Temporal and spatial resolution in hindcasts: relevance for offshore wind design work. #Resolution #Fidelity

C2WIND

2018-11-12 VindkraftNet meeting

Areas of Expertise

In this presentation

#BulletPoints<3 #IEC61400-3

Hindcasts = {Reanalysis; Downscaled Reanalysis (for ex using WRF)}

Resolution and Fidelity, relevance for*:

- Normal Wind Conditions
- Normal Sea State

} Fatigue Loads

- Extreme Sea State
- Severe Sea State

} Extreme Loads (for ex: 1/50 annual probability)

*foundation design; IEC61400-3 terminology

Main topic for discussion

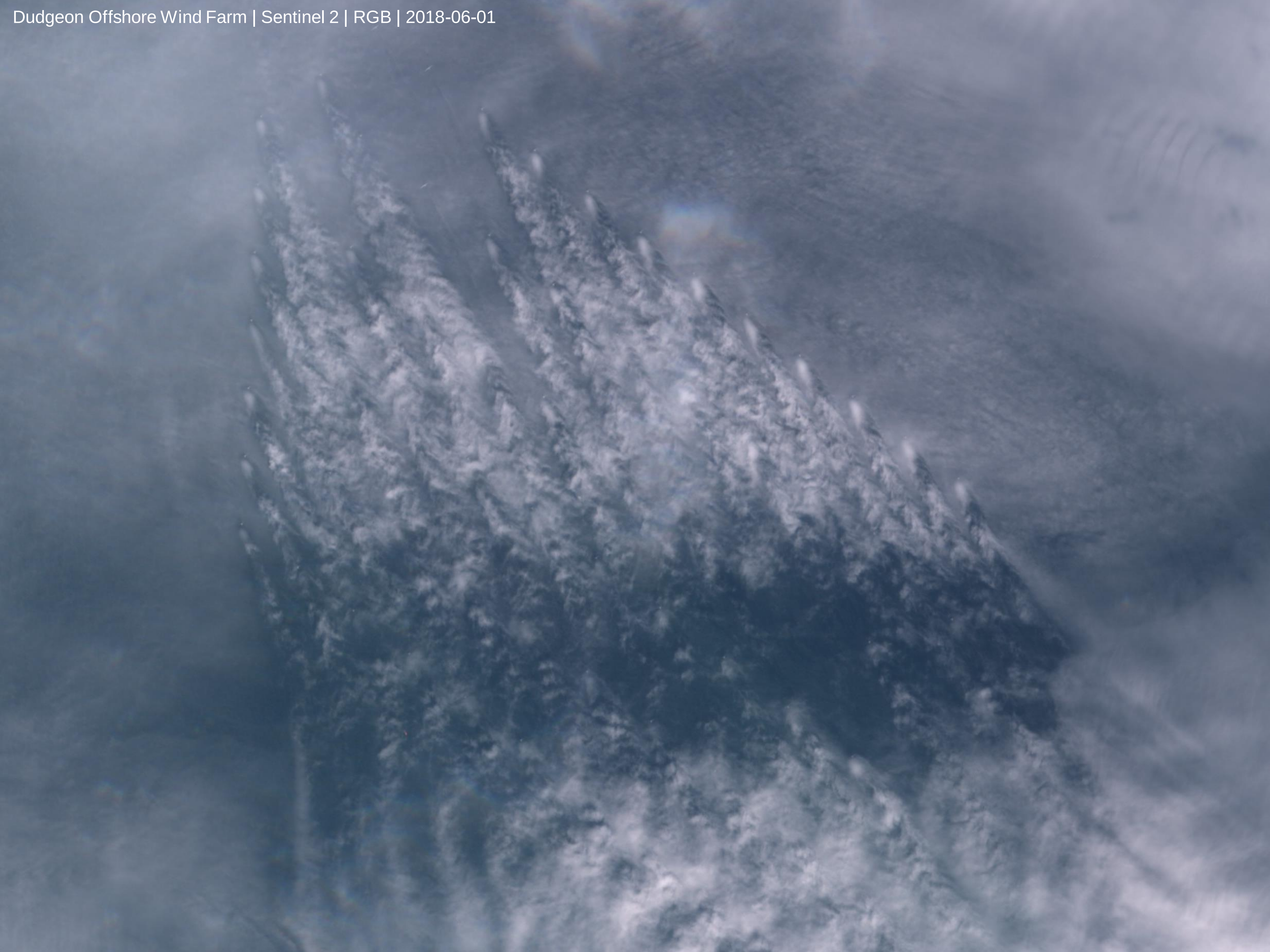
#BulletPoints<3 #IEC61400-3

Trivial to say it: wind, waves, water level and currents vary in time and space, with scales covering several orders of magnitudes.

We typically have, at hand for design work, a variety of wind information:

- ➢ What datasets for what type of analysis ?
- ➢ How do they fit together in the Design Basis ?

Source	Spatial resolution		Temporal resolution			
	Horiz.	Vert.	Averaging.	Frequency (step)	Sampling.	Length.
Cup measurements.	1 m	1 m	10 min	1 s	10 min	1 year
LiDAR measurements.	10 m	10 m	10 min	1 s	10 min	1 year
Mesoscale models	1 km	10 m	10min to 1h	1-10s	1 h	10 year
Reanalysis models	10 km	100 m	1 h	1 min	1 h	10-100 year


Dudgeon Offshore Wind Farm | Sentinel 2 | RGB | 2018-06-01

Hindcasts: Reanalysis

#Plethora #Free #GladeUsers

Global.

Atmosphere/Ocean.

Datasets.

~10-100km
Surface + ~100m AGL

1-12 hours.

10-100+ years.

Free.

Hindcasts: Downscaled Reanalysis

#ModelsNestedInModelsNestedInModels

Mesoscale Models

Atmosphere.

Use Reanalysis as input.
Refined landuse/orography.

1-10 km
Surface + [10,20,…,250

Hourly.

10-30 years.

Commercial product.

RUNE project, DTU Wind Energy, Final Report. Chapter 3.

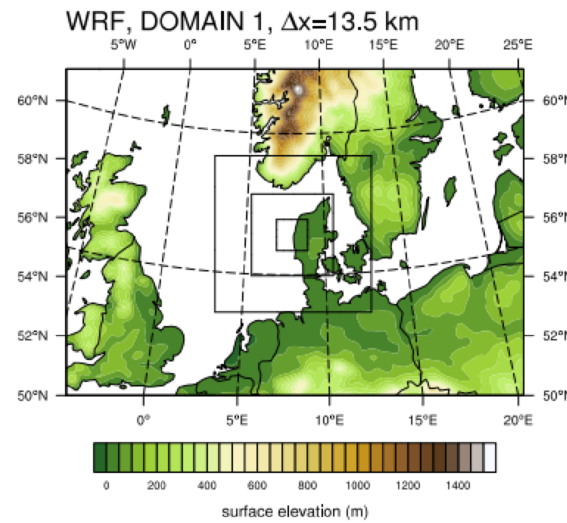


Figure 3. Surface elevation (m) of the outer domain with the location four nested model domains indicated.

