Federal Waterways Engineering and Research Institute (BAW)
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TrilaWatt

Digital hydro-morphological twin of the Trilateral Wadden Sea

Geomorphology and Surface Sediments

Diego Pineda Leiva

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Federal Ministry for Digital and Transport

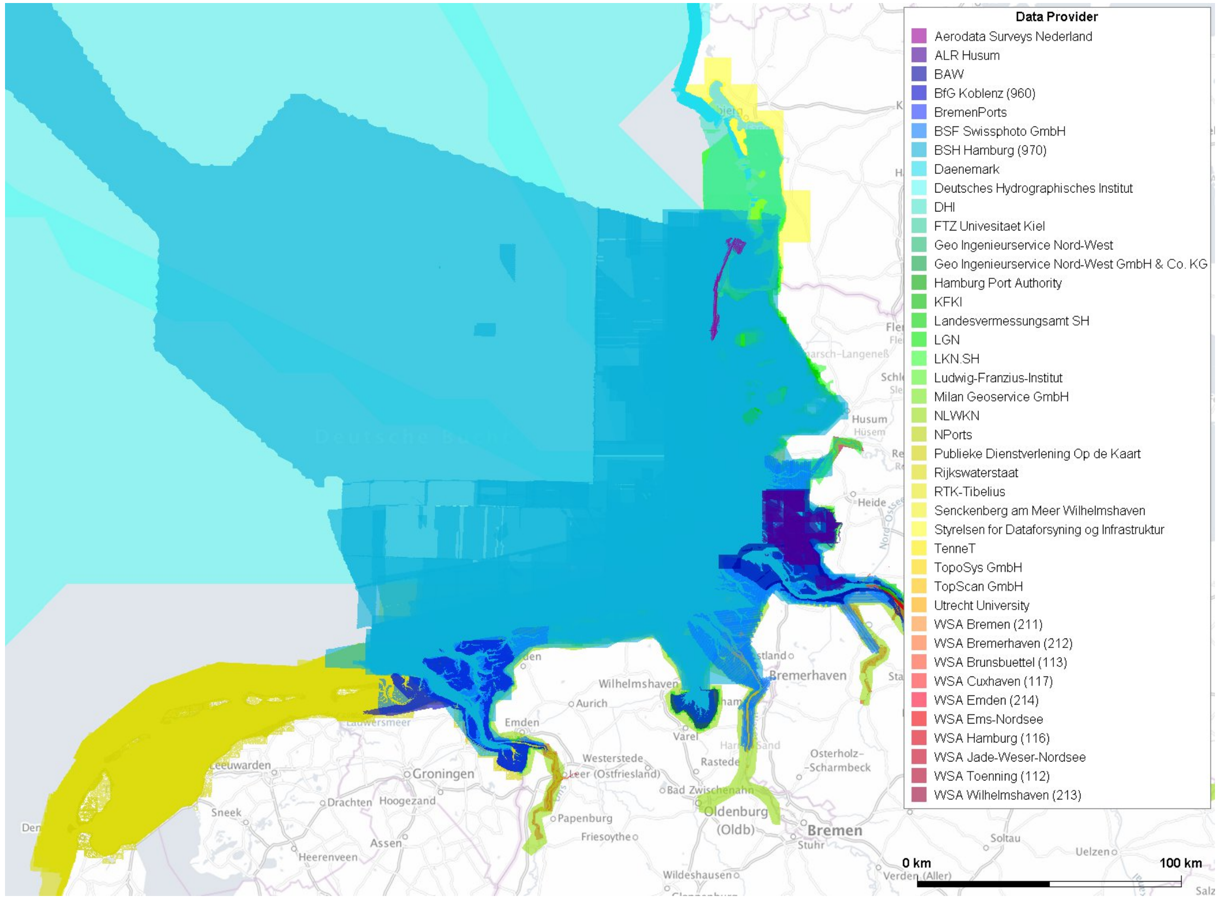
Overview

- **Topography**
  - Datasets
  - Functional Seabed Model
  - Products
  - Data Source Maps
  - Inconsistencies

- **Geomorphological Analysis:**
  - Minimum and maximum elevation [m NHN]
  - Bed Elevation Range
  - Morphological Drive

- **Sedimentology:**
  - Sediment samples collection
  - Modelling process
  - Sedimentological analysis products
  - Petrographical Maps

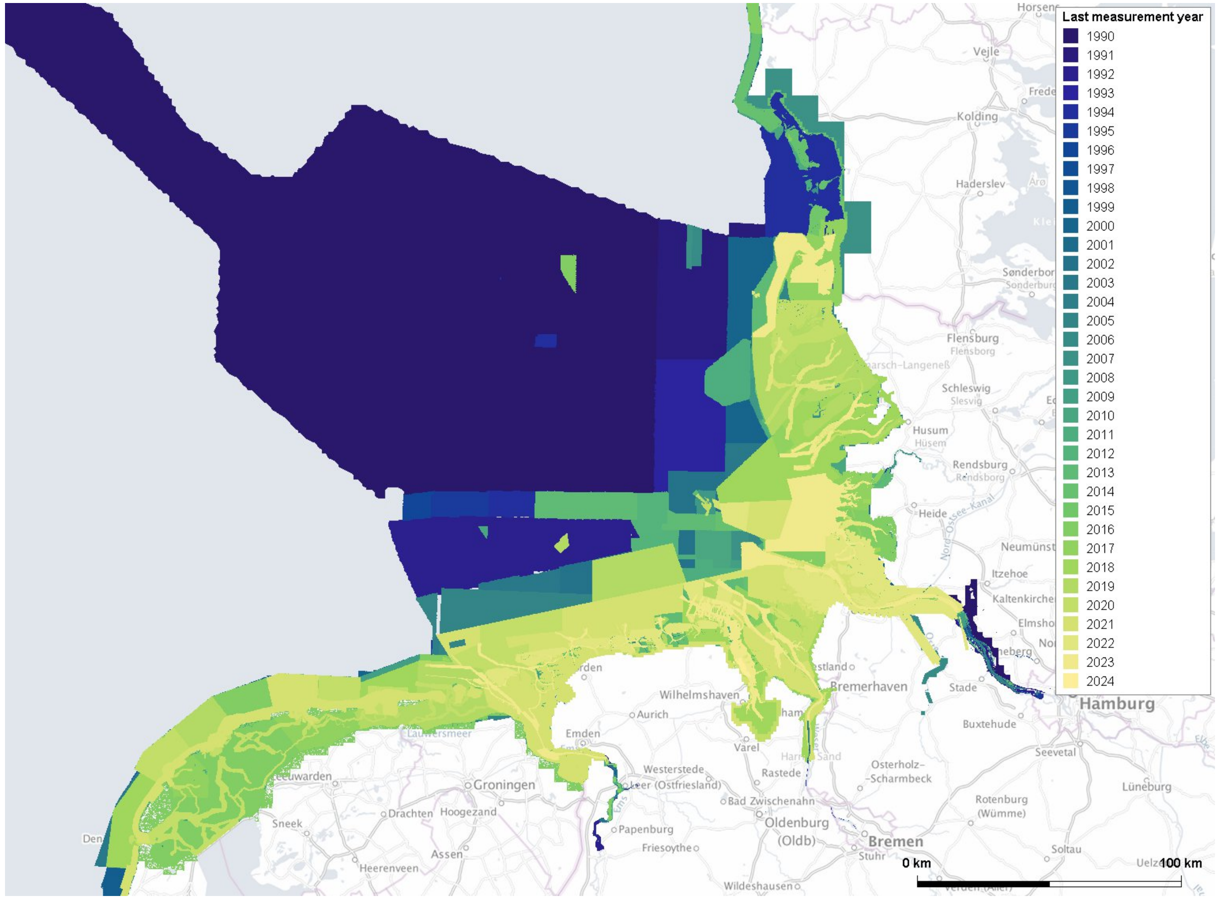
Topography



Polygons delimiting the area covered by each dataset and colored based on the data provider.
Background image: BKG TopPlusOpen

- <u>**Datasets**</u>
  - Approximately 144,000 topographic surveys, around 370 billion data points, have been collected from various sources

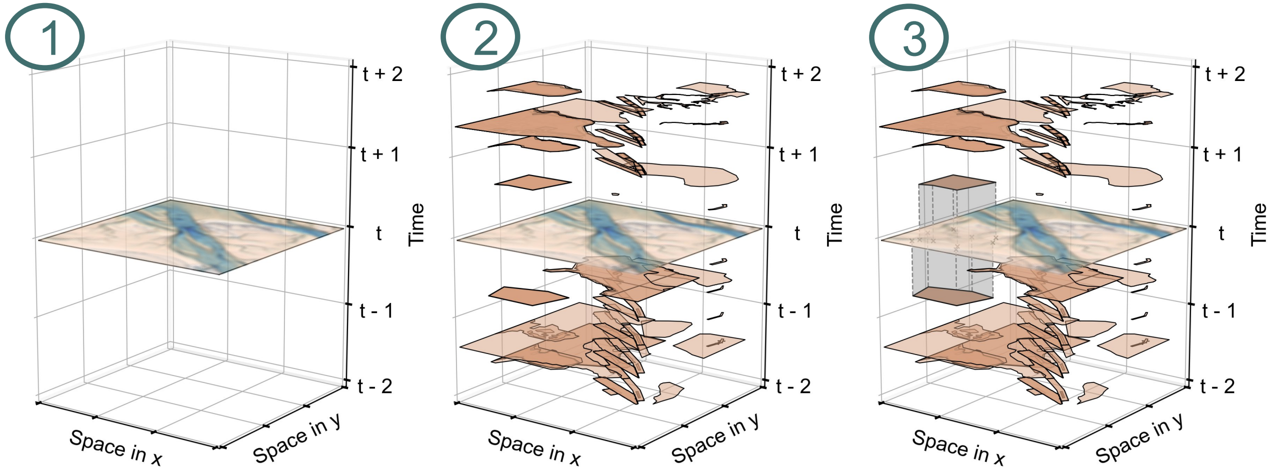
Topography



Polygons delimiting the area covered by each dataset and colored based on the year the measurement was taken. Datasets selected from time period 1900-2024. Background image: BKG TopPlusOpen

- **Datasets**
  - Approximately 144,000 topographic surveys, around 370 billion data points, have been collected from various sources
  - Surveys span from the early 1900s to 2024
  - Channels in the Wadden Sea are the most frequently surveyed areas, while tidal flats are not covered annually

