SnT 2023

CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

HOFBURG PALACE - Vienna and Online

19 TO 23 JUNE

Gravimetric investigation of geological structural anomalies

Nishath Ranasinghe, Charlotte Rowe

Earth and Environmental Sciences -17, Los Alamos National Laboratory, Los Alamos, NM, U.S.A. (LA-UR-23-24981)

Los Alamos NATIONAL LABORATORY

INTRODUCTION

We report on advances in capabilities toward detailed three-dimensional (3-D) density evaluation of shallow underground features at the Nevada National Security Site.

METHODS/DATA

The models ingested by the algorithm are built upon a grid of right rectangular prisms with associated densities. The gravitational contribution of each prism is estimated using the method of Nagy (1966) for each measurement position in a survey

START

RESULTS

We present the forward modeling of Aqueduct Mesa and both forward and inverse modeling a simple model using SimPEG software.

CONCLUSION

Forward modeling of Aqueduct Mesa agrees with larger trends in the observed gravity data, but details of the void space have yet to be addressed. We will conduct both forward and inverse modeling of both Aqueduct Mesa and Rock Valley.

Place your QR Code here after removing this text box!

P1.2-523

Introduction

- Gravity surveys can provide geophysical data that allow for interpretation of the subsurface geology and its features in a quick, non-invasive approach. Although, it is a potential method, hence does not independently provide unambiguous results, in combination with other information -- borehole data, seismic models, EM surveys or detailed geologic knowledge of the site -- gravity can validate assessments gleaned from other methods and offer an important constraint for joint characterizing of the subsurface.

- We are currently evaluating gravity data acquired at two different locations on the Nevada National Security Site (NNSS).

- The first target is Aqueduct Mesa in the northwest portion of the NNSS, where extensive tunnels have been mined and used for underground explosions. In 2018 a gravity survey was undertaken throughout the P Tunnel complex at roughly 300 m below the mesa, as well as across the top of the mesa above. Our goal is to compare the observations to predictions from a 3D density model, to ascertain whether underground cavities can be detected using gravimetry.

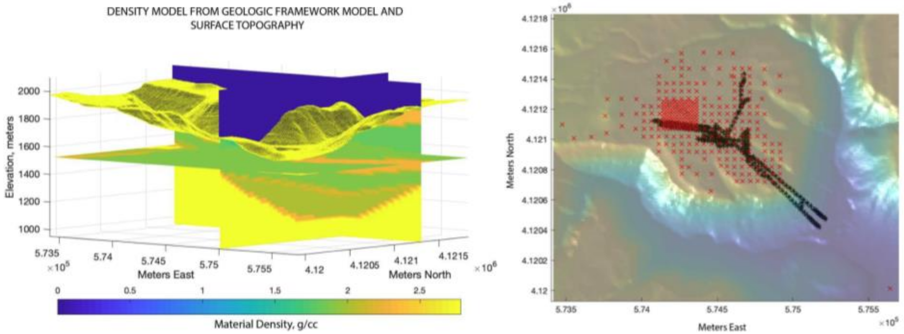
- The second target is Rock Valley, in the southern part of the NNSS. This is an area exhibiting numerous faults and the source of frequent micro- and moderate-sized earthquake activity and is the target of an experiment to compare an explosion signal to earthquake signals arising from the same location. To better characterize the subsurface and improve our confidence in the fault locations, we have collaborated with Sandia National Laboratory to acquire a dense gravity grid in the target location, which will allow for both density modeling and joint inversion with high-precision active and passive seismic results.

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

Place your QR Code here after removing this text box!

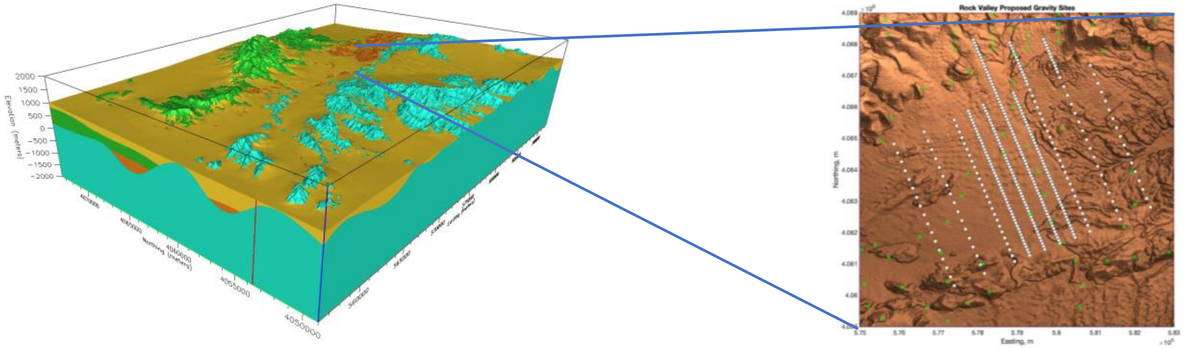
Objectives

Gravimetric data at the Aqueduct Mesa (2018) and the Rock Valley (2023) sites on the Nevada National Security Site, south central Nevada, U.S.A., were acquired using a Lacoste & Romberg gravimeter, and a combination of traditional EDM surveying methods underground and Trimble handheld GPS for aboveground position-finding.



