D5.1: Improved wave and wind design data

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Nomenclature

swh	Significant Wave Height
H_s	Significant Wave Height
CLS	Collect Localisation Satellites
CFSR	Climate Forecast System Reanalysis
NOAA	National Oceanic and Atmospheric Administration
NCEP	National Centers for Environmental Prediction
SSHA	Sea Surface Height Anomaly
LRM	Low Resolution Mode
PLRM	Pseudo Low Resolution Mode
SAR	Synthetic Aperture Radar
U_{10}	Wind speed
L2	Level-2
BIAS	Mean Error
RMSE	Root Mean Square Error

1. Abstract

The objective of this report was to use the high-resolution wave height and wind speed products from the SRAL SAR to improve the wave and wind design data in marine engineering.

SAR data are a valuable source of information in coastal areas, where limited other information is available. Potential applications of such data could e.g. be for offshore wind farms, oil/gas platforms or marine infrastructure projects, in particular when located in remote areas.

In this study, improved wave and wind design data were demonstrated in terms of fast assessment of wind and wave conditions and in terms of improved validation of numerical models at a spatial scale including assessment of along-track distributions of extreme waves.

The data basis included SAR (Synthetic Aperture Radar) processed altimeter data with 1 and 20Hz resolution covering the North East Atlantic (NE Atlantic) during a 2-year period (2012-05-01 – 2014-04-30). The basis further included LRM (low resolution mode) altimeter data (Jason-2), wave model data (from DHI), and atmospheric model data (from CFSR).

An example of model validation (BIAS of H_s and U_{10}) using the CryoSat-$2_{SAR,\ 1Hz}$ is shown in Figure 1.1. There was generally a good agreement between the model and the SAR 1Hz data. The BIAS and RMSE for the 20Hz SAR data were very similar to the 1Hz SAR data offshore, but somewhat higher in the nearshore areas. The SAR data were thus proved to be a valuable source of data for model validation nearshore, supplementing other altimeter missions of LRM data offshore and in-situ measurements. At this stage, the SAR 1Hz data set may be more appropriate for model validation nearshore compared to the 20Hz data.

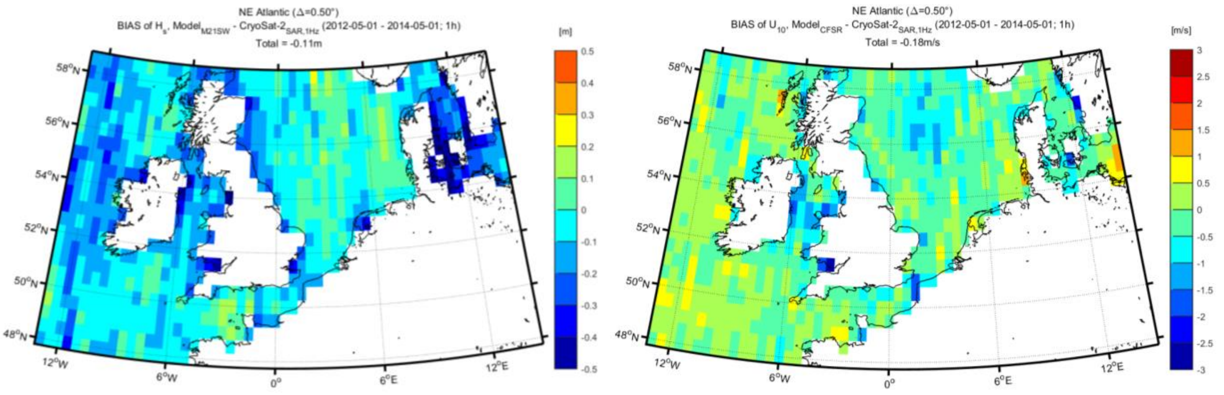


Figure 1.1 BIAS of H_s (left) and U_{10} (right) in the NE Atlantic (model data ÷ CryoSat-$2_{SAR,\ 1Hz}$)

Methodologies and preliminary validation of SAR data versus model data are shown above. The overall conclusion was that the SAR data were of high enough quality to support and improve modelling results, especially in areas with low data coverage. The data and methodologies will clearly be able to contribute to modern day metocean databases and design methods e.g. for offshore wind.

Topics for further work on this study could e.g. include improving model data based on re-calibrated model set-ups and potentially enhance understanding of physical processes leading to improved model code. Additional work on the SAR data could e.g. include processing/smoothing of the (along-track) data for more robust verification as well as inclusion of SAR wave spectra. Both of which could possibly also be useful for quality screening (assessing outliers in SAR data).

2. Data basis

The data basis for this study was adopted from deliverable D4.5: Assessment of Cryosat-2 Ocean Prototype Data, (LOTUS, 2015), and the relevant information is summarized below.

The data basis included altimeter data from various processing modes and numerical model data of significant wave height (H_s) and wind speed at 10m height (U_{10}).

2.1. Altimeter data

Processed Level-2 (L2) altimeter data from CryoSat-2 were provided by CLS, while data from Jason-2 were provided by DHI.

