CHALLENGES IN MARINE GEODESY

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Nordic Geodetic Commission Summer School
„From Struve To The Space“, Tartu, Aug. 25-29, 2025

Motivation of the study

Geodesists are mainly focused on “dry land” applications

Geoid based vertical datums

FAMOS and BalMarGrav projects

Implementation of the Baltic Sea Chart Datum2000, conducted within BSHC-CDWG

Multiple partners, many different fields, necessary to understand the Big Picture

FAMOS
FINALISING SURVEYS FOR THE BALTIC MOTORWAYS OF THE SEA

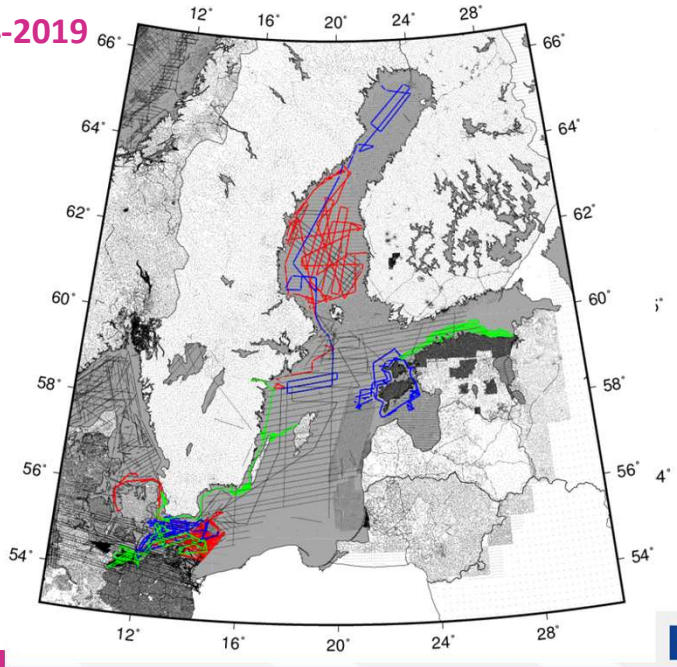
Interreg Baltic Sea Region
Co-funded by the European Union

BLUE ECONOMY
BalMarGrav

BALTIC SEA HYDROGRAPHIC COMMISSION
IHO

Chart Datum, Water level and Currents Working Group (CDWCWG)

FAMOS 2014-2019



- DENEB 2015
- Airisto 2015*
- Jacob Hägg 2015
- Jens Sørensen 2015

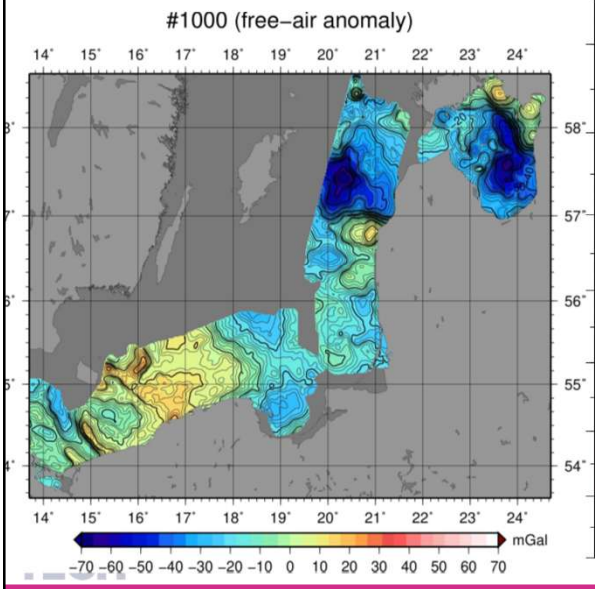
- DENEB 2016
- Jacob Prei 2016*
- Jacob Hägg 2015
- Jens Sørensen 2016

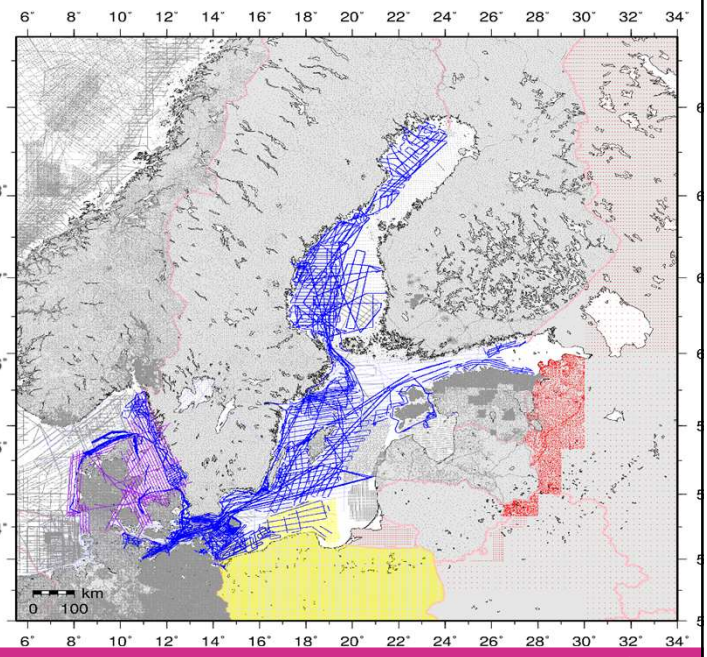
- DENEB 2017*
- Sektori 2017
- Jacob Hägg 2017a
- Jacob Hägg 2017b

* = see below.