3D density model for Aqueduct Mesa derived from Geologic Framework Model, and map of acquired gravity readings. Red stations are mesa top, black are in-tunnel.

The raw data have been processed to correct for elevation, latitude, instrumental drift, tidal oscillations and mid-survey dial adjustments. We are using detailed geologic framework models and high-resolution digital elevation models (DEMs), whose features have been converted to 3-D density models which will provide Bouguer and Terrain corrections.



Geologic Framework Model for Rock Valley, with gravity survey sites projected onto target location.

gravity data acquisition on Aqueduct Mesa (left two images), in Rock Valley (center image) and inside P Tunnel (right image)

Place your QR Code here after removing this text box!

Methods/data

- We perform forward modeling for the target geologic model, building upon a grid of right rectangular prisms with associated densities based on Nagy (1966). The software is developed based on Python framework with parallelization to reduce runtime. The forward model is compared to the reduced observations.

- The open source SimPEG software, a Python utility developed by Cockett *et al.* (2015) is used for both forward and inverse modeling of the gravimetric data.

- This code leverages the Nagy formulation to predict gravity at each specified measurement location on a block model as described above, then applies Gauss-Newton misfit minimization with a conjugate gradient approach to adjust the starting model according to data misfit. The code has a default of Tikhanov regularization operating on L_2 norms, but is extensible such that other measures, such as an L_1 norm, can be used instead.

Using the basic equation for gravitational attraction of a volume,

$$g_z = \int^v G * \Delta\rho * \frac{z}{r^3} dv$$

we can calculate for each model cell as a rectilinear box (Nagy, 1966) as follows:

$$g_z(mgal) = G * \Delta\rho * \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2}\mu_{ijk} *$$

$$\left[\Delta z_k * \arctan\left(\frac{\Delta x_i \Delta y_j}{\Delta z_k R_{ijk}}\right) - \Delta x_i \log\left(R_{ijk} + \Delta y_j\right) - \Delta y_j \log\left(R_{ijk} + \Delta x_i\right)\right]$$

Where:

g_z vertical component of gravitational attraction

G universal gravity constant = $6.67e^{-11} m^3 Kg^{-1} s^{-2}$

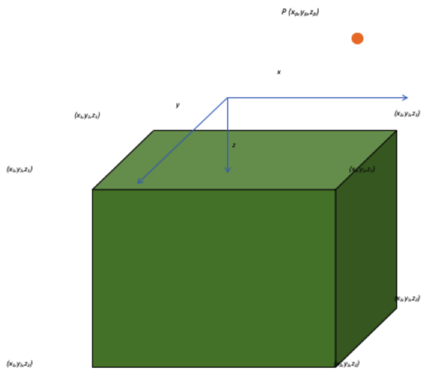
$\Delta\rho$ (kg/m³) density contrast of prism

$\mu_{ijk} = (-1)^i(-1)^j(-1)^k$

$\Delta x_i = (x_i - x_p)$, $\Delta y_j = (y_j - y_p)$, $\Delta z_k = (z_k - z_p)$

R_{ijk} (distances from each corner to point p)

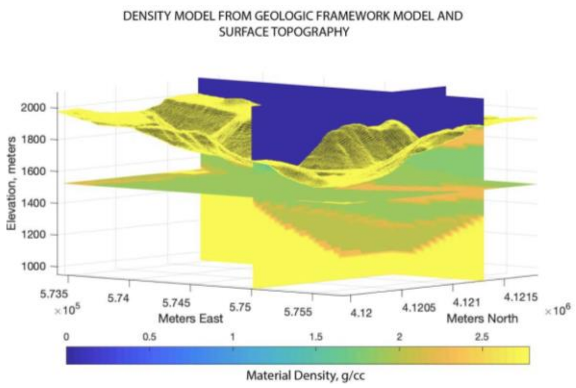
$= sqrt(\Delta x_i^2 + \Delta y_j^2 + \Delta z_k^2)$



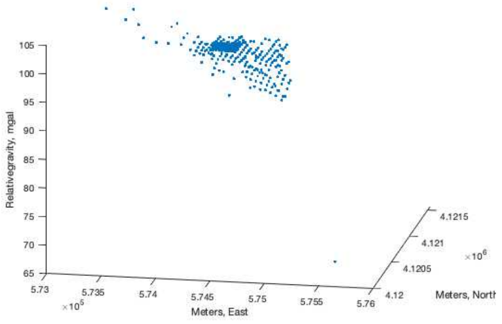
Place your QR Code here after removing this text box!

