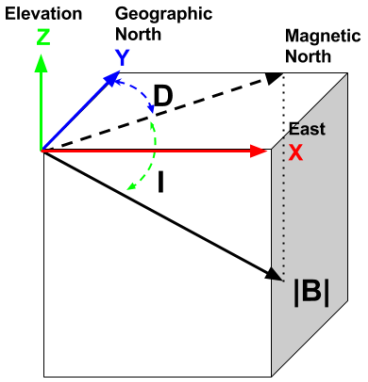
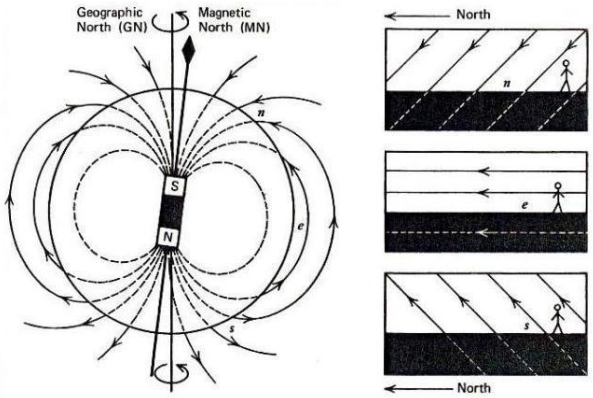
From last time

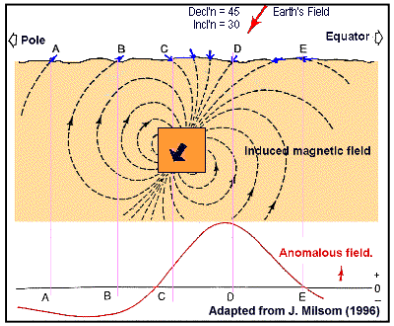
- Earth's magnetic field acts as a source

- It is defined by inclination, declination and amplitude





- The Earth's field induces magnetization in susceptible bodies



From last time

- Induces magnetization is parallel to the Earth's field

$$\vec{M} = \kappa \vec{H}$$

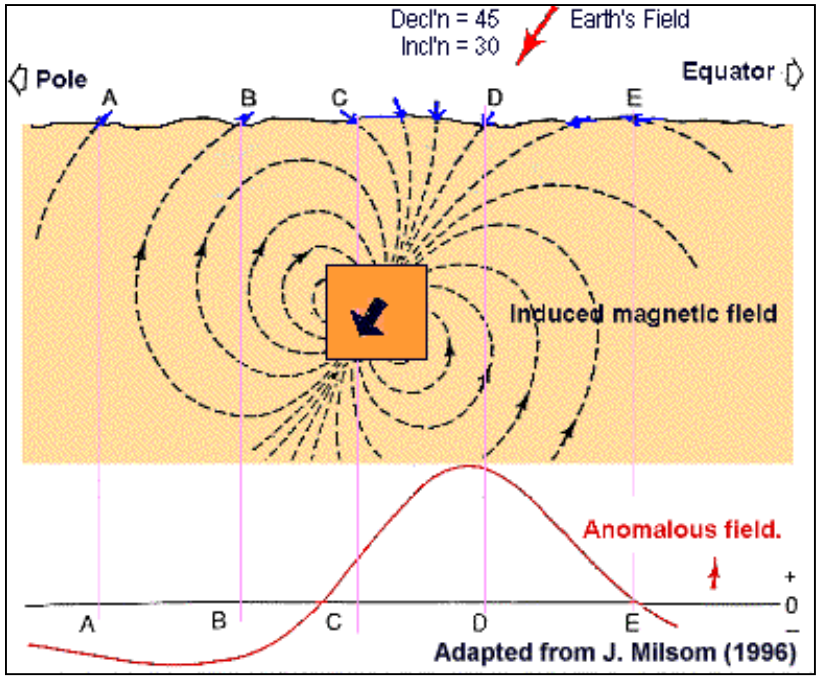
- The total magnetization is induced + remanent (if it exists)

$$\vec{M_T} = \vec{M_I} + \vec{M_R}$$

- The measured field is

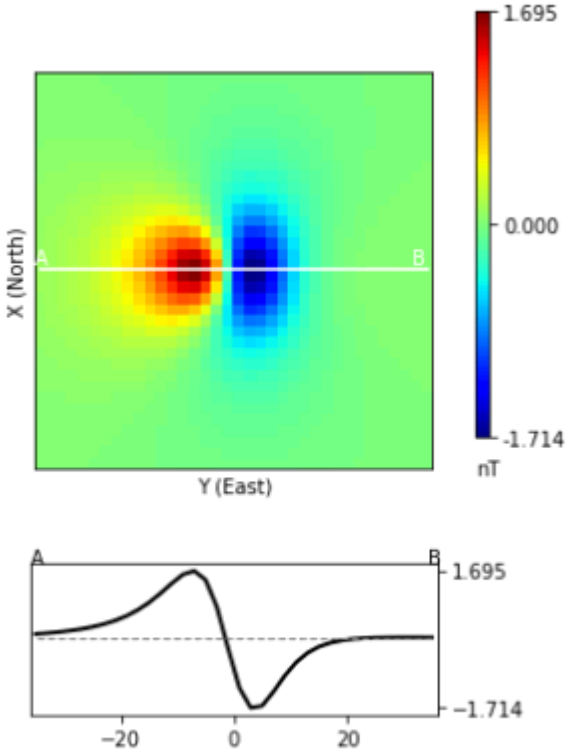
$$B = B_0 + B_A$$

- Anomaly depends on strength and direction of anomalous field relative to B_0

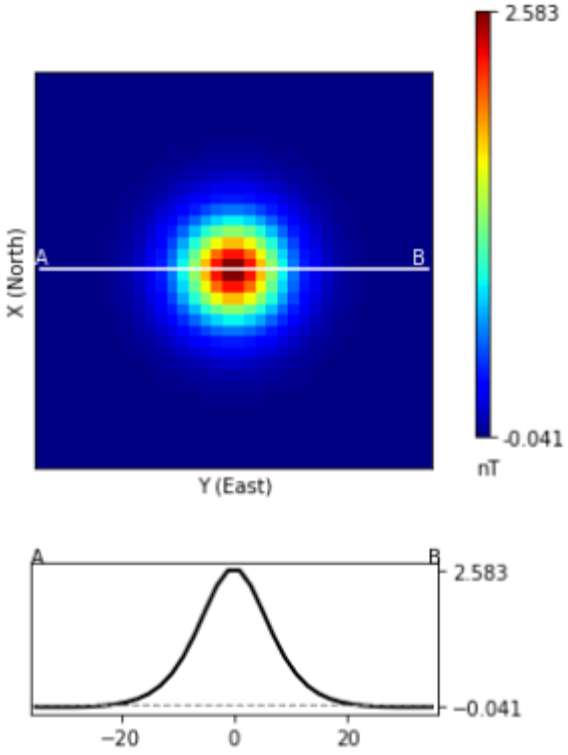


From last time

Dipole

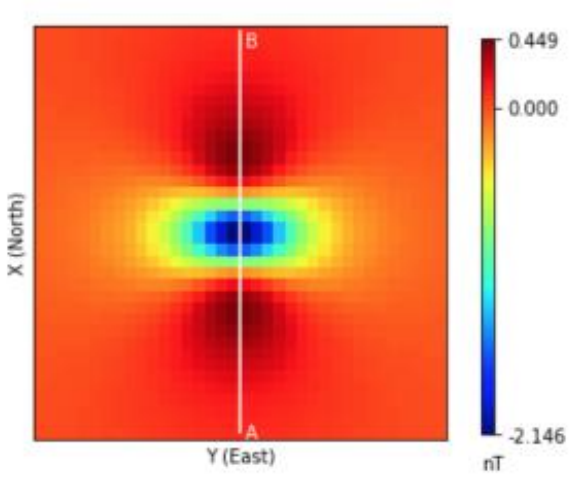


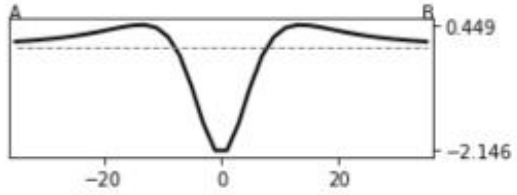
Monopole



From last time

Same object buried at different locations on the earth yields different total field anomalies





