# Final VRF grids

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## Document history

| Revision | Date | Organisation | Initials | Revised pages | Short description of changes |
|---|---|---|---|---|---|
| First Draft | May 25, 2011 | NSI, DTU | RF | All | Major update of text and computations |
| Draft 2 | | | | | |
| Draft 3 | | | | | |
| Draft 3.2 | | | | | |
| Draft 3.3 | | | | | |
| Draft 3.4 | | | | | |
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**BLAST WP 3.5 – Final VRF grids (Aug 25, 2011)**

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This note describe the updates of the basic BLAST data grids for MSS, LAT etc. This document is an update to document *[R1] "BLAST WP 3.5 status – May 1, 2011".*

The transformation parameters for the land VD's have been outlined in the report *G. Strykowski, O. Andersen and R. Forsberg: "BLAST vertical datums: conventions and decisions".* The note in the sequel outlines the computation of the "final" marine surfaces, for use in the transformation tool.

## Transform parameters for the North Sea area [WP 3.5.5]

The fundamental vertical datums (VD's) to be considered in the North Sea area are shown in Fig. 1. P is a point on land or sea. The different height types are outlined below. The corresponding depths must be specified as negative heights.

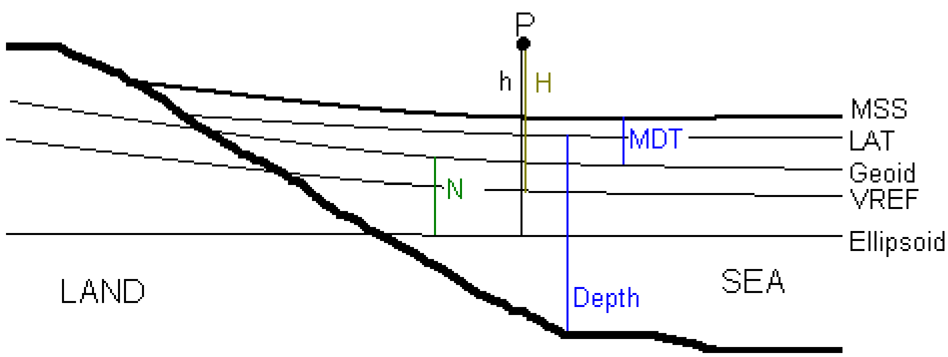


*Fig. 1. Fundamental VDs in the BLAST project*

The *reference ellipsoid*, in the case the WGS84 ellipsoid. A point P above the ellipsoid, either at sea or on land, has a height $H_{ELL}$ (conventional name is "h").

The *VREF is the fundamental VD for levelling.* For the BLAST project this land VD is selected as the European Vertical Refence Frame 2007 (EVRF2007), the result of a comprehensive adjustment of the joint European levelling networks. The VREF differs from the geoid mainly due to the ocean mean dynamic topography (MDT). There will additionally be a set of national VREF surface for each of the national land height VDs. Because of problems with the EVRF2007 in the UK, this surface will not at present be useful for a North Sea marine reference surface.

The *geoid* will in the BLAST project be the European Gravimetric Geoid 2008 (EGG2008), computed by H. Denker, Institut für Erdmessung, University of Hannover. The EGG2008 geoid model is based on GRACE and comprehensive terrestrial gravity, and is the currently overall best available model for the region. As is seen below, EGG2008 actually fits quite well (<10 cm) to the EVRF2007 datum, except in the UK. We will therefore in BLAST use the EGG2008 as the fundamental VD, and provide transformations from/to this datum in the software tool.

The basic grids underlying the interpolations of the BLAST transformation tool are [1] to [4] below:

[1] EGG-geoid, cf. Fig. 2 below. *File name:* ***egg2008.blast.zeta.gri***
[2] MDT-surface, i.e. MSS-GEO checked by GPS at tide gauges, Fig. 5. *File:* ***dtu10mdt1.gri***
[3] LAT surface, i.e. MSS-LAT, cf. Fig. 4. *File name:* ***lat_blast.gri***
[4] EVRF-DIF surface, i.e. $H_{ELL} – H_{EVRF} – N$, cf. Fig. 3. *File name:* ***evrf-dif1.gri***

Fig. 2 below shows the EGG2008 and the comparison to EVRF2007, and Fig. 3 the corresponding modelled difference surface between the geoid and the EVRF2007.