Topography



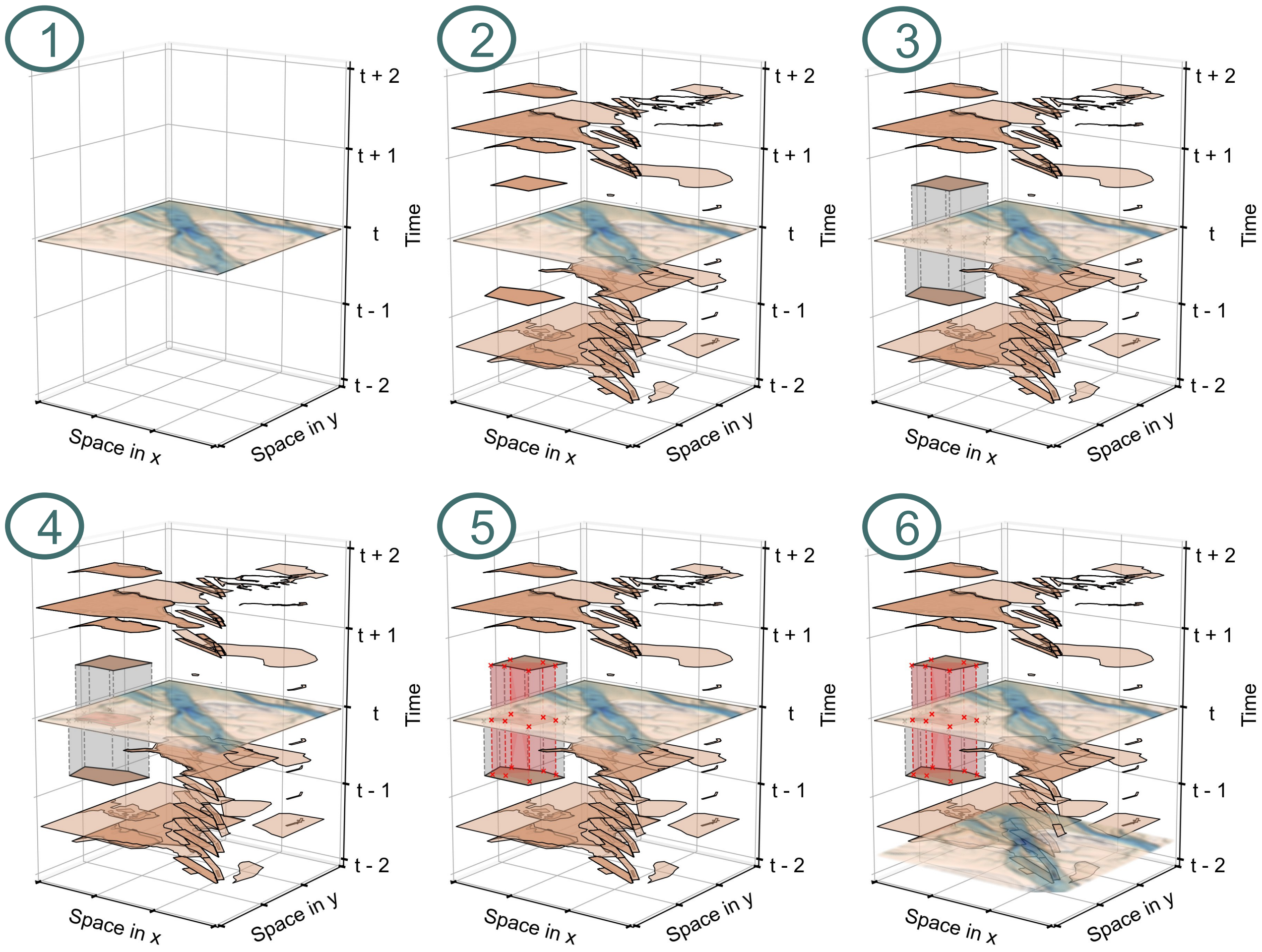
- **Topography products are created using the Functional Seabed Model [1] modelling approach and databases**

  (1) A specific target date, e.g. July 1, 2015, is chosen.

  (2) Datasets from different measurement years within the area of interest are considered.

  (3) For each point in the final raster product, the closest datasets measured before and after the target date are identified.

Topography



Step by step process of the spatio-temporal interpolation approach from Sievers et al. (2021). Figure source: Pineda Leiva et al. (n.d.) [2]

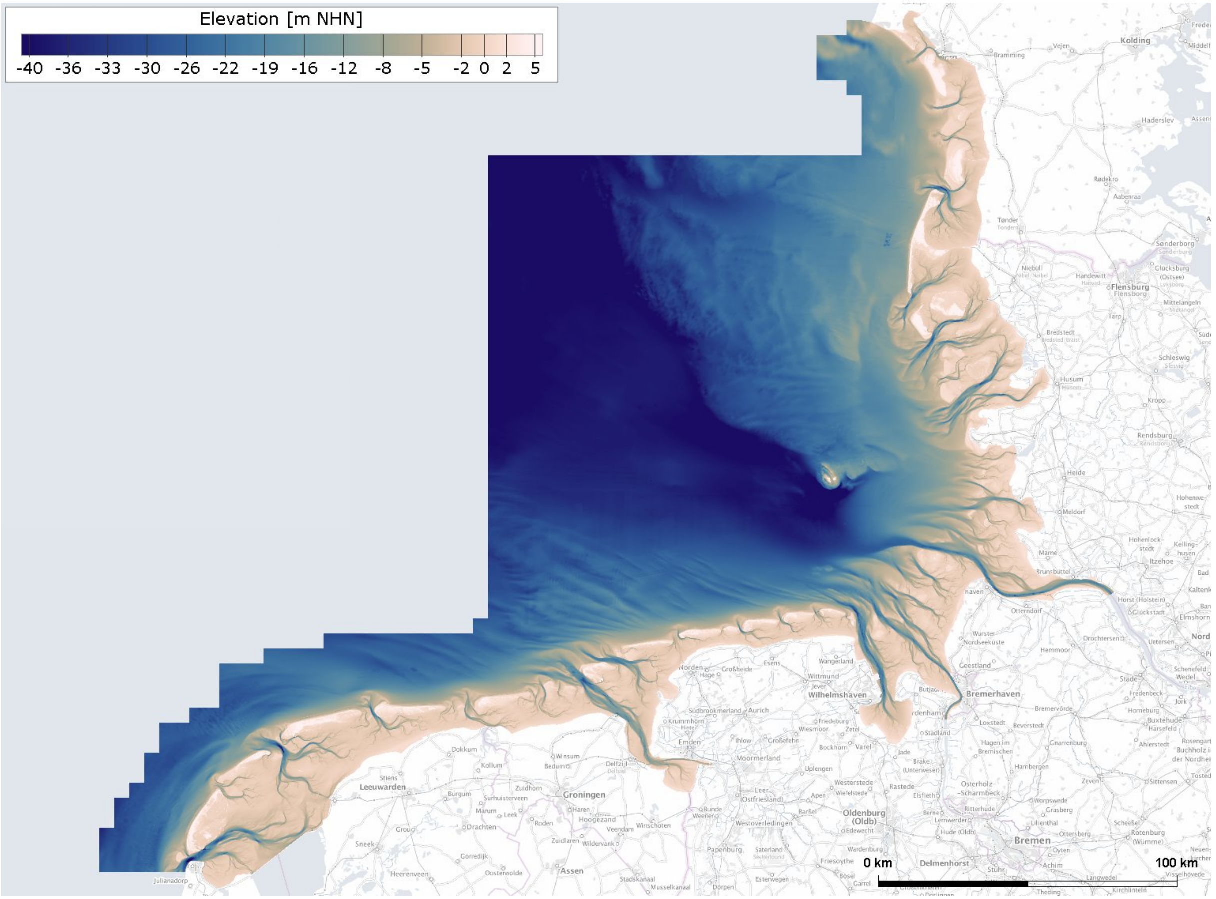
- **Topography products are created using the Functional Seabed Model [1] modelling approach and databases**

  (4) In this example, the red polygon outlines the area influenced by both of these nearest datasets.

  (5) Within this red area, the elevation values for each point are determined using various interpolation methods, with appropriate weighting factors applied to the datasets.

  (6) Additional models can also be generated for other target dates, e.g. July 1, 2013.

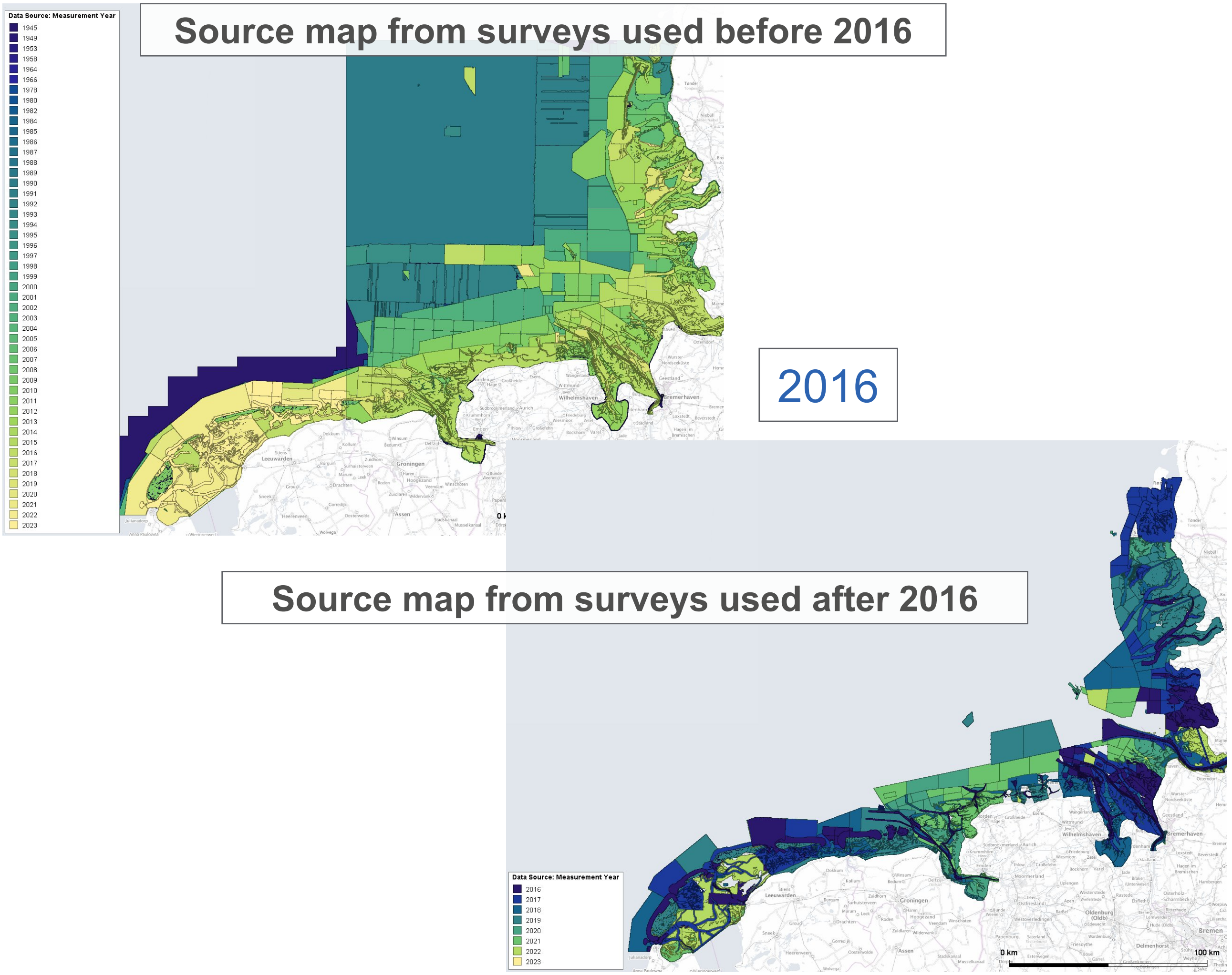
Topography



Topographic (bathymetry) model created for 2020. Background image: BKG TopPlusOpen