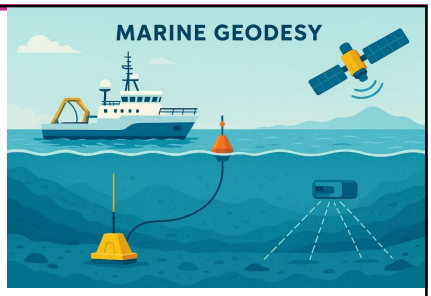
Co-financed by the European Union
Connecting Europe Facility

BalMarGrav 2022-2024





Marine Geodesy and its sub-fields



1.Mapping the Ocean Floor

- Using sonars to measure underwater topography (bathymetry).

2.Monitoring Sea Level

- Measuring and analyzing sea level changes (global and regional), using tide gauges and satellite altimetry.

3.Defining Marine Boundaries

- Determining precise maritime boundaries for countries (important in legal and territorial claims).

4.Tectonic Plate Movements

- Measuring crustal movement under oceans using GNSS, acoustic sensors, and satellite data.

5.Gravity and Geoid Modeling at Sea

- Measuring Earth's gravity field over the oceans to better model the geoid (the "true" shape of Earth's surface).

TAL TECH

Aspect	General Geodesy	Marine Geodesy
Scope	Measures and models the Earth's entire shape, gravity field, and rotation.	Focuses on ocean areas: seafloor, sea level, and maritime boundaries.
Environment	Land, sea, atmosphere, and ice-covered areas.	Primarily oceanic and coastal environments.
Applications	Mapping, Earth deformation, tectonics, satellite positioning, global geoid modeling.	Bathymetry, sea level change, crustal movement under oceans, marine boundary delimitation.
Measurement Tools	GNSS, VLBI, SLR, gravimeters, terrestrial surveying.	Satellite altimetry, GNSS at sea, sonar, acoustic ranging, tide gauges, marine g-meters.
Challenges	Terrain variability, atmospheric effects, gravity modeling.	Remote locations, ocean dynamics, lack of stable reference, underwater positioning.
Reference Surface	Geoid and ellipsoid are used for global reference frames.	Vert.datum, ellipsoid, also considers **Mean Sea Level** (MSL) as a dynamic surface. Nowadays geoid as well

The context– big questions/problems that marine geodesy helps to solve

•How can we contribute to the efficiency and environmental friendliness of the marine transport system?
•How can we increase the safety of marine traffic and transport?

•How do seas and oceans function and what is their significance for the future?
•How do you measure and model the interaction between ice, atmosphere and ocean, so that sea level rise can be reliably predicted?
•How do we bridge different scales when modeling dynamic (liquid) systems?

•How can we protect society against flooding in a nature-friendly manner?

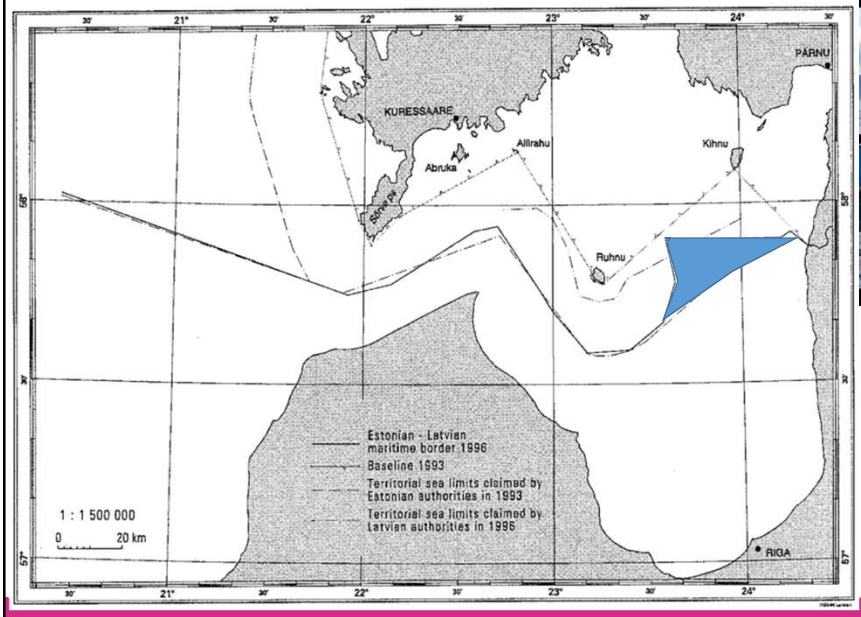
•How can we manage water carefully in the future?