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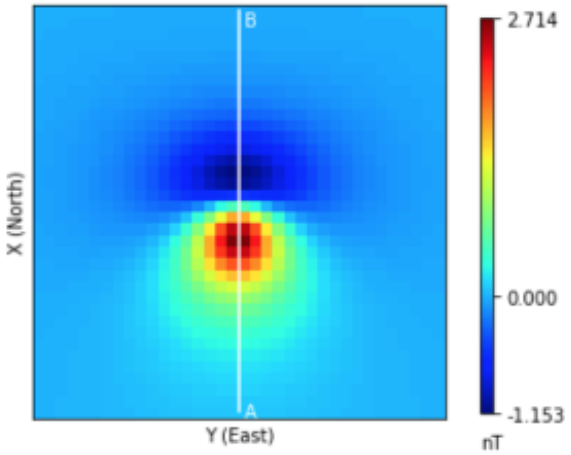
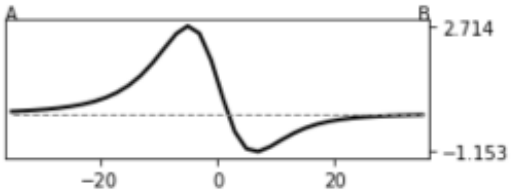
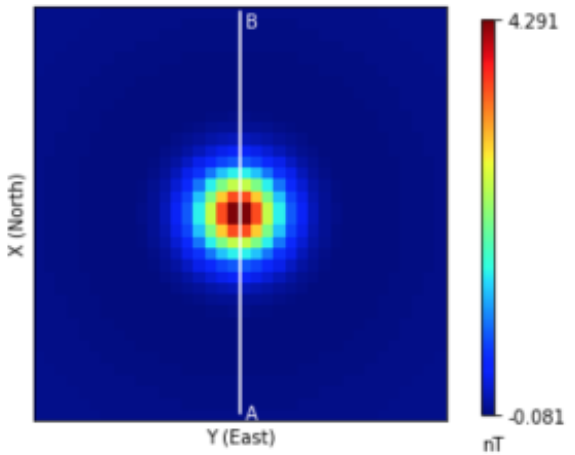
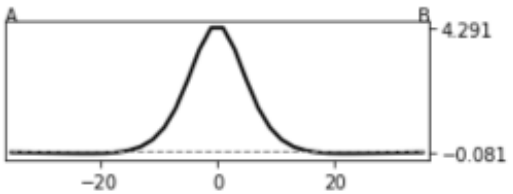




Inclination=45





Inclination=90

Today’s topics

- Survey
- Data
- Processing

Survey

Reading on the GPG:

https://gpg.geosci.xyz/content/magnetics/magnetics_survey.html

Magnetic surveys

- Very common mineral exploration tool to aid with geologic mapping.
- One of the **cheapest** geophysical surveys to execute on land or with an aircraft.
- Used on regional and deposit scale to identify geologic boundaries and structures (such as faults or folds).
- Many mineral deposits are found on geology boundaries or faults so magnetic maps are useful for target prospective areas.

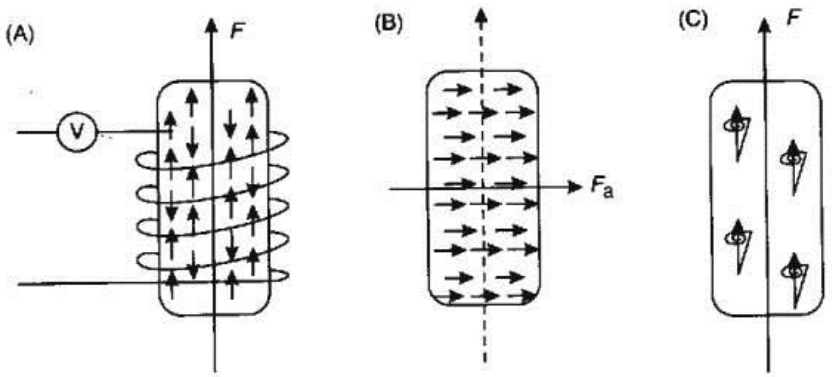
Survey

Some good questions:

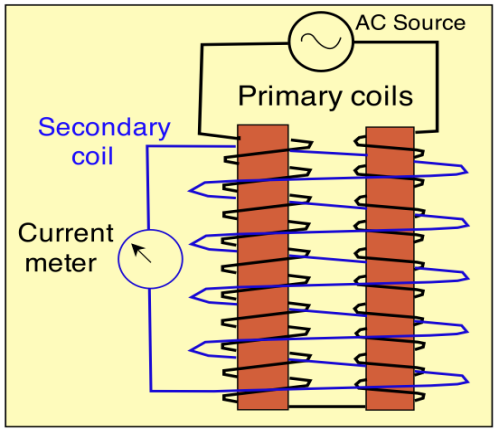
- What instrument should we use?
- What are we looking for?
- What is the scale of the problem?
- Do we fine or coarse definition of anomalies?

Magnetometers

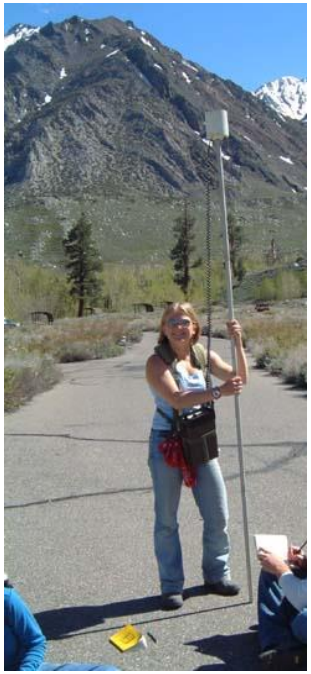
- Total field $|B_0|$
  - Proton procession
  - Cesium vapour magnetometer



- Vector field B_x, B_y, B_z
  - Fluxgate
  - SQUID: superconducting quantum interference devices



Magnetic sensors to acquire data

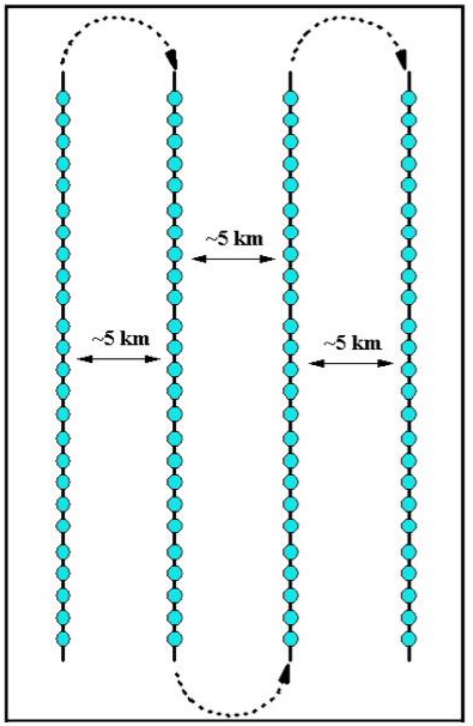


Basic survey principles

- Design criteria: Capture anomaly, (3 or 4 points per halfwidth); acquisition area

- Large enough to see the anomaly

- Airborne surveys
  - Dense In-line data
  - Line spacing
  - Flight direction might require data correction



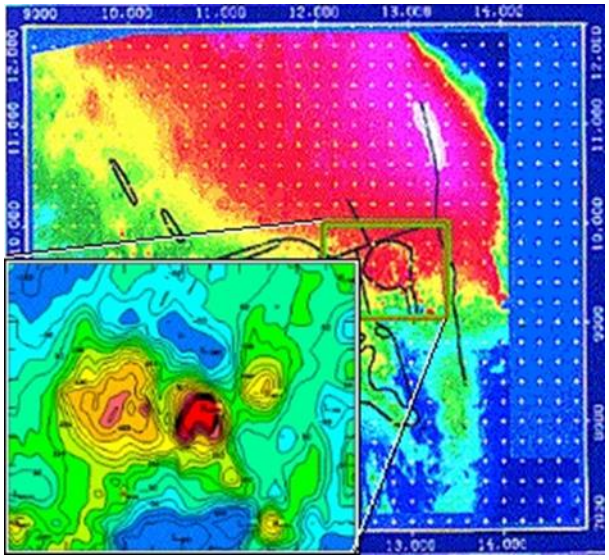
Data

Reading on the GPG:

