Memo

To
RVO

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Subject
Hollandse Kust Zuid Wind Farm Zone
Persistance Tables

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1 Introduction

In the Dutch Energy Agreement for Sustainable Growth the goal has been set of having 4,450 MW of offshore wind power capacity operational before 2023. Currently three offshore wind farms are operational. One of the zones to be developed is the Hollandse Kust Zuid Wind Farm Zone (hereafter Hollandse Kust WFZ). Rijksdienst voor Ondernemend Nederland (RVO) requested Deltares to provide wind and wave persistence tables for the Hollandse Kust WFZ to support the tender phase for the Geophysical Site Investigation in Q4 2015 and Q1 2016.

The zone will be developed from 2017 onwards. Tendering parties can use the persistence tables to provide a first indication of expected weather windows. For this phase persistence tables are requested at a single location in the centre of the wind farm zone.

The Hollandse Kust WFZ has a total surface area of about 220 km^2 and the water depth varies there approximately between 12 and 25 m. The site is located about 22 km off the coast of the Dutch province Zuid Holland (see Figure 1.1).

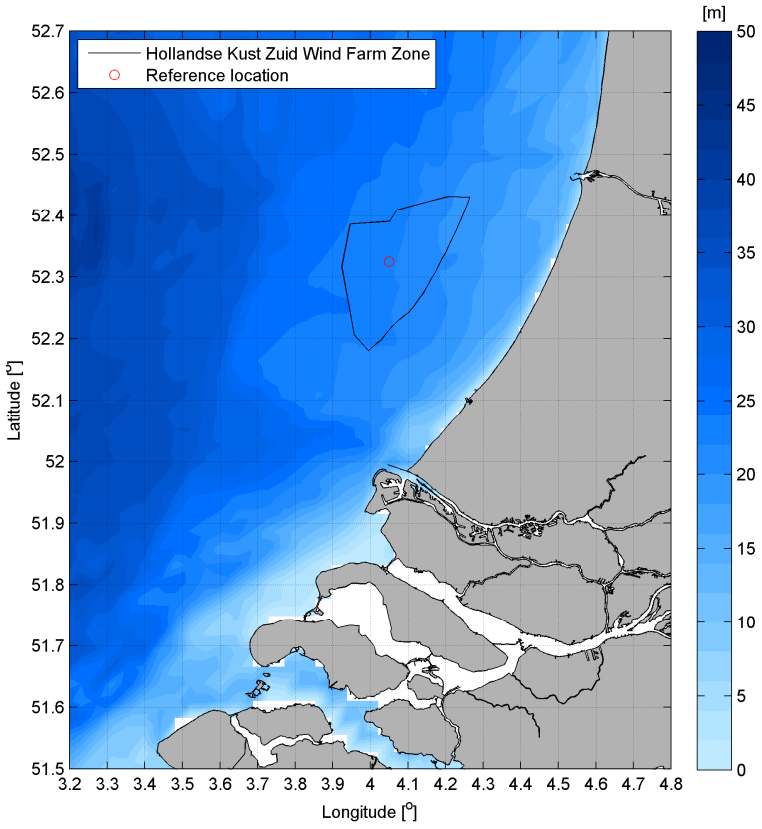

Figure 1.1 Overview location Hollandse Kust Zuid wind farm

2 Data

2.1 Available data

Various sources of measurement and hindcast data are available in the vicinity of the Hollandse Kust Zuid Wind Farm Zone:

- Wave **measurements** carried out by the Dutch Ministry of Public Works (Rijkswaterstaat, RWS) at YM6 (IJmuiden munitiestortplaats) and MPN (Meetpaal Noordwijk). The data are available 3 hourly from 1979 until 2008.
- Wind **measurements** at offshore station K13 by the Dutch Meteorological Institute (KNMI). The data are hourly from 1983 to 2009.
- Wind **hindcast** data from KNMI's weather forecast model HARMONIE (Baas, 2014). The data are available hourly from 1979-2013 at a 2.5 km x 2.5 km grid. In-house data offshore are available on a 10 km x 10 km grid.
- Waves and winds from the European Centre for Medium-range Weather Forecast (ECMWF) most recent reanalysis, the ERA-interim data (Dee et al., 2011). The **hindcast** data are 6 hourly, from 1979 until 2013 and available on a global grid with a resolution of about 0.75° x 0.75°.
- The German coastDat-1 **hindcast** wave data (Weisse and Günther, 2007, http://www.coastdat.de/data_all/index.php). The data are hourly from 1958 until 2007 and on a North Sea grid with a resolution of about 0.10° x 0.05°.

