The Use of GPS and Numerical Improvements in Aeromagnetic Compensation

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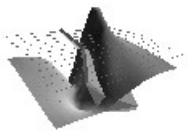
TOPICS

- Background
- The role of highpass filtering
- The use of synthetic aircraft magnetic effects
- Compensation using GPS data



Motivation

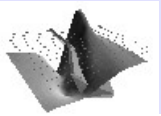
- Modern systems acquire very high quality data
- Aircraft are magnetic – source of interference
- Interference varies with attitude

➢ ***Compensation is a limiting factor in obtaining highly accurate data***

Theory

Three sources of magnetic interference:

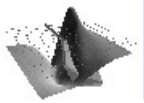
- Permanent: its angle with earth's field changes
- Induced: polarity and magnitude change
- **Eddy-Current: currents caused by the aircraft's conductive structures moving in the earth's magnetic field which are proportional to the time change rate of change of magnetic flux through some parts of aircraft**



Leliak 1961, 18-term interference model

$$H_T = c_1 \cos X + c_2 \cos Y + c_3 \cos Z +$$
$$+ \left\|\vec{H}\right\| \{c_4 \cos^2 X + c_5 \cos X \cos Y + c_6 \cos X \cos Z +$$
$$+ c_7 \cos^2 Y + c_8 \cos Y \cos Z + c_9 \cos^2 Z\} +$$
$$+ \left\|\vec{H}\right\| \{c_{10} \cos X (\cos X)' + c_{11} \cos X (\cos Y)' + c_{12} \cos X (\cos Z)' +$$
$$+ c_{13} \cos Y (\cos X)' + c_{14} \cos Y (\cos Y)' + c_{15} \cos Y (\cos Z)' +$$
$$+ c_{16} \cos Z (\cos X)' + c_{17} \cos Z (\cos Y)' + c_{18} \cos Z (\cos Z)'\} = \sum_{i=1}^{18} c_i a_i$$

- ✓ c_i, i=1,3 - permanent
- ✓ c_i, i=4,9 - induced
- ✓ c_i, i=10,18 - induced EM
- ✓ $\vec{H}$ total field vector
- ✓ cos X, cos Y, cosY directional cosines of aircrat's axes and $\vec{H}$, usually obtained via 3-component vector fluxgate magnetometers



Filtration and Solvers: The Issue of Noise

Noise Sources

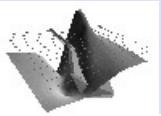
- Local gradient of total field
- Geologic noise
- Micropulsation, etc

Purpose of Filtration

- Restrict the frequency bandwidth of the data to be centered around the primary frequency modes for the aircraft maneuvers

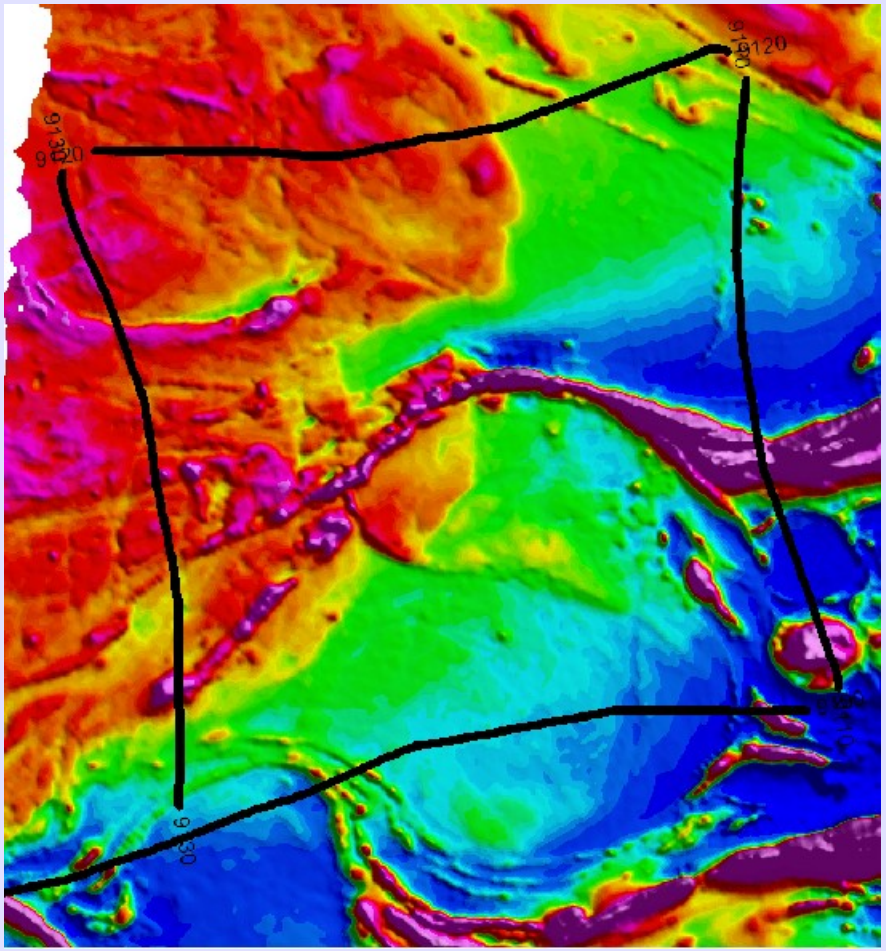
Techniques for Solving the Linear Equation System

- Singular Value Decomposition (SVD)
- Ridge Regression



Compensation Box

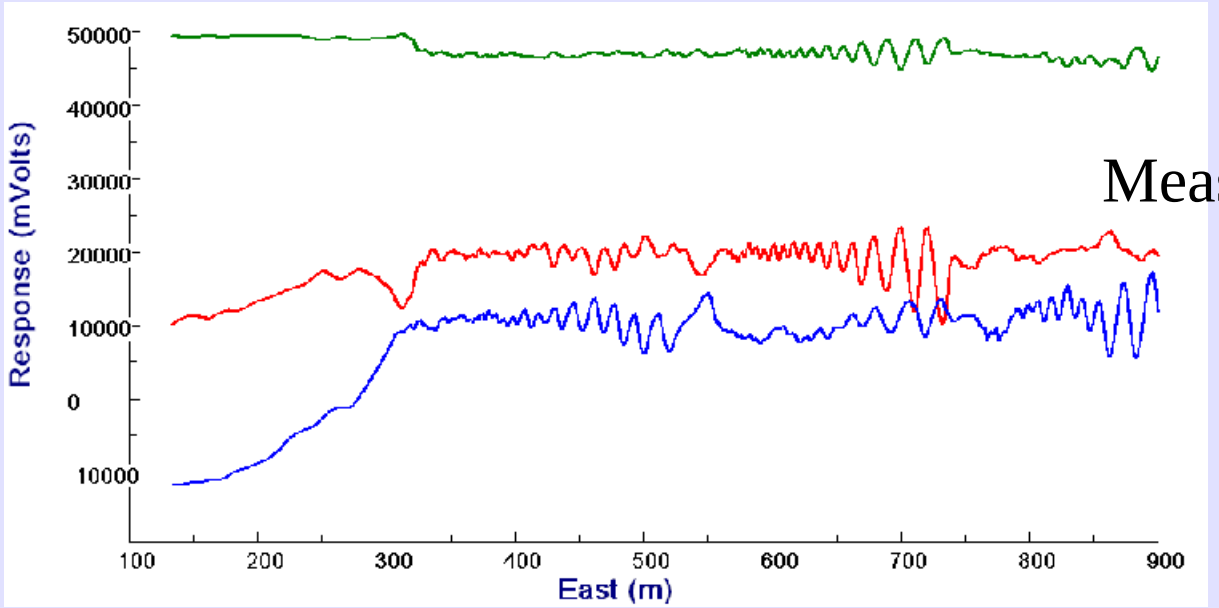
- ✓Comp box is usually flown above 3000m
- ✓Flight Headings are along the heading of survey and tie line flight headings
- ✓Series of maneouvers to determine the coefficients
- ✓Apply coefficients of compensation box to survey data with appropriate heading



