Development of Mechanistic Models

Mechanistic Model for the Inner Danish Waters

Hydrodynamic model documentation

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The expert in **WATER ENVIRONMENTS**

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The model development presented in this technical note represents the hydrodynamic model development for the Inner Danish Waters (IDF-model). The IDF-model is part of a larger model complex comprising a number of mechanistic models developed by DHI and several statistical models developed by Aarhus University (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 Inner Danish Waters: The IDF-model. This specific model includes 35 Danish water bodies, some of which are also covered by other mechanistic models:

Water Body*)	Number	Water Body*)	Number
Nordlige Øresund	6	Djursland Øst	140
Isefjord, ydre	24	Århus Bugt, Kalø og Begtrup Vig	147
Musholm Bugt, indre	26	Kattegat, Læsø	154
Sejerøbugt	28	Isefjord, indre	165
Kalundborg Fjord	29	Kattegat, Nordsjælland	200
Smålandsfarvandet, syd	34	Køge Bugt	201
Guldborgssund	38	Jammerland Bugt	204
Langelandsbælt, øst	41	Kattegat, Nordsjælland >20 m	205
Hjelm Bugt	44	Smålandsfarvandet, åbne del	206
Grønsund	45	Femernbælt	208
Fakse Bugt	46	Det Sydfynske Øhav	214
Østersøen, Bornholm	56	Lillebælt, syd	216
Østersøen, Christiansø	57	Lillebælt, Bredningen	217
Langelandssund	90	Århus Bugt syd, Samsø og Nordlige Bælthav	219
Storebælt, SV	95	Kattegat, Aalborg Bugt	222
Storebælt, NV	96	Nordlige Lillebælt	224
Hevring Bugt	138	Nordlige Kattegat, Ålbæk Bugt	225
Anholt	139		

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

The IDF 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 can eventually 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 IDF hydrodynamic model was developed successfully for the entire model period 2002-2016, and from the validation we conclude:

- On average the P-Bias is 1.0% with respect to salinity. This covers 64 stations with a difference between model and measurement of less than 10% (corresponding to an 'excellent' model) and 3 stations with a difference of less than 20% (corresponding to a 'very good' model) and one station with a difference between 20-40% ('good' model).

  For water temperature the average P-Bias is -6.0% covering 49 stations with an absolute difference of less than 10% ('excellent' model), 14 stations with an absolute difference of less than 20% ('very good' model) and five stations with differences between 20-40% ('good' model).

- With respect to the Spearman Rank Correlation the average numbers are 0.84 and 0.96 for salinity and water temperature, respectively. This covers 23 stations evaluated as 'excellent' and 42 stations as 'very good' and three stations as good/poor with respect to salinity and 64 stations evaluated as 'excellent' regarding water temperature, and 4 stations evaluated as 'very good'.

- The average Modelling Efficient Factor (MEF) for salinity is 0.57 corresponding to a 'very good' model. This covers 21 stations evaluated as 'excellent', 32 stations evaluated as 'very good' and 9 stations evaluated as 'good'. 6 stations are evaluated as 'poor', most of them overlapping other models.

  The average Modelling Efficient Factor (MEF) for temperature is 0.89, and 62 stations are evaluated as 'excellent' and six stations as 'very good'.

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 Inner Danish Waters 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 Inner Danish Waters (IDF-model). The IDF-model is part of a larger model complex comprising a number of mechanistic models developed by DHI and several 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 Inner Danish Waters. This specific model includes the Danish water bodies listed in Table 2.1 and shown in Figure 2.1.

Table 2.1 Water bodies included in the IDF-model.

Water Body*)	Number	Water Body*)	Number
Nordlige Øresund	6	Djursland Øst	140
Isefjord, ydre	24	Århus Bugt, Kalø og Begtrup Vig	147
Musholm Bugt, indre	26	Kattegat, Læsø	154
Sejerøbugt	28	Isefjord, indre	165
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Østersøen, Christiansø	57	Lillebælt, Bredningen	217
Langelandssund	90	Århus Bugt syd, Samsø og Nordlige Bælthav	219
Storebælt, SV	95	Kattegat, Aalborg Bugt	222
Storebælt, NV	96	Nordlige Lillebælt	224
Hevring Bugt	138	Nordlige Kattegat, Ålbæk Bugt	225
Anholt	139		

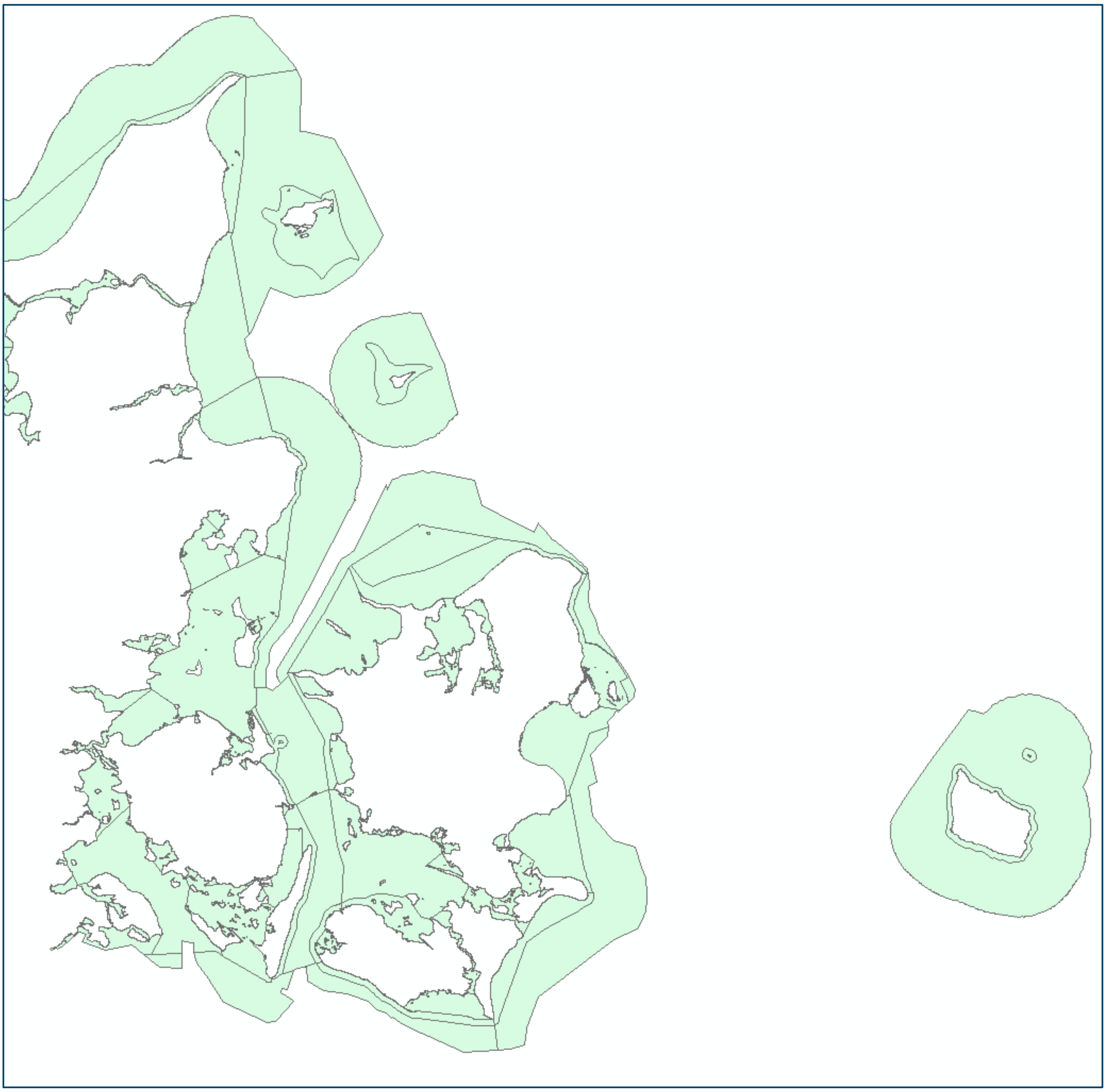


Figure 2.1 Danish water bodies (according to the water bodies defined as part of the River Basin Management Plans 2015-2021) of which 35 are potentially covered by the IDF model.

