Advances in Airborne Gravity and Magnetics

J Derek Fairhead* JD GeoConsultancy Ltd., & School of Earth and Environment, University of Leeds, UK

Gordon R J Cooper, School of Geosciences, University of the Witwatersrand, Johannesburg, SOUTH AFRICA

Stephan Sanders, Sander Geophysics www.sgl.com

Technical Session

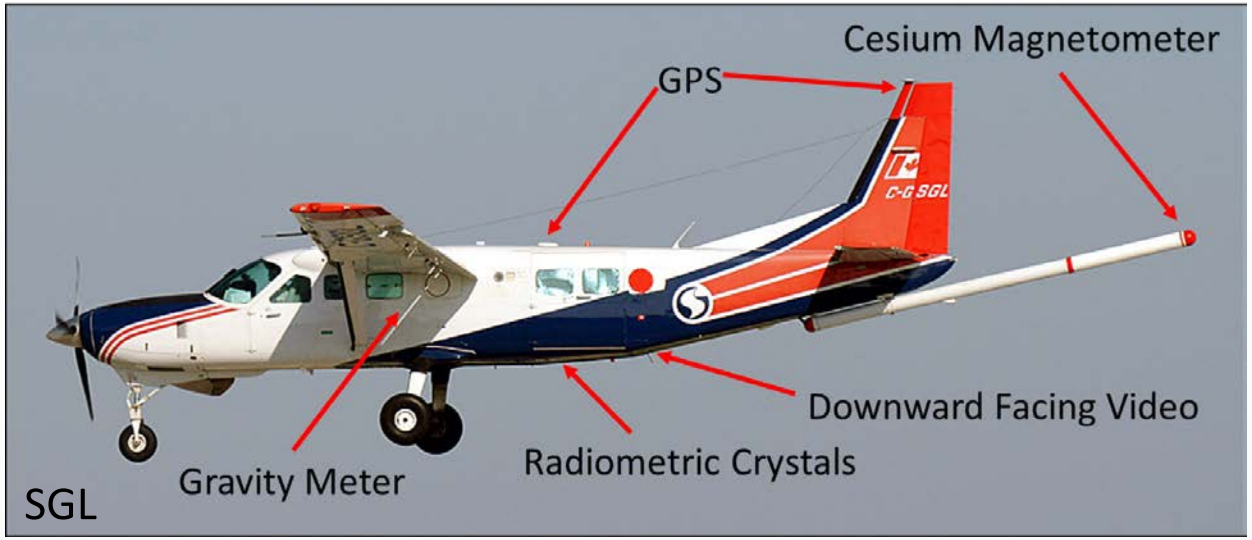
Advances in Airborne Gravity and Magnetics (2007-2017)

The talk will focus on:

- **Developments in Data Acquisition**
  - Aeromagnetic
  - Gravity
  - Gravity Gradiometry
- **Using Local Phase and Wavenumber in Advanced Processing**
  - Tilt Angle (after Miller and Singh, 1994 & Verduzco et al., 2004)
  - Depth Estimation using Finite Tilt-Depth
  - Stable Downward Continuation of the Tilt Angle
- **Looking to the future**

Aeromagnetic Systems

General Layout of Survey Equipment



Tail Plane Vertical Gradiometer Stinger

Helicopter suspended

Various configurations of magnetometers

Fixed Wing Aircraft

1. Single tail plane mounted singer (left)
2. Tail plane vertical gradiometer (bottom)
3. Wing tip magnetometers (not shown)

or

4. Combination of above

Helicopters

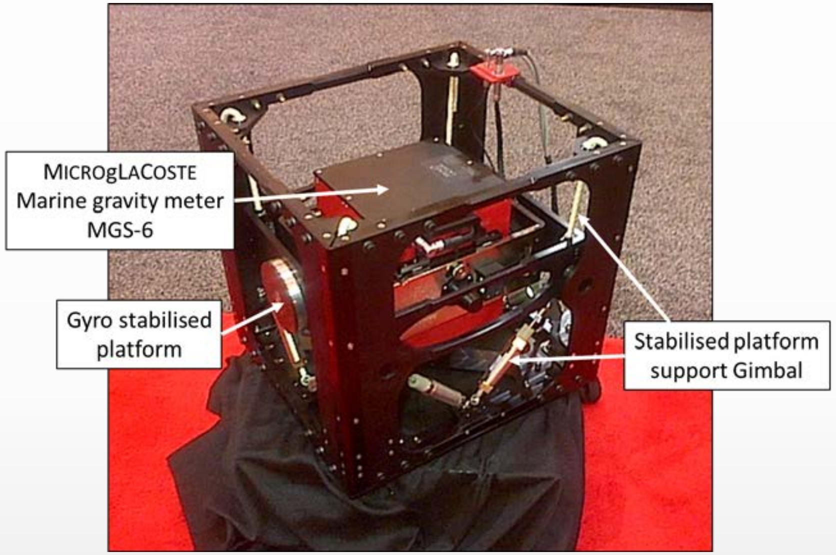
5. Suspended vertical gradiometer (bottom)

Optically Pumped Magnetometers

Triaxial Fluxgate Magnetometers;

e.g. Mag-0.3MSL used as sensors within the aircraft as part of the magnetic compensation system.

Dynamic Airborne Gravity Systems



TAGS-6 gravity system
www.microglacoste.com

Evolved from the LaCoste-Romberg highly damped zero-length spring gravity sensor of mid 1990's
(commercially available)

GT-2A
www.canadianmicrogravity.com

Available originally as GT-1A but now upgraded to better handle turbulent flight conditions
(commercially available)

AIRGrav
www.sgl.com

Consists of three orthogonal accelerometers, independent of turbulent flight conditions
(proprietary)

Dynamic Airborne Gravity Systems:

GT-2A

Installed in BN-2A Islander aircraft

Installed in Helicopter

Dynamic Airborne Gravity Systems:

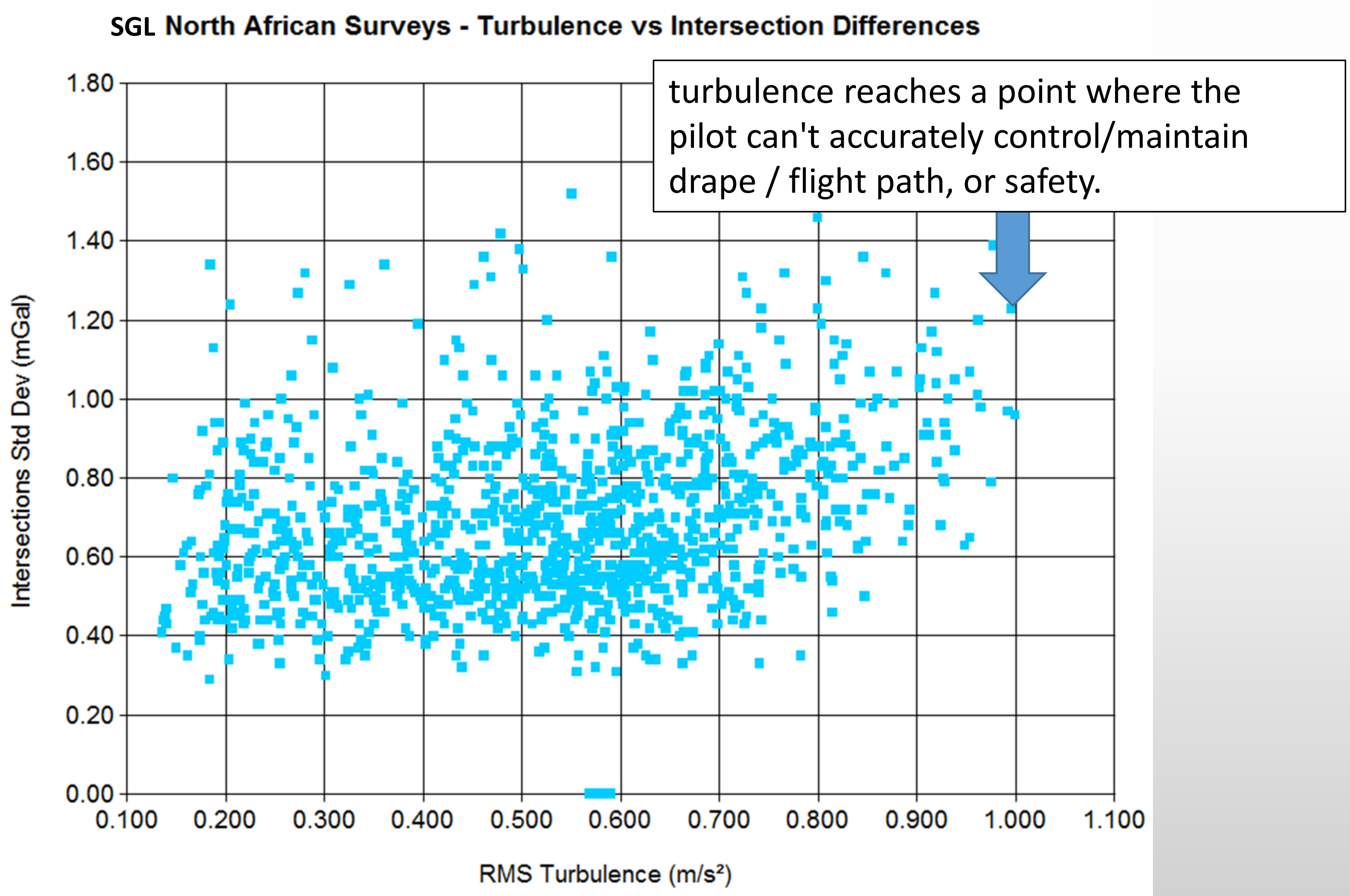
AIRGrav

Installed in Cessna Grand Caravan aircraft

Installed in Helicopter

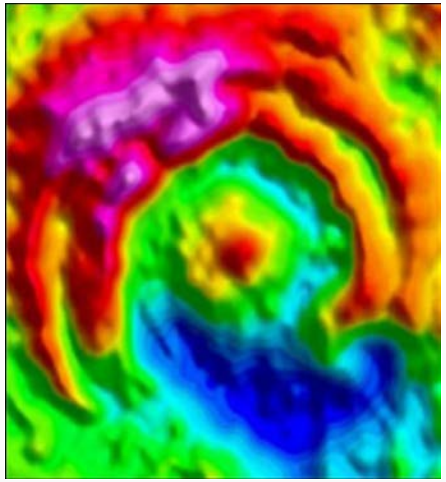
Dynamic Airborne Gravity Systems:

AIRGrav & Turbulence

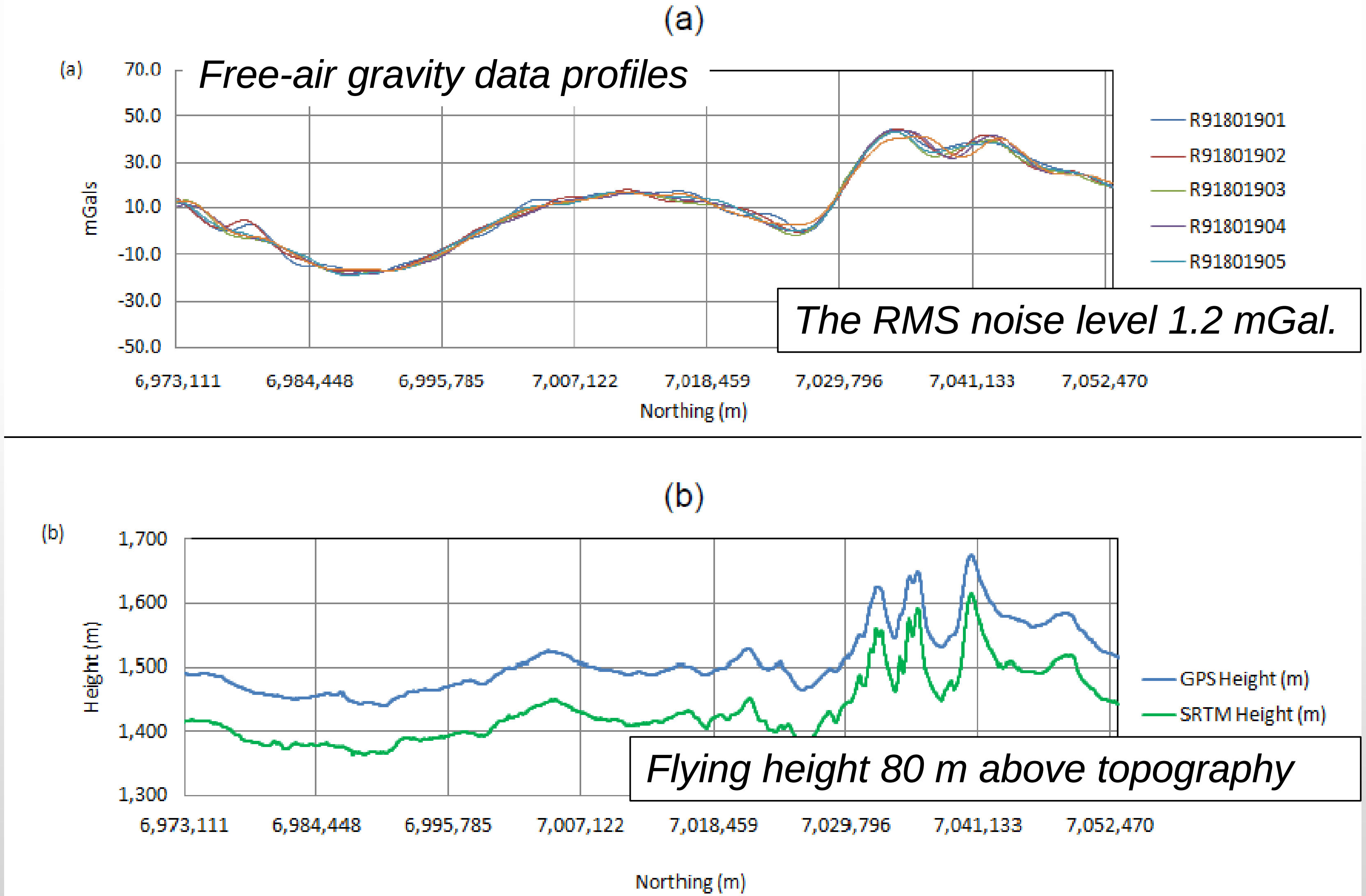


Dynamic Airborne Gravity Systems:

GT-2A: Showing 6 Repeat Lines over Vredefort Dome impact crater



GT-2A Airborne gravity Survey in a BN-2T Islander aircraft



(Dan Olson, Airborne Gravity 2010 ASEG Workshop 20 pages)