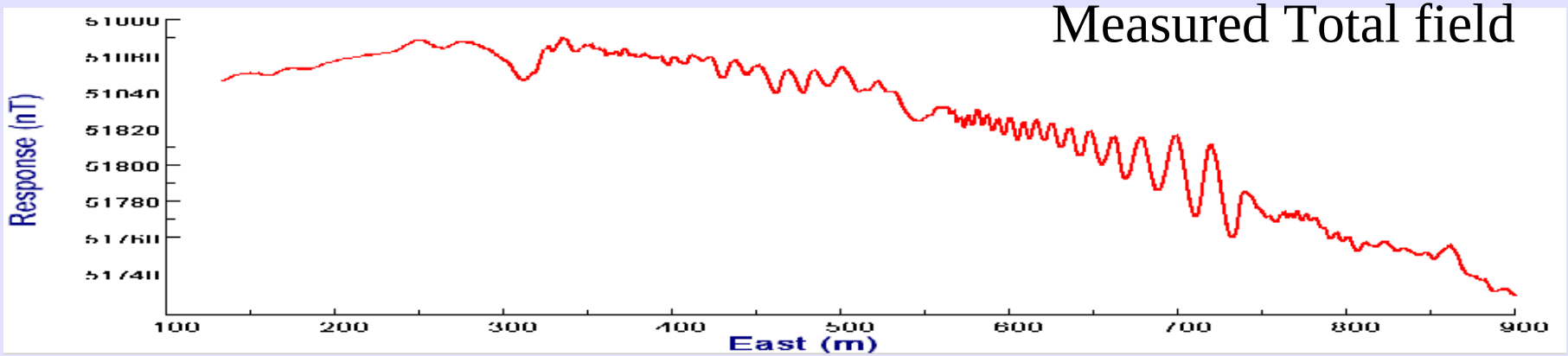
High Pass Filtering VS. Compensation

Helicopter Example

- Heading: WNW



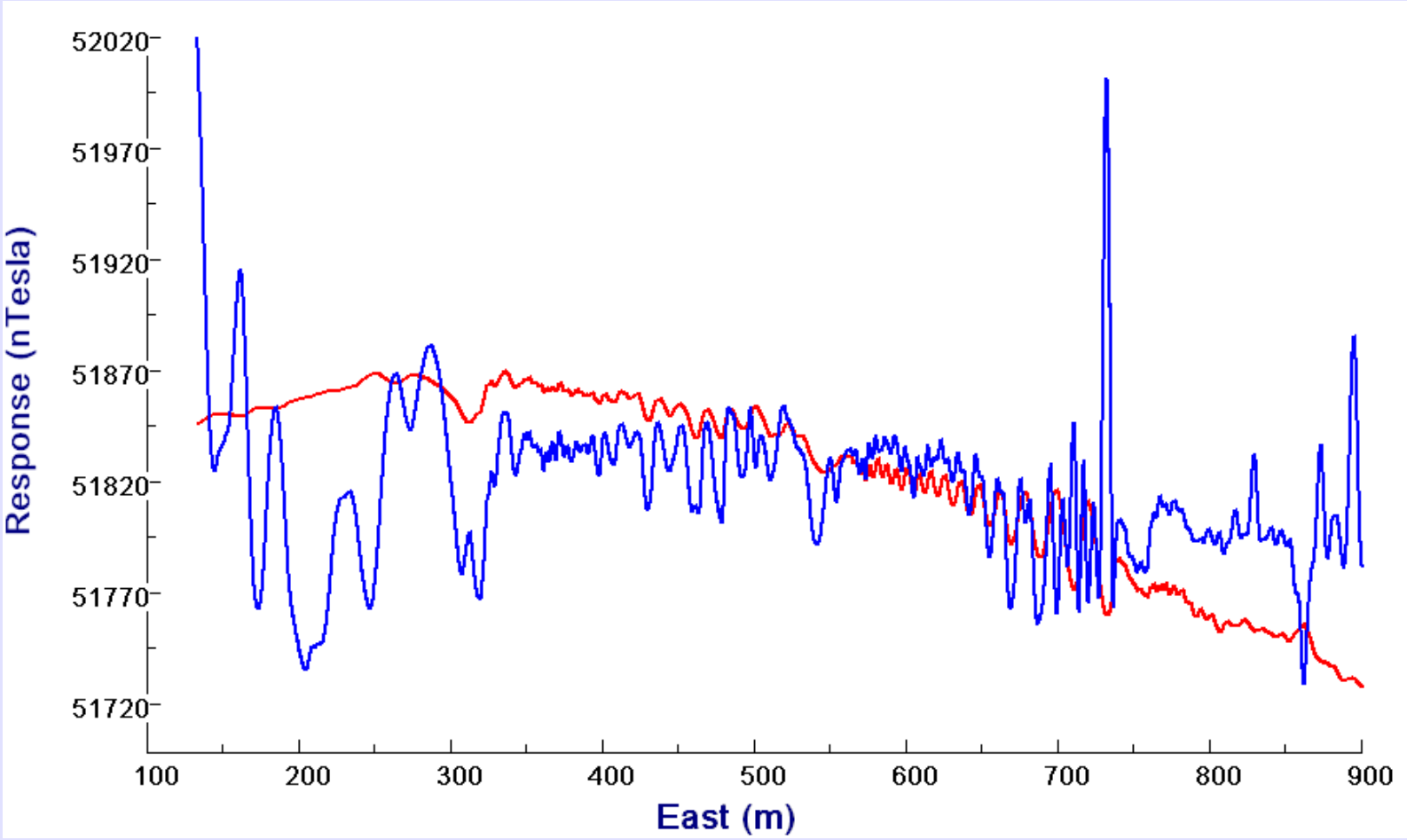
Measured fluxgate Channels



Measured Total field

Data thanks to Oakridge

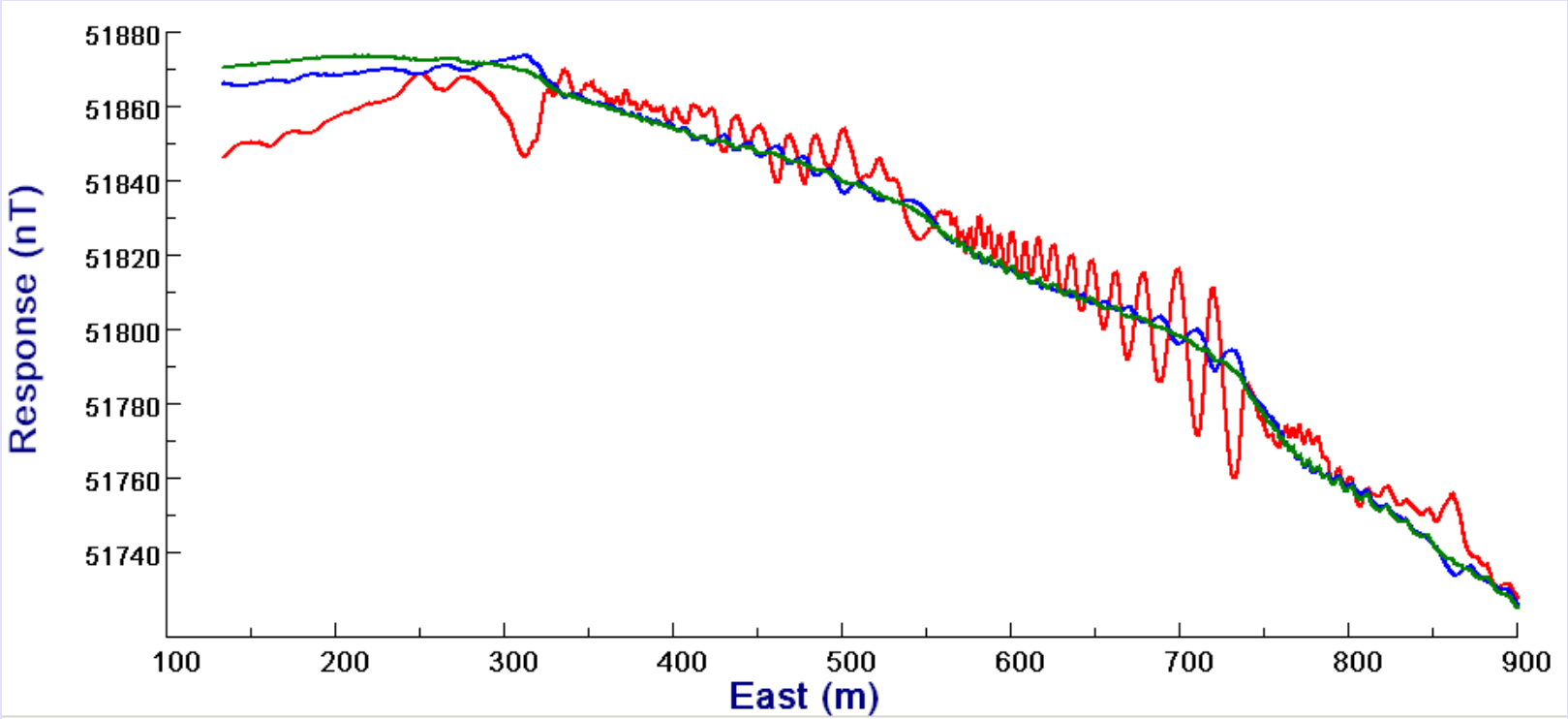
Filtration is necessary



Red: Measured Total field

Blue: compensated without filtration

Compensation Results with Different Filters

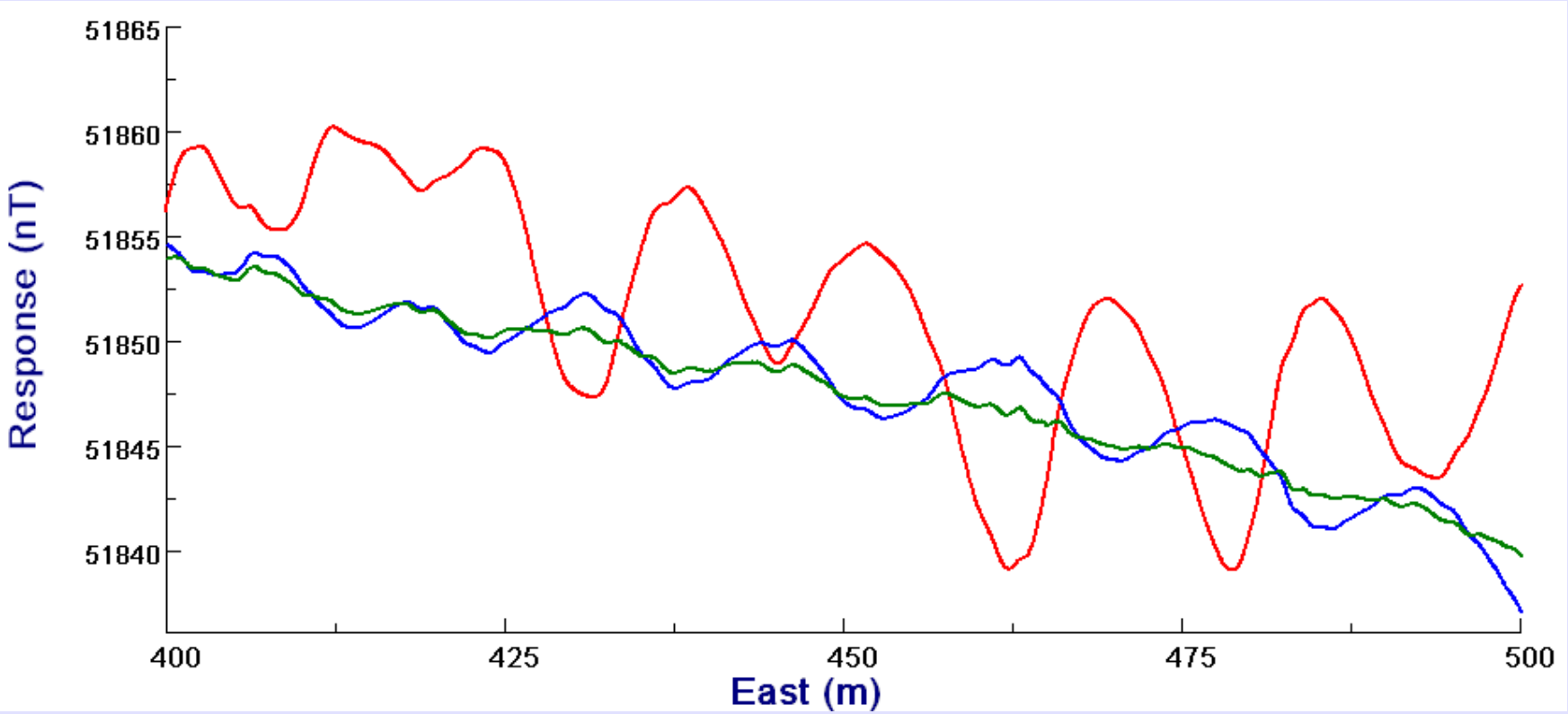


Line-to-Line Compensation

- Red: measured total field (FOM=472)
- Blue: compensated with tight filter (FOM=94)
- Green: compensated with wider filter (FOM=67)

(Figure of Merit (FOM): sum of peak-to-peak levels)

