ISN’T GRAVITY A CONSTANT?

Speaker Information

The Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA)

- Robert Wylie
- Product Line Director, Drilling Applications
- National Oilwell Varco
- March 4th, 2016

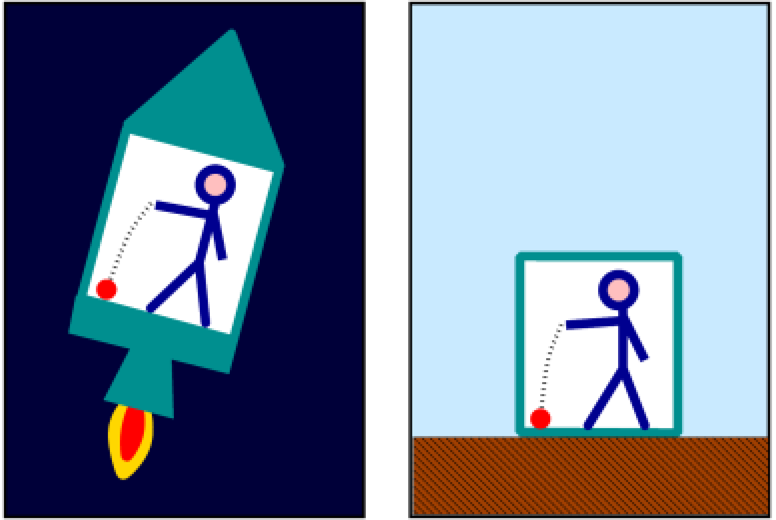
Summary

- 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 (none)
- Why TGF QC is important
    - Effect of scale factor error
    - Effect of bias error
    - Effect of movement
    - Effect of gravitational waves
- 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”

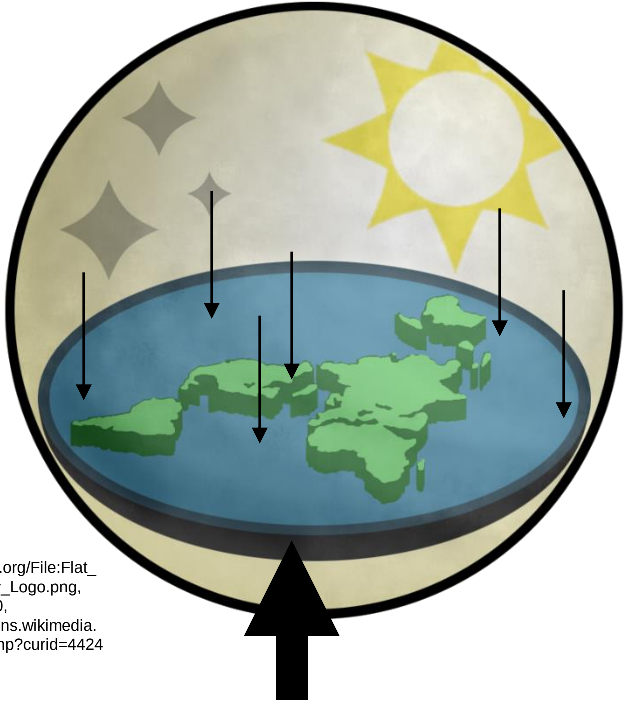
UNIVERSAL ACCELERATION



The equivalence principle.

Wiki

Flat Earth Society – constant "g"



By Blanko - http://wiki.tfes.org/File:Flat_Earth_Society_Logo.png, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=44242127

