HETEROGENEOUS GRAVITY DATA COMBINATION FOR EARTH INTERIOR AND GEOPHYSICAL EXPLORATION RESEARCH

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1. INTRODUCTION

GOCE gravity gradient data may improve the understanding and modelling of the Earth's interior and its dynamic processes, contributing to gain new insights into the geodynamics associated with the lithosphere, mantle composition and rheology, uplift and subduction processes. To achieve this challenging target, GOCE should be used in combination with additional data sources. Goal is to use as much as possible the original GOCE gravity gradients.

In the context of the ESA STSE: GOCE+ Theme 2, it is proposed to invert satellite gravity and gravity gradients, and terrestrial gravity in the well explored and understood North-East Atlantic Margin and to compare the results of this inversion, providing improved information about the lithosphere and upper mantle, with results obtained by means of models based upon other sources like seismics, magnetic field information or other in-situ data.

One of the outcomes will be a sensitivity matrix that will be used as input to study the Rub' al-Khali desert in Saudi Arabia. In terms of modelling and data availability this is a frontier area. Here gravity gradient data will be used to better identify the extent of anomalous structures within the basin, with the purpose to improve the modelling for hydrocarbon exploration purposes.

2. STUDY OUTLINE

The GOCE gravity gradients in the gradiometer reference frame (GRF, Fig. 1) will be used in forward and/or inverse modelling in the North-East Atlantic Margin and the Arabian Peninsula. Not only will the original gravity gradients be used, but they will also be combined with other gravity data, e.g. from GRACE or terrestrial gravimetry (Fig. 2 and 3). On the one hand, grids of gravity gradients will be computed, for example at mean GOCE altitude, on the other hand regional, high-resolution gravity fields will be computed using a multi-scale representation (Fig. 4).

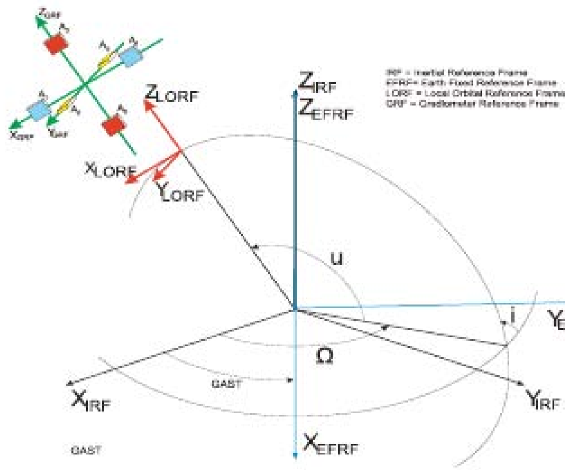

Figure 1. GOCE gradiometer reference frame.

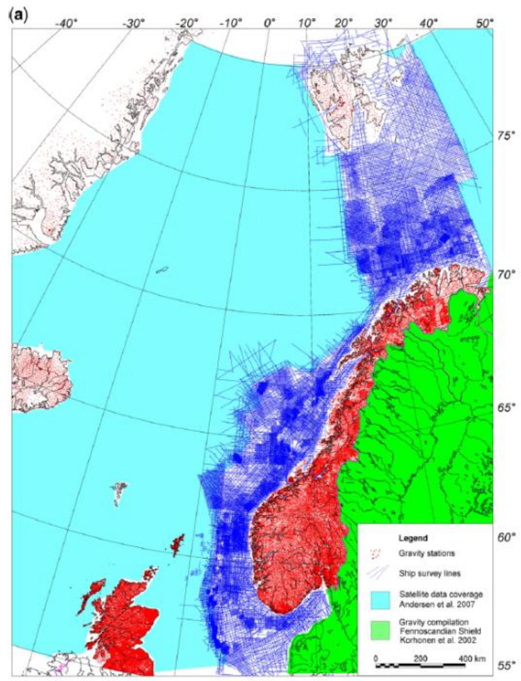

Figure 2. Available gravity data for the North-East Atlantic Margin [2].

