Gefördert durch:
Bundesministerium für Digitales und Verkehr
aufgrund eines Beschlusses des Deutschen Bundestages

Dr.-Ing. Robert Lepper

TrilaWatt

A digital twin of the Wadden Sea

Final result presentation

06. February 2025

Funding No.: 19F2206-A

BAW
Federal Waterways Engineering and Research Institute

mFUND

TrilaWatt

Outer Weser estuary (Bremerhaven) Source: BAW

Agenda: Final result presentation

1. A digital twin of the coast at the Wadden Sea (Robert Lepper, BAW)
2. Use-Cases and collaborate applications (Robert Lepper, BAW)
3. Geomorphology and surface sediments (Diego Pineda, smile Consult GmbH)
4. Hydrodynamics, sediment transport, and tidal analyses (Markus Reinert, BAW)
5. A web-based coastal information system (Hendrik Aue, PlanGIS)
6. Discussions, acknowledgements, and concluding remarks (Robert Lepper, BAW)

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The TrilaWatt Team

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- **smile Consult GmbH**
  - Schiffgraben 9, 30159 Hannover, Germany
  - Diego Pineda, Peter Milbradt
- **PlanGIS GmbH**
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  - Hendrik Aue, Frank Simmering

Research objective and work packages

Research objective:

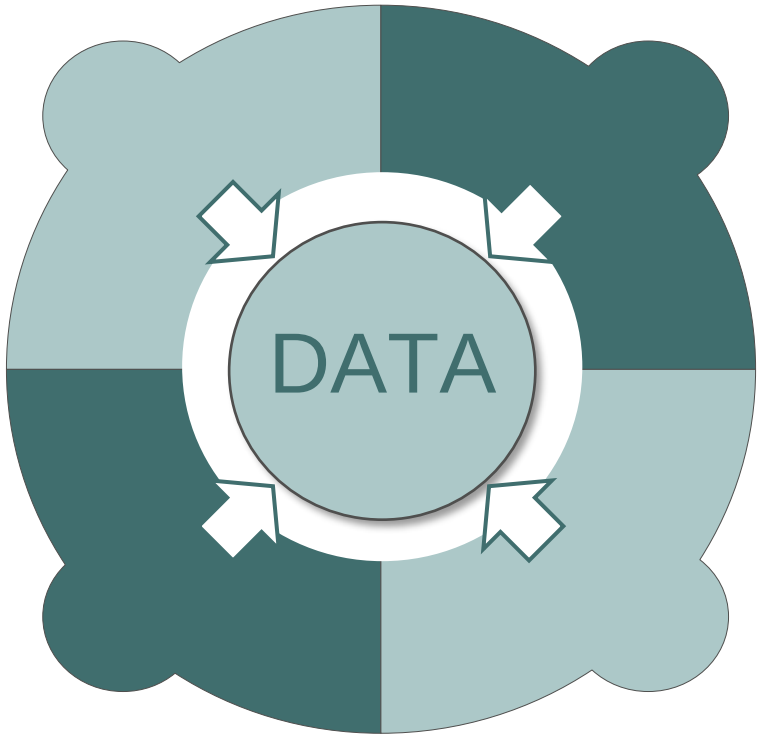
Our goal is to synthesize data in the Wadden Sea area to unified products for research, consulting, and governmental decision-making in the period of 2015 to 2021 in a web-based information system.

(A) Geomorphology

Annual topography data and geomorphological analyses

(B) Surface Sediments

Estimate of a probable surface sediment distribution using sediment samples and numerical modeling



(C) Physical Oceanography

Numerical simulations of the entire North Sea to describe tides, salinity, heat flux, waves, and sediment transport

(D) Coastal information system

Enabling users from different backgrounds to navigate our big data collection efficiently

Specific project goals and how they were accomplished

I

Gather and unify data in the trilateral Wadden Sea area

Complex data interpolation, numerical modeling, a hydrographic survey 2015-2021

II

Develop and apply generic analyses methodology in a web app

Implementation of an open, web-based interactive web-viewer with WPS-functionality.

