Constrained 3D forward modeling using advanced interpretation and visualization

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Summary
Processing and modeling of geoid, gravity and magnetic data and their gradients together with constraining information was done by the aid of the IGMAS+ software (Interactive Geophysical Modeling Application System) using three-dimensional (3D) model geometry, advanced calculation features and GIS functionality. In the case studies of our poster, which stem from the projects of our working group, we will present some of the new features of IGMAS+: 3D stereoscopic visualization and the possibility to use IGMAS+ in immersive virtual reality (VR) setups will be lined out. To refine the modeling parameters like density or susceptibility, parameter inversion has been integrated into the software and can support the modeling process in different stages. Coordinate-independent invariants from field gradients of the presented case studies can be calculated and will be shown. Taking into account the wealth of functionality, IGMAS+ proves to be an integrating modeling tool for geophysical interpretation of potential field data.

Introduction
The new software package IGMAS+ is under steady development in our scientific working group at the University of Kiel, the Transinsight GmbH (Dresden, Germany) and STATOIL (Stavanger/Trondheim, Norway). It provides three-dimensional (3D) interactive forward modeling (http://www.gravity.uni-kiel.de/igmas or www.potentialgs.com). The migration process of the formerly UNIX-based toolkit to the JAVA-platform represents a big step forward not only in means of portability and ease of use through an enhanced graphical user interface (GUI), but also opened the way for features like stereo visualization and integration into VR setups including 3D human-interface-devices (HIDs), granting the user direct access to the virtual 3D model space and thus leading towards an immersive forward modeling workflow.

Inversion algorithms (C. Haase, pers. comm.) integrated into IGMAS+ can guide the process of forward modeling very well. Moreover, advanced interpretation techniques like invariants of the analytically derived Eötvös tensor are presented for case studies in order to show their capability to model regions of complicated lithospheric structures.

We are demonstrating the impact of these enhancements and new features of the IGMAS+ tool for the modeling process by some selected case studies.
**Methodological extensions**

Because of the triangular model structure, IGMAS can handle complex structures (multi Z surfaces) like the overhangs of salt domes very well.

**Inversion:**

Advanced density inversion using MMSE (Minimum Mean-Square Error; Bjørn Sæther, 1997; Claudia Haase, 2009)

**Invariants:**

Invariants of the Eötvös tensor provide a convenient option for gravity anomaly interpretation. The invariants $I_1$ and $I_2$ (cf. Pedersen and Rasmussen, 1990) make use of all tensor components simultaneously and lead to anomaly maps that are – unlike gravity gradients – independent of the direction of the coordinate axes. Furthermore, invariants yield convergence of field anomalies closer towards the projection of high density contrasts. Thus, they are a useful, additional visualization tool for gravity data and their gradients (Gutknecht, 2008). Figure 2b shows an example of $I_1$ for one of our case studies.

**IGMAS+ - enhanced visualization and modeling**

As a JAVA3D application, IGMAS+ is platform independent and takes advantage of up to date visualization components like Direct3D and OpenGL. Several 2D and 3D views can be generated. The possibilities to visualize a 3D model scenario and carrying out constrained 3D forward modeling on a normal computer screen with IGMAS+ have been improved ever since the long term development history of this application and its unix-based predecessor, thus reaching a very realistic impression of depth.

A 3D stereoscopic visualization lab was built at the Institute of Geosciences at the Christian-Albrechts-Universität in Kiel (Fig. 1). Optical tracking was integrated, making especially modeling of volumetric underground structures more interactive. Using this setup for geophysical forward modeling, various types of additional information (points, lines, polygons, surfaces and bodies) can be seen and evaluated by a scientist at the same time to refine a model.