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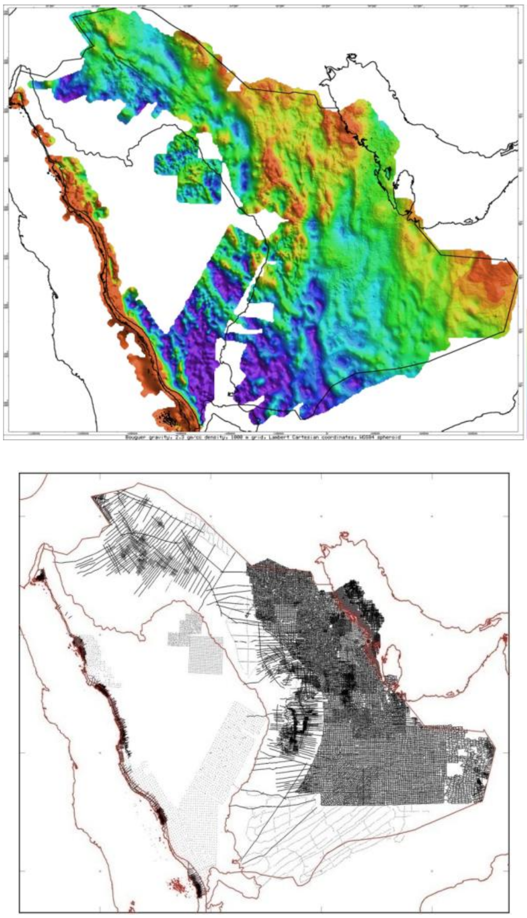

Figure 3. Gravity anomaly map (top panel) and gravity stations in Saudi Arabia (lower panel) used to create the anomaly map. The number of stations is 508397 (Saudi Geological Survey).

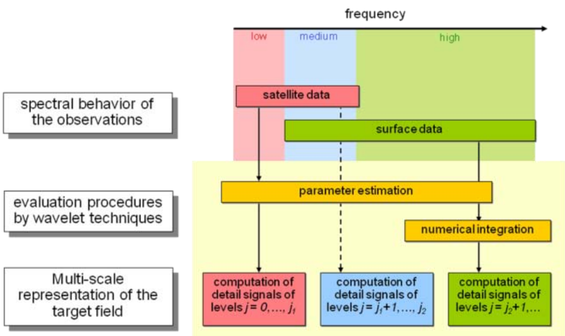

Figure 4. Scheme of multi-scale representation from satellite and surface data.

Existing 3D geophysical models for the Arabian Peninsula and the North-East Atlantic Margin will be used in the forward modelling. Fig. 5, 6 and 7 show examples of the models and input data.

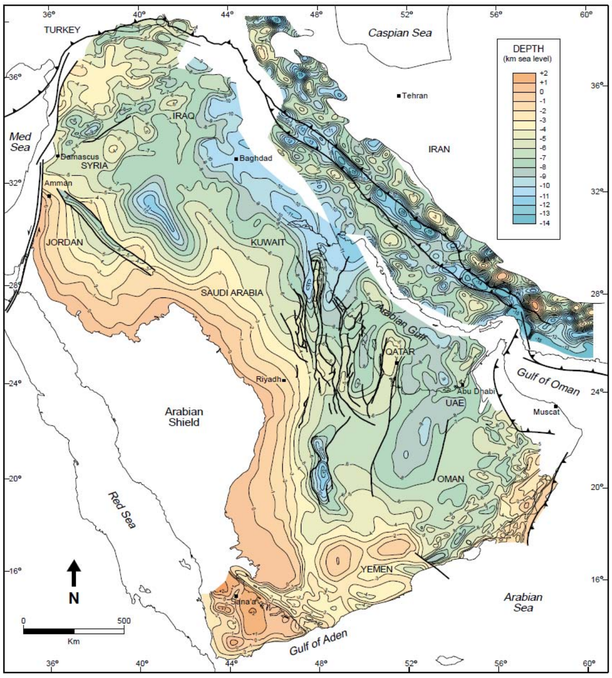

Figure 5: Basement depth map of the Arabian Plate [4].

