SUSTech Southern University of Science and Technology

南方科技大学 SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

地球与空间科学系 DEPARTMENT OF EARTH AND SPACE SCIENCES

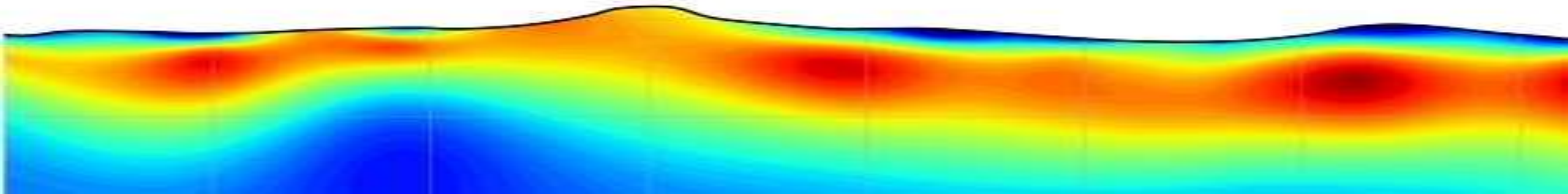
ESS302 Applied Geophysics II

Gravity, Magnetic, Electrical, Electromagnetic and Well Logging

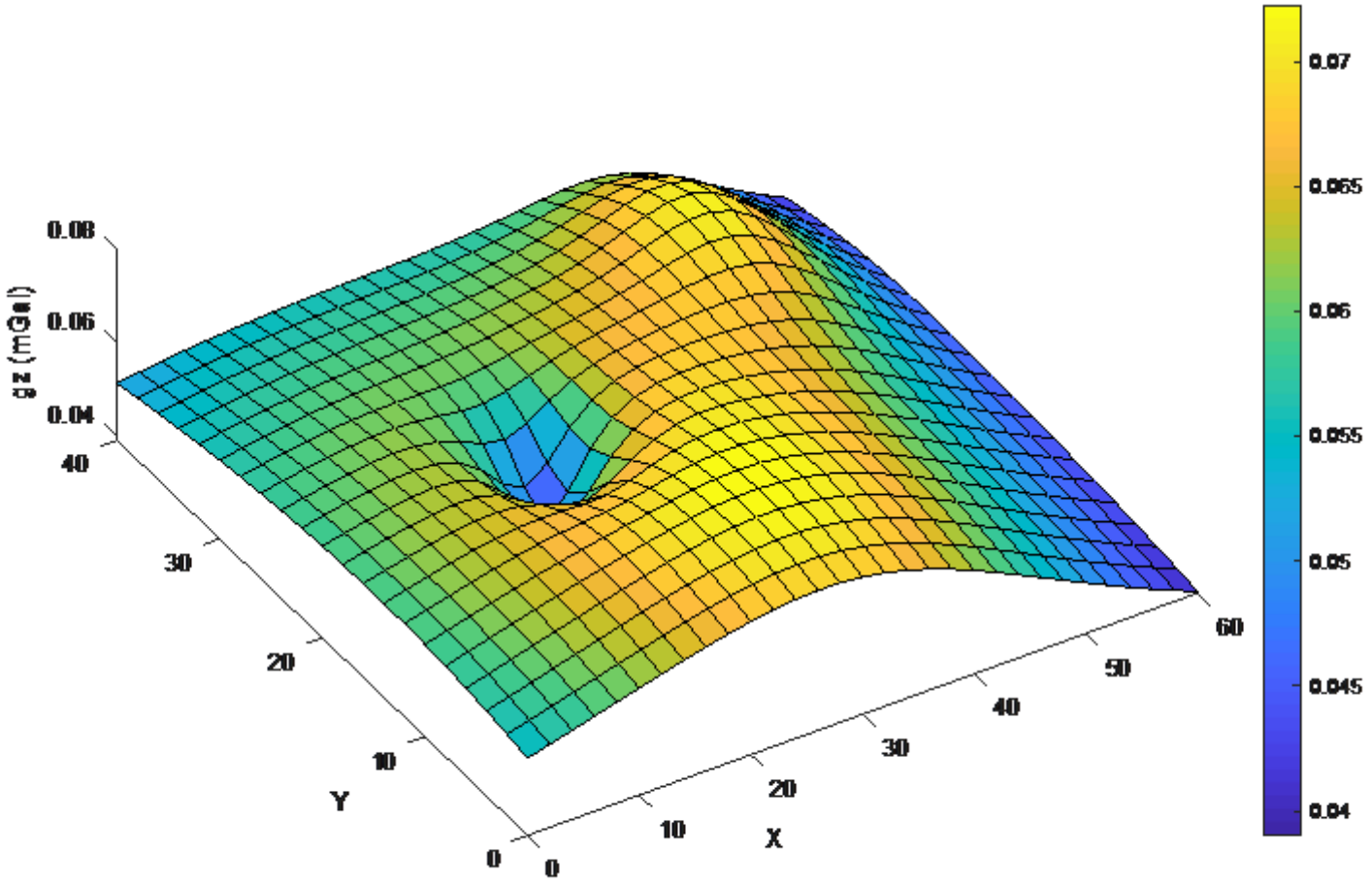
Gravity 3: Applications

Instructor: Dikun Yang

Feb – May, 2019



From the Last Lecture



Inherent ambiguity

- How many objects?
- How big/dense?
- Where are they?

Contents

- Upward and downward continuation
- Gravity gradiometry
  - Horizontal and vertical derivatives
  - Full tensor gravity gradient
- Gravity inversion
  - Geometric inversion
  - Pixel/voxel inversion
- Gravity applications
  - Planetary science
  - Environmental
  - Military

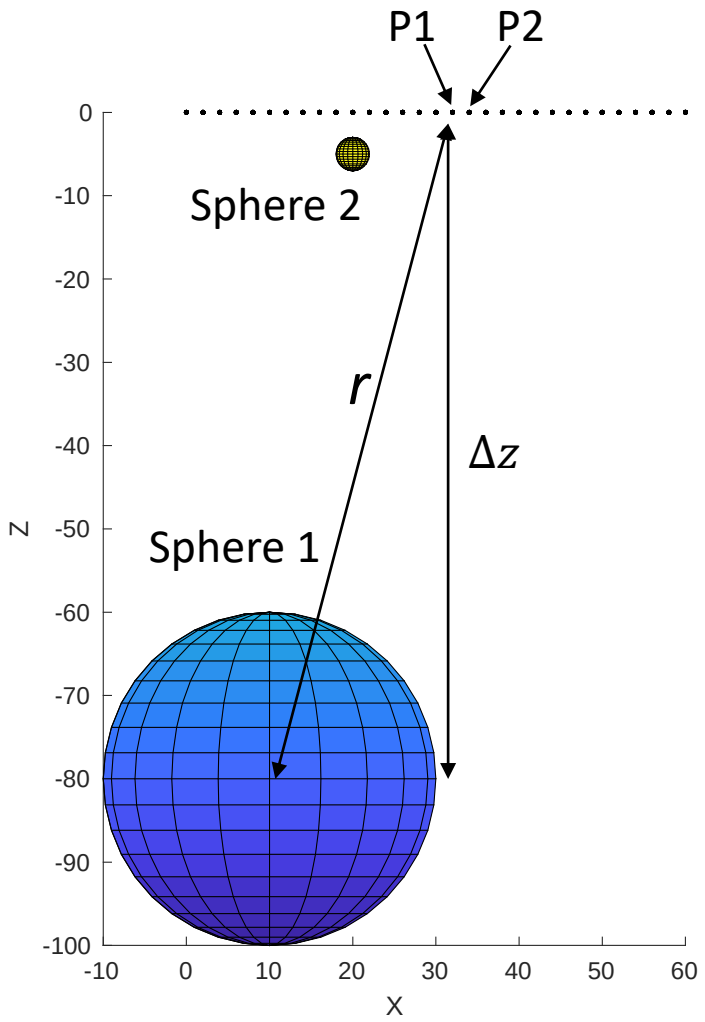
Gravity Signal Decays as $1/r^2$

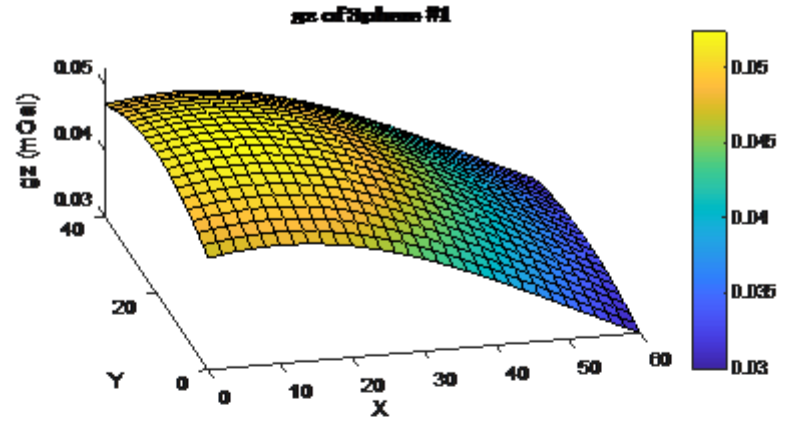
We measure the vertical component of *g* on the surface

