



Scientific Final Research Report 2020 for mFund-Project: EasyGSH-DB

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**Establishing an application oriented synoptic reference
data on geomorphology, sedimentology and hydrody-
namics in the German Bight (Deutsche Bucht: DB)
(EasyGSH-DB)**

**Collective final scientific research report
with contributions of all five sub-projects:**



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Hamburg, at 19/12/2022

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Summary

The goal of EasyGSH-DB is the creation of application oriented synoptic reference data on geomorphology, sedimentology, and hydrodynamics in the German Bight for a time span of 20 years.

Within the framework of the EasyGSH-DB joint project, comprehensive, harmonized and quality-assured **reference data sets** for geomorphology and sedimentology as well as hydrodynamics in the German Bight are being developed under the leadership of the BAW. For this purpose, all available and extensive **field data** were linked to various data- and process-based **simulation models**, some of them which were newly processed within the project. Subsequent numerical simulations over a period of 20 years (hind cast: 1996 - 2015) led to temporally and spatially highly resolved synoptic reference data sets. Together with tidal characteristic and partial tide analyses, **EasyGSH products** were derived from these and made available to the (specialist) public free of charge as source data for their own applications (<https://mdi-de.baw.de/easygsh/>).

Calibrated and comprehensively validated process-based hydrodynamic-numerical simulation models were used for this purpose. Two independent modeling systems for the simulation of tidal dynamics, salinity and waves were deployed by the project consortium in a **multi-model approach** for quality assurance of the results. These are the UnTRIM/SediMorph/UnK model family on the one hand and the TELEMAC model family on the other. In addition, SWAN was used as another wave model. All simulation models were running with identical boundary conditions/values, wind fields and annual bathymetry. The multi-model approach limited model-related uncertainties by comparative observations at discrete points (e.g., tidal gauge positions) and improves the possibilities to assess the quality of model results for areas where no measured values are available.

Thus, the geomorphological and sedimentological products were based on databased hind cast simulation models, which were linked by process-adapted spatio-temporal interpolation and approximation methods. **Annual bathymetries** and sedimentological products were produced, which together form the basis for the **synoptic** / process-based simulations of hydrodynamics in the North Sea with a particular focus on the German Bight. These are both synoptic data and **annual characteristic value analyses**, which are available for download via the EasyGSH data portal.

The main EasyGSH products include **tide-independent** analyses for long-term parameters and **tide-dependent** analyses for tidal parameters. These describe both the synoptic parameters as time- or tide-independent frequency distributions and characterize the tidal dynamics as well as their spatial/temporal changes. All parameters are available as spatial data for the entire German Bight and can be downloaded as GeoTiff on a 100 m grid raster (see <https://mdi-de.baw.de/easygsh/download>).

The aim of the **participation process** accompanying the project was to ascertain **user needs** regarding the reference data sets to be created and to develop application-oriented data products in a participatory manner. A comprehensive stakeholder analyses identified a large number of potential users from the research, government, and business sectors. For this purpose, a total of 50 people from 23 institutions were surveyed in individual and small group discussions and questioned in the form of structured interviews. A representative number of stakeholders were then directly involved in the development of **prototype products**.

The results of the needs analyses were condensed into product ideas by means of **participatory product development** in working groups of project partners and interested users and further developed into prototype applications. A total of eleven **prototyping partnerships** (PPs) were initiated by a group of more than 20 stakeholders from 13 different institutions. Over a period of two years, these PPs worked on issues of various subject areas such as geomorphology and sedimentology, hydrodynamics, modeling, data provision requirements or complex cross-sectoral

tasks such as ecological settlement potential. Different working approaches have been successfully pursued and applicable data products with different development stages, e.g., ranging up to practical applications in administration, have been established.

In addition to a standardized description for synoptic reference data including **metadata** an **information platform** was set up and linked to the project portal (<http://easygsh.wb.tu-harburg.de/> <https://mdi-de.baw.de/easygsh/Informationsportal.pdf>). The EasyGSH information platform provides clearly structured in-depth information on the products and their applications and on another relevant knowledge by means of a topic map. The intuitive operation via different entry points and variable information depths allows the users quickly to access the products and applications for the models and data sources used, important physical processes and the German Bight project area.

For the first time, the product range includes not only the very extensive analyses data but also the **synoptical model data** in a standardized spatially gridded and high temporal resolution as **netCDF files**. This allows users to run their own models or start analyses, for example.

The synoptic reference data are published on a **portal**, set up specifically for this purpose (<https://mdi-de.baw.de/easygsh/EN>), which is operated and maintained by BAW on a long-term basis via the German Marine Data Infrastructure [MDI-DE](#). By using standardized services, downloads and visualizations in conjunction with metadata, the results can be used in different systems. Publishing the metadata in portals such as *mCLOUD*, MDI-DE, GovData and GDI-DE helps to make the data accessible and available to a larger user community.

The legal framework for making the data available is implemented as **CC by 4.0 license** through the obligation to give it to the *mCLOUD*. This means that the data can be freely used as open data by all interested parties, but only attribution is mandatory.

1 Introduction

1.1 Reference to the funding call „*mFUND*“ of the BMVI

Since the year 2016 the BMVI (Federal Ministry of Transportation and Digital Infrastructure, <https://www.bmvi.de/EN/Home/home.html>) develop research- and development projects around digital, data-based applications for the mobility 4.0 as part of a mobility fund – “*mFUND*” for the development of digital, data-based business ideas based on mobility-, geo- and weather data. The Federal Waterways Engineering and Research Institute (BAW, <https://www.baw.de/EN.html>) and the project partners set up an application for this *mFUND* funding call. The project has been granted by the BMVI with letter dated February 28th, 2017. The assurance of the BMVI has been transmitted to the BAW on March 1st, 2017, by the promotor VDI/VDE-IT (<https://vdivde-it.de/en>).

According to the BMVI the approval period runs from February 1st, 2017, to December 31st, 2019, together with a following cost-neutral renewal until April 30, 2020.

The BMVI formulates research goals, essential investigation contents and research fundamentals respectively:

- Development and utilization of existing and future data and
- especially, available public data of the higher federal authorities shall be distributable for the general public and for the subject public.

1.2 Project goal

1.2.1 Overall goal

The aim of the project was to put together resp. produce detailed and quality assured, yet not now existing high-resolution reference data for the region of the German Bight. This data is a component of marine geo data resulting from measurements, hydrodynamic simulations, and analyses obtainable at the higher federal authorities. These should be made readily available for the general public as well as for the subject public / technical community as basic data concerning their own applications.

In this case essential target groups are federal, state and municipal administrations (Ministries of Transport and of the Environment, Coastal protection and environmental agencies), public research institutions (oceanography, coastal engineering, environmental sciences,...), and also the wide general public existing of NGOs (Non-Governmental Organizations e.g. environmental associations, environmental protect organizations, tourism, sailing association,...) such as the economy (energy producer, engineering offices, fishing,...).

Application examples shall be systematically worked out and prototypically converted also by the potential users. The proposed project focusses on the compilation resp. the production of consistent and synoptically

- geomorphological basic data of bathymetry and sedimentology** and
- hydrological data of hydrodynamic, salt- and sediment transport** and of **waves**.

Right from the start the realization focuses on the project activities due to the early involvement of stakeholders and practice examples of relevant products.

The integration of the geo data and products produced by EasyGSH-DB into the MDI-DE (Marine-Data Infrastructure Germany) and the information systems of the Federal Maritime and Hydrographic Agency (BSH) as well as the provision via *mCLOUD* guarantee the practical irretrievability and its long-term availability.

1.2.2 Partial goals

The following partial goals have been formulated to achieve this overall aim:

Partial goal A „Quality assured soil data“: Consistent areal sedimentological and geomorphological basis products (e. g. yearly bathymetries) shall be brought together for a big data base derive from existing marine survey data and sedimentological data (sediment samples and side-scan-sonar recordings, resp. –mapping).

Partial goal B „Quality assured simulations data“: For characterization of the dynamic conditions within the German Bight data are considered over a time period of 20 years (1996 – 2015) which represent a complete nodal cycle of the partial tides of the moon (18.6 years). This line of action describes an adequate recent period which is already sufficient for many questions and planning tasks.

Partial goal C „Identification of the stakeholder and their requirements/demands“: The Target of the stakeholder analyzes means to identify more potential user as well as their demands and to organize a pro-active exchange of supply and demand. It is concentrated on the identification of practice relevant products. So, solutions for a representative selection of demands can be practically developed and tested in common with the potential users (participative product development) and finally published via the project web portal.

Partial goal D „Analyzes of the soil data and compilation of products“: This partial target focusses on the compilation of complex geomorphological products and methods to the spatial interpolation of grain size distribution and properties depending to the sea surface sedimentology of discretized cumulative grain size distribution and the hydrodynamic conditions as well. In this way, classifications and descriptions of the different seabed types will be produced due to soil physical and sediment dynamic characteristics.

Partial goal E „Analyzes of the simulation data and the compilation of products“: The high spatial and temporal resolution and the achieved model quality build the base of multiple characteristic value analyzes and parameter as well as their changes over the years.

Partial goal F „Data storage and –publication“: The easy accessibility to the collected geo data and the created products builds an essential requirement for the acceptance and utilization by the target groups, addressed in the overall goal. In this case the IT-infrastructure components at the BAW must be expanded and adapted with meta data and data services. Convenient entry points, previews and download components should be integrated.

Partial goal G „E-Learning“: An E-Learning module will be built as an incentive for the intuitive and descriptive dealing with the results and products of this project as well as a basis for simple and clear data handling. Thereby, the results of the project are also represented in the field of teaching (universities, schools and interested professionals). Which denotes a transition/crossing from (purely) E-Learning to an information platform.

1.3 Project organization

Abbreviations used:

BAW:	Federal Waterways Engineering and Research Institute – Hamburg
BfG:	Federal Institute of Hydrology – Koblenz
BSH:	Federal Maritime and Hydrographic Agency – Hamburg
smile:	smile consult GmbH – Hannover
TUHH:	Technical University of the Free and Hanseatic City of Hamburg
WSV:	Federal Waterways and Shipping Agency – Bonn (GDWS)
KuR:	Küste und Raum GbR – Bremen

The BMVI research project „creation of application oriented synoptic reference data on geomorphology, sedimentology and hydrodynamics in the German Bight for a time span of 20 years (**EasyGSH-DB**) with a running time of three years (01.03.2017 – 31.12.2019) has been authorized on April 4th, 2017, by the PTJ. It has been extended cost-neutrally to April 30, 2020. The whole project has been coordinated by the BAW (Dr.-Ing. A. Plüß) and exists out of five partial projects:

- **EasyGSH_Boden:** Geomorphology [**smile**]
- **EasyGSH_ModPort:** Simulation, Analyzes, Data-storing and publication [**BAW**]
- **EasyGSH_ModLearn:** Simulation and E-Learning [**TUHH**]
- **EasyGSH_Dialog:** Stakeholder interviews and Prototyping Partnerships [**KuR**]

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2 Description of the project

In the first phase of the EasyGSH-DB project two parallel work threads have been followed based on the targets of the *mFUND* joint project to create areal, harmonized and quality-assured data sets for geomorphology, sedimentology and hydrodynamic within the German Bight for a period of 20 years (1996 – 2015). This represents a holistic hind cast comprising all sectoral, distributed presented heterogeneous official data. On the one hand the focus was on the development of a data base by collecting resp. creating quality-assured soil- and simulation data. Consistent areal sedimentological and geomorphological basis products have been set up due to the data of the business areas of the federal government (BSH, BAW, BfG and WSV) as well as by completing with data of the LKN.SH.

The linkage between the extensive nature data and model data of the different simulation systems (multi model approach) creates the base for synoptic reference data sets to the respective geomorphological, sedimentological and hydrodynamic conditions within the German Bight and the adjacent estuary mouths. Here data for a time period of 20 years (1996 – 2015) are considered first which show a complete nodal cycle of the partial tide of the moon. They describe a sufficiently recent period which is adequate for many questions and planning tasks.

On the other hand, an extensive participation process has been initiated with the target to provide a wider group of users of administration, research and private economy with the resulting quality-assured reference data. The use of the products created by EasyGSH-DB depends to a large extent on the professionally or institutionally characterized requirements on the data provided and their structure. EasyGSH-DB takes this into account by integrating potential user during the complete project period through a feedback participation process. As a first step the persons, institutions and authorities have been identified as part of a stakeholder analyzes who deal with the research object hydro-, sediment- and morphodynamic in the region of the German Bight. The requirements, deficits and needs of existing and future data infrastructures have been worked out together with this group of users out of companies, authorities and research in further analyzes steps.

In a second project phase groups of interested stakeholders and consortium partners develop existing product ideas beginning with prototypes up to application maturity. The participation of the practice partners guarantees that also user with another background of experience can efficiently use/apply the results obtained and the processed data. In a row of workshops, the prototyping partnerships have been initialized (workshop 1) and afterwards their interim results have been discussed and made available for all participants (workshop 2). In the third workshop the finished products have been represented to the involved stakeholders. After further optimization they have been put at the disposal of a wider audience. Another information portal is assigned to this data portal which can be understood as online manual.

3 Conceptual Approach

3.1 EasyGSH-DB Workflow

The central objective of the joint research project EasyGSH-DB was to create hitherto unavailable quality-assured high-resolution reference data sets for the German Bight area based on a part of marine geo data from measurements, hydrodynamic simulations and analyzes obtainable at higher federal authorities. These should be made available easy way to the generality.

The generation of all products of the joint project EasyGSH-DB can be described by a generalized workflow (see Figure 1)

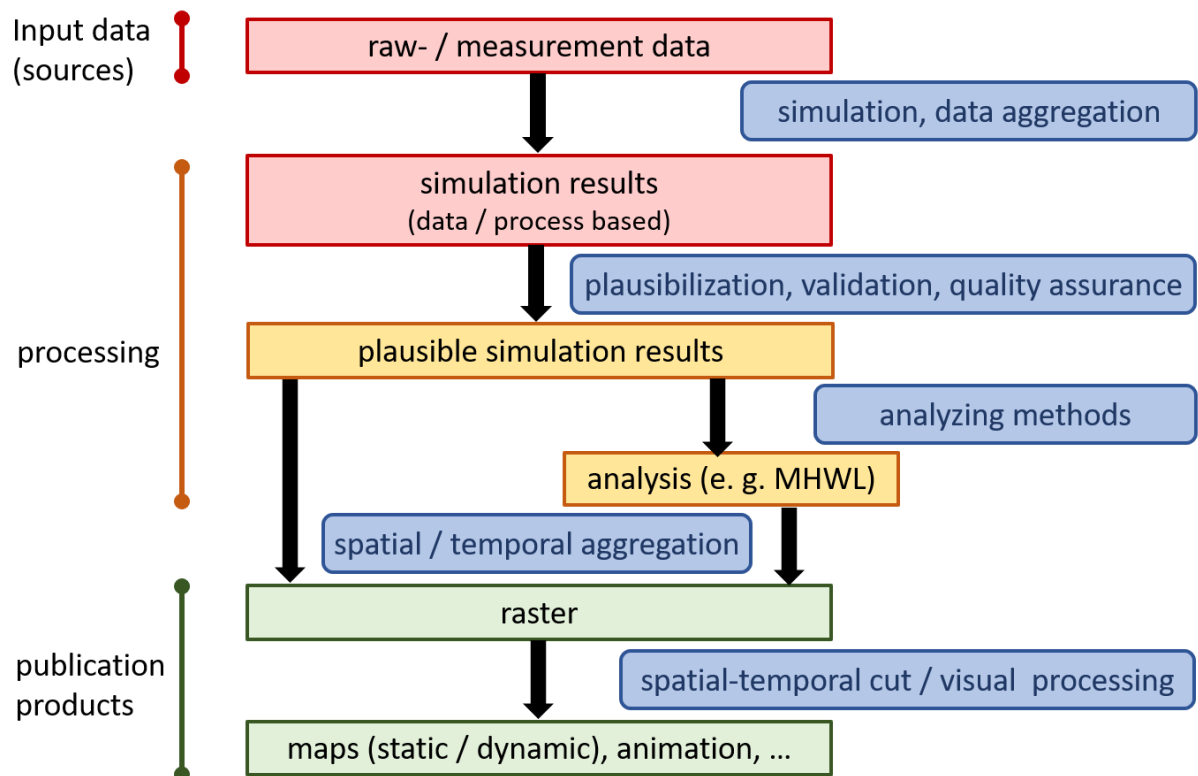


Figure 1: EasyGSH-DB workflow¹

The raw- and measurements data as well as basic simulation results generated from the numerical models are provided with project-specific meta data in the first step and then stored based on the planned further processing. The raw- and measurements data and also the basic simulation results will not be made available.

The gridded products and/or analyzes were then derived based on both the plausibility checked data- and process-based simulation results.





The gridded basic products and analyzes, as well as the maps derived from them with advanced products, were made available to the interested professional public via the EasyGSH-DB web infrastructure.

¹ MHWL: mean high water level

3.2 EasyGSH-DB Products

Here and in the following, the term “product” is defined for result data and analyzes within this project. The term is not to be understood in the sense of a commercially exploitable commodity “product”.

The EasyGSH-DB products can be divided into the following categories:

	<p>Basic (Basis) products have the highest information content and so they form the basis for all other analyzes- and user products.</p>
	<p>Analyzes (Analyse) products derived from the basic products which are available via the EasyGSH-DB data portal.</p>
	<p>Products which the user (Anwender) can create himself from the basis and analyzes products provided.</p>
	<p>Additional descriptive products may be provided for the standard metadata (Metadaten).</p>

The geomorphological products with the two components bathymetry (Chapter 4.2) and surface sedimentology are described below.

4 Bathymetry

The German Bight contain a wide range of pronounced morphological forms. Especially in the areas of the amphibious coastline and in the estuaries, there is a great spatial and, above all, temporal variability in the water depths. Forelands, Wadden areas, shallow water areas, widely ramified gullies, and deep tidal channels form the basic elements of the landscape predominantly covered with water. So, the currently largest Wadden sea in the world within the German Bight has developed. In 2009 it has been recognized as an UNESCO world natural heritage.

High solution yearly bathymetries have been created in the project to take the major temporal variability of the amphibious coastline into account. Based on the data situation in the transition area of the German Bight to the North Sea, only a rather roughly resolved bathymetry could be created for the complete region of the AWZ to the year 1996.

4.1 Basics

The so-called **functional seabed model (FSM)** with its two components bathymetry and surface sedimentology builds the basis for all geomorphological products. The bathymetric component of the FSM forms the basis for the creation of the consistent yearly bathymetries on July, 7 of the year under review from 1996 to 2016. The FSM is based on spatiotemporal observation data which describe the surface of the seabed. They are also linked with spatial and temporal interpolation methods (Figure 3) to build a continuous, data based hind cast simulation model of the seabed.

4.1.1 Database

The digital bathymetrical terrain model component of the FSM consists of more than 110 thousand data sets with over 92 milliards of data points which cover a period from 1946 to 2018 (status February 2020). The survey data of different institutions are supplemented by digitalized historical work cards of the hydrographic surveying as well as by construction and replacement models. The coastal bathymetric data are available in an acceptable to relatively high resolution from 1948 until today. Seaward, bathymetric data are rare (approximately from a water depth of 15 m).

These digital bathymetric data are stored in a database, described by associated meta data. The meta data contain information about the data provider, the measurement method and, the measurement period (see Figure 2). According to the structure of the survey data which depends on the respective measurement method (profile measurements, single or multi beam echo sounder and LIDAR data) the metadata contain information concerning the validity range as well as the recommended local spatial interpolation resp. approximation method.

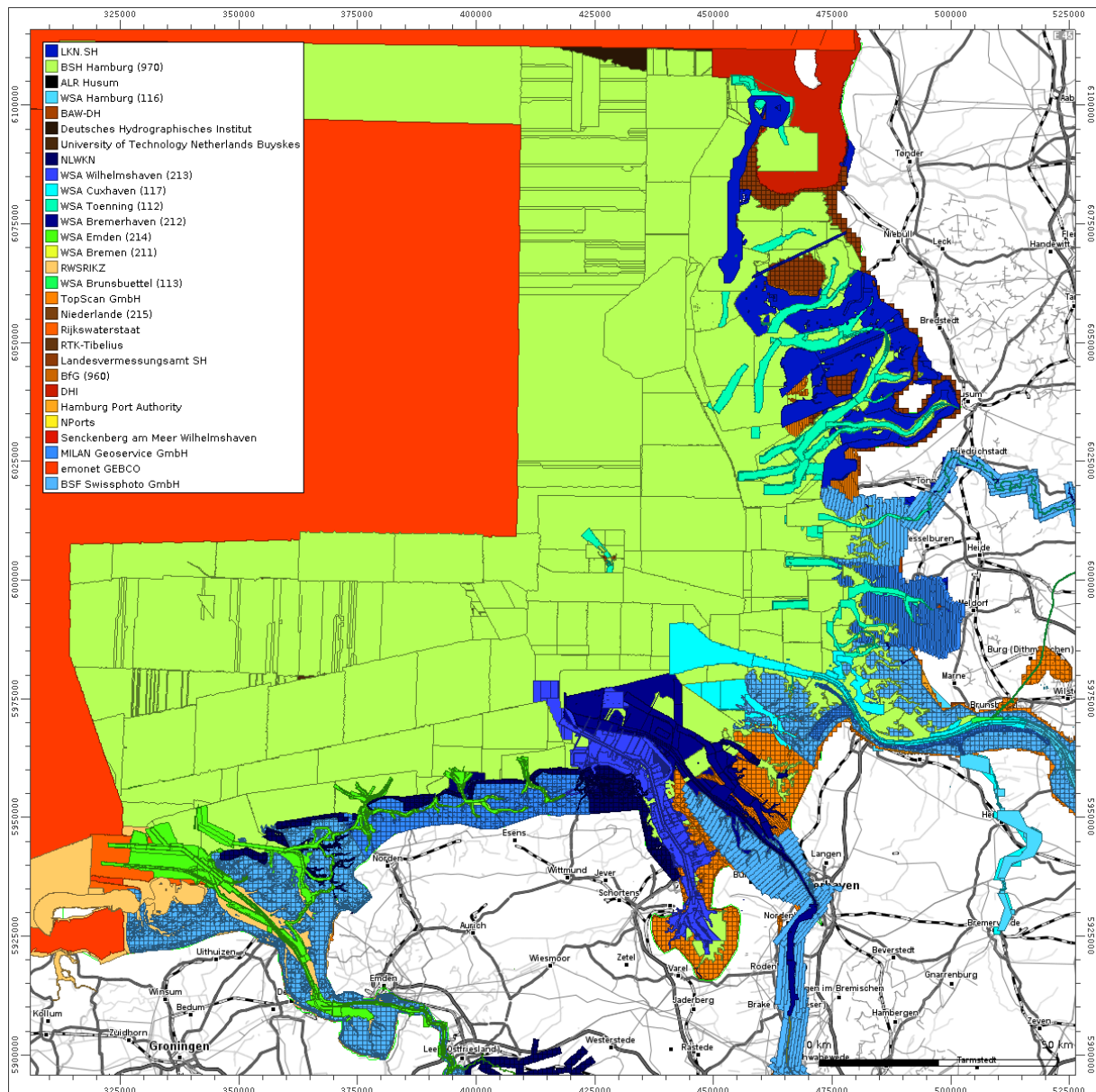


Figure 2: Metadata of the bathymetric component of the FSM, colored after data owner and data collector (background: Open Street Map)

4.1.2 Interpolation / Interpretation

In regions where many measurements are available, the points in time of the earliest and the last one built the limits of continuous space time bathymetry (see Figure 3). Inside this consecutive space time bathymetry, quasi synoptically depth distribution can be calculated by the space time interpolation methods implemented in the FSM. A quasi synoptically bathymetry means the horizontal cut through the continuous space time bathymetry (Milbradt 2011).

The interpolation of a quasi-synoptically surface of the seabed is realized by a spatial and temporal interpolation. For the place and time to be interpolated, first the previous and subsequent measurements are searched which contain the location in the statement area. In both measurements the z-value is spatially interpolated and then interpolated in time like it is represented schematically in Figure 3.

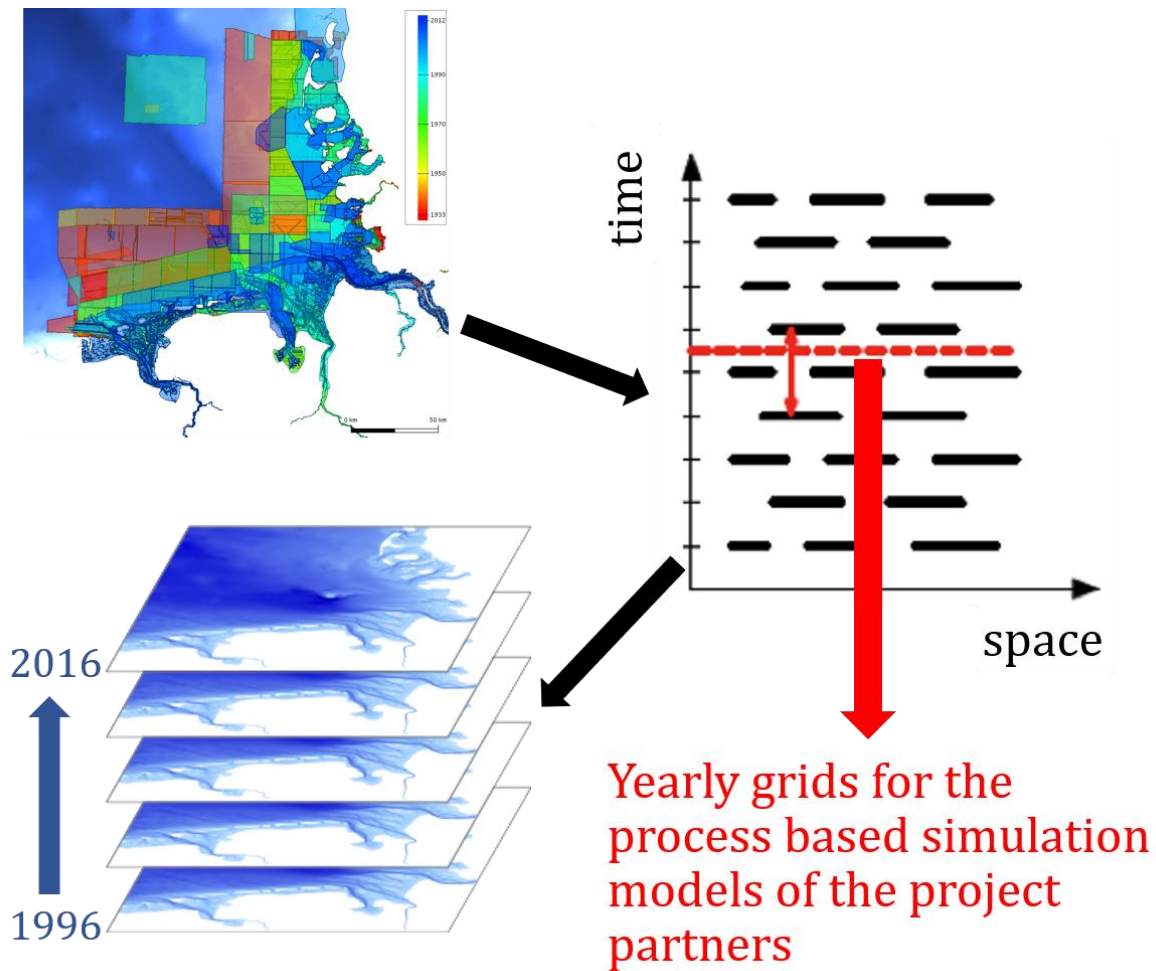


Figure 3: Scheme of the spatial temporal interpolation method

4.2 Basis products

The consistent yearly bathymetries of the German Bight on July 1st, 1996, to 2016 in a raster resolution of 10 m build the bathymetric product base. These can be supplemented by a further digital bathymetric model of the AWZ inside the German Bight on July 1st, 1996, in a resolution of 250 m.

In addition to the documentation on standard metadata one map of the underlying data density and two data sources maps are made available.

4.2.1 Yearly bathymetric products

The essential bathymetric basic products constitute the yearly rasterized digital bathymetric models of the German Bight in a resolution of 10 m on July 1st, 1996, to 2016. The expansion of the products can be seen in Figure 4. It reaches usually up to about 200 m behind the dike line resp. the high water 100 line.

Due to the low measurement frequency in time and in the spatial resolution of the surveys inside the AWZ these data are only distributable for one digital bathymetric model on July 1st, 1996, with a resolution of 250 m. These products are available as Geo/TIFF (see Chapter 9.2.2).

4.2.2 Data sources maps

To enable traceability of the survey data used for space time interpolation, additional data sources maps have been created. Concerning the data based hind cast simulation of the quasi synoptically

bathymetries of the FSM at a point of time, older as well as newer survey data will be considered. There are usually two data sources maps. One of them sums up all data **before** the interpolation time, and the other one all data **after** that.

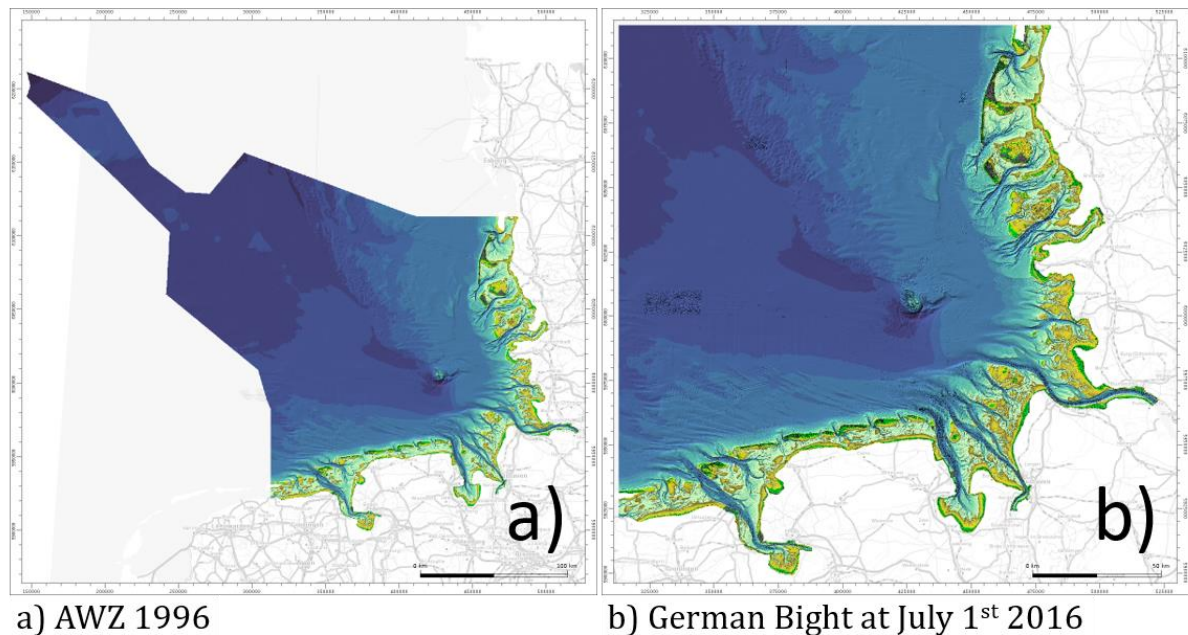


Figure 4: Bathymetric basic products: a) Exclusive Economic Zone (AWZ) (1996) and b) German Bight (1st July 2016)

While deriving the spatial temporal interpolation all grid points of each tile are constructed and the z-values are interpolated in one pass. At the same time two more points are generated for each grid point where the essential metadata from before and after, used for interpolation measurement data are buffered. The essential metadata include, among other things, the name and the identifier of the data set, the data type, the data provider as well as the start and end date of data acquisition. In the second step, points with the same attributes (belonging to the same survey data set) are combined to attributed areas. This creates two data sources maps (**before** and **after**) which document completely the survey data used for the creation of the digital terrain model (DGM). So, the data sources can be represented e. g. by the recording year (see Figure 5) or by data provider (see Figure 6).

4.2.3 Data density maps

The measurement data compiled in the database of the FSM have been collected by using very different measurement methods and often also by varying targets. Due to the measurement methods used the basic data sets have inconsistent spatial resolutions. Knowing the underlying data density, it is possibly helpful for accessing the quality of the derived digital bathymetric models. A dual density data set can be assigned to each bathymetric resp. topographic data set. This consists of the same points, elements and polygon as well as the associated metadata like the actual survey data set.

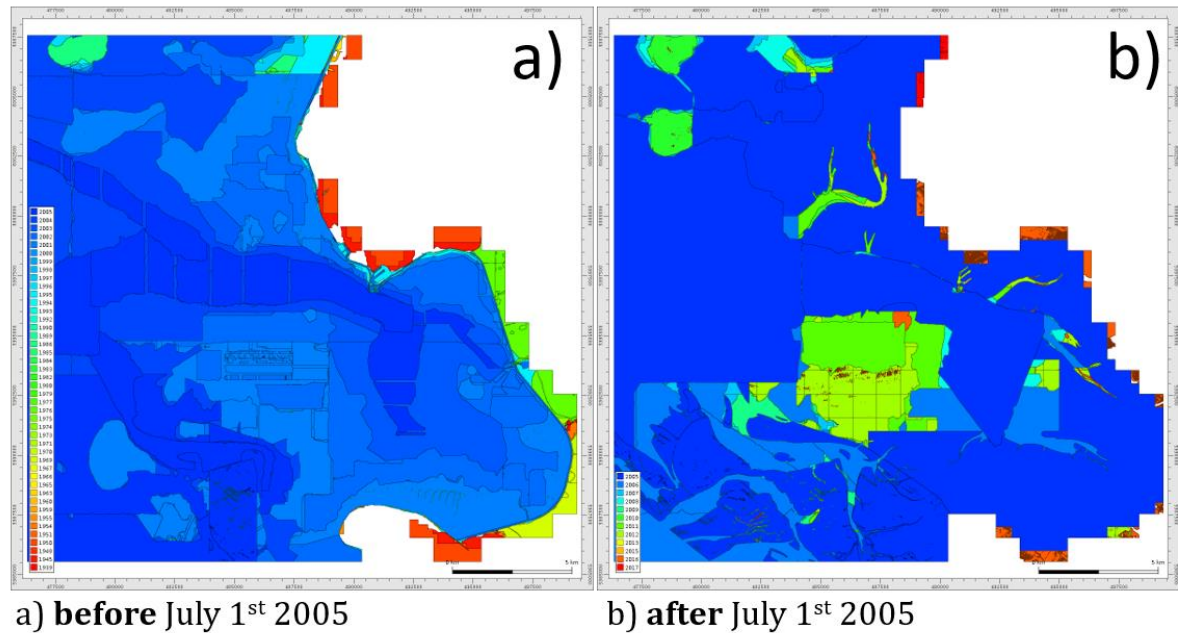


Figure 5: Data source map according to the recording year

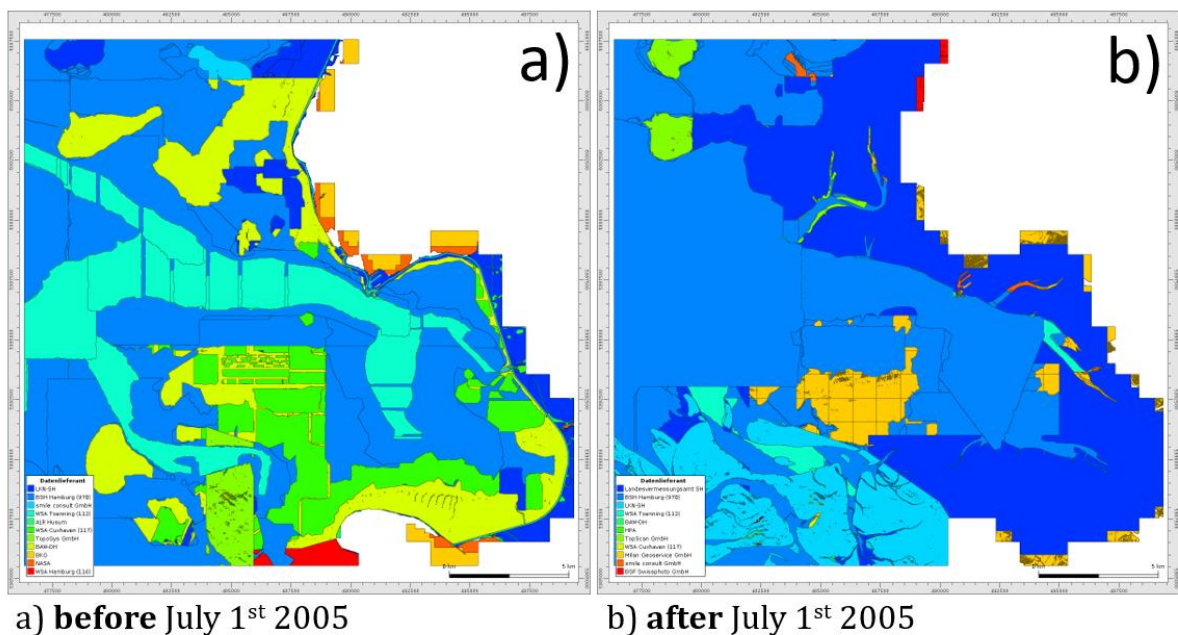


Figure 6: Data source map according to the data provider

Instead of the **terrain height**, the **model density** is stored at the nodes for the density maps. The data density is calculated according to the data structure:

- in the case of grids, the grid width is used as density
- concerning triangulated data, the medium length adjacent to the node under consideration is calculated and filed over all edges
- the radii defined in the interpolations are used for unstructured survey data as multi beam echo sounder or ambient light sensing (ALS) measurement setup.

and then adjusted or set according to their meaning:

- the density at nodes which are linked with structure polygons will be halved
- if the data set is a building model, the density is set to zero and
- if the data set is a dike model, the density is set to 2 m.

Another time-variant density model (database) is built with this dual density data sets. The metadata are essentially taken over, so that the time-variant density model based on this database can be interpolated in the same way as for the actual survey data.

Figure 7 shows exemplary a 1 x 1 m rasterized model for the region of the Meldorfer Bucht with the associated data.

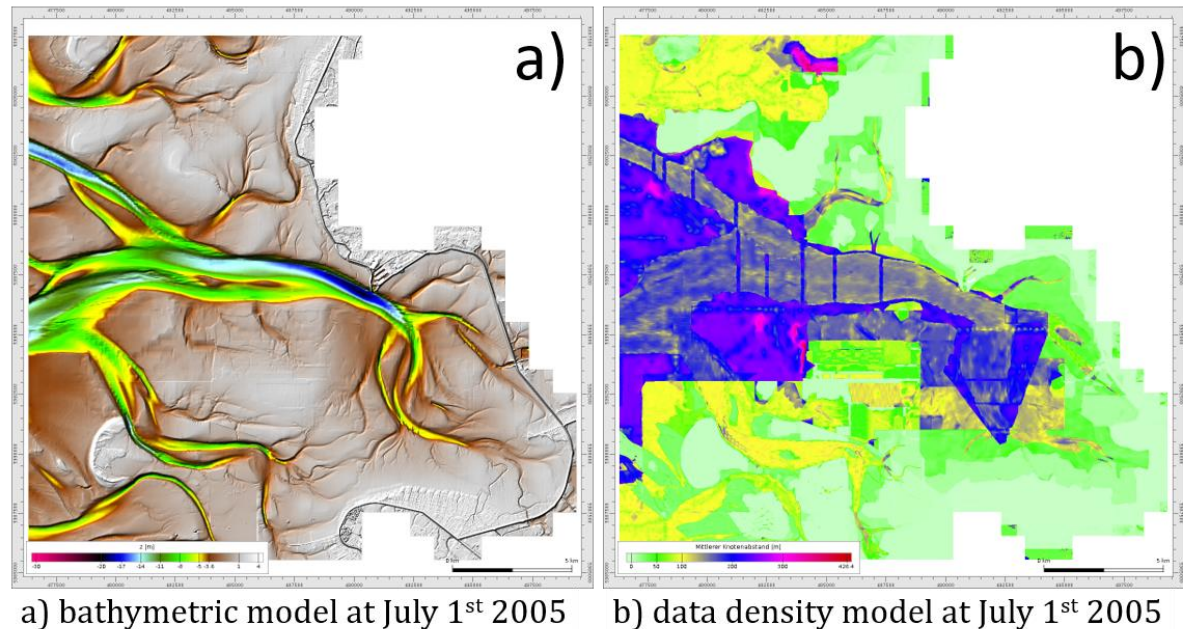


Figure 7: Digital bathymetric and data density model (July 1st, 2005)

4.3 Analyzes products

The products derived from the **basic products** (see Chapter 0) are referred as **analyzes products** hereafter. The minimal and maximal observed z-values are among the most important analyzes products. The difference between these is called **morphological space** (see Figure 8 a).

The difference of each z-value between two yearly bathymetric models is calculated, determining the balance sheet in m per year. This calculation can be conducted by any user in a conventional geographical information system (GIS). Therefore, this analysis is set in as **user product**.

According to the plus-or-minus sign, the annual balance sheets describe the yearly erosion and sedimentation rates. If the respective minimum and maximum are determined over the 20 year-period and then the difference from these is calculated, this is called **morphological drive** (see Figure 8b).

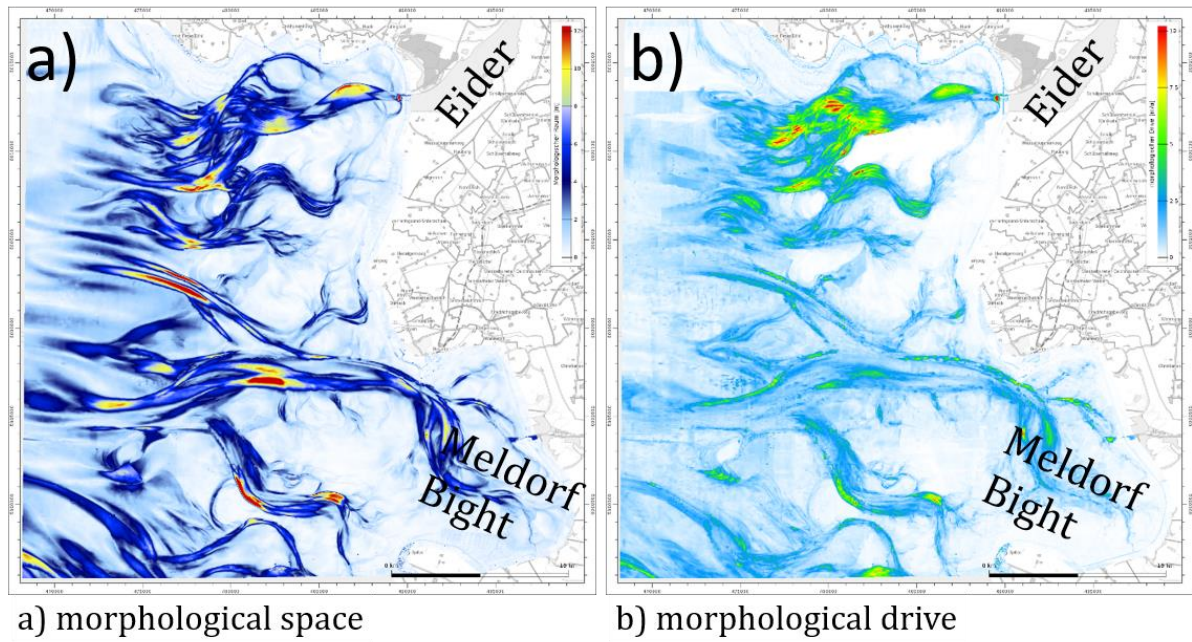


Figure 8: Morphological space and drive in the region of Eider and Meldorf Bight

5 Sedimentology

The sedimentological model component of the FSM describes the characteristics of the marine surface sediment of the seabed (top 10 cm) concerning the particle size distribution and porosity. Further properties are conceptually intended, but they do not lead to spatiotemporal models due to imperfect data. The grain size distributions are saved in the FSM as cumulative curves on logarithmic scale according to their resolution (phi scale). The cumulative grain size curve is interpolated using a monotonically cubic spline (Kruger 2004), and the porosity is described as a scalar value (details see Chapter 5.1.2.1). The transfer of the selected cumulative grain size distribution to the surface takes place by spatial-temporal interpolation considering the bathymetrical conditions and development as well as hydrodynamic characteristics values.

5.1 Basics

The data of the sedimentological component are related to the bathymetrical model component of the FSM. They thus form the basis for creating consistent marine surface sedimentology (of the sediment composition of the top 10 cm of the seabed) within the German Bight.

5.1.1 Database

The compiled sedimentological database is impressive for the German Bight and the German Estuaries. However, its time and space coverage cannot be compared with the data of the bathymetrical measurement.

The sedimentological model component exists (current state: February 2020) of about 63,000 sediment samples in various resolutions and of different data collectors and providers from the period 1941 to 2018. Circa 44,000 of these are in the area of the German Bight (see Figure 9).

A high level of dynamic in the sediment compositions is to be expected especially in the area of highly dynamical active Wadden areas, estuary mouths and offshore islands. Figure 10 shows the location of the sediment samples, which are colored according to the year of recording.

It can already be seen in Figure 10, that there is only a very sparse spatial coverage available for the spatial interpolation for a single year within the project period.

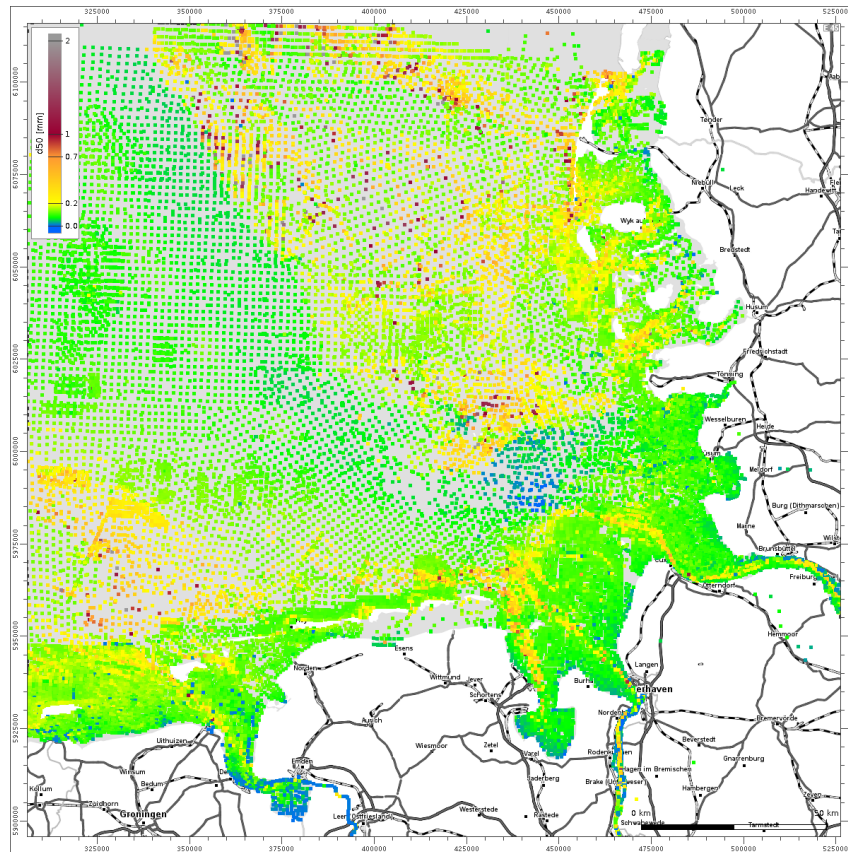


Figure 9: Direct usable surface sediment samples d50, German Bight, inked by record year (pink) and low morphodynamic activity (green), (background: Open Street Map)

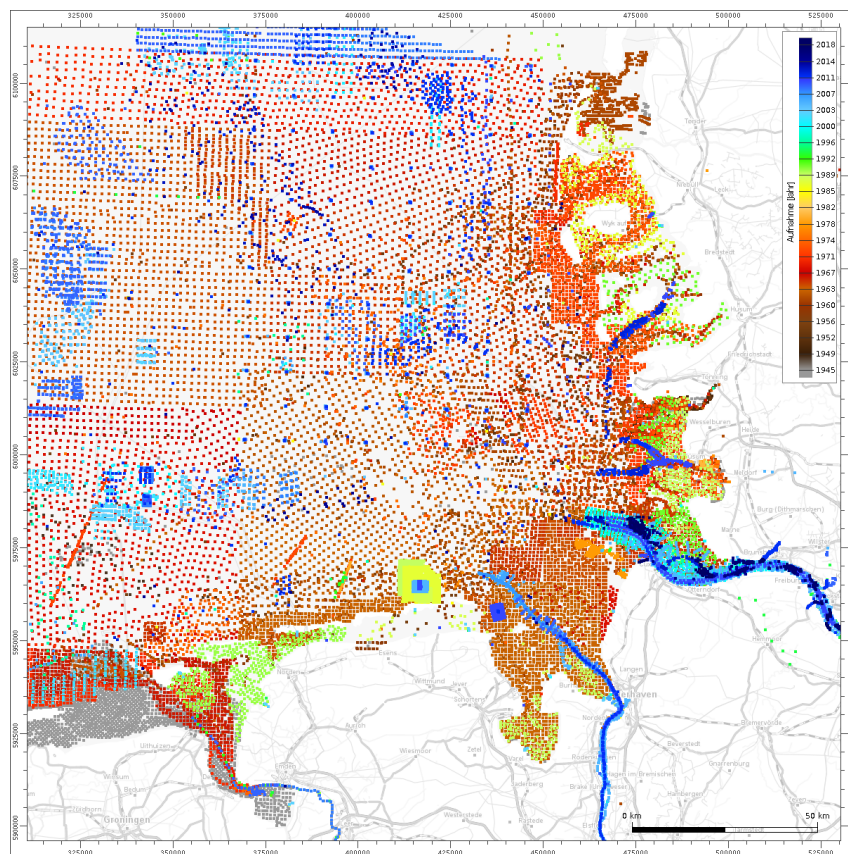


Figure 10: Location of sediment samples in the German Bight, inked by record year (background: Open Street Map)

Scales of grain-size

Most of the English-language publications of grain size distributions are not applied to the usual German metric (mm) scale for grain sizes. But the Φ -Scale, at which the grain sizes are transformed according to equation (1)², was introduced in the 1930s by Krumbein (1934, 1936, 1938).

$$\Phi = -\log_2 \left(\frac{d}{d_0} \right) \text{ mit } d_0 = 1\text{mm} \quad (1)$$

The transformation from the Φ -Scale to metric is given by

$$d = 2^{-\Phi} \cdot d_0 \quad (2)$$

So, each grain size fraction can be given due to the same amount of space (in the presentation).

5.1.2 Interpolation / Interpretation

The surface sediment samples were recorded using very different methods and analyzed in the laboratory. Almost all sediment samples were classified as grain size weight distribution. The range of granularity of the description includes the specification of d_{50} , 3 sieve classes and also high resolution analyzes in $\Phi/2$ to $\Phi/4$ classes. These sample data (e.g., for the Dutch territorial waters) are displayed by $\Phi/4$ classes. The grain size spreading can be represented as density or distribution functions.

The density functions (frequency distribution) of grain sizes weight distributions have positive values, they can have several local maxima and the integral over the entire domain is 1. Already this requirement, that the integral under the density function must always be one, makes the transition from the usually measured discrete frequency class to a continuous presentation difficult. This makes local interpolation even more difficult and nearly impossible

The cumulative grain size curve is far more suitable for representation of the grain size weights analyzes and their interpolations. The function values of the cumulative grain size curve range between 0 and 1, and the function is monotonously increasing. Both properties are retained in a linear combination, the basis for precisely spatial coordinate interpolations. The discretization of the individual cumulative grain size curve does not matter here.

5.1.2.1 Cumulative grain size distribution

A cumulative grain size curve arises if the total weight fractions of the sediment, whose grain size is smaller than the limit diameter of the sieve passage plotted on the abscissa are put on the ordinate.

Any function can be used between the measured support points as long as it takes values between 0 and 1. It should also be increasing monotonously in the case of the metric scale resp. Φ -scale (Figure 11). The linear interpolation between the support points fulfills these requirements, for example. As a rule, interpolations and high order polynomials do not cover this restriction. For high order interpolations monotonously, cubic splines are used in the FSM.

²The relation to the reference diameter d_0 in the equation wasn't included in the original equation and was introduced 1963 by D. A. McMangus (1963), to prevent for misunderstandings using the Φ -Scale.