Airborne Gravity & Magnetic Systems

2007-2017 Decade Summary

Aeromagnetic Data Acquisition: Major advances in previous decades, so for this last decade incremental improvements in

Sensor design: in terms of its robustness, sensitivity and weight

Magnetic compensation system measurements

Airborne Gravity Data Acquisition: Major and significant on-going improvements in

Sensor design and performance: repeatability and reduced effects of air turbulence

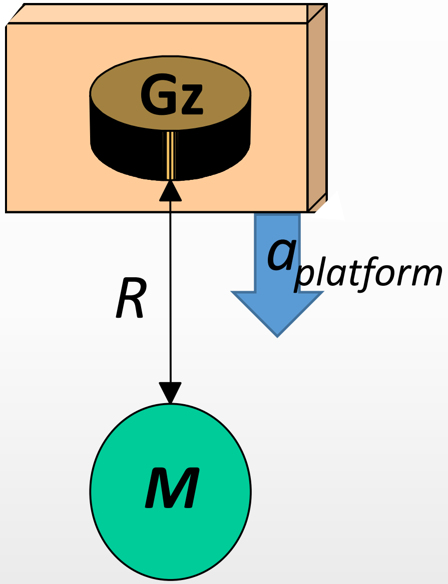
Combined Advantage:

Ability to acquire both gravity and magnetic data at the same time from the same aircraft using drape survey method.

Now common practice to jointly conduct gravity and magnetic drape surveys

Airborne Gravity Gradiometer Systems:

Gravity Meter (measures Gz α $^{1}/_{R^2}$)

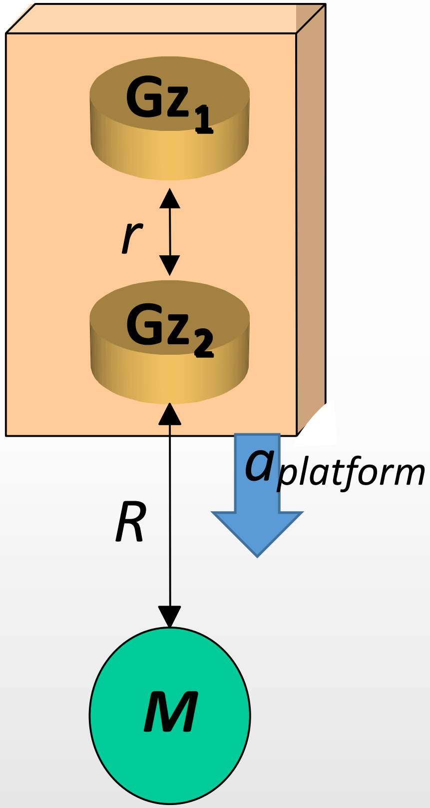


$$Gz = \frac{GM}{R^2} + a_{platform}$$

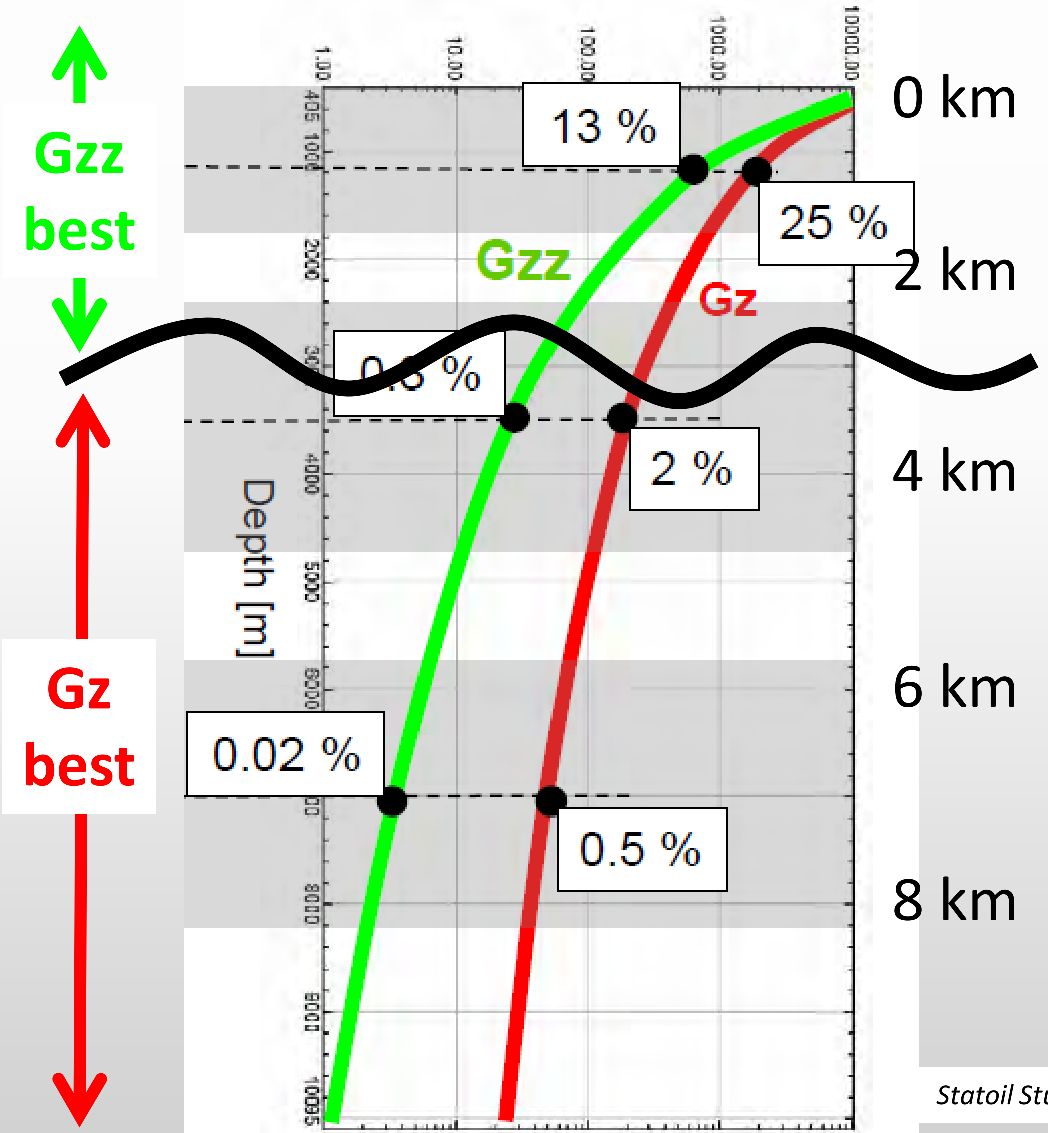
$a_{platform}$ = vertical accel. due to platform motion

Bell Geospace

Gradiometer (measures Gzz α $^{1}/_{R^3}$)



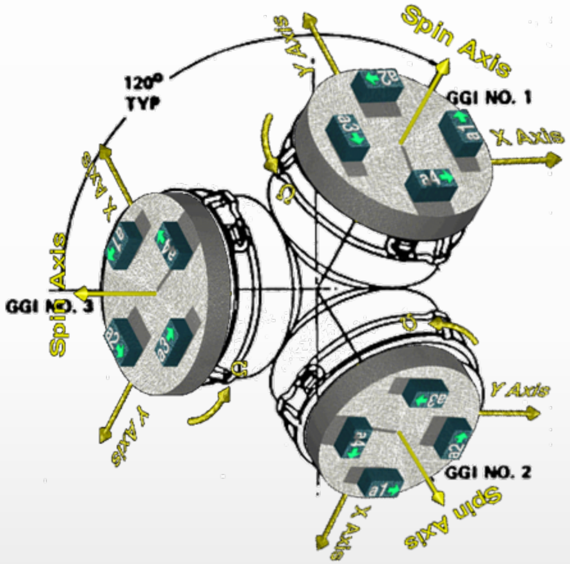
$$Gzz = Gz_1 - Gz_2 = GM\left(\frac{R^2 - (R+r)^2}{R^2 (R+r)^2}\right)$$