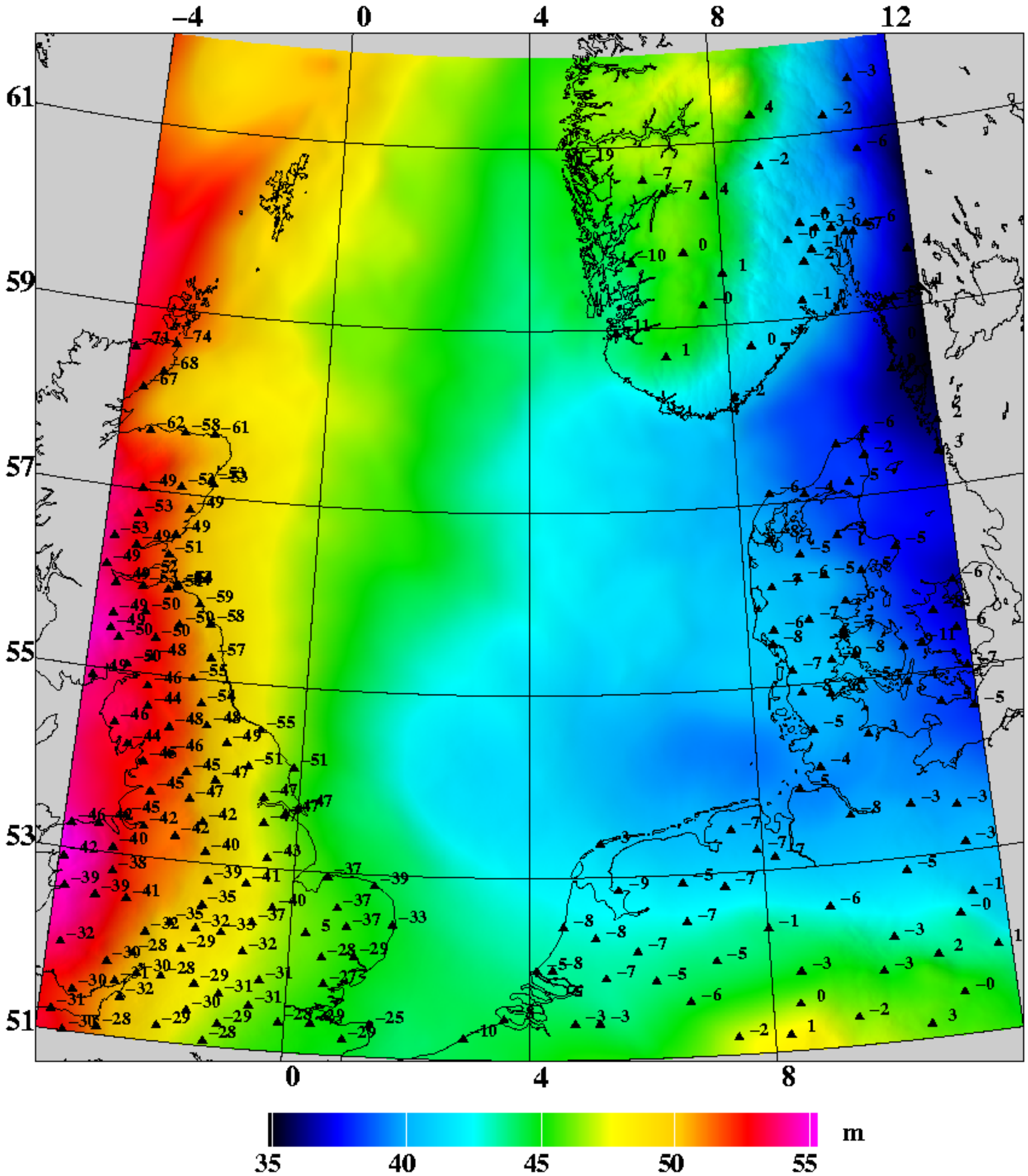


*Fig. 2. Height differences between GPS-levelling geoid ($H_{ELL}$-$H_{EVRF}$-N) in cm, overlain on the EGG2008 geoid. Because of the apparent tilt of the UK levelling, it has been decided to use the EGG2008 VD as the fundamental BLAST VD, both on land and at sea.*

