Examining Mean Dynamic Topography Using Geodetic and Oceanographic Approaches for the Baltic Sea

V. Jahanmard[1], N. Delpeche-Ellmann[2], A. Ellmann[1]

[1]Geodesy group, Department of Civil Engineering and Architecture, Tallinn University of Technology
[2]Department of Cybernetics, School of Science, Tallinn University of Technology

email: vahidreza.jahanmard@taltech.ee

Introduction

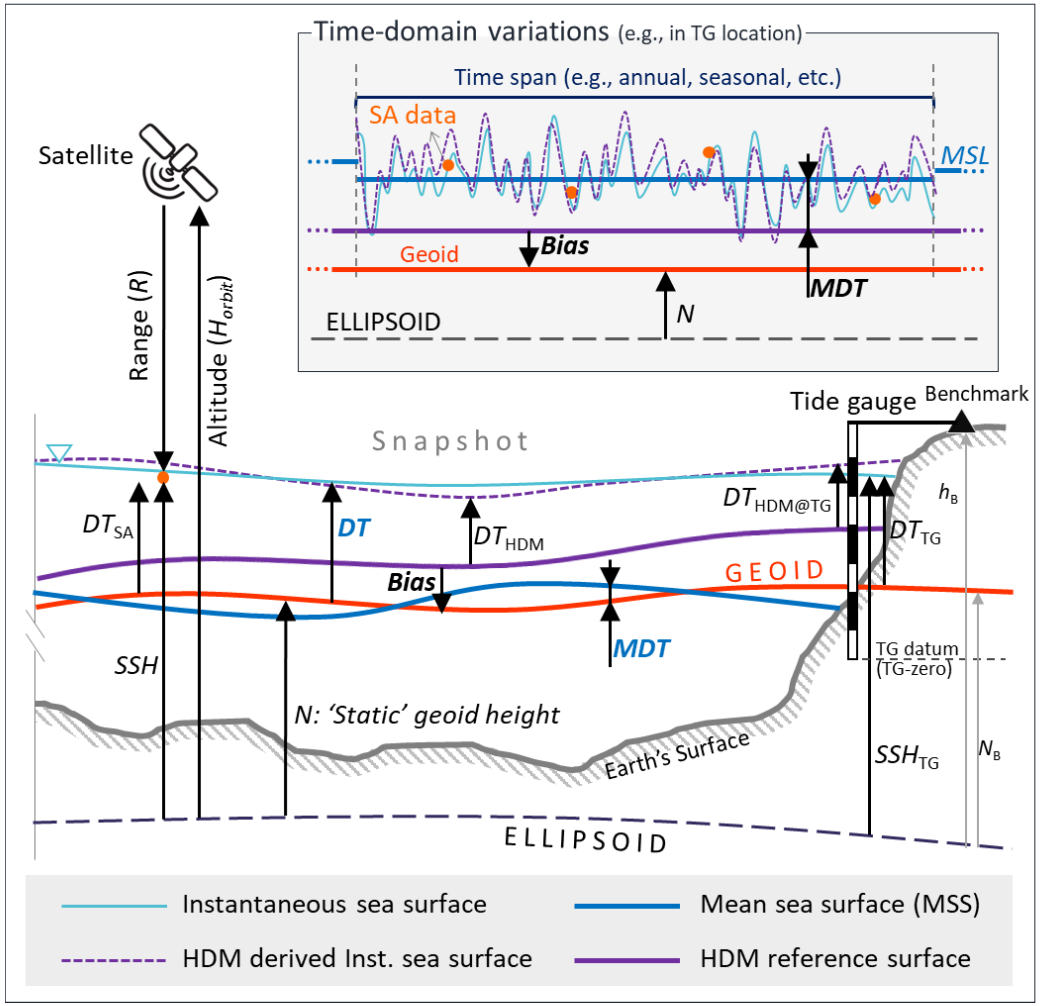
Mean dynamic Topography (MDT) represents a realistic quantification of ocean dynamics (e.g., ocean's mean circulation).

MDT may be determined by **oceanographic approach** or **geodetic approach**.

- Oceanographic – involves the hydrodynamic models (HDM) and the MDT is temporal averaging over a given period.
- Geodetic – relies upon determining separation between satellite altimetry (SA) derived mean sea surface (MSS) or tide-gauge (TG) derived mean sea level (MSL) and a marine geoid model.