2.1.1. Processing modes

The CLS data included SAR (Synthetic Aperture Radar) and PLRM (Pseudo Low Resolution Mode) processed data at 1Hz and 20Hz. The SAR and PLRM data respectively were derived from coherent and incoherent processing of the same returning echoes. Both data sets were related to the same ground location, over identical sea states, allowing direct comparison. The retrieval of SAR data was based on a numerical ocean/coastal re-tracking routine, while the PLRM data were obtained from the standard MLE-4 ocean waveform re-tracking algorithm. The DHI Jason-2 data were in LRM at 1Hz as provided by NOAA. A summary of the altimeter data sets is given in Table 2.1.

Table 2.1 Altimeter data sets

Mission	Provider	Processing Mode	Return Cycle	Applied Parameters
CryoSat-2	CLS	PLRM, 1Hz	369 days*	H_s, U_{10}
CryoSat-2	CLS	SAR, 1Hz	369 days*	H_s, U_{10}
CryoSat-2	CLS	PLRM, 1Hz	369 days*	H_s, U_{10}
CryoSat-2	CLS	SAR, 20Hz	369 days*	H_s, U_{10}
Jason-2	DHI	LRM, 1Hz	10 days	H_s, U_{10}

*With 30 day sub-cycle

2.1.2. Quality screening

CLS provided quality flag and SSHA (sea surface height anomaly) parameters. Only data with quality flag = 0 and |SSHA| < 2m were applied cf. CLS recommendations. The DHI data (Jason-2) were quality screened according to GlobWave guidelines (GlobWave, 2010). Only data with a quality flag of 0 ('Probably good') were adopted for this study (data with quality flags of 1 ('Generally acceptable') and 2 ('Probably bad') were omitted).

2.1.3. Data coverage

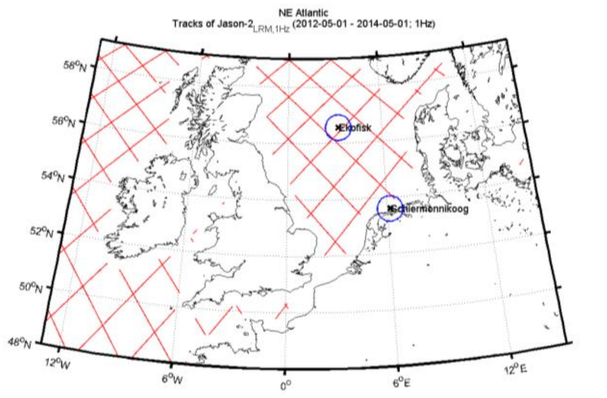
The available data periods were: 2012-05-01 – 2014-04-30 (2 years) and the common geographical coverage was: NE Atlantic: W13.0° – E15.0° - N48.0° - N59.0°.

The return cycle of CryoSat-2 is 369 days (with 30-day sub-cycle), while the return cycle of Jason-2 is 10 days. The altimeter coverage in NE Atlantic (after quality screening) is shown in Figure 2.1. The very dense coverage (in space) of CryoSat-2 compared to Jason-2 is related to the long return cycle of

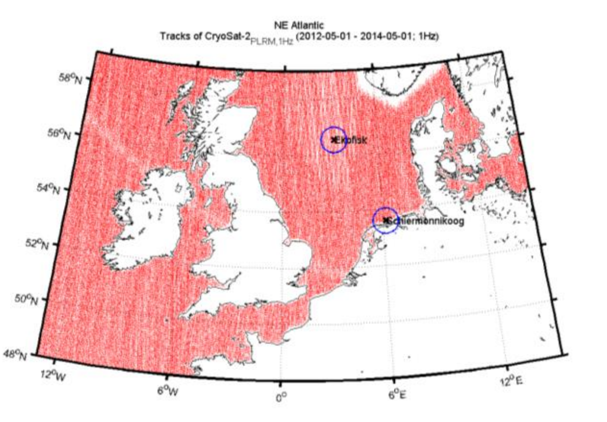
CryoSat-2. In turn Jason-2 provides a much higher temporal coverage along the tracks compared to CryoSat-2.

It is noticed that all the CryoSat-2 data sets had no data of the Norwegian coast. Also there appeared to be slightly less coverage in an area in central northern North Sea. The CLS data had few tracks on land for 20Hz wind speed.

Jason-2 (LRM, 1Hz) DHI



CryoSat-2 (PLRM & SAR, 1Hz) CLS



CryoSat-2 (PLRM & SAR, 20Hz) CLS

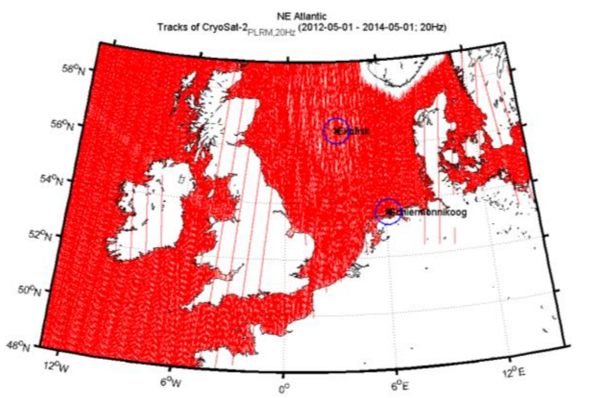


Figure 2.1 Altimeter coverage in NE Atlantic (after quality screening) (and in-situ verification stations used in (LOTUS, 2015))

2.2. Numerical model data

Modelled U_{10} was adopted from CFSR (Climate Forecast System Reanalysis), a global atmospheric modelling system provided by NOAA NCEP. These data had a resolution of 0.2° in space and 1h in time.