Compensation Results

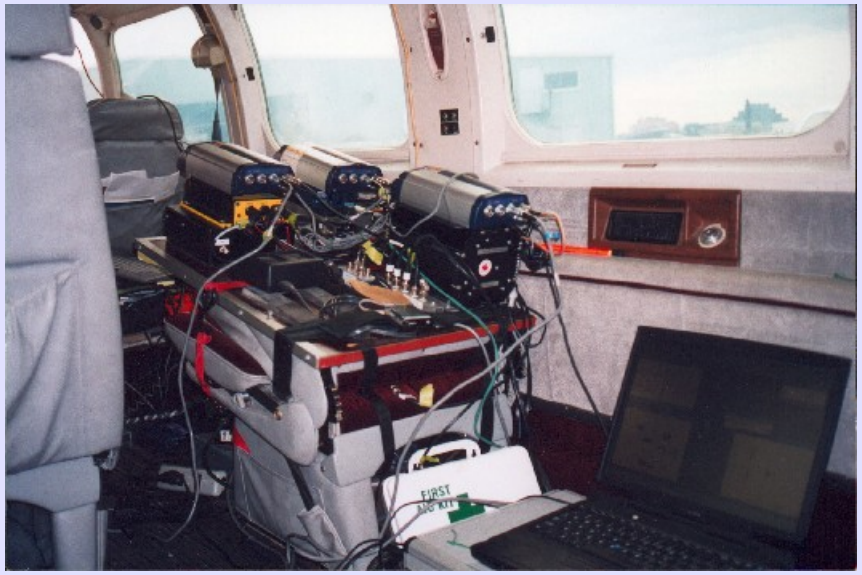


Zoom-in display

- Red: measured total field (FOM=60)
- Blue: compensated with tight filter (FOM=17)
- Green: compensated with wider filter (FOM=3)