3 Modelling Concept

3.1 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 to predict 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. In addition, numerous 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 finalized, they will be applied for scenario modelling, although the specific scenarios are not yet defined.

3.2 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 IDF-model is defined as a regional model. The mechanistic model complex developed as part of the present project 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 water bodies in and around Smålandsfarvandet.

- Specific estuary 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 2019a), 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.

3.3 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-coordinated transformation approach. The scientific documentation of MIKE 3 HD FM is given in DHI (2017a).

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 IDF model being one of DHI's general regional models, the model domain was chosen to include the inner Skagerrak, Kattegat, the Belt Sea and the Baltic Sea. The model has one open boundary in Skagerrak towards the North Sea.

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 IDF model the horizontal mesh mainly consists of triangular elements of varying sizes, but also quadrangular elements have been applied for resolving certain deep channels in the Belt Sea.

The horizontal resolution varies gradually from 500-1000m in the Belt Sea coastal areas to 4-6km in the Baltic offshore areas. Generally, the mesh is finer in coastal water and coarser in open water. The mesh applies spherical coordinates (Latitude/Longitude) and refers to the WGS-84 geographical datum.

The model bathymetry is based on the general 500m x 500m gridded bathymetric data set established during the Fehmarn Belt environmental studies (FEHY, 2011). The water depths refer to DVR90.

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

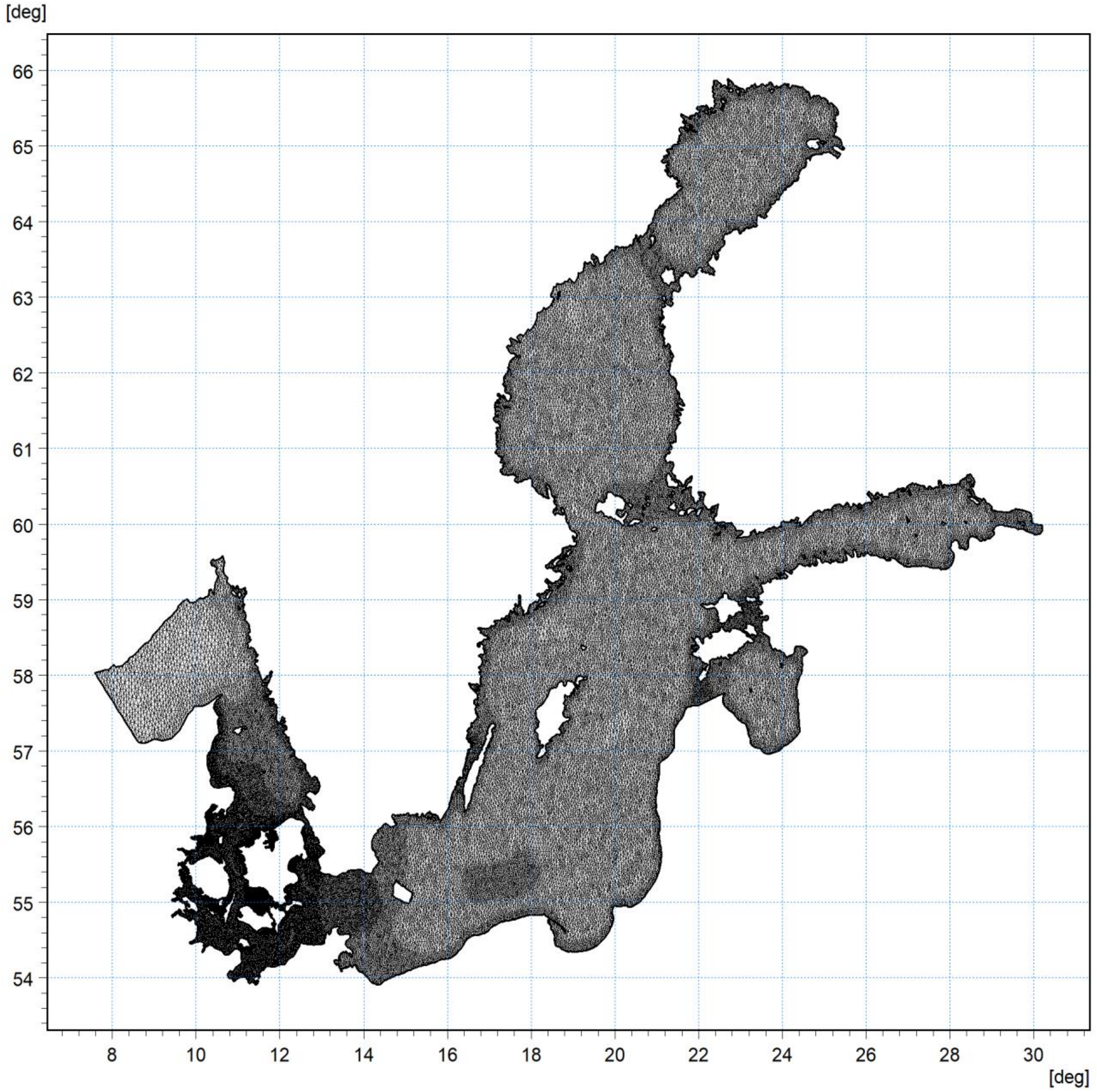


Figure 4.1 Horizontal model mesh of the IDF model (DKBS2-HD75). The model has one open boundary in Skagerrak towards the North Sea.

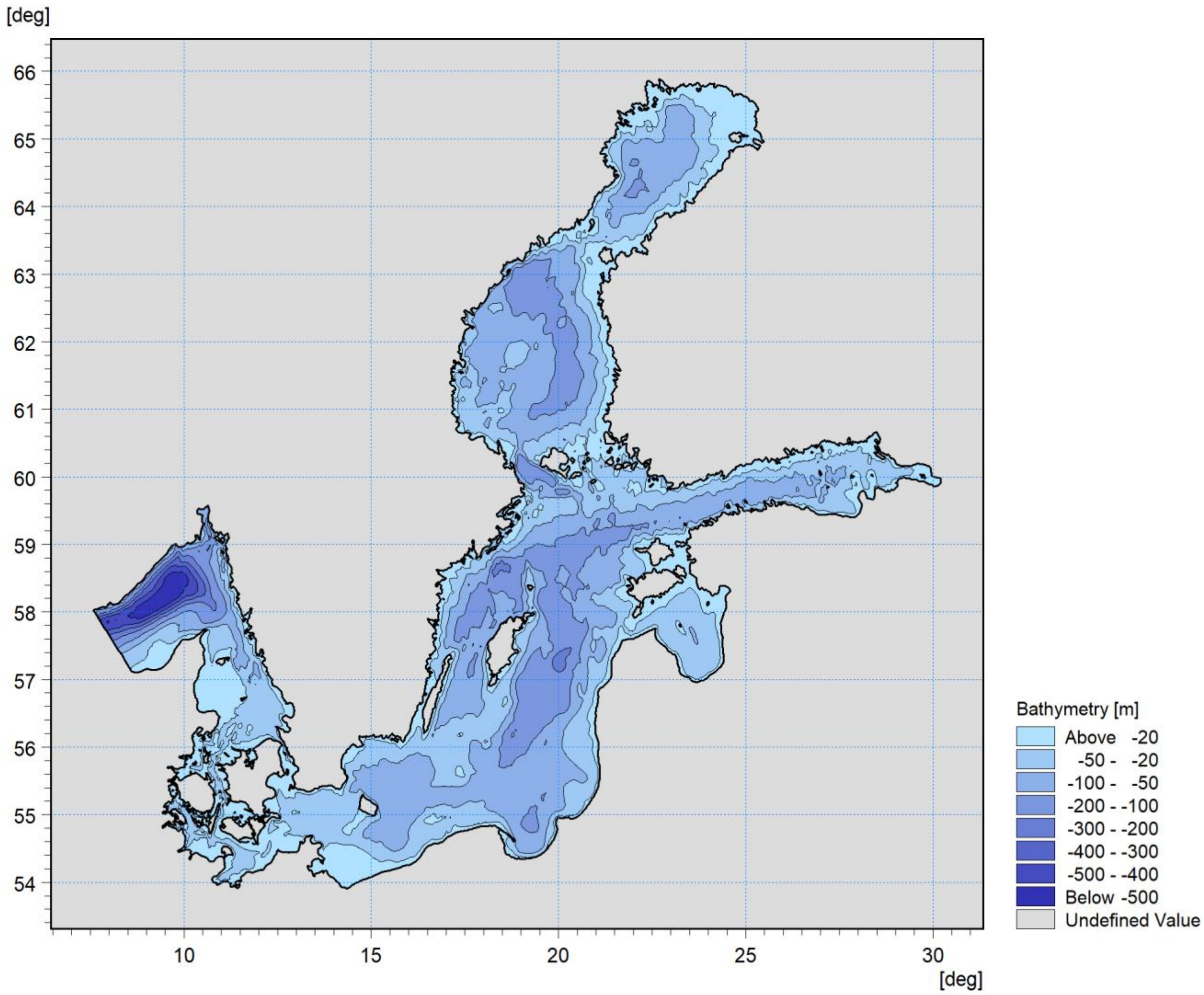


Figure 4.2 Model bathymetry of the IDF model (DKBS2-HD75). Water depths refer to DVR90.