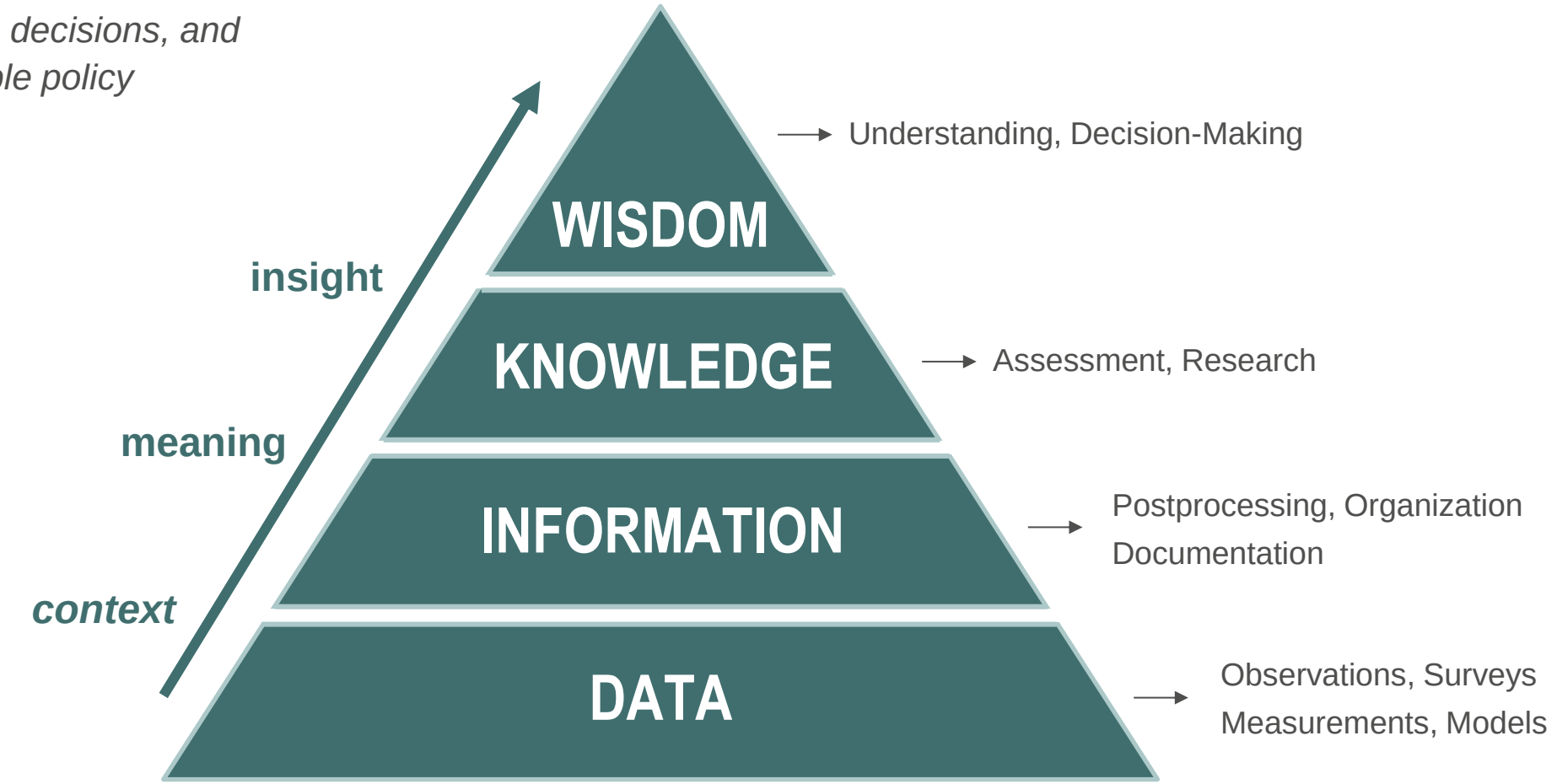
III

Identify stakeholder requirements and develop use-cases

Use-Case reports, networking activities, social media presence

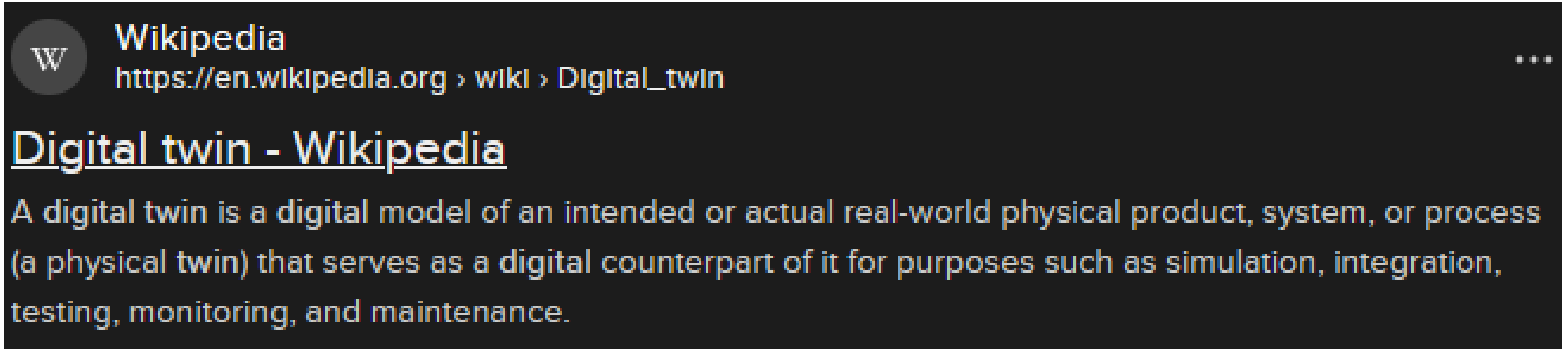
Data facilitates sustainable decisions

Data is the foundation for research, decisions, and sustainable policy



The data-information-knowledge-wisdom (DIKW) concept to collect, organize, interpret data to achieve wisdom for sustainable decisions. With compliments to Tedeschi (2019).

What is a digital twin in the Earth Sciences?



- The concept of a digital twin of Earth envisages the convergence of Big Earth Data with physics-based models in an interactive computational framework that enables monitoring and prediction of environmental and social perturbations for use in sustainable governance. (Li et al., 2023)
- The term 'digital twin‘ […] specifically refers to the comprehensive utilization of physical models, sensors, historical operational data, and additional relevant information to simulate multidisciplinary and multiscale processes. The goal is to create a virtual representation that can mirror the entire lifecycle of its corresponding physical entity. (Glaessgen and Stargel, 2012)