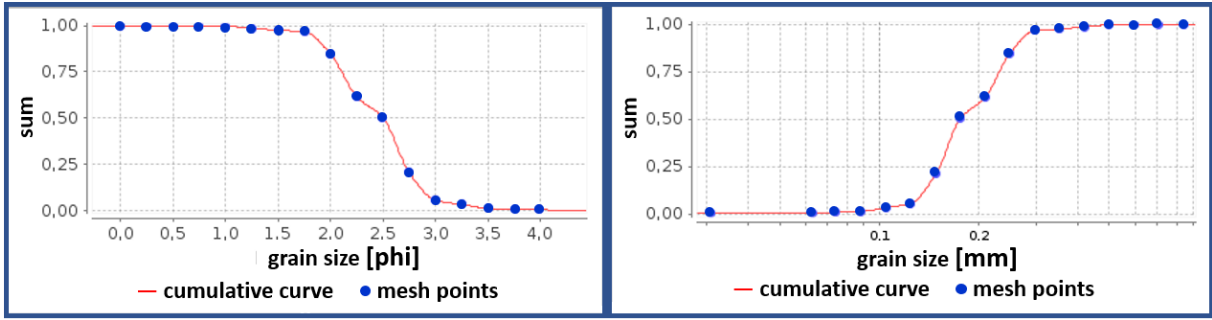


Figure 11: Monotone cubic spline interpolation

Cumulative grain size curves can be described using analytic functions, if only the parameters of the grain distribution are known. An example of this is the (inverse) logistic function in Φ

$$F(\phi) = \frac{1}{1 + \exp\left(\frac{1.7 \cdot (\phi - \phi_{50})}{(so - sk \cdot \tanh(\phi - \phi_{50}))}\right)} \quad (3)$$

with

- ϕ_{50} the median grain size diameter
- so the grain sorting and
- sk the skewness of the grain size distribution.

Formula 3 applies to $so > sk \cdot \tanh(\phi - \phi_{50})$. For $so \leq sk \cdot \tanh(\phi - \phi_{50})$ applies $F(\phi) = 1$ if $sk > 0$ and $F(\phi) = 0$ if $sk < 0$.

Porosity

The relationship from hollow volume to total volume of the sediment mixture is known as porosity and is an important parameter in the bottom evolution equation of process-based hydro-morphodynamical simulation models. The porosity is roughly equivalent to the water content of the sample (following DIN EN ISO 14688).

Unfortunately, information on the water content or porosity was only available in a very small part of the measured samples. Regarding the samples with no such information a logistic fitting according to (Wilson et al. 2018) was used:

$$n = \left(10^{-0.436 + \frac{0.366}{1 + e^{\frac{-\log_{10}(d_{50}) + 1.227}{-0.270}}}} \right) * \frac{1}{1 + so \cdot \sqrt{w_c(d_{50})}}$$

with d_{50} in mm, so rate of descent of the sediment, and w_c fall velocity of the sediment.

The following Figure 12 shows the course of porosity approximation over the grain diameter (sediment designation) for different grades.

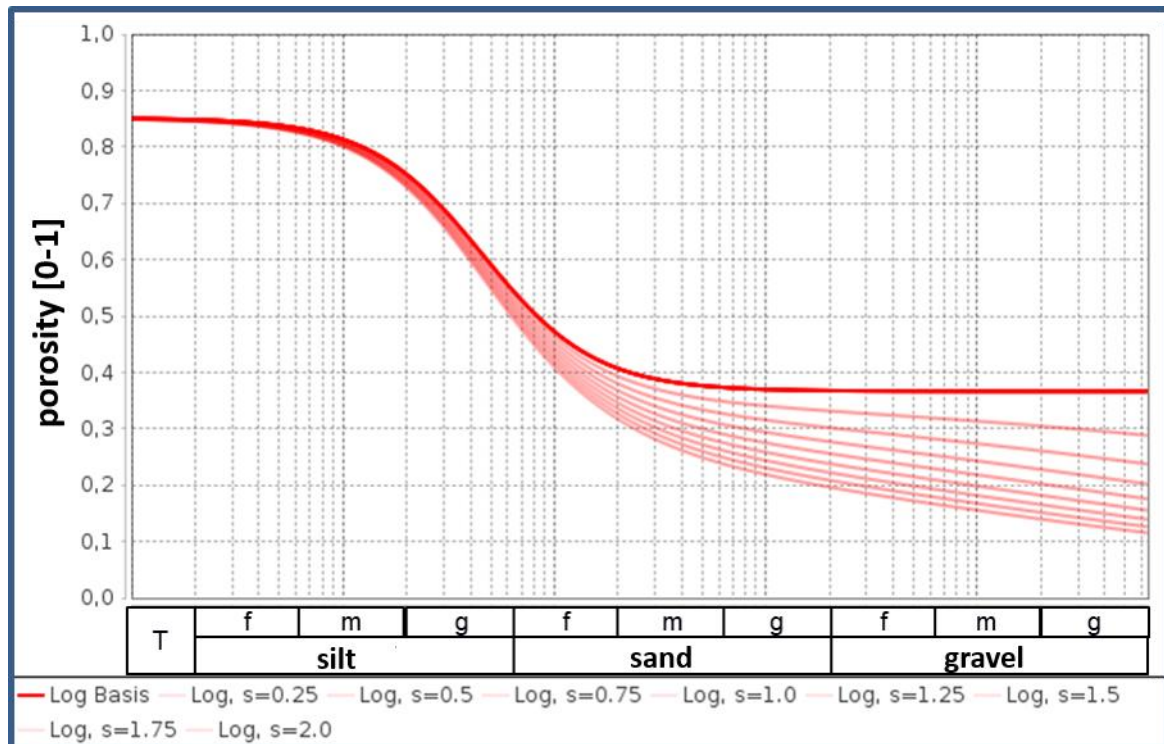


Figure 12: Course of porosity for different textures after (Wilson et al. 2018)

5.1.2.2 Spatiotemporal interpolation of the cumulative grain size curves

The spatial interpolation on non-evenly distributed data requires specially adapted interpolation methods. For example, only 94 sediment samples are available for creating a sedimentological distribution in the German Bight for the year 1996. These sediment samples can be added by further samples in morphodynamic inactive regions. Especially in the deeper areas of the German Bight there is only slight sediment dynamic to be observed. In morphologically stable regions (small morphological room) a longer period of validity of the sampled sediments can be assumed. Figure 13 shows the samples that can be used directly for areal interpolations regarding the recording year (pink) and the morphological activity (green).

Despite the high number of about 11,600 sediment samples wide areas, especially the morphodynamic high active ones, remain without sample coverage.

The cumulative grain size distribution is interpolated in the period until July 1st, 1996, to be able to use all ca. 44,000 sediment samples quasi consistently in the project area. In the case of temporal interpolation

- the bathymetric development at the sample location on basis of the FSM and
- the average in the vicinity of the sample location for the
 - sediment sorting, and
 - largest and smallest grain diameter of the available sediment

are considered.

In this way, about 44,000 sediment samples can be used for the spatial interpolation (see Figure 14).

An anisotropic Shepard interpolation is used for the spatial interpolation of the cumulative grain size curves. The classic circular metric will be distorted on the base of the vector field of the resulting bed shear stresses and the bathymetric characteristics of the surroundings to a parabolic metric (Milbradt et al. 2015b). Nevertheless, for a plausibility check the mean bed shear stress and, if necessary, adjustments of the interpolated grain cumulative curves are used.

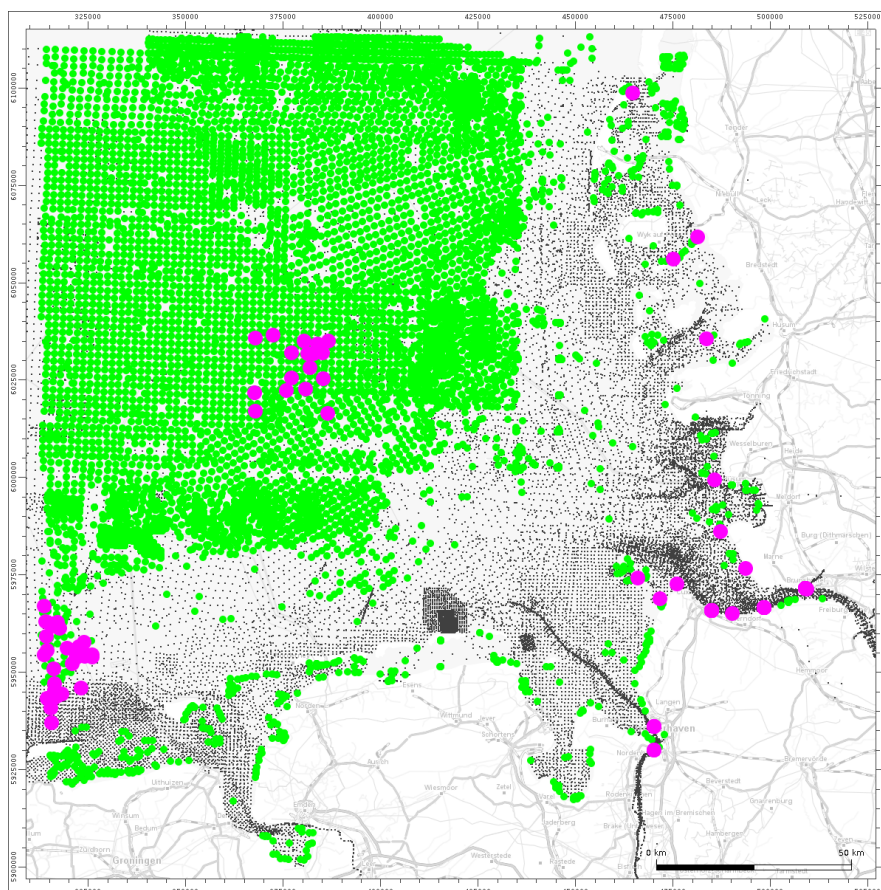


Figure 13: Directly usable surface sediment samples in the German Bight for 1996 samples of the recording year (pink)/with low morphological activity (green)

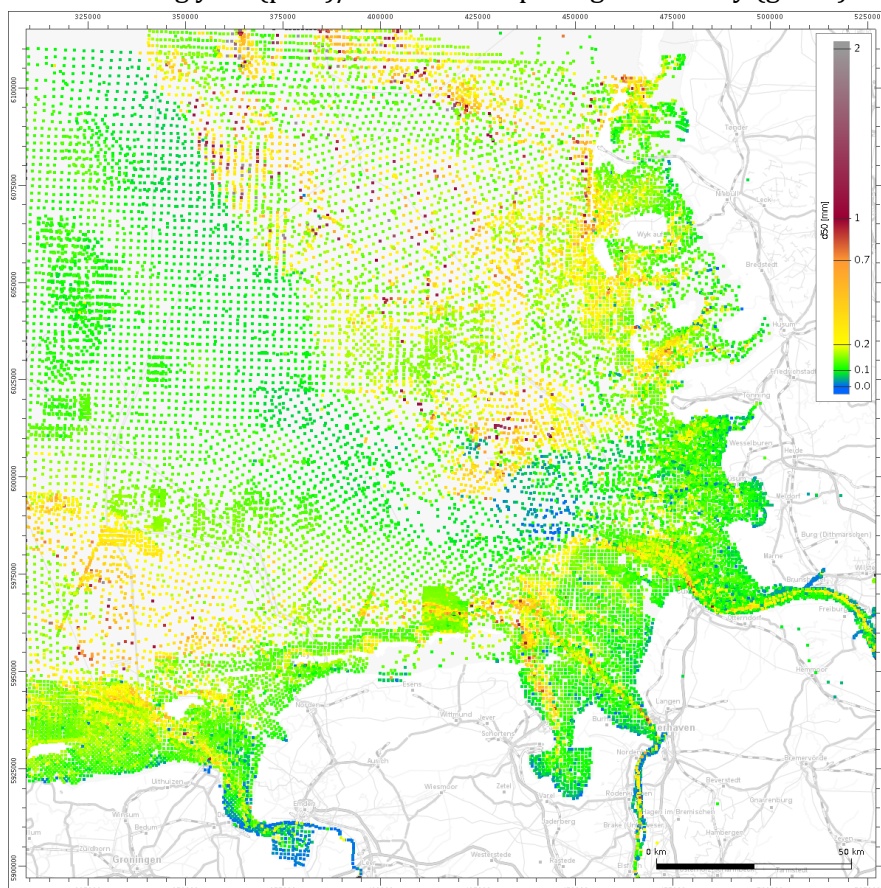


Figure 14: Quasi consistent surface sediment samples in the German Bight for 1996

5.2 Basic products

Based on this spatio-temporal interpolation, sedimentological grid products have been created. Which basically have a resolution of 250 m concerning the AWZ and the year 1996 and a resolution of 100 m for the German Bight for years 1996, 2006 and 2016. There is a cumulative grain size curve at each support point which was exported and discretized in $\Phi/4$ steps. As an export format, the CSV-data format is provided; all other products, for example a grid of the d_{50} are provided as Geo TIFFs (see Figure 15), and are derived from the grain size cumulative curves (Sievers et al. 2019).

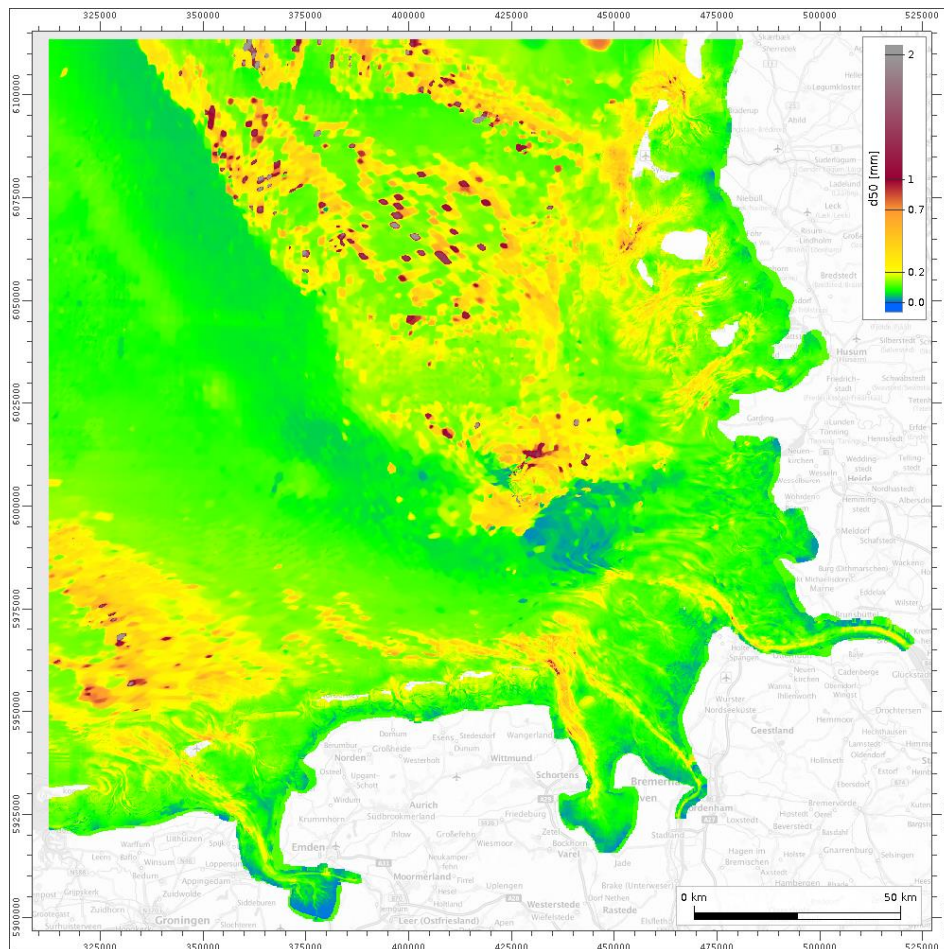


Figure 15: Grid of the surface sediment (d_{50}), in the German Bight for July 1st, 1996

5.3 Analyses products

Further marine surface sedimentological products can be derived from the gridded basic product, at whose support points the grain cumulative curve is stored. Additional to the grid of the d_{50} (see Figure 15) these are for example grids of the skewness or porosity (see Figure 16).

Special derivative products represent the sedimentological maps according to EN ISO 14688. These are provided as attributed ESRI shapes and describe surface sediment composition by linguistic abbreviations (Sievers et al. 2019). Two variants were delivered:

- The short form (see Figure 17) does not allow the grainsize cumulative curve to be reconstructed without loss of information.
- The long form enables an entire reconstruction of the grain size cumulative curve based on linguistic descriptions.

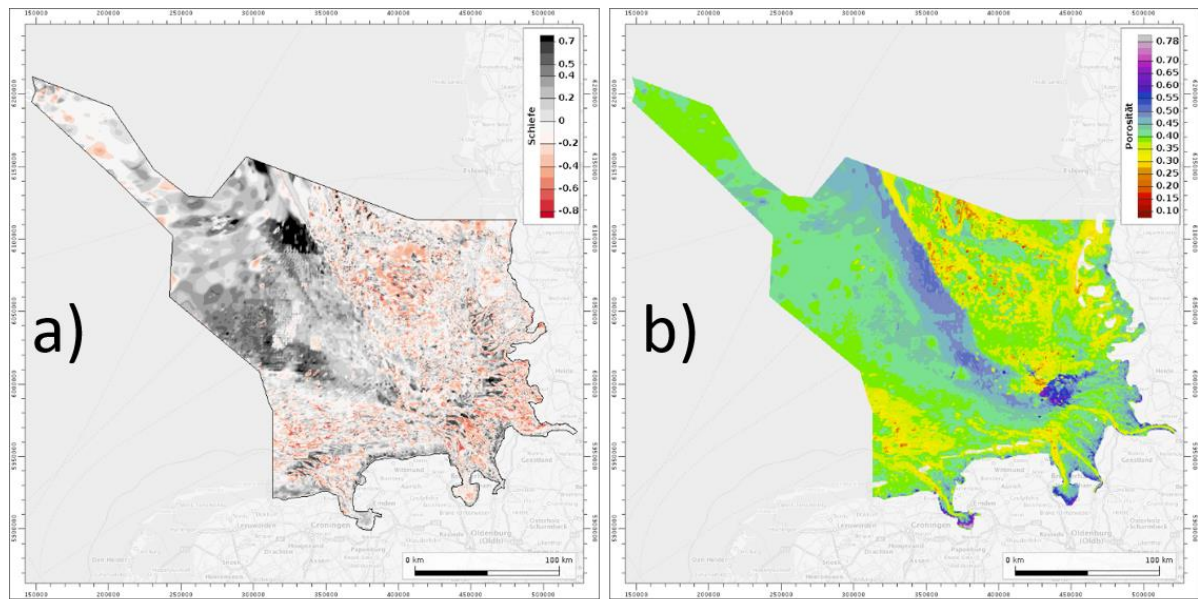


Figure 16: Gridded models of skewness and porosity for marine surface sediments - German Bight with AWZ, 1996

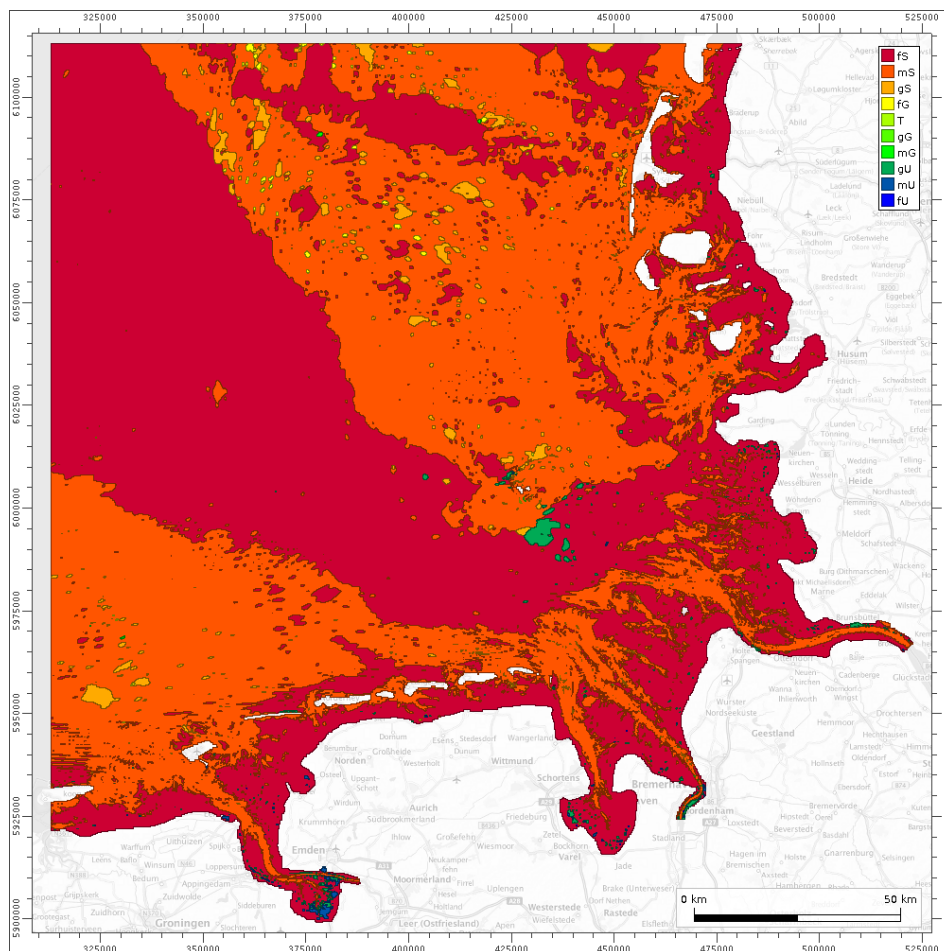


Figure 17: Petrographic map – short form – German Bight, 1996

6 Hydrodynamic numeric modeling

Hydrodynamics in the German Bight as part of the shelf sea North Sea dominated by tides and waves which are in constantly interacting with the seafloor morphology (see Chapter 4) and sedimentology (see Chapter 5). Complex, nonlinear transformations of tidal motion and waves occur especially the coastal nearshore areas.

Observations of sea surface elevation, currents and waves is usually carried out on gauges, measuring piles or buoys. Strong nonlinear phenomena of hydrodynamics make a simple interpolation of the local values in the plane unfeasible. A suitable interpolation approach is a calibrated and fully validated process-based simulation model which reproduce the considered area and the relevant processes in detail. Such models were set up in the project to generate spatial, harmonized, and quality-assured data sets for hydrodynamics in the German Bight in the period 1996 – 2015 (20 years).

Observed gauge values of the parameters above were used for calibration and validation. Subsequently, consistent data products and/or analyses were created based on simulation results.

To ensure the quality of the generated and published data, two different independent modeling systems for simulation of tidal dynamics, salinity, sediment transport, and sea state were deployed, calibrated, and validated in the course of a multi model approach. The method of multi model approach has been in use for years in the region of hydrodynamics ((Plüß und Schüttrumpf 2004); (Plüß, Andreas and Heyer, Harro 2007); (Rozante et al. 2014); (Milbradt et al. 2015a), (Fu 2018)).

As part of this project, both the Federal Waterways Engineering and Research Institute (BAW) and the Hamburg University of Technology (TUHH) carried out simulations of tidal dynamics, salinity, and waves with the following simulation frameworks:

- BAW: UnTRIM2 / SediMorph / UnK
- TUHH: TELEMAC2D / SISYPHE / TOMAWAC & SWAN (standalone)

6.1 Model family UnTRIM/SediMorph/UnK

All following information can be found completely in the validation document for UnTRIM²-SediMorph-UnK resp. the associated annual short validation (Bundesanstalt für Wasserbau, 2019a, 2019b; (Malcherek et al. 2002)).

6.1.1 Conceptual model description

UnTRIM is a semi implicit finite differences / finite volume method which solves steady and unsteady flow and transport problems on unstructured orthogonal grids (Casulli und Walters 2000). It solves the Reynolds averaged Navier-Stokes equations (RANSE), which consists out of the continuity equation of incompressible fluids and the momentum equations concerning the three spatial directions as well as the unsteady advection-diffusion equation.

For treatment of the turbulence, three different turbulence closure models of 0, 1st and 2nd order are used for the solution. The physical values water level variation, flow velocity, substance concentration, turbulence and fluid density are output as a result.

Thanks to modern methods, bathymetric data can be processed in a high resolution. To transfer this level of detail in the numerical model, calculation grids with disproportionately high number of nodes must be generated (Casulli und Stelling, 2011).

The finite volume / finite differences method in UnTRIM uses the volume dependency of the mass flows in the elements and defines sub polygons within the computational grids where the volume dependent, non-linear differential equations are solved. This process described as sub grid

technology refines the bathymetry resolution of a computational cell by one predefined refinement level (e.g., 4 means a fourfold higher resolution of the bathymetry). Further information can be found amongst others at (Casulli 2009) and (Sehili et al. 2014).

SediMorph (Malcherek, 2002) was developed as a morphodynamic module by the BAW. It calculates the bottom roughness based on the sediment inventory as a combination of the grain roughness and small-scale bed forms (ripples) as form roughness. The sediment inventory is mapped / depicted fractionally. Hence grain classes with specific characteristics (concentration, diameter, fall velocity, mode of transport – bed load, suspension or intermittent -) can be prescribed. Current and bottom roughness are used to estimate bottom shear stress which is thereafter used to estimate bedload sediment transport as well as erosion and deposition fluxes from the bed.

The wave module K-model was expanded for the BAW on basis of unstructured orthogonal grids (Casulli und Walters 2000) (**Un**structured grid **K**-Model: UnK). The K-model is a wave model which solves the energy balance of the sea state via source and sink terms in the spectral range (Schneggenburger et al. 2000). The model was used for calculation of the generation, spreading and dissipation of waves in ocean, coastal waters, and estuaries. It is coupled to UnTRIM² through the transfer of acceleration to the shallow water equations as source and sink terms. The models can either be coupled offline (without direct back coupling to the tidal dynamic) or online.

6.1.2 Model design

A hydrodynamic numerical model (HN-model) was created based on the previous KFKI-project “development of integrated model systems for analyzes of the long-term morphodynamic in the German Bight” - AufMod (Zeiler et al. 2014) as well as on the latest findings from literature to depict hydrodynamics in the complete German Bight.

The model area covered the entire North Sea with a focus on the German Bight. About 75 % of all computational grid nodes were located within the German Bight. The model resolution was increased threefold in contrast to its predecessor AufMod-project.

The estuaries of Ems, Weser, and Elbe were taken account because up to their tidal weir. Inland of the -20 m depth isoline, grid elements with less than 1 km edge length are specified. The resolution varied between 200 m and 400 m near the coast and between 40 m and 400 m in the estuaries. A sub grid was defined with a refinement level of 4 for the entire model, 6 in the German Bight, 8 in the coastal zone, and up to 12 within the estuaries areas to improve the volume representation of the computational grid for all simulations.

Figure 18 shows the whole model area and the focus area (light blue) and additionally two sections: the Hörnum basin south of Sylt in North Frisia (top right) and the island of Norderney in Eastern Frisia (bottom right), which represent the resolution of the grid in the Wadden Sea. The grid consists of 203,480 elements and 320,724 edges. The vertical resolution was set at 54 z-layers with a 1 m resolution down to the -20 m-NHN water depth isobath. The model also includes the main coastal structures, weirs and training walls in the German Bight as well as in the estuaries of Ems, Weser, and Elbe.

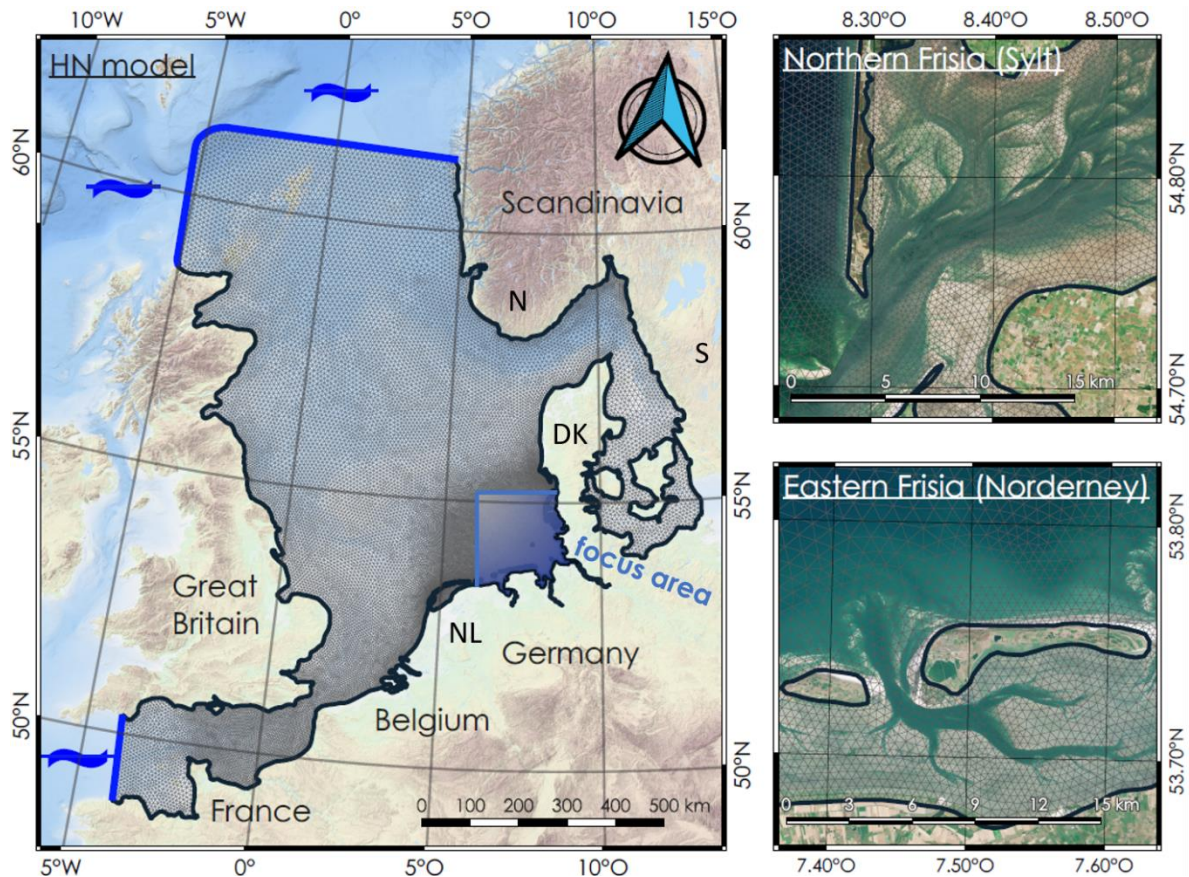


Figure 18: EasyGSH-DB North Sea Model (UnTRIM²: Grid) with the focus area (light blue), open (dark blue) and closed (gray black) boundaries. Background: EMODnet Bathymetry Consortium, 2016 with modified Copernicus Sentinel Data after 2018.

The simulation model was forced at the open boundaries to the Atlantic with data from the global tide model (FES 2014b) was produced by Noveltis, Legos and CLS and distributed by Aviso+, with support from Cnes (<https://www.aviso.altimetry.fr/en/data.html>). The meteorology was adapted from the reanalysis product COSMO-REA6 of the German Weather Forecast (DWD) and measured resp. climatological run off data in the German and Dutch Wadden Sea and in the estuaries was prescribed.

External surge was assimilated at the seaward open boundary using measurements. It therefore contains short and long-term fluctuations of the water level such as sea level rise.

6.1.3 Calibration and validation of water levels and currents

Built on a series of tests, and a plausibility and sensitivity assessment the model calibration was carried out carefully where the numerical parameters of a model were adjusted to fit observational data. The bottom friction is the most important calibration parameter to fit the model to observed sea surface heights.

The year 2006 was chosen for calibration purpose as it has strong storm surges (November, 2006) and extreme fresh water discharges (April, 2006) (Bundesanstalt für Wasserbau et al. 2019). The calibration was performed iteratively using tidal constituents (harmonic analyses of the sea surface height) by adjusting the bottom roughness to fit dominant tidal constituent M2 of the measurement with the model. The resulting roughness distribution (Nikuradse roughness) is shown in Figure 19.

The result of the model calibration is shown below based on the difference of the tidal constituent M2 between measurement and model. The mean absolute error (MAE) and the root mean square error (RMSE) are also given. Gauge names here can be found in Chapter 12.

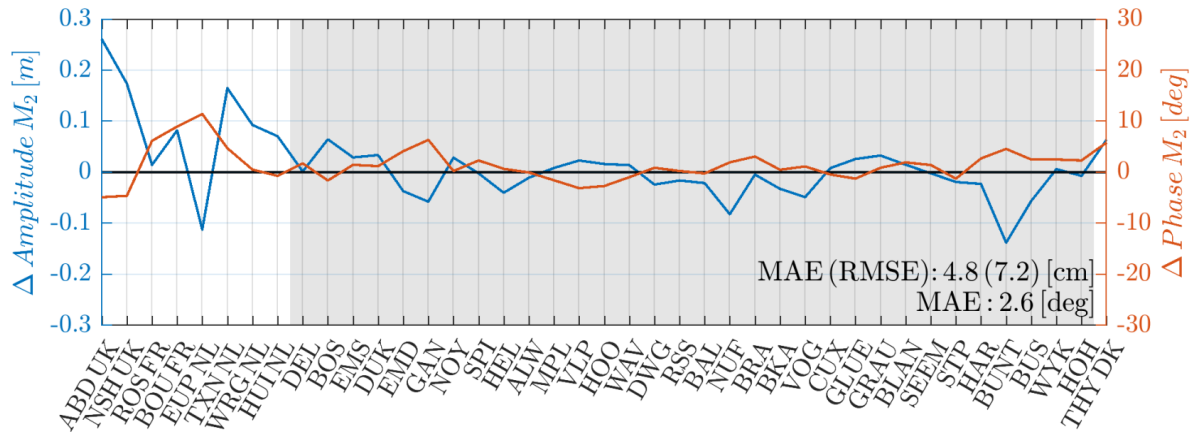


Figure 19: Calibration: difference of PT M2: measurements vs. model [cm resp. °] - 2006.

The RMSE of the M2-**amplitude** in the calibration year 2006 is 7.2 cm for all gauges. Figure 19 shows clearly that the agreement of the partial tide (PT) M2 in the German Bight (gray area between DEL and HOH) is consistently good, excepting BUNT.

The RMSE solely in the German Bight account for 4.0 cm. The **phase error** is small in the entire model area. Table 1 shows clearly that the agreement in the German Bight (gray area between DEL and HOH) is consistently good, excepting BUNT.

A model validation is called after van Waveren (van Waveren 1999-) a comparison of independent model and measurement data with the aim of defining the quality of a model. Ideally, other periods and gauges are used in the validation (Gunn und Stock-Williams 2013).

Table 1: RMSE of partial tide M2 (North Sea) - all gauges in comparison with the literature

Model description	RMSE amplitude (cm)	RMSE phase (°)
EasyGSH-DB (year 2006 UnTRIM ² / BAW)	7.2	2.3
EasyGSH (year 2006, TELEMAC / TUHH)	6.1	4.6
DCSM (Zijl et al. 2013)	6.4	5.1
GETM (Gräwe et al. 2016)	7 to 11	-
SCHISM (Jacob et al. 2016)	≤ 20	5 to 10
BAW-North Sea model (Plüß)	5.16	-
UnTRIM (Zeiler et al. 2014)	≤ 20	-
TELEMAC3D (Putzar und Malcherek 2015)	≤ 23	-

For the validation of the EasyGSH-DB-North Sea model every year of the considered period 1996 to 2015, except for the calibration year 2006, may be used. We chose the year 2012 for validation because of good observational data availability for current velocity, salinity, and the complex storm surge event “Andrea”.

Compared to calibration only freshwater discharge, external surge, local wind, and the boundary conditions were adapted to the new period at the open model boundaries.

Figure 21 shows the differences of the partial tide M2 in the focus area German Bight. This results in a RMSE of 3.3 cm for the amplitude and of 2.8 ° for the phase. These results exceed the goodness-of-fit achieved in calibration. In the Ems estuary (DEL to NOY) the maximum errors occur in Gandersum (GAN) and Emden (EMD) which can be explained with the temporary closure of the Ems storm surge barrage. The error is about 2 cm in East Frisia and the Jade (SPI to HOO). The biggest error range was observed in the Weser (DWG to EFL) at Nordenham Unterfeuer (NUF) at approx. 7 cm. The error in the Elbe varied between -3 and 4 cm.

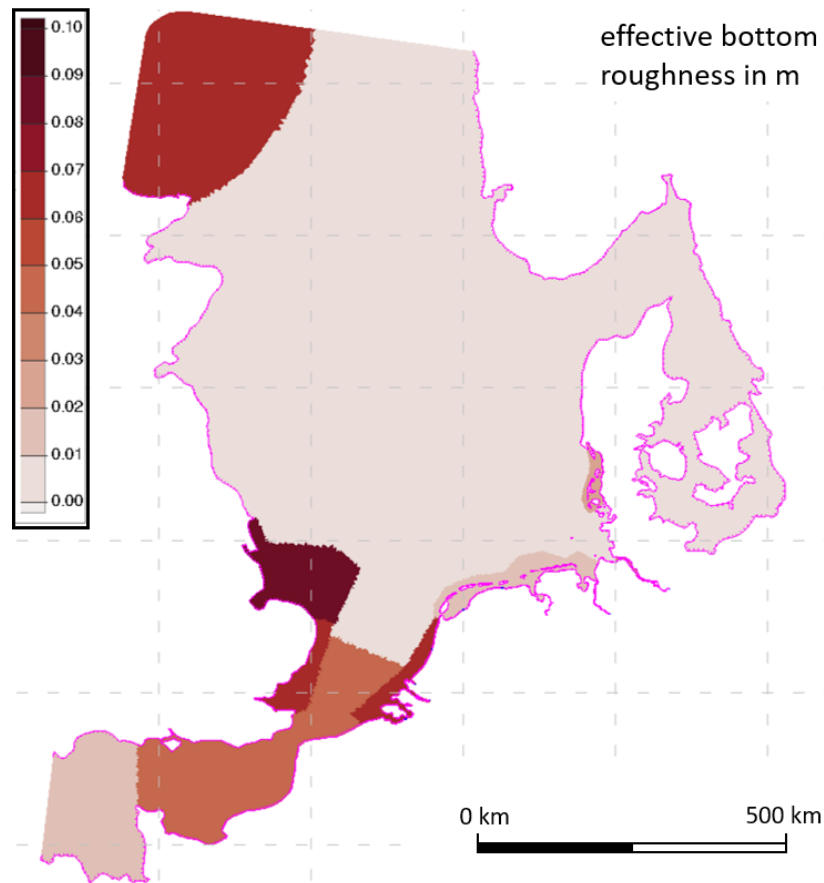


Figure 20: Bottom roughness of the EasyGSH-DB North Sea model (1996-2015).

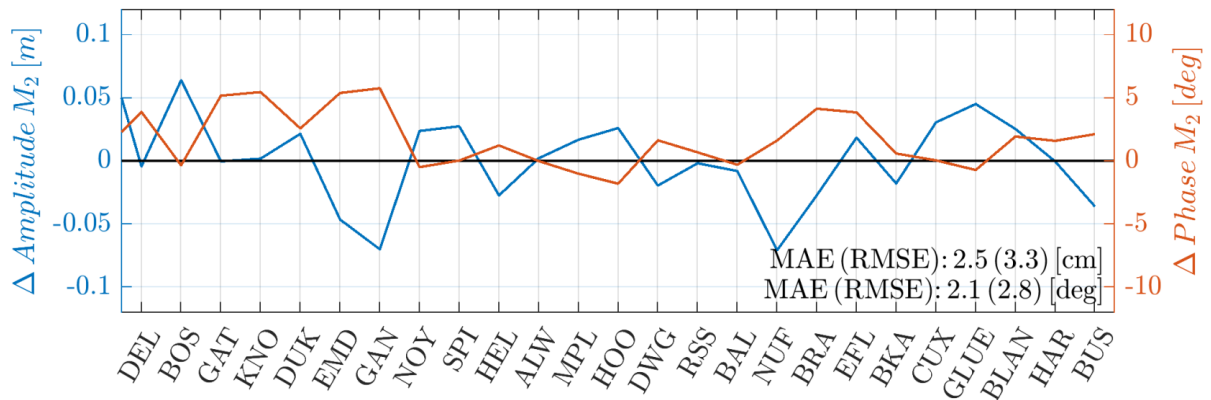


Figure 21: Validation: difference tidal constituent M2: measurements vs. model [cm resp. °] - 2012.

In summary, the model can reproduce the tidal constituent M2 well at different gauges and times. Thus, the fundamental tidal oscillation of the model is sufficiently validated.

Final sea surface heights were adjusted with the wind setup and the external surge. The exact procedure can be found in the validation document (Bundesanstalt für Wasserbau et al. 2019). The MAE and the RMSE again given below, where these errors were calculated from the differences between measurement and model at each comparison point in time. There is a maximum of 52,560 comparison time points (10-minute model output).

In Figure 22, the time series at Hooksielplate (HOO) is documented for the validation year 2012. The modeled sea surface height reproduces the annual variability based on gravitational forces, astronomy, meteorology, and external surge. The model shows pronounced east wind conditions (February 2012), storm surges (January 2012), and normal situations (e.g., July 2012). In the

lower part of Figure 22 (January 5th–7th) the storm surge “Andrea” is shown which lasts during a period of 5 tides. The model well reproduces the top surge water levels of storm surges whereat the first two peaks given slightly worse than the maximum peak on January 6th.

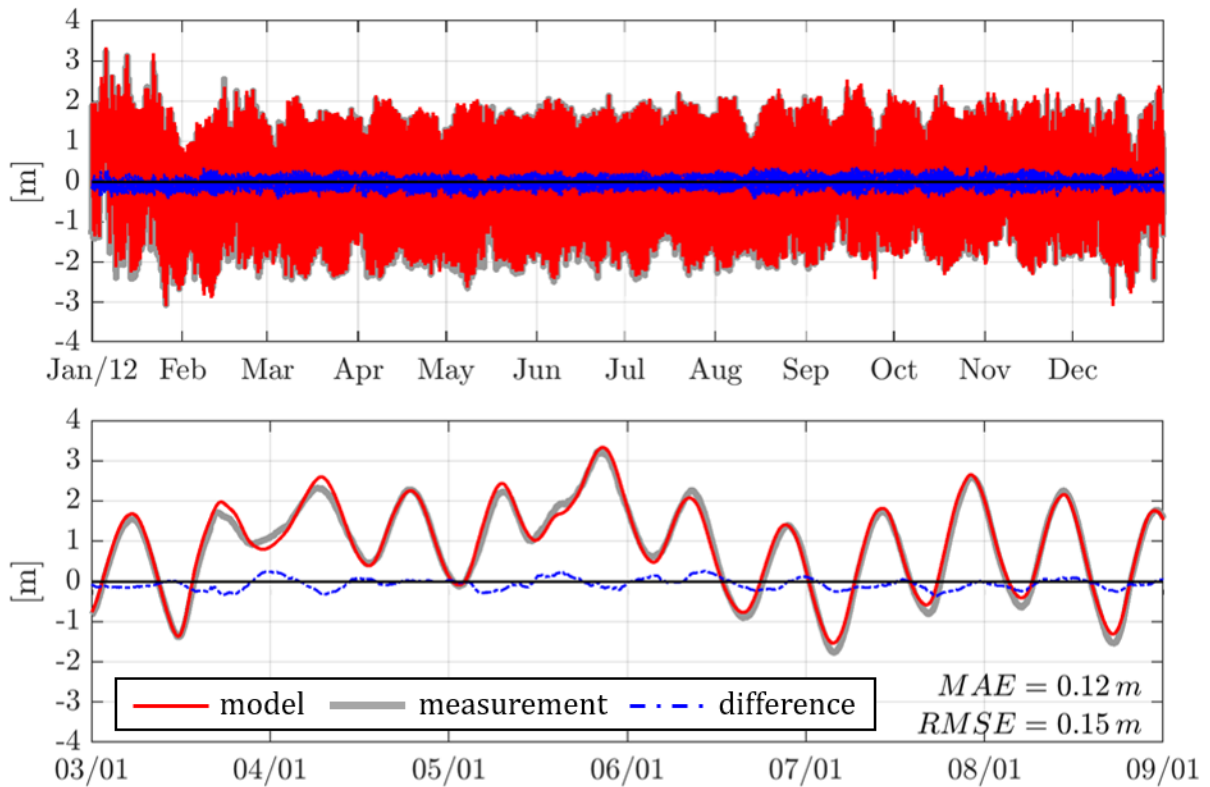


Figure 22: Water level at gauge Hooksielplate (H00) – validation year 2012

The MAE and RMSE are listed in Table 2 for further water level gauges. The Pearson correlation R and the regression parameter m and b are also documented, m indicates the slope of a linear regression and b represents its y-axis intercept.

Table 2: MAE, RMSE, Pearson Correlation and linear regression parameter (m , b)

Gauge	MAE (m)	RMSE (m)	R (-)	m (cm)	b (m)
BOS	0.095	0.117	0.994	1.049	0.052
EMD	0.120	0.151	0.995	0.967	0.095
NOY	0.088	0.108	0.993	1.010	0.032
ALW	0.085	0.104	0.995	0.997	-0.088
HOO	0.127	0.148	0.993	1.009	0.024
RSS	0.111	0.137	0.996	0.995	0.068
CUX	0.095	0.117	0.995	1.016	0.016
BLA	0.091	0.115	0.996	1.009	-0.005
WYK	0.112	0.131	0.997	1.006	0.105

The listing of the parameters for evaluating the model quality (skill) from Table 2 shows a consistent distribution of MAE and RMSE concerning all gauges with the smallest deviations at Nordey Riffgat (NOY), Leuchtturm Alte Weser (ALW) and with highest at Hooksielplate (HOO) and Emden (EMD).

6.1.4 Calibration and validation of the wave model

The spectral wave model UnK was two-way-coupled (online) to the hydrodynamic model UnTRIM which implies that current velocity, water level and meteorological forcing were communicated between the models at every time step. The grid resolution in the area of morphologically stable

pronounced tidal channels and tidal flats is increased significantly because the wave model UnK cannot use the sub grid method of UnTRIM.

The wave model was validated with measurements of the significant wave height, mean wave direction and mean wave period (Bundesanstalt für Wasserbau, 2019a). Wave observations are subject to great differences in quality and therefore they must be used carefully during calibration. Modeled significant wave height (H_{m0}), mean wave direction (Θ_m), mean wave period (T_{m02}), as well as peak wave period (T_p) were available as results from the spectral wave model. All wave buoys, piles and stationary platforms which are used for validation during the 20 years of simulation of EasyGSH-DB were shown and named in the attachment (Chapter 13.1).

Figure 23 shows the wave model (grid) similarly to the numerical grid in Figure 19.

The interaction between waves and tidal dynamics occurs where the grid of the wave and the tide model are congruent. Subsequently, no wave impact on the hydrodynamic was calculated in the areas without cover from the wave model grid. In contrast to the hydrodynamic grid, the southern English Channel, the upper estuaries in the German Bight, and parts of the Baltic Sea were neglected to save computational power. The grid density in regions of large depth gradients needs to be increased to ensure the volume interpolation of bathymetry because no sub grid method can be used in the wave model. In EasyGSH-DB the seaward parts of the barrier islands, the estuary mouths, Helgoland, and the great tide channels were represented in high-resolution. The wave model grid consists of 220,306 unstructured triangular elements with a minimum edge length of 53 m around Sylt.

Due to the poor measurement data quality, representative time series were exemplary shown for validation of the significant wave height and the error metrics MAE and RMSE were given. Figure 24 shows the model results and measurements in Westerland (Sylt). It can be seen that the model reproduced observational data with an underestimation at big significant wave heights. The RMSE for all time points was below 0.4 m for both stations concerning the complete time series. The correlation of the signals was ≥ 0.90 . For this reason, the accuracy of the significant wave height was considered sufficient at this point.

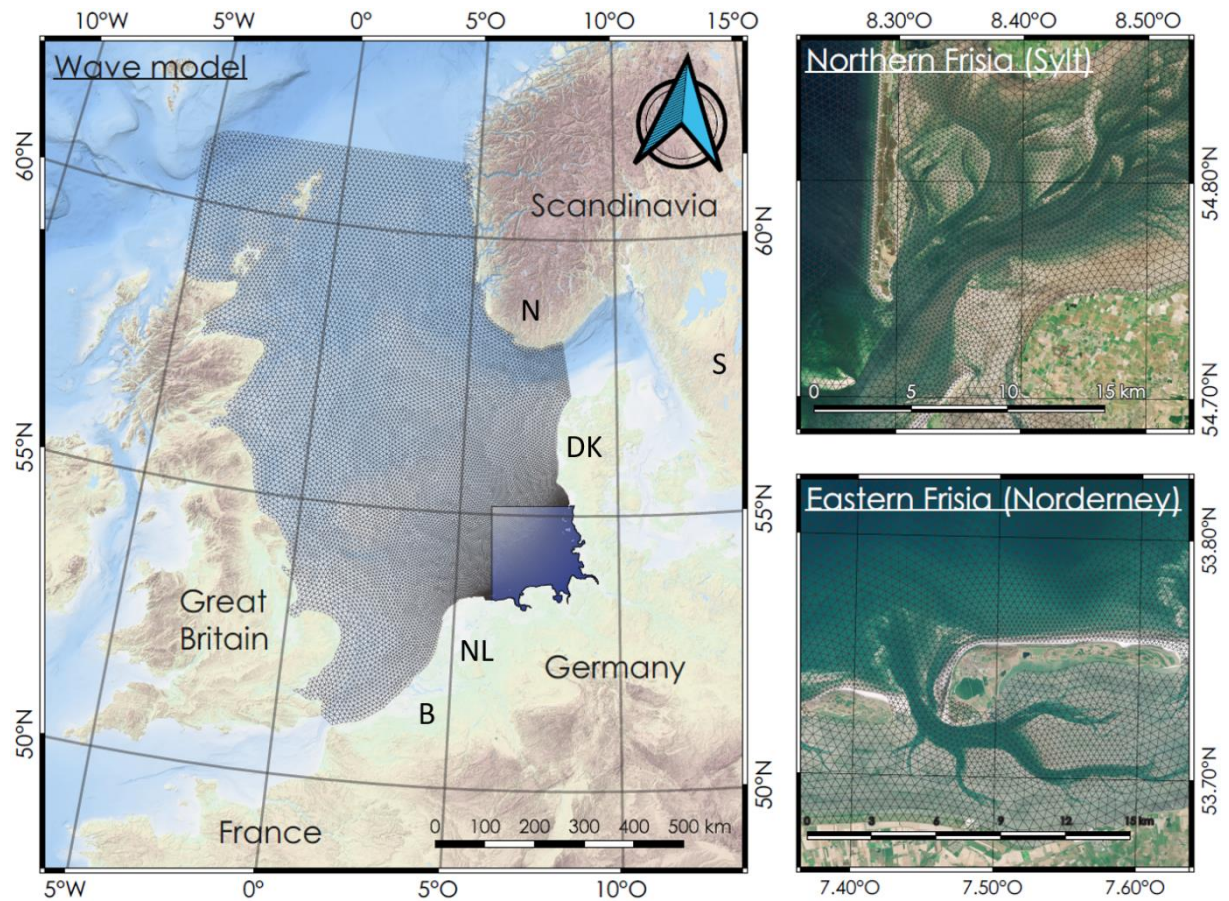


Figure 23: EasyGSH-DB North Sea wave model (UnK: Grid).