The data overview is summarized in Table 2.1. Figure 2.1 gives a spatial overview of the available data.

Table 2.1 Overview of the considered data

Dataset	Location	Type	Availability	Variables	Source
YM6	4.06°E, 52.55°N	measurements	3 hourly 1979-2008	waves	RWS Dutch Data ICT Service
MPN	4.30°E, 52.27°N	measurements	3 hourly 1979-2008	waves	RWS Dutch Data ICT Service
K13	3.22°E, 53.21°N	measurements	hourly 1983-2009	wind	RWS Dutch Data ICT Service
HARMONIE	2.5 km x 2.5 km grid *(10 km x 10 km grid)*	hindcast	hourly 1979-2013	wind	KNMI
ERA-interim	global 0.75º x 0.75º grid	hindcast	6 hourly 1979-2013	wind waves	ECMWF
coastDat-1	North sea 0.10º x 0.05º grid	hindcast	hourly 1958-2007	waves	Helmholtz-Zentrum Geesthacht

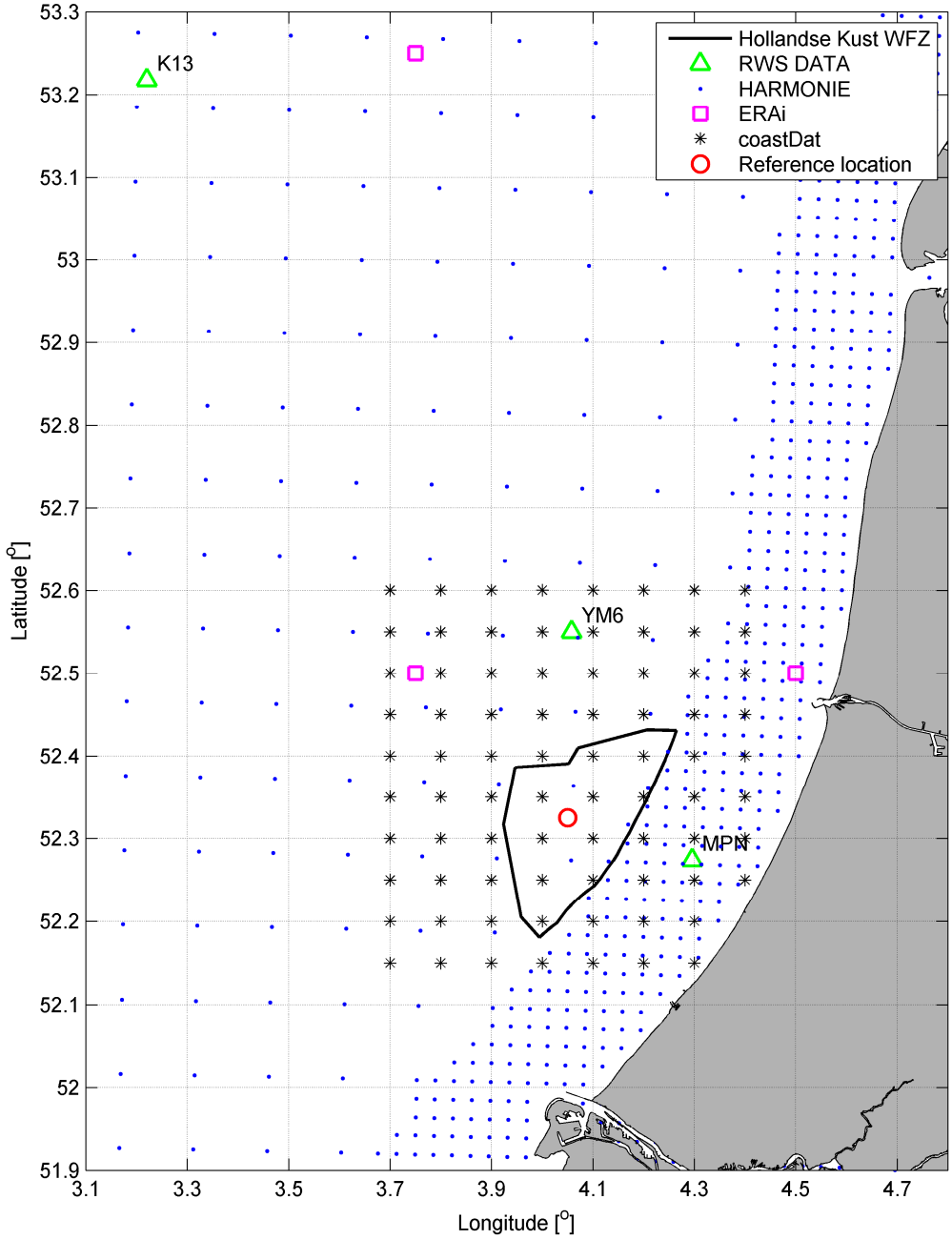

Figure 2.1 *Overview of the considered data*

2.2 Data validation and approach

2.2.1 Wave data

Two sources of hindcast wave data are available for Hollandse Kust Zuid Wind Farm Zone area: coastDat-1 and ERA-interim. Both data sources are applied in the approach to provide the best possible estimated of the wave conditions at the chosen reference location. Based on our experience the ERA-interim data provides the best basis for the determination of the local wave conditions at the Hollandse Kust WFZ. The location of the available data is, however, at a distance from the Hollandse Kust WFZ site (see Figure 2.1). The data, therefore, needs to be transformed to the Hollandse Kust WFZ location first. Before the transformation, the ERA-interim data needs to be validated. For the validation of the data we use the wave measurements at YM6. For the transformation or calibration of the data to the Hollandse Kust WFZ site we use the coastDat data. The coastDat data are available with a higher spatial and time-resolution than the ERA-interim data and there are a number of coastDat grid points in the vicinity of the ERA-interim location and in the Hollandse Kust WFZ. These data could also have been