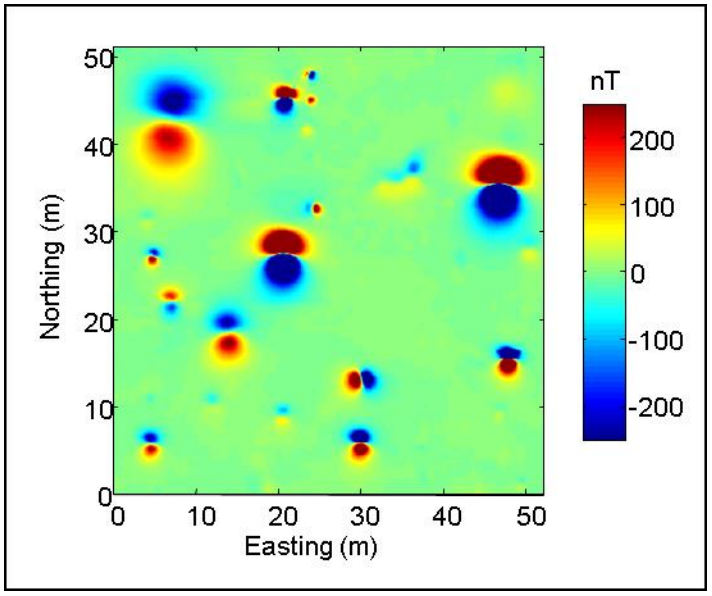
https://gpg.geosci.xyz/content/magnetics/magnetics_data.html

Examples of magnetic anomaly data

Large-scale data



Small-scale data



Processing

Reading on the GPG:

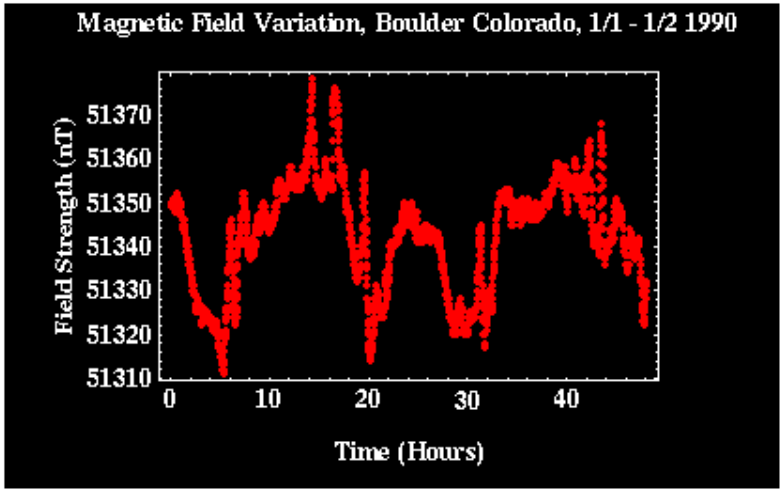
https://gpg.geosci.xyz/content/magnetics/magnetics_processing.html#processing

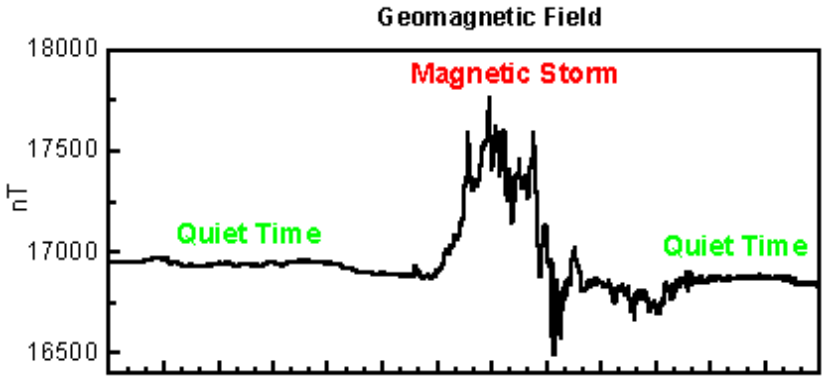
Processing

Go from raw data to data that is more easy to interpret.

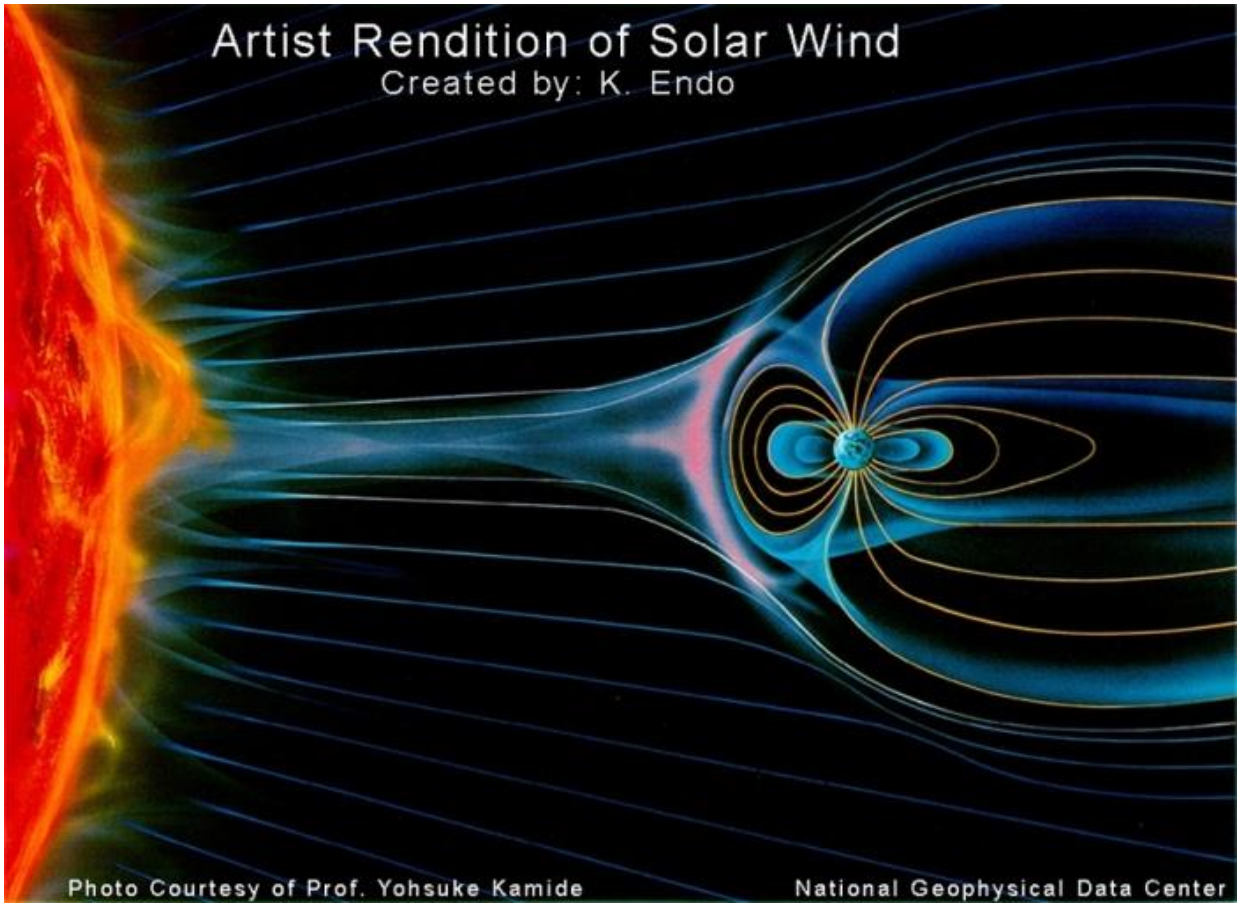
Processing: Time-Variation in Source Fields

- External sources
  - Solar wind (micro-seconds, minutes, hours)
  - Solar storms (hours, days, months)
- Man made sources
  - Power lines (50/60 Hz plus harmonics) DC
  - Motors, generators, electronic equipment
- Internal sources
  - Fluctuations in core (days to millions of years)





Processing: Time-Variation in Source Fields



24 hours: solar wind interacting with earth's field and rotation
Solar storms: hours to days + 27 day recurrence
Sun spot cycle: 11 years

