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Comparative Assessment of 3D Gravity Inversion Strategies Using SimPEG: A Case Study from Campos Basin, offshore Brazil

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Introduction

This work explores a 3D gravity inversion case study applied to Campos Basin using SimPEG version 0.24.0, an open-source geophysical modeling framework designed for flexible and extensible geophysical inversion workflows. The focus is on comparing inversion strategies and parameter configurations to evaluate their influence on the recovered subsurface density models. The study specifically incorporates the seismic volumes R0302_3D_PSDM_JUN_CAX_PIRA_JUB, located in the exploratory area of Parque das Baleias, and 0363_RSB_BMC33_MAZ3D, situated in the exploratory region of Raia Manta and Raia Pintada fields, both within the BM-C-33 exploration block—a region of considerable geological complexity and hydrocarbon potential. The polygons delineating each seismic volume were included to geographically contextualize the study area and facilitate the integration of seismic and potential field data. This integration enables future detailed investigations and seismic interpretation to better characterize local geological features observed regionally.

Method and/or Theory

The inversion workflow involved resampling gravity data from 0258_MAG_2D_SPP_2Q_1999 survey onto a regular observation grid with 8 km spacing. A tensor mesh was constructed with core cell sizes of 4 km horizontally and 2 km vertically, complemented by logarithmically scaled padding cells to adequately capture subsurface variations while optimizing computational efficiency. Two inversion approaches were evaluated: weighted least-squares (L2) and iteratively reweighted least-squares (IRLS). A series of tests were conducted, varying regularization weights and assumed data uncertainties (ranging from 1% to 5% of the maximum anomaly), to resolve density contrasts and assess the sensitivity of the inversion results to parameterization and noise assumptions.

Results and Conclusions

The L2 inversions produced smooth models with limited resolution of possible geological interfaces. In contrast, IRLS inversions—particularly those employing directional regularization with emphasis on the vertical (z) component—proved more effective in recovering sharper and geologically plausible structures. The best-performing models revealed distinct density contrast patterns surrounding known reservoir locations at various depths (−10 km, −20 km, and −40 km). These findings highlight the importance of selecting appropriate inversion strategies and demonstrate the applicability of SimPEG for regional gravity studies. Associations with the basin's preferential structural trends are also suggested by the outcomes of some inversion tests. The proposed methodology provides a robust foundation for future joint inversion applications integrating gravity, magnetic, and well data in the basin. When data uncertainty was reduced to 1%, the inversion became less sensitive to the depth of certain positive anomalies, particularly within a zone located in the southwestern Campos Basin. In future work, this anomaly zone will be specifically investigated using the SimPEG framework for magnetic and joint gravity–magnetic inversion, along with the interpretation of seismic and well data in the region. This investigation will also examine the hypothesis that the anomaly may be associated with a NE–SW-oriented sinistral (left-lateral) strike-slip component and its possible connection to structurally controlled hydrothermal processes in Campos Basin.