On some innovations in gravimetric inversion methodology: structural and geodynamic applications

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We present an inversion methodology by which potential field data can be interpreted in structural or geodynamic studies. The method consists of several steps: removal of regional trend, depth-wise separation of signal of sources, line segments approximation of sources, and inversion by the method of local corrections yielding star-convex homogenous source bodies and/or contrasting contact surfaces. First we demonstrate a static application of the methodology on a case study devoted to identifying an intrusion in structural tectono-geological investigation in the area of the Kolárovo gravity and magnetic anomalies of the Danube Basin in the Western Carpathian–Pannonian region of Central Europe. Next we demonstrate the capabilities of the methodology in geodynamic studies when studying the movement of magma/hydrothermal fluids in restless volcanic areas on a case of the 2004 unrest of Teide volcano, Tenerife, Canary Islands.

The presented inversion methodology produces a set of several admissible solutions that all are equally admissible from the viewpoint of observed gravity or magnetic data. Using additional geoscientific constraints or cognition, these solutions can be discriminated in terms of their geologic or tectonic feasibility. In the case of the Kolárovo gravity and magnetic anomalies the following solutions are presented: a single ellipsoidal intrusion below a sedimentary basin with determined morphology of its lower boundary (solution A, Fig. 1), a single intrusion of a complex shape (solution B, Fig. 2), an uplift of the lower crust (solution C, Fig. 3), and an intrusion above uplifted lower crust (solution D, Fig. 4). Joint inversion of magnetic and gravity data gives insights into magnetic properties of the intrusive body.

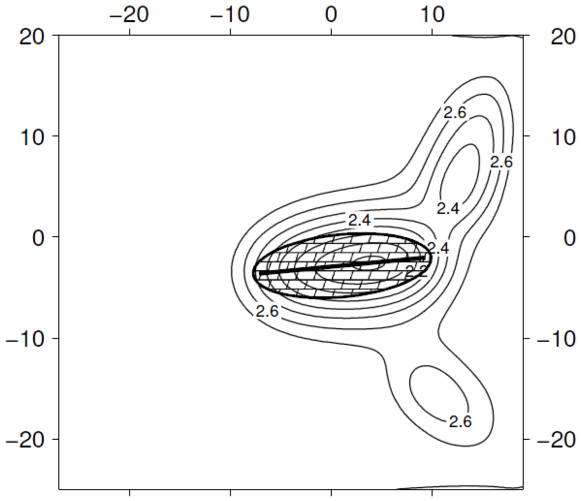

Fig. 1a. Solution A, map view.

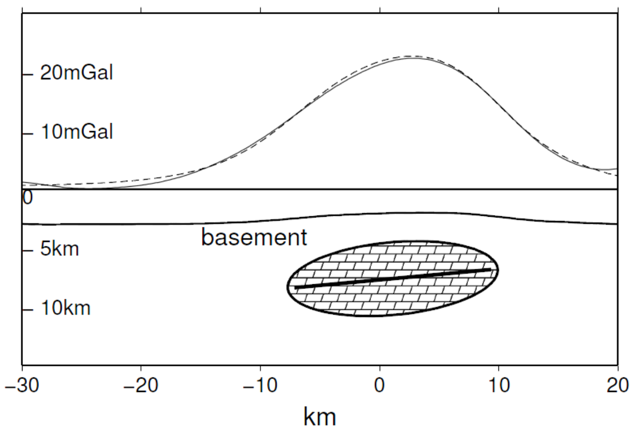

Fig. 1b. Solution A, vertical section

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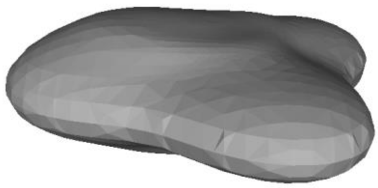

Fig. 2. Solution B

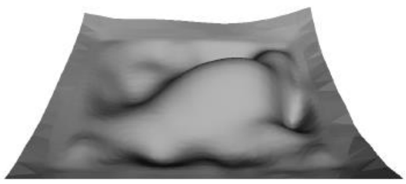

Fig. 3. Solution C

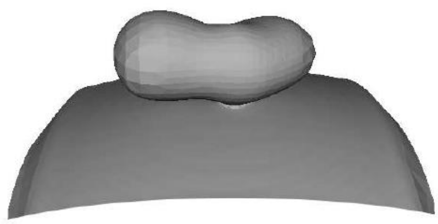

Fig. 4. Solution D

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Next we proceed with geodynamic application of our gravimetric inversion methodology. During the 2004/5 seismic unrest at the central volcanic complex (CVC) on Tenerife bulk gravity increase was recorded across a network at the CVC between May 2004 and July 2005 [5]. Here we aim at interpreting the gravity signal in terms of multiple sources using a non-linear inversion based on line segments approximation. The gravity changes were corrected for water table changes [5] and extrapolated onto an equidistant grid with a step of 500 m (Fig. 5). A trend, determined as a 2D harmonic function within the survey area, coinciding with the observed data on the boundary [6] was removed, in order to minimize the edge effects and truncation errors. Residual gravity changes after the removal of trend are shown in Fig. 6.