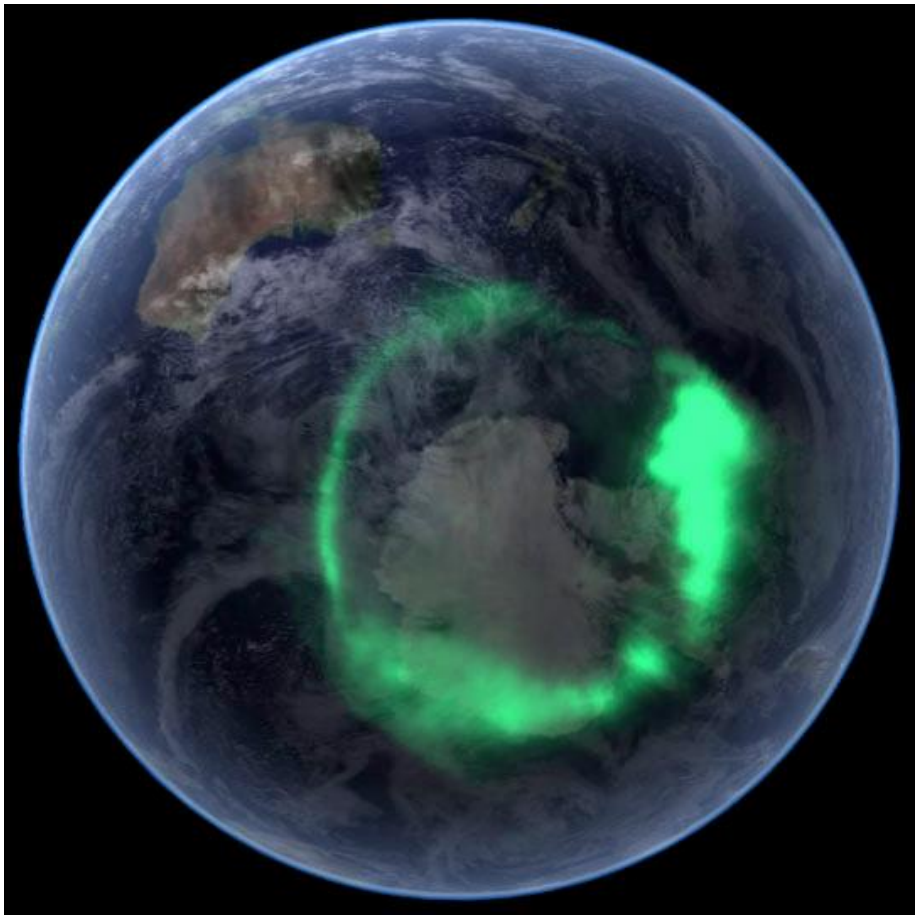
Processing: Time-Variation in Source Fields

Government of Canada / Gouvernement du Canada

Space weather

Reviews and forecasts: https://www.spaceweather.gc.ca
Useful for planning surveuys
No correlation between space weather and tropospheric weather

Processing: Time-Variation in Source Fields



Aurora australis (11 September 2005) as captured by NASA's IMAGE satellite, digitally overlaid onto The Blue Marble composite image.

The aurora borealis from the ground at Bear Lake, Alaska.

The motion of electronic charges produce magnetic fields.

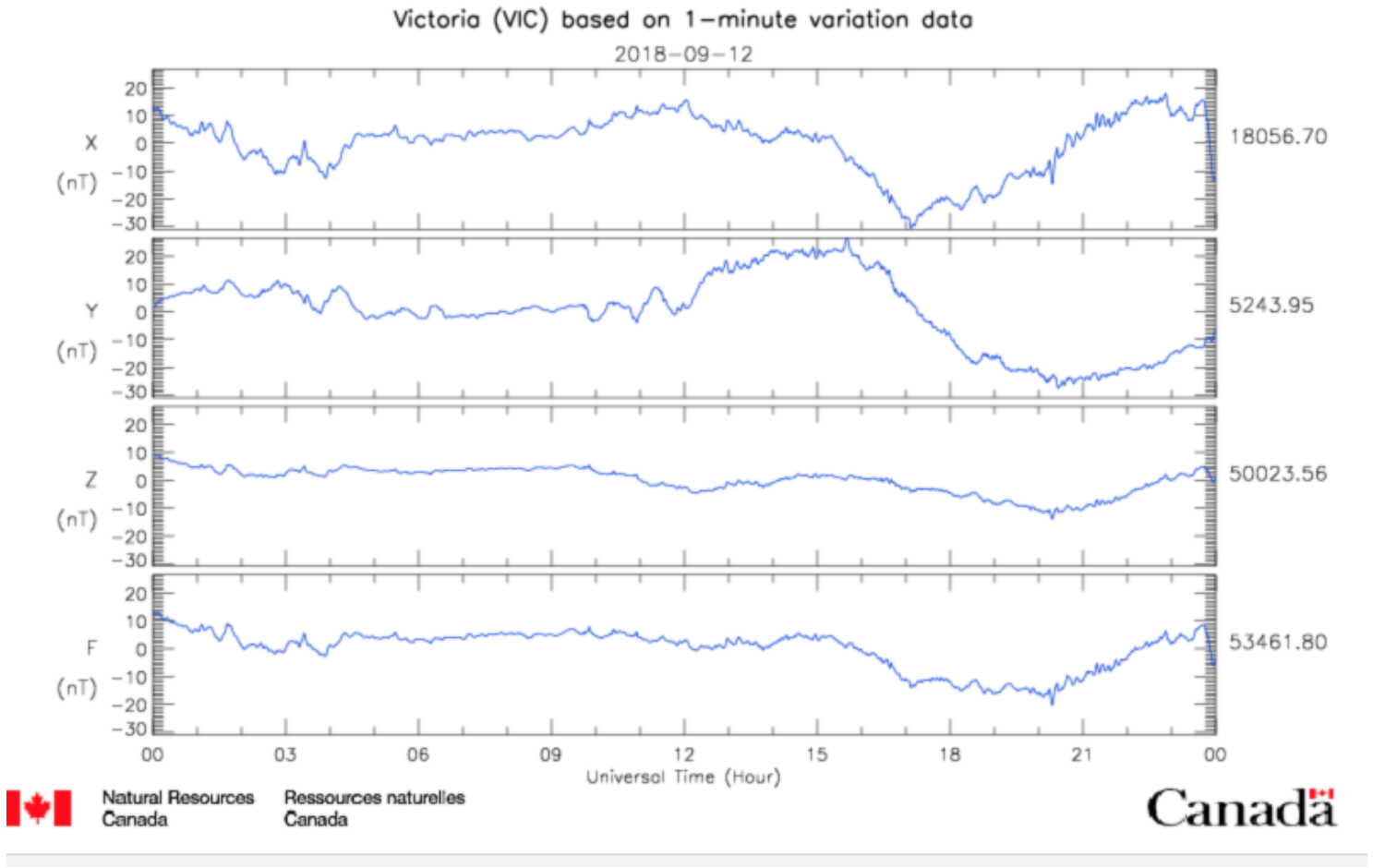
Processing: Time-Variation in Source Fields

