FINALISING SURVEYS FOR THE BALTIC MOTORWAYS OF THE SEA

Evaluation of MDT Models over Baltic Sea

Co-financed by the European Union
Connecting Europe Facility

1. INTRODUCTION

The Mean Dynamic Topography (MDT) is a fundamental surface for a large number of oceanographic applications and it is a representation of the ocean's mean circulation. The MDT can be derived with two different approaches, namely ocean and geodetic approach [Ophaug et al., 2015]. The ocean approach is based on numerical ocean models, while the geodetic MDT is the result of the difference between the Mean Sea Surface (MSS) and an accurate geoid model.

In this work both ocean and geodetic MDT are presented and compared. Table 1 shows a summary of the models here analysed. Note that the "Ocean" characterisation is assigned only to models that are completely independent from geodetic data, whereas the "Geodetic" definition is applied to the models that include geodetic data. The last 7 ocean models are all physical reanalysis products provided by Copernicus project for Marine Environment Monitoring Service. In section 2 the single models are illustrated.

Each MDT is provided with a certain spatial resolution and time coverage. However, a consistent comparison requires same MDT characteristics [Ophaug et al., 2015], therefore all the models have been previously resampled with a spatial resolution of 1/4×1/4 degrees, and shifted along the time span 1996-2000, that is the common time domain as ECCO2. Another issue to be considered is the fact that each model is derived with respect to different reference surfaces [Jaine, 2006]. For this reason, the comparison is performed among the MDT anomalies, which are the de-meaned values computed for each surface.

Model	Resolution (°)	Time Span	Approach
DTU13MDT	1/60 × 1/60	1993-2003	Geodetic
MAXIMENKO	1/2 × 1/2	1992-2002	Geodetic
CLS	1/4 × 1/4	1993-2012	Geodetic
NEMOQ	1/4 × 1/4	1996-2000	Ocean
NEMO12	1/12 × 1/12	1996-2000	Ocean
L-MITf	1/5 × 1/6	1996-2000	Ocean
OCCAM	1/12 × 1/12	1996-2000	Ocean
ECCO2 – JPL	1/4 × 1/4	1992-Present	Geodetic
ECCO – GODAE	1 × 1	1992-2007	Geodetic
GECCO	1 × 1	1952-2001	Geodetic
GOCE1	1/4 × 1/4	1996-2000	Geodetic
GOCE2	1/4 × 1/4	1996-2000	Geodetic
ORAP5	1/4 × 1/4	1979-2013	Ocean
MJM105b	1/4 × 1/4	1993-2013	Ocean
HIROMB	1/20 × 1/20	1989-2013	Ocean
CGLORS	1/4 × 1/4	1982-2013	Ocean
GLORYS2V3	1/4 × 1/4	1993-2013	Ocean
UR025.4	1/4 × 1/4	1993-2010	Ocean
DMI	1/10 × 1/10	1990-2009	Ocean

Table 1: Summary of the MDT models used in this work.

2. MODEL DESCRIPTION

In this section a short description with the graphical illustration of each MDT is provided.

2.1 DTU13MDT

DTU13MDT is a global model that refers to the Topex/Poseidon ellipsoid, and it is obtained from the combination of the DTU13MSS Mean Sea Surface model (derived from 20 years of altimetry data – from 1993 to 2013) and the geoid model EGM2008 [Andersen and Knudsen, 2009]. The resolution available for DTU13 is of 1, 2, 5, or 12 minutes. Figure 2.1 shows the DTU13MDT at 1 minute resolution over the Baltic. Higher values are registered in the Gulf of Bothnia, while lower values are found westward, towards the Atlantic Ocean.

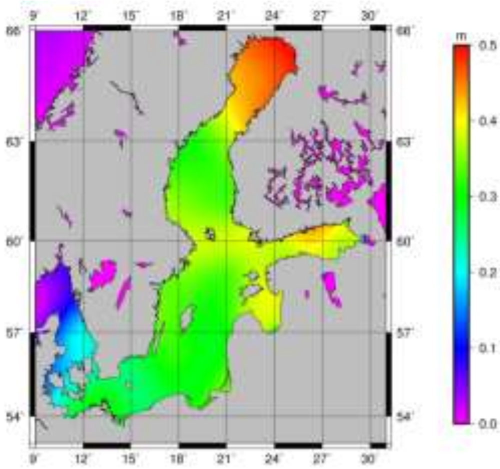

Figure 2.1: DTU13MDT in the Baltic

2.2 Maximenko Mean Dynamic Topography

The Maximenko global model has a resolution of 0.5° and it has been derived by combining data of satellite altimetry, near-surface drifters, and the GRACE geoid model, with a total coverage of 10 years (1992-2002) [Maximenko et al., 2009]. Maximenko model is represented in figure 2.2. Higher values appear in the Finnish and Swedish gulfs, showing similar behaviour with DTU13MDT.

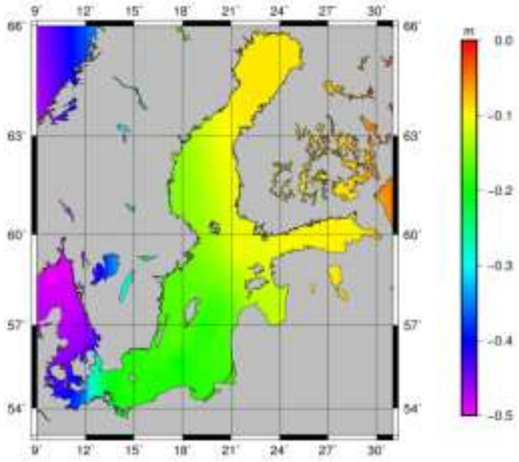

Figure 2.2: Maximenko MDT in the Baltic

2.3 MDT_CNES-CLS13

MDT_CNES-CLS13 refers to the Topex/Poseidon ellipsoid. In this case the surface is obtained first by computing the MDT using the MSS model MSS_CNES-CLS11 and the EGM-DIR-R4 geoid model. Then, the result is combined with the estimates derived by the difference between 20 years (1993-2012) of sea level anomaly values and in-situ measurements of the ocean state.

The resolution available for the CLS13 MDT model is of 0.25°. The surface shows low sensitivity over the Baltic, and this can be noticed by observing the Danish Straits, where higher fluctuations occur, figure 2.3.

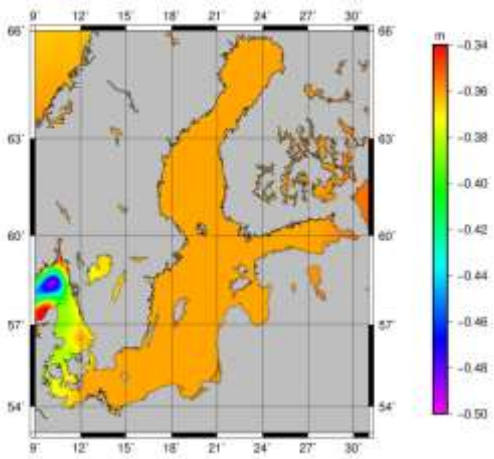

Figure 2.3: CLS MDT in the Baltic

2.4 NEMOQ and NEMO12

The Nucleus for European Modelling of the Ocean (NEMO) models were supplied directly for the time span 1996-2000 and differ in resolution: NEMOQ is given with ¼×¼ degree grid spacing while NEMO12 is delivered with a 1/12x1/12 degree resolution [Ophaug et al., 2015]. Higher values of around 10 cm are found in NEMOQ with respect to NEMO12, figure 2.4.