Fixed Wing GPS Compensation

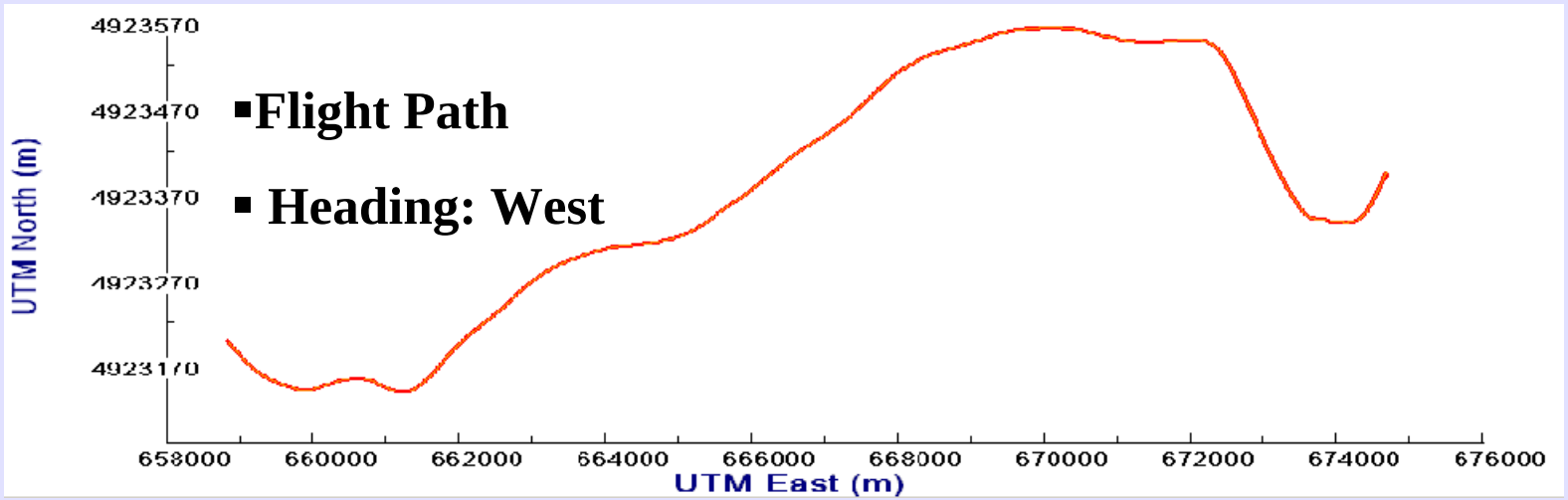

Terraquest's aircraft

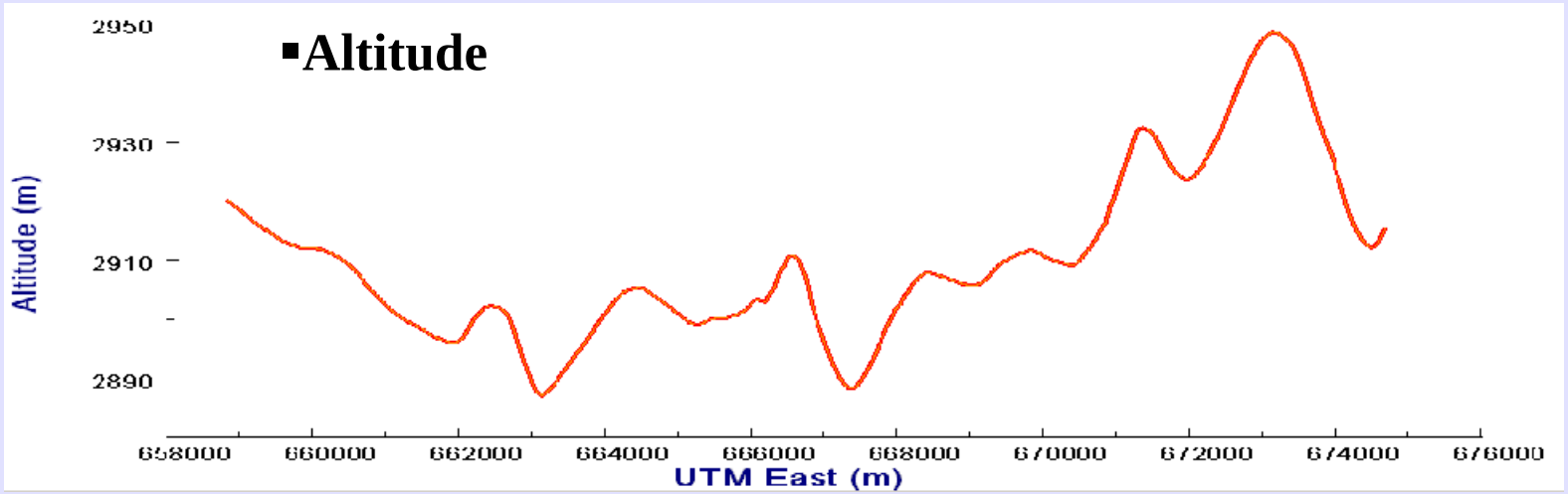


Three GPS receivers were installed on wingtip, fuselage and stinger

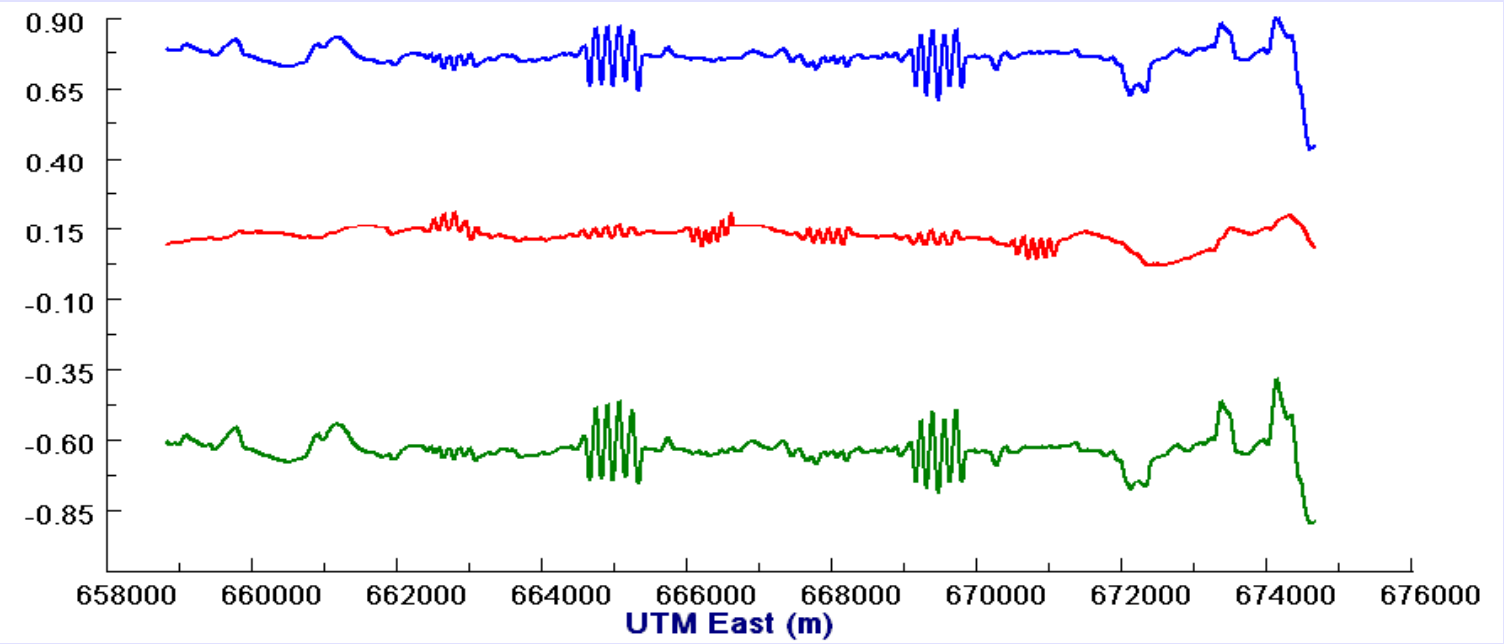
- Field tests were done with 3 Novatel Millenium geodetic grade, dual frequency GPS's on Terraquest's Navajo
- GPS's were sampled at 10 Hz
- GPS base station was 40 to 70 kms away
- base station a Novatel Millenium sampled at 10 Hz
- differential corrections done with WayPoint software

Real Flight