- Lightening

- Electronic infrastructure

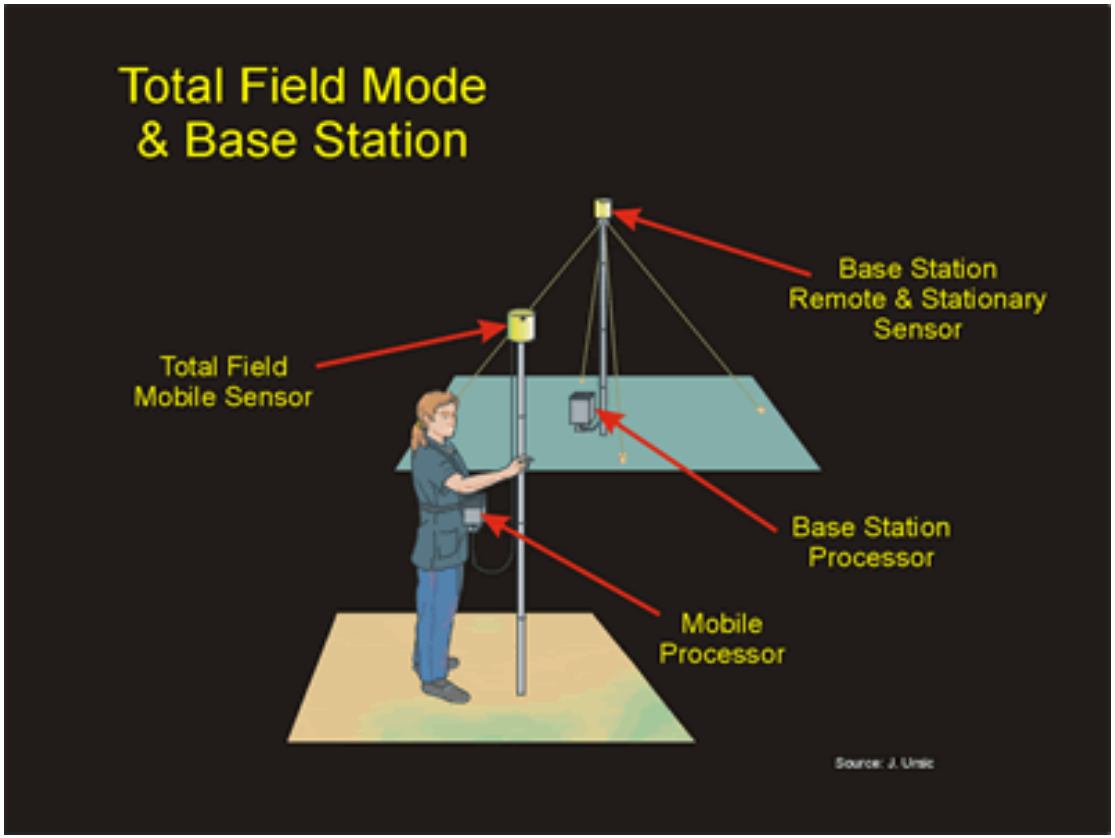
Variation of magnetic field: Victoria, BC

http://www.spaceweather.gc.ca



Processing: Time-Variation in Source Fields → Base station correction

- Set out another magnetometer (base station)
- Assume time-dependent variations at the base stations are the same as at the observation location
- Synchronize the times
- Perform a correction by subtraction

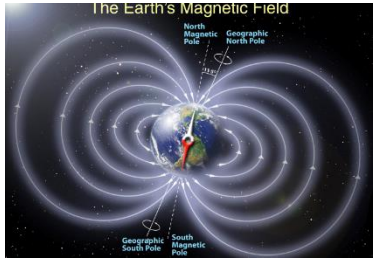


Processing: Regional/Background Removal

- Any magnetic measurement is superposition of fields from many objects at different scales
- Example: magnetic data for UXO could include

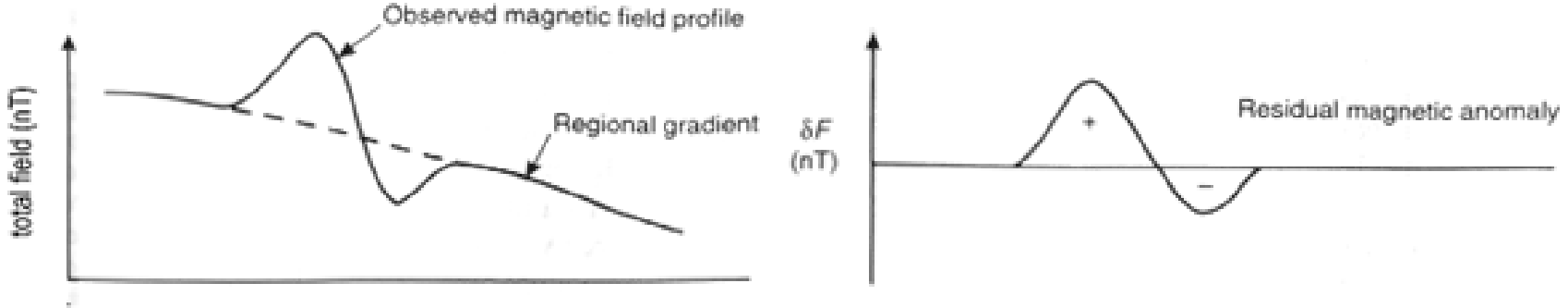

+

+


+


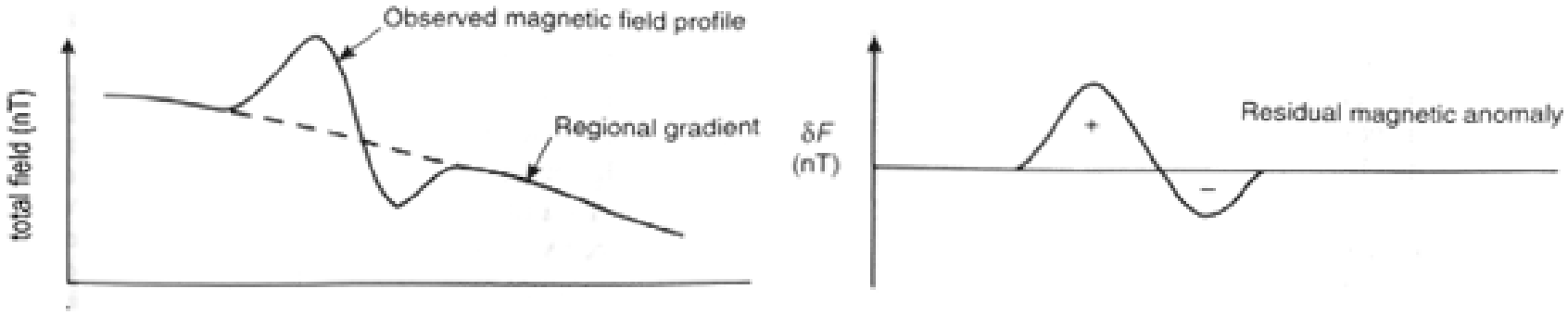
+…

- Regional removal (assuming no magnetic objects larger than a certain length scale)
- Highlights smaller features

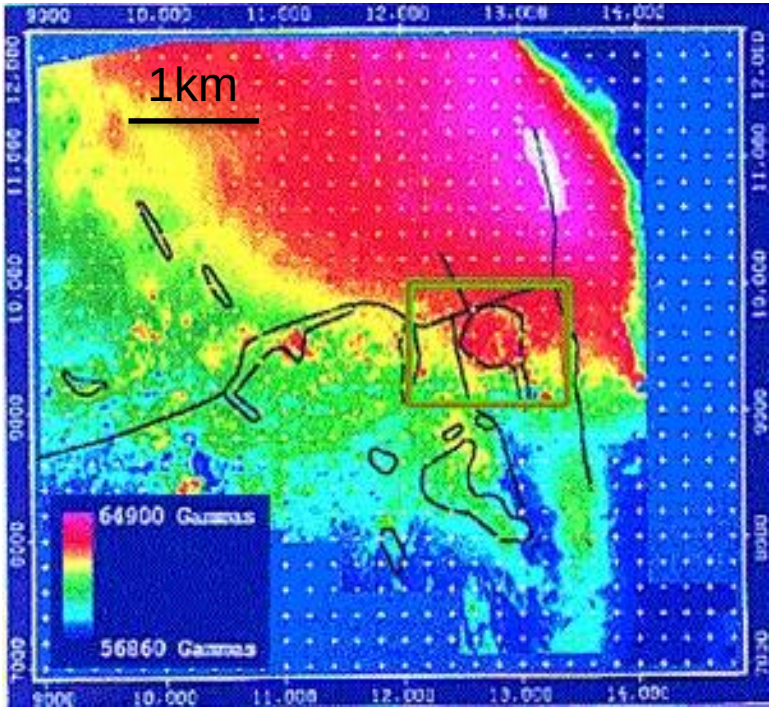


Processing: Regional/Background Removal

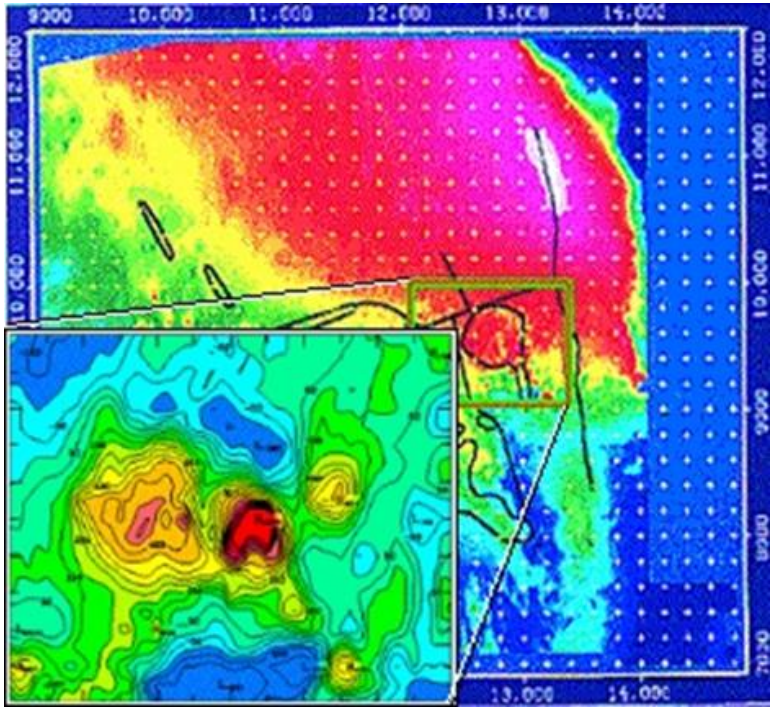
- Background field is generally anything that is smoothly varying over your region of interest and is much larger than the footprint of the body you are interested in.
- Deciding what is background is a subjective decision.