Modelled H_s was adopted from the DHI hindcast database. These data were based on a calibrated MIKE Powered by DHI Spectral Wave Model (MIKE 21 SW) forced by CFSR wind data.

For in-situ verification of the model data, reference is made to deliverable D4.5, (LOTUS, 2015).

3. Improved wave and wind design data

This section demonstrates examples of improved wave and wind design data based on SAR data. This includes fast assessment of wave and wind conditions (a stand-alone product) and validation of wave and wind model data at a spatial scale (a derivative product) including along-track distribution of extreme events. Fast assessment of wind and wave conditions may be important in an early phase of the design, while improved validation may increase the confidence in model data and potentially indicate options for improved calibration/accuracy and model code.

3.1. Fast assessment of wave and wind conditions

The purpose of providing fast assessments of wave and wind conditions is mainly to support early stages of development and design estimates, in particular for remote coastal areas with limited other sources of information. This may supplement other initial assessments e.g. for planning and design of offshore wind farms, oil/gas platforms or marine infrastructure projects.

A fast assessment of wave and wind conditions, based on SAR data alone, may e.g. include time series, histograms and overall statistics. An example is shown for the coastal site Schiermonnikoog (~10km of Dutch coast) in Figure 3.1 (H_s) and Figure 3.2 (U_{10}). All SAR data within 0.1° were included, totalling about 2.700 data points. This close to land, there is very limited data available from traditional altimeters such as Jason-2, see Figure 2.1.

3.1.1. Significant wave height

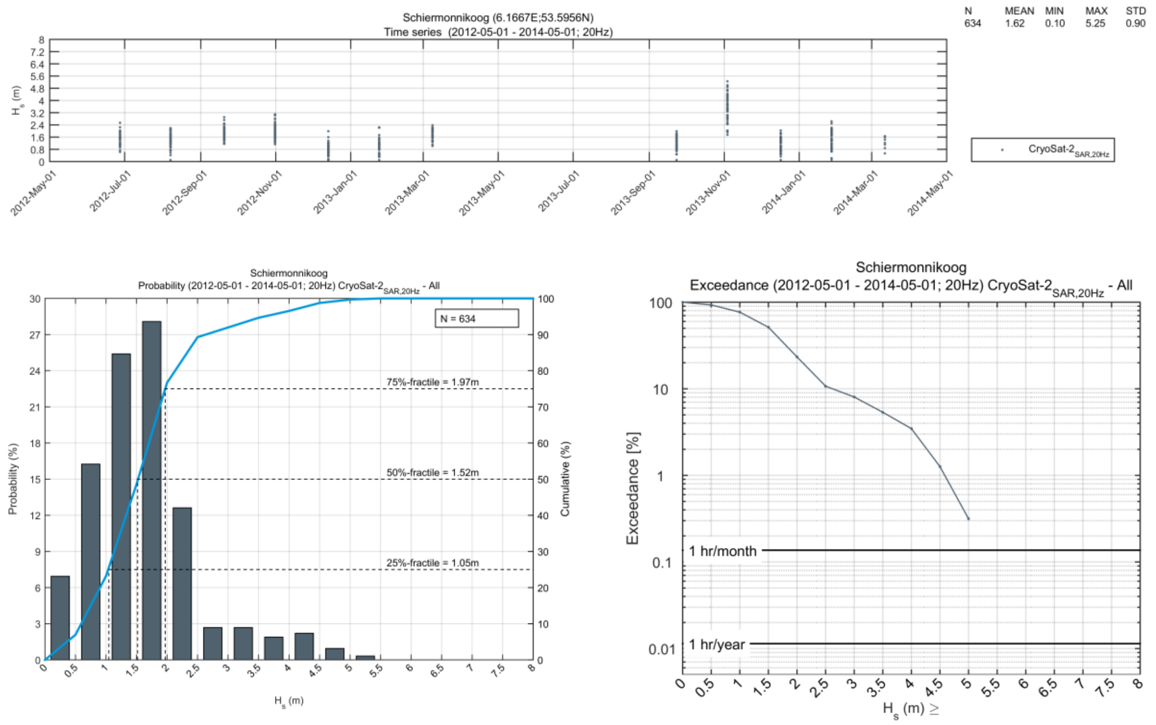


Figure 3.1 Time series, histogram and exceedance distribution of CryoSat-$2_{SAR,20Hz}$ H_s at Schiermonnikoog