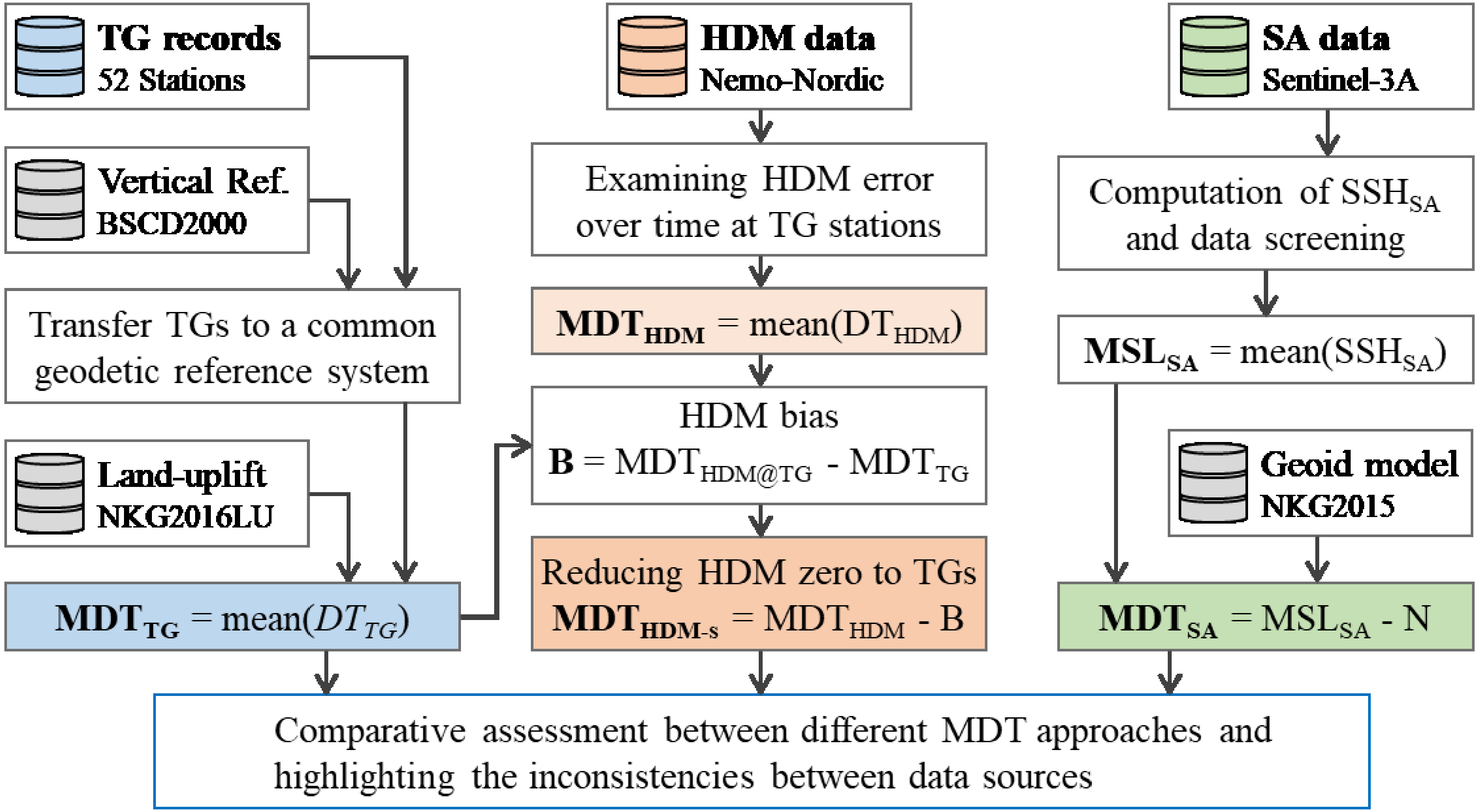
Challenge: Different sources refer to different vertical reference datums

Motivation: Transfer datasets to a common reference surface (which geoid is a key component to link different sources), and compare MDT derived from two approaches.



The inter-relation between hydrodynamic parameters, different sources of sea level and used vertical references

General Methodology



General methodology of mean dynamic topography (MDT) determination by oceanography and geodetic approaches

Data Acquisition

Tide gauge:

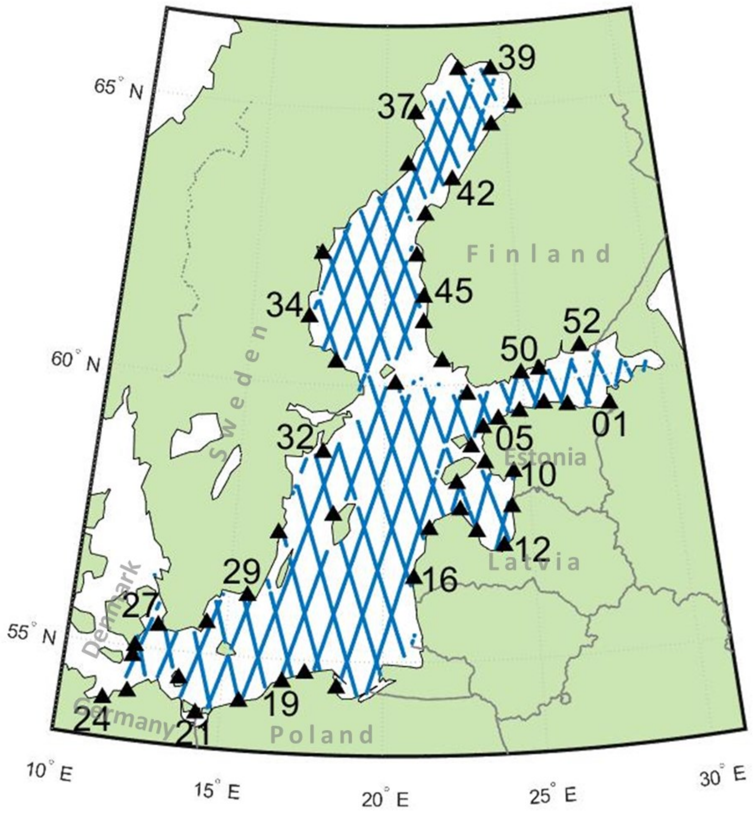
- 52 stations sourced from seven Baltic countries (Dec 2016–Jun 2021)
- Transfer the zero level of all stations to national datums complying with BSCD2000

SA data: Sentinel-3A

- High-frequency (20Hz) along-track SA data (Jan 2017 – Jun 2021)
- Sourced from EUMETSAT
- Corrections have been obtained from AVISO

$$SSH_{SA} = H_{orbit} - (R + WT + DTC + IONO + SSB + SET + PT + IMB)$$

$\boldsymbol{H_{orbit}}$: altitude of satellite; ***R***: Ku band corrected ocean altimeter range; ***WT***: wet tropospheric correction ***DTC***: dry tropospheric correction; ***IONO***: ionospheric correction; ***SSB***: sea state bias correction; ***SET***: solid earth tide height; ***PT***: geocentric pole tide height; ***IMB***: inter mission bias



Study area (Baltic Sea), location of tide-gauges stations (black triangles; numbered clockwise starting from the eastmost Estonian tide gauge station as shown in black in some stations) and ground tracks of Sentinel-3A (blue dots)

Data Acquisition

HDM: Nemo-Nordic NS01

- Three-dimensional coupled ocean-sea ice model which is developed by SMHI based on the NEMO-3.6
- Data assimilated version with an hourly temporal resolution and a horizontal resolution of 1 nautical mile
- For the period of Dec 2016 – Jun 2021 (4.5 years)

Geoid model: NKG2015_zt

- The most recent official geoid model over the Baltic countries
- This high resolution gravimetric quasi-geoid model agrees with GNSS/levelling data with a SD of 2.85 cm