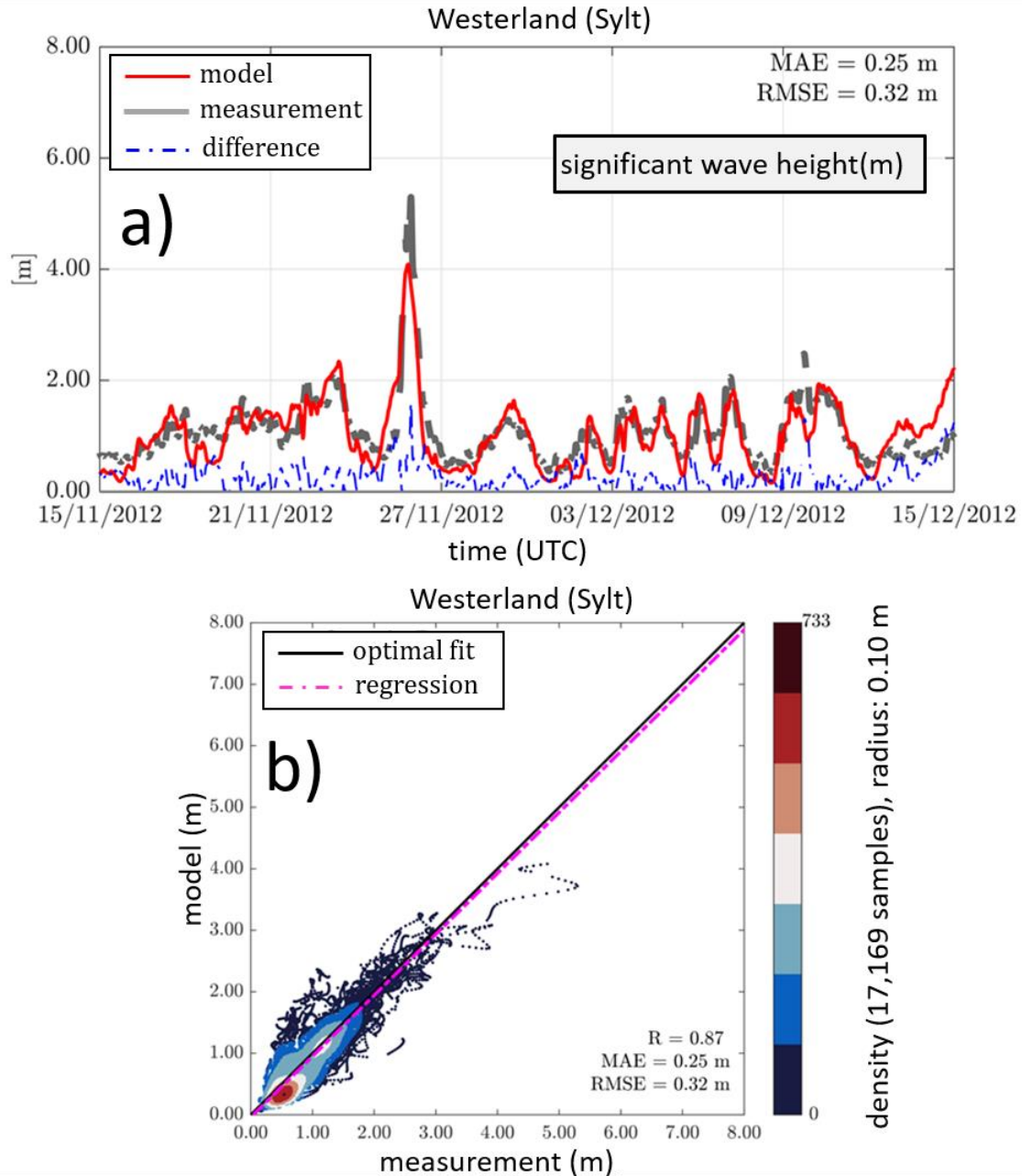


Figure 24: Significant wave height in Westerland (Sylt) measurement vs. model a) hydrograph, b) scatter plot measurement (x-axis) vs. model (y-axis) at the same time.

6.2 TELEMAC model family

The validation of the simulation results generated by the TELEMAC model system is explained in detail in a separate document (Schrage et al. (2020)). The validation results are summarized below as examples.

6.2.1 Conceptual description of the model family

The TELEMAC modeling system is used for numerical simulation of water levels, currents and transport processes. It consists of the modules for simulation of water levels and currents including transport (TELEMAC2D/TELEMAC3D - Electricité de France, 2010b), waves (TOMAWAC - (Fouquet 2016), Electricité de France, 2011) as well as sediment transport and morphodynamic (SISYPHE - Electricité de France, 2010a).

Hydrodynamics are calculated on the basis of the Reynolds averaged shallow water equations in depth averaged approach with TELEMAC2d (**TEL**) or layered three-dimensionally with TELEMAC3d (**T3D**). Therein the classical shallow water equations, the wave equation, and the Boussinesq equations are available. In the wave equations, the velocity components are first eliminated in the continuity equation by inserting the momentum equations and later calculated by back-substitution of the determined water level field. The Boussinesq equations correspond to the shallow water equations which are extended by a not hydrostatic term.

To solve the equations, either the finite element method or the finite volume method is available. Semi implicit schemes can be used for time discretization which theoretically brings independence from Courant-Friedrichs-Levy-criteria. Therefore, longer simulation time steps are allowed. For turbulence modeling, a zero or a two-equation model can be used. In the case of the zero-equation model, the quantities for turbulence modeling are incorporated as parameters in the equation system. These do not depend on the solution and can therefore be explicitly determined. Concerning the two-equation mode, the turbulent viscosity is determined dependent on two further parameters which represent the turbulence production and dissipation. These parameters depend implicitly on the flow field; thus, the equation system has to be extended by two equations. The use of two-equation turbulence model is more computationally expensive. **TEL** allows the utilization of different approaches to take the bottom friction into account. A general description of the models **TEL** and **T3D** with their possible applications can be found in (Ata 2018) und (Mattic 2017). The theoretical basics are described in-depth by (Hervouet 2007).

TOMAWAC (TOM) is the complementary numerical model from the TELEMAC model family for the simulation of the sea state based on a simplified equation for determining the frequency and direction dependent wave energy density. In addition to the spatial discretization described below, the model works with a frequency and direction dependent discretization. **TOM** is one of the phase averaged sea state models of the third generation which model explicitly the relevant physical processes of the sea state formation, interaction and dissipation (e.g. wind energy input, Whitecapping, quadruplet interaction and bottom friction) without fundamental restrictions on development of the sea state spectrum (Booij et al. 1999b). The model is documented in (Awk 2018).

The equation systems of the two modules **TEL** and **TOM** are solved based on the basis of unstructured triangular grids. A great advantage in using the finite elements method is the flexibility in the composition of the computational grid which leads to a significant increase in efficiency. Regions of special interest e.g., near the coast, in estuaries or in Wadden areas can be represented in a high grid resolution while other areas as the deep water, for example, can be resolved much coarser. This approach avoids the creation of disproportionately high numbers of nodes without leading to a loss of accuracy. The equations are solved for each vertex (node) of a triangle. The use of a higher approximation order is also possible so that more nodes are introduced at the edge centers and the center of the triangles. For the coupling of flow and sea state, the same spatial grid has to be used, while the time increments can be selected independently. The online coupling takes place through mutual exchange of the influencing variables under specification of a coupling time step.

The execution of a TELEMAC calculation consists of a sequence of steps:

1. Compilation
2. Partitioning,
3. Simulation and
4. Reconstruction.

The steps 2 to 4 essentially form the actual simulation using parallel processors on the simulation computer. As part of EasyGSH-DB the system has been configured for operation on the High-Performance Cluster at TUHH. When partitioning, the area is divided into sub-areas which are assigned to the individual processors. After finishing the simulation, the distributed shared simulation results are reconstructed into a consistent overall model result. A special feature is the

compilation sequence: TELEMAC allows the individual expansion of the possibilities by the user if the standard available functionalities are insufficient. Individual functions of the source code can be adapted to this and then, at the start, be compiled to an executable file.

Within EasyGSH-DB a coupled current - sea state model with the modules TEL using the wave equation and TOM is run for the years 1996 to 2015. A T3D model using 15 horizontal layers is employed exemplary for the year 2011. Considering the additional expenditure on computing power in relation to the differences in the results, the decision was made to carry out the productive simulation for the whole 20 years only on the base of the 2d model.

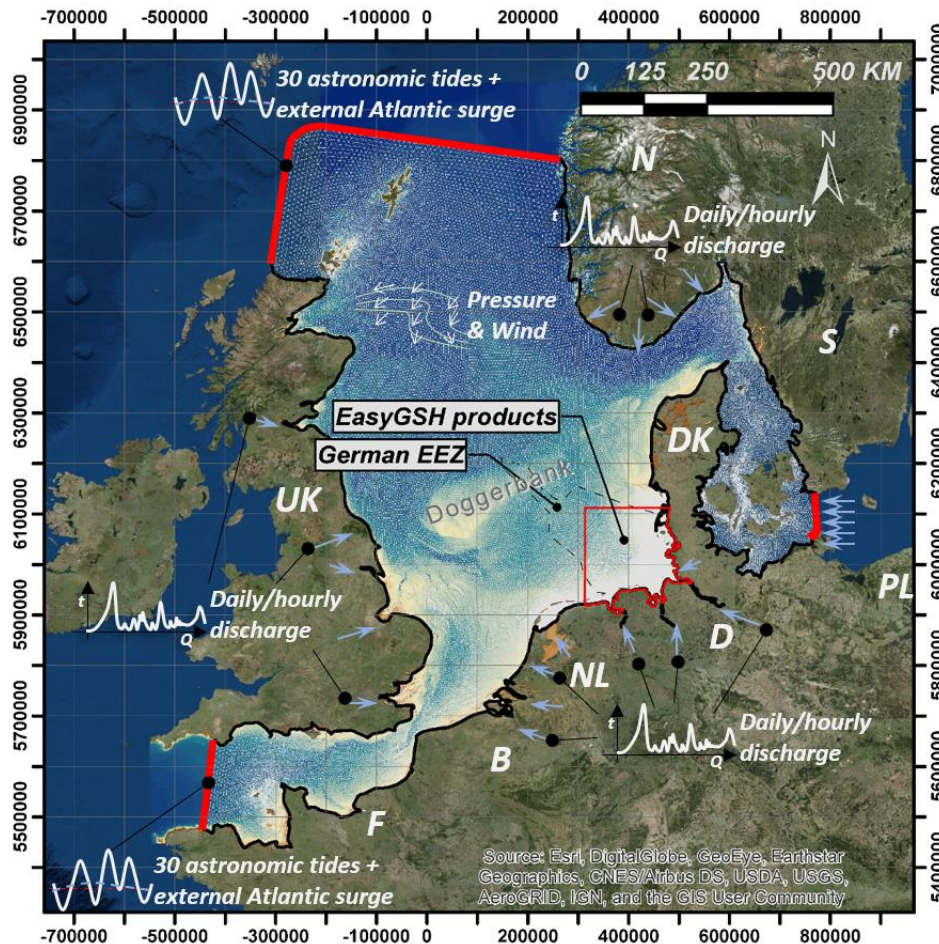


Figure 25: EasyGSH-DB North Sea Model (TELEMAC-2D) open (red) and closed (black) boundaries (Background: ESRI "World Imagery Map". Access 04/2019).

6.2.2 Model construction

Figure 25 shows the basis of the conceptual model. The model area covers the entire North Sea as well as western parts of the Baltic Sea. The focus area German Bight is located in the center of the model area and is resolved in a much higher level of detail compared to the rest of the model area. At the open model boundaries to the Atlantic Ocean (in the west and north), water level time series are prescribed. These boundary values include the astronomical components as well as the influence of the external surge coming from the Atlantic Ocean. The atmospheric influence over the North Sea is introduced into the water body by utilization of areal wind and pressure fields. Data of the global tide model FES 2014b and the DWD-reanalysis COSMO-REA& of the DWD (Bollmeyer et al. 2015) are used just like for the UnTRIM model (see Chapter 6.1.2). The determination of the external surge from the Atlantic is carried out methodically after (Plüß), by interpreting the water level differences between the astronomical and meteorological driven model to the measurements at the gauge Helgoland (partially also gauge Alte Weser) as external surge. These values are added up by time shifting of 14 hours to the astronomical boundary values of the northern margin.

A constant mean inflow is prescribed at the open boundary of the Baltic Sea. The fresh water sources (rivers) around the North Sea are integrated in the model as hydrographs of the run-off resp. freshwater discharge.

The entire model is spatially approximated by an unstructured triangular grid. The following criteria were defined as requirements for discretization:

1. Structures of the Wadden area have to be resolved by a high resolution.
2. The same triangular grid has to be used for all years.
3. The level of detail (amongst other things: small-scale structures, volume consistency) should be comparable to the UnTRIM² grid, considering the different approaches and requirements for discretization.

The model boundary, the outlines of islands, and further specific edges form the basis for the triangular simulation grid. The specific edges are used to force the position of element edges to adopt the alignment of the elements to the structures of the area. The combination of the requirement to use only **one spatial discretization for all years** and thereby depicting the morphodynamic Wadden structures with the tidal channels and mud flats in a consistent approximation quality, poses a special challenge. Therefore, the location of the constrained edges in the area of the mud flats of the data set was derived to the morphological space (MR) (see Chapter 4.3). In this data set the position of the tidal channels can be recognized by elongated resp. funnel shaped areas of large maximum amounts of the changes of the bed level in the MR data set.

The specific edges which mark the position of the channels are created centrally in this funnel. Wadden areas are marked in the data set to the MR by compact areas of small maximum amounts of bed level changes. The surroundings of these regions are specific edges as well.

The final computational grid consists of around 580,000 elements with app. 300,000 computation nodes. The edge lengths vary between 50 m and 300 m in the Wadden areas, up to 400 m seawards the - 20 m depth isobath and till 2,500 m in the open sea. The **functional seabed model (FSM)** provides the annually varying bathymetric data set along the North Sea coast from the Netherlands until Denmark as well as for the German Bight. Regarding the regions of the model area for which the FSM does not provide any information, the global available Emod-Net data set (<https://www.emodnet.eu/bathymetry>) is used.

The elevations of the grid points are determined true to volume as the mean (average) of the height information in the Voronoi polygon of each grid point. Figure 26 shows excerpts of the computational grid from a) the North Frisian Wadden Sea, b) the East Frisian Wadden Sea, and c) the mouth of the Elbe estuary. The color representation corresponds to the height distribution due to assignment of the bathymetry values to the calculation grid. On closer inspection, the differentiation of the element sizes in the channels and on the Wadden areas can be seen. The red lines represent the specific constrained edges to be considered in the grid generation.

Based on the necessary bandwidth of the frequencies from Holthuijsen (Holthuijsen 2010) and the TOMAWAC documentation (Awk 2018), the sea state is discretized with 15 wave frequencies between 0.04 Hz and 0.4 Hz as well as with 18 wave directions.

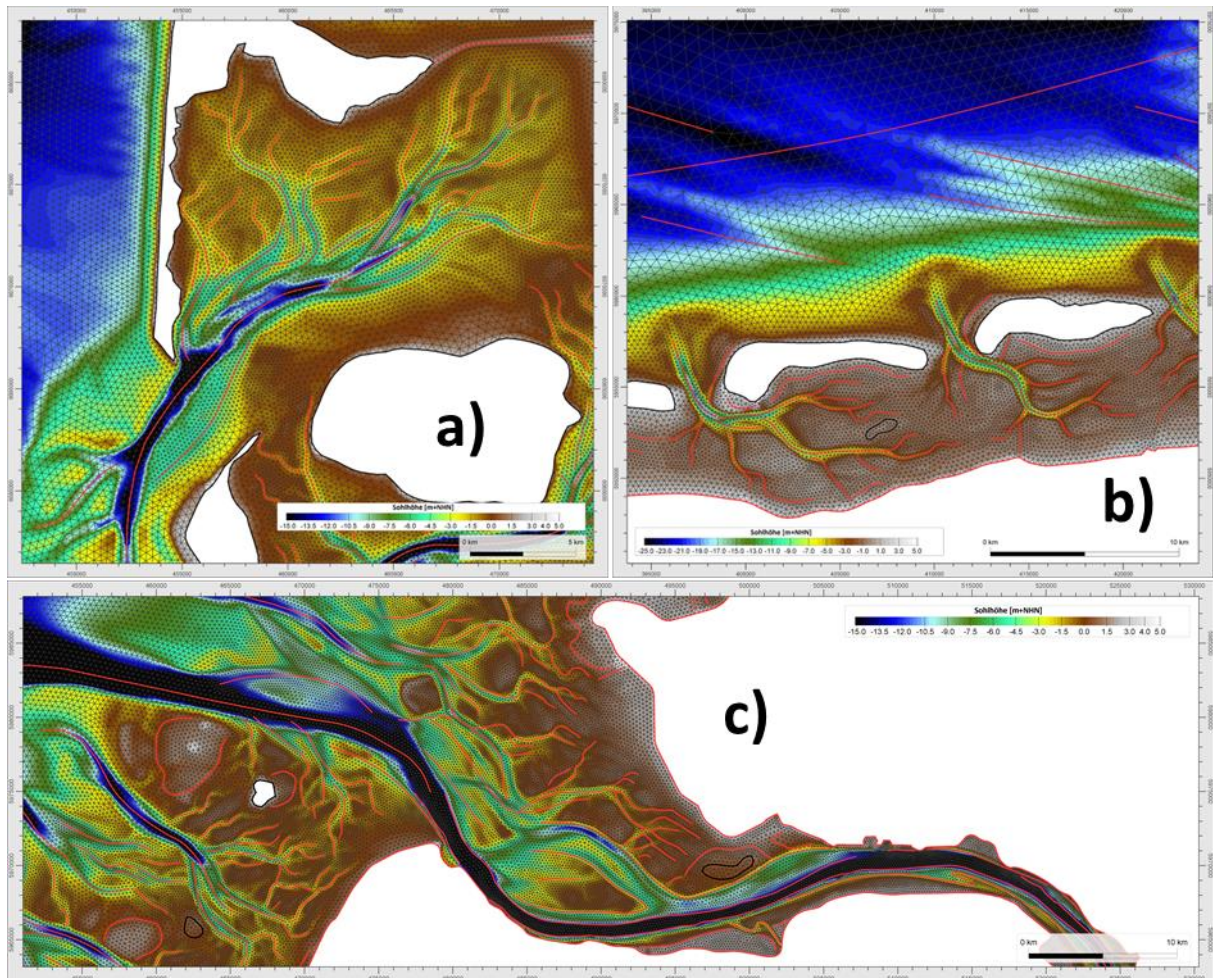


Figure 26: TELEMAC grid cutout, bathymetry 2010, a) North Frisia, b) East Frisia c) mouth of the Elbe with the considered specific edges (red: polylines; black: polygons).

The model system is adapted to the requirements of the project with some programming. On the one hand, for each individual boundary node values should be specified separately. The implementation was taken over from the TELEMAC user community.³ Meteorological conditions as air pressure and wind cannot be assigned variably in space and time with the standard resources, although the interface for this case is already provided in the TELEMAC source code. (Gourgue et al. 2014) have programmed for their modeling of storm surges on the Belgian North Sea coast such an extension and made it freely available. This extension reads meteorological input data in the netCDF format. For this the integration of the UCAR netCDF libraries is also required⁴. The projection from WGS84 (ETRS4326) to UTM zone 32N (EPSG: 25832) takes place by programming the coordinate transformation method according to the International Association of Oil & Gas Producers (IOGP) (2016)). Incomplete meteorological data are first closed spatially with the help of the Shepard interpolation using the weighting exponent $p = 2$ as long as the number of missing values does not exceed the amount of 15 % in the time step. Otherwise, whole time steps will be skipped. The temporal interpolation is linear based on valid temporally adjacent time slices of the meteorological data set.

³Discussion-comment #749: TELEMAC-user forum (<http://www.opentelemac.org/index.php/kunena/16-telemac-2d/747-spatial-and-temporal-varying-boundary-conditions#749>)

⁴ <https://www.unidata.ucar.edu/software/netcdf/docs-fortran/>

6.2.3 Calibration and validation of sea surface elevation and currents

A subjective calibration with an optimal result is practically impossible due to the multitude of potential variations and measurement data. An objective procedure would be necessary for a real calibration. This is not affordable due to the spatial temporal size of the model and the computing resources available in the project framework. Only one parameter adjustment that is valid for all simulated years is carried out to get the best possible model configuration. Bottom roughness, turbulence parameter as well as corrections to wind magnitude were varied.

This procedure corresponds in principle to a calibration. Against the background of the real possibilities the designation “calibration” is not used indeed. Rather, a detailed validation takes place by showing the approximation quality of the model results achieved over the years based on direct graphic comparisons with identification of the error values. As part of the validation, the sea surface elevation is differentiated according to tide-dependent and tide-independent parameters, and also currents and sea state were analyzed. In principle, the simulation results with as many measured values as possible are put in relationship to each other. It should be noted that in the evaluation of the model validity the main focus is lying on the measuring stations in the German Bight. An overview of the available gauges can be found in the attachment (Chapter 13.1). The entire scope of the validation is documented separately. At this point, the validation results for a spatially and temporally restricted section are shown. For direct comparability with the UnTRIM²-model from the validation in Chapter 6.1 the explanations are related below to the years 2006 and 2012. Comparisons between simulation results and measured value are carried out here for the water level parameters with partial tide analyzes and tide-independent comparisons as well as for sea state.

The uTide tool (Codiga 2011) was used for the partial tide analyzes. Detailed validation results can be found in the associated model documentation. An important finding from the validation is, that above all the partial tides M2, S2, and N2 which are significant for the sea surface elevation, have little differences between measurements and simulation. Furthermore, it is to be noted, that the courses do not show any oppositeness from a qualitative point of view.

The differences between the model results and the measured values provide information of the approximation quality of the partial tides through the numerical models. The comparisons for the partial tide M2 are shown in Figure 27 (2006) and Figure 28 (2012) below. The error rates are of the same order of magnitude for both years. It is worth mentioning for classification that the amplitudes per partial tide and gauges position fluctuate and therefore different, relative deviations would result. These cannot be derived directly from the specified error ranges. In addition, the phase shifts are related to the associated frequency of the individual partial tides. For example, M2 and S2 are semidiurnal partial tides so that for both a phase shift or phase shift difference between simulation and measurement of 5 ° correspond to a temporal offset of about 10 minutes.

Table 3 shows the error rates for further partial tides. The figures clearly show that especially the three partial tides with the highest amplitude (M2, S2, and N2) have very low error rates. So, the evaluations for the M2 tide at the 52 considered locations in 2006, resp. 30 considered locations in 2012 show a mean deviation of the amplitude of 0.5 cm, resp. 0.4 cm at a MAE (RMSE) of 4.7 cm (6.1 cm), resp. 4.2 cm (5.8 cm). In the phase a shift on average -1.3 °, resp. -1.8 ° at a MAE (RMSE) of 3.3 ° (4.6 °) is to be recorded compared to the evaluation of the measured data. These deviations are of the same order of magnitude as represented for the UnTRIM² model in Chapter 6.1 (compare Table 1). The error rates for the selected tides over all simulated years can be found in the accompanying documentation (Schrage et al. 2020).

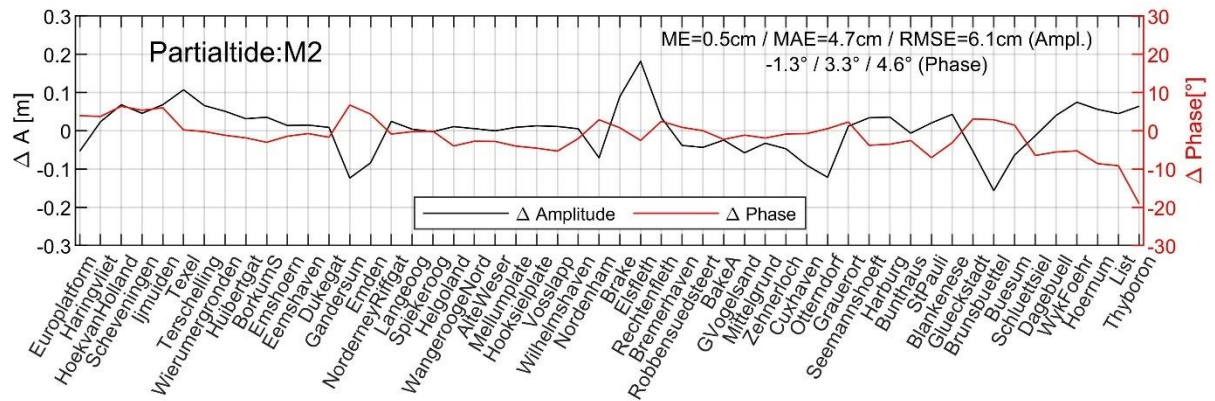


Figure 27: Comparison of the PT M2 (amplitudes / phases) calculation 2006 with error metrics (The points are linked with lines for better readability).

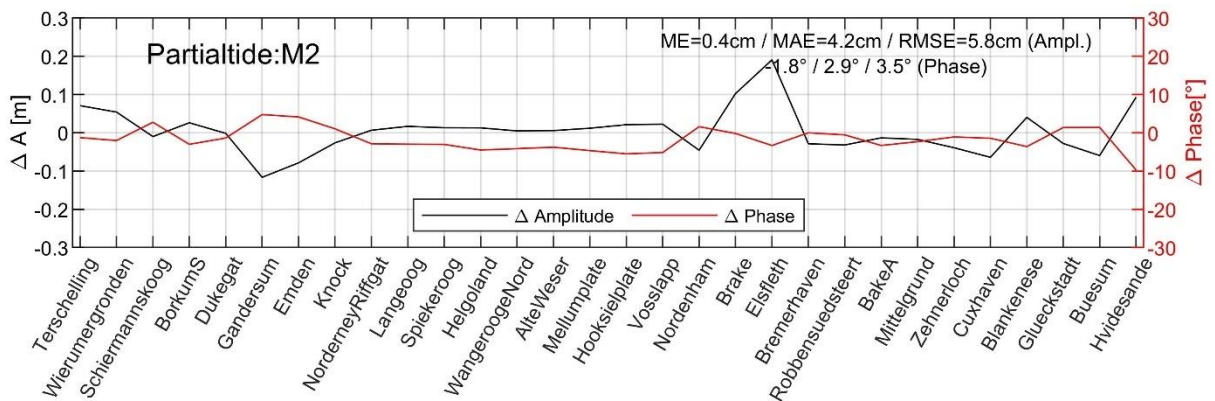


Figure 28: Comparison of the PT M2 (amplitudes / phases) calculation 2012 with error metrics (The points are linked with lines for better readability).

Table 3: Error metrics of PT approximation of M2, S2, N2, O1, K1, Q1, M4 and M6 2006/2012, comparison of PT between measurements and TELEMAT-results.

PT	2006 (52 gauges considered)						2012 (30 gauges considered)					
	Amplitude			Phase			Amplitude			Phase		
	ME [cm]	MAE [cm]	RMSE [cm]	ME [°]	MAE [°]	RMSE [°]	ME [cm]	MAE [cm]	RMSE [cm]	ME [°]	MAE [°]	RMSE [°]
M2	0.5	4.7	6.1	-1.3	3.3	4.6	0.4	4.2	5.8	-1.8	2.9	3.5
S2	0.2	1.3	1.8	1.7	4.1	5.7	0.6	1.3	1.7	0.9	2.8	3.8
N2	0.2	0.8	1.1	0.0	3.8	5.3	0.7	0.9	1.2	-2.4	3.4	4.0
O1	0.6	0.7	0.8	3.7	3.9	4.7	0.6	0.6	0.8	10.2	10.2	10.7
K1	1.8	1.8	1.9	1.5	5.6	6.8	1.0	1.0	1.1	6.2	6.6	7.4
Q1	-0.5	0.5	0.5	-7.3	7.3	8.4	-0.1	0.1	0.2	7.3	7.4	8.9

In addition to the partial tides, absolute water levels were considered. In this way, the influences from meteorology and external surges are included in the assessment additionally to the basic oscillation. This enables a direct comparison of the measured and simulated current velocities. The comparison between sea surface elevations from simulation and measurements is given below for the gauge Norderney (Riffgat) concerning the years 2006 and 2012 (Figure 29). The hydrographs and their differences are shown on the left in the illustration. It can be recognized qualitatively that the differences run evenly over time. Larger amplitudes can be seen temporally in the area of higher absolute water levels. The uniformity to be observed is also due to the application of the external surge correction of the boundary values. The scatterplots on the right clarify the accordance of the simulation results and the measured values. Using the linear regression, the similarity between model and measurements is quantifiable. The closer the gradient $m = 1$ and the regression $b = 0$, the better the approximation between measurements and calculation is.

The observation at the gauge Norderney Riffgat is also confirmed by the calculated mean error of only 4.7 cm, resp. 5.5 cm in 2006 or 2012. As a further criterion for a good approximation, in addition to the regression line, the spread is to be seen. Numerically this can be indicated by the MAE resp. RMSE. At the gauge Norderney Riffgat the MAE varies between 8.9 (2006) and 9.0 (2012) resp. the RMSE is equal in 2006 and 2012 (11.1). The range compared to all other gauges between measurements and TEL-calculation is in the lower / mid band. The relation to the other gauges is explained below.

The results shown in Figure 29 represent a typical pattern that also can be seen in the direct comparisons between simulation results and measured values at other gauges, although the specific deviations in the regression line and the scatter plots are of course numerically different. Table 4 shows in summary the error rates and the corresponding linear regression parameters which were determined from the TEL model results compared to the measured values. The gauge selection corresponds to the list used before in connection with the UnTRIM model in Chapter 6.1. It can be seen that the error rates vary with a constant order of magnitude. The mean deviations between -0.7 cm and 6.4 cm in 2006 and 0.5 cm to 9.9 cm in 2012 show an overestimation of the sea surface elevation for the gauge selection by the model whereby the results at the Blankenese gauge fall out of the scheme. It may be assumed that this results from the position of the gauge in the Elbe at Hamburg, approx. 100 km away from the North Sea. With a view of on the focus area in EasyGSH-DB (the German Bight) for which the products are created and provided, such a deviation is tolerable at distant gauges.

The different slopes of the regression lines have no clear systematics. This is proven by the model results show no general deviation samples at low or high tide. The spread of deviations can be classified with the MAE and RMSE. The MAE varies in 2006 between 8.4 cm and 13.6 cm, and in 2012 between 8.5 cm and 14.7 cm to a very similar extend. The RMSE is 2.1 cm to 3.3 cm greater than the corresponding MAE in all cases shown. The Emden gauge is an exception where the RMSE is about 4 cm larger.

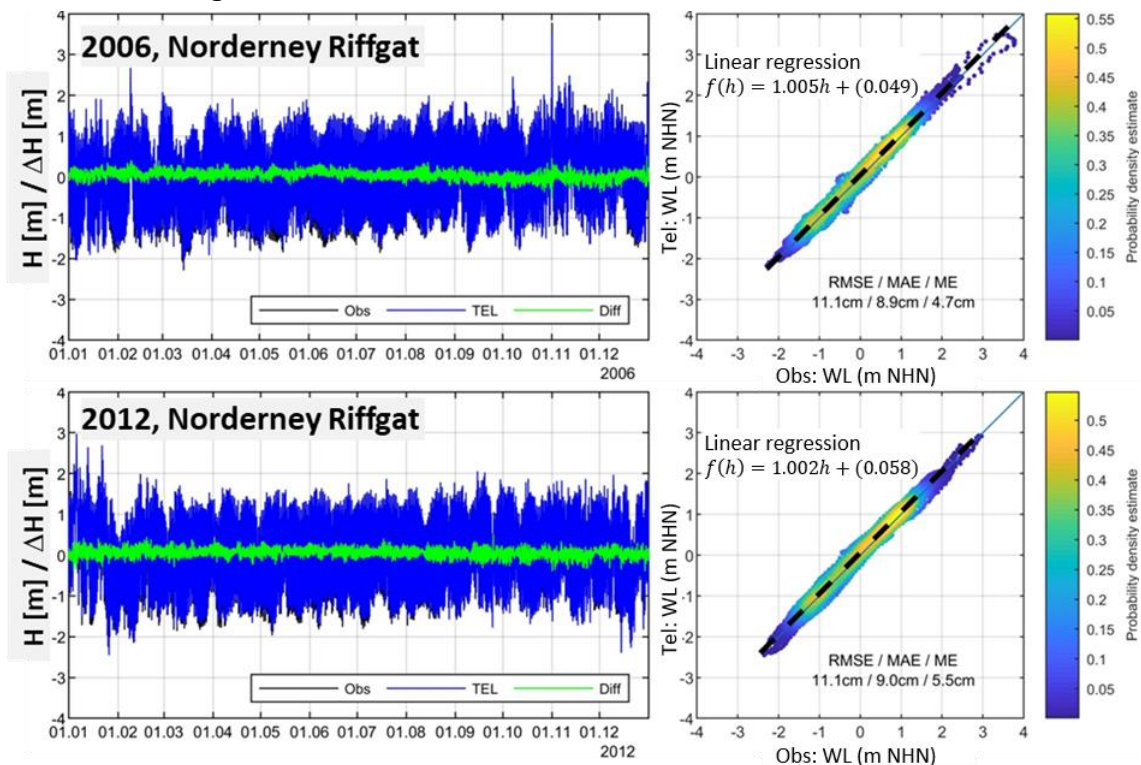


Figure 29: Sea surface elevation comparison measurement/simulation, Norderney (2006, 2012) as direct contrast of the time series, differences, and as scatter plots.

The validation of the model results for the years 2006 and 2012 shows, that the tide events for both considered years concerning sea surface elevation with a deviation of a few centimeters

compared to the measurements can be reproduced very well. In this context it is pointed out again that the parameterization for all years is identical. It should also be noted that the similarity of the model results with the measured values was achieved by global modifications of model parameters. For the productive runs, only the driving forces sea surface elevation, discharge, meteorology) and the bathymetry were adjusted.

Table 4: Error rates / lin. regression of the water level 2006 and 2012 Comparison between TELEMAC results and measured values at selected gauges.

Gauge	2006					2012				
	Sea surface elevation					Sea surface elevation				
	ME [cm]	MAE [cm]	RMSE [cm]	m [-]	b [m]	ME [cm]	MAE [cm]	RMSE [cm]	m [-]	b [m]
BOS	2,9	8,4	10,5	1,021	0,030	4,1	8,5	10,5	1,020	0,043
EMD	6,4	13,6	17,6	0,945	0,066	6,1	12,9	17,1	0,946	0,062
NOY	4,7	8,9	11,1	1,005	0,049	5,5	9,0	11,1	1,002	0,058
ALW	-0,7	8,6	10,9	1,000	-0,007	0,6	9,1	11,5	1,006	-0,005
HOO	1,7	11,0	13,7	1,007	0,017	2,1	13,1	16,0	1,010	0,024
RSS	4,5	10,4	13,7	0,977	0,044	5,3	10,7	13,9	0,984	0,056
CUX	0,9	10,5	13,2	0,946	0,015	0,5	9,7	12,5	0,962	0,008
BLA	-6,7	11,5	14,3	1,030	-0,081	-4,2	11,5	14,4	1,032	-0,057
WYK	2,3	11,8	14,5	1,047	0,018	9,9	14,7	17,9	1,046	0,098

6.2.4 Calibration and validation of the wave model

The wave model is coupled with the current model and base upon the same spatial discretization as the TELEMAC2d model. The validation of the simulation results is carried out for the significant wave height (H_{m0}), the mean wave period (T_{m02}), and the mean wave direction (θ_m). The documentation is limited here to the evaluations of the significant wave height.

While measure data of the sea surface elevation in the German Bight and the North Sea are available at a relatively large number of gauges over comparatively long periods of time, the use of measured data of the sea state is (very) limited in terms of time and space. In addition, the data sets often have temporary gaps due to the higher complexity of the sea state measuring devices and the higher maintenance effort. The North Sea Buoy II (BSH) is one of the few stations for which the measured values in the years 2006 and 2012 are available. Figure 30 shows the comparisons of the time course of the significant wave height (SWH) from the simulation results (TWC) and the measurements (Obs) for the years 2006 (above) and 2012 (below) for the measuring station North Sea Buoy II.

It should be noted that the differences are given as absolute values. It can be seen clearly that the simulated values underestimate the measured values. The amount of underestimation tends to increase with larger significant wave heights. This qualitative impression is confirmed by the slope of the linear regression line which is in order of magnitude of $m = 0.9$ for both years. It thus indicates a slight divergence of the simulated and measured values with increasing amounts of the significant wave height. Presumably, a better fit of the model results to the measured sea state values could be given by a stronger energy input from the wind. The wind strength of the COSMO-REA6 input data, which are also model results, is still not escalated (calibrated) upwards to maintain the consistency with the propulsion of the currents model. Otherwise, the wind strength would also have to be scaled up as a drive. However, this would significantly worsen the calculated results of the hydrodynamic shown above.

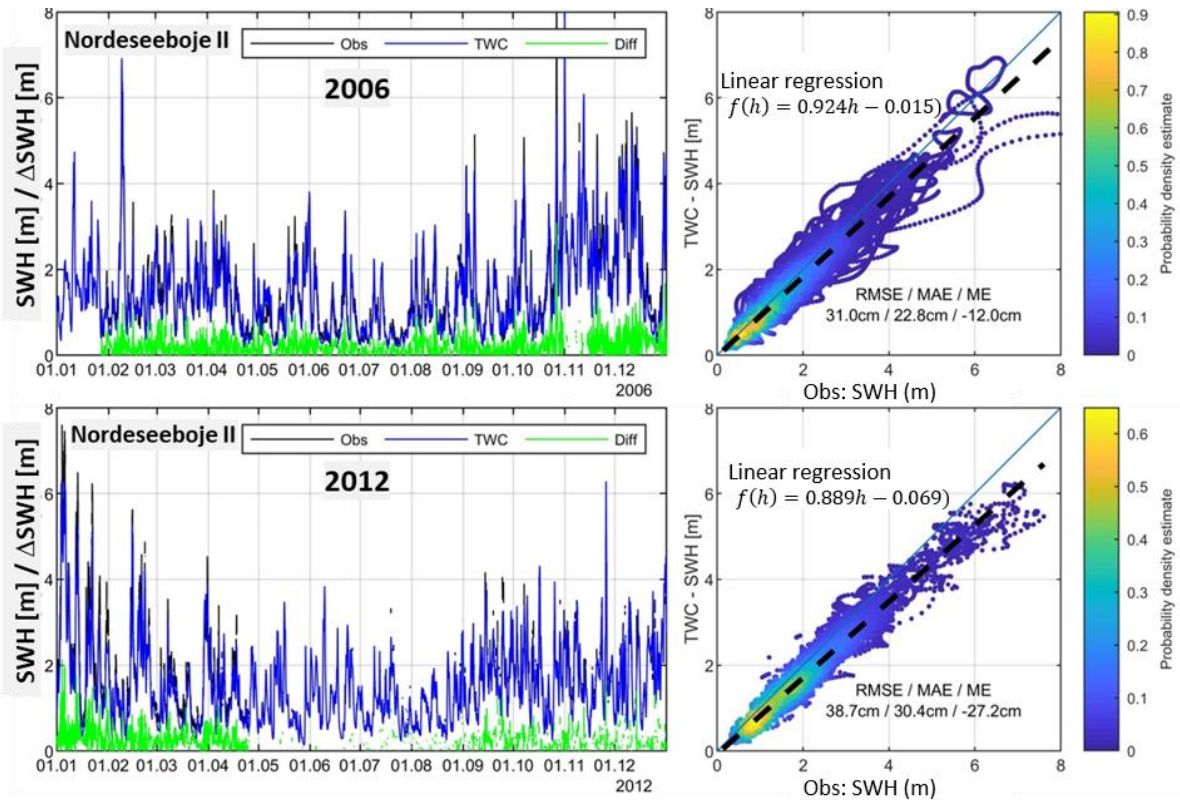


Figure 30: Significant wave height (SWH) comparison measurement/simulation, Nordseeboje II, (2006 and 2012) as direct contrast of the time series, differences, and as scatter plots.

Table 5 shows the error rates for all evaluable stations in the years 2006 and 2012. From this you can learn that the wave model, in the given configuration, reproduces the sea state conditions in a good quality but basically underestimates as can be seen in the graphics of the Nordseeboje II (North Sea Buoy II). The MAE varies between 15.5 cm and 24.7 cm in 2006, resp. 16.4 cm and 32.7 cm in 2012. The RMSE is about 5 cm to 10 cm higher than the MAE and thus in the same order of magnitude as the RMSE which was determined in the context of the comparison of the results of the UnK model and measurement data (Chapter 6.1.4). The two models of comparable quality thus provide a basis for the multi model approach.

Table 5: Error rates / lin. regression of the significant wave height für 2006 and 2012, TOMAWAC model vs. Measured values at selected locations.

Gauge	2006					2012				
	Significant wave height					Significant wave height				
	ME [cm]	MAE [cm]	RMSE [cm]	m [-]	b [m]	ME [cm]	MAE [cm]	RMSE [cm]	m [-]	b [m]
ALW	-17.3	22.5	32.1	0.599	0.150	-19.1	23.1	33.2	0.600	0.149
WES	-	-	-	-	-	8.3	16.4	21.4	0.987	0.091
WES-II	-7.2	15.5	22.5	0.898	0.035	-	-	-	-	-
FINO-I	-22.7	27.4	37.4	0.817	0.032	-31.2	32.7	42.2	0.786	0.025
HEL	-16.2	21.0	29.4	0.757	0.088	-	-	-	-	-
NSB-II	-12.0	22.8	31.0	0.924	-0.015	-27.2	30.4	38.7	0.889	-0.069
NSB-III	-19.3	24.7	33.2	0.860	0.005	-	-	-	-	-

6.2.5 *Summary calibration and validation of TELEMAC*

Finally, some statements can be made based on the presentation of the years 2006 and 2012. With reference to the partial tides the current model reproduces the reality with deviations of only a few centimeters. The pattern of the water levels which does not only depend on tide (partial tides, meteorology, external surges) shows deviations of 10 cm to 20 cm. The significant wave heights vary about 20 cm to 40 cm. All specified differences relate to the MAE and RMSE. The coupled current sea state model set up with TELEMAC2D and TOMAWAC forms a solid basis for the multi model comparison aimed within the scope of this project considering the given deviations from the measurement data.

6.3 SWAN

As part of EasyGSH-DB, the sea state model SWAN (Booij et al. 1999a) was used as a supplement to the sea state models UnK and TOMOWAC. The integration of SWAN serves to expand the model portfolio of the multi model approach on the one hand. On the other hand, the model results were used for producing yearly station-related resp. areal sea state products in the German Bight for the period 1996 to 2015 (see Chapter 6.6).

6.3.1 *Conceptual description of the model*

The spectral sea state model of the third generation SWAN was used in the version 41.20A (2019) which utilizes, compared to earlier versions, adapted parameterizations of the bottom friction and wind drag coefficients leading to a better agreement between measured and calculated sea state parameters during storm event resp. under measurement situations (van der Westhuysen et al. 2012) and (Zijlema et al. 2012).

In a series of national (Niemeyer und Kaiser 2003); (Herman et al. 2007); (Fraza 1998) (Mai et al. 2004) and international studies (Groeneweg et al. 2009); (Zijlema et al. 2012); (van der Westhuysen et al. 2012); (van der Westhuysen 2008); (Groeneweg et al. 2009); (van Dongeren et al. 2010), the general suitability of SWAN for reproduction of characteristic sea state parameters and spectra in the strongly structured Wadden areas also influenced by wind and tide at the North Sea was noted. The model is able to depict “the temporal and spatial variability of the sea state” (Herman et al. 2007) on the outer coast of the East Frisian Islands, especially in the strongly structured regions of the reef inlet between the islands. SWAN has also been used successfully several times for determination of calculation assessment parameters both on the outer coast as well as in the Wadden area of the East Frisian Islands (TUHH 2015, 2016).

The simulations were carried out on the basis of the unstructured grid which was also used for the simulations with the HN model TELEMAC (see Chapter 6.2.2.). A large main memory and computing time requirement arises due to the comparatively large model area extension of about 1.400 km x 1.200 km towards north south or west east as well as to the variable spatial resolution (up to 50 m in the coastal area) and the selected spectral resp. directional resolution. Therefore, all simulations were carried out by OMP parallelization (shared memory system) on multiprocessor-cluster systems at the data center of TUHH (High Performance Cluster) and finally evaluated partly automated in post-processing (e. g. generation of station-related resp. areal wave products for supply in the EasyGSH-DB data portal).

The following physical processes were considered for the modeling:

- Waves growth due to wind influence fetch (exponentially after (Komen et al. 1984),
- Whitecapping (Komen et al. 1984),
- Non-linear wave interactions in deep water (Quadruplets, Hasselmann et al. 1985) and
- Water depth dependent wave breaking (Battjes und Janssen 1978).

The aforementioned processes are active by default in SWAN.

Additionally, non-linear wave interactions in the transition zone (Triad-Interactions, (Eldeberky et al. 1996)) and the bottom friction with constant friction coefficient (Hasselmann et al. 1973) was activated. For further information regarding to the aforementioned approaches, please refer to the SWAN documentation (The SWAN Team 2018b, 2018a).

6.3.2 Model setup

Different from the simulations with UnTRIM/UnK and TELEMAC/TOMAWAC, which based on an online coupling of the water levels, the simulations with SWAN are carried out for a constant mean water level (MSL). From this, it follows that the results of SWAN are to be regarded as reliable only in deep water conditions while the other both models represent the local sea state conditions in the deep water and transition zone. This wind drive forcing is also used to operate the currents models (Chapter 6.1.2. and Chapter 6.2.2.). The wind data have been processed by the software „Climate Data Operators/CDO“⁵. The depth information was taken from the annual varying bathymetries (annual bathymetries: FSM, see Chapter 4.2.1). The simulations were realized on a regular geographic coordinate system (WGS84).

The question arises especially with large wave models, in what extent on the open boundary of the model sea state parameters must be specified as boundary conditions over the time. That depends on the distance between the open boundary and the actual study area, here the German Bight. Comparative calculations with and without specifications on the model boundary were carried out in a sensitivity analyzes with a North Sea model on the basis of SWAN (TUHH). As boundary conditions on the open boundaries (north and west margin of the model area), wave parameters from the historical archive of the NCEP (NOAA) were used in this regard. NCEP is a global wave model based on Wavewatch III (Tolman und Chalikov 1994). As a result of the sensitivity analyzes it was found that the sea state conditions in the study area are not influenced by those at the outer model area edge. Therefore, the sea state conditions are not considered for the EasyGSH re-analyzes running. From this it follows that the model results are representative only for the conditions in the German Bight.

By default, the output occurs during the calculation with an hourly output interval for the:

- i) areal output of the
 - water depth d
 - significant wave height $H_s = H_{m0}$
 - mean wave periods T_{m01} and T_{m02}
 - energy resp. peak period $T_{m-1,0}$ resp. T_p
 - mean wave direction θ_m
 - standard deviation of the wave direction σ_θ
 - wind vector components u, v
 for each grid point of the unstructured simulation grid in a binary MATLAB-format (file extension *.mat), see Chapter 6.6.2
- ii) punctual output of the time series of aforementioned wave parameters and wind components at locations listed in Chapter 6.6.1 in a freely readable ASCII-text format (file extension *.tab)
- iii) selected output of 1D/2D wave spectra at the locations listed in Chapter 6.6.1 in a freely readable ASCII-text format (file extensions *.spec1d or *.spec2d)

6.3.3 Calibration and validation of sea state

The choice of the basic model parameters and for spectral discretization of the SWAN model took place on the base of experience from previous investigations to determine the sea state conditions

⁵ <https://code.zmaw.de/projects/cdo>

along the North Sea coast (e. g. University of Rostock 2009). The wave spectra computed by SWAN were resolved with 144 directions and 42 frequency support points (0.02 Hz to 1 Hz).

In a sensitivity analyzes with another North Sea model on the basis of SWAN (TUHH 2016), the spin up time required for the transient wave Δt for the complete development of sea state until the beginning of storm events was meant to $\Delta t = 10$ days. The number of iteration steps required per time step was elected to $n = 20$ based on comparative calculations which are not explained in more detail here.

The characteristic sea state parameters calculated by SWAN, significant wave height, mean wave period, peak period and mean wave direction are shown as an example in Figure 31 as well as measured values of sea state in the near of the location “FINO1” for the year 2007. The calculated error rates (RMSE, MAE or ME) are summarized exemplary for selected locations and for the year 2007 in Table 6. The calculated sea state spectra were used for both analyzes of the sea state conditions and model validation in the frequency range. There was a good accordance between the measured and simulated sea state spectra during storm events in the deep water, for example in the vicinity of the location “FINO1” during the storm “Xaver” in 2013 (Figure 31).

As a result, the agreement was found good to very good between measurement data and simulation results which confirms the suitability of the model for multi model comparisons and generation of products (Dreier et al. (2020)). Larger deviations, for example of the significant wave height and mean wave direction, can in any case be traced back to the constant water level used in the SWAN simulations (e. g. in the vicinity of the measuring station “Westerland/Sylt”).

Under deep water conditions (for example nearby the measuring stations “FINOI”, “NSB.II” and “Elbeboje”), on the other hand, the error rates are lower than expected and are, for example, for the mean absolute error (MAE), for the significant wave height ≤ 26 cm, for the mean wave period or peak period ~ 1 resp. 2.8 s and for the mean wave direction $\leq 25^\circ$.

Also, measurement data directly from the respective databases were used for the comparisons without further correction or plausibility checks. This can lead to major deviations in individual parameters or in the near of single measurement stations. An example is the peak period which is often only very roughly resolved in measurements especially for long periods analogous to the measured spectrum. In addition, the evaluation of the quality of the modeled wave direction is only possible to a limited extent because the mean wave directions ($\theta_{m,SWAN}$) calculated with SWAN had to been compared with the measured wave directions at the peak frequency ($\theta_{p,measurement}$) due to the fact that the mean wave direction was not available in the measurement data bases.

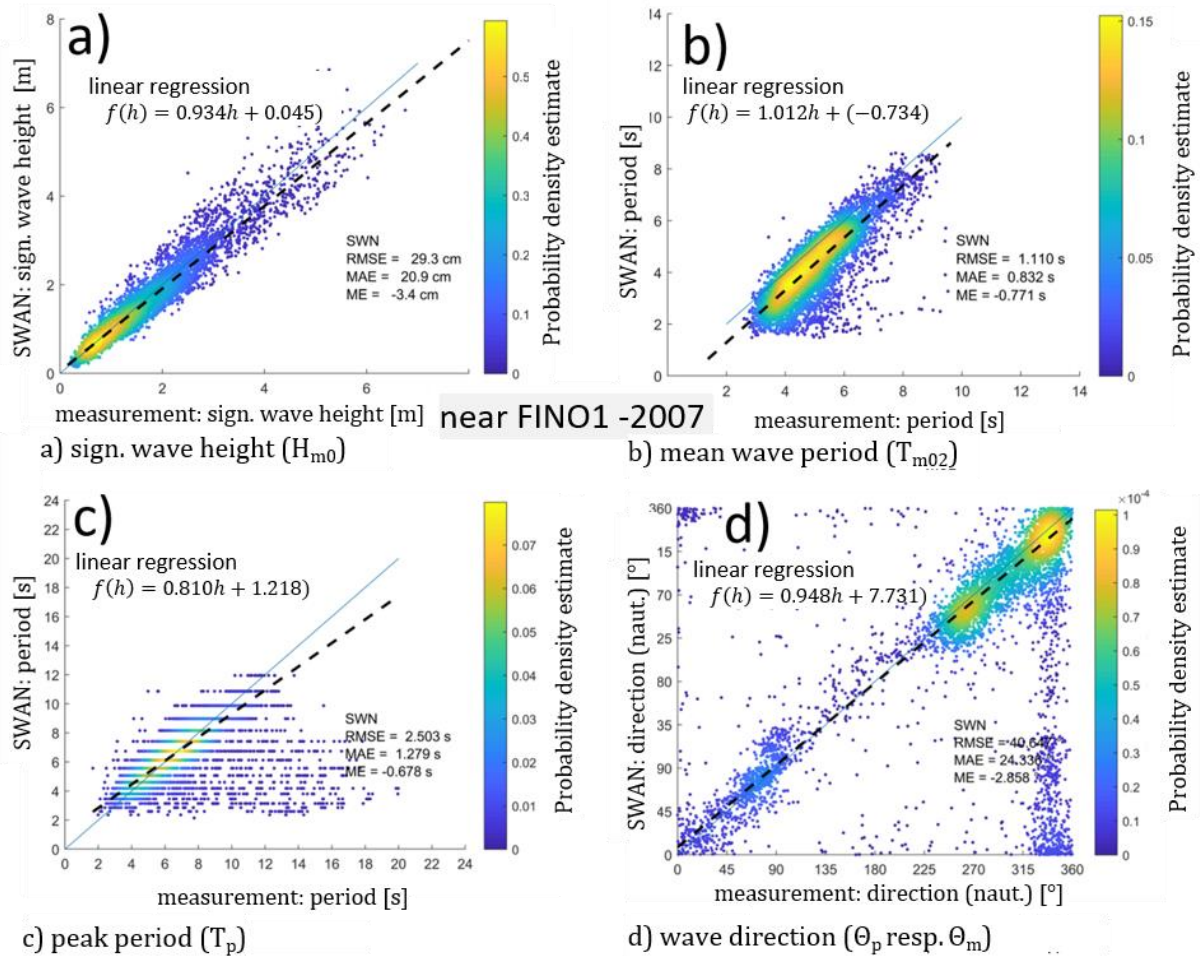


Figure 31: Comparison measurement vs. SWAN (near FINO1 -2007), a) sign. wave height (H_{m0}), b) mean (H_{m0}) and c) peak (T_p) period, and d) direction (Θ), as scatter plots.