- **<u>Topographic Models</u>**
  - For TrilaWatt, annual digital elevation models (DEMs) were generated for the Dutch and German Wadden Sea from 2015 to 2021.
  - Due to limited data availability in the Danish Wadden Sea, only a single DEM for 2020 has been created.
  - The DEMs are provided in TIF format, with separate files for each country to ensure a user-friendly download experience.
  - Additionally, prototype DEMs have been created for the Dutch Wadden Sea for the years 1996–2014 and for both the Dutch and German Wadden Sea for 2022.

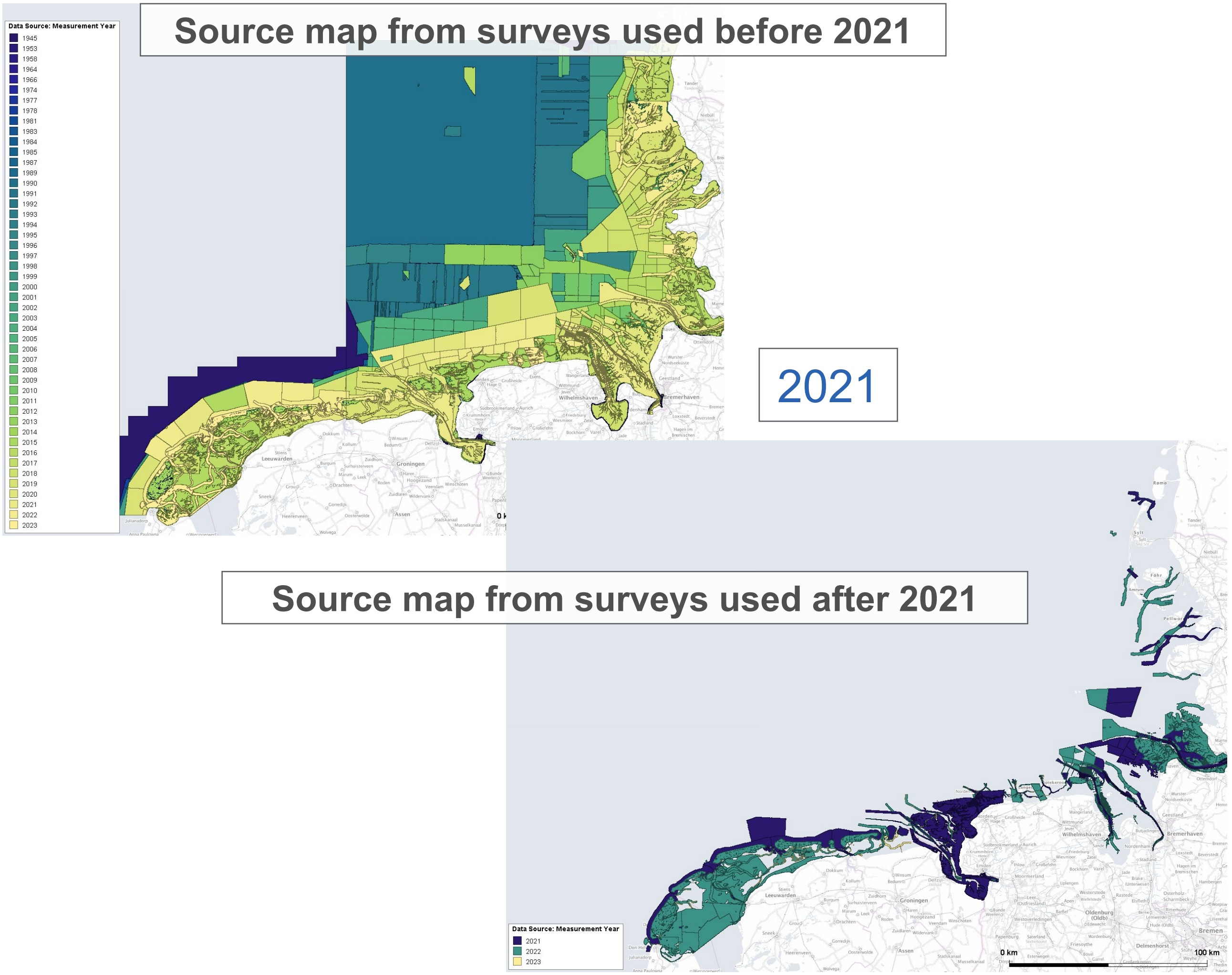
Topography



Data source map of the year 2016. On the left is the source map of the data sets used with dates older than 01.07.2016, and on the right, earlier 01.07.2016. Background image: BKG TopPlusOpen

- **Data Source Maps**
  - These maps are available for every generated topographic model and are provided as two ESRI Shapefiles.
  - Each shapefile contains polygons that outline the datasets used for each raster point — one for the dataset before and one for the dataset after the target date.
  - Each polygon includes detailed information about the dataset used to interpolate elevation values at each point, such as
    - Data Provider
    - Date of Measurement
    - Type of Measurement (e.g. Airborn laser, Multibeam echosounder, etc.)

Topography



Data source map of the year 2021. On the left is the source map of the data sets used with dates older than 01.07.2021, and on the right, earlier 01.07.2021. Background image: BKG TopPlusOpen

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    - – Data Provider
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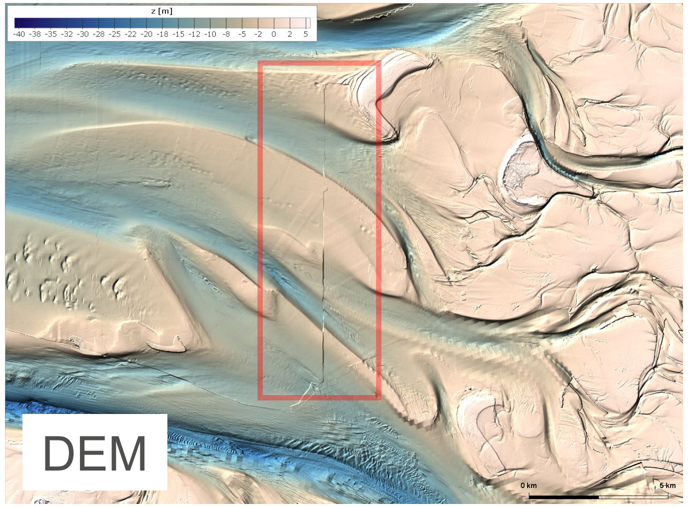
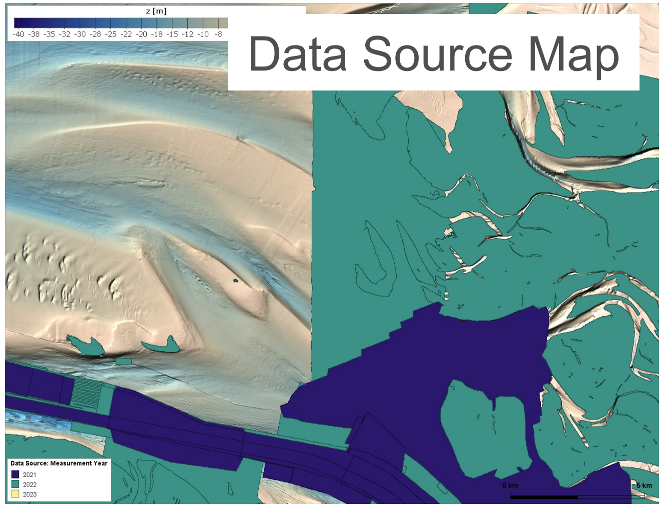
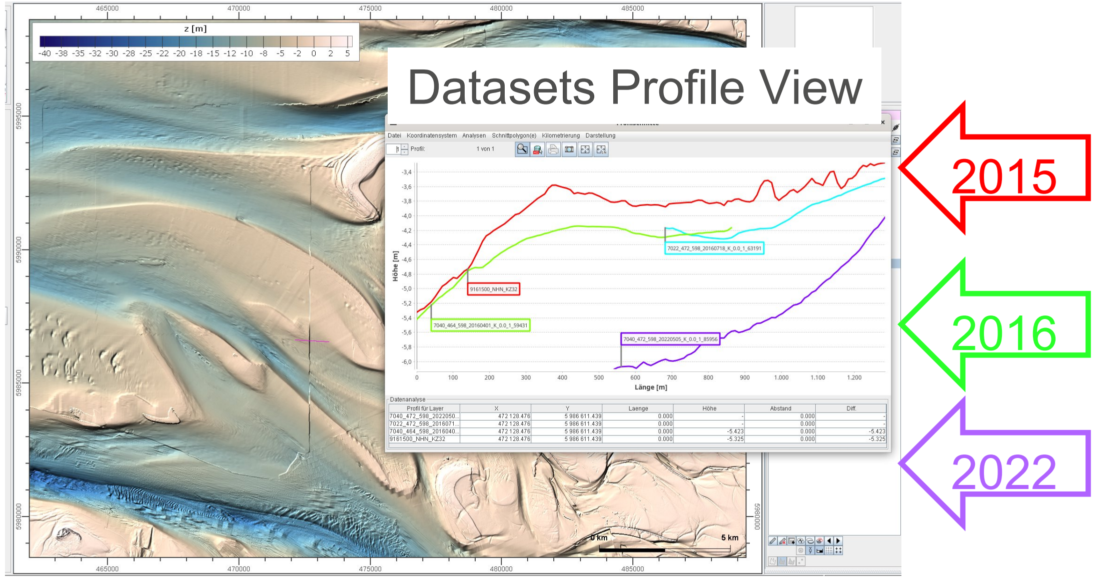
Topography