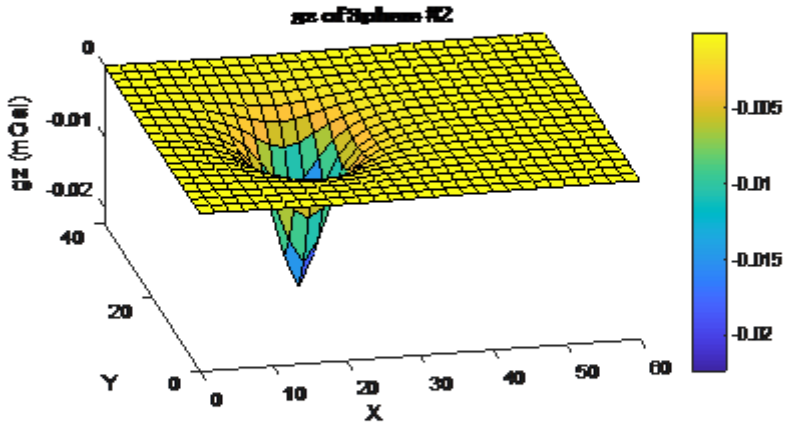
$$g_z = \frac{GM\ \Delta z}{r^3}$$

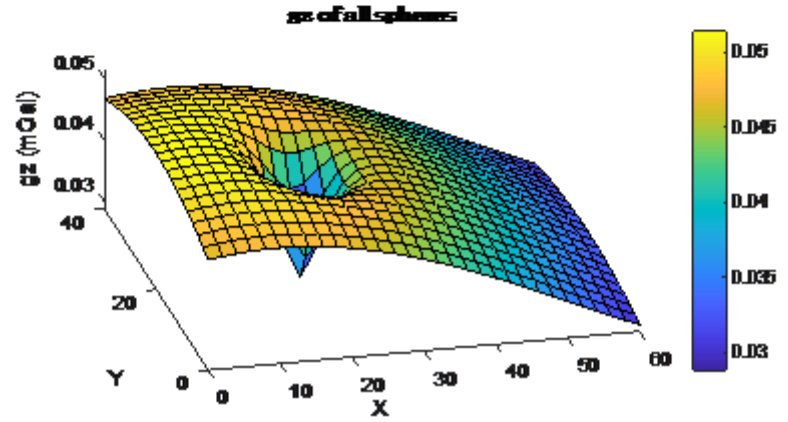
Large distance: long-wavelength

Small distance: short-wavelength

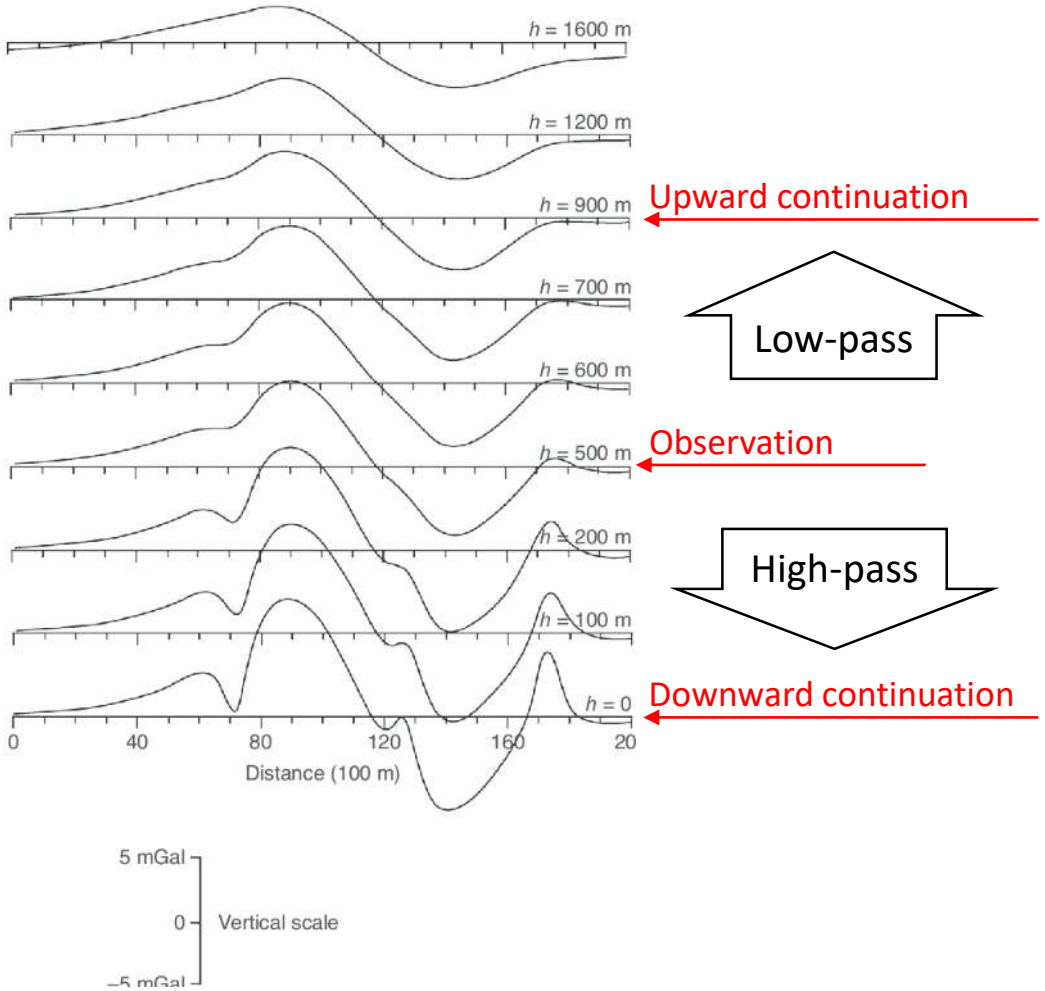


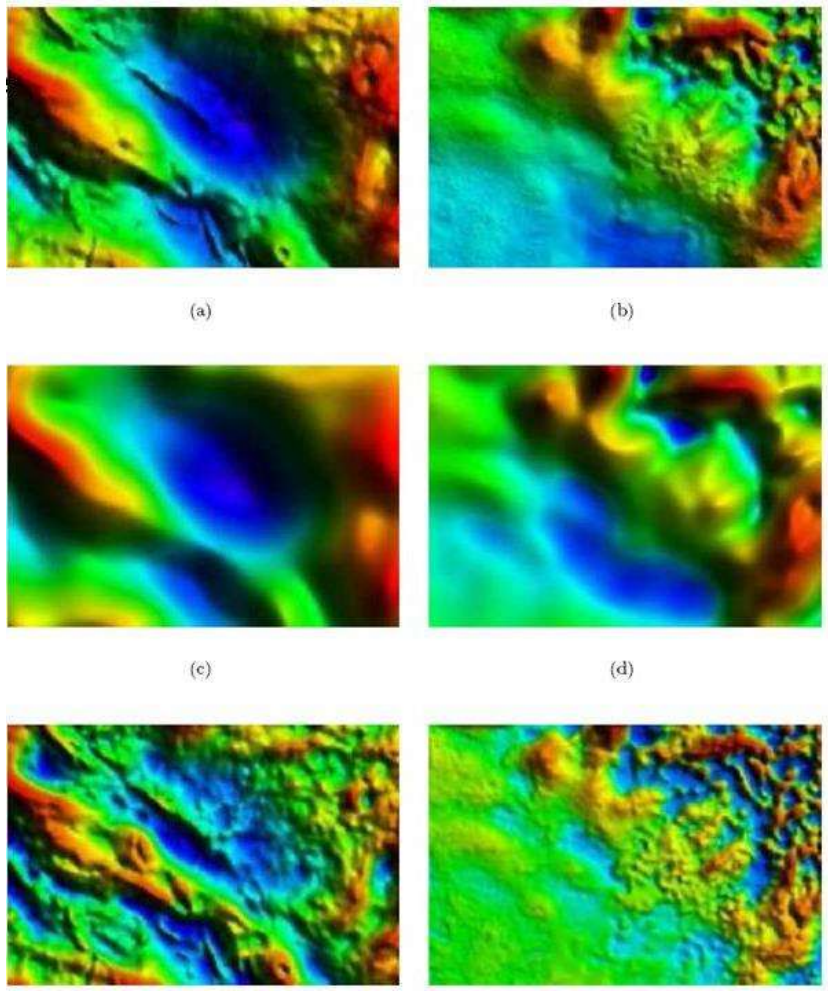






Upward and Downward Continuation





Original

Upward continued

Residual

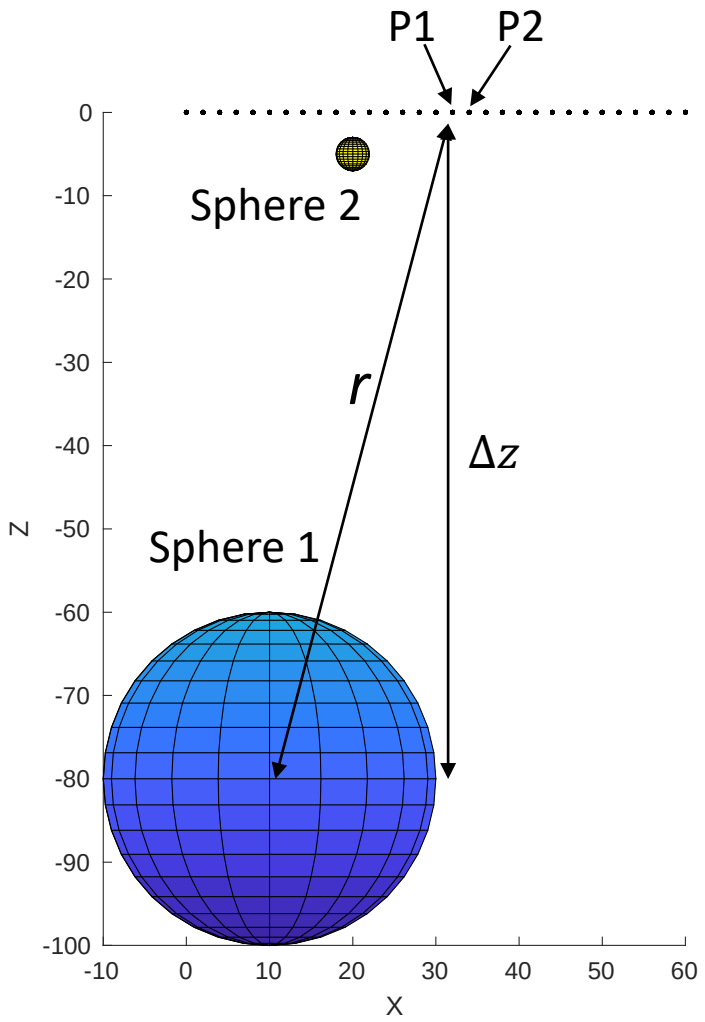
Gravity Signal Decays as $1/r^2$

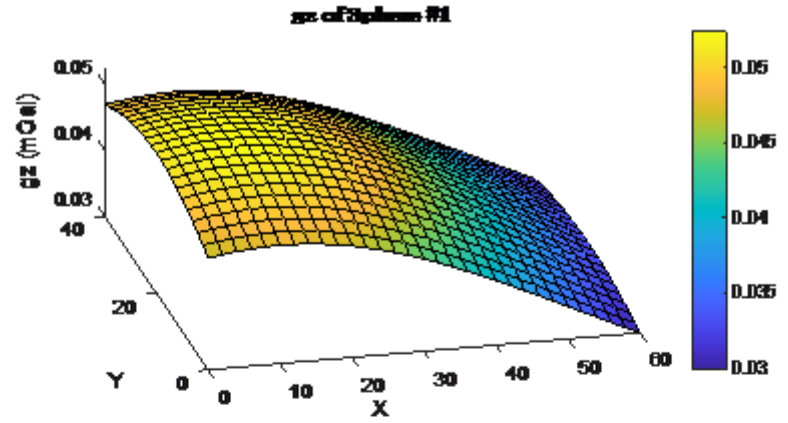
We measure the vertical component of *g* on the surface

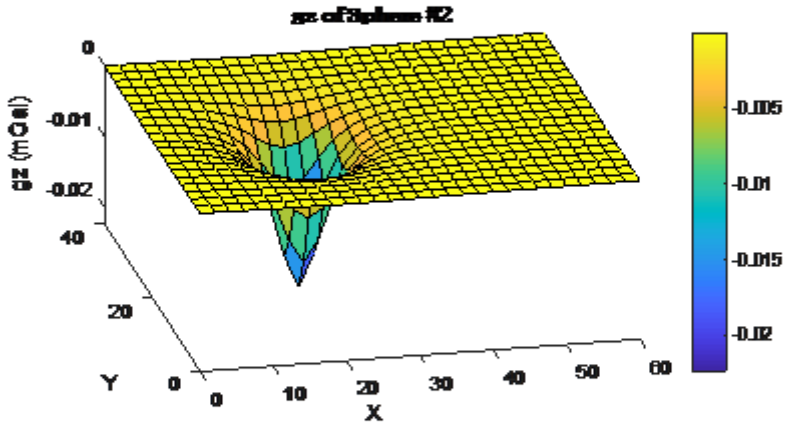
$$g_z = \frac{GM\ \Delta z}{r^3}$$

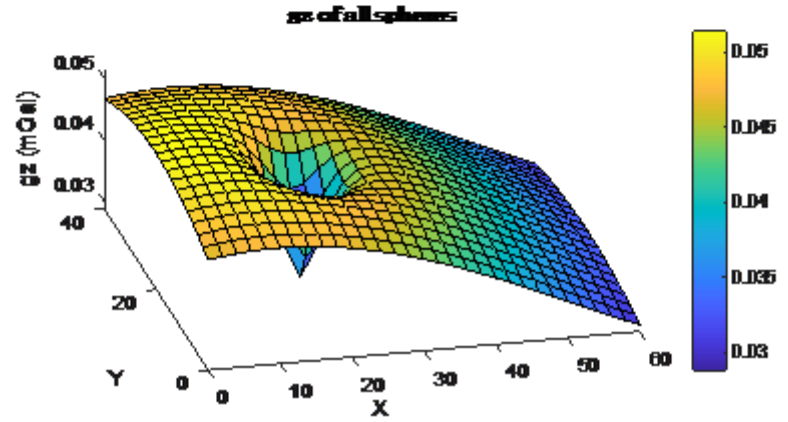
Large distance: long-wavelength

Small distance: short-wavelength

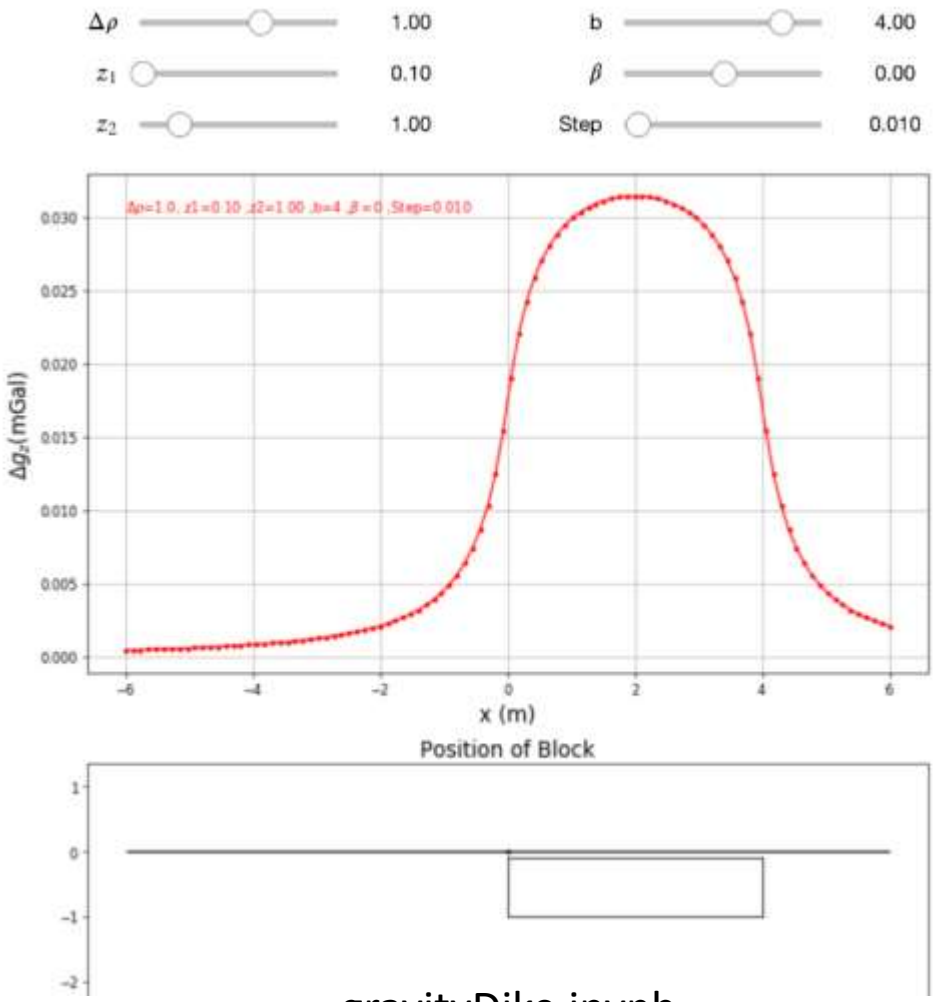








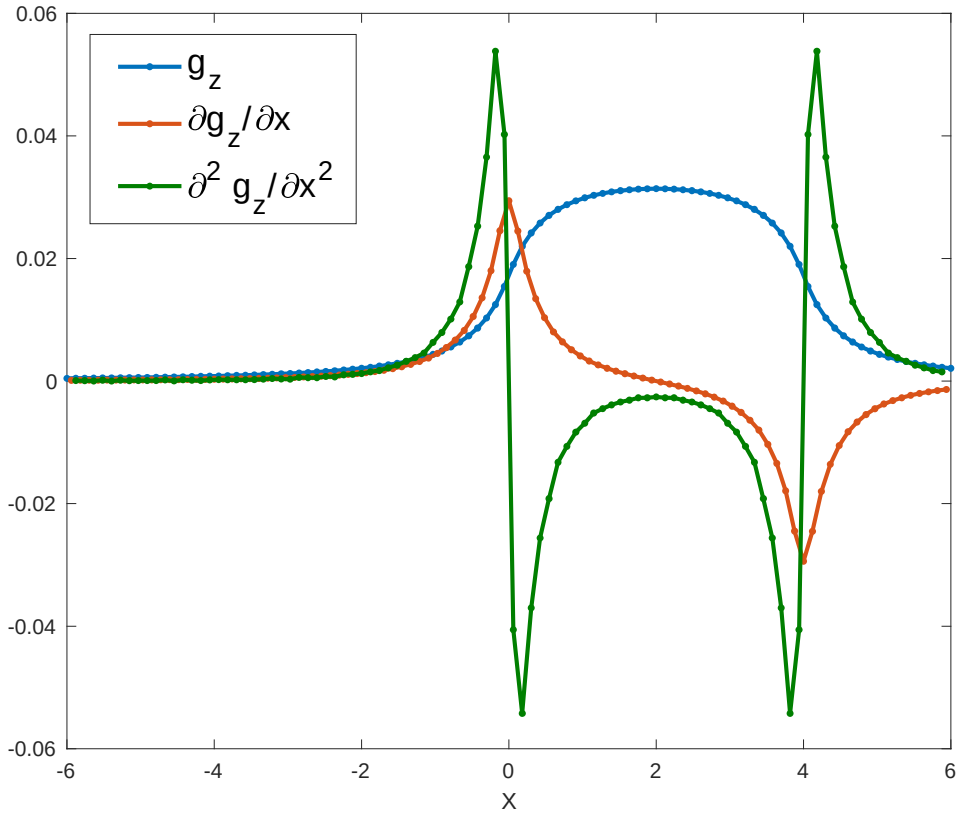
Horizontal Derivative



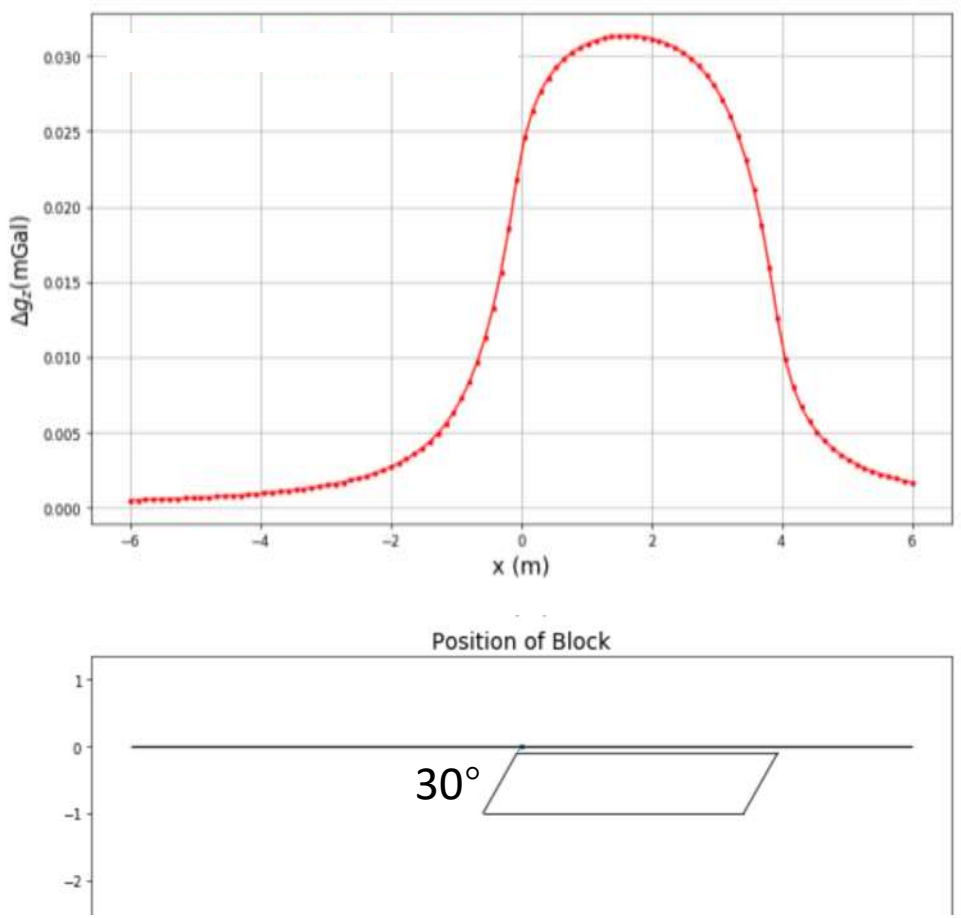
gravityDike.ipynb

Draw the first and second horizontal derivatives

Which derivative is more useful in defining the edges?