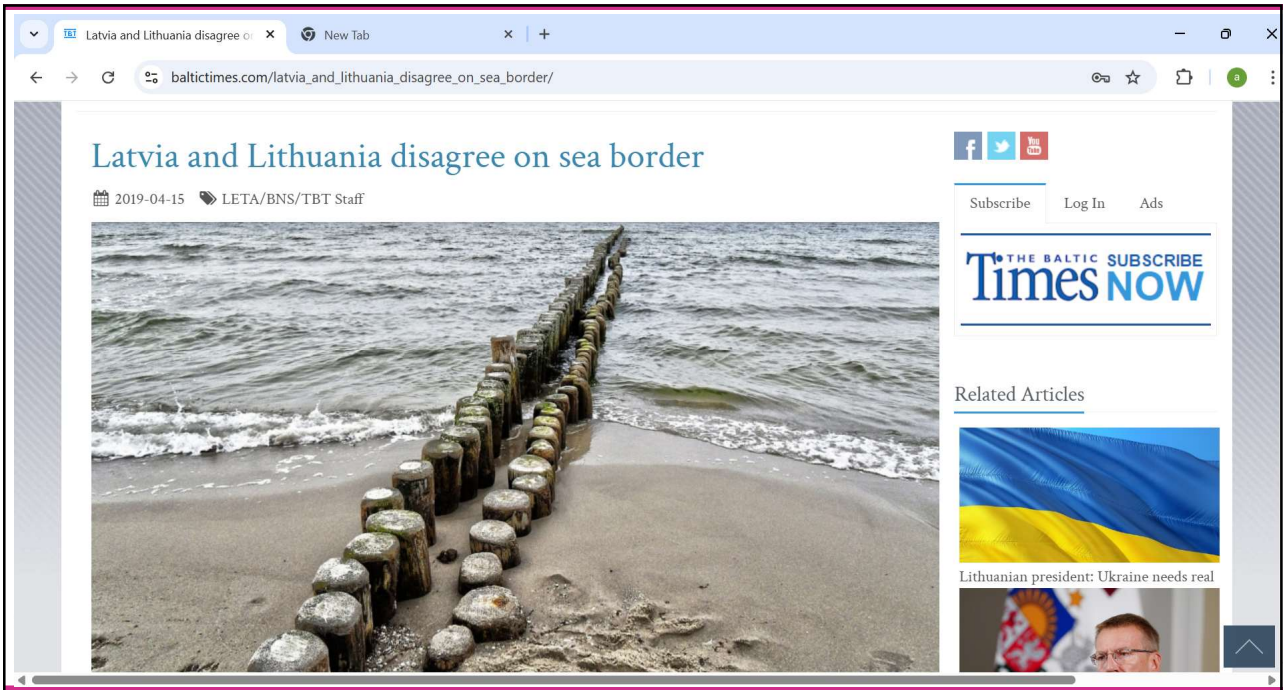
•How can we optimally use rivers, lakes, seas and oceans for energy production?

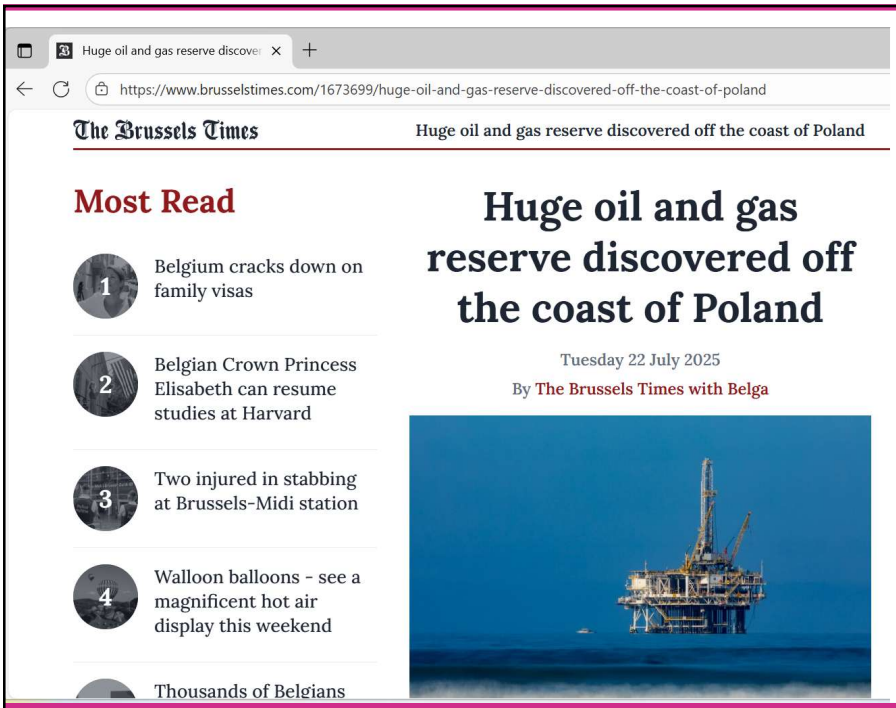
Applications of Marine Geodesy

- **Accurate seafloor mapping**
- **Maritime navigation and safety**
- **Scientific understanding of seafloor structures and tectonics, predicting seismic activity and tsunamis**
- **Coastal management (erosion and sedimentations) and planning**
- **Marine habitat conservation and biodiversity studies (carbon sequestration)**
- **Climate change and oceanographic studies (e.g., sea level rise, flooding)**
- **Infrastructure planning - Submarine cable and pipeline routing, detection of disruptions**
- **Legal claims under UNCLOS (United Nations Convention on the Law of the Sea) / GALOS**