Table 6: Error rates between SWAN simulation results and measurements (2007) significant wave height (H_{m0}), mean wave period (T_{m02}), Peak period (T_p) and wave direction ($\Theta_{m,SWAN}$ bzw. $\Theta_{p,measurement}$) at three locations (d = water depth m NHN).

	H_{m0}			T_{m02}			T_p			Θ_m		
	RMS E (m)	MAE (m)	ME (m)	RMS E (s)	MAE (s)	ME (s)	RMSE (s)	MAE (s)	ME (s)	RMSE (s)	MAE (s)	ME (s)
FINO1 (h=29 m)	0.29	0.21	-0.03	1.11	0.83	-0.77	2.50	1.28	-0.68	40.7	24.3	-2.9
Westerland (h=14 m)	0.56	0.40	0.38	1.26	0.83	-0.48	3.11	1.78	-0.41	47.8	29.0	0.9
Elbeboje (h=25 m)	0.20	0.15	-0.01	1.10	0.92	-0.90	1.53	0.93	-0.14	40.6	24.7	2.7
NSB-II (h=44 m)	0.39	0.28	0.01	0.86	0.66	-0.37	2.14	1.14	-0.35	37.9	23.6	-2.8

Further information on the validation of the model is given in a separate validation document (Dreier et al. 2020).

6.4 Multi-Model-Approach, comparison and evaluation

Process based HN-simulation models are based on the discrete decomposition of the study area, initially and boundary conditions and use different parameterization of physical conditions. Here, the models are usually based on time variant systems of partial differential equations which are

solved with different numerical methods. The calibration and associated validation of the model families used (TELEMAC and UNTRIM) have been presented in the previous chapters.

The comparison with nature data leads to deviations between model results and measured values due to model simplification and measurement accuracies. A multi model approach opens up the possibility to quantify the range of model-related deviations. On the one hand, this can be done for discrete points (for example the gauge positions) but also for the complete simulation results in time and space.

In the context of the comparative calculations carried out here, identical model input data (bathymetry, boundary values of water level, external surges, freshwater discharges and the meteorological forcing (wind/air pressure) are used. Different specifications had to be made for the construction and operation of the model systems according to the model specific requirements. This affects for example the grid resolution and arrangement (topology) as well as the physical parameterization and the numeric parameters.

The same quality-assured measurement data were used for calibration.

The simulation results were converted to a uniform data format (netCDF) to reduce the differences in results only on the specific features of the model. The comparisons of the calculation results are based on the identical analyzes (software) for an entire year (characteristic value analyzes of BAW) and their differences. By doing this, the differences in the results are only limited to the model internal numerical and procedure-dependent characteristics (see Figure 32).

Identic	Multi-Model-Approach for Tide-Dynamics			Specific
Module	Analogy	UnTRIM		TELEMAC
Bathymetry / Sedimentology	equal basisdata	Yearly bathymetry and sea-surface-sediment-assignment by means of FBM (data / methods)		
boundary conditions / steerage	equal steerage	Waterlevel and external surge at open see boundaries and same river discharge values		
meteorology	identic	COSMO-REA6 from DWD (wind and air-pressure)		
calculation grid: resolution / - topology	model specific demands	restrictions relating to orthogonality, homogeneity / Sub-Grid-Method	restrictions according the FEM-Method and depth approximation	
num. modell: physically and numerically paramterization	model specific requirements	restrictions relating to time step, friction, closure of turbulence, num. diffusion	Restrictions according CFL-criterion, friction, closure of turbulence, num. diffusion	
calibration method	Parameter variations	model spezific parameter variation	model spezific parameter variation	
calibration data	identic data base	both simulation results are compaired with the same measurement data		
result data	Converting to one solely dataformat: netCDF			
analysis	identical software for analysing tidal characteristic values (BAW)			
differences	identical software for generating aerial differences (BAW)			

Figure 32: Structure of the Multi-Modell-Approach for tidal dynamics.

6.4.1 Current model

6.4.1.1 Station-related comparisons

The easiest way of direct comparison of the model results is the direct comparison of hydrographs at different locations. This type of direct comparison provides a visual (qualitative) control over form and tendency of the course of the simulated values. Ideally, model results are not just match with one another but also visualized in relation to the available measured values. Figure 33 shows by way of example the comparison of water levels calculated by UnTRIM (U09) and TELEMAC (TEL) with the measured values for a 14-day period in July 2014. In addition to the direct comparison of the hydrographs, the differences are also shown. This kind of comparison provides an impression of the principal simulation of the measured values by the models. Among other things, phase shifts in the water level hydrographs can be detected immediately.

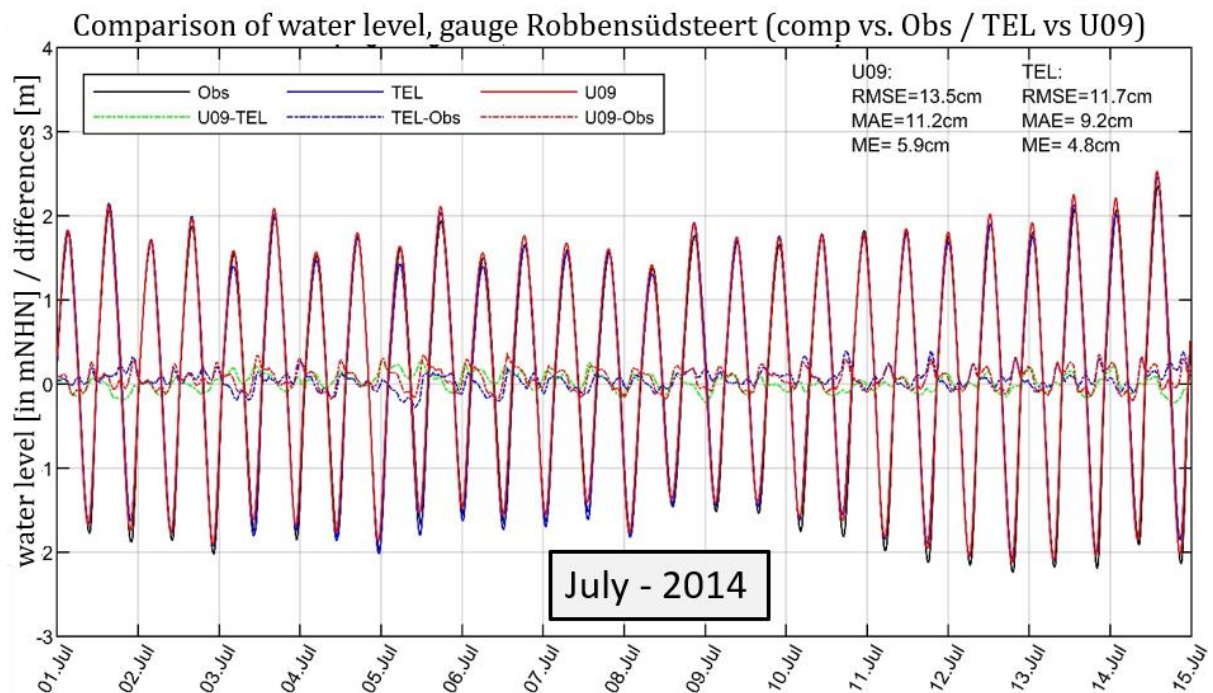


Figure 33: Comparison water level (UnTRIM vs. TELEMAC) -gauge Robbensüdstteert for a four-day period in July 2014 (exemplarily).

Due to the large number of measuring stations and the long period considered, a comprehensive direct comparison of hydrographs is not expedient in case of evaluation of the basic replication of the measured values in its entirety. Instead, the comparison of error rates delivers a summary and overview. Already in the previous chapters on validation these were applied and introduced as an important measure for classifying the model quality.

The errors are calculated using the same method on the basis of the presentation here to exclude methodological differences. The calculation has been carried out based on 10 minutes time steps for the complete year. The direct comparison for the year 2006 is to be seen in Figure 34 and Figure 35 shows it for the year 2014. The error rates ME, MAE and RMSE) are applied counter-clockwise all around along the coastline of the North Sea. The most left station shown corresponds to the southern bank of the English Channel (France), the station on the far right to the northern bank of the English Channel (Great Britain).

It turns out that both models deliver very similar results regarding the water levels. The calculated error rates are very small overall. Nevertheless, minor differences can be made out. The water levels simulated with UnTRIM are a few centimeters higher than the values generated with TELEMAC due to the course of the mean error (ME) shown on the figures below. For the year 2006,

the absolute and quadratic/square mean error rates of the TELEMAC results in the area of the North Frisian Islands between the Elbe estuary and List (Sylt) deviate a few centimeters more from the measured values than the UnTRIM results. At the same time the mean error for the TELEMAC results is slightly smaller. Spatially, this indicates a somewhat lower tidal range, or a slight phase shift compared to the measures in the TELEMAC model.

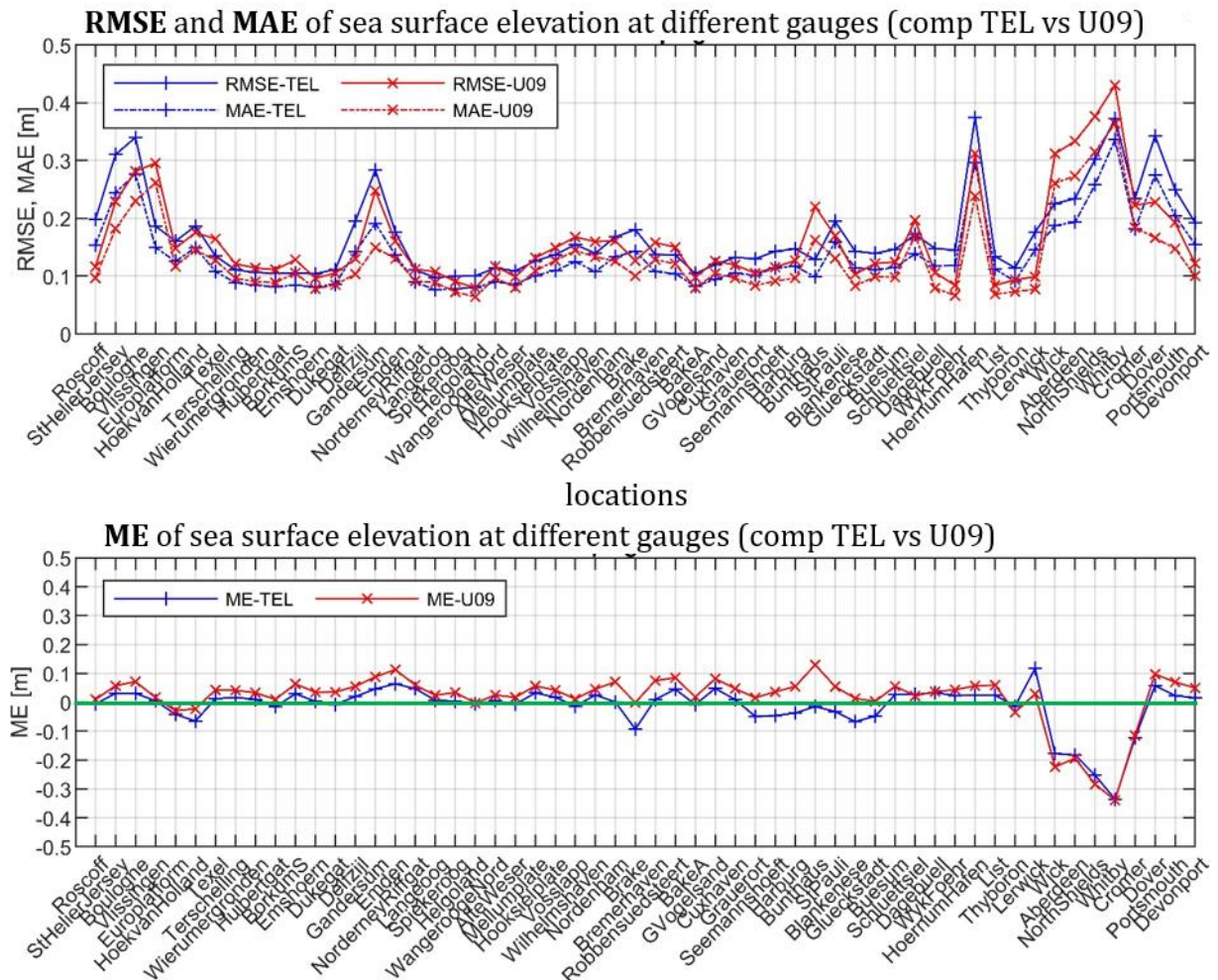


Figure 34: Comparison of error metrics for UnTRIM² and TELEMAC (2006- North Sea): RMSE / MAE (top) and ME (bottom) of the water level counterclockwise along the North Sea coast. From the comparison of the data for the year 2014, the aforementioned tendency for the water levels in the region of the Frisian Islands observed for 2006 cannot be identified in the sense of a systematic pattern. But it repeats by itself that the mean error rates (ME) of the UnTRIM² model are slightly above the mean error rates of the TELEMAC model in terms of value but not in terms of amount. This is a systematic deviation of the models from another which is also evident in other years. Therefore, the simulated water levels of the UnTRIM² model are always slightly above the TELEMAC results. The conclusion of a systematic under- or overestimation of the measured values by one or the other model, however, does not result from this observation.

Tidal characteristic values

Analyzes such as tidal characteristic values allow a deeper insight into the simulation results and can further specify the findings depicted above. In addition, the characteristic values are used to describe the characteristics of model results. The comparison of characteristic values provides two important findings/knowledges. On the one hand, comparisons are clear because many individual space-time-variable values from measurement resp. simulation can be combined into a few

parameters/characteristic values. On the other hand, aspects of the system behavior are compared in a condensed manner, and they can reveal a tendency deviation of simulation models versus measurement data.

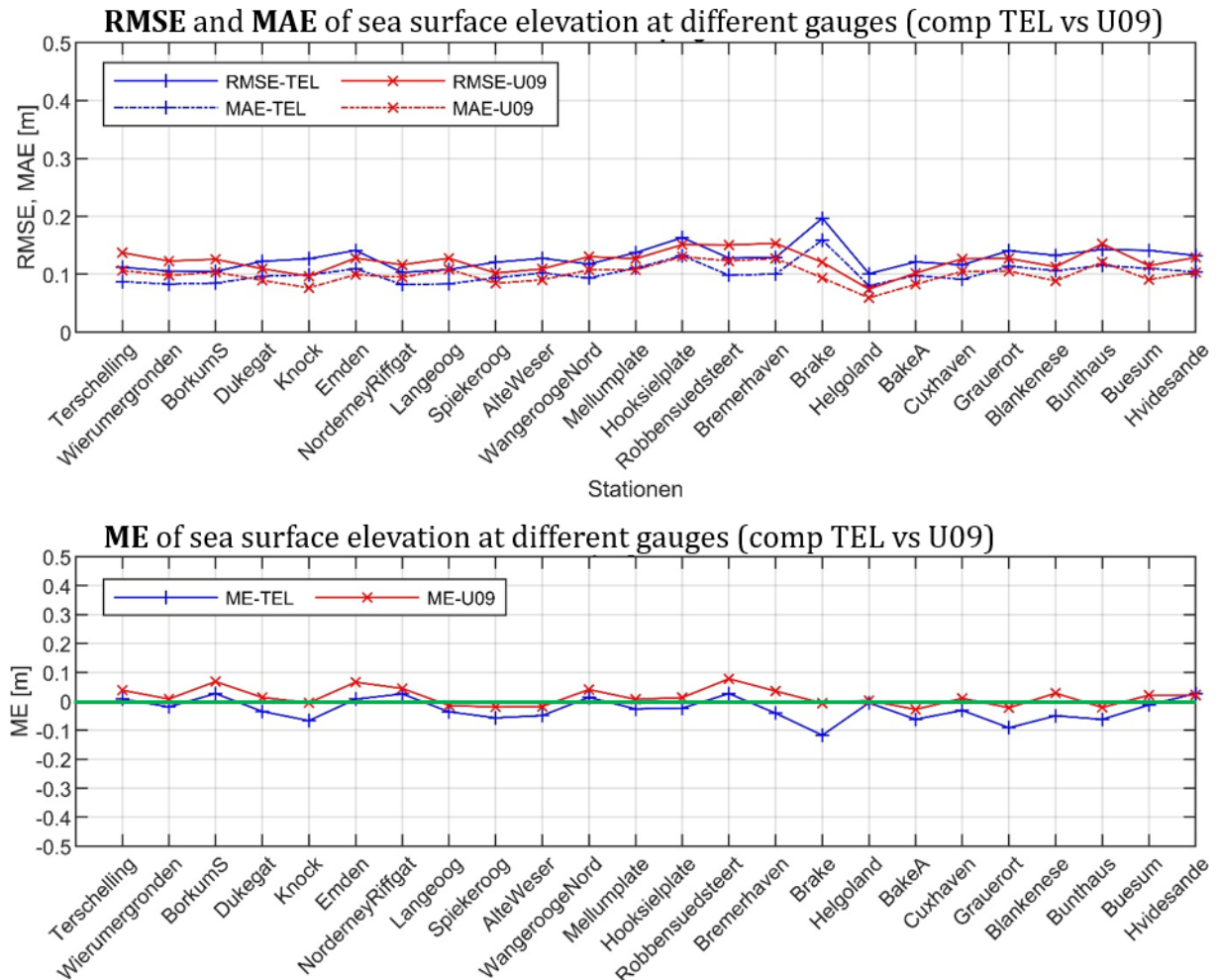


Figure 35: Comparison of error metrics for UnTRIM² and TELEMAC (2006- Wadden Sea): RMSE / MAE (top) and ME (bottom) of the water level counterclockwise along the Wadden Seacoast. The following figures give an example of an excerpt of the measurement positions. The graphics show mean tide high water level (MHW), mean tide level (MTL) and mean tide low water level (MLW) along the North Sea coast with a focus on the German Bight for the years 2006 and 2010. The mean values were calculated for all tides of the year. Both models used reflect the mean tide conditions very well. No significant deviation from the system of the simulation results versus measured values can be seen. In analogy to the general tendency from the previous section that the mean error of the UnTRIM² model will always be numerically (not in terms of amount) slightly above the mean error rates of the TELEMAC model, the tide characteristic values of the UnTRIM² model tend to be slightly higher than those of the TELEMAC model.

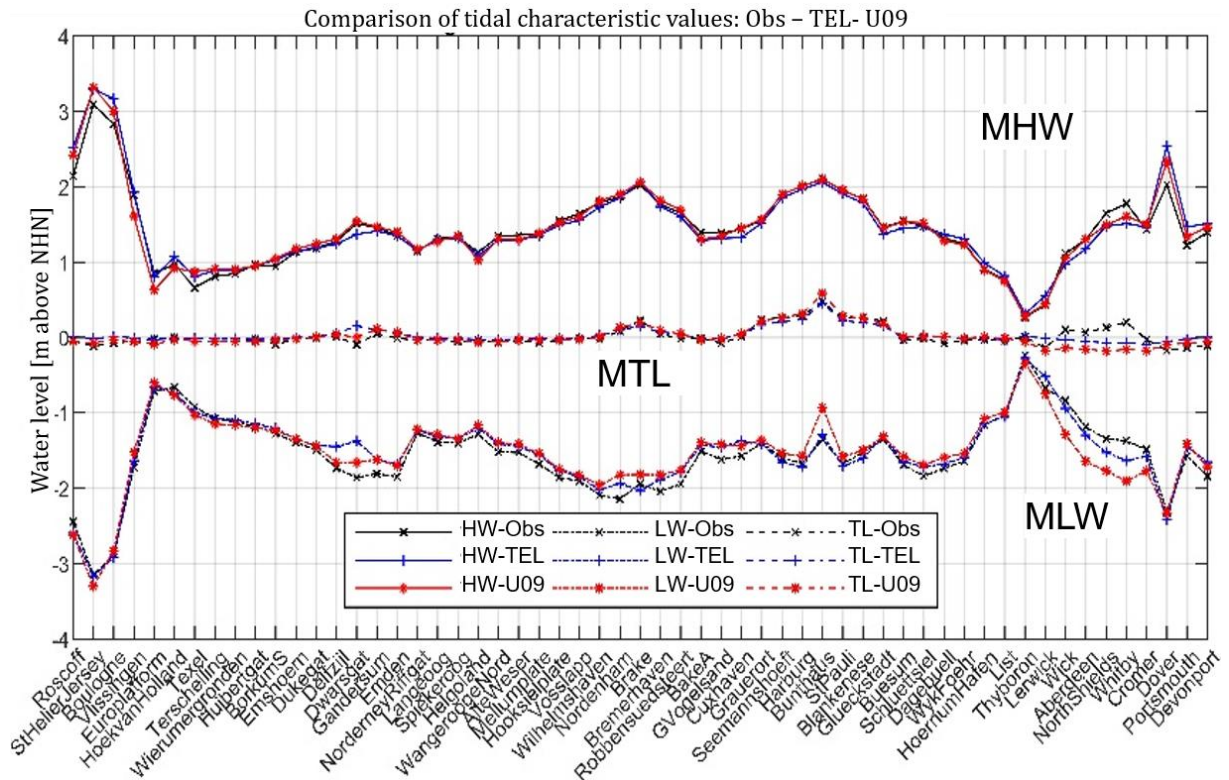


Figure 36: Comparison measurements with UnTRIM/TELEMAC (2006 - North Sea): mean tide high water level (MHW), mean tide level (MTL) and mean tide low water level (MLW) from measurements (Obs), UnTRIM (U09) and TELEMAC applied counter-clockwise.

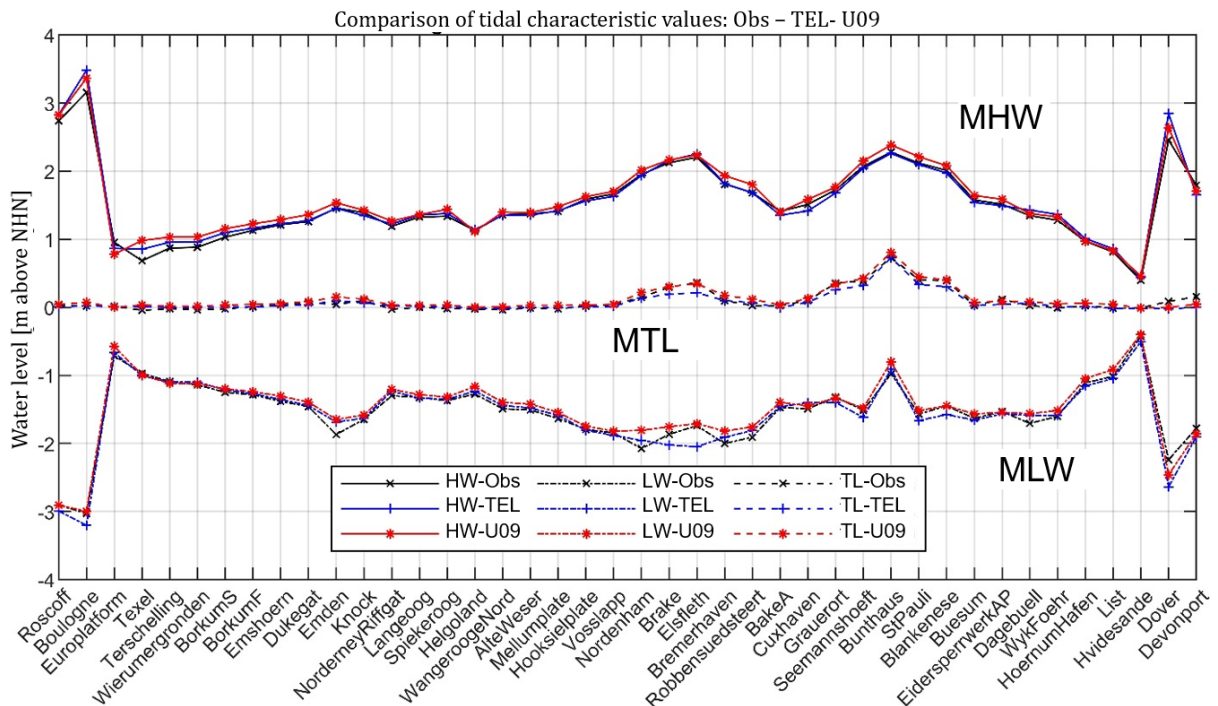


Figure 37: Comparison measurements UnTRIM/TELEMAC (2010 - North Sea): mean tide high water level (MHW), mean tide level (MTL) and mean tide low water level (MLW) from measurements (Obs), TELEMAC (TEL) and UnTRIM (U09) applied counter-clockwise.

6.4.1.2 Areal comparisons

Both simulations were calibrated separately by gauge measurements and documented as part of the model validation. To what extent the results of the different model systems apart from the gauge stations or measured points show comparable areal effects, should be documented here by the partial or characteristic value analyzes (compare Chapter 6.5.2).

Both simulation results were processed, documented and presented as differences with the identical software (BAW). As an example, Figure 38 shows the course of the M2 - partial tide based on TELEMAC and UnTRIM and the difference (TEL - UTR). The basic patterns of the M2 – amplitude conditions in the German Bight are reproduced by both model systems, especially the increase in the area of the inner German Bight between Jade-Weser and Elbe estuary. In this respect, only minor differences/disparities in the respective PT – analyzes are visible in the areal representation of the differences. This is a quality feature for the reproduction of the most important PT (MT) by both model systems!

Due to deformation of the tidal wave in the shallow water area, shallow water tides (Horn 1948), (Pugh 1987), (Pansch 1988), (Plüß; Plüß)); were generated with the most important component PT-M4. In combination with the M2-PT essential transformations of the tidal wave are generated or described (Friedrichs und Aubrey 1988). Even with this component with relatively low amplitudes, the differences in the results of the two HN-models are small (see Figure 39).

The differences between the analyzes of the water levels of the TELEMAC and UnTRIM simulations show only minor differences for the 50 %q-Thw / 50 %q Tnw (see Figure 40) and the tide mean water (Tmw)/ 50 %q-water level (see Figure 41).

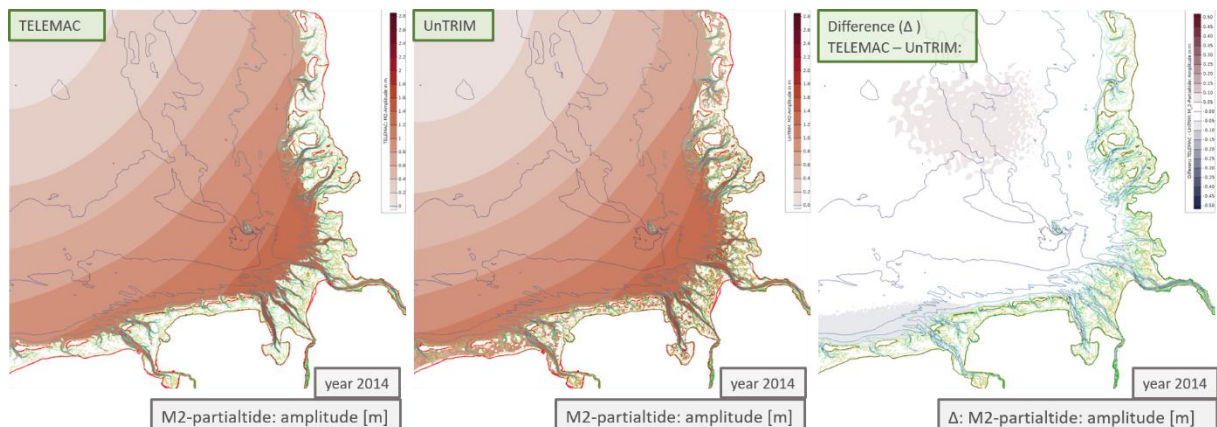


Figure 38: Comparison TELEMAC vs. UnTRIM: M2 partial tide (amplitude) year 2014.

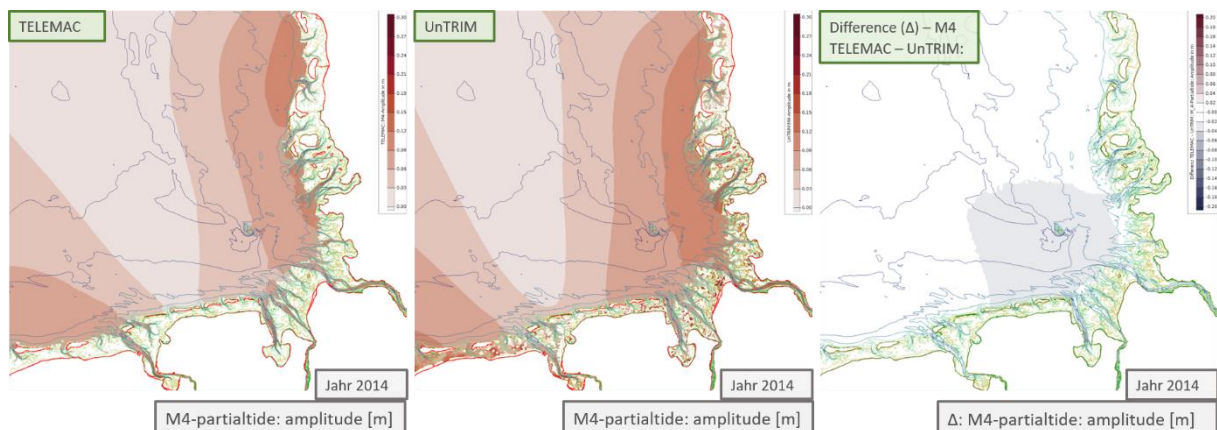


Figure 39: Comparison TELEMAC vs. UnTRIM: M4 partial tide (amplitude) year 2014.

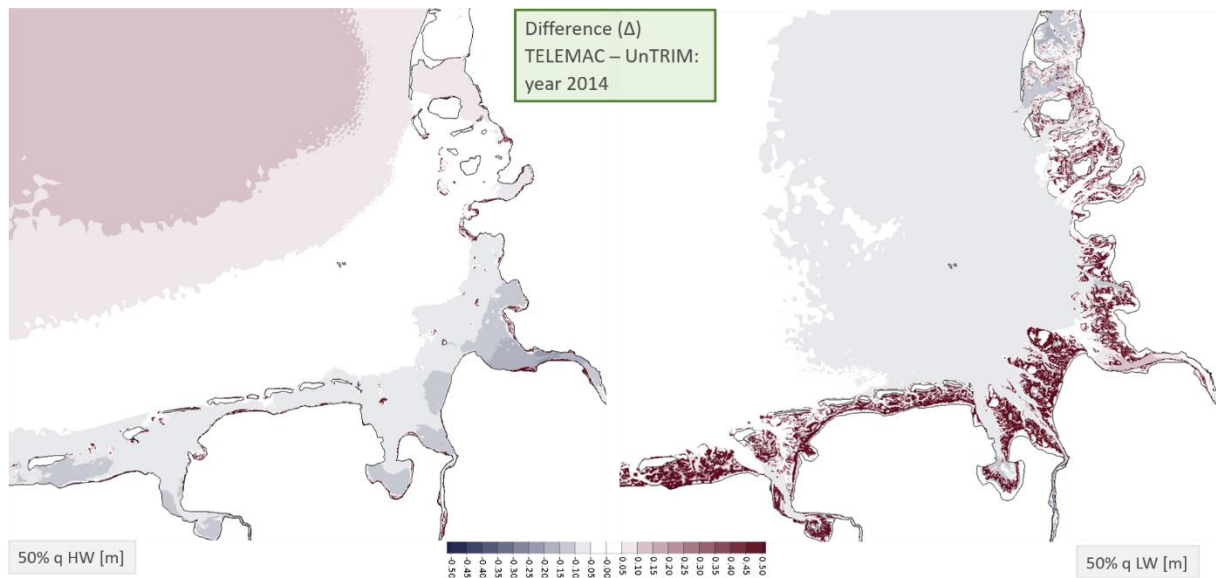


Figure 40: Comparison TELEMAC vs. UnTRIM: 50 %q-HWL/ 50 %q-LWL (m): year 2014, dark red = dry fallen areas (Wadden, outer sands, ...).

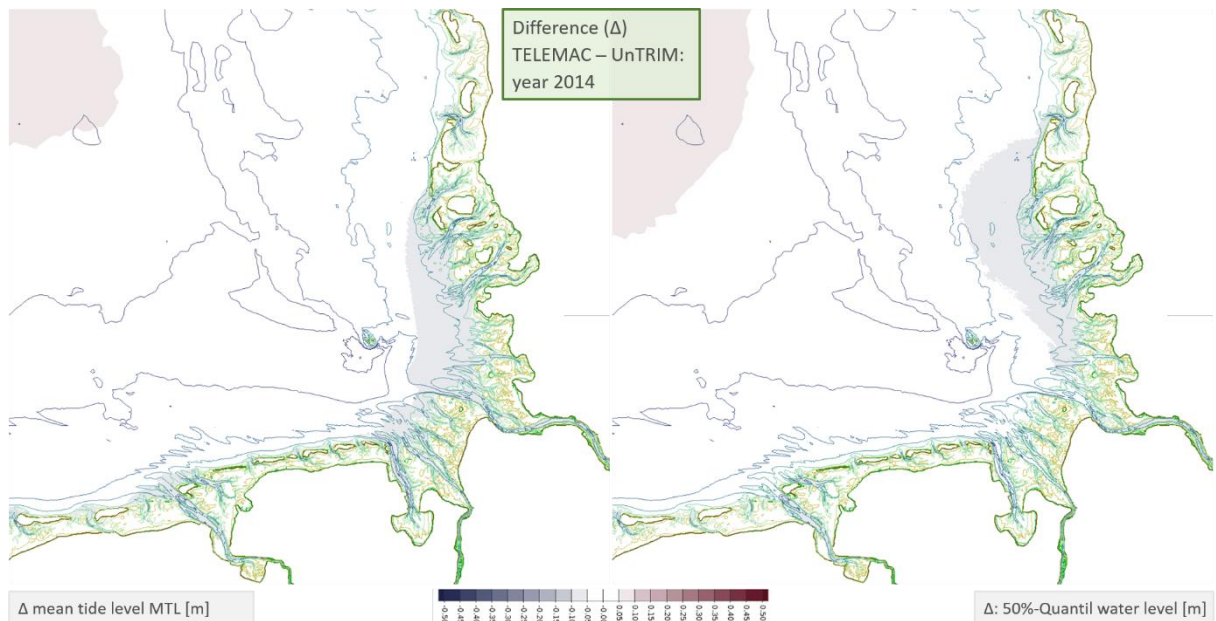


Figure 41: Comparison TELEMAC vs. UnTRIM: MTL/ 50 %q-Tnw (m): year 2014.

6.4.2 Wave model

As a part of the multi model approach, the three sea state models UnK (BAW), TOMAWAC and SWAN (both TUHH) were applied and used to assess the areal as well as the station-related results. The models UnK and TOMAWAC have been operated online coupled with the respective complementary hydrodynamic model (UnTRIM² or TELEMAC) for consideration of the local currents and water level. In contrast, the SWAN model was operated with a temporally and spatially constant mean water level (NHN + 0 m) without hydrodynamic impact.

For classification of the station-related simulation results of the three sea state models UnK, TOMAWAC and SWAN, direct comparisons of the significant wave height between the simulation results and the measured values of the year 2013 concerning the deep water and transition area are shown below.

In Figure 42 the measurement results are compared to the calculated significant wave heights of the three sea state models at an exemplary selected location in deep water (research platform

“FINO1”). One can see from the comparisons that the calculated significant wave height of the three models has different fluctuations compared to the measured values. The bandwidth of the calculated significant wave height is the lowest compared to the measurement values at this selected location in deep water for this period for the SWAN model. On the other hand, the direct comparison of the measured values and simulation results provides information about a possible systematic over- or underestimation of the measured values through the individual models. So, Figure 43 shows for example the systematic underestimation (ME) of the measured significant wave height (nearby the LKN measuring position “Westerland” (Sylt)) through the models UnK or TOMAWAC, especially for significant wave heights with $H_{m0} > 2$ m. For the SWAN model the underestimation of the measurement data is only very slightly.

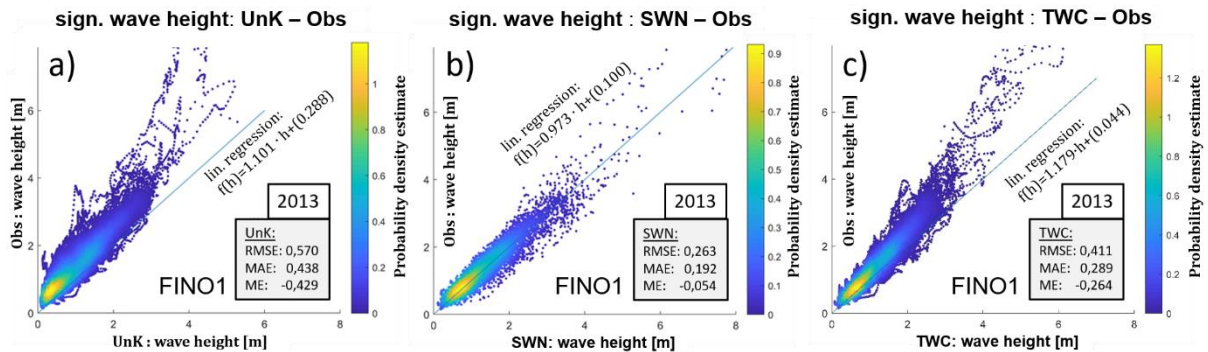


Figure 42: Comparisons of the sea state models UnK-SWAN-TOMAWAC (2013-FINO1), calculated (x) or measured significant wave height (y), in 2013 nearby “FINO1”, water depth ~29 m, for the models UnK (a), SWAN (b), and TOMAMWAC (c).

In the case of the aforementioned comparisons, however, the different temporal resolutions of the models have to be considered. So, the wave models UnK and TELEMAC produce six times more than the results of SWAN because of the calculation time step of 10 minutes compared to hourly simulation results of SWAN. However, not too much should change in the basic trend of deviations also considering the temporal resolutions.

A comparison of the calculated and measured significant wave height in transition area is shown in Figure 43. There is a better match for the sea state models with an online coupling of the current and the water level (UnK and TOMAWAC) between measurement and simulation results. The range of fluctuation (f. e. expressed by the RMSE) also decreases. The tendency to underestimate the measured significant wave height (f. e. expressed by the ME) is clearly lower in the transition area than in deep water conditions. However, there is a systematic underestimation of significant wave heights $H_{m0} > 2$ m in the aforementioned models which is probably due to the parameterization of the wave breaking behavior of individual waves.

In the transition area, however, the meaningfulness/validity of the results of the SWAN model is limited due to the constant water level in the simulations. It is therefore not compared to the other model results at this point.

Conclusions about the quality of the model results can be drawn based on these and other multi-model comparisons at measuring locations, e. g. for the calculated sea state spectra or further spectral parameters derived from the spectrum as the mean wave period (T_{m02}), energy period ($T_{m-1,0}$), the Peak period (T_p), the mean wave direction (Θ_m) and the directional spreading (Ψ). These findings can be used to interpret the quality of the areal resp. station-related results even in unobserved areas.

Further results of the multi-model comparisons with the sea state are documented in a separate scientific publication.

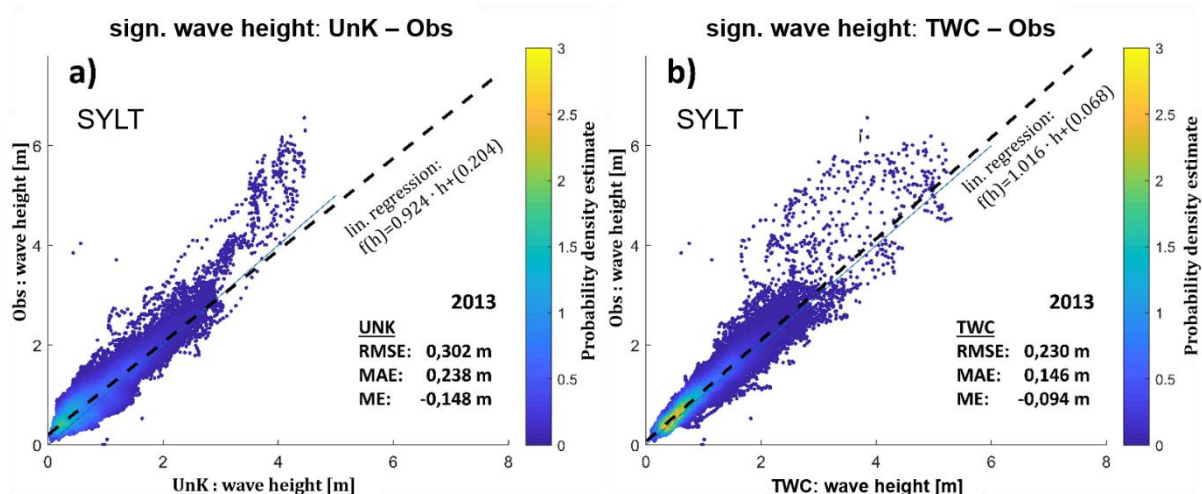


Figure 43: Comparisons of the sea state models UnK-TOMAWAC (2013-SYLT), calculated (x) or measured sign. wave height (y), in 2013 nearby the LKN measuring position “Westerland” (Sylt), water depth ~13 m (NHN), for the models a) UnK and b) TOMAWAC.

6.4.3 Summary of the multi-model approach

The station-related comparisons at the gauge positions show that both current models reproduce the absolute water levels and the tidal characteristics very well. No systematic deviation of the simulation results compared to the measured values can be recognized. The spatial comparison of simulated water levels indicates a very high reliability of the model results for the focus area of the project (inner German Bight). This can be seen in the small deviation of the model results from the measurements as well as in the small deviation of the models among each other. In the areas which are not in the focus of investigations as the inner estuaries, the results can only be used to a limited extent.

This and further multi-model comparisons significantly expand the possibilities to assess the quality of model results in unobserved areas. A high approximation quality of the models according to the nature can be assumed if the deviations between the model results are of the same order of magnitude like the deviations determined in the area of gauge positions. A correspondingly careful interpretation of the simulation results is necessary when the discrepancies between the model results compared to the determined deviations in the measurement positions become larger. Furthermore, the distance from the location approximated by the model to the closest measuring position must also be considered. These may already show tendencies in the deviations.

Where comparisons with measured data indicate similar systematic misjudgments by both models, the results are to be critically examined in the area.

6.5 HN modeling products

The results of the HN simulations are made available as synoptic simulation data and additionally in terms of yearly analyzes.

6.5.1 Synoptic HN simulation results

The synoptic data of the hydrodynamic model UnTRIM² were stored every 20 minutes on a raster of 1.000 X 1.000 m and are ready for download as netCDF files. The sea state results are also available as station-related product points on the model margin of the German Bight in “*.dat or *.txt” format. These files contain the complete spectra which can be used for modeling sea state (e. g. SWAN).

6.5.2 Analyses of the HN simulation results

Different analyzes are calculated and made available as products of the HN simulations. The **tide-independent** analyzes of the HN simulation results are referred to as long-term parameters (e.g., top search water level) which detect the synoptic parameters as frequency distribution, that means time or tide independent. The **tide-dependent** analyzes of the HN simulation results are named tidal characteristic values as for example tide high water (HW), tide low water (LW) and flood duration. The definitions are based on DIN 4049-3 (DIN 4049-3) and describe the tidal dynamics and its changes. All characteristic values are available as areal data for the entire German Bight and can be obtained as GeoTiff on a 100 m grid.

The areal analyzes carried out here (partial tide analyzes and calculation of the parameters) are described in detail in the document „Flächenhafte Analysen numerischer Simulationen aus EasyGSH-DB“ (in German only: https://mdi-de.baw.de/easygsh/Flaechenhafte_Analysen.pdf).

6.5.2.1 Partial tide analyzes of the tide

Tidal oscillations can be separated into harmonic oscillations, so called **partial tides**. These are characterized by a large planar dependency e. g. (Foreman et al. 2009) and (documentation at: https://wiki.baw.de/Harmonic_Analyses_Water_Level). Especially in the German Bight, noticeable deformations of the individual partial tides are to be observed due to the complex bathymetry (tidal channels, Wadden plates, outer sands, ...) and the influences of the estuaries.

A frequency analyzes is applied by the BAW program [NCANALYSE](#) to calculate the partial tides. The harmonic analyzes is well documented in (Doodson 1921, 1928; Pugh 1987; Godin 1986). The eight most important partial tides of the North Sea and especially for the German Bight are shown in Table 12.

The harmonic analyzes are carried out in EasyGSH-DB for a period of one single calendar year, each from 1996 (Jan. 1st 00:00 h) to 2015 (Dec. 31st 12:23:50 h). The spatial distribution of the amplitude of the M_2 -partial tide for the year 2014 is shown in Figure 44 as an exemplary product. It can also be found on the portal www.easygsh-db.org and in literature (Godin 1973).

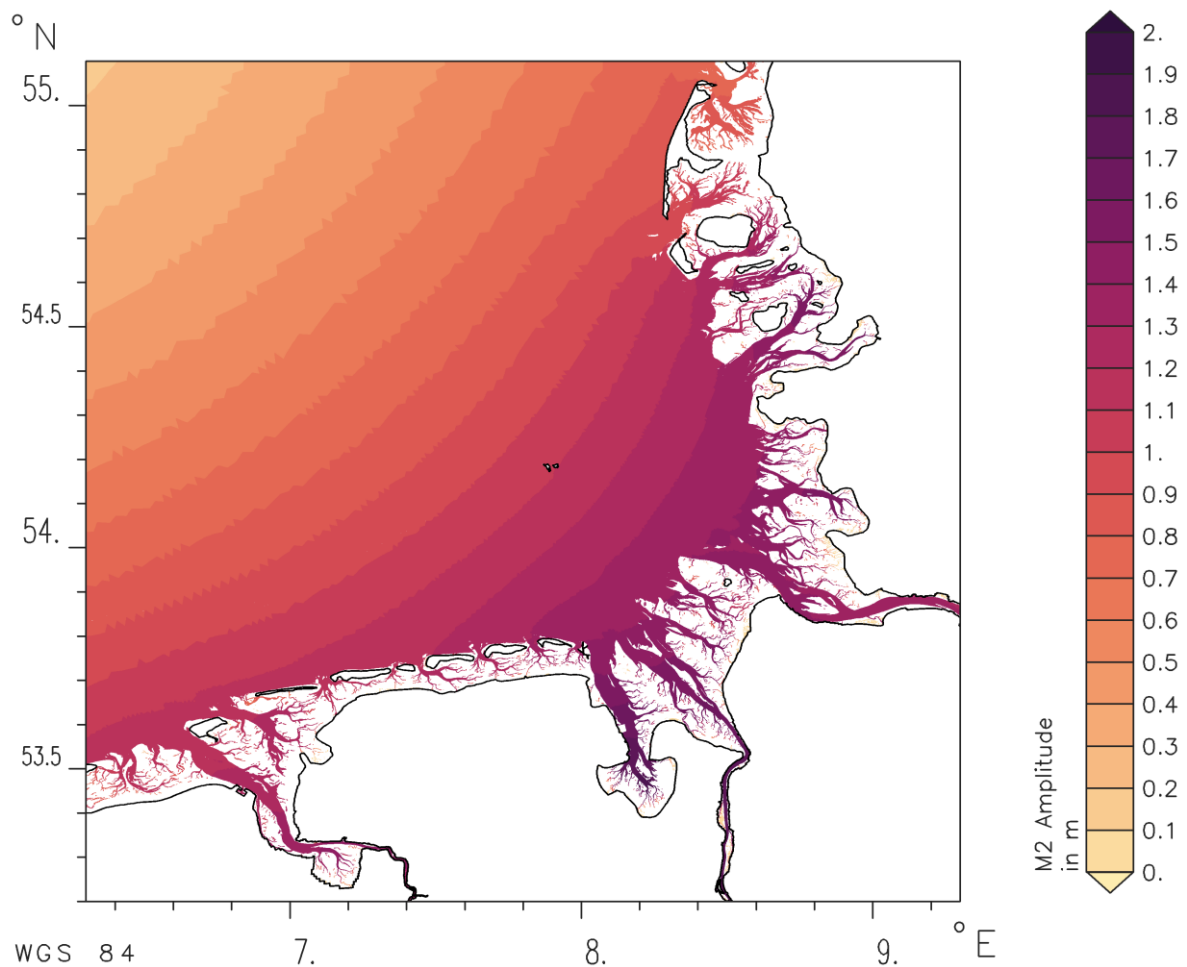


Figure 44: Distribution of the M2-partial tide for year 2014.

6.5.2.2 Tidal characteristic values

Tidal characteristic values are unambiguously described numbers for tide affected areas (DIN 4049-3 1994).

The calculation of the tidal characteristic values in EasyGSH-DB is carried out with the BAW program [NCANALYSE](#), which enables a spatial calculation of characteristic values for a study area. The [NCANALYSE](#) first determines all tides in the analyzes period. For the individual tides the tidal characteristic values are calculated and the annual mean, maximum and minimum values as well as the quantiles are calculated from the collective of all tides per year. A detailed description of the methodology can be found in the document „EasyGSH-DB: description of the analysis“ (<http://mdi-de.baw.de/easygsh/index.html#p4>).

Within the project EasyGSH-DB calculated and published are:

Tidal characteristic values of water level:

- 5 %, 50 % und 95 % quantile tidal range
- 5 %, 50 % und 95 % quantile tidal low water level
- 5 %, 50 % und 95 % quantile tidal high water level
- 50 % quantile of mean tidal water level
- Number of der tide high- and tide low water level
- Flooding duration

Tidal characteristic values of currents:

- 5 %, 50 % und 95 % quantile of maximum ebb velocity

- 5 %, 50 % und 95 % quantile of maximum flood velocity
- Mean ebb velocity
- Mean flood velocity
- x-coordinate of mean flood velocity
- y-coordinate of mean flood velocity
- x-coordinate of mean ebb velocity
- y-coordinate of mean ebb velocity
- Relation between mean flood and mean ebb velocity to the mean velocity per tide per tide

Tidal characteristic values of salinity:

- 5 %, 50 % und 95 % quantile of the mean salinity per tide

Tidal characteristic values of bottom shear stress:

- 50 % und 95 % quantile of max. effective bottom shear stress during flood
- 50 % und 95 % quantile of max. effective bottom shear stress during ebb
- x-coordinate mean. effective bottom shear stress during flood
- y- coordinate mean. effective bottom shear stress during flood
- x- coordinate mean. effective bottom shear stress during ebb
- y- coordinate mean. effective bottom shear stress during ebb

All tidal characteristic values are calculated for the extended German Bight (focus area); the high water (HW), low water (LW) and tidal range are additionally calculated for the AWZ.

The characteristic values for the flood inundation period and the number of high and low water events are an exception. These values are only calculated for the 12 nautical miles zone (coastal sea and coastline), because the study area is permanently flooded.

Figure 45 shows examples of the tidal characteristic values of water level, currents, salinity, and bottom shear stress for the year 2014. The flow velocity is significantly higher in the deeper gullies of the estuaries than in the other parts of the study area. When evaluating salinity, the entry of fresh water becomes clear due to the lower salinity in the river run-off from the estuaries into the German Bight. In the north-western areas, on the other hand, the salinity increases due to the influence of the North Sea. The tidal range rises towards the coast with decreasing water depths and increasing distance from the amphidromic point.