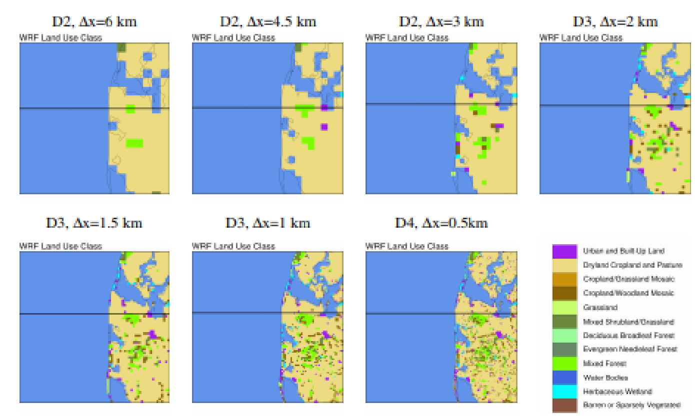
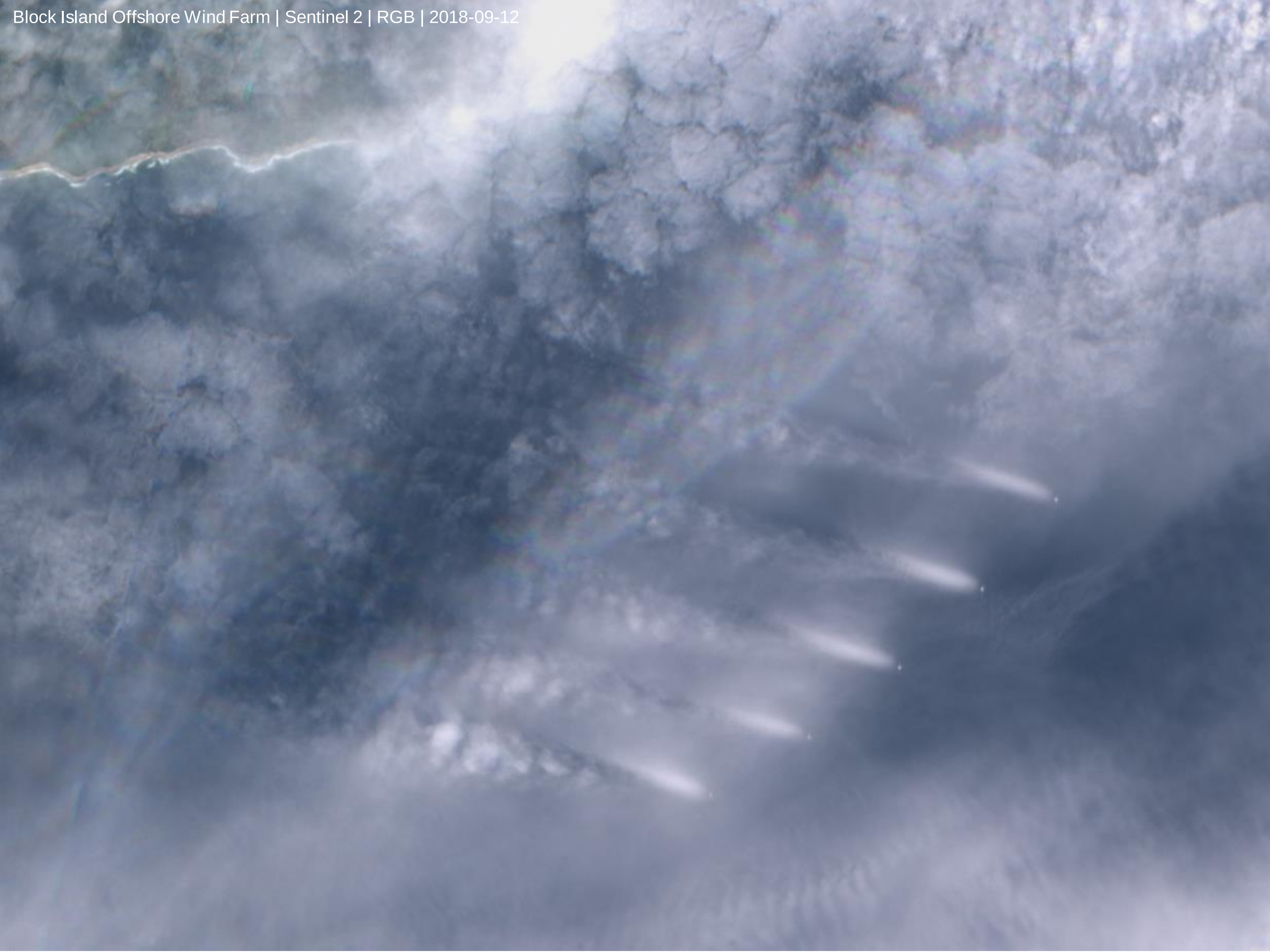


Figure 4. Land use classes derived from the CORINE dataset in the region of the fourth domain. The solid line shows the location of the cross section analyzed in Sec. 6.3.


Block Island Offshore Wind Farm | Sentinel 2 | RGB | 2018-09-12

Normal Wind Conditions

Normal Wind Conditions = Wind distribution + Shear exponent + Free Stream *TI*

Not in this presentation.

State of the Art:

measurements

+ long-term correction (reanalysis/mesoscale)

+ spatial extrapolation.

Typical problem:

- I have some long-term corrected wind distribution at height *h* at location *A*, while the wind farm is at location *B*.
- I can choose between several model products, for ex:
  - A map over average 20-years wind speeds, at *h*, which covers *A* and *B*.
  - A time series at location *A*, and one at location *B.*
- The spatial resolution of both products vary between the suppliers.
- What product should I choose ?

Normal Wind Conditions

#WindResourceAssessmentIsLaw

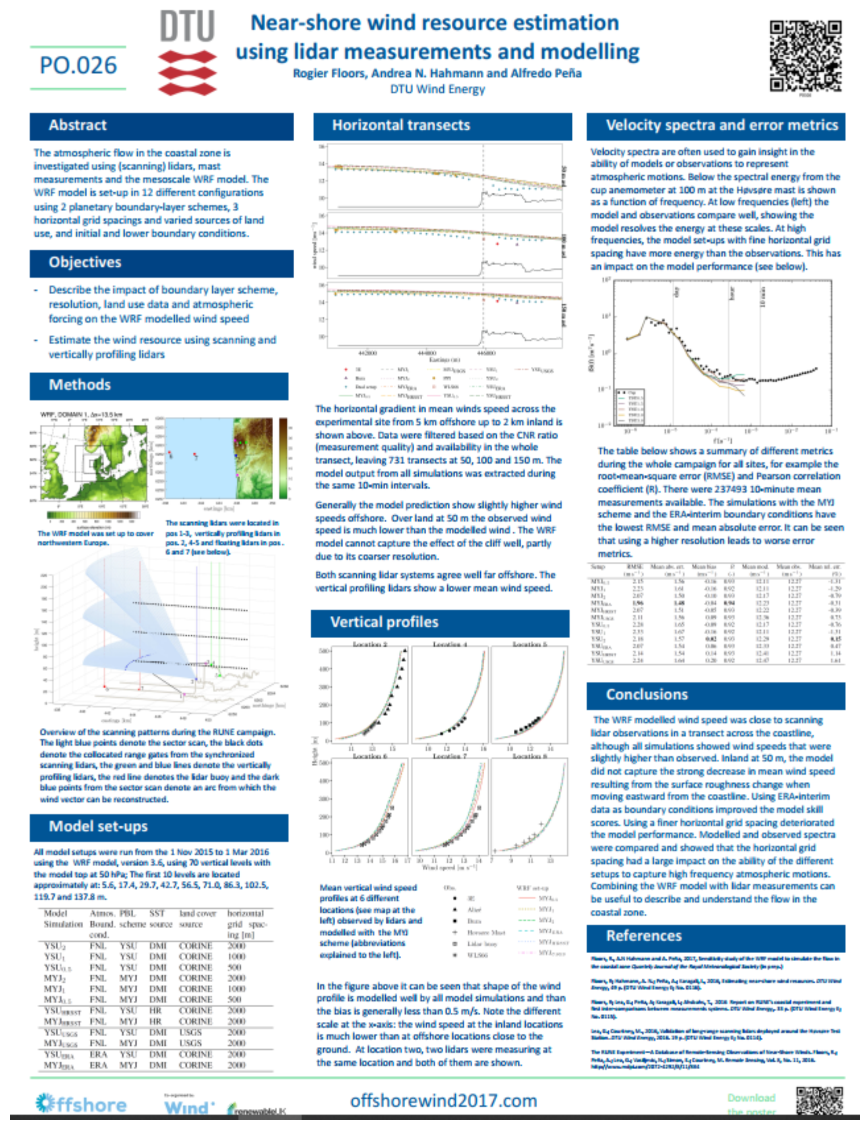
For design of foundations, the mean wind conditions + shear are of lesser importance compared to the wave conditions and park *TI*. The accuracy demand is less than that of wind resource assessment.