Estonia-Latvia marine boundary dispute in the 1990-ies

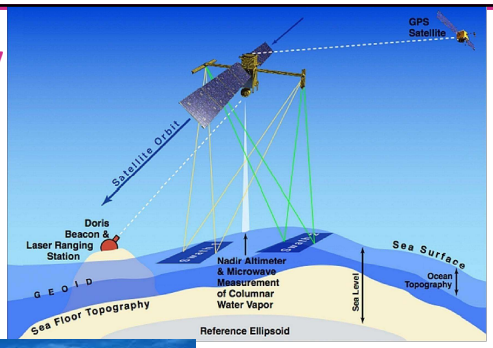


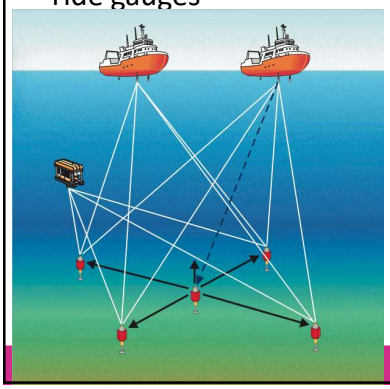


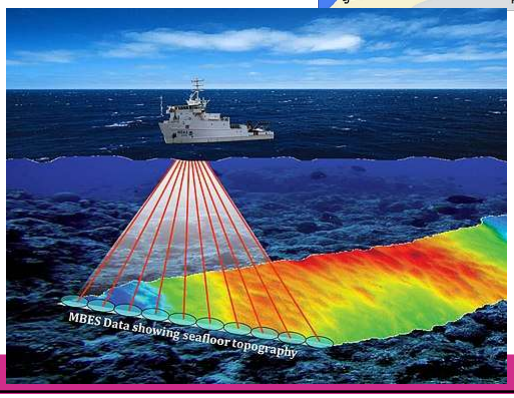


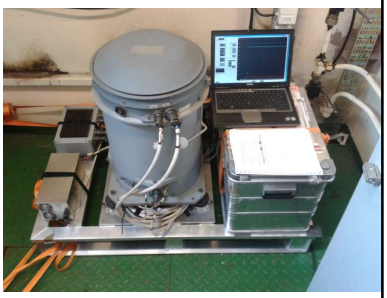
Techniques and methods of Marine Geodesy

- GNSS (Global Navigation Satellite Systems)
- Satellite altimetry (e.g., missions like SWOT, Jason, Sentinel-6)
- Multibeam echo sounders
- Gravimeters
- Acoustic positioning systems
- Tide gauges