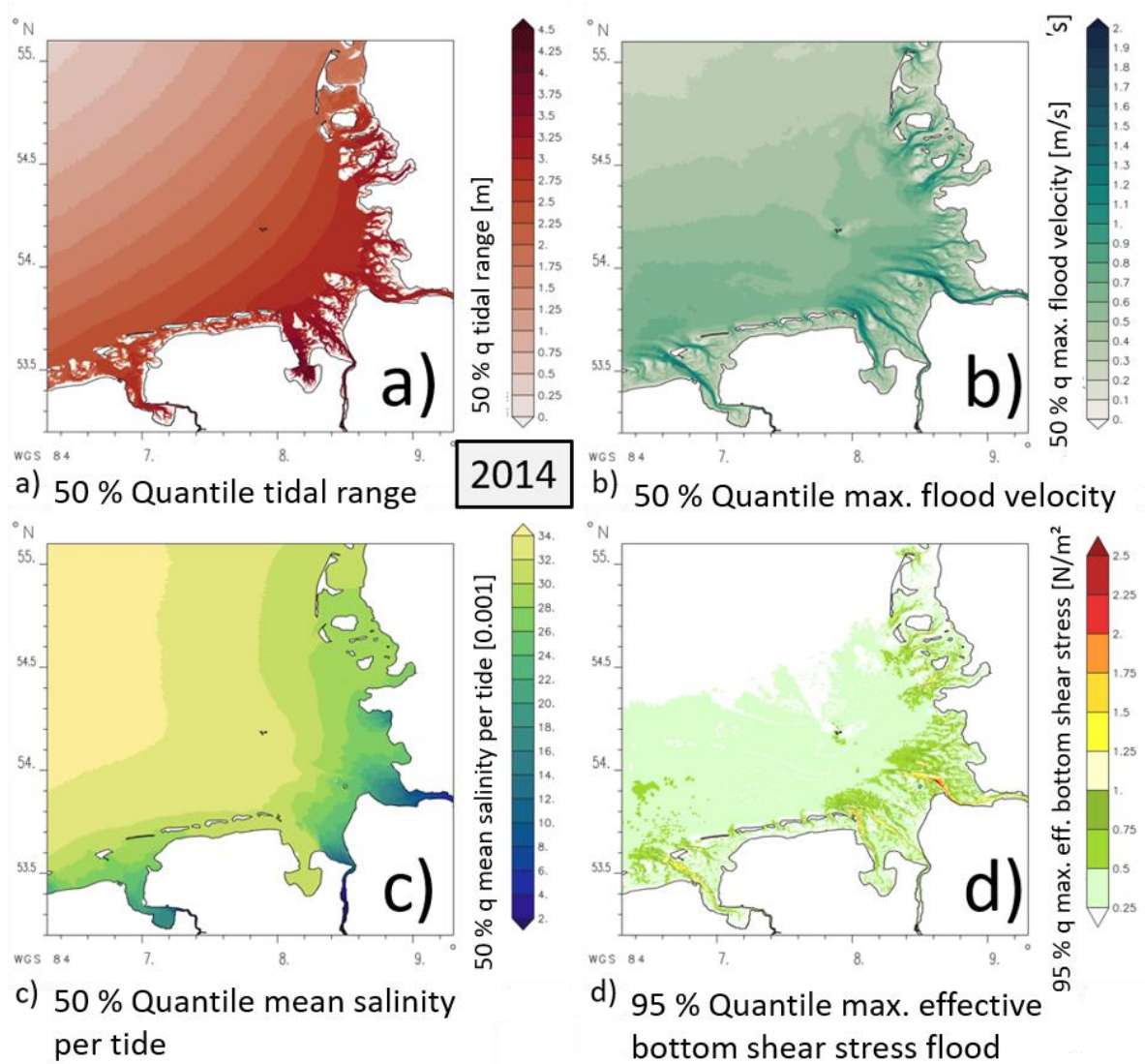


Figure 45: Tidal characteristic values in the German Bight (2014), a) water level, b) flow velocity, c) salinity and d) bottom shear stress.

The tidal characteristic values enable the comparison or evaluation between the different years in EasyGSH-DB. The tidal low water over 20 individual years, which is shown in Figure 46 for the years 1996, 2000, 2005, and 2010, is an example for this. All 20 years are visible online in the [animation](#). So, the tidal low water in 1996 is higher than in the following years. In 2010, the influence of the construction of the Jade-Weser-Port (JWP) can also be clearly seen in the outer Jade. The comparison between the different years shows the natural variability. Consequently, the tidal low water on average cannot be considered as a fixed time-independent value.

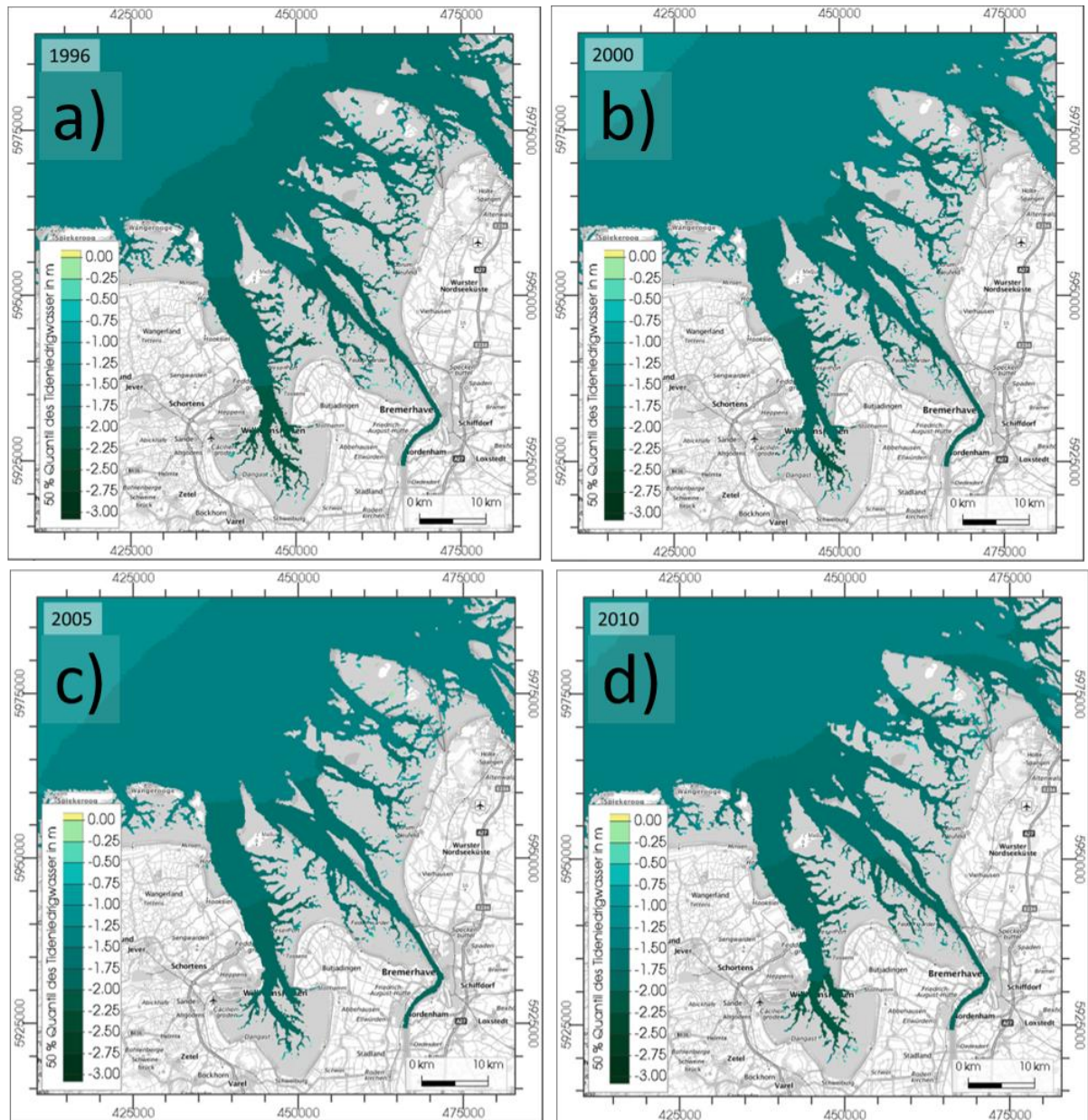


Figure 46: 50 % quantile of the tidal low water level for the years 1996, 2000, 2005, and 2010, a) 1996, b) 2000, c) 2005, and d) 2010 in the area of the Jade-Weser, available [here](#) as animation for 20 years.

6.5.2.3 Long-term characteristic value analyzes

The analyzes of the long-term characteristic values calculate **tide-independent** characteristic values over every 20 years in contrast to the **tide-dependent** tidal characteristic value analyzes (Chapter 6.5.2.2). Quantiles of the water level are computed from the long-term characteristic values. The quantiles are calculated for every 20 years from January 1st 00:00:00 to December 31st 23:50:00. The 1 % and 99 % quantiles are calculated with the long-term characteristic value analyzes.

Figure 47 shows the 99 % quantiles of the water level and salinity as a result of the long-term characteristic value analyzes.

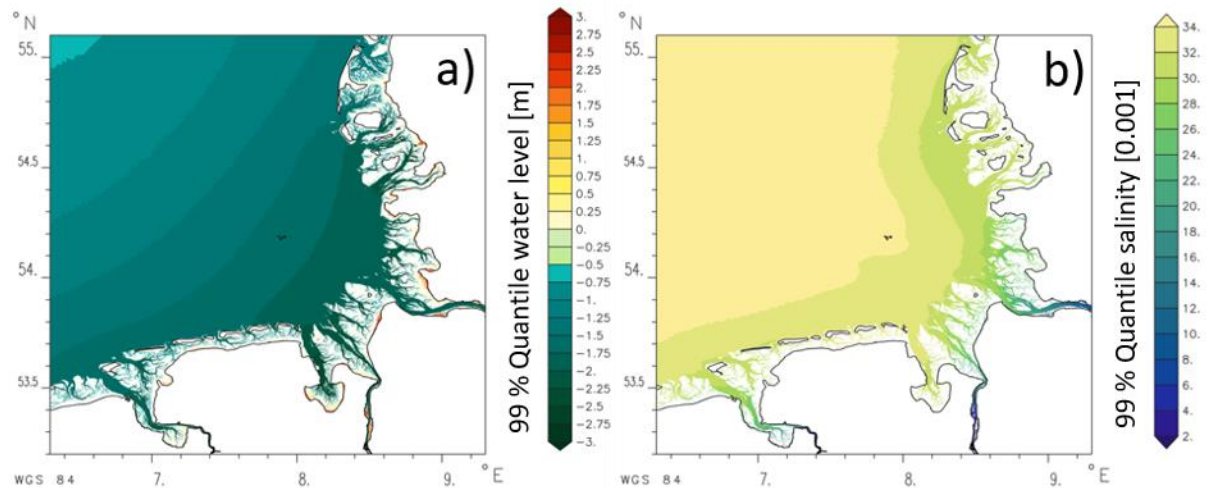


Figure 47: 99 % quantile of the long-term characteristic values: a) water level, b) salinity.

6.6 Products from wave modeling

Because of the simulation results of the sea state model SWAN, station and spatial-related yearly sea state products for different applications were generated in the deep-water area (see Chapter 6.3.2). In the following, the most important station-related (Chapter 6.6.1) as well as areal sea state products (Chapter 6.6.2) are presented. All directions refer to the nautical convention (North 0° or 360°).

6.6.1 Station-related products

The station-related products were derived for a group of points which are located at the boundary of the product area/German Bight (product points “DB-boundary”, see yellow points in Figure 48) and for a further group of points which are close to the 20 m depth isoline near the transition area shallow to deep water (product points “COAST”, see red points in Figure 48).

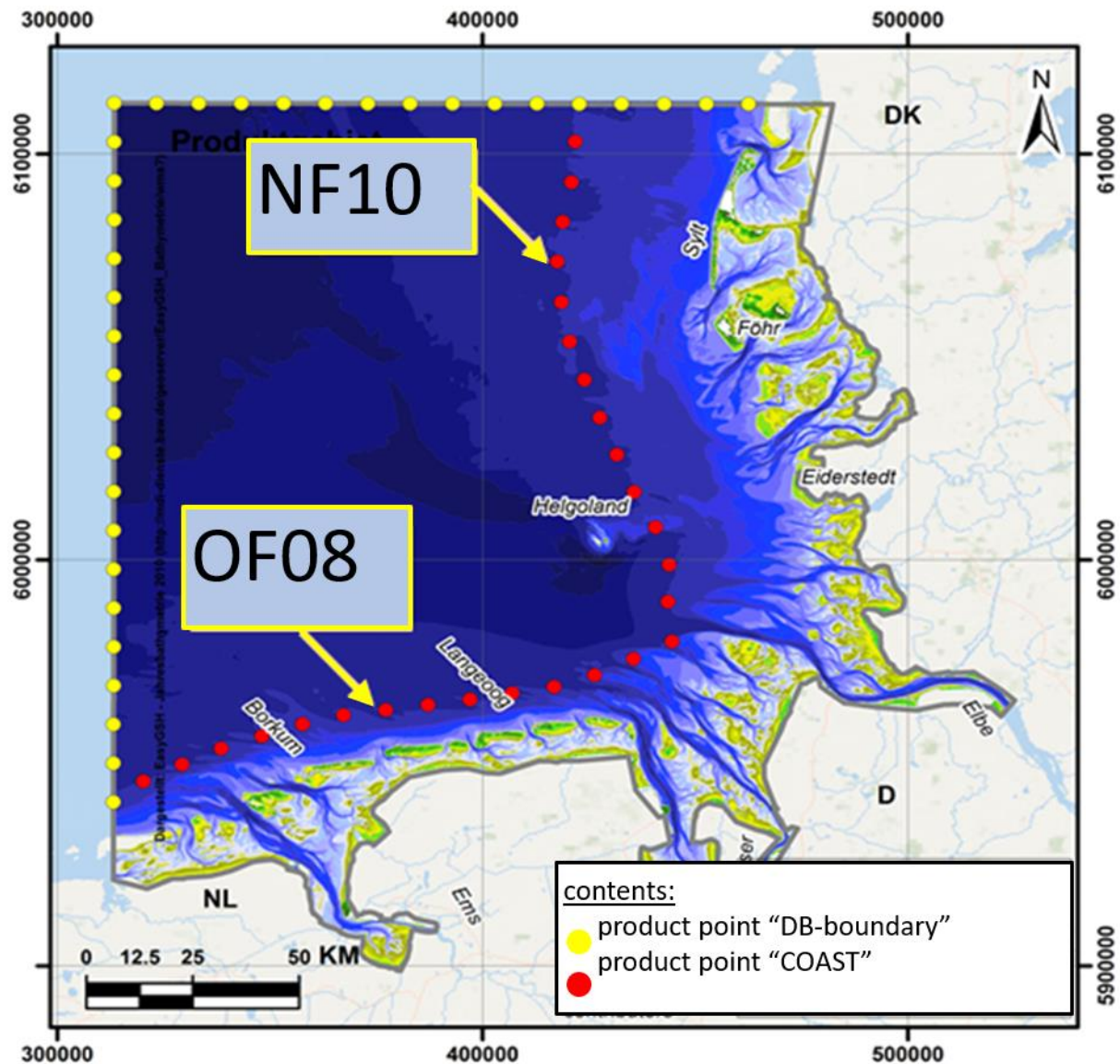


Figure 48: Station-related wave products at the boundary of the product area (yellow) and near the 20 m depth line (red) as well as selected product points as examples along the East or North Frisian coast („OF08“ or „NF10“).

6.6.1.1 Product points “DB-boundary”

The products derived from the results at the product points “DB-boundary” (e. g., wave spectra and spectral sea state parameters) are provided as boundary values for the operation of detail models for the German Bight. The products can be viewed and downloaded in the EasyGSH-DB data portal in the field of “synoptic hydrodynamic”.

Figure 49 shows an example for a sea state spectrum calculated by SWAN nearby the North Sea measurement station “FINO1” in a water depth of about 29 m (height reference NHN) for a selected time period during the storm „Xaver“ (2013-12-05 22UTC). The spectral sea state parameters derived from the sea state spectrum by SWAN are:

$H_{m0} = 7.8\text{m}$, $T_p = 13.1\text{s}$, $\theta_m = 318^\circ$ and $\theta_p = 316^\circ$.

Furthermore, the following values are available for the 34 product points “DB-boundary”: significant wave height (H_{m0}), mean wave period (T_{m02}), energy period ($T_{m-1,0}$), peak period (T_p), mean wave direction (θ_m) as well as the directional spreading of the directions according to the mean directions (Ψ_m).

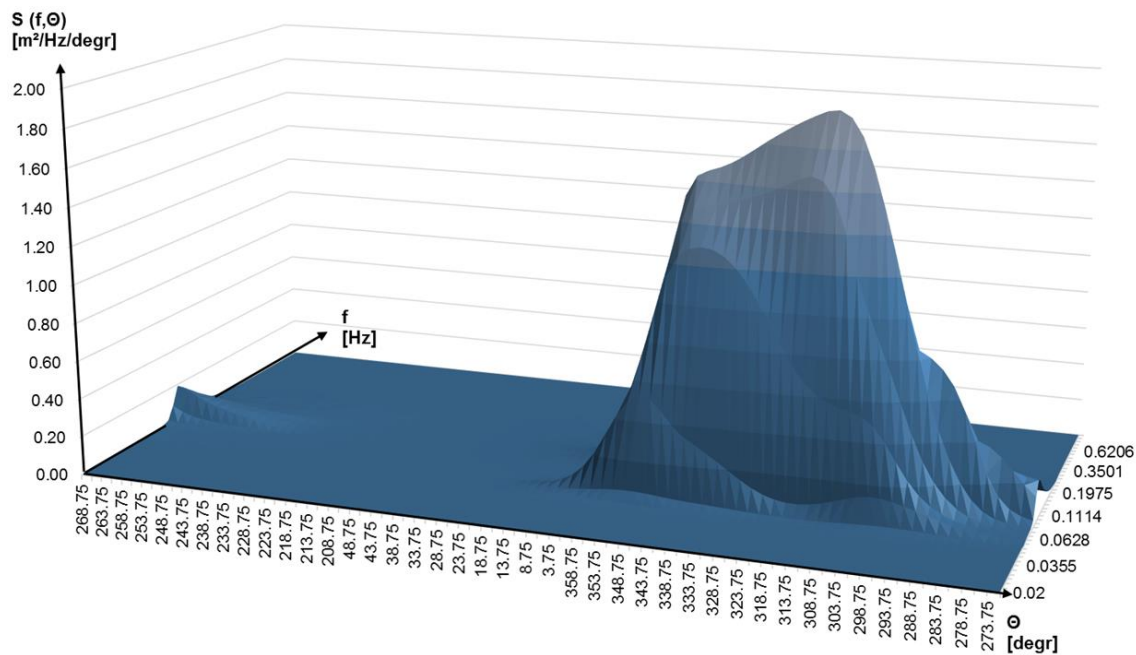


Figure 49: SWAN-wave spectra nearby the measuring device „FIN01“ during the storm „XAV-VER“ (2013-12-05 22UTC).

6.6.1.2 Product points “COAST”

The products derived from the results on the product points “COAST” (e. g. two-dimensional frequency distribution of the significant wave height, the mean wave direction and the indication of further spectral parameters and the yearly maximum of the significant wave height) are provided against the background of possible applications in coastal protection (e. g. statistical analyzes). The products can be viewed and downloaded in the EasyGSH-DB in the fields “Hydrodynamic” / year / Characteristic Numbers for Wave and Sea State - independent or tides (WAVS)” (for example 1996: https://mdi-de.baw.de/easygsh/EasyEN_DownloadH.html#1996).

Figure 50 and Figure 51 show exemplary frequency distributions at selected product points on the East and North Frisian coast for the year 2013 (for location of the product points, see Figure 48).

The maximum significant wave height in the year 2013 occurred at both points during the storm event “Xaver”. The frequency distributions also provide information about the spatial variation of the sea state conditions. For example, larger significant wave heights occur at the selected point North Frisian coast („NF10“) for wave directions from northwest to southwest and at the selected point on the East Frisian coast („OF08“) primarily from northwest.

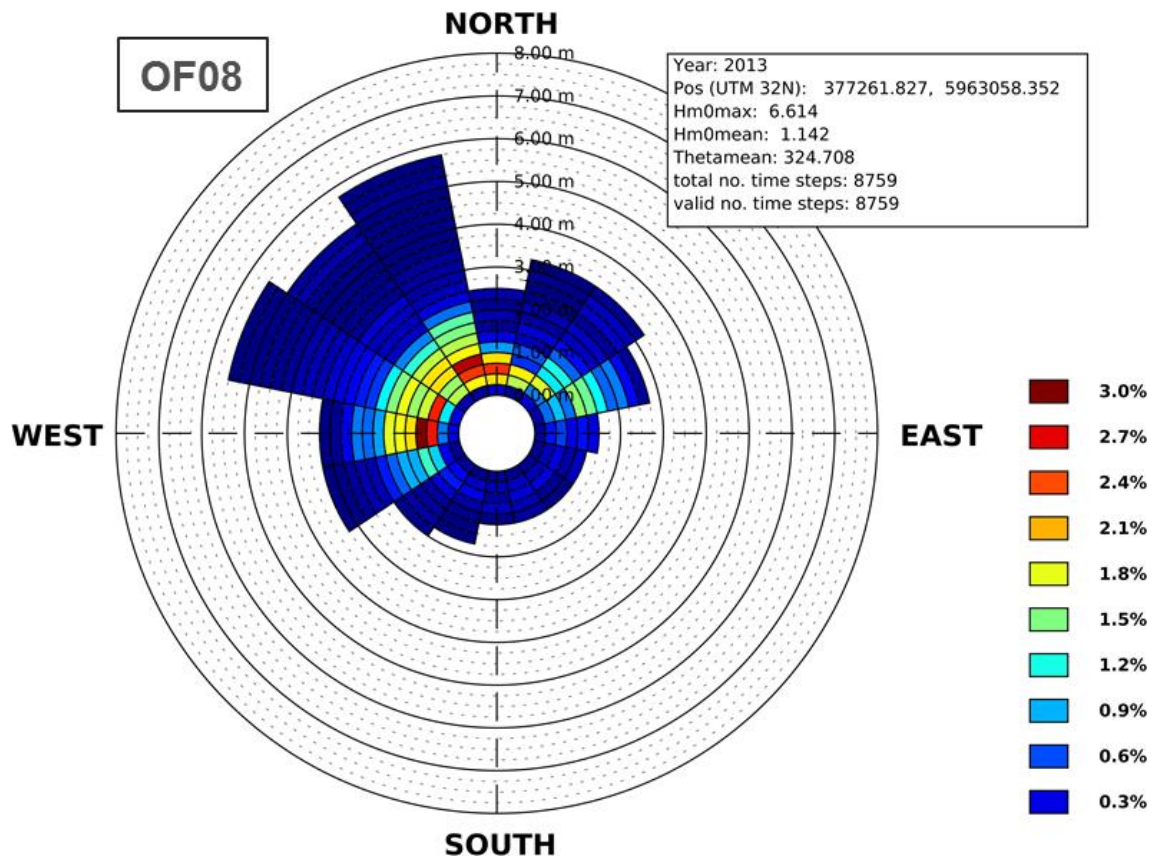


Figure 50: Frequency distributions 2013, East Frisian coast („OF08“): sign. wave height (H_{m0}) and mean wave direction (Θ_m).

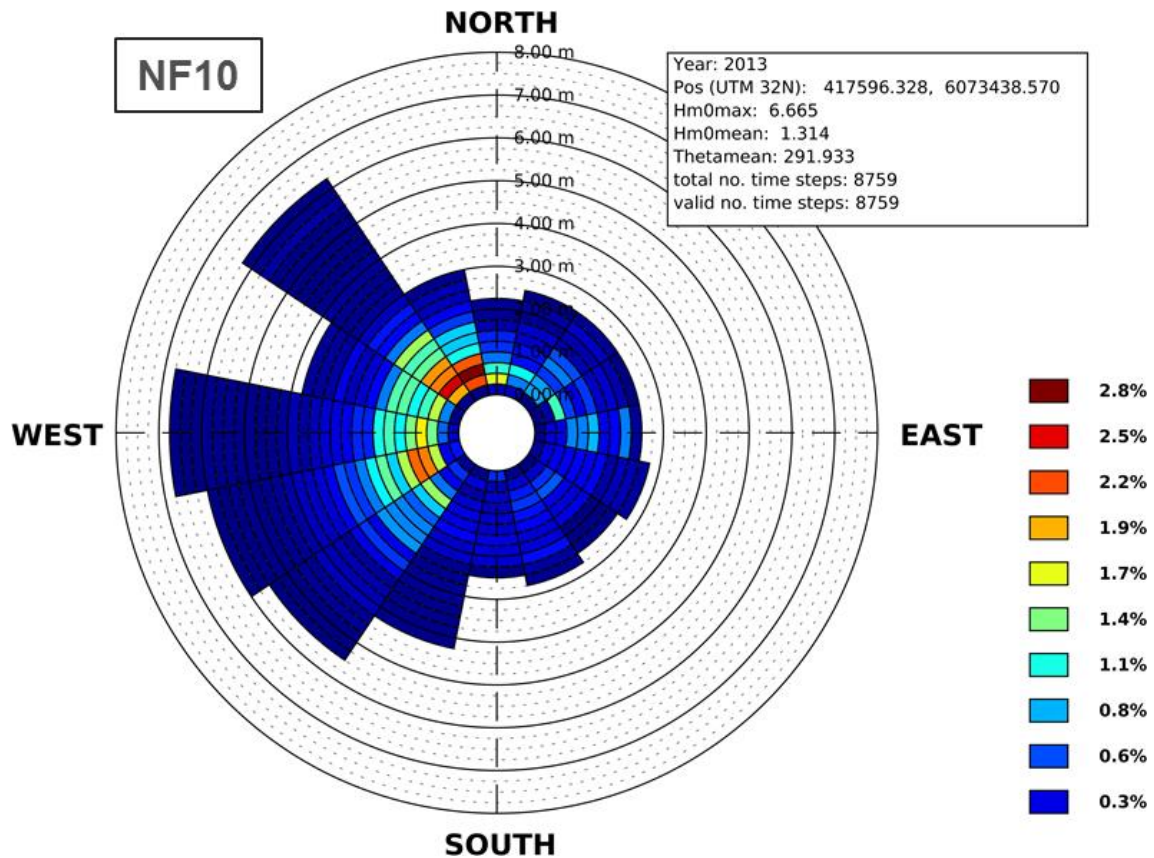


Figure 51: Frequency distributions 2013, North Frisian coast („NF10“): significant wave height (H_{m0}) and mean wave direction (Θ_m).

6.6.2 Areal products

For the region of the German Bight (gray bordered area in Figure 48) areal sea state products (so-called analyzes, e.g. in terms of annual averages and percentiles) are available which are based on the simulation results of the SWAN model. Selective information (product points “DB-Rand”, see Chapter 6.6.1.1) is also provided for points along the boundary of the German Bight). The results have also been made available for possible applications in coastal defense (e.g. statistical analyzes).

Figure 52 shows an example for the analyzes of the simulation data for the year 2013 in terms of a combined frequency distribution of significant wave height and mean wave direction for one grid point near the location “FINO1”. Furthermore, it shows the mean value and the maximum of the significant wave height (and the time of its occurrence) as well as the average value of the mean wave direction. The maximum significant wave height appeared also at the selected point from northwest during the storm event “Xaver”.

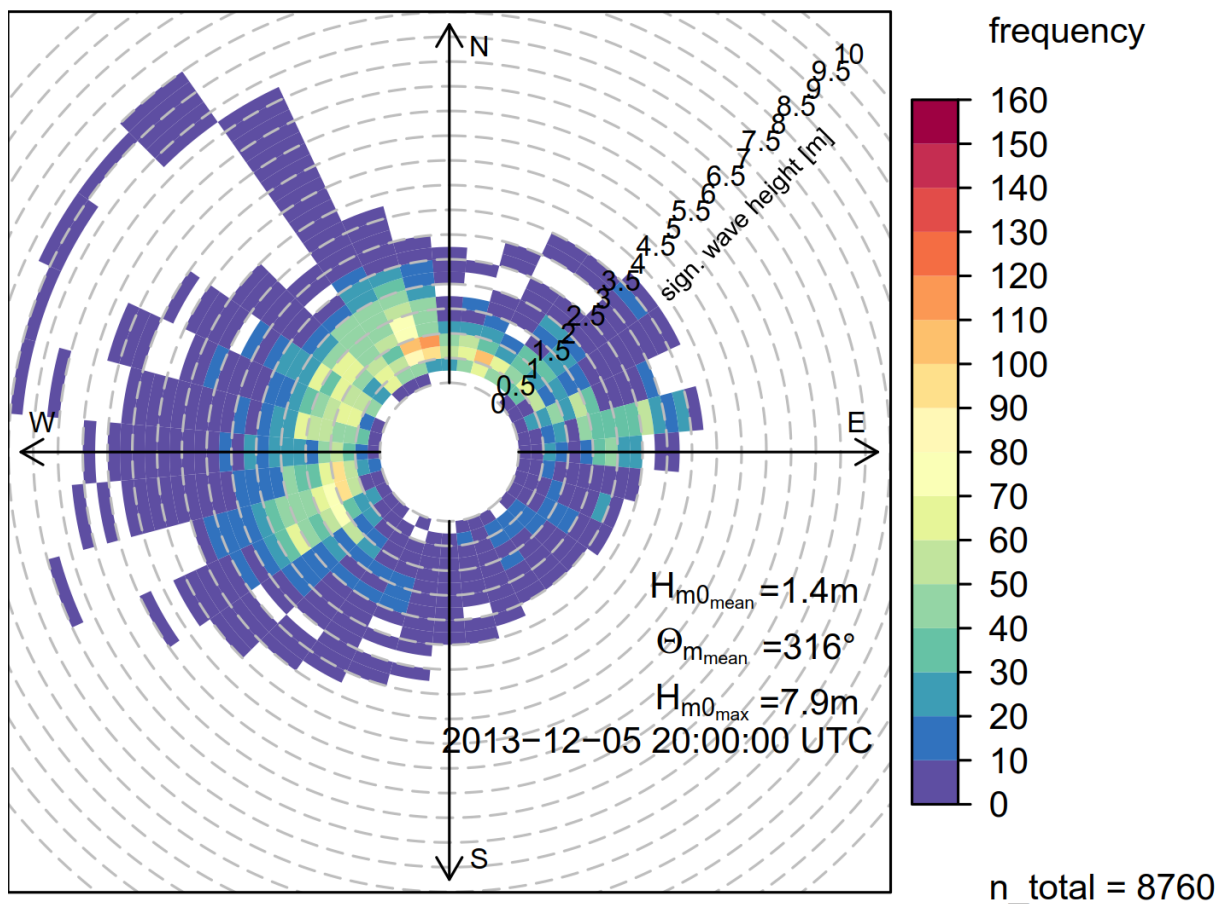


Figure 52: Combined frequency distribution nearby “FINO1” (SWAN-2013): significant wave height and mean wave direction.

Yearly characteristic values resp. products were generated and documented from the areal simulation results in the product region by means of statistical methods in the report: https://mdi-de.baw.de/easygsh/EasyEN_index.html#publication.

The generated yearly products (surface representations) can be viewed and downloaded in the EasyGSH data portal in the field of “Hydrodynamic” / year / Characteristic Numbers for Wave and Sea State - independent or tides (WAVS)”.

All data are provided in a georeferenced TIFF-raster data format (GeoTiff) and can be visualized and further processed in various applications (e.g. ArcGIS). For partly automated evaluation and conversion of the areal unstructured SWAN result files into the GeoTiff raster data format as part

of post processing, an interface based on various program routines (e. g. MATLAB, CDO etc.) was developed and used to generate the products.

Figure 53 shows the calculated annual mean values of the significant wave height, Peak period, sea state energy and energy weighted mean wave direction as an example for the year 1996.

Another example of the evaluation of the mean values of the significant wave height in selected years (1996, 2000, 2010 and 2015) can be seen in Figure 54. Based on the comparison of the annual mean values shown, the yearly variability of the significant wave height in the German Bight can be seen. In combination with other representations, as for example the energy weighted mean wave direction in Figure 53, conclusions can be drawn about the annual energy input on the coast.

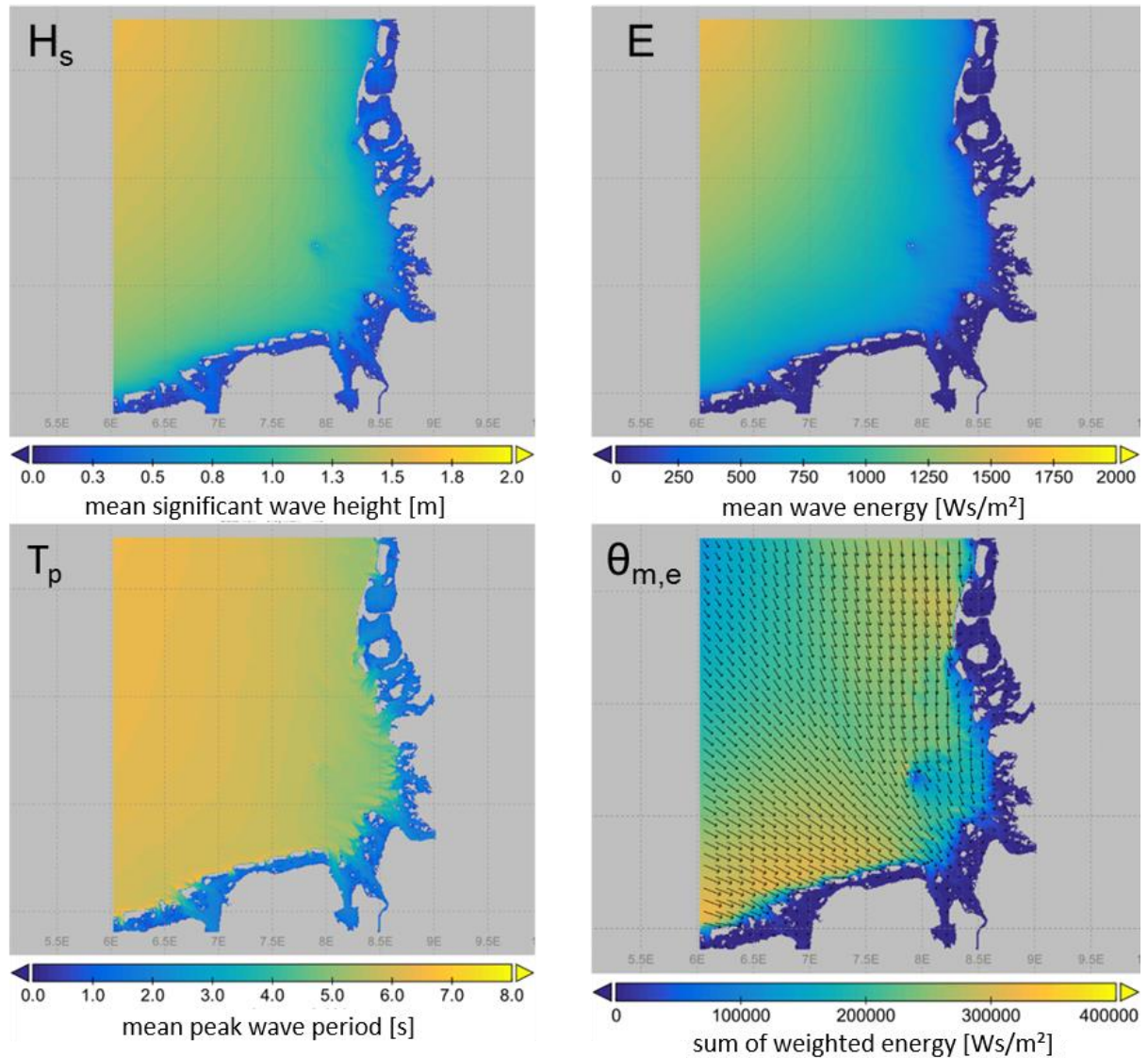


Figure 53: Mean value of the sea state parameters – 1996, region of the German Bight: significant wave height ($H_s=H_{m0}$), mean sea state energy (E), peak period (T_p) and mean energy weighted wave direction (black arrows, $\theta_{m,e}$).

For the evaluation of statistical parameters (e. g. higher percentiles), regions with a significant influence of the sea state parameters by local water levels or currents have been grayed out in the areal representations of the SWAN results in the GeoTiff-format. Figure 55 shows this for the calculated 99 % percentile of the significant wave height for the year 1996.

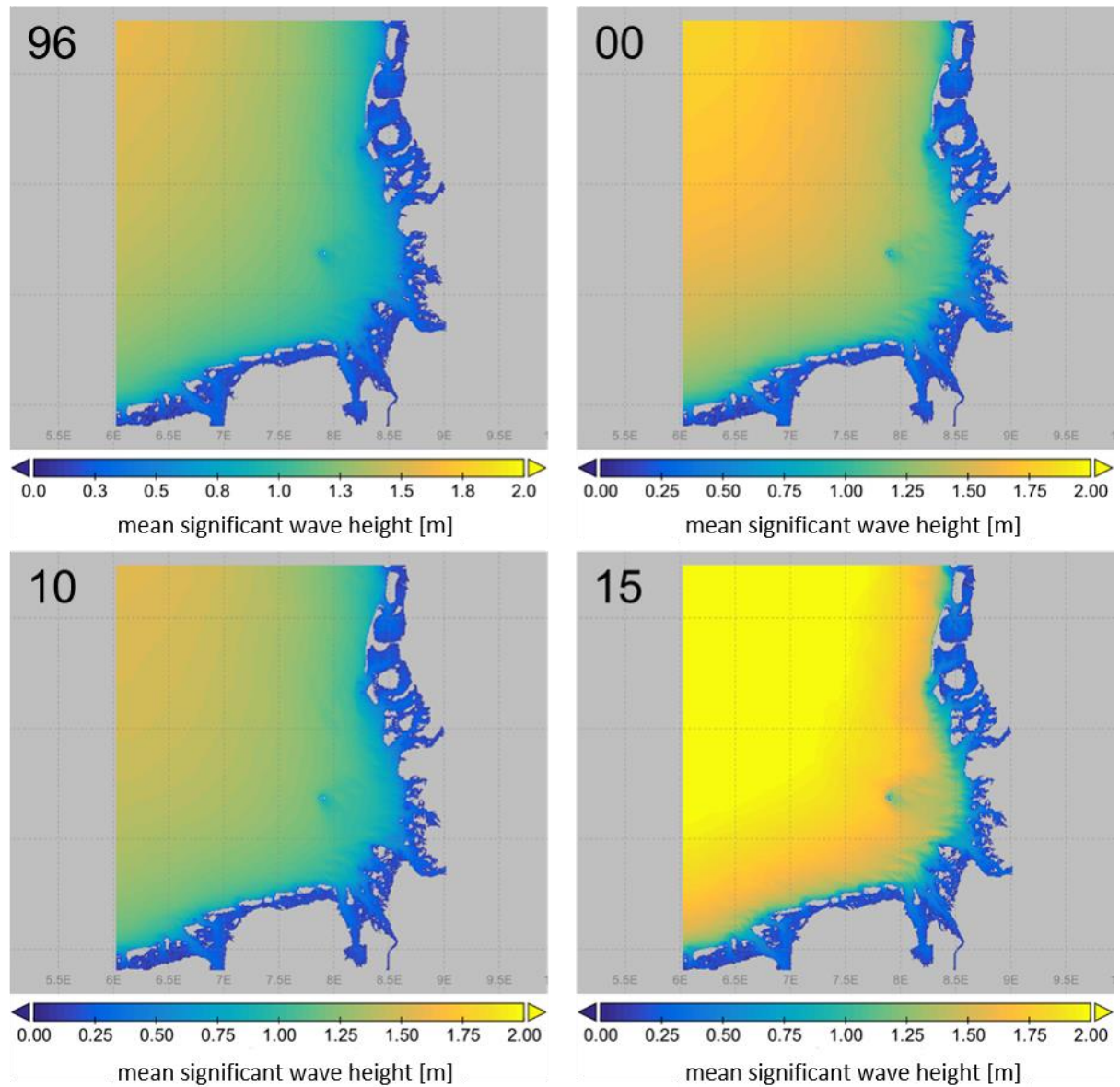


Figure 54: mean values of sign. wave height (H_s) – 1996, 2000, 2010 and 2015: German Bight area.

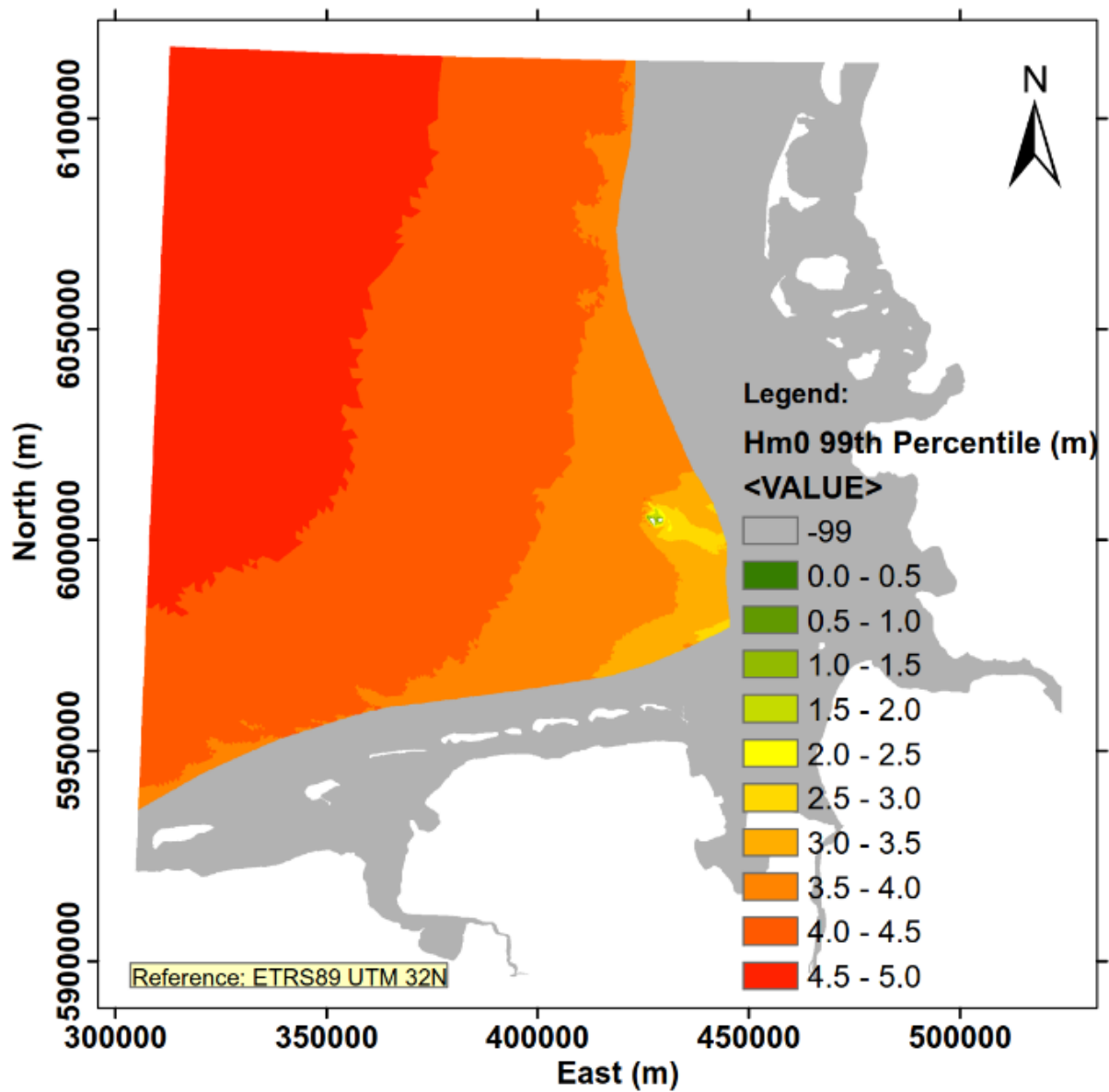


Figure 55: 99 % percentile of the significant wave height (H_s), 1996 in the German Bight.

7 Participatory product development

7.1 Objective and goal

Objective

The requirements for data provisioning have increased due to the Environmental Information Act (Umweltinformationsgesetz = UIG), where in §3 is stated that “every person (...) in accordance with this law, has the right to free access to environmental information, (...), without having to demonstrate a legal interest. Numerous authorities must make the existing data available to the public or interested citizens upon request. The ways in which the existing data are provided can be different. One possibility would be complete transparency another would be the reasonable selection of the public accessibility of certain data. Other existing data sets could then be released based on specific requests. Due to the legal framework changed by the Environmental Information Act federal authorities (amongst others the BAW) are obliged to make the existing coastal related data available to the general public.

In addition, to providing these data sets, the in EasyGSH-DB generated reference data set can serve as a basis for special tasks from other authorities, for example for those within the framework of European guidelines (Water Framework Directive, Marine Strategy Framework Directive).

These new requirements give rise to questions such as “**how**” an adequate availability can occur, or “**which**” data should or can be made available. A supply of raw data⁶ is not possible or not expedient in many cases. For example, data holder and data generators do not necessarily have to match so that raw data cannot be passed on. Furthermore, the processing of the raw data is usually only possible with an appropriate expertise. So, an unfiltered availability does not seem expedient.

The coordinated product creation process within EasyGSH-DB differentiates between various data classes. Raw and measurement data to simulation results and analyzes are processed further through possibility checks and validation (Figure 1 in Chapter 3.1). These final products are freely accessible, and the work steps of their generation are documented comprehensively (see Chapter 9.2). A publication of raw and measurement data is not possible because Easy GSH-DB is often / mostly not the originator of these data sets.

While answering the questions “**how** and **which**” mainly concerns the (data) supply side, the question for “**what**” arises from the demand side. What do potential users need to answer questions related to coastal problems or to carry out legally prescribed tasks? In addition to the legal obligation, to make data available to the public, further questions occur:

- How can a sufficiently quality-assured reference data set be provided which may accessed publicly? (See Chapter 9.2.2)
- How can suitable data products look on the basis of the quality-assured reference data set, so that a wide variety of users will have access to them?
- What requirements do potential users from coastal area have on existing data sets and products?
- Which deficits exist from the point of view of the potential users with the previously available possibilities to obtain or use data?

Answering these questions with the aim of developing user relevant products through participatory product development builds the main focus of the subproject (TP) “Dialog” (Figure 56).

⁶ Definition see Chapter 0

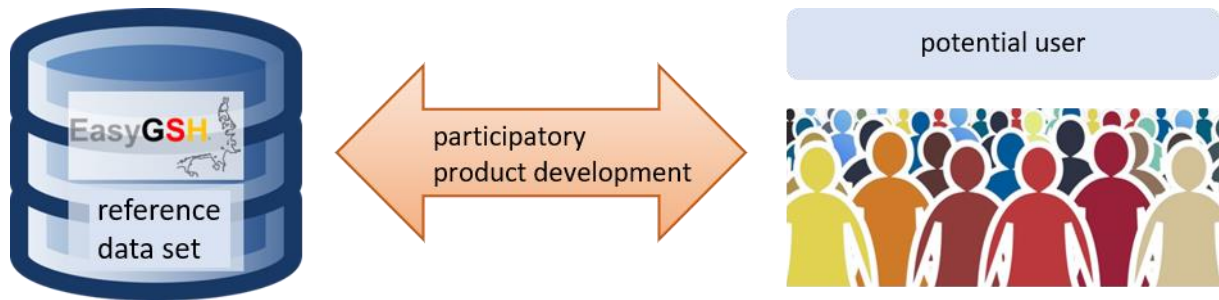


Figure 56: Participatory product development between reference data set and potential users.

Goals

The goals of this part of the project are derived from the questions mentioned above:

- Who are the potential users of coastal related data?
- What requirements do the different users place on existing data records?
- Which deficits do the potential users see with the previous data offered and which products would users like to have access to?

The answers are given in the following sections. In addition, a procedure was developed and applied as part of the participative product development which supports the joint creation of prototypical products. This includes the direct exchange between the requirements of potential users and the partners of the EasyGSH-DB project. For this, tailor-made products (“EasyGSH-DB Products”, explanation in Chapter 0) were compiled for the specific questions and tasks in close cooperation with the potential users. This made opportunities, challenges and limits of the 20 year hind cast reference data set for geomorphology, sedimentology and hydrodynamic provided by EasyGSH-DB clear.

7.2 Approach (Methodology)

The procedure for participation processes outlined in (Ahlhorn 2018) forms the basic framework for integrating potential users and joint development of prototypical products. At the beginning there is the classic stakeholder analysis with the help of which suitable actors from the coastal region, but also beyond that, can be identified. Stakeholder addressing all persons, institutions or organizations that could have an interest in the data provided by EasyGSH-DB. All operating persons in connection with coast-related topics or data requirements are seen as actors. The set of stakeholders comprises the sum of all actors, but the latter is smaller. The potential users are recruited from both the number of stakeholder and the actors.

For the stakeholder analysis, the partners involved in the EasyGSH-DB project were first asked about relevant institutions and organizations with data requirements in the coastal area. Internet research for other possible stakeholders completed the list that was created in this way.

Based on the experience of the consortium, of participating partners from the federal administration (BAW, BSH) from the research (TUHH) and the free economy (smile consult, Küste und Raum), it was advisable to carry out a first rough subdivision into Administration (federal, state and communal level) and free economy (see Table 7 for Economy, Administration and Research).

After sorting the institutions and organizations, suitable stakeholders for closer involvement in the EasyGSH-DB project were selected. This was made because of the participation and experience on numerous coastal-related projects of the involved project partners. Through the intensive support of various legal proceedings in the coastal area, there is a good networking arisen.

Generally, three forms of the involvement of potential users to be contacted (= selected stakeholder) have been differentiated: informing, consulting and collaborating. Due to the designed participation ladder for the degrees of involvement of stakeholders in participation or

administrative processes (Arnstein 1969) the approach followed here is based on the considerations of the EU Water Framework Directive (EC, 2000). The level of involvement is increasing from Informing towards Collaborating (see Figure 57).

All stakeholders identified were informed on the status of the project whereby the currently valid data protection regulation (**Datenschutzgrundverordnung: DSGVO**) of the European Union was to be observed. The channels available for this are, for example, the project's own website (www.easygsh-db.org), or the continuous provision of project information in internet-based networks (e. g. <https://www.researchgate.net>).

At certain intervals, newsletters on specific topics were sent out by the project (https://mdi-de.baw.de/easygsh/EasyEN_publication). Overview texts for the project were published in the relevant print media as in Schiff & Hafen (Ahlhorn et al. 2019) and in publications organs of the der attending institutions (e. g. BAW aktuell <https://www.baw.de/en/bawaktuell.html>), in order to arouse the interest of various stakeholders.

At the same time, research was carried out continuously on potential interested parties using the internet, which indicated possible applications of the data sets created in this project (e. g. proposal conferences from the companies TenneT and Amprion according to sea cable routes (Seekabeltrassen 2030) for connecting Off-Shore-Energy windfarms to the mainland.

The other alternatives for integrating stakeholders in the project work are more labor-intensive but of essential importance for the success of the project, so that they are presented separately in the following sections. The participative product development of the EasyGSH-DB project can only succeed together with cooperating potential data users.

7.2.1 Consulting: structured interviews

Consulting means that direct discussions took place with selected stakeholders (structured interviews). The aim of these conversations was on the one hand to investigate the need of data and also the task in the respective institution for which these data are required. On the other hand, deficits named by the interviewees were queried for data availability and provision (deployment and formats) as well as data quality (Figure 58).

The long list of stakeholders mentioned above was analyzed and reduced to the possibility to contact persons or institutions directly. This shows that a straight contact followed by subsequent interviews with approx. 30 persons seems feasible. That means that coordination and travel expenses were kept within manageable limits. It was aimed at an adequate coverage of the above-mentioned categories authorities, research and free economy mentioned above should be aimed for. In addition to the selection made by the project consortium, the willingness of the stakeholders to be interviewed was a decisive criterion. It was the approach of the EasyGSH-DB project to identify voluntary stakeholders who want to work on the development of prototypical products at the end of the consultation phase.

The needs assessment took place based on the questionnaire designed for the structured interview. Various questions about the subject area, the status-quo of the used data, requirements for existing or to be designed data products, deficits and independent product ideas were asked in this.

At the end of this project phase the consultation will be provisionally closed. However, in the case that a not yet contacted stakeholder could be more involved, the knowledge gained in the initial discussion could flow into the project (e.g., presentation of the EasyGSH-DB model at „Seekabeltrassen 2030“).