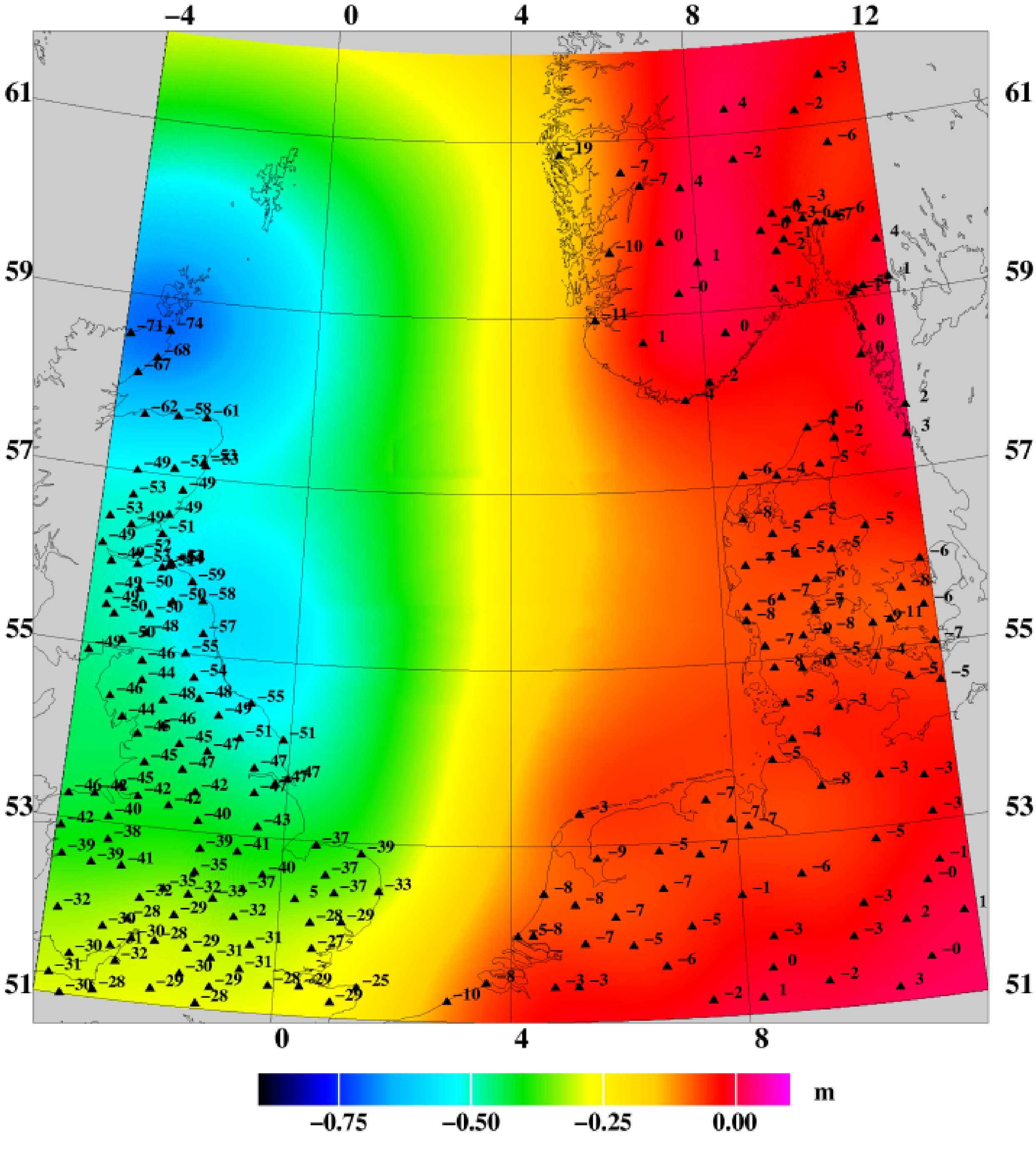


*Fig. 3. The modelled difference surface between EVRF2007 and the EGG08 geoid. The surface "EVRF-DIF" has been modelled using least-squares collocation with a correlation length of 300 km and a standard deviation of 5 cm, to ensure a smooth surface [Updated Aug 2011 to diminish some geogrid artefacts in the central North Sea].*