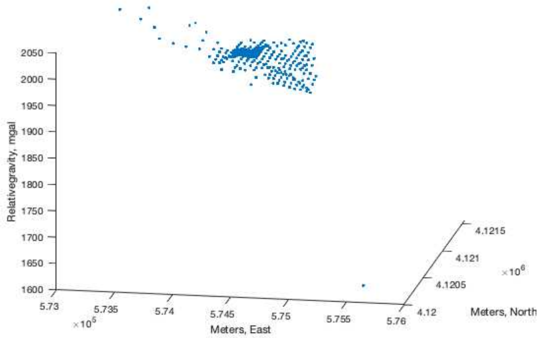
Results

Forward modeling of Aqueduct Mesa, Nevada National Security site



Using the DEM and GFM based density model for Aqueduct Mesa (*left*), our preliminary forward model using the Python codes demonstrate similar features, to first order, to the actual data. Compare the reduced gravity readings (*below, far left)* to model predictions (*below, near left)*.

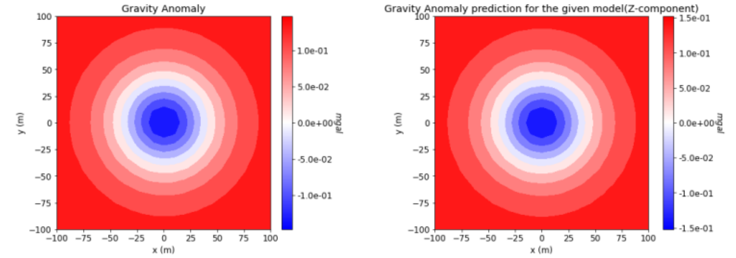


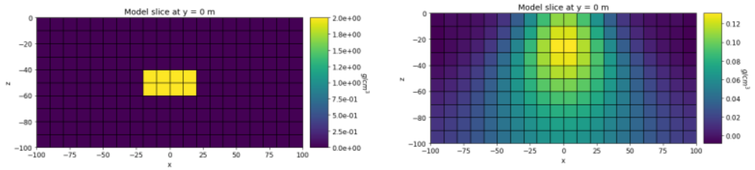


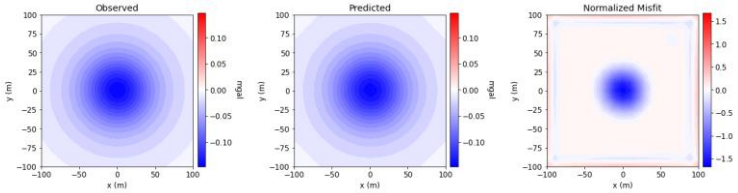
Initial tests of SimPEG Based forward and inversion modeling for a simple 3-D model

We started our tests of SimPEG with a simple model of a high density prism embedded in a low density halfspace. Forward predictions of the gravity anomaly at a grid of surface positions agree well with the anomaly as outlined in El-Tokhey *et al*. (2015). Our first inversion using the forward predictions demonstrates the need for tuning regularization parameters and applying geological or other constraints.

Top: *left*: forward modeled gravity anomaly from El-Tokhay / Nagy prisms; *right*: forward model from SimPEG. *Center: left*: Starting model; *right*: preliminary inversion. *Bottom: left*: input anomaly; *center*: output anomaly; right: difference.







INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

Place your QR Code here after removing this text box!

Conclusion

- The 3-D density model for Aqueduct Mesa produces first order gravity predictions in line with the trends observed in the reduced mesa-top data. We will be modifying the model to include tunnel voids as digitally mapped, and compare both surface and subsurface predictions to the surface and subsurface data acquired in 2018. This comparison may allow us additionally to detect explosion cavities or chimneys in the overburden and will provide a rigorous test for the SimPEG inversion code.

- We will be converting the GFM for Rock Valley into a 3-D density model,will compare the combined Sandia and Los Alamos gravity data to forward predictions based on this model and will implement the SimPEG inversion. This will require some constraints based on our synthetic tests, which may be derived from seismic models currently being generated.

- Significant testing of the SimPEG code and exploration of its regularization, smoothing and damping capabilities is in order. We will continue to compare the forward modeling with our in-house Python code for both synthetic and real data sets and models.

- Optimization of the processes will be achieved by incorporating variable cell sizes in the 3-D models. The Aqueduct Mesa model contains ~1.5 billion prisms, each of which has eight corners addressed for ~500 gravity stations. The fine-scale (1 m) resolution is only necessary in the vicinity of the tunnel itself; a larger grid can be implemented both for large regions of uniform density and for more distant volumes whose precision will not impact predictions beyond the instrumental precision (~5 μgal).

INTRODUCTION
OBJECTIVES
METHODS/DATA
RESULTS
CONCLUSION

Place your QR Code here after removing this text box!

References

- Dezsö Nagy. The gravitational attraction of a right rectangular prism. GEOPHYSICS, 31(2):362–371, 1966.
- Rowan Cockett, Seogi Kang, Lindsey J. Heagy, Adam Pidlisecky, and Douglas W. Oldenburg. Simpeg: An open source framework for simulation and gradient based parameter estimation in geophysical applications. Computers Geosciences, 85:142–154, 2015.
- Mohamed El-Tokhey, Mohamed Elhabiby, Ahmed E. Ragheb, and Mohamed A. Shebl. Gravity and density relationship (forward modeling). 2015.

Place your QR Code here after removing this text box!