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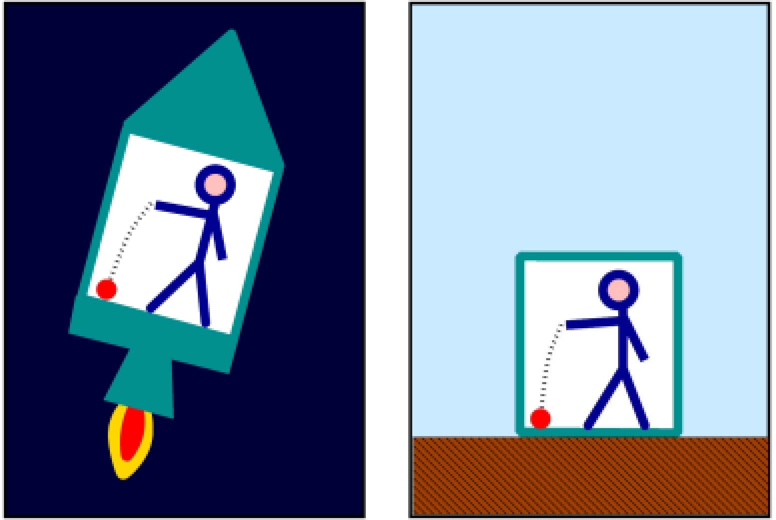

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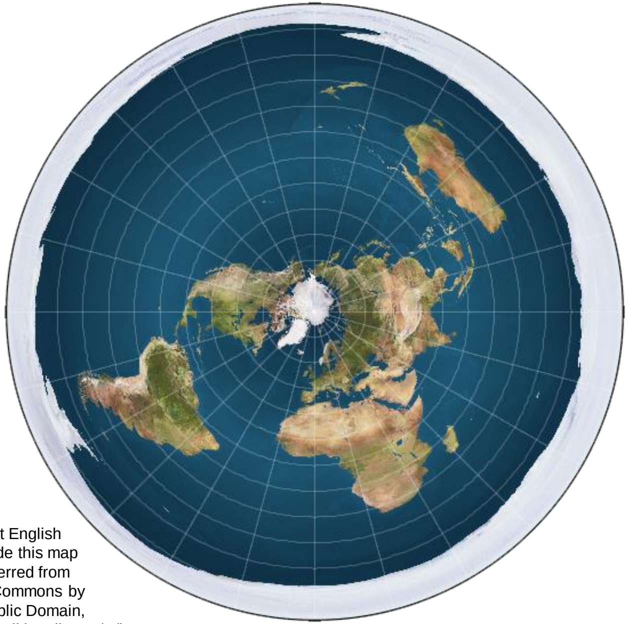
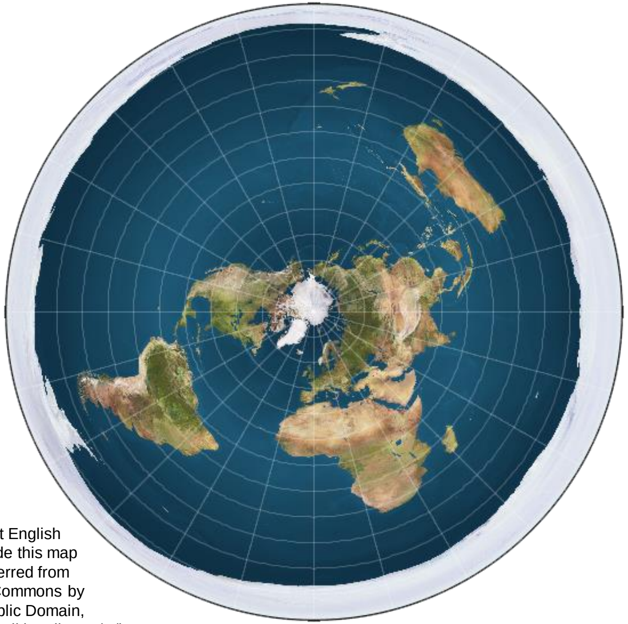
Modern view of Flat Earth from Space



By Trekky0623 at English Wikipedia ("I made this map myself") - Transferred from en.wikipedia to Commons by MathiasRav., Public Domain, https://commons.wikimedia.org/w/index.php?curid=5469541

