Memo

Date
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Subject
TKI Dutch Coastline Challenge: Description of the setup of the Delft3D Flexible Mesh model and validation of the hydrodynamics.

Contents

Reviewing procedure.

This memo is reviewed internally by the DCC project team at TUDelft (Bart van Westen, Arjen Luijendijk and Matthieu de Schipper) and aims to support the overall DCC report (DCC Syntheserapport 2023; in Dutch). Further details on the workflow and the model setup are available from the author upon request.

1 Introduction

The overall objective of the Top consortia Knowledge & Innovation project Dutch Coastline Challenge (hereafter, TKI-DCC) is to provide building blocks for climate-neutral and scalable coastal maintenance by designing and evaluating concrete coastal maintenance alternatives for the IJmuiden-Texel coastal section until 2035. The project will focus on (1) sustainable and scalable coastal maintenance concepts and (2) sustainable collaboration in the “triangle” (government, private sector, and knowledge institutions) based on smart methods of collaboration and contracting.

Within work package 2 (WP2), the main question is: Which alternative coastal maintenance concepts are available and what is their impact on the physical and ecological system? This question will be investigated on the basis of three tasks:

1) Generating a set of alternative nourishment concepts and their potential impact.
2) Evaluating the morphological predictive skill of current state-of-the-art modelling.
3) Evaluating the morphological and ecological impact of selected coastal nourishment concepts.

This memo is the second of five memos that collectively constitute the deliverables from Work Package 2 (WP2). These memos are (see Figure 1):

- Memo 1 (M1): Description of the inventory of nourishment alternatives. (*in Dutch: Inventarisatie kustonderhoudsconcepten voor de Dutch Coastline Challenge*)
- Memo 2 (M2): Description of the setup of the Delft3D Flexible Mesh model and validation of the hydrodynamics.
- Memo 3 (M3): Evaluation of the morphological predictive skills of the Delft3D FM model based on simulations of the Sand Engine.
- Memo 4 (M4): Morphological and ecological indicators for the Dutch Coastline Challenge nourishment evaluation (M5).
- Memo 5 (M5): Morphological and ecological evaluation of nourishment concepts.

Several alternative nourishment concepts are presented (*Memo 1*). To predict the (eco)morphological development of these alternatives, a process-based model is set-up (*Memo 2*) and morphologically validated (*Memo 3*). Multiple indicators are defined (*Memo 4*) and used to evaluate a selection of alternative nourishment concepts (*Memo 5*).

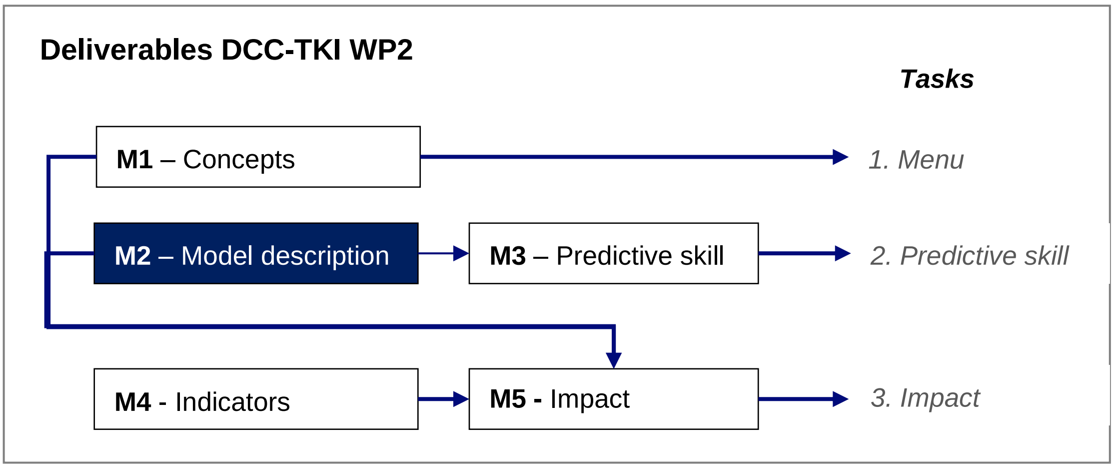

Figure 1 Overview of deliverables (memos) within the DCC-TKI project, relationship with WP2 tasks and interrelationships.

1.1 Scope

In this memo, the set-up of the numerical model for the TKI-DCC project will be described. The main aim is to provide the reader with a basic understanding of the modelling approach. This document is not meant as a complete description of the workflow and methodology.

The model validation is only performed on the hydrodynamics of the model. The (longshore) sediment transports and morphological development are validated in memo #3, as well as the model limitations and recommendations.

1.2 Reader

This memo is divided into two main chapters. In chapter 2, the model set-up will be described, containing an overview of the modelling approach, timing, the model domain and grid parameters, used bathymetry, boundary conditions and meteorological forcing. In chapter 3, the hydrodynamic model outcomes are validated based on water level, waves and currents. A number of set-up and validation figures are included in the appendices.

2 Model set-up

2.1 Modelling approach

The Dutch Coastline Challenge model is run with the Deltares hydrodynamic modeling program Delft3D Flexible Mesh (version 1.2.130.69672M) in depth-averaged mode. The advantage of Delft3D Flexible Mesh (from now referred to as FM) compared to the older (curvilinear) Delft3D v4 model is the possibility to locally refine the computational grid amongst others.

The Dutch Coastline Challenge Flexible Mesh model (DCC-FM) consists out of three individual model-schematizations:

- FM model of the Dutch Coastal Shelf model **(DCSM-FM)**
- Hydrodynamic and morphodynamic model **(DCC-FM-Flow)**
- Wave model **(DCC-FM-Waves)**

The DCSM FM model describes the water levels and currents in the greater North Sea and is used to generate the boundary conditions for coastal DCC-FM-Flow model.
The DCC-FM-Flow model is the core of the model setup and computes the water levels, currents but also the sediment transport and updates of the bed level. The wave model (D-Waves, a module based on the spectral model SWAN; Booij et al., 1999) computes the wave propagation. The D-Flow and D-Waves models are coupled using DIMR. A static coupling interval of 900 seconds (15 minutes) is applied.

The main model parameter settings per model unit and a full parameter list is given in Appendix A.4 and A.5.

A model set-up was created with the aim to enable simulations of over 15 years of morphological development with bruteforce conditions. The boundary conditions are generated for 18 years (2016 to 2034), by repeating a 6-year period (March 1st 2016 – 2022) three times. The time-related model settings are summarized in Table 2, appendix A.1.

2.2 Model subdomains and grid layouts

DCSM-FM

The DCSM-FM model (Zijl et al., 2021)[1], the Dutch Coastal Shelf Model, describes the water levels and currents in the greater North Sea and is used to generate the boundary conditions for the more detailed coastal model (DCC-FM-Flow) through nesting. The used DCSM-FM version is DCSM-FM 0.5nm which covers the entire North Sea (see Figure 2). The unstructured grid of DCSM FM and bathymetry are copies such that the DCC model is identical to the DCSM FM 0.5nm model. The grid resolution is based on the local water depth. It has a relatively coarse schematization, with minimum grid size of 800-900 m in Dutch waters. The grid is specified in geographical coordinates (WGS84).

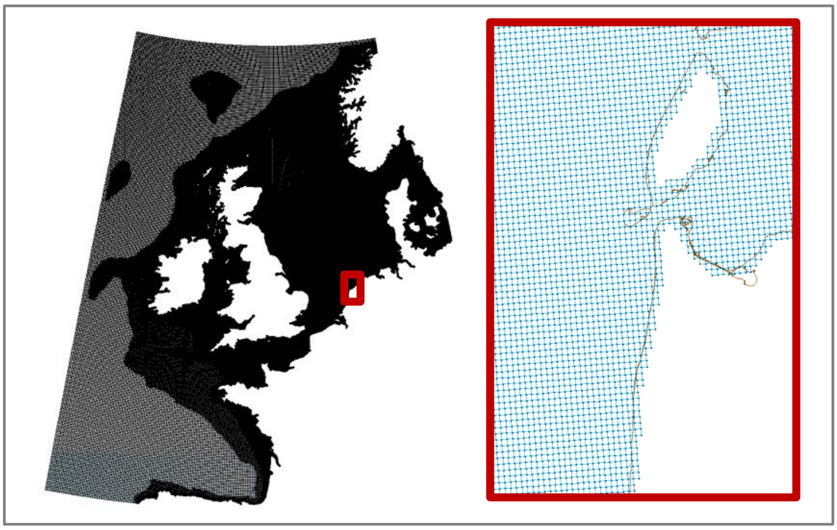

Figure 2 DCSM-FM Grid, screenshot from RGFGRID

The model is already extensively validated and widely applied. Most settings of the DCSM-FM model are used as originally provided, but some modifications have been made. These are elaborated upon below.

- Observation points are added to obtain the conditions along the boundaries of the smaller DCC-FM grid.
- The “structures input” is completely removed. This only contained the discharge from the Oosterscheldekering. Since the Oosterscheldekering is located far away (>100 km) from our area of interest, it is assumed its influence is insignificant.
- Two simulations have been carried out with the DCSM FM model, one with and without meteorological forcing (tide-only), to generate separate timeseries of the astronomical and residual tide for the hydrodynamic validation analysis (see appendix A.2).
- The original DCSM-FM model uses meteorological data from the HIRLAM model provided by the KNMI. We used the ERA5 meteorological data instead, because of the consistent availability over the entire intended evaluation period (2005-present) and spatial domain (§2.5).

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[1] https://www.deltares.nl/app/uploads/2020/12/Development-of-a-3D-model-for-the-NW-European-Shelf-3D-DCSM-FM.pdf

DCC-FM-Flow

The DCC-FM-Flow model domain extends approximately 70 km offshore and covers the entire Holland coast and the western part of the Wadden Sea. The southern boundary extends towards Scheveningen, in order to reduce boundary effects. An unstructured grid is applied. The main advantage of this is the possibility to locally refine resolution and focus on the actual area of interest. The base grid resolution varies from 3000 m offshore to 500 m nearshore (Figure 3, left). In areas where wave breaking is deemed to be important, we aim for a cross-shore resolution of ~20m. The grid is refined several times to achieve this resolution, shown in Figure 3 (right). The network is specified in Cartesian coordinates (Rijksdriehoekscoördinaten, EPSG: 28992). The grid contains ~100.000 cells in case of a refined area limited to Egmond and ~350.000 cells in case the entire Texel and North-Holland are coastlines refined.

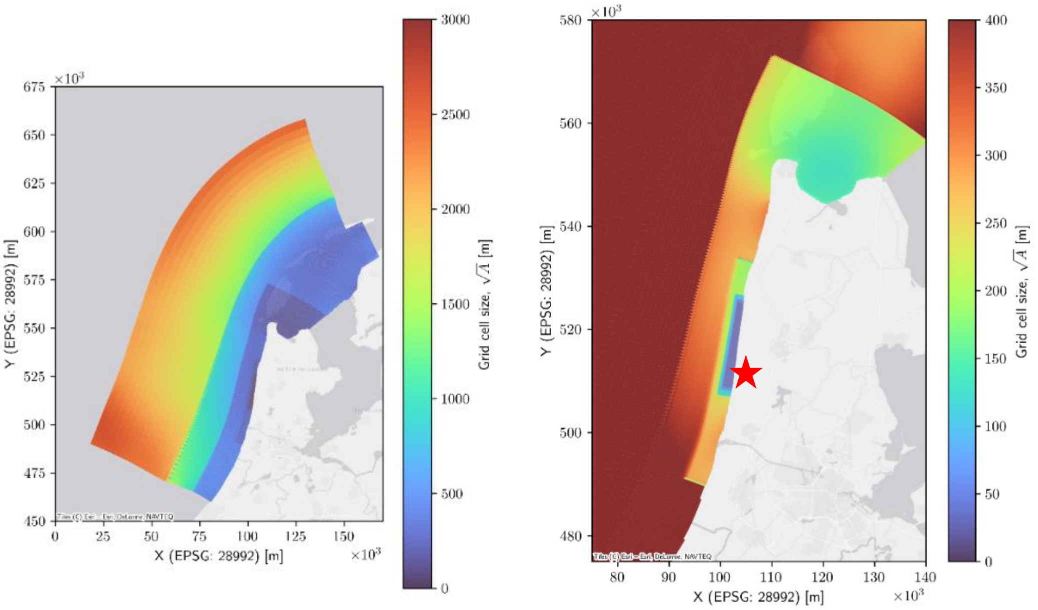


Figure 3 The domain of the DCC-FM FLOW grid including local refinement (left) and zoomed in on the refinements surrounding Egmond (right), indicated by the star.

DCC-FM-Waves

The DCC-FM-Waves module (or SWAN) is not capable of handling unstructured grids and therefore three structured grids are nested to acquire the desired resolution, without having to simulate the entire domain in high resolution. Three grid domains are nested: *fine*, *intermediate* and *coarse* (see appendix A.3, Figure 19). All networks are specified in cartesian coordinates (Rijksdriehoekscoördinaten, EPSG: 28992)

- *Coarse:* The coarsest D-Waves grid is modified from the SWAN-Kuststrook model (Gautier et al., 2018). The southern part, south of Scheveningen, is cut-off and the grid is de-refined. The resolution of the coarsest wave grid varies between 1000 – 2000 $\sqrt{m^2}$ and surrounds the DCC-FM-Flow grid.

- *Intermediate:* The main purpose of the intermediate grid is to transform the waves properly between the coarse and fine grid. The coverage of the intermediate grid varies with the area of interest. At Egmond, the grid extends approximately 10km offshore and has a resolution that varies between 200-300 m.

- *Fine:* The main purpose of the finest wave domain is to properly capture wave breaking in the surfzone. Therefore, a cut-out from the DCC-FM-Flow grid is transformed to a structural grid. The domain extends 1-2 km offshore, corresponding with a water depth of -10 to -12 m+NAP (appendix A.3, Figure 19, right). Originally a 20m cross-shore resolution was proposed, but this resulted in unfeasible computational times. As a consequence, the grid is refined to 40m cross-shore resolution. This coarse resolution means that possibly not all wave breaking processes are captured well, especially under calm conditions. This is likely to cause an underestimation of the longshore sediment transport. This underestimation is considered during morphological calibration and validation (Technische Universiteit Delft, 2023c).

2.3 Bathymetry

All bathymetric data is constructed from Vaklodingen (De Kruif, 2001) and the Hydrographic Service of the Royal Netherlands Navy (Figure 4).

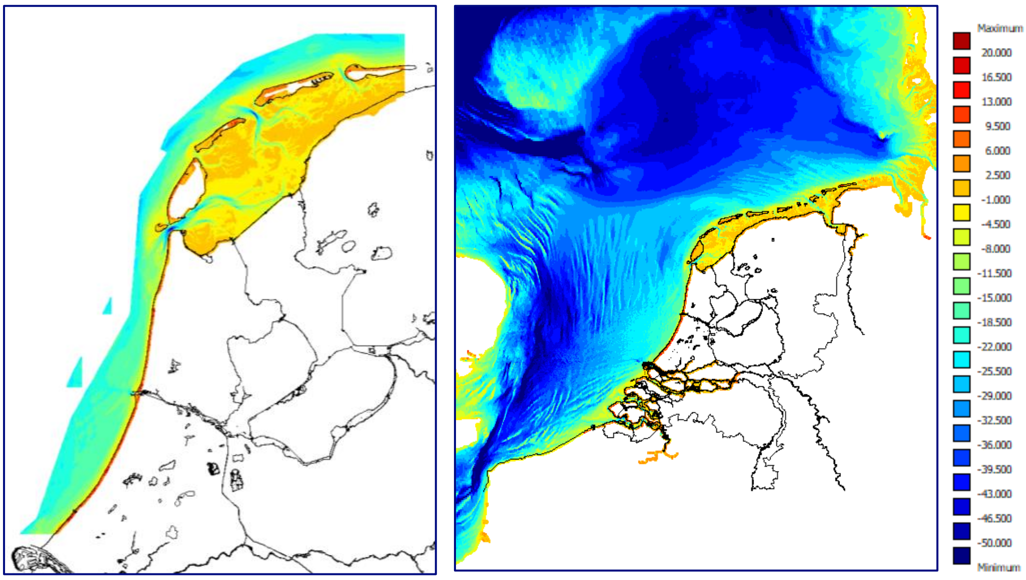


Figure 4 Available bathymetric data from Vaklodingen (left) and the Hydrographic Service of the Dutch Royal Navy / EMODnet (right)

The Vaklodingen bathymetric data has a high resolution (20m) and covers the shallow North Sea and Wadden sea area (till ~ 20m depth). The bed level data of this area is a mosaic for subsections that are surveyed once every few years. The most recent measurements are selected for each subsection, resulting in data mostly from 2016 or 2017.

DCC-Flow-FM

The resulting interpolated bathymetry on the grid of the DCC-FM-Flow model is shown in Figure 5.

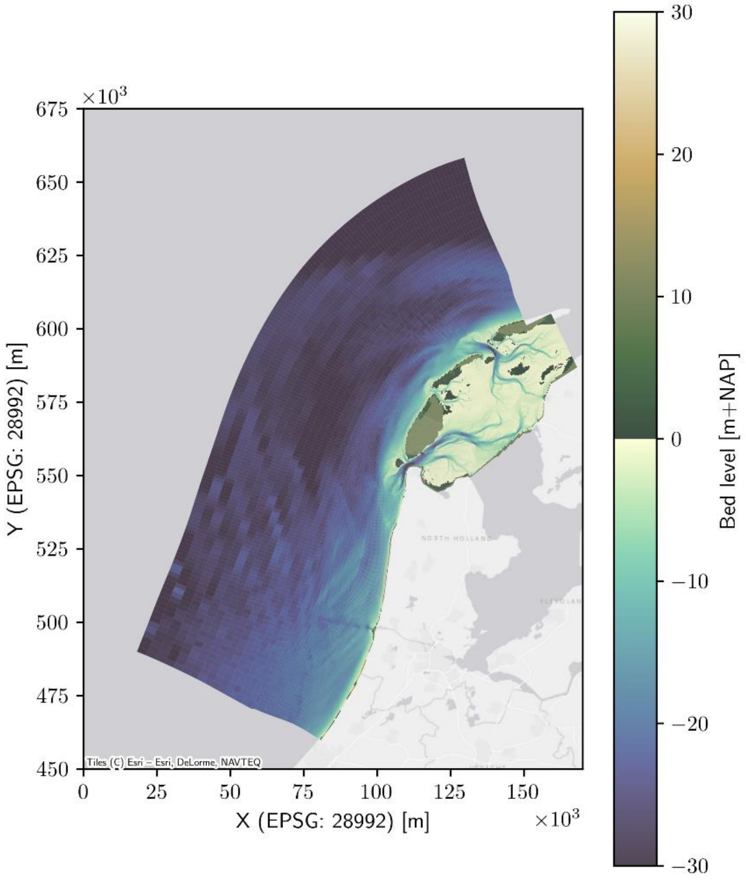


Figure 5 Bathymetry of the DCC-FM model

DCC-FM-Waves
The bathymetry for all three wave grids are based on the same bathymetric file. The bathymetry in the *intermediate* and *fine* grids is coupled to the DCC-FM-Flow bed and updated during the simulation. For the *coarse* grid computation, it is assumed that the morphological changes are relatively small compared to the grid size and therefore a static bed level is chosen.