3.1.2. Wind speed

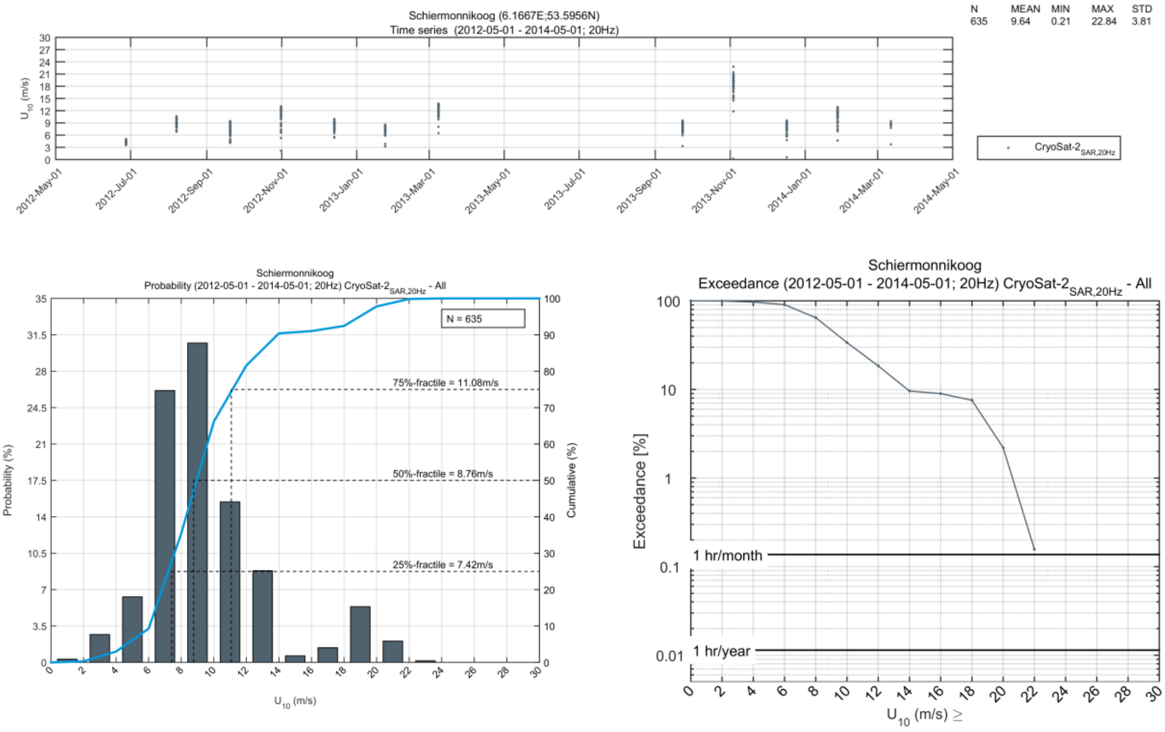


Figure 3.2 Time series, histogram and exceedance distribution of CryoSat-2$_{SAR,20Hz}$ U_{10} at Schiermonnikoog

3.2. Validation of numerical models at a spatial scale

The purposes of validating numerical models are mainly to increase the confidence in model data (reducing the uncertainty) and potentially to indicate options for improved calibration (and hence improved accuracy). The purpose in this study was further to assess the Cryosat-2 SAR data at a spatial scale.

For this study, model data were extracted for the NE Atlantic region (same as the available CryoSat-2 data) from the models described in Section 2.2 (MIKE 21 SW and CFSR).

The altimeter data sets were compiled in equidistant grid cells of 0.5° covering the NE Atlantic region. The grid cell size was chosen as a compromise between having a good spatial resolution and having a sufficient number of data points in each cell for robust statistics. Subsequently model data were extracted at the same time (linearly interpolated) and place (nearest cell) and compiled to the same grid. Only cells with a minimum of 200 points were included.

Only the CryoSat-2 SAR (1 and 20Hz) and Jason-2 (LRM, 1Hz) data sets are presented in the following (the PLRM data are not presented).

3.2.1. Significant wave height

A comparison of H_s between modelled and altimeter data in the NE Atlantic is shown in Figure 3.3 (Left: Jason-2 (LRM, 1Hz), Right: CryoSat-2 (SAR, 20Hz)). In this area, a total of ~200.000 data points were available from the Jason-1 (LRM, 1Hz), while ~$2.6x10^6$ points were available from CryoSat-2 (SAR, 20Hz)[1]. The plots show the MEAN (top), BIAS (middle) and RMSE (bottom) of H_s respectively. The following general patterns were identified:

- The overall MEAN of H_s in the NE Atlantic was about 2m in
- The BIAS offshore was generally <± 10-20cm in both data sets
- The BIAS nearshore was up to -1m in CryoSat-2 (Note: no Jason-2 data nearshore)
- The RMSE offshore was generally <0.4m for Jason-2, and <0.6m in CryoSat-2
- The RMSE nearshore was up to ~1-3m for CryoSat-2 (Note: no Jason-2 data nearshore)

In summary there was generally a good agreement for H_s (low BIAS and RMSE) between the model and the altimeter data sets offshore. The BIAS and RMSE nearshore was somewhat higher compared to offshore. No immediate explanation for the increased discrepancies nearshore compared to offshore was identified, but possibly further/improved quality screening of the SAR data could reduce this difference.

A comparison between model and CryoSat-2 SAR 1Hz data (~120.000 points) is presented in Figure 3.4. It is seen that the BIAS and RMSE for the 1Hz SAR data were very similar to the 20Hz SAR data offshore, but significantly lower in the nearshore areas.

In conclusion, the SAR data were proved to be a valuable source of data for model validation nearshore, supplementing other altimeter missions of LRM data offshore and in-situ measurements. At this stage, the SAR 1Hz data set may be more appropriate for model validation nearshore compared to the 20Hz data.

[1] Only cells with more than 20 data points were included in the plots for H_s and U_{10}. However, only cells with more than 200 data points were included in the plots for 20Hz U_{10} (since the 20Hz SAR data of U_{10} had some data on land).