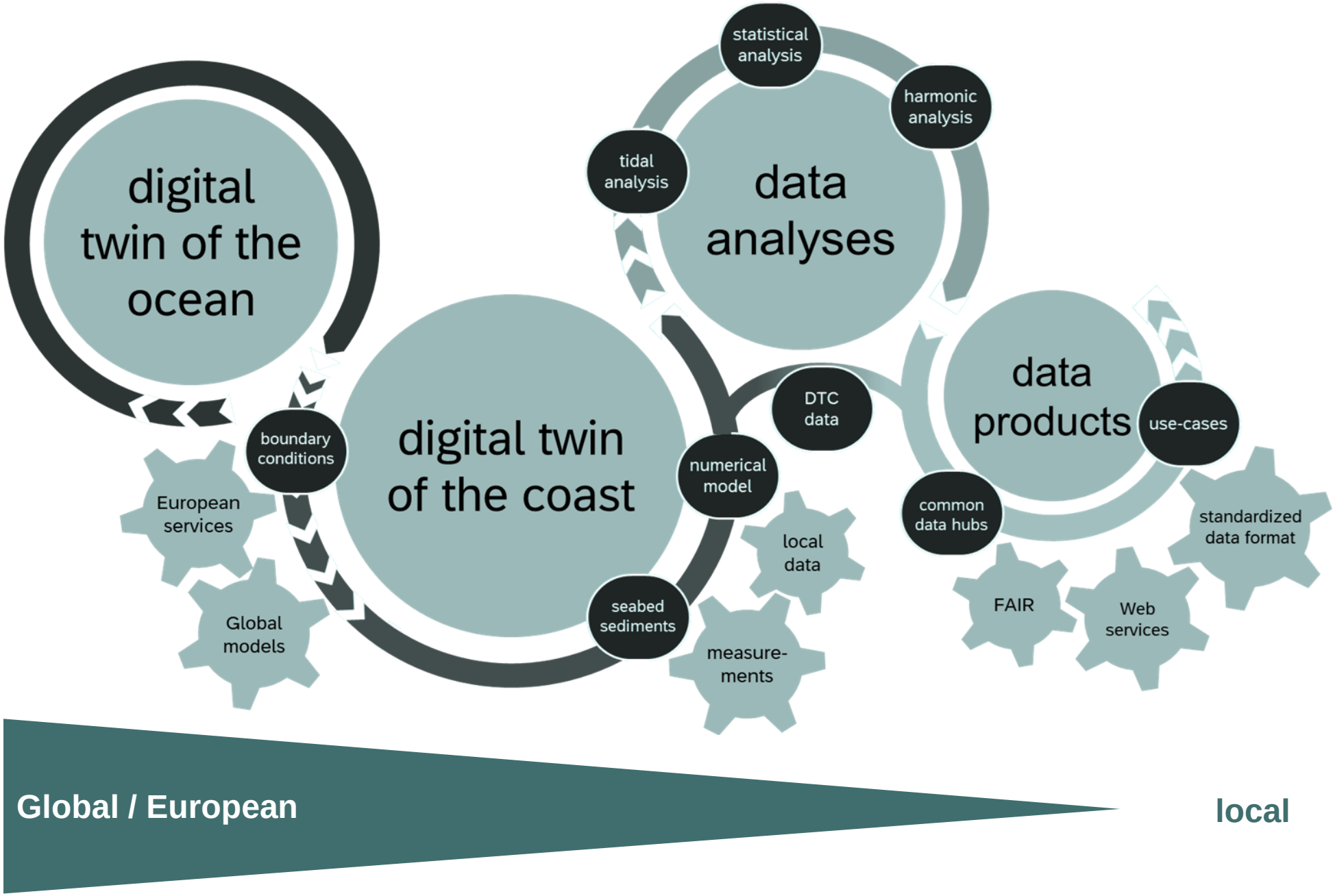
*Li, X., Feng, M., Ran, Y. et al. Big Data in Earth system science and progress towards a digital twin. Nat Rev Earth Environ **4**, 319–332 (2023). https://doi.org/10.1038/s43017-023-00409-w*

Glaessgen E, Stargel D (2012) The digital twin paradigm for future NASA and U.S. Air Force vehicles. Structural Dynamics and Materials Conference, Honolulu, pp 1818. https://doi.org/10.2514/6.2012-1818

European Commission

The DIGITAL TWIN OCEAN

An interactive replica of the ocean for better decision-making


digital twin of the ocean
boundary conditions
European services
Global models
digital twin of the coast
seabed sediments
numerical model
DTC data
local data
measure-ments
data analyses
statistical analysis
harmonic analysis
tidal analysis
data products
use-cases
common data hubs
FAIR
Web services
standardized data format
Global / European
local

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TrilaWatt Use-Cases

1. Tidal energy as a resource
2. Extent of intertidal areas in the Wadden Sea
3. Tidal propagation estimates for planning LiDAR surveys
4. A parameter intersection for habitat classification
5. A tool to plan potential cable routes in the Wadden Sea
6. Web-GIS and reference data for MSRL reporting

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Why tidal energy?

