Development of Mechanistic Models

Mechanistic Model for the North Sea

Hydrodynamic model documentation

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Prepared for	Danish EPA (Miljøstyrelsen, Fyn)
Represented by	Mr. Harley Bundgaard Madsen, Head of Section

Eelgrass in Kertinge Nor
Photo: Peter Bondo Christensen

Project manager	Anders Chr. Erichsen & Mads Birkeland
Quality supervisor	Anne Lise Middelboe

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DHI • Agern Allé 5 • • DK-2970 Hørsholm • Denmark
Telephone: +45 4516 9200 • Telefax: +45 4516 9292 • dhi@dhigroup.com • www.dhigroup.com

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1 Executive summary

The model development presented in this technical note represents the hydrodynamic model development for the North Sea. The North Sea model is a part of a larger model complex comprising a number of mechanistic models developed by DHI and a number of statistical models developed by AU, Bioscience.

The model complex is developed with the overall aim to support the Water Framework Directive (WFD) by introducing mechanistic models in as many Danish water bodies as possible, and to integrate with Bayesian statistical modelling and cross system modelling carried out by AU, Bioscience.

Here we present the hydrodynamic (HD) model setup covering the North Sea: The North Sea model. This specific model includes 7 Danish water bodies:

Water Body*)	Number	Water Body*)	Number
Lister Dyb	107	Vesterhavet, syd	119
Juvre Dyb, tidevandsområde	111	Vesterhavet, nord	133
Knudedyb, tidevandsområde	120	Skagerrak	221
Grådyb, tidevandsområde	121		

*) Water bodies defined for the River Basin Management Plans 2015-2021

The North Sea hydrodynamic model is developed to describe the physical system (water levels, currents, turbulence, mixing, salinity and water temperature). The model is developed to ensure a quality that will support a robust ecosystem (biogeochemical) model, an ecosystem model that eventually can be used for modelling a number of scenarios in support of the WFD implementation in Denmark.

As can be seen from the present technical note the North Sea hydrodynamic model has been developed successfully for the entire model period 2002-2016:

- On average the P-Bias is -0.7% with respect to salinity. This covers 6 stations with a difference between model and measurement of less than 10% (corresponding to an 'excellent' model). For water temperature the average P-Bias is -1.8% covering the 6 stations with an absolute difference of less than 10% corresponding to an 'excellent' model.

- With respect to the Spearman Rank Correlation the average numbers are 0.70 and 0.98 for salinity and water temperature, respectively. For salinity the performance measures are between 0.54 and 0.87 grouping 5 out of 6 stations at 'very good' and one less than 'good/poor' while the same values for water temperature are above 0.96, and hence, evaluated as 'excellent'.

- The average Modelling Efficient Factor (MEF) for salinity is 0.37 corresponding to a 'good' model. This covers two station evaluated as 'very good' and two stations evaluated as 'good', and two stations are evaluated as 'poor'. For water temperature all stations are evaluated as 'excellent' models.

The details behind the above data are available in Table 6-1 and Table 6-2 and time series comparisons are available here: rbmp2021-2027.dhigroup.com (Google Chrome only).

Based on the two tables and the time series (the time series are available at rbmp2021-2027.dhigroup.com) we conclude that the model describes the overall physical features of the North Sea and that the model is adequate for ecosystem model development.

2 Introduction

The model development presented in this technical note represents the hydrodynamic model development for the North Sea. This model is a special version of DHI's regional North Sea model denominated UKNS2-HD28. The North Sea model is a part of a larger model complex comprising a number of mechanistic models developed by DHI and a number of statistical models developed by AU, Bioscience.

The model complex is developed with the overall aim to support the Water Framework Directive (WFD) by introducing mechanistic models in as many Danish water bodies as possible, and to integrate with Bayesian statistical modelling and cross system modelling carried out by AU, Bioscience.

Here we present the hydrodynamic (HD) model setup covering the North Sea. This specific model includes the Danish water bodies listed in Table 2-1.

Table 2-1 Water bodies included in the North Sea model.

Water Body*)	Number	Water Body*)	Number
Lister Dyb	107	Vesterhavet, syd	119
Juvre Dyb, tidevandsområde	111	Vesterhavet, nord	133
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*) Water bodies defined for the River Basin Management Plans 2015-2021

2.1 Mechanistic modelling

The present technical note represents the hydrodynamic part of one model out of eleven mechanistic models. The eleven mechanistic models are developed to increase the knowledge of pressures and status in Danish marine waters and to provide tools for the Danish EPA as part of the implementation of the WFD.

Mechanistic models enable dynamic descriptions of ecosystems and interactions between natural forcings and anthropogenic pressures. Hence, mechanistic models can be applied for predictions of changes in specific components, like chlorophyll-a concentrations, due to climatic changes or changes in anthropogenic pressures.

The ecological conditions in marine waters are determined by a number of different natural factors like water exchange, stratification, water temperature, nutrient availability, sediment characteristics, structure of the food web etc. On top of that several anthropogenic factors, like nutrient loadings, fishery, etc., also impact the ecosystem and potentially the ecological status.

The model development in this specific project aims at supporting the Danish EPA's implementation of the WFD. In this first phase of the model development the models are developed to represent the present period (2002-2016) evaluated against NOVANA measurements. Here we use present meteorological data, present nutrient loadings, etc.

After the models are developed, they will be applied for scenario modelling, although the specific scenarios are not yet defined.

2.2 Model development

The model development consists of a 3D hydrodynamic model describing the physical system; water levels, current, salinity and water temperatures. Following the development of the hydrodynamic model is the development of the biogeochemical (ecosystem) model describing the governing biogeochemical pelagic and benthic parameters and processes like phytoplankton, dissolved oxygen, primary production, etc. The model structure is modular, meaning that a hydrodynamic model is developed independently of the biogeochemical model.

The North Sea model is defined as a regional model. The mechanistic model complex development as part of the present projects includes two regional models, three local-domain models and six estuary specific models.

- Regional models: Regional models cover both specific Danish water bodies and regional waters, such as the North Sea and a small part of the North Atlantic, which is included in the North Sea-model and the Baltic Sea, which is covered by the IDW-model (Inner Danish Waters). These models provide model results for specific water bodies but, equally important, provide boundaries to local-domain models and estuary specific models.

- Local-domain models: These models are developed to allow for resolving most small and medium-sized water bodies in the north-western Belt Sea, the south-western Belt Sea and the waters bodies in and around Smålandsfarvandet.

- Estuary specific models: Six specific estuary (fjord) models are developed to allow for detailed modelling of the particular estuary.

All mechanistic models will be set up and calibrated for the period 2002-2010 and validated for the period 2011-2016. In this note the validation will be reported according to specific indices (DHI 2019b), whereas the entire period is included as time series in a WEB-tool (rbmp2021-2027.dhigroup.com) with a few examples included in section 6.2.3. Most data used for calibration and validation originate from the national monitoring programme NOVANA, see http://odaforalle.au.dk for more details. For some models and some parameters other data are included, and the specific origin of those data will be referenced when used.

2.3 Modelling system

The hydrodynamic model is based on the modelling software MIKE 3 HD FM (version 2017) developed by DHI. MIKE 3 HD FM is based on a flexible mesh approach and has been developed for applications within oceanographic, coastal and estuarine environments.

The system is based on the numerical solution of the three-dimensional (3D) incompressible Reynolds averaged Navier-Stokes equations invoking the assumptions of Boussinesq and of hydrostatic pressure. Thus, the model consists of continuity, momentum, temperature, salinity and density equations and it is closed by a turbulent closure scheme. The free surface is taken into account using a sigma-coordinate transformation approach. The scientific documentation of MIKE 3 HD FM is given in DHI (2019a).

3 Modelling concept

3.1 Mechanistic modelling

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The ecological conditions in marine waters are determined by a number of different natural factors like water exchange, stratification, water temperature, nutrient availability, sediment characteristics, structure of the food web, etc. On top of that numerous anthropogenic factors, like nutrient loadings, fishery, etc., also impact the ecosystem and potentially the ecological status.

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After finalization, the models will be applied for scenario modelling, although the specific scenarios are not yet defined.

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4 Model setup

4.1 Introduction

The model setup comprises defining the model domain, establishing the model mesh, preparing the model forcings in terms of open boundary conditions, atmospheric forcing and freshwater inflows, preparing the initial conditions and setting up the model.

For the present project the model is set up for the period 2002-2016, which means that all model forcings need to cover this period.

4.2 Model domain

4.2.1 Introduction

The model domain is determined in accordance with the area of interest of the modelling study. Also, considerations of the area of influence, being the surrounding areas that affect the area of interest, and of suitable open boundary locations, affect the choice of model domain.

For the North Sea model being one of DHI's general regional models, the model domain was chosen to include the seas around UK and Ireland as well as the North Sea itself. Skagerrak and part of Kattegat are also included in the model. The model has three open boundaries towards the North Atlantic and one open boundary in southern Kattegat.

The model mesh is the representation of the model domain. More specifically the model mesh defines the model area, the location of the open boundaries, the land-water boundaries, the horizontal and vertical model resolution (discretization), and the water depths (bathymetry) of the model. In the following sections the details of the horizontal and vertical model mesh are described.