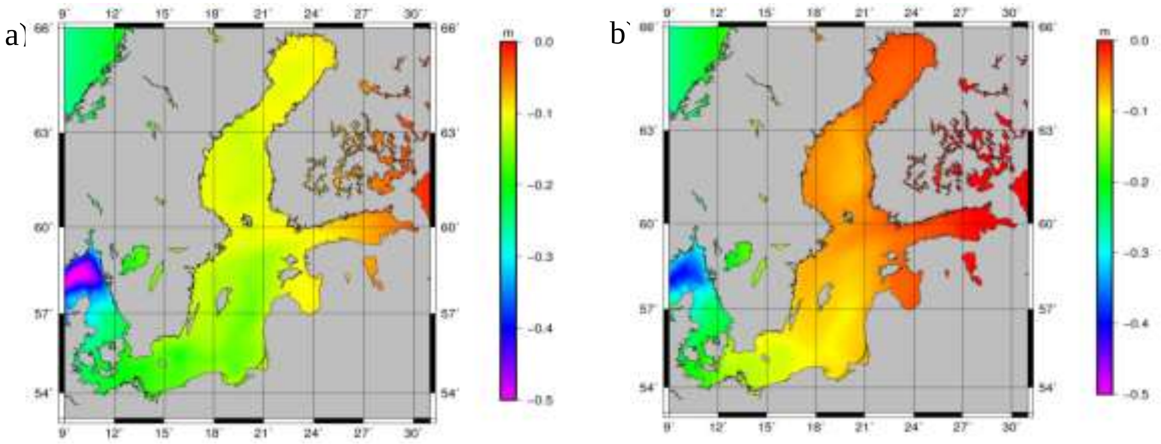

Figure 2.4: NEMO12 (a) and NEMOQ (b) in the Baltic

2.5 L-MIT

L-MIT models were computed at Liverpool University and are based on the global ocean circulation model implemented at the Massachusetts Institute of Technology (MIT). L-MITc is a coarse version with resolution 1x1 degree, while the fine version L-MITf measures 1/5×1/6 degree resolution [Ophaug et al. 2015]. Here the fine model is used. From figure 2.5 it can be observed that L-MIT model has a small value range over the Baltic, that measures between -33 and -31 cm.

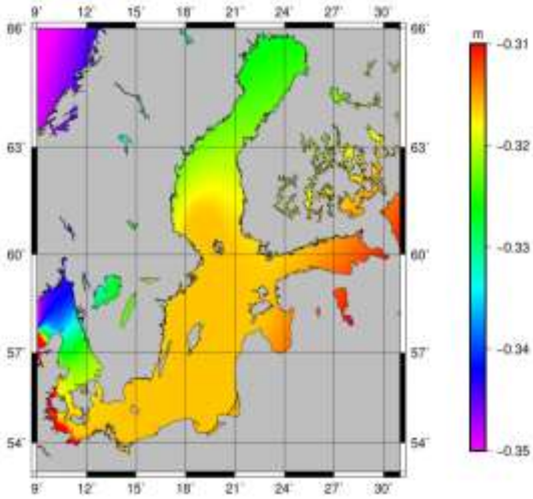

Figure 2.5: Liverpool University fine model in the Baltic

2.6 OCCAM

In the Ocean Circulation and Climate Advanced Modelling (OCCAM) project several ocean models on global scale were developed as a result of 14 years of simulation. The MDT model is computed exploiting observed hydrographic data and it is delivered at a resolution of 1/12x1/12 degrees [Coward and De Cuevas, 2005]. OCCAM registers gradually higher values northward, figure 2.6.

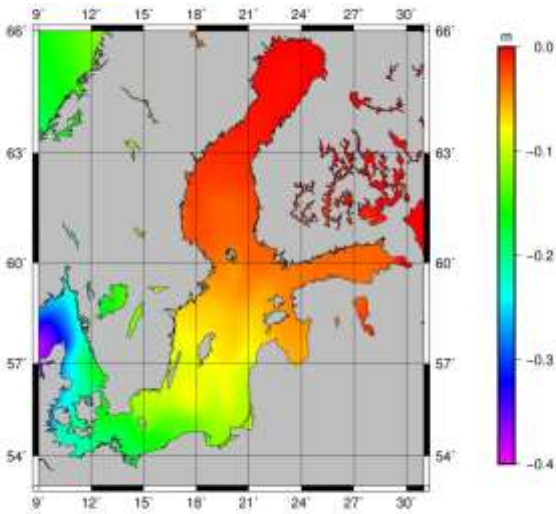

Figure 2.6: OCCAM model in the Baltic

2.7 ECCO

The ECCO2 - JPL model is computed in the Phase 2 of the Estimating the Circulation and Climate of the Ocean (ECCO) project. The estimated SSH is available with a time range that goes from 1992 to present, with a resolution of ¼ of degree and it is the result of combination of different assimilations, such as altimetric, geodetic and in-situ data [Wunsch and Heimbach, 2007].

ECCO products support the Global Ocean Data Assimilation Experiment (GODAE), from which the ECCO-GODAE MDT is derived. The third version of this model is delivered with a resolution of 1-by-1 degree and covers the time period 1992-2007. In figure 2.7a and 2.7b ECCO2 and ECCO-GODAE respectively are shown. In the Baltic ECCO2 values are around 0 cm, while ECCO-GODAE values have a small range of 1 cm.

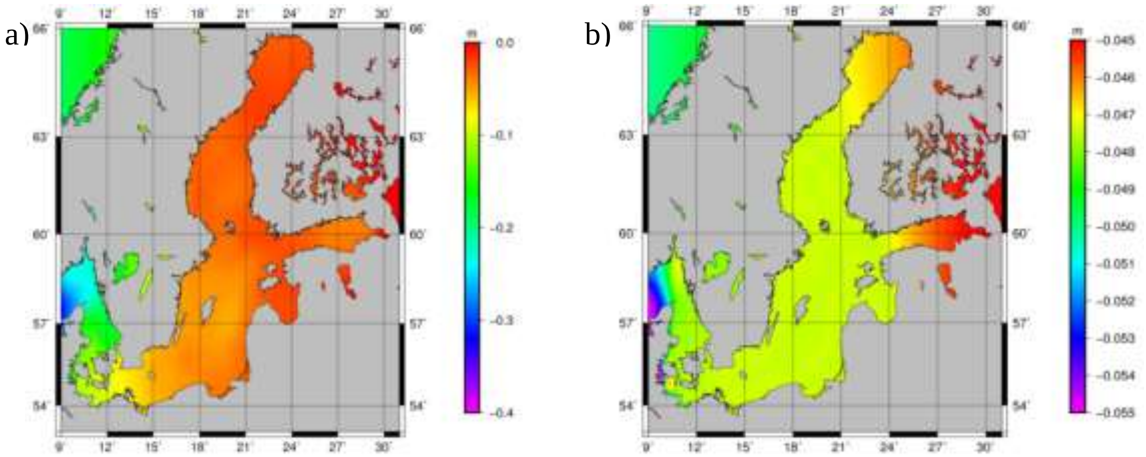

Figure 2.7: ECCO2-JPL (a) and ECCO-GODAE (b) models in the Baltic

2.8 GECCO

The German partner of ECCO consortium (GECCO) estimated the ocean circulation over a 50-year period, from 1952 to 2001. This model is based on the ECCO product and it is delivered with a resolution of 1x1 degree [Köhl and Stammer, 2007]. The GECCO product is shown in figure 2.8. With its very small range, GECCO model shows high values In the Gulf of Finland and the Gulf of Bothnia, while no value fluctuation is seen elsewhere.