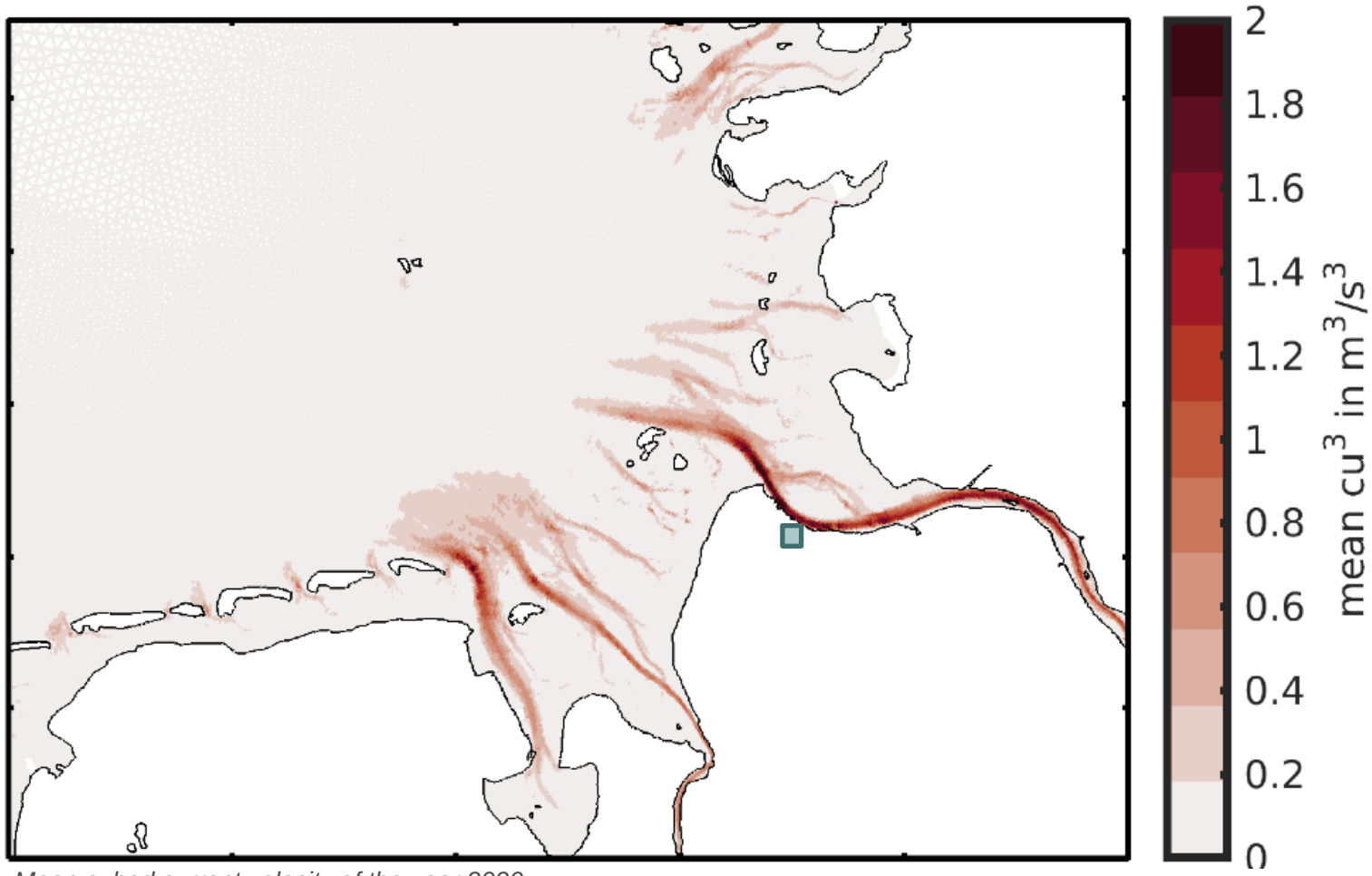
- Korte, A., Windt, C. & Goseberg, N. Review and assessment of the German tidal energy resource. *J. Ocean Eng. Mar. Energy* **10**, 239–261 (2024). https://doi.org/10.1007/s40722-023-00309-7
- Alday, Matias; Lavidas, George (2024): Assessing the Tidal Stream Resource for energy extraction in the Netherlands. In: *Renewable Energy* 220, S. 119683. DOI: 10.1016/j.renene.2023.119683.

- **Tidal Energy Potential**

$$P_{\text{mean},T} = \frac{1}{2} \cdot \rho_{SW} \cdot \sum_{i=1}^{n} (A_{\text{cross}_i} \cdot V^3_{\text{mean},i})$$