The mean sea surface (*MSS)* is based on the DTU10 multi-mission satellite altimetry surface, transformed to the zero-tide system, with no inverse barometer correction applied. Since the DTU10 MSS is given relative to the Topex reference ellipsoid, the BLAST MSS is the similar surface, transformed by a constant offset of 90 cm to match the $H_{ELL}$ of the mean sea surface at selected tide gauges around the North Sea. Fig. 4 shows the transformed DTU10 MSS, together with available GPS data on tide gauges. The tidegauge MSS data along the UK coast have been provided by M. Ziebart, UCL, from values of the UK VORF project. It is seen that the GPS MSS data have a high local variability, and no significant area-wise trend is obvious; we believe there is a lot of local noise from local oceanographic effects, the definition of the mean tidal level (same period? local subsidence?) and errors in the GPS ties. We have therefore kept the fundamental definition MDT = MSS (DTU10) - EGG08 - 90 cm, without a regional adaption to the GPS-tidegauge data, which would probably have propagated a lot of local noise into the North Sea region.

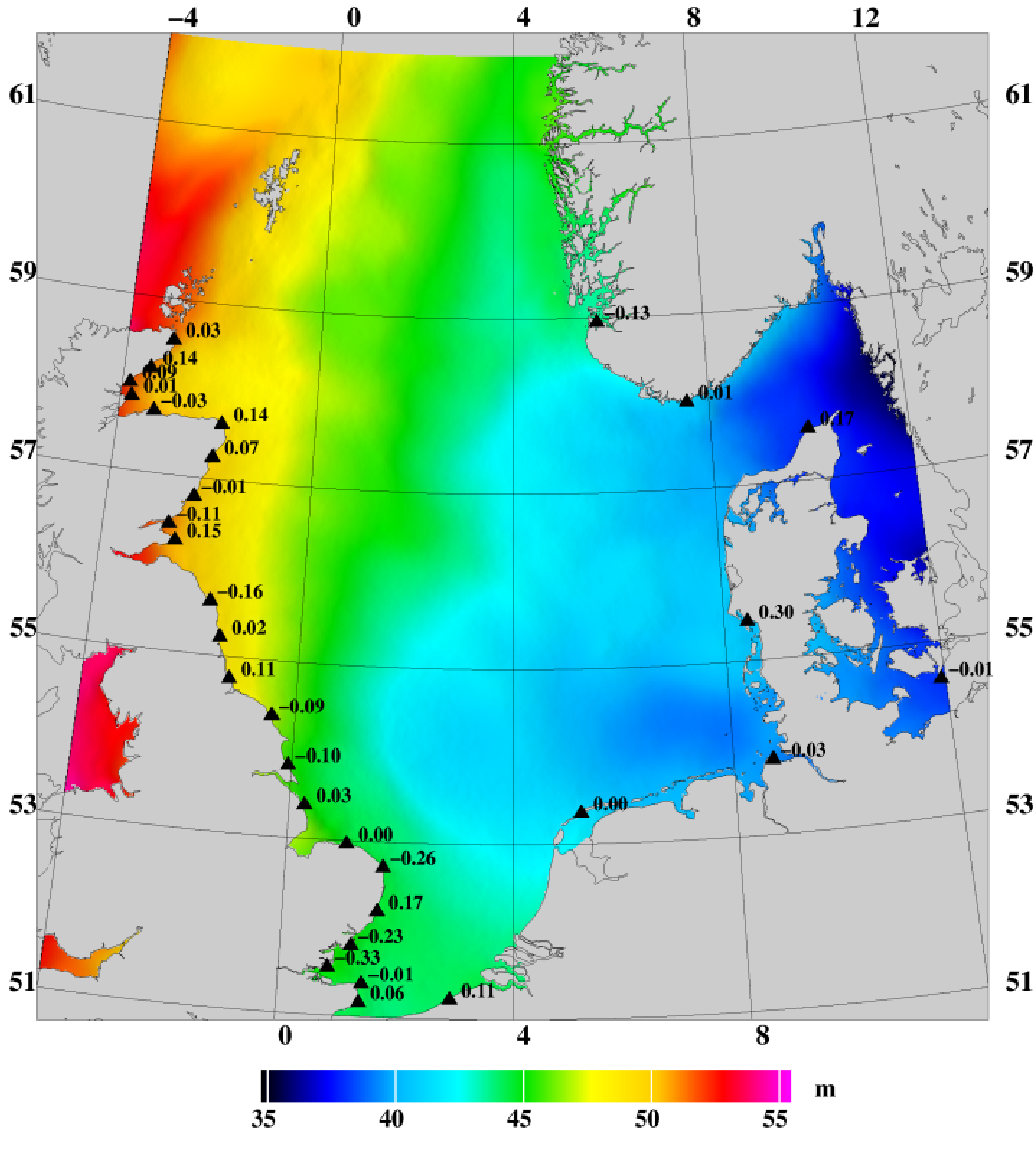


*Fig. 4. The DTU10 MSS, with differences to mean sea level $H_{ELL}$ at available tide gauges. An offset of 90 cm has been applied to make the BLAST MSS surface. It is obvious that the local heights of mean sea level in the ETRF datum are very noisy, affected by local effects and errors, so it does not make sense to propagate these offsets into the North Sea.*

The derived MDT surface (the deviation between the EGG08 geoid and the BLAST MSS) is shown in Fig. 5, after Gaussian filtering with 20 km resolution, removing the "orange skin" features inherent in satellite determination of MDT.

Significant noise is still present in the MDT, especially along the coasts. In three coast-near areas large outliers have been removed by interpolation: off Scotland (Firth of Forth; 55.9-56.3ºN, 3.4-2.2ºW), off East Anglia (52.8-53.4ºN 0-1.2ºE), and inside the Frisian Islands, north Holland (52.8-53.4ºN, 4.8-5.8ºE). Many smaller outliers are still present. These outliers are likely mainly due to errors in satellite altimetry, tidal errors, and geoid errors due to lack of gravity data close to the coasts. It is beyond the scope of the BLAST project to rectify these errors, as it would require major revisions of satellite altimetry data (including new tidal models), in-depth checking and new observations of GPS at tide gauges, and – ideally - more gravity data collection in the coastal zone.