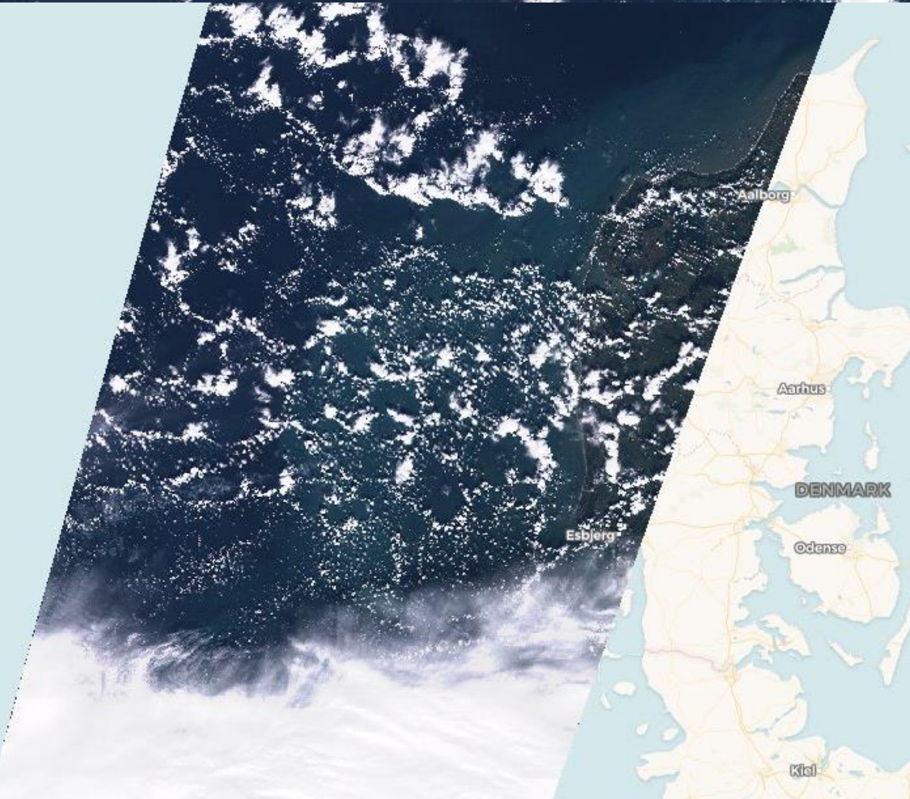
Typically: Normal Wind Conditions are taken from Wind Resource study.

Yet, it is important to capture correctly:

- the wind rose
- bi-modal distributions
- shear exponent [0.2Vref; 0.4Vref]

Reminder: from literature (and from experience), mesoscale model fidelity can decrease when the resolution increases.

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Esbjerg
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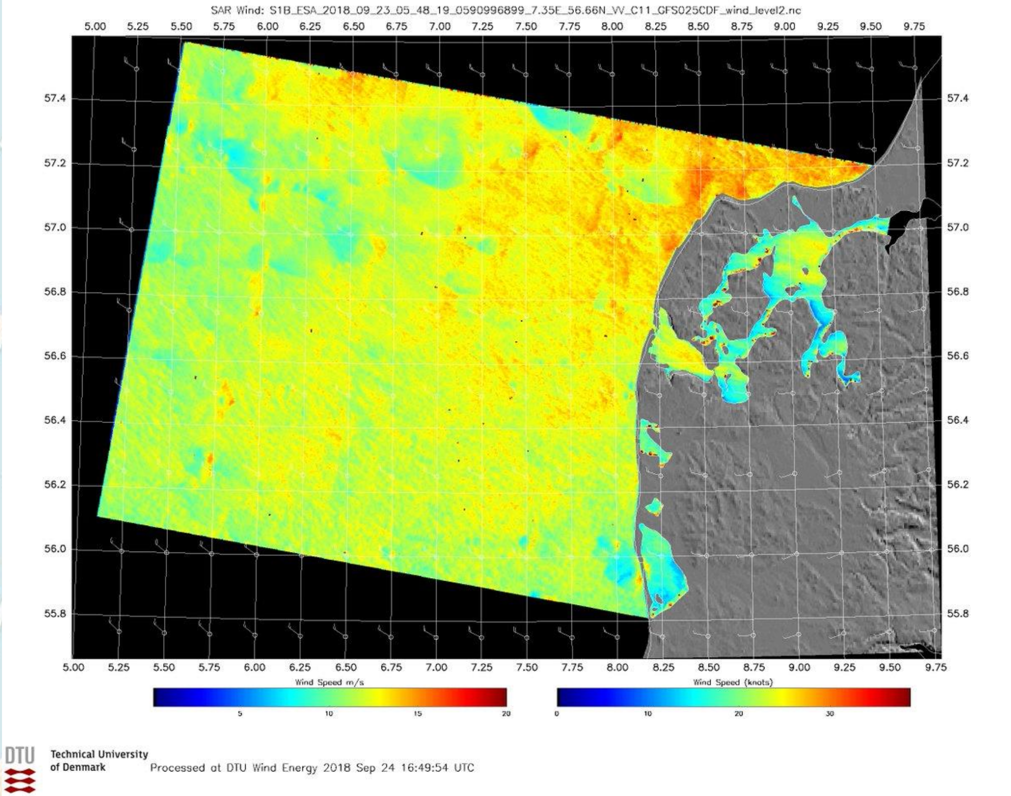
Kiel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57.4 57.2 57.0 56.8 56.6 56.4 56.2 56.0 55.8
Wind Speed m/s
5 10 15 20
Wind Speed (knots)
0 10 20 30
DTU
Technical University of Denmark
Processed at DTU Wind Energy 2018 Sep 24 16:49:54 UTC

Normal Sea State

#OneOutOf50,000

For one load calculation (wtg + fou):

Wind Speed, shear, *TI* (10-minute)

Wave Height and Period -> Wave spectrum (typically 3-hours)

Wind Direction and Wave Direction

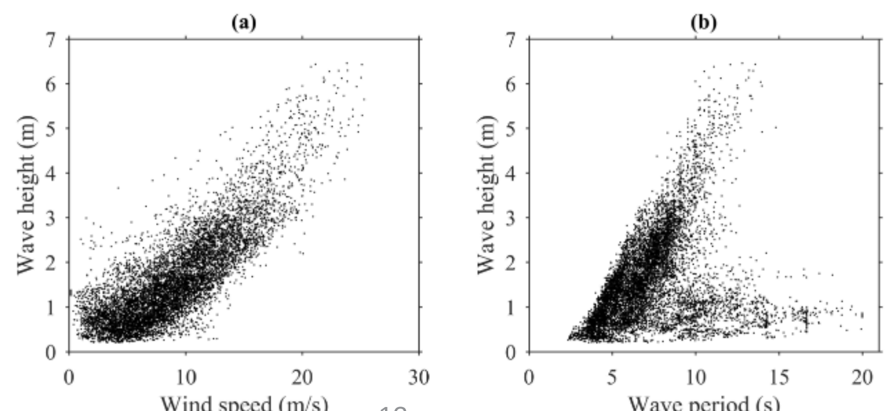
State of the Art for parametrisation of sea state: use of spectral wave model driven by a reanalysis dataset (at 10mMSL).

Article | Full-text available

Probabilistic Forecasting of Wave Height for Offshore Wind Turbine Maintenance

January 2018 · European Journal of Operational Research
DOI: 10.1016/j.ejor.2017.12.021

Fig. 4. (a) Scatter plot of wave height and wind speed. (b) Scatter plot of wave height and period.



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Normal Sea State

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How do 10mMSL extrapolated 10-minute measurements compare with 1-hour reanalysis data ?