The different nourishment concepts are implemented in bathymetry files used in the DCC-FM-WAVE and DCC-FM-Flow model domains. More information on the nourishments and their layouts is given in Technische Universiteit Delft (2023c) and Technische Universiteit Delft (2023e).

2.4 Hydrodynamic boundary conditions

DCC-FM-Flow
The conditions imposed on the open boundaries of the DCC-FM-Flow model are timeseries derived from two DCSM-FM model simulations. Both simulations are forced by an astronomical tide and one with wind-induced set-up. This enabled for the creation of timeseries with different compression values for the astronomical and residual tide (§2.6). The boundary conditions are generated for 6-year period (2016-2022), which is repeated twice to generate representative conditions for an 18-year period (2016-2034), with a time interval of 10 minutes (2.5 minutes after compression). The D-Flow model domain is enclosed by four distinct open boundaries (see Figure 6). On the two lateral boundaries (South Boundary, SB and North Boundary, NB) Neumann boundary conditions are imposed. On the other two (Offshore Boundary, OB and Wadden Sea Boundary, WB) water level boundary conditions

are imposed.

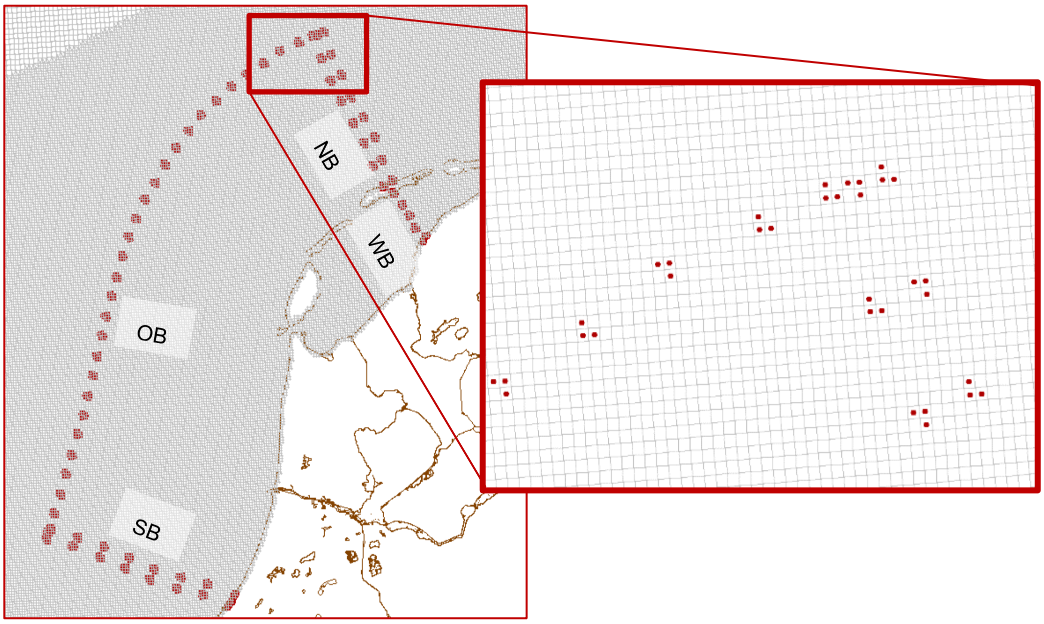


Figure 6 The four open boundaries of the DCC-FM-Flow model, indicated by the observation points generated for the DCSM-FM model. The Southern Boundary (SB), the Offshore Boundary (OB), the Northern Boundary (NB) and the Wadden Sea Boundary (WB).

DCC-FM-Waves
The SWAN offshore wave boundary conditions are obtained from the global ECMWF-WAM model (ECMWF, 2011) as 2D wave spectra. These spectra were imposed on various locations along the open boundary, with values being location dependent. The wave boundary conditions are generated for the same period as the water level conditions, following the same approach (2016-2034), with a time interval of 3 hours (45 minutes compressed). Initially it was planned to use the high-resolution ECMWF-WAM model (0.1º x 0.1º latitude-longitude), but unfortunately, that data were only available from May 2018 onward. Therefore, it was chosen to step back to the low-resolution alternative (1.0º x 1.0º latitude-longitude).

The ECMWF-WAM data is given on a two-dimensional grid covering part of the North Sea (Figure 7, black dots). In order to transform these data onto the open boundaries of the DCC-FM-Wave model, multiple locations along the outer edge of the coarse wave grid are defined (Figure 7, red crosses). The ECMWF model results are projected on these locations through linear interpolation.

There is a large gap in the data availability from 2013 to 2015 in ECMWF-WAM data. It appears that only the so-called *Sinterklaas Storm* was stored, and that continuous storage only continued after March 2015. This date ultimately determined the starting point of the boundary condition timeseries used for the DCC modelling, resulting in a 6 year timeseries (March 1st 2016 – 2022) that were repeated to attain boundary conditions of > 15 years.

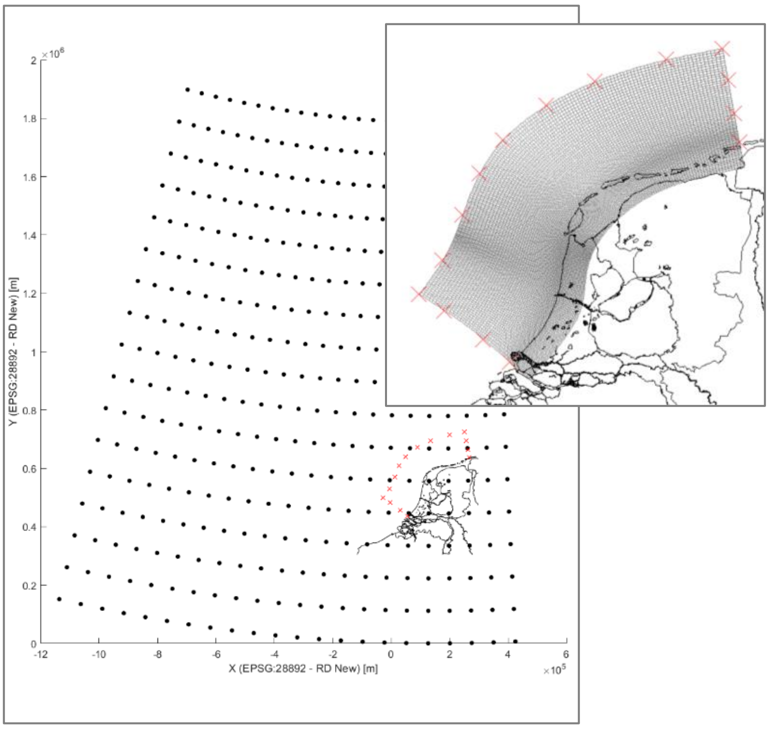


Figure 7 Two-dimensional model coverage of the ECMWF-waves data covering the North Sea (black dots), used for the generation of wave conditions at multiple locations for the coarse wave grid (red crosses).

2.5 Meteorological boundary conditions

All meteorological forcing is obtained from the ERA5 model (Hersbach, 2020). The ERA5 model has a spatial resolution of 30km. The spatial coverage and DCC-FM-Flow grid projected on top of the data are shown in Figure 8.

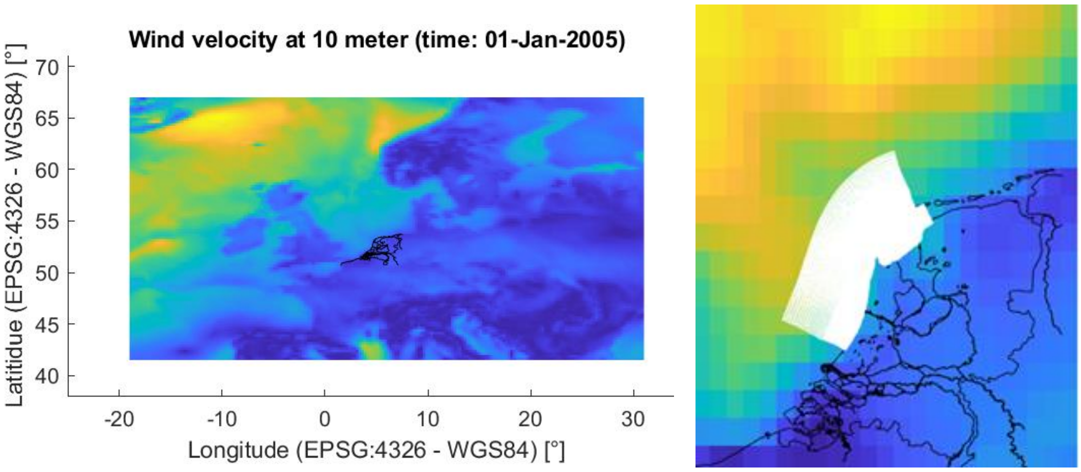


Figure 8 left: Spatial coverage of the ERA5 model (ECMWF) and showing the absolute wind speed at 10-meter height at 01-01-2005. Right: The reduced (spatially) and converted (from spherical to cartesian) ERA5 data and the D-Flow domain of the DCC-FM model (white).

2.6 Model Acceleration

The Delft3D FM model is setup with the aim of evaluating nourishments in with morphodynamic simulations. A description of the morphodynamic settings and an evaluation of the skill morphodynamic simulation is presented in Technische Universiteit Delft (2023c). The diverse scope in terms of nourishment concepts, study area, and potentially driving forces, required an unprecedented high resolution model covering a large domain with brute force time series. To enable such computations a morphological acceleration factor (*morfac*) of 4 is applied to speed-up computations.

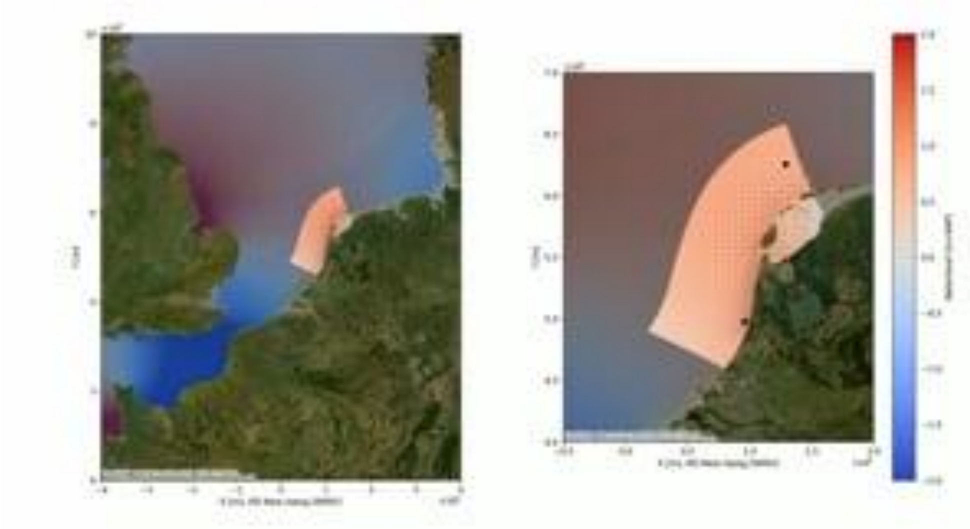
The computations are performed on Deltares' h6 Linux-cluster using 4 nodes with 4 cores each (= 16 cores). The computational speed varies based on grid resolution, forcing and even nourishment concept, but roughly comes down to 1.5-2.0 hour per simulation-day or 23-30 days per year of simulating hydrodynamics. For accelerated calculations with the *morfac* approach this results in 5.8-7.5 days per morphological year.

Although the current memo strictly discusses the hydrodynamics, the compression and *morfac* approach affect the upcoming hydrodynamic timeseries and validation. In order to include seasonality in the model, the imposed boundary conditions are compressed by a factor equal to the *morfac*. This is with exception of the astronomical tide since this would result in unrealistic horizontal tidal currents. This difference requires that the astronomical tide and residual tide are independently post-processed, see appendix A.2 and Figure 18.

3 Validation of the hydrodynamics

In this chapter, a validation is performed on the hydrodynamic model results from DCC-FM-Flow and DCC-FM-Waves on water levels (**§3.1**), waves (**§3.2**) and currents through the Marsdiep (**§3.3**) The selected validation period stretches from 01/03/2016 to 01/03/2017, which is the first (hydrodynamic) year of the simulation. Additional figures are given in appendix 0.

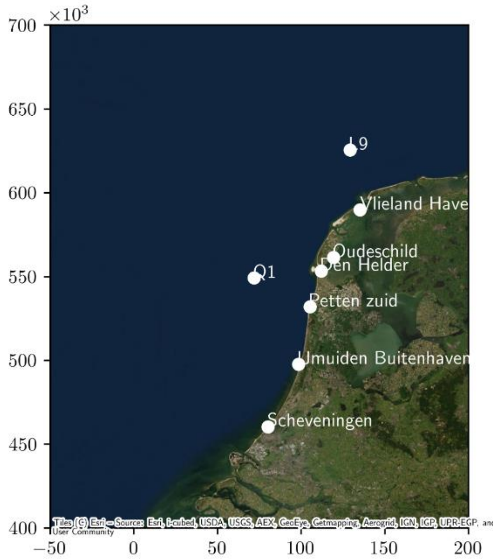
Below an animation is added to visualize the interaction between the DCSM-FM and DCC-FM-Flow domains and provide insight into how the tide propagates through both domains and how this affects the (horizontal) tidal velocities (see Video 1).



Video 1 Visualization of the tidal propagation through the DCSM-FM domain and the projection on the DCC-FM-Flow domain (left) and the resulting (horizontal) tidal velocities in the DCC-FM domain (right). Animation visible online at https://vimeo.com/734009536

3.1 Water levels

The predicted water levels by DCC-FM-Flow are compared with measurements from several observation stations within the modelling domain, shown in Figure 9.



Coastal Area	Name	RDx (m)	RDy (m)
Offshore	L9	129155	625709
	Q1	71732	549328
Nearshore	Scheveningen	79500	459886
	IJmuiden Buitenhaven	98450	497608
Wadden Sea	Vlieland Haven	135303	590119
	Den Helder	111872	553345
	Oudeschild	119001	561578

Figure 9 Selected measurement locations for the validation of water levels modelled by D-Flow

Because of the way the boundary conditions are constructed to accelerate the model, the model results cannot directly be compared to measurements. Therefore, a tidal analysis is performed to filter the astronomical and residual tides from the water level signal, for both the model- and measurement results. The analysis enables us to evaluate the skill of the model for different harmonic components individually.

The results of this tidal analysis, and a comparison of the tidal constituents, is discussed in appendix B.1. Afterwards, a statistical analysis is carried out on the astronomical and residual tide separately:

1) Astronomical tide: not compressed, hydrodynamic timescale
2) Residual tide: compressed, morphological timescale

Harmonic tidal analysis

A harmonic analysis[2] is carried on both the model and measurements results. Accuracy indicators from comparable model studies are used to evaluate the predictions (de Goede & van Maren, 2005), shown in Table 1.

Table 1 Accuracy indicators for the predictive skill of two main tidal constituents by the DCC-FM-Flow model

Parameter	M2	M4
Amplitude	RMS Error < 6%	RMS Error < 25%
Phase	Error < 10°	Error < 25°

The results show that the overall performance of the model is good, since the accuracy requirements outlined in Table 1 are met for almost all locations. This is illustrated with the comparison of the tidal amplitude at IJmuiden Buitenhaven, for which the amplitude errors are 2% and 16 % for the M2 and M4 respectively (Figure 10).

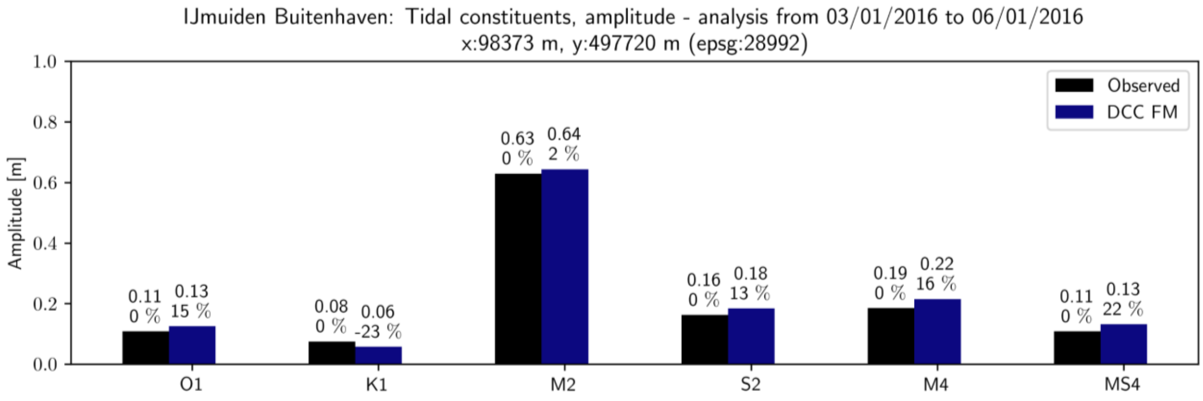


Figure 10 The amplitude of the observed (black) and modelled (blue) tidal constituents for IJmuiden Buitenhaven. Note that the dates in the titles are in the format MM/DD/YYYY, representing a period of 3 months.

The results of the harmonic analysis of for all locations are shown in appendix B.1.1 (amplitude: Figure 20 & Figure 21, phase: Figure 22 & Figure 23). Only the modelled amplitude of the M2-constituent at Scheveningen deviates more than the 6% threshold (+9%). This deviation is deemed acceptable, since Scheveningen is located at the edge of the modelled domain, with a relative coarse resolution and far away from our domain of interest.

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[2] For this harmonic analysis, the Python package *ttide_py* is used. This is a direct conversion of MATLAB's *T_Tide.* https://github.com/moflaher/ttide_py

It should be noted that these results could be further improved by further calibrating the roughness parameter. However, this roughness parameter also impacts the morphological response and is therefore not altered here.

Astronomical tide

The astronomical tide is constructed from the harmonic analysis in the previous section, for both the measured and modelled signals. Subsequently, the results are visually and statistically compared. From these results it is concluded that the tidal signal is reproduced relatively accurate, with a negligible bias and RMSE values in the order of cm’s.
This is illustrated with the comparison of the astronomic tide at IJmuiden Buitenhaven, for which the RMSE is 8.71 cm (Figure 11).Time series for all observation points are shown in appendix B.1.2 (Figure 24 & Figure 25) and scatter plots in appendix B.1.2 (Figure 26).