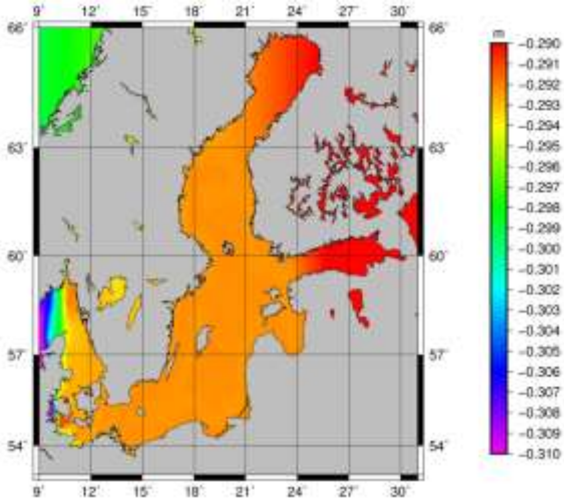

Figure 2.8: GECCO model in the Baltic

2.9 GOCE

GOCE MDT models are computed from difference between CLS Mean Sea Surfaces and the geoid information obtained from GOCE. GOCE1 is the result of the difference between CLS01 MSS and the second release of GOCE direct geoid (GOCE DIR2 [Bruinsma et al., 2013]). GOCE2 MDT is derived by subtracting the third version of GOCE direct geoid (GOCE DIR3) from CLS11 MSS. Figure 2.9 shows GOCE1 and GOCE2 models. The second version (b) shows uniform values over the whole region of interest, while GOCE1 registers higher values in the central area.

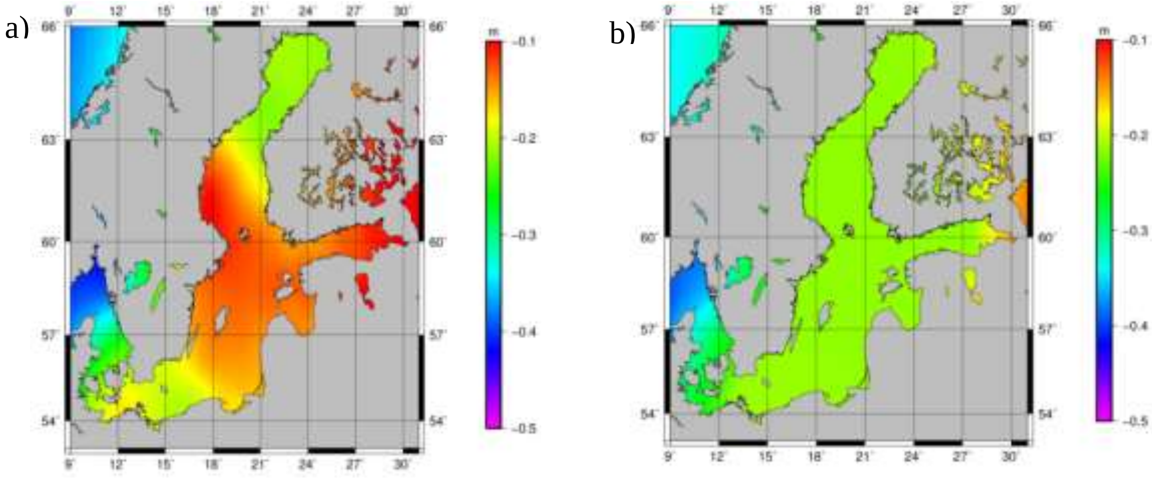

Figure 2.9: GOCE 1 (a) and GOCE2 (b) models in the Baltic

2.10 ORAP5

ORAP5.0 (Ocean ReAnalysis Pilot 5.0) is a global ocean reanalysis produced by European Centre for Medium-Range Weather Forecasts (ECMWF) as a contribution to MyOcean and MyOcean2 project. In this model data from altimetry and in-situ observations are assimilated. ORAP5.0 can be downloaded from the Copernicus catalogue as monthly or daily means, with a resolution of ¼×¼ degree and time span going from 1979 to 2013 [Ferry et al., 2015]. Figure 2.10 shows ORAP model.

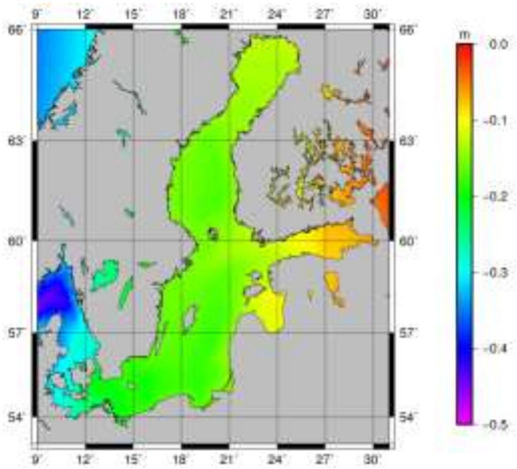

Figure 2.10: ORAP5.0 model in the Baltic

2.11 MJM105b

MJM105b (figure 11) is a hindcast model simulation with no data assimilation and it is based on the GLORYS2V3 configuration (see section 2.14). The model was developed at Laboratoire des Écoulements Géophysiques et Industriels (LEGI) and it is also part of the Copernicus ocean physical reanalysis project. Its resolution is of 0.25° in both longitude and latitude with temporal coverage of 20 years, from 1993 to 2013 [Ferry et al., 2015].

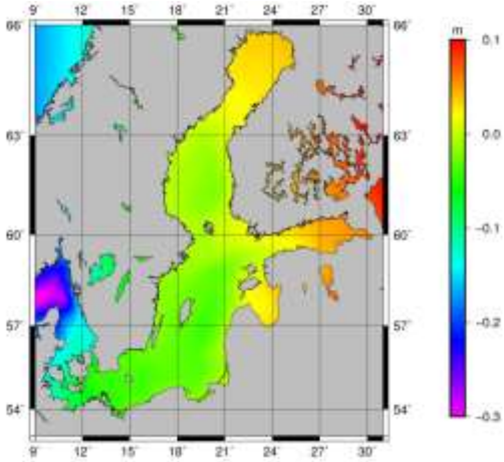

Figure 2.11: MJM105b *model in the Baltic*

2.12 HIROMB

The High-Resolution Operational Model for the Baltic (HIROMB) is a regional circulation model produced in 2014 by the Swedish Meteorological and Hydrological Institute (SMHI). HIROMB is based on both data assimilation from in situ-data and meteorological and hydrological models. The Copernicus catalogue provides this model with a resolution of 3 nautical miles, (approximately 1/20×1/20 degree) and for the time period 1989-2013 [Axell, 2015].

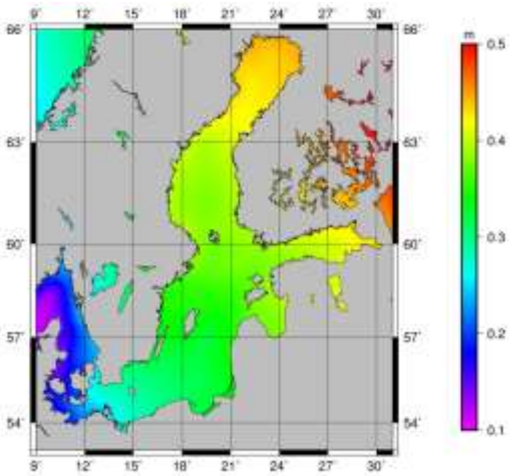

Figure 2.12: HIROMB *model in the Baltic*

2.13 CGLORS

The CMCC Global Ocean Physical Reanalysis System (CGLORS) assimilates in-situ observations along with altimetry data and includes a forecast step based on NEMO ocean model. CMCC global model provides data with a resolution of ¼×¼ degree for the timeseries 1982-2013 [Storto et al., 2011].

