Seventh Framework Programme
Theme 9 Space FP7-SPA.2009.1.1.02
Monitoring of climate change issues (extending core service activities)

Grant agreement for:	Collaborative Project (generic).
Project acronym:	**MONARCH-A**
Project title:	**MONitoring and Assessing Regional Climate change in High latitudes and the Arctic**

Grant agreement no.	242446
Start date of project:	01.03.10
Duration:	36 months
Project coordinator:	Nansen Environmental and Remote Sensing Center, Bergen, Norway

D2.2.3 Improved dynamic topography model for the Arctic Ocean.

Due date of deliverable: 31.06.2011

Actual submission date: 19.09.2011

Organization name of lead contractor for this deliverable: NERSC

Project co-funded by the European Commission within the Seventh Framework Programme, Theme 6 Environment		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission)	
RE	Restricted to a group specified by the consortium (including the Commission)	
CO	Confidential, only for members of the consortium (including the Commission)	

ISSUE	DATE	CHANGE RECORDS	AUTHOR
1	18/09/2011	Complete	J.A. Johannessen (NERSC) O.B. Andersen (DTU) P. Knudsen (DTU) D. Stammer (UOH) K. Lygre (NERSC)
2	01/10/2011	Fine tuned the layout	K. Lygre

SUMMARY

Using a new Earth gravity model based on GOCE together with merged altimetry data from ERS, Envisat and ICESat for the high latitude and Arctic region the corresponding geoid and mean sea surface are constructed. The mean dynamical topography (MDT) is the difference between these two fields and is assessed and validated against the model based and ICESat based MDTs.

A first inter-comparison demonstrates that there is a very good consistency with the dynamic topography obtained from the ICESat laser mission for the period 2004-2008. Both the general MDT patterns and the range of values are in good agreement suggesting that these two independent observation methods support each other. Compared to the model derived MDTs the results are best for the high in the Beaufort basin, noting that the model based MDT is only displaying a range of about 0.50 m in contrast to the GOCE MDT that has a range of around 0.8 m. This might partly be explained by the fact that the model integration spans the period 1970 to present.

This first GOCE based MDT for the high latitude and Arctic Ocean is based on the first 6 months of GOCE data integration for the derivation of the geoid (G) and 16 years of satellite altimetry for the derivation of the height of the mean sea surface. The MDT reveals a large scale pattern in consistence with the overall upper ocean circulation pattern in the area.

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1. Deliverables in the framework of MONARCH-A project

1.1 Main objectives of MONARCH-A project

The Arctic and northern hemisphere high latitude regions experience significant changes during past few decades, associated with climate change. The Arctic region itself is an important part of the Earth climate system, and changes that occur in this region, in turn, influence the rest of the Planet.

Due to harsh environmental conditions and inaccessibility of some of the Arctic areas, especially during winter, there is a lack of consistent historical and modern observational data. As a result, our understanding of Arctic climate related processes and ability to predict consequences of changes in this region for Europe is rather limited.

The ultimate objective of the MONARCH-A project is to provide the scientific community with subset of multidisciplinary Essential Climate Variables for the Arctic region. The information package will be based on generation of time series of observation datasets and reanalyses of past observational data enabling adequate descriptions of the status and evolution of the high latitude and Arctic region Earth system components.

1.2 Uncertainty of existing reanalyses and simulations over the Arctic

One of the main goals of WP 2 (Changes in Sea Level and Ocean Circulation) is to provide dynamically consistent reanalysis of the Arctic Ocean over the last 50 years, allowing better understanding of water mass formation, circulation, sea level and sea ice changes in this region. In so doing access to observation data will be essential both for validation and assimilation. However, the Arctic Basin remains one of the most under-sampled regions of the World Ocean. Sea ice coverage limits access of research vessels and make it hard for satellites to measure characteristics of the upper ocean layers below the sea ice. For instance, it is not possible to directly derive mean sea level estimates from altimetry due to the presence of sea ice. On this basis it is therefore a challenge to provide solid conclusions about details of the large-scale circulation in the Arctic Ocean, and especially about its inter-annual and decadal variability.

1.3 Improved dynamic topography model for the Arctic Ocean

As a first step towards Arctic Ocean reanalysis several existing long-term simulations of the Arctic Ocean has been examined in order to evaluate the performance and quality of products provided by a selection modern ocean models (see Table 1) with atmospheric forcing and without data assimilation. This was reported in deliverables D2.4.1 and D2.4.2, and included an inter-comparison of several model based MDTs. In this D2.2.3 report these MDTs will, in turn, be compared and validated against an independent derived MDT from combined use of altimetry and gravity measurements as well as the sea surface height reconstructed from ICESat data only (Kwok et al., 2011). Using a new Earth gravity model based on GOCE together with merged altimetry data from ERS, Envisat and ICESat for the high latitude and

Arctic region the corresponding geoid and mean sea surface are constructed. The differences between these two fields then yields the MDT which will be assessed and validated against the model based and ICESat based MDTs.