▪Flight Path
▪ Heading: West
UTM North (m)
4923570
4923470
4923370
4923270
4923170
658000
660000
662000
664000
666000
668000
670000
672000
674000
676000
UTM East (m)

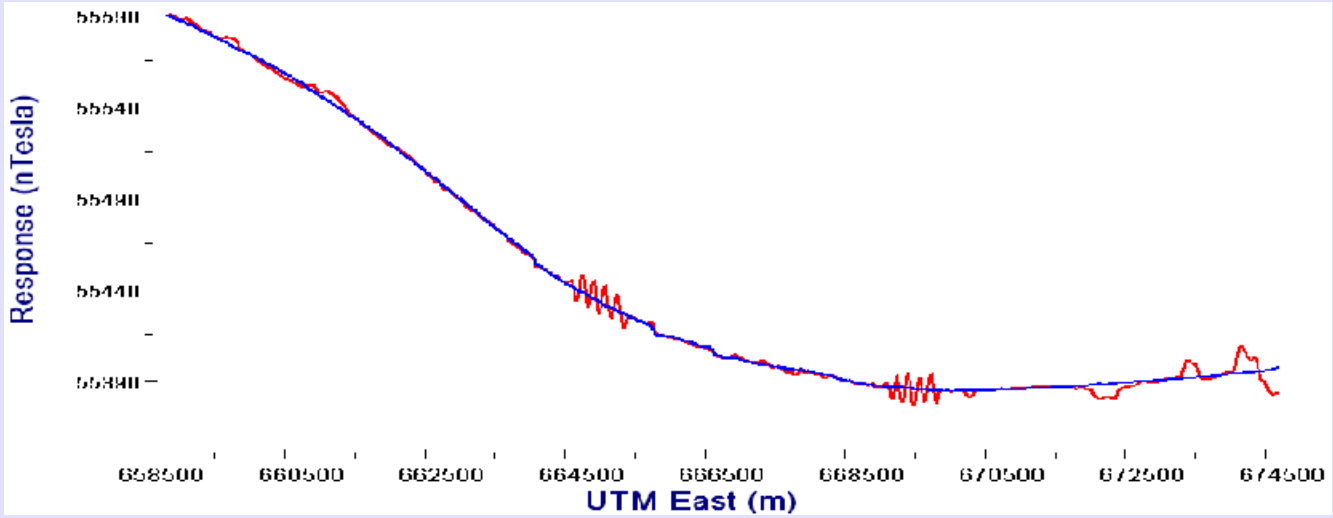

▪Altitude
Altitude (m)
2950
2930
2910
2890
658000
660000
662000
664000
666000
668000
670000
672000
674000
676000
UTM East (m)

Measured Fluxgate

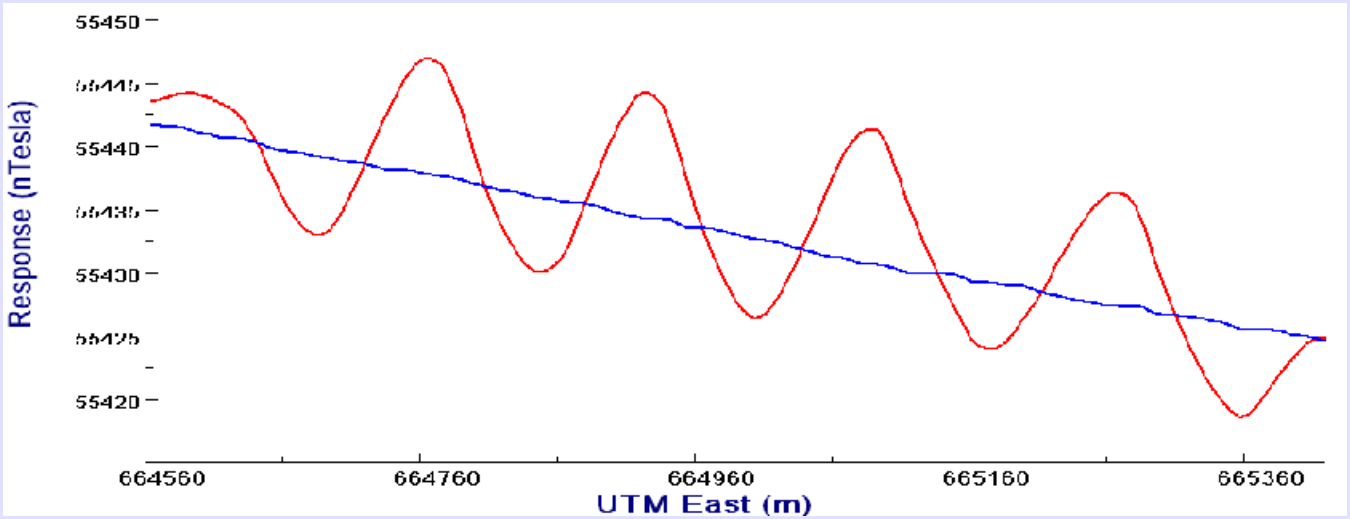


- **Red: transverse**
- **Blue: longitudinal**
- **Green: vertical**

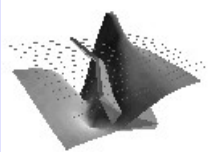
Compensation Results with Measured Fluxgate



