modeling- Regional North Sea Model

- Boundaries taken from DHI's Global Wave Model (GWM)
  - Spectral boundaries available on a 500m 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

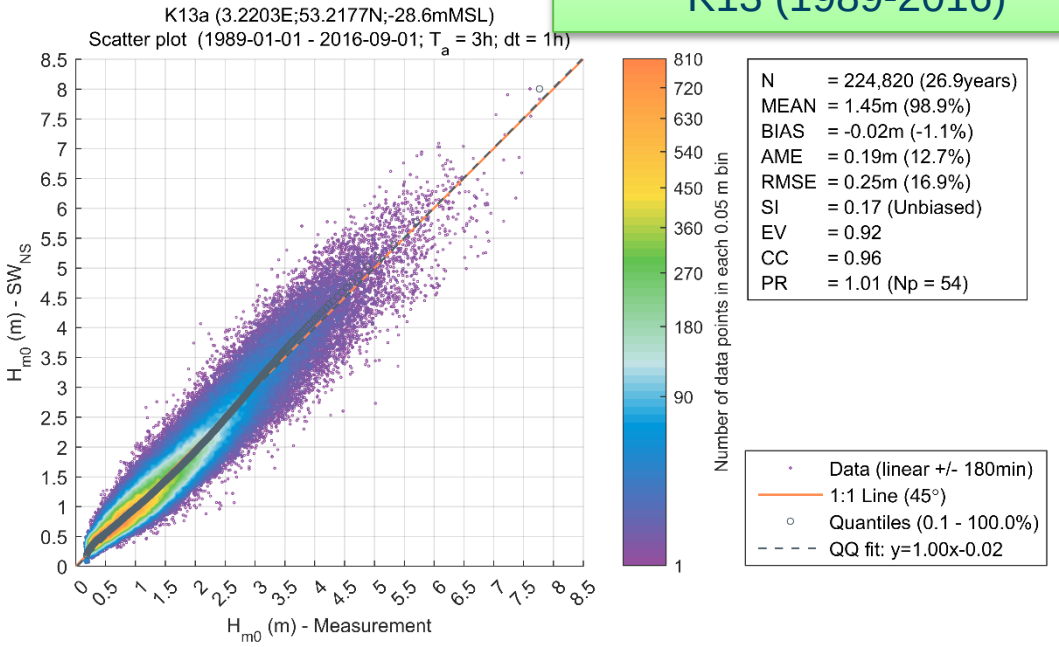


Regional Wave Model Domain and bathymetry

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

Modelled vs. Measured Significant wave height at K13 (1989-2016)



Wave Modeling- Regional North Sea Model

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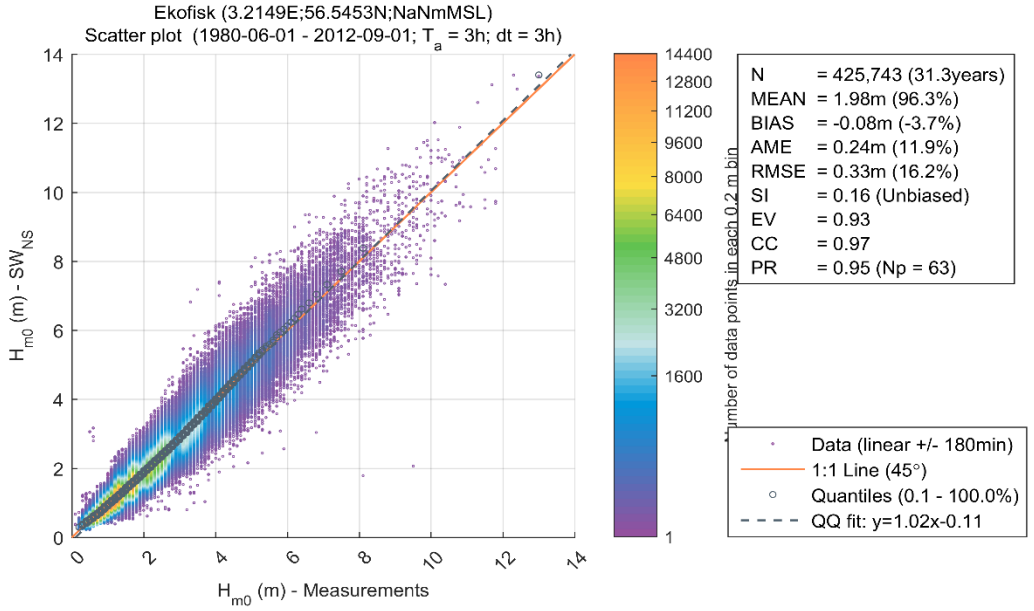
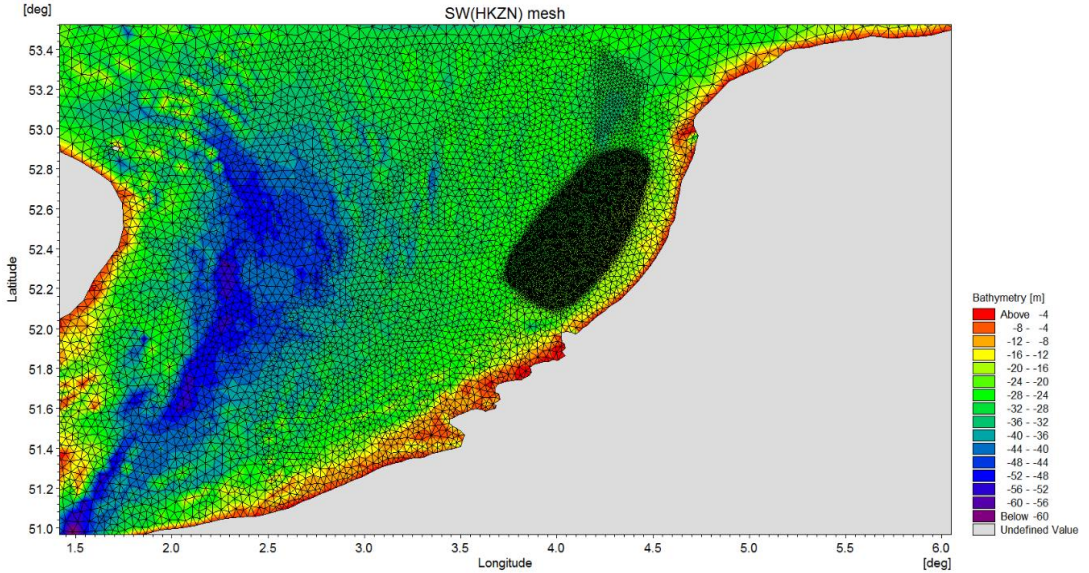
Modelled vs. Measured Significant wave height at Ekofisk (1980-2012)