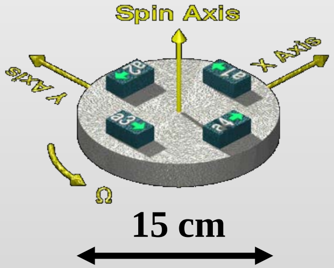
Statoil Study 2012

Airborne Gravity Gradiometer Systems

1. Full Tensor Gradiometer, FTG



FTG uses 3 such disks



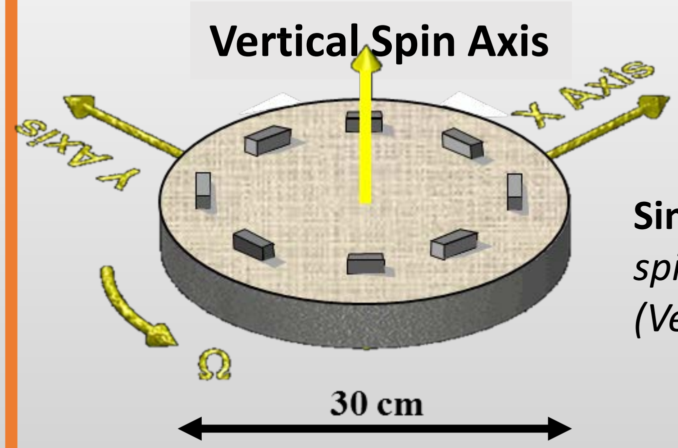
3 spinning disks configuration each with 2 pairs of accelerometers

2. Airborne Gravity Gradiometer, AGG

AGG before loading into aircraft

- One spinning disk with vertical spin axis
- Disk twice as large
- 4 pairs of accelerometers

AGG has one disk (twice the size) and 8 accelerometers



Simplistically: *A perfectly horizontal spinning disk sees Gzz (Vertical gradient of gravity)*

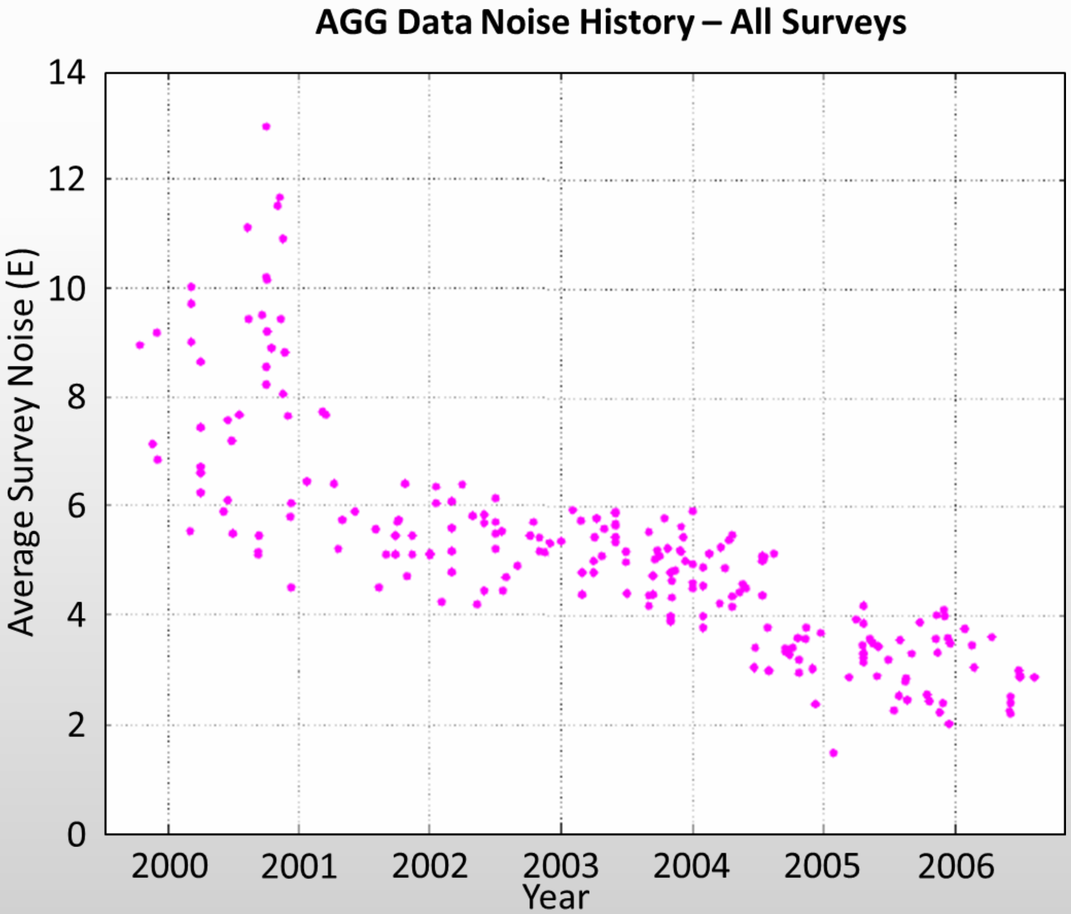
Gzz = - Gxx - Gyy

Disk located on gyro stabilised platform

Airborne Gravity Gradiometer Systems

AGG Average Survey Noise with time

2000 to 2006



2007 to 2017

AGG *(as reported by CGG)*

HeliFalcon noise levels are 2.5 to 3 Eo RMS with a 50 m ($\lambda/2$ resolution).
Standard Falcon: 2.5 to 3.0 Eo RMS with 150 m ($\lambda/2$ resolution).
Falcon Plus: 1.7 to 2.2 Eo RMS with 150 m ($\lambda/2$ resolution).
Enhanced Falcon depends on line spacing but we have had noise levels below 1.0 E RMS with 150 m ($\lambda/2$ resolution) at 100 m line spacing.

FTG *(as reported by Bell Geospace)*

Noise levels have been consistently less than 2E at 0.18hz with ~300 m ($\lambda/2$ resolution) , and achieved 1.6 Eo back in 2008.