Grid data

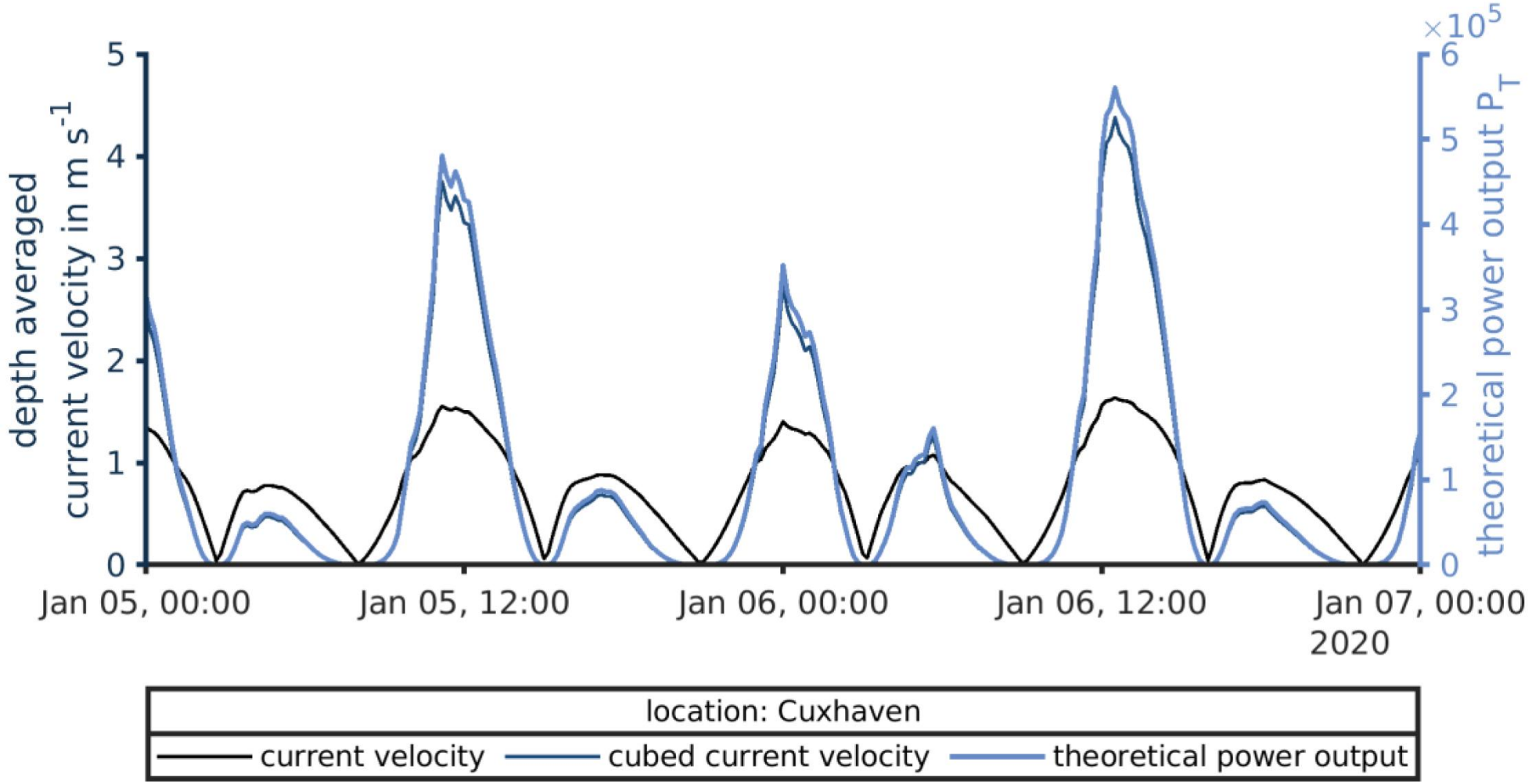
Tidal energy as a function of v^3



Mean cubed current velocity of the year 2020.

- **Data products (2015 – 2021)**
  - Annually averaged cubed current velocity (20 m grid)
  - Top / 2d / bottom current velocity (20-minute intervals, 500 m grid)
- **Practical applications:**
  - Estimator for tidal energy
  - Estimator for sediment transport capacity

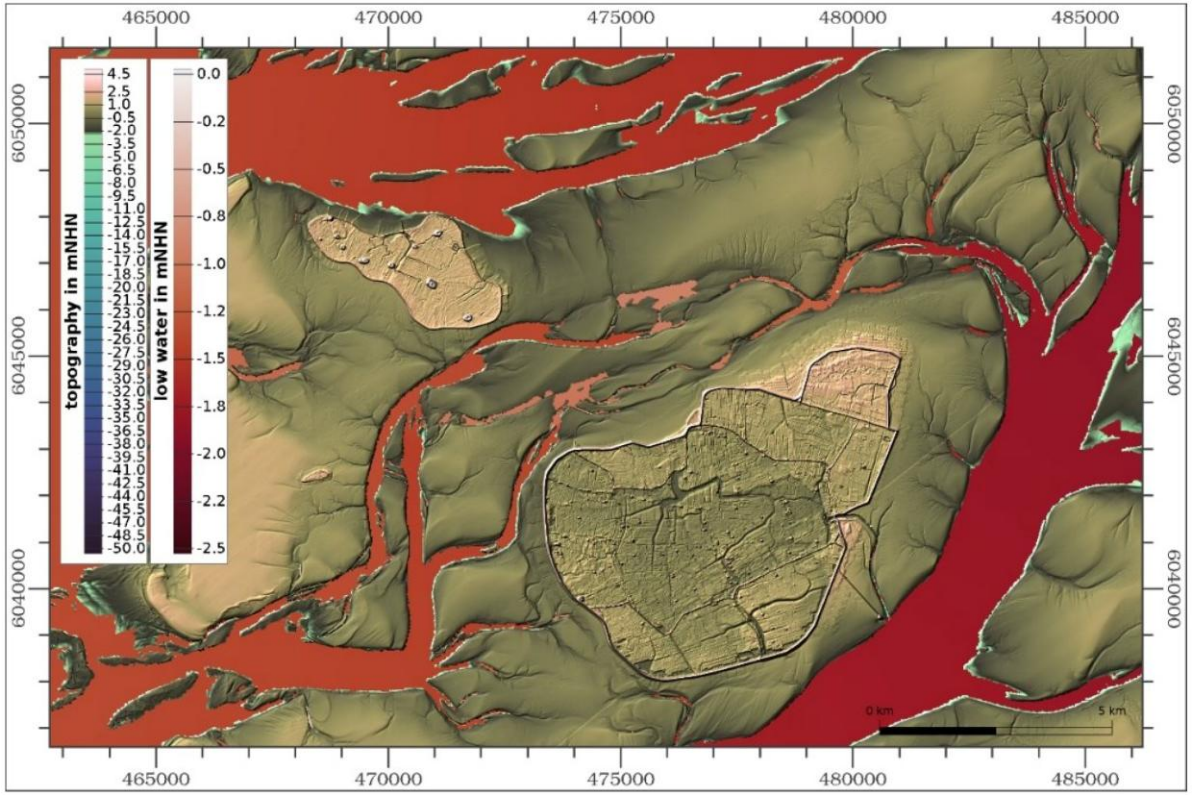
Theoretical power output at Cuxhaven



What are intertidal flats?