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 IDF model the vertical mesh consists of 10 sigma-layers down to -10m level and 233 z-layers below -10m level. From the water surface to 220m (Gotland Deep) the layer thickness is 1m and between 220m and 610m (bottom of Skagerrak) the layer thickness increases gradually from 5m to 20m.

4.3 Model Forcings

4.3.1 Open Boundary Conditions

The IDF model contains one open boundary towards the North Sea (see Figure 4.1). The boundary line starts at Tregde in Norway and ends at Hanstholm in Denmark. The hydrodynamic boundary condition is specified as a so-called Flather boundary (Flather, 1976), which implies that, apart from salinity and water temperature, both water level and current velocities are required as boundary condition.

The data for the boundary condition (water level, velocities, salinity, water temperature) are extracted from DHI's operational North Sea model (the UKNS2 model). The water level boundary is further reduced by 0.3m to make it consistent with the IDF model vertical datum.

In order to improve the modelled tidal heights a further correction of the tidal part of the water level boundary based on tidal data from the DTU10 global tide dataset (Cheng and Andersen, 2010) is undertaken.

Also, the water temperature on the open boundary has been adjusted by means of measured temperature profiles at the Lista station in the Norwegian part of Skagerrak.

4.3.2 Atmospheric Forcing

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

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

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

The model furthermore applies ice forcing from the CFSR data set from NCEP/NOAA. The ice concentration fields are provided in a resolution of 0.2° x 0.2° in hourly time-steps.

The StormGeo data are only available from 2009 and onwards. Therefore, meteorological fields from DMI (9nm, 3-hourly) were applied for the period 2002-2005 and from Vejr2 of Denmark (0.15°, hourly) were applied for the period 2005-2009. Missing meteorological parameters have been filled with CFSR data (0.3°, hourly).

4.3.3 Freshwater Sources

The IDF model includes a number of model sources representing the freshwater run-off from land to sea.

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

- DCE (Danish Centre for Environment and Energy) – Danish run-off
- E-HYPE (http://hypeweb.smhi.se/europehype/time-series/) – Non-Danish run-off

In Figure 4.3 the location of the model sources is illustrated. In Denmark 4th order area run-off distributed to main rivers and streams are applied.

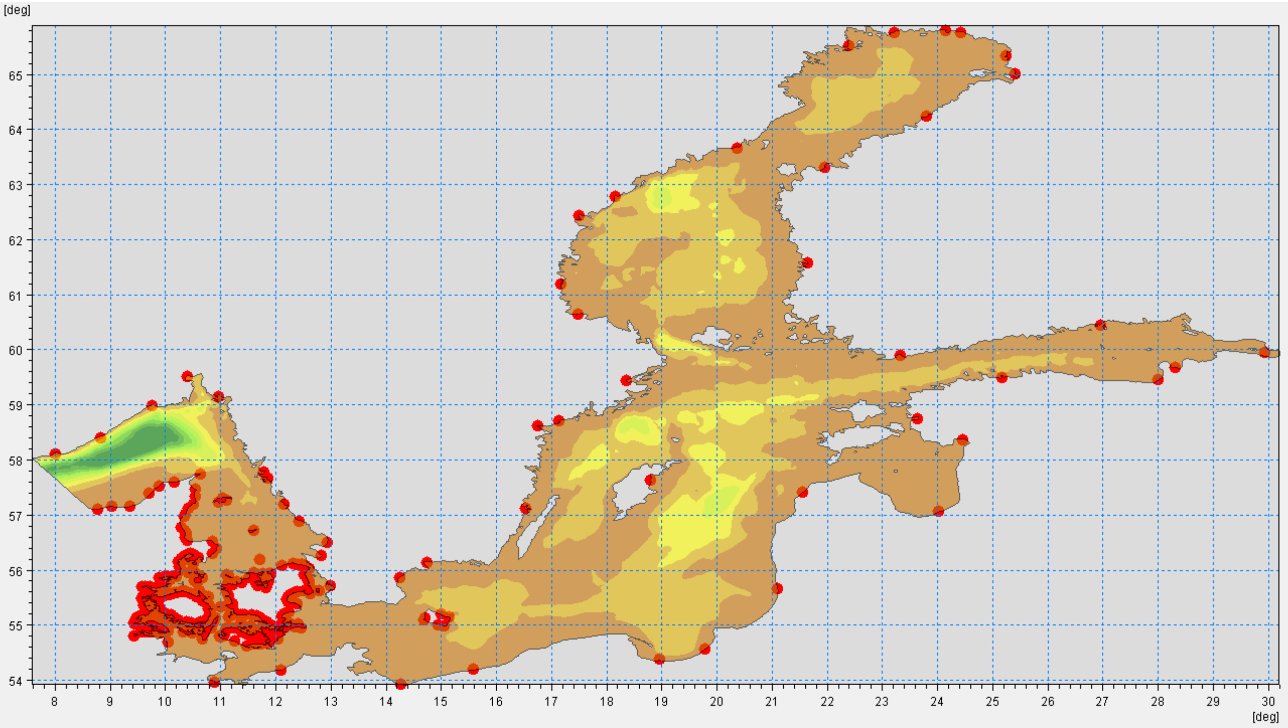


Figure 4.3 Illustration of the location of freshwater sources in the IDF model (DKBS2-HD75). The sources represent the main rivers but are scaled to include all local run-off from land to sea. In Denmark 4th order area run-off distributed to main rivers and streams are applied.

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’. However, as the IDF model covers a significant area the model is initiated with results from previous model runs of DHI’s operational models.

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.

As it is extremely important that an area like the Baltic Sea is initiated correctly, the IDF model is initiated with salinity and temperature initial fields originating from DHI’s operational models.

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 requires a well-proportioned model domain as well as adequate model forcings, and this is not always obtained at 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 IDF model (DKBS2-HD75).

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 25 m/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 = 1.0/1.0-0.01 (salinity) and 1.0/1.0 (temperature)

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 SMF-model was 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 DKBS2 hydrodynamic model was validated against measured water levels from select tide gauge stations within the model domain.

In Figure 6.1 the location of the tide gauge stations is shown and in Figure 6.2 and Figure 6.3 examples of water level comparisons are shown. Note that the plots have been adjusted for the difference in the vertical datum between the tide gauge and the model.

The water level comparison (only examples are included in this report) shows that the IDF model compares well to the measurements in terms of both tidal amplitudes and phases (mainly in Skagerrak, Kattegat and the Belt Sea) and residual (non-tidal) variability.