Red: measured (FOM = 292), Blue(FOM=97)



Red: measured (FOM = 72), Blue(FOM=0.94)



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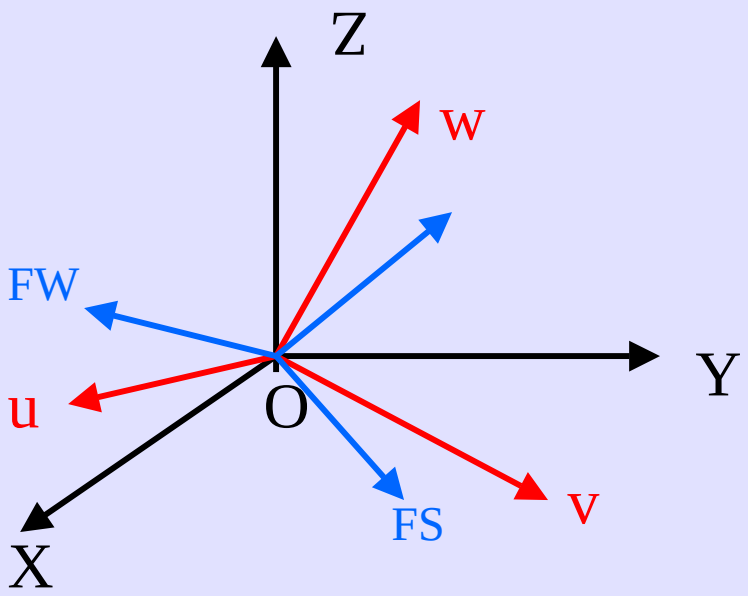
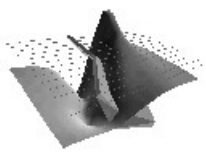
GPS Based Compensation

Steps for estimating fluxgate data utilizing GPS information

1. Determine the orientations of aircraft's axes in UTM coordinate system
2. Use IGRF inclination and declination of local field to calculate the fluxgate data



- O-XYZ: UTM coordinate system
- O-uvw: **aircraft reference system**
- **Blue: vectors are generated with GPS data, which are invariant wrt. aircraft system** O-uvw

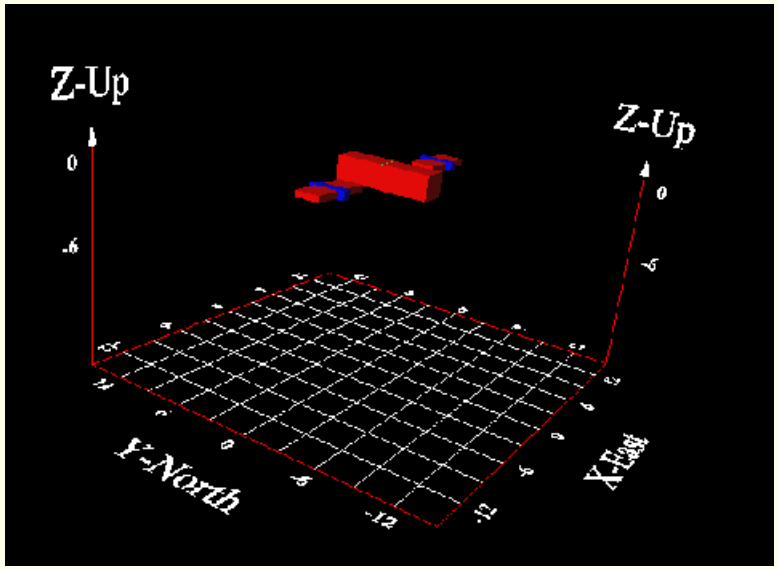


Synthetic Testing

Perspective view of the a sample block model of the “aircraft”

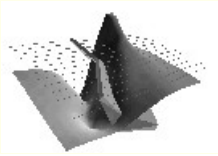
- **Permanent: blue blocks stand for two magnetic dipoles, one on each wing**

- **Induced: red blocks are 2 thin rectangular prisms representing the two wings and another long box type prism to represent the fuselage**



- **Eddy-current fields:**

Calculated by the time variation of the coupling of the tow prism structures representing the wings with the earth’s field



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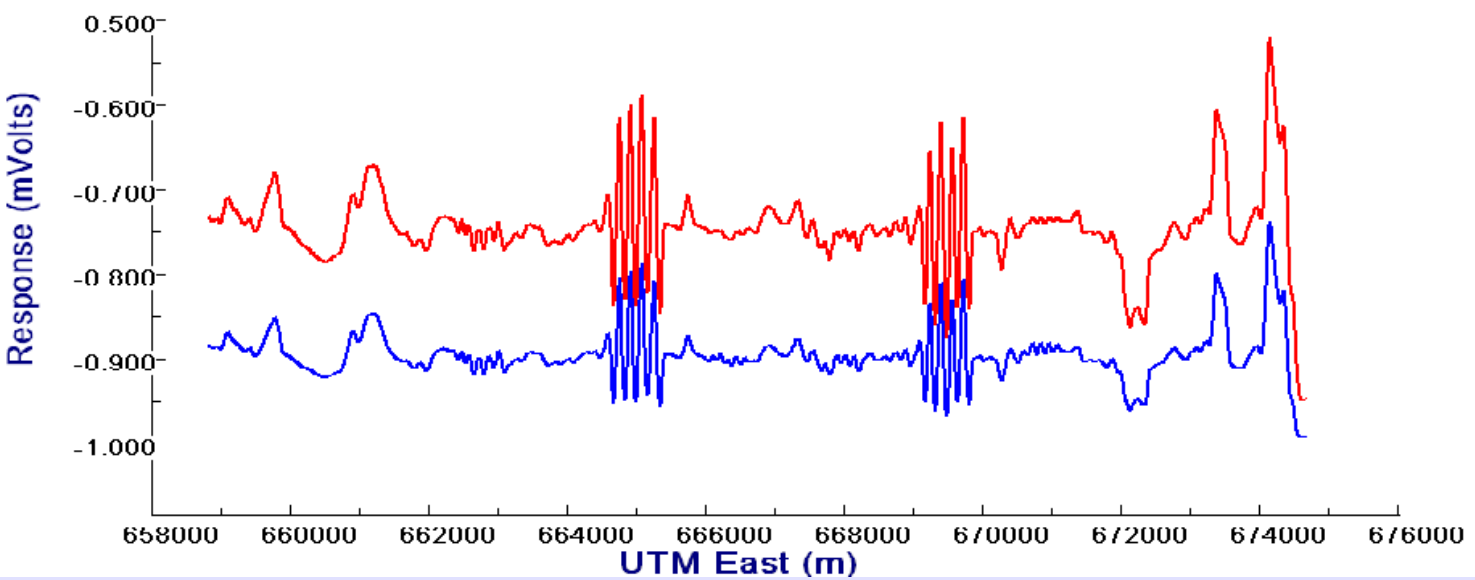
Synthetic Fluxgate Channels