Model run	Region	Mean spatial resolution in the Arctic	Period of integration	Vertical grid
ATL03	Atlantic Ocean north of 33◦S including the Nordic Seas and the Arctic Ocean.	~ 30 km	1948-2009	z-coordinates, 50 levels
ATL06	Atlantic Ocean north of 33◦S including the Nordic Seas and the Arctic Ocean.	~ 15 km	1948-2007	z-coordinates, 50 levels
ATL12	Atlantic Ocean north of 33 S including the Nordic Seas and the Arctic Ocean.	~8 km	1948-2009	z-coordinates, 50 levels
MICOM	North of 30 S with Nordic Seas and Arctic Ocean included	~15 km	1948-2007	σ-coordinates, 35 levels
MPIOM	Global	~7 km	1948-2010	z-coordinates, 80 levels

Table 1. *Model setup and simulation overview. All models are forced by the 6 hourly NCEP RA 1 reanalysis field (Kalnay et al., 1996). For more details see D2.4.1.*

2. Sea surface height

2.1 Model based sea surface height

In Figure 1 the mean sea surface height (MSSH) derived from the 5 model simulations for the period 1970 to 2007 are presented and compared to the independent estimates of the MSSH in the Arctic Ocean obtained from six years (2004-2008) of ICESat satellite observations (Kwok et al., (2011).

In general the model simulations reproduce the overall spatial structure of the SSH in the Arctic Ocean with higher values in the Amerasian basin and lower values in Eurasian basin with a mean differences in the SSH between these two basins ranging from 50-60 cm. As noted this is also in general agreement with the satellite based MSSH (Kwok et al., 2011). The different averaging periods, on the other hand, might introduce some of the observed disagreement at the finer spatial scales.

Details of the SSH spatial distribution are better represented in ATL model runs than for MICOM and MPIOM. In the three ATL simulations the largest values of SSH are located close to Canadian coast in the Beaufort Sea. Large values also propagate along Canadian Archipelago and towards East Siberian Sea in agreement with observations. MPIOM display the weakest SSH gradient across the basin and the largest values of SSH are located closer to the centre of the Arctic Ocean. MICOM also display the maximum value of SSH closer to the center of the Arctic Ocean. In addition local maxima of the SSH are found in the Laptev and East-Siberian Seas in all ATL runs and MICOM model, while it is absent in MPIOM model.