United Nations supports this view



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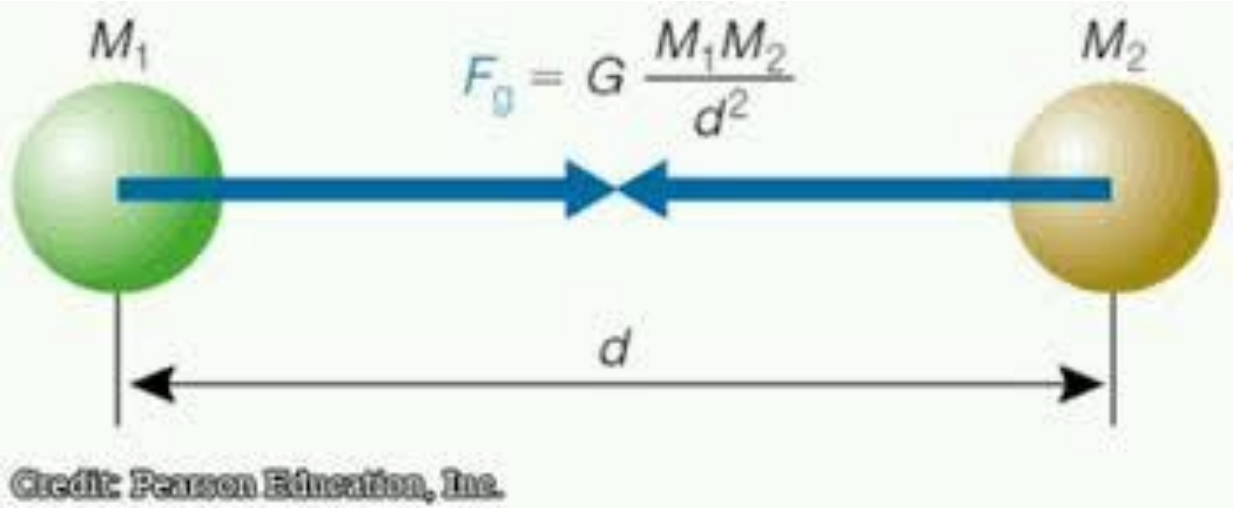
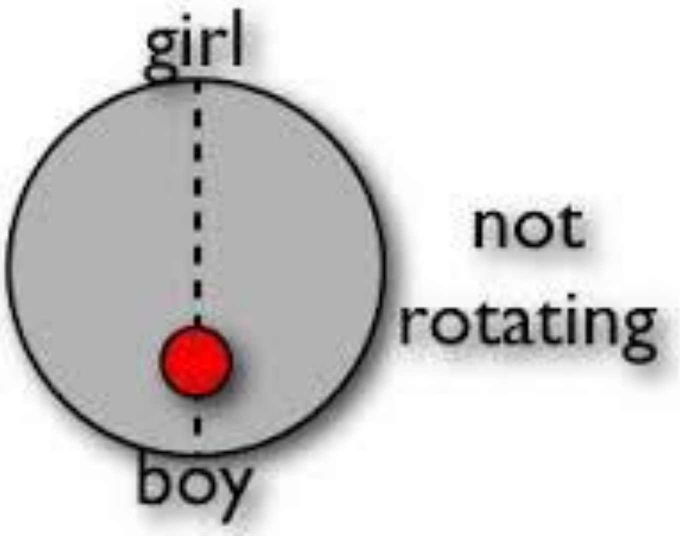
Round Earth theory