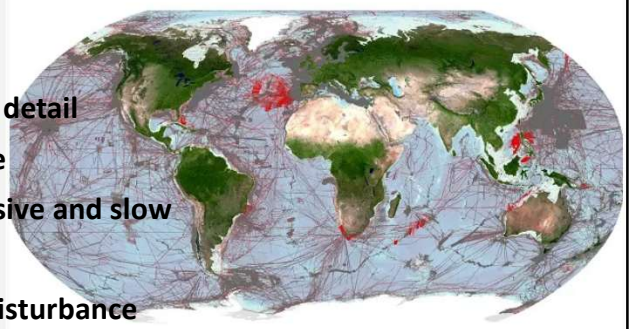








Data Acquisition Challenges



Coverage gaps: Vast areas remain unmapped in detail

Harsh environments: Storms, deep-sea pressure

High costs: Ship-based sonar surveys are expensive and slow

Remote and difficult-to-access locations

Environmental protection concerns: minimize disturbance

Global cooperation needed

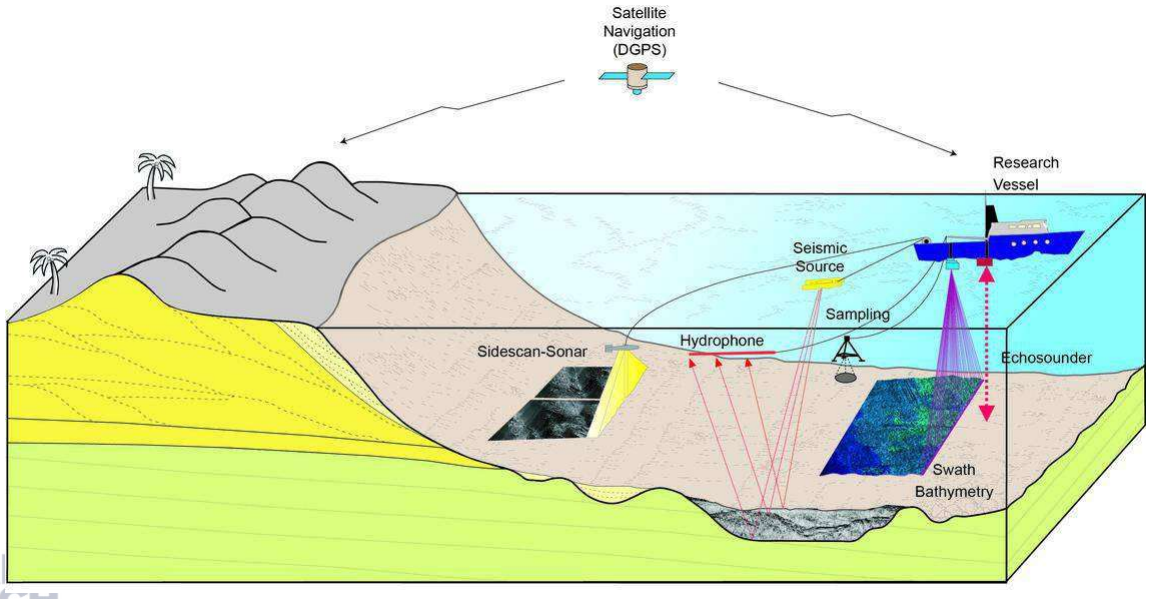
TECHNOLOGY LIMITATIONS

Satellite altimetry: Global coverage, but coarse resolution (~1–5 km)

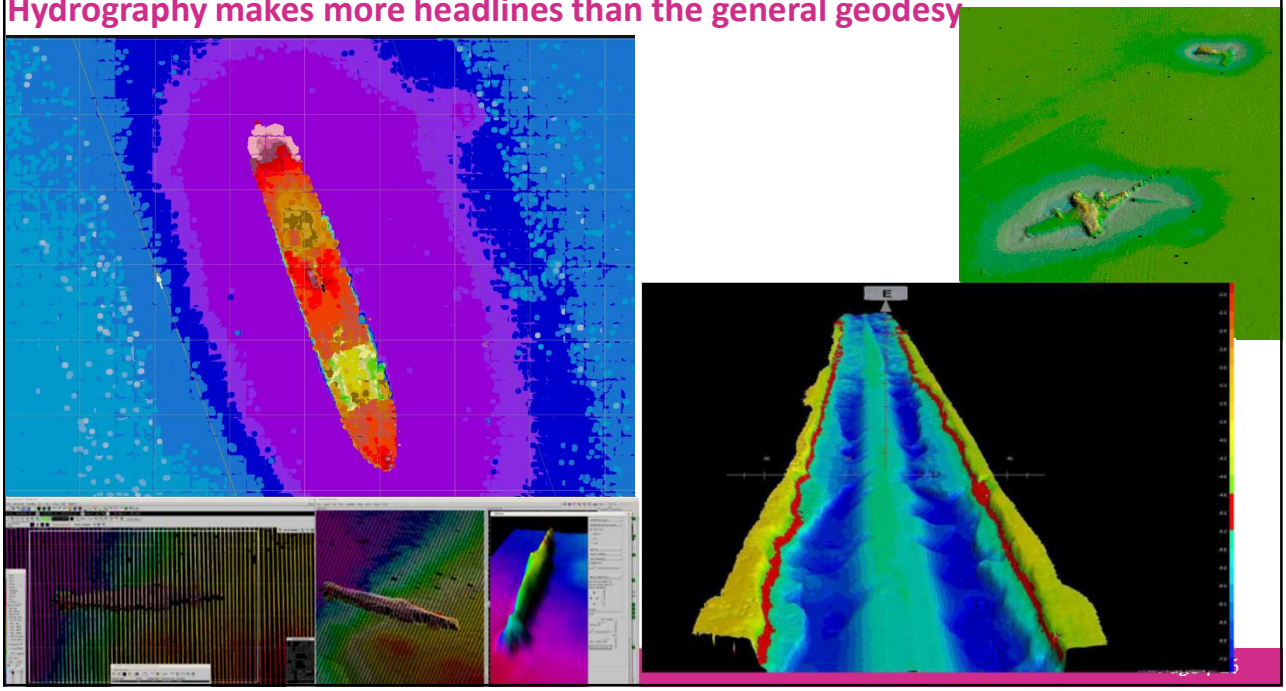
Sonar systems: High-resolution mapping, but narrow swath & depth limits