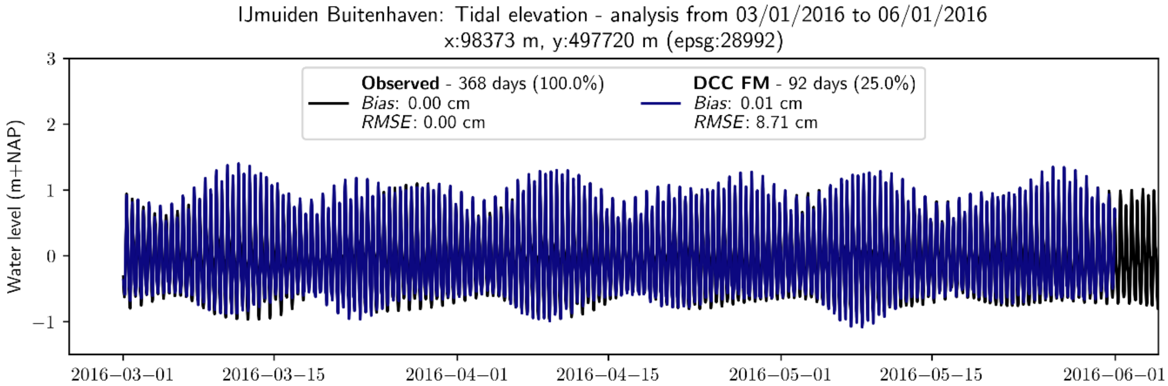


Figure 11 The astronomical tidal signal of the observed (black) and modelled (blue) time series for IJmuiden Buitenhaven, Note that the dates in the title is in the format MM/DD/YYYY, representing over one morphological year, or 3 hydrodynamic months.

Residual tide

The residual tide is constructed by subtracting the astronomical tide from the total time series. It represents the variations in water level due to meteorology, i.e. surge. The model results represent a compressed dataseries with 3 month data representing a full year of data. For a comparison with the observations this data is remapped to a similar timeline. Compared to the astronomical tide, the residual tide is more complex to accurately reproduce. Meteorological forcing and impact are harder to predict than the astronomical forcing. Slight shifts in phasing (couple of hours difference) can already off-set the entire statistical analysis. Also, the pre- and post-processing of the signal, (re-)compression and (re-)construction, potentially contribute to the modelling error.
Results show that the accuracy of the reproduced residual tide is in the order of 15 to 20 cm which is acceptable, given the assumptions and meteorological forcing. This is illustrated with the comparison of the residual tide at IJmuiden Buitenhaven, for which the RMSE is 20.02 cm (Figure 12).

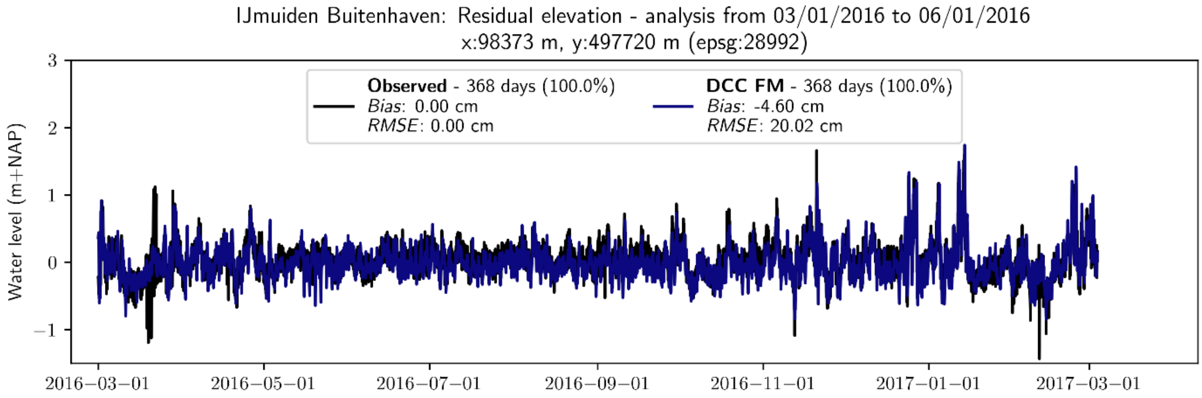
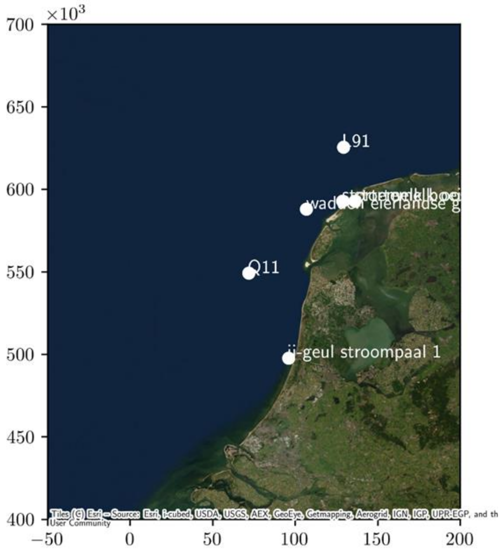


Figure 12 The observed (black) and modelled (blue) residual tidal signal for IJmuiden Buitenhaven, Note that the dates in the title is in the format MM/DD/YYYY, representing over one morphological year, or 3 hydrodynamic months.

The timeseries for all stations are shown in appendix B.1.3 (Figure 27 & Figure 28) and scatter plots in appendix B.1.3 (Figure 29).

3.2 Waves

The validation of the wave height (H_{m0}) and period (T_p) is based on observations from 6 stations in the North Sea and Wadden Sea (Figure 13). The locations are selected based on availability of measurement data in the MATROOS database for the period of interest. The validation is limited to locations located outside the surfzone which are part of the regular multi-year monitoring of the Ministry of Public Works. Modelled nearshore (surfzone) wave characteristics such as breaking in the surfzone are not validated.



Coastal Area	Name	RDx (m)	RDy (m)
Offshore	L9	129155	625709
	Q1	71732	549328
Nearshore	Wadden Eierlandse gat	106604	588063
	IJgeul Stroompaal	95924	497827
Wadden Sea	Stortemelk Boei	128471	593001
	Stortemelk Oost	136028	592921

Figure 13 Selected measurement locations for the validation of wave height, period and direction modelled by D-Waves

The wave conditions are compressed in time due to the application of a *morfac*. One year of original timeseries is condensed to approximately 3 months of wave forcing. In order to compare the computed waves in the domain with actual observations at the measurement stations, the modelled time series are mapped on the time instants in the original timeseries.

The wave height is generally well reproduced by the model, except for the more extreme wave heights. An underprediction of the higher waves could be contributed to the coarse resolution of the ECMWF-WAM data used for the generation of boundary conditions. The wave period is less accurately predicted, especially for the shorter waves.

The model performance is illustrated with the comparison of the wave height at IJ-geul Stroommeetpaal 1, for which the RMSE is 27.50 cm (Figure 14).

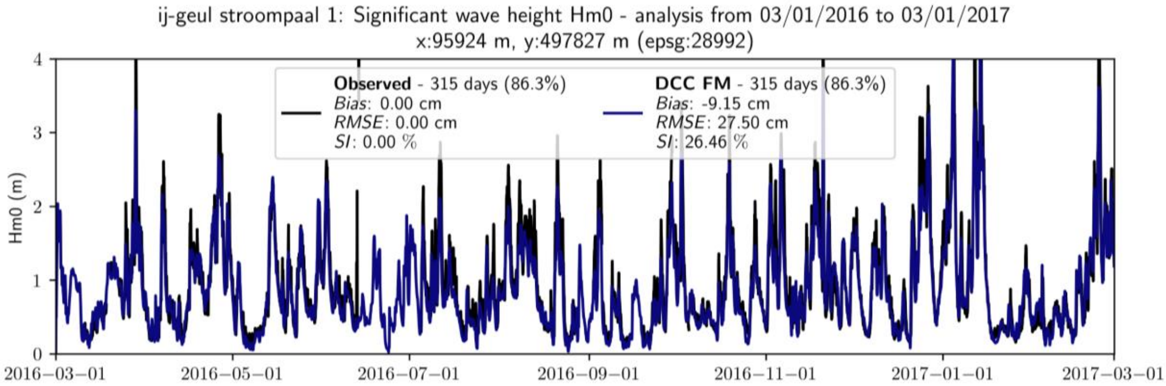


Figure 14 The observed (black) and modelled (blue) significant wave height over one morphological year for IJgeul Stroompaal

The validation results for all stations are collected in appendix B.2.1 and B.2.2 (Figure 33, Figure 34 and Figure 35).

3.3 Currents and Discharge Marsdiep

The currents through the Marsdiep are validated to verify if the model is capable of reproducing the hydrodynamics around tidal inlet(s) of the Wadden Sea. In- and outgoing currents through the inlet influence the (longshore) sediment fluxes along the North Holland and Texel coastline and thus could impact nourishment behavior. An animation is included to visualize these currents through the Marsdiep over one tidal cycle (see Video 2).

Video 2 Currents, mainly induced by tide, through the Marsdiep over one tidal cycle. May also be accessed by going to https://vimeo.com/734006004

The tidal-mean current is computed by averaging the currents over a single tidal cycle (see Figure 15). The resulting spatial pattern compares qualitatively well with measurements carried out by Buijsman & Ridderinkhof (2007), except the model predicts a small outwards tidal-mean current which is not present in the measurements. It has to be noted that the output locations are not exactly equal.

Figure 15 Modelled tidal-mean current through the Marsdiep tidal inlet, computed by averaging current velocities over one tidal cycle (left) compared to the tidal-mean current measured by Buijsman & Ridderinkhof (2007) (right).

The aggregated metric for the hydrodynamic validation of the model is the flow discharge through the Marsdiep. Again, the accuracy requirements by de Goede & van Maren (2005) are used to validate the model outcomes, which states that the net flow discharge through the Marsdiep should be -2000 m^3/s, so a net flow from the Wadden Sea into the North Sea.

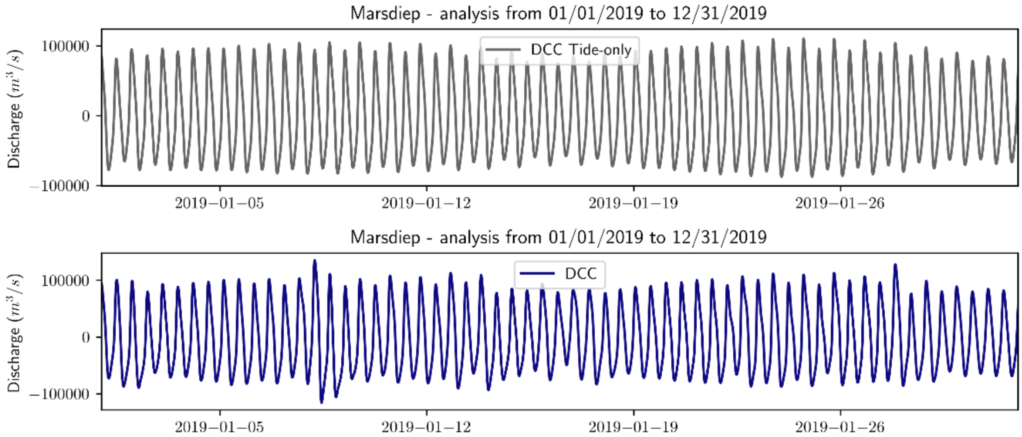


Figure 16 Modelled discharge through the Marsdiep tidal inlet over one month for astronomical tide (top) and full boundary conditions including surge (bottom). Note that the dates in the panel titles are in the format MM/DD/YYYY.

The modelled discharge through the Marsdiep varies between -100.000 and +100.000 m^3/s over a tidal cycle, which is shown in Figure 16. A net flow discharge of -2000 m^3/s is relatively small compared to the total discharge and is therefore expected to be sensitive to small model inaccuracies.

The model predicts a net outflow through the Marsdiep inlet in case of astronomical forcing (Figure 17, grey line) but underestimates the outflow by a factor two compared to the value of de Goede & van Maren (2005) (-883 m^3/s vs. -2000 m^3/s). This underestimation could be the result of the fact that only the western part of the Wadden Sea is included in the model and that the various outlets into the Wadden Sea are not included in the model schematization.

Additionally, the modelled discharge is found to be strongly dependent on the meteorological forcing. Wind set-up at the North Sea side causes the net discharge direction to switch (Figure 17, blue line). The results also nicely show that during calmer conditions (April – September) the net discharge is more similar to the astronomical simulation, while in the winter months the influence of wind set-up is more evident.

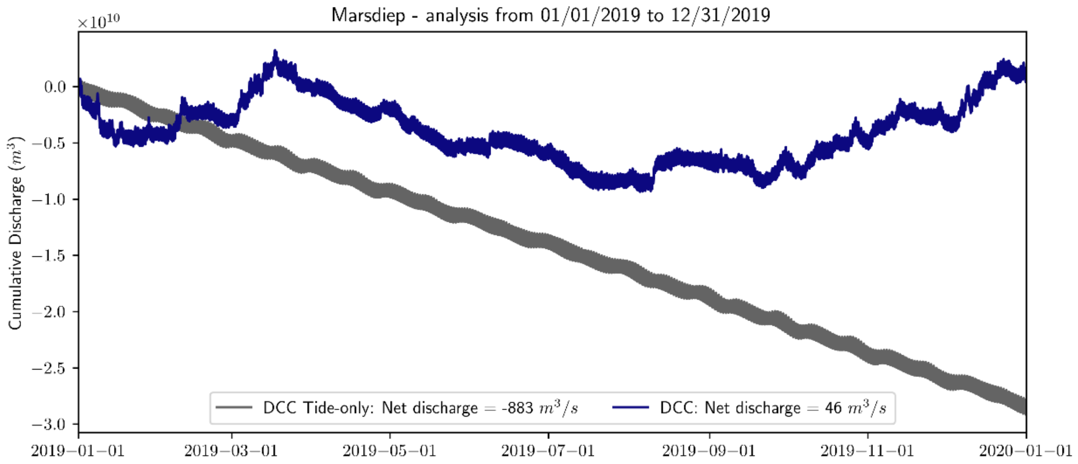


Figure 17 Cumulative modelled net flow discharge through the Marsdiep for only astronomical tide (grey line) and full boundary conditions including surge (blue line).

4 Conclusion

In this memo we present the setup of the numerical model for North Holland and Texel that will be used to evaluate different nourishment concepts. A model schematization is set up that downscales wave, waterlevel and wind conditions on the Dutch coastal shelf to the coastal hydro and morphodynamics at the Northern Holland Coast.
Besides the model setup description, the hydrodynamic outcomes (water levels, waves and currents) are validated with available measurement data. The results show that the model has good skill on the offshore waterlevels, storm surge, waveheights and wave periods. It also reproduces the flow to the nearby tidal inlet well. This performance is essential to obtain correct morphodynamics.The validation of (longshore) sediment transport and the morphodynamic behavior of the model are given in the next memo (Technische Universiteit Delft (2023c). Limitations of the model setup and the related recommendations are also handled in Technische Universiteit Delft (2023c).

The model setup outlined here is used within the TKI-DCC project to quantify several coastal performance indicators (discussed in Technische Universiteit Delft (2023d), which are then applied for the evaluation of a selection of nourishment alternatives (Technische Universiteit Delft (2023e).

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Technische Universiteit Delft (2023d). TKI Dutch Coastline Challenge: Morphological and ecological indicators for the Dutch Coastline Challenge nourishment evaluation. *Memo TU Delft.*

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A Model settings

A.1 Timing

Table 2 Overview of all the time settings related to the different model-components.

Model	Config file	Ref-date	TStart (seconds)	TStart (date)	TStop (seconds)	TStop (hydro-date)	TStop (morph-date)
DCSM	*.mdu	01-01-2005	**0**	*01-01-2005*	**542764800**	*15-03-2022*	-
D-Flow	*.mdu	01-01-2015	**36720000**	*01-03-2016*	**178718400**	*19-10-2021*	*01-03-2034*
D-Wave	*.mdw	01-03-2016[1]	**0**	*01-03-2016*	**141998400**	*19-10-2021*	*01-03-2034*
DIMR	*.xml	01-03-2016[1]	**0**	*01-03-2016*	**141998400**	*19-10-2021*	*01-03-2034*

[1] Based on the starting time of the master-component, so TStart of D-Flow

A.2 Workflow generation of compressed boundary conditions

In order to include seasonality in the model, the imposed boundary conditions are compressed by a factor equal to the *morfac*. Therefore, the astronomical tide and residual tide are independently determined and post-processed, see Figure 18.

Two simulations are run with DCSM-FM to determine the total water level (with meteorology) and the astronomical tide (without meteorology). By subtracting the astronomical tide from the total water level, the residual tide remains. The residual tide is then compressed and added to the non-compressed astronomical tide, to create the final boundary condition.

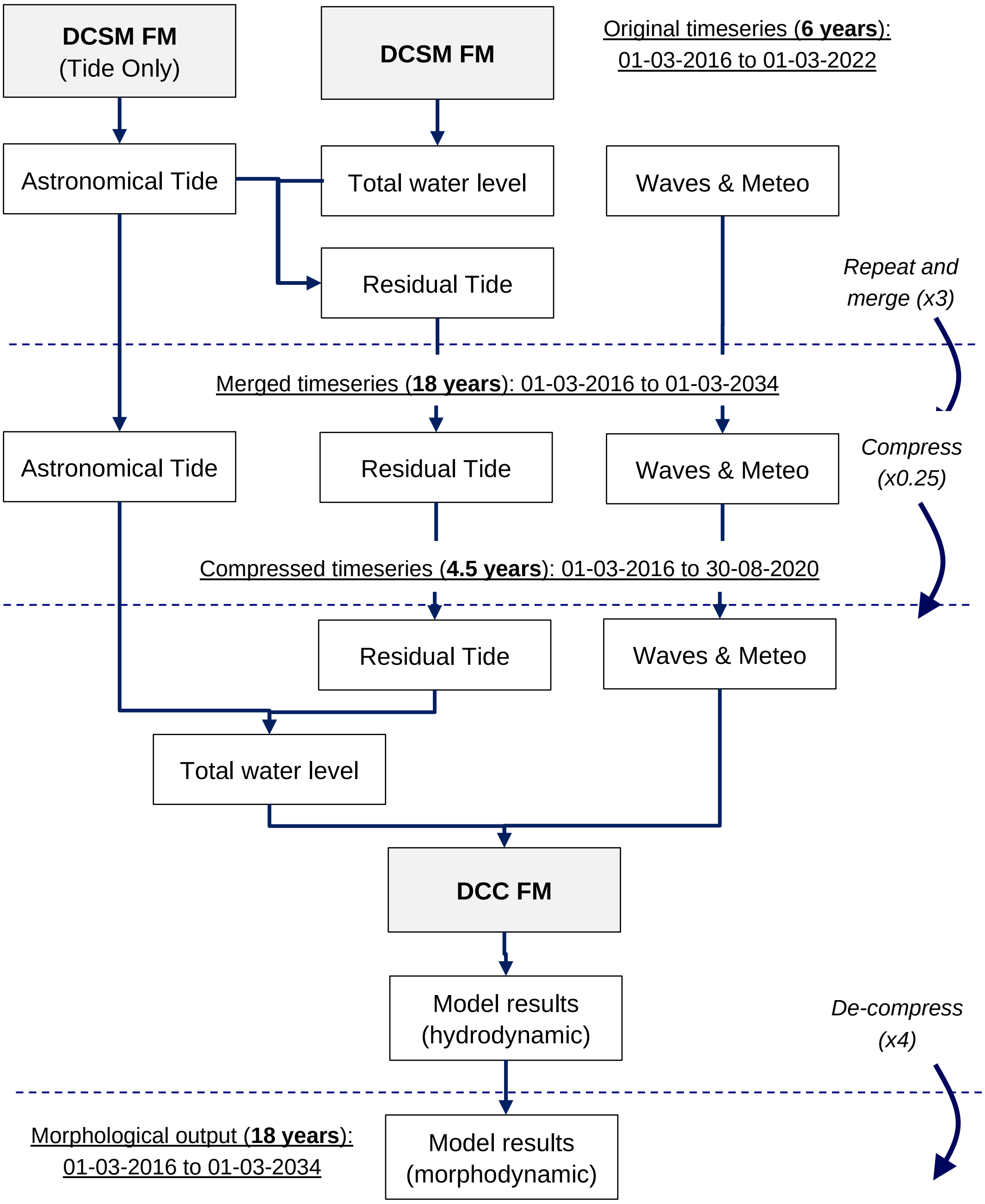


Figure 18 Workflow of the post-processing of timeseries for boundary conditions and forcing.