Processing: Regional Removal



Before: details about the deposit masked by the regional field

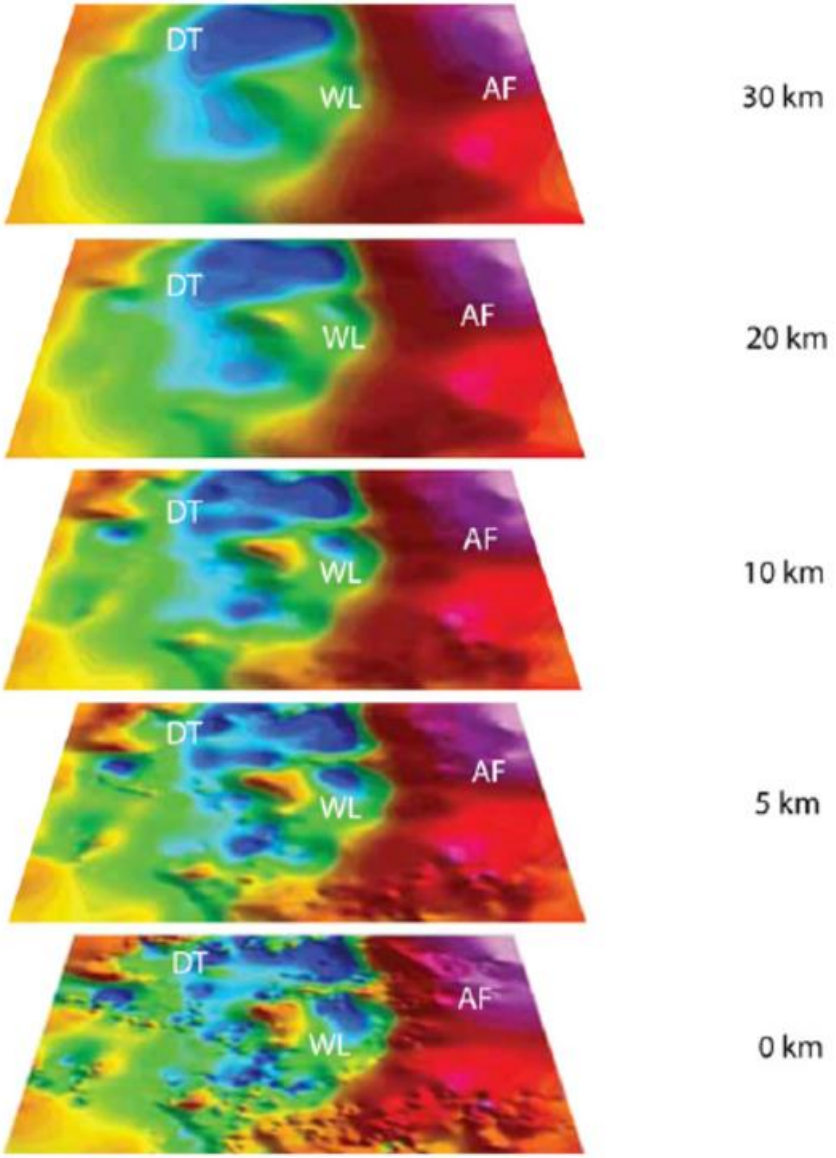


After: target of interest better revealed

$$\Delta B = B^{obs} - B^{regional}$$

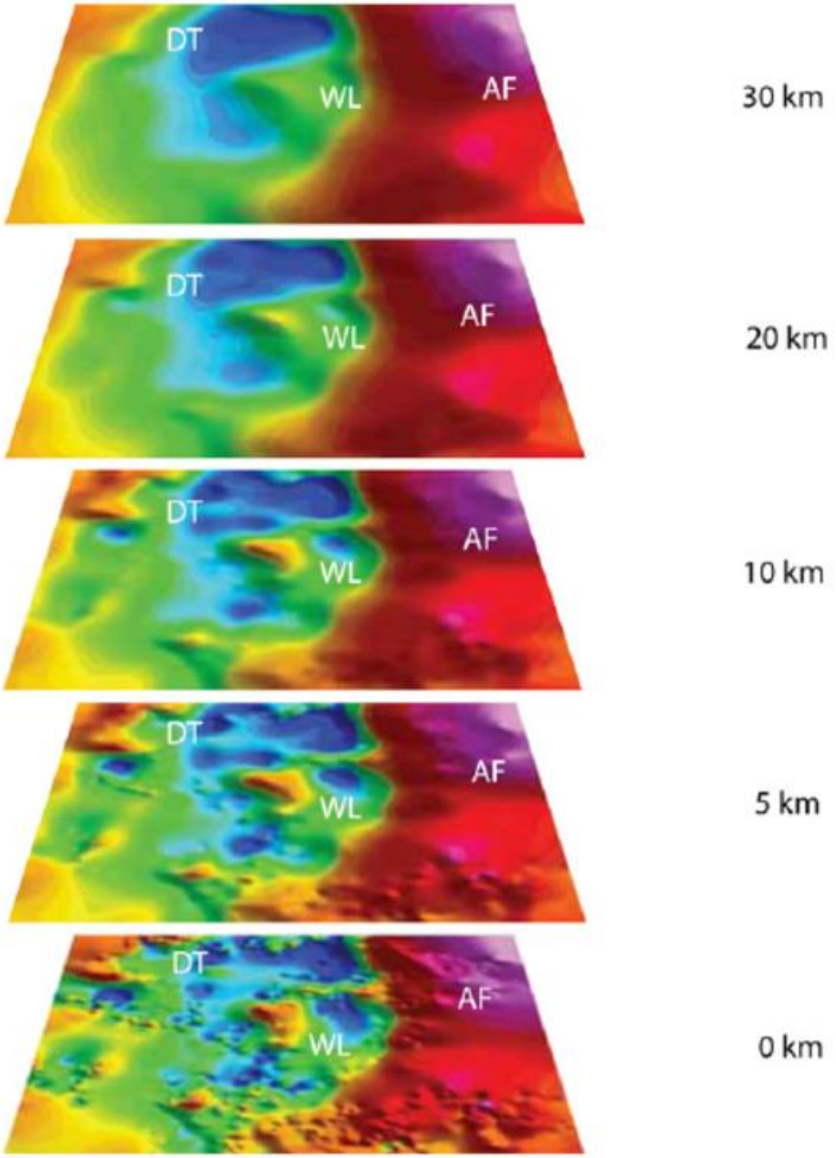
Processing: Upward Continuation

- Low-pass filter: remove short-wavelength signals from small near-surface objects
- As if data are measured at higher elevations
- Highlight regional trends