- **Inconsistencies**
  - In some cases, data coverage is insufficient in certain areas compared to their surroundings, leading to inconsistencies in the model where elevation values may abruptly differ from neighboring regions. These discrepancies can occur due to:
    - Outliers in the source data that cannot be corrected due to limitations of the data type or source. (1)

Topography







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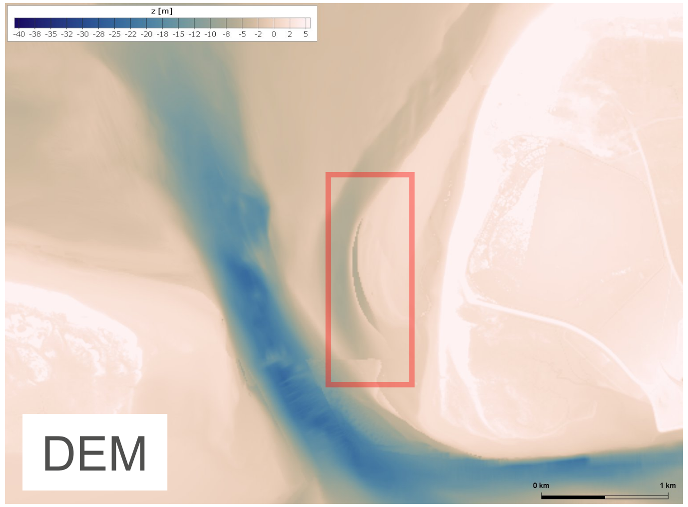
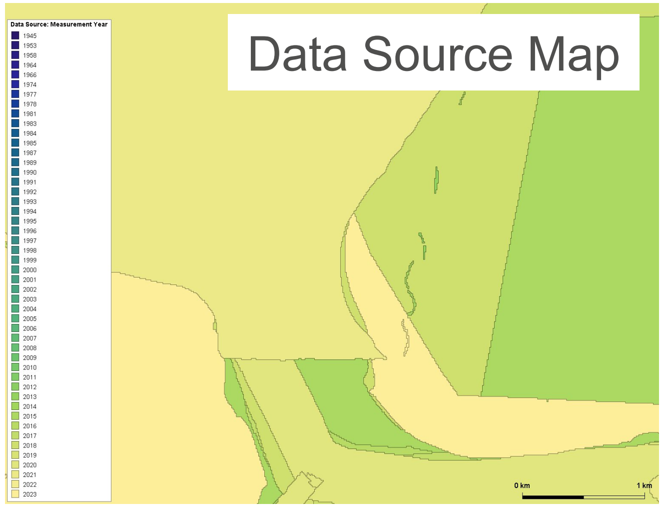
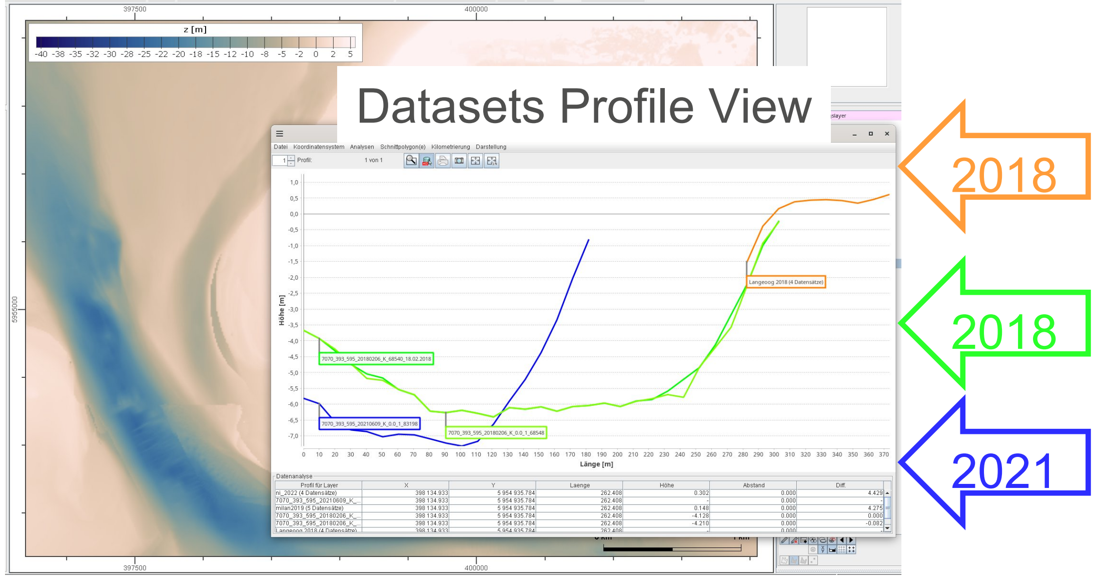
  - Missing source data for an area at earlier dates, unlike its neighboring regions. (2)

Topography







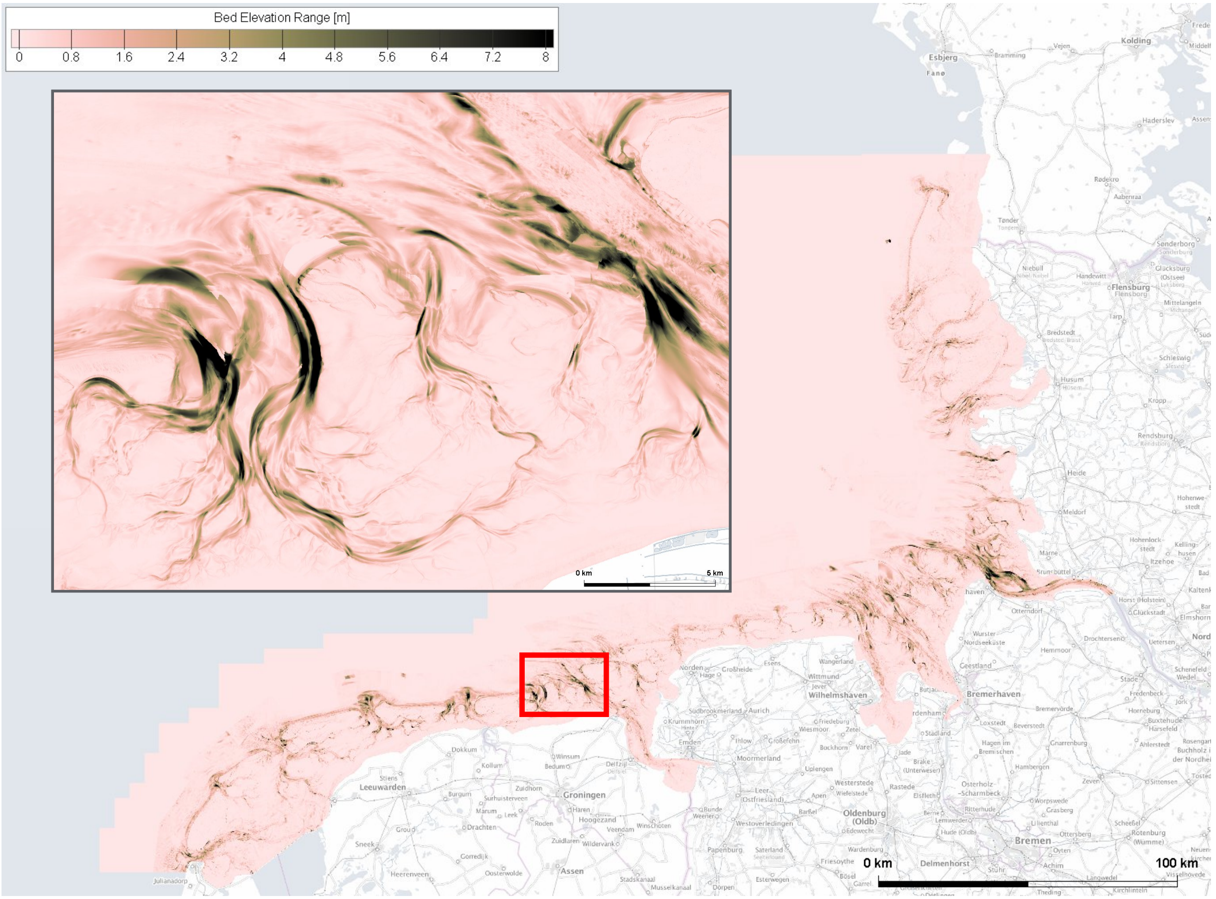
Inconsistencies

- In some cases, data coverage is insufficient in certain areas compared to their surroundings, leading to inconsistencies in the model where elevation values may abruptly differ from neighboring regions. These discrepancies can occur due to:
  - Outliers in the source data that cannot be corrected due to limitations of the data type or source. (1)
  - Missing source data for an area at earlier dates, unlike its neighboring regions. (2)
  - Small gaps in measurements where nearby datasets from closer dates show varying elevations, resulting in implausible values for the target time. (3)