Newton - gravitational attraction



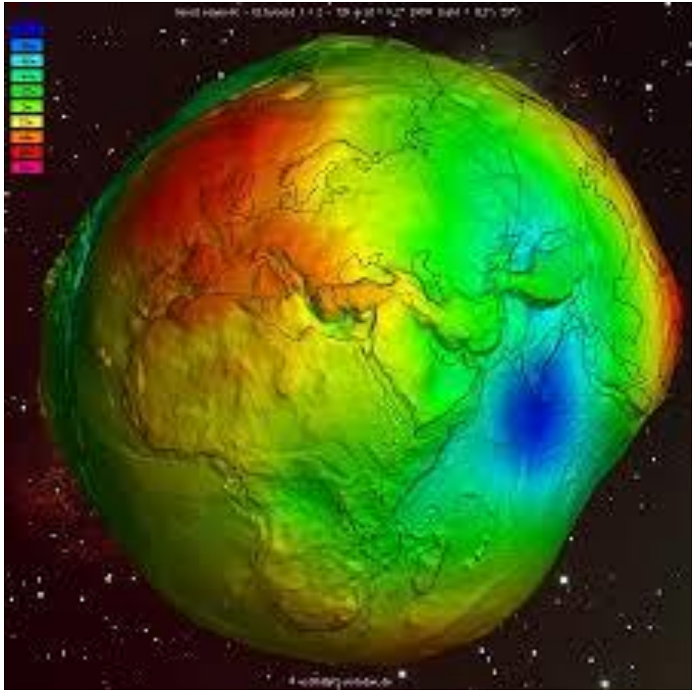
Non-gravitational attraction



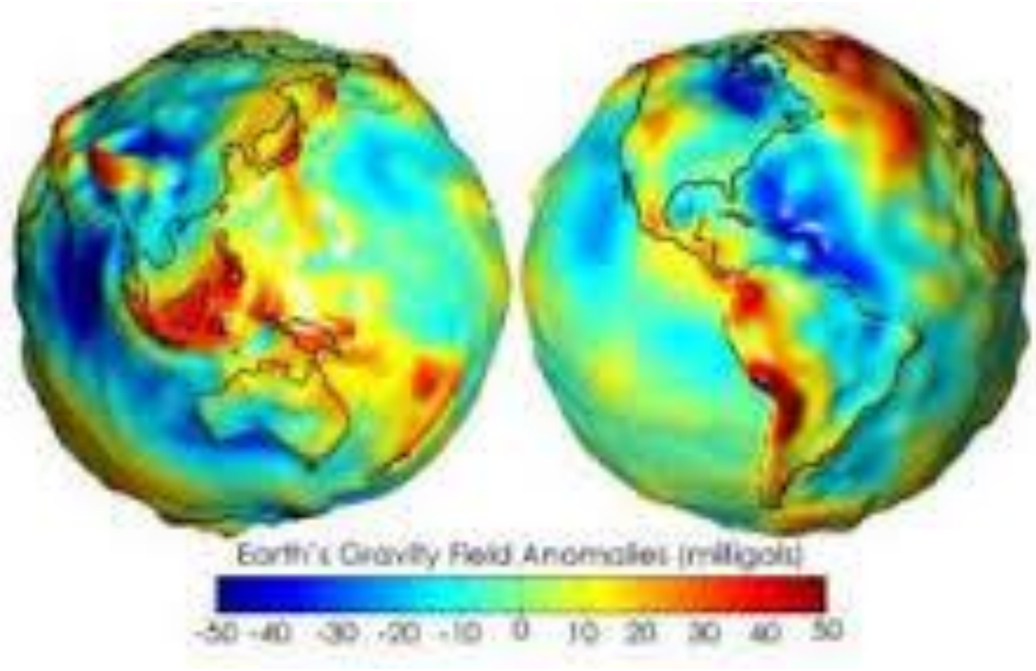
Earth from Space

But then there's centrifugal force

Gravitational Variations

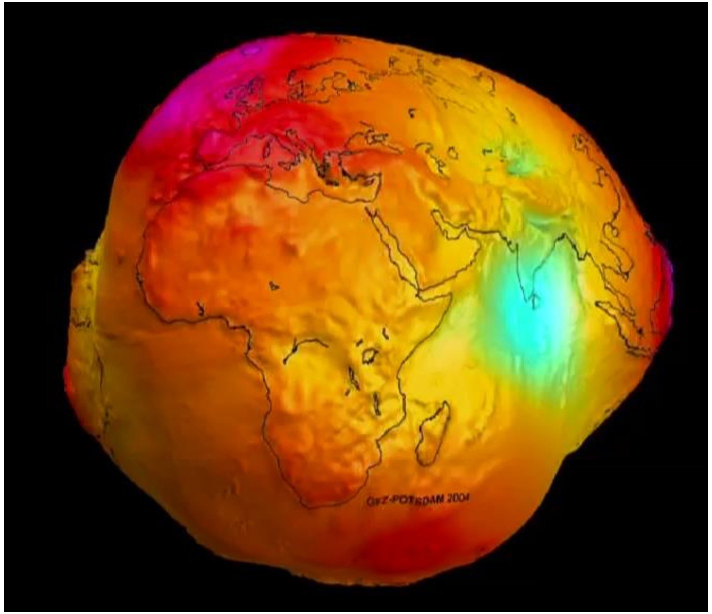


