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Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Strykowski, G. (2010). *Some practical applications of the horizontal gradients Txz and Tyz of the gravitational field.*. Poster session presented at European Geosciences Union General Assembly 2009, Vienna, Austria.

Some practical applications of the horizontal gradients Txz and Tyz

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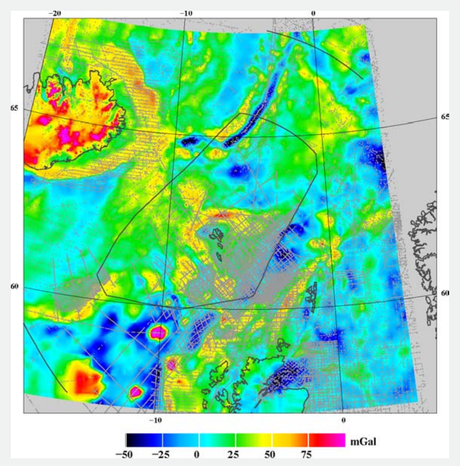
Introduction

In the classical paper by Nettleton (1939) the visible topography (the source geometry) is used to constrain the bulk density of the topographic masses ρ from the gravitational attraction Tz without the direct density measurements (density=mass/volume). In the 19th century the same idea of decoupling the source geometry from the source strength (the mass density) led to the discovery of the hypothesis of isostasy by the findings of The Survey of India. The deflection of the plumb-line caused by the Himalayas was much less than the calculated; i.e. the gravitational effect of the visible mass surplus (the topography) must be compensated by the (invisible) mass deficit in the subsurface. In other words, if the hypothesis of mass deficit was not valid, the mass density of the visible mountains that could explain the plumb-line deflection would be geophysically unrealistic (too small)!

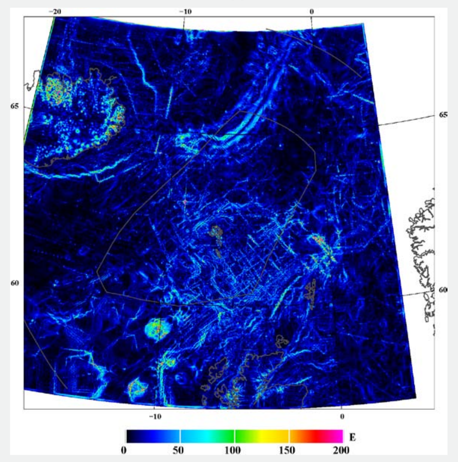
In this contribution we demonstrate how the available information about the source geometry for a large marine area in the North Atlantic around the Faroe Islands, and the geophysically plausible mass density values, can be used to costrain the geophysical information without any assumptions about the possible compensating sources. We show that the use of the horizontal surface gradients Txz and Tyz is valuable, because, compared to Tz, the relative weight of the gravitational signal from a shallow source is much higher than that of the deep sources.

Two specific applications of the horizontal gradients Txz and Tyz will be demonstrated: (i) constraining of the mass density of the bedrock; (ii) positively identifying the errors in the marine gravity data.

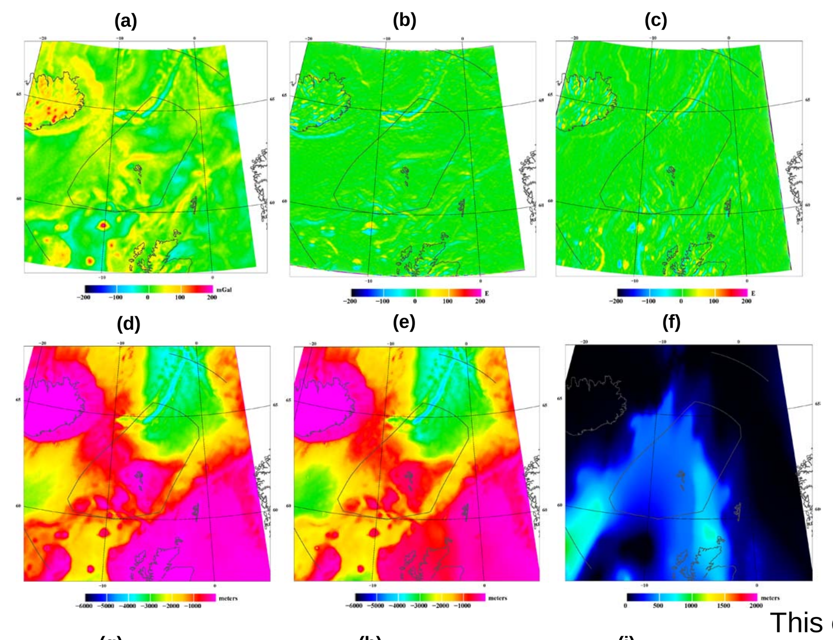
(p)