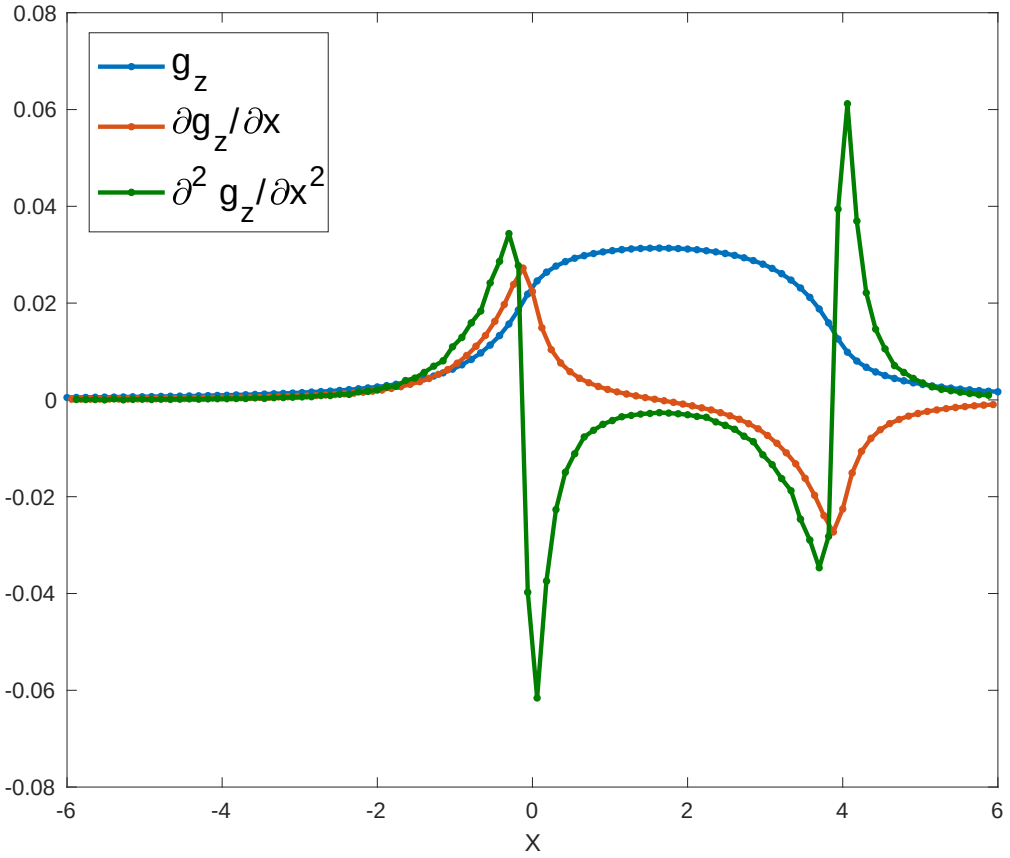


Horizontal Derivative

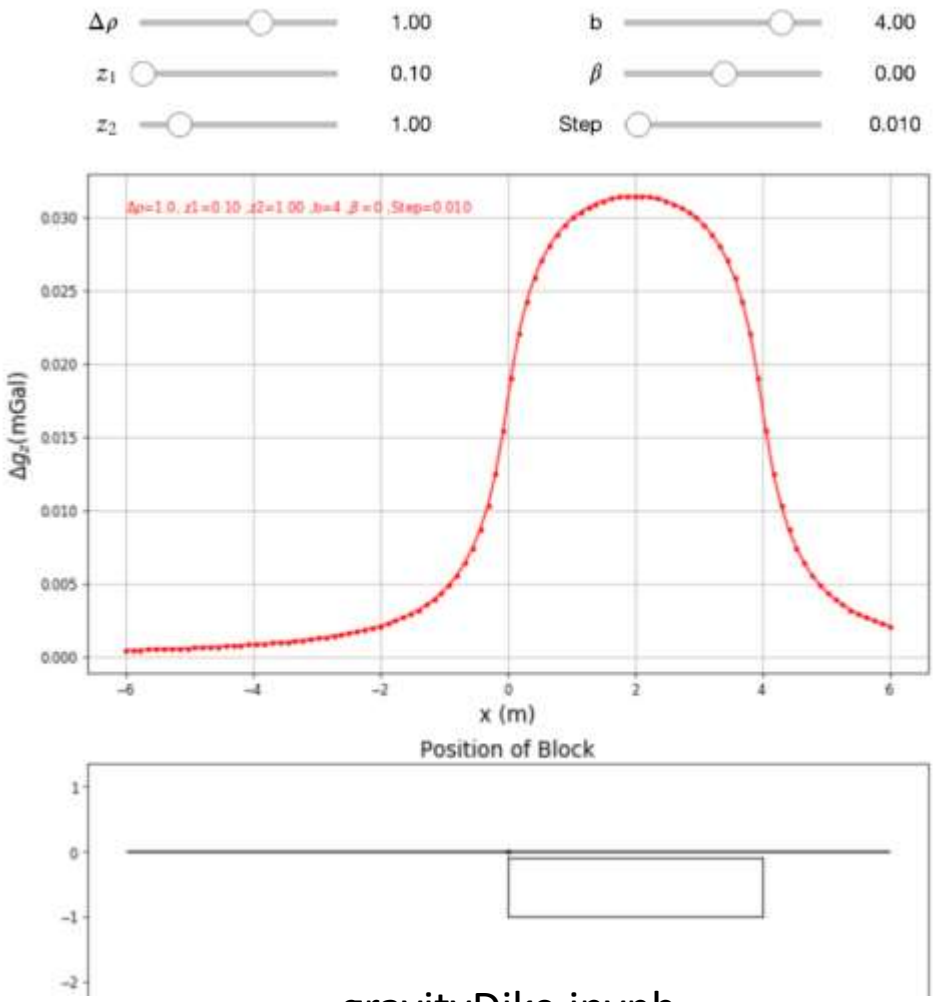


Can you tell the dipping direction from g_z?

Which derivative is more useful in finding the dip?

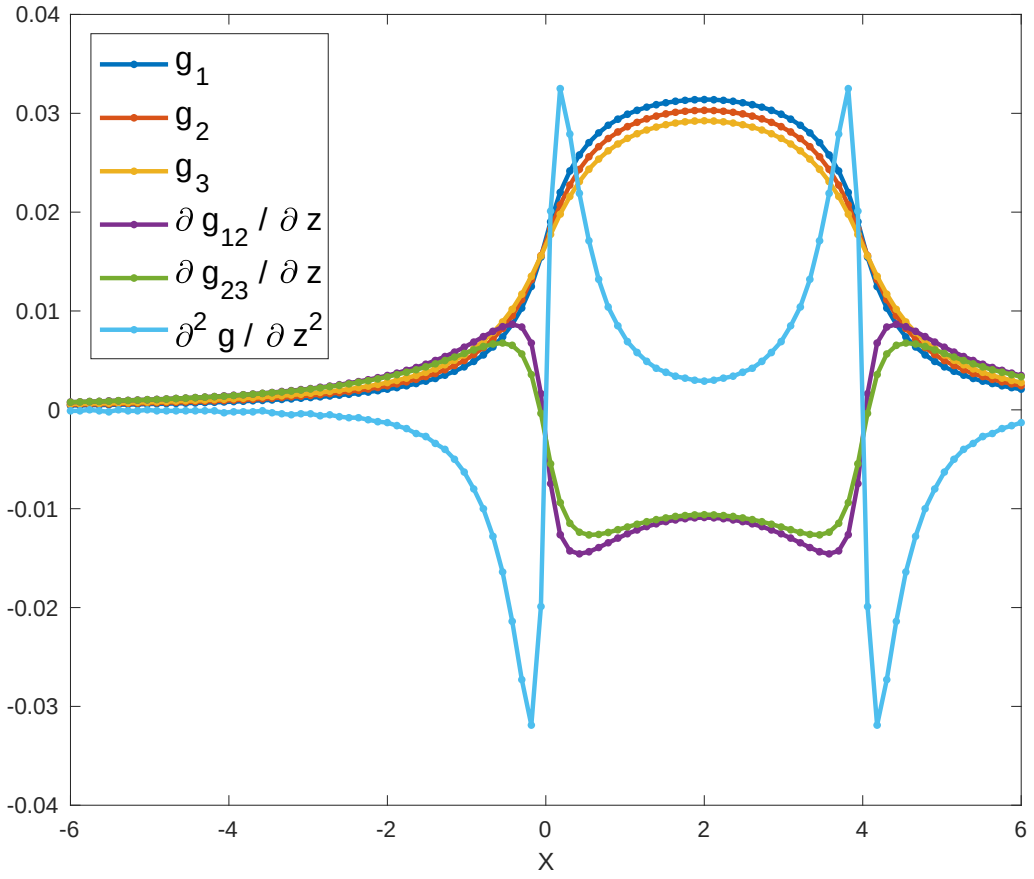


Vertical Derivatives

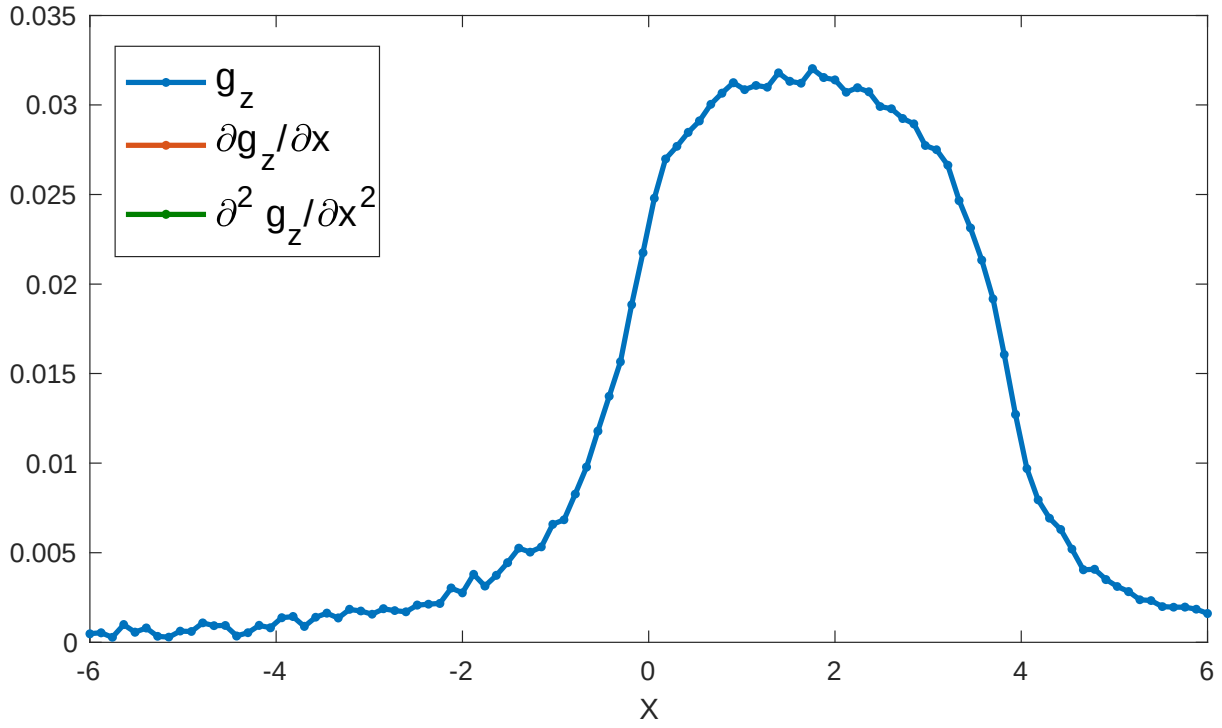


gravityDike.ipynb

g_1: 0 m above surface
g_2: 0.1 m above surface
g_3: 0.2 m above surface

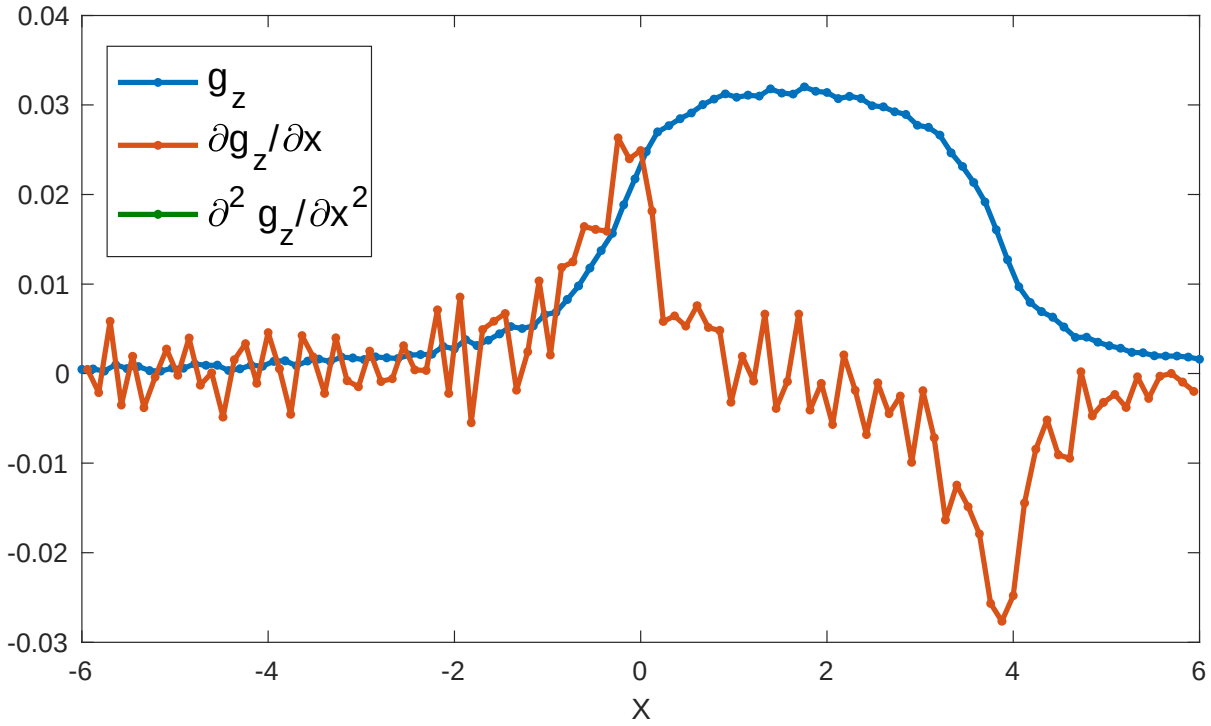


High Order Derivative?