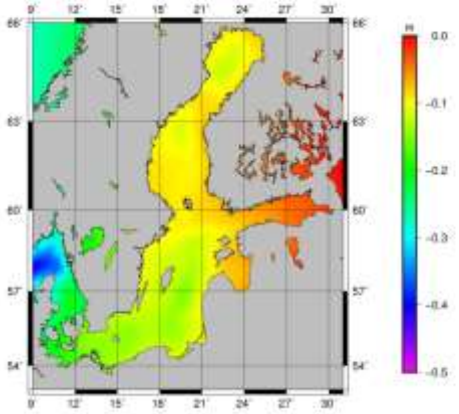

Figure 2.13: CGLORS *model in the Baltic*

2.14 GLORYS2V3

Mercator Ocean’s GLobal Ocean ReanalYses and Simulations (GLORYS2V3) is based on the NEMO ocean model and altimetry and mooring data assimilation. It covers the period 1993-2013 and it delivers sea level monthly values at ¼×¼ degree resolution [Testut et al. 2014]. In the Baltic GLORYS2V3 model shows values around 20 cm, which progressively increase in the Basins’ interior (figure 14).

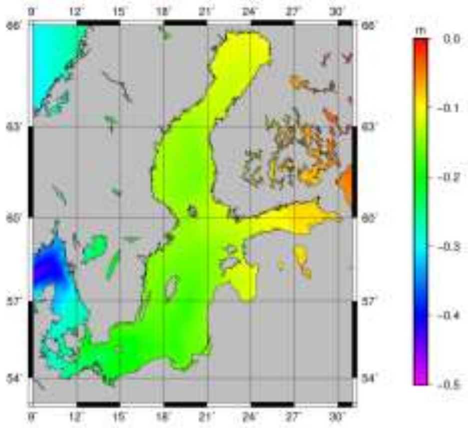

Figure 2.14: GLORYS2V3 *model in the Baltic*

2.15 UR025.4

The University of Reading provides this model, which is a reanalysis of global ocean and ice physics. UR025.4 assimilates observed data from EN3 database [Henry et al., 2012], and is based on the NEMO ocean model. The product is released as monthly means with a horizontal resolution of 0.25 degree and covers the period 1993-2003. Figure 2.15 shows the model in the area of interest.

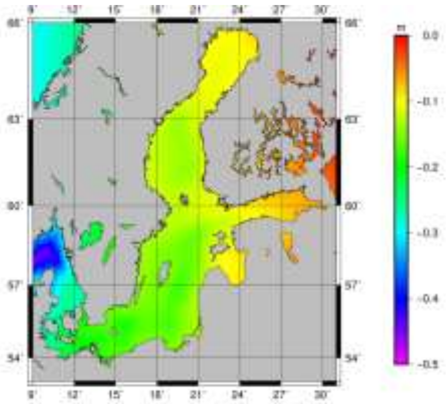

Figure 2.15: UR025.4 model in the Baltic

2.16 DMI

The Baltic Sea physical reanalysis product is derived by the Danish Meteorological Institute (DMI) with temperature/salinity data assimilation [Huess, 2015]. The model provides monthly values for the Baltic region with a resolution of 6 nautical miles (circa 1/10×1/10 degree) and a temporal coverage of 20 years, from 1990 to 2009. DMI model registers values of around 40 cm in the basin, while lower values are observed closer to Danish coasts, see figure 2.16.

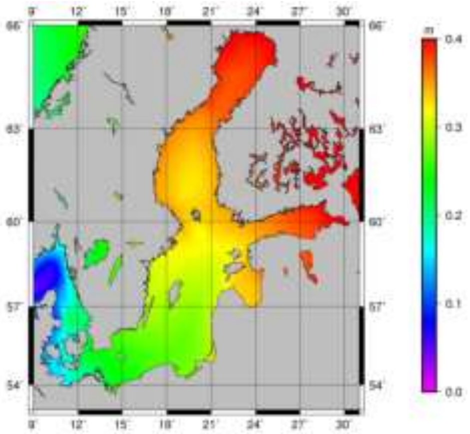

Figure 2.16: DMI model in the Baltic

3. COMPARISON OF MDT MODELS

The difficulty in comparing different MDTs stays in the fact that every model varies in time domain and reference surface. In this work the dependence from the reference surface is avoided by removing from each model its mean value, obtaining what we can call MDT anomalies. For the difference in time domain, the surfaces were adapted to the time span 1996-2000 [Ophaug et al., 2015]. Whenever possible, the models were computed by directly selecting only the data corresponding to the time range of interest. In the case of surfaces which were already computed over a different period, the model was translated from the average year of the surface to the average year of the period of interest (1998) by considering the sea level trend within these two. For example, the average period for DTU13MDT is 2003, because it covers years 1993-2013; therefore the sea level trend that would compensate the values in DTU13 is computed between 1998 and 2003. The selection of water points is based on the mask represented in figure 3.1.

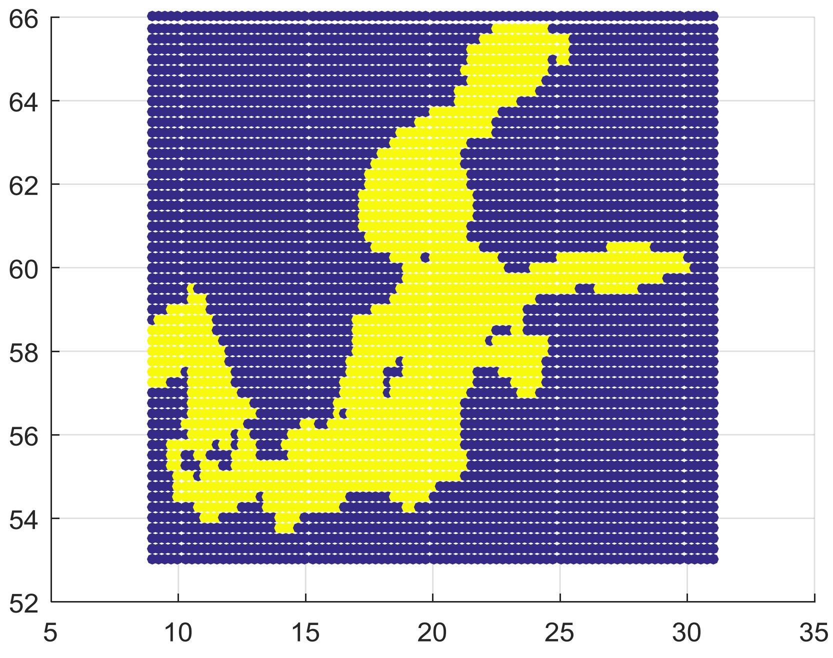

Figure 3.1: Water/Land mask used for this work

3.1 MODELS ALONG LATITUDE

We have compared MDT models along latitude for the area represented in figure 3.2. For a better visualisation the models are plotted in three different plots, with same axis scale, figure 3.3. The majority of the surfaces shows an increasing behaviour when approaching the coast at 66N. At around 60N higher values are observed, as a probable consequence of the greater sea level registered in many surfaces in correspondence to the Gulf of Finland. Low sensitivity was found for GECCO, L-MITf (both in figure 18a), and ECCO-GODAE ($ECCO_G$) and CLS surfaces (both in figure 3.3b). At latitudes > 62 GOCE1 shows a negative trend, in disagreement with the other models, figure 3.3a. A decrease is also observed in CGLORS above latitude 64, figure 3.3c.

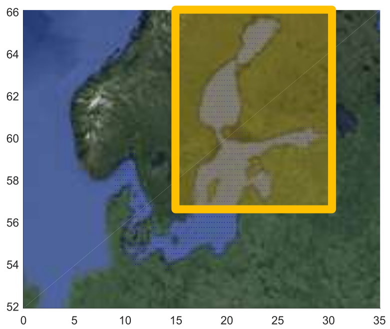

Figure 3.2: Region of interest for MDT one dimensional analysis

3.2 TAYLOR DIAGRAM

The Taylor diagram represents the standard deviation, the correlation and the centred root mean square difference (RMS) between a reference model and other models, called test models [Taylor, 2001]. In this case, the ocean model NEMO12 was chosen as reference, because of its good performances previously shown in former works, such as [Ophaug et al., 2015].