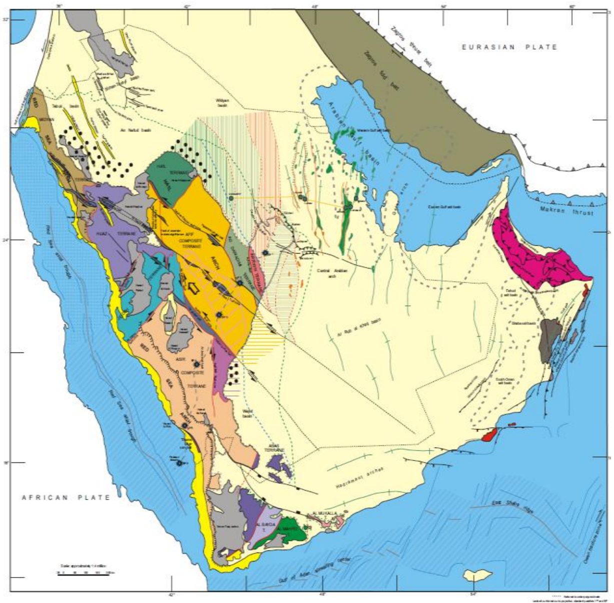

Figure 6: Tectonic map of Saudi Arabia showing the different terranes as identified at the Arabian Shield (Ministry of Petroleum and Mineral Resources, Saudi Arabia, 1998).