Airborne Gravity Gradiometer Systems

2007-2017 Decade Summary

Two gradiometer systems have had spectacular success as exploration tools in both the mining and oil industries
These instruments are:

Full Tensor Gradiometer, FTG
Airborne Gravity Gradiometer, AGG

Competition between these competing instruments has resulted in

- Significant reduction in noise levels such that average survey noise levels are now well below 2 Eötvos
- Keeping survey costs down
- Development of newer higher sensitive instruments. These include:
  - **Falcon Plus:** the AGG has been upgraded to a fully digital electronic system
  - **Full Spectrum Falcon:** This is Falcon Plus used alongside CGG's strap down gravity meter sGrav
  - **Full Spectrum Gravity:** Combines FTG data with conventional gravity data
  - **Digital FTG or dFTG:** reduces volume by 30% and weight by 40%
  - **Enhanced FTG or eFTG:** AustinBridgeporth have recently taken delivery of this instrument from Lockheed Martin and has three Falcon size spinning disks (30 cm diameter and 8 accelerometers per disk). Noise levels are expected to be 3 times lower than existing FTG systems

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Using Local Phase and Wavenumber in Advanced Processing

In last decade the Tilt derivative has become a standard advanced processing tool of choice

- Tilt Angle (after Miller and Singh, 1994; Verduzco et al., 2004)
- Depth Estimation using **Finite Tilt-Depth**
- Stable **Downward Continuation** of Tilt Angle

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Tilt Angle

Using Local Phase and Wavenumber in Advanced Processing

Local Phase

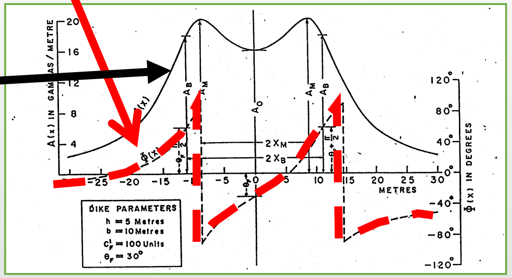
$$\theta = \tan^{-1}\left[\frac{\partial T}{\partial z} \Big/ \frac{\partial T}{\partial x}\right]$$

Tilt Derivative or Tilt Angle

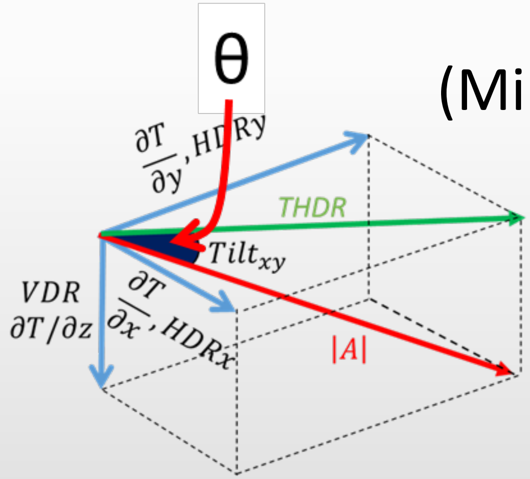
$$TDR = \tan^{-1}\left[\frac{VDR}{THDR}\right]$$

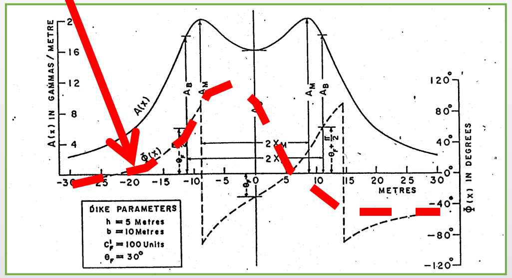
(Miller & Singh 1994; Verduzco, et al 2004)

Analytic Signal



θ Cannot be easily mapped





TDR can now be mapped but it is still a function of Inclination

Solution: work with RTP data

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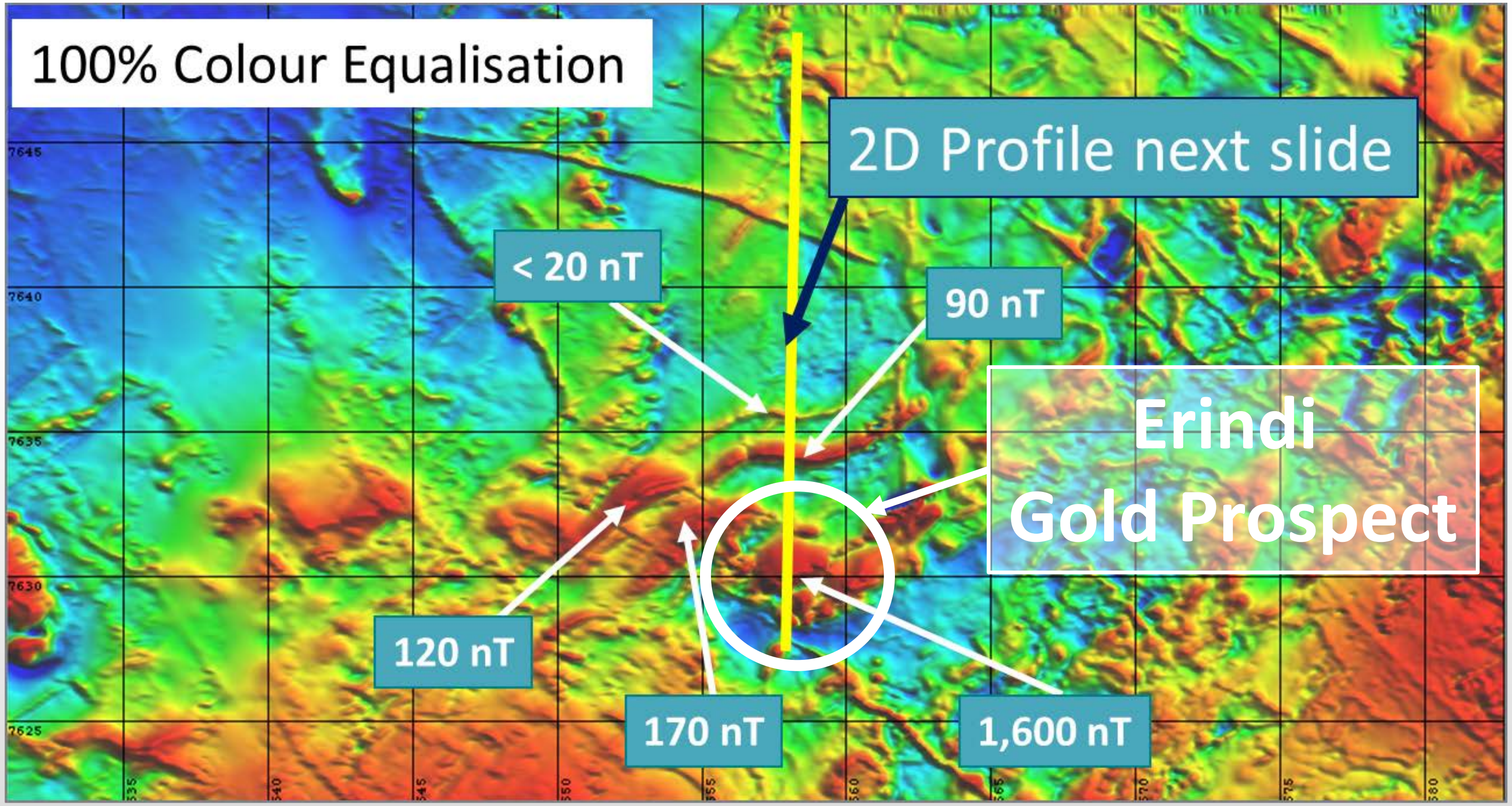
Tilt Angle

(Magnetic example)