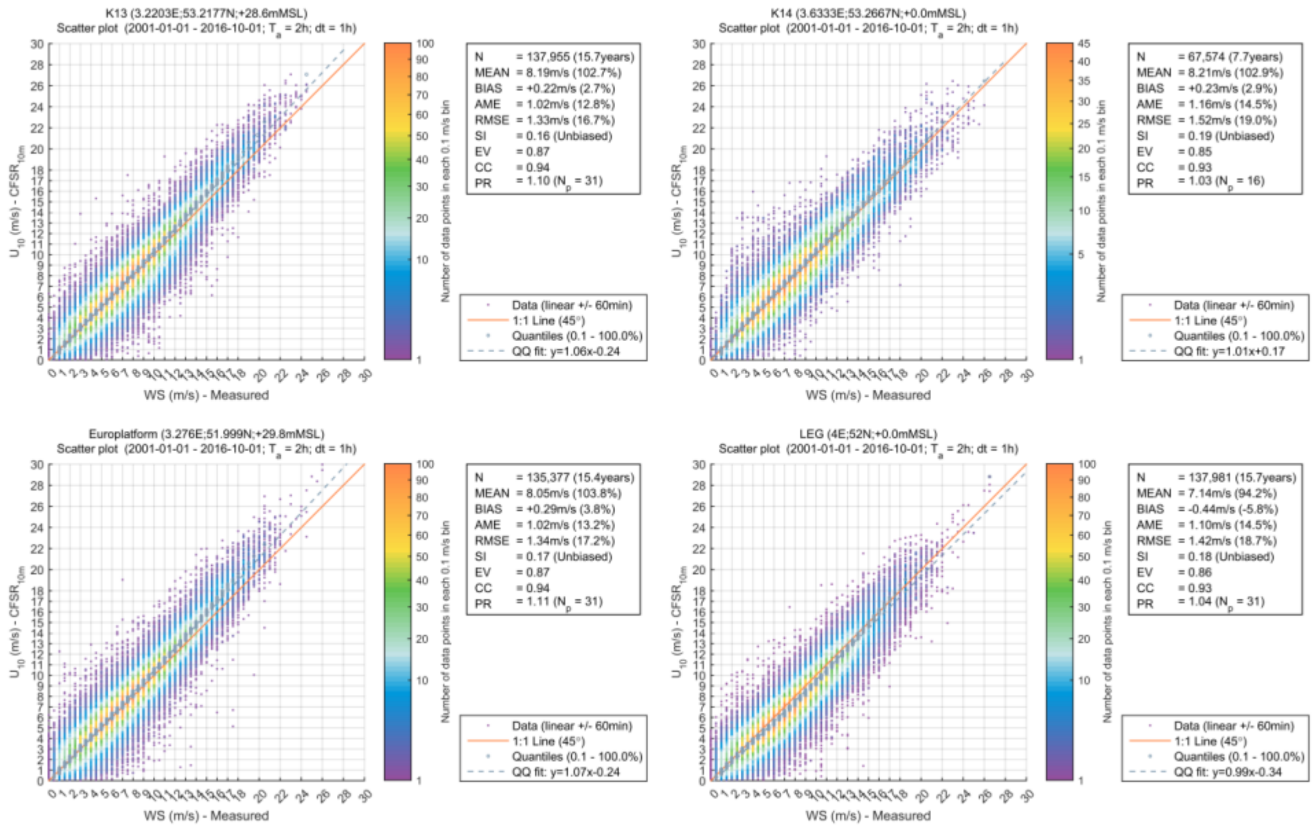

Figure 3.16 Scatter comparison of measured and CFSR wind speeds at K13, K14, Europlatform and LEG (left to right and top to bottom). Based on CFSR U_{10} data

Normal Sea State

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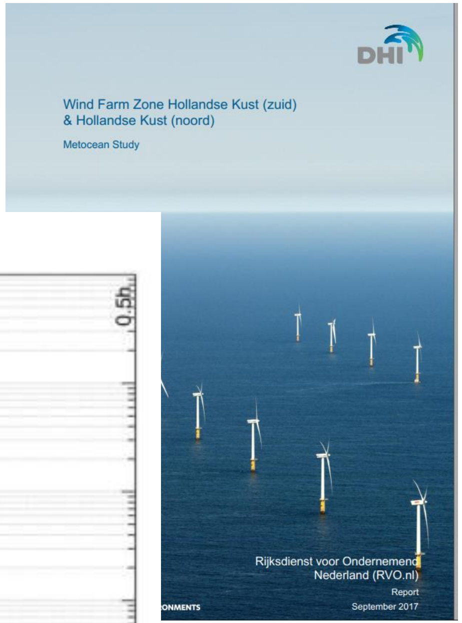
How do 10mMSL extrapolated 10-minute measurements compare with 1-hour reanalysis data ?



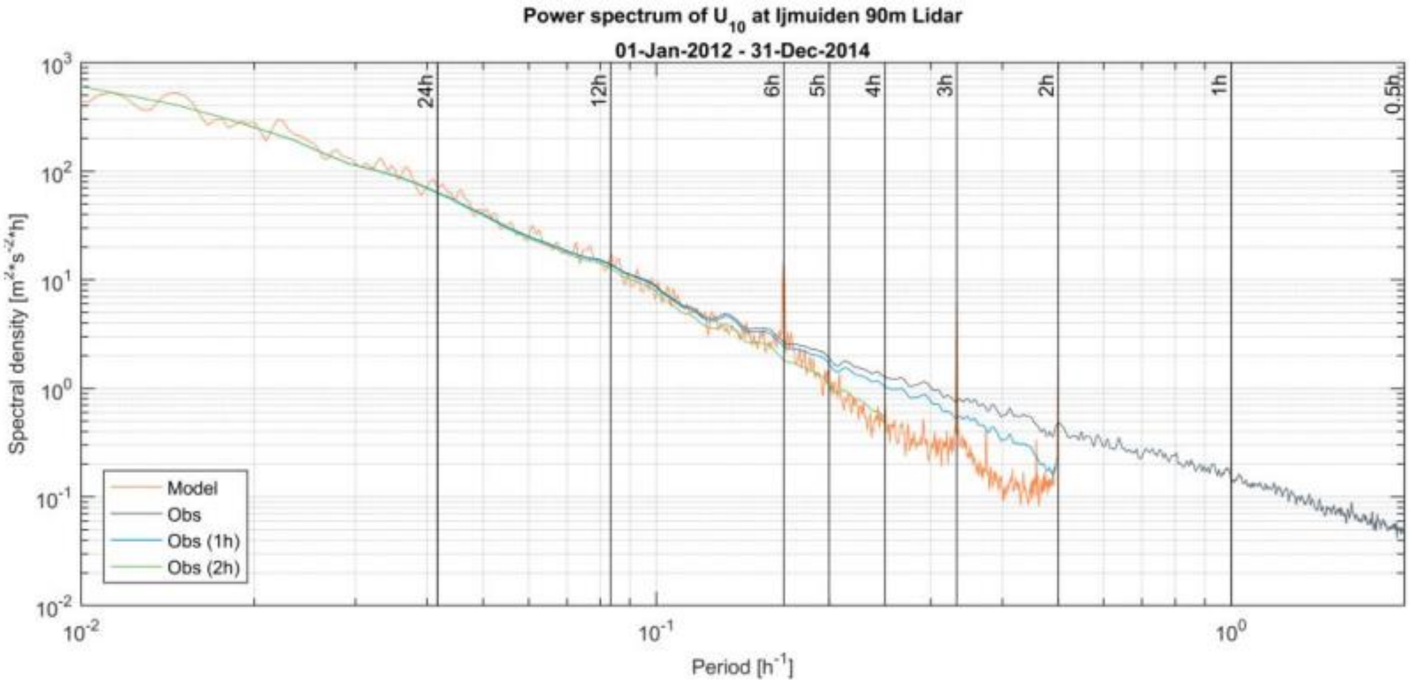


Figure 3.13 Frequency power spectrum of U_{10} at MM Ijmuiden

Normal Sea State

We now have two wind datasets, that need be used for design:

- The Normal Wind Conditions at hub height: meso- to micro scale information.
- The wind field used for driving the spectral wave model: synoptic wind information.

Method:

1) When both wind distributions can be fitted using Weibull: scale the reanalysis wind field so that it matches the one from the wind resource.
2) Derive wind/wave correlation using wind time series from 1).

In effect, the wind speed time series used for deriving the correlation has a much lower fidelity than the one from the wind resource. However, this is usually acceptable as the most important is to preserve the correlation between wind and waves.

Caveats:

- What if the distributions are not well represented by Weibull ?
- What if the wind roses show a significant difference ?
- What id the hub height is only mildly correlated with the surface wind ?
- Generally: the low-fidelity of the scaled reanalysis time series.