Gravitational Variations



Gravitational Variations

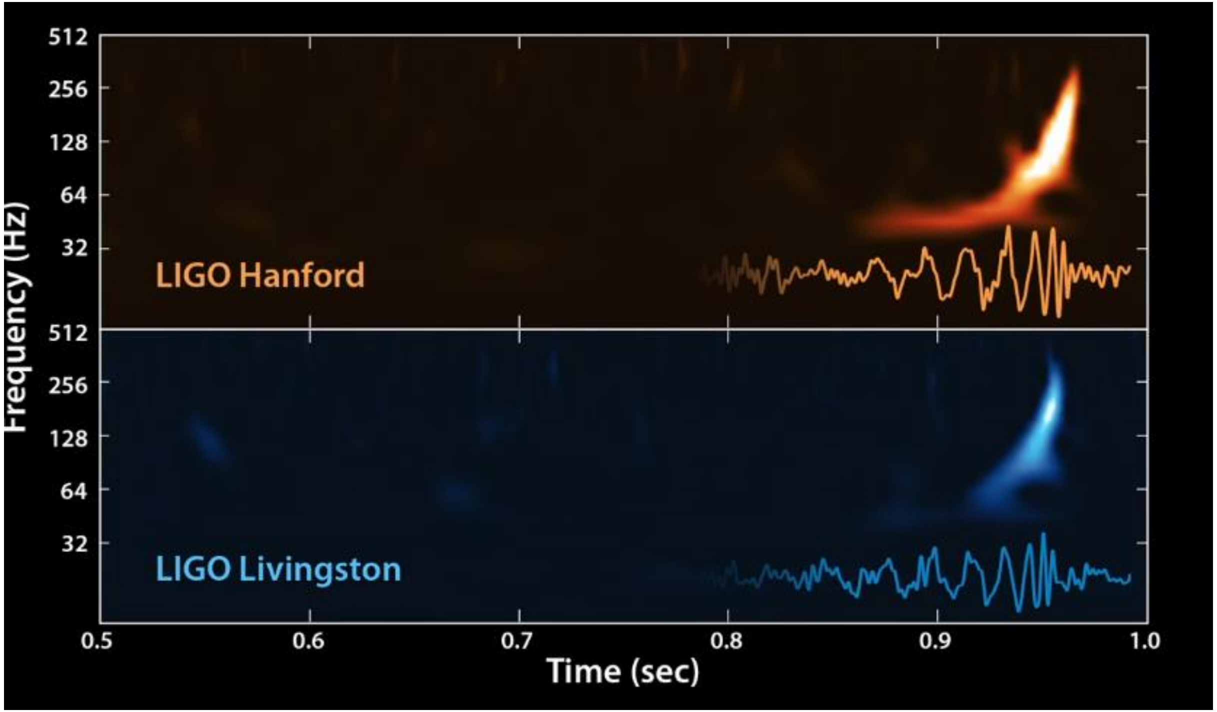
	Std Gravity	GARM*
Earth Mass	✓	✓
Earth rotation		✓
Earth shape		✓
Depth (TVD)		✓
Topography		✓
Anomalies		✓
Water/Rocks		✓
Error (1 sigma)	**~1.6 mG**	**~0.3 mG**