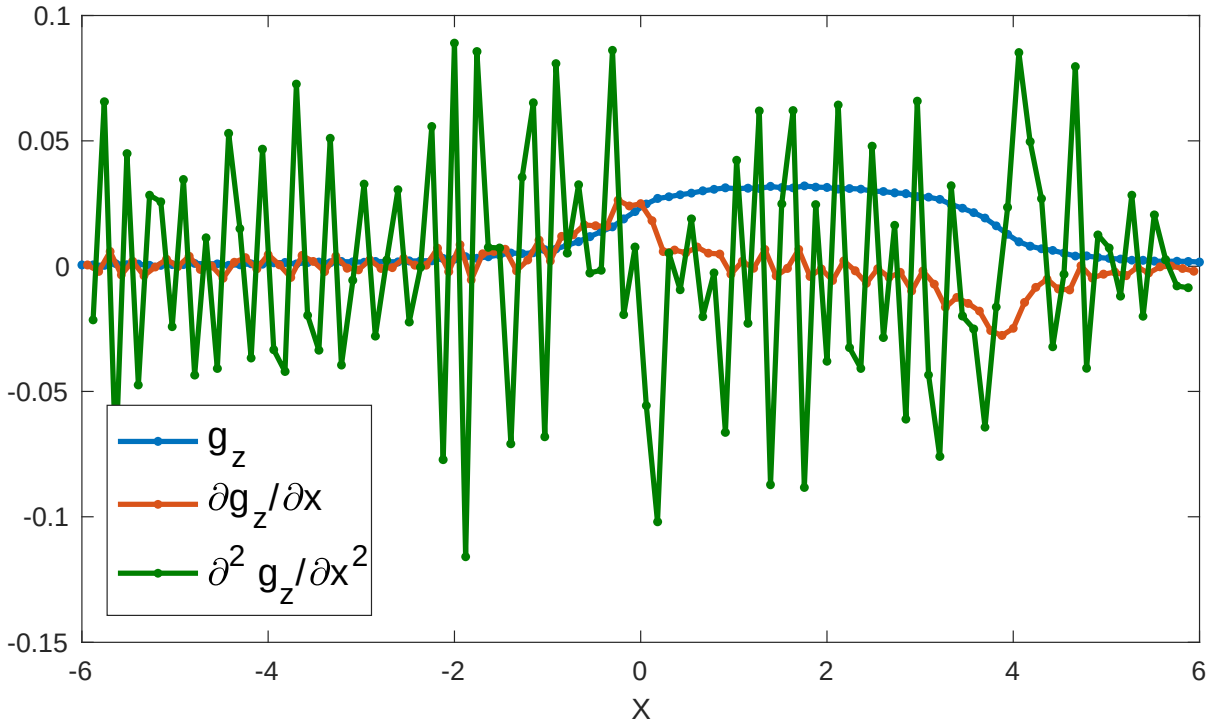
1% Gaussian noise in data

High Order Derivative?



Horizontal 1st derivative: Not too bad

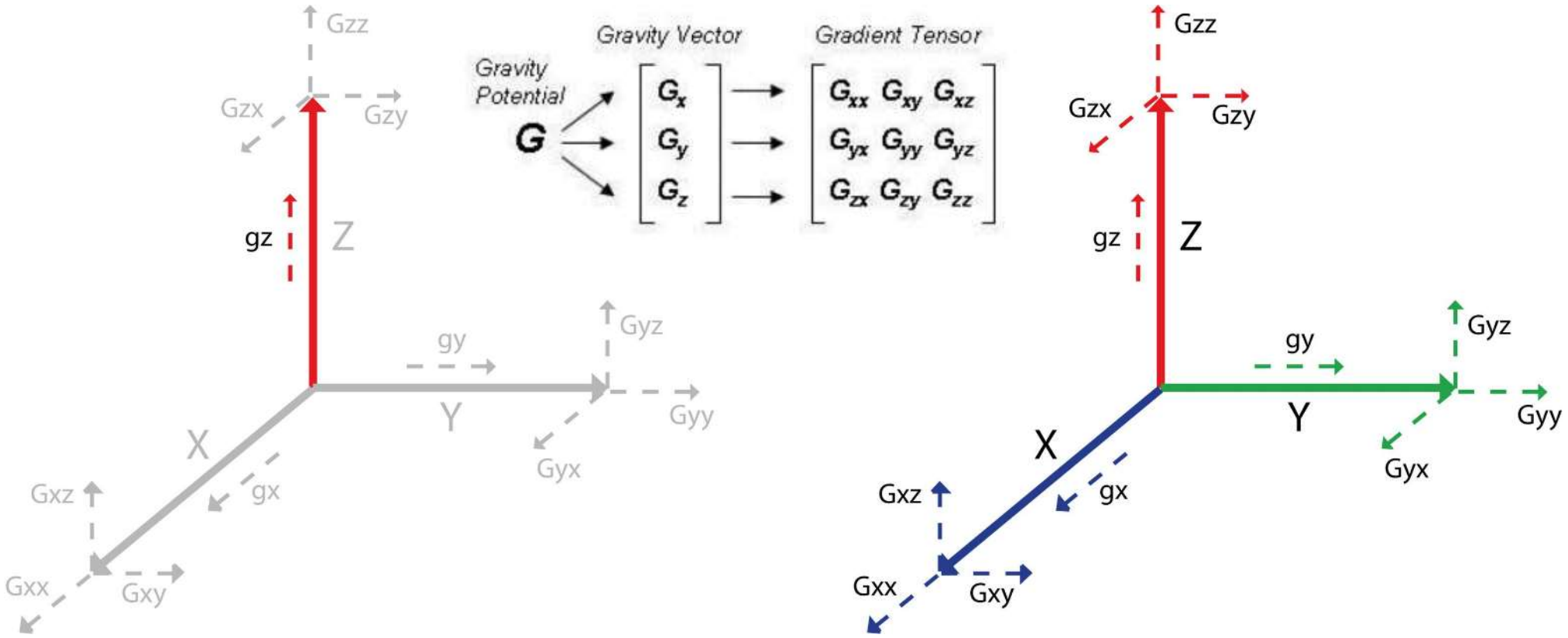
High Order Derivative?



Horizontal 2nd derivative: Caution!

Derivative magnifies noise in data

Full Tensor Gradient: More from g_x and g_y



3D-FTG

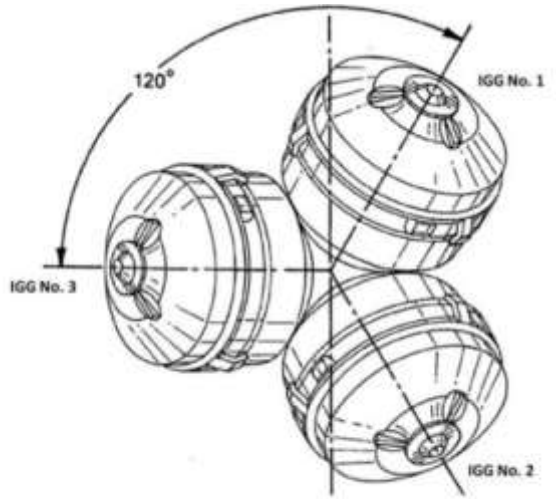


Figure 3 – Umbrella-like arrangement of Gravity Gradient Instruments (GGI) according to Brett & Brewster (2010).

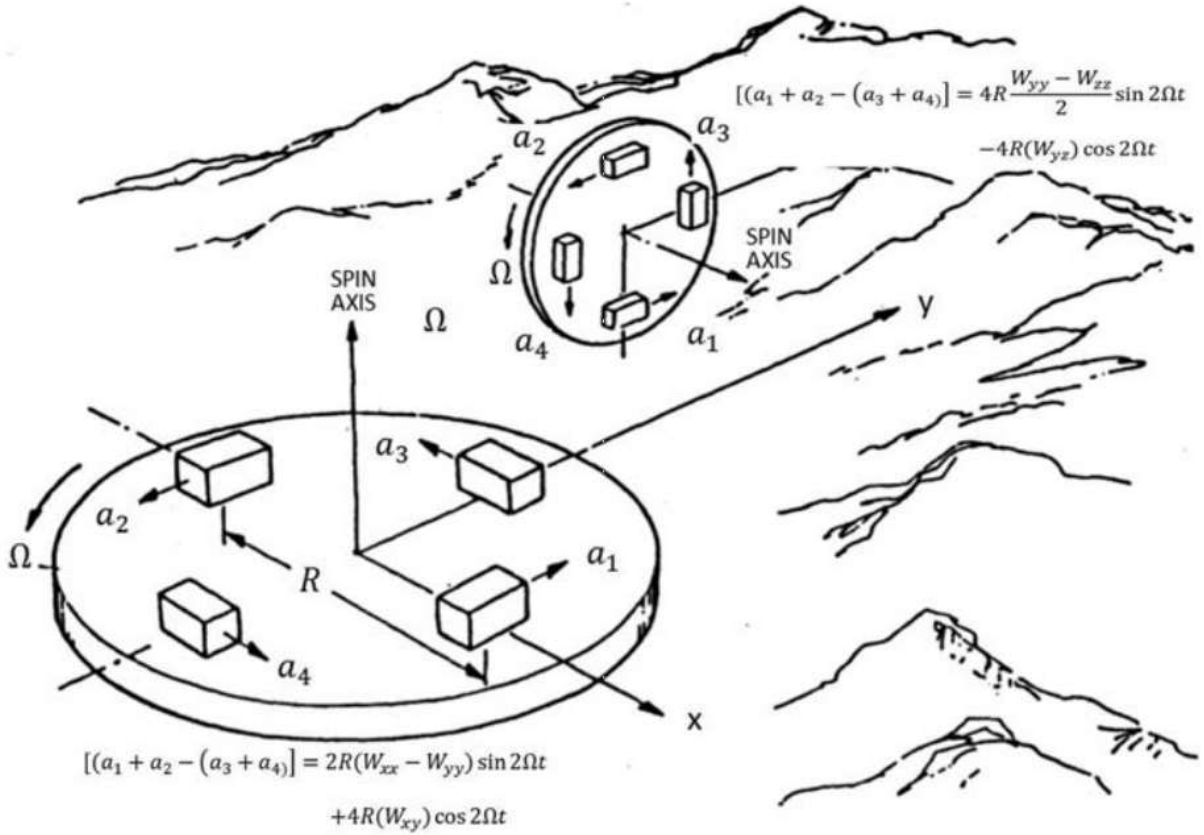
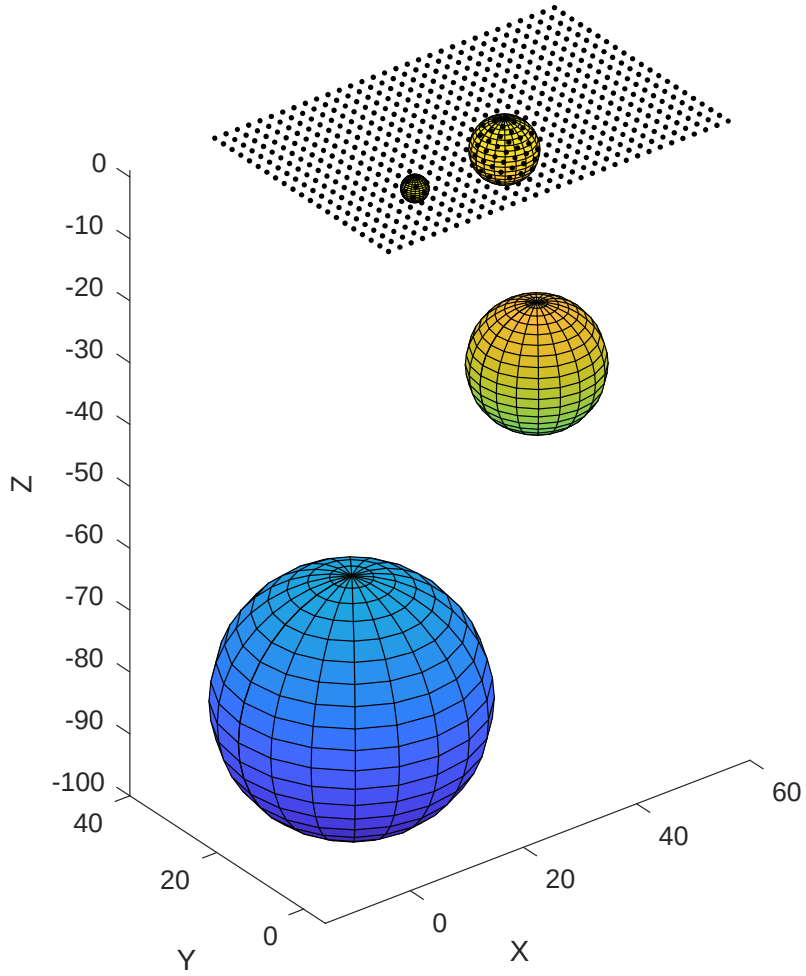
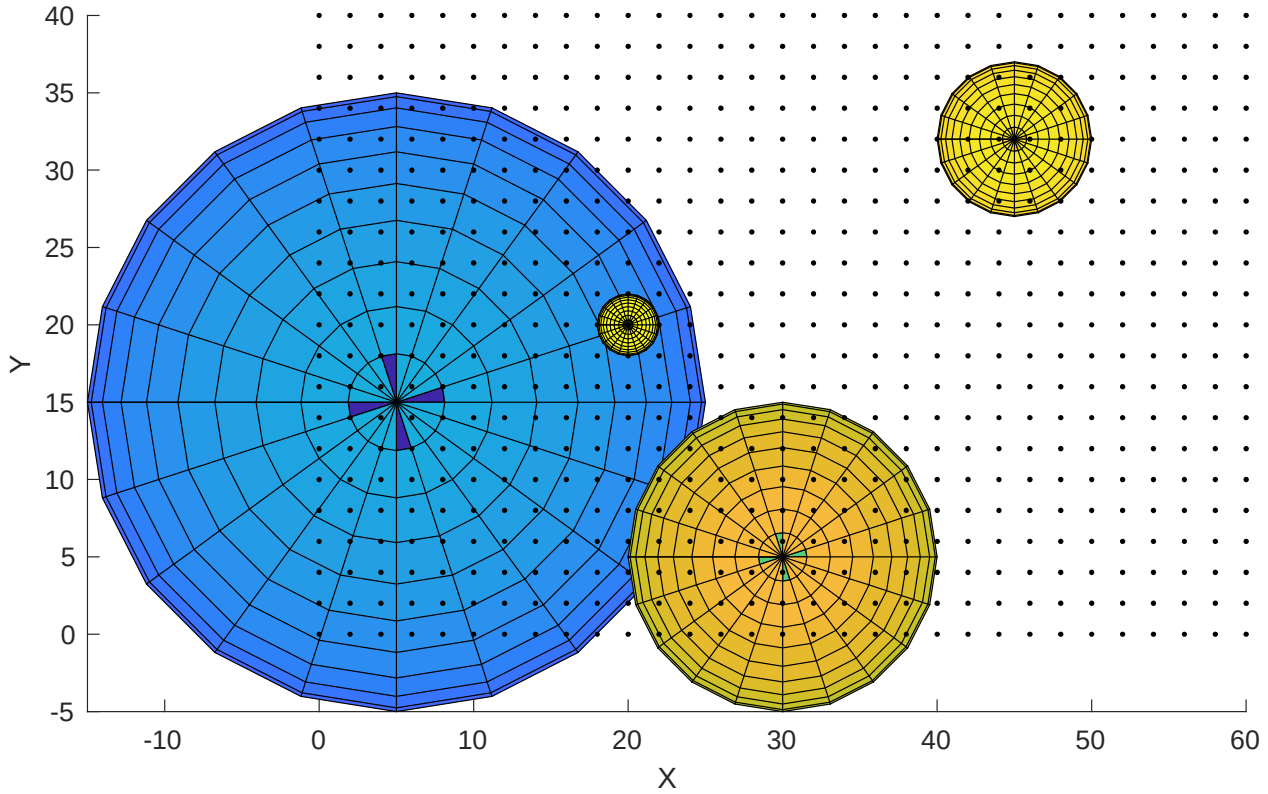