Integration issues: Difficulties harmonizing satellite & in-situ data

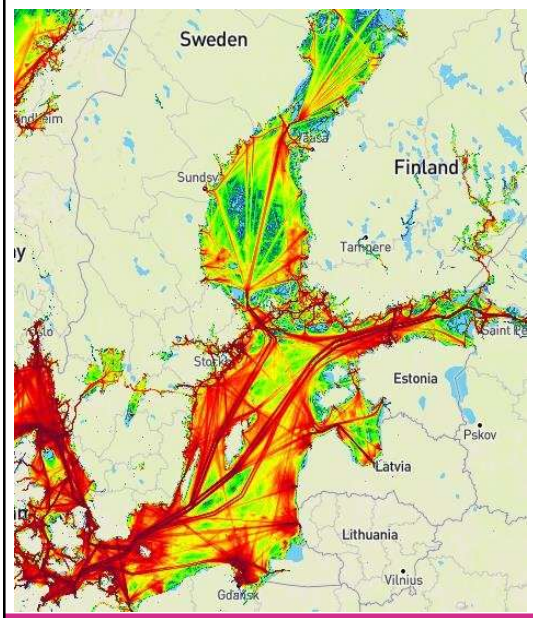
Seafloor mapping

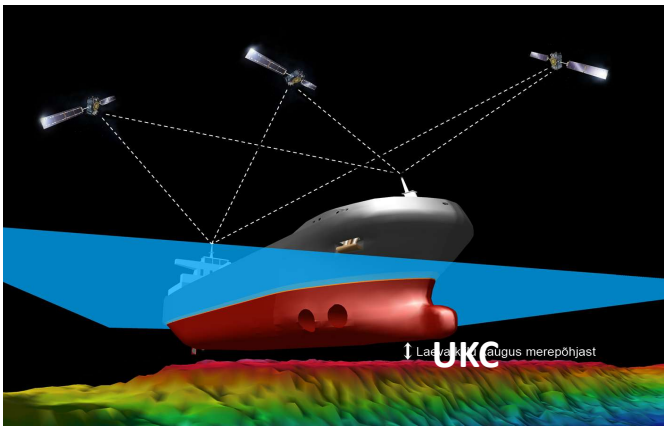


Hydrography makes more headlines than the general geodesy

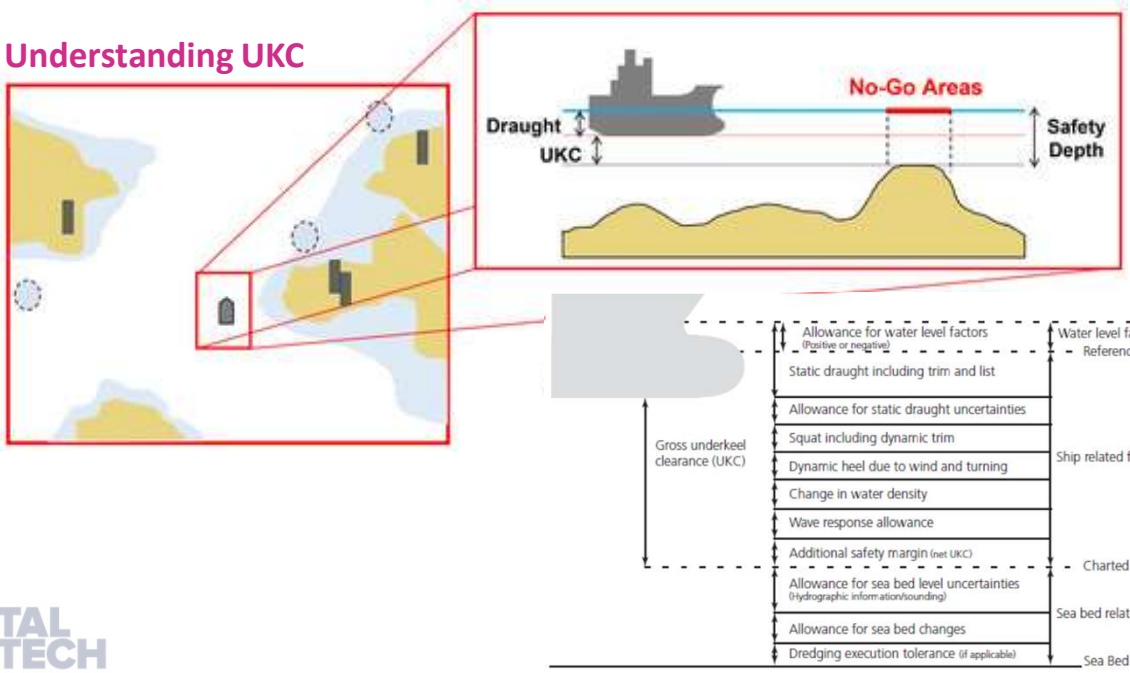


Safety of navigation - the shipping routes annual intensity plot - under keel clearance



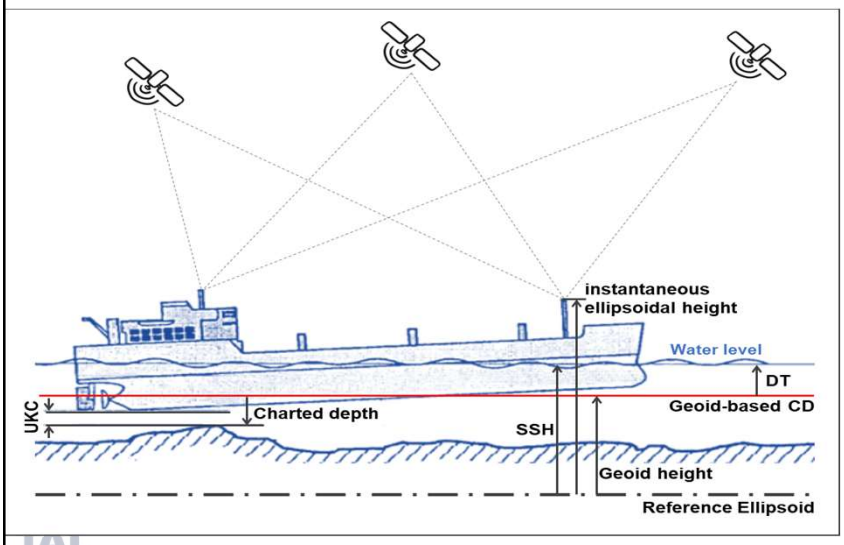


Understanding UKC



Economic impact of 1 inch extra depth in terms of cargo - multibillion $$$ business