![Fig 1: Immersive 3D forward modeling](image)

Incorporating tracking technology with stereoscopic visualization, the possibility to manipulate the model directly e.g. through a virtual pointing stick (violet in Fig. 1) arises. As constraining data can be seen all the time and directly at the scientists ‘hands’, decisions based on these additional data – e.g. from seismology, geology or geochemistry – can be made instantaneously and intuitively (Damm and Götze, 2009).
Additionally the process of doing the 3D geometry modifications in a forward modeling process can be improved using such an immersive 3D visualization system. Points at body corners or on edges can be moved to the exact desired position. Using a 2D input scenario, the same modifications are clearly possible, but limited to the particular 2D working plane used in that moment. In the area of miniaturized video glasses with two small video elements, the organic LED technology (OLED) is still evolving. These video glasses can become a working-place alternative to the room mounted stereoscopic projection setups and hence making immersive 3D modeling the normal procedure in the future, as it brings more information and a more intuitive model access.

**Case Study 1: 3D modeling of a frontier basin**
The Taoudeni Basin in West Africa is a large frontier basin located in a desert. Wintershall Holding AG holds acreage of about 68000 km². Here aero-measurements of gravity and magnetic were conducted to gain first insight about the subsurface and ease further exploration steps. The subsurface is disturbed by intrusions and a heterogeneous basement. 2D modeling of gravity produces unsatisfying results, thus 3D modeling was applied (Köther, 2009) with IGMAS+. The 3D models describe the geometry of the subsurface over the whole area and provide reliable structural approaches. The 3D visualisation of IGMAS+ improves the interpretation of the models and helps to evaluate the structure of important layers for hydrocarbon exploration. **Fig. 2a** shows the basement top which influences the oil bearing structures. A slight dip from south to north (from front to back corner) which is confirmed by geology is modelled well. Furthermore a basement depression to the east (right corner) is modeled, which was not obvious after 2D modeling because of its small extent. Thus the 3D modeling improves the significance of the measurements. These results provide new insight about the basin structures and therefore they are important contributions for future exploration e.g. the planning of seismic surveys.

**Fig. 2a**: The modelled basement top in 3D. The vertical exaggeration is 25. From North (back) to South (front) a slight dip is visible which is predicted by geology. To East (right corner) a basement depression was modeled. During 2D modeling the depression was not recognized because it is a local feature. The 3D overview facilitates a reliable interpretation of the whole basement structure. Thus the depression could be interpreted as an isolated trough. Therefore the 3D modeling and visualisation improves the interpretation. **Fig. 2b**: shows the $I_1$ invariant field for the same model. A granite plug in the northwest produces a strong local gravity anomaly with steep gradients that cause high invariant amplitudes.
A N-S lineament emphasizes a normal fault in the basement filled with sediments. To East a W-E lineament marks the edge of an interpreted intrusion. It is obvious that the invariant field is a powerful tool to emphasize the interpreted structures in a 2D view.

**Case Study 2: Salt structures in sedimentary basins**

Gravity and magnetic forward modeling was performed in a sedimentary basin to improve the knowledge of salt volume, caprock and the sedimentary basin strata. The area has also been covered by seismics and electromagnetics. Interpretations of these methods are compared to the results of 3D potential field models. The study is based on an internship at Statoil, Stavanger in summer 2008, where density models were created to constrain salt shape and volume. Also the evidence and location of caprock formations was target of this work. Constrained modeling results of gravity, gravity gradiometry and magnetic 3D modeling will be presented and thus give insight into reliability of potential field modeling.

**Conclusions**

The presented case studies have been created, modified and finally interpreted exclusively with IGMAS+. The integration of all required features into a single software speeds up the forward modeling workflow tremendously. In conjunction with additional constraining information, the scientist can build up a well defined model out of ambiguous potential field data. The simultaneous presentation of many different types of constrains together with the 3D model geometry and the resulting anomaly or residual maps in a stereoscopic visualization or even in an immersive environment is now possible with IGMAS+. Integration of new features, like advanced inversion algorithms or the calculation of invariants, can result in better informed scientist and hence in better modeling results.

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**References**


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