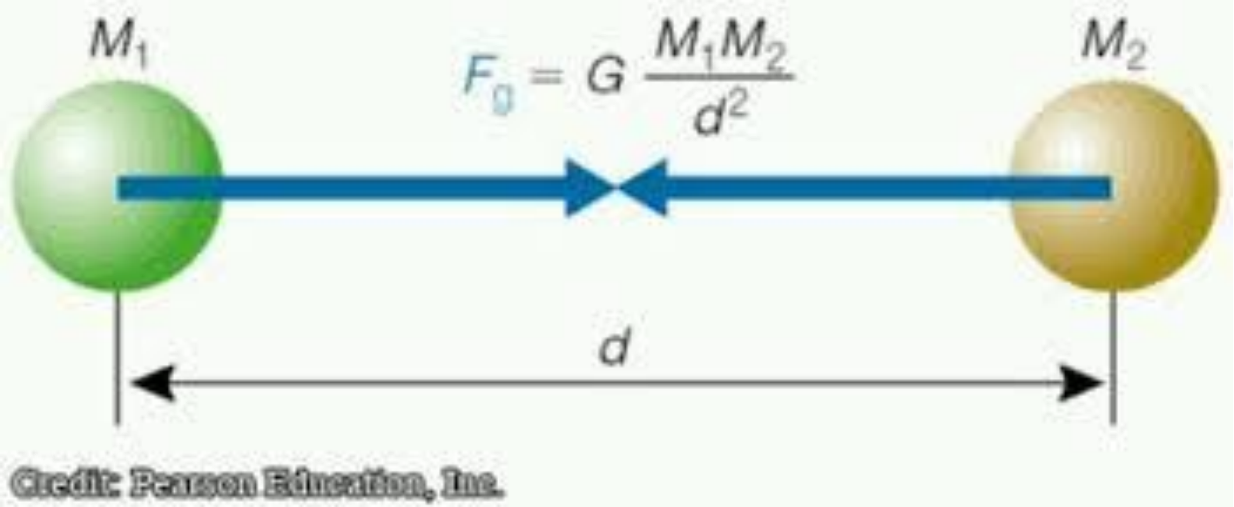
*Global Acceleration Reference Model (MagVAR/SLB)

http://www.gfz-potsdam.de

Gravitational Waves



Newton - gravitational attraction



"g" calculation at Equator

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

m_1 = mass of Earth (kg)
r = radius of Earth at equator (m)
G = Gravitational Constant

https://en.wikipedia.org/wiki/Gravity_of_Earth

General local “g” calculation

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

ϴ = latitude
h = altitude (m)

https://en.wikipedia.org/wiki/Gravity_of_Earth

Local calculations

	Equator	Andoversford	New Waverly (Texas)	Calgary	E of Shetland	Prudhoe Bay	Cusco, Peru
Latitude (degrees)	0	51.86	30.5392	51.0486	60.35	70.3265	-13.525
sin sqrd (phi)	0	0.999437409	0.59082138	0.497719	0.37566002	0.876341216	0.669786293
sin sqrd (2*phi)	0	0.002249096	0.967005908	0.999979	0.938158277	0.433469155	0.884690459
Altitude (meters)	0	200	107.9	1200	0	10	3399
local "g"	9.78033	9.82599	9.80758	9.76905	9.79976	9.82544	9.71012
Relative to Andoversford	0.9954	1.0000	0.9981	0.9942	0.9973	0.9999	0.9882
Relative to Equator	1.0000	1.0047	1.0028	0.9988	1.0020	1.0046	0.9928

Inclination calculation

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

Where,

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

If g_{total} is calculated from the three orthogonal accelerometer measurements,
where $g_{total} = \left(\sqrt{{g_x}^2 + {g_y}^2 + {g_z}^2}\right)$,
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_{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