4.2.2 Horizontal mesh

The horizontal mesh is unstructured and generally composed of triangular elements but may also include quadrangular elements. For the North Sea model, the horizontal mesh consists exclusively of triangular elements of varying sizes.

The horizontal model resolution varies from 3-6 km in the main part of the model domain to 8-12 km near the three ocean boundaries. In a 10 km band along the west coast of Denmark, Germany and Netherlands, the resolution is 2-3 km. In the Danish part of the Wadden Sea the resolution is 500-1000 m. The mesh applies spherical coordinates (Lat/Lon) and refers to the WGS-84 geographical datum.

The model bathymetry is based on EMODnet Bathymetry Consortium (2016). The vertical datum of the bathymetry is mean sea level (MSL).

In Figure 4.1 the horizontal model mesh is shown and in Figure 4.2 the model bathymetry is shown.

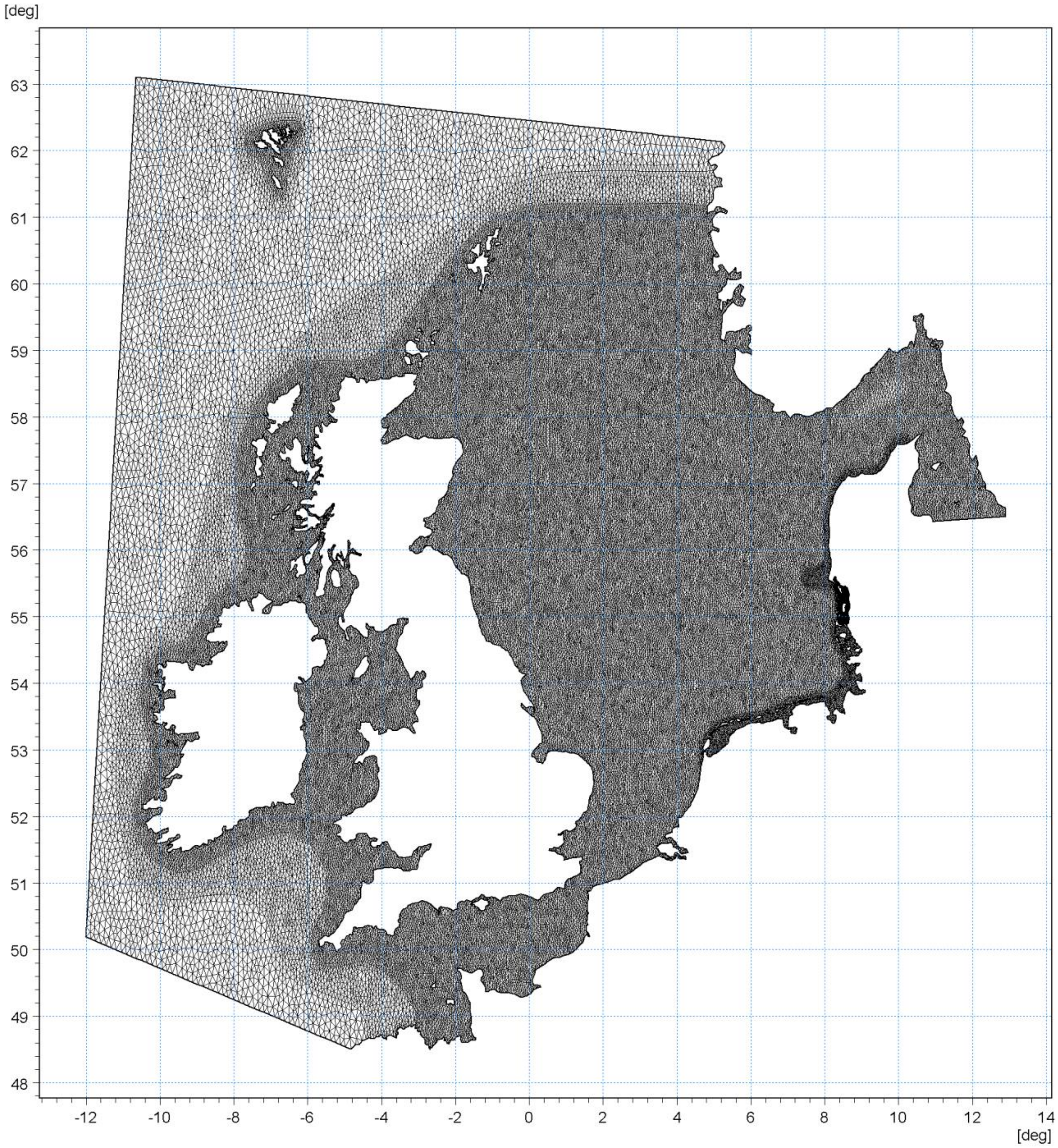


Figure 4.1 Horizontal model mesh of the North Sea model (UKNS2-HD28). The model has three open boundaries towards the North Atlantic and one open boundary in southern Kattegat.

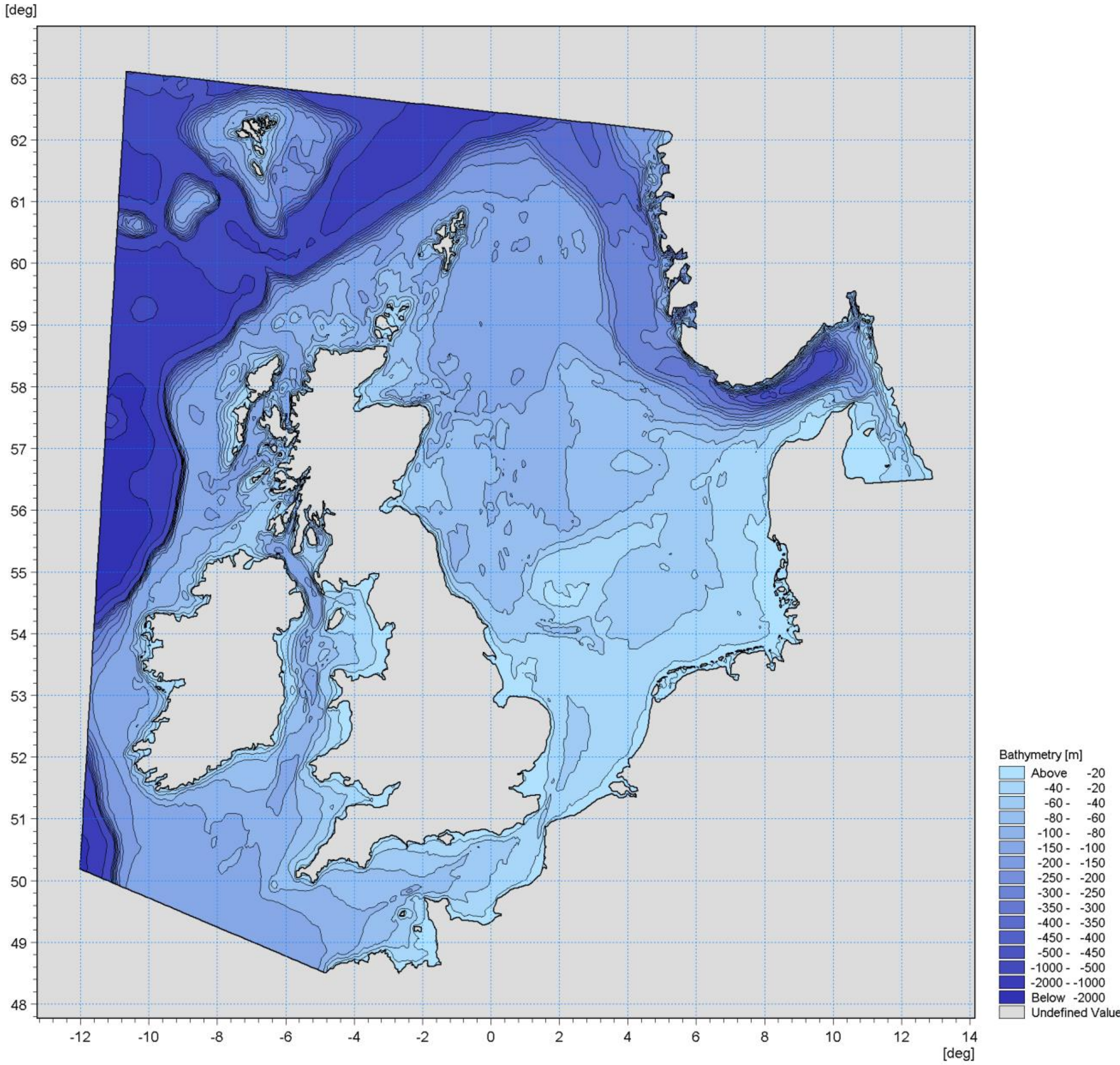


Figure 4.2 Model bathymetry of the North Sea model (UKNS2-HD28). Water depths refer to MSL.

4.2.3 Vertical mesh

The vertical mesh is structured and consists of either sigma-layers or a combination of sigma- and z-layers.