selected as the main source of wave conditions at the site. However, from previous studies we know that ERA-interim has a higher correlation with wave measurements compared to the coastDat data. Our experience is also that the coastDat data, although showing a larger scatter in comparisons with measurements, are generally unbiased (i.e. shown to have limited difference in the mean values in comparison against measurements), making it suitable for the determination of spatial correction (transformation) factors. It is noted that although the requested deliverables are persistence tables of significant wave height and wind speed only, wave directions are also assessed in the data validation and transformation to help justify the applied approach.

The ERA-interim data validation is carried out as follows:

a) The ERA-interim data (at 3.75°E and 52.5°N) are validated against the YM6 measurements.
b) The coastDat data are validated against the YM6 measurements.
c) The coastDat data at a location closest to the ERA-interim location (3.75°E and 52.5°N) are compared with the ERA-interim data.
d) The coastDat data at that location and at the YM6 location are also compared, to check whether differences between the ERA-interim data and YM6 measurements can be explained by the distance between the locations.

Starting with a), Figure 2.2 shows comparisons between the ERA-interim wave data at location 3.75°E and 52.5°N and the YM6 measurements of significant wave height (H_s), mean wave period ($T_{m-1,0}$) and mean wave direction (MWD). The figure shows that:

- although the ERA-interim and the measuring locations are at a distance of about 0.3°, the correlation between the ERA-interim and the H_s measurements is over 93% which is relatively high;
- the ERA-interim H_s data are on average 6% higher than the YM6 H_s data; and
- the $T_{m-1,0}$ and MWD ERA-interim data have a correlation of 81% and 73% with the measurements, which are also relatively high.