Wave Modeling- Local HKZN Model

- Takes the spectral boundaries from Regional North Sea model
- Same domain as the local HD model
- ~3km-600m resolution
- Uses the varying in time and domain water level and currents from the local HD model
- Fully Spectral in-stationary
- 47 frequencies and 48 directions for spectral discretization
- Simulation Period: 1979-01-01 to 2016-09-01

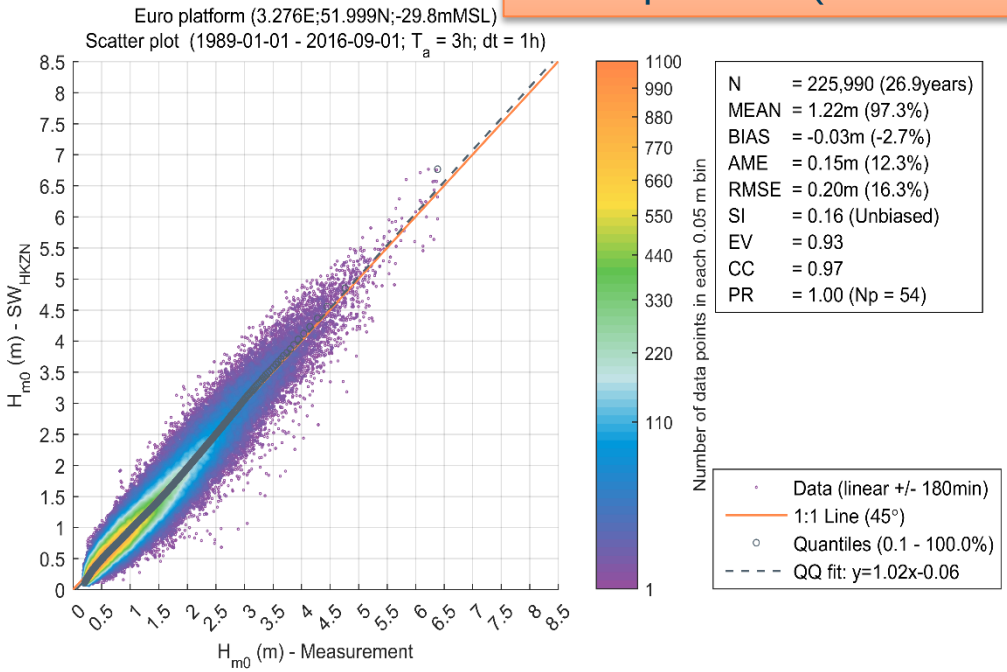


Zoomed-in picture showing the local wave model mesh along with the bathymetry (mMSL)

Wave Modeling- Local HKZN Model

- Calibration was focused on the largest storms
- Bottom friction and spectral discretization was considered important
- Results showed excellent quality both for normal and extreme conditions at the site and areas nearby

