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Complete Bouguer Correction - Statoil database Offshore Mid-Norway

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REPORT

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Title:
Complete Bouguer Correction - Statoil database Offshore Mid-Norway

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Summary:

Correction of an offshore gravity data set (free-air data) by applying Complete Bouguer Correction.
The new gravity anomaly map for the North Atlantic released in 2010 by NGU (Olesen et al. 2010) and the ocean wide gravity field DTU2010 show a significantly higher mismatch on the Norwegian shelf than expected by the estimated resolutions of the individual data sets. A possible reason for this could be the levelling procedure. The marine database of Statoil was therefore re-processed by Intrepid Geophysics (levelling and free-air calculation) which improved the data set and reduced the mismatch. NGU was asked to do the Complete Bouguer correction which contains simple Bouguer Correction (with a Bouguer slab) and Terrain Correction.
The survey is located on the Norwegian margin between 3˚E-18˚W and 58˚N-70˚N, with stations close to the coast. This proximity to land and extreme changes in topography/bathymetry require a terrain correction that considers two terrain densities, one for the onshore terrain (2670 kg/m^3) and one for the offshore terrain (1170 kg/m^3).
The CBC calculation was done using TriTop (Köther 2013). Gridding, interpolations, transformations were done with Geosoft (Oasis Montaj).

Keywords:	Geophysics	Continental shelf
Gravity	Terrain correction	

CONTENTS

FIGURES

1. INTRODUCTION

In 2010 NGU released a new gravity anomaly map for the North Atlantic (Olesen et al. 2010), Figure 1. The profile data offshore Norway have been levelled using the median levelling technique (Mauring & Kihle 2006), and gravity data from DNSC08 satellite altimetry (Andersen & Knudsen 2010) were used to fill in data gaps in the deep ocean area. The resolution of shipboard surveys is estimated to be ~1 mGal over 5–10 km wavelengths (Dragoi-Stavar & Hall 2009).

For the oceanic areas and most of the shelf the DTU10 model is based mainly on satellite altimetry, and only a limited amount of shipborne surveys (Figure 1). Such high-resolution satellite derived free-air data is estimated to have a resolution of ~3 mGal over 10–15 km wavelengths for the North Atlantic (Andersen et al. 2010). The resolution is assumed to increase with higher latitudes because of better crossing angles between satellite tracks. Overlapping satellite and marine gravity measurements in the Arctic Ocean differ 2.64–3.11 mGal (Childers et al. 2001).

Comparison between the NGU marine database and the DTU10 model showed a significantly higher mismatch, with a maximum difference of up to 15 mGal (neglecting local higher amplitudes), and a mean difference of (6.8 ± 2.8) mGal for the mid-Norwegian margin (Figure 2, within the survey outline). Comparison of the DT10 data set to other shipborne surveys of the North Atlantic shows a difference in the range of the expected standard deviation.

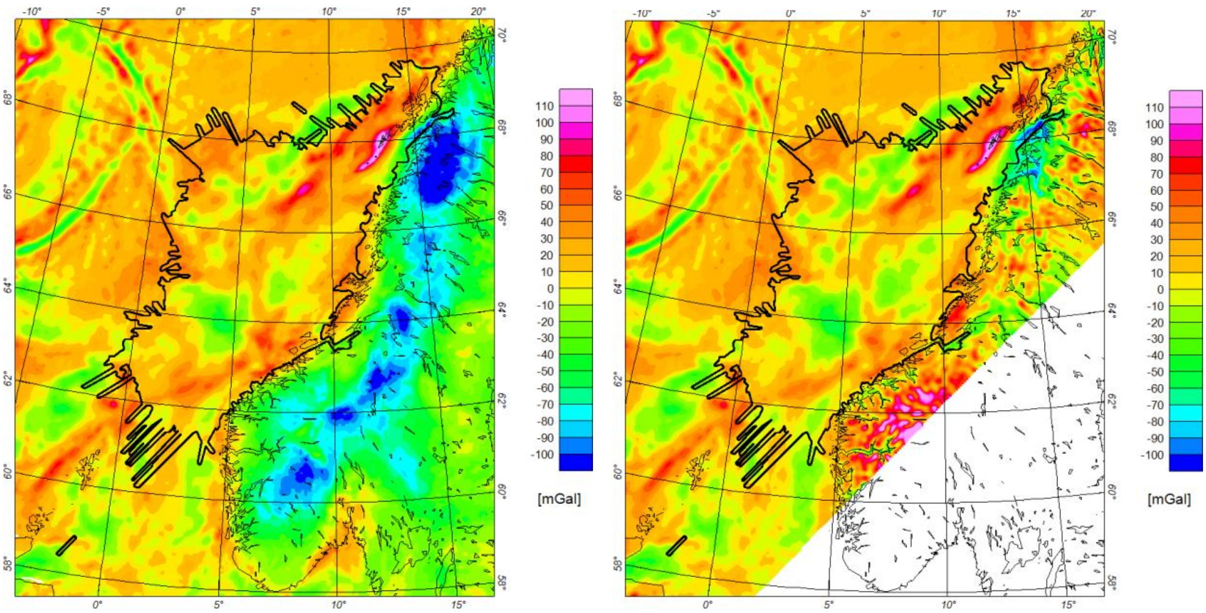

Figure 1 Left: NGU-NPD gravity data base, free-air anomaly offshore and Bouguer anomaly onshore. Right: DTU free-air gravity anomaly. The polygon outlines the area of the Statoil database.