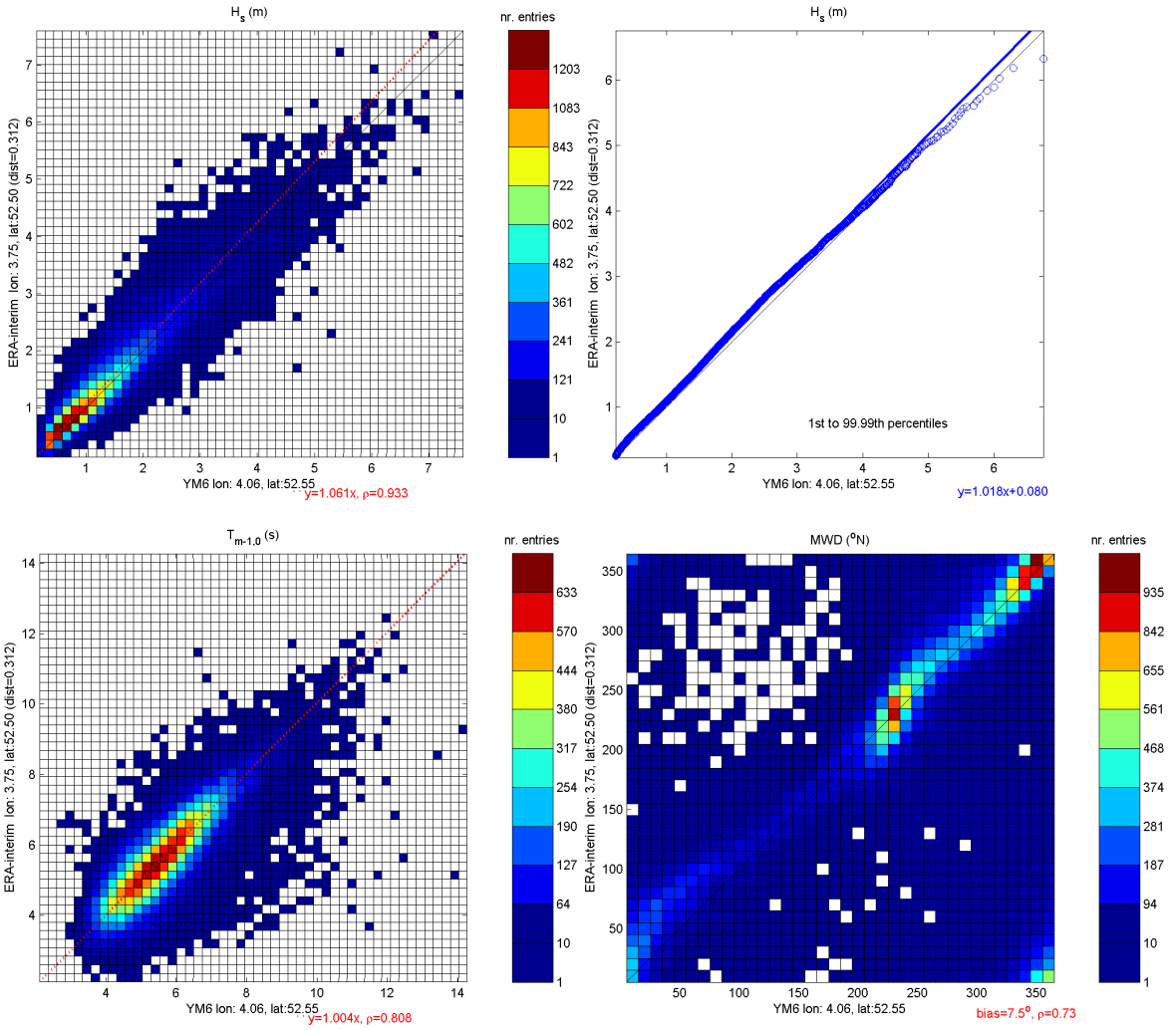

Figure 2.2 *a) Comparison between ERA-interim data and buoy measurements at YM6*

Moving on to b), Figure 2.3 shows comparisons between the measurements of H_s and MWD at YM6 and the coastDat data at its location closest to YM6. The figure shows that:

- As we already saw in other studies, that the coastDat H_s data shows almost no bias with relation to the measurements (red versus black diagonal line) and has a correlation with the measurements which is lower than that of the ERA–interim data (88% vs 93%).
- The coastDat MWD data also compares well with the measurements, although with a small bias.