Modelled vs. Measured Significant wave height at Europlatform (1989-2016)



Wave Modeling- Local HKZN Model

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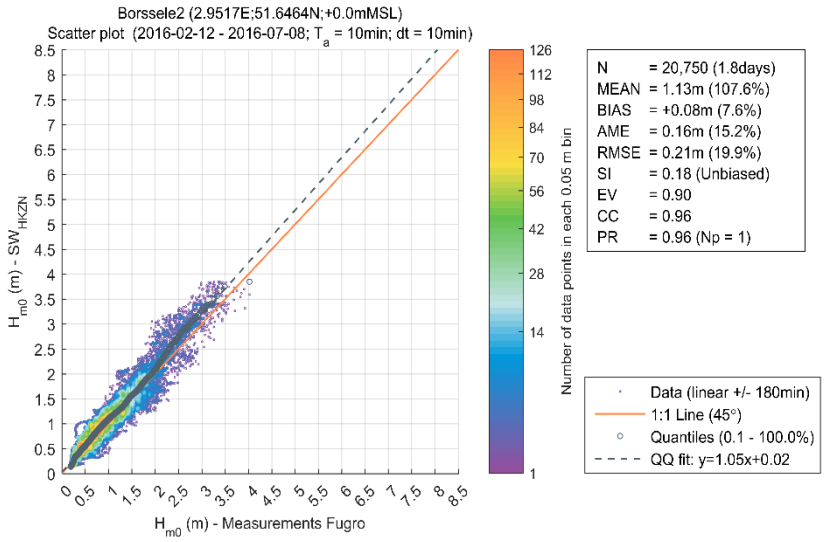