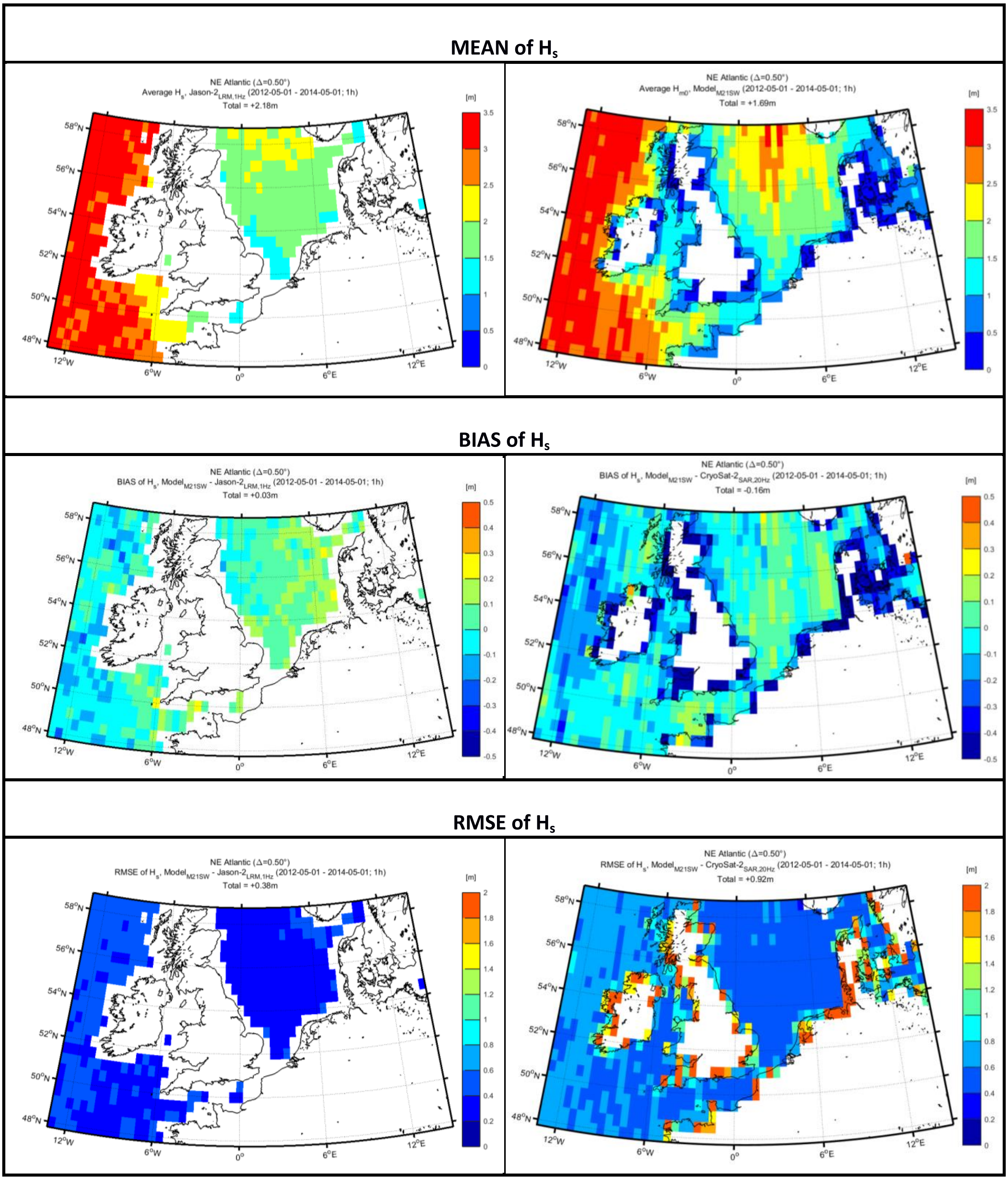
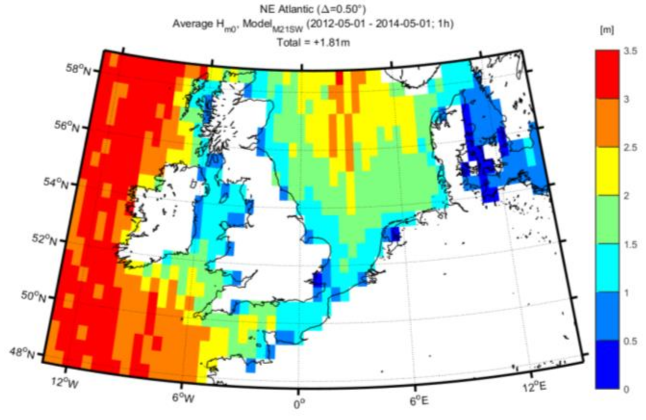
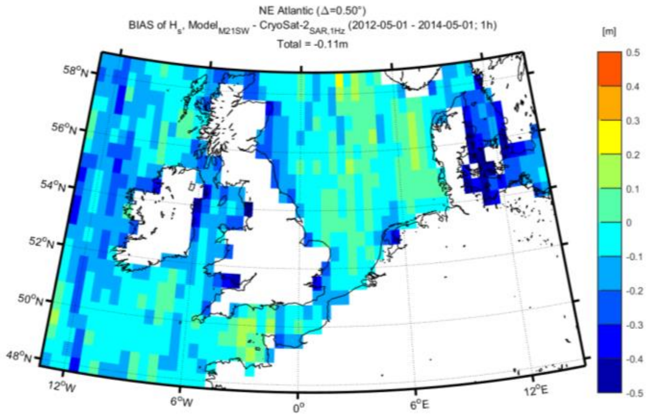