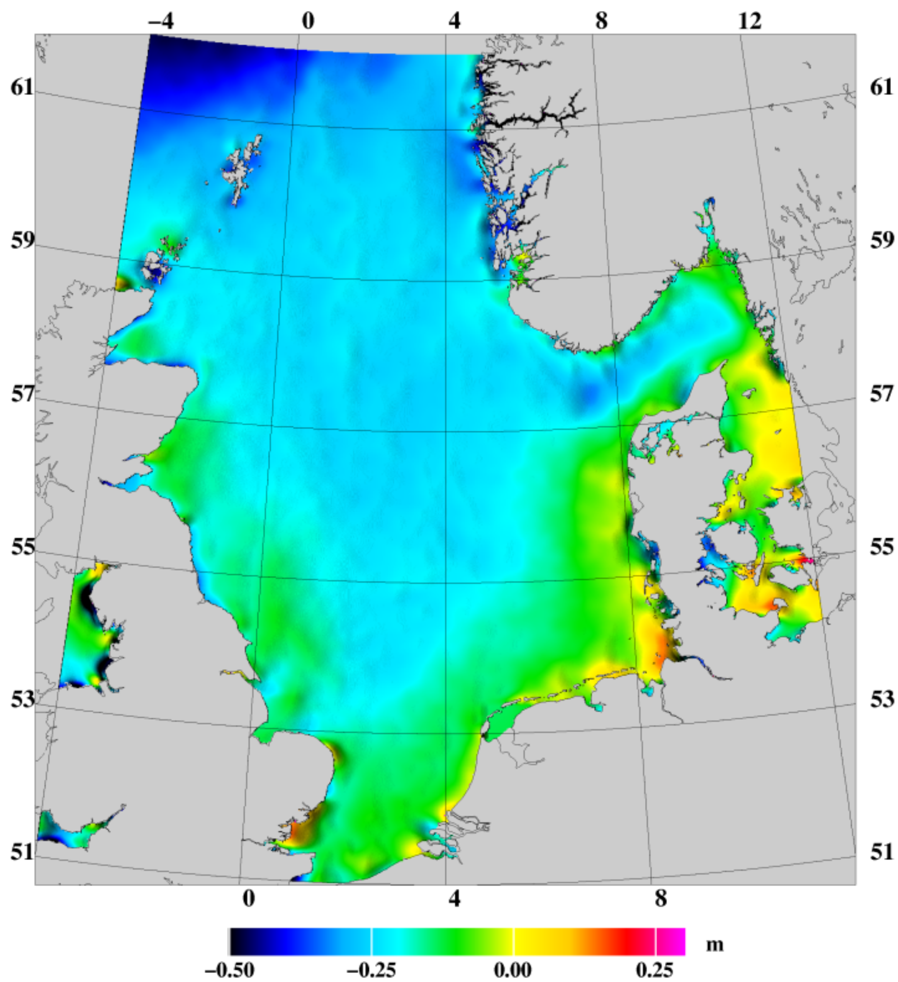


*Fig. 5. BLAST MDT surface. Outliers have been removed in 3 smaller areas off UK and Holland.*

The *lowest astronomical tide* (LAT) surface has been derived from the GOT4.7 global tidal model, using all constituents up to the 18.6 year period, as well as with the global FES2004 model, as upgraded by Youngcom (this is the tidal model underlying the DTU10 MSS). The two different global LAT models are shown in Fig 6-7.

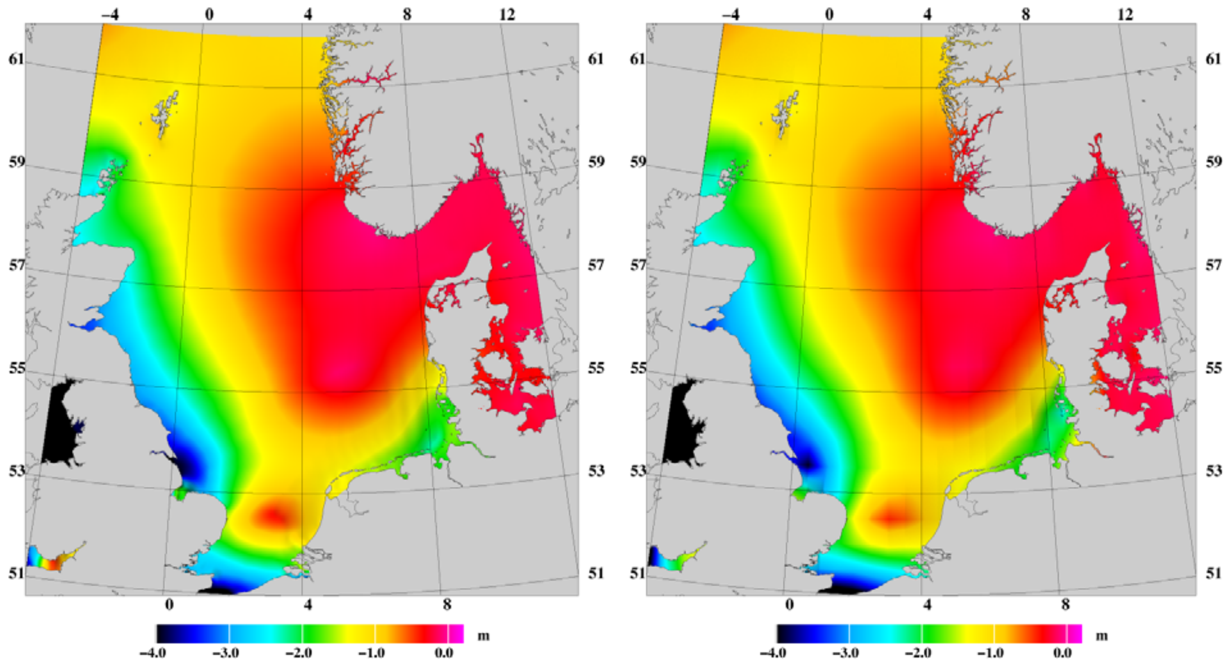


*Fig. 6. Global LAT models. Left: DTU10-FES2004; Right: GOT4.7 model*

In addition an assembly of national LAT models, as provided by the national hydrographic services in various formats (grids or point values at coastal site) have been gridded together by least squares collocation. Fig. 7 shows the results of this interpolation (along with the location of the used LAT point values in Denmark and Norway). The interpolation W of the UK or in the Danish inner waters, were no data have been used.