A.3 D-Waves nested grids

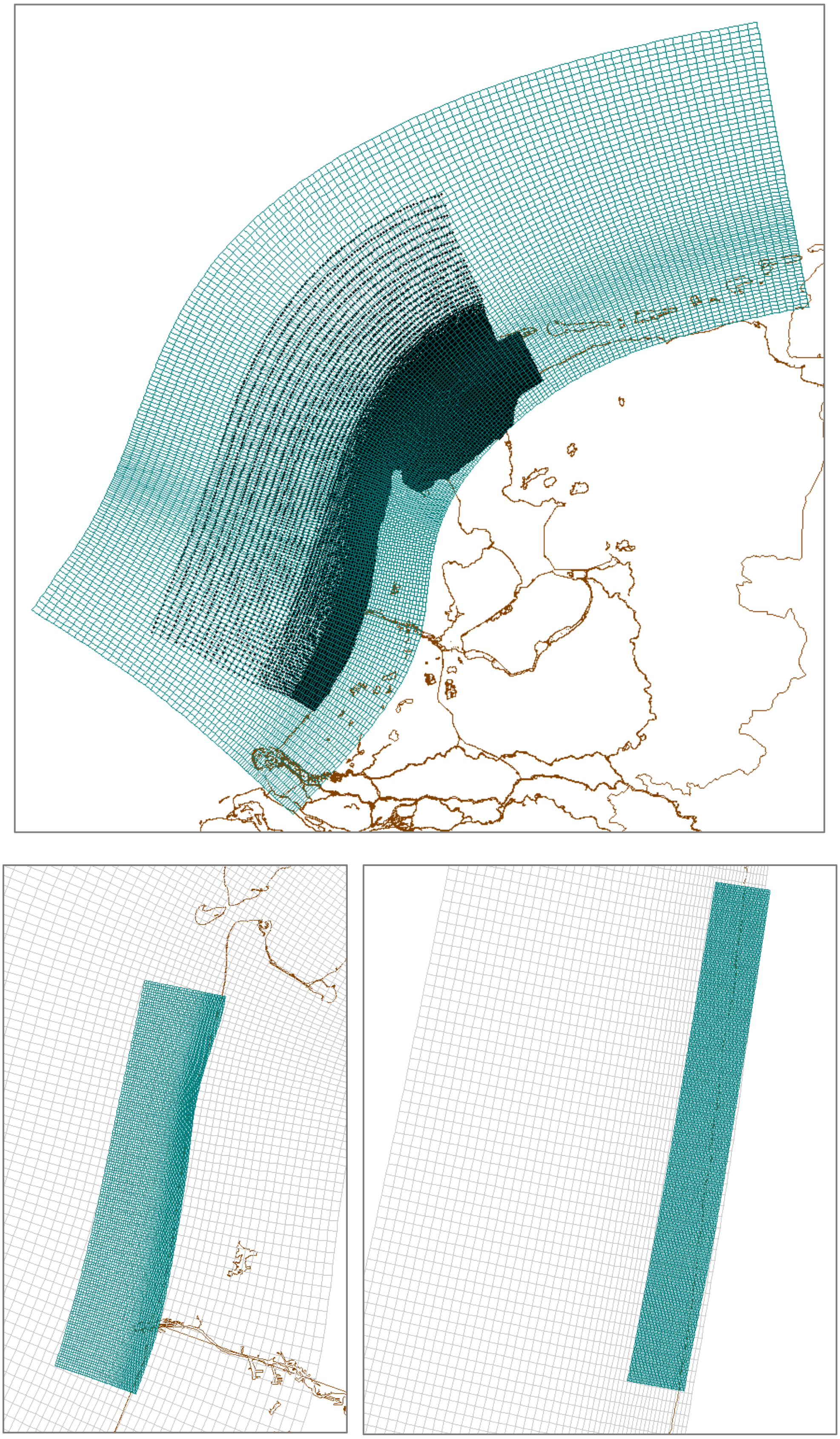


Figure 19 Top: DCC-FM-Waves grid (blue) surrounding the DCC-FM-Flow grid (black), bottom-left: Intermediate, bottom-right: fine grid for the Egmond-simulations

A.4 D-Flow full parameter list

The following section gives the main model parameter settings for the D-Flow model.

Key parameters in the D-Flow model

Model option	Selected approach/parameter value	comments
Bed friction approach	Tracytropes, Van Rijn (2007)	
Timestep (dtmax)	5	Iteratively lowered for computational stability
Threshold water depth (dry/wet)	0.1	
Friction model wave induced shear stress	Van Rijn (2004)	
Medium sand diameter (D50)	250 µm	
Morphological scale factor (morfac)	4	
Multiplication factors for suspended and bedload concentrations (sus, bed)	2	Calibrated based on longshore transport
Wave-related suspended and bedload transport factors (susw, bedw)	0.2	Lowered to stabilize cross-shore behavior
Transport formula	Van Rijn (2007)	Resulted in more realistic longshore transport in deeper water, compared to Van Rijn (1993)

A full list of the settings is visible in the ***.mdu-file** below:

[geometry]		
NetFile	Grid_net.nc	Unstructured grid file *_net.nc
ThinDamFile	../../input/geo/BreakwatersIJmuiden_thd.pli	
Uniformwidth1D	2	Uniform width for channel profiles not specified by profloc
WaterLevIni	0	Initial water level at missing s0 values
Bedlevuni	-5	Uniform bed level used at missing z values
Bedslope	0	Bed slope inclination if BedlevType > 2
BedlevType	1	Bathymetry specification
AngLat	53.5	Angle of latitude S-N, 0: no Coriolis
AngLon	4.6	Angle of longitude E-W, 0: Greenwich, used in solar heat
Conveyance2D	-1	-1: R
Nonlin2D	0	Non-linear 2D volumes, only used if ibedlevtype
Sillheightmin	0	Weir treatment only if both sills larger than this value
Makeorthocenters	0	Switch from circumcentres to orthocentres in geominit
Dcenterinside	1	Limit cell center
Bamin	1.00E-06	Minimum grid cell area, in combination with cut cells
OpenBoundaryTolerance	3	Search tolerance factor between boundary polyline
RenumberFlowNodes	1	Renumber the flow nodes
Kmx	0	Maximum number of vertical layers
Layertype	1	Vertical layer type
Numtopsig	0	Number of sigma layers in top of z-layer model
SigmaGrowthFactor	1	Layer thickness growth factor from bed up
UseCaching	1	Use caching of flow model geometry input
IniFieldFile	inifield.ini	
[numerics]		
CFLMax	0.7	Maximum Courant number
AdvecType	3	Advection type
TimeStepType	2	Time step handling
Limtyphu	0	Limiter type for waterdepth in continuity eqn.
Limtypmom	4	Limiter type for cell center advection velocity
Limtypsa	4	Limiter type for salinity transport
Icgsolver	4	Solver type
Maxdegree	6	Maximum degree in Gauss elimination
FixedWeirScheme	9	Fixed weir scheme

FixedWeirContraction	1	Fixed weir flow width contraction factor
Izbndpos	0	Position of z boundary
Tlfsmo	3600	Fourier smoothing time on water level boundaries
Slopedrop2D	0	Apply drop losses only if local bed slope > Slopedrop2D
Chkadvd	0.1	Check advection terms if depth < chkadvdp,
Teta0	0.55	Theta of time integration (0.5 < theta < 1)
Qhrelax	0.01	Relaxation on Q-h open boundaries
cstbnd	1	Delft3D type velocity treatment near boundaries
Maxitverticalforestersal	0	Forester iterations for salinity
Maxitverticalforestertem	0	Forester iterations for temperature
Turbulencemodel	3	Turbulence model
Turbulenceadvection	3	Turbulence advection
AntiCreep	0	Include anti-creep calculation
Maxwaterleveldiff	0	Upper bound on water level changes
Maxvelocitydiff	0	Upper bound on velocity changes
Epshu	0.1	Threshold water depth for wet and dry cells
[physics]		
UnifFrictType	1	Uniform friction type
UnifFrictCoef	0.021	Uniform friction coefficient
UnifFrictCoef1D	0.023	Uniform friction coefficient in 1D links
UnifFrictCoefLin	0	Uniform linear friction coefficient for ocean models
Umodlin	0	Linear friction umod, for ifrctyp
Vicouv	1	Uniform horizontal eddy viscosity
Dicouv	1	Uniform horizontal eddy diffusivity
Vicoww	0	Uniform vertical eddy viscosity
Dicoww	5.00E-05	Uniform vertical eddy diffusivity
Vicwminb	0	Minimum viscosity in prod and buoyancy term
Smagorinsky	0	Smagorinsky factor in horizontal turbulence
Elder	0	Elder factor in horizontal turbulence
Irov	0	Wall roughness type
wall_ks	0	Nikuradse roughness for side walls
Rhomean	1025	Average water density
Idensform	2	Density calulation
Ag	9.813	Gravitational acceleration
TidalForcing	1	Tidal forcing, if jsferic
Doodsonstart	55.565	TRIWAQ: 55.565, D3D: 57.555
Doodsonstop	375.575	TRIWAQ: 375.575, D3D: 275.555
Doodsoneps	0	TRIWAQ
Salinity	0	Include salinity
InitialSalinity	0	Uniform initial salinity concentration
Sal0abovezlev	-999	Vertical level above which salinity is set 0
DeltaSalinity	-999	for testcases
Backgroundsalinity	30	Background salinity for eqn. of state
InitialTemperature	6	Uniform initial water temperature
Secchidepth	2	Water clarity parameter
Stanton	-1	Coefficient for convective heat flux
Dalton	-1	Coefficient for evaporative heat flux
Backgroundwatertemperature	6	Background water temperature for eqn. of state
SecondaryFlow	0	Secondary flow
BetaSpiral	0	Weight factor of the spiral flow intensity
Temperature	0	Include temperature
[wind]		
ICdtyp	4	Wind drag coefficient type
Cdbreakpoints	0.025	Wind drag coefficient break points
Rhoair	1.2265	Air density
PavBnd	0	Average air pressure on open boundaries
PavIni	0	Average air pressure for initial water level correction
Relativewind	1	Wind speed relative to top-layer water speed
Windhuorzwsbased	0	Wind hu or zws based
Windpartialdry	1	Reduce windstress on water if link partially dry
Stericcorrection	0	Steric correction on waterlevel bnds
[waves]		
Wavemodelnr	3	Wave model nr.
WaveNikuradse	0.01	Wave friction Nikuradse ks c , used in Krone-Swart
Rouwav	VR04	Friction model for wave induced shear stress
Gammax	0.8	Maximum wave height/water depth ratio
[time]		
RefDate	20150101	
Tzone	0	Time zone assigned to input time series
DtUser	60	Time interval for external forcing update [Dd HH:MM:SS.ZZZ]
DtNodal	21600	Time interval (s) for updating nodal factors in astro. bc
DtMax	5	Maximal computation timestep
DtInit	1	Initial computation timestep

Tunit	S	Time unit for start/stop times (H, M or S)
TStart	36720000	
TStop	178718400	
AutoTimestep	1	Use CFL timestep limit or not (1/0)
[external forcing]		
ExtForceFile	../../input/ext_met/BoundaryMaster_meteo_c4.ext	
ExtForceFileNew	../../input/ext_bnd/BoundaryMaster_full_c4_bnd.ext	
[trachytopes]		
TrtRou	Y	
TrtDef	../../input/trachy/vanrijn07.trt	
TrtL	../../input/trachy/vanrijn07.arl	
DtTrt	600	
TrtMxR	8	
TrtCll		
TrtMnH	0.1	
TrtMth	1	
[bedform]		
BedformFile	../../input/trachy/vanrijn07.bfm	
[sediment]		
MorFile	../../input/mor/DCC_FM_sus2.mor	
SedFile	../../input/sed/DCC_FM.sed	
Sedimentmodelnr	4	
MorphoPol	../../input/mpol/mpol.pol	

A full list of the sediment-related settings is visible in the ***.sed-file** below:

[SedimentOverall]		
Cref	1.00E+06	[kg/m3] CSoil Reference density for hindered settling calculations
[Sediment]		
SedTyp	sand	
RhoSol	2.65E+03	[kg/m3] Specific density
SedDia	2.50E-04	[m] Median sediment diameter (D50)
CDryB	1.60E+03	[kg/m3] Dry bed density
IniSedThick	2.00E+01	[m] Initial sediment layer thickness at bed
FacDSS	1.00E+00	[-] FacDss * SedDia
TraFrm	-2	Integer selecting the transport formula
[Sediment]		
SedTyp	sand	
RhoSol	2.65E+03	[kg/m3] Specific density
SedDia	2.50E-04	[m] Median sediment diameter (D50)
CDryB	1.60E+03	[kg/m3] Dry bed density
IniSedThick	0.00E+00	[m] Initial sediment layer thickness at bed
FacDSS	1.00E+00	[-] FacDss * SedDia
TraFrm	-2	Integer selecting the transport formula

A full list of the morphology-related settings is visible in the ***.mor-file** below:

[Morphology]		
EpsPar	false	Vertical mixing distribution according to van Rijn (overrules k-epsilon model)
IopKCW	1	Flag for determining Rc and Rw
RDC	0.01	[m] Current related roughness height (only used if IopKCW <> 1)
RDW	0.02	[m] Wave related roughness height (only used if IopKCW <> 1)
MorFac	4.00E+00	[-] Morphological scale factor
MorStt	8.64E+04	[s] Spin-up interval from TStart till start of morphological changes
Thresh	2.00E-01	[m] Threshold sediment thickness for transport and erosion reduction
MorUpd	true	Update bathymetry during FLOW simulation
EqmBc	true	Equilibrium sand concentration profile at inflow boundaries
DensIn	false	Include effect of sediment concentration on fluid density
AksFac	1.00E+00	[-] van Rijn's reference height
RWave	1.00E+00	[-] Wave related roughness
AlfaBs	1.00E+01	[-] Streamwise bed gradient factor for bed load transport
AlfaBn	1.50E+01	[-] Transverse bed gradient factor for bed load transport
Sus	2.00E+00	[-] Multiplication factor for suspended sediment reference concentration
Bed	2.00E+00	[-] Multiplication factor for bed-load transport vector magnitude
SusW	2.00E-02	[-] Wave-related suspended sed. transport factor
BedW	2.00E-02	[-] Wave-related bed-load sed. transport factor
SedThr	3.00E-01	[m] Minimum water depth for sediment computations
ThetSD	1.00E+00	[-] Factor for erosion of adjacent dry cells
HMaxTH	1.00E-03	[m] Max depth for variable THETSD. Set < SEDTHR to use global value only
FWFac	0.00E+00	[-] Vertical mixing distribution according to van Rijn (overrules k-epsilon model)

A.5 D-Waves full parameter list

The following section gives the main model parameter settings for the D-Waves model.