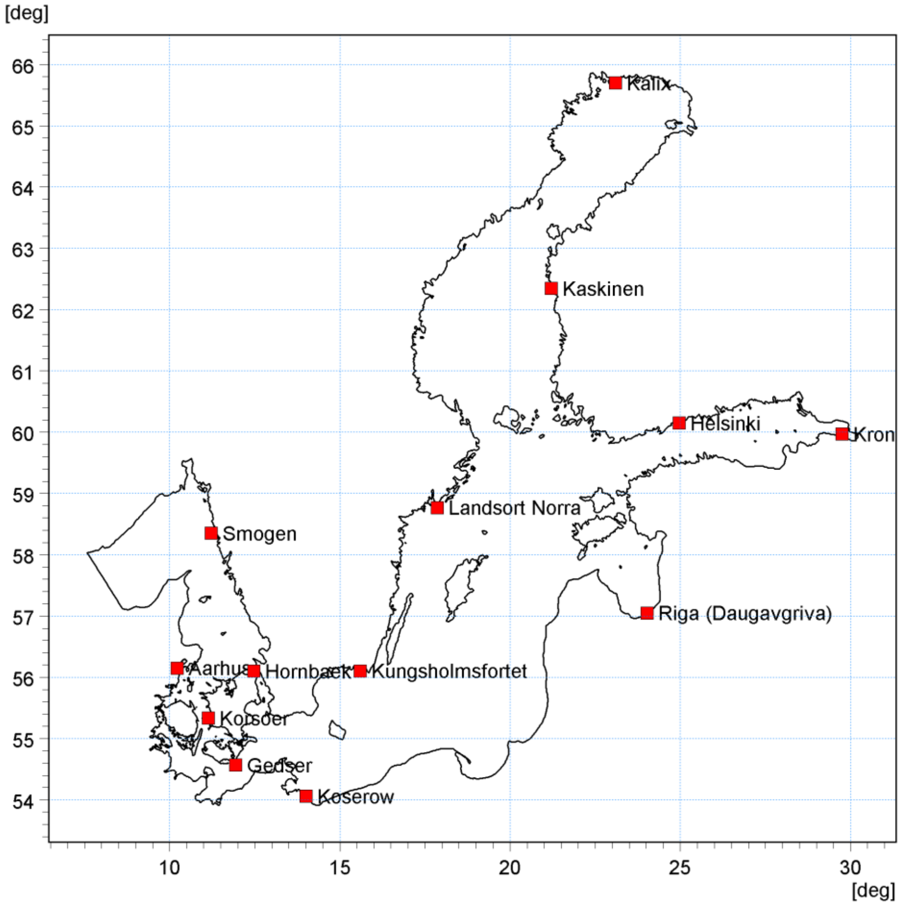


Figure 6.1 Location of applied tide gauge stations.

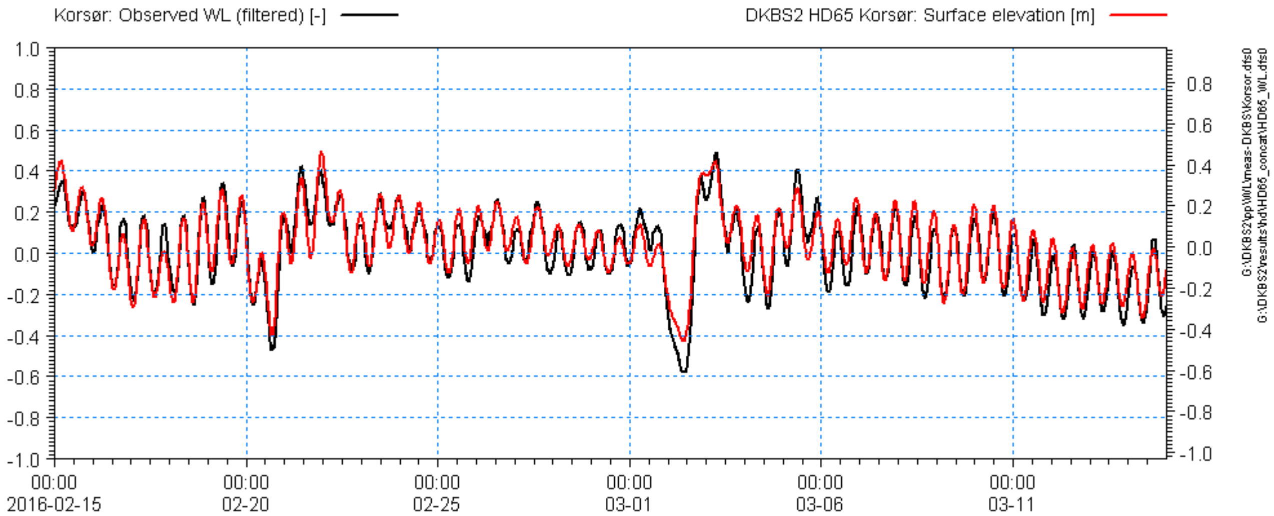


Figure 6.2 Comparison of measured and modelled water level at Korsør.

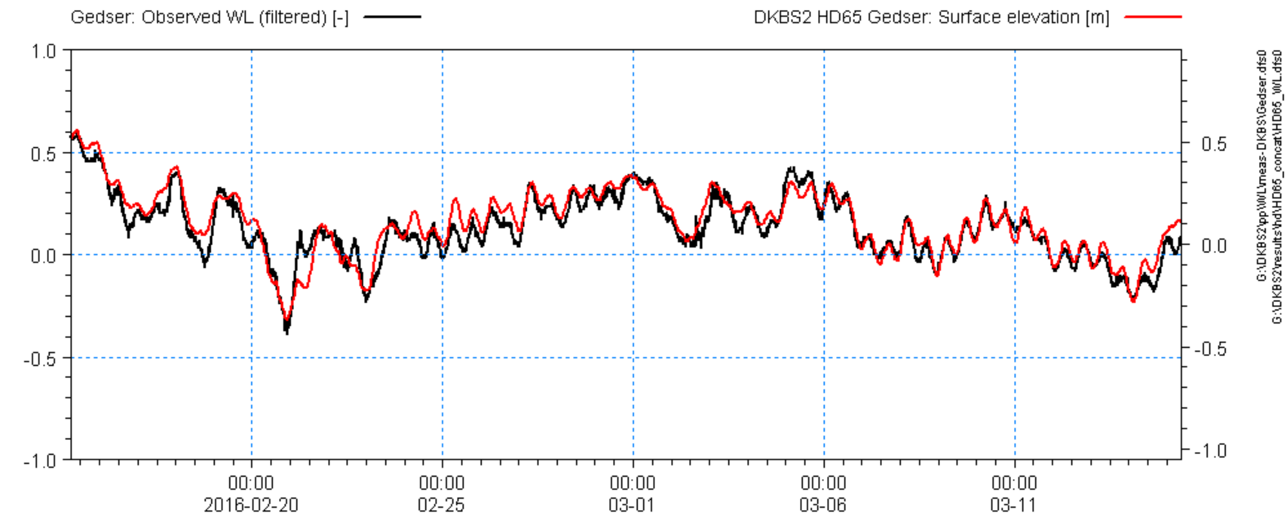


Figure 6.3 Comparison of measured and modelled water level at Gedser.

6.2.2 Discharge Through Danish Straits

In Figure 6.4 the water discharge through Great Belt, Øresund and Little Belt in 2011 is shown. The modelled mean outflow for the period 2008-2017 is 533 km^3/year, which is in accordance with the value of about 500 km^3/year established in the literature.

In Figure 6.5 linear regressions between instantaneous discharge at Great Belt and Øresund, and Great Belt and Little Belt, respectively, are shown. The slope terms from the regressions are in fair agreement with the established ration of 1:7:3 between Little Belt, Great Belt and Øresund, respectively.