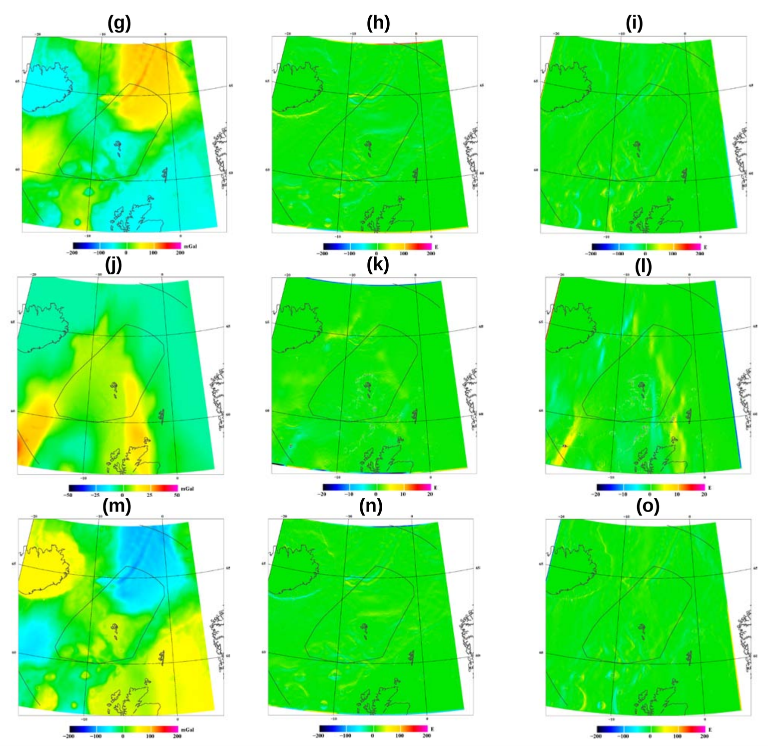
(r)



The study area and the available information



Figures (for details see the Theory section)**:**
- (a) Tz from DNSC08 (Andersen et al., 2009)
- (b) Txz from Tz by spectral methods using GRAVSOFT
- (c) Tyz from Tz by spectral methods using GRAVSOFT
- (d) DNSC08 depth to the sea bottom (on land: zero height)
- (e) Depth to the base of sediments from (d) and (f)
- (f) Thickness of sediments (Divins, 2003)
- (g) Zero mean and unit mass density Tz from sea water
- (h) Zero mean and unit mass density Tyz from sea water
- (i) Zero mean and unit mass density Txz from sea water
- (j) Zero mean and unit mass density Tz from sediments
- (k) Zero mean and unit mass density Tyz from sediments
- (l) Zero mean and unit mass density Txz from sediments
- (m) Zero mean and unit mass density Tz from bedrock
- (n) Zero mean and unit mass density Tyz from bedrock
- (o) Zero mean and unit mass density Txz from bedrock



This example originated from DTU Space's involvement in supporting a potential claim by the Danish Government on behalf of the Faroe Islands under the UNCLOS Article 76 for extended jurisdiction. The marine gravity anomalies from satellite altimetry used were DNSC08 (Andersen et al., 2009). This high quality global gravity data set was used as a fill-in data in the latest global Earth's gravity model EGM08 (Pavlis et al., 2008). The current and publicly available version of DNSC08 includes the free-air gravity anomalies from satellite altimetry for the marine areas and EGM08 free-air gravity anomalies on land, so that the transition from land to sea is adequately covered by the gravity data. Furthermore, DNSC08 model includes also a detailed 1' x 1' global bathymetry-topography model based for the marine areas on GEBCO-1 (British Oceanography Data Centre, 2008).

The study area is defined as: 57°N- 68°N and 20°W- 4°E
The grid spacing is lat x lon: 0.0125°× 0.025°

This work was done using the GRAVSOFT programs package (Forsberg and Tscherning, 2008)

Theory

Some elements of the method used have been published in the past (Strykowski and Forsberg, 1998; Strykowski, 1998, 1999, 2000):