The good agreement between the national models and the global solutions is quite satisfactory, and only in a few cases along the coasts some differences are visible. The final BLAST LAT has therefore been selected as a filtered DTU10-model, with some coastal corrections off the UK and Germany, cf. Fig. 8.

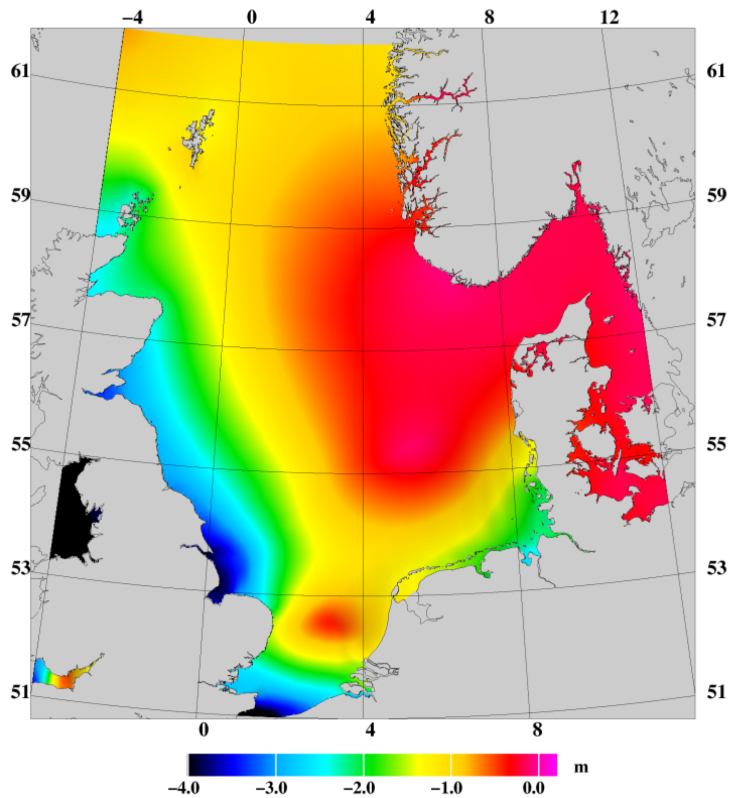


*Fig. 7. LAT constructed by collocation of national models*

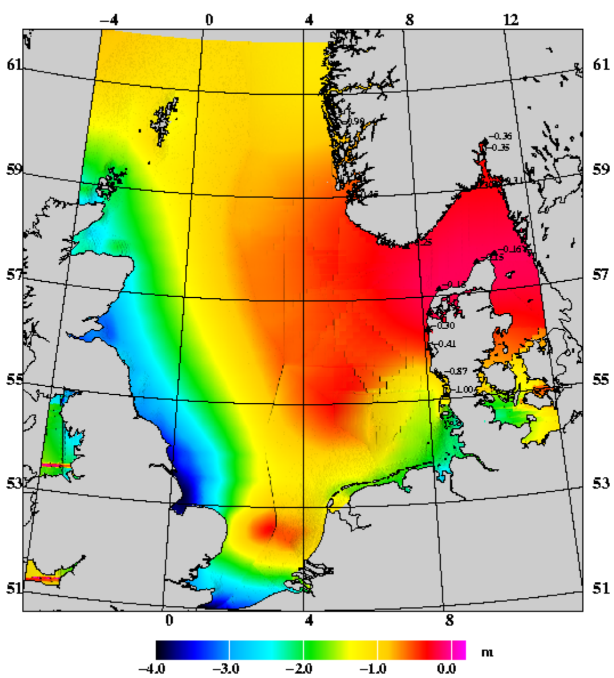


*Fig. 8. The BLAST LAT surface, based on the DTU10-FES04 updated model, and local LAT corrections offshore two regions in the UK (same as for the MDT) and the inner German Bight.*

## Evaluation of EGG08 with new geoids from GOCE

A comparison of the EGG08 with NKG04, OSGM05 and EGM08 was outlined in the document [R1]. Below we investigate the quality of EGG08 in the longer wavelengths by comparison to new satellite data from the GOCE (Global Ocean Circulation Explorer) satellite mission. The GOCE solution is the “time-wise” solution released by ESA in May 2011, based on 6 months of GOCE data.