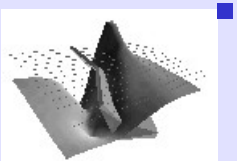
Local Field:

- Inclination 71.3 degrees
- Declination: 11 degrees west to the north



Vertical Fluxgate Channel

- Red: measured
- Blue: synthetic



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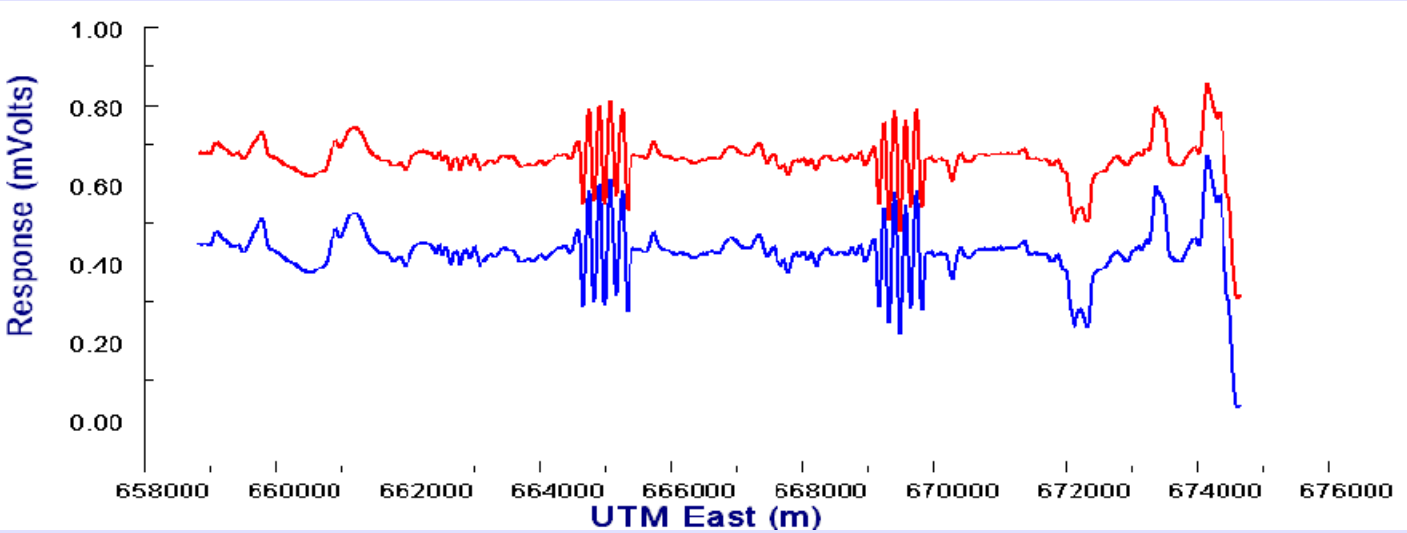
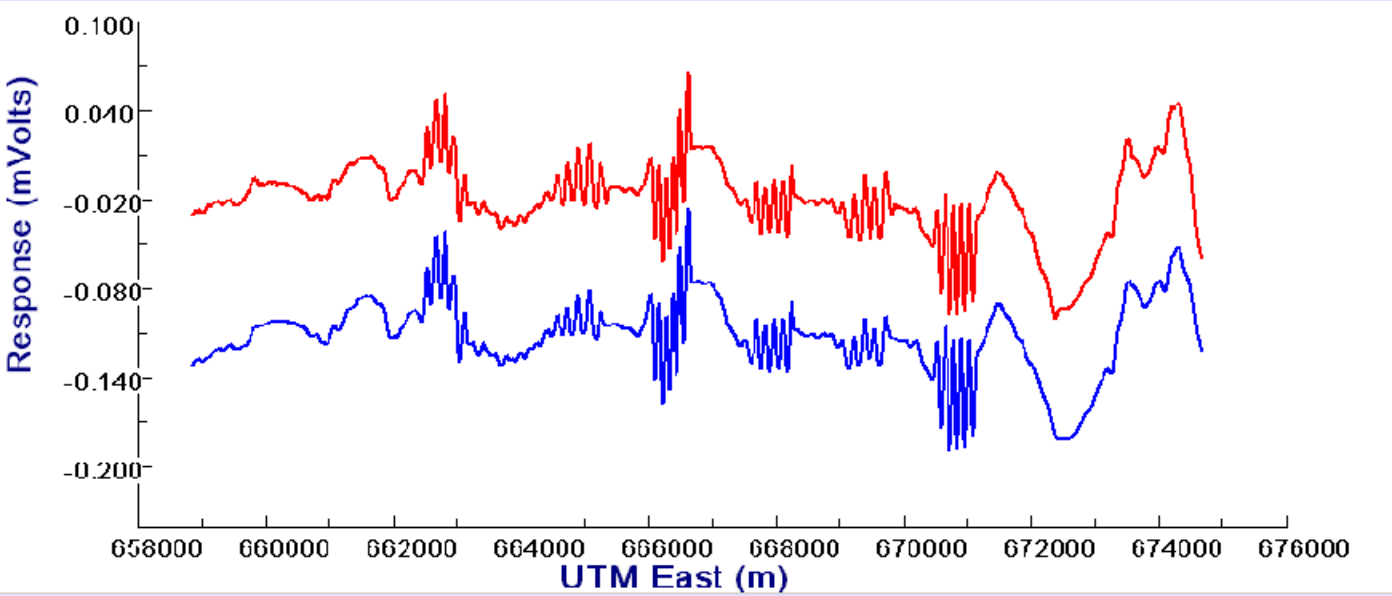
Synthetic Fluxgate Channels