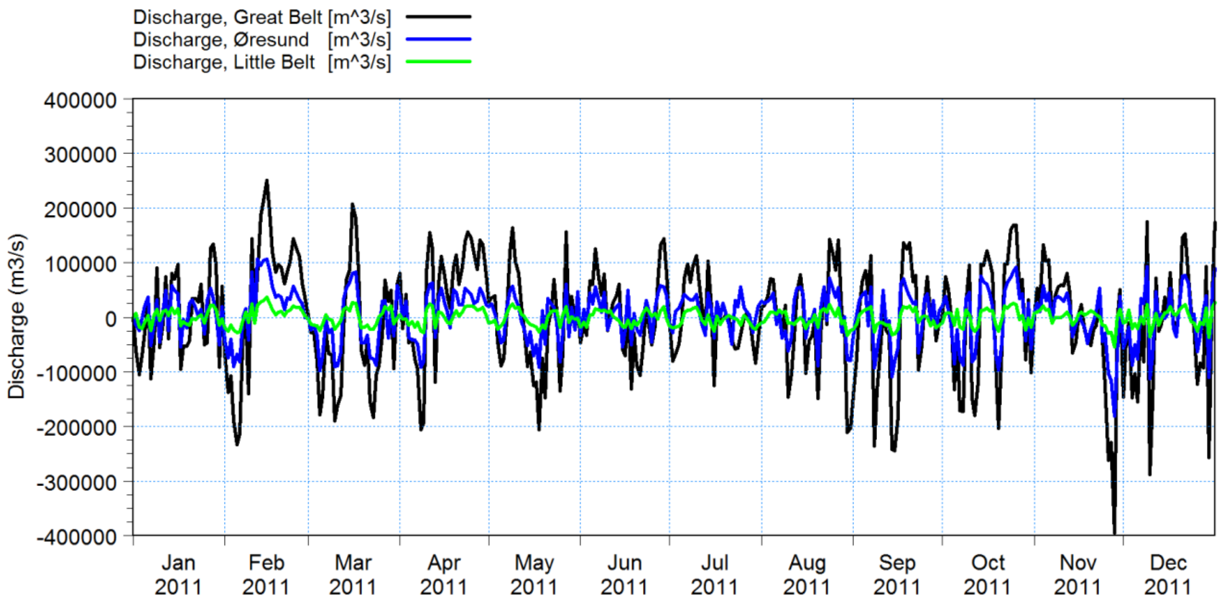


Figure 6.4 Instantaneous discharge at Great Belt, Øresund and Little Belt shown exemplarily for 2011. Positive numbers represent outflow (northward), negative numbers inflow (southward) events.

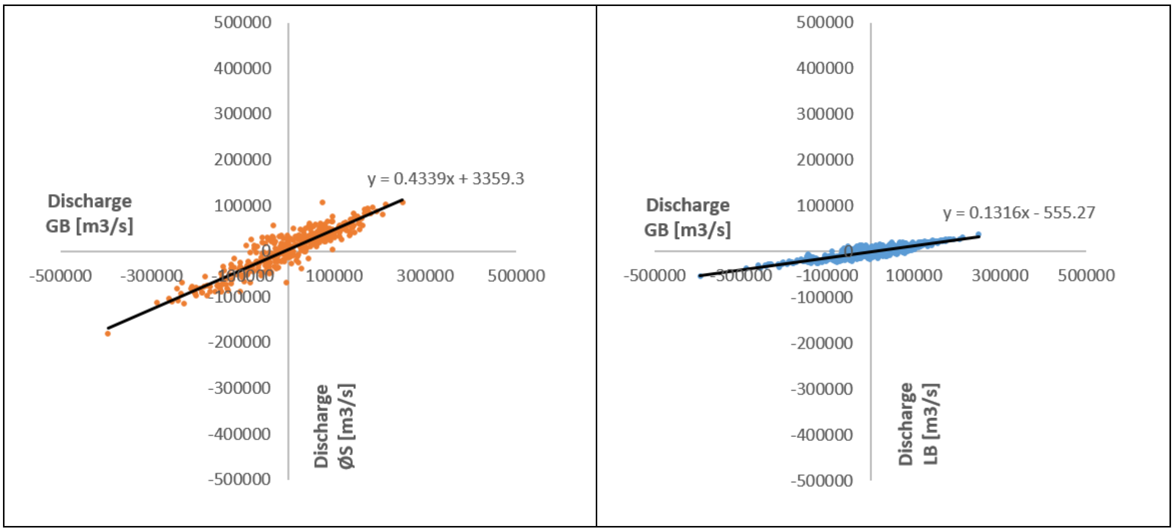


Figure 6.5 Scatter plots of instantaneous discharges at Great Belt (horizontal axes) vs Øresund and Little Belt (vertical axes) for the year 2011.

6.2.3 Salinity and Water Temperature

Modelled salinity and water temperature time series have been compared to measurements at a number of stations. In Figure 6.6 to Figure 6.8 all stations used for the validation within the Danish waters are shown. All corresponding time series comparison plots can be seen in the WEB-tool (rbmp2021-2027.dhigroup.com).

In Figure 6.9 and Figure 6.10 two examples of salinity and water temperature comparisons are included. Model results used for this specific project cover the period 2002-2016, but here we compare measured data and modelled results for the period 2008-2017.

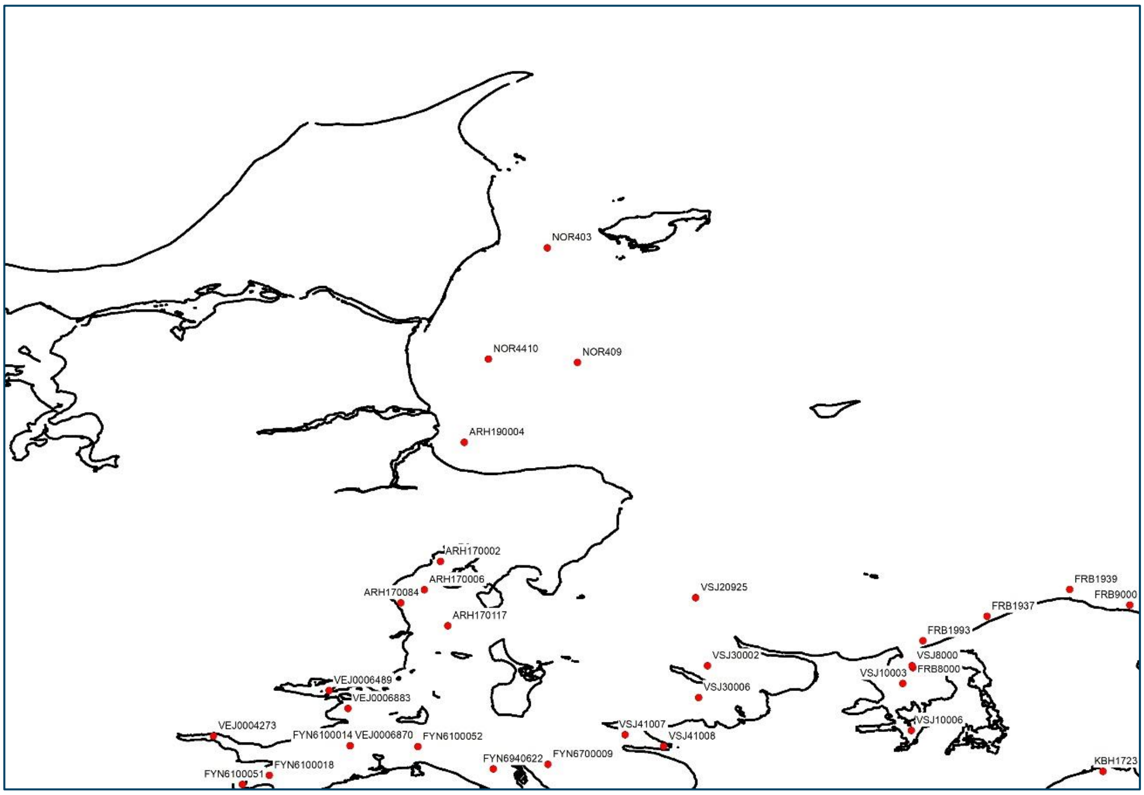


Figure 6.6 Zoom and naming of the different validation stations for salinity and temperature in the northern part of the IDF-model used in the model performance, see Table 6.1 and Table 6.2.

