ISN’T GRAVITY A CONSTANT?
Speaker Information

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- March 4th, 2016
Summary

- Gravitational attraction
  - Gravity constant
  - Gravity strength around the world
  - Flat earth
  - Round earth
  - Real earth shape
  - Satellite image?
  - How we measure gravity
  - Lab / calibration
  - Down hole
  - Difference between gravity and movement of sensor

- Why TGF QC is important
  - Effect of scale factor error
  - Effect of bias error
  - Effect of movement
  - Effect of gravitational error

- Effect of movement error
  - on inclination
  - on azimuth

- Proposed solution
  - Calibrate to standard gee
  - Survey companies who do this already
  - Reminder to ensure that tools in transition are identified
Newton – which way is down?
We measure acceleration not “g”
Flat Earth Society – constant “g”
Modern view of Flat Earth from Space
United Nations supports this view
Round Earth theory
Newton - gravitational attraction

\[ F_0 = G \frac{M_1 M_2}{d^2} \]
Non-gravitational attraction
Earth from Space
But then there’s centrifugal force
Gravitational Variations
Gravitational Variations
# Gravitational Variations

<table>
<thead>
<tr>
<th></th>
<th>Std Gravity</th>
<th>GARM*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Mass</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Earth rotation</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Earth shape</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Depth (TVD)</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Topography</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Anomalies</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Water/Rocks</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Error (1 sigma)</td>
<td>~1.6 mG</td>
<td>~0.3 mG</td>
</tr>
</tbody>
</table>

*Global Acceleration Reference Model (MagVAR/SLB)

http://www.gfz-potsdam.de
Gravitational Waves
Newton - gravitational attraction

\[ F_G = G \frac{M_1 M_2}{d^2} \]

Credit: Pearson Education, Inc.
“g” calculation at Equator

\[ g = G \frac{m_1}{r^2} = (6.67384 \times 10^{-11}) \frac{5.9722 \times 10^{24}}{(6.371 \times 10^6)^2} = 9.8196 \text{m}. \text{s}^{-2} \]

\[ m_1 = \text{mass of Earth (kg)} \]
\[ r = \text{radius of Earth at equator (m)} \]
\[ G = \text{Gravitational Constant} \]

General local “g” calculation

\[ g_0 = 9.780327(1 + 0.0053024 \sin^2 \theta - 0.0000058 \sin^2 2\theta) - 0.000003086 \, h \]

\( \Theta \) = latitude

\( h \) = altitude (m)

## Local calculations

<table>
<thead>
<tr>
<th></th>
<th>Equator</th>
<th>Andoversford (Texas)</th>
<th>Calgary</th>
<th>E of Shetland</th>
<th>Prudhoe Bay</th>
<th>Cusco, Peru</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Latitude (degrees)</strong></td>
<td>0</td>
<td>51.86</td>
<td>30.5392</td>
<td>51.0486</td>
<td>60.35</td>
<td>70.3265</td>
</tr>
<tr>
<td><strong>sin sqrd (phi)</strong></td>
<td>0</td>
<td>0.999437409</td>
<td>0.59082138</td>
<td>0.497719</td>
<td>0.37566002</td>
<td>0.876341216</td>
</tr>
<tr>
<td><strong>sin sqrd (2*phi)</strong></td>
<td>0</td>
<td>0.002249096</td>
<td>0.967005908</td>
<td>0.999975</td>
<td>0.938158277</td>
<td>0.433469155</td>
</tr>
<tr>
<td><strong>Altitude (meters)</strong></td>
<td>0</td>
<td>200</td>
<td>107.9</td>
<td>1200</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td><strong>Relative to Andoversford</strong></td>
<td>0.9954</td>
<td>1.0000</td>
<td>0.9981</td>
<td>0.9942</td>
<td>0.9973</td>
<td>0.9999</td>
</tr>
<tr>
<td><strong>Relative to Equator</strong></td>
<td>1.0000</td>
<td>1.0047</td>
<td>1.0028</td>
<td>0.9988</td>
<td>1.0020</td>
<td>1.0046</td>
</tr>
</tbody>
</table>
Inclination calculation

\[
\text{Inclination} = \cos^{-1}\left(\frac{g_z}{g_{\text{total}}}\right)
\]

Where,

- \(g_z\) = the acceleration measured along the tool (borehole) axis
- \(g_{\text{total}}\) = the total gravitational field
- Inclination = the angle from the tool axis to vertical

If \(g_{\text{total}}\) is calculated from the three orthogonal accelerometer measurements,
where \(g_{\text{total}} = \left(\sqrt{g_x^2 + g_y^2 + g_z^2}\right),\)
then Inclination is Scale Factor independent.

But, if one axis has an error due to tool acceleration during measurement for example, then that error will show up in Inclination, and also in Azimuth. This error may not be noticed during QA/QC unless \(g_{\text{total}}\) can be compared to the expected local value.
Calibration

Purpose: To reduce errors in accuracy through one or more of the following:

- Primary Standard
- Secondary Standard, with a higher accuracy than the instrument
- Known input source

Directional instruments calibrated against a known input source

Earth’s gravity field
Earth’s magnetic field

The method of calibration used is a system minimising errors to achieve optimum performance.

Relevant Error Sources

- Noise and drift
- Scale Factor (Gain)
- Datum (Offset)
- Temperature coefficients
- Axis (misalignment)

Electronics (Scalar)
Magnitude (Scalar)
Magnitude (Scalar)
Magnitude (Scalar)
Positional (Vector)
Error model assumptions – 2.5mg error

Error in Gx at Inc = 45deg & Az = 90 deg

Error in Gx at Inc = 45deg & Az = 0 deg

Error in Gz at Inc = 45 deg & Az = 90 deg

Error in Gz at Inc = 45 deg & Az = 0 deg
Error model assumptions

• +/- 2.5mg?
Effect of incorrect Scale Factor?

• Reduces ability to detect tool movement during survey through QA/QC
  • Leading to inaccurate inclination and hence azimuth

• Multi Station Analysis of accelerometer values?

• 3rd party reviews of raw data?
and thus... the Myth of Gravity any questions?