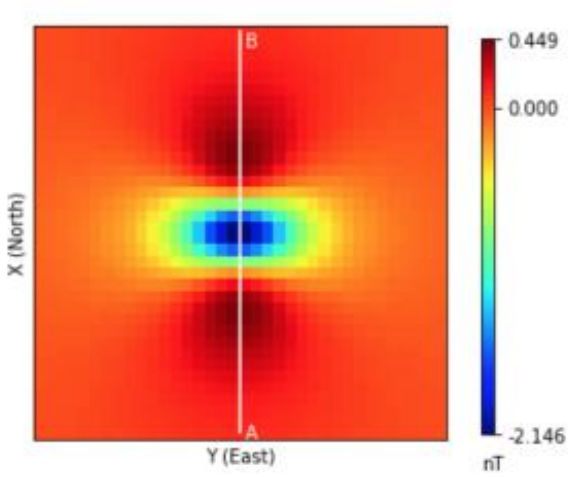
Processing: Downward Continuation

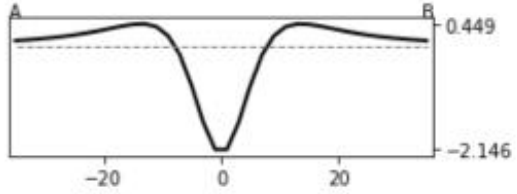
- High-pass filter: remove long-wavelength signals from large regional-scale geologies
- As if data are measured at lower elevations
- Highlight small scale variations



Processing: Reduction to Pole

Same object buried at different locations on the earth yields different total field anomalies





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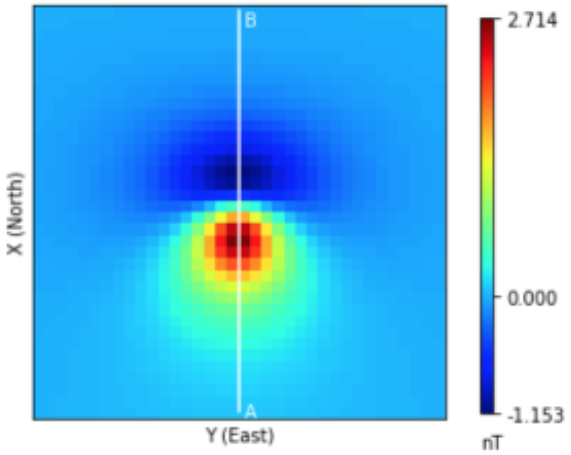
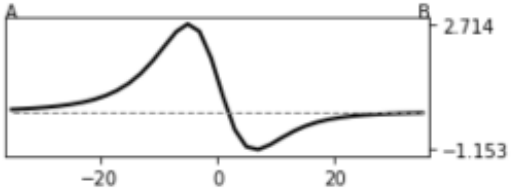
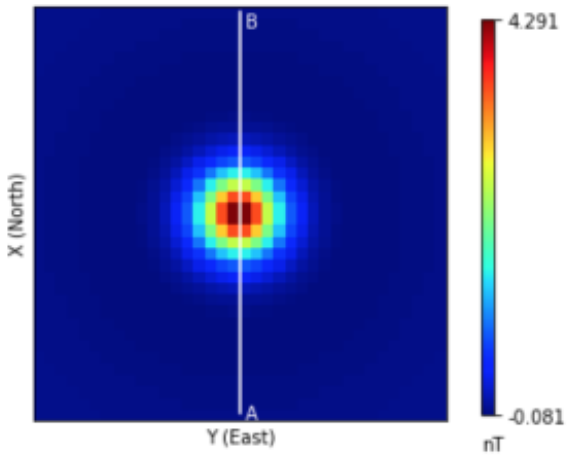
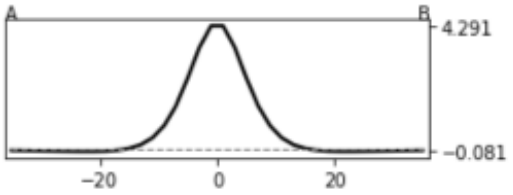




Inclination=45

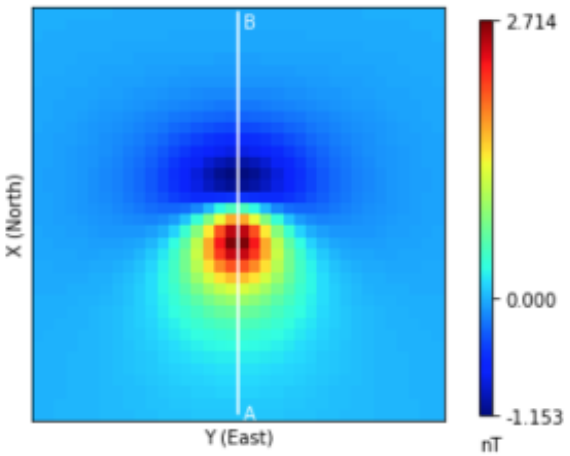




Inclination=90

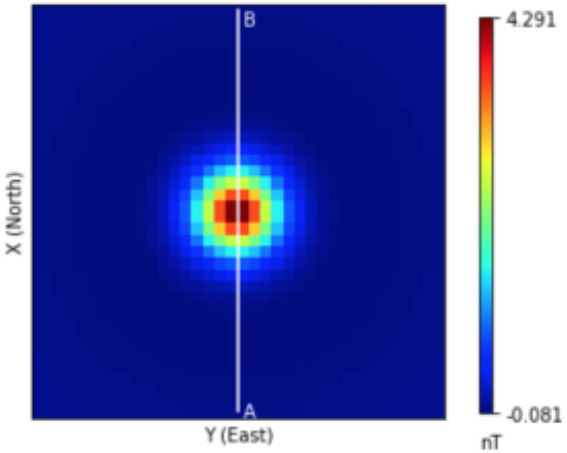
Processing: Reduction to Pole

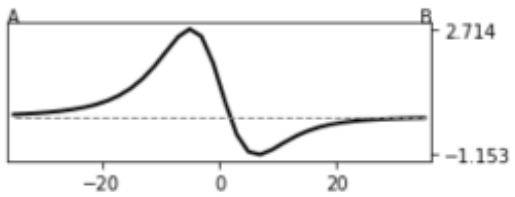
Filter the data to emulate the response as if the survey was taken at the pole. (Earth's field is vertical; measure vertical component of the anomalous field)

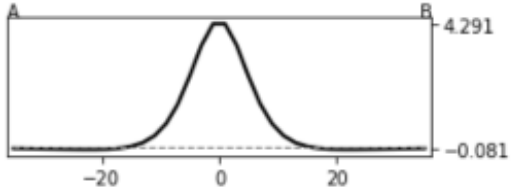


2D Fourier Filter

→







This simplifies interpretation. Causative body lies beneath the peak

Processing: Reduction to Pole

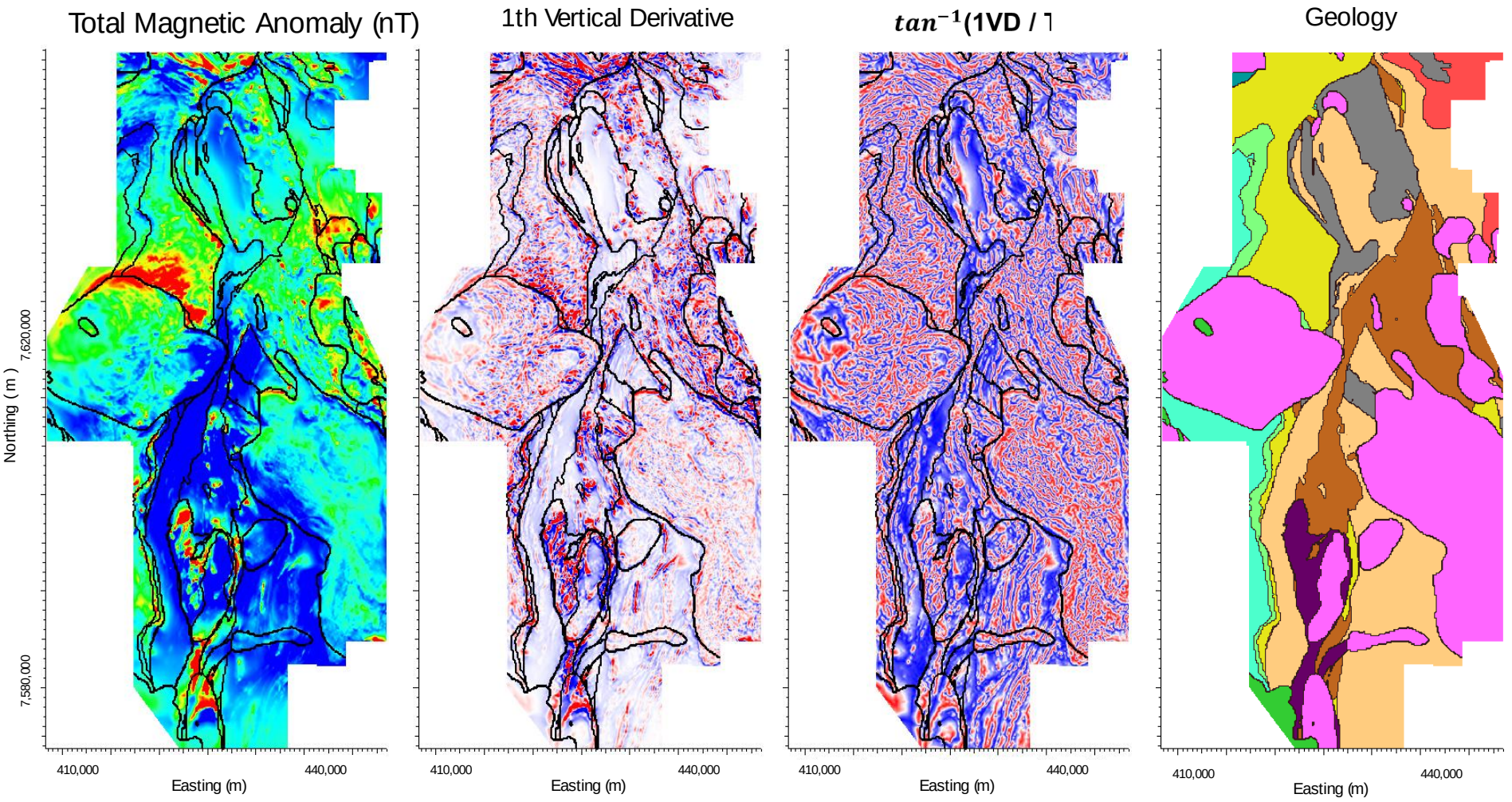
- Magnetic signatures are complicated because the same object provides different data depending where it on the earth (ie depends upon strength and direction of the inducing field.