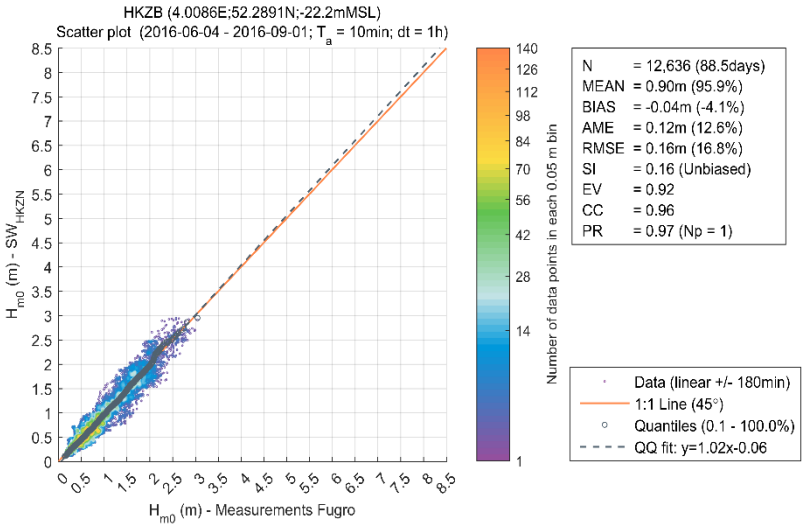
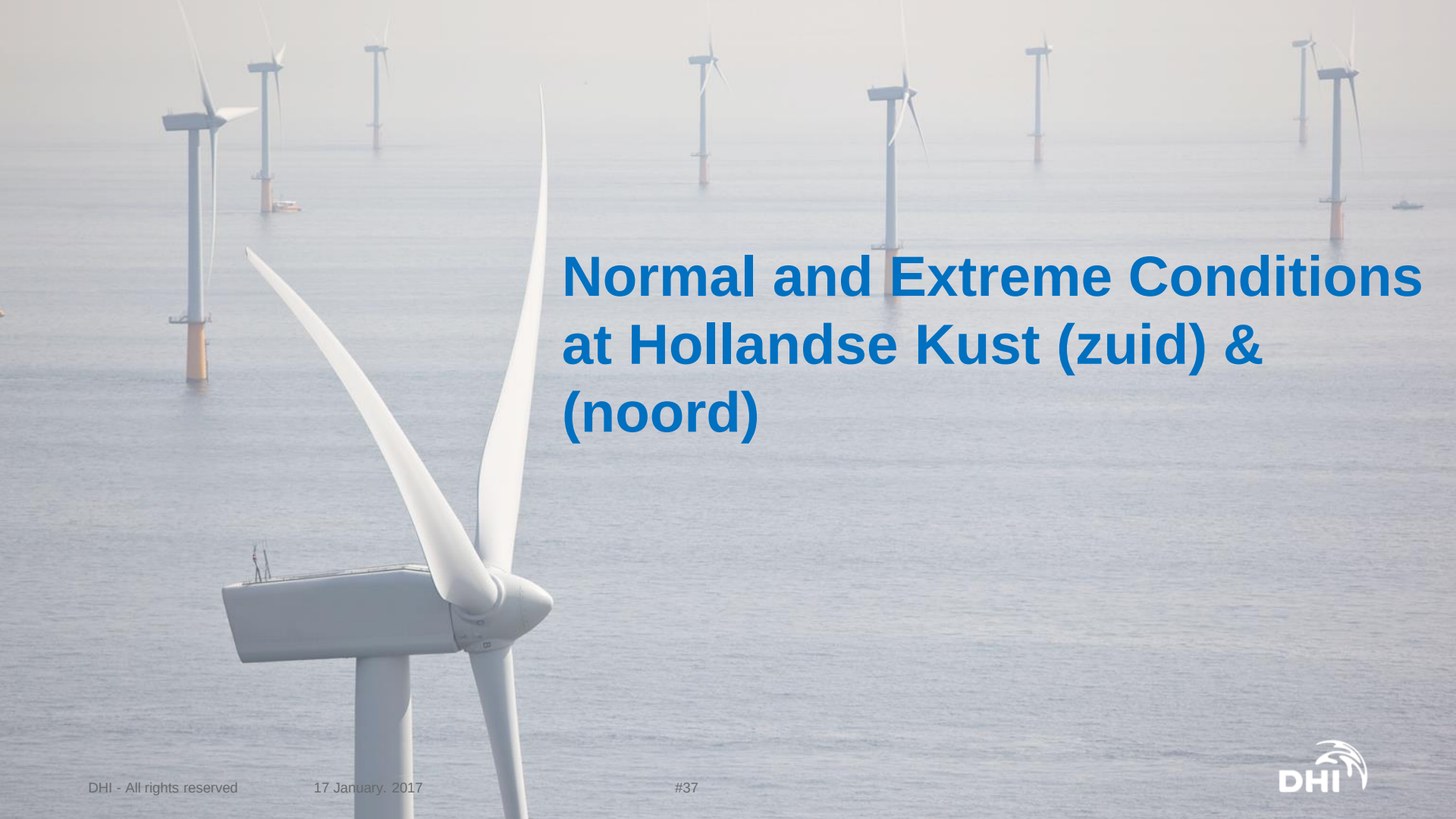
Modelled vs. Measured significant wave height at Borssele2 (2016)