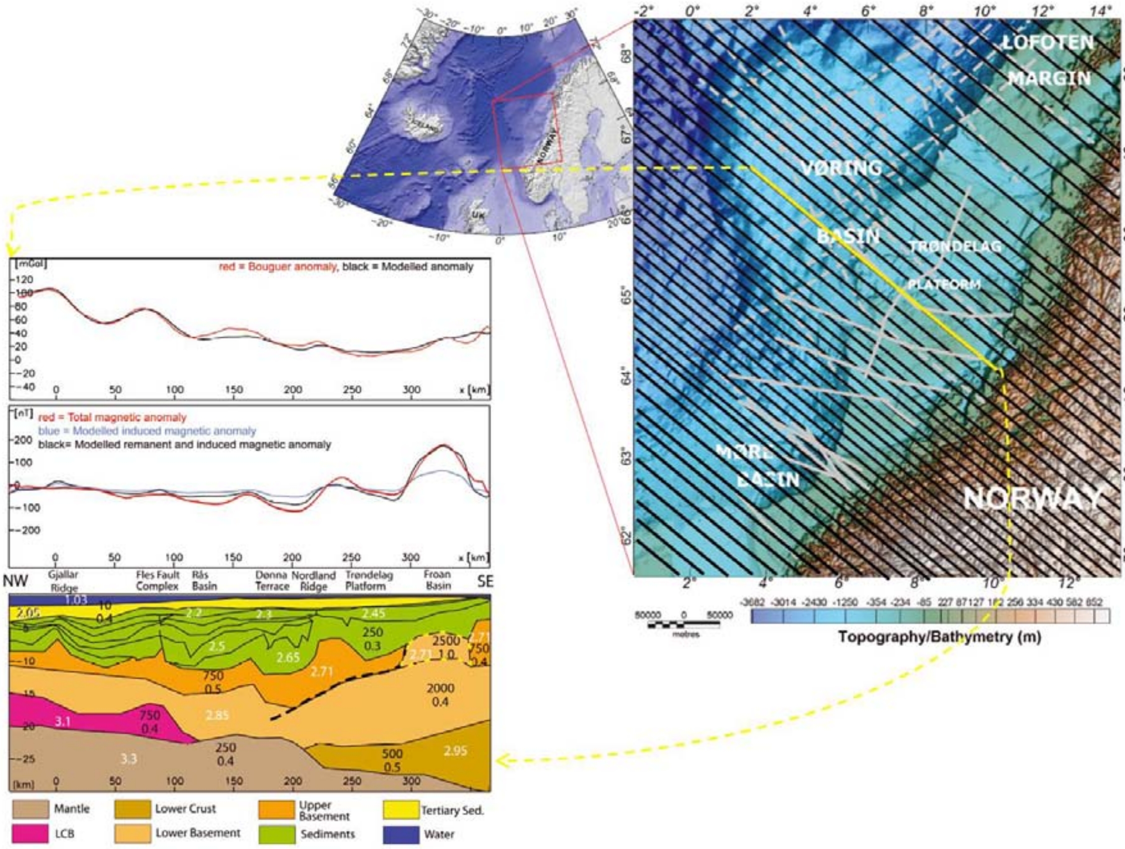

Figure 7: Example of 3D model resolution for the mid-Norwegian margin (after [1]). Grey lines show the location of OBS profiles and selected wide-angle reflection profiles used in building the 3D geometry. The black lines show the set-up of the 3D model, which is illustrated by one central profile. White numbers in profile are density values in Mg/m^3; black numbers show magnetic susceptibility (10^{-5} SI) and Q-ratio. LCB: lower crustal body.

3. EXAMPLE FENNOSCANDIA: GRAVITY, GRADIENTS AND INVARIANTS FOR CRUSTAL THICKNESS

Gravity and gravity gradients are dependent on the orientation of the coordinate system, which may differ from the orientation of *random* geological features. Reference [3] demonstrated the use of rotational invariants of the gravity tensor:

$$
\begin{aligned}
I_1 &= V_{XX}V_{YY} + V_{YY}V_{ZZ} + V_{XX}V_{ZZ} - V_{XY}^2 - V_{XZ}^2 - V_{YZ}^2 \\
I_2 &= V_{XX}(V_{YY}V_{ZZ} - V_{YZ}^2) + V_{XY}(V_{YZ}V_{XZ} - V_{XY}V_{ZZ}) + \\
&\quad + V_{XZ}(V_{XY}V_{YZ} - V_{XZ}V_{YY})
\end{aligned}
\tag{1}
$$

These rotational invariants are independent from the orientation of the flight lines and facilitate to detect sources randomly orientated in any coordinate system.

As an example, the left panel in Fig. 8 shows a map of the crustal thickness in the North-East Atlantic Margin. The gravity effect of this crustal thickness at the Earth's surface is shown in the middle panel of Fig 8, whereas the right panel of Fig 8. shows the gravity effect at GOCE altitude (250 km above the Earth's surface). For comparison, Fig. 9 shows the crustal thickness signal in terms of gravity gradients at GOCE altitude (gravity gradients in the North-West-Up frame). Compared with the gravity signal at GOCE altitude the gravity gradients show more detail and contain 3D information. However, as said above, the gradient information depends on the orientation of the measurement frame.

Fig. 10 shows the invariants from Eq. (1) at GOCE altitude. Comparing the crustal thickness map Fig. 8 with the invariants, one sees that the interpretation of the invariants is not straightforward and requires further attention. In addition, the GOCE gradients V_{XX}, V_{YY}, V_{ZZ} and V_{XZ} are measured with high accuracy, whereas V_{XY} and V_{YZ} have a much lower accuracy (about a factor of 200). How this problem can be overcome will be part of the study.