Safety of navigation – using GNSS and an appropriate vertical datum



Geoid and DT

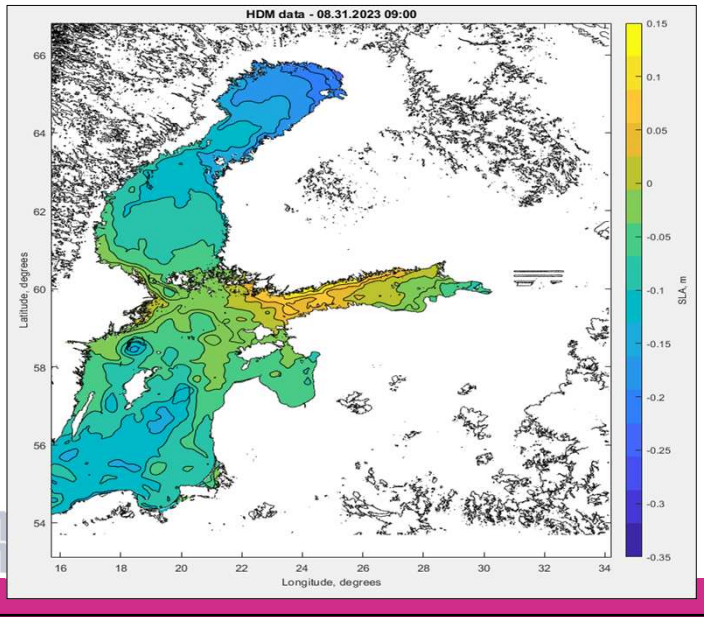
- Geoid is a stable/static surface that should ideally be used as the zero-reference surface for sea level variations.
- Sea level variation relative to geoid surface is 'Dynamic Topography' (DT)

DT in the tideless Baltic Sea easily +/- 1 m

Sea Level Data Sources

	Tide gauge (TG)	Satellite altimetry (SA)	Air-/shipborne GNSS/ LiDAR profiles	Hydrodynamic model (HDM)
Type	Observation (DT)	Observation (*SSH*)	Observation (*SSH*)	Model (*DT*)
Land motion	Relative sea level	Absolute sea level	Absolute sea level	Absolute with *unknown* ref. epoch
Temporal res.	High (Hourly)	Low (r. 10-35 days)	Arbitrary, dedicated routes	High (Hourly)
Horizontal res.	Single point at coast	300 m along the tracks	High (<1x1 m)	Gridded, high (1x1 nmi)
Vertical reference and accuracy	TG benchmark (BSCD2000) 0.01 m	Reference Ellipsoid (GRS 80, T/P) 0.05 m	Reference Ellipsoid (GRS 80) 0.02 m	{*undisclosed*}, due to parameterization schemes, time steps and modelling discretization, topography, and uncertainties in boundary conditions and forcing inputs
Coastal data	Good quality	poor	good	Good, but smoothed

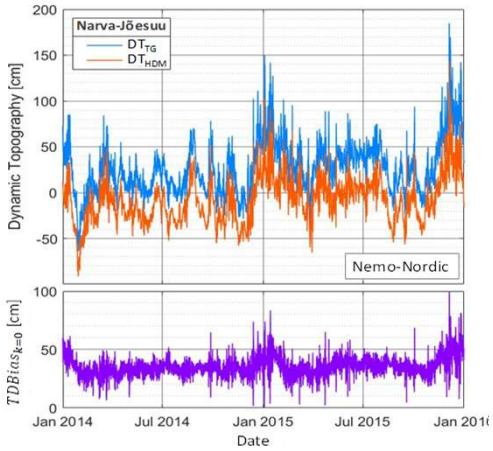
Hydrodynamic models – good (continuos from coast to offshore) spatial coverage and hourly temporal resolution

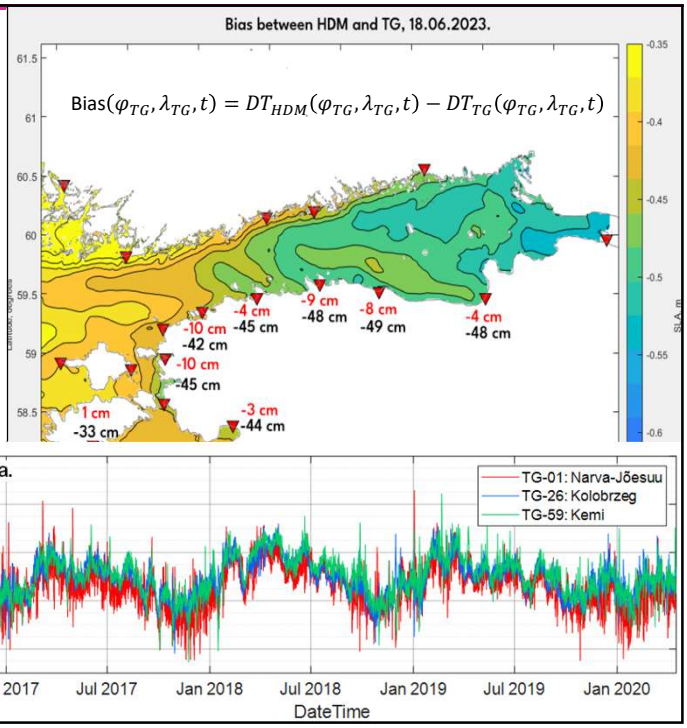


Provides continuos surface - can be used as a base to integrate various sea level data sources with different resolutions.