Modelled vs. Measured significant wave height at HKZB (2016)

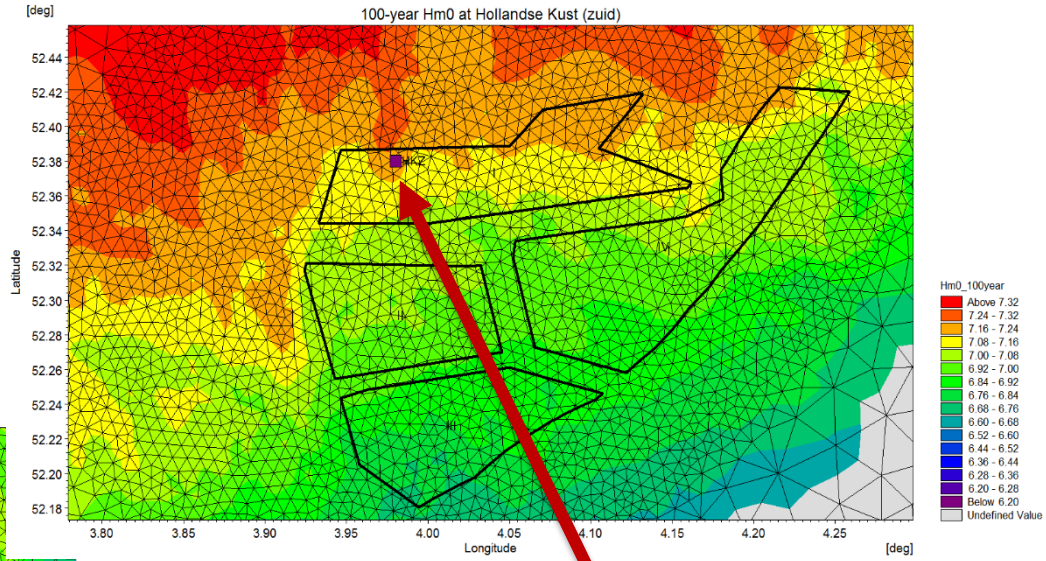


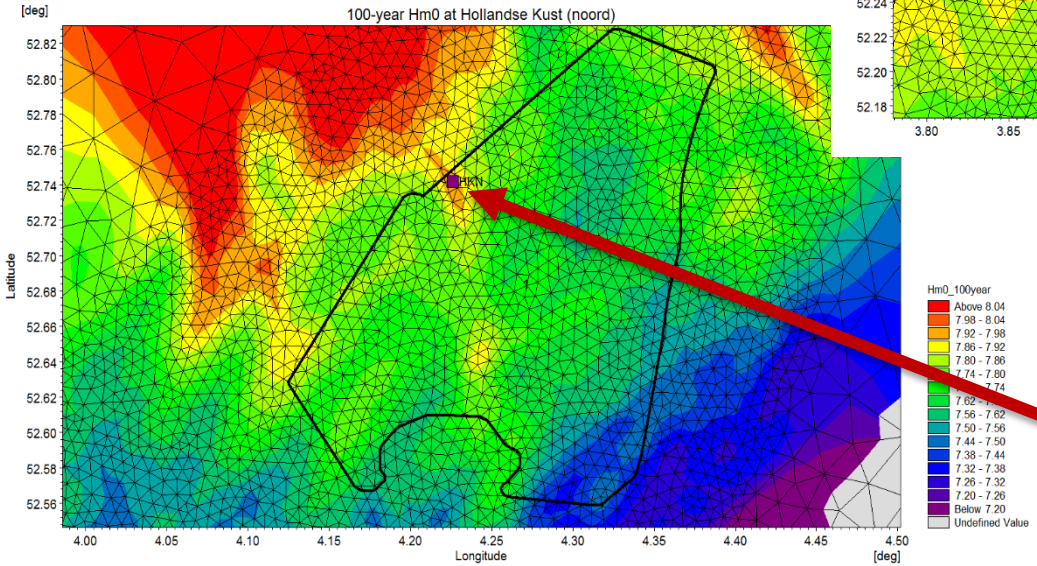


Normal and Extreme Conditions at Hollandse Kust (zuid) & (noord)

Analysis Points

- Detailed Normal and Extreme conditions are presented at two points in the report
- Based on 100-year extreme Hm0





100-year Hm0 in Hollandse Kust (zuid)

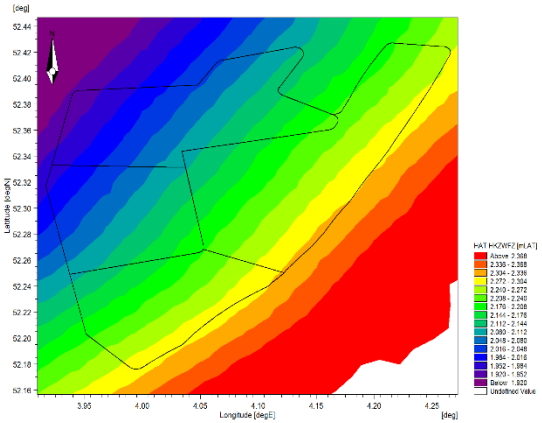
100-year Hm0 in Hollandse Kust (noord)

Normal Conditions

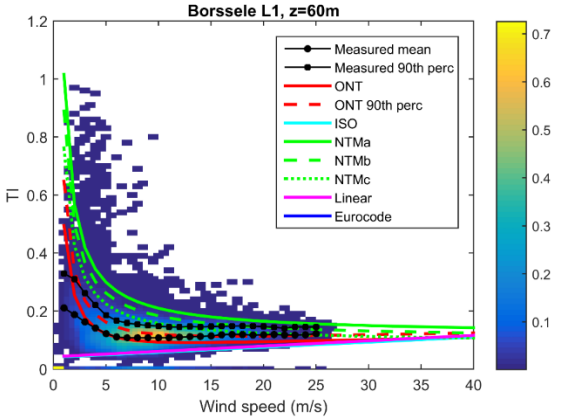
Common Parameters:

- Time series
- Rose plots
- Scatter diagrams
- Persistence
- Misalignment
- Astronomical tide
- Weibull parameters
- HT-scatter
- Wind and wave spectra
- Surface maps

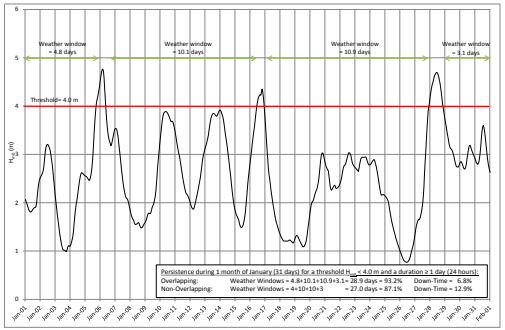
Examples:



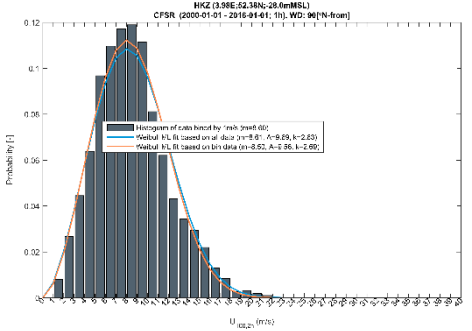
Surface map of HAT



Turbulence intensity



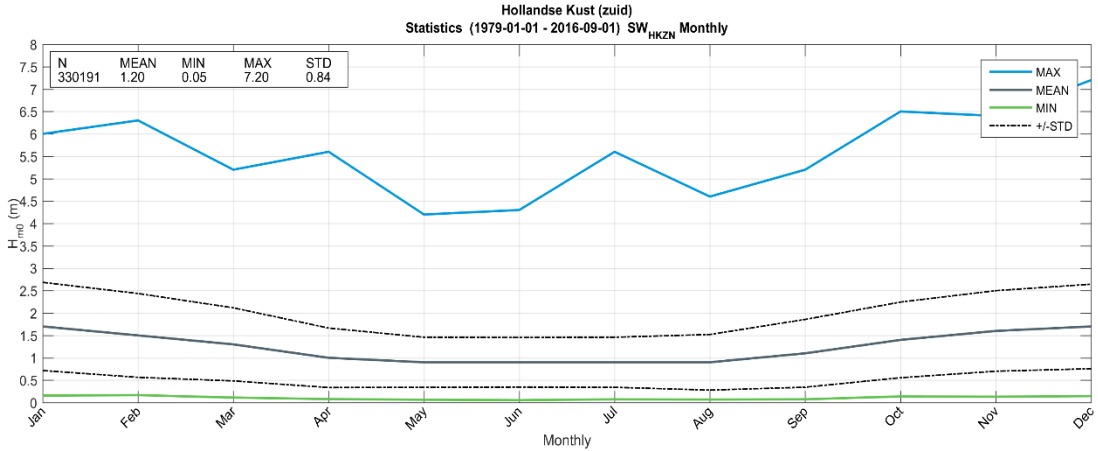
Persistence (weather windows)



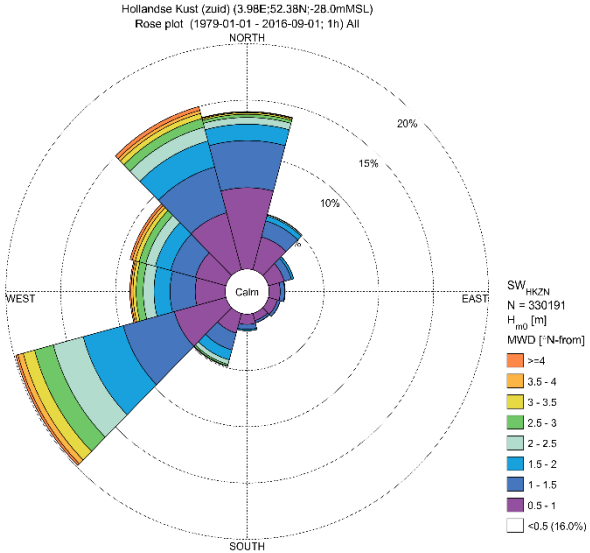
Weibull parameters

Normal Conditions - Summary

Monthly Statistics of Hm0 at Hollandse Kust (zuid)



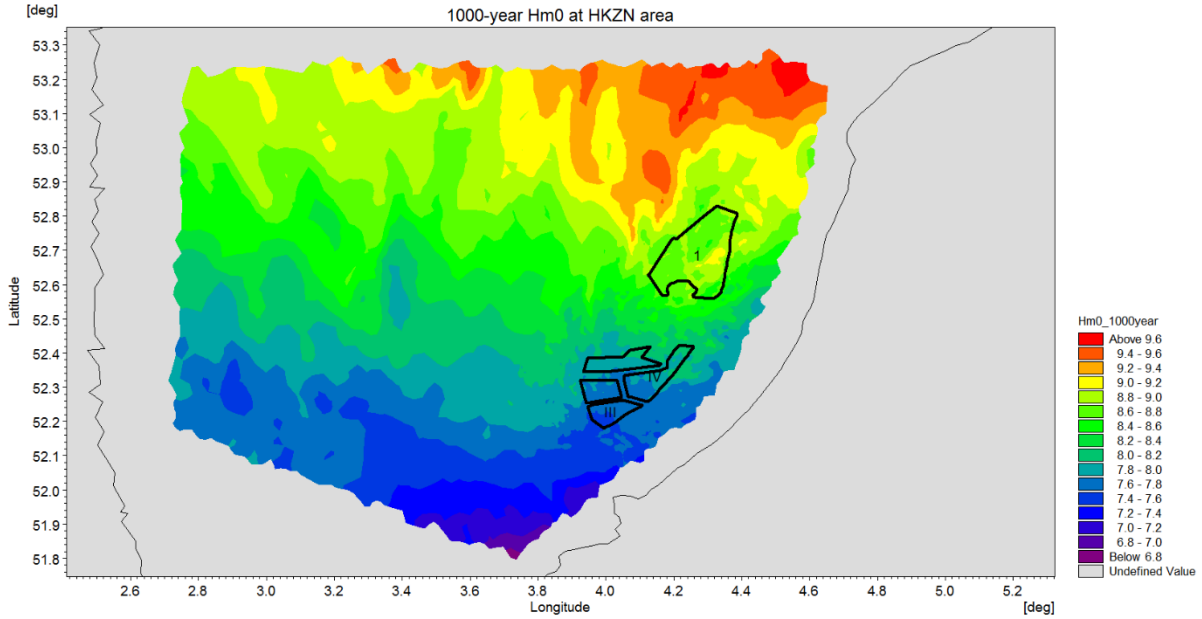
Wave Rose at Hollandse Kust (zuid)