In the North Sea model, the vertical model discretization consists of 13 sigma-layers down to −61m level and 33 z-level layers from -61m level and below. The thickness of the sigma-layers varies from app. 1.5 m at the surface to app. 10 m at -61 m level (and proportionally less at water depths less than 61m). The thickness of the z-layers is 10 m down to the -200 m level. Below the -200 m level the thickness increases gradually from 20 m to several hundred meters in the deepest part. In Figure 4.3 the vertical mesh is illustrated.

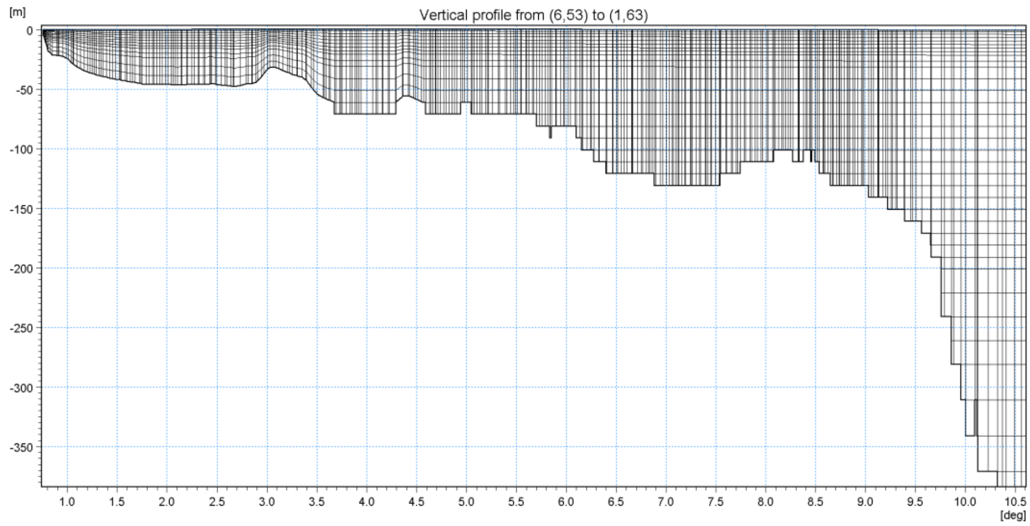


Figure 4.3 Vertical model mesh of the North Sea model (UKNS2-HD28) in transect from the Dutch coast and northwards. The bottom-following sigma-layers down to -61m level and the horizontal z-layers from -61 m level and down are shown.

4.3 Model forcings

4.3.1 Open boundary conditions

The North Sea model contains four open boundaries: Three boundaries towards the North Atlantic and one boundary in southern Kattegat (see Figure 4.1). The three North Atlantic open boundaries are specified as Flather boundaries (Flather, 1976), which implies that, apart from salinity and water temperature, both water level and current velocities are required as boundary condition. The Kattegat boundary is specified as a velocity boundary.

The boundary conditions for the three open boundaries towards the North Atlantic are created as a superposition of pure astronomical tide boundary conditions and oceanic boundary conditions using DHI's oceanographic downscaling concept, DHI (2013). The boundary conditions are based on the following data:

- Tidal data from the DTU10 global tide dataset (Cheng and Andersen, 2010).
- Oceanographic model data from the Copernicus Marine Environment Monitoring Service (http://marine.copernicus.eu/).

The water level boundaries (1D transects) are created by superimposing the tidal and oceanic water level components, the velocity boundaries (2D transects) are created by superimposing the tidal and the oceanic velocity components, and the salinity and temperature boundaries (2D transects) are based solely on the oceanic data.

The three ocean water level boundaries are further corrected (elevated) by 0.5 m to make them consistent with the North Sea model vertical datum, and, finally, they are subjected to an atmospheric pressure correction during model run-time.

The boundary conditions for the Kattegat boundary in terms of velocities, salinity and water temperature (2D transects) are extracted from DHI's DKBS2 regional model covering the Baltic Sea, Belt Sea, Kattegat and Skagerrak.

4.3.2 Atmospheric forcing

The atmospheric forcing of the North Sea model is provided by StormGeo in terms of temporally and spatially varying fields of:

- Wind
- Atmospheric pressure
- Precipitation
- Air temperature
- Cloud cover

The applied atmospheric data are from StormGeo's WRF meteorological model covering the North Atlantic. The data are provided in a resolution of 0.1° x 0.1° in hourly time steps.

The StormGeo data are only available from 2009 and forward. Therefore, meteorological fields from Vejr2 of Denmark (0.15°, hourly) were applied for the period 2005-2009 and meteorological fields from Climate Forecast System Reanalysis (CFSR) (0.3-0.5°, hourly) were applied for the period 2002-2005.

4.3.3 Freshwater sources

The North Sea model includes a number of model sources representing the freshwater run-off from land to sea. Note that the Baltic Sea inflow (run-off) to the North Sea is included in the model through the Kattegat open boundary.

The model sources are specified as daily discharge time series and are based on the following data sources:

- DCE (Aarhus University) - Denmark
- E-HYPE (http://hypeweb.smhi.se/europehype/time-series/) – Ireland, UK, France, Sweden, Norway
- ECOHAM (Hamburg University) – Belgium, Netherlands, Germany

While the DCE and E-Hype data cover the full modelling period from 2002-2016, the ECOHAM data only cover until 2014. The ECOHAM data have been extended to also cover 2015-2016 by applying 10-year monthly means for this period.

In Figure 4.4 the location of the model sources is illustrated. In Denmark 4th order area run-off distributed to main rivers and streams are applied.

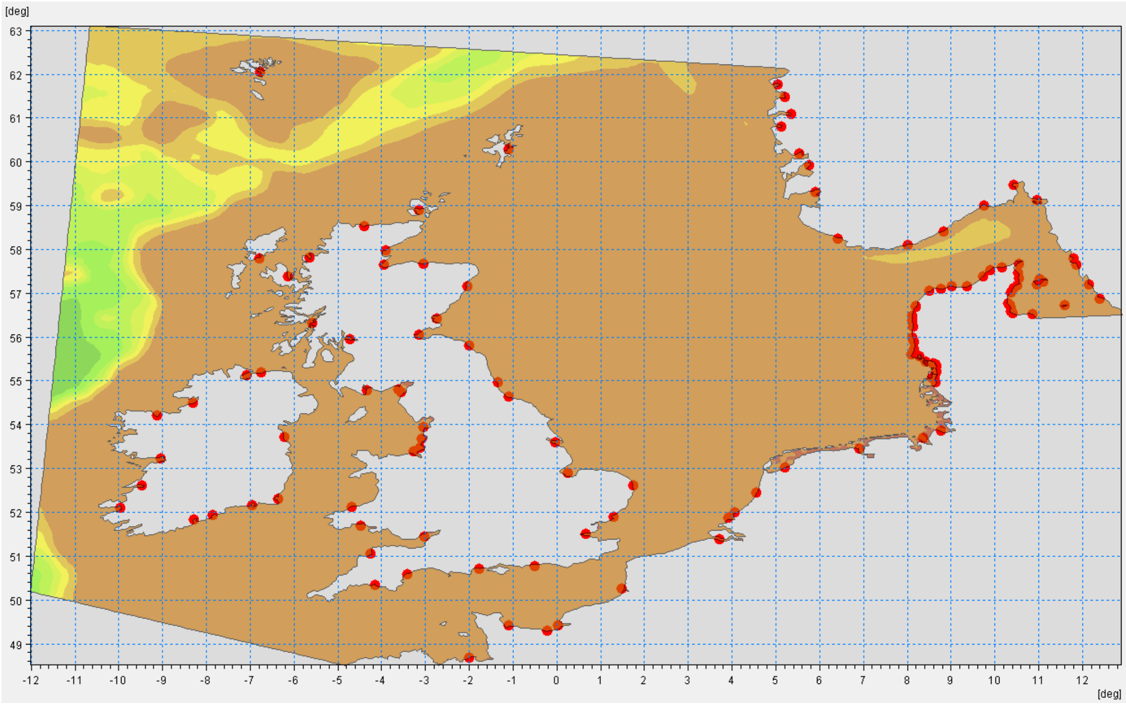


Figure 4.4 Illustration of the location of freshwater sources in the North Sea model (UKNS2-HD28). The sources represent the main rivers but are scaled to include all local run-off from land to sea. In Denmark 4th order area run-off distributed to main rivers and streams are applied.

4.4 Initial conditions

4.4.1 Introduction

In order to properly initiate a model simulation, the model requires initial conditions for the various state variables. For the hydrodynamic model the state variables comprise water level, current, salinity and water temperature.

4.4.2 Initial water level and current conditions

The normal procedure for water level and current is to apply a so-called ‘cold start’. This means that the water is stagnant with no currents initially. Immediately after starting the simulation the water begins to move under the influence of the model forcings, and after a short time (~1-2 days) the model has ‘warmed up’.

4.4.3 Salinity and water temperature

Contrary to water level and current the warm-up time for salinity and water temperature is typically long (months or years), which is not useful. Consequently, 3D fields of salinity and water temperature at the simulation start time are prepared and applied as initial conditions for the simulation. These fields are typically established based on results from an encompassing (larger) model or based on local monitoring data.

