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

- Site Conditions
- Foundation Design
- Integrated Load Analysis
- Project Management
Hindcasts = \{\text{Reanalysis; Downscaled Reanalysis (for ex using WRF)}\}

Resolution and Fidelity, relevance for*:

- Normal Wind Conditions
- Normal Sea State
- Extreme Sea State
- Severe Sea State

\{\text{Fatigue Loads}\}

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

*foundation design; IEC61400-3 terminology
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?

<table>
<thead>
<tr>
<th>Source</th>
<th>Spatial resolution</th>
<th>Temporal resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cup measurements.</td>
<td>1 m</td>
<td>1 m</td>
</tr>
<tr>
<td>LiDAR measurements.</td>
<td>10 m</td>
<td>10 m</td>
</tr>
<tr>
<td>Mesoscale models</td>
<td>1 km</td>
<td>10 m</td>
</tr>
<tr>
<td>Reanalysis models</td>
<td>10 km</td>
<td>100 m</td>
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</tbody>
</table>
Hindcasts: Reanalysis

Global.

Atmosphere/Ocean.

Datasets.

~10-100km
Surface + ~100m AGL

1-12 hours.

10-100+ years.

Free.
Hindcasts: Downscaled Reanalysis

Mesoscale Models

Atmosphere.

Use Reanalysis as input.
Refined landuse/orography.

1-10 km
Surface + [10, 20, ..., 250]

Hourly.

10-30 years.

Commercial product.
Normal Wind Conditions

Normal Wind Conditions = Wind distribution + Shear exponent + Free Stream $T_f$

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?
For design of foundations, the mean wind conditions + shear are of lesser importance compared to the wave conditions and park $T_{1/2}$. 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 [0.2$V_{ref}$; 0.4$V_{ref}$]

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

For one load calculation (wtg + fou):
- Wind Speed, shear, $T_l$ (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).
Normal Sea State

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 U10 data
Normal Sea State

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 if the hub height is only mildly correlated with the surface wind?
➢ Generally: the low-fidelity of the scaled reanalysis time series.
Normal Sea State

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

CSFR

CSFR v2
Normal Sea State

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 a 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 5.4  Domain of the regional DHI North Sea wave model, SWNS

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

Figure 5.35  Zoom at the HK area from the local mesh
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.
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.

Figure 49: Comparison between WRF-MIKE and CFSR-MIKE over 15 storms. A statistical representation of significant wave height ($H_{\text{red}}$) 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.