Geomorphological Analysis

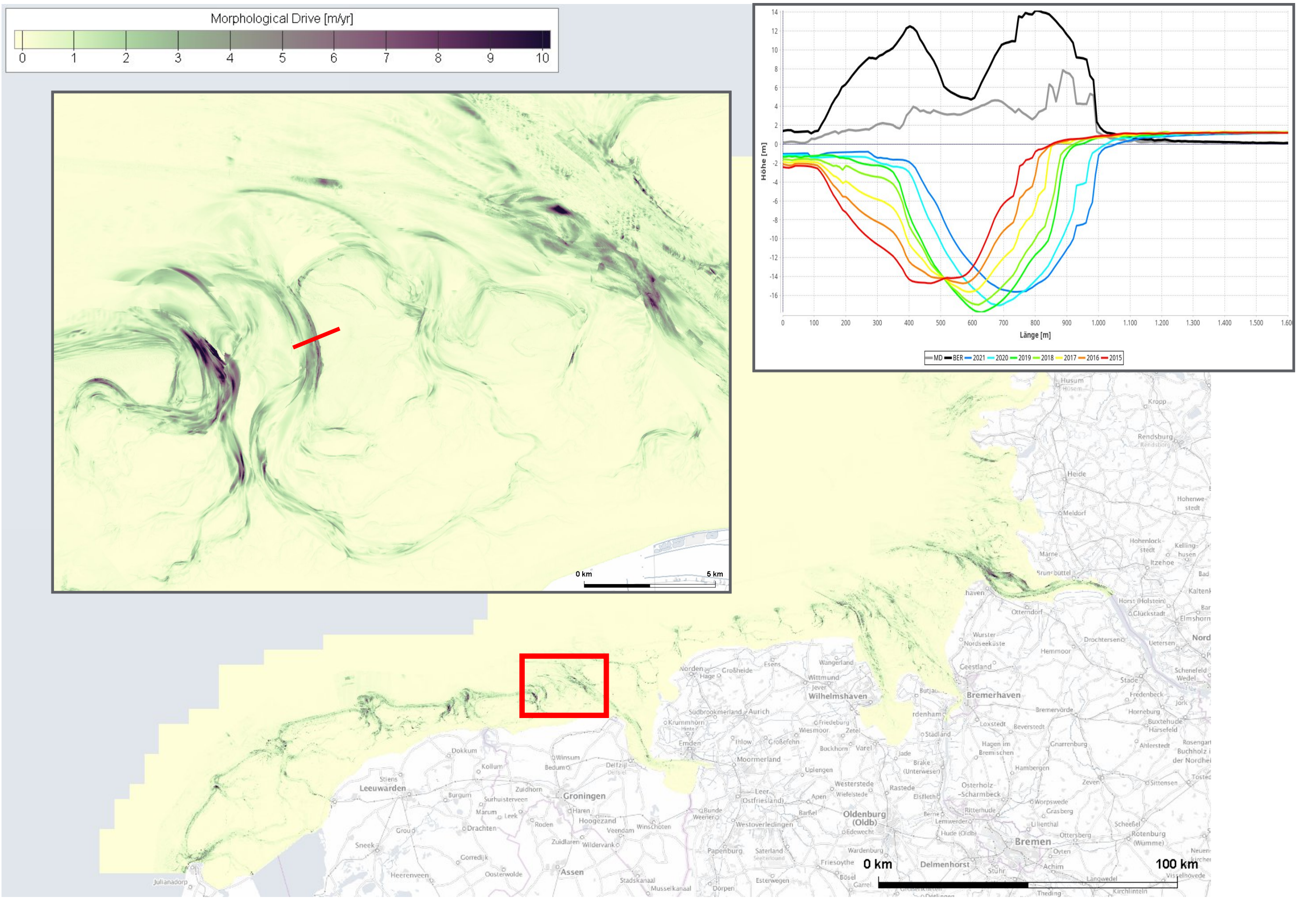
As additional products we published digital models based on descriptive statistics that were derived from the DEMs of 2016-2021.

- **<u>Minimum and Maximum Elevation Models</u>**
  - ➢ The minimum and maximum elevation value for each raster point between the time period for our models.
- **<u>Bed Elevation Range</u>**
  - ➢ Is described as the range between the maximum and minimum elevation values over the whole time period.
  - ➢ Offers visual support for identifying areas that have undergone significant elevation changes.

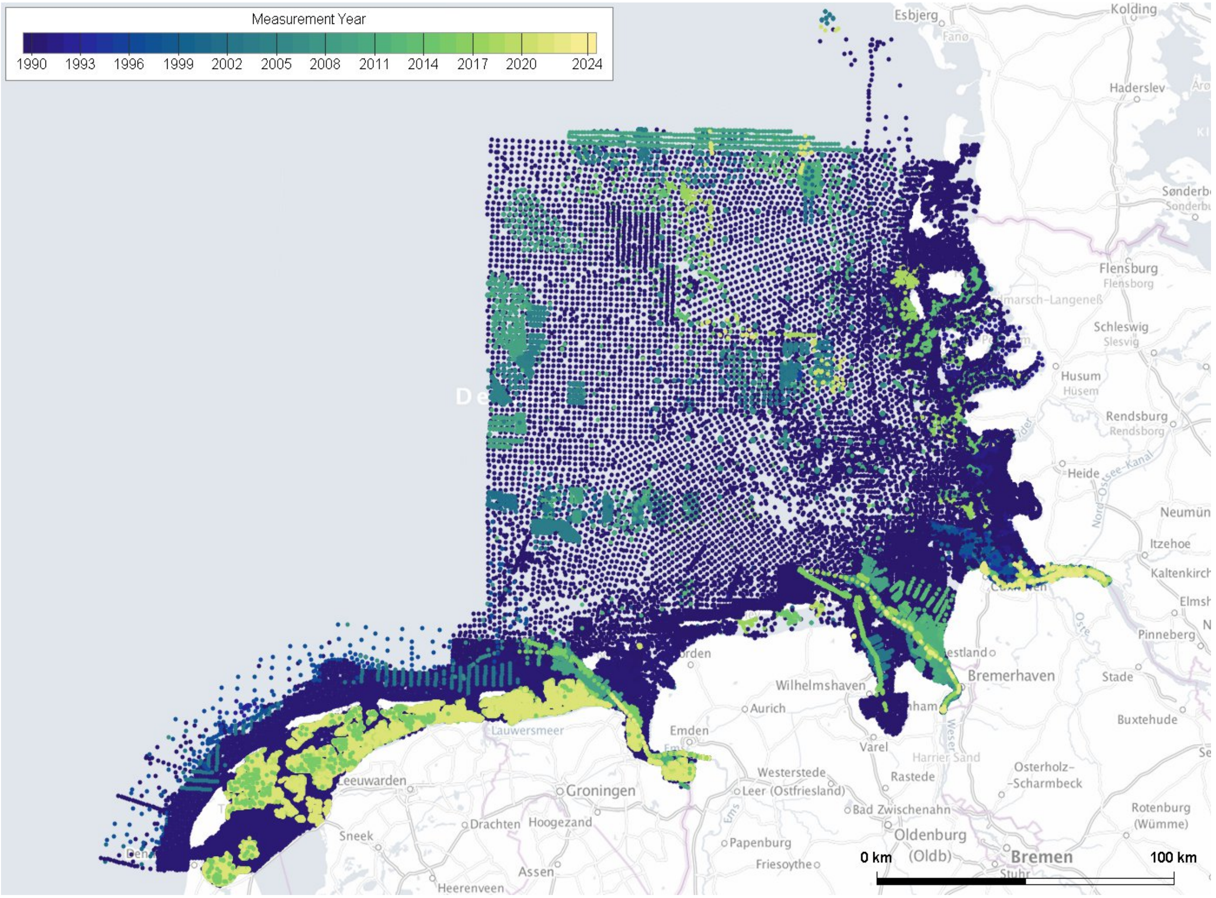


Geomorphological Analysis

- **Morphological Drive**
  - The range of maximum and minimum elevation change rates — quantifies the variability in elevation dynamics over time
  - It analyze the rates of change between sets of 2 consecutive years over the time period and returns the range between the highest rate of change and the lowest rate of change
  - Not to be confused with rates derived from statistical trends!
  - The goal is to quantify and rank areas based on their stability or variability. The term can be understood as an instability index



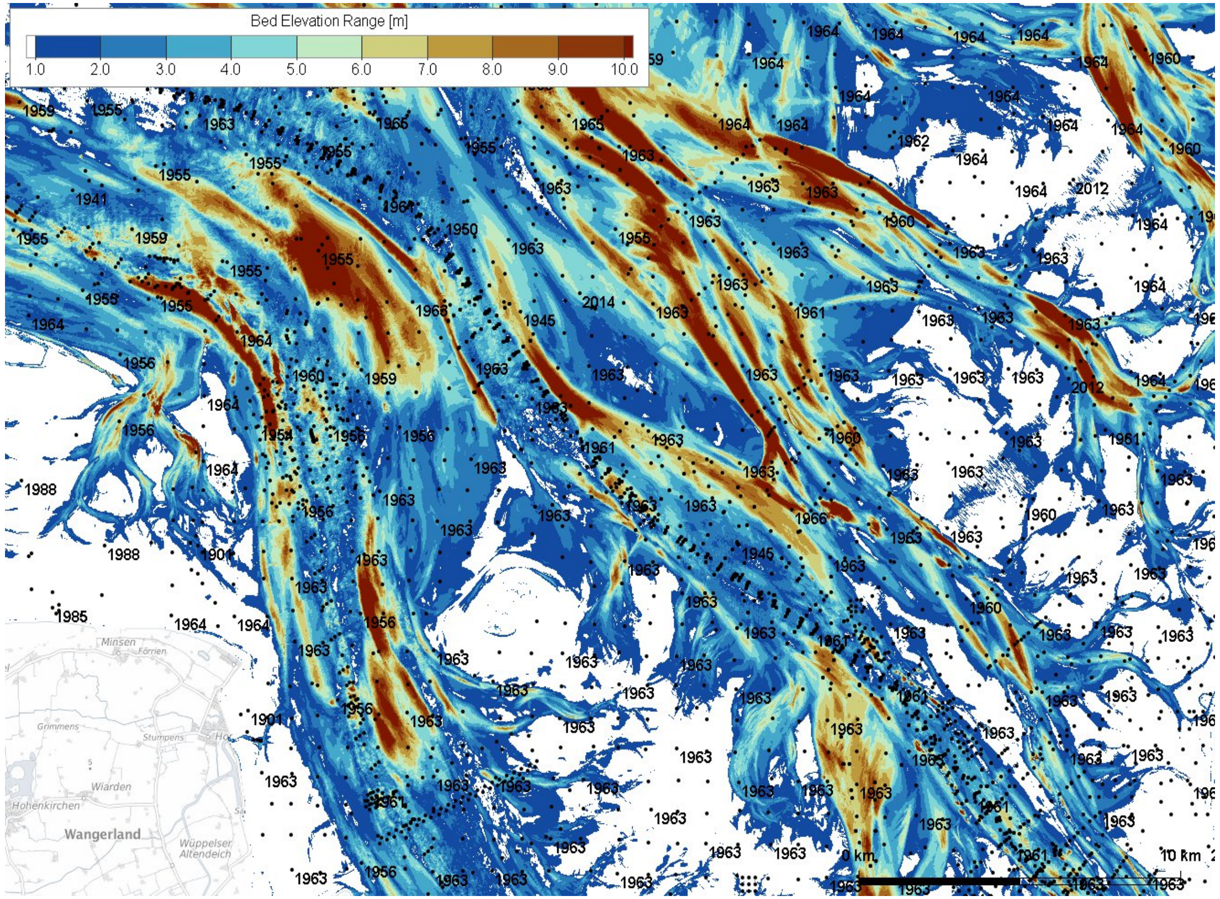
Sedimentology



Distribution of sediment samples across the project area, with colors indicating the year each sample was collected. Background image: BKG TopPlusOpen

- **Samples**
  - Approximately 86.000 sediment samples in the project area (>145.000 in total) with information such as
    - Data provider
    - Date of sample taken
    - Sample coordinates
    - Grain size distribution
    - Organic content (in some cases)
  - While the samples provide relatively “good” spatial coverage, many areas of the Wadden Sea and the German Exclusive Economic Zone (EEZ) have low temporal coverage. Despite this, sedimentological models were developed and calculated within the TrilaWatt project area.