Two limitations—modelling errors and their undisclosed reference surface—hinder direct data fusion methods for combining dynamic topography (DT) from other sources into HDMs.

HDM models – spatio-temporal bias





The HDM bias is corrected by using all the available TG stations around the Baltic Sea

Conclusions

Sea level data can be measured using diverse techniques, each characterized by:

- different spatial and temporal resolutions,
- distinct vertical references,
- associated errors and uncertainties.

An ideal solution would be the synergy of these various data sources to obtain accurate, consistent, and continuous sea surface in space and time.

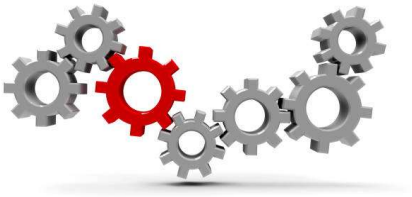
A high-resolution marine geoid plays an important role in integrating data sources.

Hydrodynamic model (HDM) can be used as the main reference surface to represent dynamic topography (sea level), since it is the best spatio-temporal mathematical representation of marine dynamics.

However due to the HDM undisclosed reference level it must be at first corrected using sea level data from the TG-s or SA.

Emerging Solutions in Marine Geodesy

Autonomous systems: Unmanned sensors lower costs and risks

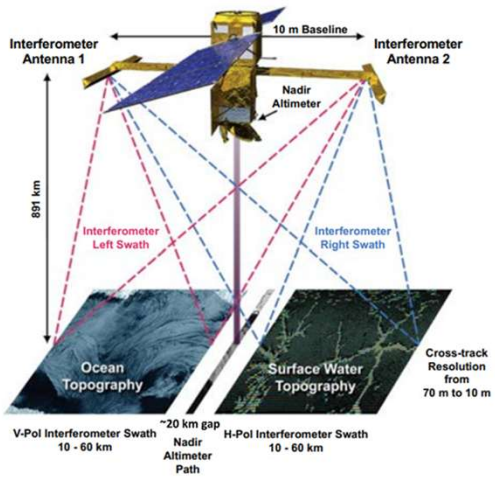


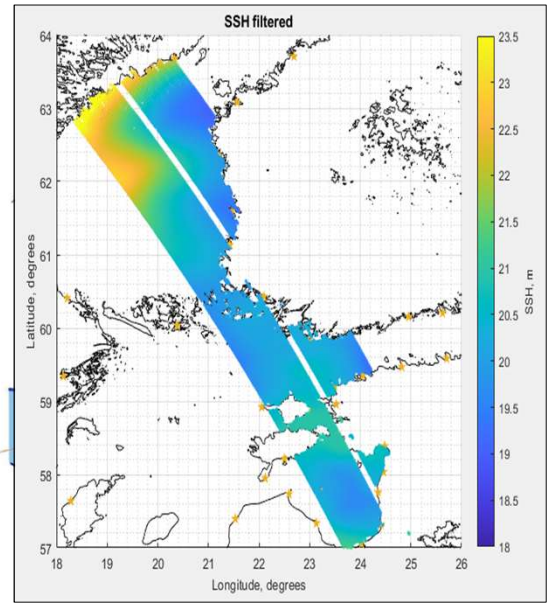
New satellite missions: SWOT already has improved spatial resolution of the sea level

Open data initiatives: International collaborations

Data integration: AI & machine learning enhance accuracy

New possibilities with the SWOT satellite altimetry





Would it possible to obtain Real time or near-real time sea level (UKC) information for the duration of the entire voyage of a vessel?

DEVELOPMENT OF CONTINUOUS DYNAMIC VERTICAL REFERENCE FOR MARITIME AND OFFSHORE ENGINEERING BY APPLYING GEODETIC AND MACHINE LEARNING STRATEGIES

TALTECH (ESTONIA) GEODESY RESEARCH GROUP –

ARTU ELLMANN, N. DELPECHE-ELLMANN, S. VARBLA, S. RAJABI KIASARI, V. JAHANMARD, A. KUPAVÕH

Motivation of the study

Continuous dynamic vertical reference in offshore is of vital importance for:

- reaching the engineering requirements of **offshore renewable energy plants**
- for optimizing shipping routes and improving the **vessels clearance management (UKC)**
- IHO updated framework of **maritime data standards** (S-101, S-102, S-104, S-111, etc), requirement
- Identifying/quantifying **ocean circulation** processes (currents)