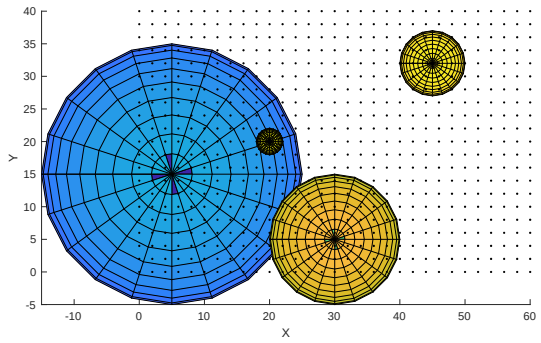
Figure 2 – Representation of rotational accelerometers gravity gradient according to Metzger (1986).

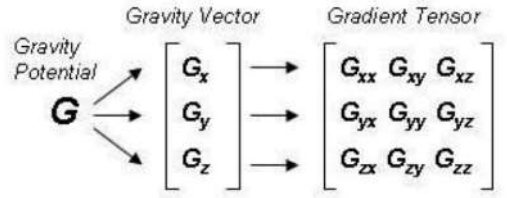
The Four-Sphere Model

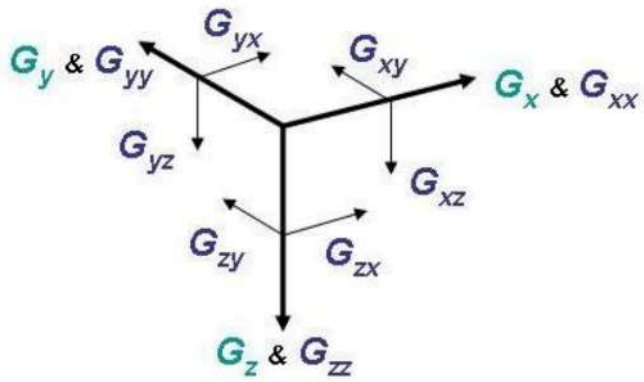


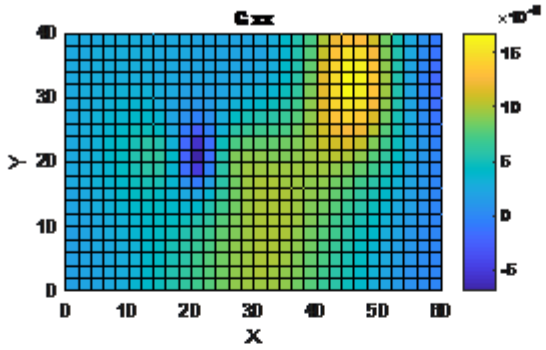


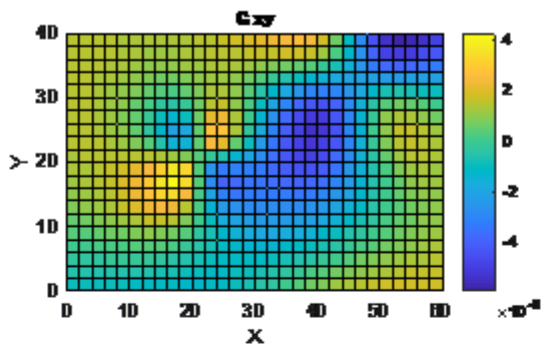
Full Tensor Gravity Gradient

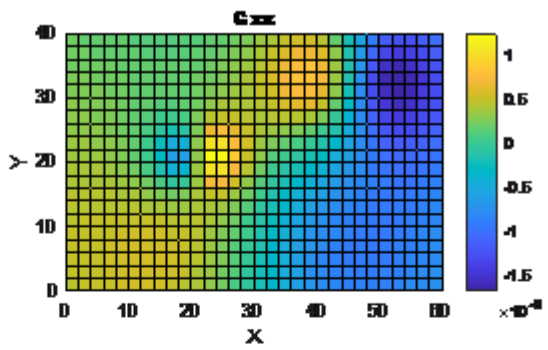


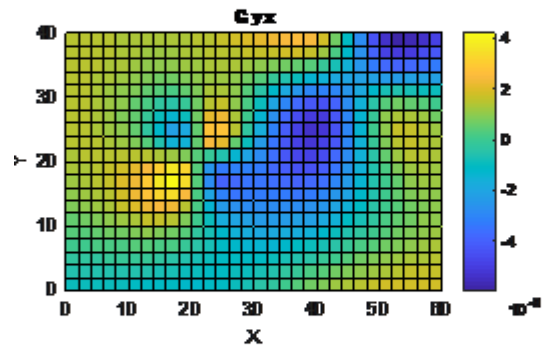


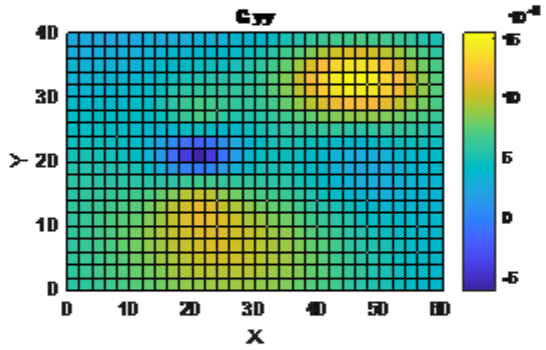


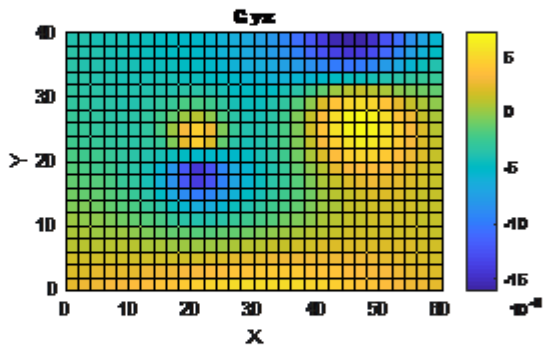


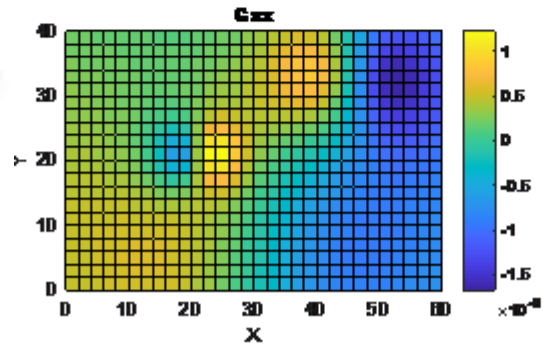


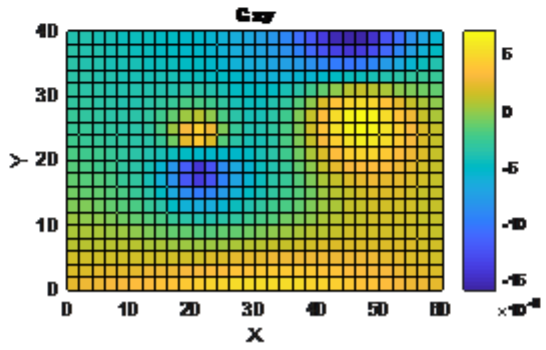


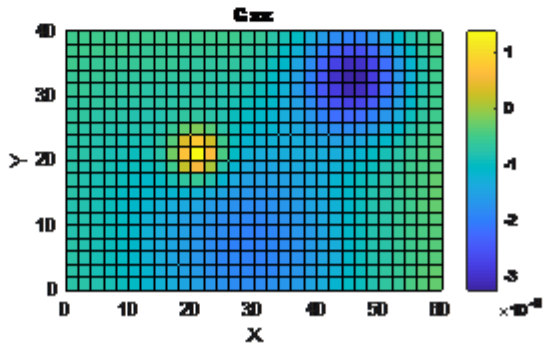




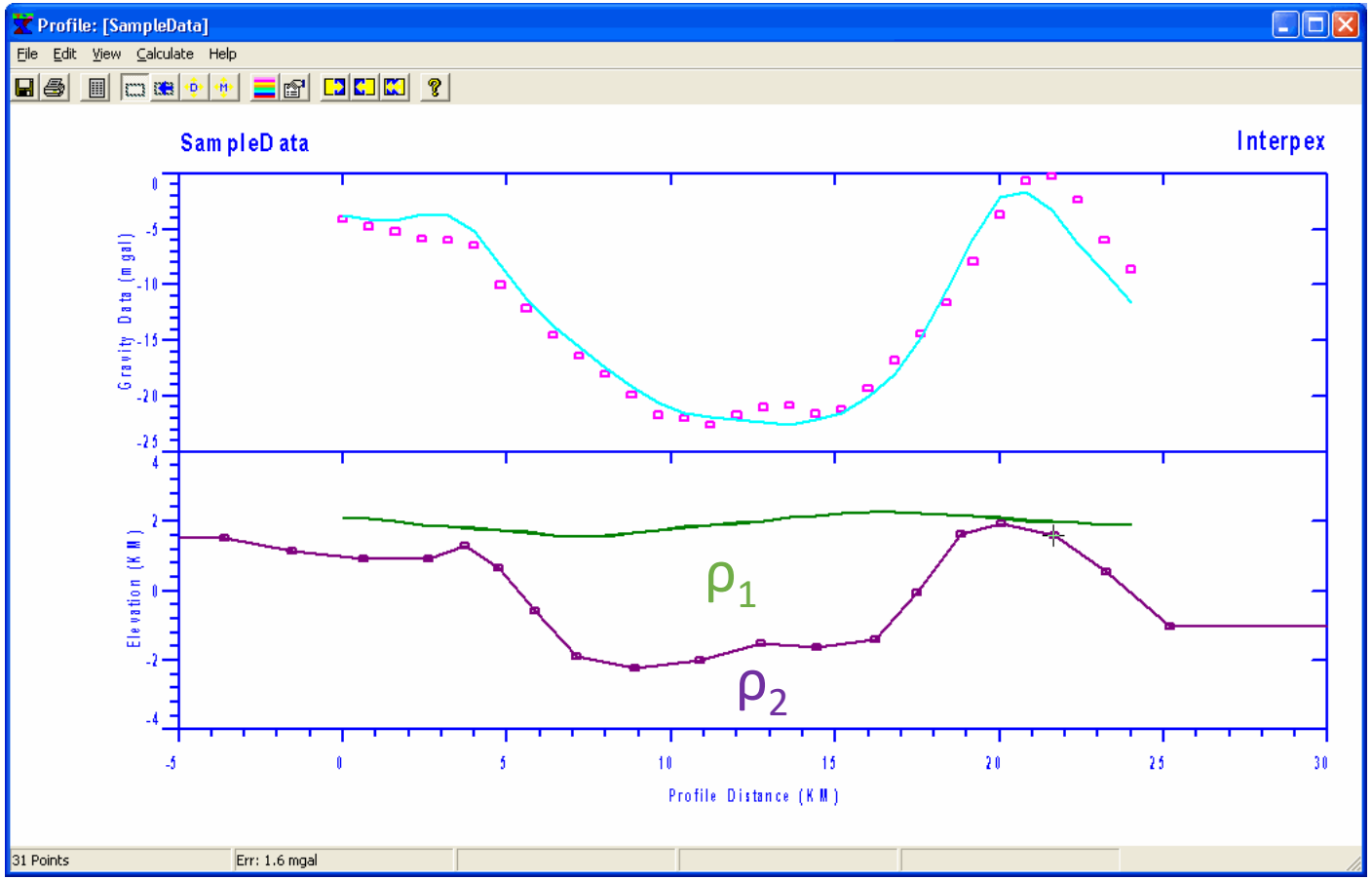




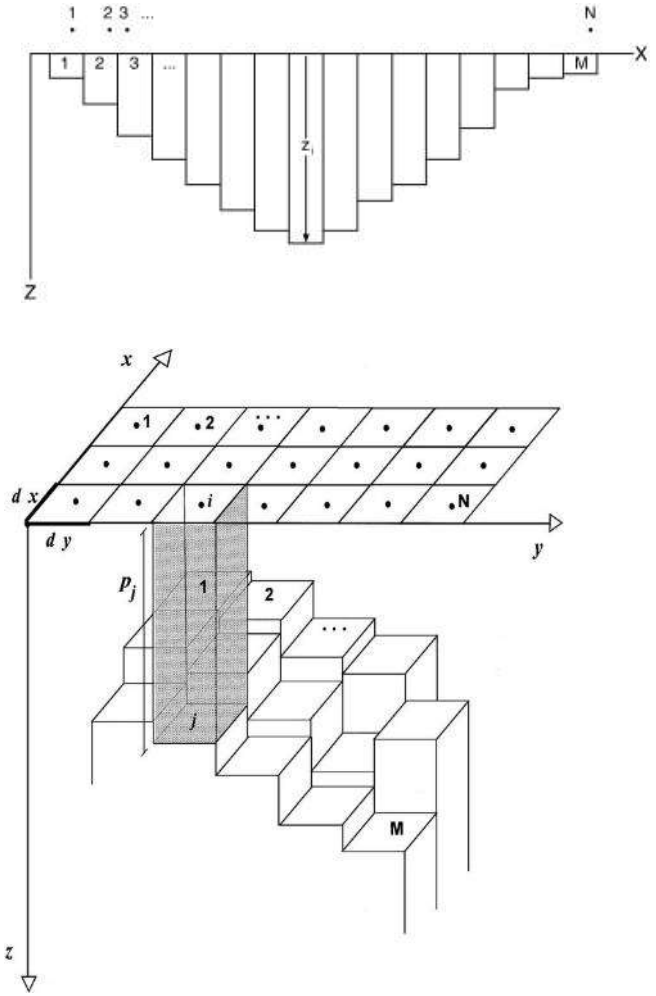


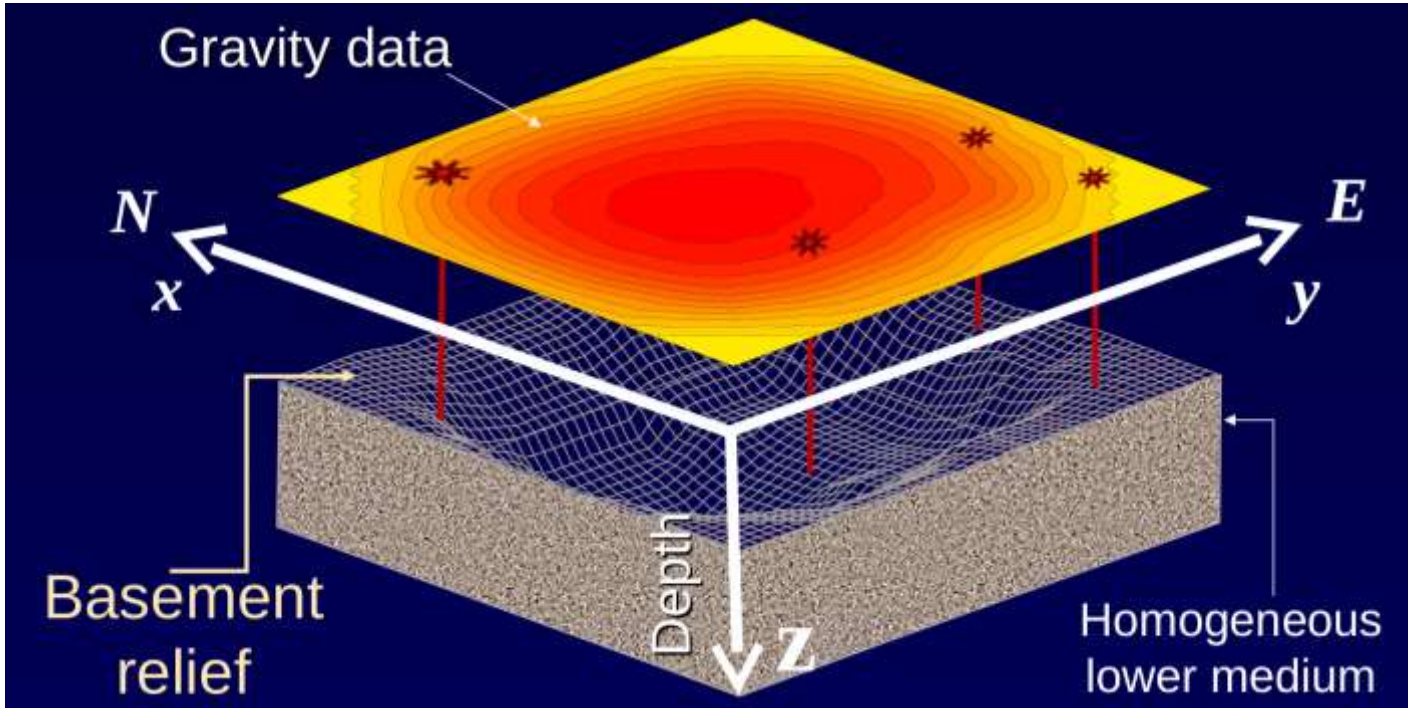