Erindi Gold Prospect, Namibia



5 km Graticule

Flight spacing: 200m, Flying height: 80m
Flight Direction: N-S

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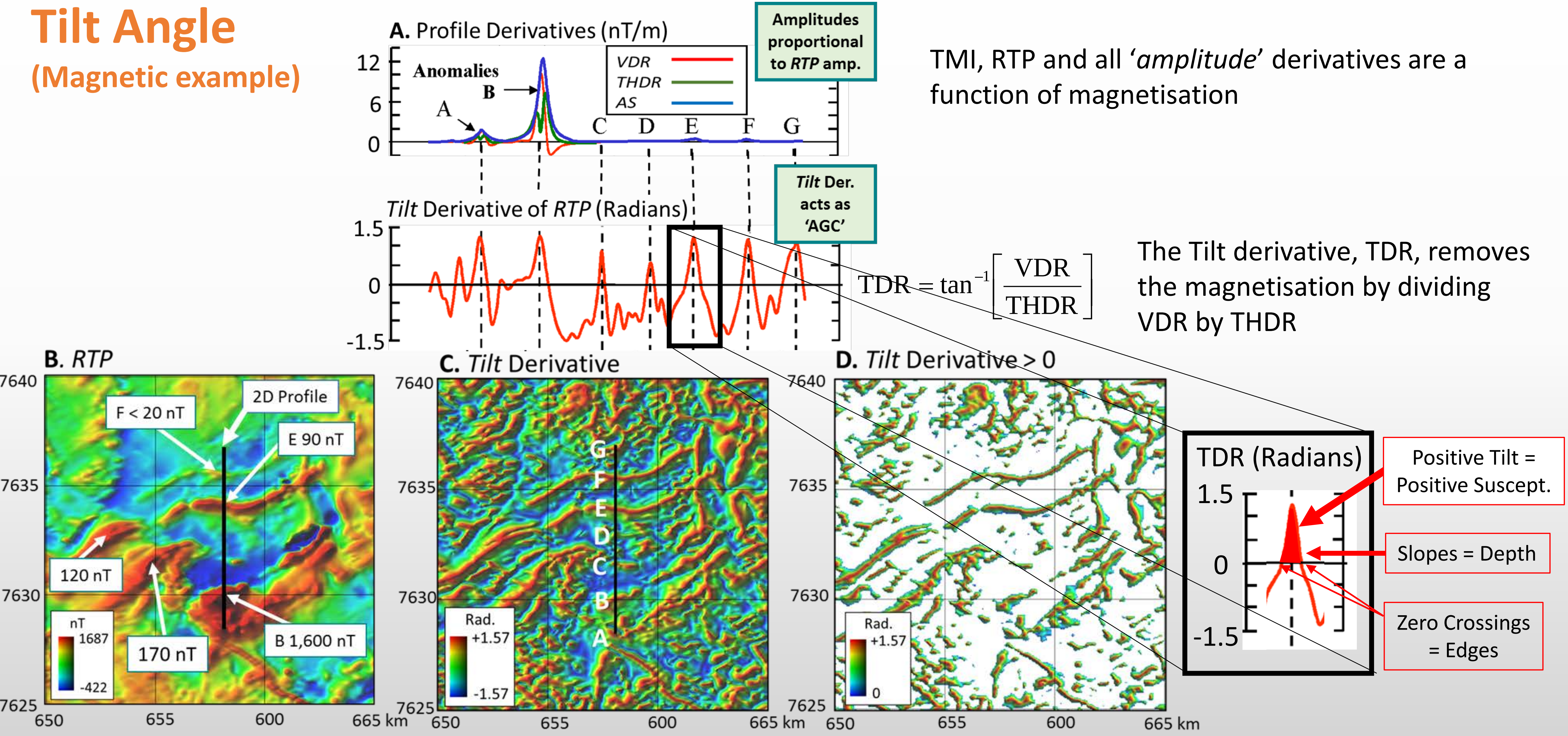
Tilt Angle

(Magnetic example)



TMI, RTP and all '*amplitude*' derivatives are a function of magnetisation

$$TDR = \tan^{-1}\left[\frac{VDR}{THDR}\right]$$

The Tilt derivative, TDR, removes the magnetisation by dividing VDR by THDR

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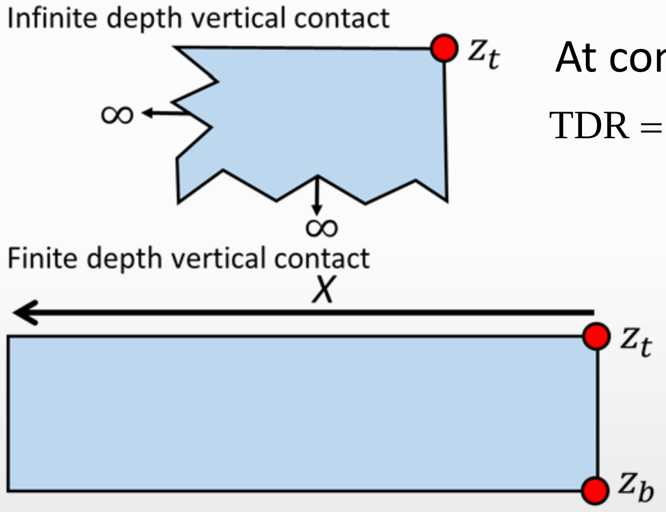
Tilt Angle & Depth to Top, z_t.

Tilt-depth method

(Magnetic example)



At contact

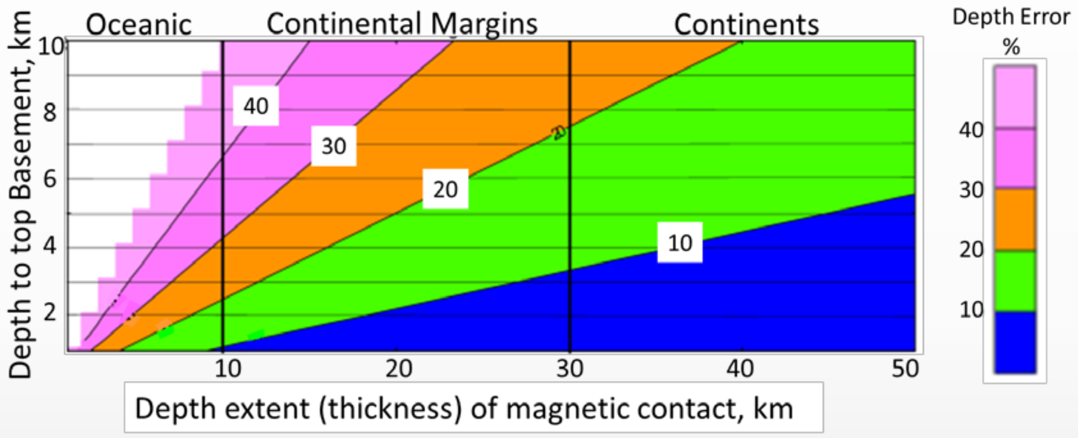
$$TDR = 0 = \tan^{-1}\left[\frac{\Delta x}{z_t}\right]$$

Mineral Exploration

Prof Bill Morris's group (Lee et al., 2010) clearly demonstrated that the depth to top, z_t is underestimated if z_b is not factored in.