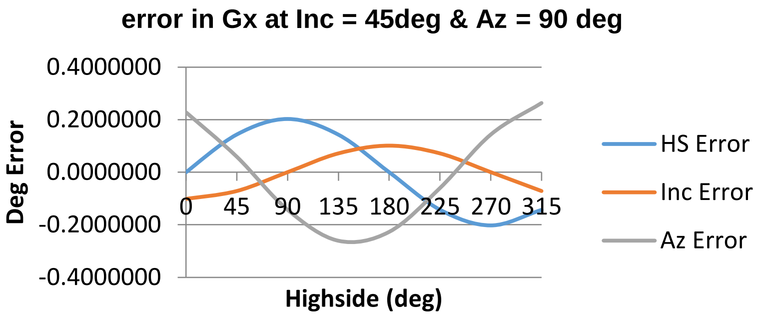
Earth's gravity field
Earth's magnetic field

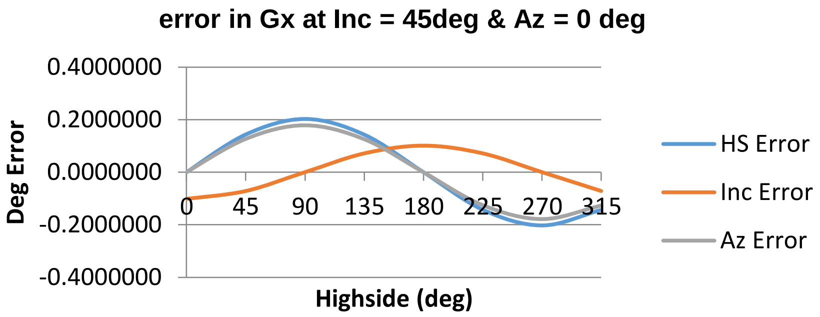
The method of calibration used is a system minimising errors to achieve optimum performance.

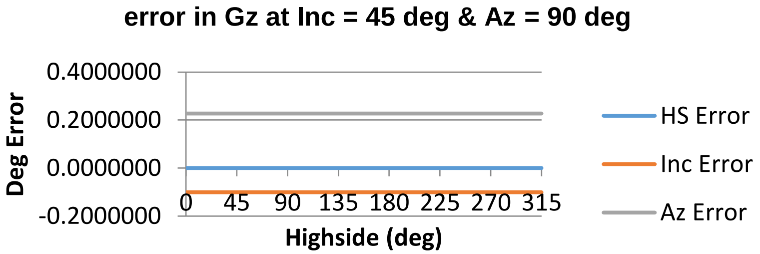
Relevant Error Sources

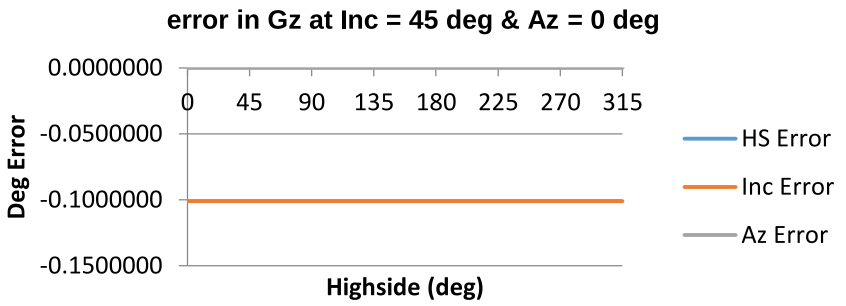
• Noise and drift	Electronics (Scalar)
• Scale Factor (Gain)	Magnitude (Scalar)
• Datum (Offset)	Magnitude (Scalar)
• Temperature coefficients	Magnitude (Scalar)
• Axis (misalignment)	Positional (Vector)