Geometric Inversion - Interactive

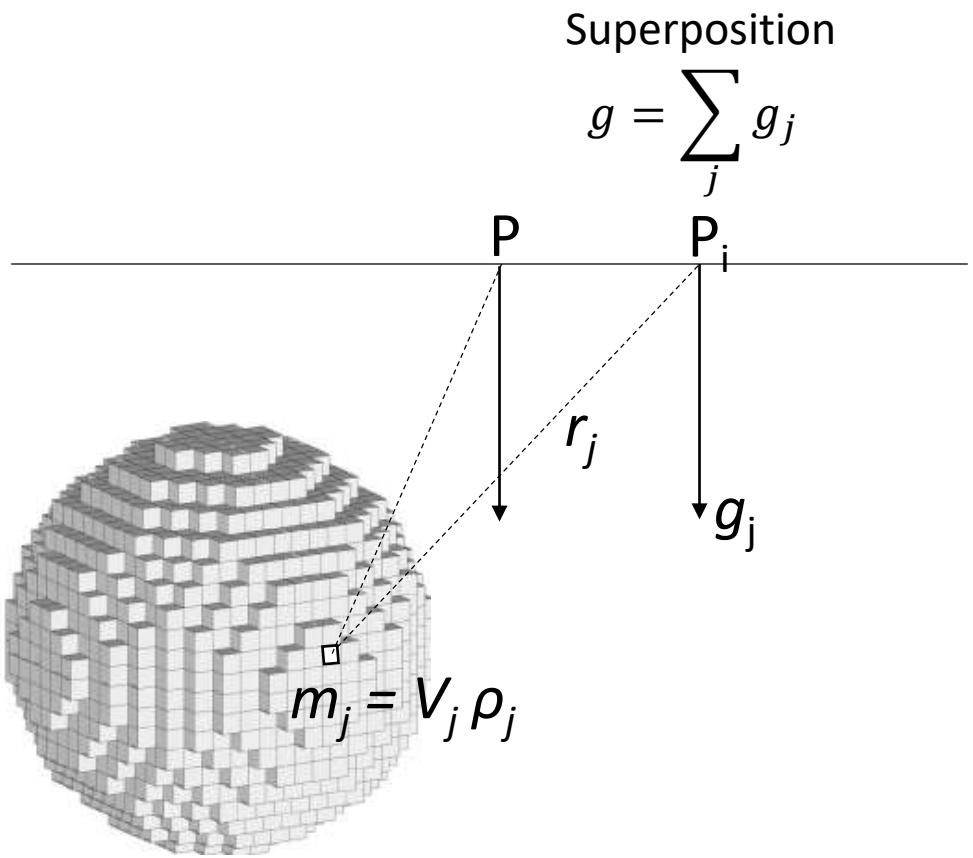


Geometric Inversion - Basement Relief





Pixel/Voxel Inversion



Data = Integration over a volume:
Not enough information to fully recover the true model

$$\begin{bmatrix} & A & \end{bmatrix} \begin{bmatrix} \boldsymbol{\rho} \end{bmatrix} = \begin{bmatrix} \boldsymbol{d} \end{bmatrix}$$

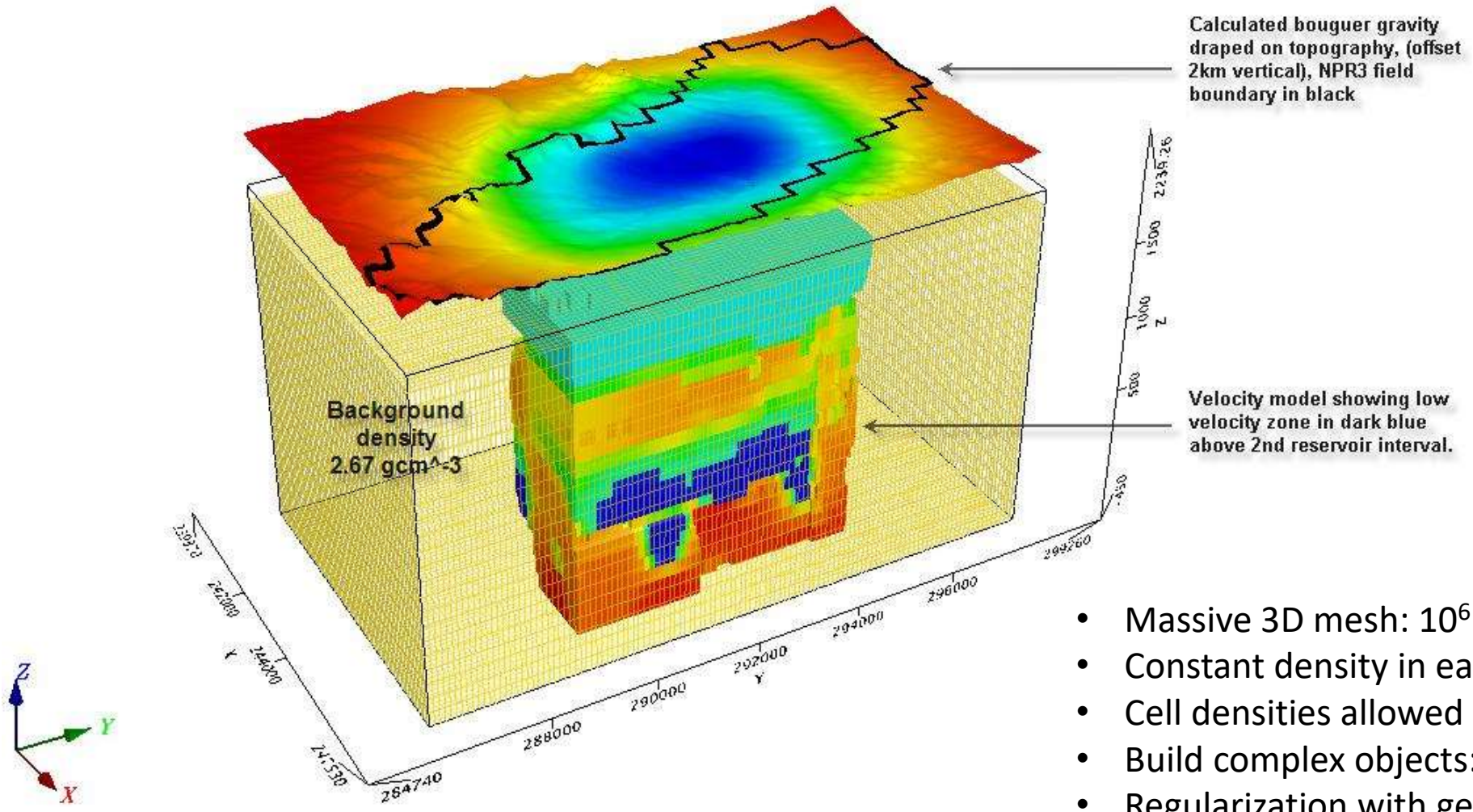
A_{ij}: Contribution of the j^{th} element to the i^{th} datum

Linear problem but the **inverse problem is ill-posed**!

So the piece-wise constant density model $\boldsymbol{\rho}$ is

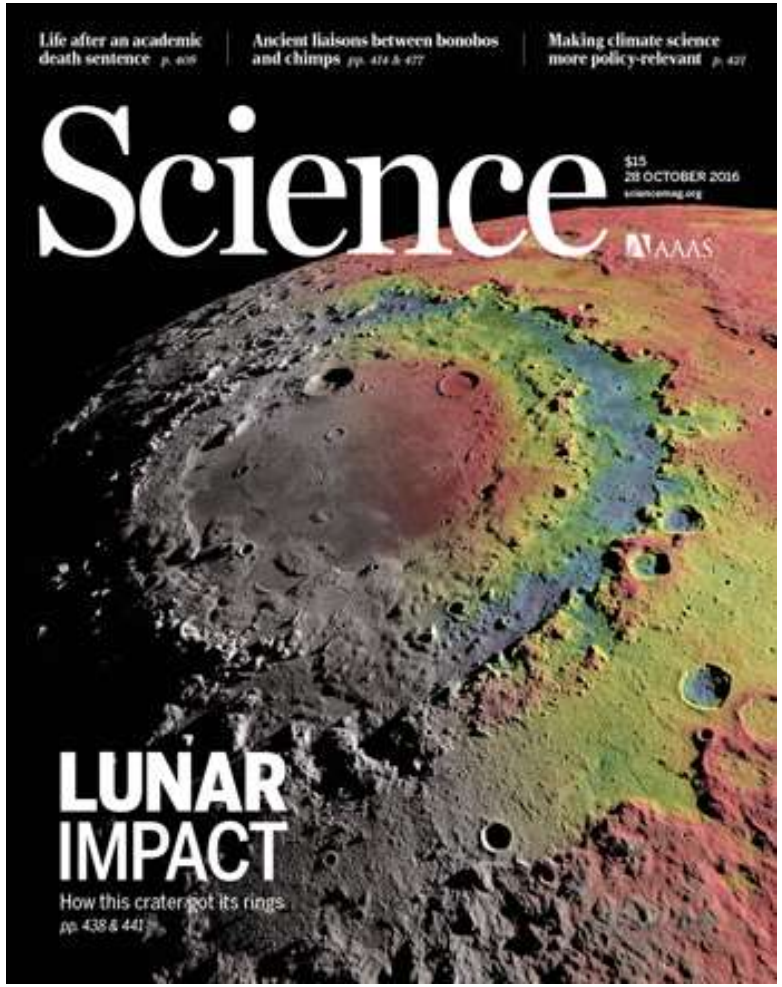
$$\begin{bmatrix} \boldsymbol{\rho} \end{bmatrix} = \begin{bmatrix} & A & \end{bmatrix}^{-1} \begin{bmatrix} \boldsymbol{d} \end{bmatrix}$$???