Key parameters in the D-Waves model

Model settings	Selected approach/parameter value
Breaking parameter	0.73
White capping	Komen
Swan iterations	5
Cutoff criterium iterations	98
Number of frequency bins	20
Number of directional bins	45

A full list of the settings is visible in the ***.mdw-file** below:

`[WaveFileInformation]`	
`FileVersion`	`2.00E+00`
`[General]`	
`ReferenceDate`	`2015-01-01`
`DirConvention`	`nautical`
`SimMode`	`stationary`
`TimeStep`	`6.00E+01`
`TimeInterval`	`2.88E+03`
`OnlyInputVerify`	`false`
`FlowVelocityType`	`depth-averaged`
`DirSpace`	`circle`
`NDir`	`4.50E+01`
`StartDir`	`0.00E+00`
`EndDir`	`3.60E+02`
`NFreq`	`2.00E+01`
`FreqMin`	`3.00E-02`
`FreqMax`	`1.00E+00`
`WaterLevel`	`0.00E+00`
`XVeloc`	`0.00E+00`
`YVeloc`	`0.00E+00`
`ObstacleFile`	`Waves.obt`
`SwanMode`	`lib`
`ScriptName`	`../../input/wave/swansh`
`[Output]`	
`WriteCOM`	`true`
`COMFile`	`../dflowfm/output/DCC_FM_com.nc`
`COMWriteInterval`	`15`
`AppendCOM`	`false`
`MassFluxToCOM`	`true`
`MapWriteInterval`	`7200`
`WriteTable`	`true`
`WriteSpec1D`	`false`
`WriteSpec2D`	`false`
`LocationFile`	`Waves.loc`
`UseHotFile`	`true`
`TestOutputLevel`	`1`
`TraceCalls`	`false`
`MapWriteNetCDF`	`true`
`NetCDFSinglePrecision`	`false`
`[Constants]`	
`WaterLevelCorrection`	`0`
`Gravity`	`9.81`
`WaterDensity`	`1025`
`NorthDir`	`90`
`MinimumDepth`	`0.05`
`[Processes]`	
`GenModePhys`	`3`
`WaveSetup`	`false`

Breaking	true
BreakAlpha	1
BreakGamma	0.73
Triads	true
TriadsAlpha	0.05
TriadsBeta	2.5
BedFriction	jonswap
BedFricCoef	0.038
Diffraction	false
DiffracSteps	0
DiffracProp	true
DiffracCoef	0.2
WindGrowth	true
Quadruplets	true
WhiteCapping	Komen
Refraction	true
FreqShift	true
WaveForces	dissipation 3d
[Numerics]	
DirSpaceCDD	0.5
FreqSpaceCSS	0.5
RChHsTm01	0.02
RChMeanHs	0.02
RChMeanTm01	0.02
PercWet	98
MaxIter	5
[Boundary]	
Definition	fromsp2file
OverallSpecfile	../../input/wave/ECMWF_2015_2034_c4.SP2
[Domain]	
Grid	coarse_deref.grd
BedLevel	coarse_deref.dep
MeteoFile	../../input/meteo/Meteo_20160301_20340301_refDate_20150101_EPSG_28992_c4.amu
MeteoFile	../../input/meteo/Meteo_20160301_20340301_refDate_20150101_EPSG_28992_c4.amv
Output	true
FlowBedLevel	0
FlowWaterLevel	2
FlowVelocity	0
FlowWind	0
[Domain]	
Grid	inter_cut.grd
BedLevel	inter_cut.dep
NestedInDomain	1
Output	true
FlowBedLevel	1
FlowWaterLevel	1
FlowVelocity	0
FlowWind	1
[Domain]	
Grid	fine_40m.grd
BedLevel	fine_40m.dep
NestedInDomain	2
Output	true
FlowBedLevel	1
FlowWaterLevel	1
FlowVelocity	0
FlowWind	1

B Hydrodynamic validation results

B.1 Water levels

B.1.1 Harmonic tidal analysis

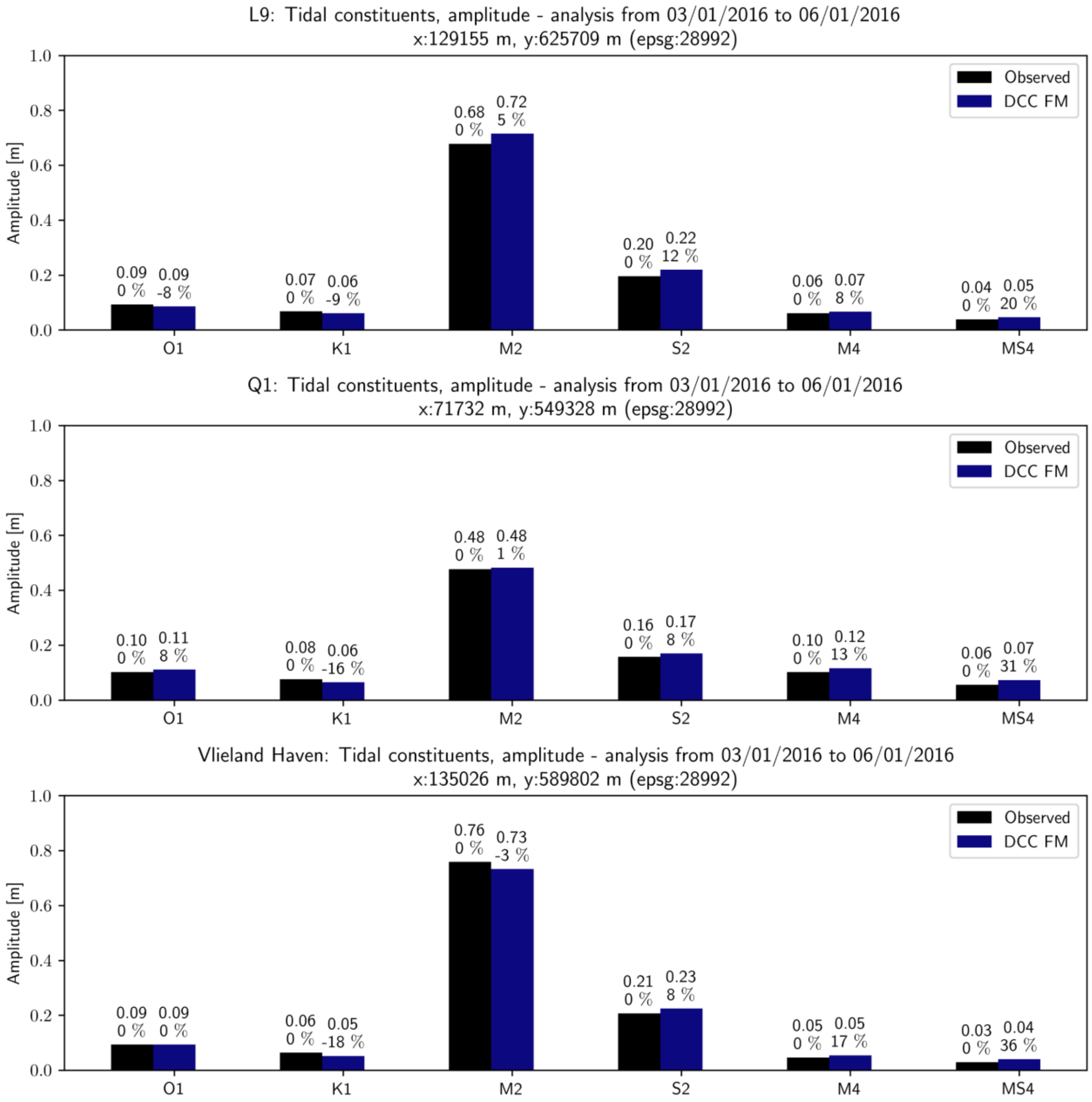


Figure 20 The amplitude of the observed (black) and modelled (blue) tidal constituents for the L9, Q1 and Vlieland Haven locations. Note that the dates in the titles are in the format MM/DD/YYYY.

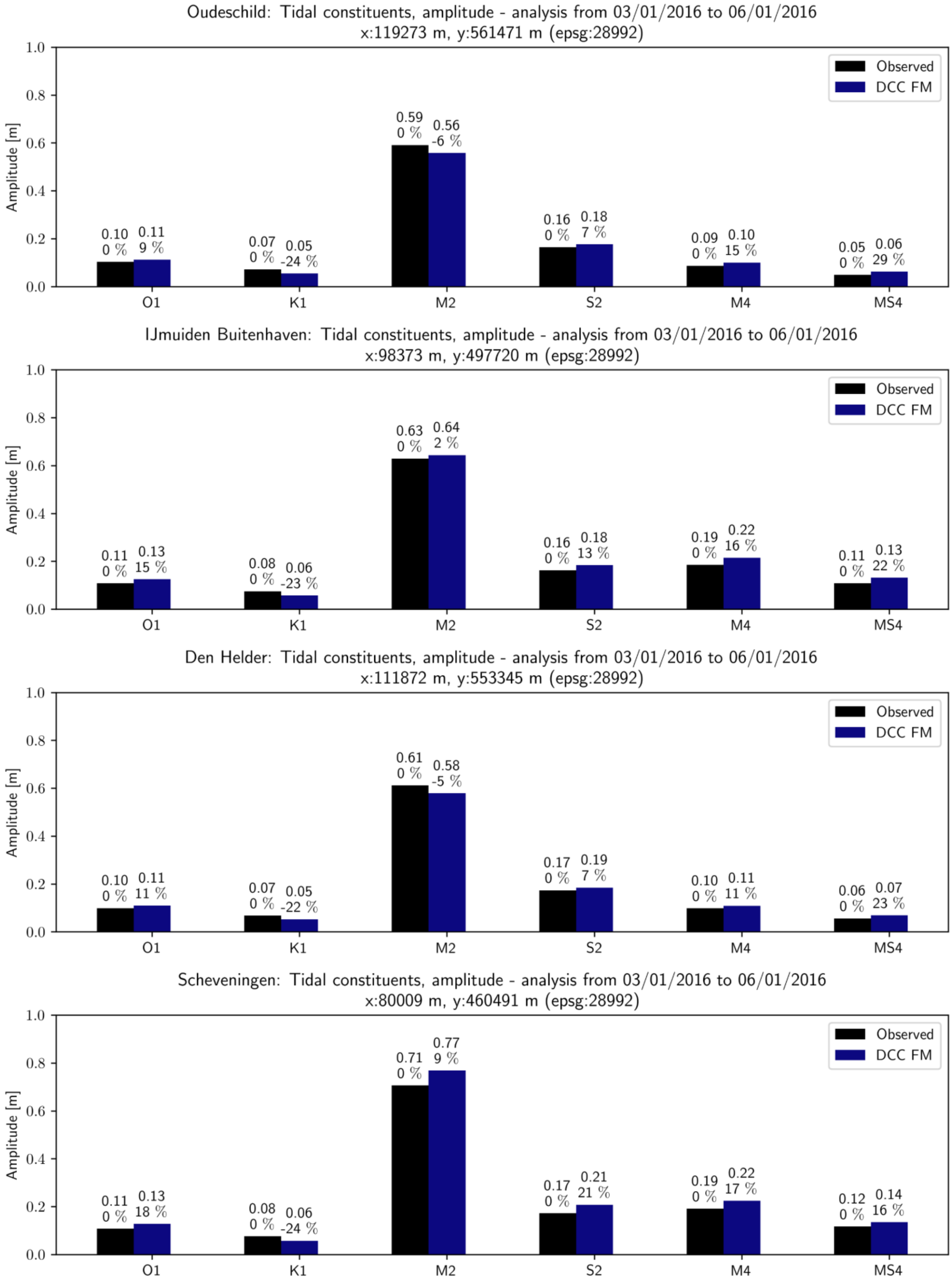


Figure 21 The amplitude of the observed (black) and modelled (blue) tidal constituents for the Oudeschild, IJmuiden Buitenhaven, Den Helder and Scheveningen locations. Note that the dates in the titles are in the format MM/DD/YYYY.

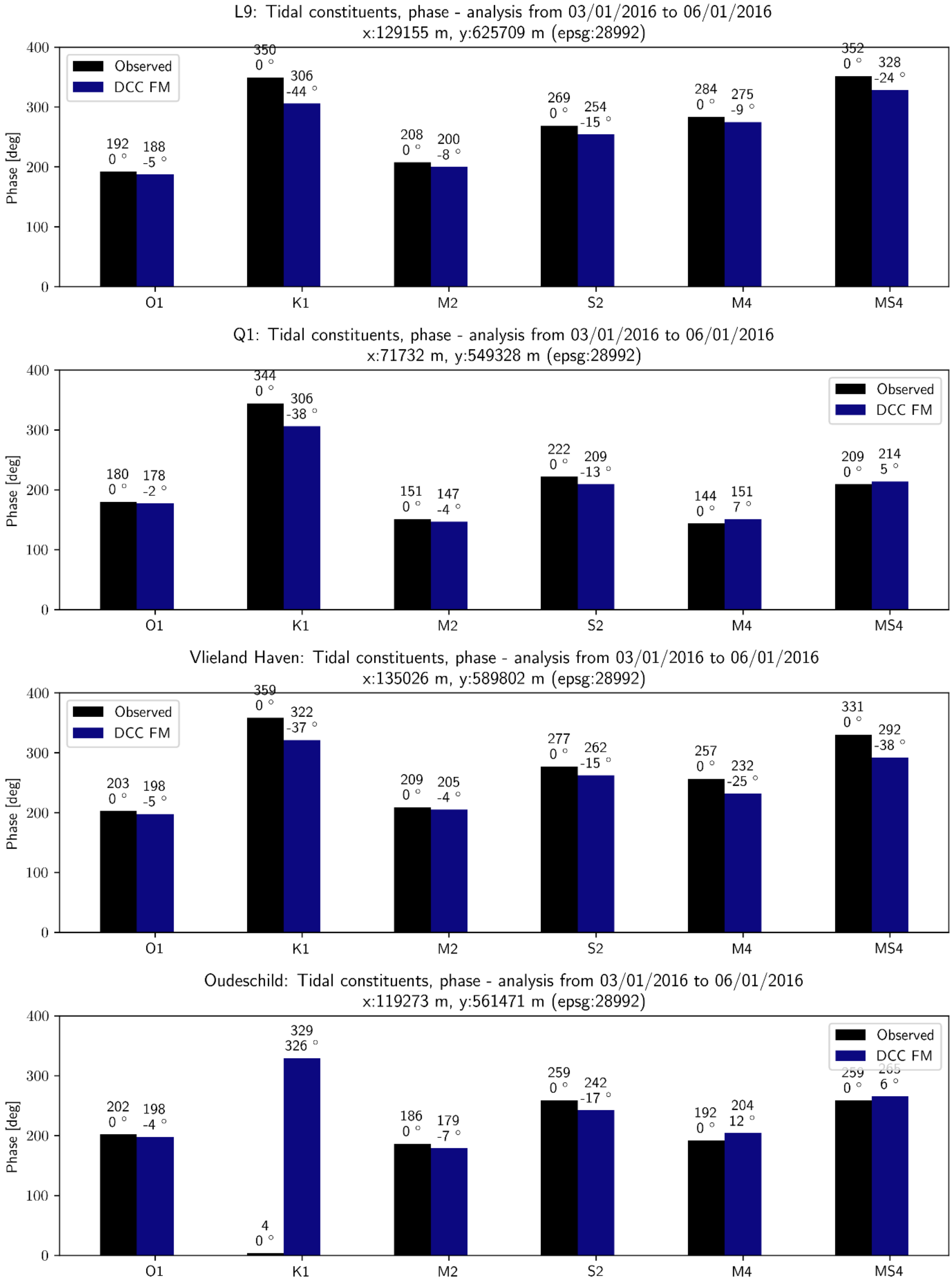


Figure 22 The phase of the observed (black) and modelled (blue) tidal constituents for the L9, Q1, Vlieland Haven and Oudeschild locations. Note that the dates in the titles are in the format of MM/DD/YYYY.

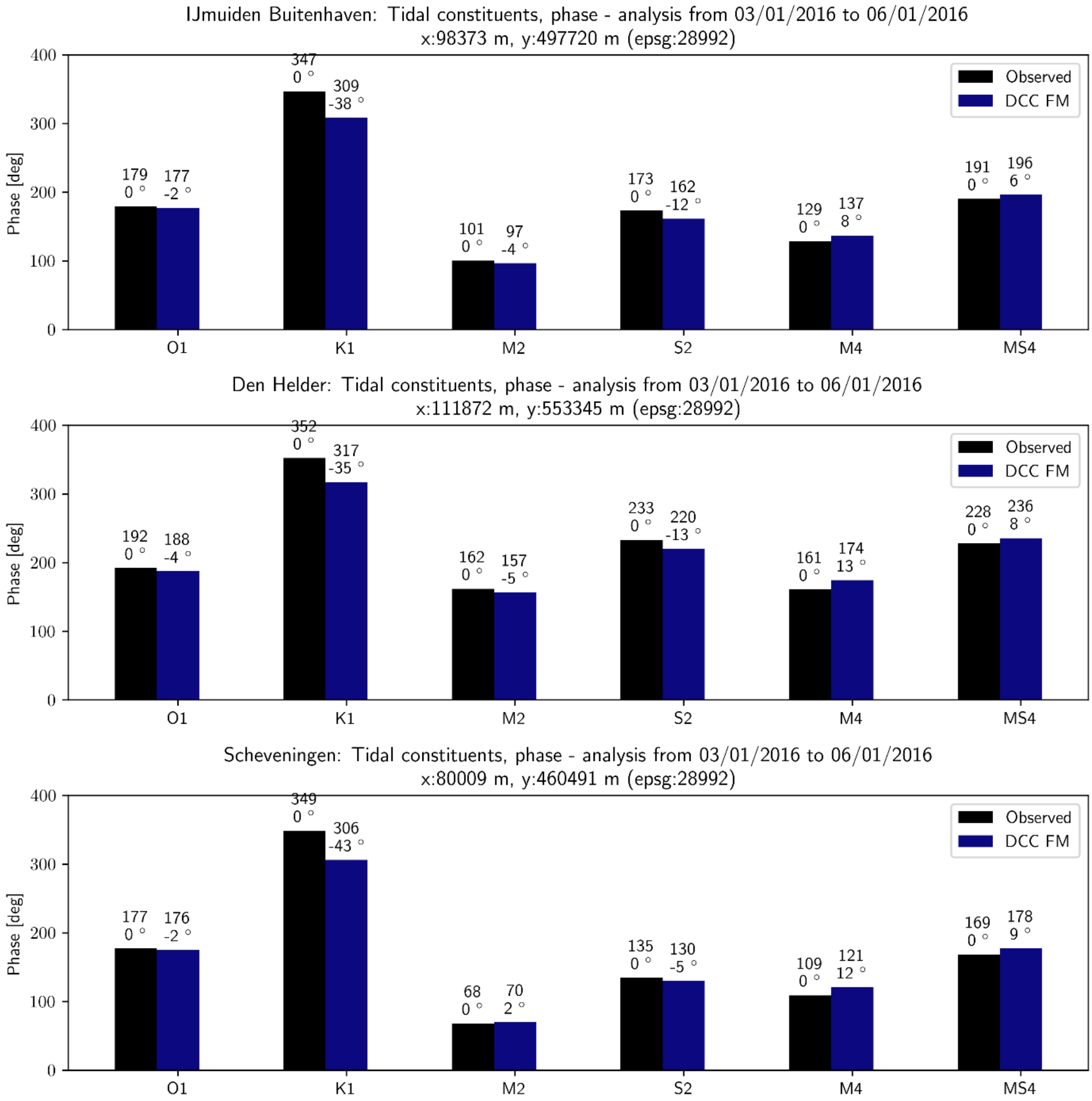


Figure 23 The phase of the observed (black) and modelled (blue) tidal constituents for the IJmuiden Buitenhaven, Den Helder and Scheveningen locations. Note that the dates in the titles are in the format of MM/DD/YYYY.