Extreme Conditions

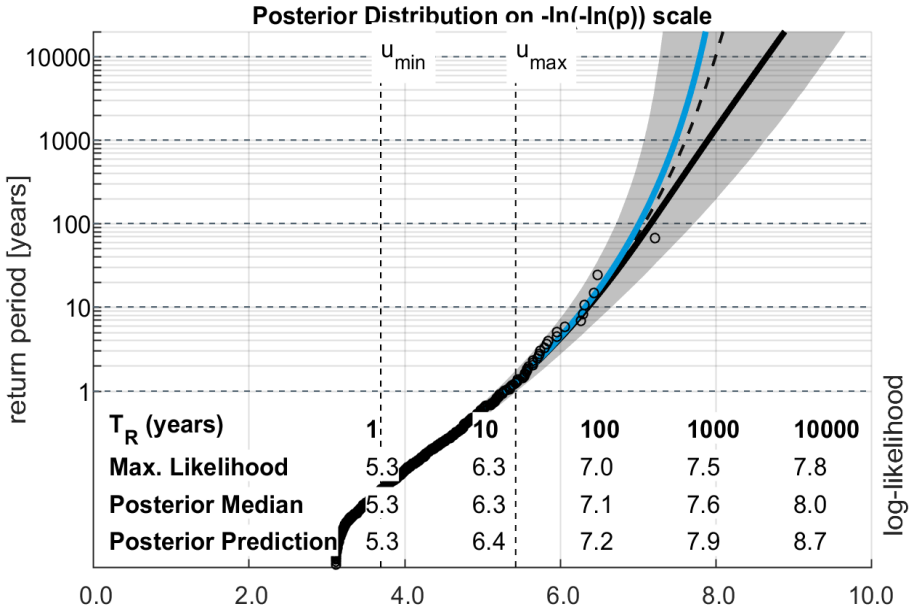
Parameters
Marginal distributions: U10, U100, U125, U150, U200, CS & WL for 1, 2, 5, 10, 50, 100 year return periods
Marginal distributions: Hm0, Hmax & Cmax for 1, 2, 5, 10, 50, 100, 1000 & 10000 year return periods
Omni, monthly & directional extremes – For HWL and LWL conditions
Associated parameters, e.g Tp, T02, THmax
Storm Duration
Surface maps (2D spatial maps)

1,000-year Hm0 in HKZN area



Extreme value analysis methodology

- Directional basis EVA
- Deriving the omni-directional extremes from the directional extremes
- Using the advance Markov Chain Monte Carlo analysis (MCMC) to derive reliable 1,000 and 10,000 year extremes
- Optimizing the directional values to keep the overall failure probability (based on DNV guideline)
- Values are fit for purpose and can be directly used for design