Dataset	Vertical Ref.	Tide system	Geodetic CRS	VLM correction
Tide-gauge (01 – 52)	EVRS (BSCD2000)	Zero-tide	ETRF2000	Rel. SL (NKG2016_abs)
Nemo-Nordic (HDM)	N/A†	Mean-tide	N/A	-- (Abs. SL)
Sentinel-3A (SA)	WGS 84	Mean-tide	ITRF2008	-- (Abs. SL)
NKG2015_zt	GRS 80	Zero-tide	ETRF2000	Geoid Rise

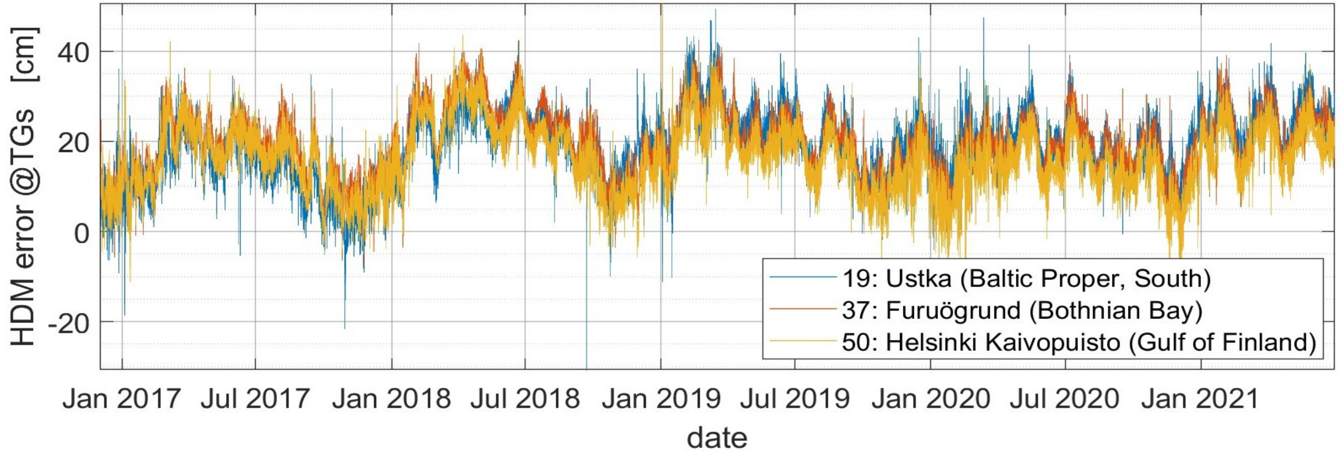
† *HDMs typically lack a well-defined vertical reference. However, according to the fluid dynamics, the reference surface coincides with an equipotential surface of the Earth's gravity field.*

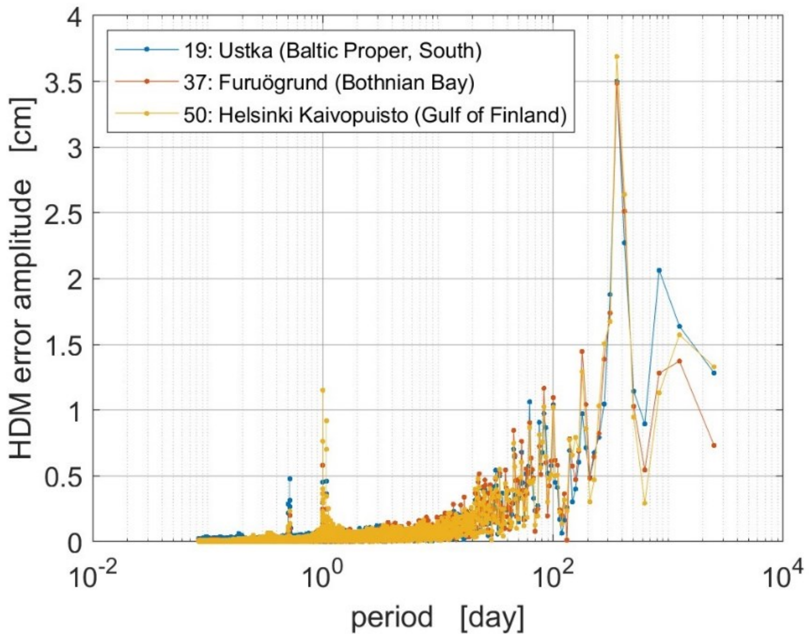
Datasets have been transformed to the mean-tide system (*Ekman, 1989*), GRS80 and ETRF2000 (*Altamimi, 2018*)

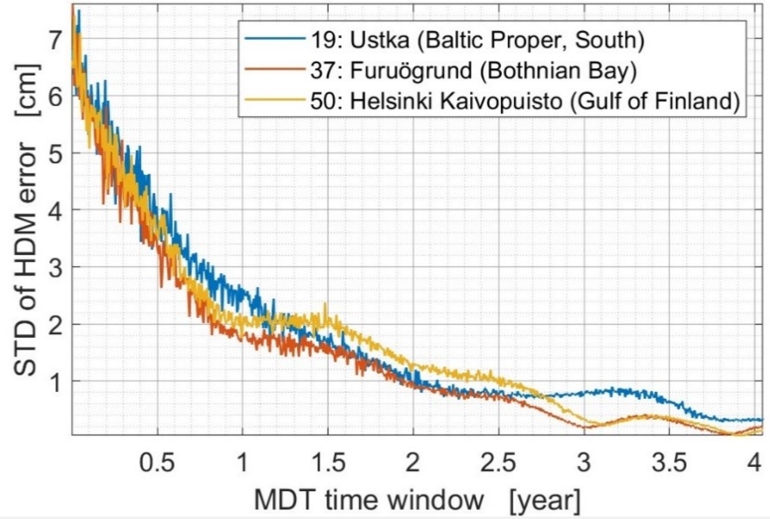
HDM Errors Over Time

HDM dynamic topography contains both high and low-frequency errors (E) with respect to the TG records (from -20 to 50 cm)

$$\text{HDM error: } E = DT_{HDM}(\varphi_{TG}, \lambda_{TG}, t) - DT_{TG}(\varphi_{TG}, \lambda_{TG}, t)$$