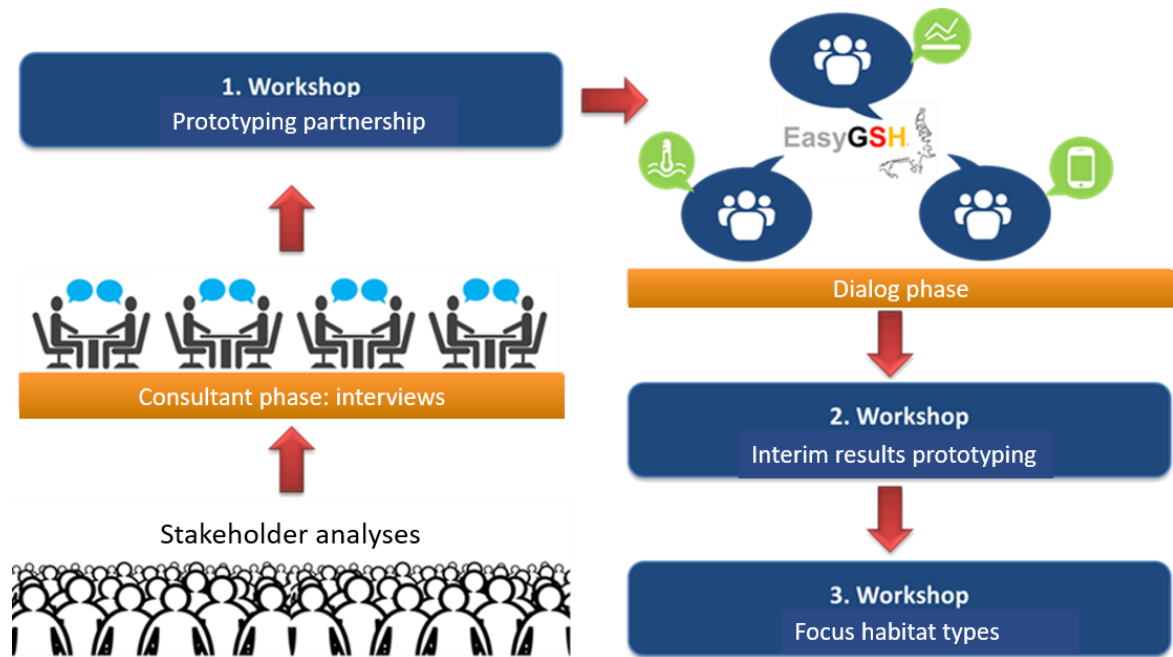


Figure 57: Overview of the work phases and sections for “participatory product development”.

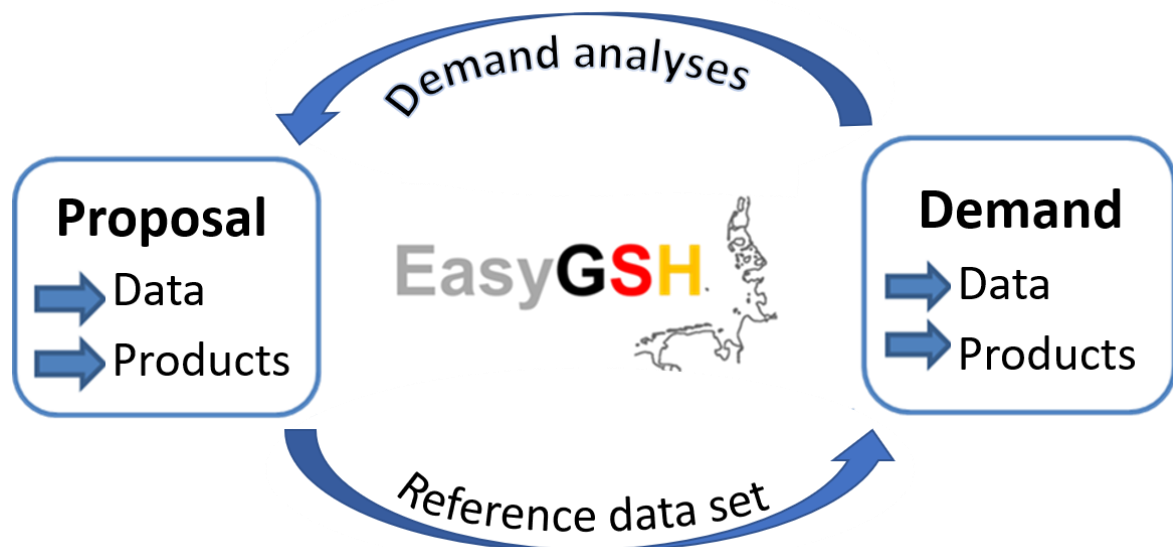


Figure 58: Work content of the TP “Participatory product development”.

7.2.2 Collaborating: Participatory prototyping

The goal of this work phase and of the entire project was to motivate potential users to participate in the development of user-oriented products. At the end of the dialogue phase (see Figure 57), prototypical products should have been developed which are considered as needs-based solutions of selected tasks of respective stakeholders.

Discussions with interested stakeholders carried out during the consultation phase showed which participant would like to be more closely involved in the project. A series of workshops was initiated to create a comprehensive mutual exchange and the establishment of working groups on specific topics and questions (see Figure 57). In this way, potential “cooperating” stakeholders are integrated into the project.

	teamwork result card				
Theme:	hydrodynamic				
Processor EasyGSH-DB partner:		supporter (single person):			
interested participant:					
product ideas:					
please choose priority					
data structure:	raw data measurements	basic simulation results	plausibilised simulation results	raster	maps / animation

Figure 59: Template for documentation of the need of participants at the first workshop
(Subject area hydrodynamics), which serves as preliminary work for initiation of topic-specific prototyping partnerships.

The results and findings from the first workshop and the interviews carried out were presented to all participants. There was another possibility here to make any additions on the part of the participants. Furthermore, the EasyGSH-DB project partners presented the planned work steps and contents of their respective project parts so that the participants got a first detailed impression of the data records available at the end of the project.

In the second part of the first workshop, effort was carried out in smaller working groups to get a direct exchange between the potential users and the project partners. After naming the requirements and needs from participants, an initial assessment of the possibilities of satisfying this need was made by the project partners. At the end of the first workshop, several working groups were formed who want to work together as “prototyping partnerships” in selected key areas (Chapter 7.3.3, Table 8).

In the phase between the first and second workshop there was an intensive exchange on a bilateral basis. Project partners and interested users worked together on prototype products, which were then presented and discussed as the first intermediate result at the second workshop. It was also intended for this workshop that the participants made mutual cross-references to the products that had been developed up to that point. So, these gave new offers for answering the respective questions and tasks of other stakeholders.

According to the discussions during the second workshop, questions related to the subject areas of habitat types and habitats in the coastal Wadden Sea area of great interest. Thus, the focus was placed on this subject area in the phase between the second and third workshop. The opportunities, challenges and limits of data-driven identification of habitat types in the Wadden Sea were discussed intensively here. The results obtained in this phase were subject of the third workshop.

A detailed presentation of all results of the respective PP'en can be found on the website of the EasyGSH-DB project (https://mdi-de.baw.de/easygsh/EasyEN_index.html#home). For up-to-date events and health considerations (nationwide prohibition of assembly to constrain the coronavirus), these results could not be discussed in a large auditorium (closing event at the end of

the project with more than 80 interested participants). This discussion could have provided further important information of the opportunities, limits and challenges in handling and using the data set.

7.3 Presentation of results

While the methodology of the integration of interested stakeholder or potential users was written in the previous sections, the following is about the presentation of the results from the respective work steps. We limit ourselves to selected examples, especially, the results and work of the prototyping partnerships (PPs) because a complete documentation of the extensive work results would go beyond the scope of this publication.

7.3.1 Stakeholder analyzes

Chapter 7.2 described that the project partners have created an initial collection of possible interested stakeholders. This list included more than 100 institutions from administration (Federal, State and local level), research institutions and free economy. After intensive discussion, 76 out of 105 institutions and organizations were selected who should be informed continuously and directly according to the progress of the project. All other identified stakeholders can find more about the media and channels (e. g. internet forums and internet platforms as researchgate.net) that are publicly available to them.

The list of 76 stakeholders to be informed directly was also used as the basis for the selection of potential interview partners. As described above (section 7.2.1), a total number of 30 people as interview partners from different areas (administration/authorities, research and free economy) can be processed successfully. The final selection in the consultation phase of stakeholders to be interviewed yielded 29 persons coming from the federal, state and municipal administration, research and free economy. Next to the state offices or companies from the areas of Lower Saxony and Schleswig Holstein waterways and shipping offices were included in the survey. Different persons from working groups of relevant research institutes as the IBCM of the University of Kiel, the Leichtweiß Institute (University of Braunschweig) or Franzius Institute (University of Hannover) have been interviewed. From the private sector, mainly engineering companies with hydraulic or ecological services for the planning of offshore wind farms or river conservancy and port construction measures were approached. During the process, 50 persons from 23 institutions could be interviewed in individual and small group discussions (see Table 7).

Table 7: Interviewed stakeholder within the participation process of EasyGSH-DB.

Economy		
Form of usage	Usage group	User
Port economy	Coast and port construction	Inros Lackner AG – Hamburg
		WK Consult – Hamburg
Wind energy	Wind farm operator	WPD
	Network operator	TenneT
Associational Nature conservation	Wadden sea protection	WWF
Consulting	Marine engineering	Ramboll IMS – Hamburg
		Ingenieurbüro Mohn – Husum
	Pipeline construction	de la Motte & Partner – Reinbek
Administration		

Form of use	Spatial reference	Administration
Port economy	Hamburg	Hamburg Port Authority (HPA)
Shipping	Niedersachsen	WSA Bremerhaven WSA Cuxhaven
Coastal-, nature- and flood protection	Niedersachsen	NLWKN Forschungsstelle Küste NLWKN Oldenburg-Brake NLWKN Norden
	Schleswig-Holstein	Landesamt f. Landwirtschaft, Umwelt u. ländliche Räume
	Niedersachsen	Nationalparkverwaltung Niedersächsisches Wattenmeer

Research		
Form of use	Research focus	Research institutes
Marine systems and Infrastructure	Coastal-, water- and port engineering	Franzius-Institut f. Wasserbau, Ästuar- u. Küsteningenieurwesen
Wind energy	Technical development	Fraunhofer Institut f. Windenergie u. Energiesystemtechnik
Geoinformatics	Technical development	HafenCity Uni. HH, Labor Geoinformatik u. -visualisierung
Technical universities and Marine research	Hydraulic engineering	RWTH Aachen
	Ecology	TU Braunschweig - Institut für Geoökologie
	Sedimentology	Senckenberg am Meer
	Fisheries	Johann Heinrich von Thünen-Institut

7.3.2 Needs assessment

In Figure 60, the list of requirements stated by the representatives of the administration is specified. The first column lists the functional demands mainly mentioned by the administration. The frequency of mention decreases from top to bottom. The representatives of the administrations asked principally for the bathymetry and in this context for the demonstration of an existing dynamics in it. The change of the depth of channels and fairways FAHRRINNEN is relevant for many questions in nature and coastal protection as well as in port administration. The existing sediment plays an important role concerning the settlement and/or identification of different habitat types. The administration often asks for processed basic data and already created visualizations (maps, graphics or animations) based on existing raw and measured data. One question was whether hind cast or current data sets are preferably used in the respective institutions. EasyGSH-DB provides a 20-year reference data set from 1996 until 2015 at its project end, so based on answering the question the relevance of this offer could be estimated. The relationship of hind cast to current data requirements is 80 to 20 as shown in the right column of Figure 60.


Requirements - Administration			
Functional	Frequency of mention	Data / Technic	Hindcast - Present
Bathymetry, change (dynamics)		Processed basic data	80% - 20%
Sediment, Surface, Habitats		Data-based visualization	
Sediment, Transport		Raw data	
Hydrodynamic		Measurement data	
Identification extreme events (water level)		Model output data	
Usage relevant changes			

Figure 60: List of the requirements of the respondents from the administration.

The “visualization of dynamic processes” (mainly for the bathymetry) could be used as an example for the demand of administration. The primary reason of this data requirement is linked to the visualization of the sediment transport, the tidal processes and/or the morphological development in the Wadden Sea area. This example was mentioned due to the interest of the representatives of the administration concerning certain subspaces within the dynamic Wadden Sea area. In addition, corresponding representations would be suitable in order to comply with the required reporting obligations in the European marine strategy framework directive in a simplified manner.


Requirements - Research			
Functional	Frequency of mention	Data / Technic	Hindcast - Present
Bathymetry, change (dynamics)		Raw data	45% - 55%
Water levels		Measurement data	
Sediment, also foundation soil		Processed basic data	
Suspended solids		Data-based representation	
Soil physics			
Wind, waves			

Figure 61: List of the requirements of the research respondents.

In research, a somewhat different picture emerges when it comes to stated functional requirements. The needs described in the left column (Figure 61) list the bathymetry as the most commonly mentioned, immediately followed by records, which are used as input for the calibration of simulation models. This is also reflected in the formats mentioned for data requirements. Here the provision of raw and measurement data is mainly desirable. A clear change can be seen in the requirement for the actuality of the data set provided. The research representatives would prefer more recent data sets, but a hind cast data set is also helpful for own modeling approaches.

An improved coordination for data collection between the federal agencies (e. g. BSH) and the competent authorities in the coastal countries stands as an application example for research. In addition, the desire for quality-assured data, which can increase discoverability through a suitable reference (e. g. with a **Digital Object Identifier = DOI**) , was often expressed.

Another picture showed the evaluation of respondents from the free economy (Figure 62). The most frequently mentioned functional requirements for which the data should be used were

documents for the construction planning for e.g., offshore wind farms, cable routes or electricity construction work. Service providers from the ecological sector need a wide variety of data sets for the nature conservation assessment of the development of habitats within the scope of the legally prescribed investigations in environment impact and strategic environmental assessment. Here, too, raw and measurement data as original data, which would then be fed into existing modeling or assessment tools are in the foreground for the mentioned needs. Due to the legal requirements in approval process, data sets that are more recent are preferred (Figure 62). Nevertheless, hind cast data sets are used to estimate the historical development of fairways and sand banks or mudflats for example.

The establishment of a central data portal is clearly preferred for companies of free economy. The existing quality-assured data sets should also actually be downloadable from this and as free of charge as possible. The comprehensive documentation of the metadata for the existing data sets was mentioned as another important criterion.


Requirements – Free economy			
Functional	Frequency of mention	Data / Technic	Hindcast - Present
Calculation of construction planning		Raw data	55% - 45%
Screening construction area		Measurement data	
Conservation assessment		Data-based representation	
		Processed basic data	

Figure 62: List of the requirements of the free economy.

7.3.3 Prototyping partnerships

The prototype development of application-related products can only succeed with the help of interested users. Therefore, a direct communication between the EasyGSH-DB partners and the workshop participants was organized in the first workshop. This direct exchange of needs and the possible data/products to be delivered as well as the questions to be answered, helped both sides to make a realistic assessment concerning the available reference data set. Problems and questions from the ranks of the participants were related, among other things, to support in the reporting obligations to EU legislation, but also to the persistent coverage of laid cable routes or pipelines in morphological active areas. Related to electricity construction work and adjustment of the estuaries Weser and Elbe, questions about morphological activity in certain outer areas of these estuaries arose.

In the further course of the participation process, the interim results of the prototyping partnerships were presented and a focus on the final products was promoted together with the stakeholders involved.

A total of eleven prototyping partnerships (PP'en) were initiated, which worked over a period of two years with different intensities on the respective questions. A wide range of different topics were touched upon. In addition to the central tasks of EasyGSH-DB concerning the geomorphological, sedimentological and hydrological development of the German Bight, questions about data provision and modeling as well as the interdisciplinary topic of the development of habitat types were worked out intensively. All in all, more than 20 stakeholders from 13 different institutions participated in the common development of applicable prototypes.

A brief description of the content of the respective partnerships can be found in Table 8. Only four prototyping partnerships are discussed in detail in this report which were also worked on in depth as sub-projects:

- The EasyGSH-DB data portal, because it was an express wish of everyone involved (see Chapter 9.2.1).
- The information platform, because there is detailed and well-founded information about many aspects of the EasyGSH-DB project (see Chapter 8).
- The prototyping partnerships “habitat types” and “morphological stability maps”, because the products developed there can be used for various questions.

All PPs are presented in detail at the information platform (<http://www.easygsh-db.org/>).

Data portal

The data portal described in more detail in Chapter 9.2.1 was a fundamental goal of the EasyGSH-DB project. Structures with comparable content were often requested by the interviewees to obtain published datasets via internet-based access. The data requirements as well as the data formats, which should be made available in the data portal, were queried as part of the first workshop. Any user can view and download the records in different formats and provided with thumbnails.

Table 8: Schedule of active prototyping partnerships in the project.

#PP	Designation of the prototyping partnership	Short description of the work content
1	Morphological stability maps	Identification of morphodynamic potentials in the area of sea cable routes corridors within the Wadden sea
	Risk model	Accounting of erosion and accumulation of sediments and their impacts on the development of sea grass stocks
	Regeneration model	Effects of the crab fishery on sediment composition within the Wadden see
2	Cuxhaven Watt	Estimation of the situation of erosion and accumulation within the Cuxhaven Watt
3	Delivery of boundary values	Delivery of boundary values of the EasyGSH-DB model for regional simulation models for example the projects STENCIL, FAUST
4	Dealing with uncertainties	Description and analysis of occurring model inaccuracies
5	Analysis of intertidal maps	Identification of the land water boundary in the coastal area of the German Bight in cooperation with the WSV
6	Determination of mudflat edges	Identification of the land water boundary within the coastal area of the German Bight in cooperation with the DLR
7	Tide regime	Joint development of products for description of a “good morphological status of the Wadden Sea” according to WRRL
8	Sea state parameters	Determination of sea state parameters in the Schleswig-Holstein Wadden Sea and the offshore sea area (10 nm) for selected wind speeds and directions
9	Data portal	Provision of the EasyGSH-DB products on a download platform with full metadata description
10	Easy-GSH DB Information platform	Detailed explanation and visualization of general information and EasyGSH-DB products concerning the German Bight
11	Habitat types	Creating of potential maps for different habitat types in the Wadden Sea of Lower Saxony

Information platform

The extensive 20-year reference data set, the EasyGSH-DB products as well as the two model families used for the hydrodynamic modeling (Chapter 6.1 and Chapter 6.2) require an explanation and should serve as the basis for an E-learning module. The information platform is described in more detail in Chapter 8. It represents an important source of information for all users having questions on the possibilities and limits for the usage of the reference data set of the EasyGSH-DB project. General information about the German Bight is also included as the explanation of basic hydrodynamic values.

In the following sections, two prototyping partnerships, their approach, and the work results achieved therein are described exemplary. A comprehensive description of all activities would go beyond the scope of this report. Therefore, work content and results of all prototyping partnerships are presented in detail on the information platform (<http://www.easygsh-db.org/>).

Prototyping partnership: habitat types

Realization of the communication processes

The Lower Saxon National Park Wadden Sea Authority is intended to create potential maps for selected habitat types. These are mainly the habitat types such as sandbanks, reefs (geogenic, biogenic) and shells. For the first two, there are so-called basis definitions by which they can be characterized.

Concerning the third workshop one of the EasyGSH-DB partners tried to convert these descriptive characterizations into numerical values so that they can be used for data-based identification in the corresponding record of the EasyGSH-DB. Through the elimination process in the bathymetry of the year 2012, all surfaces which did not meet the above conditions were cut out. It was difficult to filter out reliable structures from the existing data sets with a diameter greater than 64 μm . This resulted in a relevant need for discussion with the Administration experts about possibilities and limits of data-driven identification of habitat types. The course of the participation and work process within the framework of a prototyping partnership is shown for the PP habitat types in Table 9 as an example.

Table 9: Exemplary course of a prototyping partnership (here: habitat types).

Meeting	Contents
NLPV Colloquium	Presentation of the data and products of the EasyGSH-DB project
Bilateral meeting	Specifying the selection parameters for different habitat types which should be used for identification by the EasyGSH-DB project
3. EasyGSH-DB Workshop	Presentation and discussion of the first results of the data-driven identification of different habitat types
Bilateral meeting	Presentation and discussion of different model approaches for identification of blue mussel potential maps for the Lower Saxony Wadden Sea National Park Administration: i) Statistical model approach ii) Process of elimination about EasyGSH-DB products

The investigation of potential areas for blue mussel beds was examined more intensively. Based on defined influencing factors like grain size distribution, sedimentation rate, dry fallen times, and flow rates, the possibilities of data-based detection have been matched with existing blue mussel beds on the GIS maps provided by the authority and the relevant boundary conditions. In Figure

63, the examined influencing factors (drivers) are marked by a colored box that shows for which of the required influencing factors target-oriented data products are directly available as the basis products of this project (blue) and for which influencing factors, generated by additional working steps out of the EasyGSH-DB-products, could be generated (orange) (see Chapter 0). The result is that this data-driven identification approach provides too great area shares in the Wadden Sea where no blue mussel beds have been found so far. This means an indication with furthermore parameters should be used for the settlement and persistence of blue mussel beds.

A methodological comparison with the result of a purely statistical ecological model for the creation of blue mussel potential maps is still pending. The EasyGSH-DB project provided a comprehensive data set for the feed into the mentioned model.

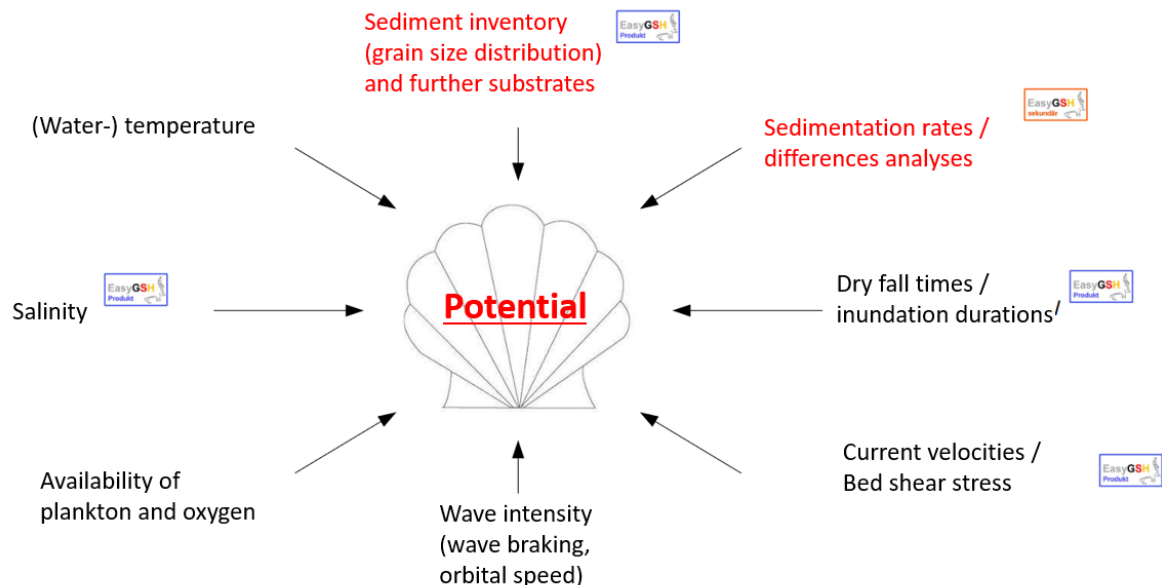


Figure 63: Influencing factors for the settlement and persistence of blue mussel beds.

In intensive bilateral communication between user (National Park Authority: NLVP) and EasyGSH-DB project partners, the created EasyGSH-DB products were further developed to application maturity. The final products are now actively used and thus form a working basis for the Lower Saxony Wadden Sea National Park Authority concerning the habitat type “mussel bed”.

Procedure and working results

Blue mussels and shell accumulations represent an important ecological component in the German Bight. During the past few decades, the picture of mussel deposits within the German Bight has changed significantly. So, the Pacific Oyster (*Crassostrea gigas*) immigrated to the German Wadden Sea from the west, and it has invaded the biggest part of the previously existing blue mussel beds (*Mytilus edulis*) (Nehring et al., 2009). Due to strong land growth rates, oyster reefs have been formed, which are extremely resistant to mechanical stress. It can also be observed that habitat communities of oysters and blue mussels have emerged, whereby the blue mussels retreat into the emerging protection and find support there.

Exemplary for the analyzes and evaluations, observed eulittoral and subtidal mussel occurrence in the Schleswig-Holstein Wadden Sea are considered in collaboration with the “Research and Technology Center West Coast” located in Büsum. The aim was to be able to use the combined environmental factors as framework conditions for the creation of a potential map for mussel settlements afterwards.

Local settlement and survival of all kinds of mussels depend on a variety of influencing environmental factors (see Figure 63), presented below and illustrated partly exemplified in Figure 64.

The sediment inventory found at a location plays a decisive role. This is represented, for example, by the median grain diameter (see Figure 64a). Too fine sediment with large portions of silt is disadvantageous concerning the settlement of mussels and it also reduces their erosion stability while coarser substrates are favorable for resettlement. In addition to the actual sediment, this also includes admixtures like shell chill and the presence of conspecifics. Also, the soil type can favor a settlement of mussels. In this way, peatlands e. g. have a positive effect on positional stability of mussel settlements (Buck, 2007, Brenner und Buck, 2010).

Furthermore, erosion and sediment processes, as shown in Figure 64b, are very significant. While sediment as well as mussels were removed during erosion processes, too high sedimentation rates require a filling which leads to suffocation or starvation of the individuals.

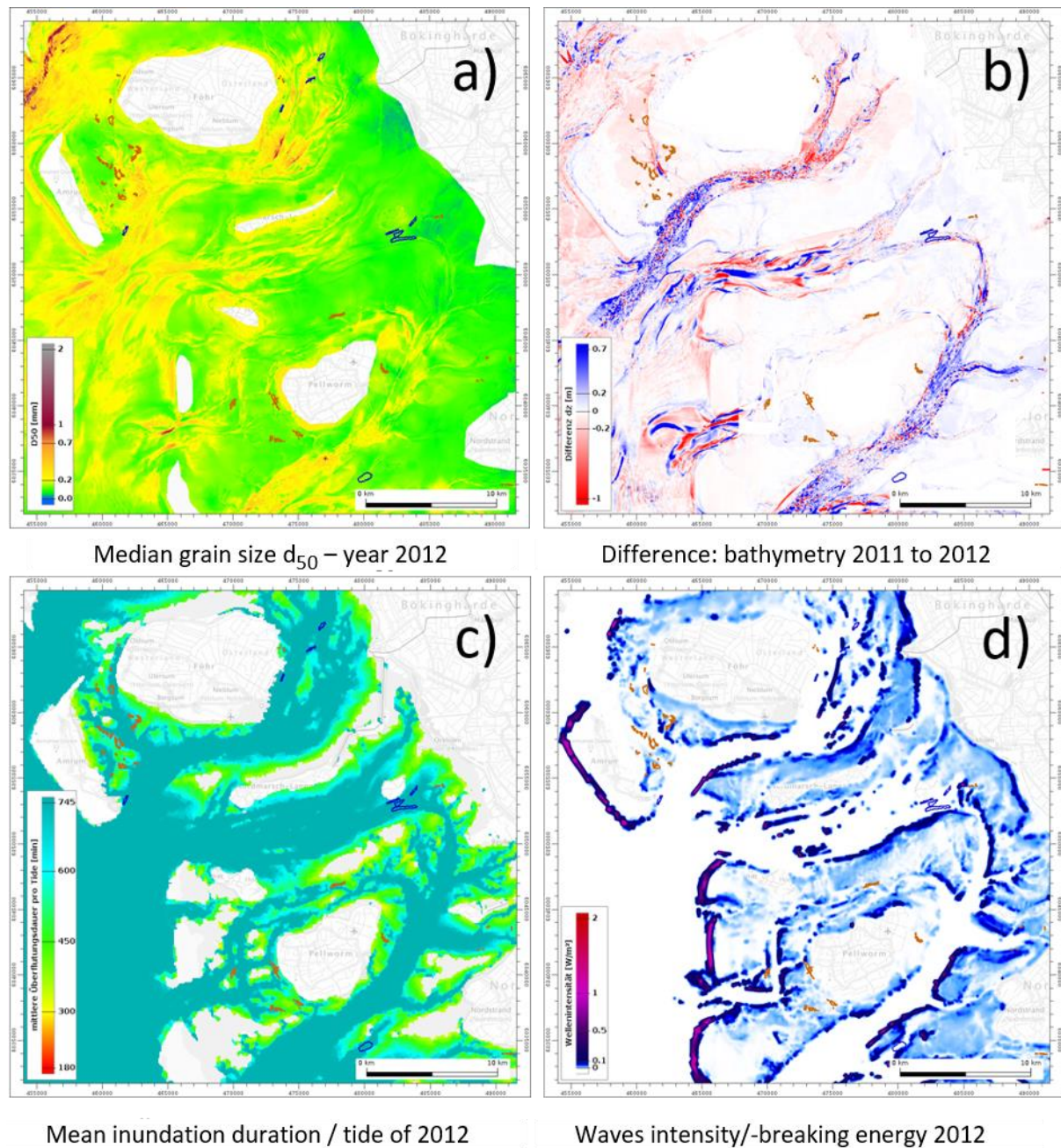


Figure 64: Examples of influencing factors related to blue mussels : Settlement and position stability of established mussel socializations, brown: eulittoral blue mussel deposits, blue: subtidal blue mussel deposits, in the background BKG: TopPlus-Web-Open.

The inundation duration (see Figure 64 c) resp. the tide depending dry fall part is essential when it comes to mussel-friendly habitat conditions. While subtidal socializations live permanently below sea level, eulittoral mussel populations are regularly exposed to predators from the air or they are planned off by ice floes in cold seasons. Blue mussels are only found in areas which are characterized by an adequate flooding duration per tide to prevent these dangers.

Furthermore, blue mussels must also be able to withstand more or less strong waves as shown in Figure 64d. Too strong wave intensities cause a large energy transfer to the ground surface whereby mussels can be removed, or settlements can be prevented.

In addition to enough salt, mussels also need sufficient food in the form of plankton and oxygen to survive. The necessary quantities vary from kind to kind. Therefore, different mussels can settle in various water depths depending on the availability of the substances mentioned.

The water temperature can also influence the positional stability of mussel deposits. In blue mussels which use their Byssus-threads to cling to surfaces the power of these decreases at high water temperatures. So, they become more vulnerable to currents.

Flow and orbital velocities as well as bed shear stresses are basically a limiting factor in terms of favorable environmental conditions for mussel habitats. Excessive velocities/speeds and shear stresses lead to the fact that mussels are released and relocated from the bottom surface or that an initial settlement is not even possible. Too little water movements in turn have the effect that the supply of food and optionally oxygen is no longer adequately guaranteed.

All environmental factors considered within the framework of these analyzes are listed in Table 10. They have been derived for the eulittoral and subtidal mussel deposits of the Schleswig-Holstein Wadden Sea from the underlying basic products of the EasyGSH-DB project for each parameter for the year 2012 minimum and maximum as well as median values. The values marked in Table 10 can be used as limited values from data of necessary constraints for the existence of blue mussel deposits.

Table 10: Determined limit values (bold) for influential environmental factors.

<i>Environmental parameters</i>	Eulittoral mussel deposits			Subtidal mussel deposits		
	<i>Minimum</i>	<i>Maximum</i>	<i>Median</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Median</i>
Erosion-/sedimentation rate [m / year]	-0,2	0,7	–	-0,2	0,6	–
Sediment distribution d50 [mm]	0,079	0,652	0,175	0,104	0,377	0,166
relation dry fall duration/tide [%]	0	42,210	14,163	0	0	0
Mean ebb current [m/s]	0,025	0,311	0,155	0,115	0,389	0,287
Mean flood current [m/s]	0,023	0,317	0,153	0,084	0,404	0,238
Orbital velocity [m/s]	0,074	0,504	0,290	0,097	0,417	0,256
Bed shear stress ebb [N/m ²]	0,026	0,979	0,259	0,123	0,744	0,312
Bed shear stress flood [N/m ²]	0,026	1,309	0,213	0,163	0,794	0,355
Wave intensity/- breaking [W/m ²]	0	0,21	0,001	0	0	0
Salinity [‰]	18,676	27,717	24,379	22,863	24,754	23,598

Based on these limit values all regions within the study area, in which one or more environmental parameters lie outside of the conditions necessary for mussel socialization are identified in a first step. These areas can be excluded as mussel habitats on the basis of the parameters examined while the remaining areas meet all requirements. So, they are to be understood as potential

For an estimation of variable potentials for mussel habitats, membership functions are created as combinations of sine-, cosine- and exponential functions based on the minimum, maximum and median values determined above (compare e.g., Formula 2).

with

- The formula applies to $x_{med} \leq x \leq x_{max}$ with the assumption that at $x = x_{med}$ the resulting individual potential for the considered environmental parameter maximal (= 1) is and at $x = x_{max}$ minimal (= 0).

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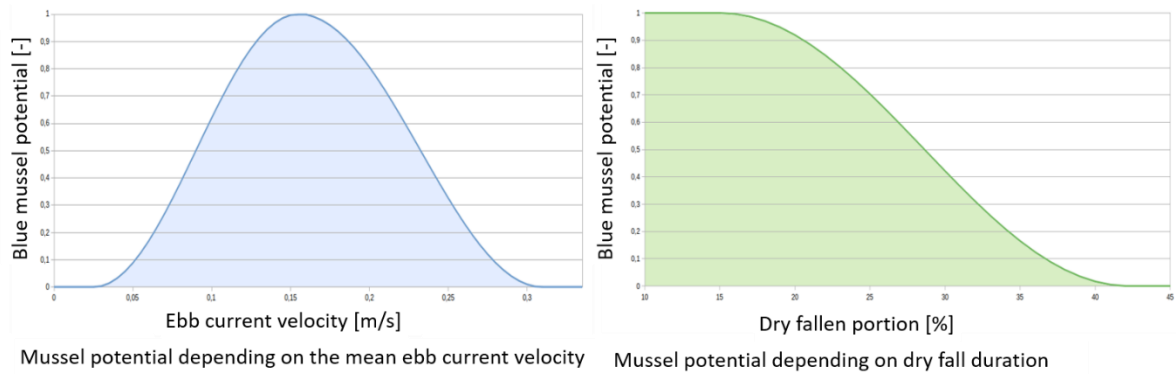


Figure 66: Mussel potentials depending on individual predominant environmental factors.

By using the geometric mean (see Formula 3) the different individual potentials can be summarized to form an overall potential which represents the environmental conditions at the point under consideration for the study year.

$$Pot_{ges} = \sqrt[n]{Pot_{Uf(1)} * Pot_{Uf(2)} * Poz_{Uf(3)} * \dots * Pot_{Uf(n)}} \quad (3)$$

with

- Pot_{ges} = resulting overall potential
- n = number of individual potentials

This is how a potential card for mussel socializations (see Figure 67) is created in which the read value is to be understood as a characteristic value for favorable and unfavorable overall environmental conditions.

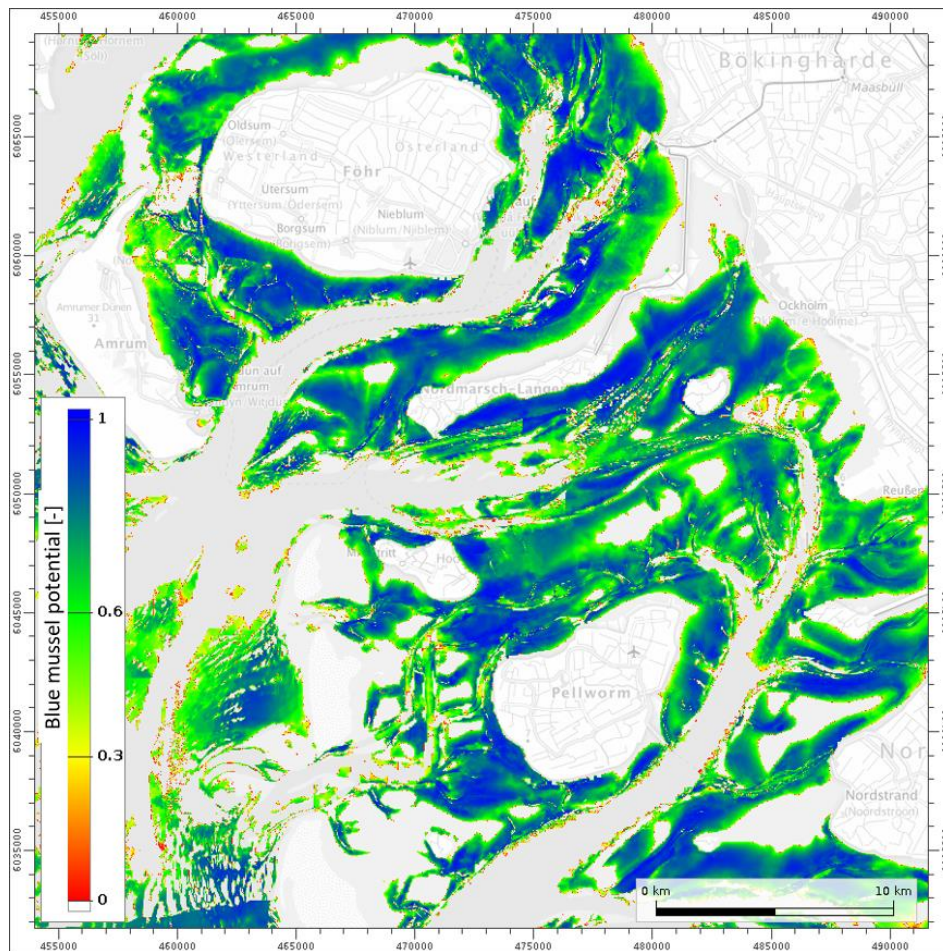


Figure 67: Potential card dependent on predominant environmental conditions, (mussel potential: 0 = bad to 1 = good).

Prototyping partnership morphological stability map

Execution of the communication process

The application conference concerning a spatial planning procedure for the sea cable connection of offshore wind farms to the mainland took place in the district of Friesland in autumn 2019. As part of the spatial planning process “Seetrassen 2030” priority corridors for sea/submarine cable routes in the coastal area near Baltrum and Langeoog with regard to such an application were planned (Source: www.arl-we.niedersachsen.de/Seetrassen-2030/seetrassen-2030-181711.html). These were analyzed below in cooperation with the “Amt für regionale Landesentwicklung Weser-Ems (ARL)” as well as the responsible network operators “TenneT Offshore GmbH” and “Amprion GmbH” concerning to the conditions prevailing morphologically high dynamic in the area (see. Figure 68).

Various products have been developed and made available at the EasyGSH-DB project which would be suitable, for example, for estimating the exposure potential of submarine cables to be buried under the Wadden Sea floor. Therefore, the project contacted the responsible office for regional development in Oldenburg and submitted an offer for the presentation of the efficiency of the products of the EasyGSH-DB project.

In spring 2020, a meeting with representatives of the ARL, both network operators TenneT and Amprion as well as project partners of EasyGSH-DB took place in Oldenburg. During the presentation of possible products to be used of EasyGSH-DB, their significance was discussed with the participants, for example, for the optimization of the cable routes through a highly dynamic

Wadden Sea. The following section describes both the procedure for the development of morphological stability maps and the EasyGSH-DB products made available to the network operators.

Procedure and work results

Wind has been always made available as an energy source for technical purposes and it is very important for renewable energies as part of the energy transition. Unlike wind turbines on the mainland, comparatively continuous and higher mean wind velocities prevail at locations of Off-shore wind farms whereby these are characterized by a high occupancy rate. The connection of wind farms takes place via sea cable to the coast where the energy is fed into the general power grid.

The focus here is on the potential routes and laying depths which are examined and estimated by sediment relocation/rearrangement in terms of their exposure potential.

To estimate and evaluate potential routes and laying depths for cables, the maximum observed depths at each point in the study area are determined for the period 1996 to 2019, shown here in Figure 68b. The surface generated in this way represents the one under which a cable would have had to be laid in 1996 so that it could not have been uncovered until 2019.

In connection with the minimum observed depths (see Figure 68 c) the morphological activity space (difference between minimum and maximum depth) can also be described, shown in Figure 68d. This one expresses the maximum depth change over the entire investigation period from 1996 to 2019 at each point in the study area. For example, areas can be identified in which strong morphological changes (depth changes of more than 2 m – corresponds to the typical minimum laying depth in the Wadden Sea (Meißner et al. 2006)) have taken place since 1996. They are therefore potentially to be regarded as unfavorable for the course of the route.

The morphological activity space previously presented in the area can also be shown at a profile along the course of the existing preferred corridors. Figure 69 shows this as an example along the “Vorzugskorridor C3”/preferred corridor C3 in the tidal flats south of Baltrum. This representation illustrates especially the scale of channel movement. In addition, it provides information about the morphological stability of tidal flats.

Furthermore, by lowering the maximum depth observed during the investigation period by 2 m, a potential depth course for the preferred route is determined and displayed, and the laying depth for power cables in relation to the water bottom depth 2019 is estimated (see Figure 70).

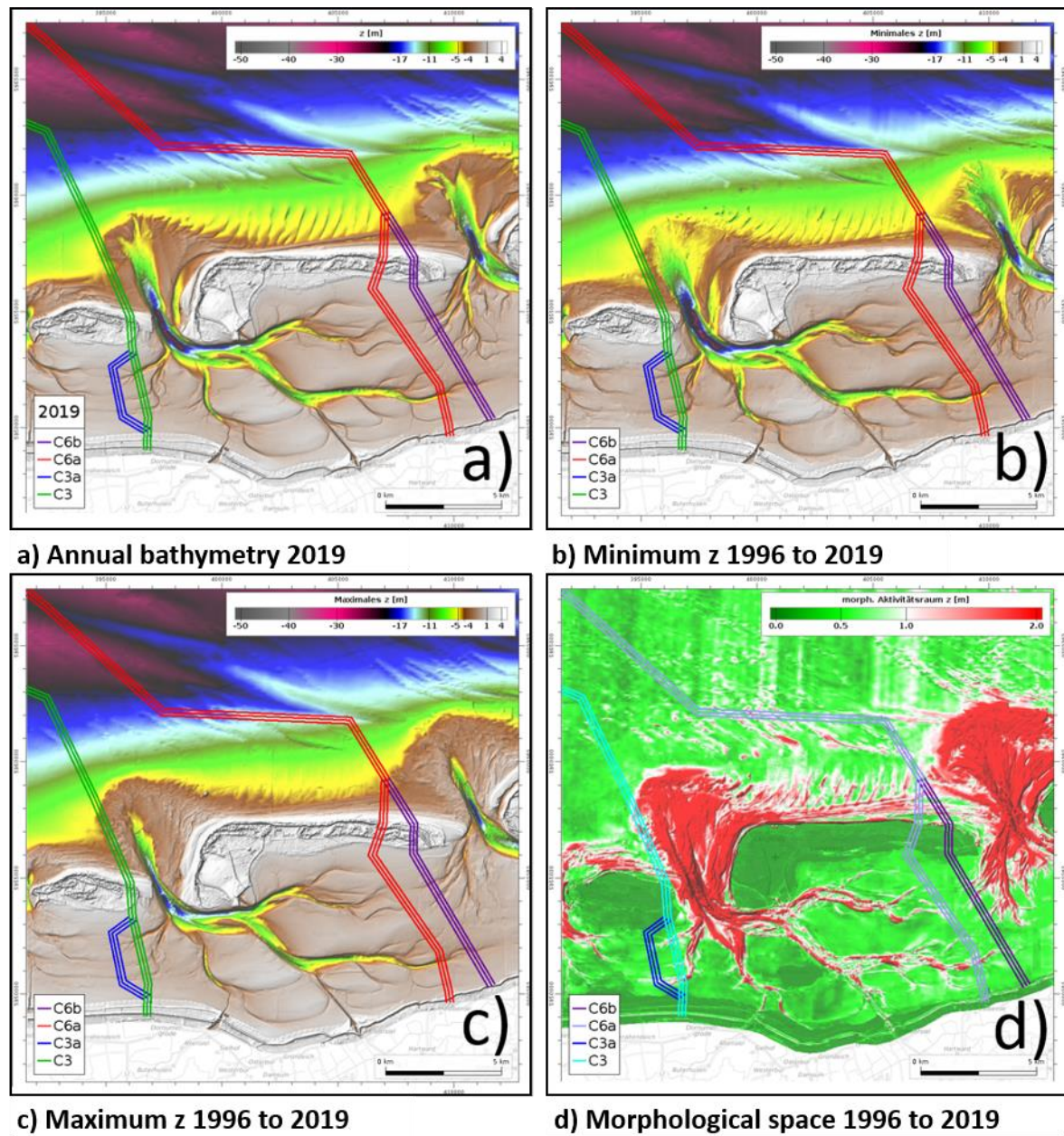


Figure 68: Priority corridors with regard to the morphological conditions,, in the back-ground BKG: TopPlus-Web-Open.

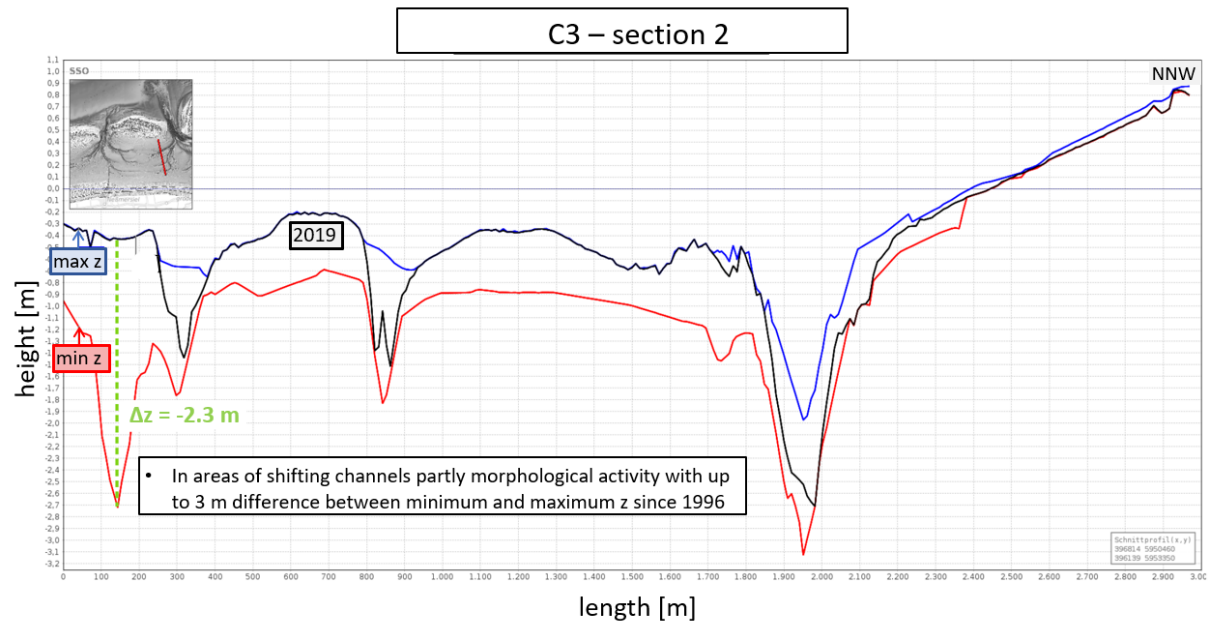


Figure 69: Morphological activity space in profile, black: water bottom surface 2019, blue: max. z 1996 – 2019, red: min. z 1996 – 2019.

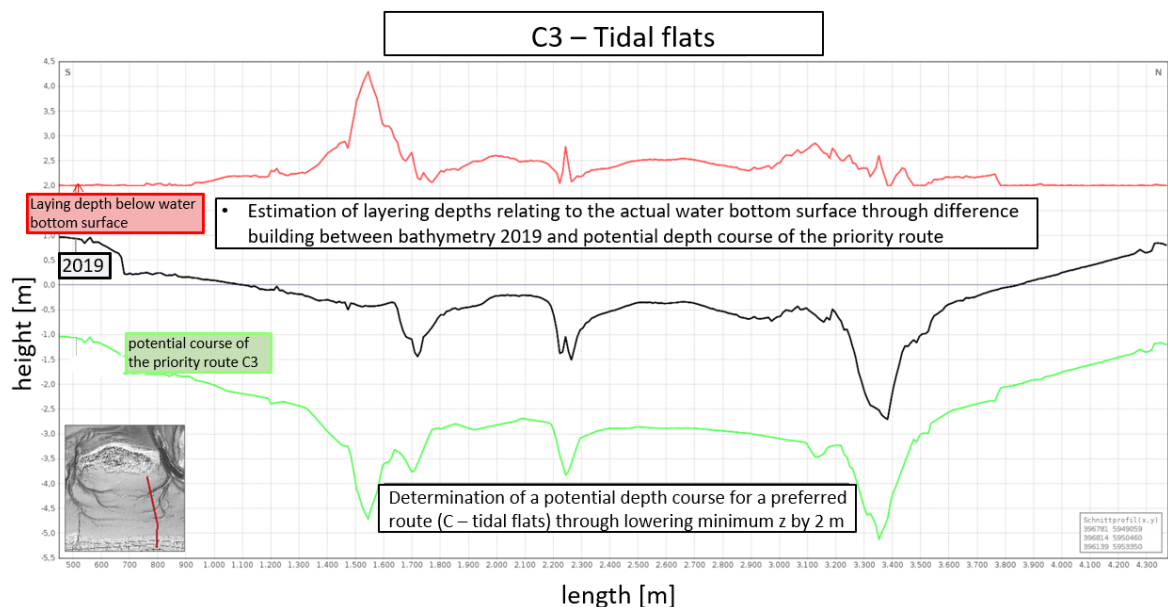


Figure 70: Estimated potential course of the priority route C3, black: water bottom surface 2019, red: laying depth below bottom surface, green: potential course of the priority route C3.

7.4 Result evaluation

The innovative approach to link the coastal data with the needs assessment of potential users was constantly positive. Project partners of the EasyGSH-DB project have learned that the data sets provided by them arouse great interest. Potential users were given the opportunity to work directly on application-related products. The path of a direct and intensive participation in the prototypical products to be used for own purpose is helpful and goal oriented. However, the work processes and the time quota in most authorities, research institutes and in particular the free economy are only available to a limited extent. On the one hand, the innovative approach of the project for the direct and intensive involvement of potential users was very much welcomed.

Otherwise, the willingness for extensive and close cooperation was only available to a few users (for example: National Park Administration Lower Saxony and Schleswig-Holstein in cooperation for the creation of mussel potential maps).

In addition, tasks, especially in the free economy, are usually dependent on current data sets so that a 20-year hind cast dataset can be used only for assessment of past developments. Nevertheless, products that could be used by different companies could be created using the existing datasets which, for example, record morphologically highly active areas for planned sea cable corridors.

After completion of the project, the task of data-providing Federal Agencies means to keep them in a common format that can be used by most users and to update them as much as possible. Some of the interviewed users indicated that they would like to use prepared visualizations of the data to get an impression which tendencies the relevant study area would show in terms of height development. This resulted in different requirements for the provision of the data concerning quality, actuality and formats. EasyGSH-DB project responded to these by dividing the provided products into categories basic -, analysis - and user product as well as metadata (see Chapter 0). Therefore, every user can see which category of products that were created as part of a prototyping partnership (PP) and are available on the data portal for download as user products it is.

In summary, it can be said that the intensive and time-consuming approach to ask potential users about their needs and their involvement in prototypical product development process was successful. The cooperating users recognized the added value and the potential of the data provided. Due to the intensive exchange in the prototyping partnerships the limits and challenges associated with the reference dataset provided by the EasyGSH-DB project were also made clear to them.

8 Information platform (E-Learning)

The development of the digital world is accompanied by a rapid increase of the amount of directly available information. Despite increasing media affinity among the population, deficits in **media literacy** concerning finding, interpreting and rating can arise. Especially, scientific databases and data husbandry systems are characterized by the fact that, despite defined and established interfaces, they are not clearly arranged and difficult to access. Therefore, they can be used many times only by professionals. This also applies to a lesser extend to the extensive product collection that was generated as part of EasyGSH-DB and is available online for free use.

The addressed user group is just as diverse as the product collection which consists of a wide ranged circle of users from the maritime economy, administrations at federal, regional and community level, bearer of public interests, research and **non-governmental organizations** (NGO). It is imperative to assume that the different user groups approach the products with different knowledge and understanding.