In the present North Sea model, the applied salinity and water temperature initial fields representing 1 Jan 2002 are based on the results of earlier North Sea model versions.

5 Model calibration

5.1 Introduction

Having set up the model, the model calibration is undertaken. The model calibration is the process of adjusting model settings and model constants in order to obtain satisfactory agreement between observations and model results. In practice the model setup and the model calibration are often performed iteratively, since a good comparison between observations and model results require a well-proportioned model domain as well as adequate model forcings, and this is not always obtained in the first attempt.

5.2 Model settings

In Table 5.1 a summary of applied model settings and constants is given.

Table 5.1 Summary of applied hydrodynamic model settings and constants in the North Sea model (UKNS2-HD28).

Feature/Parameter	Setting/Value
Flooding and drying	Included with parameters: 0.1m, 0.2m and 0.3m
Wind friction coefficient	Linearly varying between 0.001255 and 0.002425 for wind speeds between 7 and 25m/s
Bed roughness	Varying from 0.02-0.05m
Eddy viscosity	Horizontally: Smagorinsky formulation, C_s=0.28 Vertically: k-ε model with standard parameters and no damping
Solution technique	Shallow water equations: Low order Transport equations: High order
Overall time-step	300s
Heat exchange	Light extinction coefficient 0.4, otherwise standard parameters Humidity: Constant = 88%
Dispersion (S/T)	Scaled to Eddy viscosity. Horizontal/vertical scaling factors = 1.0/0.5

6 Model validation

6.1 Introduction

The model validation is the process of comparing observations and model results qualitatively and quantitatively to demonstrate the suitability of the model. The qualitative comparison is typically done graphically, and the quantitative comparison is typically done by means of certain performance (goodness of fit) measures. As such the model validation constitutes the documentation of the model performance.

The North Sea model has been run for the period 2002-2016, but the validation period was defined as the 6-year period 2011-2016. Model comparison plots and performance measures are consequently presented for this period, whereas model results and measurements of salinity and temperature are presented for the entire period using a WEB-tool (rbmp2021-2027.dhigroup.com).

6.2 Model performance

6.2.1 Water level

The North Sea hydrodynamic model has been validated against measured water levels from select tide gauge stations within the model domain.

In Figure 6.1 the location of a number of tide gauge stations is shown. The model has been validated for all stations but here we only show validation data for the two stations close to the Danish waters: Helgoland (Figure 6.2) and Hanstholm (Figure 6.3). In two figures the water level comparisons are shown. Note that the plots are adjusted for the difference in the vertical datum between the tide gauge and the model.

Generally, the North Sea model compares well to the measurements in terms of both tidal amplitudes and phases as well as residual (non-tidal) variability. The performance measures in the figures also show a good agreement between measurements and model results.

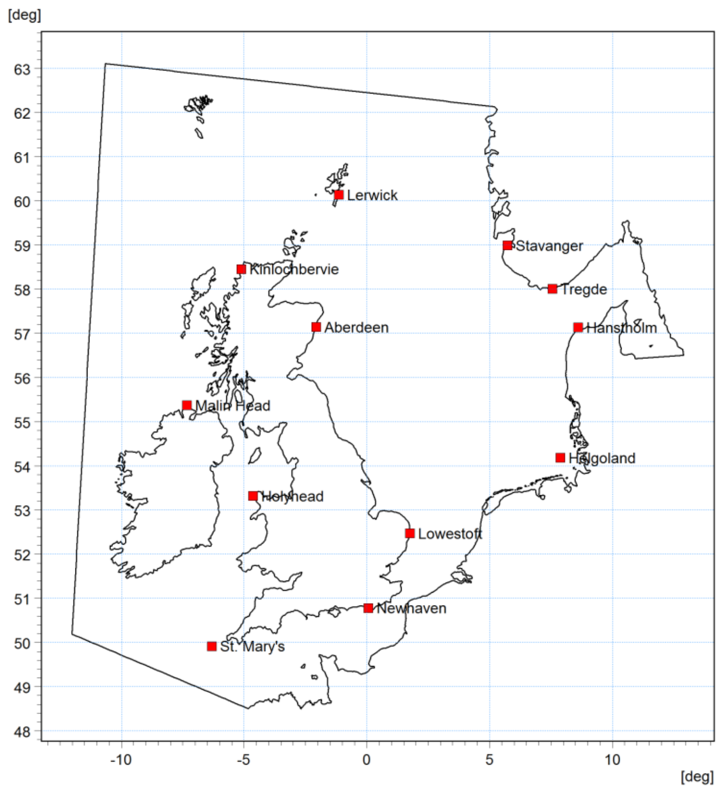
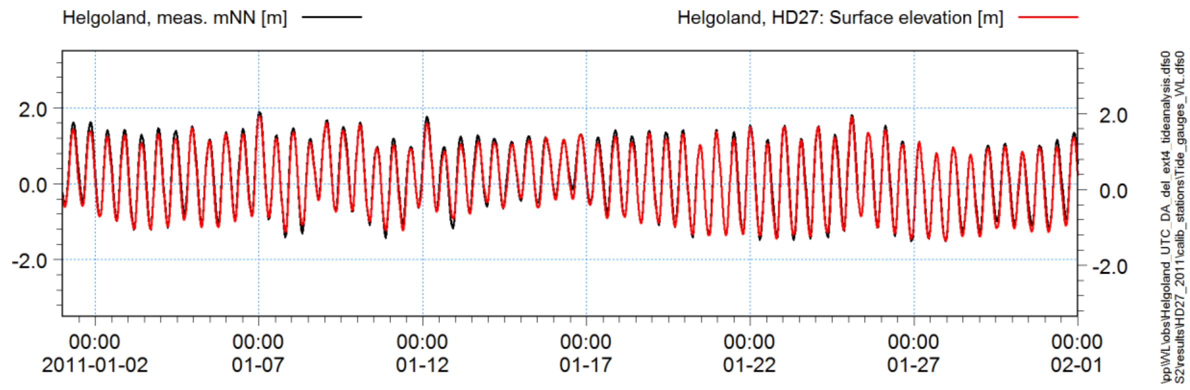


Figure 6.1 Location of tide gauge stations.



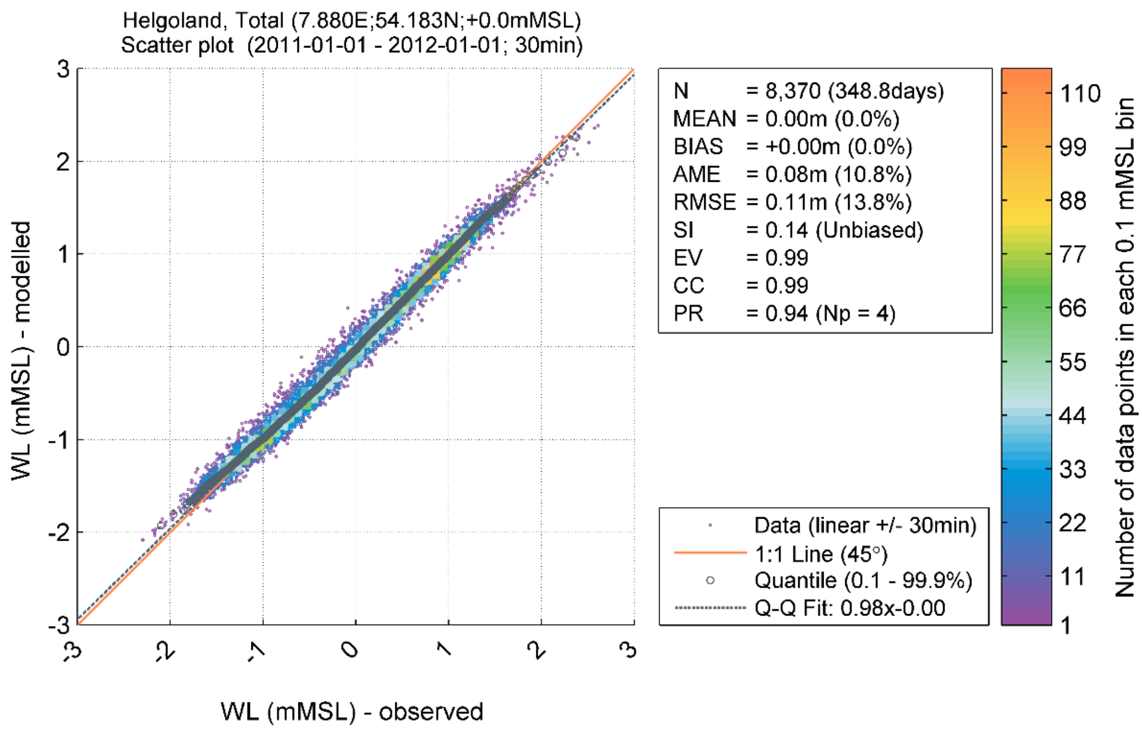


Figure 6.2 Comparison of measured and modelled water level at Helgoland. In the lower panel bias-corrected scatter plot and performance measures for the year 2011 are given.