Longitudinal Fluxgate Channel

- Red: measured
- Blue: synthetic

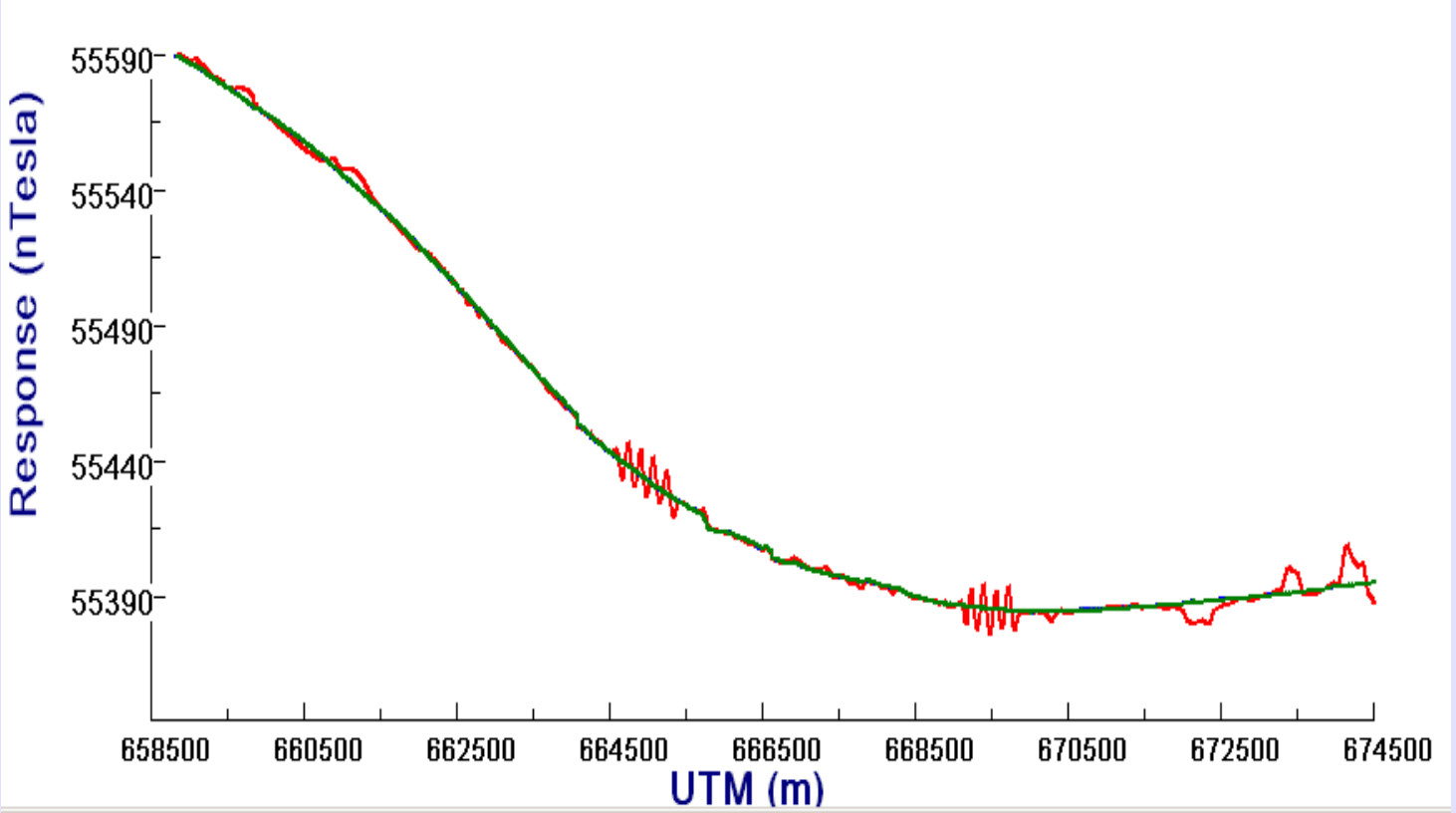
Synthetic Fluxgate Channels



Transverse Fluxgate Channel

- Red: measured
- Blue: synthetic

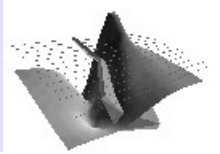
Compensation Results with Measured Fluxgate



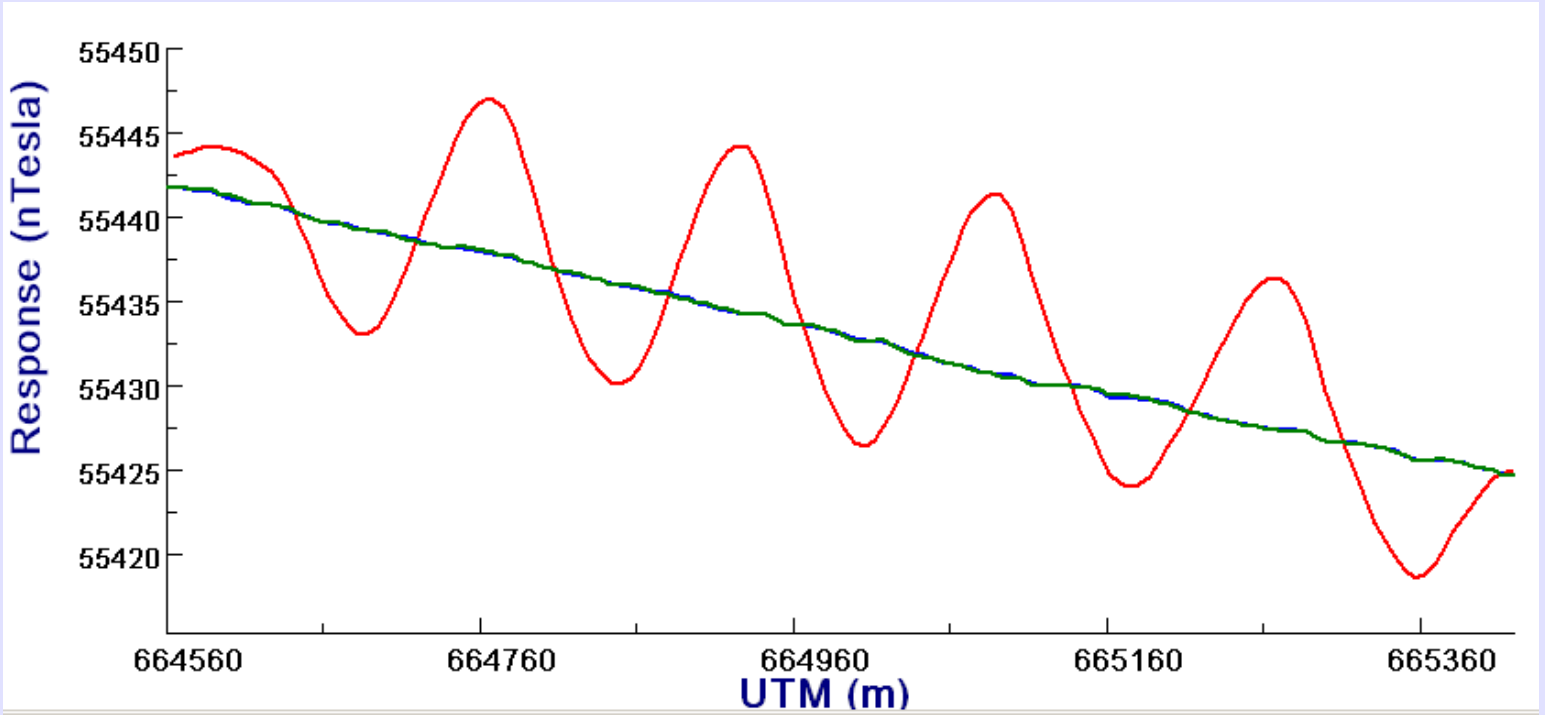
Red: measured (FOM = 292)

Blue: compensated with measured Fluxgate (FOM=97)

Green: compensated with synthetic Fluxgate (FOM=94)



Compensation Results with Measured Fluxgate



Zoom-in display

Red: measured (FOM = 72)

Blue: compensated with measured Fluxgate (FOM=0.94)

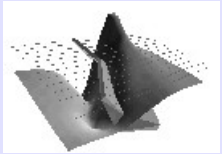
Green: compensated with synthetic Fluxgate (FOM=0.9)

Conclusions

- Based on a function calculating Figure of Merit (FOM), an optimum filtration can be selected.
- Aeromagnetic compensation can be accomplished using 3 GPS sensors mounted on aircraft
- Capable of building synthetic the aircraft's magnetic effects based on GPS information

Direction:

- Compensate Fluxgate data utilizing GPS information



Acknowledgements

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  for their helpful discussions and suggestions