Good correlation can be found among the models, independently from which approach was used, see figure 19. Very low standard deviation is registered for GECCO, ECCO-GODAE, CLS, and L-MITf, as it was previously observed in the one-dimensional plots along latitude. From the zoom shown in figure 3.4, it can be noticed that DTU13 model shows very close values to DMI ocean model, and the models NEMOQ, ORAP5.0, CGLORS, GLORYS, MJM105 and UR0.25 have a low RMS and a correlation that goes between 0.95 and 0.99.

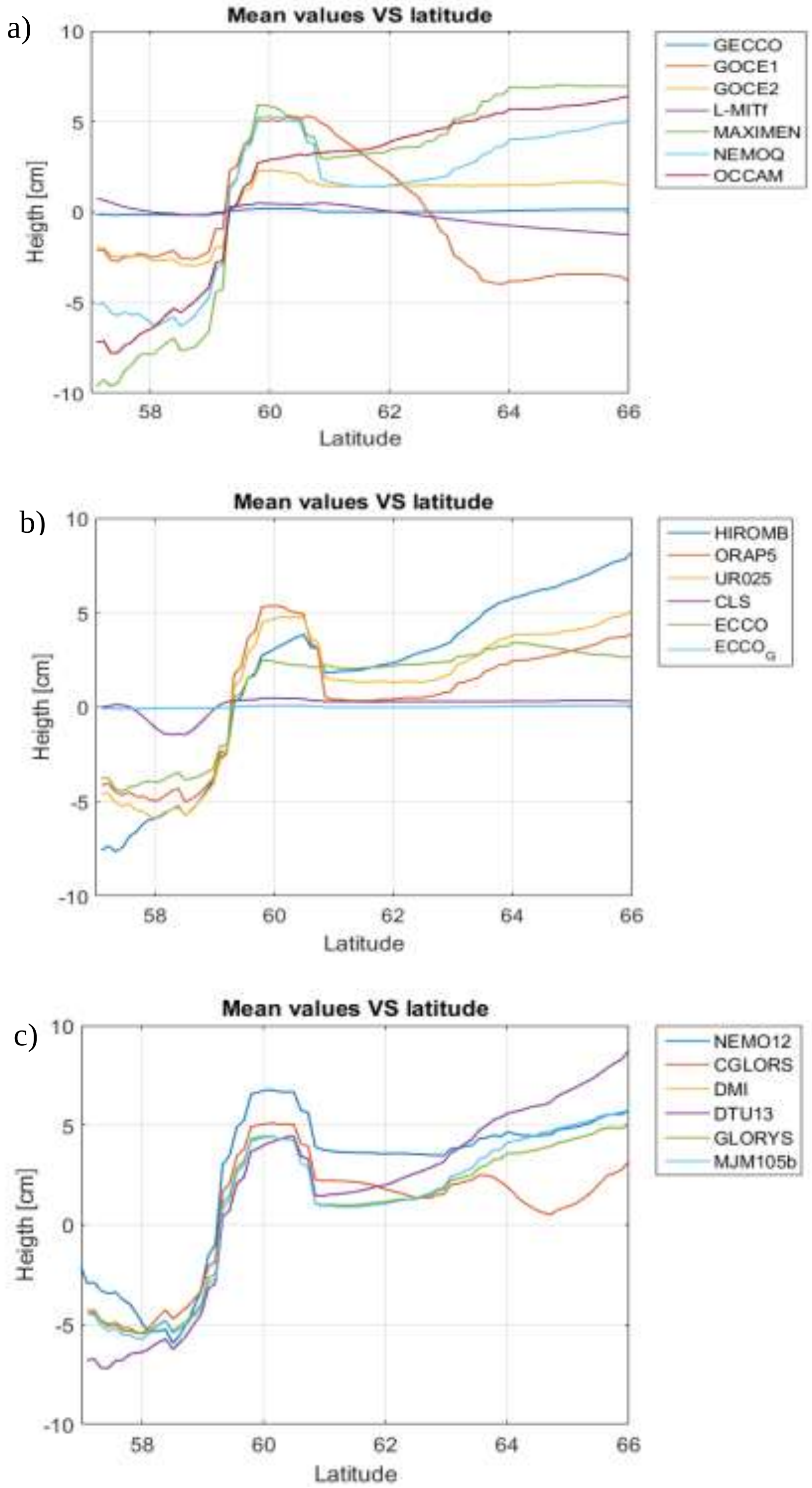

Figure 3.3: mean MDT values along latitudes 57-66.

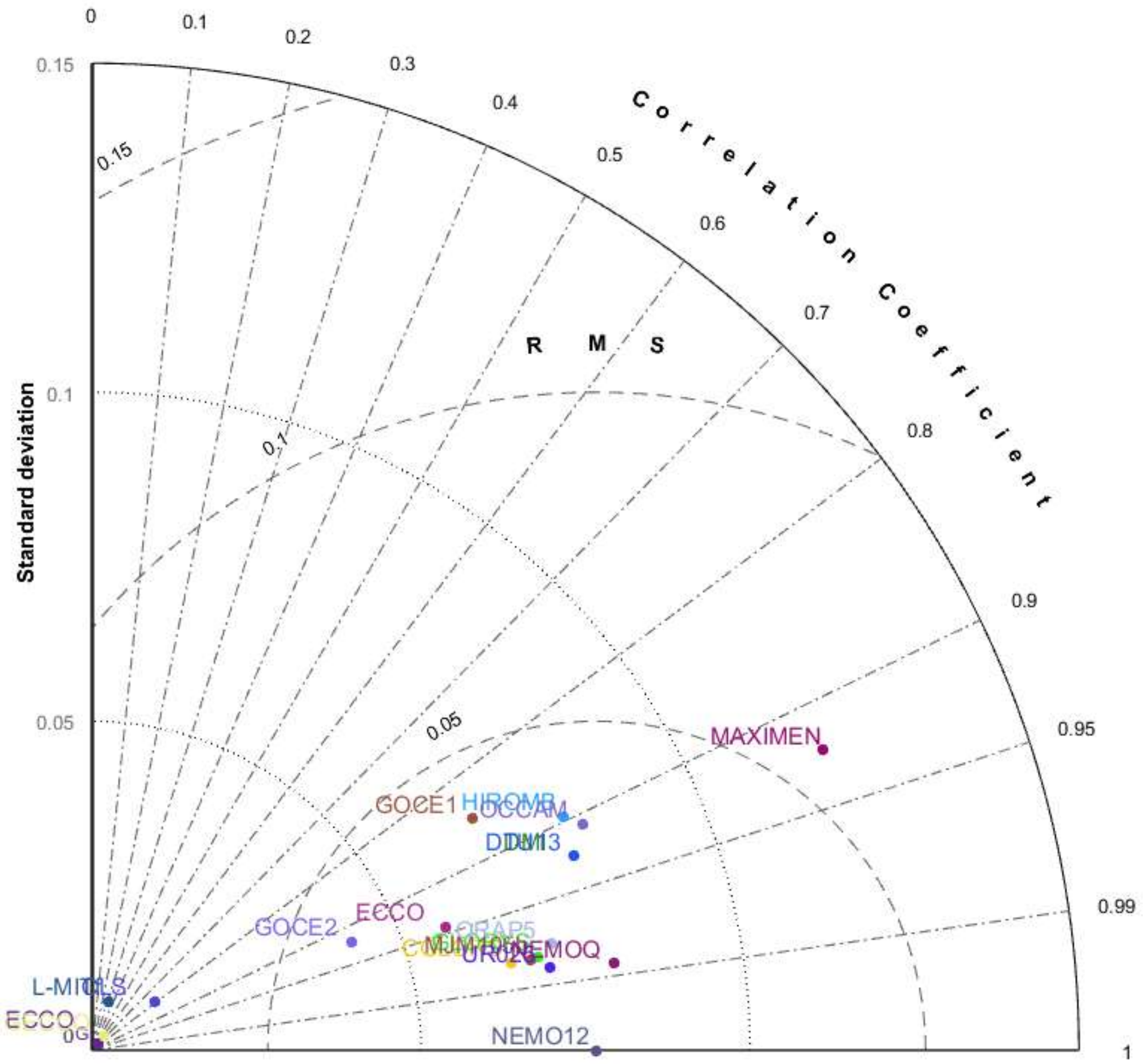

Figure 3.4: Taylor diagram for MDT models.