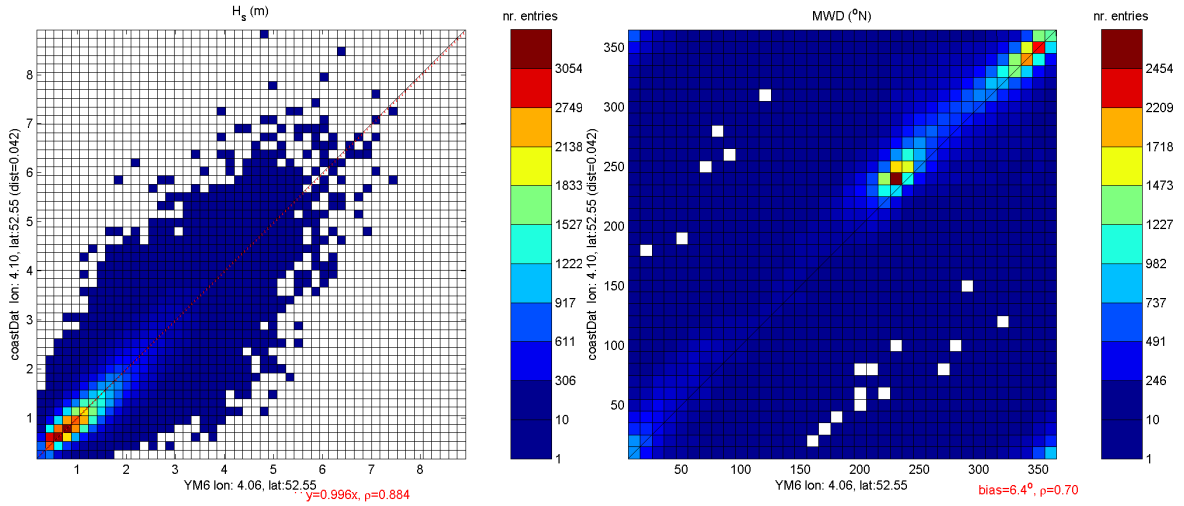

Figure 2.3 *b) Comparison between coastDat data and buoy measurements at YM6*

In accordance with c), Figure 2.4 shows comparisons between ERA-interim data (from location 3.75°E and 52.5°N) and coastDat data from the location closest to the ERA-interim location. The figure shows that:

- The coastDat and the ERA-interim data compare rather well.
- The good comparisons between the ERA-interim and the coastDat data along with the fact that both datasets also compare well with measurements (Figure 2.2 and Figure 2.3) can be taken as evidence that both datasets are quite reliable.

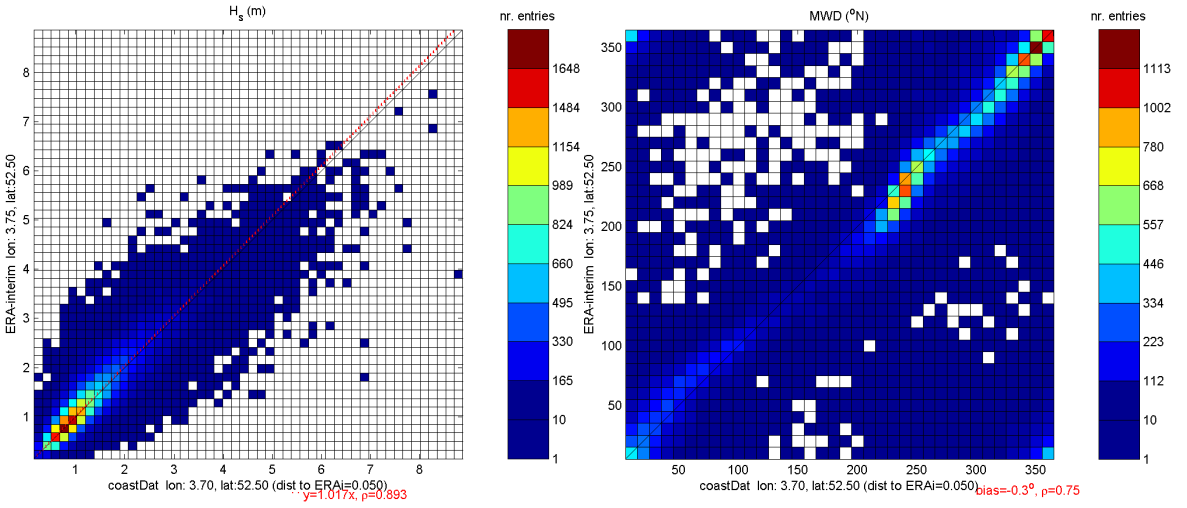

Figure 2.4 *c) Comparison between ERA-interim data and the coastDat data from its closest location*

Finally, in order to check whether the deviation between the ERA-interim and the YM6 H_s measurements are due to the distance between the data locations, d), Figure 2.5 shows the comparison between the coastDat data at the location closest to the considered ERA-interim and at the YM6 location. The figure shows that the coastDat data at the ERA-interim location is on average 5% higher than those at the YM6 location. This ratio of 1.05 is rather close to the 1.06 ratio found between the ERA-interim data and the YM6 measurements. Especially, taking into account that the considered data periods (YM6 3-hourly 1979-2008, ERA-interim 6-hourly 1979-2013, coastDat hourly 1958-2007), and therefore also the data considered in the comparisons, differ.