Figure 3.3 MEAN, BIAS and RMSE of H_S in NE Atlantic (model ÷ altimeter).
Left: Jason-2 (LRM, 1Hz) $_{DHI}$, Right: CryoSat-2 (SAR, 20Hz) $_{CLS}$

MEAN of H_s



BIAS of H_s



RMSE of H_s

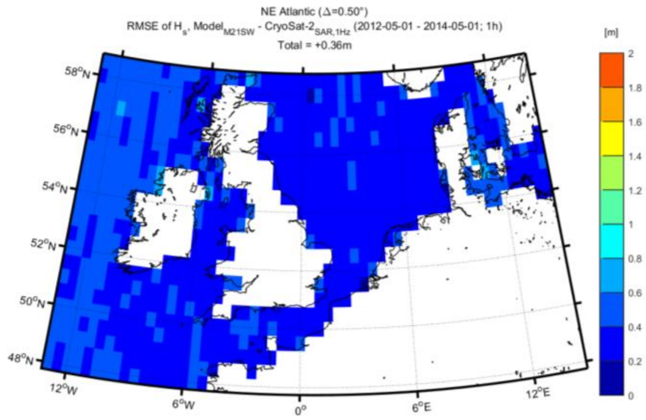


Figure 3.4 MEAN, BIAS and RMSE of H_S in NE Atlantic (model ÷ altimeter).
Left: -, Right: CryoSat-2 (SAR, 1Hz) $_{CLS}$

3.2.2. Wind speed

A comparison of U_{10} between modelled and altimeter data in the NE Atlantic is shown in Figure 3.5 (Left: Jason-2 (LRM, 1Hz), Right: CryoSat-2 (SAR, 20Hz)). The plots show the MEAN (top), BIAS (middle) and RMSE (bottom) of H_s respectively. The following general patterns were identified:

- The overall MEAN U_{10} in the NE Atlantic is about 8m/s
- The BIAS was generally positive of 0.5-1.0m/s for Jason-2 (average of 0.8m/s)
- The BIAS was generally within ±0.5m/s for CryoSat-2 (average of 0.1m/s), although with some exceptions, in particular nearshore
- The RMSE was generally within 1-2m/s for Jason-2
- The RMSE was generally within 1-2m/s for CryoSat-2; however, there was somewhat higher spatial variation compared to Jason-2

In summary, the findings for U_{10} were similar to those for H_s. There was generally a good agreement for U_{10} (low BIAS and RMSE) between the model and the SAR 20Hz data offshore, but somewhat increased discrepancies nearshore. The BIAS of Jason-2 was on average 0.7m/s higher compared to CryoSat-2 (SAR, 20Hz).

A comparison between model and CryoSat-2 SAR 1Hz data (~120.000 points) is presented in Figure 3.6. Again it is seen that the BIAS and RMSE for the 1Hz SAR data was very similar to the 20Hz SAR data offshore, but significantly lower in the nearshore areas.