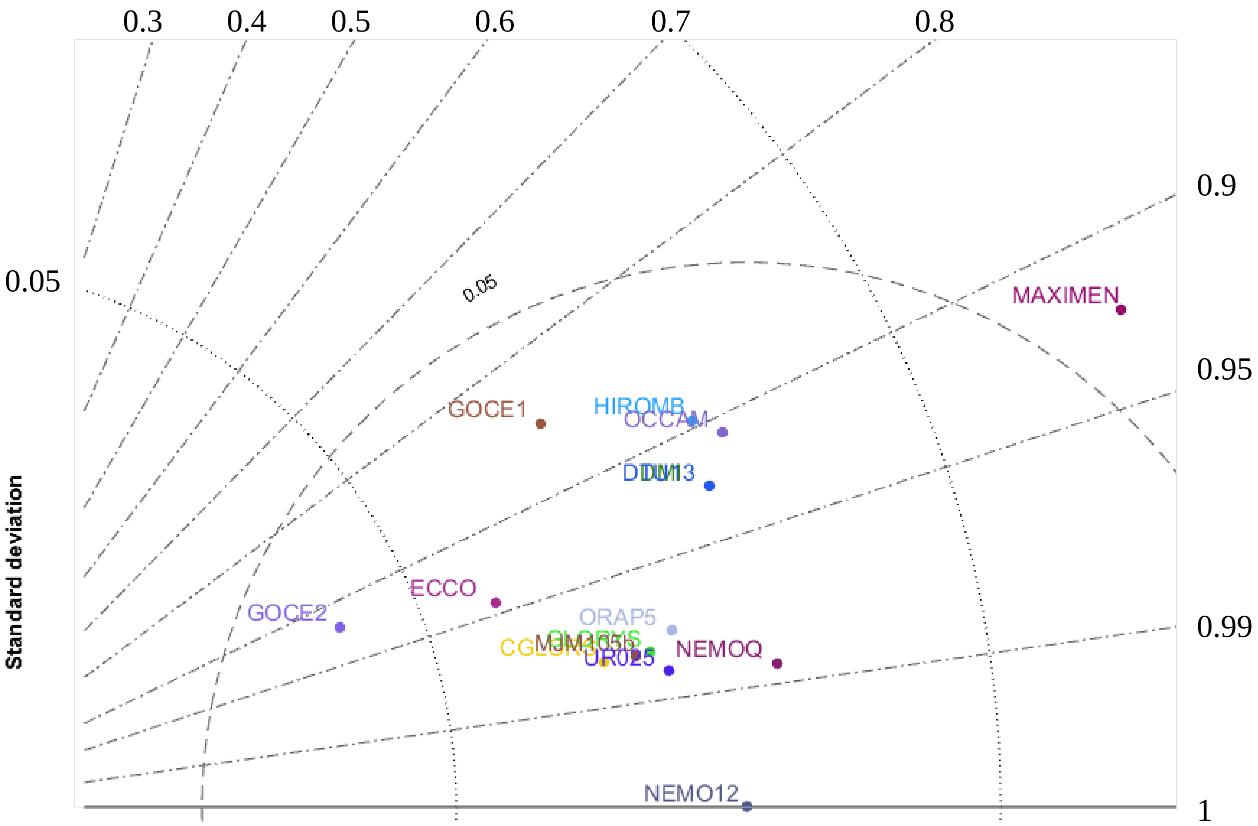

Figure 3.5*: Zoom of Taylor diagram for MDT models.*

4. DIRECT COMPARISON BY SURFACE DIFFERENCE

The direct comparison between the MDT models can help to understand the spatial similarities among surfaces. As in the previous section, the anomalies got from NEMO12 model are taken as reference surface (it is always: NEMO12 minus the other surface). The range of the difference is set between -10 cm and 7 cm. It can be observed that very small difference is registered in the comparison between NEMO12 and CGLORS, GLORYS, MJM105b, NEMOQ, ORAP5.0, UR0.25, which are represented in figure 4.1, 4.7, 4.10, 4.14, 4.16, 4.17, respectively. The main differences with the other models can be found in the Gulf of Bothnia and the Gulf of Finland. The models CLS, ECCO-GODAE, GECCO, and L-MITf, which measure a low standard deviation in the Taylor Diagram, and have all values close to zero in their 1-D profiles, show the same pattern in the comparison with NEMO12. These features can be seen in figures 4.2, 4.5, 4.6, 4.12 respectively, and all show values ranging 3-7 cm above 59N. Low values between -7 to -3 cm can be noticed in the Gulf of Bothnia in the comparison with DMI, HIROMB, Maximenko, and OCCAM, respectively figure 4.3, 4.11, 4.13, 4.15. Good agreement can be found also in the comparison between NEMO12 and ECCO, where a higher difference of circa 7 cm is registered in the Gulf of Finland, figure 4.4. The GOCE models show different behaviour: for GOCE1 negative values appear below latitude 60N, while values of 7 cm can be seen in the Gulf of Bothnia, figure 4.8. GOCE2 shows high values in the Gulf of Finland, and a difference of around 3 cm above 59N, figure 4.9. In figure 4.18 the comparison NEMO12-DTU13MDT shows negative values above 57N. In particular, in the Gulf of Bothnia registers a difference lower than 10 cm.