Normal Sea State

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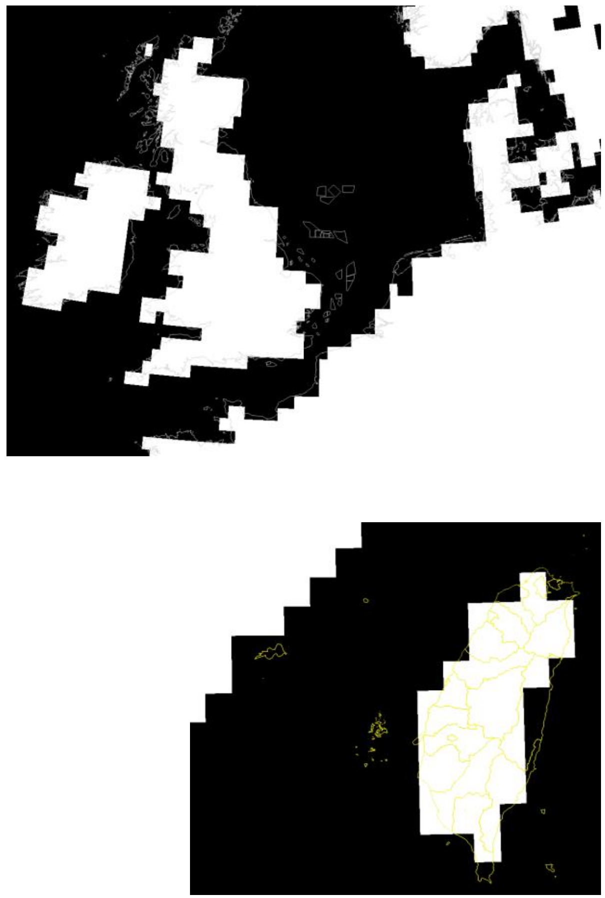
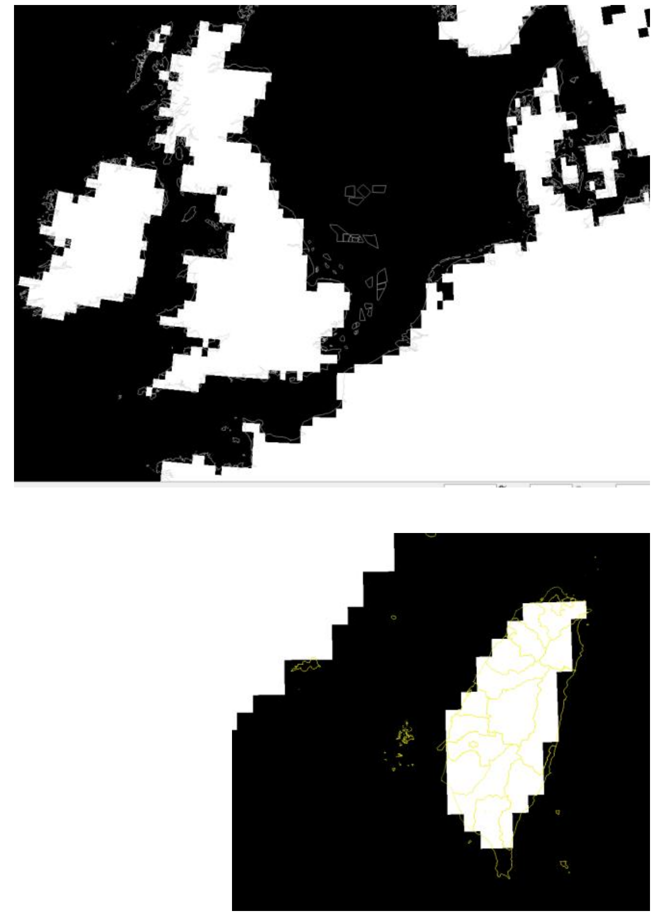
Note on the importance of the landmask spatial resolution of the reanalysis dataset:



CSFR



CSFR v2

Normal Sea State

#ERA5vsCFSR

Caveats:

- What if the distributions are not well represented by Weibull ?
- What if the wind roses show a significant difference ?
- Generally: the low-fidelity of the scaled reanalysis time series, for any other use..

So how could this be improved ? By driving the wave model with a wind dataset which contains both an good fidelity 10m and 100m wind. For instance:

- The best-reanalysis-dataset-ever-so-far: ERA5. It contains both a quality 10m and a quality 100m wind time series that require less adjustments than other reanalysis.
- Or, use a mesoscale model (WRF) wind dataset to drive the spectral wave model.

Caveats:

- Need make sure that there is no loss of fidelity of the wave model (!). Only part of the wave spectrum is driven by local winds, therefore wave model nesting is crucial for success. Calibration is always expected in any case.
- With WRF: one mesoscale time series is (of course) not enough. Large custom-made domains are needed. Therefore this is a more expensive option.

Normal Sea State

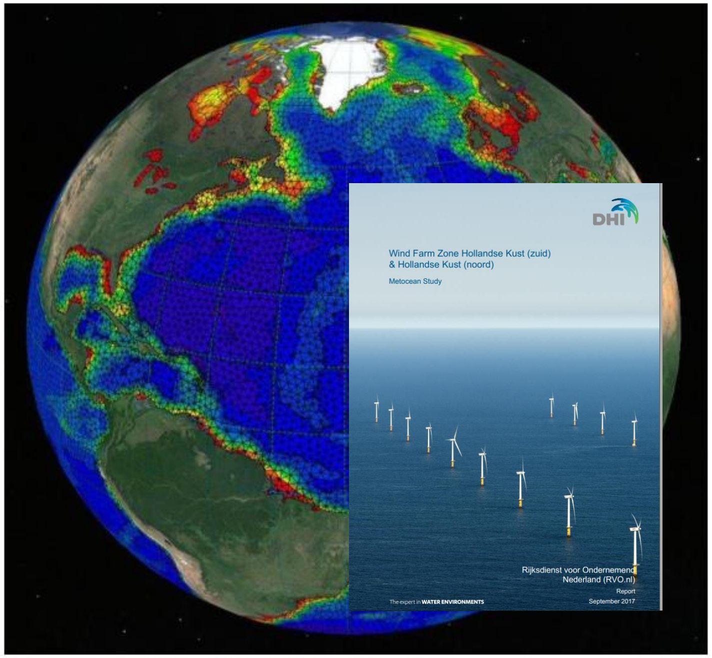


Figure 5.1 Computational mesh of DHI's Global Wave Model (GWMv3)

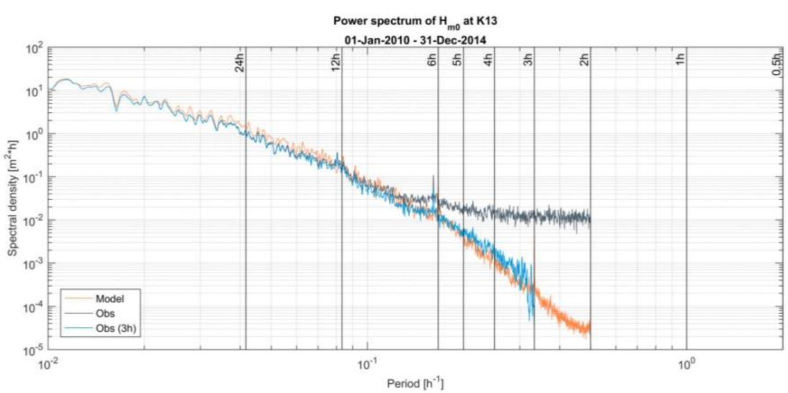


Figure 5.26 H_{m0} power spectra comparison at K13 for model and observations with different window averaging