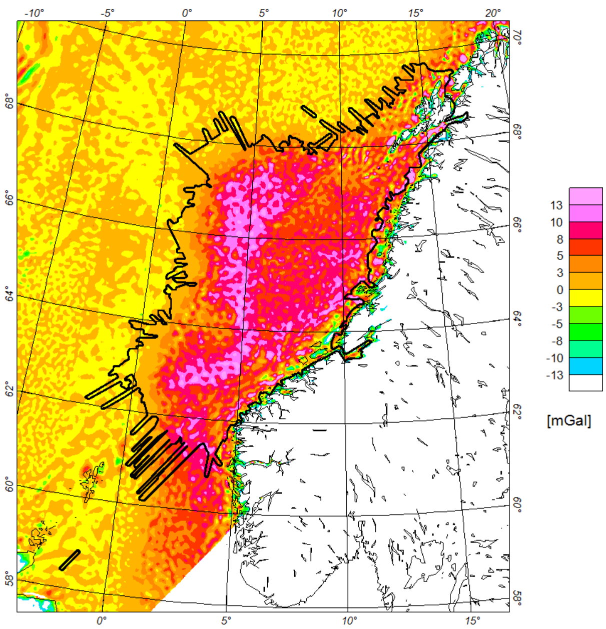

Figure 2 Difference between the NGU-NPD compilation (Olesen et al. 2010) and the DTU2010 gravity model (Andersen & Knudsen 2010). The colour scale is clipped to enhance the relevant part on the Norwegian shelf, where differences reach values up to >15 mGal.

The reason for the differences between the two datasets on the shelf has been suggested to be the levelling procedure. Both at the coast and towards the oceanic part the models are consistent, as they are linked here. In between a long wavelength misfit might be introduced, where no direct control on the long wavelength field is given. The difference maps shows also a form of ringing, which is caused by short wavelength features (<15 km), which have a poor resolution in the satellite altimetry.

For this reason, Statoil asked Intrepid Geoscience to reprocess the Statoil internal marine gravity database with the Intrepid levelling tools. In addition to reprocessing, the second motivation was to consistently process vintage data with new data sets acquired in the past years.

NGU had the task to perform a complete Bouguer correction, as the Bouguer anomaly is more useful for modelling and interpretation.

2. METHODOLOGY

2.1 Definition of gravity anomalies

The free-air anomaly reflects all masses in the subsurface as well as the affect of the bathymetry and topography. For interpretation, the masses by topography and bathymetry are considered known and are usually removed by the Bouguer reduction.

The Bouguer reduction accounts for the attraction of materials between the station and the datum plane (here the ellipsoid WGS84). The simple Bouguer Correction applies a Bouguer slab correction, assuming that excess mass underneath elevated observation points can be approximated by a horizontal slab of uniform thickness and density. The downward pull of this slab must be subtracted from the observed gravity because the rock mass between the datum and the station exerts a downward pull on the gravimeter. The simple Bouguer correction approximates all mass above sea level with a homogeneous, infinitely extended slab of thickness equal to the height of the observation point above sea level and given by

$$g_{sb} = 2\pi\gamma\rho h_s$$

Where g_{ba} is Bouguer anomaly, γ is gravitational constant, ρ is density of the slab, and h_s is station elevation.

For the marine Bouguer reduction, the gravity stations are reduced by the infill density between rock ρ_r and water ρ_w and instead of the station elevation the water depth $d_w$is used:

$$g_{Msb} = 2\pi\gamma(\rho_w - \rho_r)d_w$$

By taking into account the simple Bouguer correction, the simple Bouguer anomaly for marine gravity data is given by

$$\Delta g_{sb} = \Delta g_{fa} - g_{Msb}$$

where Δg_{sb} is simple Bouguer anomaly, Δg_{fa} is free-air anomaly and $g_{Msb}$is the simple Bouguer correction.

In regions of extreme topography the simple Bouguer Correction must be supplemented also by a Terrain Correction. The slab correction only accounts for masses between station and datum but not for excess/deficit mass in the vicinity of the station or in the case of marine data for abrupt changes in bathymetry and topography.

$$\Delta g_{cb} = \Delta g_{sb} + g_{tc}$$

The terrain correction is usually done with a high-resolution topography and computational time-demanding. In general for terrestrial gravity measurements, the terrain correction is positive and added to the measurement because the measurement is deflected - towards the area of excess mass and away from the area of deficit mass. In case of satellite measurements or marine measurements in shelf region (steep bathymetry) the terrain correction has as well negative values.

2.2 Methods for computation

For the simple Bouguer anomaly calculations, we used the Gravity Processing module of Oasis Montaj. For the terrain corrections and to calculate the complete Bouguer anomaly we used the software TriTop (Köther 2012; Köther 2013)

TriTop take into account the earth's curvature as it calculates the effect of topography/bathymetry with an exact surface integral of a polyhedron on a sphere. It also allows to define different densities for the onshore and offshore gravity reduction. The software outputs both the onshore and offshore corrections independently, which can simply be added to calculate the Bouguer and terrain reduction.

TriTop does not provide the individual contributions of the simple Bouguer and terrain correction, but only the sum of them. TriTop requires geographical coordinates in order to perform the spherical calculation. Therefore, all input data had to be projected from UTM coordinate to geographical coordinates before calculation.

3. DATA

3.1 Gravity data

Figures 3 shows the marine data from the Statoil database which is located on the Norwegian margin between 3˚E-18˚W and 58˚N-70˚N. The original database has in total 6,654,829 data points.

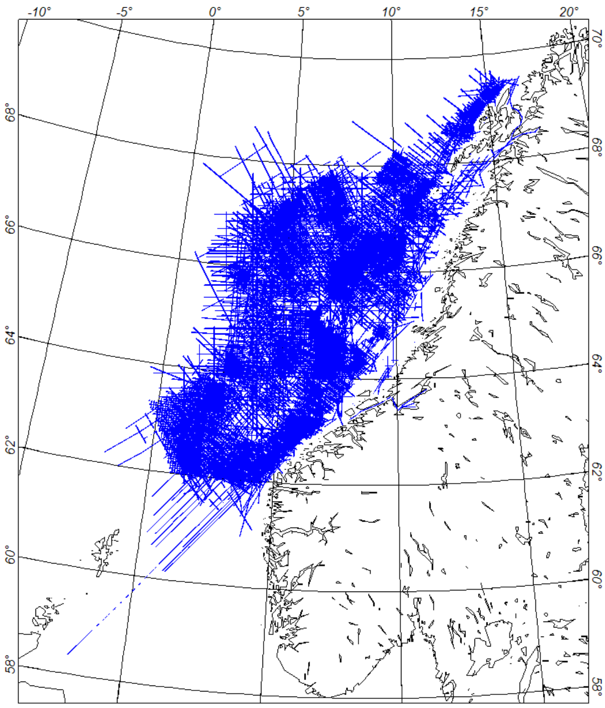

Figure 3 Location plot of marine gravity data in the Statoil database.