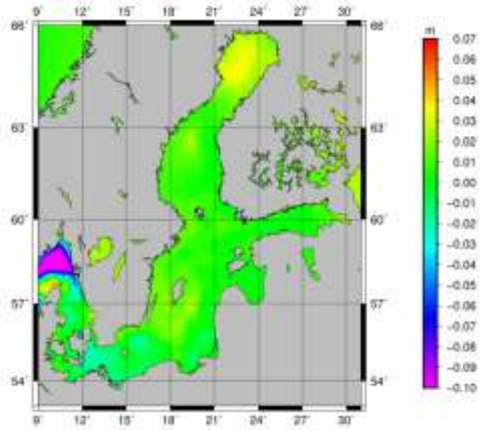

Figure 4.1: difference between NEMO12 and CGLORS model

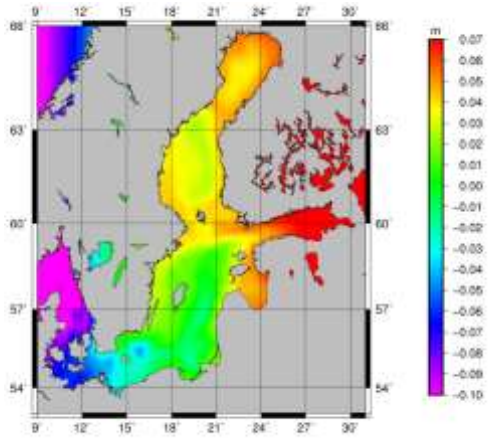

Figure 4.2: difference between NEMO12 and CLS model

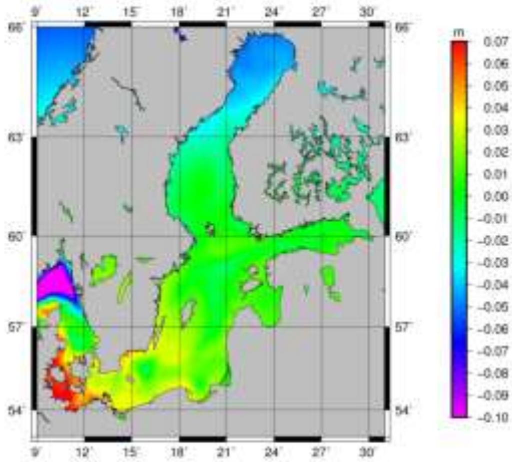

Figure 4.3: difference between NEMO12 and DMI model

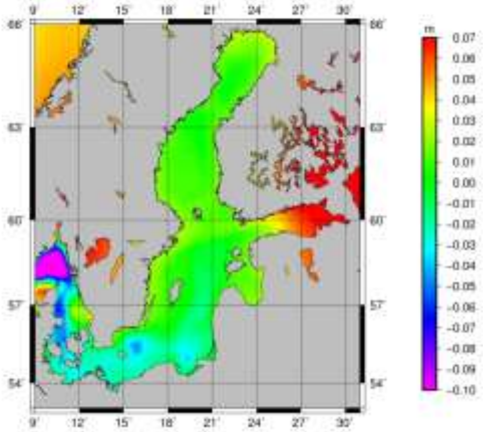

Figure 4.4: difference between NEMO12 and ECCO model

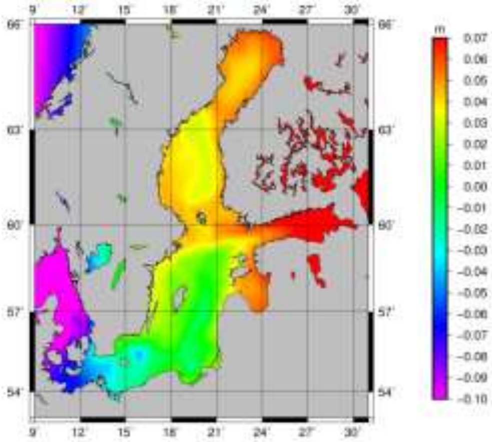

Figure 4.5: difference between NEMO12 and ECCO-GODAE model

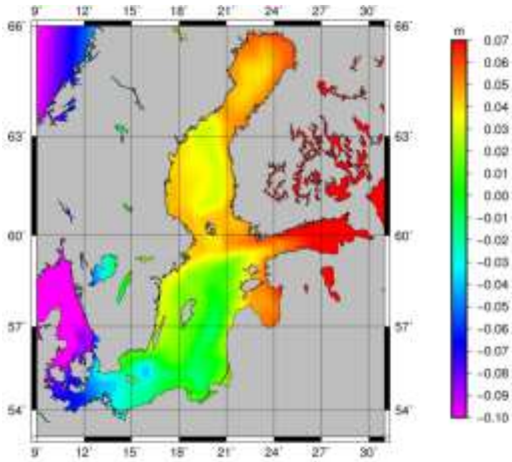

Figure 4.6: difference between NEMO12 and GECCO model

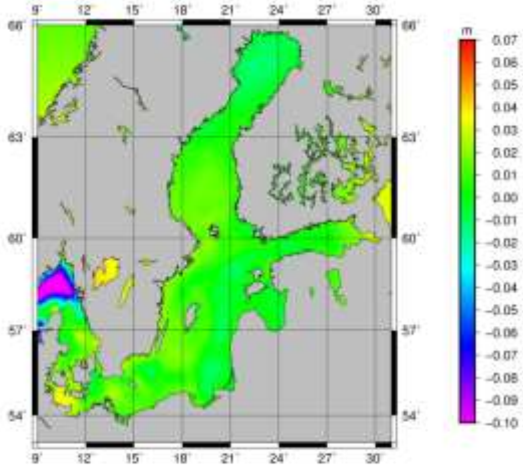

Figure 4.7: difference between NEMO12 and GLORYS model

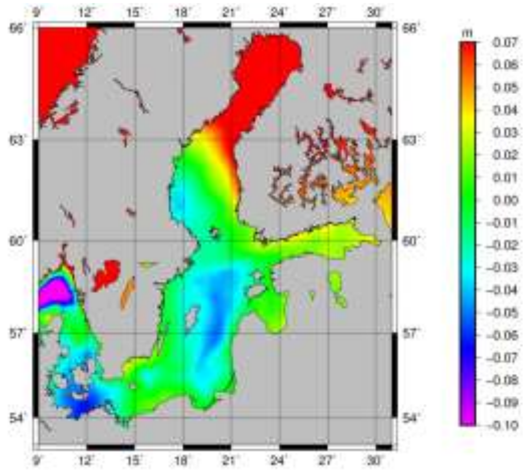

Figure 4.8: difference between NEMO12 and GOCE1 model

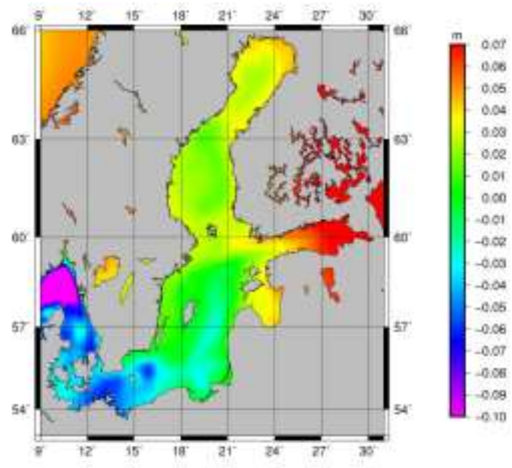

Figure 4.9: difference between NEMO12 and GOCE2 model

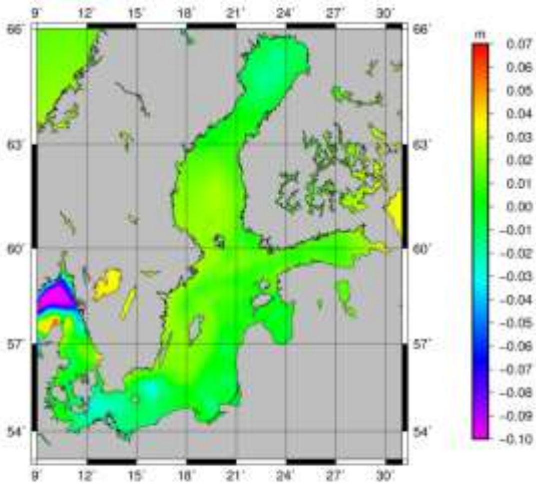

Figure 4.10: difference between NEMO12 and MJM105b model

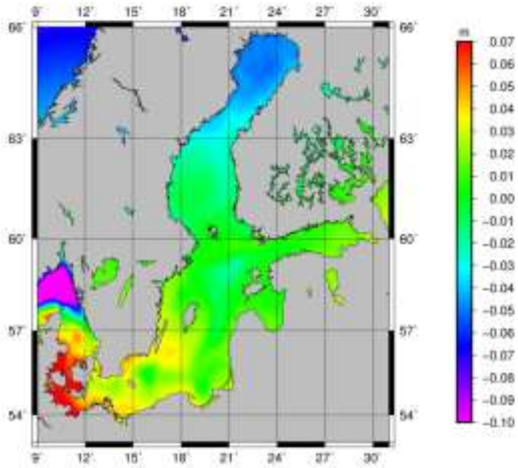

Figure 4.11: difference between NEMO12 and HIROMB model

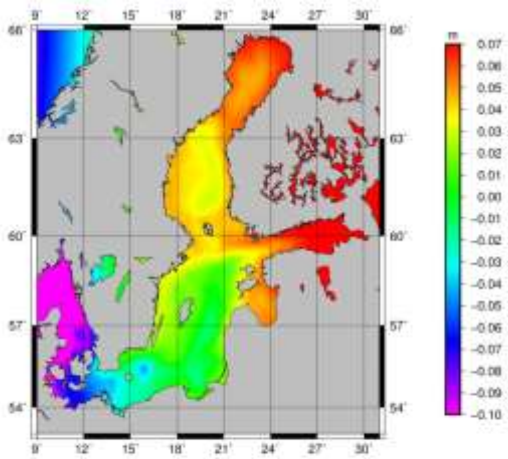

Figure 4.12: difference between NEMO12 and L-MITf model

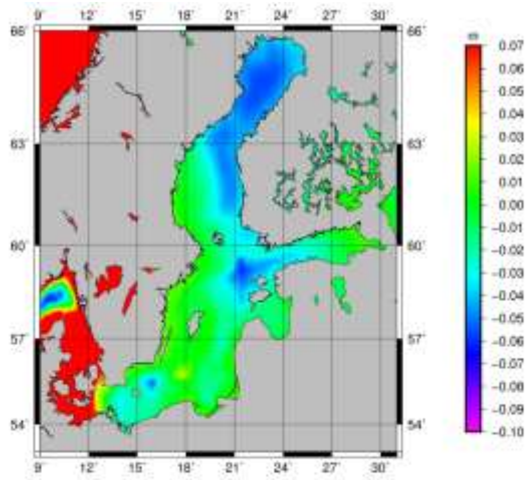

Figure 4.13: difference between NEMO12 and Maximenko model

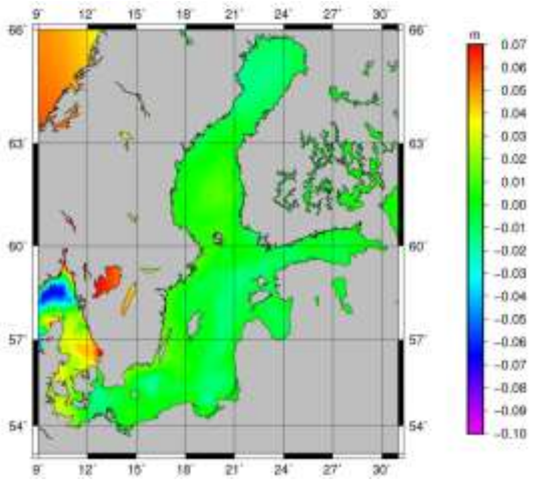

Figure 4.14: difference between NEMO12 and NEMOQ model

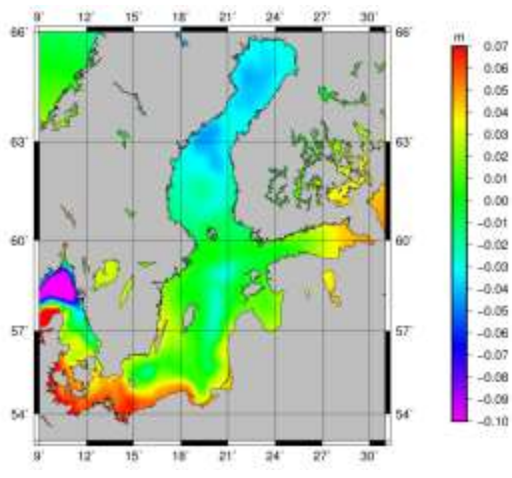

Figure 4.15: difference between NEMO12 and OCCAM model

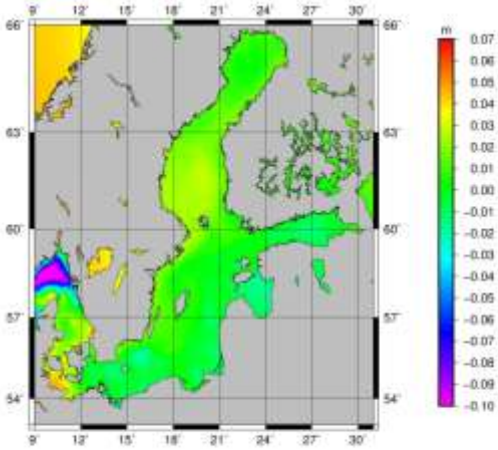

Figure 4.16: difference between NEMO12 and ORAP5 model

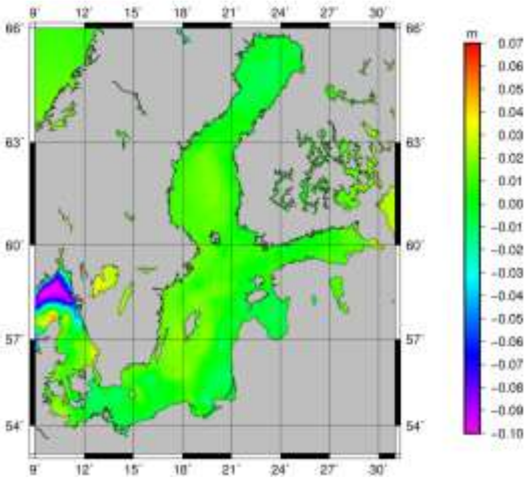

Figure 4.17: difference between NEMO12 and UR025.4 model

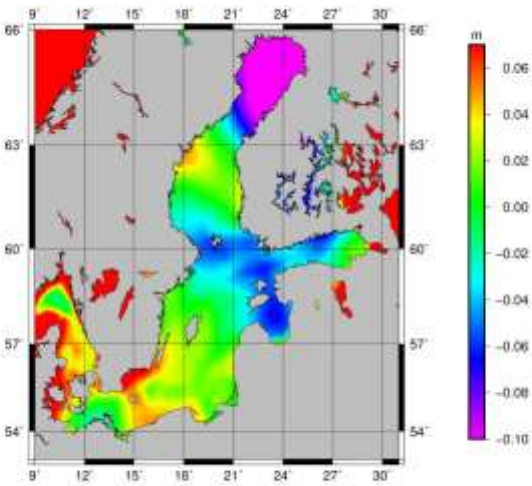