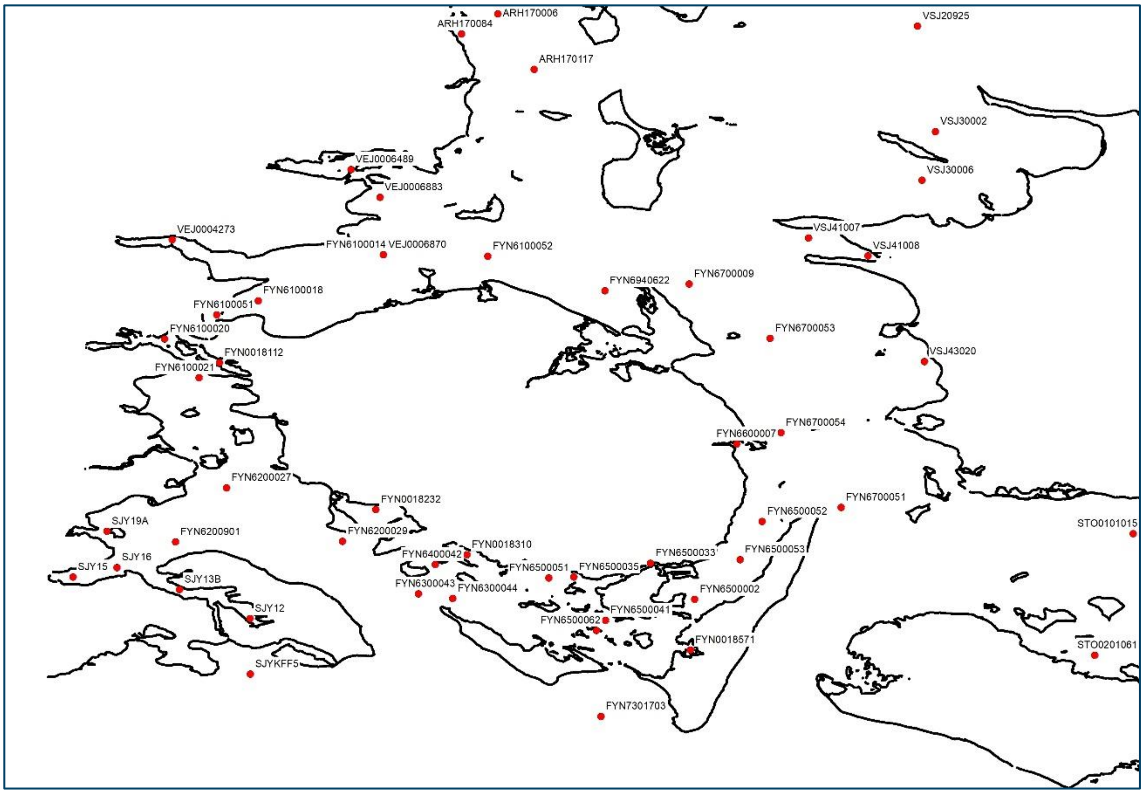


Figure 6.7 Zoom and naming of the different validation stations for salinity and temperature around Funen used in the model performance, see Table 6.1 and Table 6.2.

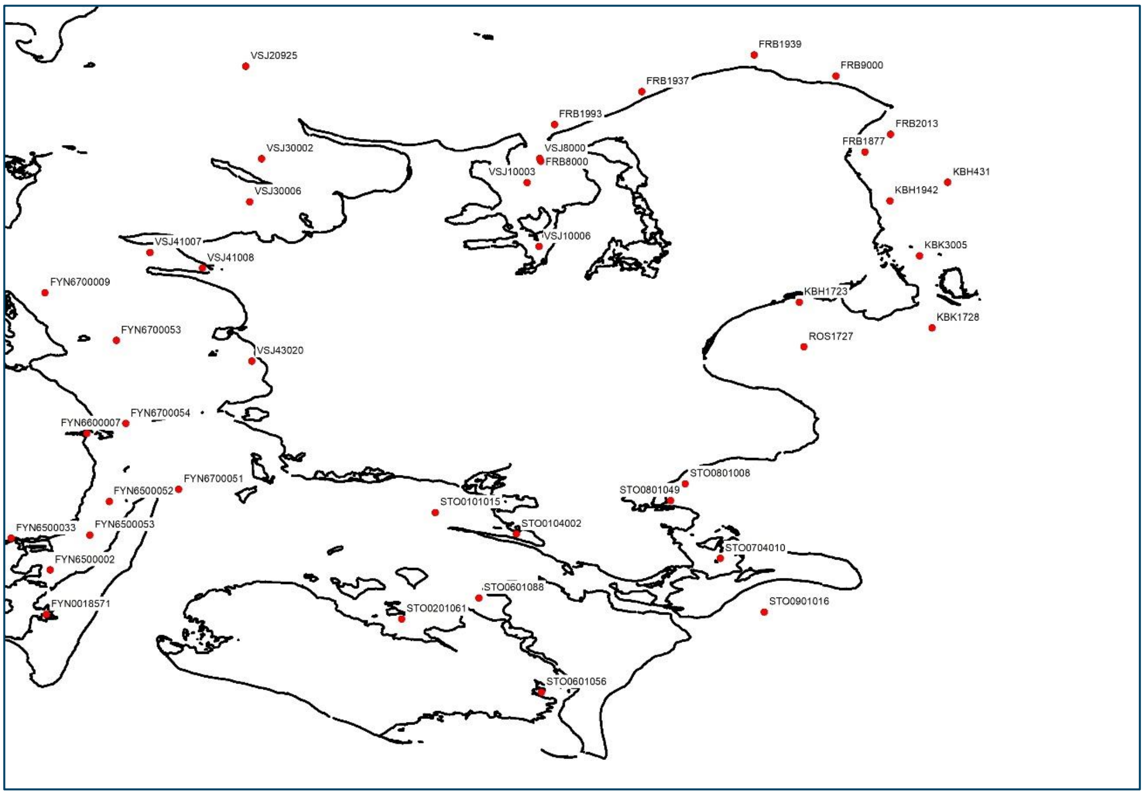


Figure 6.8 Zoom and naming of the different validation stations for salinity and temperature around Zealand used in the model performance, see Table 6.1 and Table 6.2.

In Table 6.1 and Table 6.2 the model performance is evaluated according to DHI (2019a) based on three performance measures: P-Bias, Spearman Rank Correlation and Modelling Efficiency Factor. Representative stations with good coverage available for the period 2011-2016 are included, and the entire station network in the IDF-model domain is shown in Figure 6.6 to Figure 6.8. In the tables colour codes are included to highlight the overall model performance as 'excellent', 'very good', 'good' or 'poor'.

The model covering the Inner Danish Waters includes a relatively large amount of individual water bodies (35 water bodies[1]) with varying tidal and flushing characteristics and varying freshwater influence. Furthermore, most of the areas are stratified whereas some areas and water bodies are well mixed. For the hydrodynamic model covering Inner Danish Waters 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 68 stations. Some of these 68 stations overlap with stations also used for validation of other models, but they are still included here as they provide an overview of the model performance in all areas and also provide some evidence of improvements obtained while developing local models.

According to Table 6.1, the model salinity meets 'excellent' or 'very good' in 92% of all measures at all stations. Similarly, the modelled water temperature (see Table 6.2) meets 'excellent' or 'very good' in 98% of all measures at all stations.

Hence, we conclude that the hydrodynamic model covering the Inner Danish Waters is well suited for continued biogeochemical model development as part of the overall development of mechanistic models towards the RBMP 2021-2027.

[1] The 18 water bodies refer to the water bodies defined according to RBMP 2015-2021