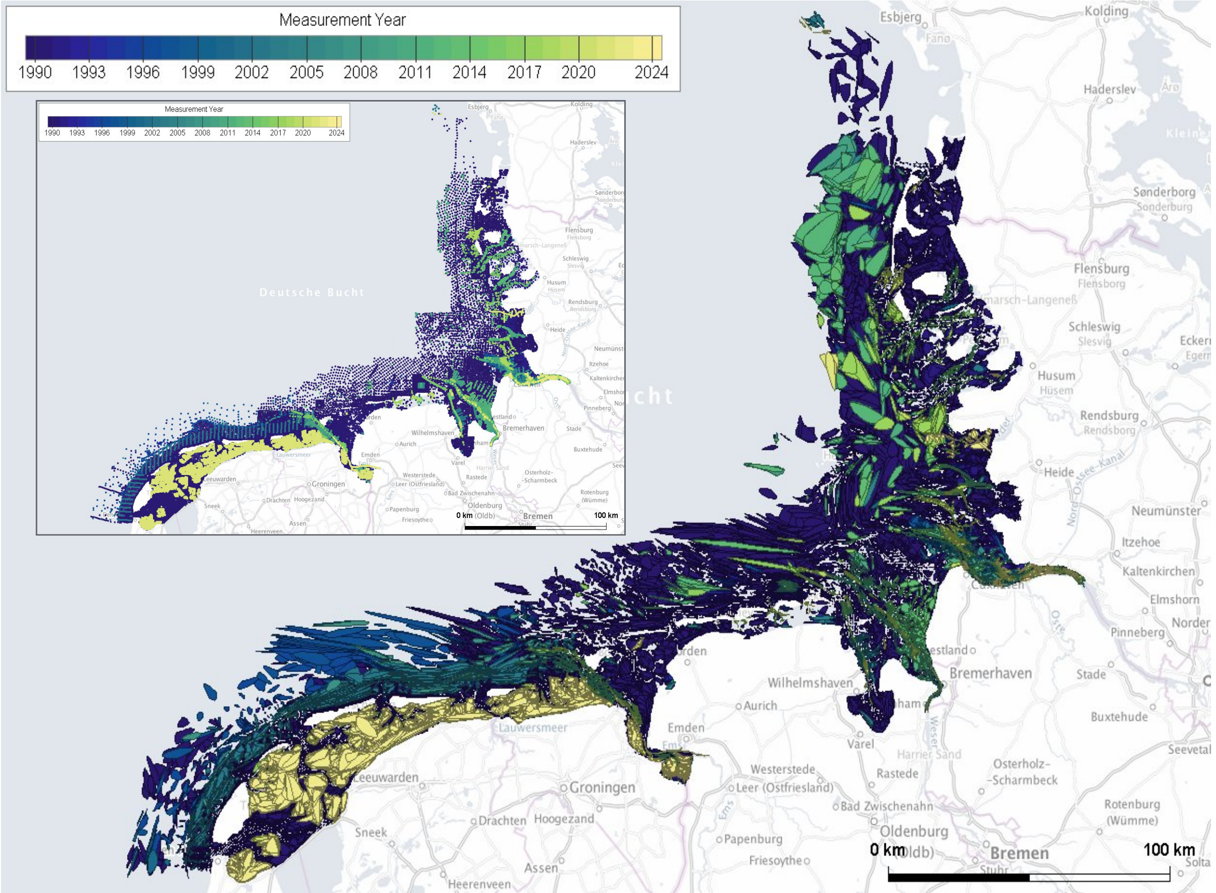
Sedimentology



Measurement year of sediment samples represented as points located in high dynamic zones detected with help of the bed elevation range model for the period 1960-2022. The area correspond to the outer Jade-Weser estuary. Background image: BKG TopPlusOpen

- **Sample considerations**
  - Many samples in our database, collected during the mid to late 1900s, fall within high-dynamic areas that have experienced significant erosion and accretion over time.
  - These samples cannot reliably represent conditions at a different point in time without accounting for changes in sediment properties due to shifting bed surfaces. Simply interpolating them across time would fail to provide a complete or accurate picture.

Sedimentology

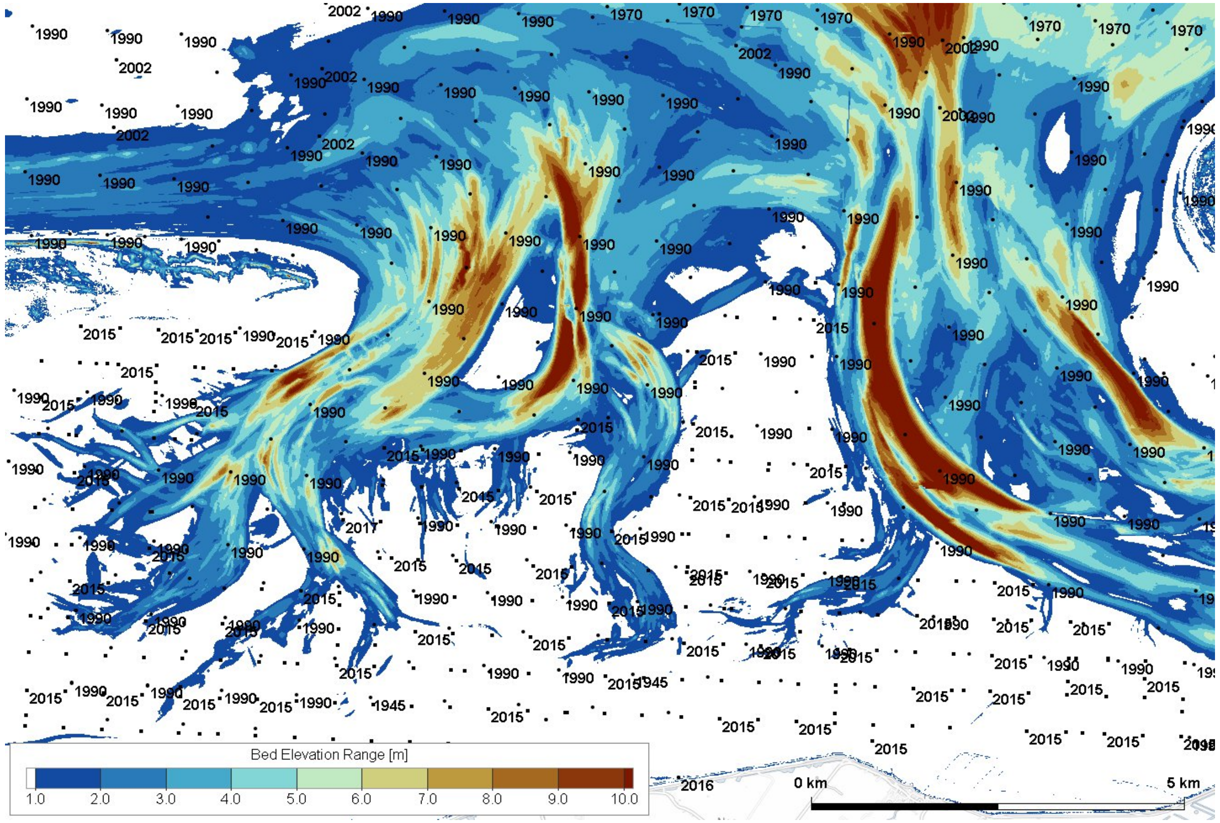


Topography-alike boundaries (bigger image) for each sediment sample (smaller image) in the project area. Each polygon is calculated to expand the influence of each sample temporally and spatially based on topographic similarities surrounding each sample. Background image: BKG TopPlusOpen

- **Sample considerations**
  - To address the challenge of limited sediment sample coverage and assess their influence in highly dynamic areas, topography-alike areas were determined and created as polygons. These polygons identify similar topographic regions at the time the sediment sample was taken, with sample influence decreasing closer to the polygon boundaries.
  - Temporal limits are also considered within this polygons based on changes in the bed surface. In less dynamic areas, such as tidal flats, a sample's influence extends over a longer time span. On the other hand, in highly dynamic areas like gullies and channels, the temporal influence of a sample is much shorter.

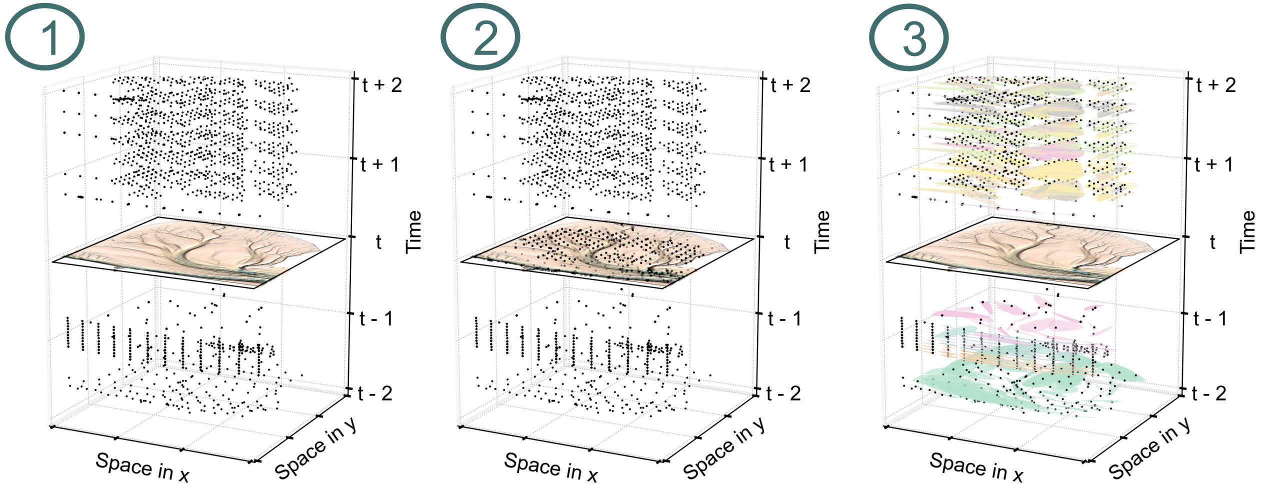
Sedimentology

- **Assumptions**
  - In the Netherlands, we have approximately 8,000 samples with no recorded date of measurement. To incorporate these into our model, we assigned a date of measurement for these samples to 01.07.1990 (Start year where we have complete topographic coverage in the Netherlands).