B.1.2 Astronomical tide

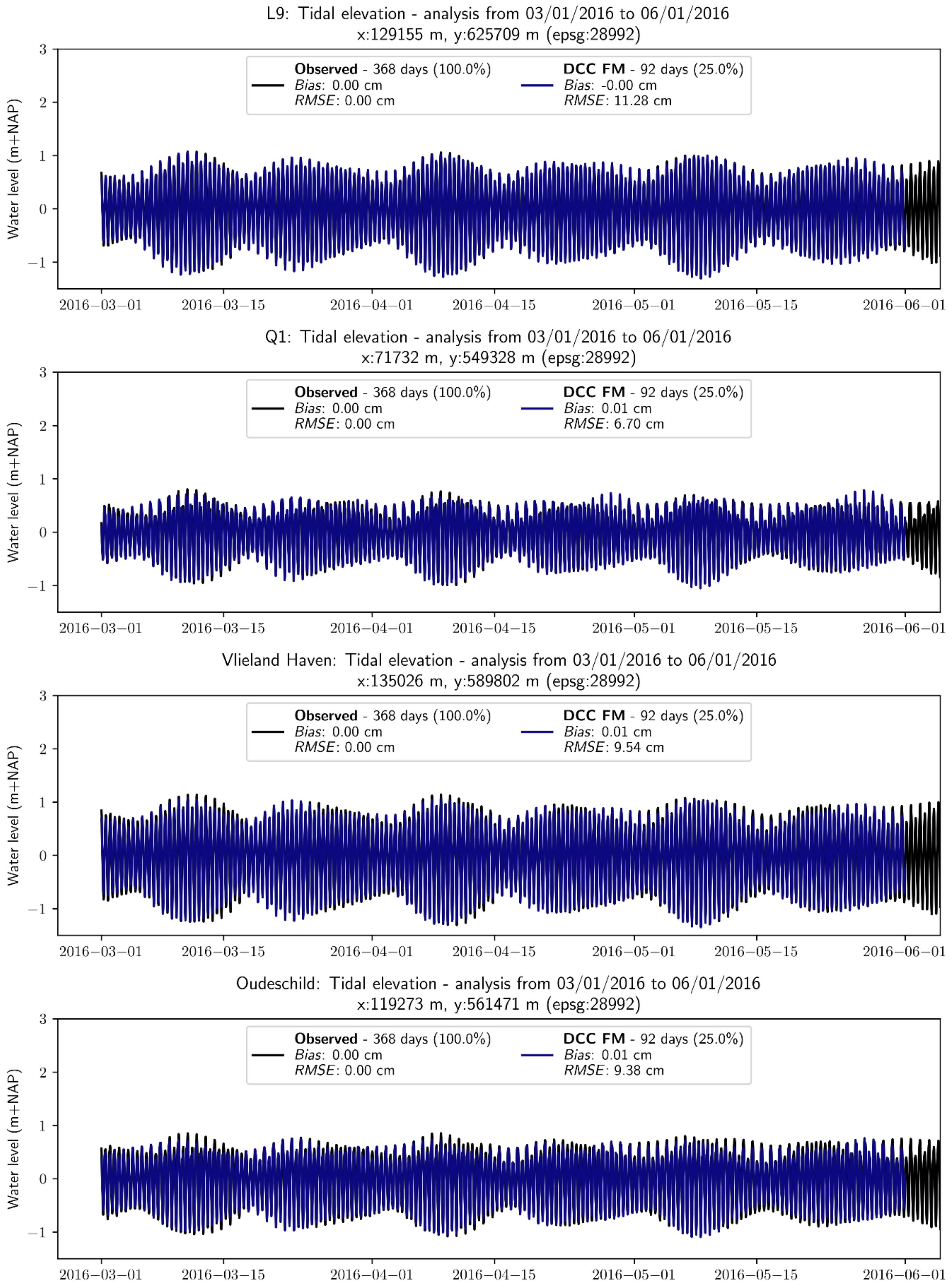


Figure 24 The astronomical tidal signal of the observed (black) and modelled (blue) timeseries of the over one morphological year, or 3 hydrodynamic months, for L9, Q1, Vlieland Haven and Oudeschild).

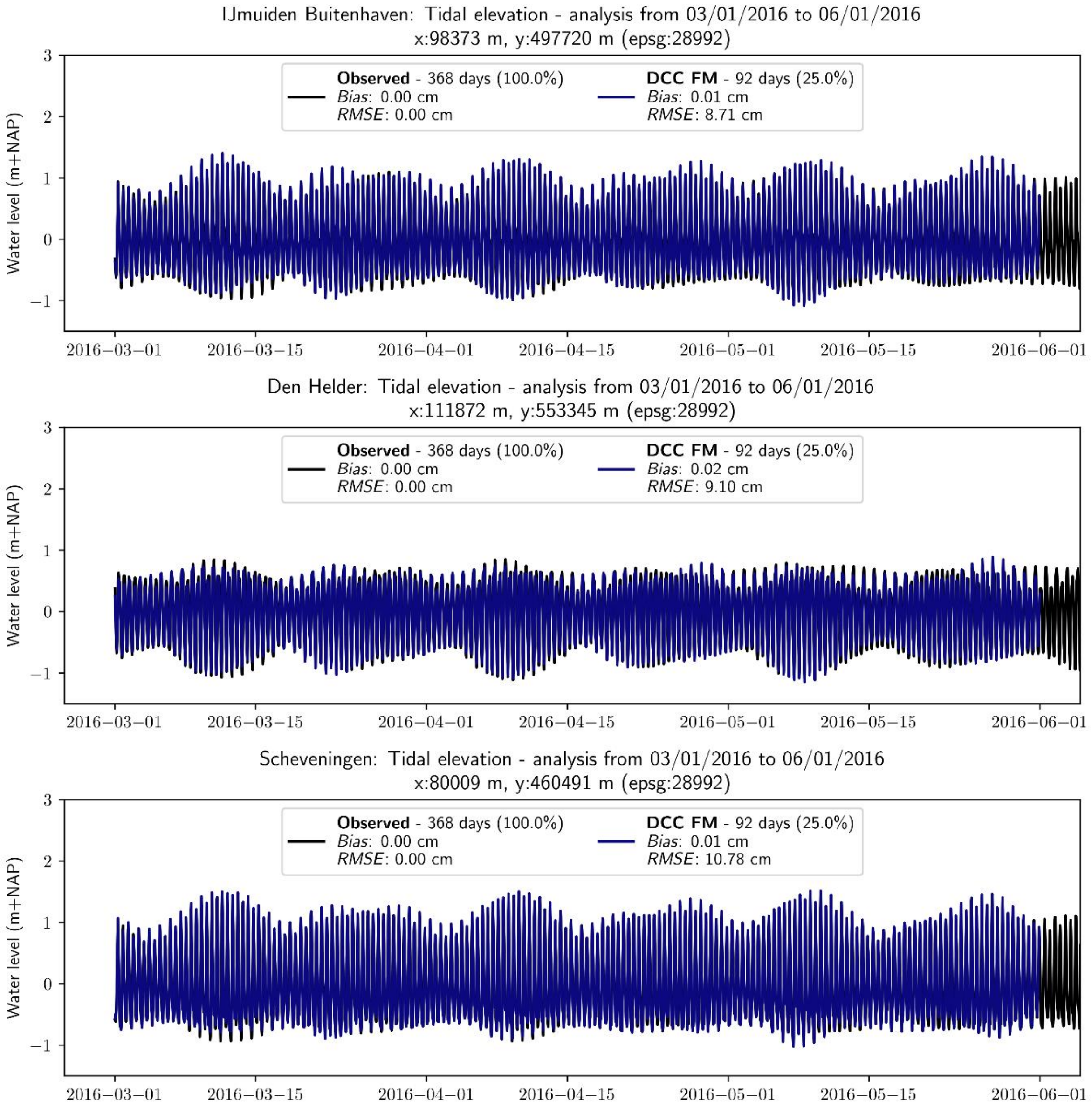
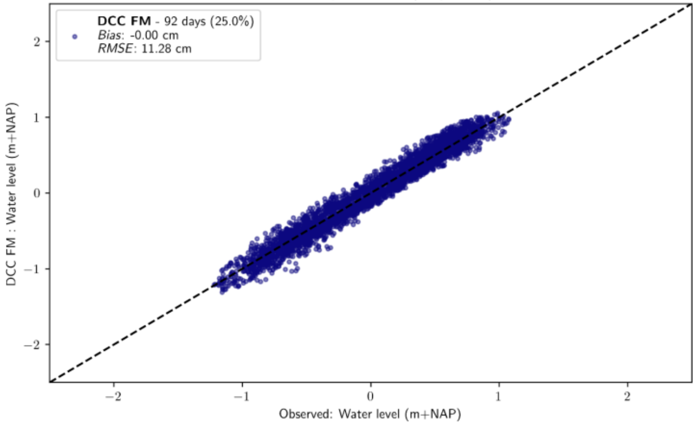
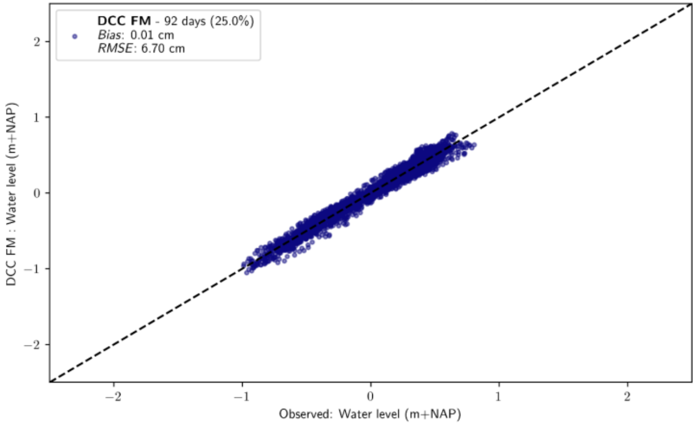


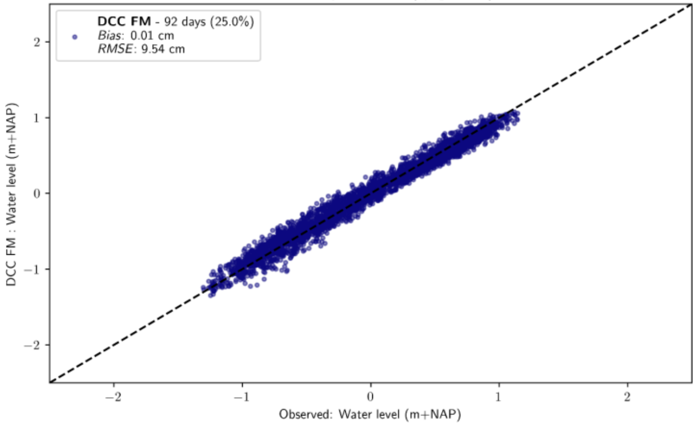
Figure 25 The astronomical tidal signal of the observed (black) and modelled (blue) timeseries for IJmuiden Buitenhaven, Den Helder and Scheveningen. Note that the dates in the titles are in the format MM/DD/YYYY.



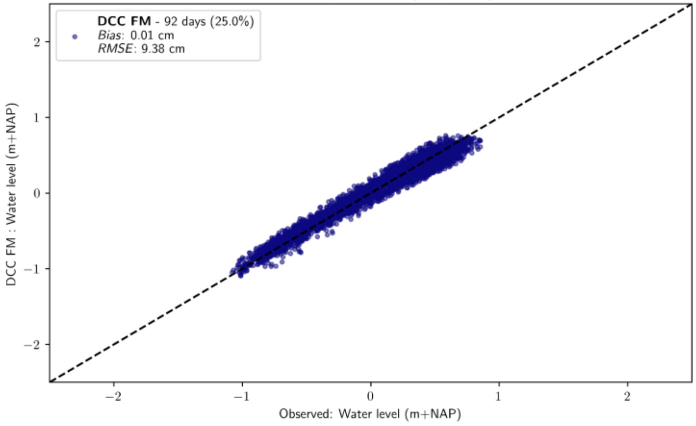
L9: Tidal elevation - analysis from 03/01/2016 to 06/01/2016
x:129155 m, y:625709 m (epsg:28992)



Q1: Tidal elevation - analysis from 03/01/2016 to 06/01/2016
x:71732 m, y:549328 m (epsg:28992)



Vlieland Haven: Tidal elevation - analysis from 03/01/2016 to 06/01/2016
x:135026 m, y:589802 m (epsg:28992)



Oudeschild: Tidal elevation - analysis from 03/01/2016 to 06/01/2016
x:119273 m, y:561471 m (epsg:28992)

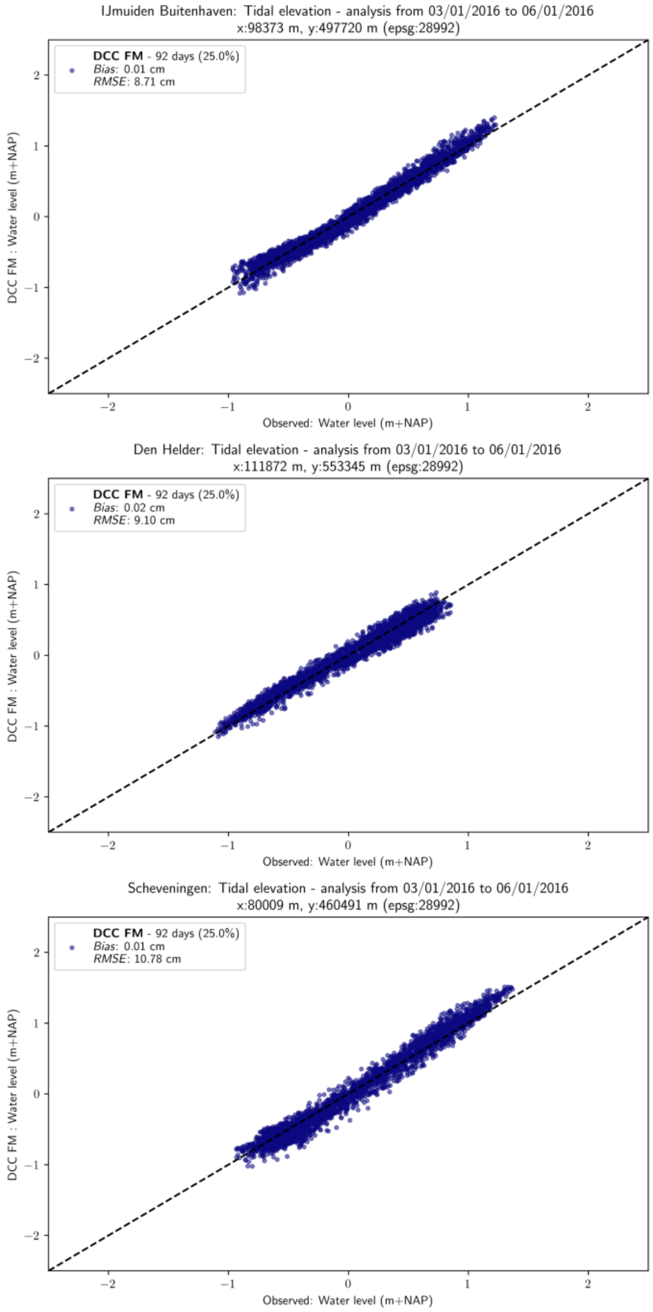
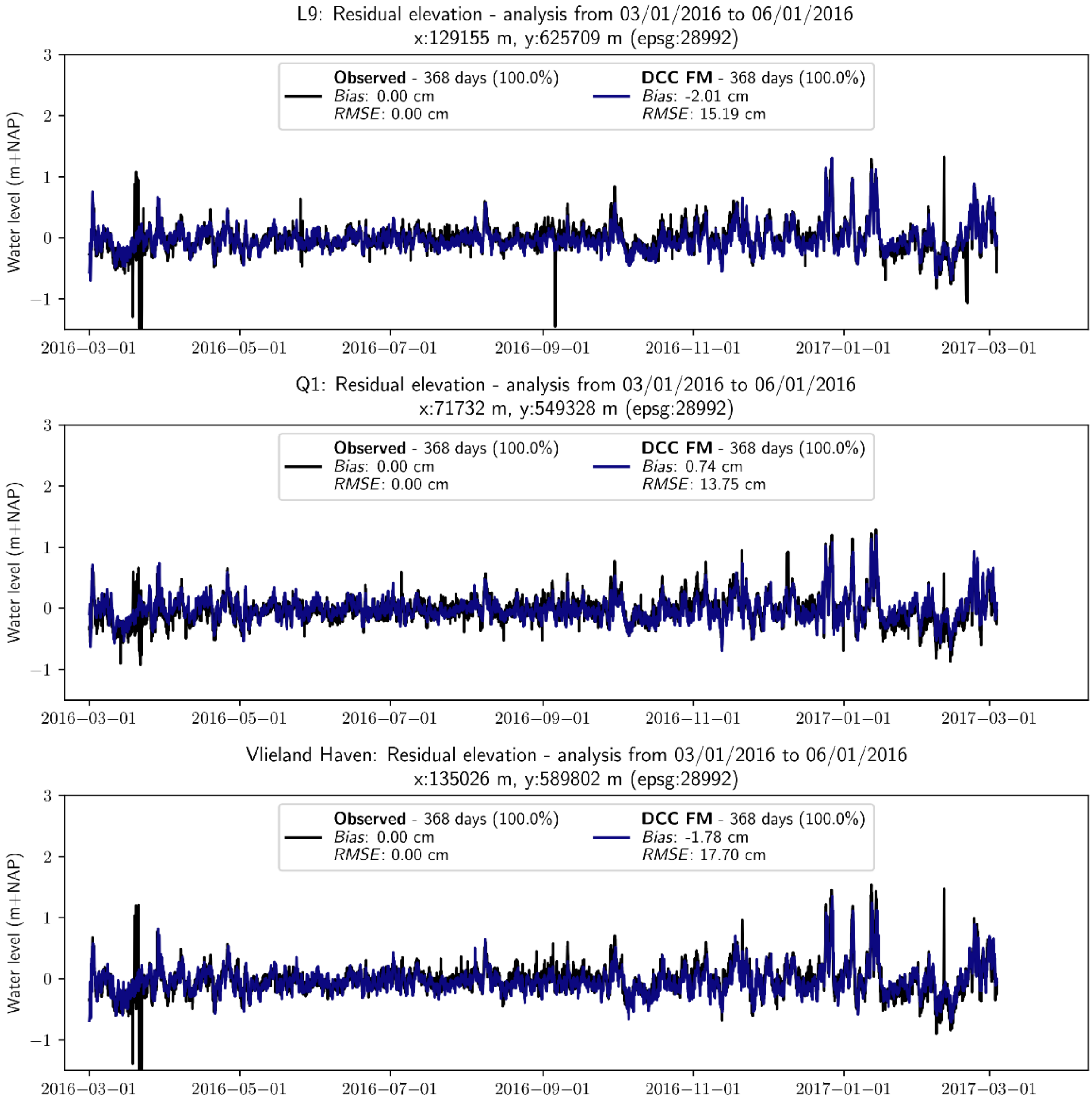


Figure 26 Scatter plot the modelled tidal signal compared to the observed signal. Note that the dates in the titles are in the format MM/DD/YYYY, representing three hydrodynamic months.