The comparison is based on filtering the EGG08 and GOCE by exactly the same band-pass filter, from approximately spherical harmonic degree 60-150 (spatial resolution 3 deg to 1.2 deg), and comparing the filtered grids. Fig. 8 (left) shows the filtered EGG08, and Fig. 8 (right) the differences. No systematic effects are seen, and the random structure of the differences point to the source of these errors being mainly high-frequency GOCE noise (since similar features are not showing up in the MDT). We therefore conclude that the EGG08 is confirmed by GOCE to be a good geoid model, suitable as the basic BLAST reference.

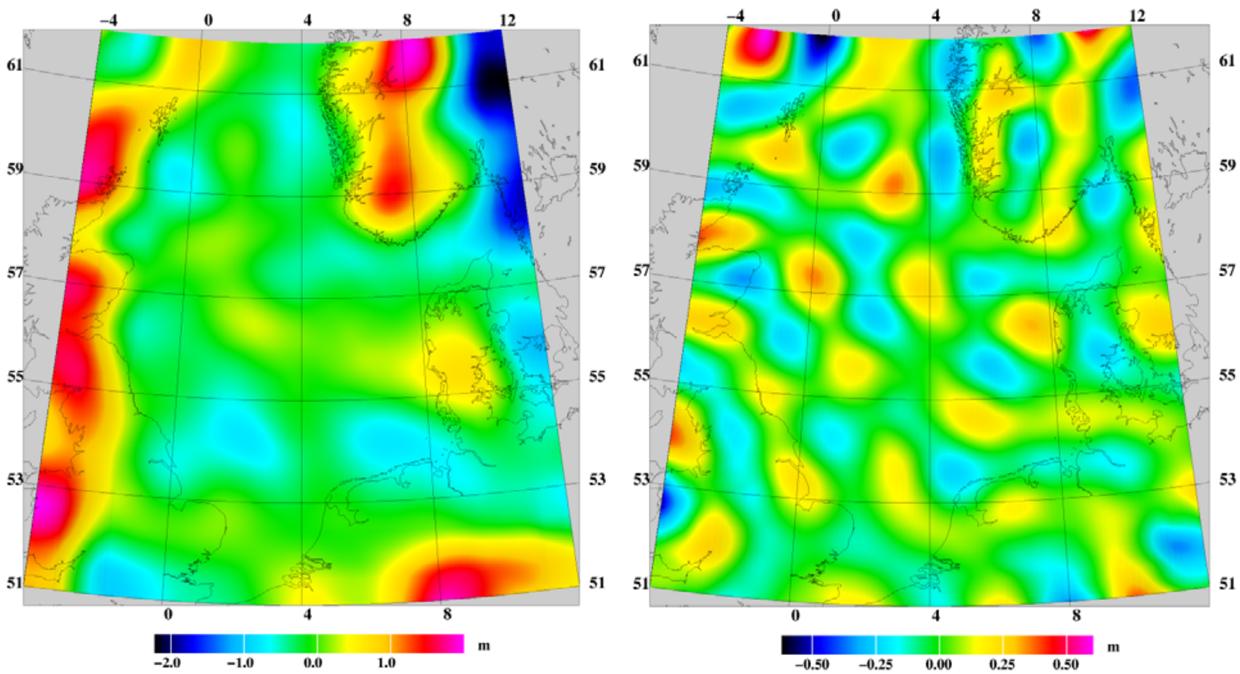


*Fig. 8. Left: Filtered EGG geoid (harmonic band 60-150), and difference to the “timewise” GOCE geoid in the same band. Note the difference in colour scale.*