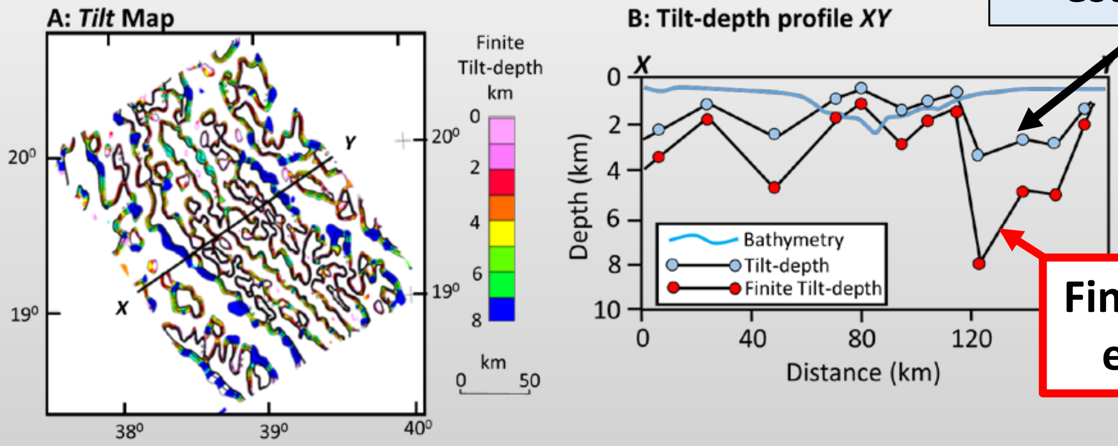
Oil & Gas Exploration

Over continental margins the depth to magnetic basement can be underestimated by a factor of 2 or more.



Model Errors (after Salem et al., 2014)

Red Sea Example



Infinite depth estimate

Finite depth estimate

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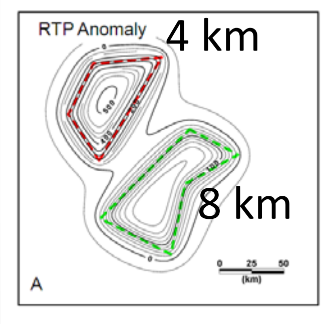
Tilt Angle & Downward Continuation

(Magnetic example)

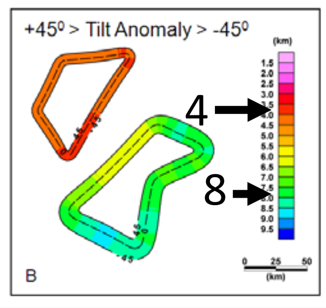
Tilt-depth method

For an Infinite **Tilt-depth** model Salem et al (2007) showed that the Tilt contour is zero over the contact. $Tilt = tan^{-1}(\Delta x / z_t)$ (*Δx* is often taken as the half distance between +/- 45^0 contours)

RTP of models



Tilt of RTP showing only 3 contours (-45^0, 0^0 & $+45^0$)



At contact

$$TDR = 0 = \tan^{-1}\left[\frac{\Delta x}{z_t}\right]$$

For Δx between 0 & 45 deg

Contours $\Delta x = z_t$

If z_t = 50 m then $Tilt = tan^{-1}(^{\Delta x_1}/_{50})$

If z_t = 100 m then $Tilt = tan^{-1}(^{\Delta x_2}/_{100})$

Cooper (2016) has shown that the only difference between these equations is a factor 2 inside the arctan function. Hence the Tilt image of a vertical contact can be transformed to a similar contact at the same depth by application of a scaling factor, α .

Thus if $R = VDR/THDR$ then $Tilt_\alpha = tan^{-1}(R\alpha)$

For factor α of 2, 3 or 4 the resulting $Tilt_\alpha$ *moves to within* $\frac{1}{2}, \frac{1}{3}$ *and* $\frac{1}{4}$ *of the depth to the source*

- *Tilt solution never exceeds source depth*
- *Does not preferentially increase noise*
- *True Depth = α x Tilt-depth*

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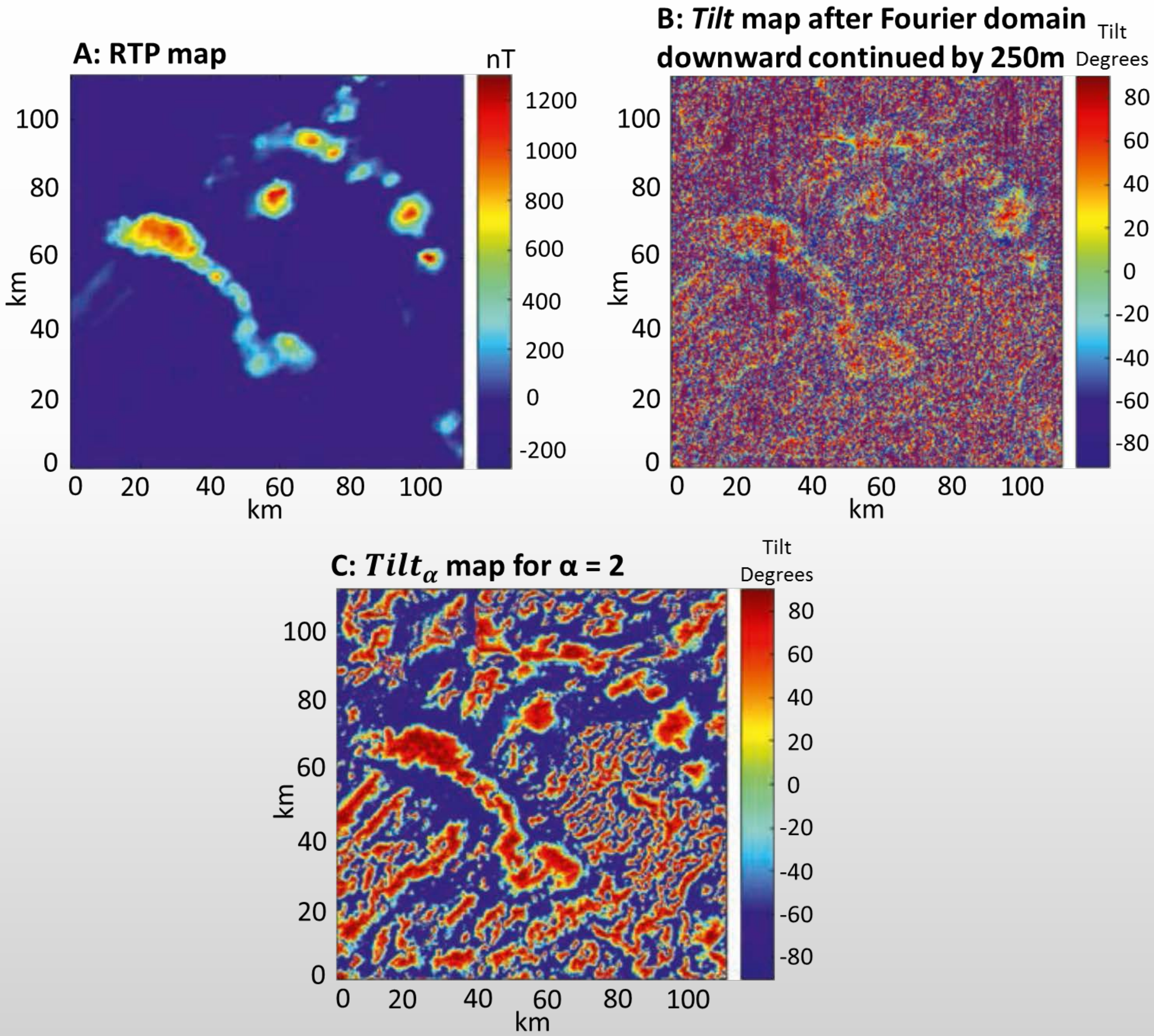
Tilt Angle & Downward Continuation

(Magnetic example)