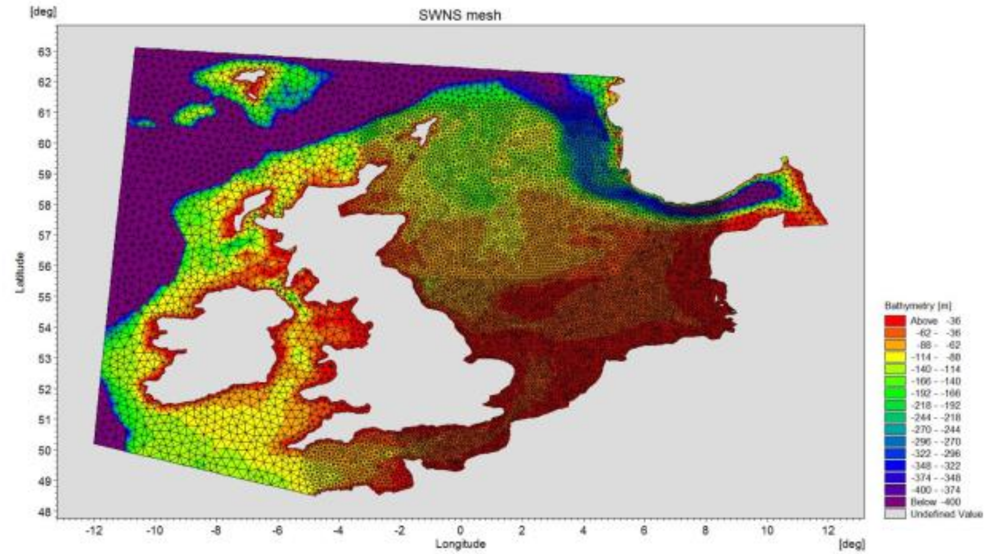


Figure 5.4 Domain of the regional DHI North Sea wave model, SW_{NS}

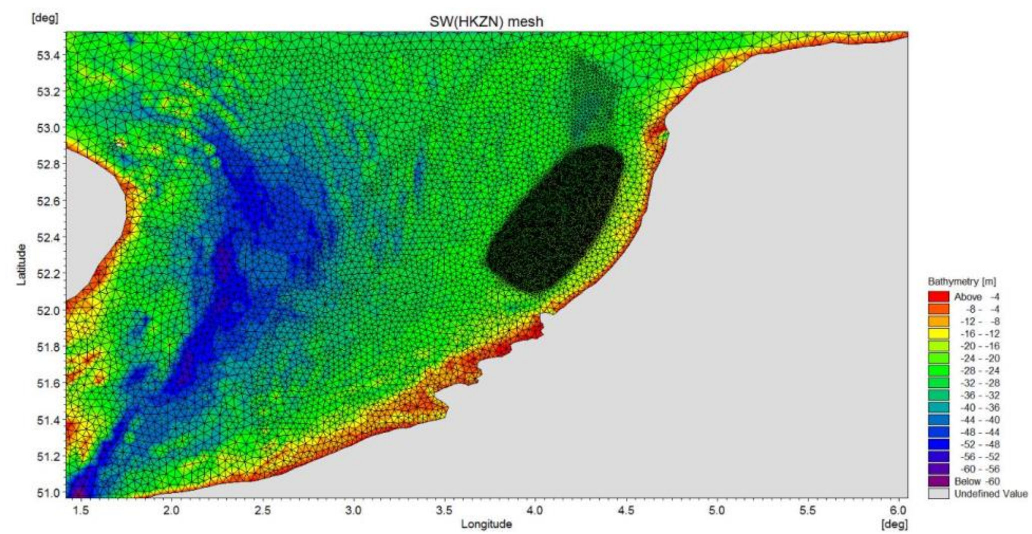


Figure 5.35 Zoom at the HK area from the local mesh

Block Island Offshore Wind Farm | Sentinel 2 | RGB | 2018-08-03

Extreme Sea State

Assessment of extreme loads from wind and waves. Here, extreme 10-minute wind speed need be combined with extreme 3-hour seastate. Reanalysis data is not an option for assessing the 10-minute extreme wind.

Extreme wind estimate can be made using WRF, but the results need be corrected. Here again, increasing the spatial resolution may not help.

Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Extreme Winds in the New European Wind Atlas

To cite this article: David Bastine *et al* 2018 *J. Phys.: Conf. Ser.* **1102** 012006

View the article online for updates and enhancements.

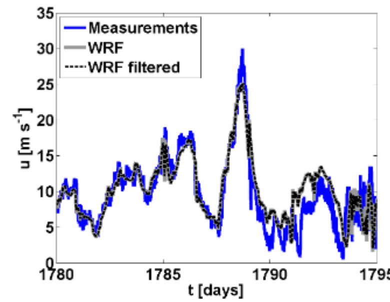


Figure 2. Wind speed time series at the location of FINO1.

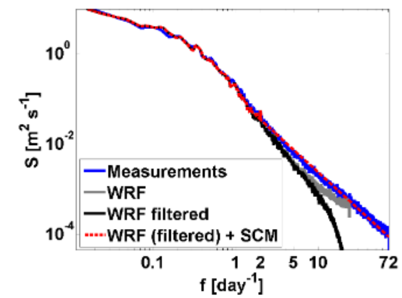


Figure 3. PSD of measurements (blue) and simulations (gray) and filtered simulations (black). The red dashed line shows the corrected PSD based on the filtered spectrum.

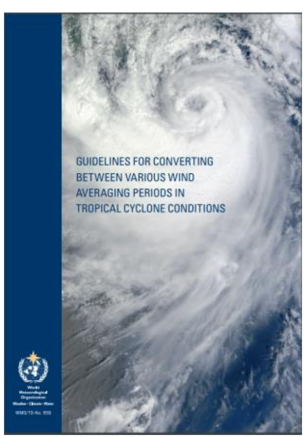


Table 1.1 Recommended wind speed conversion factors for tropical cyclone conditions.

Exposure at +10 m: Class	Description	Reference Period T_o (s)	Gust Factor $G_{\tau,To}$ — Gust Duration τ (s): 3	60	120	180	600
In-Land	Roughly open terrain	3600	1.75	1.28	1.19	1.15	1.08
		600	1.66	1.21	1.12	1.09	1.00
		180	1.58	1.15	1.07	1.00	
		120	1.55	1.13	1.00		
		60	1.49	1.00			
Off-Land	Offshore winds at a coastline	3600	1.60	1.22	1.15	1.12	1.06
		600	1.52	1.16	1.09	1.06	1.00
		180	1.44	1.10	1.04	1.00	
		120	1.42	1.08	1.00		
		60	1.36	1.00			
Off-Sea	Onshore winds at a coastline	3600	1.45	1.17	1.11	1.09	1.05
		600	1.38	1.11	1.05	1.03	1.00
		180	1.31	1.05	1.00	1.00	
		120	1.28	1.03	1.00		
		60	1.23	1.00			
At-Sea	> 20 km offshore	3600	1.30	1.11	1.07	1.06	1.03
		600	1.23	1.05	1.02	1.00	1.00
		180	1.17	1.00	1.00	1.00	
		120	1.15	1.00	1.00		
		60	1.11	1.00			

?

Annual average max. [$m\,s^{-1}$]	FINO1	FINO2	FINO3	Cabauw
WRF	27.8 ± 0.6	26.2 ± 0.6	27.4 ± 0.6	20.8 ± 0.4
WRF + SCM	30.0 ± 0.7	28.3 ± 0.7	29.6 ± 0.6	22.3 ± 0.4
Measurements	30.7 ± 1.1	28.4 ± 0.8	30.8 ± 1.0	24.4 ± 1.1
50-year wind [$m\,s^{-1}$]				
WRF	32.8 ± 2.3	31.6 ± 2.3	32.2 ± 2.2	24.3 ± 1.5
WRF + SCM	35.9 ± 2.5	34.8 ± 2.5	34.7 ± 2.3	26.1 ± 1.6
Measurements	39.3 ± 3.6	35.3 ± 3.0	38.5 ± 3.5	34.0 ± 3.9

Table 2. Extreme wind speeds: Estimates of average annual maxima and 50-year winds for measurements, WRF simulations and the corresponding corrected value. The statistical uncertainties are denoted as one standard deviation.

	FINO1	FINO2	FINO3	Cabauw
WRF + SCM (Correction factor)	1.08	1.08	1.08	1.07
Annual average maxima (Measurements/WRF)	1.10	1.08	1.12	1.17
50-year wind (Measurements/WRF)	1.20	1.12	1.20	1.38

Table 3. Estimated correction factors and ratios of measured and simulated extreme winds.

Extreme Sea State

9.2 Offline CFSR-MIKE modeling 15 storms: assessment of CFSR wind forcing

The calibrated MIKE 21 SW model was also forced with the global CFSR wind field (corrected for atmospheric stability, see section 5.5.1) for the 15 calibration storms. The results are presented in the following sections. It should be noted that the wave model was calibrated to the WRF wind field (see section 5.6) and not the CFSR wind field, however a comparison was still made to assess the impact of the different wind fields.

The results from the model test are presented in Fig. 49 to 50. The significant wave height produced from the CFSR wind field forced MIKE 21 SW model produced a reasonable representation of the observations for the North Sea and western Danish Coastline. From the Taylor diagrams on the left hand side of Fig. 50 and Fig. 51, a comparison to the final calibration of the WRF forced model can be made. Of these stations, neither the CFSR or WRF forced wave model is suggested to outperform the other. Note that the full storm list cannot be compared as CFSR forced model was only run for the 15 calibration storms, and thus comparisons are limited, however with these results there is no strong evidence of significant differences on wave modelling when using CFSR reanalysis or WRF downscaling.