An experiment with 100 random MDT_{HDM} was performed to determine the standard deviation of cumulative errors for different MDT time windows w:

$$STD = std\left(\left\{\frac{1}{w+q-1}\sum_{i=q}^{w+q-1}(E_i)\right\}_k\right), \qquad \exists\, q \in \{U(1, L-w)\}\ \&\ k = 1 \dots 100$$

where U is uniform random variable, and L is the length of available HDM time series

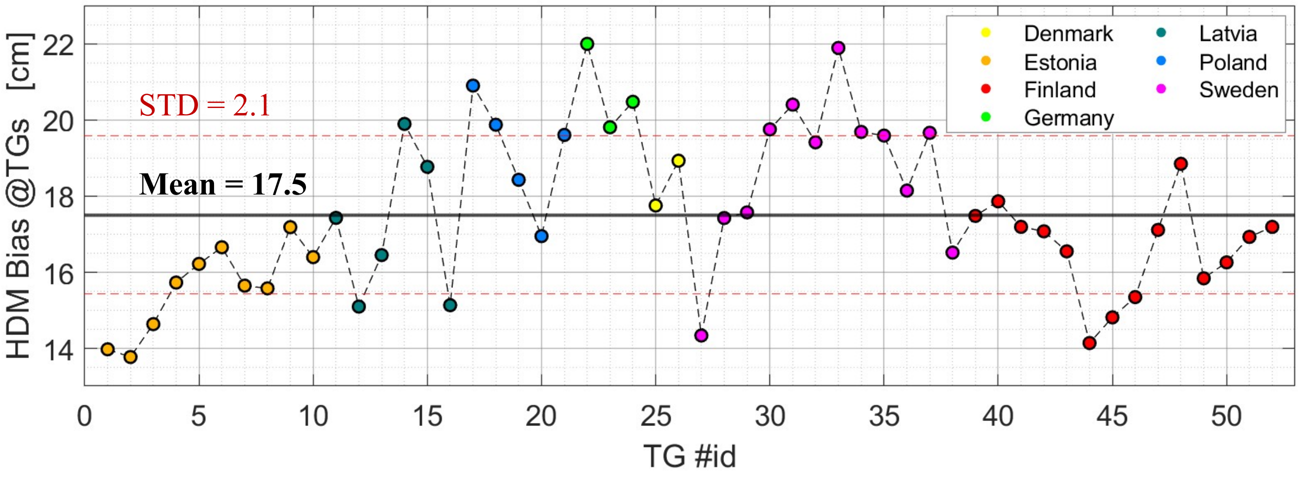
MDT: Oceanographic Approach

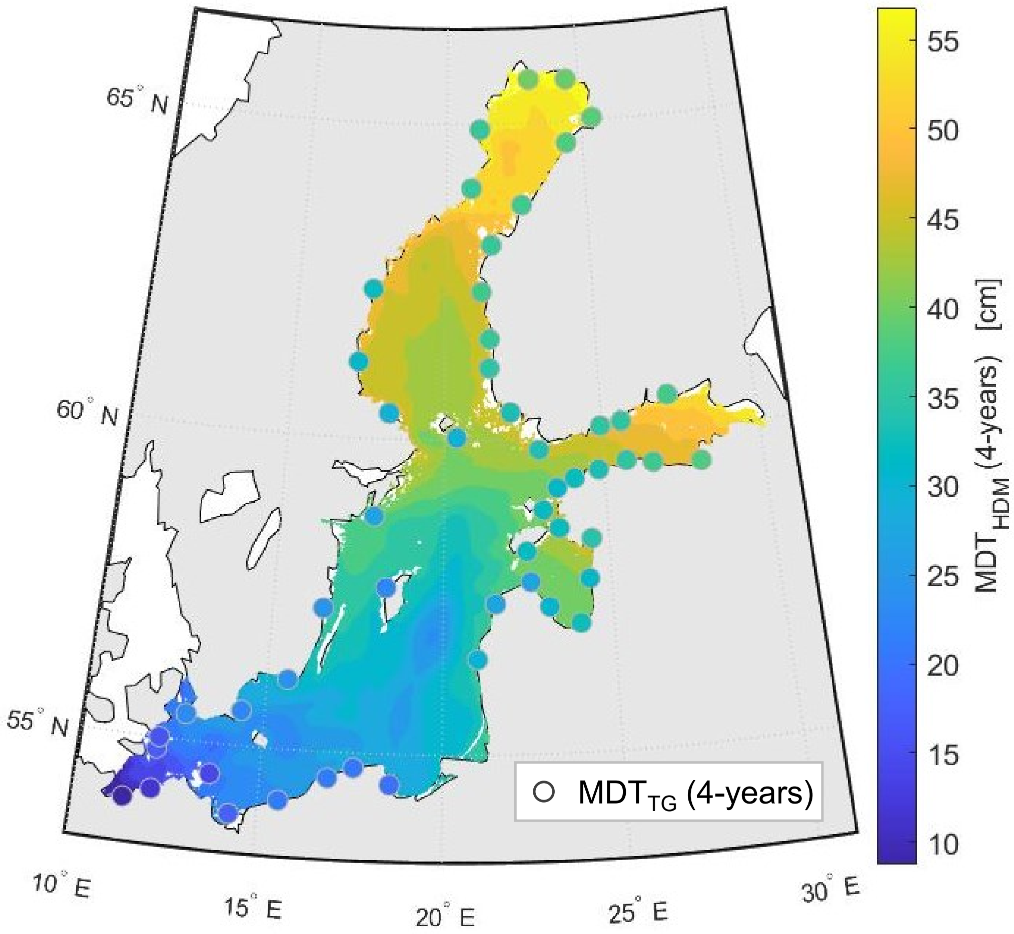
$$MDT_{HDM}(\varphi,\lambda) = \frac{1}{n}\sum_{i=1}^{n} DT_{HDM}(\varphi,\lambda,t_i)$$

$$MDT_{TG}(\varphi,\lambda) = \frac{1}{n}\sum_{i=1}^{n} DT_{TG}(\varphi,\lambda,t_i)$$

where n is number of 4-years hourly data.