The database is given in UTM coordinates (ED50 / UTM zone 32N). Gravity data are given as Free-air anomaly (FA, Figure 4). Bathymetry is also provided.

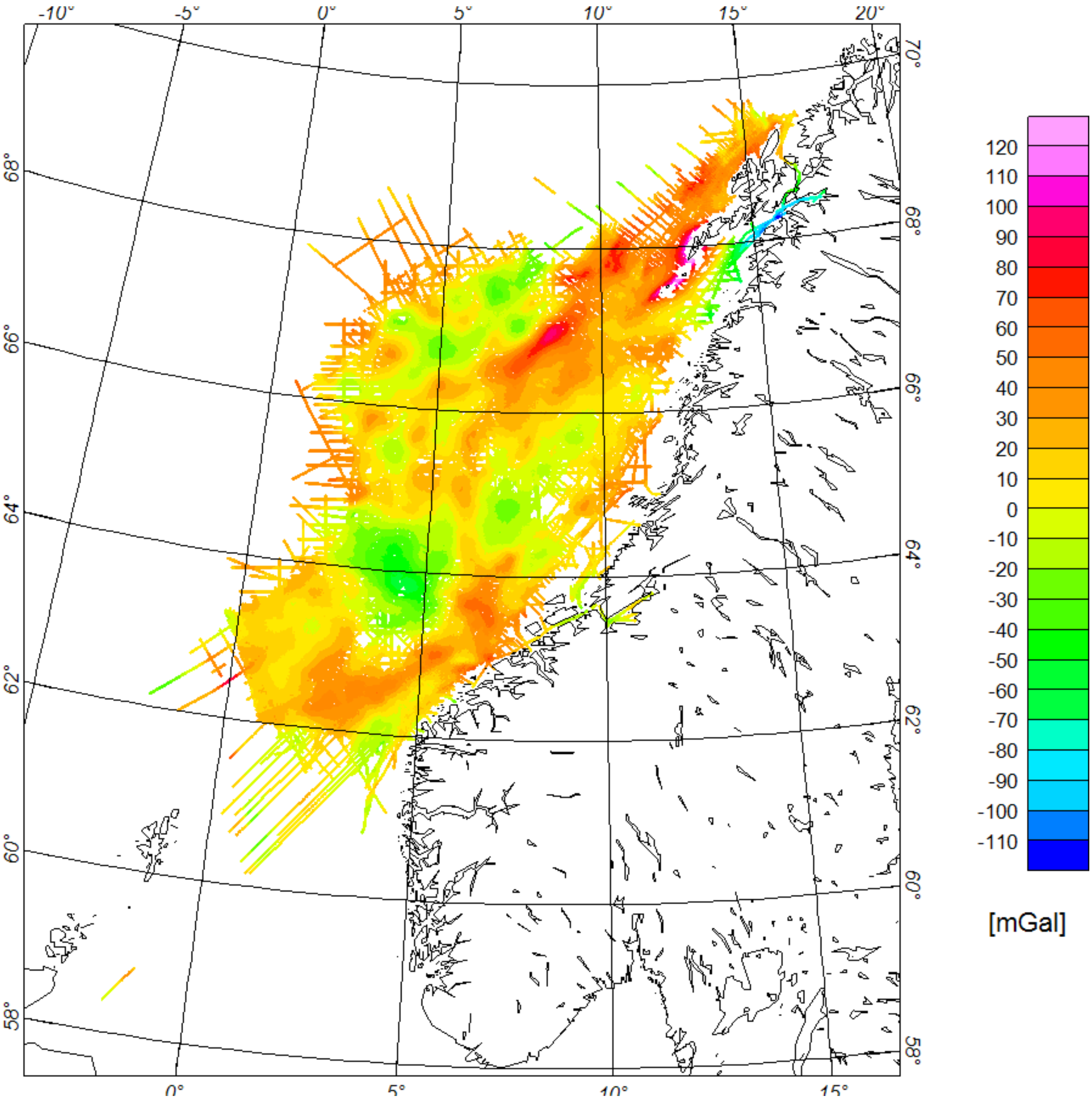

Figure 4 Statoil database free-air anomaly (FA) on a 250 m grid

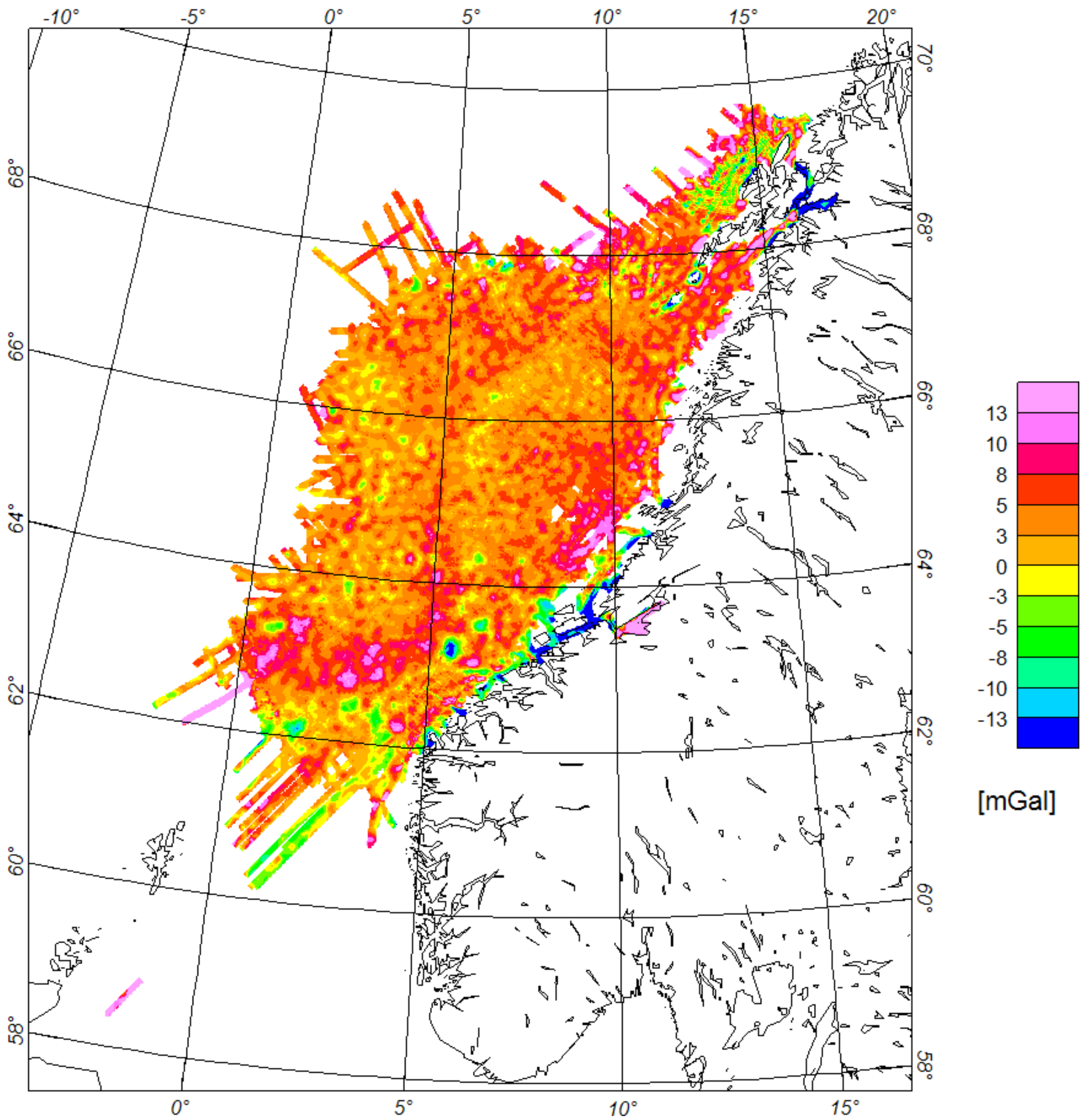

Figure 5 New Statoil database compared to the DTU2010. Shown is the residual free-air anomaly (Statoil – DTU).

Figure 5 shows the difference between the Statoil database and the DTU2010 model. A comparison with Figure 2 shows the improvement on the shelf gained by the new leveling of the data. Differences in the critical area are now reduced to (3.4 ± 4.9) mGal. The high standard deviation is caused by the partly increased differences in the fjords.

3.2 Bathymetry

For the terrain correction a Digital Elevation Model (DEM) is required. We used a NGU compilation, which has a resolution of 250 m (Figure 6). The grid was roughly cut down to the relevant area, still allowing for terrain corrections with a radius of 200km around each station. This grid contained some dummies which were filled using linear interpolation. The water depth (or bathymetry) channel in the Statoil database was also updated using this grid. The differences, which in parts reach up to ±100 m, are shown in Figure 7. In the study area the DEM contains 68,800,704 data points.