Technical University of Denmark

X-WIWA

ABOUT X-WIWA | PARTNERS | PUBLICATIONS | DATA | MAIN RESULTS

Home › Publications › Project report

- Conference papers
- Journal papers
- PhD and Master theses
- The modeling system
- Project report

Project report

The project has delivered all planned deliverables in time. Though some of the planed deliverables have been merged into one due to the overlapping content and relevance between them. All deliverables have been presented to energinet.dk in Interim report format. The following list is an overview of the deliverables with the references included.

D1.1: The offline coupling system and the online coupling system (Interim report I \ Only the technical reports in the original Interim report are provided. The description of the work progress and financial budget as in the original report can be found with energinet.dk)

D1.2: Implementation of wave stress in the atmospheric model WRF (Access Interim report V here)

D1.3: MIKE 3 coupling added value (Access Interim report VI here)

D1.4+D1.9: Database of simulated storms. (Available at www.xwiwa.dk/data)

D1.5: Atlas of the 50-year return wind at hub height for the Danish coastal zone. (Available at www.xwiwa.dk/data)

D1.6: Journal paper about the improved atmospheric modeling of storm cases (Access journals here)

D1.7: Journal paper about the sensitivity of the modeling on the resolution

REPORTS

- Interim report II
- Interim report III
- Interim report IV
- Interim report V
- Interim report VI
- Interim report VII
- Final project report

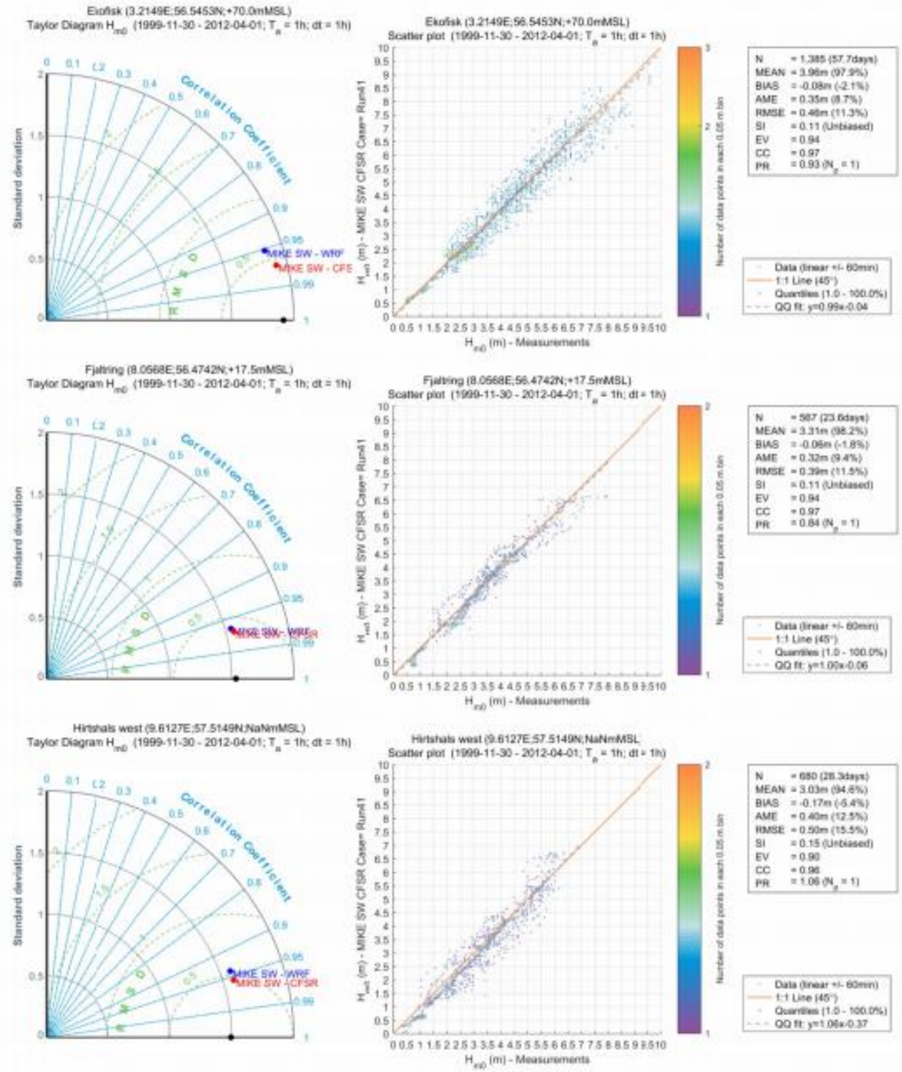


Figure 49: Comparison between WRF-MIKE and CFSR-MIKE over 15 storms. A statistical representation of significant wave height (H_{m0}) at Ekofisk (upper panels), Fjaltering (middle panels) and Hirtshals West (lower panels) for the two offline MIKE 21 SW model with WRF (blue) and CFSR (red) wind forcing through a Taylor Diagram (left panel). The black point represents the observations. Scatter plot of the modelled significant wave height with forcing from the global CFSR wind field for the 15 calibration storms between Nov-1999 and Apr-2012 (right panel, corresponding to red point in Taylor diagram).

Severe Sea State

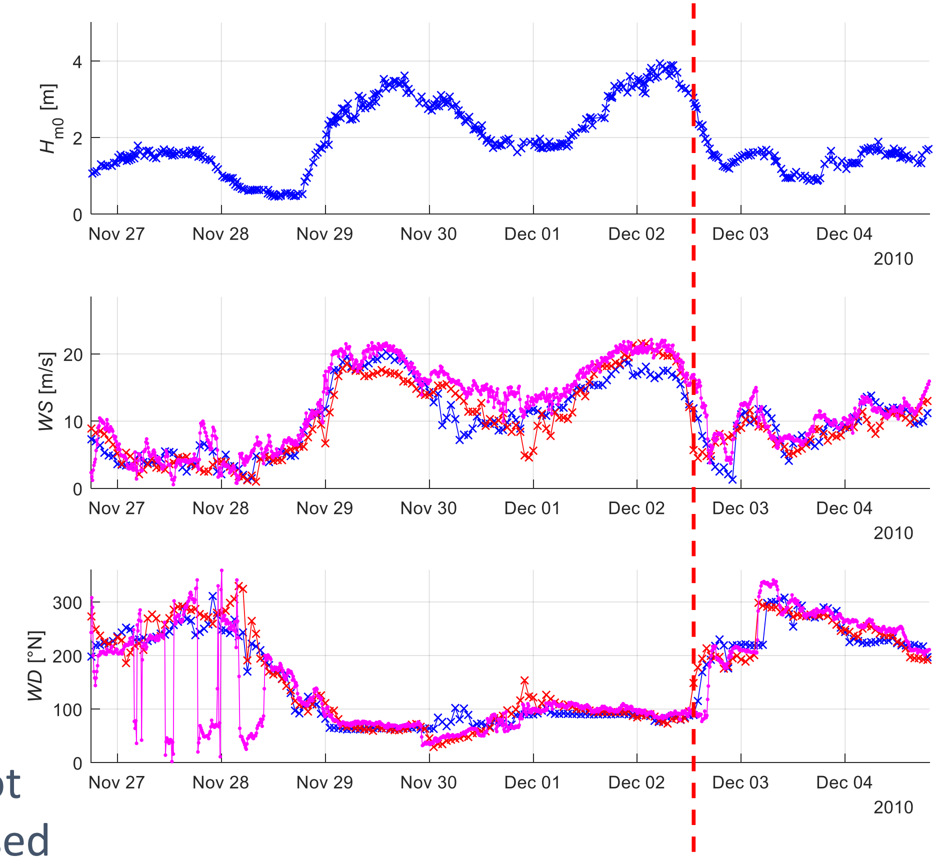
#

Here, we estimate, for normal wind conditions (for instance 6 m/s), what the extreme 3-hour seastate is.