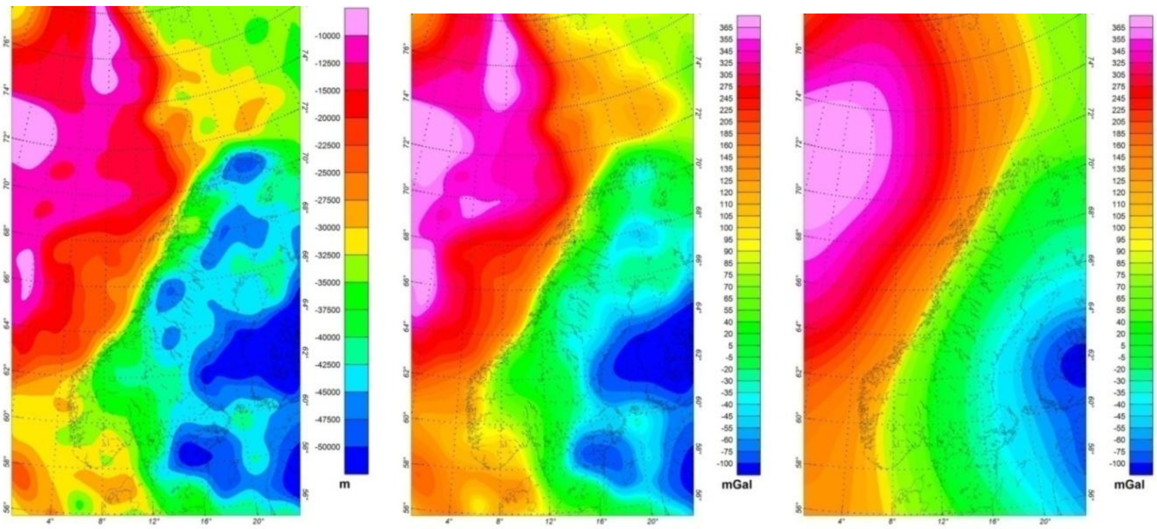

Figure 8: Crustal thickness for the North-East Atlantic Margin (left panel) and the resulting gravity signal at the Earth's surface (middle panel) and at GOCE altitude (right panel).