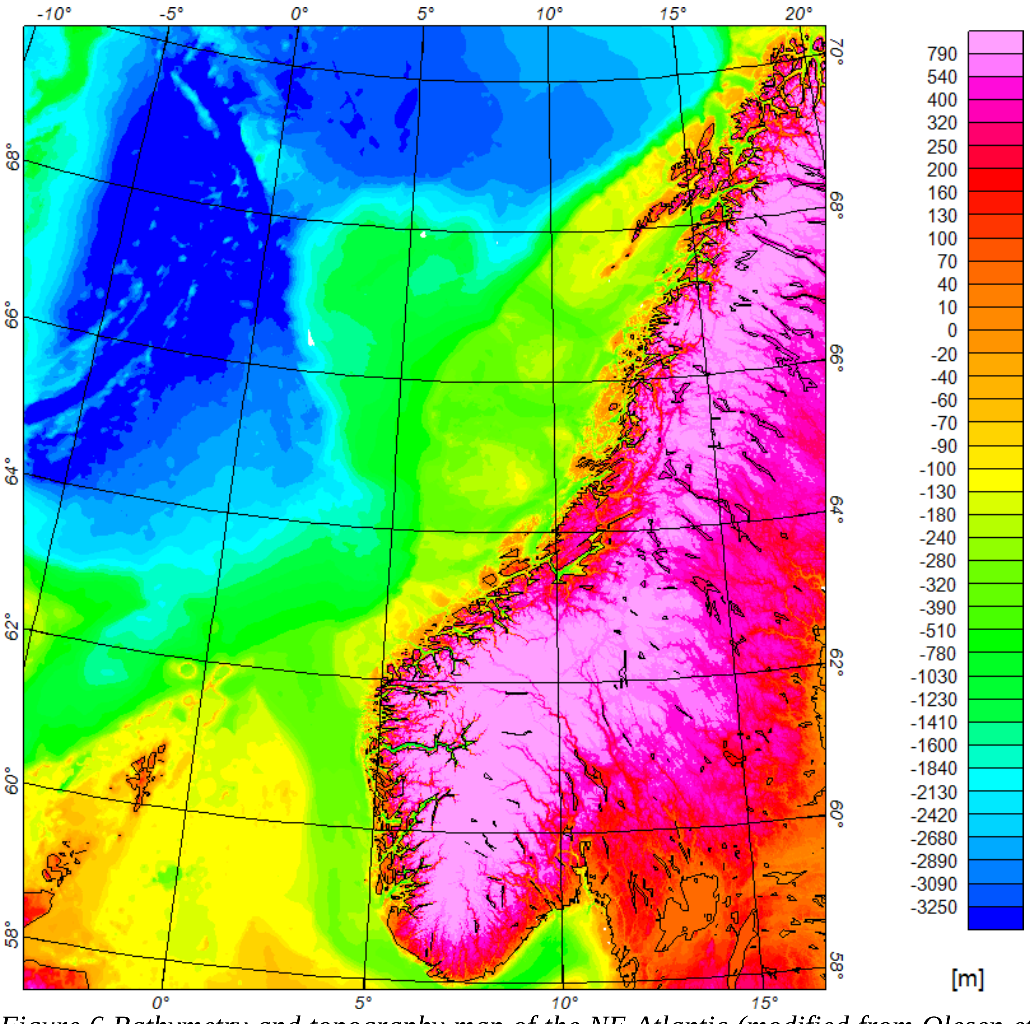

Figure 6 Bathymetry and topography map of the NE Atlantic (modified from Olesen et al. 2010). The 250 x 250 m grid represents an updated version of the Dehls et al. (2000) compilation using new releases of bathymetric data from the Arctic Ocean, IBCAO v. 2.23 (Jakobsson et al. 2008) and the world oceans (GEBCO). High-resolution topography data (100 x 100 m) for Norway and the adjacent land areas were supplied by the Norwegian Mapping Authority and the US Geological Survey, respectively.

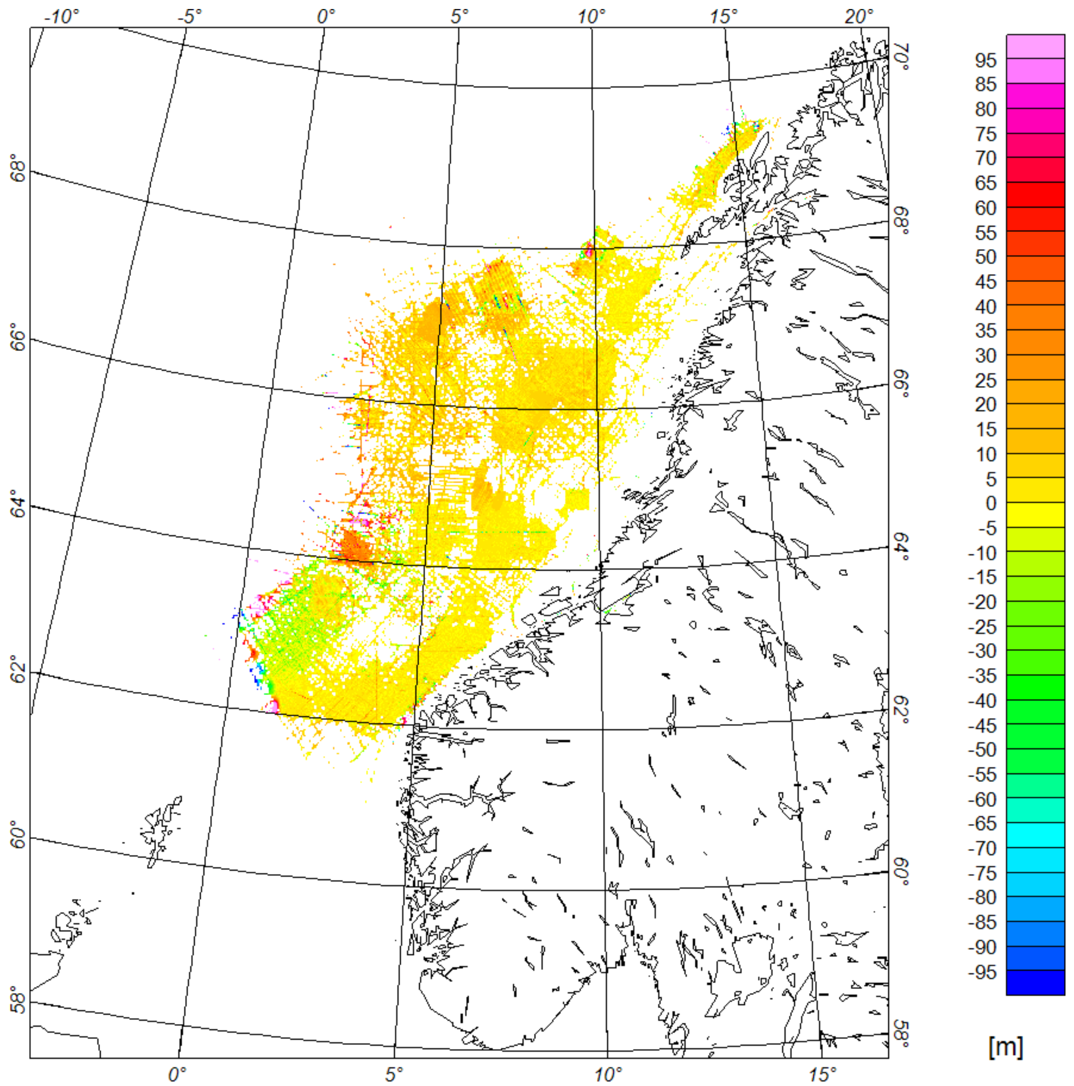

Figure 7 Differences in bathymetry between NGU compilation and bathymetry of marine gravity data base.