B.1.3 Residual tide



L9: Residual elevation - analysis from 03/01/2016 to 06/01/2016
x:129155 m, y:625709 m (epsg:28992)

Q1: Residual elevation - analysis from 03/01/2016 to 06/01/2016
x:71732 m, y:549328 m (epsg:28992)

Vlieland Haven: Residual elevation - analysis from 03/01/2016 to 06/01/2016
x:135026 m, y:589802 m (epsg:28992)

Figure 27 The observed (black) and modelled (blue) residual tidal signal over one morphological year (upper) for L6, Q1 and Vlieland Haven

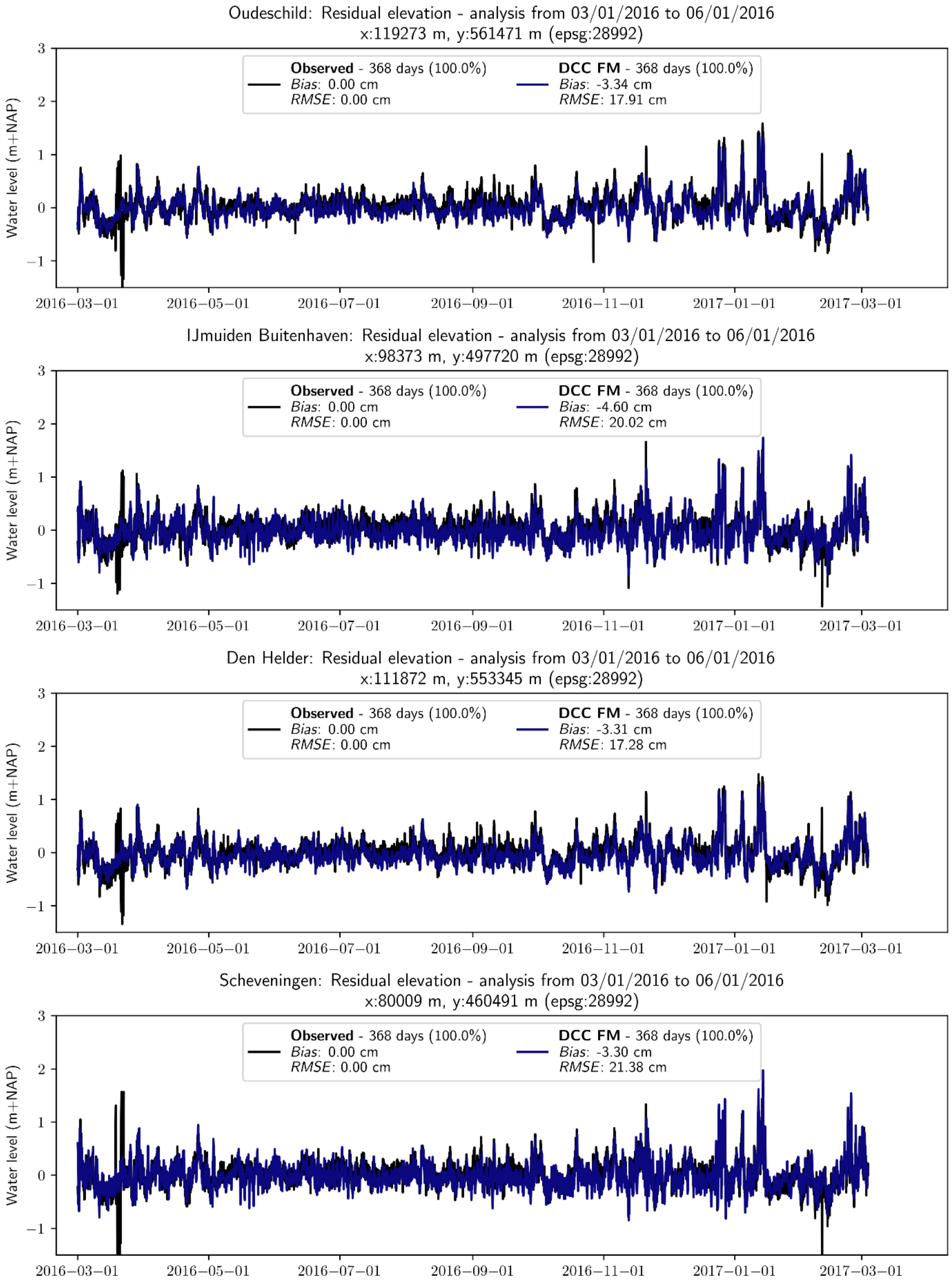
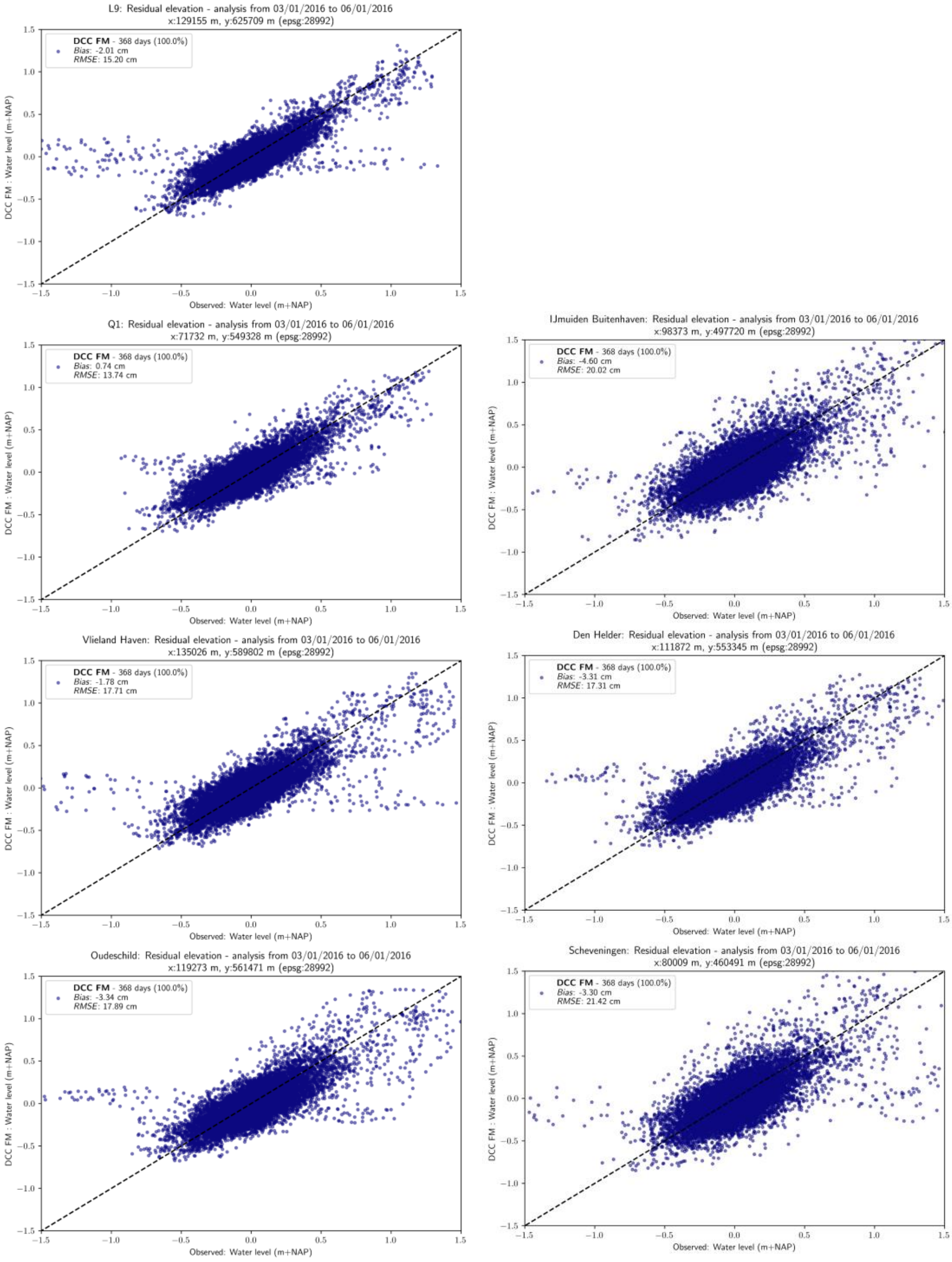


Figure 28 The observed (black) and modelled (blue) residual tidal signal over one morphological year (upper) for Oudeschild, IJmuiden Buitenhaven, Den Helder and Scheveningen



L9: Residual elevation - analysis from 03/01/2016 to 06/01/2016
x:129155 m, y:625709 m (epsg:28992)

Q1: Residual elevation - analysis from 03/01/2016 to 06/01/2016
x:71732 m, y:549328 m (epsg:28992)

IJmuiden Buitenhaven: Residual elevation - analysis from 03/01/2016 to 06/01/2016
x:98373 m, y:497720 m (epsg:28992)

Vlieland Haven: Residual elevation - analysis from 03/01/2016 to 06/01/2016
x:135026 m, y:589802 m (epsg:28992)

Den Helder: Residual elevation - analysis from 03/01/2016 to 06/01/2016
x:111872 m, y:553345 m (epsg:28992)

Oudeschild: Residual elevation - analysis from 03/01/2016 to 06/01/2016
x:119273 m, y:561471 m (epsg:28992)

Scheveningen: Residual elevation - analysis from 03/01/2016 to 06/01/2016
x:80009 m, y:460491 m (epsg:28992)

Figure 29 Scatter plot the modelled residual tidal signal compared to the observed signal for all locations

B.2 Waves

B.2.1 Significant wave height

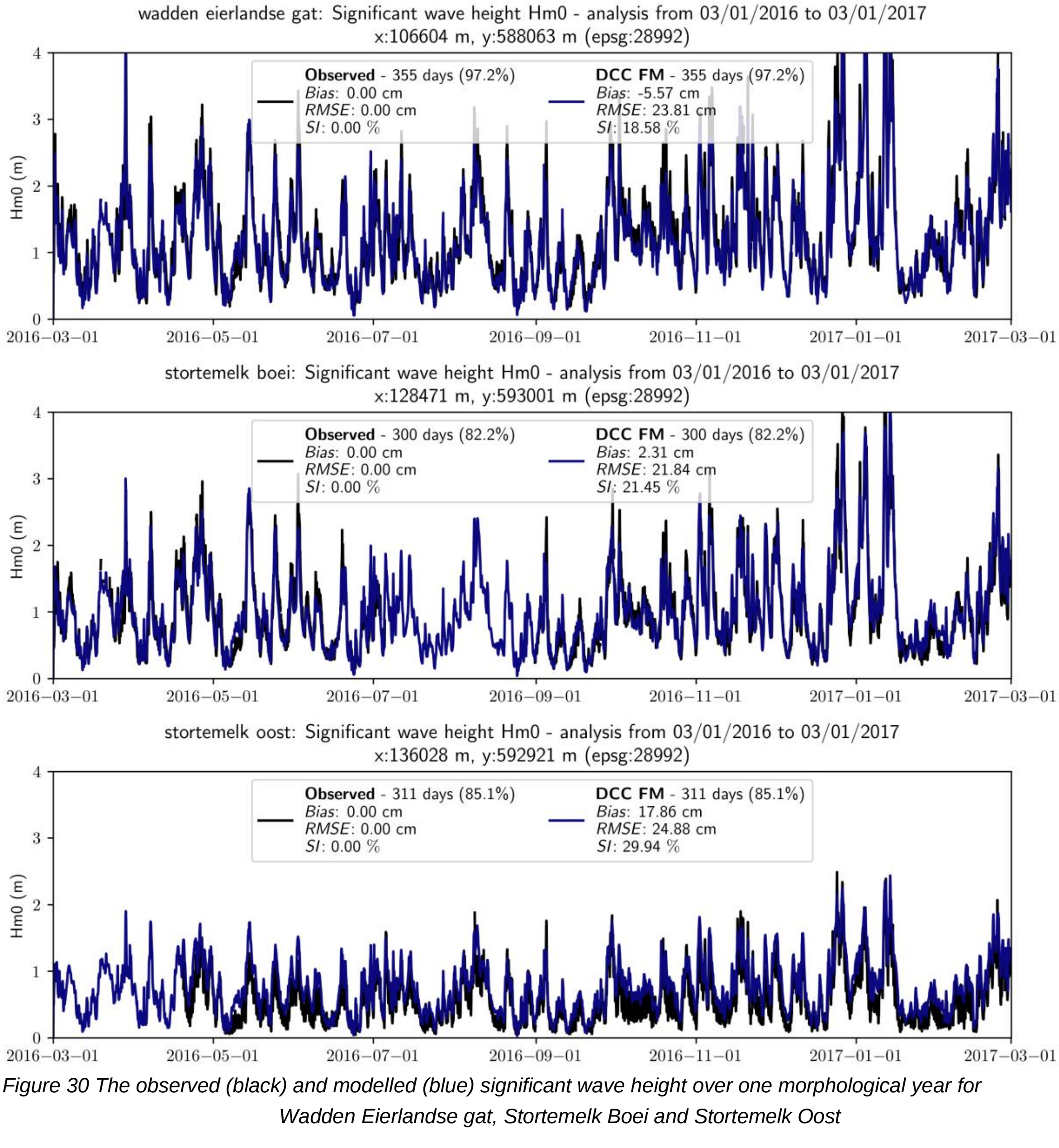
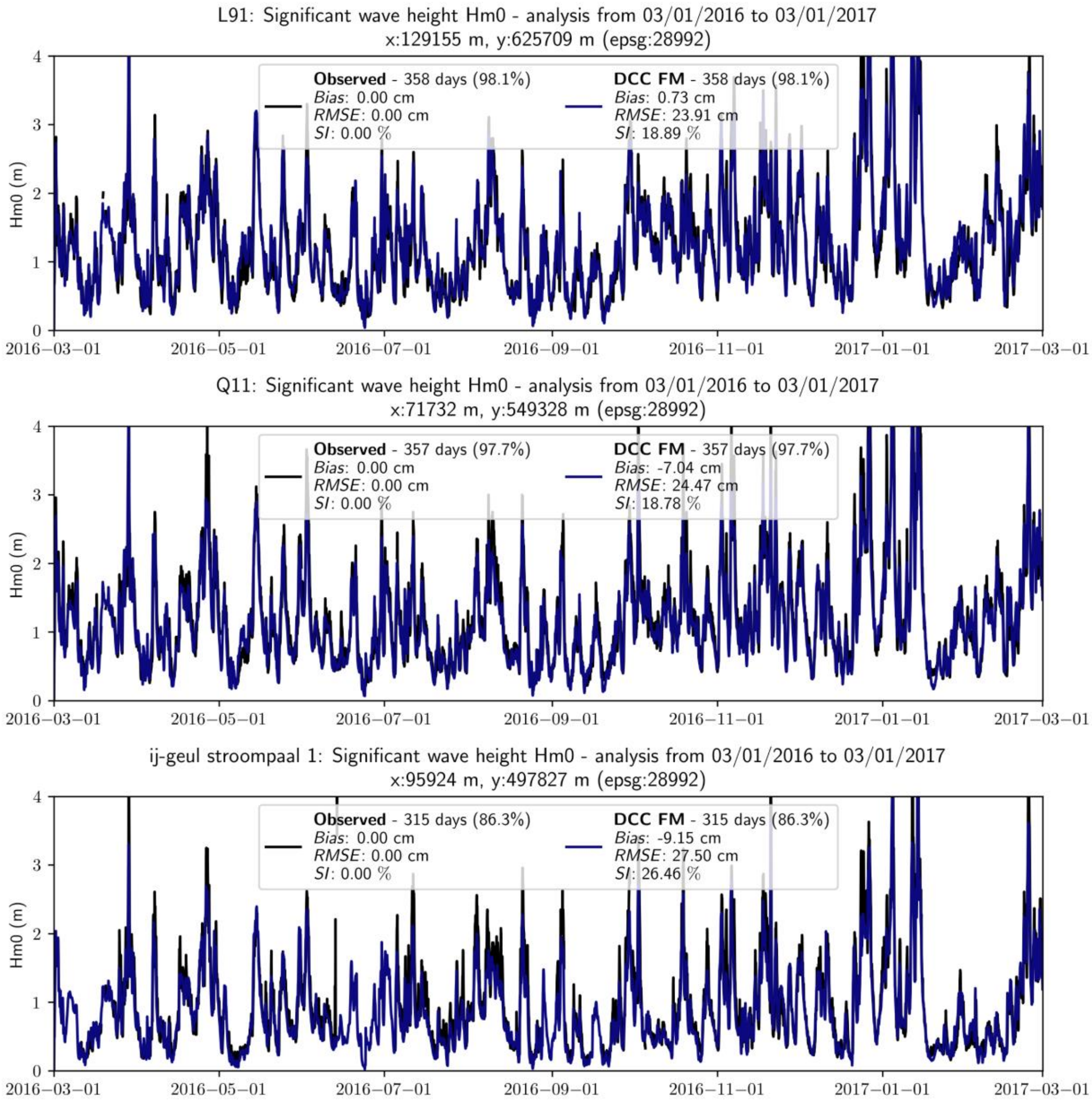


Figure 30 The observed (black) and modelled (blue) significant wave height over one morphological year for Wadden Eierlandse gat, Stortemelk Boei and Stortemelk Oost


L91: Significant wave height Hm0 - analysis from 03/01/2016 to 03/01/2017
x:129155 m, y:625709 m (epsg:28992)

Q11: Significant wave height Hm0 - analysis from 03/01/2016 to 03/01/2017
x:71732 m, y:549328 m (epsg:28992)

ij-geul stroompaal 1: Significant wave height Hm0 - analysis from 03/01/2016 to 03/01/2017
x:95924 m, y:497827 m (epsg:28992)

Figure 31 The observed (black) and modelled (blue) significant wave height over one morphological year for L91, Q1 and IJgeul Stroompaal

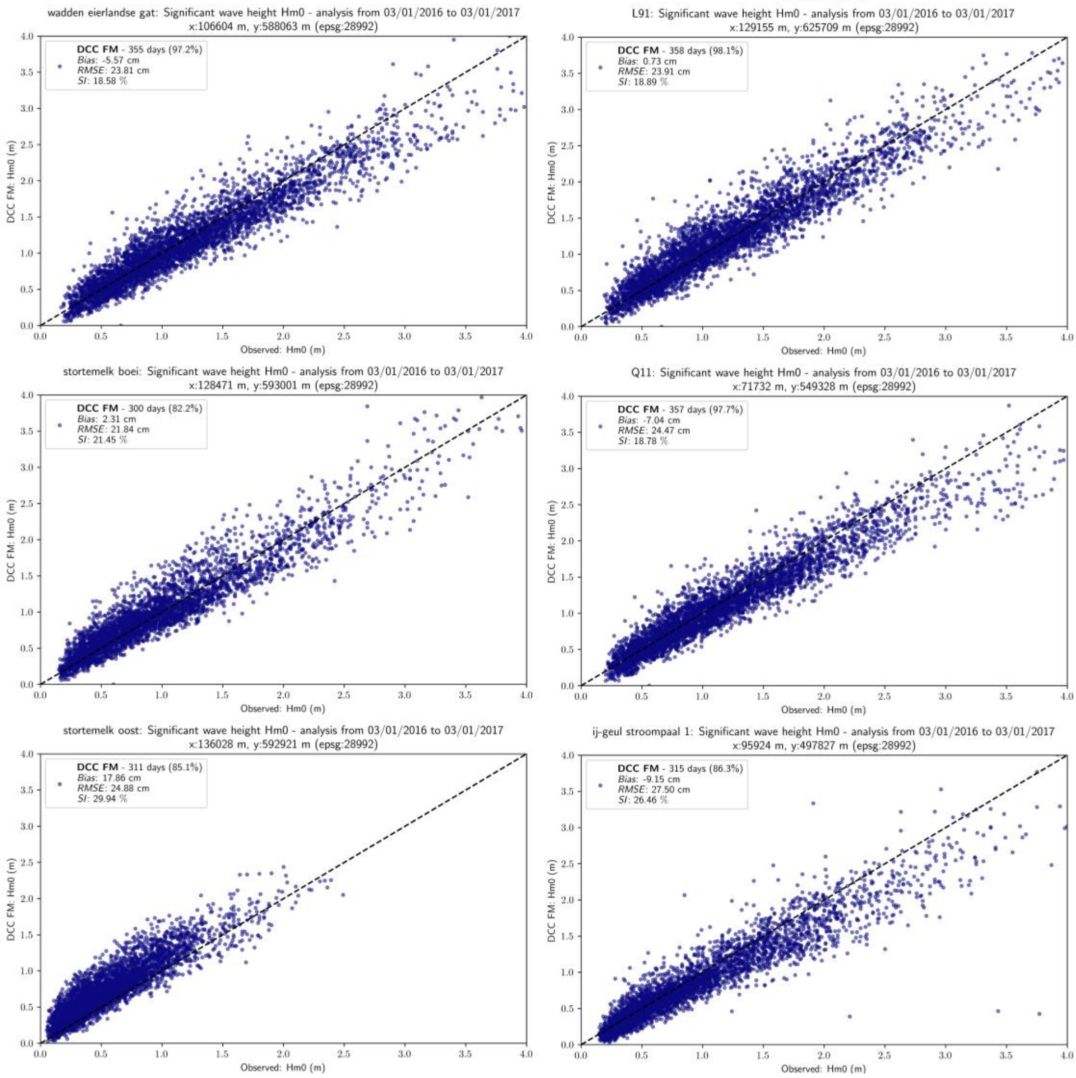


Figure 32 Scatter plot of the modelled significant wave height compared to the observed signal