$$\boldsymbol{Bias} = mean(MDT_{HDM@TG} - MDT_{TG})$$

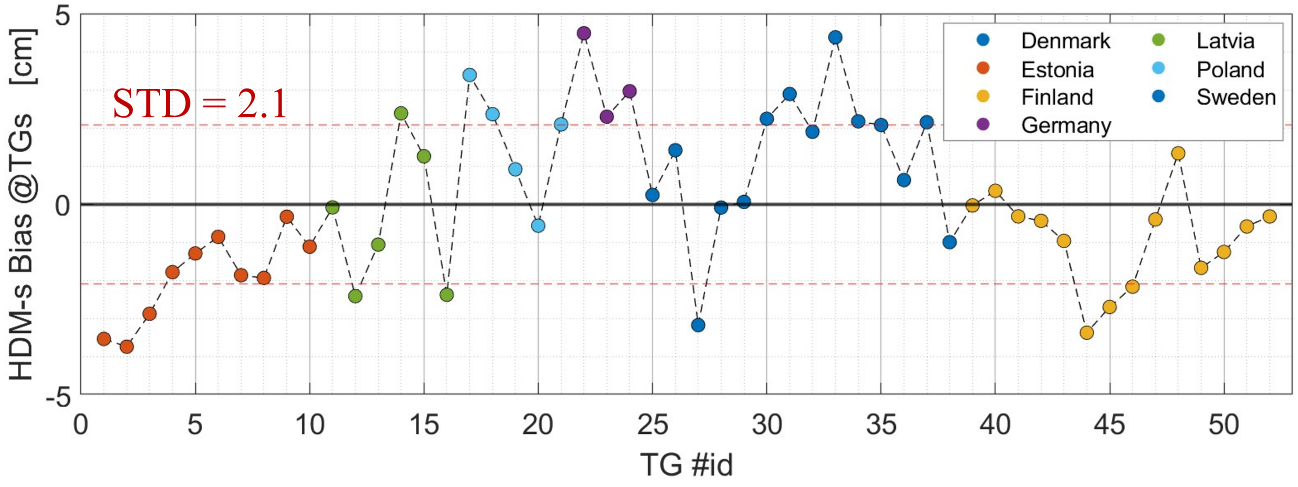


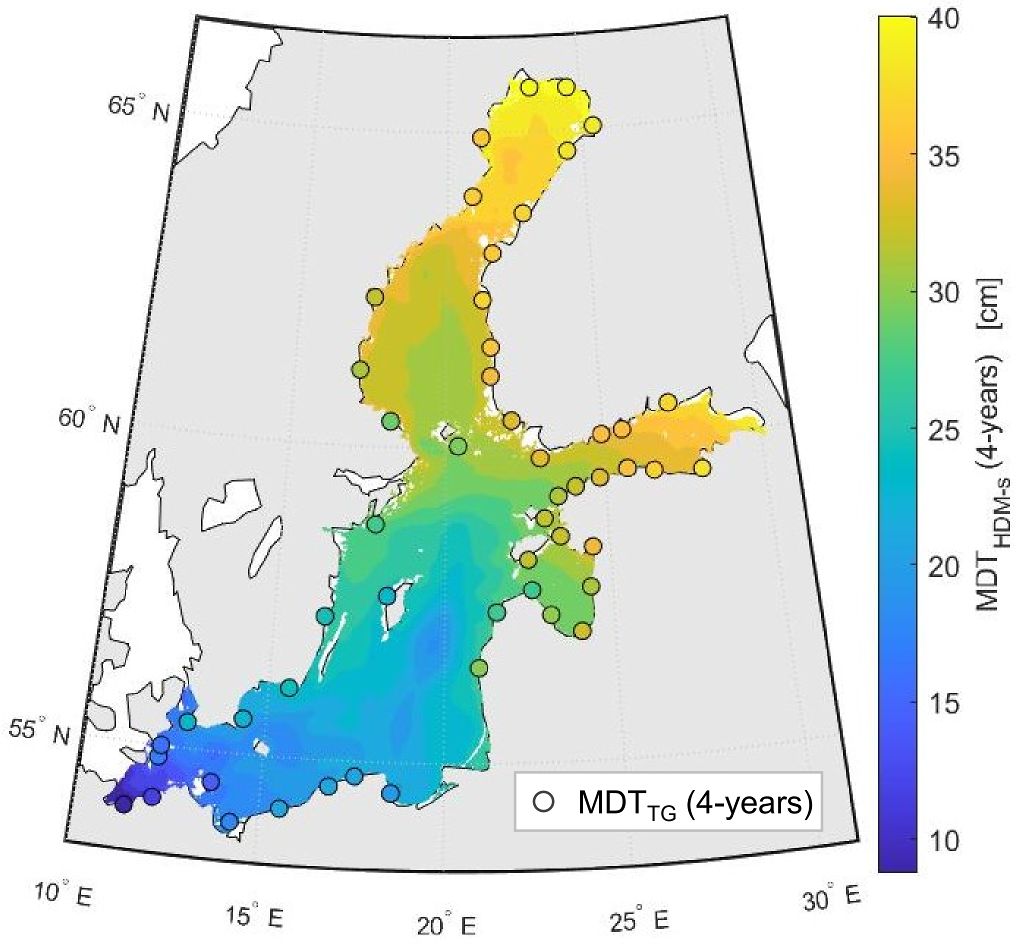


HDM Bias Correction

Thus, the MDT_{HDM} was shifted as much as the bias between HDM and TG–derived MDTs:

$$\boldsymbol{MDT_{HDM-s}}(\varphi, \lambda) = MDT_{HDM} - Bias$$

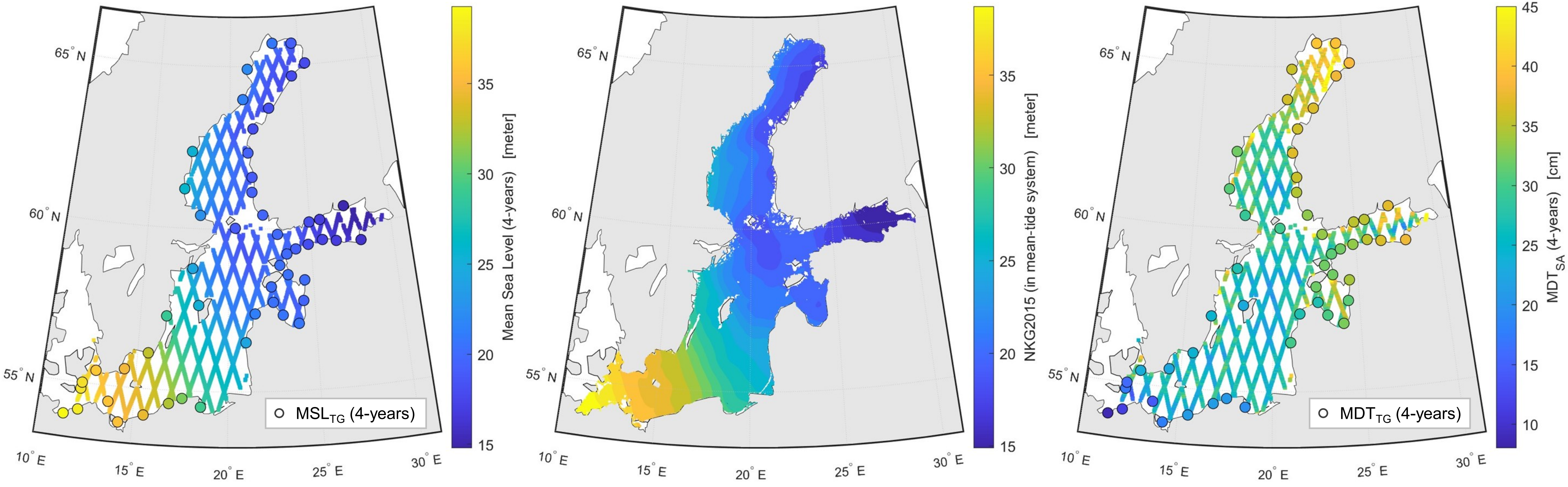




MDT: Geodetic Approach

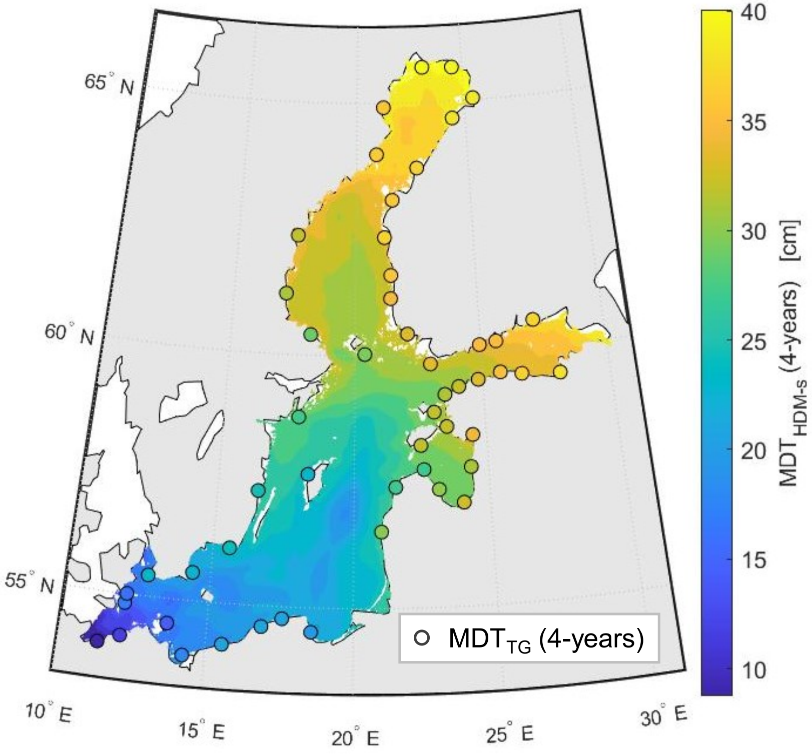
$$MDT_{SA} = MSL_{SA} - N_{mean-tide}$$

$$N_{mean-tide} = NKG2015\_zt + (0.29541(\sin^2\varphi - \sin^2\varphi_{NAP}) + 0.00042(\sin^4\varphi - \sin^4\varphi_{NAP})$$