4. COMPLETE BOUGUER CORRECTIONS

For the complete Bouguer corrections, we use an onshore density of 2670 kg/m^3 and an infill density of 1170 kg/m^3 (difference between sea water density of 1030 kg/m^3 and offshore rock density 2200 kg/m^3 which represents sedimentary rocks).

The large amount of gravity stations and elevation points have been a challenge and cannot be handled by TriTop due to memory and computation time problems. Therefore, the number of gravity stations was reduced (along longitude and latitude) using the Geosoft tool 'decimate' with a factor 100. Along the ship tracks the marine gravity data are highly redundant and no loss of information occurred. The reduced data set contains 69746 stations and calculation for these data took up to a week.

In areas where bathymetry is smooth the complete Bouguer correction for the redundant station could be made by interpolation from the smaller subset data set. However, in areas of large changes in elevation (e.g. at the coast and continental edge), this leads to incorrect interpolated values.

Therefore, in a second step the original gravity data set was split into small segments which contain maximum 600,000 stations each. This allowed us to run several calculations of TriTop in parallel. A total of 2,908,228 stations has been calculated in high resolution. The decimated data and the high resolution data were then merged. Where available the low resolution data were directly replaced by high resolution data (Figure 8).

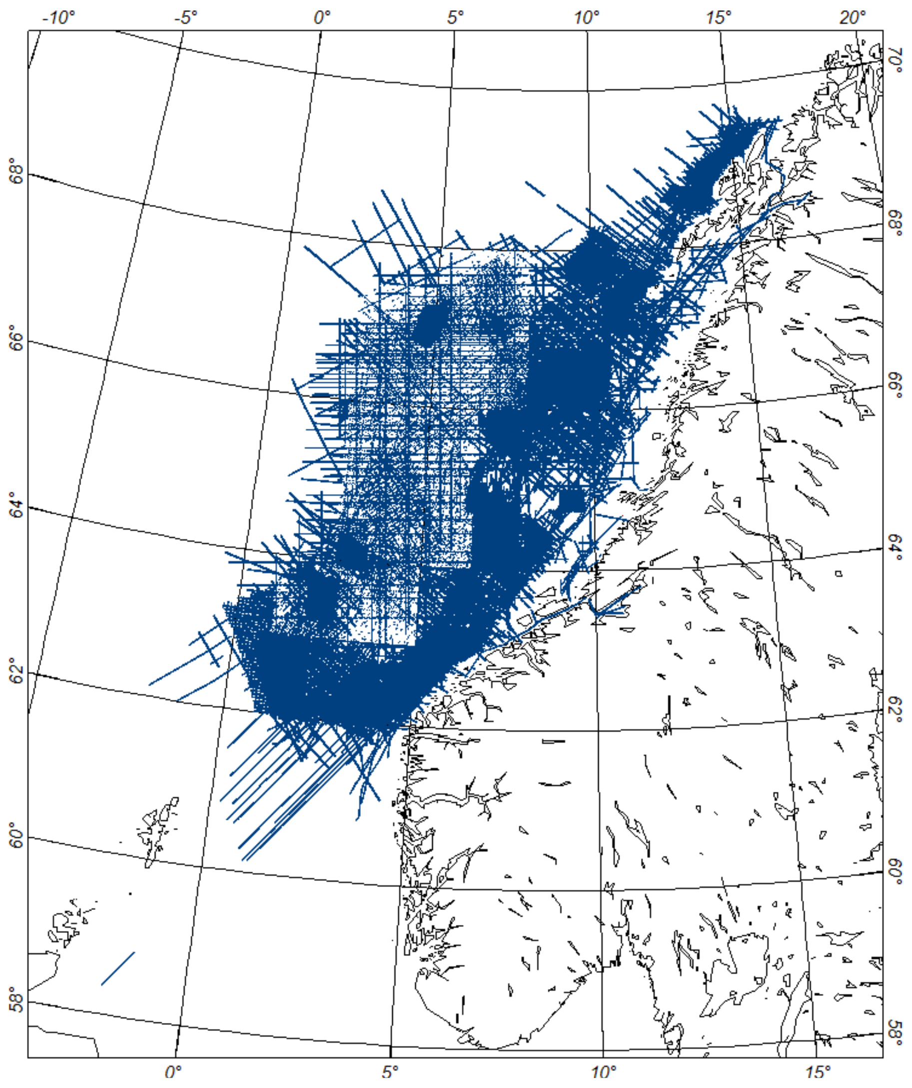

Figure 8 Location plot of high resolution data merged with decimated data set.

This gravity of topographic masses file was then imported into a Oasis Montaj database. The data was re-projected to UTM coordinates and then gridded on a 1000 m grid (Figure 9). The grid was then sampled into the original Statoil database and compared as well to the original calculations. Differences between the sampled and calculated values were minimal.