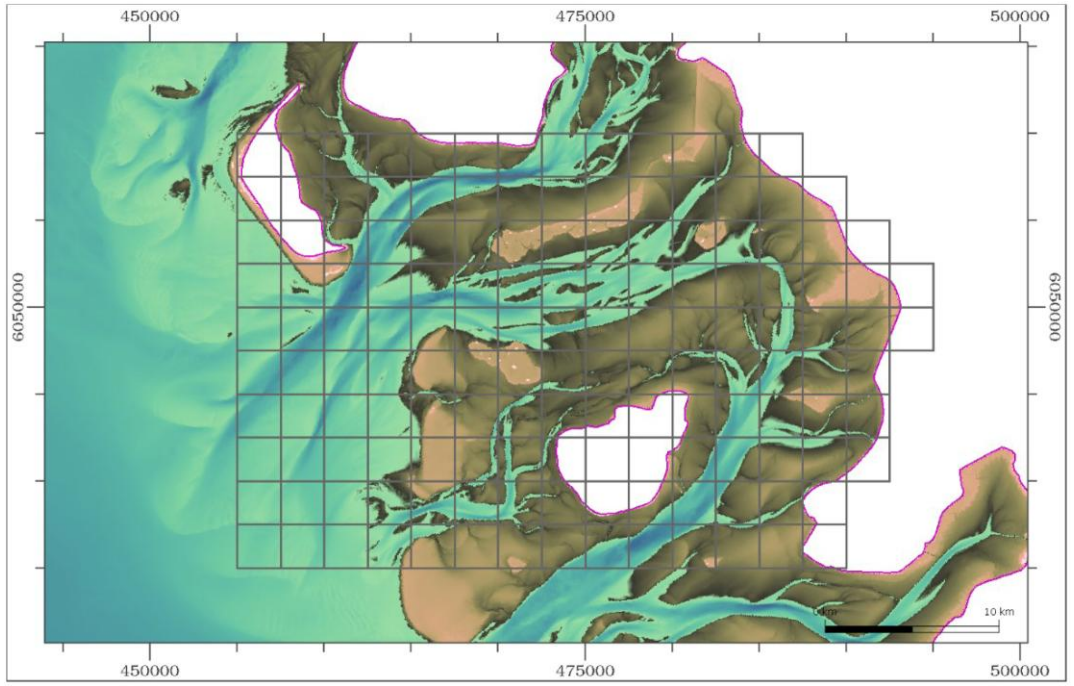
- **Definition:**
  - All areas between tidal high and tidal low water
  - These areas comprise the intertidal zone

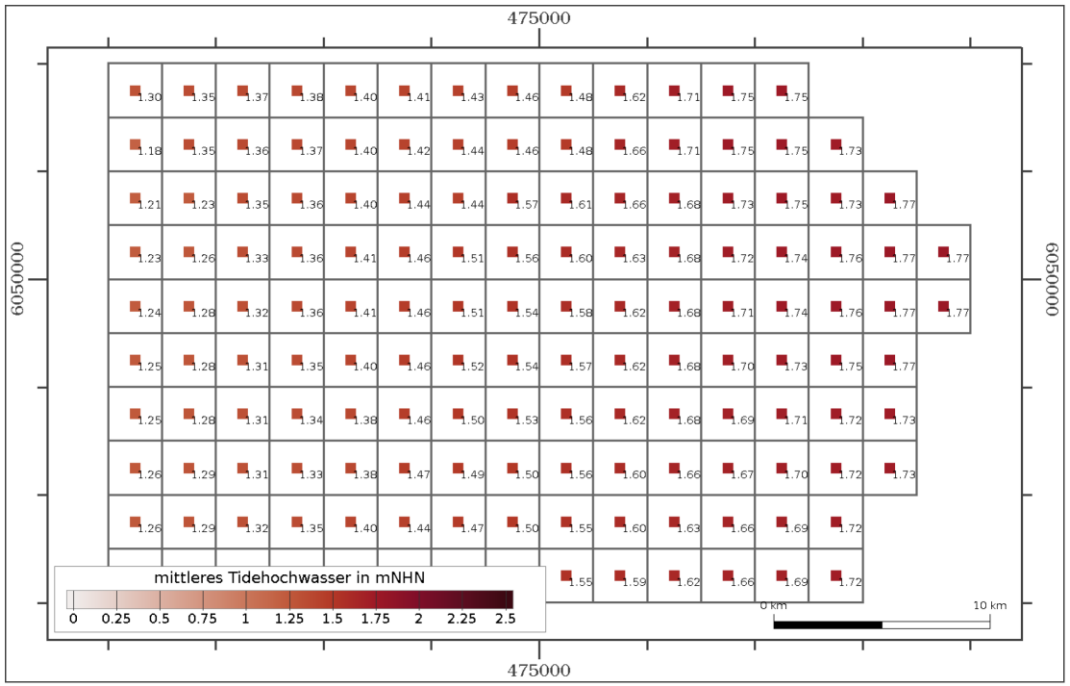
- **So what's the problem?**
  - Which high and low water is relevant?
  - Low and high water vary each year.
  - Low and high water vary spatially.
  - Low and high water are only available at gauges.



- **Our solution**
  - Mini-morphological units to unify data with vastly different resolution and spatial extent.