Figure 4.18: difference between NEMO12 and DTU13MDT model

5. SUMMARY

In this document we have presented and compared Mean Dynamic Topography models derived with ocean or geodetic approach.

Most of the models are characterised by long time coverage, in particular the MDT obtained from the physical reanalysis. The majority of the product is delivered with a resolution of 0.25°, while only DTU13MDT and HIROMB are available with a resolution higher than 3 minutes of degree.

From the direct comparison in section 3 the models CLS13, L-MITf, GECCO, and ECCO-GODAE show low sensitivity over the basin. Also, dubious values are found for GOCE1 above latitude 62, which are in disagreement with all the other models. A similar behaviour is found also for CGLORS above 64°. The 1-D plot, together with the Taylor diagram, shows a good correlation among the other models.

In section 4 good agreement within the order of few centimetres (circa ± 2 cm) is observed among most of the ocean models, while large difference is registered for the geodetic models with respect to NEMO12. In particular, higher contrast is found in proximity of islands and in the Gulf of Finland and Bothnia.

For the purpose of this project we suggest to prefer a MDT model that represents a good compromise between time coverage and resolution. A longer data time series ensures a robust model, and a resolution higher than 0.25° is more desirable in the Baltic, where the average longitudinal size is of only 5° in the main basin. From these considerations, a reasonable choice could be the DMI or the HIROMB as the ocean model, and DTU13MDT as geodetic model.

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