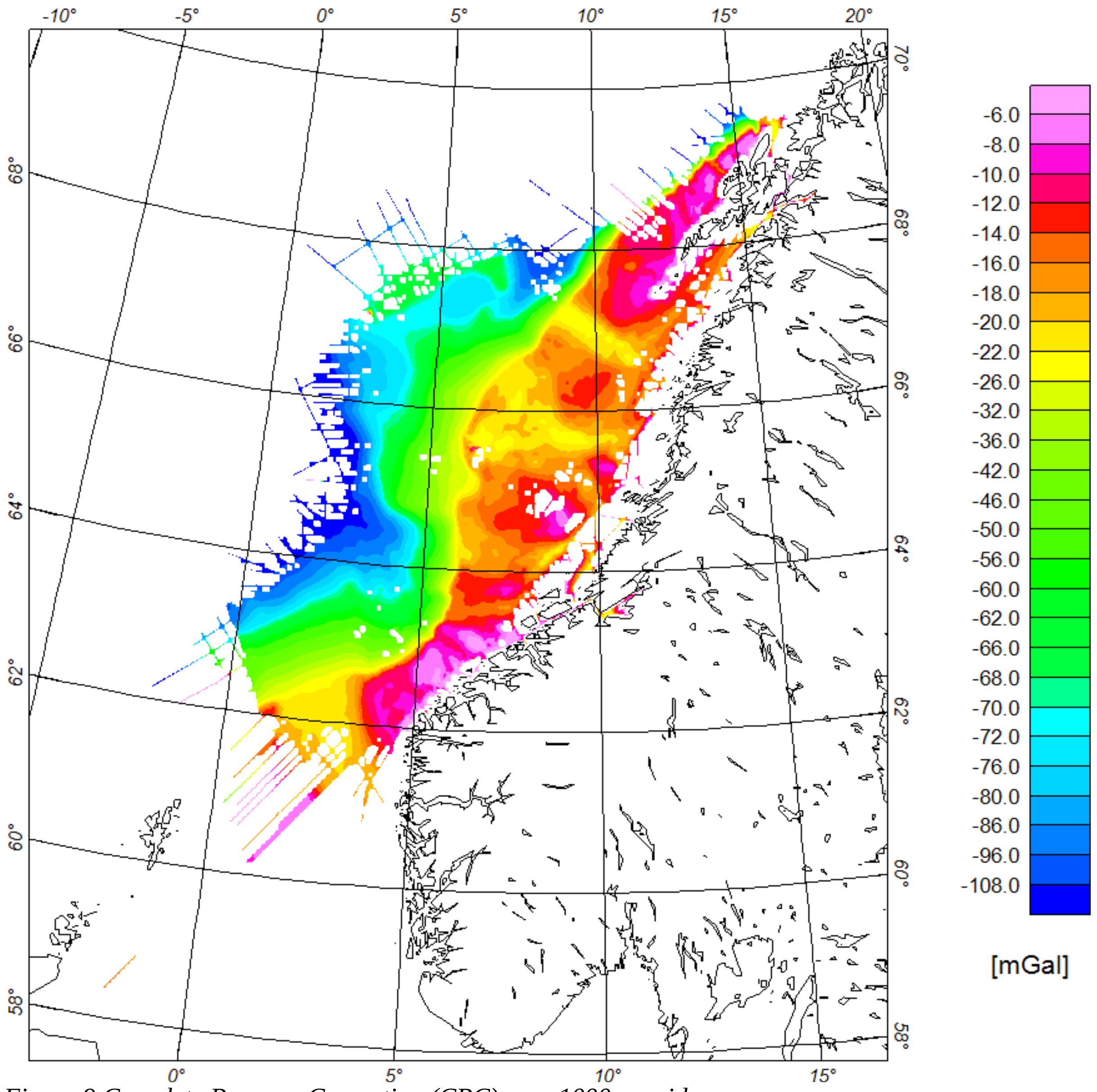

Figure 9 Complete Bouguer Correction (CBC) on a 1000 m grid.

To estimate the effect of terrain on the gravity, we subtracted the Complete Bouguer correction from the simple Bouguer correction (the latter was calculated with the Gravity module of Oasis Montaj, Geosoft). The result is shown in Figure 10. The terrain effect lies mainly in the range from 3 to -7 mGal with some extreme outliers (up to ± 150 mGal) at the survey borders. Those are most likely artefacts caused by gridding and projection of data points.