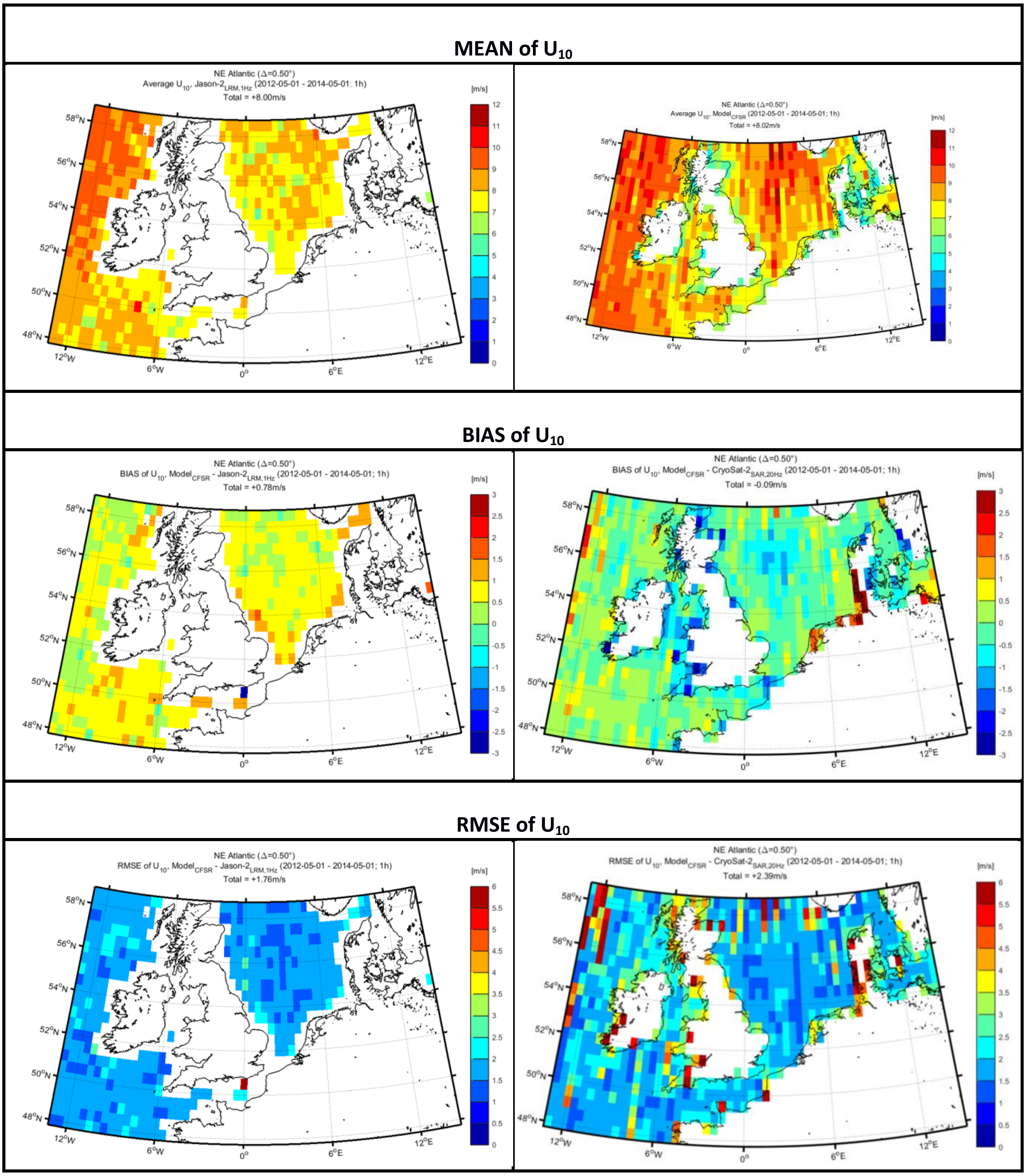
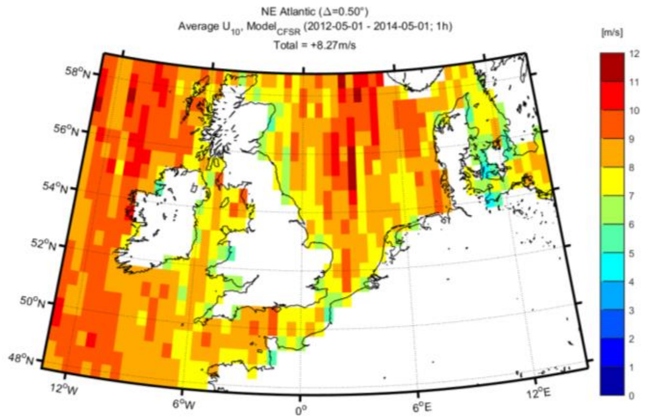
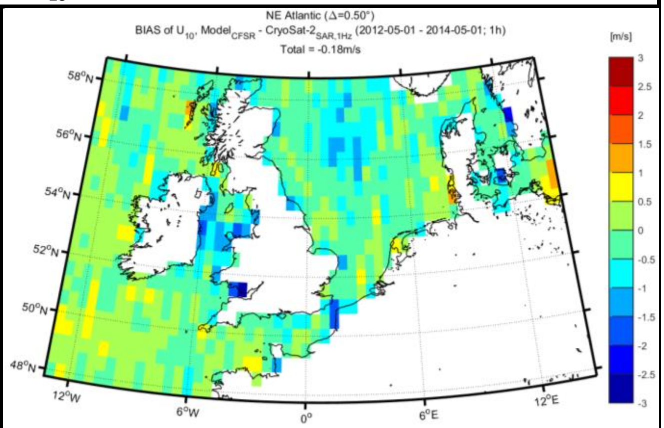


Figure 3.5 MEAN, BIAS and RMSE of U_{10} in NE Atlantic (model ÷ altimeter).
Left: Jason-2 (LRM, 1Hz) $_{DHI}$, Right: CryoSat-2 (SAR, 20Hz) $_{CLS}$

MEAN of U_{10}



BIAS of U_{10}



RMSE of U_{10}

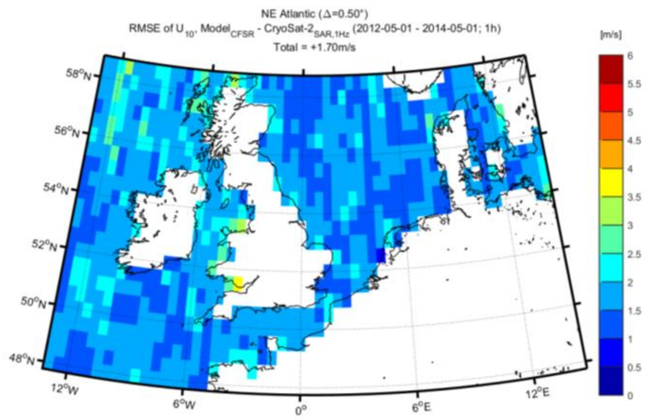


Figure 3.6 MEAN, BIAS and RMSE of U_{10} in NE Atlantic (model ÷ altimeter).
Left: -, Right: CryoSat-2 (SAR, 1Hz) $_{CLS}$

3.3. Along-track distribution of extreme waves and wind

Assessment of the spatial distribution of extreme wind and waves is often an important part of marine design studies for better understanding and estimating the extreme events. Methods to assess this typically include model and altimeter data. An example of along-track comparison of H_s between Jason-2 and model data during Hurricane 'Bodil' (2013-12-05) in the North Sea is shown in Figure 3.7.