3D Voxel Inversion



- Massive 3D mesh: 10^6 cells
- Constant density in each cell
- Cell densities allowed to vary
- Build complex objects: like Lego
- Regularization with geological a prior information

Planetary Science – Crater on Moon



Gravity field of the Orientale basin from the Gravity Recovery and Interior Laboratory Mission

Maria T. Zuber[1,*], David E. Smith[1], Gregory A. Neumann[2], Sander Goossens[3], Jeffrey C. Andrews-Hanna[4,5], James W. Head[6], Walter S. Kiefer[7], Sami W. Asmar[8], Alexander S. Konopliv[8], Frank G. Lemoine[2], Isamu Matsuyama[9], H. Jay Melosh[10], Patrick J. McGovern[7], Francis Nimmo[11], Roger J. Phillips[5], Sean C. Solomon[12,13], G. Jeffrey Taylor[14], Michael M. Watkins[8,15], Mark A. Wieczorek[16], James G. Williams[8], Johanna C. Jansen[4], Brandon C. Johnson[1,6], James T. Keane[9], Erwan Mazarico[2], Katarina Miljković[1,17], Ryan S. Park[8], Jason M. Soderblom[1], Dah-Ning Yuan[8]

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– Hide authors and affiliations

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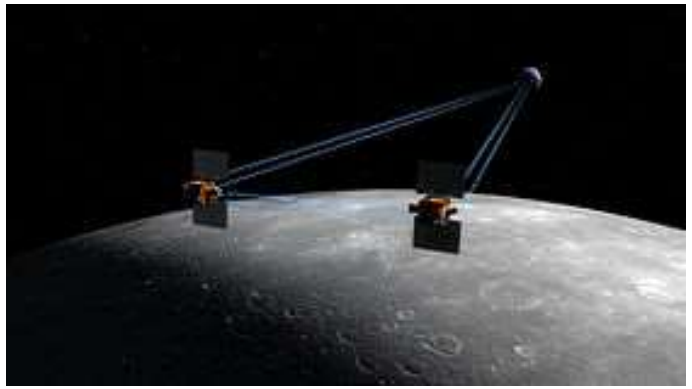
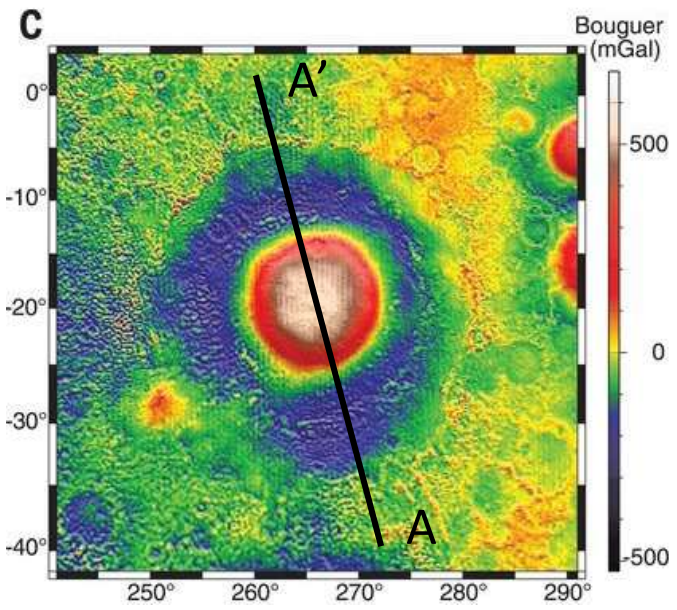
http://science.sciencemag.org/content/354/6311/438

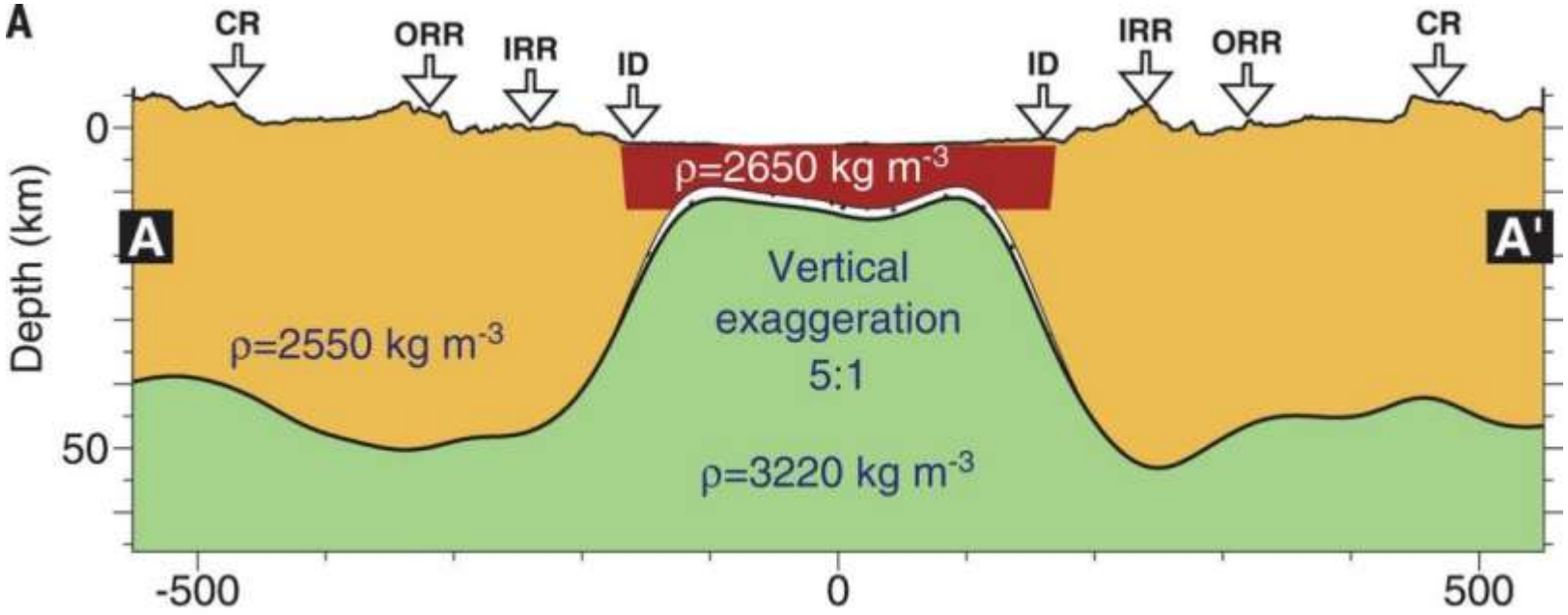


GRAIL

https://youtu.be/_hknIsPNsl8

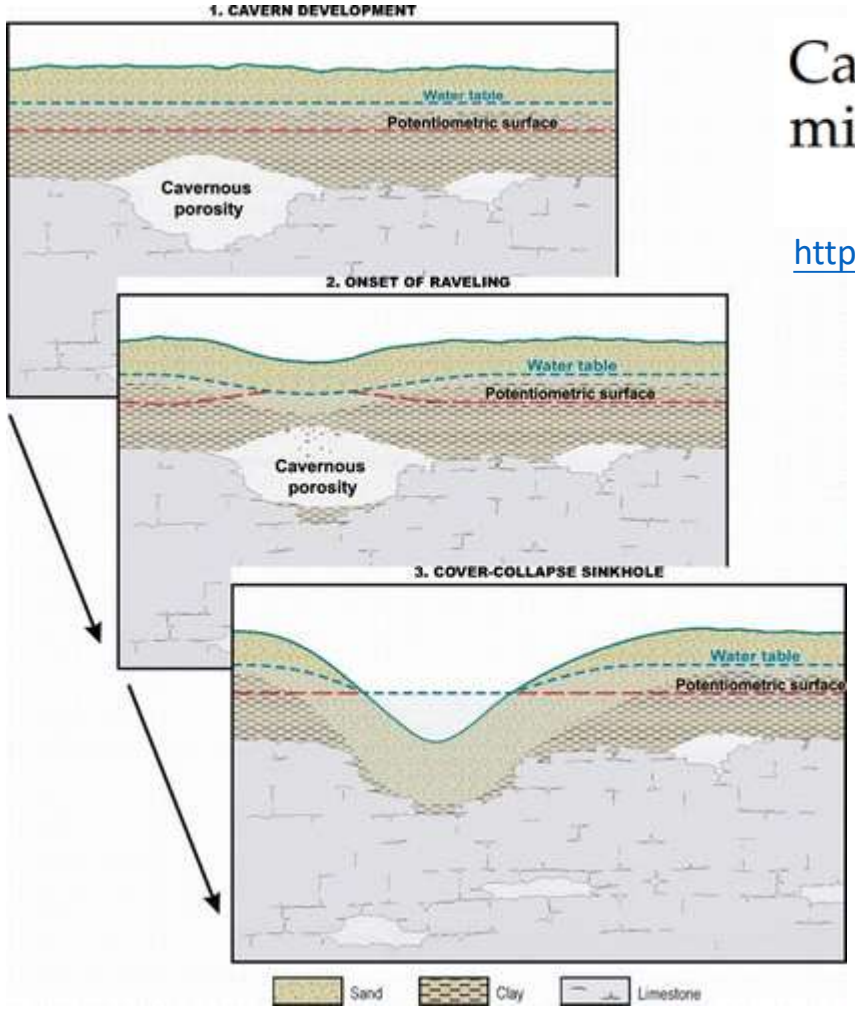
Density of the Moon's Interior





Can you sketch a density structure along the cross section A-A'?

Environmental – Sinkholes

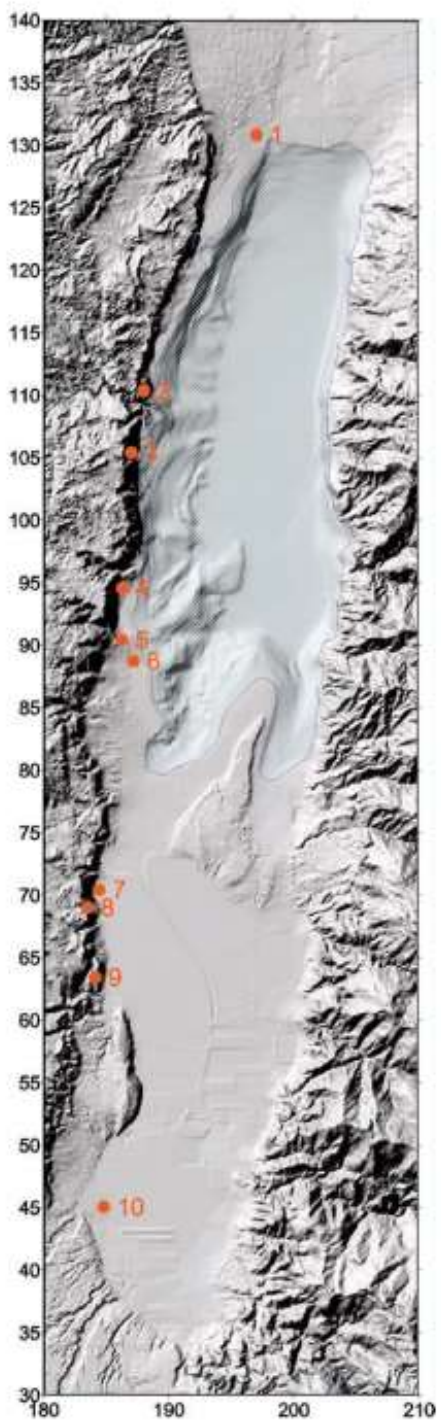


Cave detection and 4-D monitoring: A microgravity case history near the Dead Sea

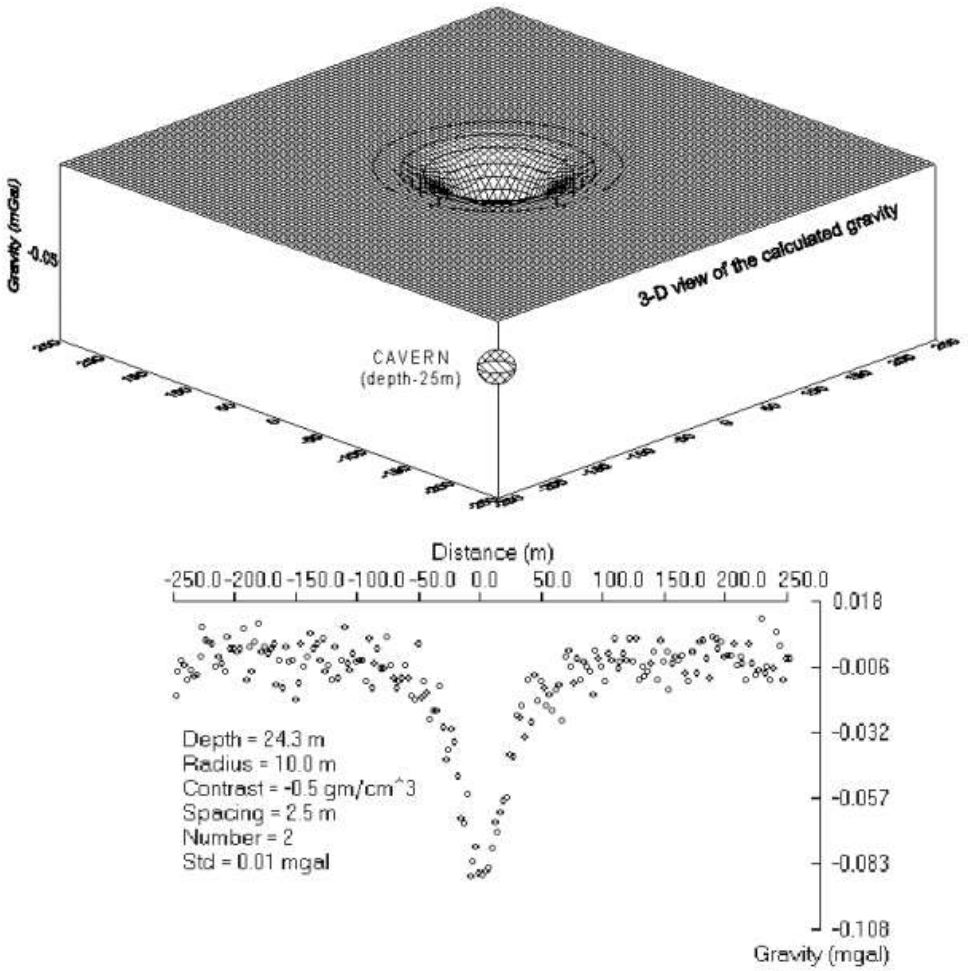
M. Rybakov, V. Goldshmidt, L. Fleischer, and Y. Rotstein, The Geophysical Institute of Israel

https://library.seg.org/doi/pdf/10.1190/1.1487303n

Figure 2. One of largest sinkholes in the Dead Sea area (after Gilat, 1999).