Based on this validation, which is fully in line with our past experience, we conclude that:

- the ERA-interim data are of high quality;
- the ERA-interim data are suitable to form the basis of this study; and
- that the expected spatial variations in the wave conditions in the considered region are well described in the coastDat data.

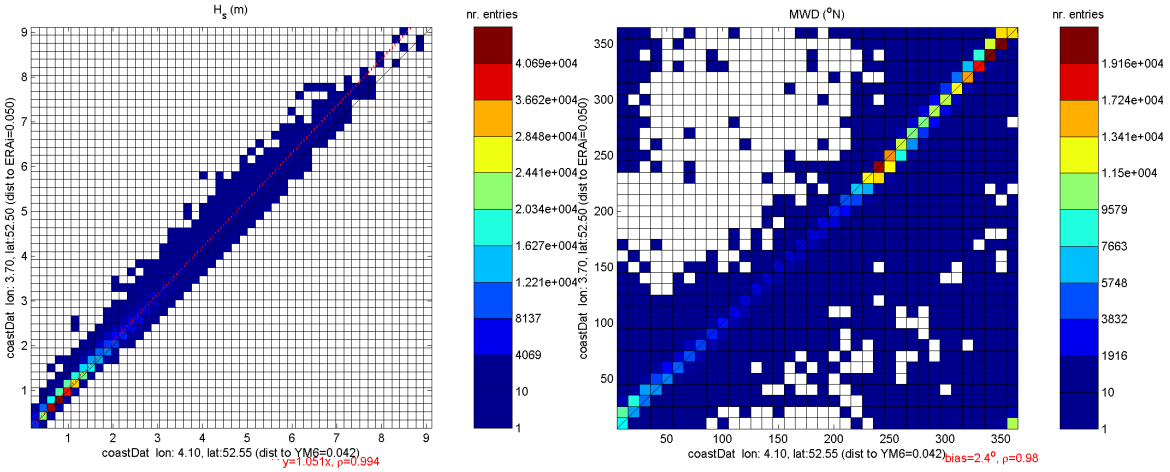

Figure 2.5 d) Comparison between coastDat at YM6 and the ERA-interim locations

Having presented the validation of the ERA-interim data at 3.75°E and 52.5°N, we now look at how to transform the data to the Hollandse Kust WFZ site. As motivated above, the transformation is computed using the coastDat data. Table 2.2 shows the relation between coastDat data at the location close to the considered ERA-interim location and four coastDat locations surrounding the reference location (see Figure 2.1). The table shows that the ratio between H_s at the ERA-interim and the Hollandse Kust WFZ region varies between 0.85 and 0.91. Based on these figures, we have decided to transform the ERA-interim H_s data (from location 3.75°E and 52.5°N) to the reference location by using the upper limit of these values; multiplying it by 0.91.

Table 2.2 Transformation factors H_s and MWD

Location	Hs factor [-]	MWD rotation [°]
4.00°E, 52.30°N	0.89	-1.4
4.00°E, 52.35°N	0.91	-1.7
4.10°E, 52.30°N	0.85	-2.5
4.10°E, 52.35°N	0.88	-2.4

2.2.2 Wind data

Wind data at the reference location is directly available from the Dutch Meteorological Institute's (KNMI) forecast model HARMONIE. A comparison of HARMONIE wind against wind measurements is presented for the offshore station K13 (cf. Figure 2.1). Figure 2.6 shows the comparisons between the HARMONIE and the K13 measurements of the 10-metre wind speed (U_{10}) and direction (U_{dir}). The obtained correlations of 91% and small relative differences between the datasets attest for the quality of the HARMONIE wind data. A bias is observed between the wind directions but this is considered acceptable as the wind direction measurements at K13 may be biased due to the geometry of the platform.