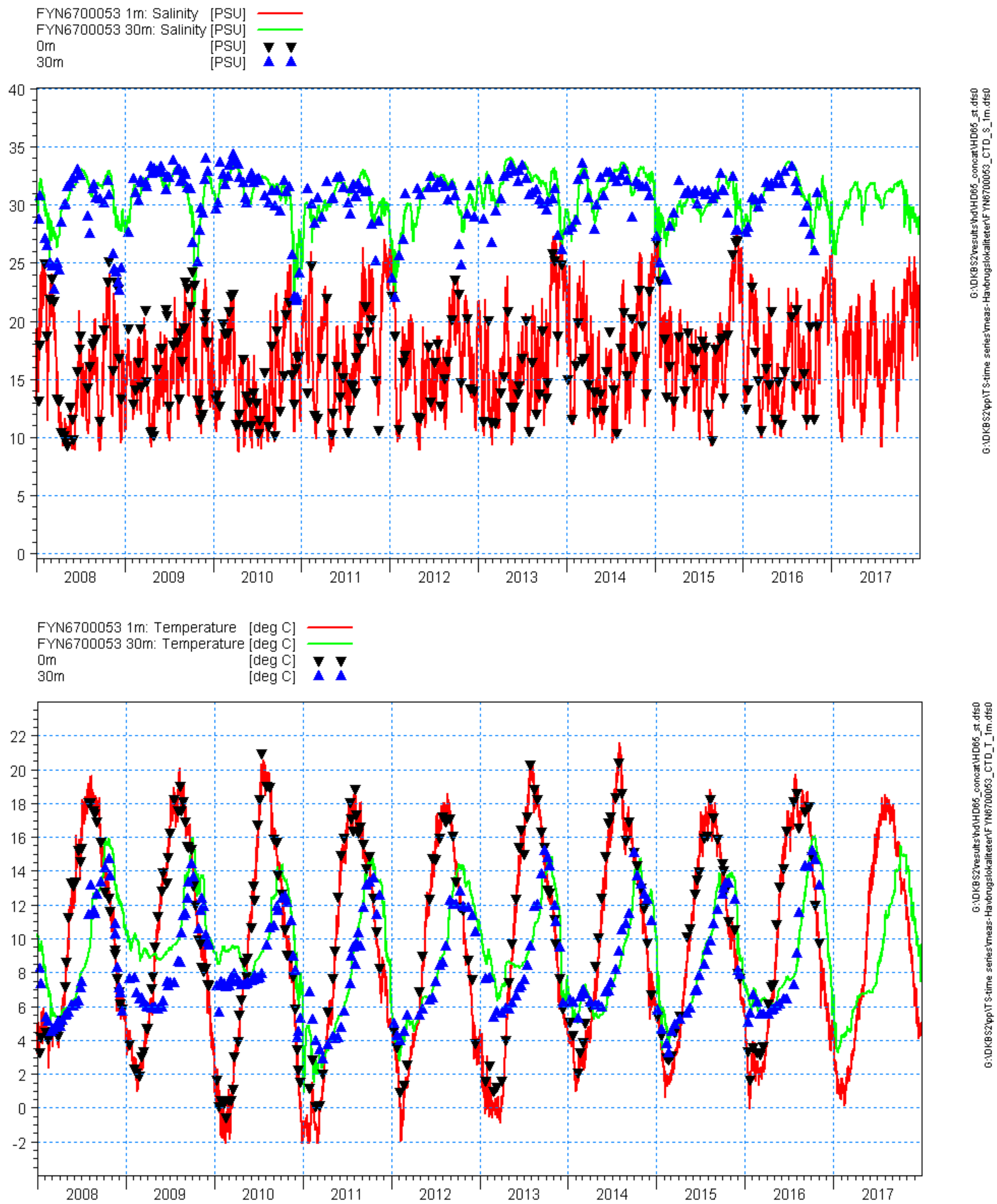
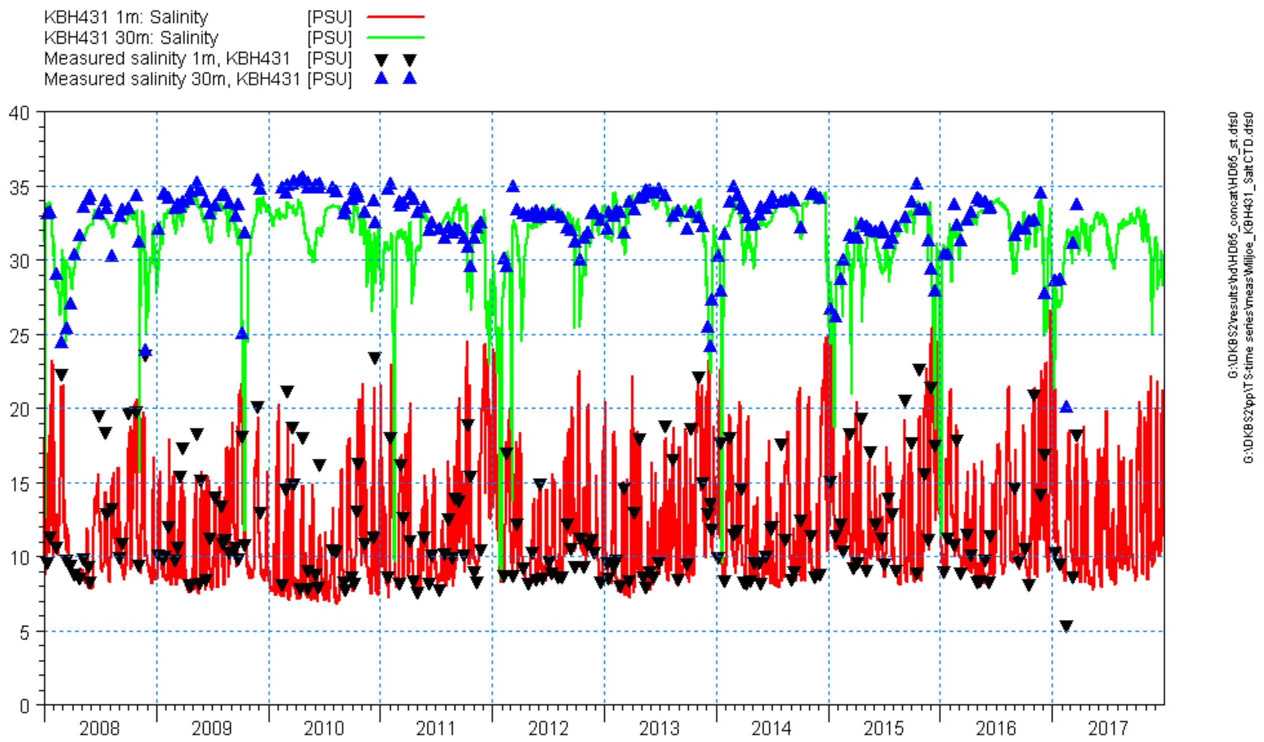


Figure 6.9 Comparison of measured and modelled salinity (top) and water temperature (bottom) at FYN6700053 station.



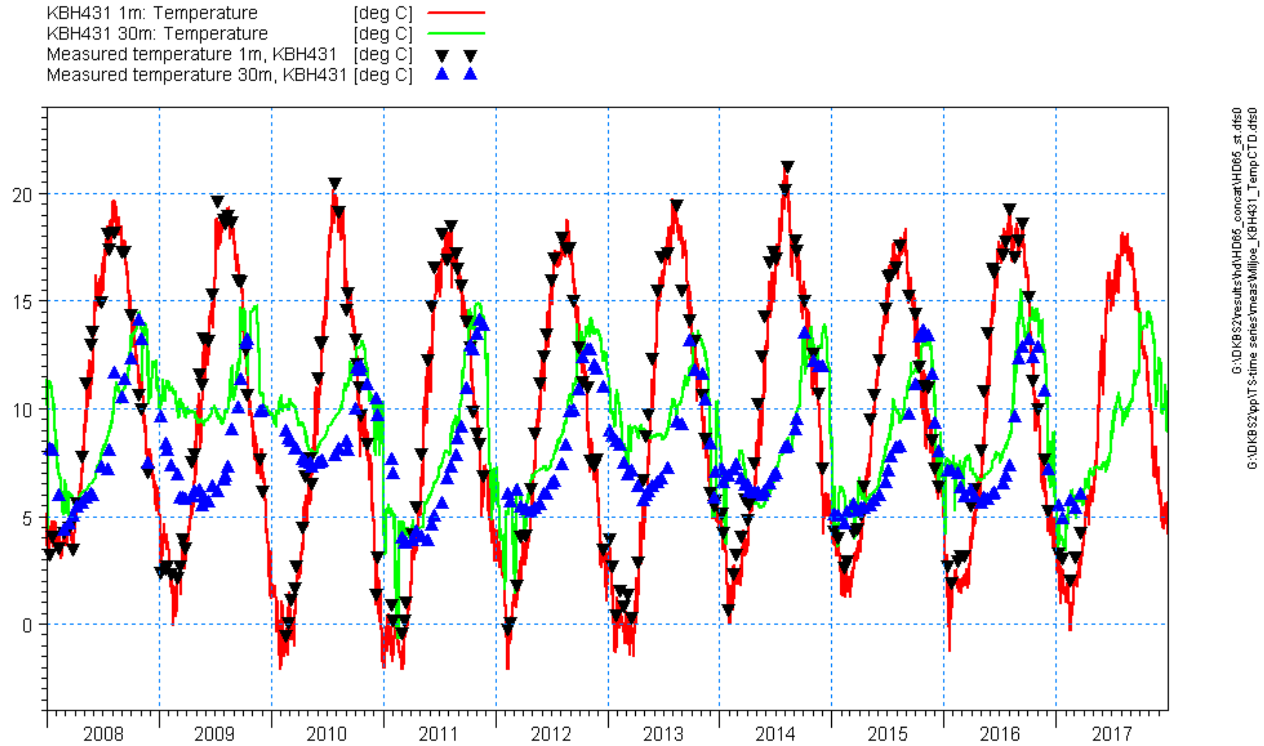


Figure 6.10 Comparison of measured and modelled salinity (top) and water temperature (bottom) at KBH431 station.