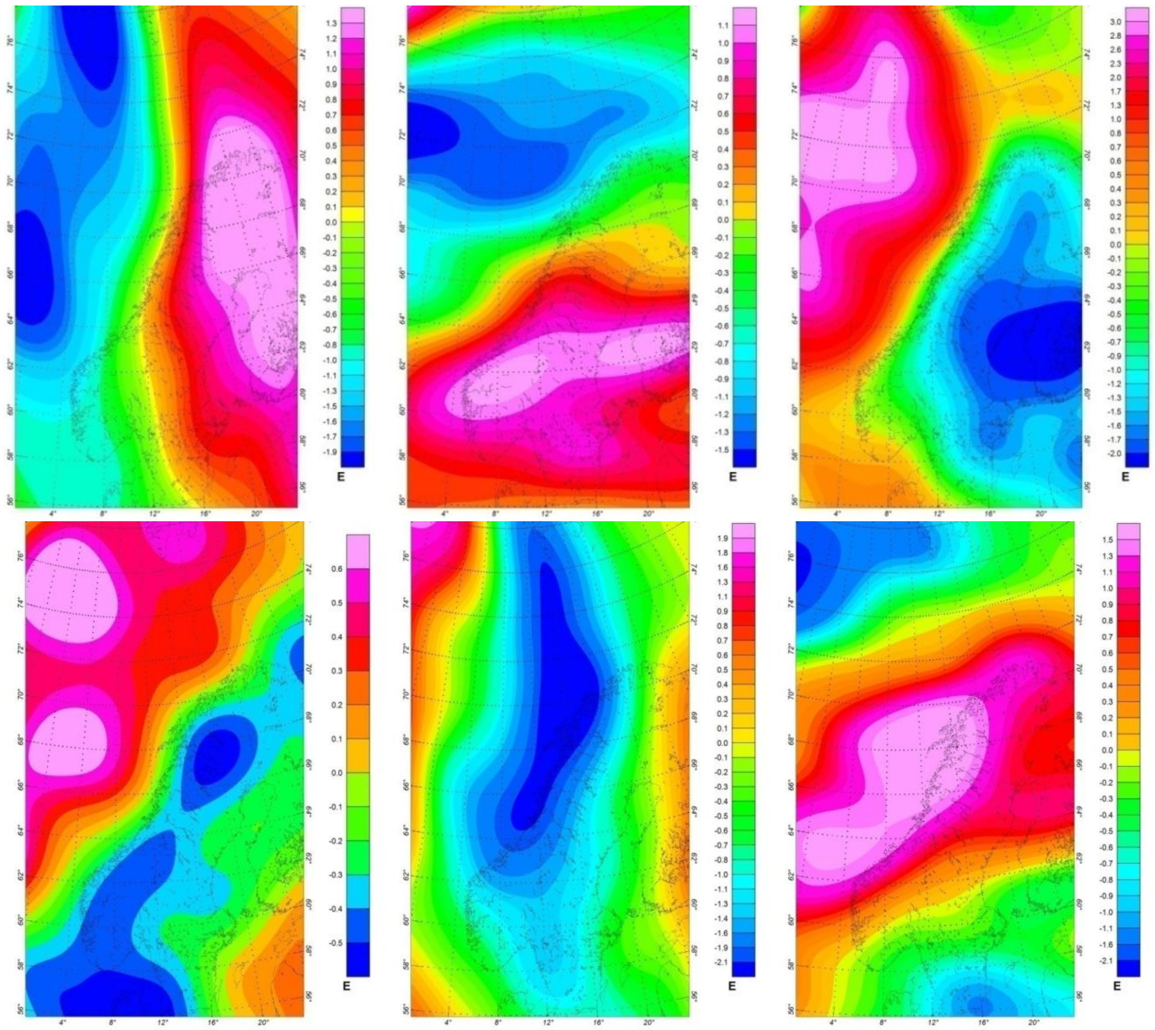

Figure 9: Gravity gradient signal at GOCE altitude due to crustal thickness for the North-East Atlantic Margin. Top row from left to right: V_{XX}, V_{YY} and V_{ZZ}. Bottom row from left to right: V_{XY}, V_{XZ} and V_{YZ}.

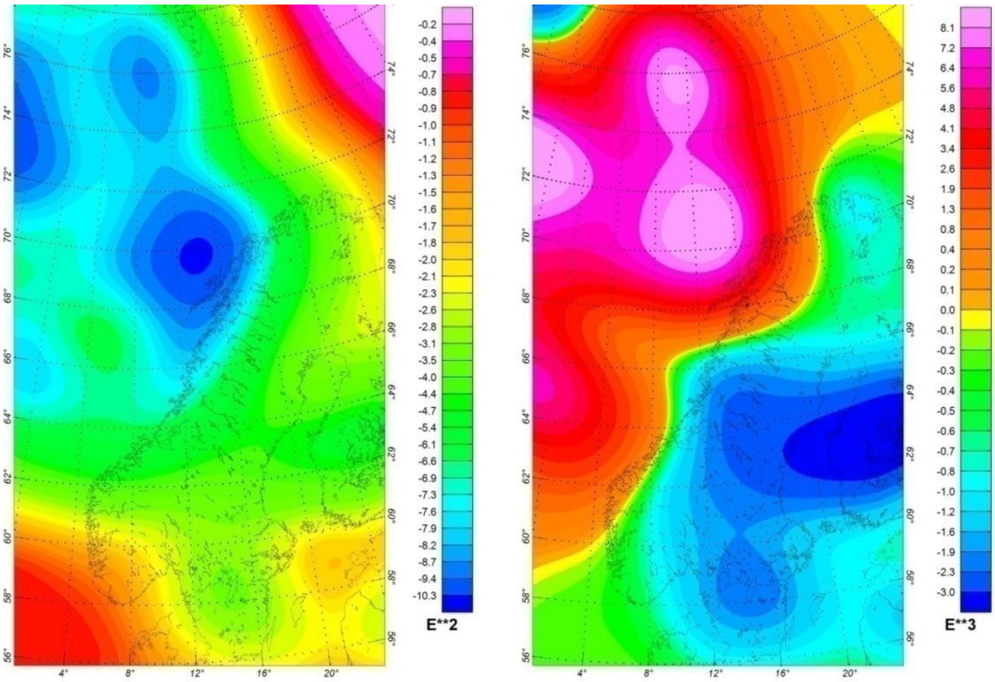

Figure 10. Invariants I_1 (left panel) and I_2 (right panel) at GOCE altitude.

4. USER GROUP

We intend to establish a User Group to ensure involvement of the user community in the study. On the one hand, the User Group could contribute to the definition of the required products. For example, would gravity gradients in grids at satellite altitude be required or at the Earth’s surface or both? Or would it be beneficial to provide gradients after a collinear track analysis? On the other hand, the User Group could be involved in the evaluation of the products that will be generated to assess their use for Earth interior modelling.

5. REFERENCES

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[4] Stern RJ, Johnson P (2010): Continental lithosphere of the Arabian Plate: A geologic, petrologic, and geophysical synthesis. *Earth-Science Reviews*, 101, Issue 1-2, 29-67