Mini morphological units for a smooth data intersect

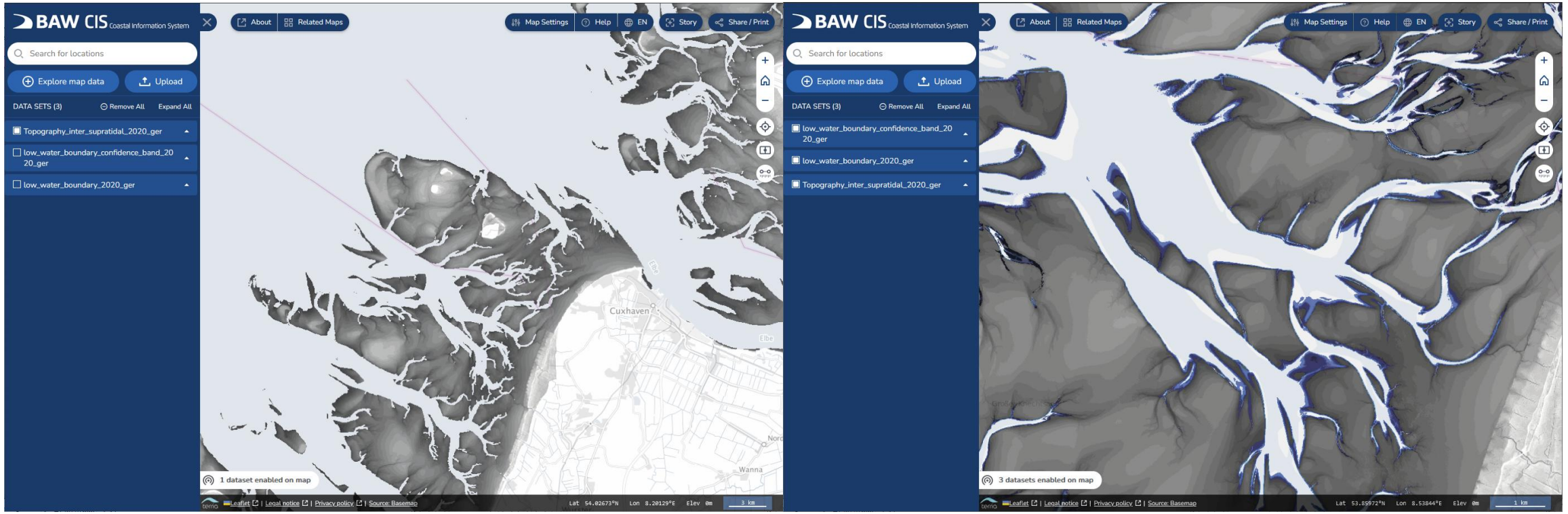




- Tidal low and high water are averaged in small (1x1 km) cells
- Cells with insufficient data are filled using nearest neighbor
- A spatial distribution of tidal low and high water from the morphologically averaged data is used for classification
- Benefit: Spatially varying tidal high and low water for intertidal zone classification
- Drawback: Model information is coarsened, nearest neighbor values may be unsuitable

Intertidal topographies

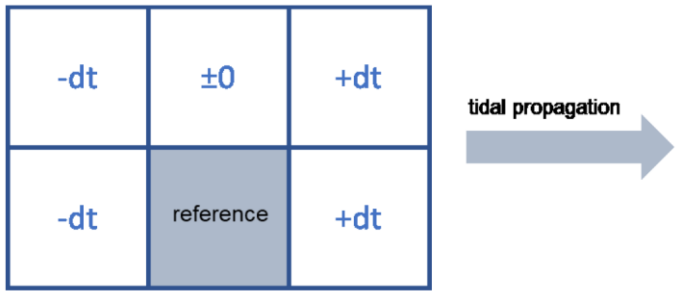
- **Data products (2015 – 2021 for Germany and the Netherlands)**
  - Topography of (only) the intertidal zone
  - Tidal high water and tidal low water lines + their area of confidence
  - https://doi.org/10.48437/5a882d-b3a571

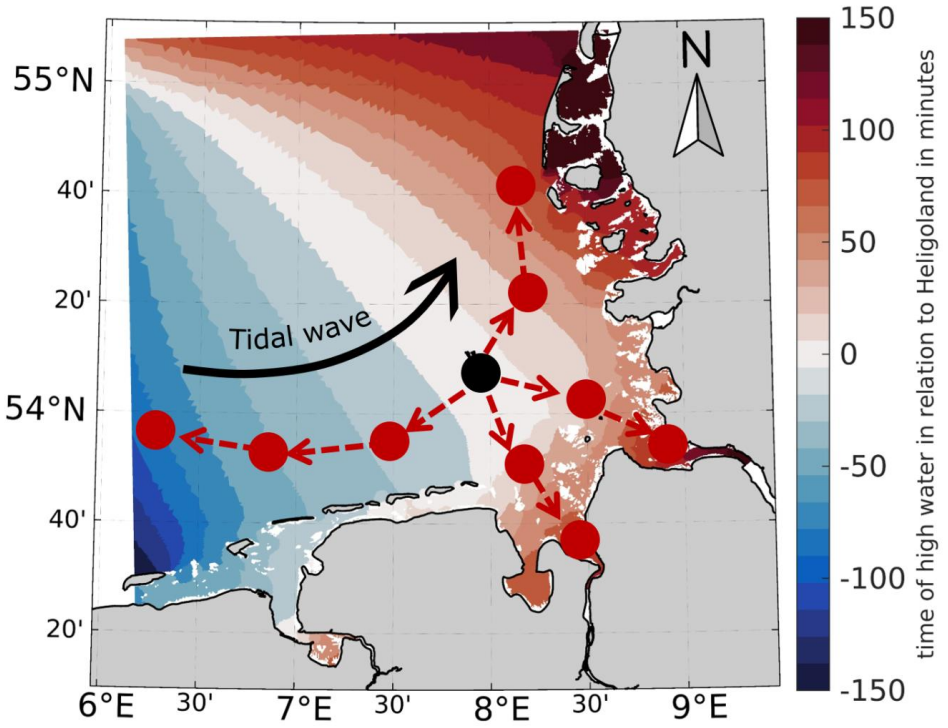


For what purpose do we need tidal propagation?

- **Problem**
  - When planning an airborne LiDAR campaign, surveying at low water is beneficial.
  - For this, knowledge about the tidal propagation is crucial “When is my low water where?”