This can lead to restrictions in the use resp. interpretation of the products in two forms between which the transitions are smooth:

- For users which are professionally trained in relation to the physical processes in the North Sea as well as methodically and manually qualified concerning the data processing, quality, traceability and discoverability of the products must be adequately documented. This includes e. g. the origin of the basic data or the precise description of the data processing. It can be assumed that the importance of the particular products and their application potential are clearly visible to these users.
- For users whose physical process understanding is not in the foreground due to their own professional orientation, it can be difficult to understand the meaning of many particular products. Consequently, there is also a lack of application relevance, which means that the potential usefulness of the data for further analyses is also closed to these groups.

The EasyGSH-DB information platform provides all potential users with the necessary information so that they have the opportunity to participate.

8.1 Target groups and requirements

The potential user groups can be assigned to different sectors of Science, Administration and Private economy with different areas of focus (see Chapter 7). A classification of the main tasks- and activity fields was made for the conception of the information content according to Figure 71. These assignments are not to be considered exclusive. The findings and observations from the first stakeholder workshop (April 2018) as well as the needs analysis (Chapter 7.3.2) provided valuable information. So, different requirements for an accompanying information platform were determined. The main goals in the conception of the information platform are accordingly:

- 1.) Search and registration of the products
- 2.) Reference information about the product
- 3.) Conveyance of background knowledge

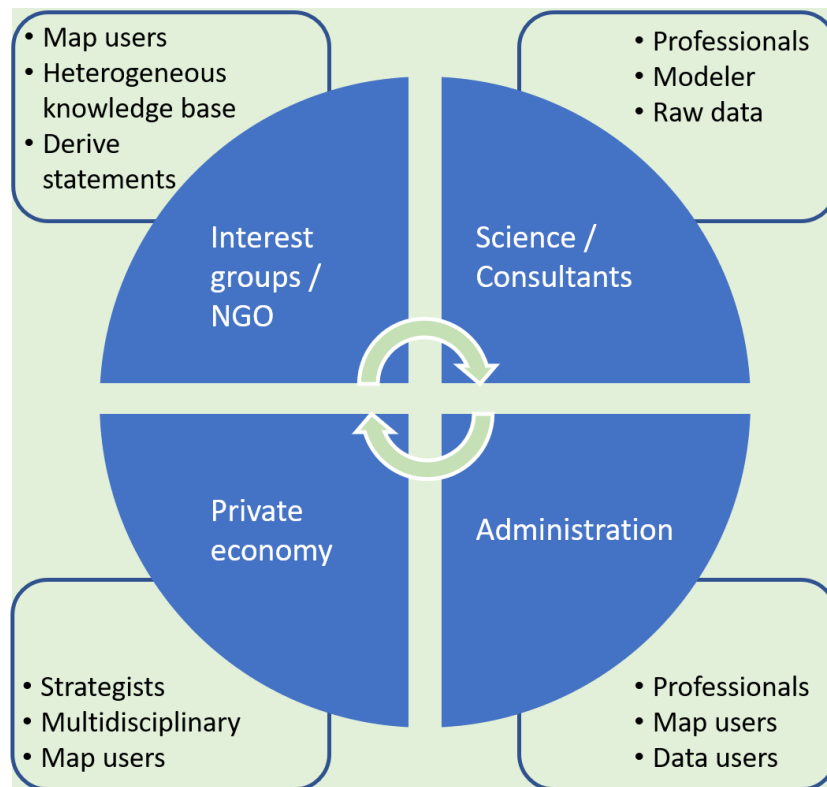


Figure 71: Classification of stakeholders, their classification and main fields of activity
(Knowledge base).

Variable depth of information

The contents in the depth of knowledge are created variably to meet the requirements resulting from the heterogeneity of the data users. A user should be able to choose which content to view and in what depth. In principle, this is possible in any type of document, but the point here is to simplify in the interest of the user needs. To support the selection, the information platform should thus be equipped with information packages that the depth of information can be controlled in a targeted manner. On the other hand, the overall context should not be closed to the users if they skip more detailed information. This has been ensured by making the selected depth of information clear to the users just by the visual representation. The knowledge contents are therefore subdivided into levels. It is important to differentiate this subdivision into levels from a document structure since the latter (in contrast to the former one) does not provide any information about the depth of information of the text written in a chapter.

Different entry points

The entry point when a user approaches the topic is another aspect to consider. One extreme are users who want to get an immediate overview of the available products and are motivated with the targeted thought of data download. The other extreme are users who need to acquire background knowledge to develop consent for the products. That means that various topics must be immediately available as broadly and hierarchically as possible in the same level.

Content links / Context

The generation of the products including all work of data research and collection, the data validation via linking the data in the models, the result validation, the result analysis and interpretation up to further processing into application products is a highly complex work process with implicit dependencies among each other. To document the complexity, the representation of dependencies and relationships between individual subjects was an important requirement for the information provided.

Product search

A dedicated website (see Chapter 9.3 Download portal) for the download of the different products is available in addition to the information platform. All these as well as the search in *mCloud*⁷ or MDI-DE⁸, allow a keyword search of products. So, a further keyword search was not helpful within the framework of the information platform. To address the need nonetheless, a visual search option with a sorting by topic was provided.

Product topicality

The meaning of topicality and reachability of contents was derived from the results of the stakeholder workshops and the survey results from the need assessment (see Chapter 7.3.2). In relation to the product documentation, it is important to know that changes to the basic products do not lead to a content obsolescence or technical disability by e. g. “dead” information platform links.

Rejection of self-tests and course-like character

An original idea to deliver training-like content with possible self-tests was clearly contradicted from the participants of the first workshop. This type of content would be primarily associated with the goal to create a range of courses with the aim of training. In the case at hand, the information option is intended to represent an optional accompanying offer for the actual product range.

8.2 Solution

The literature has different definitions and discussions concerning the term E-Learning whose processing is not relevant here. Basically, it can be deduced that the learning content is conveyed through E-Learning using digital media. Fischer (2013, S. 32) summarizes this as “fusion of educational processes with digital technologies”. The term “E-Learning” is a broad one, because the processed definitions education and digital technologies are also very extensive.

In terms of content support for the products of this project E-Learning means a website which meets the above-mentioned requirements in terms of content and didactics. The implementation with interactive elements allows the sufficient flexibility for individual navigation through the topics. At the same time, the technical complexity is limited not to displace the focus of the content. The more innovative elements lead to a higher complexity of the system, the greater the effort and thus the duration until a learner can use the system for its intended purpose (Fischer 2013, S. 101). Therefore, it is an important requirement for implementation that the technical finesse of the information platform is not in the foreground in order not to push the knowledge transfer into the background.

8.2.1 Context based representation of topics

For the linked representation of topics, various approaches exist, some of them visual, which can also be used for sorting and structuring thoughts or hierarchical structuring of documents.

As already indicated above, a concept with a hierarchical structure is not effective. A classic outline which can be also mapped with a simple content menu of a website with the purpose of transport of course contents follows a hierarchical structuring of a document. The main idea is to structure contents in a coordinated but hierarchical manner. This format cannot meet the requirement to create flexible entry points. Furthermore, the context-based link of topics is not or at least only partly intuitively possible.

⁷ <https://www.mcloud.de> (Das offene Datenportal des BMVI)

⁸ <https://www.mdi-de.org> (Marine Dateninfrastruktur)

Mind maps also work hierarchically even flatter in representation. Topics and subtopics are arranged in an arbitrarily branched but directed tree structure around a central theme. The basic concept of a mind map allows the balanced arrangement of topics and their detailed subtopics around a central main term. At least it is possible to define resp. interpret the branching depth in a mind map tree structure as level of detail. An advantage of a mind map is that despite the structuring the logical dependency of the individual main branches is cancelled. Each topic that is arranged in the first branching level under the central theme point is thus self-contained. Unfortunately, the context through cross-connections is syntactically not allowed. One possibility is to interpret the graphical proximity of topics in a mind map as proximity in terms of content.

A more flexible alternative to this is a theme or knowledge map. In it, topics are flexibly positioned in the structure of an undirected graph. Therefore, a theme map allows graphical distribution of countless topics free from any hierarchy. The context or thematic proximity can be indicated by spatial proximity and be made explicitly by any links between individual topics. The graphical distribution of topics creates completely free entry possibilities to the general overview. It is disadvantageous in terms of the requirement of detail depths that it cannot be reflected by the hierarchy freedom.

Due to the mentioned arguments, a theme map was defined as the basis for the information platform. The deficits in relation to the requirements and here in particular the representation of the depth of detail were eliminated by further graphic modifications. On the one hand, the depth of detail can be structured in levels by visual highlighting of individual topics. In addition, a thematic assignment within the topic map was planned. Each of the themes works in a way like a hierarchical mind map with the difference that any other links may be added. One can thus imagine the topic map three dimensions with the depth of detail as the third dimension.

8.2.2 Documentation of the products

A central aspect is the documentation of the EasyGSH-DB data products. Metadata are always provided for the published data products that supply descriptive information. The metadata structurally follow the schema of ISO 191115 and, in addition to some basic information, also optionally enable the specification of the data quality. There are two types for this. On the one hand, data quality elements are defined as completeness, consistence and accuracy with different reference like space, time, units etc.; on the other hand, the lineage of the data can be defined. However, the standard leaves out the scope to what extent this information has to be filled. According to a study of (Díaz et al. 2012) for example only ca. 20 % of ca. 97,000 geo data sets of the **Global Earth Observing System (GEOSS) Clearinghouse**, see (Yang et al. 2014), were tagged with data quality terms resp. 16 % with lineage information.

The lineage specification represents an alternating sequence of source data (“source”) and processing process steps (“step”) to get the final data product. Figure 72 illustrates the procedure in the lineage. Different numbers of source data sets can be processed in one process step into a new source data set of the next process step. The individual steps can be provided with additional information which significantly increases understanding. The schema has been supplemented with explanatory information about the source data sets which in particular describe external data sets that are not set with metadata and indicate their lineage.

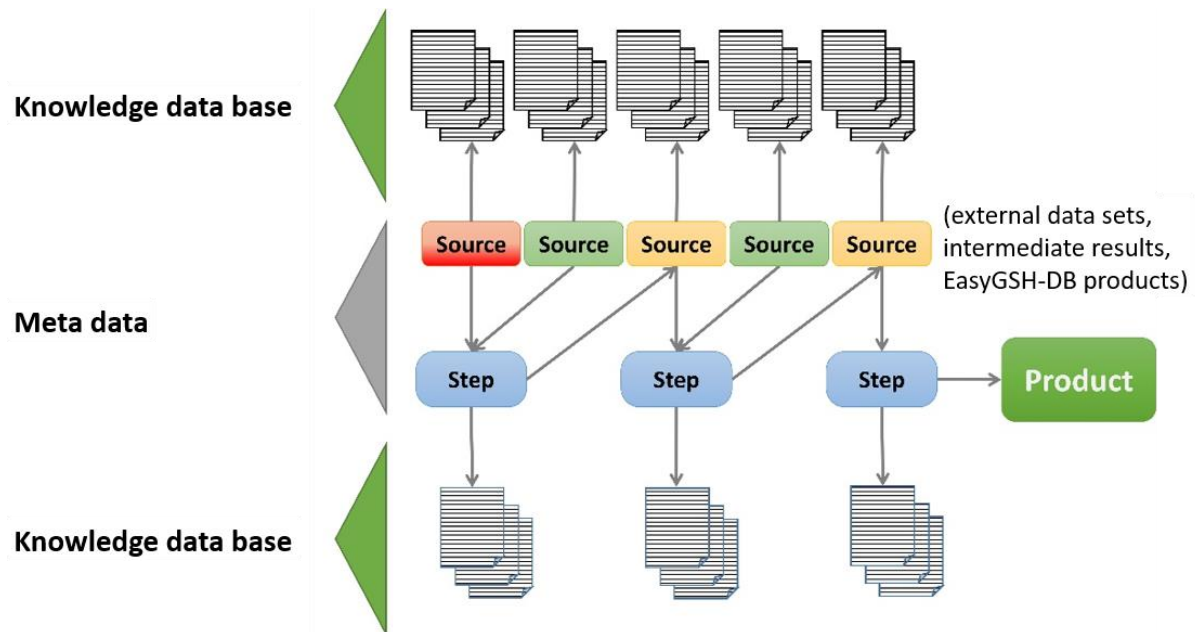


Figure 72: Representation of lineage and indication of origin of the descriptive information (Changed according to <https://wiki.earthdata.nasa.gov/display/NASAIISO/Lineage+Information> -last checked 04/2020).

The additional description of the process and source data sets follows in the concept of the information platform. Since not all descriptive texts and graphics can be stored in the metadata, the descriptive information can be called up separately in a database. In this context, information platform serves as a link between the metadata and the knowledge base, which connects related components and prepares them in a legible manner.

8.3 Technical realization

Clues for possible standards in the technological implementation are not only to be found in university teaching because of the target group of users, but also in the environment of private and industrial companies. Companies are increasingly turning to internal digital solutions for employee training as well as documentation of working processes because this enables immediate access to teaching materials. According to (Niegemann et al. 2008) SCORM⁹, AICC¹⁰ or IMS¹¹ are examples of relevant systems. The goal of these systems is standardization. The objective of standards in e-learning is, among other things, the establishment of compatibility between systems and the rationalization for easy reuse of contents. The first point plays only a subordinate role from a technical point of view concerning the implementation within EasyGSH_ModLearn. A far more important aspect is the granularity and reusability of the information. The concept on which the standards are based means **Re-Usable Learning Objects (RLO)**. A learning object is a completed learning unit with a fixed learning objective that can be used in isolation and also in different overall contexts see (Carstensen und Barrios 2004). With the use of RLO it is possible to define small modular information units which can be combined into entire page content reused in different contexts.

⁹ SCORM – Sharable Content Object Reference Model

¹⁰ Aviation Industry CBT Committee

¹¹ IMS Global Learning Consortium; das Akronym IMS wurde als Eigenname beibehalten, wobei die Bedeutung der Abkürzung nicht mehr verwendet wird.

The EasyGSH-DB information platform was implemented with Open Source tools like Java Script, PHP and Ajax Technology for data processing and presentation. The data are stored in a MySQL database. The platform database divides the data into two logical groups. The first group consists of cached and primarily processed metadata records. These are each related to one product and are generated and updated by the data server on which the data products are available for access. This data includes attributes which contain information about the data sources, positioning, level of detail, reachability, and links between each other. The second group consists of RLOs classified into articles and definitions categories. Requested page contents are generated for visualization from the link of metadata and RLO articles based on page templates. Concerning important keywords and terms, the RLO definitions can be called up by moving the mouse pointer over the word in a small pop-up window.

The final implementation was realized in cooperation with the startup company [kontextlab](https://www.kontextlab.com). Kontextlab provides interactive online software that meets the listed requirements. The approach of [kontextlab](https://www.kontextlab.com) (<https://www.kontextlab.com>), last access at 8.4.2020) derives initially from online-journal [DerKontext](https://derkontext.com) (<https://derkontext.com>), last access at 8.4.2020). The concept of this commercial journalism is to grasp a comprehensive topic for the journal subscribers in all its complexity with the help of an interactive topic map. The individual connections should also be made clear, and the exact technical implementation of the graphic representation is therefore not part of the documentation. The technical interaction takes place through distributed generation of the page content on the server of [kontextlab](https://www.kontextlab.com) and the Institute of river and coastal engineering at TUHH. The virtual database platform together with the contents is instantiated on a server of the institute of river and coastal engineering.

Alternative free implementations of the graphical operation were tested with different approaches from the Data Driven Documents (<https://d3js.org>) without the support of [kontextlab](https://www.kontextlab.com). None of the results led to such a mature implementation like that of [kontextlab](https://www.kontextlab.com).

8.4 Product information platform

As a result, a knowledge platform (<https://easygsh.wb.tu-harburg.de/>) was implemented which clearly provides the relevant knowledge about the project in the form of a theme map. In terms of content, the information platform offers interested users the opportunity,

- to get an overview of the model area and an insight into the field of contrasting contexts, in which the individual actors move (category “German Bight”)
- to find out about the most important and considered physical processes (physical processes”),
- to understand the individual data sources and methods used (“models and data sources”) and
- to browse the products and possible applications in a visually structured way (“find and understand products”).

The theme can immerse into the topic map according to the categories mentioned via the start page (Figure 73). As the zoom level increases, more and more background information and linked knowledge is presented (Figure 74). Ultimately, the users decide according to their interests and information needs which topics are most important for them.

The central category of the information platform is dedicated to the (“find and understand products”). The focus is on the products generated in the project and the exemplary applications within the framework of the prototyping partnerships. Figure 75 shows the information provided exemplary for the product Bathymetry. This information consists of the one hand of processed metadata of the product like download information, thumbnails, data generation, contact information and legal restrictions and on the other hand of knowledge blocks e. g. explanations about the product.

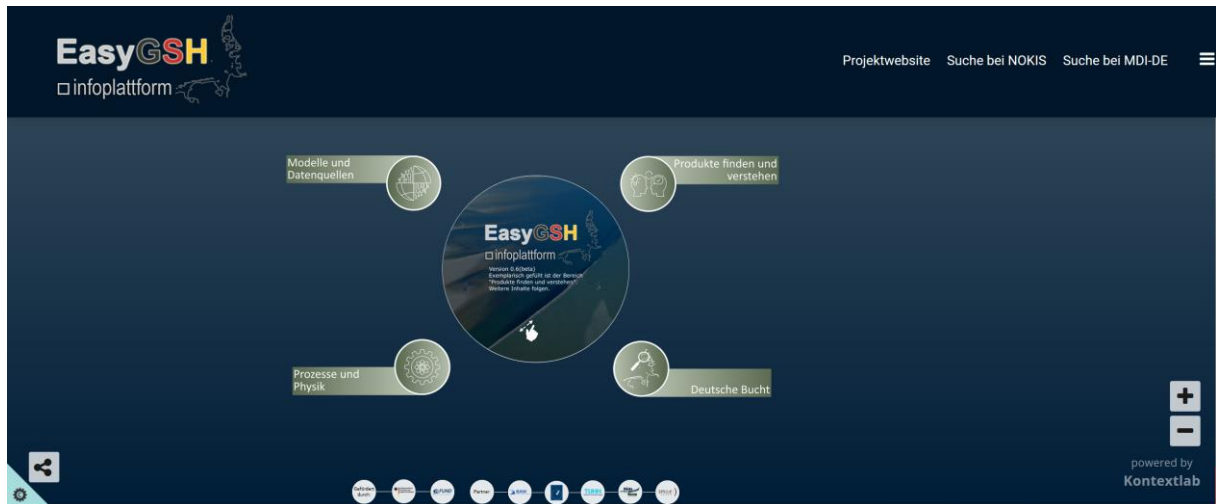


Figure 73: EasyGSH-DB-Information platform: start page.

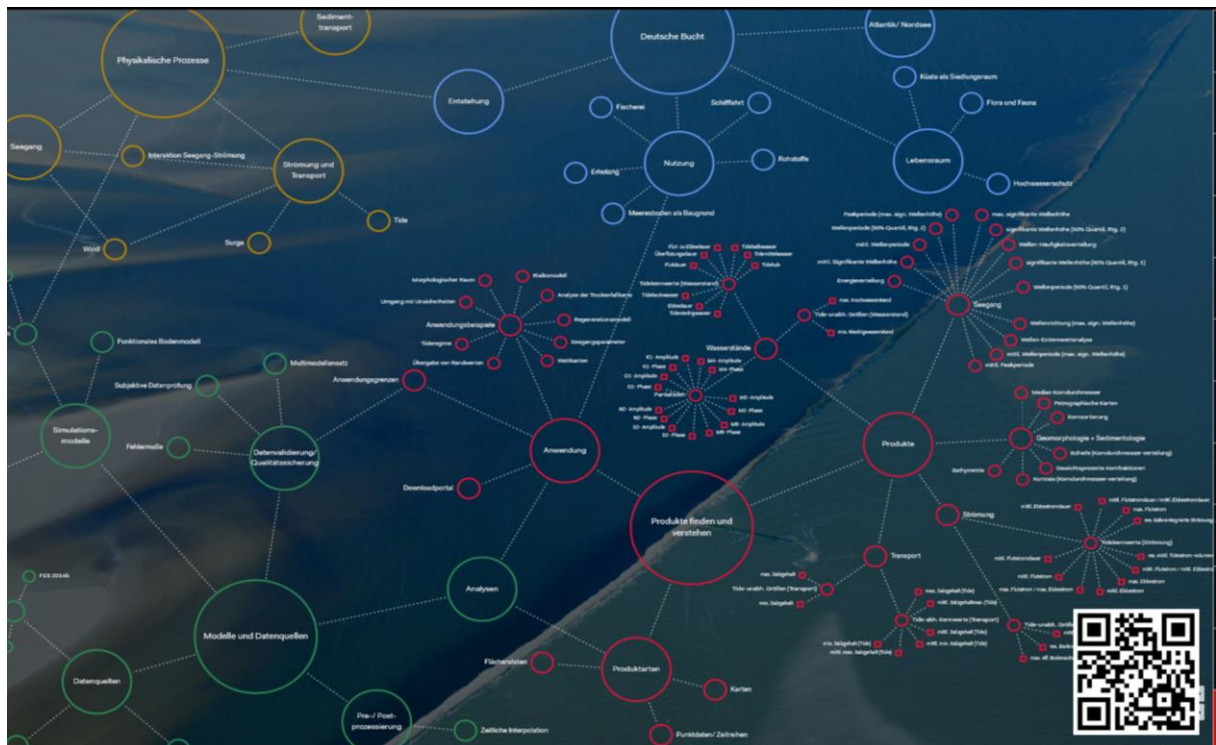


Figure 74: EasyGSH-DB-Information platform: theme map.

The page is set up on-the-fly after the user clicks. The prototyping partnerships are discussed in the application examples (Figure 76). Information about each prototyping partnership is provided here in the form of a fact sheet containing work content, question, spatial reference, time reference, topic reference, products, work steps, results.

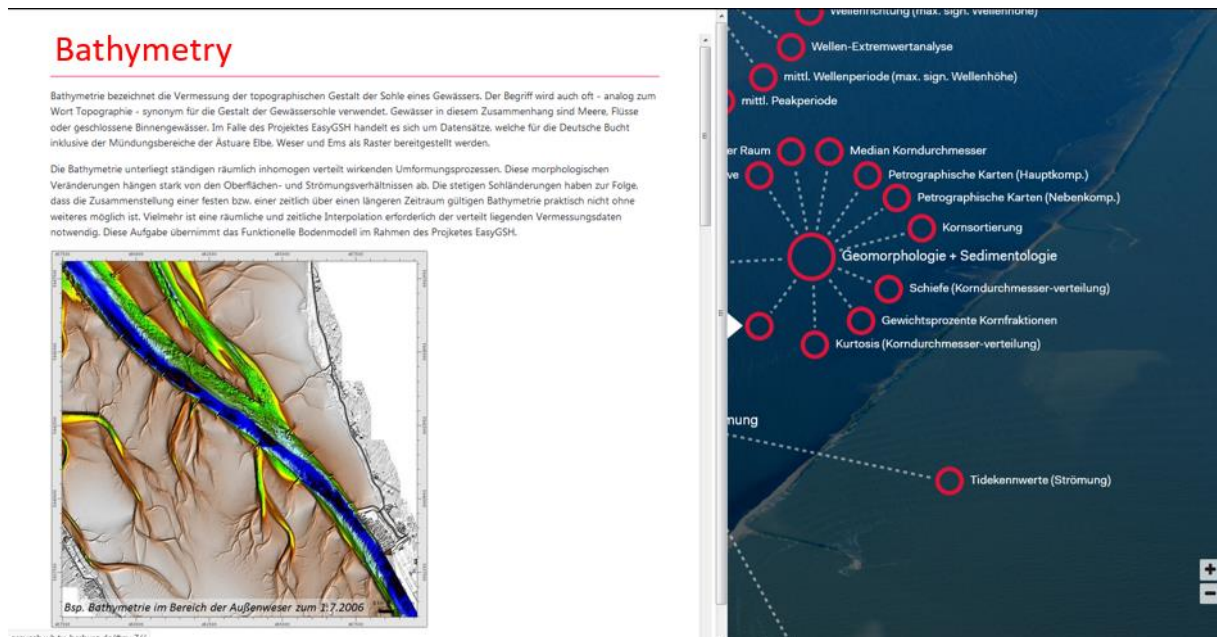


Figure 75: Processed information on EasyGSH-DB products: Bathymetry.

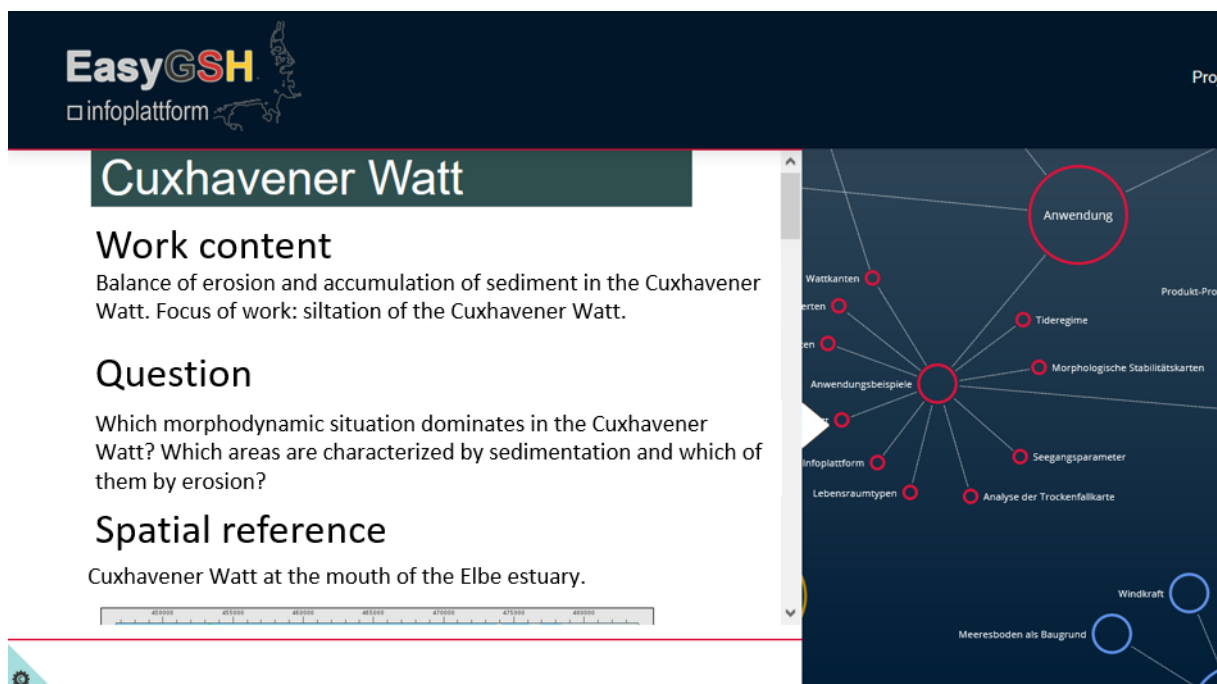


Figure 76: Fact sheet of EasyGSH-DB prototyping partnership: „Cuxhavener Watt“.

9 Data management

Data and products are often forgotten after the end of a research and development project (R & D). Therefore, early in the EasyGSH-DB project, thoughts were given to the data storage and publication beyond the project duration.

Although the data from the R & D projects are not yet covered by the Electronic Administration Promotion Act (**E-Government-Gesetz**: EGovG 2013) or the INSPIRE-guideline (Infrastructure for Spatial Information in the European Community) these specifications of guidelines were considered. The increase of regulations for supply of project results rises for example by the Environmental Information Act (UIG 2013). The transparency intended by this and the associated increased offer of data sets, however, cause problems. At the beginning of a project, data volumes and scope are difficult to estimate. Therefore, a data management plan must be revised throughout to meet technical requirements. There are many open questions in the areas of data storage and publication, formats, licenses, quality assurance, metadata, and the technical implementation of standards to ensure the interoperability between the systems and portals. These questions create a need for clarification which exceeds the scope of a project, especially, if publications of research results become an increasing part of R & D projects.

EasyGSH-DB dealt intensively with the various ways of data publication to achieve easy accessibility to the created products as an essential precondition for acceptance and use by the addressed target groups. The infrastructure components of the BAW were used and further expanded for the implementation. Metadata and data services were written and created and simple entry points, previews and download components were generated.

During the course of EasyGSH-DB, several terabytes (TB) of raw data for the Functional Seabed Model (FBM, see Chapter 4) and the hydrodynamic model (HN-models, see Chapter 6) were prepared and processed on the basis of UnTRIM-SediMorph-UnK (see Chapter 6.1) und TELEMAC / TOMAWAC / SWAN (see Chapter 6.2). The data or products that are resulting from these models contain more than 2,500 data sets which have been processed and published.

9.1 Data management in the infrastructure node of the BAW

The products of EasyGSH-DB are provided via the infrastructure node of the BAW. This describes the hard- and software components of a local server architecture with which (geo-)data and metadata are managed (Figure 77). At the same time, this data can be made available via standardized services. The NOKIS metadata editor (Lehfeldt und Reimers, 2008) is used to record metadata. Its metadata can be reflected via the Open Geospatial Consortiums (OGC) service as Catalogue Service Web (CSW) (Nebert et al. 2016) from external portals. So, that they can be found on other portals. Metadata are connected to the different data sources or storages via links. The data storages differ according to the format offered in web server and FTP server; other storages can be added as needed.

The Open Source solutions of Geoserver and a Thematic Real-time Environmental Distributed Data Server (THREDDS) (Unidata, 2018) are used as software on the web servers (Figure 77). The Geoserver is used for the publication of the analyzed results of geomorphology, sedimentology, and hydrodynamics in connection to a PostgreSQL data base with PostGIS extension for spatial services. OGC services like Web-Map-Service (WMS) see (La Beaujardiere 03-15-2006), Web-Feature-Service (WFS) (Vretanos, 2010) and Web-Coverage-Service (WCS) (Implementation Standard WCS, 2017) can be implemented via Geoserver in a standard-compliant manner.

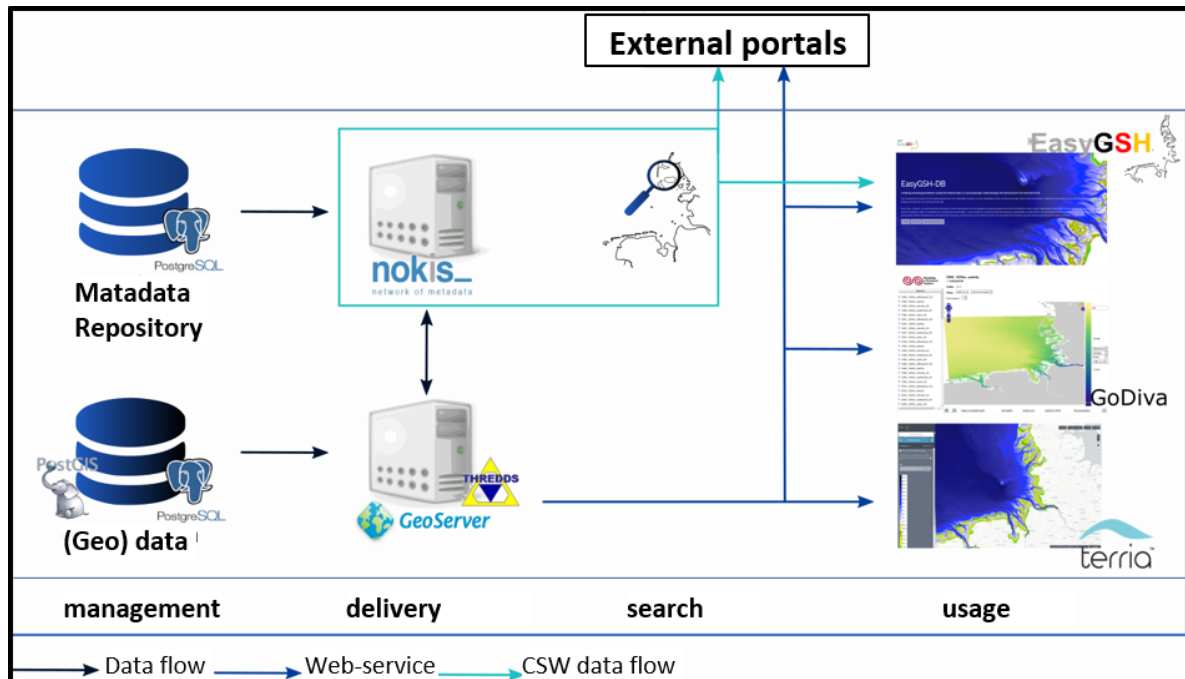


Figure 77: Data management in the structure node of BAW.

For the first time, the simulation results from the hydrodynamic modeling are provided in a gridded form for the whole German Bight. Due to the high data volume of model data the THREDDS data server is used, who stores the data and provides a direct download which can be built into portal solutions. The ncWMS is a WMS for geodata stored in CF-compatible NetCDF files.

Several online offers for the products of EasyGSH-DB were set up to make the results visually appealing and at the same time make it easier for the user to understand the data. All described ways of using the data are linked in the EasyGSH-DB data portal while the EasyGSH-DB information portal offers detailed explanations. Above all, the individual parameters can be considered and compared in the viewers. The data from the OGC services are called up directly from the server (see Chapter 9.2.3). So, the current version of data and metadata is always available to the user.

9.1.1 Data changes over the project period

Since the beginning of EasyGSH-DB, the data have changed from the model up to the publication due to adjustments and improvements. At four points in time the data were evaluated with markings 1 to 10 according to

- Processed and generated data saved on servers (*Volume*),
- Velocity of data transfer (*Velocity*),
- Velocity of data transfer (*Value*),
- Details of additional information and metadata for traceability and control (*Veracity*) and
- Number of data formats processed or published (*Variety*)

This was done to monitor the changes in the data and to identify the need for improvement. 1 to 10 stands for:

- *Volume* (1: <50 GB; 10: 150-130 TB),
- *Velocity* (1: 30 days, 10: <=1 min),
- *Value* (1: inhomogeneous data, many sources; 10: data basis 20 years),
- *Veracity* (1: no metadata, 10: complete metadata with documents and data links) and
- *Variety* (1: only measurement data; 10: measurement data, sensor data, structured data, raster, vector data and more).

While volume, variety and velocity relate directly to the data, veracity and value reflect on the usage to be understood as a functional analysis. The four time points describe the data situation

a) before modeling, b) after modeling, c) after the analysis and the stakeholder survey and d) after finished and released products (Figure 78).

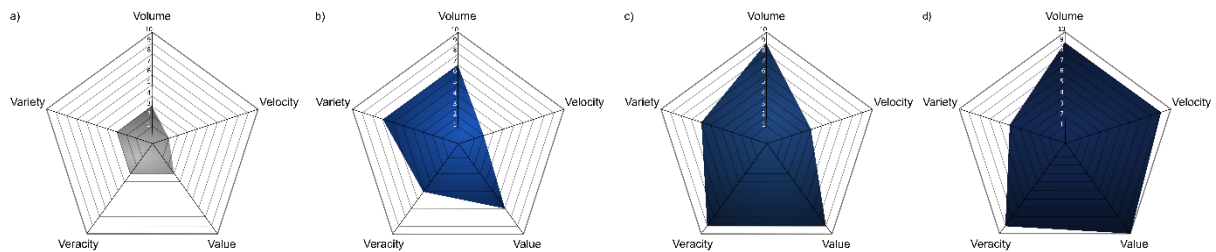


Figure 78: Change of data criteria during project period.

The project starts with a high level of inconsistency in the input data, undocumented uncertainties and a distributed data volume with different data formats. The distributed data situation made sure, that several data had to be obtained via long request paths. The general differences (e. g. technique, format or spatial / time resolution) made usability more difficult. The data were processed with the modeling, reviewed for errors and uncertainties, and the inconsistencies were eliminated through harmonization. As a result, the data volume of the simulation data of the North Sea Model calculated for 20 years increased steadily. The description using validation documents and annual identification sheets for disclosure of ambiguities and uncertainties increased the volume of data enormously.

The usability increased through understanding of user requirements for special data from the analysis and modeling with the implementation of stakeholder surveys. All data have been provided with metadata at this point. With the finished product in the final formats (Variety) the number of different data formats fell by screening. In this way, the data processing speed could be improved online, and the combinations of data yielded new results.

9.2 Data publication

Comprehensive metadata documentation is necessary for the long-term publication of the extensive and homogeneous data. The infrastructure node of the BAW served as the basis. This made it possible to use the OGC-conform services through the software of the web server. The application of OGC CSW allowed building project websites without being dependent on the website when displaying the data. Products are also offered in different formats; this encouraged use of the OGC services.

A WMS was used for the presentation of vector and raster graphics – both in the viewer and for thumbnails. Download possibilities were realized by a WFS for vector data and a WCS for raster data. An OGC-compliant service is simply referred to as a service.

Users of geographic information systems can utilize the data on their computers through the addresses of the services regardless of websites. This structural basis allowed extensive publication of the EasyGSH-DB products. The data are divided into the subject category's geomorphology, sedimentology, hydrodynamics, and prototypical products to put in order the large volume of data and the publication. Each subject categories got a data DOI.

Two publications concerning the **data collections** are available:

- An Integrated Marine Data Collection for the German Bight – Part I: Subaqueous Geomorphology & Surface Sedimentology
J. Sievers, P. Milbradt, R. Ihde, J. Valerius, R. Hagen & A. Plüß
<https://doi.org/10.5194/essd-2021-47>
- An Integrated Marine Data Collection for the German Bight – Part II: Tides, Salinity and Waves (1996–2015 AD),

R. Hagen, A. Plüß, R. Ihde, J. Freund, N. Dreier, E. Nehlsen, N. Schrage, P. Fröhle & F. Kösters

<https://doi.org/10.5194/essd-2021-45>

9.2.1 Data portal

A data portal serves as the central element for the presentation of the data from the project EasyGSH-DB. It offers an easy start and provides the user with all relevant information or references for use and understanding of the EasyGSH-DB data. The focus of this data portal lies on:

- free data download,
- the fast and visually appealing visualization,
- providing technical documentation e. g. for model validation,
- providing the documents from stakeholder workshops, conferences, or other publications.

The data portal can be reached under www.easygsh-db.org (see Figure 79), which is a domain forwarding to <https://mdi-de.baw.de/easygsh/EN>, which is a part of the infrastructure of the BAW. The domain forwarding was set up for better reusability and due to the visually appealing name.

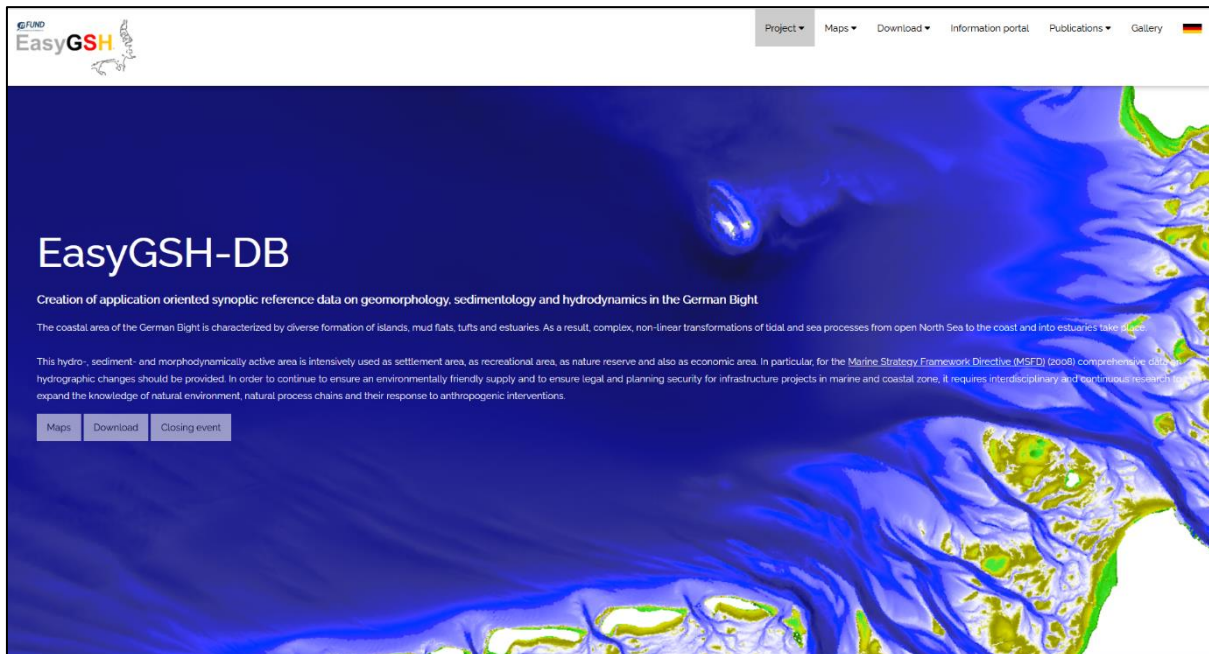


Figure 79: Homepage of EasyGSH-DB-portal.

In addition to the data portal the information portal (<http://easygsh.wb.tu-harburg.de>) was created which then links all relevant information to explanatory information clusters (see Chapter 8).

9.2.2 Download

Obtaining data is often difficult and associated with user registration, fees or inquiries. Therefore, it should be particularly simple to obtain data in the project EasyGSH-DB. Stakeholder surveys made clear, that access must be easy and quickly to be found. Therefore, there are a total of three entry points above:

- 1) task bar,
- 2) the "download" button on the home screen of the data portal and
- 3) the digital catalogue (Figure 80)

In addition, paths for calling up the data packages and the web service are stored in the metadata. Therefore, they can be reused on the information platform via utilization of the CSW services.

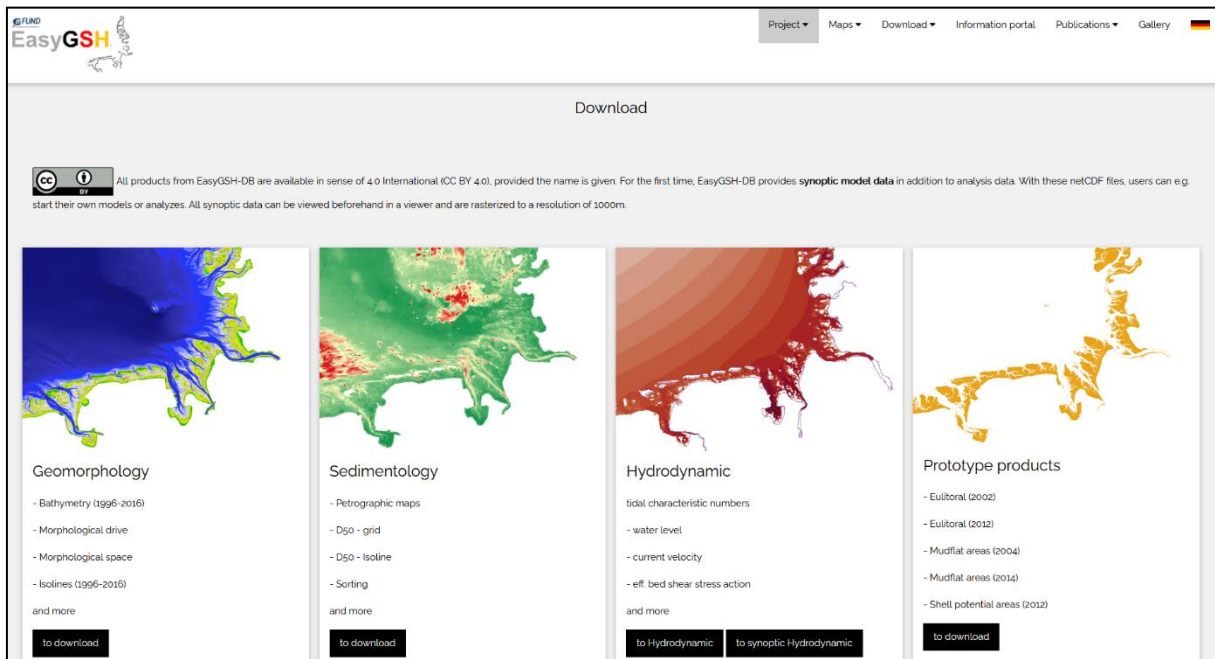


Figure 80: Download blocks within the EasyGSH-DB-portal each subject area has its own entry sector (see Figure 81) and is subdivided to the publication year and the relating product.

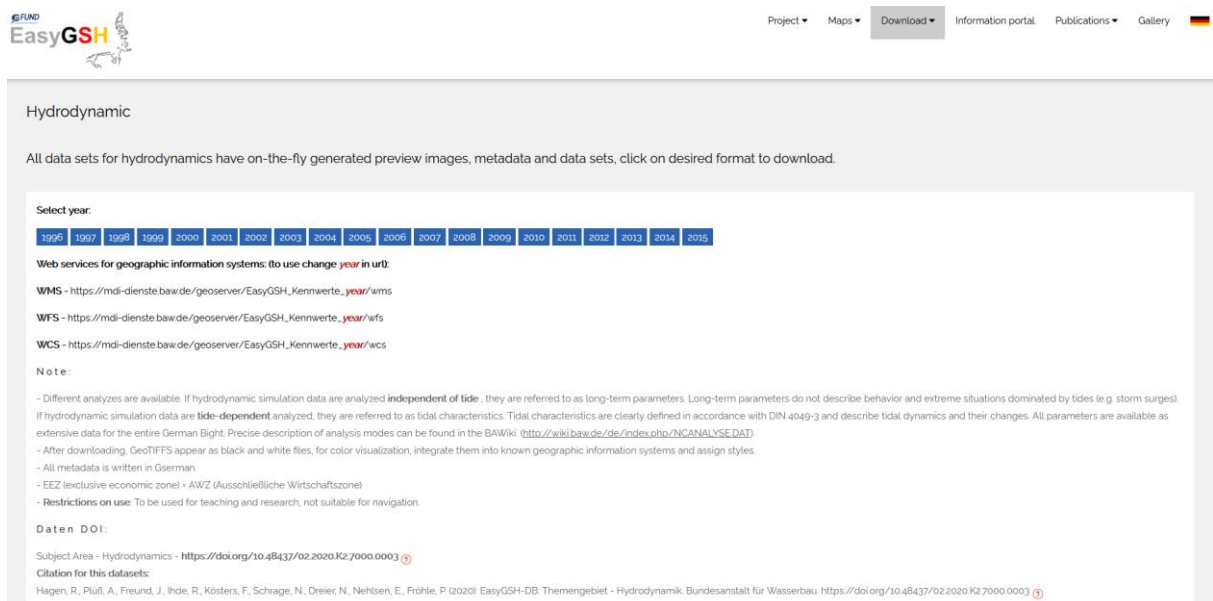


Figure 81: Entry into the download area of hydrodynamics with listing the years, in which data were available, web services for geographic information systems, links to documents, data DOIs and comments regarding notes on possible download problems.

The subject areas are subdivided into year → group of characteristic value → product (Figure 82). Each product is downloaded via a direct service call whereby the WFS for the vector data and the WCS for the raster data can be called up in the background. WFS call can call up the download formats JSON, GML, Shape or CSV. A WCS call can return similar formats like a WMS. A WCS primarily returns more information including metadata. As a result, a WCS is a WFS for raster data.

The direct download calls are done under "Format" where the respective loadable format is listed. For the preview image the WMS function is used and an illustration from the Geoserver is created.

The metadata is also delivered via a service, in this case offered as PDF and XML about the CSW request. The user can request the download, the preview and metadata as needed. This will keep

the actual data transport volume low but at the same time all relevant information is available.

A disadvantage of querying on demand is the time that the server needs to generate the desired for the high resolution 10 m data. The query can take up to 2 minutes, especially if the server is very busy. Therefore, ready-made zip packages would also be offered for some products that are on an FTP server. These packages contain additional information like styles or - if available – data source maps and data density maps.

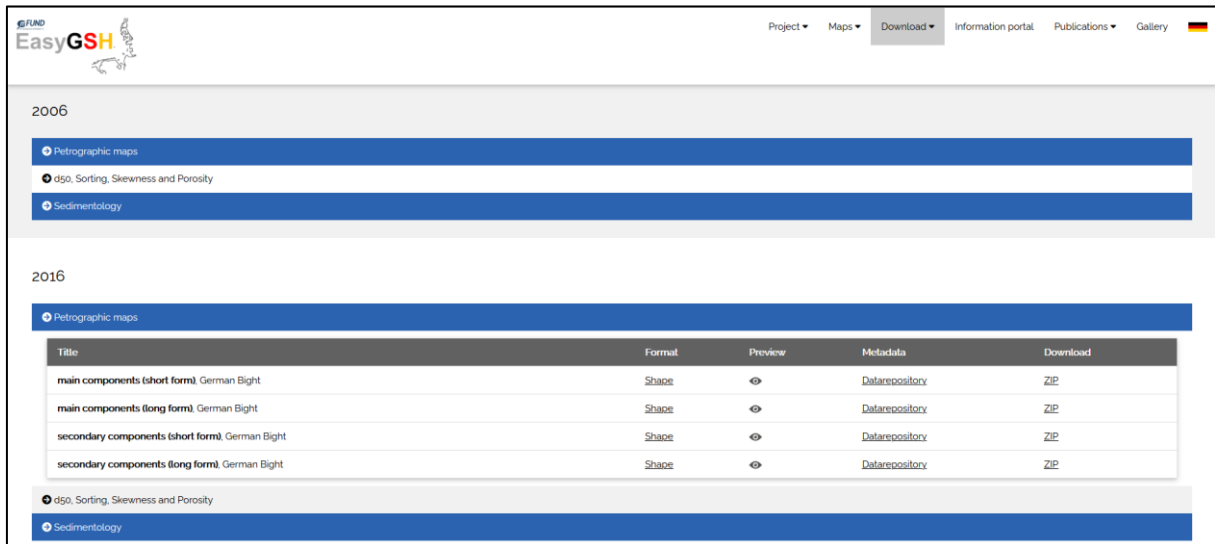


Figure 82: Example for sedimentology in 2006 with the characteristic value groups. “Petrographic data”, “d50, sorting, skewness and porosity” as well as “sedimentology”.

The options to download are offered via the format, a preview, metadata or a zip package for the products.

Not all products can be represented by vector or raster data. Therefore, other available data formats are of type *.csv, *.txt and *.dat. Above all, the simulation results for the synoptic hydrodynamics in NetCDF format require a special solution due to their data volume. The THREDDS data server was used for this kind of data and stores it in the netCDF format and so offers the possibility to make this data available to the user via a HTTP server service for download. Furthermore, data's own metadata can be read and offered out of the netCDF header (NCML).

All data that is created and offered over the course of the EasyGSH-DB project are under the Creative-Commons-License 4.0 (by attribution 4.0 International (CC BY 4.0)). This means that the data may be shared and reproduced in each formula and that the data may be processed, changed, and be used for any purpose, including commercial use, under condition of attribution.

The attribution must receive appropriate copyright and right information as well as information about changes to the original data. This should not give the impression that the project EasyGSH-DB particularly supports this use.

A total of 2500 data records for download are offered in EasyGSH-DB and considering the different data formats. A comprehensive table with all data products is in the appendix (Chapter 0).

9.2.3 Web service of EasyGSH-DB

EasyGSH-DB offers, in addition to the direct downloads, a number of OGC-conform web services. These uniform resource pointers enable users to load the various web services in their own geographic information systems or their web applications. The paths can be found via the menu item “Maps -> Overview” or in the general information and control areas of the downloads (see Figure 81). A list of addresses for WMS, WPS and WCS can be seen in Table 11.

Table 11: URL of the web services of EasyGSH-DB products for GIS. For the simulated characteristic values of the hydrodynamics, the desired year (in *red*) must be inserted in the URL.

Theme	Service – WMS
Geomorphology	http://mdi-dienste.baw.de/geoserver/EasyGSH_Bathymetrie/wms
Sedimentology	http://mdi-dienste.baw.de/geoserver/EasyGSH_Sediment/wms
Hydrodynamic	http://mdi-dienste.baw.de/geoserver/EasyGSH_Kennwerte_year/wms
Prototyping Products	http://mdi-dienste.baw.de/geoserver/EasyGSH_ProtoProdukte/wms
	Service – WFS
Geomorphology	http://mdi-dienste.baw.de/geoserver/EasyGSH_Bathymetrie/wfs
Sedimentology	http://mdi-dienste.baw.de/geoserver/EasyGSH_Sediment/wfs
Hydrodynamic	http://mdi-dienste.baw.de/geoserver/EasyGSH_Kennwerte_year/wfs
Prototyping Products	http://mdi-dienste.baw.de/geoserver/EasyGSH_ProtoProdukte/wfs
	Service – WCS
Geomorphology	http://mdi-dienste.baw.de/geoserver/EasyGSH_Bathymetrie/wcs
Sedimentology	http://mdi-dienste.baw.de/geoserver/EasyGSH_Sediment/wcs
Hydrodynamic	http://mdi-dienste.baw.de/geoserver/EasyGSH_Kennwerte_year/wcs

9.2.4 Viewer

Two viewers were set up for the web presentation of EasyGSH-DB products. Both of which represent their content on the basis of web services (Figure 83). The viewer for the NetCDF data can be reached under <http://mdi-dienste.baw.de/ncWMS2/Godiva3.html> and the second viewer under https://mdi-dienste.baw.de/terria_en/.