Measurement year of sediment samples represented as points located in high dynamic zones detected with help of the bed elevation range model for the period 1960 to 2022 in the left, 1996 to 2022 in the right. Sample area between Ameland and Schiermonnikoog.

Sedimentology



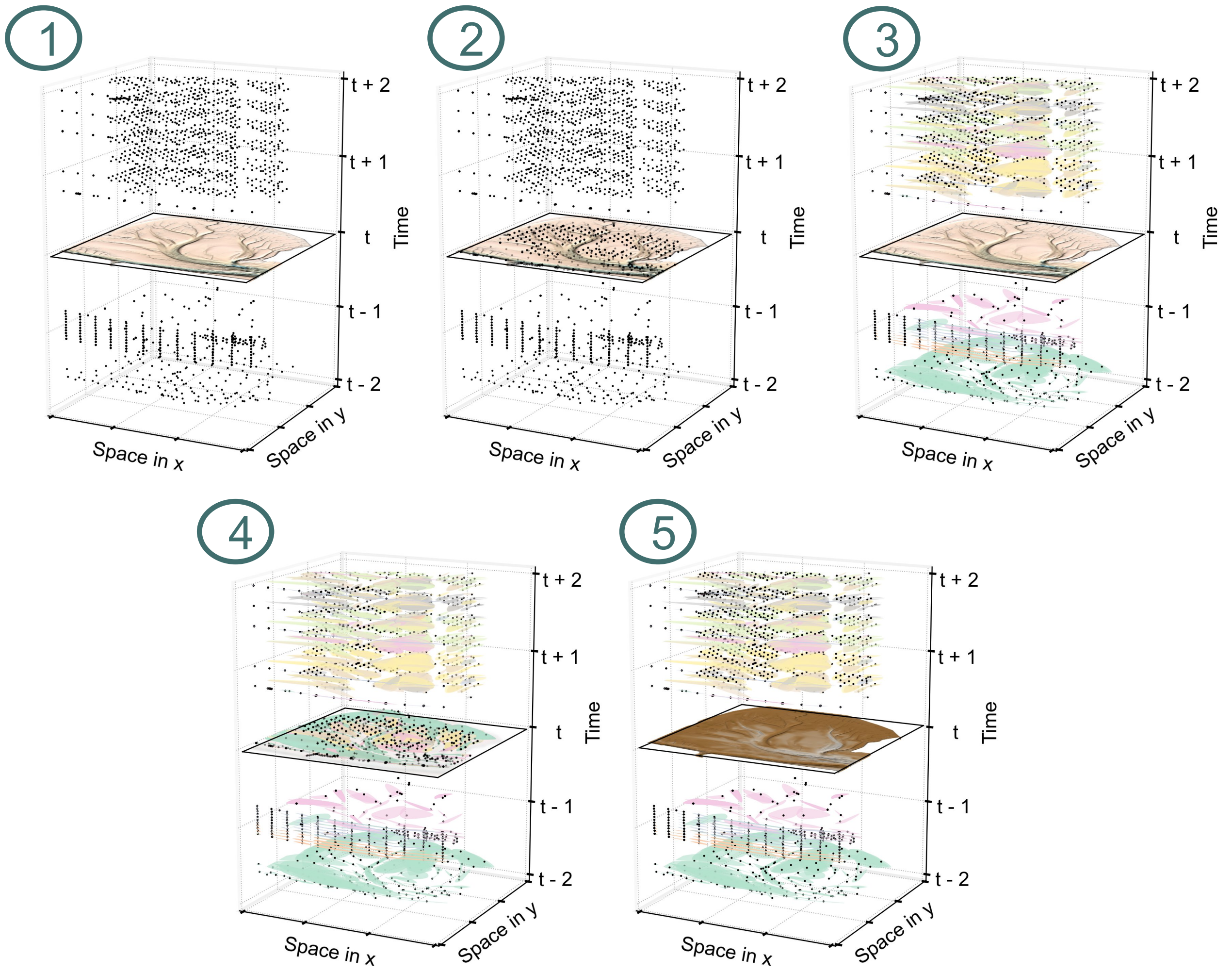
- **<u>Sedimentology products are created using the Functional Seabed Model [1] modelling approach and databases</u>**

  (1-2) Sediment samples collected from different measurement years on a area of interest are considered to influence the initial conditions of the sediment model calculated for a year in the past, e.g. 1950.

  However, sediment samples mirrored on sample area mirrored in the DEM hints low coverage on a high resolution raster grid.

  (3) Topography-alike areas are determined for each sample at the time it was taken and delimited as polygons. These polygons are key for defining the spatial and temporal influence of a sediment sample on its surroundings for the initial modelling.

Sedimentology



Step by step process of the spatio-temporal interpolation approach from Sievers et al. (2021) and Sievers (2022)[3].

- **Sedimentology products are created using the Functional Seabed Model [1] modelling approach and databases**

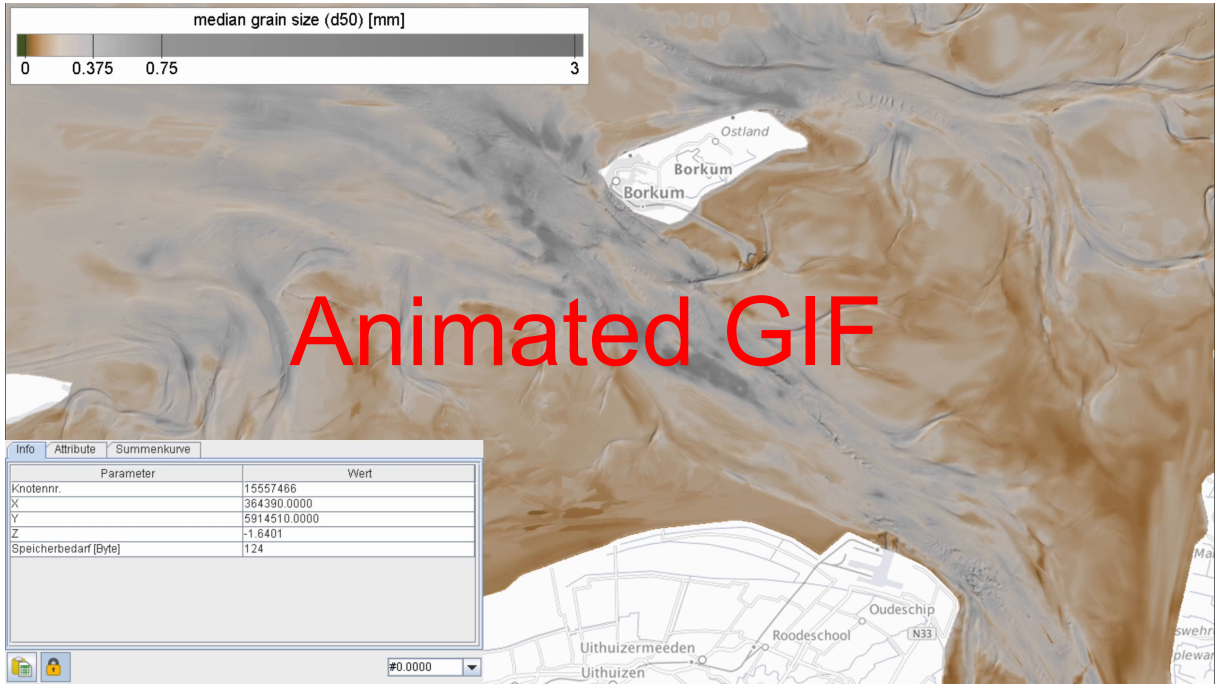
  (4) Topography-alike polygons increase the coverage of each sediment sample. Once initial conditions are determined, a yearly model is calculated considering

  - Erosion-accretion processes the seabed surface experienced.
  - Samples have higher influence on the measurement years they were taken
  - Shear stress derived from current and orbital velocity
  - propagation of wave energy and turbulence

  (5) The output is a raster grid with a grain size distribution and sediment properties for each point. Here, the median grain size model is shown.

Sedimentology

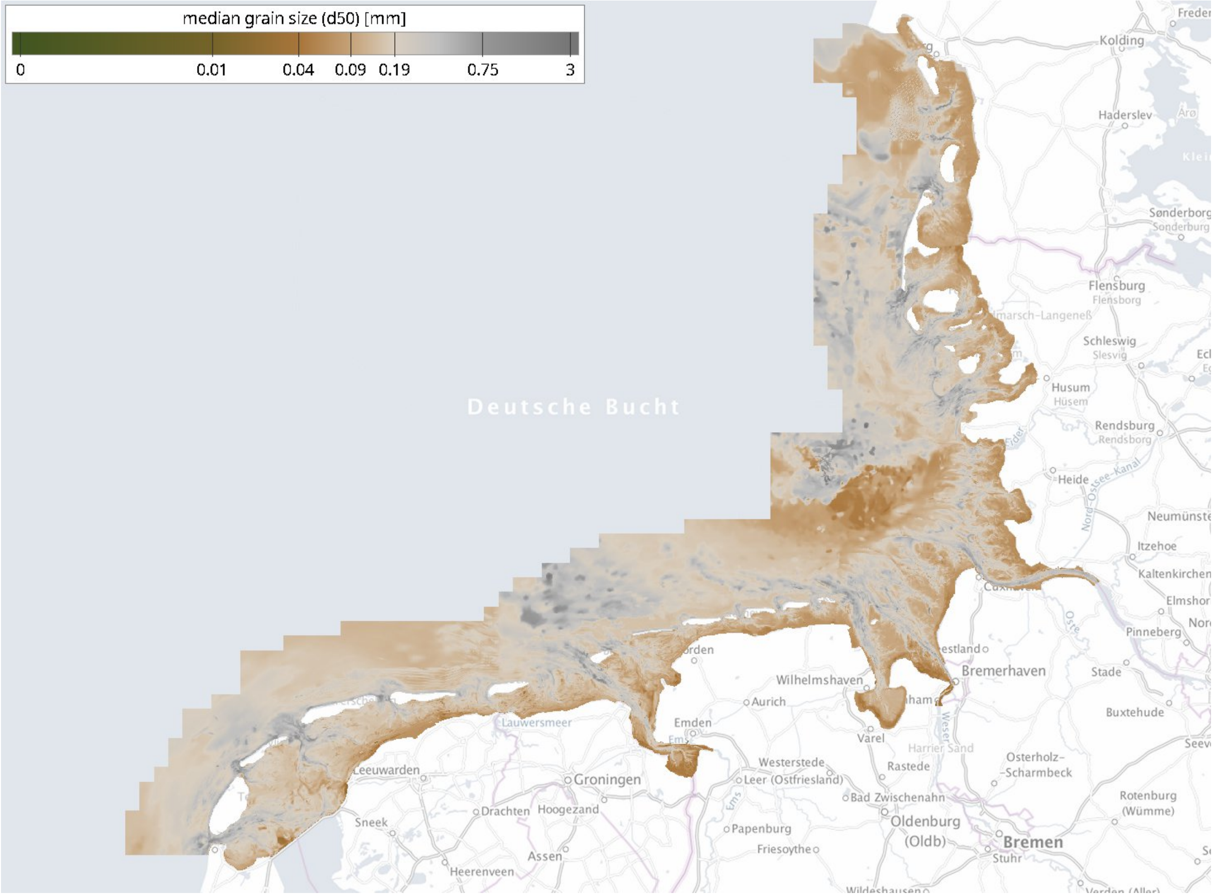
Median grain size (d50) with grain distribution curves