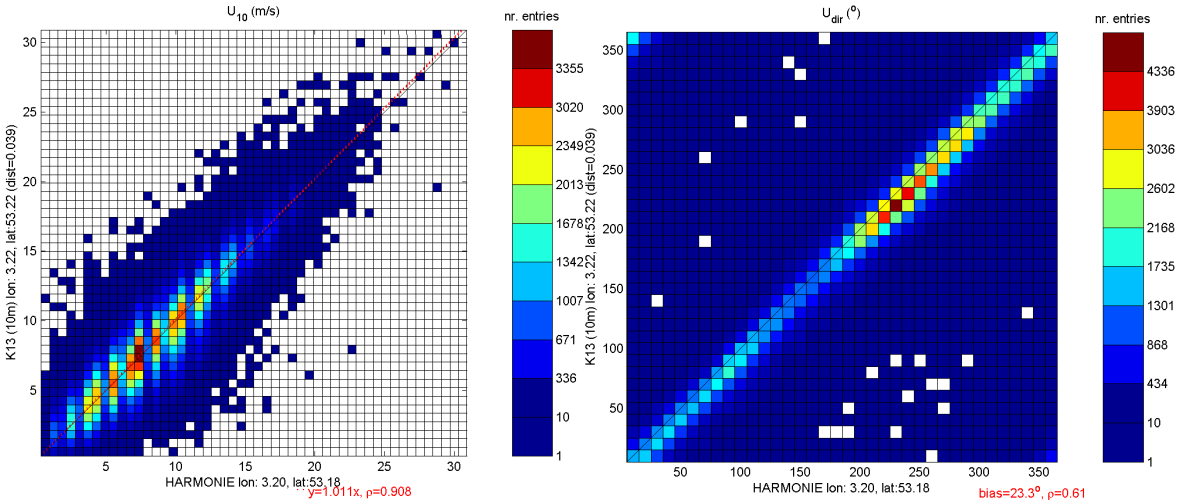

Figure 2.6 Comparison between HARMONIE and K13 wind measurements

3 Analysis

Based on the selected and adjusted ERA-interim wave and HARMONIE wind data, persistence tables are prepared for the reference location according to the following requested classes and conditions:

- Wave height thresholds: 0.5m, 0.75m, 1.0m, 1.25m, 1.5m, 1.75m, 2.0m, 2.25m, 2.5m, 2.75m, 3.0m, 3.5m, 4.0m, 4.5m, and 5.0m;
- Wind speed thresholds: 2m/s, 4m/s, 6m/s, 8m/s, 9m/s, 10m/s, 11m/s, 12 m/s, 15 m/s, 20 m/s, and 25m/s.;
- Durations of 2, 4, 6, 8, 12, 24, 36, 48, and 72 hours
- Probability of exceedance percentages (quantiles) of 20%, 50%, and 80%;
- Monthly and all year

ERA-interim wave data have been interpolated to one hour interval values to be able to fulfil the request for durations lower than the original data interval of 6 hours. The marginal persistence tables for wind and wave conditions and the bivariate persistence tables of wind and wave conditions are presented in separate Excel files. The tables show for certain thresholds of the wave height and wind speed the 20%, 50% and 80% quantiles of the probability of non-exceedance of these thresholds. The quantiles have been computed by carrying out the analyses per year, leading to 35 values of each statistic (monthly and yearly non-exceedances); from which the 20%, 50% and 80% quantiles were determined. In principle the 50% quantile can be seen as a best/mean estimate, the 80% quantile a lower bound estimate and the 20% quantile as an upper bound estimate.

References

Baas, P., 2014: *Final report of WP1 of the WTI2017-HB Wind Modelling Project*. KNMI Scientific Report; WR 2014-02 (http://www.knmi.nl/bibliotheek/knmipubWR/WR2014-02.pdf), August 2014.

Dee, D. P. and co-authors, 2011: The ERA-Interim reanalysis: configuration and performance of the data assimilation system, Q. J. R. Meteorol. Soc., 137 (656), 553-597, doi:10.1002/gj.828.

Weisse, R. and H. Günther, 2007: Wave climate and long-term changes for the Southern North Sea obtained from a high-resolution hindcast 1958-2002. *Ocean Dynamics*, doi:10.1007/s10236-0060094-x.