Error model assumptions – 2.5mg error









Error model assumptions

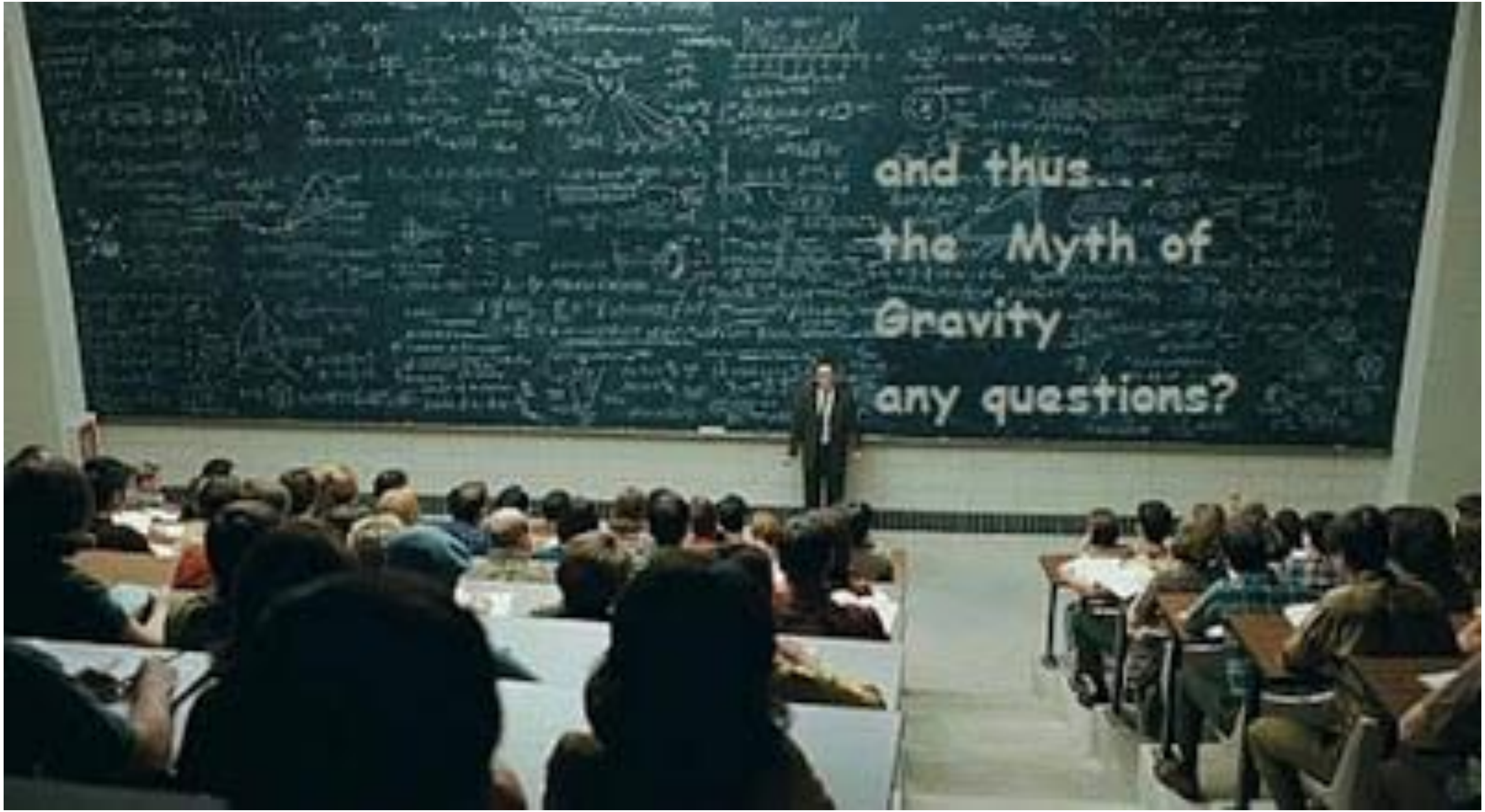
- +/- 2.5mg?

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?