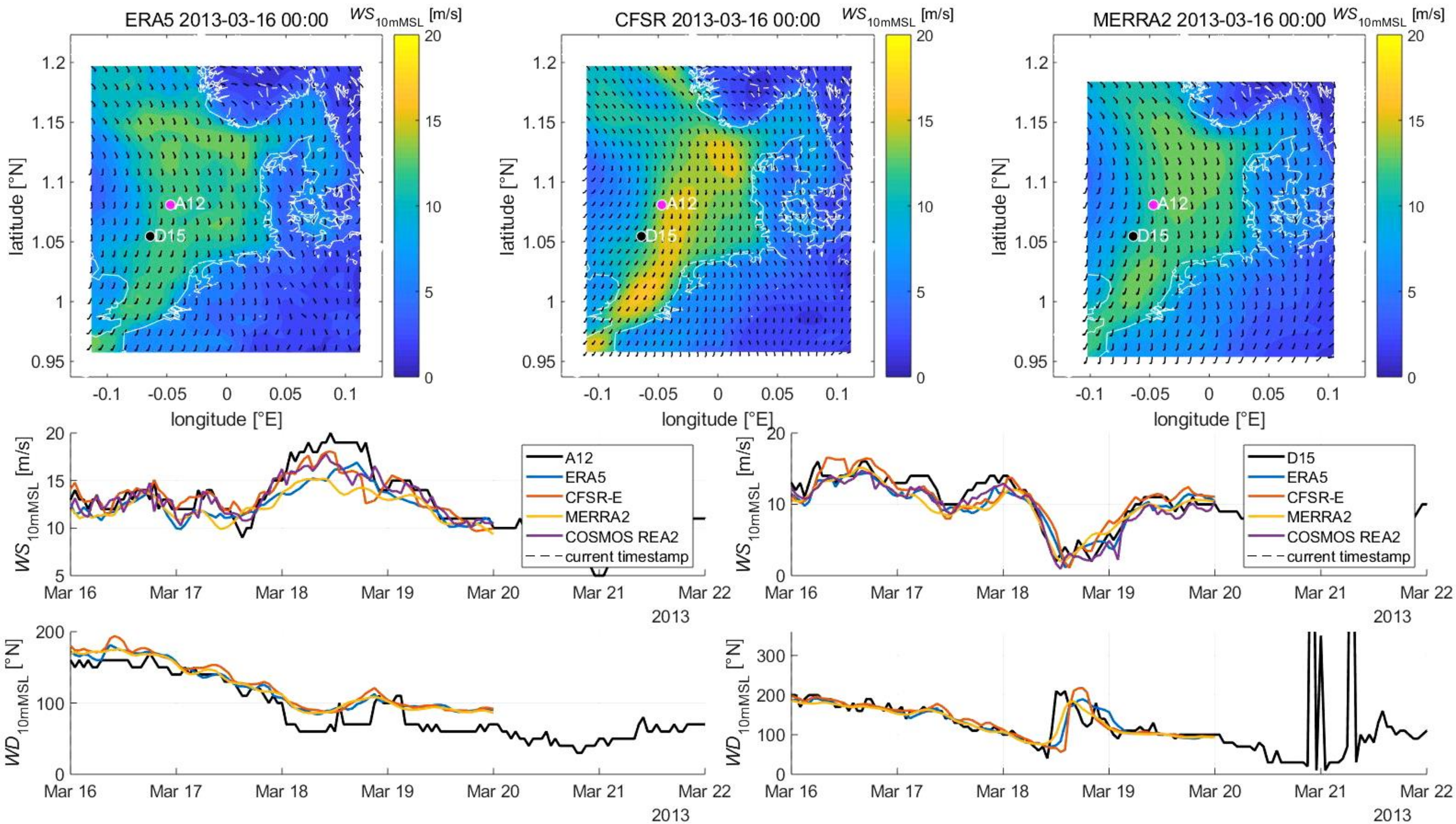
This happens for instance when the wind speed suddenly drops after a long-lasting storm.

Generally well captured by WRF-driven models, and not well captured when using reanalysis datasets.

However, these load cases are generally not design-driving, and they can be characterised conservatively.



A medium storm that is hard to catch



Wrap-up

For Normal Wind Conditions:

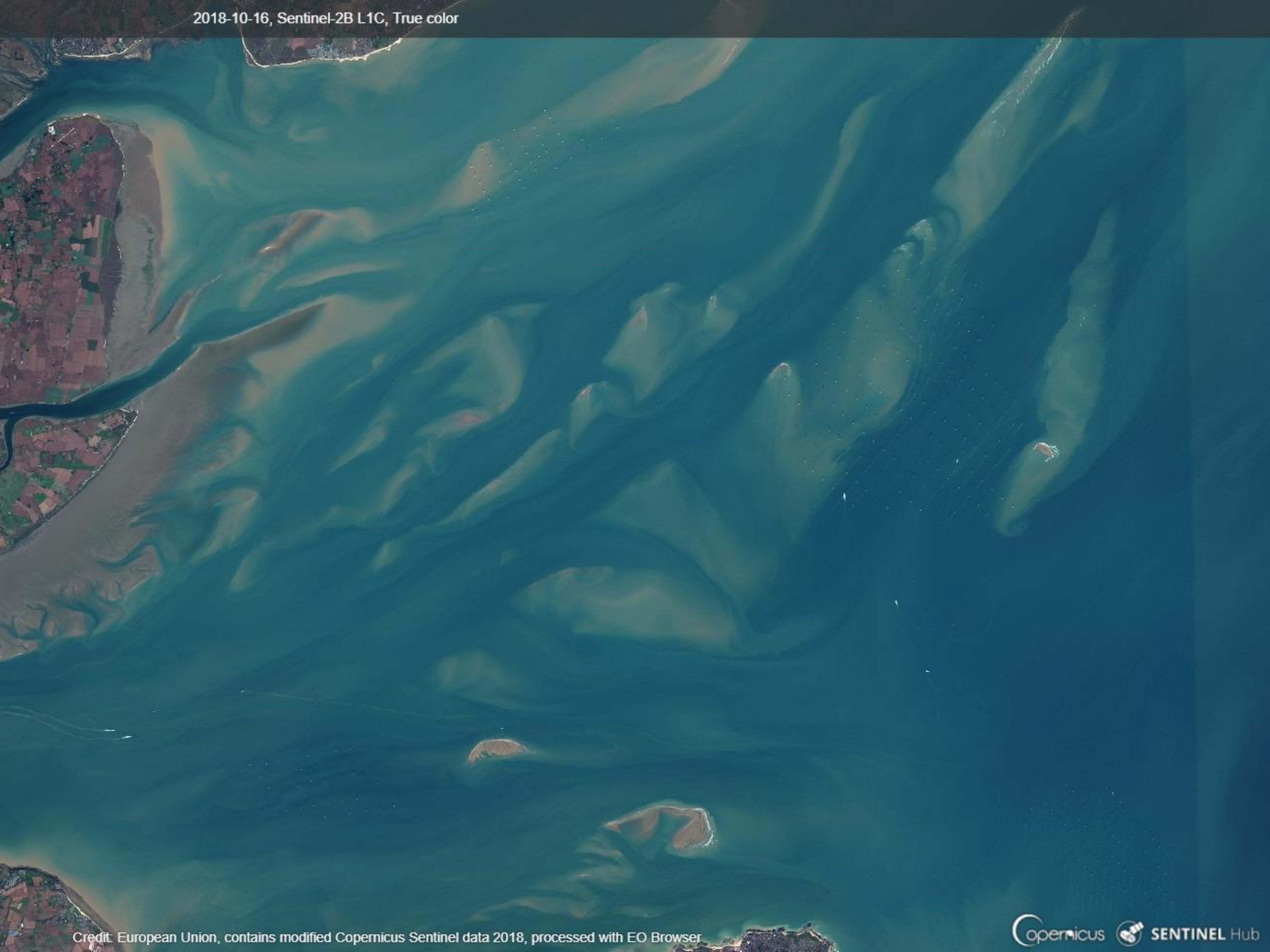
- Best is to rely on detailed wind resource assessment (measurements + mesoscale).
- For that purpose, increased spatial resolution of the mesoscale model is not always key.
- Recommended to focus instead on the parametrisation schemes and the orography/landuse input.
- The model is very likely making an error – need to guess and assess uncertainty.

For Normal Sea State:

- Spectral wave models driven with reanalysis data work satisfactorily.
- Always need to assess effect of land/sea mask.
- Local wave models driven by higher fidelity wind data do not necessarily perform much better, but provide a hub height wind time series that requires only small adjustments -> increased fidelity.

For Extreme and Severe Sea State:

- Advantage in using mesoscale time series compared to reanalysis.
- Yet, the 10-minute extreme wind speed is out of reach for models.



2018-10-16, Sentinel-2B L1C, True color
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