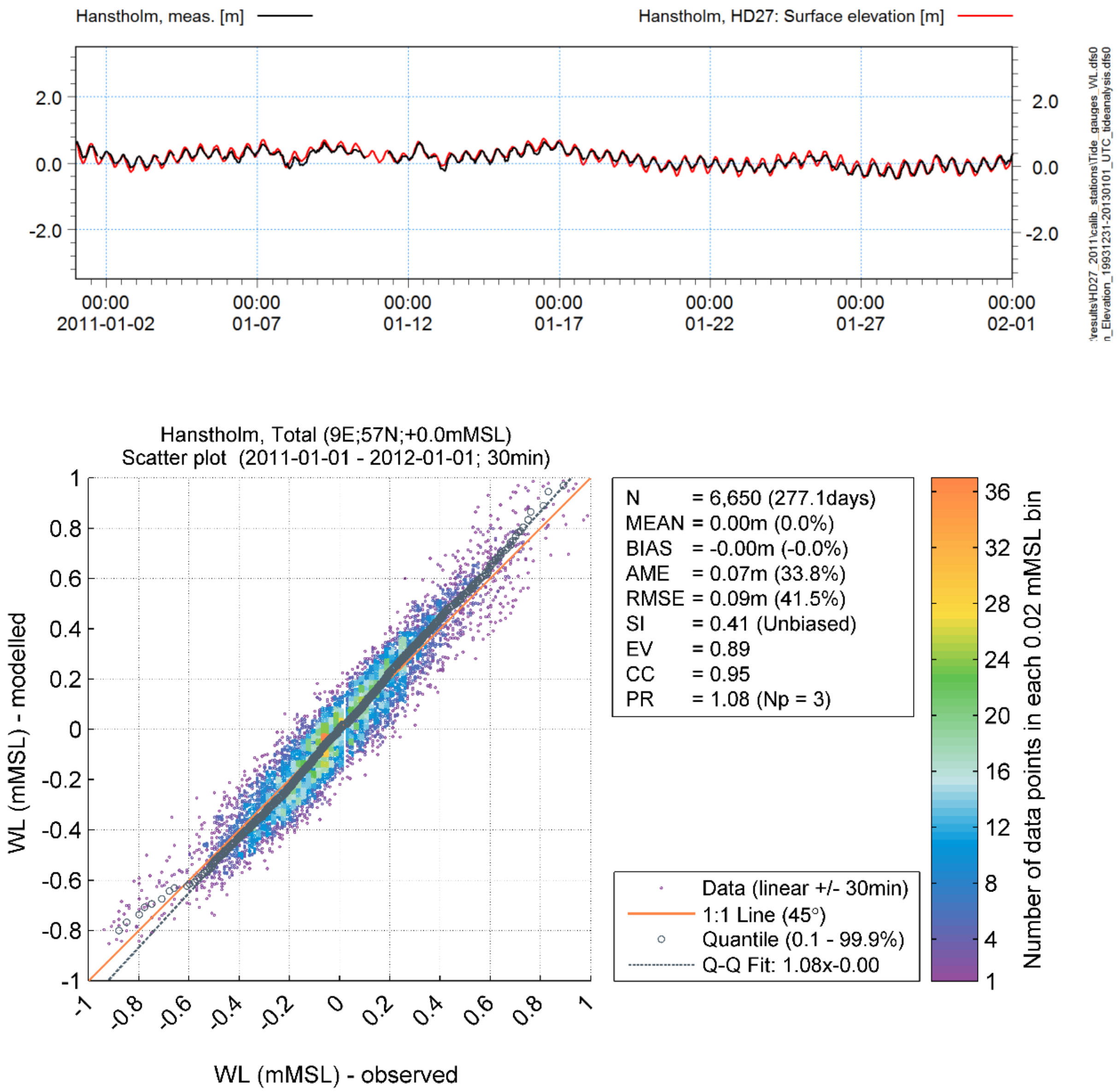


Figure 6.3 Comparison of measured and modelled water level at Hanstholm. In the lower panel bias-corrected scatter plot and performance measures for the year 2011 are given.

6.2.2 Circulation

6.2.2.1 Mean circulation

In Figure 6.4 a schematic diagram of the general circulation in the North Sea is shown and in Figure 6.5 the North Sea modelled surface net flow for 2011 is shown.

In both figures the main ocean and sea currents within the model area may be observed. Among these are the Gulf Current north of Scotland, the Fair Isle Current and the inflow of Atlantic water from the north, the Baltic outflow and the Norwegian Coastal Current, the northeast-ward coastal current along the continental west coast and the north-eastward net flow through the English Channel. The North Sea model represents all these currents appropriately.

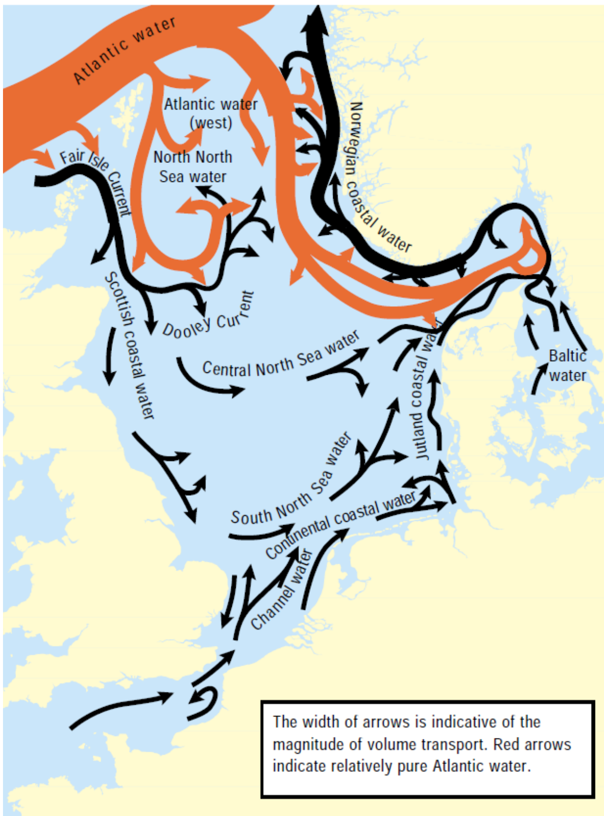


Figure 6.4 Schematic diagram of general circulation in the North Sea (Source: OSPAR (2000) after Turrell (1992)).

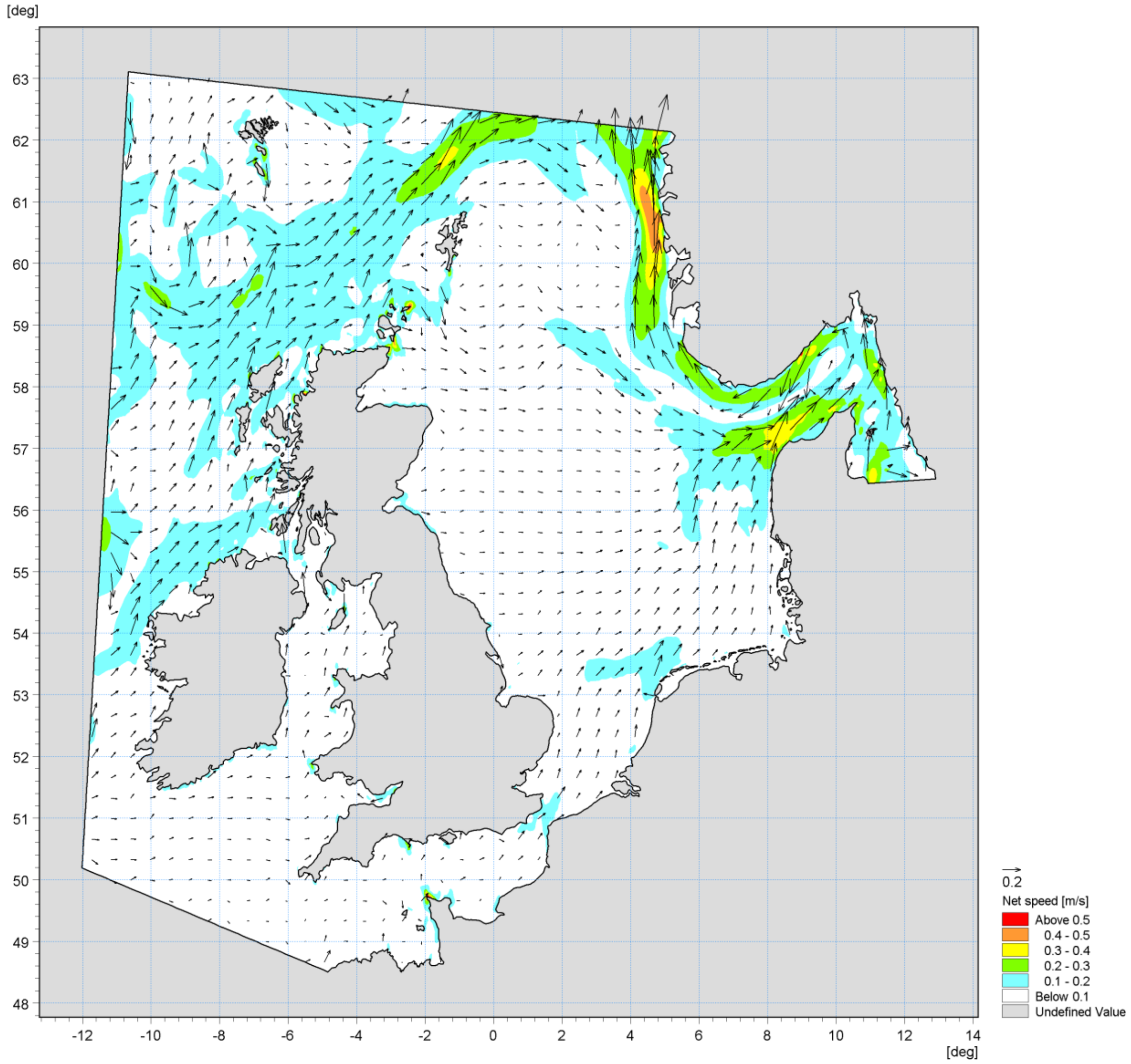


Figure 6.5 Modelled surface net flow for the year 2011.