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Possible Future Trends

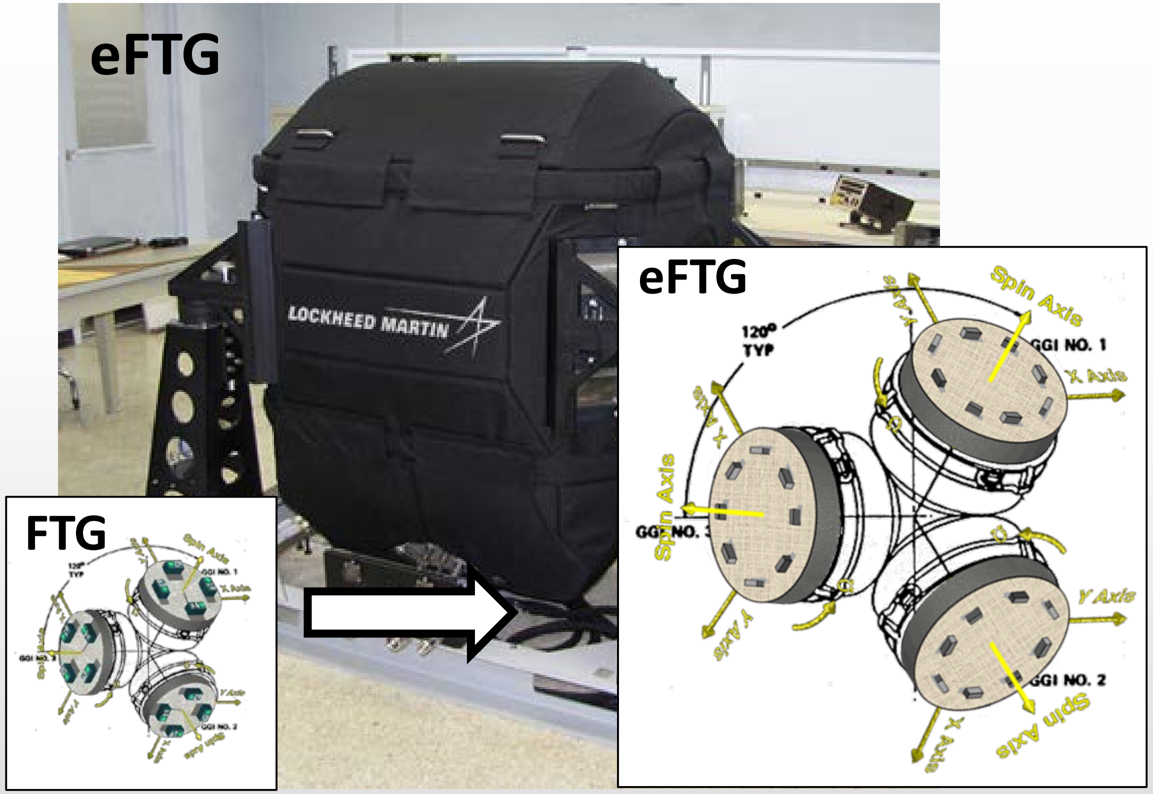
Further development of Drone/UAV technology

Good for DGPS, Aeromagnetics

Problems

- Miniaturisation of gravity equipment
- Security concerns
- Aviation clearance to fly

Gradiometer Advances



Enhanced Full Tensor Gradiometer, eFTG

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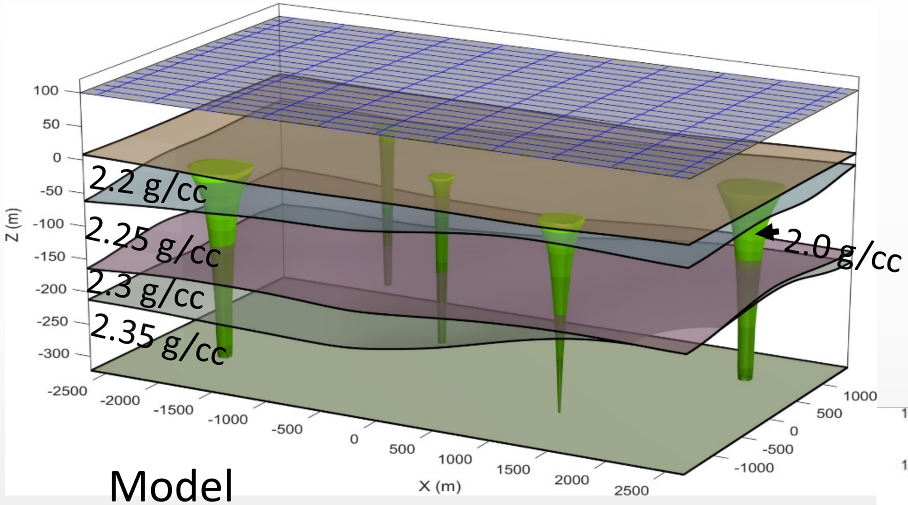
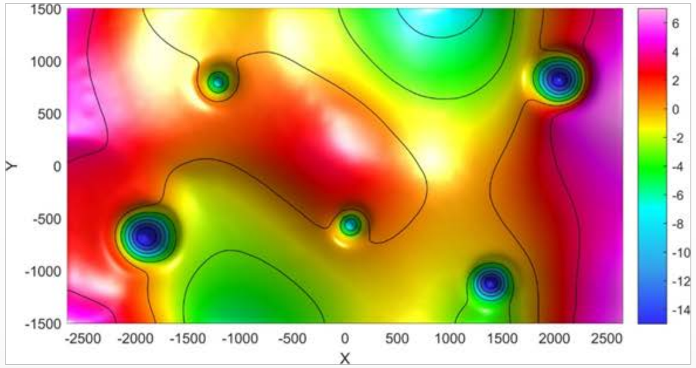
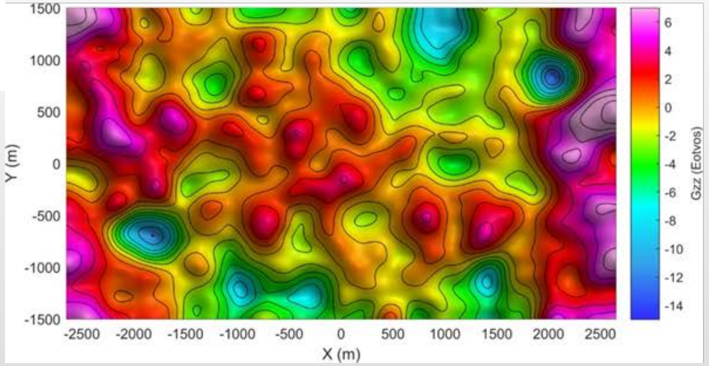
Possible Future Trends: Gradiometers



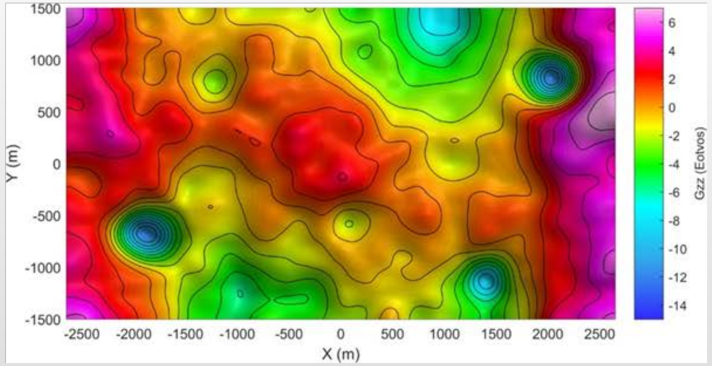
Gzz Model



Gzz airborne FTG simulation



Gzz airborne eFTG simulation



FTG and eFTG model studies with noise level reduction by factor of 3

AustinBridgeporth