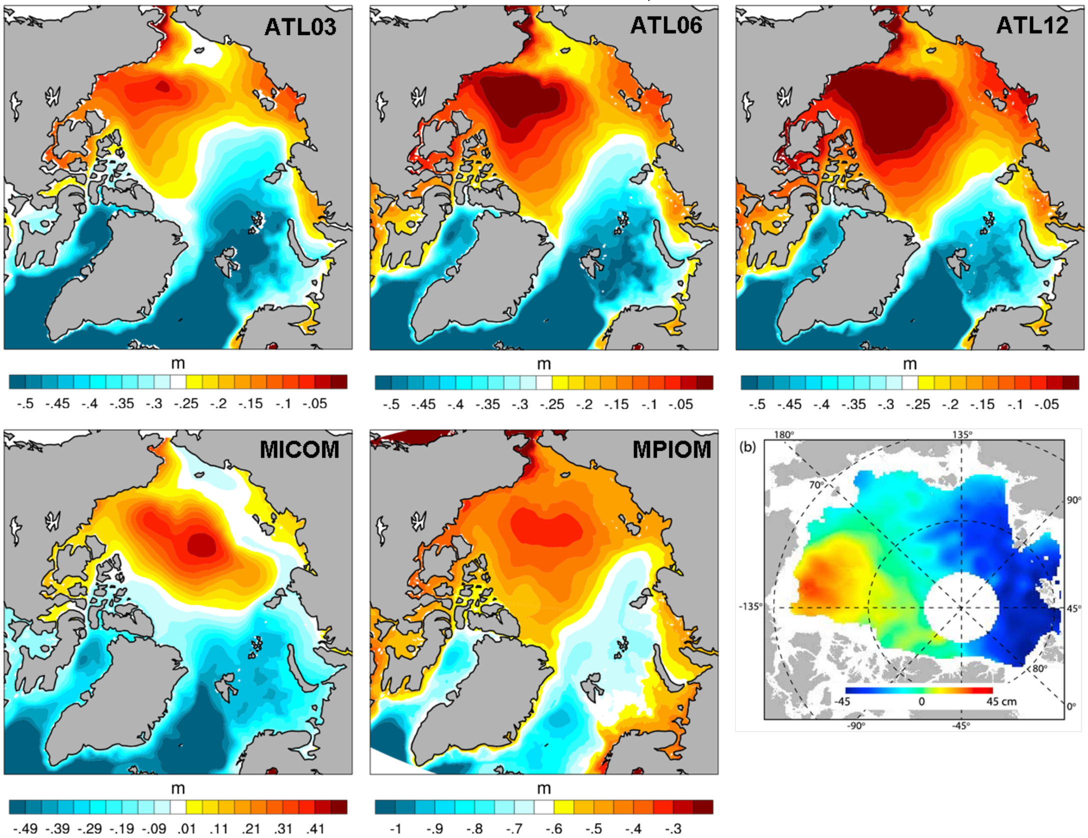

Figure 1. *Mean SSH for the period 1970-2007 and (in lower right) satellite based dynamic ocean topography estimate for the period 2004-2008 (Kwok et al., (2011).*

2.2 GOCE based mean dynamic topography

The GOCE observations of the gravity field and the geoid (G) at a spatial resolution of about 200 km in combination with the mean sea surface (MSS) allows the reconstruction of the mean dynamic topography (MDT) according to the relationship:

$$MDT = MSS - G$$

A surface for which the local gravity field is everywhere perpendicular is a representation of the geoid as schematically illustrated in Figure 2. The MSS derived from altimetry largely mimic this geoid. So by measuring the gravity field from GOCE (and GRACE) we can derive the geoid which in combination with the measurements of the MSS from altimetry allows us to estimate the MDT.

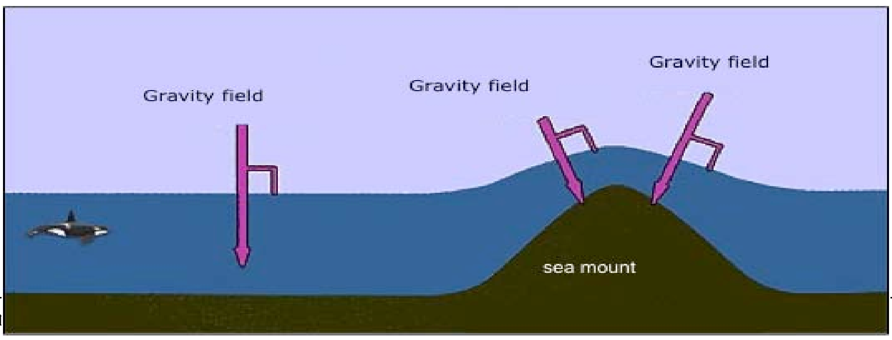

Figure 2. *Schematic relationship between a seamount, the gravity field and the geoid.*

In this report we use the recent MSS delivered by DTU (see Figure 3) and the geoid derived from GOCE after 6 months of data integration (see deliverable D2.1.1). Note that the GOCE mission duration is now approved for extension to the end of 2012. Hence, the geoid is expected to gradually emerge with better and better accuracy and spatial resolution as we progress towards the end of the MONARCH-A project. This report should thus be updated accordingly towards the end of the project.

The MSS in the high latitude and Arctic (Figure 3) shows a distinct structure with predominantly low surface height along the Siberian shelves, a minimum in the Beaufort Sea and then a gradual sea level increase in a 100 degrees sector southward from the North Pole towards Greenland and the Franz Josef Islands culminating with a maximum in the Norwegian and Greenland Seas. The corresponding height difference ranges between 50 and 60 m. By subtracting the GOCE derived geoid (which is comparable in magnitude to the MSS) from the MSS, the MDT is then derived as shown in Figure 4.

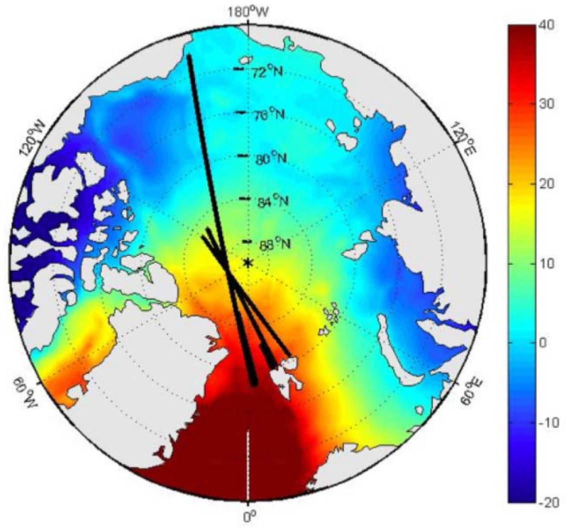

Figure 3. *Mean sea surface height (in meter) from DTU reconstructed for the period 1993-2009.*