6.2.2.2 Flow through the English Channel

The flow through the Dover cross-section represents the English Channel inflow to the North Sea.

In Figure 6.7 the modelled discharge through the Dover cross-section is shown. The figure shows that the modelled instantaneous discharge through the Channel roughly varies between +/- 1.5 Sv (1,500,000 m^3/s).

The modelled annual mean discharge through the Channel for the years 2011-2016 is 5,015 km^3/year (northeast-flowing) as compared to literature values of around 3,156-5,365 km^3/year (Winther and Johannessen, 2006).

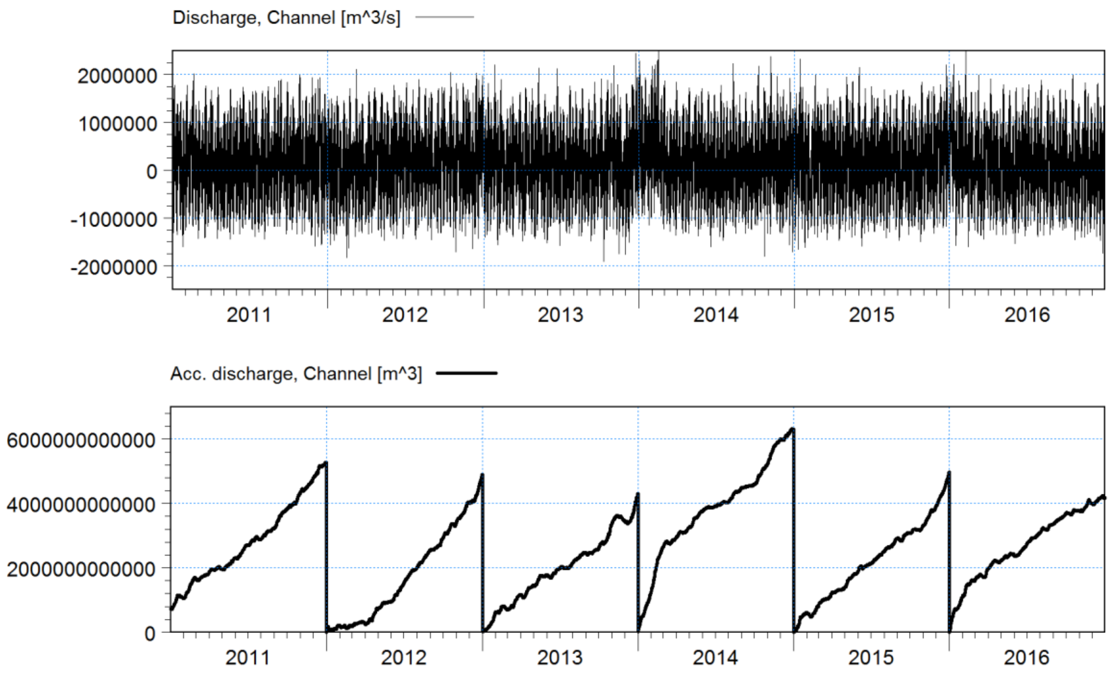


Figure 6.6 Modelled instantaneous (top) and accumulated (bottom) discharge through the English Channel. Note that the accumulated discharge in the plot is reset to zero every year. The modelled annual mean discharge through the Channel is 5,015 km^3/year.

6.2.2.3 Flow through Kattegat

The flow through the Kattegat cross-section represents the Baltic inflow to the North Sea.

In Figure 6.7 the modelled discharge through Kattegat is shown. The figure shows that the modelled instantaneous discharge through Kattegat roughly varies between +/- 0.5 Sv (500,000 m^3/s).

The modelled annual mean discharge through Kattegat for the years 2011-2016 is 549 km^3/year (north-flowing), which is comparable to long-term literature values of around 473-505 km^3/year (Ospar (2000), Winther and Johannessen (2006)).

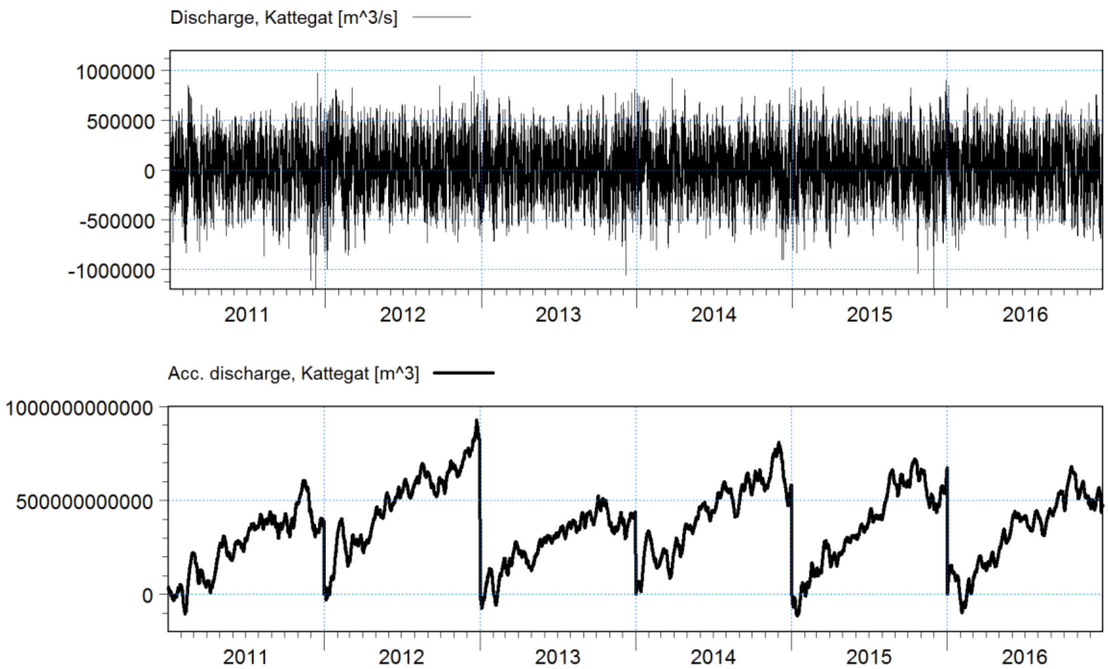


Figure 6.7 Modelled instantaneous (top) and accumulated (bottom) discharge through Kattegat. Note that the accumulated discharge in the plot is reset to zero every year. The modelled annual mean discharge through Kattegat is 549 km^3/year.

6.2.2.4 Current

Only few current data are available for the North Sea model and all in areas outside Danish waters. The model has been validated against these data, but data are not included in the present report.

6.2.3 Salinity and water temperature

6.2.3.1 Stratification

The North Sea is permanently or seasonally stratified in the northern and central parts whereas it is permanently mixed or intermittently stratified in the southern part.

In Figure 6.8 an example of the mean summer stratification in the northern North Sea in a transect between Scotland and Norway is shown, while in Figure 6.9 similar modelled transects for May-August 2011 are shown.

When comparing the two figures it is observed that although the absolute values are not identical the structure and strength of the stratification are very similar.