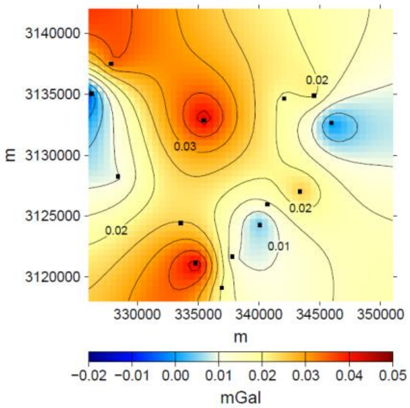

Fig. 5. Observed field.

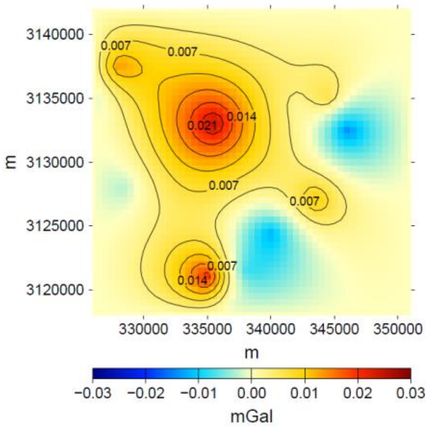

Fig. 6. Residual field.

Next we decomposed the residual gravity changes (Fig. 6) into a “shallow field” generated by presumed shallow sources and a “deep field” generated by deep sources. The division level of 4 km below sea level (b.s.l.) was chosen to match roughly the upper boundary of the two seismogenic zones determined by [3]. The decomposition procedure, based on stepwise upward, downward and upward sequential harmonic continuations, is described in [6]. The shallow and deep fields resulting from the decomposition are presented in figures 8 and 9, respectively.

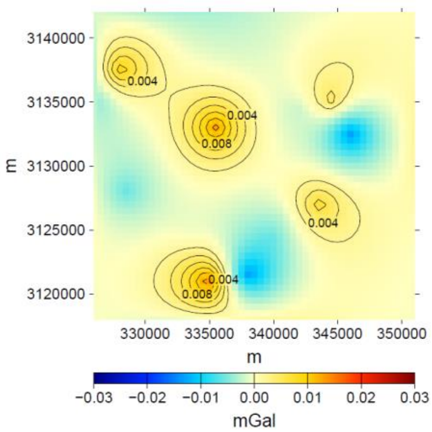

Fig. 8. Shallow field.

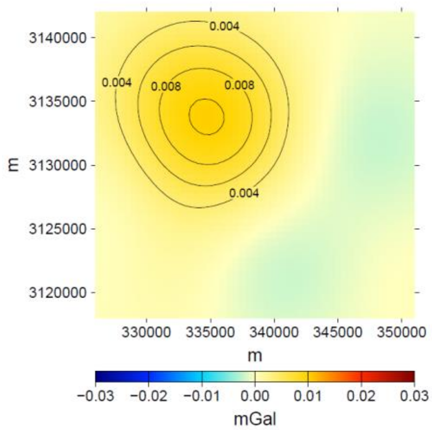

Fig. 9. Deep field.

The shallow and deep fields (Figs. 8 and 9) were then respectively best-fitted with the gravitational effect of line segments, each being defined by seven sought parameter, twice the triplet of coordinates and a line density [7]. These parameters were determined by minimizing residuals in L2 norm by means of non-linear minimization procedure, using the gradient method of [4]. The line segments represent sources of temporal mass-density changes. This inversion resulted in 3 shallow segments and 2 deep short and connected segments (one bent segment), see Fig. 10. The shallow and deep fields are approximated with rms of 2.3 and 0.7 μGal, respectively. Due to the spatial distribution of the shallow segments and the position of the deep one, as well as their spatial correlation with the seismogenic zones of [3], we interpret the shallow segments as sources of hydrothermal fluids, while the short deep segment as a magma injection at a depth of about 6 km b.s.l., within the NW zone of VT events swarm identified by [3]. This hybrid nature of the observed unrest is best explained by the migration of hydrothermal fluids as a result of magma injection. The time span in-

between the last three historic eruptions is roughly a century (93 and 111 years, respectively). Conspicuously enough, the 2004 unrest follows a similar repeatability pattern (95 years after Chinyero). We may consider the 2004 hybrid unrest on Tenerife a failed eruption. Our gravimetric picture indicates no rejuvenation of the central phonolitic plumbing system of the twin stratovolcanoes,instead it shows magma input following the patways of the mafic system associated with the rifts of Tenerife.