Extreme distribution of Hm0 at HKZ derived from MCMC method

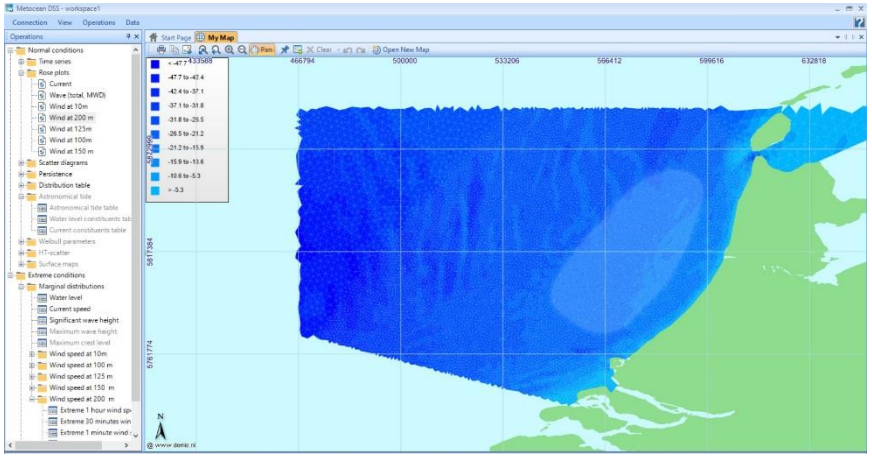
Digital MetOcean Database

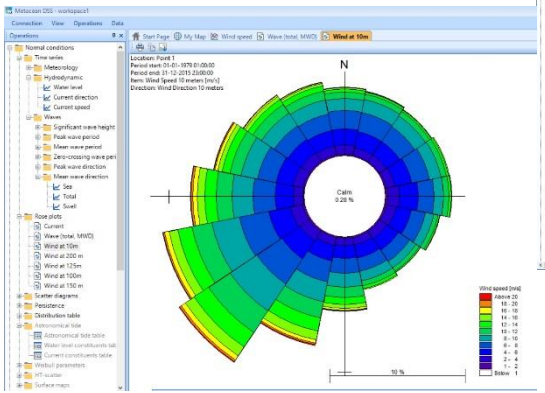
Based on MIKE OPERATIONS

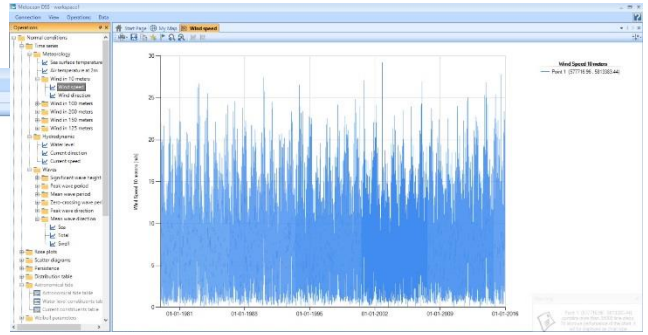
MIKE
Powered by DHI

Dedicated GIS based MetOcean Database

- The metocean database is a solution based on the MIKE Operations components
- Huge amount of data (10+ TB) can be handled by the MIKE IPO Mesh Database technology
- The database features are accessed through a GIS-based user interface (desktop application)



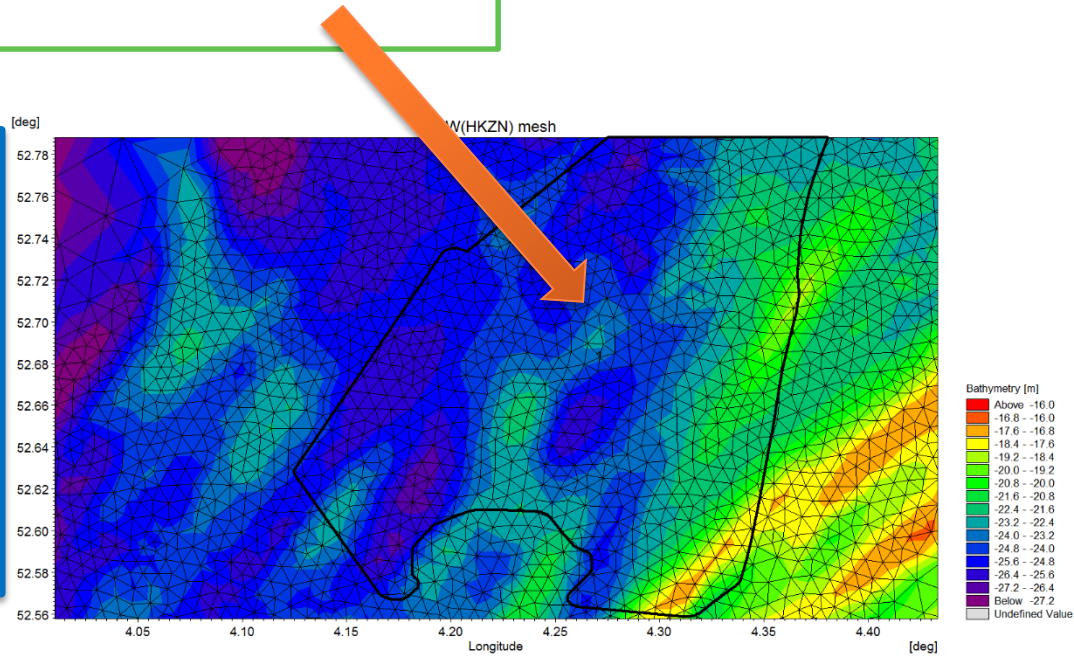




Dedicated GIS based MetOcean Database

Easily accessible data at any point by just a click!

- Normal conditions
- Extreme conditions
- Joint Occurrences
- Data for Design and Operations
- Extract tables, relevant reports etc.
- Extract Time Series, surface maps, etc.
- Access Spectral data



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Thank you!