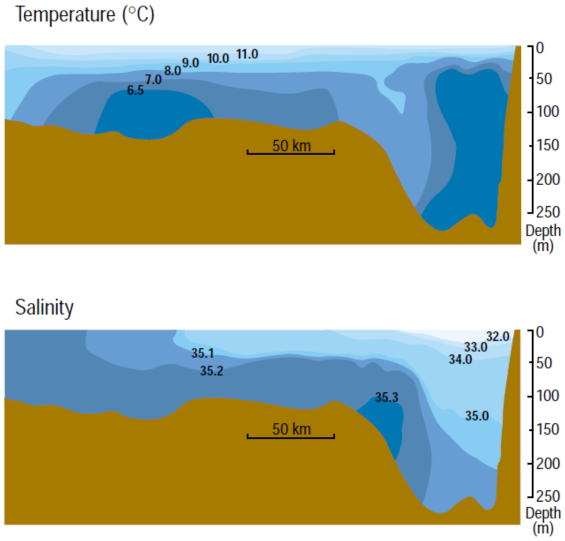


Figure 6.8 Exemplary mean summer temperature (top) and salinity (bottom) transects between Scotland and Norway (OSPAR, 2000)

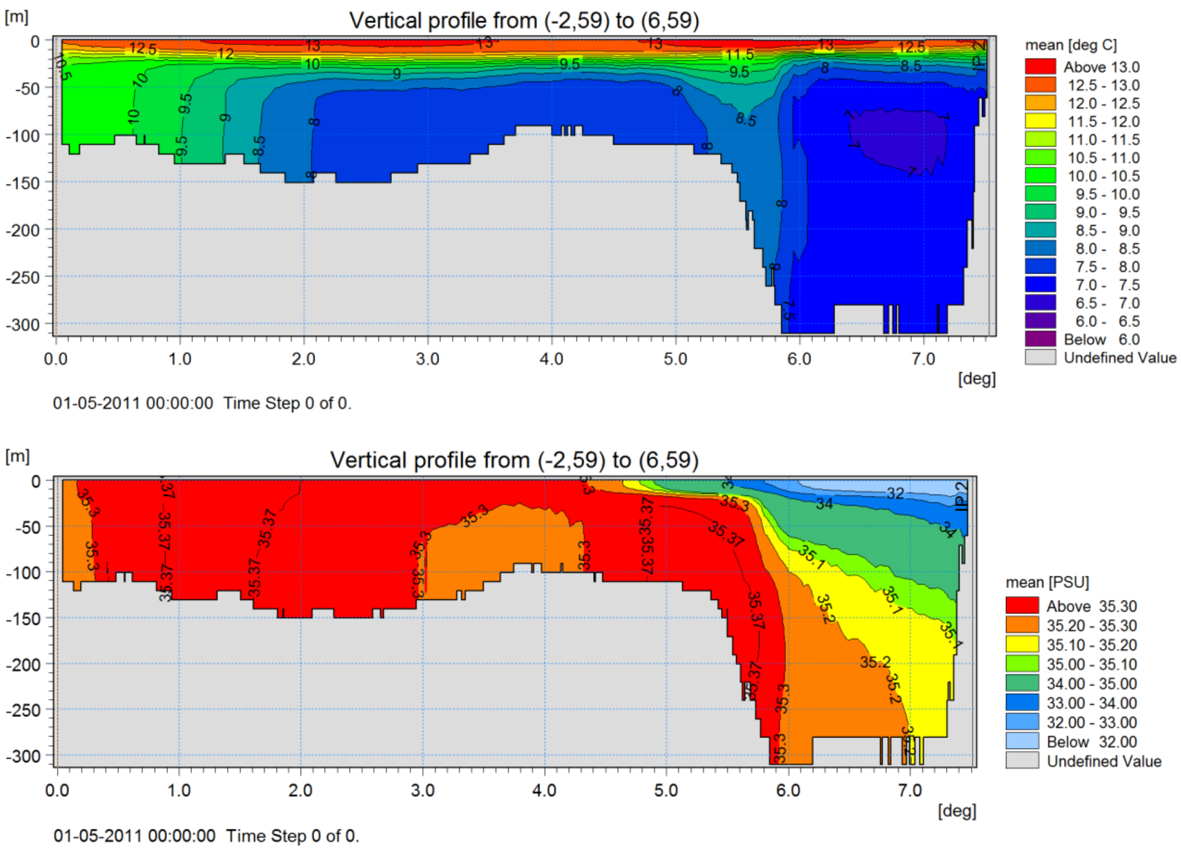


Figure 6.9 Modelled mean summer (May-August 2011) temperature (top) and salinity (bottom) transects between Scotland and Norway (along 58.5°N).

6.2.3.2 Measured salinity and water temperature

Modelled salinity and water temperature time series have been compared to measurements in a number of stations in the North Sea. Here we present a few examples from the North Sea (outside Danish waters) and refer to rbmp2021-2027.dhigroup.com (Google Chrome only) for more details on the Danish measurement stations.

In Figure 6.10 a number of measurement stations with salinity and water temperature exists and in Figure 6.11 and Figure 6.12 some examples are included. Note that the figures compare both surface and bottom salinities and temperatures.

The comparisons show a good agreement between the measurements and the North Sea model for both salinity and temperature.

For salinity, the absolute salinity levels as well as the stratification and the short-term variability and seasonality of the surface layer salinity are well represented by the model. For water temperature, the absolute levels and seasonality are also well represented by the model. Also interannual variability is well represented by the model.

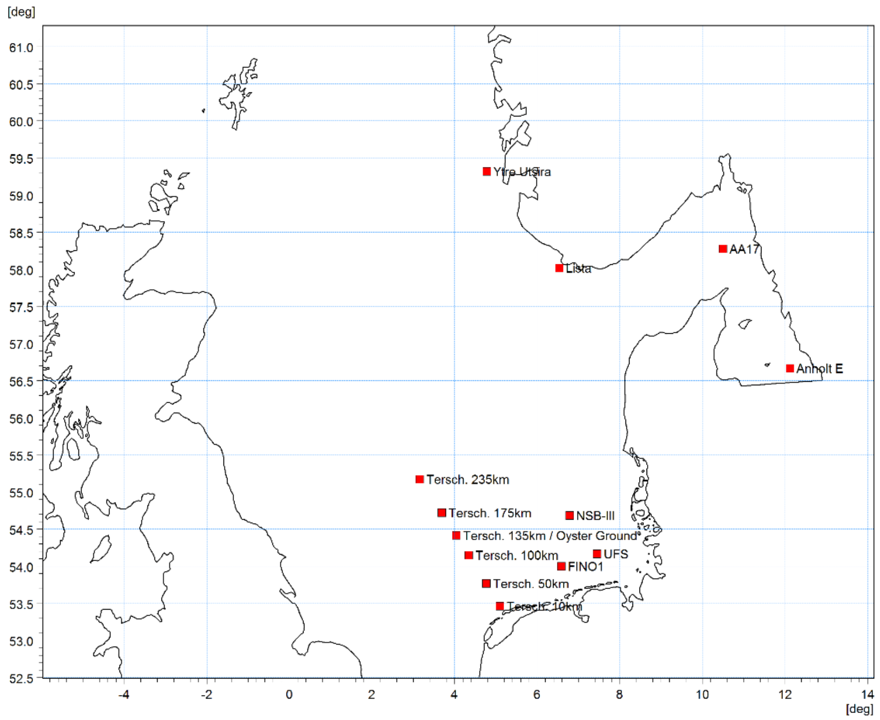


Figure 6.10 Location of salinity and temperature at various measurement stations within the North Sea.

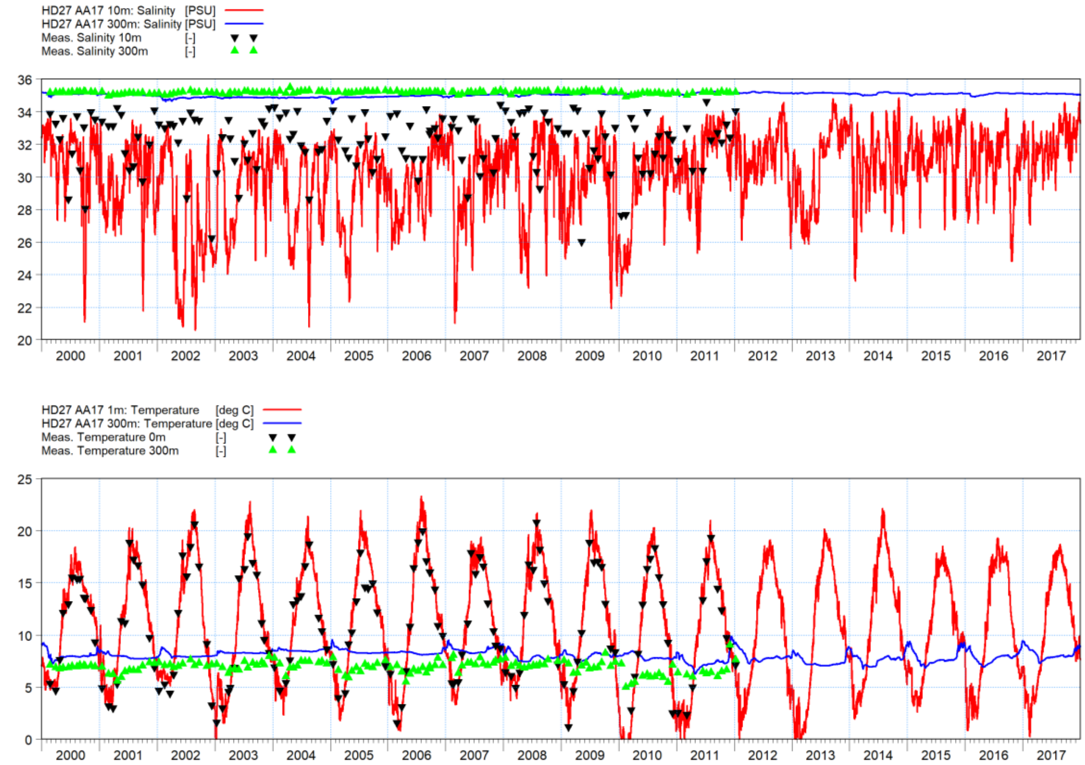


Figure 6.11 Comparison of measured and modelled salinity (top) and water temperature (bottom) at AA17 station.