Each point includes coordinates, sediment attributes, and a plot of the cumulative grain size distribution curve. Sediment samples in the area shortly displayed at the end. Background image: BKG TopPlusOpen

- **Sedimentological Products**
  - Output models:
    - Grain distribution curves in .CSV format
    - Median grain size
    - Porosity
    - Sorting
    - Skewness
    - Petrographical Maps (based on the DIN* 4022 norm)

Sedimentology

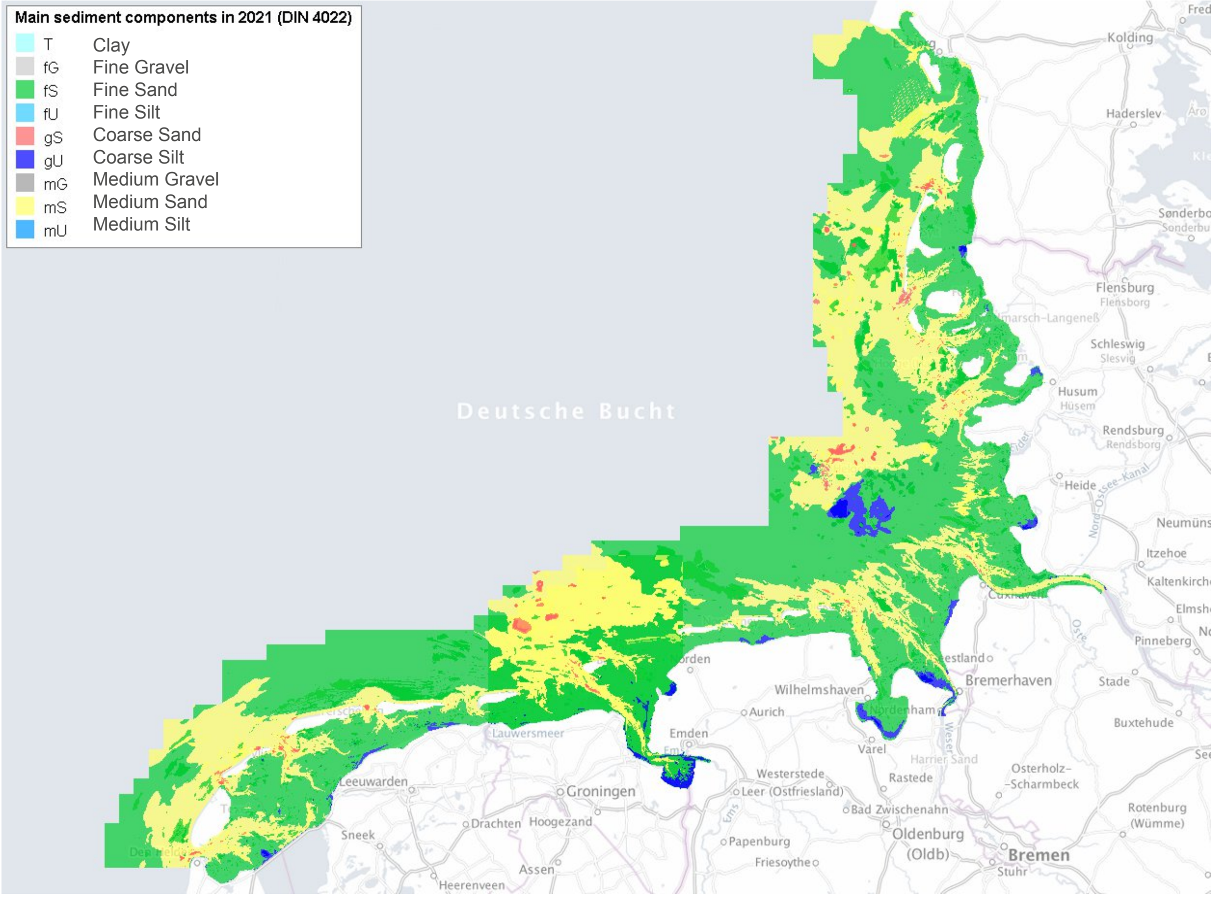


Surface sediment modell for the year 2020. Displayed is the median grain size at each raster point in the grid. Background image: BKG TopPlusOpen

- **Sedimentological Products**
  - For TrilaWatt, annual digital surface sediment models were generated for the Dutch and German Wadden Sea from 2015 to 2021.
  - Due to limited data availability in the Danish Wadden Sea, only a single model for 2020 has been created.
  - The models are provided in TIF format, with separate files for each country to ensure a user-friendly download experience.

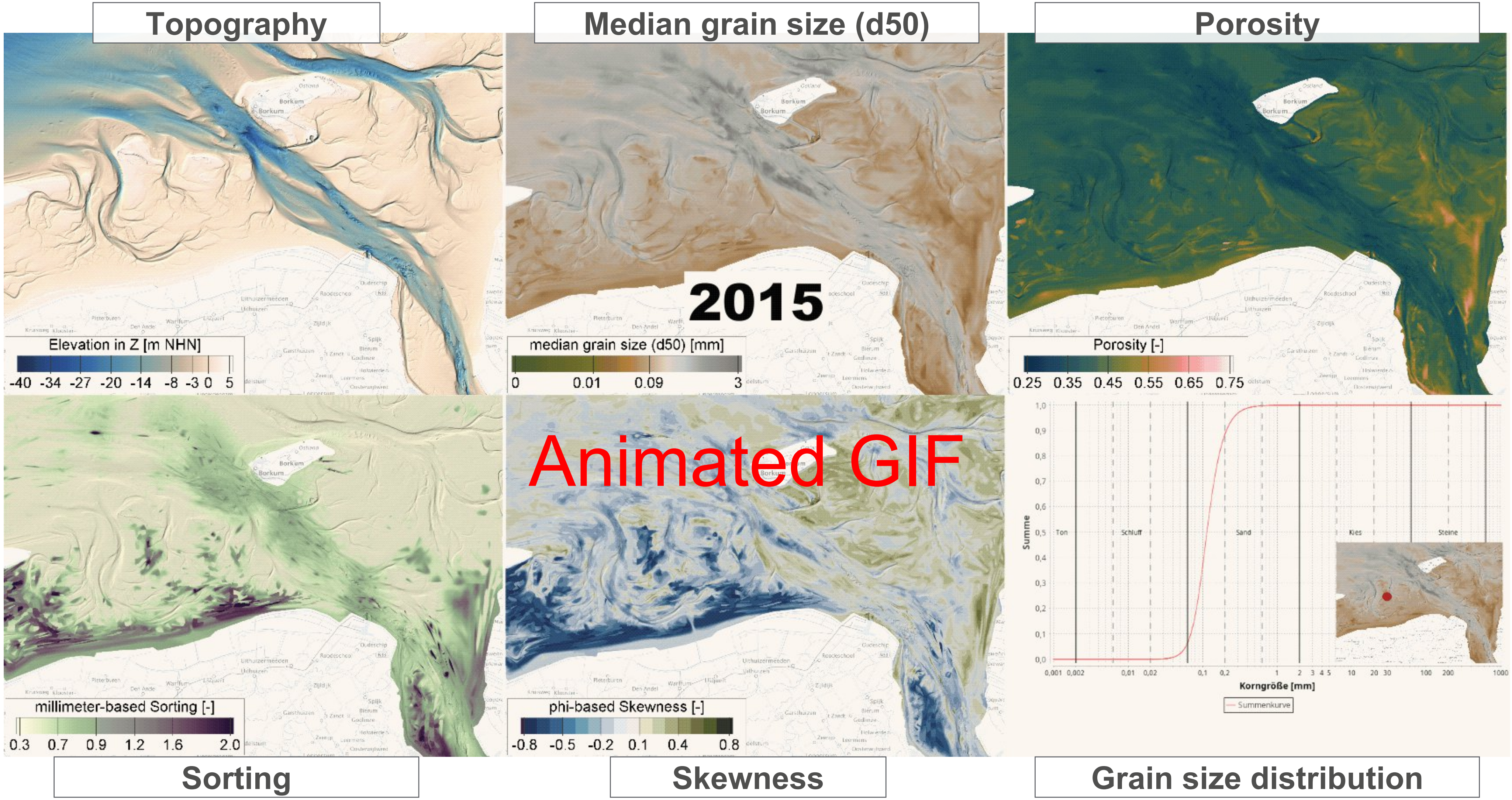
Sedimentology

- **Sedimentological Products – Petrographical maps**
  - Petrographical classify grain size distributions are transformed into SEP-3 linguistic descriptions, aligning with DIN 4022 grain fraction categories.
  - Maps of main and side sediment components in both detailed (long) and simplified (short) formats.
  - Provided as shapefiles with polygon attributes representing sediment composition.



Petrographical map derived from the sediment modell for the year 2021. Displayed is the main sediment grain component at each raster point in the grid. Background image: BKG TopPlusOpen

Sedimentology



References

- [1] Sievers, J., Milbradt, P., Ihde, R., Valerius, J., Hagen, R., & Plüß, A. (2021). An integrated marine data collection for the German Bight—Part 1: Subaqueous geomorphology and surface sedimentology (1996–2016). *Earth System Science Data, 13*(8), 4053–4065. https://doi.org/10.5194/essd-13-4053-2021
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- [3] Sievers, J., 2022. Entwicklung und Anwendung eines datenbasierten Multikomponenten-Küstenevolutionsmodells am Beispiel der deutschen Nordseeküste. Hannover : Institutionelles Repositorium der Leibniz Universität Hannover, 2022
- Sievers, J., & Milbradt, P. 2023. "High-resolution data-based geomorphological analyses of the trilateral Wadden Sea." Paper presented at ICOE 2023 in Aachen, Germany.

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