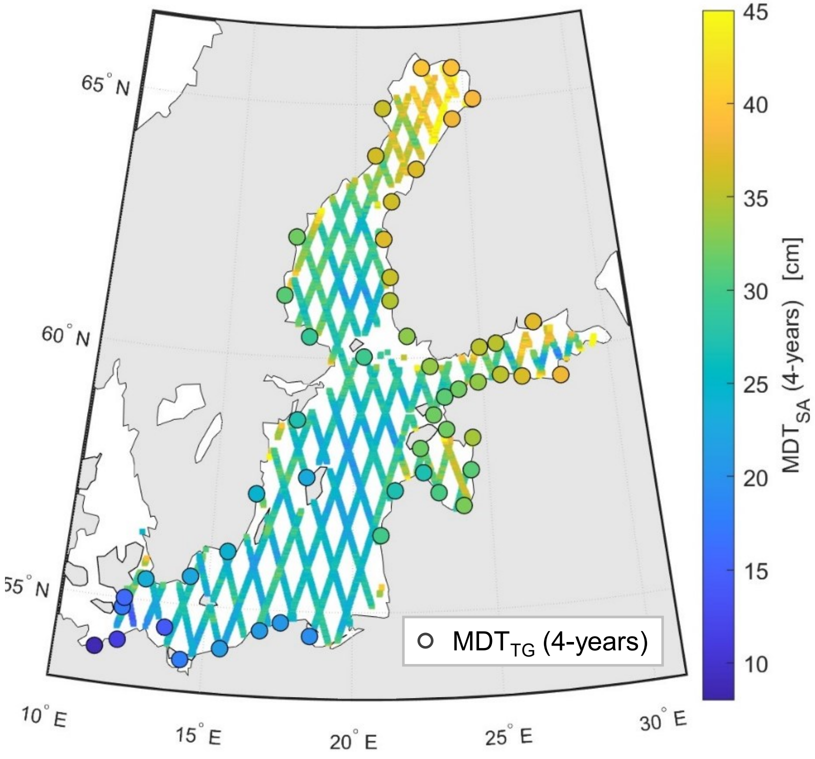


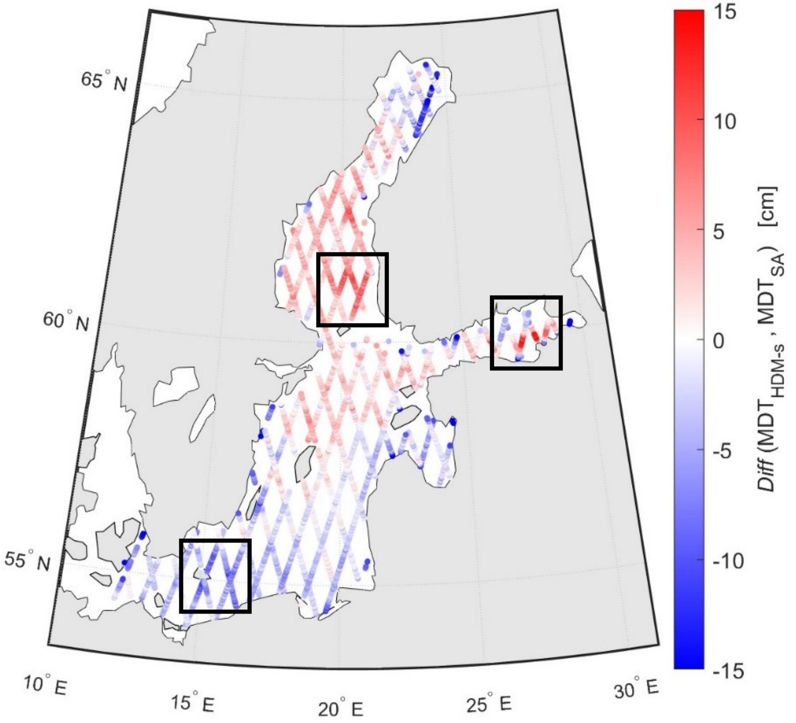
Results: Comparative Assessment

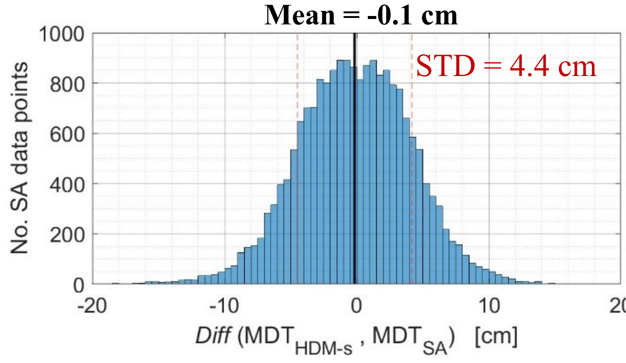
Oceanographic approach



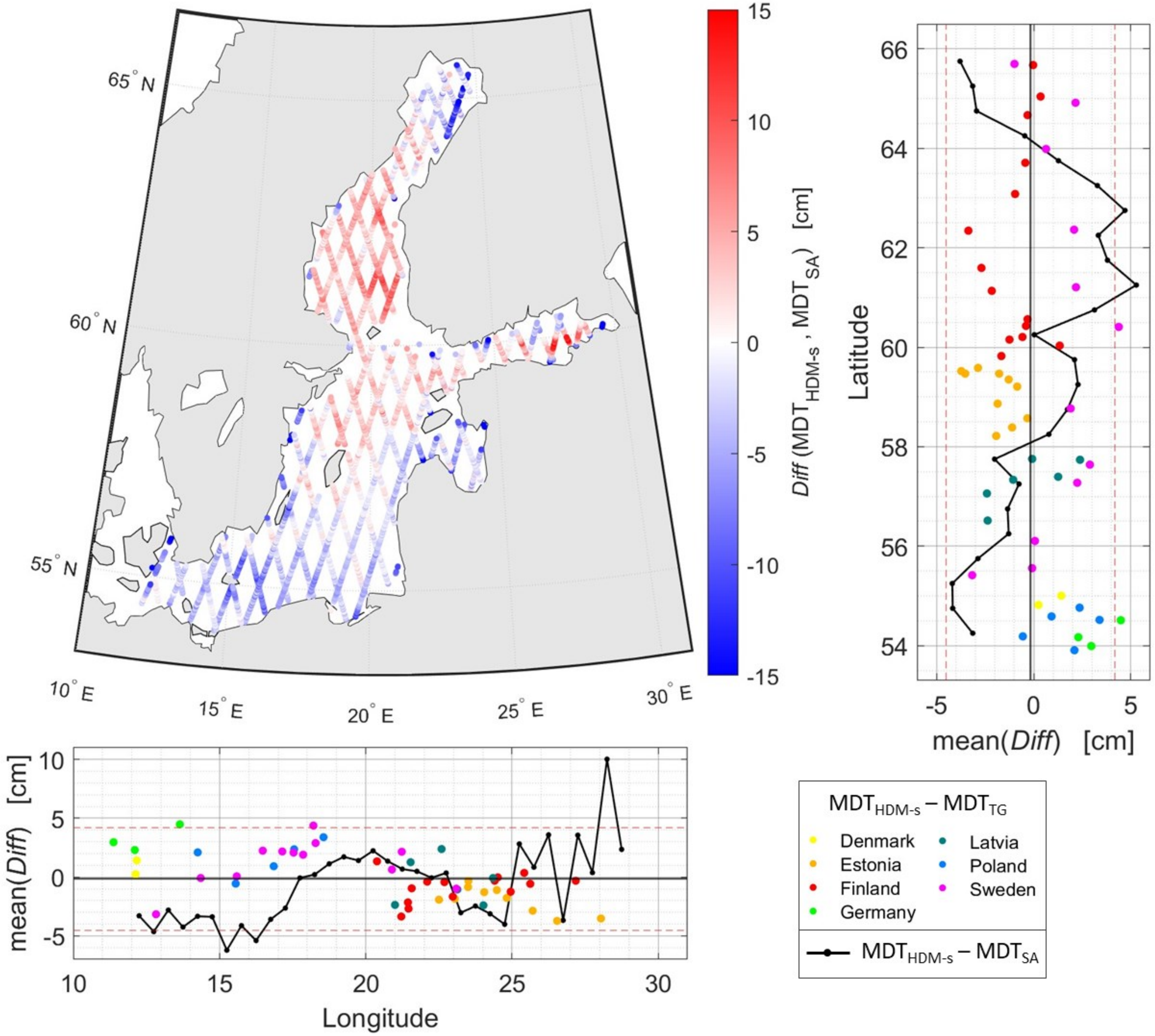
Geodetic approach





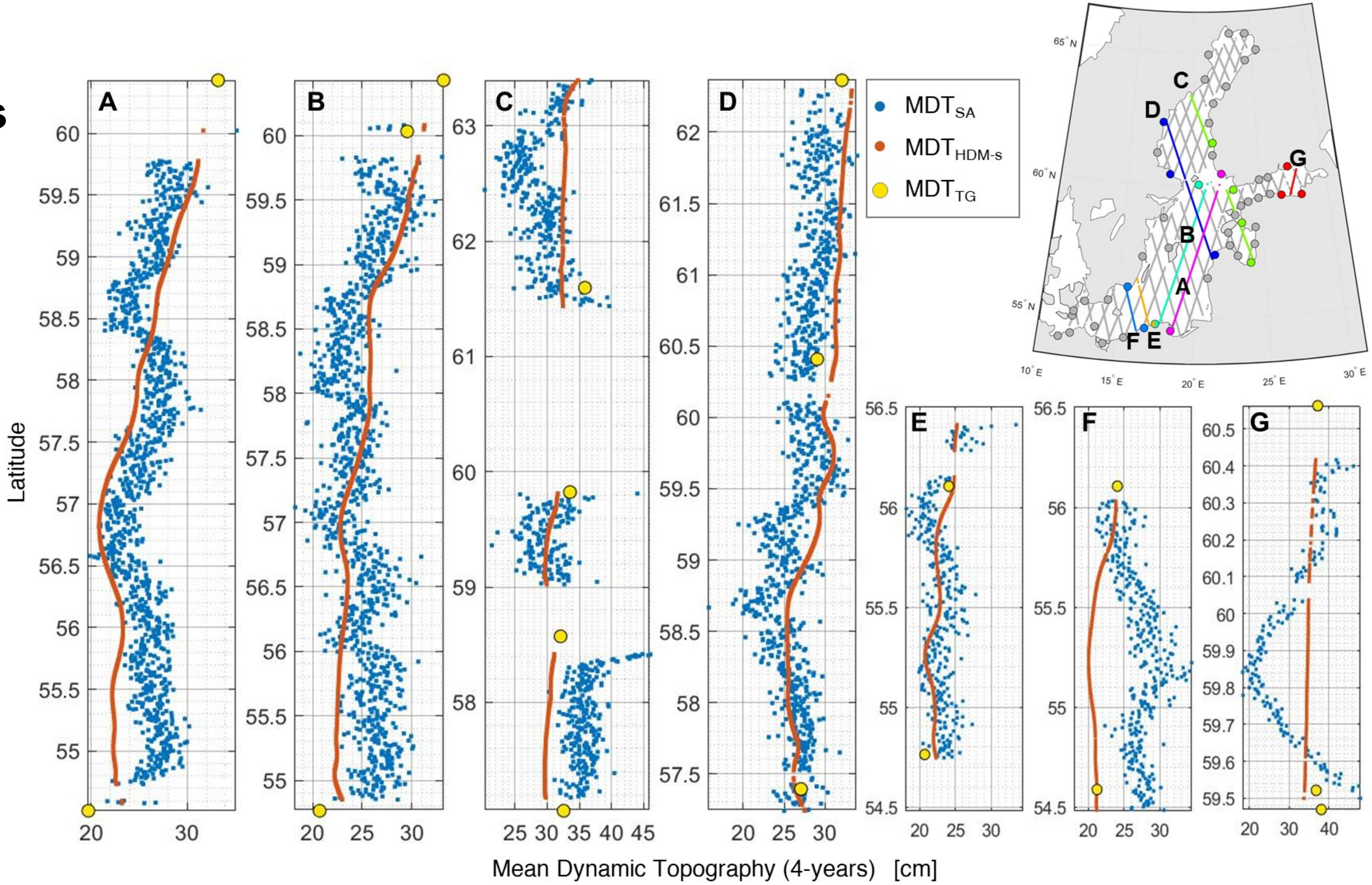


Results



65° N
60° N
55° N
10° E
15° E
20° E
25° E
30° E
15
10
5
0
-5
-10
-15
Diff (MDT_HDM-s , MDT_SA) [cm]
Latitude
mean(Diff) [cm]
mean(Diff) [cm]
Longitude
MDT_HDM-s – MDT_TG
Denmark
Estonia
Finland
Germany
Latvia
Poland
Sweden
MDT_HDM-s – MDT_SA

Results


A
B
C
D
E
F
G
Latitude
Mean Dynamic Topography (4-years) [cm]
MDT SA
MDT HDM-s
MDT TG
65° N
60° N
55° N
10° E
15° E
20° E
25° E
30° E

Conclusion

- The Nemo-Nordic model contains periodic time-domain errors with respect to the tide gauges. Nevertheless, the standard deviation of the cumulative error is roughly zero (less than 0.3 cm) for a 4-years MDT.
- The Hydrodynamic model–derived MDT (4-years) has a bias of 17.5 cm relative to geoid-referenced tide gauges, with a standard deviation of 2.1 cm.
- The comparison between oceanographic (with corrected model) and geodetic (Sentinel-3A and NKG2015) approaches revealed an agreement with a bias of about zero and standard deviation of 4.4 cm over the Baltic Sea.
- The along track differences also reveal a positive–negative pattern from north to south of the Baltic Sea, as well as the problematic areas such as the eastern part of the Gulf of Finland and Bornholm basin.
- Synergy of TG, HDM, SA data, and geoid model allows us to identify inconsistencies between data sources to improve reliability and identify problems with each of them.

Polar bear on ice floe
Photograph by Michal Bednarek (2020)

Thank you for your attention

“any questions are welcome