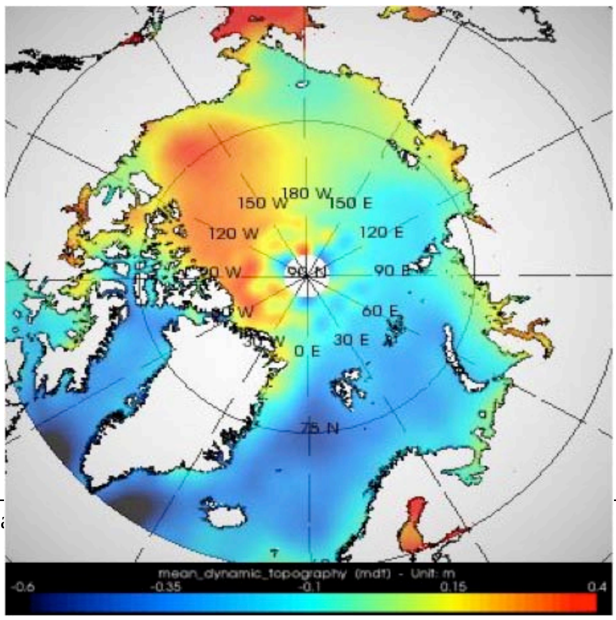

Figure 4. *Mean dynamic topography (in meter) using 6 months of GOCE data and the MSS from DTU reconstructed for the period 1993-2009.*

This MDT, derived after subtraction of two fairly large numbers, ranges from a high of about 0.4 m in the Beaufort Sea to a low of -0.4 m in the Greenland Sea. As such it has a pattern almost opposite to that seen for the MSS (Figure 3) although distinctly smaller in magnitude. The lowest MDT signal is noted in the Sub-polar gyre south of Greenland. The perturbed structure around the North Pole is assumed due to the GOCE geoid errors. These errors are expected to gradually weaken as more gravity and geoid observations are integrated during the extended GOCE mission duration.

All in all the large scale MDT shape is consistent with the general circulation pattern in the Nordic Seas and the Arctic Ocean. The inflow of Atlantic Water to the Norwegian Sea and its continuation northward along the Norwegian shelf break are depicted as is the extension onwards into the Arctic Ocean either via the Barents Sea or the Fram Strait. In the Arctic Ocean the clockwise circulation in the Beaufort gyre is clearly visible while the evidence of the trans-polar drift is somewhat masked by the geoid errors. At present the spatial resolution of the MDT is about 200 – 250 km. Hence the slope and corresponding strength of the mean surface geostrophic current might be underestimated. This is expected to improve with increasing length of the GOCE mission that ultimately will lead to finer spatial resolution of the order of 100 km.

A first inter-comparison to the MDTs displayed in Figure 1 clearly demonstrates that there is a very good consistency with the dynamic topography obtained from the ICESat laser mission for the period 2004-2008. Both the general MDT patterns and the range of values are in good agreement suggesting that these two independent observation methods support each other. Compared to the model derived MDTs (Figure 1) the agreement is not as good. Here the results are clearly best for the ATL12 simulation with the high in the Beaufort basin. However, the model based MDT is only displaying a range of about 0.50 m in contrast to the GOCE MDT that has a range of around 0.8 m. This might partly be explained by the fact that the ATL12 model integration is from 1970 to present.

3. Conclusions

The first GOCE based mean dynamic topography (MDT) for the high latitude and Arctic Ocean has been constructed and presented. This is based on the first 6 months of GOCE data integration for the derivation of the geoid (G) and 16 years of satellite altimetry for the derivation of the height of the mean sea surface (MSS). The MDT reveals a large scale pattern in consistence with the overall upper ocean circulation pattern in the area. The accuracy of this GOCE based MDT surface is not yet established. However, it is expected to sharpen up and improve further as the GOCE mission continues to collect high quality gravity data. In results the GOCE based MDT produced towards the end of 2012 will have a much finer spatial resolution in the order of 100 km as well as reduction in error contributions. Accordingly this D2.2.3 deliverable should be updated towards the end of the MONARCH-A project.

4. References

D2.1.1 - Satellite altimetry-based gridded sea level time series since 1993 in the Arctic Ocean, MONARCH-A report delivered by DTU, September 2011.

D2.4.1 - Assessment of existing descriptions of the Arctic Ocean circulation and its transport properties. MONARCH-A report delivered by UoH, April 2011.

D2.4.2 - Assessment of shortcomings that need to be improved through an Arctic Reanalysis. MONARCH-A report delivered by UoH, April 2011.

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