Forward Modeling: Feasibility Study



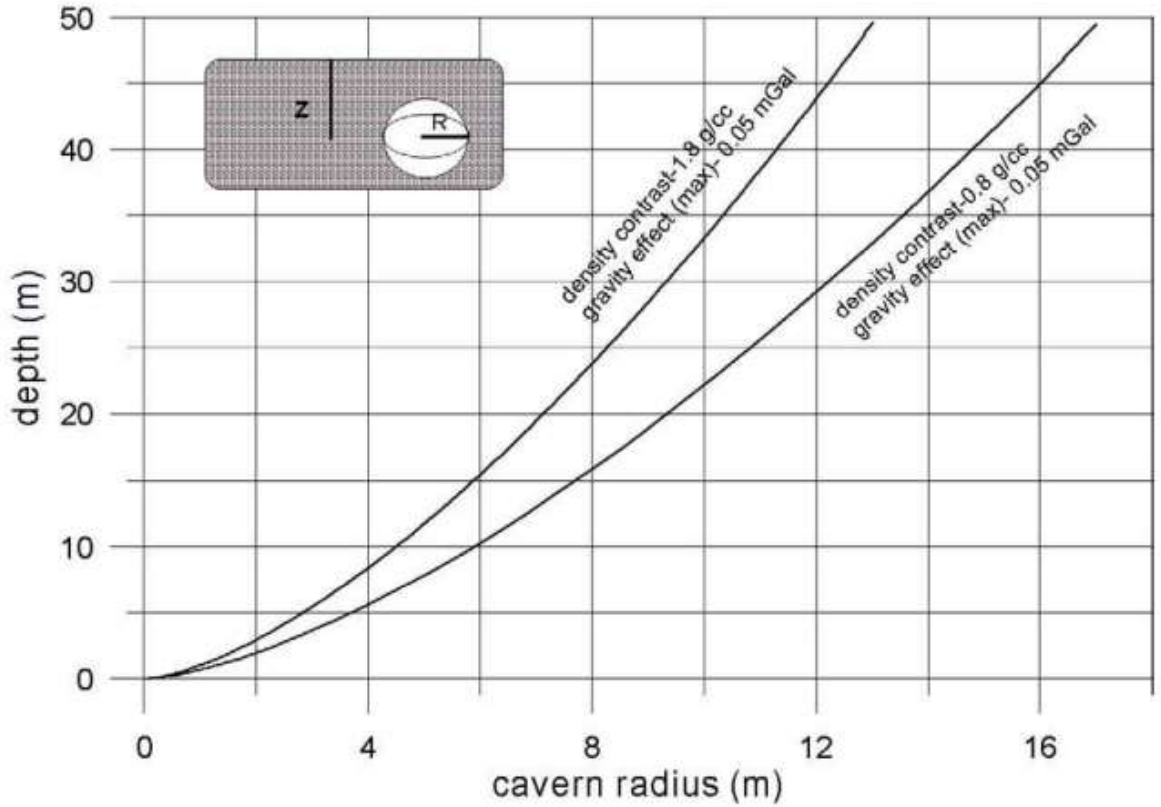
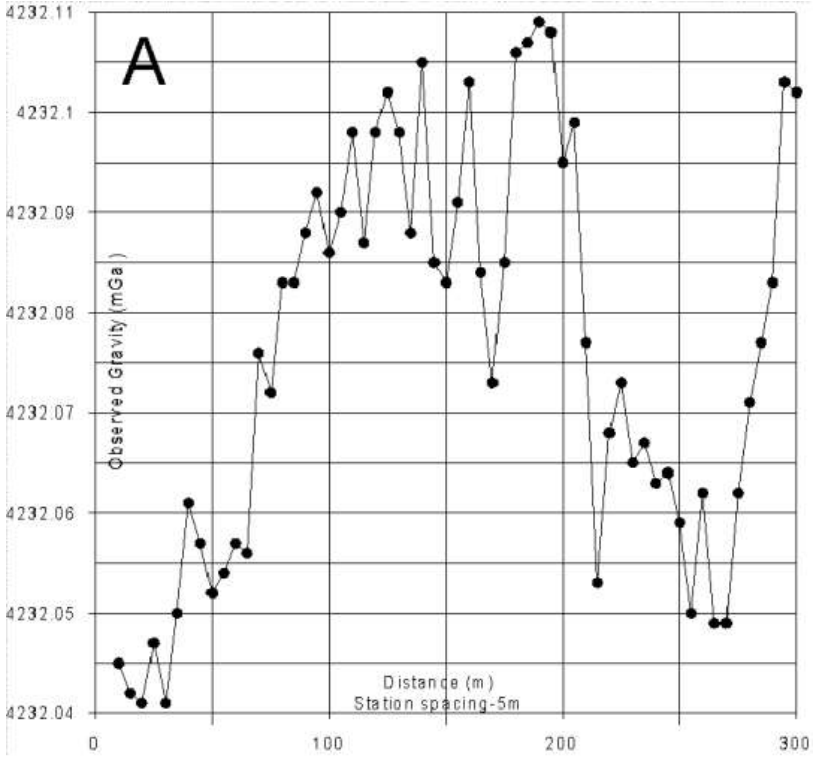


Figure 6. Effect of detectability threshold level and density contrast—maximum depth for detection of spherical concealed cavern. Large density contrast corresponds to air-filled cavern and small density contrast to saltwater-filled cavern.

Cavern Mapping Result



Raw gravity data along a line

- Gravimeter accuracy 0.005 mGal
- Scintrex CG-3M: 0.001 mGal
- Geodetic control: Laser Total Station (a few mm)
- Real-time elevation of the instrument
- Base station repeated hourly
- Repeat measurement: 10% of all stations
- Fully terrain corrected: 25-m grid DTM + precise local survey near the station

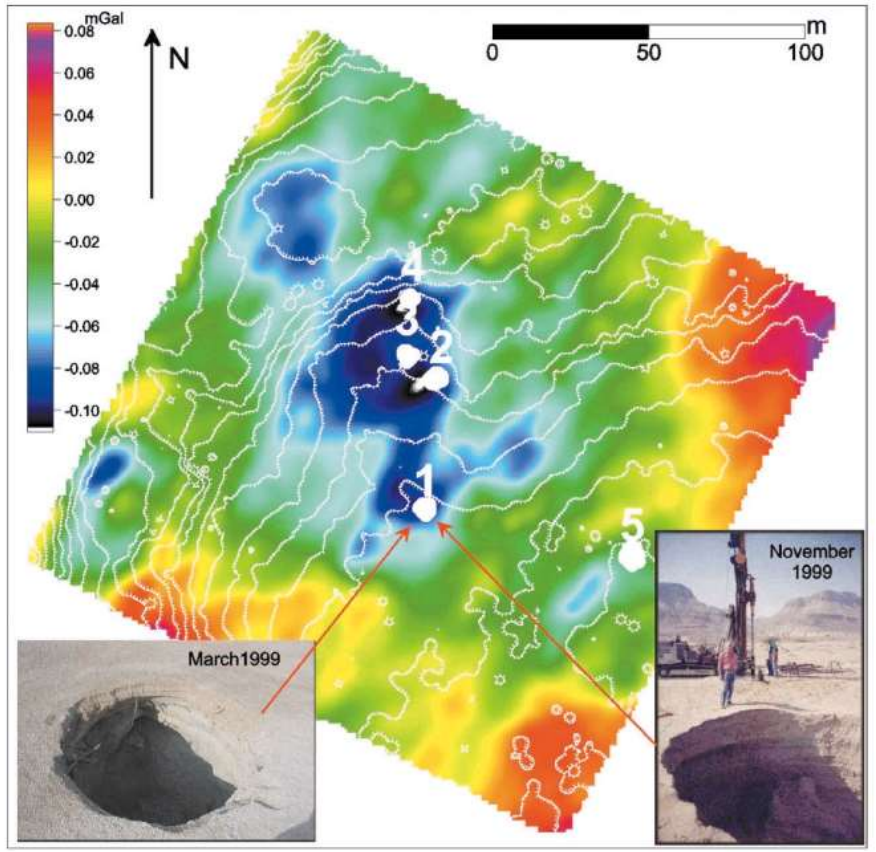
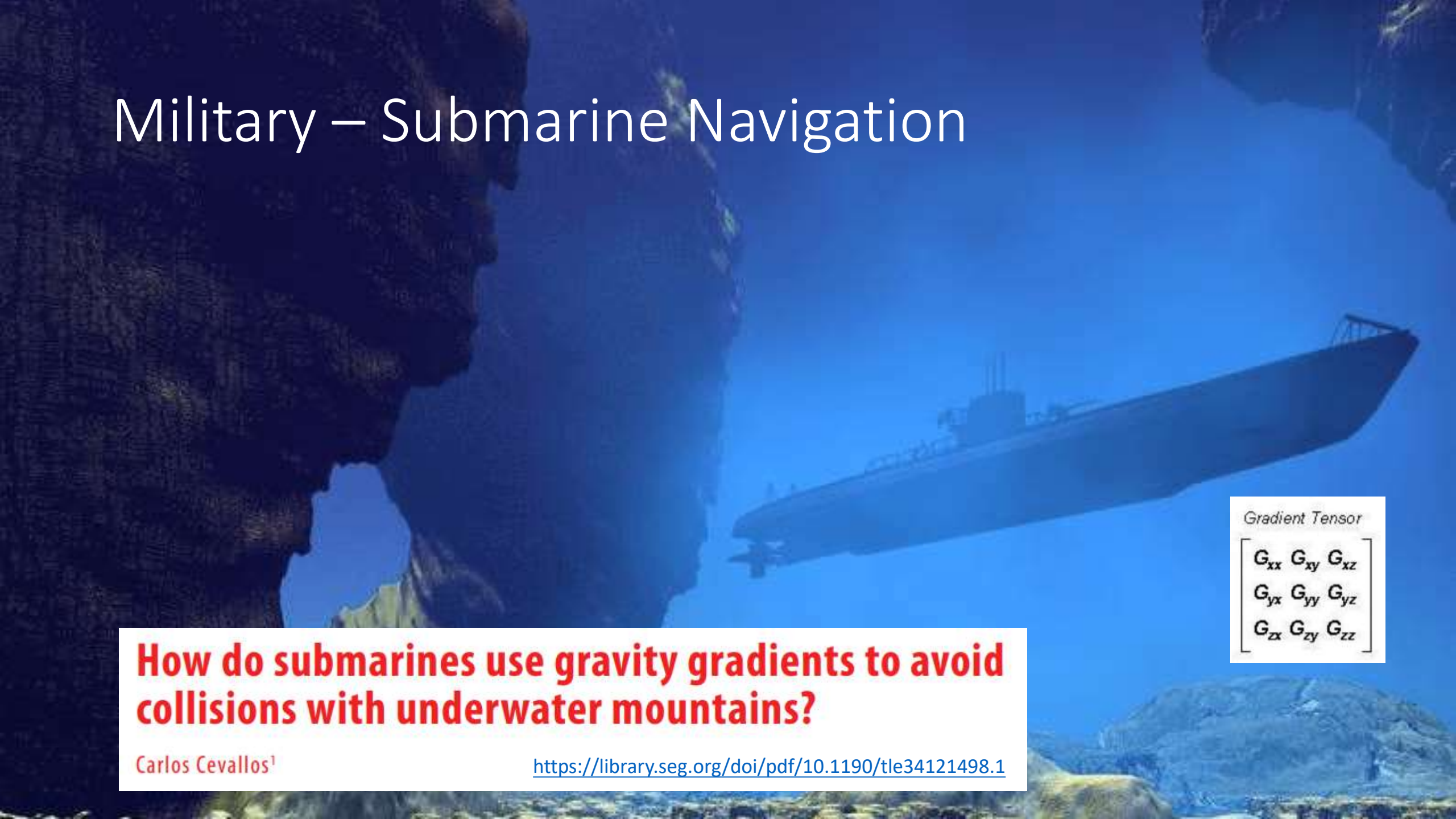


Figure 9. Residual gravity map of the Hever site superimposed by detailed topography (white contours - 0.25-m interval). White circles denote open sinkholes. Photos show growth of sinkhole 1 between March and November 1999.

Military – Submarine Navigation

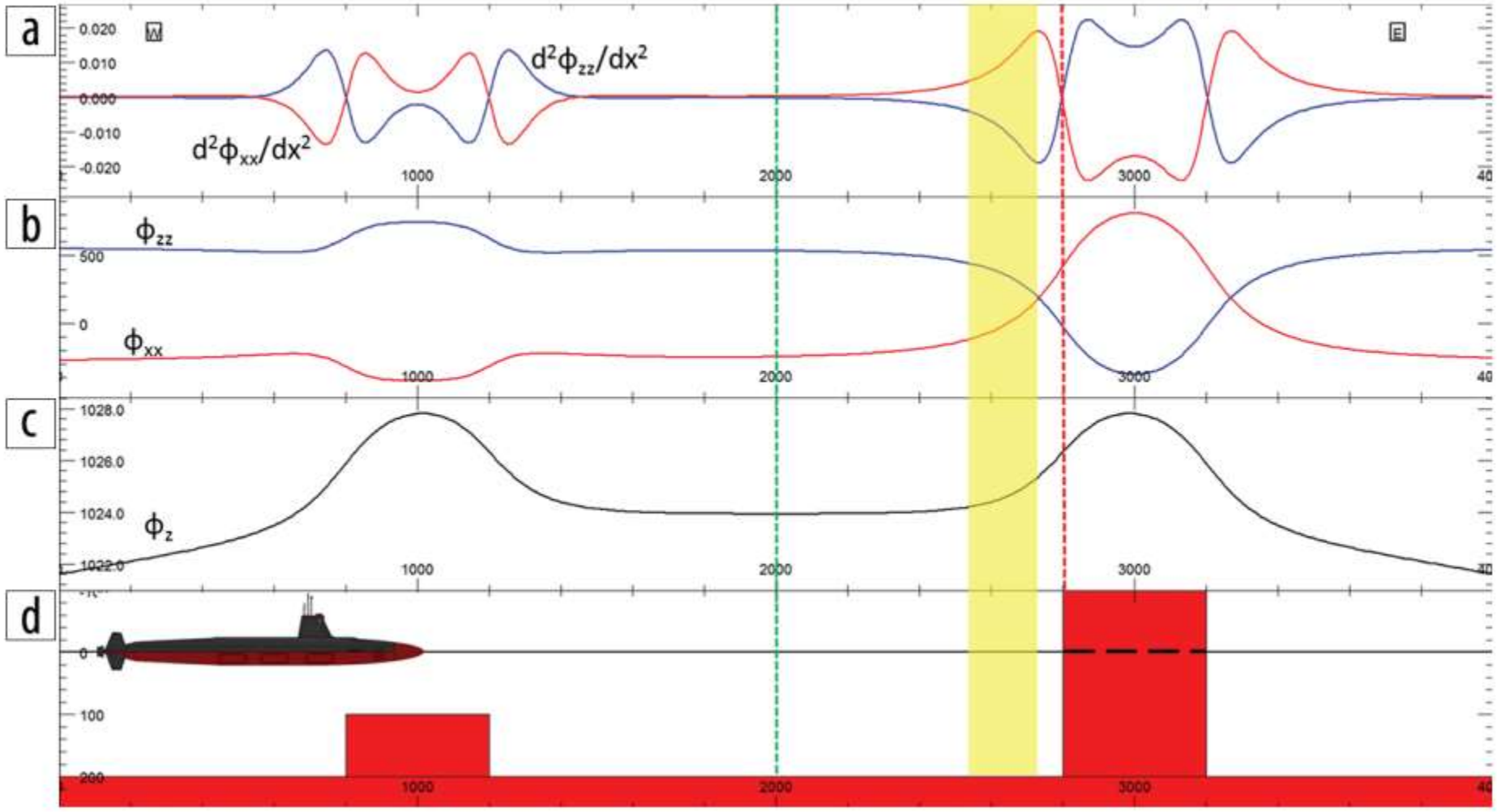


How do submarines use gravity gradients to avoid collisions with underwater mountains?

Carlos Cevallos[1]

https://library.seg.org/doi/pdf/10.1190/tle34121498.1

Military – Submarine Navigation



Collision warning:

- **Φxx** is increasing
- **Φzz** is diminishing
- The second horizontal derivatives of **Φxx** and **Φzz** attain a maximum and a minimum, respectively

Can gravity gradient be used to detect another submarine?

Summary

- Nature of gravity data: Ambiguity
- Approaches to identify sources of signals:
  - Regional removal
  - Upward/downward continuation
  - Derivatives
  - Full tensor gradients
- Gravity inversion
- Applications: Planetary science, environmental, military, basin, etc.
- What’s your impression about the gravity method?