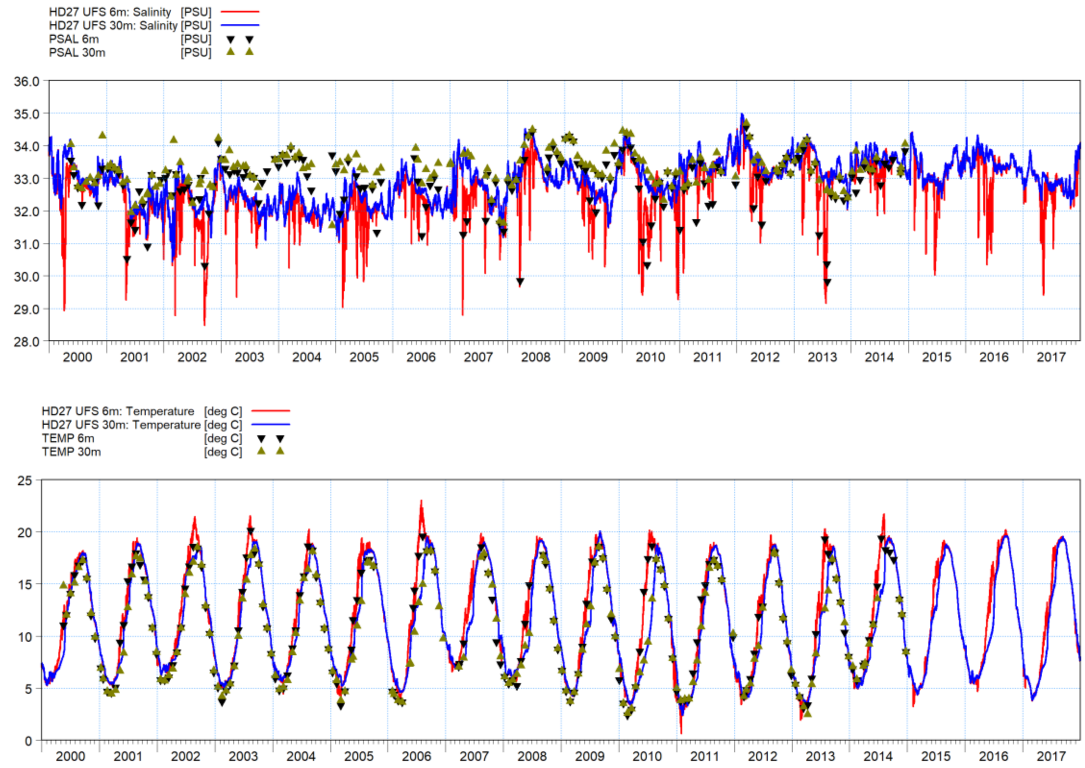


Figure 6.12 Comparison of measured and modelled salinity (top) and water temperature (bottom) at UFS station.

6.2.3.3 Validation in Danish waters

Figure 6-13 and Figure 6-14 show the different Danish locations with salinity and temperature (ST) measurements during the period 2002-2016. These data are presented using the WEB-tool. For the validation period (2011-2016) stations NOR7715, RKB43, RIB1510007, RIB1610002, RIB1620014 and SJY3 had sufficient data to be included in the model validation.

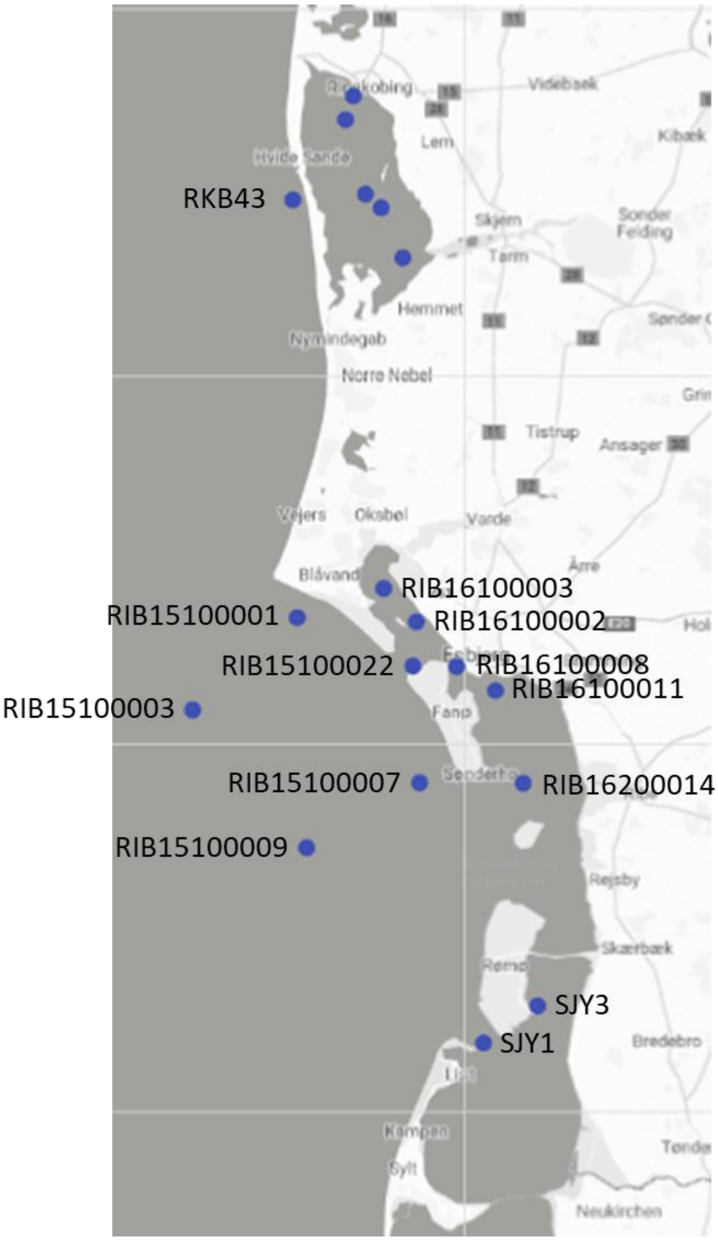


Figure 6-13 Locations used for performance measures in the southern part of the North Sea for salinity and temperature.

Figure 6-14 Locations used for performance measures in the northern part of the North Sea for salinity and temperature.

In Table 6-11 and Table 6-2 the model performance is evaluated according to DHI (2019b) based on three performance measures: P-Bias, Spearman Rank Correlation and Modelling Efficiency Factor. Time series are available at rbmp2021-2027.dhigroup.com (Google Chrome only).

Representative Danish stations with good coverage available for the period 2011-2016 are included in the tables, and the entire network of Danish measurement stations in the North Sea model domain is shown in Figure 6-13 and Figure 6-14.

In the tables color codes are included to highlight the overall model performance as 'excellent', 'very good', 'good' or 'poor'.

For the hydrodynamic model covering the North Sea we aim at 'excellent' or 'very good' model performance at more than 3 out of 4 measurement stations. For salinity the model performance was evaluated against the three different quality measures at six stations, and according to Table 6-1 the model meets 'excellent' at all stations for P-Bias and at least 'very good' at 5 out of 6 for Spearman Rank Correlation, whereas the model performance meet 'very good' at two stations, 'good' at two stations and 'poor' at two stations for Modelling Efficiency Factor. For water temperature (see Table 6-2) the model meets 'excellent' at all stations for all measures.

Here, we conclude that the hydrodynamic model covering the North Sea is well suited for continued biogeochemical model development as part of the overall development of mechanistic models towards the RBMP 2021-2027.

Table 6-1 Review of model performance based on measured and modelled salinities for the validation period 2011-2016. The performance is evaluated according to DHI (2019b) and blue colour indicates an 'excellent' model, dark green indicates a 'very good' model, light green indicates a 'good' model and yellow indicates a 'poor' model.

Station	P-Bias	Spearman Rank Correlation	Modelling Efficiency Factor	Number of observations
NOR7715	0.6	0.54	0.10	222
RKB43	-1.4	0.71	0.34	134
RIB1510007	-3.4	0.87	0.64	288
RIB1610002	-0.2	0.70	0.55	164
RIB1620014	-0.3	0.66	0.11	285
SJY3	0.7	0.76	0.46	261

Table 6-2 Review of model performance based on measured and modelled water temperatures for the validation period 2011-2016. The performance is evaluated according to DHI (2019b) and blue colour indicates an 'excellent' model, dark green indicates a 'very good' model, light green indicates a 'good' model and yellow indicates a 'poor' model.

Station	P-Bias	Spearman Rank Correlation	Modelling Efficiency Factor	Number of observations
NOR7715	-4.1	0.96	0.91	223
RKB43	0.8	0.98	0.95	261
RIB1510007	1.5	0.99	0.96	136
RIB1610002	8.4	0.98	0.93	288
RIB1620014	2.4	0.98	0.94	164
SJY3	2.9	0.98	0.95	261

7 References

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