B.2.2 Wave period

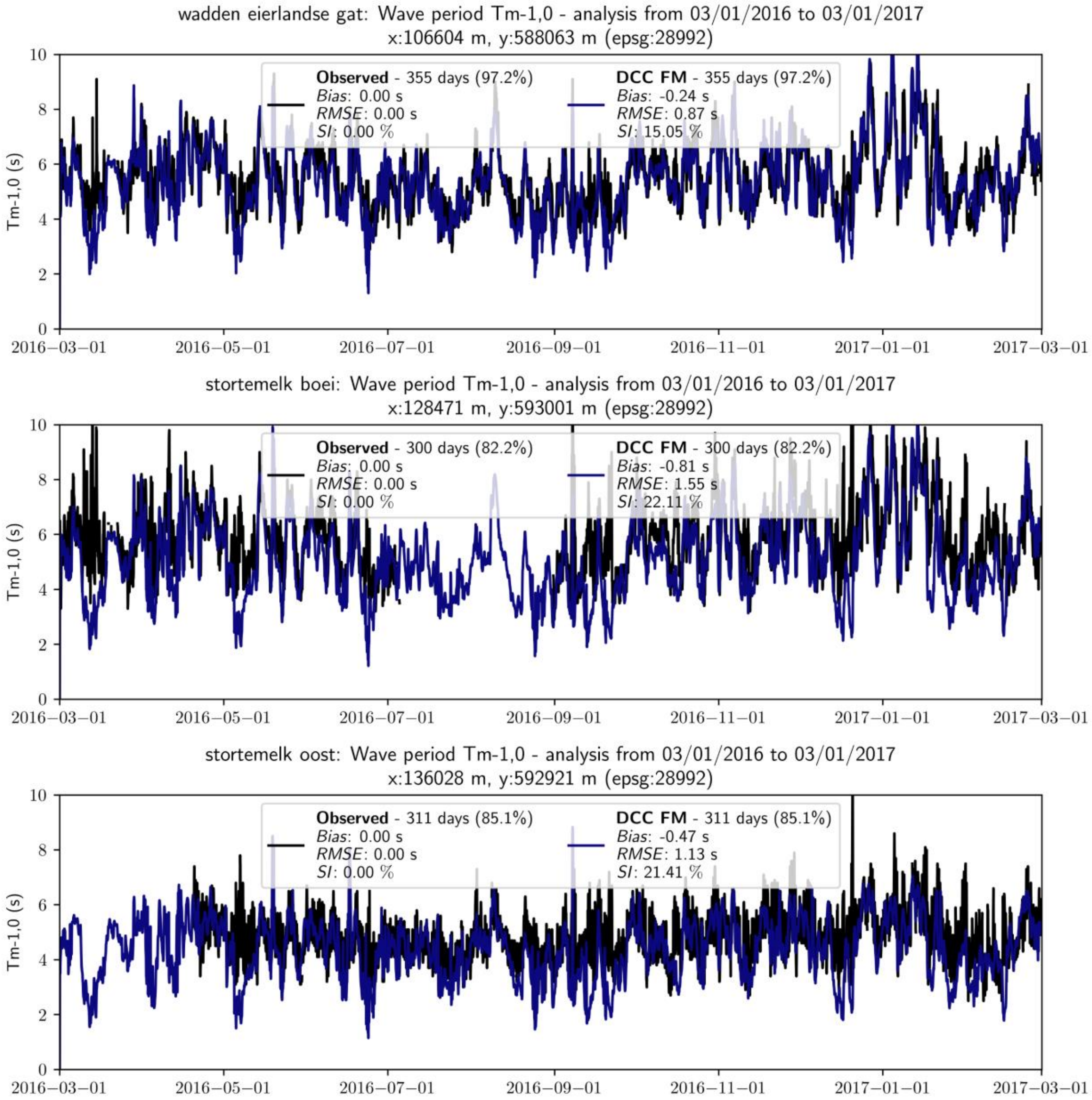
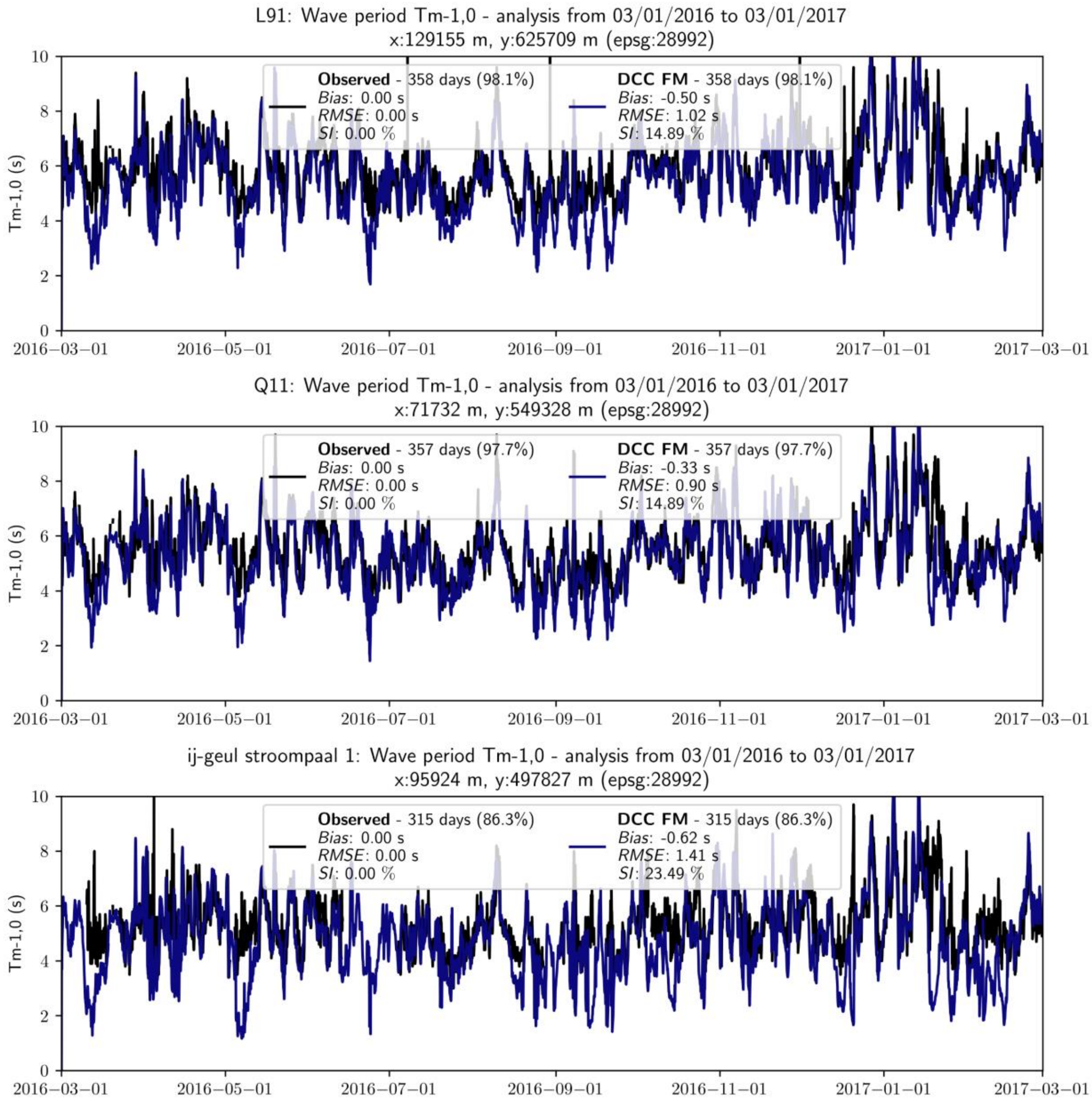


Figure 33 The observed (black) and modelled (blue) wave period over one morphological year for Wadden Eierlandse gat, Stortemelk Boei and Stortemelk Oost

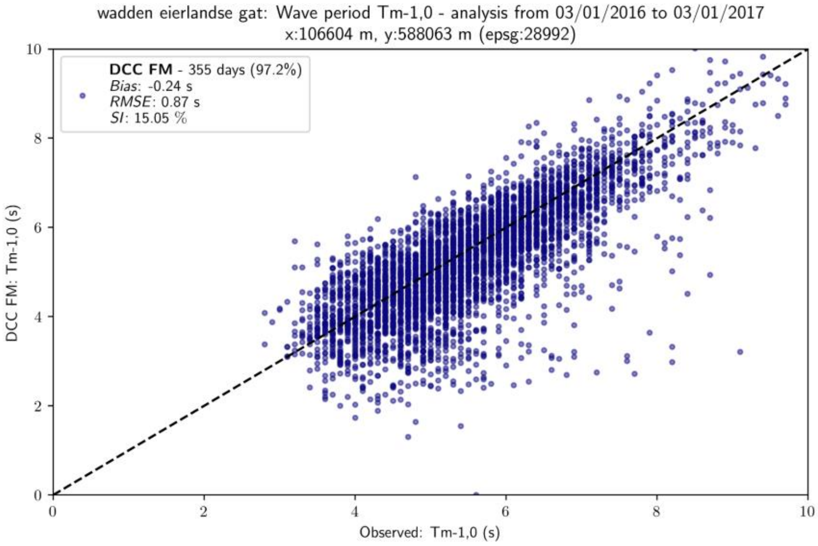


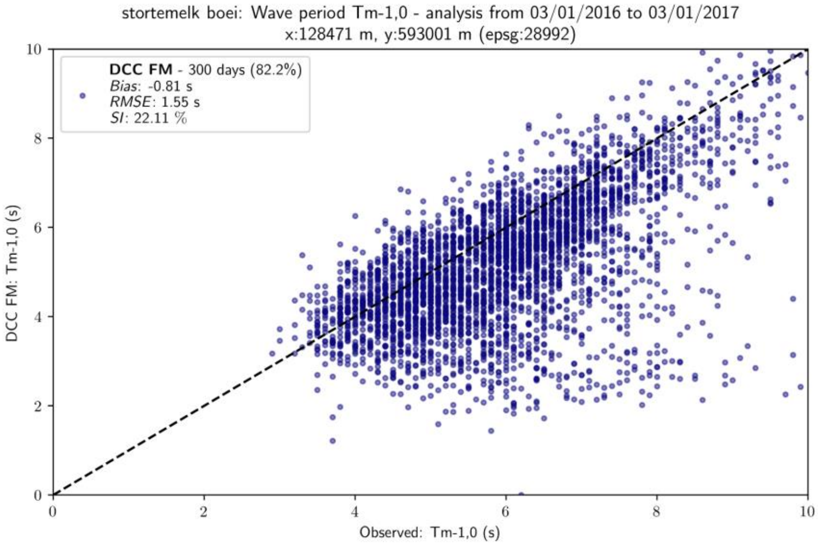
L91: Wave period Tm-1,0 - analysis from 03/01/2016 to 03/01/2017
x:129155 m, y:625709 m (epsg:28992)

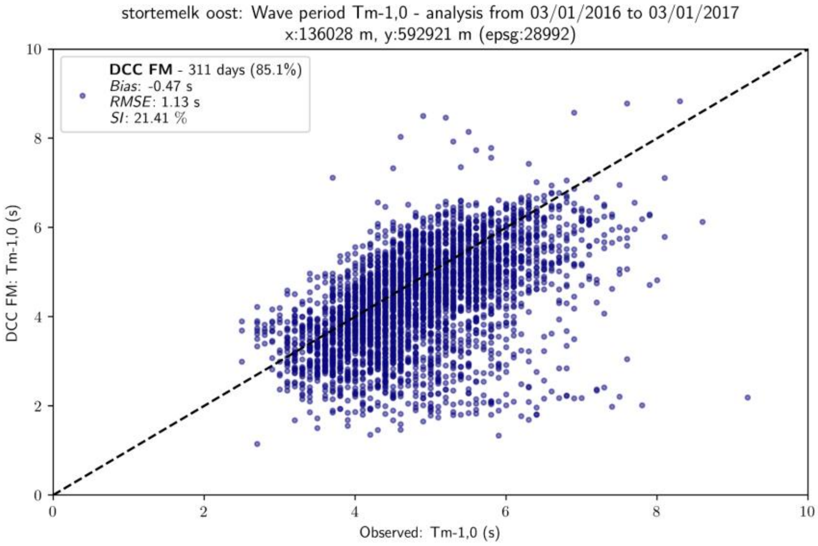
Q11: Wave period Tm-1,0 - analysis from 03/01/2016 to 03/01/2017
x:71732 m, y:549328 m (epsg:28992)

ij-geul stroompaal 1: Wave period Tm-1,0 - analysis from 03/01/2016 to 03/01/2017
x:95924 m, y:497827 m (epsg:28992)

Figure 34 The observed (black) and modelled (blue) significant wave period over one morphological year for L91, Q1 and IJgeul Stroompaal


wadden eierlandse gat: Wave period Tm-1,0 - analysis from 03/01/2016 to 03/01/2017
x:106604 m, y:588063 m (epsg:28992)
DCC FM - 355 days (97.2%)
Bias: -0.24 s
RMSE: 0.87 s
SI: 15.05 %
DCC FM: Tm-1,0 (s)
Observed: Tm-1,0 (s)
0
2
4
6
8
10


stortemelk boei: Wave period Tm-1,0 - analysis from 03/01/2016 to 03/01/2017
x:128471 m, y:593001 m (epsg:28992)
DCC FM - 300 days (82.2%)
Bias: -0.81 s
RMSE: 1.55 s
SI: 22.11 %
DCC FM: Tm-1,0 (s)
Observed: Tm-1,0 (s)
0
2
4
6
8
10


stortemelk oost: Wave period Tm-1,0 - analysis from 03/01/2016 to 03/01/2017
x:136028 m, y:592921 m (epsg:28992)
DCC FM - 311 days (85.1%)
Bias: -0.47 s
RMSE: 1.13 s
SI: 21.41 %
DCC FM: Tm-1,0 (s)
Observed: Tm-1,0 (s)
0
2
4
6
8
10

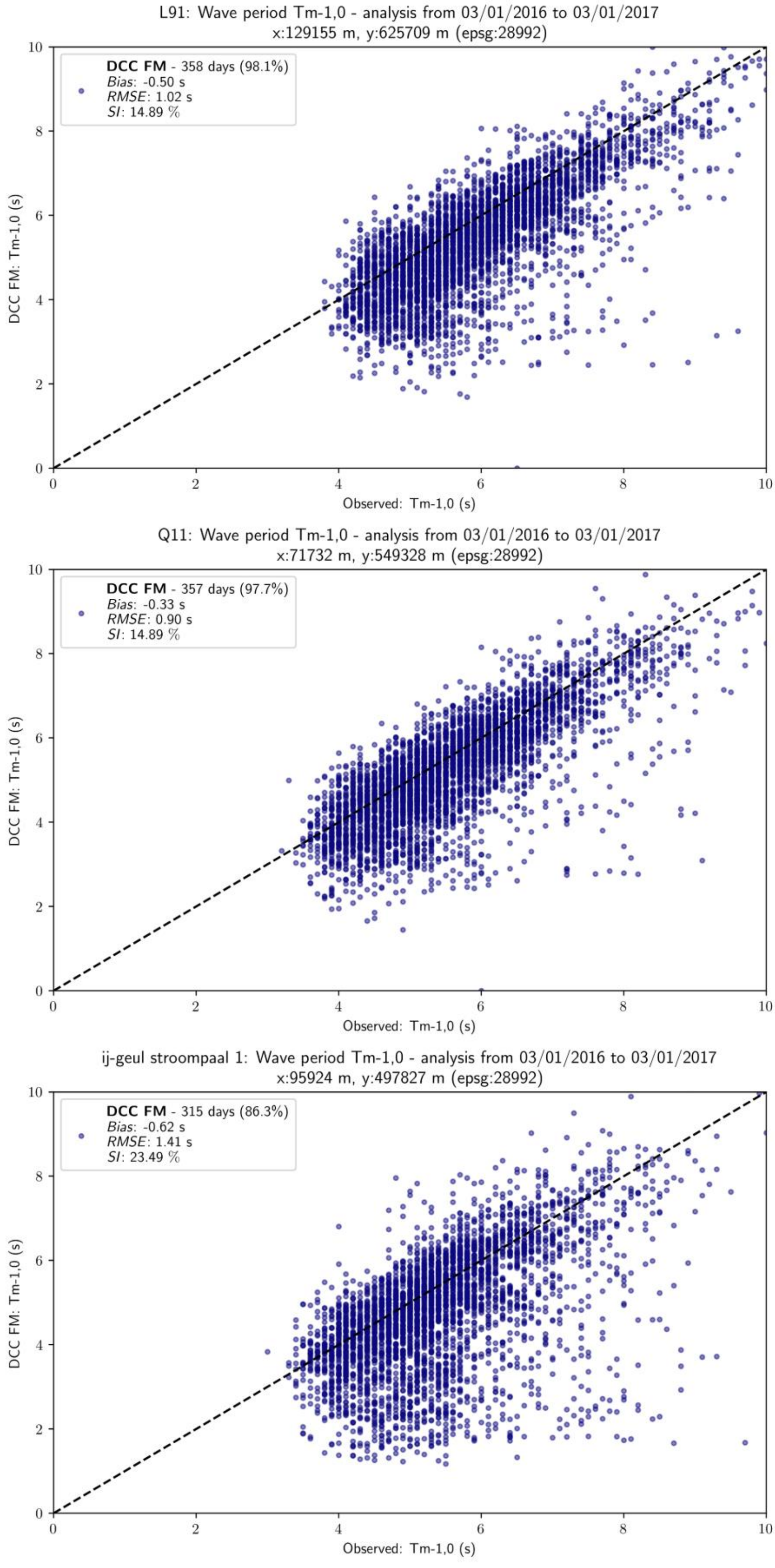


Figure 35 Scatter plot of the modelled wave period (vertical axis) compared to the observed wave period (horizontal axis) for different stations.