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 (2019a) 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
ARH170002	-0.6	0.86	0.72	306
ARH170006	-0.6	0.92	0.85	328
ARH170084	1.6	0.90	0.81	94
ARH170117	-0.8	0.91	0.86	316
ARH190004	-0.5	0.71	0.57	48
ARH250032	35.7	0.59	-1.21	94
FRB1993	-8.5	0.85	0.45	292
FRB2013	-3.2	0.92	0.78	50
FRB9000	-5.1	0.91	0.87	52
FYN0018112	2.4	0.76	0.56	280
FYN0018232	7.1	0.84	0.18	274
FYN0018310	5.8	0.87	0.55	276
FYN0018571	4.0	0.87	0.63	272
FYN6100016	0.4	0.92	0.83	92
FYN6100018	0.4	0.93	0.84	56
FYN6100020	1.0	0.88	0.76	52
FYN6100021	3.2	0.92	0.80	286
FYN6100051	-3.1	0.86	0.68	54
FYN6100052	-0.2	0.96	0.92	100
FYN6200027	3.4	0.92	0.80	96
FYN6200029	7.7	0.92	0.62	92
FYN6300043	6.3	0.95	0.81	290
FYN6300044	6.7	0.92	0.65	142
FYN6400042	5.0	0.81	0.45	54
FYN6500033	-1.2	0.86	0.55	48

Station	P-Bias	Spearman Rank Correlation	Modelling Efficiency Factor	Number of observations
FYN6500051	2.8	0.83	0.59	310
FYN6500052	0.7	0.84	0.76	56
FYN6500053	0.5	0.89	0.79	286
FYN6700009	0.3	0.95	0.91	90
FYN6700051	5.2	0.95	0.89	62
FYN6700053	0.9	0.97	0.96	232
FYN6700054	2.5	0.97	0.92	58
FYN6940622	0.3	0.93	0.87	297
FYN7301703	9.7	0.95	0.72	290
KBH431	-2.2	0.94	0.97	274
KBK3005	-10.0	0.83	0.67	56
NOR403	2.0	0.87	0.83	99
NOR409	2.8	0.83	0.66	276
NOR4410	0.9	0.81	0.61	274
NOR7715	0.3	0.48	-0.33	207
ROS1727	6.1	0.81	0.60	271
SJY12	0.6	0.80	0.66	275
SJY13B	2.8	0.75	0.52	118
SJY15	2.8	0.88	0.74	282
SJY16	3.1	0.81	0.63	92
SJY19A	1.8	0.81	0.64	50
SJY19	5.9	0.86	0.60	48
SJYKFF2	3.3	0.41	0.00	120
SJYKFF5	3.2	0.86	0.70	284
STO0101015	-8.1	0.68	0.32	288
STO0101023	-13.0	0.74	0.27	291
STO0101124	-4.9	0.76	0.35	52

Station	P-Bias	Spearman Rank Correlation	Modelling Efficiency Factor	Number of observations
STO0104002	-0.2	0.76	0.63	251
STO0201061	-5.4	0.79	0.66	272
STO0601056	3.8	0.71	-0.25	272
STO0704010	10.3	0.81	0.34	270
STO0801008	9.4	0.82	0.56	296
VEJ0004273	-1.8	0.88	0.79	276
VEJ0005790	-6.8	0.76	0.38	284
VEJ0006489	0.2	0.83	0.70	102
VEJ0006870	-1.1	0.92	0.84	292
VEJ0006883	1.8	0.91	0.82	92
VSJ10003	-8.4	0.90	0.31	268
VSJ10006	-5.9	0.78	-2.39	30
VSJ20925	-2.2	0.94	0.95	264
VSJ30002	-4.4	0.97	0.88	50
VSJ30006	-6.6	0.77	0.42	52
VSJ43020	-3.2	0.87	0.78	282

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 (2019a) 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
ARH170002	-11.1	0.98	0.91	306
ARH170006	-5.2	0.98	0.94	328
ARH170084	-2.1	0.97	0.92	94
ARH170117	-4.0	0.98	0.95	316
ARH190004	-3.0	0.95	0.91	48
ARH250032	-13.2	0.89	0.77	94

Station	P-Bias	Spearman Rank Correlation	Modelling Efficiency Factor	Number of observations
FRB1993	-9.4	0.99	0.95	298
FRB2013	1.8	0.90	0.86	50
FRB9000	1.3	0.94	0.92	52
FYN0018112	-16.3	0.99	0.88	280
FYN0018232	-13.7	0.99	0.92	274
FYN0018310	-12.5	0.99	0.92	276
FYN0018571	-21.9	0.99	0.83	272
FYN6100016	1.1	0.93	0.90	92
FYN6100018	0.1	0.93	0.91	56
FYN6100020	-0.7	0.91	0.93	48
FYN6100021	-7.5	0.99	0.95	286
FYN6100051	1.8	0.88	0.83	54
FYN6100052	2.0	0.96	0.91	100
FYN6200027	-0.6	0.96	0.93	96
FYN6200029	0.7	0.96	0.93	92
FYN6300043	-3.1	0.98	0.94	290
FYN6300044	0.7	0.95	0.92	142
FYN6400042	-0.9	0.93	0.87	54
FYN6500033	-5.1	0.99	0.90	48
FYN6500051	-11.1	0.98	0.94	310
FYN6500052	2.4	0.86	0.77	56
FYN6500053	-6.4	0.97	0.93	286
FYN6700009	1.2	0.96	0.92	90
FYN6700051	-0.4	0.95	0.91	62
FYN6700053	-2.9	0.98	0.96	232
FYN6700054	1.2	0.97	0.94	58
FYN6940622	-3.3	0.98	0.95	297

Station	P-Bias	Spearman Rank Correlation	Modelling Efficiency Factor	Number of observations
FYN7301703	-4.1	0.98	0.95	290
KBH431	-1.5	0.96	0.93	282
KBK3005	2.8	0.93	0.85	56
NOR403	-3.9	0.96	0.92	99
NOR409	-4.2	0.97	0.95	276
NOR4410	-4.6	0.98	0.95	274
NOR7715	-3.4	0.96	0.91	208
ROS1727	-6.2	0.98	0.96	279
SJY12	-19.2	0.98	0.84	274
SJY13B	-3.6	0.93	0.88	118
SJY15	-8.2	0.97	0.92	282
SJY16	-0.3	0.93	0.90	92
SJY19A	-1.8	0.91	0.87	50
SJY19	-10.6	0.98	0.92	48
SJYKFF2	0.0	0.86	0.71	120
SJYKFF5	0.6	0.94	0.83	284
STO0101015	-7.4	0.98	0.92	287
STO0101023	-2.6	0.94	0.81	289
STO0101124	-4.4	0.99	0.92	52
STO0104002	-23.2	0.98	0.78	251
STO0201061	-18.4	0.98	0.85	272
STO0601056	-27.2	0.98	0.72	272
STO0704010	-20.3	0.97	0.83	270
STO0801008	-10.0	0.98	0.94	296
VEJ0004273	-12.6	0.97	0.88	276
VEJ0005790	-22.9	0.98	0.79	284
VEJ0006489	-12.1	0.97	0.87	102

Station	P-Bias	Spearman Rank Correlation	Modelling Efficiency Factor	Number of observations
VEJ0006870	-3.3	0.98	0.93	292
VEJ0006883	-1.1	0.97	0.93	92
VSJ10003	-11.7	0.99	0.95	276
VSJ10006	-13.0	0.96	0.90	38
VSJ20925	-1.8	0.97	0.95	272
VSJ30002	2.3	0.91	0.85	50
VSJ30006	1.1	0.90	0.86	52
VSJ43020	-9.3	0.99	0.95	282

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