- **Method**
  - Lagrange-like tidal analysis
  - All SSH signals analyzed for individual tidal waves
  - All tidal waves linked to each other
  - Tidal low and high water times converted to time lags

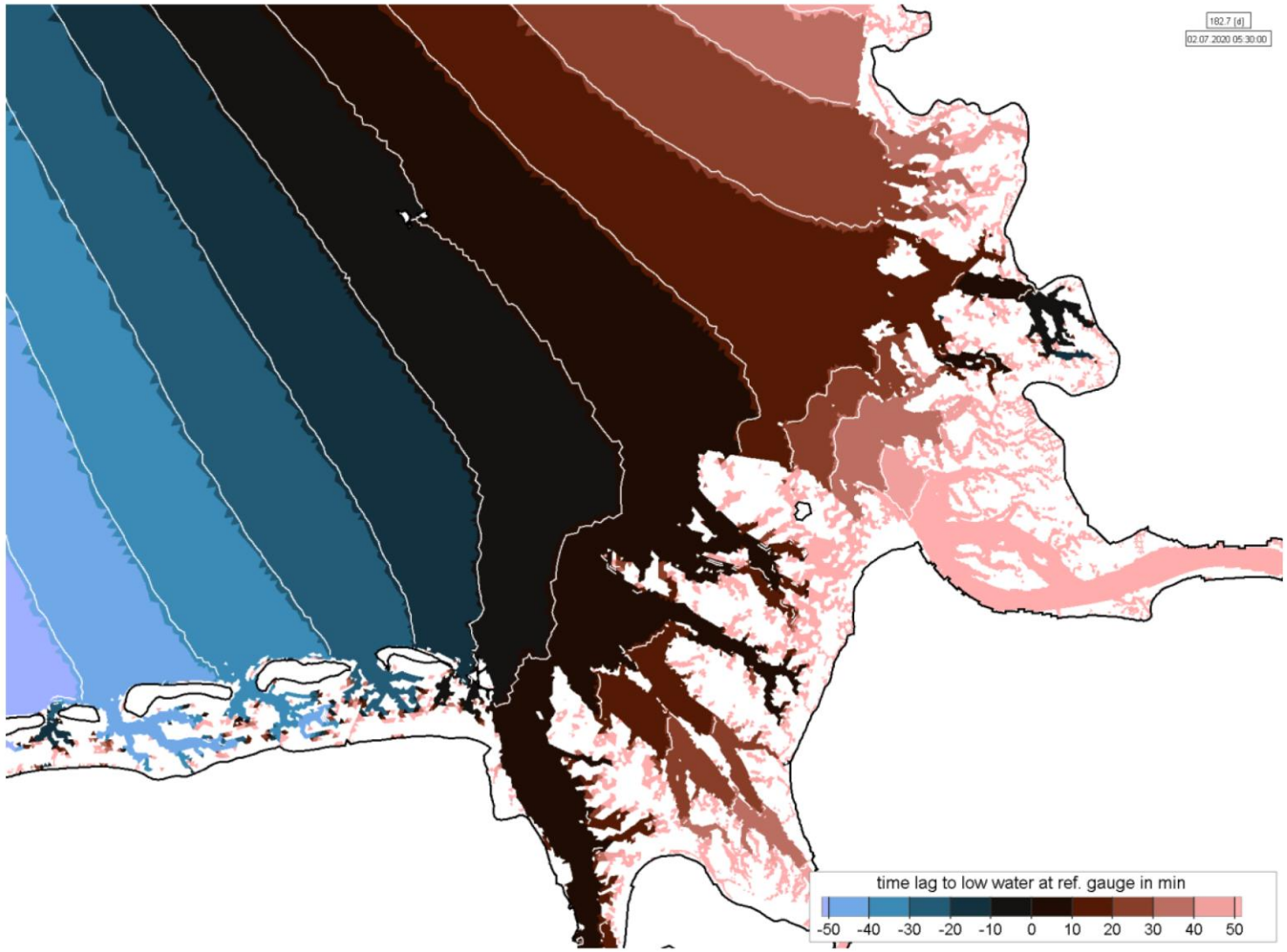




Hagen et al. (2021)

Hagen, R., Plüß, A., Ihde, R., Freund, J., Dreier, N., Nehlsen, E., Schrage, N., Fröhle, P., and Kösters, F.: An integrated marine data collection for the German Bight – Part 2: Tides, salinity, and waves (1996–2015), Earth Syst. Sci. Data, 13, 2573–2594, https://doi.org/10.5194/essd-13-2573-2021

Tidal time lags to reference position as estimator for tidal propagation



- **Data products (2015 – 2021)**
  - Annually averaged tidal low water lag to gauge “Alte Weser”
  - Annually averaged tidal high water lag to gauge “Alte Weser”
- **Practical applications (e.g.)**
  - Planning flight paths for ALS surveys
  - First estimator for Lagrangian particle tracks

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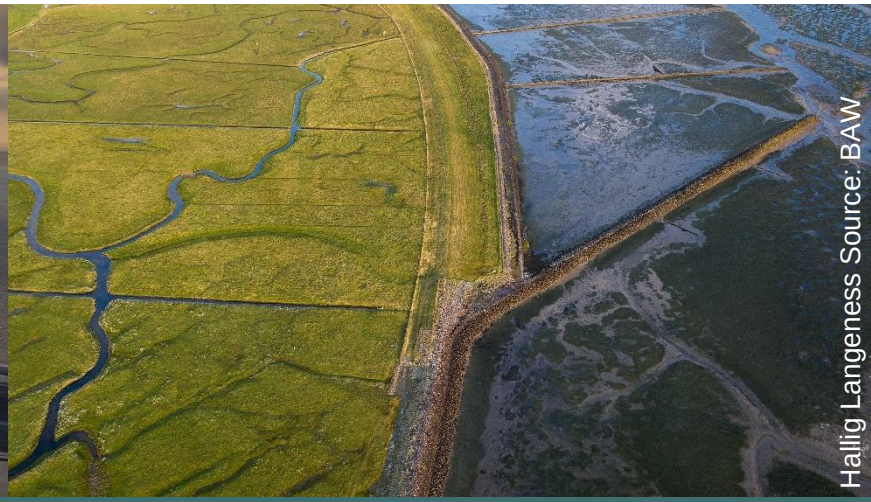
North Frisia Source: BAW



Hallig Langeness Source: BAW

Next: Geomorphology and surface sediments

by Diego Pineda (smile Consult GmbH)

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