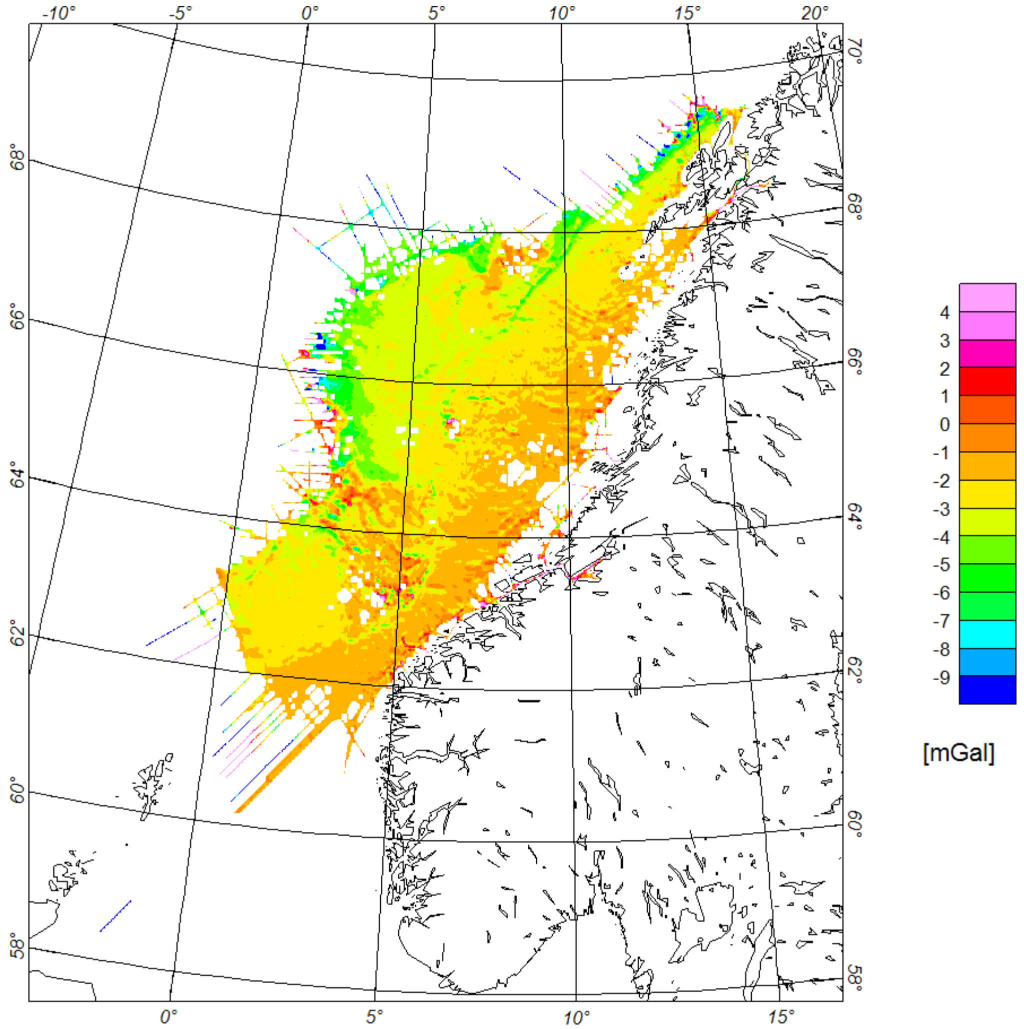

Figure 10 Gravity effect of terrain (simple Bouguer minus complete Bouguer correction).

Finally the Complete Bouguer Anomaly (CBA) was calculated by subtracting the CBC from the Free-air (FA) anomaly. The Complete Bouguer Anomaly is gridded on a 1000 m grid and shown in Figure 11.

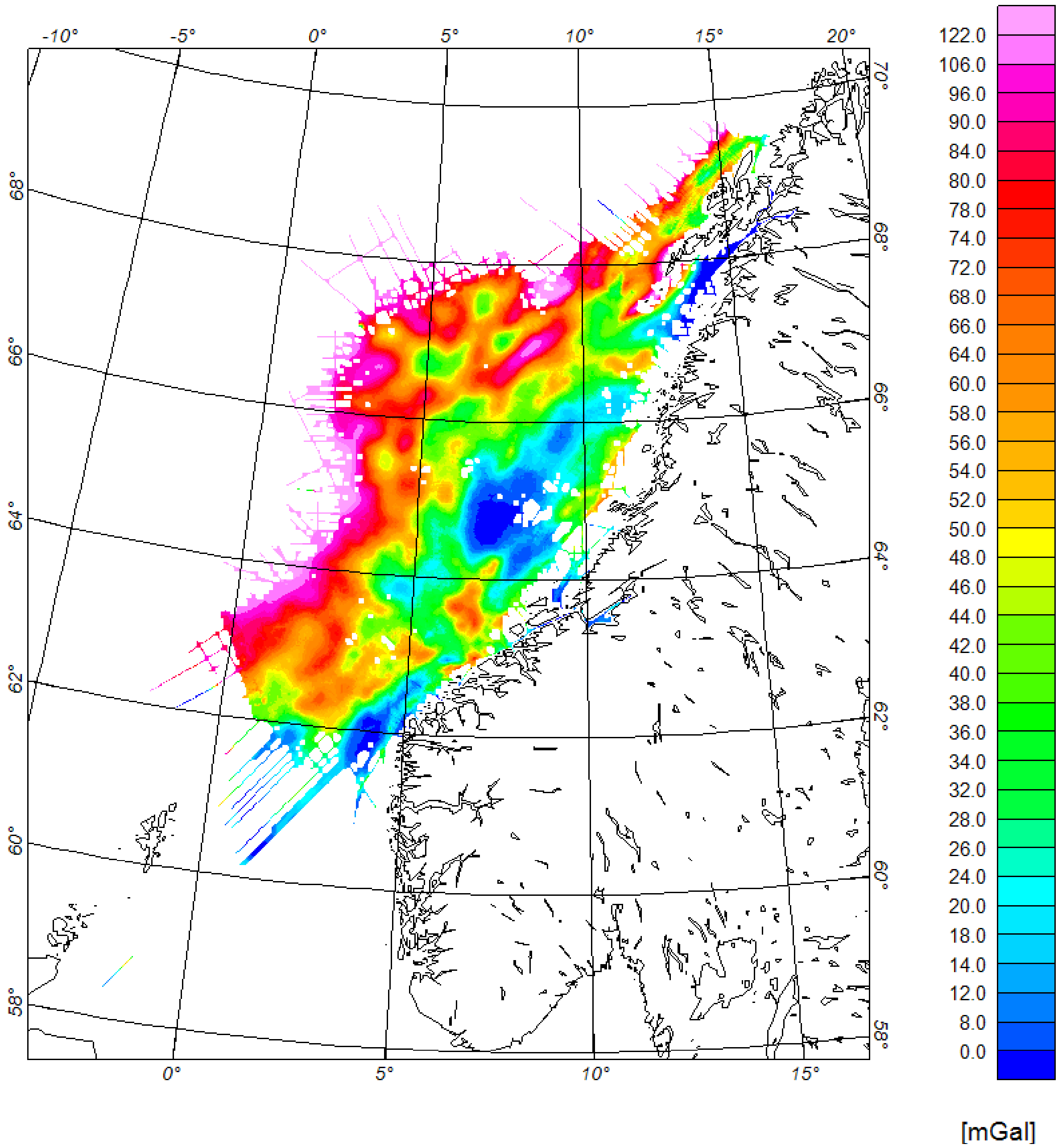

Figure 11 Complete Bouguer Anomaly (CBA) on a 1000 m grid.

5. CONCLUSIONS

The newly levelled marine database from Statoil has an increased fit to satellite gravity models. Terrain correction is important, especially in the near-coastal areas and at the continental edge. The differences in the bathymetric models and the remaining differences between the marine data set and the satellite model let us suggest that an improved levelling could be achieved by adjusting to satellite-only gravity models as available from combination of GRACE and GOCE data sets (e.g. Mayer-Guerr 2012) and by incorporating levelling and Bouguer and terrain correction in one consistent workflow.

The final data sets were submitted to Statoil on 24.05.2013

Final database: Statoil_Marine_gravity_HQ_and_LQ_withCBA.gdb

Final grids: CBC_on267off117_1000m.grd
CBA_on267off117_1000m.grd

They are stored in the NGU archive.

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