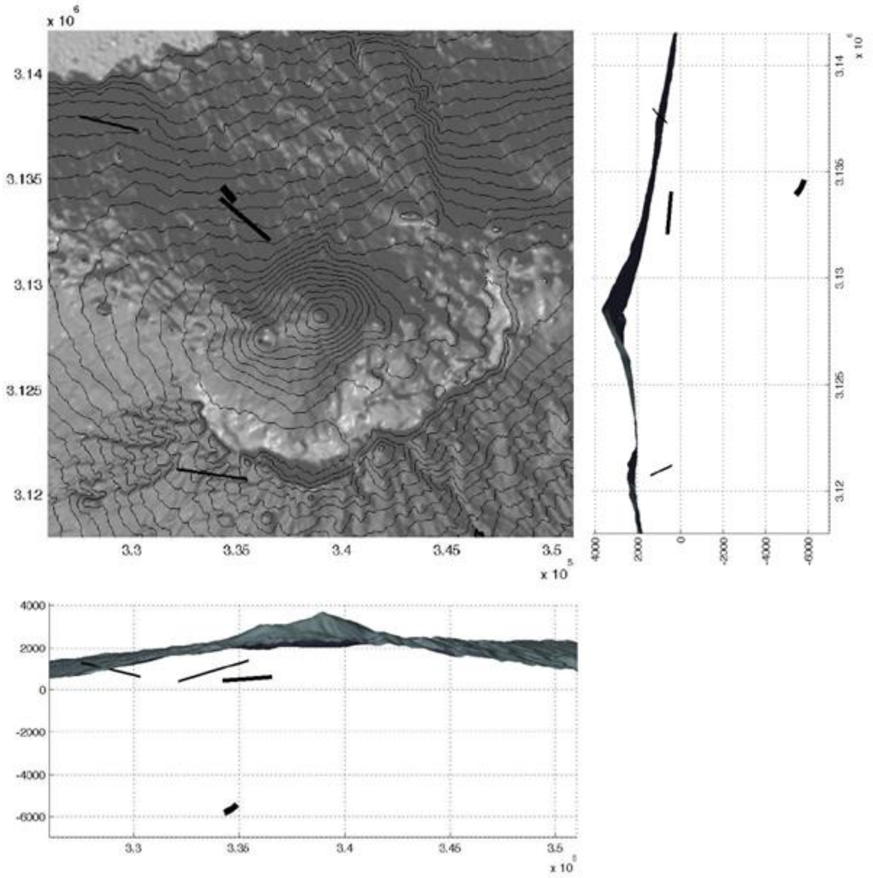

Fig. 10. The shallow and deep line segments. Top left plot is plan view, right plot is S–N cross-section, and bottom plot is W–E cross-section.

Acknowledgements

Jo Gottsmann acknowledges support by the Royal Society University Research Fellowship and EC FP7 project “VUELCO” (grant # 282759). Peter Vajda was supported by the Slovak Research and Development Agency (contract No. APVV-0724-11) and by Vega grant agency (projects No. 2/0067/12 and 1/0095/12).

References

1. Ablay, G.J., Martí J.: Stratigraphy, structure, and volcanic evolution of the Pico Teide – Pico Viejo formation, Tenerife, Canary Islands, J. Volcanol. Geotherm. Res., 103(1–4), 175–208 (2000)
2. Andújar, J., Costa, F., Martí, J.: Magma storage conditions of the last eruption of Teide volcano (Canary Islands, Spain). Bulletin of Volcanology 72, 381–395 (2010)
3. Cerdeña D.I., del Fresno C., Rivera L.: New insight on the increasing seismicity during Tenerife's 2004 volcanic reactivation. J. Volcanol. Geotherm. Res. 206, 15–29 (2011)
4. Fletcher R., Powell, M.J.D.: A rapidly convergent descent method for minimization. The Computer Journal 6(2): 163–168 (1963)
5. Gottsmann, J., Wooller, L., Martí, J., Fernández, J., Camacho, A.G., Gonzalez, P.J., Garcia, A., Rymer, H.: New evidence for the reawakening of Teide volcano. Geophys. Res. Lett., 33, L20311 (2006)
6. Prutkin I., Vajda P., Tenzer R., Bielik, M.: 3D inversion of gravity data by separation of sources and the method of local corrections: Kolarovo gravity high case study. Journal of Apllied Geophysics 75(3), 472–478 (2011)
7. Vajda P., Prutkin I., Tenzer R., Jentzsch G.: Inversion of temporal gravity changes by the method of local corrections: A case study from Mayon volcano, Philippines. J. Volcanol. Geotherm. Res. Vol. 241–242, 13–20 (2012)