The availability of high-resolution SAR altimeter data allows such assessment and comparisons also in more remote and/or nearshore areas. An example of along-track comparison of H_s between CryoSat-2 (SAR, 20Hz) and model data during Hurricane 'Bodil' (2013-12-05) in the Inner Danish Waters (where no Jason-2 data are available) is shown in Figure 3.8. Some deviations between the CryoSat-2 and model data are seen, but the average values appear to be similar. It is likely that the 1Hz SAR data would show less discrepancies to the model compared to the 20Hz data in such nearshore areas (as indicated in the previous section).

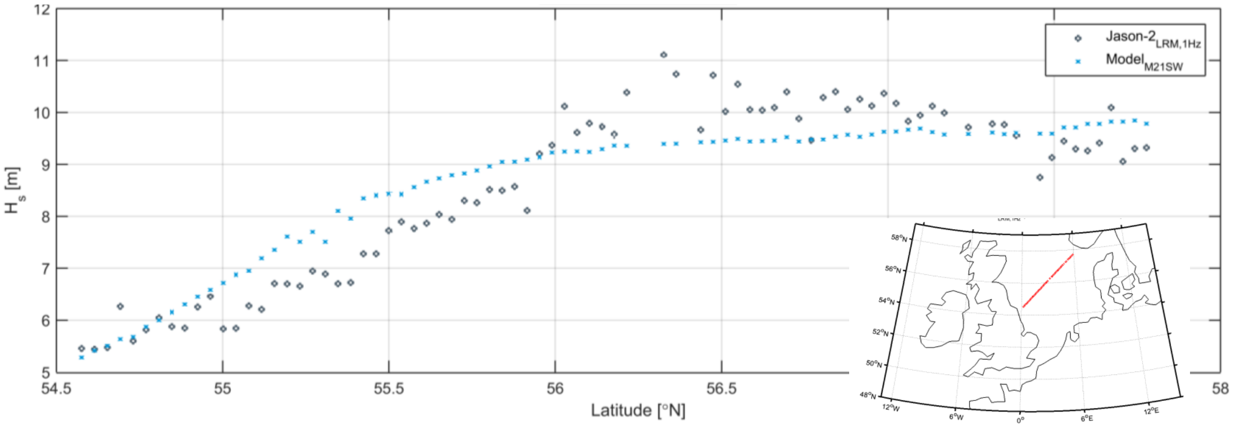


Figure 3.7 Along-track distribution of H_s during Hurricane 'Bodil' (2013-12-05) in the North Sea (Jason 2 (LRM, 1Hz) and Model (MIKE 21 SW))

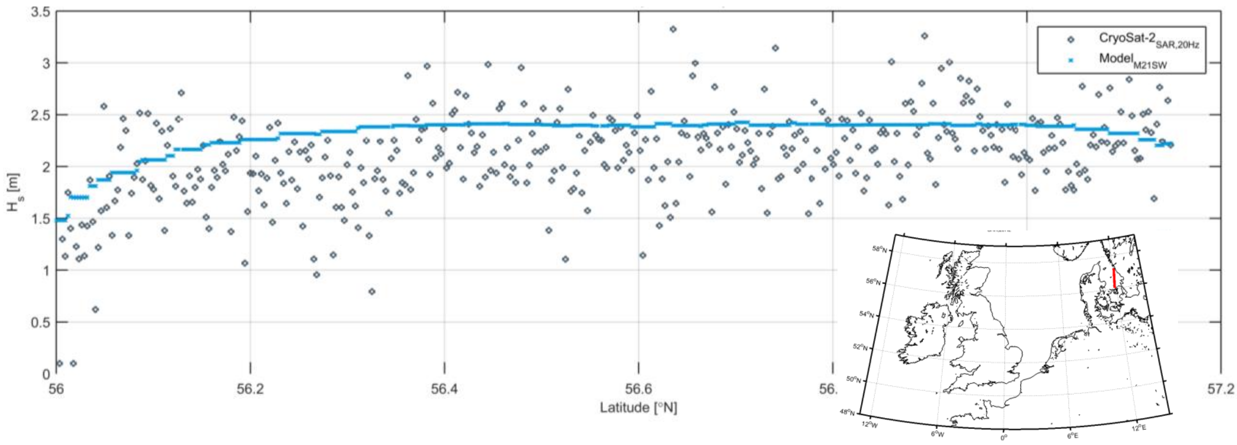


Figure 3.8 Along-track distribution of H_s during Hurricane 'Bodil' (2013-12-05) in the inner Danish waters (CryoSat-2 (SAR, 20Hz) and Model (MIKE 21 SW))

4. References

GlobWave. 2010. *Deliverable D5 - Product User Guide.* 2010.

LOTUS. 2015. *D4.5: Assessment of Cryosat-2 Ocean Prototype Data.* 2015.

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