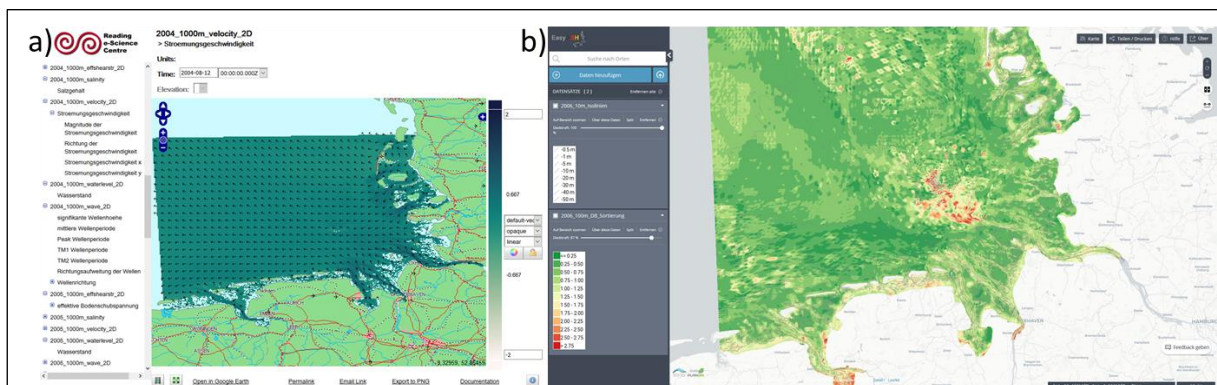


Figure 83: Viewer for presentation of synoptic hydrodynamic a) on basis of netCDF-format; b) viewer to present the web services from Chapter 9.2.3.

THREDDS provides, besides the ability to publish and localize netCDF files, also the possibility to analyze and visualize them. Smile consult GmbH developed a grid tool which converts the unstructured data to structured raster data to represent the unstructured simulation data via THREDDS. These structured raster data can be used from the THREDDS web map service application, the ncWMS (software version 2.4.1., developed by Reading e-Science Center (ReSC)). This enables the netCDF-Java Common Data Model to recognize the coordinate system of the data and to generate a ncWMS service. The ncWMS is a WMS for geodata which have been saved in CF-compatible netCDF files. The Web-Client GoDiva3 (see Figure 83), which was developed for the ncWMS2 software, visualizes the map service and allows additional functions like animation, creation of local time series as well as their download. The document „Visualisierung der synoptischen Hydrodynamik - Kurze Einführung für den Umgang mit dem Godiva Webinterface zur Visualisierung der synoptischen Hydrodynamik aus dem mFUND-Projekt: EasyGSH- is to be found on homepage

https://mdi-de.baw.de/easygsh/EasyEN_index.html#publication || and in German only: https://mdi-de.baw.de/easygsh/assets/Dokumente/Info/Visualisierung_syn_Hydrodynamik.pdf.

The second viewer (Figure 83) serves to display the vector and raster data which are not available on netCDF base. For this the free software TerraJS from *CSIRO's Data61* were used in which the OGC-conform web services (Chapter 9.2.1) were integrated. Hundreds of layers can be processed at different labels. So, the user can answer questions by superimposing data or add his own data via “add data → my data” and evaluate them together e. g. through the comparison tool. The individual information as offered for each product derives from the metadata on the Geoserver. The data can also be downloaded directly here.

9.3 Metadata

It is fabulous to provide data for download free of charge! However, data alone is difficult or impossible to understand without additional explanations. Metadata is required for this. The aim of EasyGSH-DB project is to generate metadata. These serve as the basis for data provided to be comprehensive, usable, findable and combinable as well as online and offline (Figure 84). Correctly written metadata answers the important questions: *Who, Where, Why, What, When, and How*.

All metadata created within the scope of the EasyGSH-DB project were described with ISO- and GDI-DE-compliant metadata. The standard from ISO 19115: „Geographic Information – Metadata“ (ISO 19115:2003), with extensions to the new status 19115:2014 was used as a basis. The INSPIRE (European Commission Joint Research Center, Metadata Drafting Team 2010) requirements have been considered too.

The standard of ISO 19115 provides information about the geographic data or the geographic services. The standard of ISO 19115 provides information about the geographic data or the geographic services. The so-called metadata minimum component must be filled in with information to make metadata usable. These consist of about 22 elements among other identification, scope, quality, spatial representation, spatial reference or distribution. Filling the minimum mandatory subsets of the ISO standards leads to interoperability between different metadata information systems. Comparability, semantic integrity and a rough quality assurance are made by standardization. As a result, metadata can be searched for and passed over across systems.

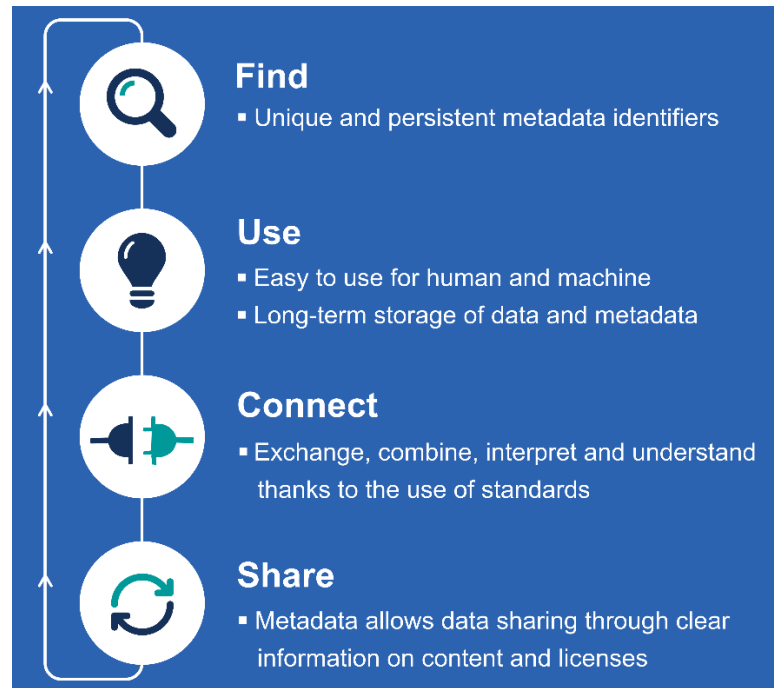


Figure 84: Goal of creation / usage of metadata.

The minimum component of metadata is not sufficient for comprehensive use of the associated data sets. Therefore, an extended metadata profile was used in EasyGSH-DB. The usability of the metadata is significantly increased by applying additional optional elements of origin, purpose and use (ISO 19115-1:2014, Ahlhorn 2018) to the mandatory elements. With the revised version of ISO 19115-1:2014 much of the data quality elements have been moved to ISO 19157 „Geographic Information – Data Quality“ (ISO 19157:2013). Data quality is expressed by the data quality elements. These are described by data quality measurements (like test suites), evaluation of data quality (in case of quality flags), and the overall metadata. The ISO standard writes that the data quality can be recorded in the metadata and in standalone quality reports.

Particularly in the context of metadata collection it was determined that the standard elements are not sufficient to capture numerical simulation results from hydrodynamics in netCDF format. In addition, the header of the netCDF files is therefore automatically filled with metadata by the BAW project DMQS. This metadata can be viewed on the website of EasyGSH-DB under the rubric: synoptic hydrodynamics. Quality reports in terms of a validation document for the North Sea Model and the annual identification sheets have been written and linked into the metadata by DOIs to increase quality. For final improvement the metadata quality was verified by the XML checker „zur Bewertung der Metadatenqualität (Beta-Version- German)“ in a working group of „Küstenforschung Nord- und Ostsee (KÜNO)“. This web application searches the XML for certain quality elements and creates a quality label on the basis of SeaDataNet. The best achievable quality rating is momentary “Quality checked: (Probably) Good”. EasyGSH-DB metadata got it.

By using the ISO standards, metadata can be reflected from the infrastructure node to other external portals via the CSW interface. This process is called harvest mechanism and allows other portals to provide the metadata without supplying data by themselves. This is done by linking of databases on serves and metadata and keeps the data transport volume low without losing relevant information about the data. A clean and comprehensive linkage between data, services and metadata is important thus service-oriented portal architectures like MDI-DE and metadata-oriented portal architectures like *mCLOUD*, GovData or GDI-DE can harvest the same quality of data (Figure 85). The required key words are used as merging element for the EasyGSH-DB data products with external portals e. g. “*mFUND*-project: EasyGSH-DB” and “*mFUND*-FKZ: 19F2004” for the *mCLOUD*.

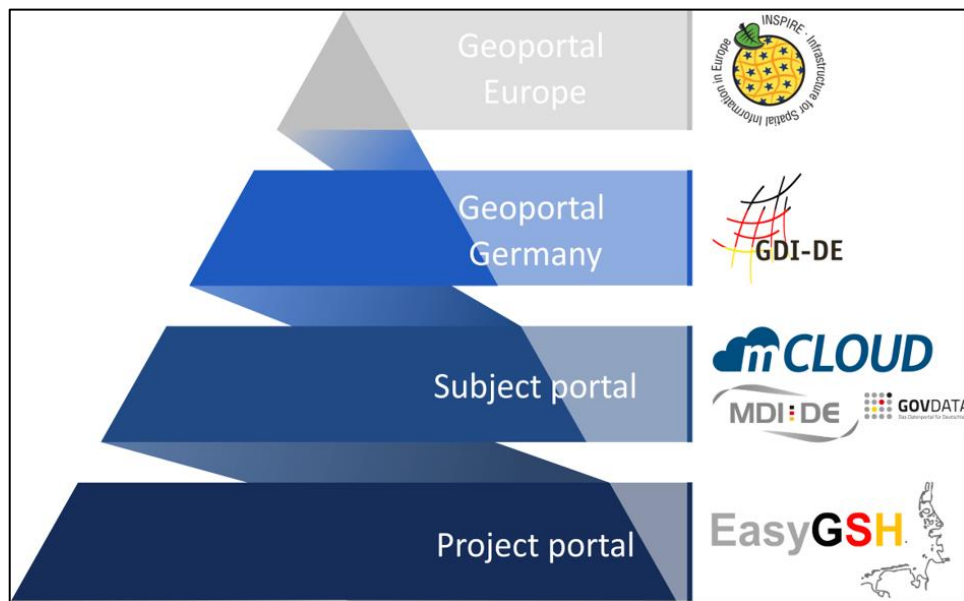


Figure 85: Harvesting path from project portal to the individual geoportals. Over the CSW-interface different metadata information systems / -catalogues provide data and metadata and be applicable for a wider user community.

9.4 Result evaluation

Results only had to be prepared once for the web and can still be used in different systems due to the use of standardized services, downloads and visualizations in connection with metadata. This consistently processed publication of the data allows a simple and quality-assured utilization of the R & D data of EasyGSH-DB. In the end, 2525 datasets (as of March 2020) were published within the project for downloading (Figure 86). Linkage through metadata to portals as *mCLOUD*, MDI-DE, GovData and GDI-DE help to make the data available to a large user community. However, it must be also considered that effort has been incurred for the data provision in the project. The usability is dependent on the efficiency of the available IT hard- and software environment. The basic feasibility for a limited number of user accesses could be shown within the framework of the project for the databases generated there.

The legal framework for providing the data could be implemented as **CC by 4.0 licenses** through the obligation to deliver to *mCLOUD*. As a result, the data can be freely used as open data by all interested parties, but only attribution is mandatory.

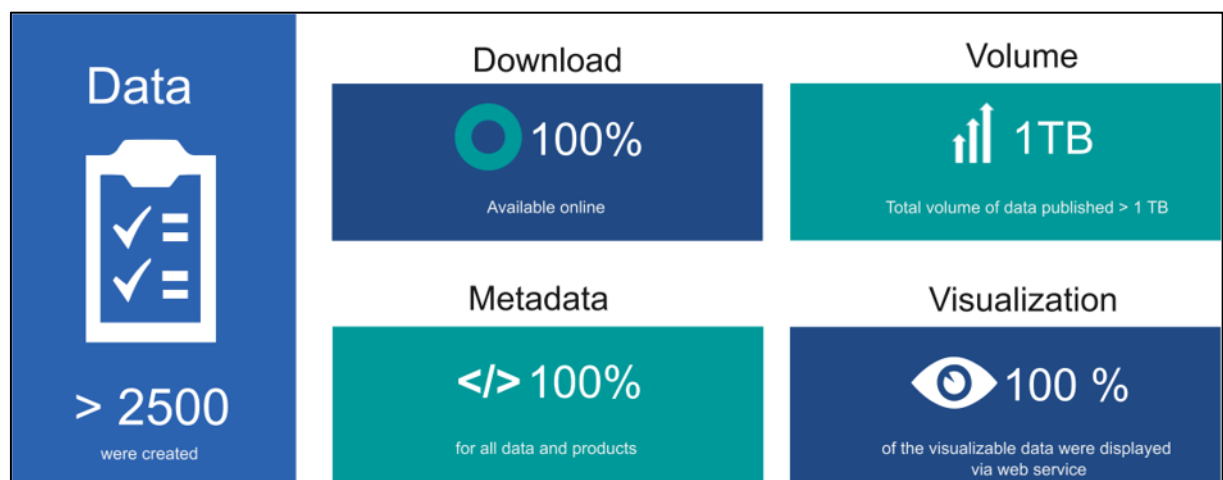


Figure 86: Summary of data management and -visualization in EasyGSH-DB.

10 Summary

In the framework of the joint project EasyGSH-DB under the direction of the BAW spatial, harmonized and quality-assured **reference data sets** for geomorphology and sedimentology as well as hydrodynamics in the German Bight are worked out. For this purpose, all available and extensive **nature measurement** data are linked with different **simulation models**, some of which were newly developed in the project. Temporally and spatially highly resolved synoptic reference data sets result from the subsequently performed numerical simulations over a period of 20 years (hind cast: 1996 – 2015). With numerous analyzes the EasyGSH-DB products are derived. They are made freely available to the (professional) public as starting data for their own applications (<https://mdi-de.baw.de/easygsh/>).

The **geomorphological** and **sedimentological** products are based on data-based hind cast simulation models on the basis of an extensive data base of measurements and samplings. These are linked via process adapted spatial-temporal interpolation and approximation methods. The annual bathymetries thus generated are supplemented by the sedimentological products. They form the basis for the synoptic / process-based simulations of hydrodynamics in the North Sea with a special focus on the German Bight.

Regarding the quality assurance of the data generated and published here, two independent modeling systems for simulation of tidal dynamics, salt transport and waves are used as a part of **the multi model approach**. One of these is the model family UnTRIM/SediMorph/UnK. The other one is the model family TELEMAC. Furthermore, SWAN is used as third sea state model. These simulation models were operated with the same boundary conditions, wind fields and annual bathymetry distributions. Due to the multi model comparisons, model-related uncertainties are limited by considerations at discrete points (e. g. gauge positions). In addition, the options to assess the quality of the model results in unobserved areas have been significantly expanded.

The later use of the generated spatially and temporally high resolution simulation results is guaranteed by the calculation and provision of EasyGSH-DB products for the German Bight. These are **synoptic** data and **annual characteristic analyses** which can be downloaded via the EasyGSH-DB data portal.

Some **tide-independent** analyzes (long-term characteristics) are calculated as EasyGSH-DB products. They describe the synoptic parameters as a frequency distribution, so they are independent of time or tide. Otherwise, **tide-dependent** analyzes (tidal characteristics) are carried out which define the tide dynamics and their spatial / temporal changes. All characteristic values are available as spatial data for the entire German Bight and can be obtained as GeoTiff on a 100 m grid (see <http://mdi-de.baw.de/easygsh/index.html#p4>)

Goal of the project-accompanying **participation process** was collecting **user needs** regarding the reference data sets to be created and the participatory development of application-oriented data products. Due to a comprehensive stakeholder analysis a large number of potential users from the areas of research, administration and economy could be identified which were included in the further course of the project through various information offers. A representative number of stakeholders were selected and directly integrated in order to be able to successfully implement the goal of direct application-oriented cooperation between project partners and stakeholders for the creation of prototyping products. In the framework of the survey of user needs, 50 persons in total from 23 institutions were consulted in individual and small discussions and they were questioned in terms of structured interviews.

The results of the **need analysis** were condensed into product ideas in terms of **participative product development** which were further developed in the course of the project in working groups of project partners and interested users up to prototypical application. Eleven prototyping partnerships (PPs) could be initiated out of a group of participants from more than 20 stakeholders from 13 different institutions. They worked over a period two years on questions from various

subject areas like geomorphology and sedimentology, hydrodynamics, modeling, data provision requirements or complex cross-sectional tasks as ecological settlement potential. Various approaches have been successfully pursued and applicable data products at different level of development up to concrete applications in the administration were produced.

Additional to a formally standardized description of synoptic reference data on **metadata**, a so-called **information platform** was set up (<http://easygsh.wb.tu-harburg.de/> and linked to the project portal https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/Informationsportal.pdf). The EasyGSH-DB information platform provides in-depth information of the products and their possible use and for further relevant knowledge, e. g. on the used models and data sources, important physical processes and of the project area German Bight, clear and structured in the form of a thematic map. Intuitive operation via different entry points and variable information depth enables the user to quickly get started with the products and applications of EasyGSH-DB reference data sets.

In addition to the very extensive analysis data, the **synoptic model data** is provided in a standardized spatial grid and temporal resolution as **netCDF files**. This allows users to e. g. drive their own models or start analyzes. Due to the intensive exchange in the prototyping partnerships the limitations and challenges that come along with the reference data set supplied from EasyGSH-DB project became clear.

The publication of the synoptic reference data takes place on a **portal** designed for this purpose (<https://mdi-de.baw.de/easygsh/EasyEN>) which is operated and maintained by the BAW in the long term. Thanks to use of standardized service, downloads and visualizations in connection with metadata, the results only had to be prepared once for the web. Nevertheless, they can be used in different systems. Linking through metadata to portals like *mCLOUD*, MDI-DE, GovData and GDI-DE will help to make the data available to a large user community in the future.

The legal framework for making the data available is implemented as **CC by 4.0 licenses** through the obligation to give it to the **mCLOUD**. This means that the data can be freely used as open data by all interested parties, but only attribution is mandatory.

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12 Glossary

ALS	Ambient light sensing / air borne laser scan
AufMod	Model-based analyses of long-term morphodynamic processes in the German Bight (https://edocs.tib.eu/files/e01fb14/780783271.pdf)
AWZ	German exclusive economic zone (BJNR, ELWIS).
CSV	Comma separated Value
CSW	Catalog Service Web
DB	Deutsche Bucht, Engl: German Bight
DGM	digitales Geländemodell, Engl: digital terrain model
DMQS	Datenmanagement und Qualitätssicherung (BAW) (http://misdb1.karlsruhe.baw.de)
DOI	Digital Object Identifier (https://www.doi.org/)
DSGVO	Datenschutzgrundverordnung (https://dsgvo-gesetz.de/)
EGovG	Gesetz zur Förderung der elektronischen Verwaltung (E-Government-Gesetz, Engl: Act to promote electronic government).
EPSG	European Petroleum Survey Group -EPSG: a Geodetic Parameter Dataset for collecting definitions, coordinate reference systems, and coordinate transformations - may be global, regional, national or local in application. (https://epsg.org)
F&E	Forschung und Entwicklung – Research and Development, Engl: Research and development – R & D
GDI-DE	Geodateninfrastruktur Deutschland, Engl: Geodata Infrastructure Germany (https://www.gdi-de.org/DE/GDI-DE/gdi-de.html?lang=de)
GML	Geography Markup Language is the XML grammar defined by the Open Geospatial Consortium (OGC) to express geographical features
HENRY	HENRY - Hydraulic Engineering Repository, a service of BAW (https://henry.baw.de)
Hind cast	A test of a mathematical model by using data from a past event
HTML	Hypertext Markup Language
http	Hypertext Transfer Protocol - is a stateless protocol
INSPIRE	Infrastructure for Spatial Information in the European Community
JSON	JavaScript Object Notation
LIDAR	Light Detection and Ranging is an optical remote sensing technique
MAE	Mean absolut error
MDI-DE	Marine-Data Infrastructure Deutschland (https://www.mdi-de.org/mapapps/?lang=de)
ME	Mean error
MR	Morphological Raum (Engl: morphological space)
MSL	Mean Sea Level
MSRL	Meeresstrategie-Rahmenrichtlinie, Engl: Water Framework Directive (WFD)
netCDF	Network Common Data Format: scientific data exchange format
NCML	NetCDF Markup Language: XML-Visualization for scientific NetCDF-Metadata
ncWMS	netCDF-Web-Map-Service is a WMS for Geodata, which is stored in CF-compatible NetCDF-files
OGC	Open Geospatial Consortium
OpenMP OMP	Open Multi-Processing is a programmer interface Shared-Memory-Programming on Multiprocessor-Computer
PDF	Portable Document Format
R & D	Research and development
RANSE	Reynolds-averaged Navier-Stokes Equations
ReSC	Reading e-Science Centre
RMSE	Root mean square error
SCORM	Shareable Content Object Reference Model: is a set of technical standards for eLearning software products which tells programmers how to write their code so

	that it can “play well” with other eLearning software and is the de facto industry standard for eLearning interoperability (https://scorm.com/)
sm	Seemeile , 1 sm = 1,852 km, Engl: nautical mile NM
TB	Terrabyte
THREDDS	Thematic Real-time Environmental Distributed Data Server
UIG	Umweltinformationsgesetz , Engl: Environmental Information Act http://www.gesetze-im-internet.de/bundesrecht/uig_2005/gesamt.pdf
URL	Uniform Resource Locators
WGS84	World Geodetic System 1984 - https://gisgeography.com/wgs84-world-geodetic-system/
WRRL	Wasser-Rahmenrichtlinie – https://www.UBA/WRRL Engl: EU Water Framework Directive - https://ec.eu/environ/water-framework
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
WWW	The World Wide Web
XML	Extensible Markup Language
ZIP	File format to compress datafiles

13 Appendix

13.1 Gauge location map

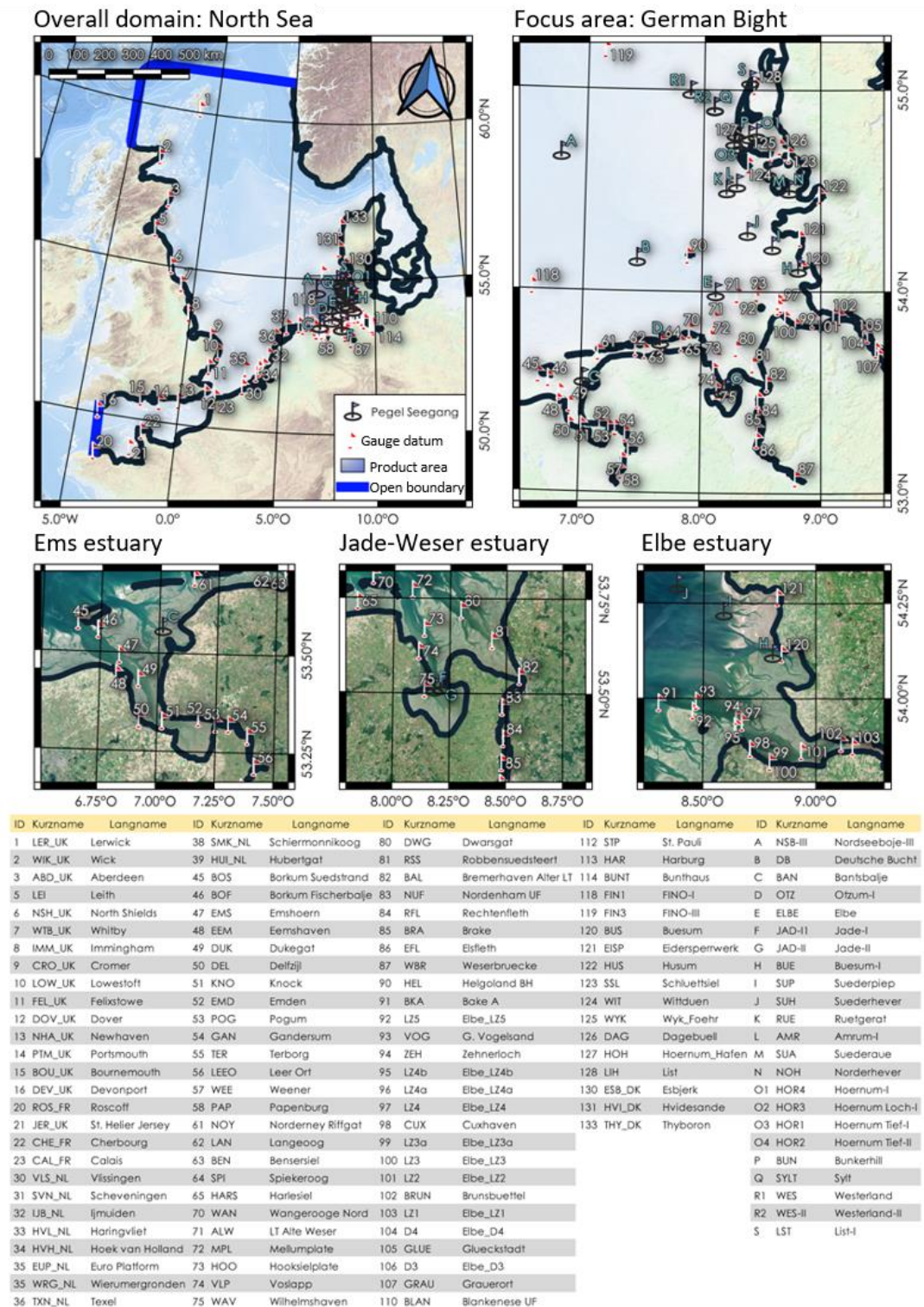


Figure 87: Overview of all gauging stations in EasyGSH-DB North Sea (upper left), focus area (upper, right), Ems (lower, left), Jade-Weser (lower, mid) and Elbe (lower right). Background: (EMODnet Bathymetry Consortium, 2016), changed Copernicus Sentinel Data since 2018.

13.2 Overview: Partial Tides

Table 12: Overview of here considered partial tides

acronym	Partial tide description	Transformation within the German Bight
K1	One-day main declination-tide	The amplitudes show values in the range of 10 - 11 cm in the area of Borkum, Heligoland and Amrum.
O1	One-day main lunar-tide	The maximum amplitudes range between 8 -9 cm in the area of Borkum, East Frisia, Jade and Weser up to Eiderstedt.
Q1	Elliptic tide 1 st order to O1	The amplitudes are app. 4 cm in the mouth of the Ems estuary / Borkum and 3 cm in the coastal area of the German Bight.
M2	Semidiurnal lunar-tide	The dominant partial tide in the German Bight with a range of 1.5 - 2.5 m, rising from northwest up to the estuaries. In the open sea the isolines of equal phase are approximately equidistant. Near the coast the phase isolines are distorted due to the shallow bathymetry / frictional effects. Especially in the mouths of Jade, Weser and Elbe the isolines deformed due to the anti-clockwise rotating tide (Kelvin-wave).
S2	Principal solar semidiurnal constituent	The distribution concerning phase and amplitude correspond largely to M2. The amplitudes reach only app. 23% to those of M2, with a phase shift of about 63 °.
M4	Quarter-day main lunar-tide / Shallow water tide	The amplitudes of M4 are distinct embossed by the deformation of the propagating tidal wave in the German Bight due to bottom friction and currents and range from 7 to 12 cm
M6	Sixth-day main lunar-tide / Shallow water tide	The amplitudes of M6 (2 nd overtide to M2) are significant smaller as M4 and reach only 1 -5 cm
Details in BAWiki: https://wiki.baw.de/en/index.php/Harmonic_Analysis_of_Water_Level		

13.3 Product list / -catalog

Table 13: EasyGSH-DB products: geomorphology

Time span	Characteristic value	Domain	Format
1996	- Bathymetry - Isolines (10m, 0.5m)	- DB, AWZ	- GeoTIFF, Shapefile - Shapefile
1997	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
1998	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
1999	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2000	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2001	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2002	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2003	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2004	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2005	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2006	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2007	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2008	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2009	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2010	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2011	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2012	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2013	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2014	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2015	- Bathymetry - Isolines (10m, 0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
2016	- Bathymetry - Isolines (0.5m)	- DB	- GeoTIFF, Shapefile - Shapefile
1996 – 2016	- Morphologic Drive - Morphologic Space - Maximum z - Minimum z	- DB	- GeoTIFF - GeoTIFF - GeoTIFF - GeoTIFF

Table 14: EasyGSH-DB products: geomorphology

Time span	Characteristic value	Domain	Format
1996	<ul style="list-style-type: none"> - Petrographic map: main components, short form - Petrographic map: main components, long form - Petrographic map: addition components, short form - Petrographic map: addition components, long form - Median-grain diameter d50 - Median- grain diameter d50 (as isolines) - Skewness - Sorting - Porosity - Sedimentology 	- DB, AWZ	<ul style="list-style-type: none"> - Shapefile - Shapefile - Shapefile - Shapefile - GeoTIFF, Shapefile - Shapefile - GeoTIFF - GeoTIFF - GeoTIFF - CSV
2006	<ul style="list-style-type: none"> - Petrographic map: main components, short form - Petrographic map: main components, long form - Petrographic map: addition components, short form - Petrographic map: addition components, long form - Median-grain diameter d50 - Median- grain diameter d50 (as isolines) - Skewness - Sorting - Porosity - Sedimentology 	- DB	<ul style="list-style-type: none"> - Shapefile - Shapefile - Shapefile - Shapefile - GeoTIFF, Shapefile - Shapefile - GeoTIFF - GeoTIFF - GeoTIFF - CSV
2016	<ul style="list-style-type: none"> - Petrographic map: main components, short form - Petrographic map: main components, long form - Petrographic map: addition components, short form - Petrographic map: addition components, long form - Median-grain diameter d50 - Median- grain diameter d50 (as isolines) - Skewness - Sorting - Porosity - Sedimentology 	- DB	<ul style="list-style-type: none"> - Shapefile - Shapefile - Shapefile - Shapefile - GeoTIFF, Shapefile - Shapefile - GeoTIFF - GeoTIFF - GeoTIFF - CSV

Table 15: EasyGSH-DB products: synoptic hydrodynamic, data stored on a 1000 m-raster.

Time span	Characteristic value	Domain	Format
1996-2016	Effective bottom shear stress 2D	- 12 NM	- netCDF - CSV (at Locations)
	- magnitude of effective bottom shear stress - direction of effective bottom shear stress - effective bottom shear stress x - effective bottom shear stress y		
1996-2016	salinity 2D	- DB	- netCDF - CSV (at Locations)
	- salinity		
1996-2016	Sea state 2D	- DB	- netCDF - CSV (an Locations)
	- Significant wave height - Mean wave period - Peak wave period - TM1 - wave period - TM2 - wave period - Directional spreading of waves		
1996-2016	Current velocity 2D	- DB	- netCDF - CSV (an Location)
	- Magnitude of current velocity - Direction of current velocity - X - component of current velocity - Y - component of current velocity		
1996-2016	Water level 2D	- DB	- netCDF - CSV (an Location)
	- Water level		
1996-2016	- Station related 1D- & 2D Wave spectra - Spectral sea state parameter	- DB	- .txt - .dat

Table 16: EasyGSH-DB products: station-related sea state parameter.

Time span	Characteristic value	Domain	Format
1996 - 2015	Station-related Sea state parameter		
	- 1D- & 2D Wave spectra - Spectral sea state parameter	- DB	- .txt - .dat

Table 17: EasyGSH-DB products: Characteristic values of hydrodynamic.

Time span	Characteristic value	Domain	Format
1996 - 2015	Tidal characteristic value: water level (TDKW)		
	<ul style="list-style-type: none"> - Tide high water, 5% quantile - Tide high water, 50% quantile - Tide high water, 95% quantile - Tide low water, 5% quantile - Tide low water, 50% quantile - Tide low water, 95% quantile - Tidal range, 5% quantile - Tidal range, 50% quantile - Tidal range, 95% quantile - Mean tide level, 50% quantile - Mean inundation duration - Number of HWL events - Number of LWL events 	<ul style="list-style-type: none"> - DB, AWZ - 12 NM 	<ul style="list-style-type: none"> - GeoTIFF, Shapefile
1996 - 2015	Tidal characteristic value: current velocity (TDKV)		
	<ul style="list-style-type: none"> - max. flood current velocity, 5% quantile - max. flood current velocity, 50% quantile - max. flood current velocity, 95% quantile - max. ebb current velocity, 5% quantile - max. ebb current velocity, 50% quantile - max. ebb current velocity, 95% quantile - X-mean flood current velocity - Y- mean flood current velocity - X- mean ebb current velocity - Y- mean ebb current velocity - mean flood current velocity - mean ebb current velocity - Relation mean flood current velocity /mean tide current velocity - Relation mean ebb current velocity /mean tide current velocity 	<ul style="list-style-type: none"> - DB 	<ul style="list-style-type: none"> - GeoTIFF, Shapefile - GeoTIFF - GeoTIFF, Shapefile

Table 18: EasyGSH-DB products: Partial tide (harmonic analysis).

Time span	Characteristic value	Domain	Format
1996 - 2015	Harmonic analyses of water level (FRQW)		
	- M2: Amplitude - M2: Phase	- DB	- GeoTIFF, Shapefile

Table 19: EasyGSH-DB products: Characteristic values of bottom shear stress

Time span	Characteristic value	Do-main	Format
1996 - 2015	Tidal characteristic value: bottom shear stress (TDKB)		
	<ul style="list-style-type: none"> - max. eff. bottom shear stress (flood) 50% quantile - max. eff. bottom shear stress (flood) 95% quantile - max. eff. bottom shear stress (ebb) 50% quantile - max. eff. bottom shear stress (ebb) 95% quantile - X- mean eff. bottom shear stress (flood) - Y- mean eff. bottom shear stress (flood) - X- mean eff. bottom shear stress (ebb) - Y- mean eff. bottom shear stress (ebb) 	- DB	<ul style="list-style-type: none"> - GeoTIFF, Shapefile - GeoTIFF

Table 20: EasyGSH-DB products: non-tidal characteristic numbers

Time span	Characteristic value	Domain	Format
1996 - 2015	Non-tidal characteristic numbers of water level (LZKW)		
	<ul style="list-style-type: none"> - Water level, 1% quantile - Water level, 99% quantile 	- DB	- GeoTIFF, Shapefile
1996 - 2015	Non-tidal characteristic numbers of salinity (LZKS)		
	<ul style="list-style-type: none"> - Salinity, 1% quantile - Salinity, 99% quantile 	- DB	- GeoTIFF, Shapefile
1996 - 2015	Non-tidal characteristic numbers of sea state (LZSS)		
	<ul style="list-style-type: none"> - Significant wave height, 50% quantile - Significant wave height, 95% quantile - Significant wave height, 99% quantile - Maximum significant wave height - Mean wave period at max. significant wave height 	- DB	- GeoTIFF, Shapefile

Table 21: EasyGSH-DB products: characteristic numbers of sea state

Point in time	Characteristic values	Domain	Format
1996 - 2015	Characteristic values of sea state		
	<ul style="list-style-type: none"> - Frequency distribution of sign. wave heights, mean wave directions and dedicated mean peak period - Mean significant wave height - 50%-percentile of significant wave height - Mean peak period - 50%- percentile of mean peak period - Energy weighted mean wave direction 	<ul style="list-style-type: none"> - DB, Coast - DB - DB - DB - DB - DB 	- GeoTIFF

Table 22: EasyGSH-DB products: for Prototyping Partnerships

Time span	Characteristic values	Domain	Format
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2002, 2012	- Eulittoral	- DB	- Shapefile
2004, 2014	- Mudflats	- DB	- Shapefile

13.4 Stakeholder in the participation process of EasyGSH-DB

Table 23: Stakeholder from private companies.

Economy			Land	Partizipation		
Way of utilization	Utilization group	User		inform	consult	collabo- rate
Harbour economy	Umschlagsbetriebe	BLG Logistics Solutions GmbH & Co. KG - WindEnergy Logistics	GER	x		
	Küsten- und Hafenbau	DEME	GER	x		
		Hochtief Construction AG	GER	x		
		Inros Lackner AG	GER		x	
		STRABAG / Josef Möbius Bau AG	GER	x		
		WKC – Hamburg	GER		x	
Shipping	Freizeitschiff-fahrt	Deutscher Motoryachtverband	GER	x		
		Deutscher Seglerverband	GER		x	
Wind energy	Windparkbetreiber	BARD Engineering GmbH	GER	x		
		BEC Energie Consult GmbH	GER	x		
		EnBW Erneuerbare Energien GmbH	GER	x		
		Offshore Windpark Butendiek	GER		x	
	Stromversorger	EON Climate & Renewables	GER	x		
		EWE Aktiengesellschaft	GER	x		
	Netzbetreiber	TenneT	GER		x	
	Anlagenherst.	Areva Wind GmbH	GER	x		
	WP-Projektentwickler	Gesellschaft f. Energie & Ökologie mbH	GER	x		
		Nördlicher Grund	GER	x		
		Overspeed GmbH & Co KG	GER	x		
		Rennergys GmbH	GER	x		
		Windland Energieerzeugungs GmbH	GER	x		
		wpd offshore solutions GmbH	GER	x		
		WTM Engineers, HH	GER	x		
	WP-Versorger	O.S. Energy GmbH Marine Power Solutions	GER	x		
Federational nature protection	NGO's	BUND	GER	x		
		NABU	GER	x		
		WWF	GER		x	
Consulting	Sediment	DB Sediments	GER	x		
	Marine Technik	DNV GL	GER	x		
		IMS – Hamburg	GER		x	
		IMS Ingenieurgesellschaft mbH	GER	x		
		Ingenieurbüro Mohn – NL Husum	GER		x	
		Nemos GmbH	GER	x		
	Rohrleitungsbau	de la Motte & Partner	GER		x	
	Technologie / Raumentwicklung	DHI Denmark	DK	x		
		Deltares	NL	x		
	Energie	Ecofys Germany GmbH	GER	x		
		ENOVA Beratungs- u. Vermittlungs GmbH	GER	x		
	IT	innoVent GmbH	GER	x		
		KED Ingenieure	GER	x		
	Versicherungen	Munich Re	GER		x	

Table 24: Stakeholder from administration.

Administration			Land	Partizipation		
Way of utilization	Spatial relating	Authority		inform	consult	collabo- rate
Harbour economy	Bremen	bremen ports	GER		x	
	Hamburg	Hamburg Port Authority (HPA)	GER	x		
	Niedersachsen	Niedersachsen ports	GER	x		
Shipping	Bund	Generaldirektion Wasserstraßen und Schifffahrt (GDWS)	GER	x		
	Niedersachsen	Nds. Ministerium für Wirtschaft, Arbeit und Verkehr	GER	x		
	Bremen	WSA Bremen	GER	x		
		WSA Bremerhaven	GER		x	x
	Niedersachsen	WSA Cuxhaven	GER		x	
		WSA Wilhelmshaven	GER	x		
		WSA Emden	GER	x		
	Schleswig-Holst	WSA Tönning	GER	x		
Hamburg	WSA Hamburg	GER	x			
Coastal- and floodwater conservation	Niedersachsen	NLWKN Direktion	GER	x		
		NLWKN Forschungstelle Küste	GER		x	x
		NLWKN OL-BRA	GER		x	
		NLWKN Norden	GER		x	x
	Hamburg	Landesbetrieb Strassen, Brücken und Gewässer (LSBG)	GER	x		
	Schleswig-Holstein	Landesbetrieb für Küstenschutz, Nationalpark und Meeresschutz	GER		x	x
	Bund & Küstenländer	Harvariekommando - Central Command for Maritime Emergencies	GER	x	x	
Protection of nature and landscape	Bund	Bundesanstalt für Gewässerkunde (BfG)	GER	x		
		Bundesamd für Naturschutz (BfN)	GER	x		
		Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit	GER	x		
	Schleswig-Holstein	Landesamt für Landwirtschaft, Umwelt und ländliche Räume (LLUR)	GER		x	x
		Ministerium für Energiewende, Landwirtschaft, Umwelt und ländliche	GER	x		
	Niedersachsen	Nds. Ministerium für Umwelt, Energie und Klimaschutz	GER	x		
Nationalparkverwaltung Niedersächsisches Wattenmeer		GER		x		
Meteorology	Verwaltung	Deutscher Wetterdienst (DWD)	GER	x		

Table 25: Stakeholder from research institutions.

Research			Land	Partizipation		
Way of utilization	Research focus	Research institution		inform	consult	collaboration
Marine Systems and Infrastructure	Küsten-, Wasser und Hafenbau	Franzius-Institut für Wasserbau, Astuar- und Küsteningenieurwesen	GER		x	
		TU Braunschweig - Institut für Geoökologie, Abt. Landschafts-ökologie u. Umweltsystemanalyse	GER		x	
		Technische Universität Braunschweig - Leichtweiß-Institut für Wasserbau	GER	x		
		HTG FA – Küstenschutzwerke	GER	x		
		HTG FA – Sportboothäfen	GER	x		
		Universität Rostock - Lehrstuhl für Geotechnik und Küstenwasserbau	GER	x		
		Ghent University, Faculty of Engineering	BE	x		
Shipping / harbour economy	Geotechnik	HafenCity Universität Hamburg Arbeitsgebiet Geotechnik	GER		x	
	Nautik	Hochschule Bremen	GER	x		
Wind energy	Logistik	BIBA- LogDynamics Bremen	GER	x		
		Research Cluster for Dynamics in Fraunhofer-Center für Maritime Logistik und Dienstleistungen CML	GER	x		
		Institut f. Seeverkehrswirtschaft u. Forschungszentrum Jülich GmbH - Institut für Energie- und Klimaforschung	GER	x		
		Fraunhofer Institut für Windenergie und Energiesystemtechnik (IWES)	GER		x	
		Reiner Lemoine Institut	GER	x		
		Forschungsverbund Windenergie (FVWE)	GER	x		
		ForWind – Zentrum für Windenergiefors	GER	x		
Technical universities		Beuth-Hochschule für Technik Berlin	GER	x		
		Centro de Estudios de Puertos y	ES	x		
		Duke University	USA	x		
		Technische Universität München	GER	x		
		RWTH Aachen	GER		x	
Ocean research	allgemein	Alfred-Wegener-Institut (AWI)	GER		x	
		ICBM - Uni Oldenburg	GER	x		
		IO'w Rostock Warnemünde	GER	x		
		Marum Bremen	GER		x	
		Senckenberg am Meer	GER	x		
		Helmholtz-Zentrum Geesthacht	GER	x		
	Fischerei	Johann Heinrich von Thünen-Institut	GER		x	
Klima and Atmospheric research	Meteorologie	Karlsruhe Institut of Technology; Institute for Meteorology a. Climate Research	GER	x		
		Max-Planck-Institute for Meteorology, HH	GER	x		
	Geophysik	Universität Hamburg, Institut für Geophysik	GER	x		
Research	allgemein	Leibniz Universität Hannover	GER	x		
		Hochschule Osnabrück	GER	x		
		Lund University	S	x		

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The summation of the stakeholder in Table 25 includes data from Table 23, Table 24 and Table 25.

13.5 Link-List

Data

Data portal

www.easygsh-db.org - or - <https://mdi-de.baw.de/easygsh/>

Information Portal

<http://easygsh.wb.tu-harburg.de/>

Data collection

Subject Area - Geomorphology → <https://doi.org/10.48437/02.2020.K2.7000.0001>

Subject Area - Bathymetry → <https://doi.org/10.48437/02.2020.K2.7000.0002>

Subject Area - Sedimentology → <https://doi.org/10.48437/02.2020.K2.7000.0005>

Subject Area - Hydrodynamics → <https://doi.org/10.48437/02.2020.K2.7000.0003>

mFUND

<https://www.bmvi.de/SharedDocs/DE/Artikel/DG/mfund-projekte/EasyGSH-hochaufgeloeste-maritime-referenzdatensaetze.html>

MDI-DE

<https://www.mdi-de.org>

under theme gallery: Basis data and Oceanographic values

Web pages where EasyGSH-DB can find by catchwords:

<https://www.geoportal.de>

<https://www.govdata.de>

<https://www.mcloud.de>

<https://www.researchgate.net/project/EasyGSH-DB>

<https://www.kuestendaten.de/>

Publications

EasyGSH-DB: Data products

An integrated marine data collection for the German Bight:

Part 1: Subaqueous geomorphology and surface sedimentology (1996–2016)

<https://essd.copernicus.org/articles/13/4053/2021/> || <https://doi.org/10.5194/essd-13-4053-2021>

Part 2: Tides, salinity, and waves (1996–2015)

<https://essd.copernicus.org/articles/13/2573/2021/> || <https://doi.org/10.5194/essd-13-2573-2021>

EasyGSH-DB: Update

https://mdi-de.baw.de/easygsh/assets/Dokumente/Update/Updates_Okt18.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Update/EasyGSH_Update_02_I2019.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Update/EasyGSH_Update_3_2019.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Update/EasyGSH_Update_4_sep19.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Update/EasyGSH_Update_5_Okt19.pdf

mCloud Conference

https://mdi-de.baw.de/easygsh/assets/Dokumente/Poster/Easy_mFUND-Konferenz_2017.pdf

KFKI Colloquium

EasyGSH-DB: project overview (poster)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Poster/EasyGSH_DB_Poster_Projektuebersicht_06a_2018.pdf

EasyGSH-DB: North Sea Model (poster)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Poster/EasyGSH_DB_Poster_Nordseemodell_2018.pdf

EasyGSH-DB: product overview (poster)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Poster/EasyGSH_DB_Poster_Produkte_2019.pdf

EGU2019

Impact of natural bathymetry changes (poster)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Poster/On_the_impact_of_natural_bathymetry_changes_EGU2019.pdf

Providing metadata and visualization (poster)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Poster/Providing_metadata_and_visualization_EGU2019.pdf

Spatial characteristic analyses of the German Bight (poster)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Poster/Spatial_characteristic_analyses_of_the_German_Bight_EGU_2019.pdf

EGU2020

Model approach to estimate the potential for mussel beds in a Wadden Sea area (poster)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Veroeffentlichungen/EGU2020-3574_Rubel_2020_presentation.pdf

Workshop Presentations

1. Stakeholder Workshop – Presentation of EasyGSH-DB:

EasyGSH Introduction

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_23042018/EasyGSH_Einfuehrung.pdf

EasyGSH sub-project: Bottom

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_23042018/EasyGSH_Boden.pdf

EasyGSH sub-project: Dialog

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_23042018/EasyGSH_Dialog.pdf

EasyGSH sub-project: ModLearn

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_23042018/EasyGSH_ModLearn.pdf

EasyGSH sub-project: ModPort

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_23042018/EasyGSH_ModPort.pdf

2. Stakeholder Workshop - Prototyping Partnerships

Geomorphology

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/Geomorphologie.pdf

Hydrodynamic & analyses products

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/Hydrodynamik_Analysen_EasyGSH.pdf

EasyGSH-DB Information platform

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/Informationsportal.pdf

Handling with uncertainties

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/PP_Fuzzy_BEMUDA.pdf

Morphologic development of Cuxhaven Watt

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/Morph_Entwicklung_Cux_Watt.pdf

Tide regime

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/PP_Tideregime.pdf

Analysis idea dry fallen areas

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/Auswertungsidee_Trockenfallflaechen.pdf

Identification of von mudflat edges

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/PP_Bestimmung_von_Wattkannten.pdf

Assessment of cable routes

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/Beurteilung_von_Trassen.pdf

Sea state parameter

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/PP_Seegangparameter.pdf

Delivery of boundary data

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/PP_Randwerte_Sylt.pdf

Workshop minutes

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_25032019/Protokoll_2_WS_EasyGSH-DB_small.pdf

3. Stakeholder Workshop - Habitats & Living space

Agenda

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_14112019/Agenda_EasyGSH_3_Workshop_Entwurf.pdf

Automated detection of sand banks

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_14112019/Automatisierte_Detektion_von_Sandbaenken_corp_Design.pdf

Habitat classification and risk potential maps

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_14112019/Habitatklassifikationen_und_Risiko_Potential-karten_corp_Design.pdf

Habitat types of risk potential maps

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_14112019/Lebensraumtypen_Risiko_Potential-karten_corp_Design.pdf

Bathymetric products

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_14112019/Bathymetrische_Produnkte_corp_Design.pdf

Optimization and finalization of sedimentological products

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_14112019/Optimierung_und_Finalisierung_sedimentologischer_Produnkte_corp_Design.pdf

Analyses results for bathymetry, sedimentology, tidal characteristic values and sea state

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_14112019/Analyseergebnisse_zu_Bathymetrie_Sedimente_Tidekennwerte_Seegang.pdf

Variation of tidal low and mean water in the Jade Bay and the mouth of the Weser estuary

https://mdi-de.baw.de/easygsh/assets/Dokumente/Workshop_14112019/Variation_des_Tideniedrig_und_mittelwassers_im_Bereich_der_Jade_und_Wesermuendung.pdf

Closing event (in German only)

Invitation and program

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_Einladung_Abschlussveranstaltung_20200317.pdf

Vorstellung EasyGSH-DB

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_Einfuehrung.pdf

Datenprodukte - Teil 1: Geomorphologie und Sedimentologie

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_Geomorphologie_Sedimentologie.pdf

Datenprodukte - Teil 2: Hydrodynamik

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_Hydrodynamik.pdf

Datenportal

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_Datenportal.pdf

Informationsplattform

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_Informationsplattform.pdf

Vorstellung des Beteiligungsprozesses

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_Vorstellung_des_Beteiligungsprozesses.pdf

PP Randwerte

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_PP_Randwerte.pdf

PP Lebensraumtypen

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_PP_Lebensraumtypen.pdf

PP Trockenfallkarten

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_PP_Trockenfallkarten.pdf

PP Wattkanten

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_PP_Wattkanten.pdf

PP Morphologischer Raum

https://mdi-de.baw.de/easygsh/assets/Dokumente/Abschlussveranstaltung/EasyGSH_DB_PP_Morphologischer_Raum.pdf

Further publications

Forschung Xpress BAW (in German only)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Veroeffentlichungen/27-Februar_2018_ForschungXpress_BAW.pdf
https://mdi-de.baw.de/easygsh/assets/Dokumente/Veroeffentlichungen/114-Dezember_2018_ForschungXpress_BAW.pdf

BAW-Aktuell (in German only)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Veroeffentlichungen/BAW_Aktuell_03_2019_Web.pdf

Schiff&Hafen (in German only)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Veroeffentlichungen/SchiffUHafen_10_2019_EasyGSH_Artikel.pdf

Presentations

https://mdi-de.baw.de/easygsh/assets/Dokumente/Veroeffentlichungen/Hagen_2018_PECs_TX.pdf

[https://mdi-de.baw.de/easygsh/assets/Dokumente/Veroeffentlichungen/\[INTERGEO2019\]_EasyGSH-DB.pdf](https://mdi-de.baw.de/easygsh/assets/Dokumente/Veroeffentlichungen/[INTERGEO2019]_EasyGSH-DB.pdf)

Validation documents (in German only) ||

Hagen, R., et.al., (2019), Validierungsdokument - EasyGSH-DB - Teil: UnTRIM-SediMorph-Unk, doi: https://doi.org/10.18451/k2_easygsh_1

Freund, J., et.al., (2020), Flächenhafte Analysen numerischer Simulationen aus EasyGSH-DB, doi: https://doi.org/10.18451/k2_easygsh_fans_2

Annual characteristics - Jahreskennblätter (in German only)

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_1996.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_1997.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_1998.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_1999.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2000.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2001.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2002.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2003.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2004.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2005.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2006.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2007.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2008.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2009.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2010.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2011.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2012.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2013.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2014.pdf

https://mdi-de.baw.de/easygsh/assets/Dokumente/Jahreskennblaetter/easygsh_kennblatt_2015.pdf