• Information about the source geometry is translated to the surface gravitational signal Tz,i for the source *i* (where *i=1,2,3* corresponds to 1: sea water, 2: sediments, 3: bedrock to a depth of 6000 m). Tz,i is computed using a unit mass density (ρ_u=1000 kg/m^3) space-domain prism integration technique on a spherical Earth. Each surface signal is centred (i.e. a zero mean over the area), see figs. (g),(j) and (m), corresponding to that the mean density value in each depth has been subtracted.
• The geometry of "known geology" in 3D can be viewed as pieces of a jigsaw-puzzle forming a 6000 m thick part of a spherical shell bounded by the parallels and meridians bounding the area. Similarly, the sum of the gravitational signals Tz,i is zero.
•The contribution of the known geology (assuming a constant mass density ρ_i, $\rho_i=\alpha_i\rho_u$ for each unit i) Tz,known to the surface signal Tz is:

Tz,known = ∑ α_iTz,i and **Tz = Tz,known+ Tz,unknown**

The new aspect is to differentiate the "source base functions" Tz,i with respect to x- and y yielding Txz,i and Tyz,i, see figs (h)-(i), (k)-(l) and (n)-(o). Partial differentiation is a linear operator translating the above to:

Txz,known = ∑ αiTxz,i and **Txz = Txz,known+ Txz,unknown**
Tyz,known = ∑ αiTyz,i and **Tyz = Tyz,known+ Tyz,unknown**

Problem:

What can be learned about the mass density of the geological units and the residual signal from Tz, Tyz and Txz in the above setup?

The numerical example

The challenge here is to constrain the (scalar) parameters α_i, i=1,2,3 from the available information. The meaning of these parameters is intuitively clear; the number equivalents the bulk mass density (in g/cm^3). For the sea water we can therefore safely assume that α_1=1.03. Assume initially that α_2 = α_3 (the gravitational effect of the sediments is minor).

If Tz,unkown, Txz,unknown and Tyz,unknown is correlated (negatively) with, respectively, Tz,kown, Txz,known and Tyz,known it translates to the apparent parameters $\alpha_{app,z}$ (for Tz), $\alpha_{app,xz}$ (for Txz) and $\alpha_{app,xz}$ (for Tyz), each of which is less than α_{true} (= α_2 = α_3 for known sources), and each of which will minimize the standard deviation of the residuals for the respective field. In general: $\alpha_{app}=\alpha_{true}+\Delta\alpha$, where Δα is a parameter linking the surface signal from unknown sources with the signal generated by the known sources, e.g. Txz,known= Δα•Txz,unknown, and which is negative if the two surface signals (known/unknown) are negatively correlated. Δα depends on the geometrical factor of the unknown source, i.e. whether the geometry of the unknown source can be approximated by a constant time known source, the factor related to the depth of burial (upward continuation) and the density of the unknown source. The only factor that differ between Tz and Txz,Tyz is associated with the upward continuation. Even though Δα is unknown, the relative difference in the upward continuation part can be quantified for reasonable depths of burial between 4 km and 10 km by a parameter *w* (see below). α_2 = α_3 were changed in steps of 0.05 from 2.67 to 1.1. The following apparent parameters we found: $\alpha_{app,z}$ =1.20 and $\alpha_{app,xz}$ = $\alpha_{app,yz}$ = 1.60.

Tz: $1.20 = \alpha_{true} + w\cdot\Delta\alpha$
Tzx and Tyz: $1.60 = \alpha_{true} + \Delta\alpha$

The upward continuation tests for the seawater signals from depths between 4 km and 10 km yields factor *w* between 0.7 (shallow source) and 2 (deep source). This gives α_{true}(=α_2= α_3) between 2.0 and 2.6. Knowledge of the depth of burial of the unknown source will further constrain α_{true}.

Results and Conclusions

In this work, in an extended method of Nettleton for correlated sources, we have shown, for a marine area in the North Atlantic around Faroe Islands, that the use of the horizontal gradients Txz and Tyz together with Tz, and without other assumptions except that the unknown sources are buried in depths between 4 km and 10 km, can constrain the density of the bedrock to between 2000 kg/m^3 to 2600 kg/m^3. This result seem not to be very impressive as the same constraints (and better) could be drawn from the knowledge of the realistic mass density values for the bedrock. However, if additional information about the depth of burial of the compensating sources was included (e.g. one seismogram), it could narrow (through a specific factor *w*, see above) the mass density of the bedrock considerably.

One other related result and conclusion about the use of Txz and Tyz (not discussed here) is the positive detection of the errors in marine data for a gravity map compiled from some 1.6 mill data in the area (Strykowski and Kasenda, 2008). Fig (p) shows the free-air gravity map compiled from these data. Fig (r) shows the data transformed to $(Txz^2 + Tyz^2)^{1/2}$. Assuming no sources between sea floor and the surface (which is obvious) the signal correlating with the location of the ship tracs must be an error.

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