- Applet example

- This ambiguity can be reduced by processing the data by “Reducing to the Pole”

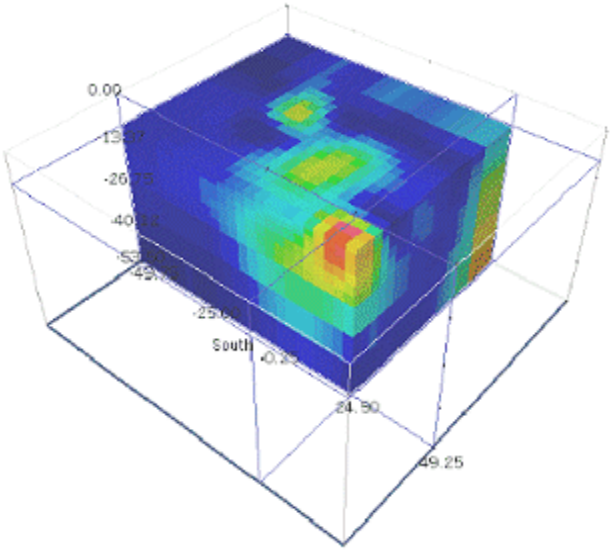
Processing: Derivatives

Source: Queensland Government, Australia

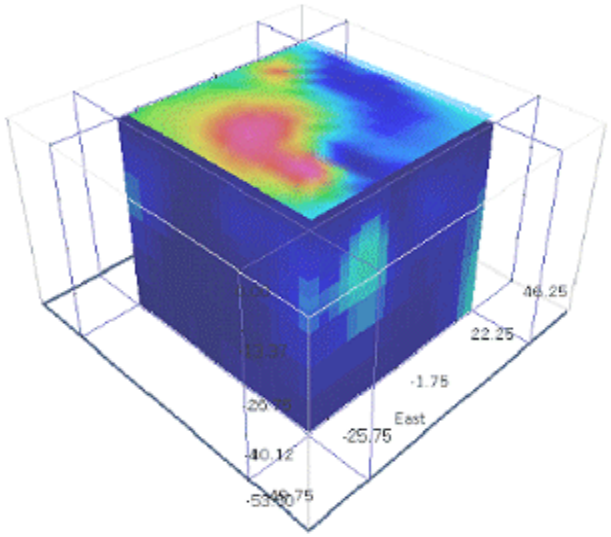


Processing: Geophysical Inversion

A complicated earth model

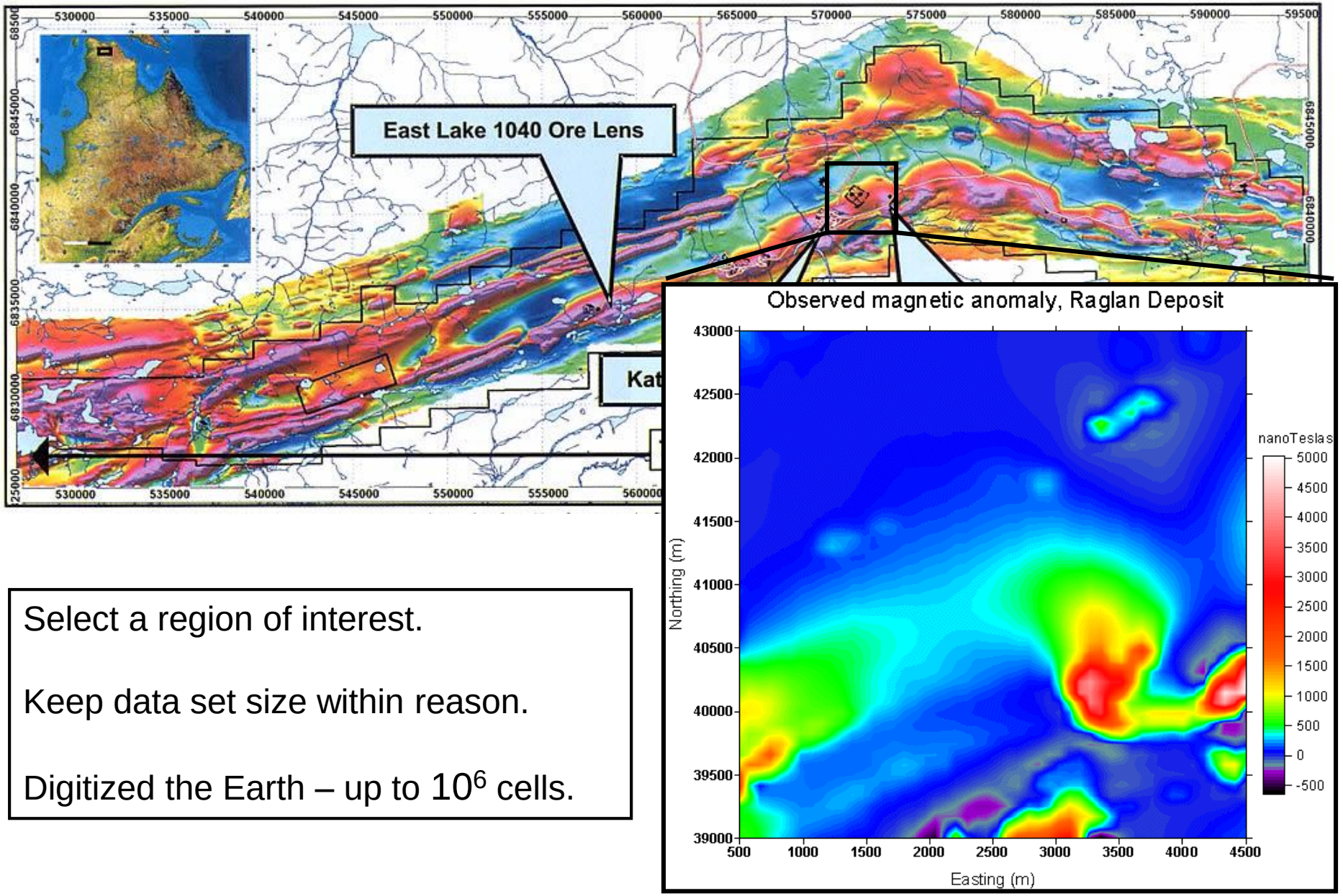


Magnetic data for a complicated earth model.



To interpret field data from a complicated earth we need to have formal inversion procedures that recognize non-uniqueness. Think about finding the causative magnetization of each prism.

Example: Raglan aeromagnetic data



Select a region of interest.

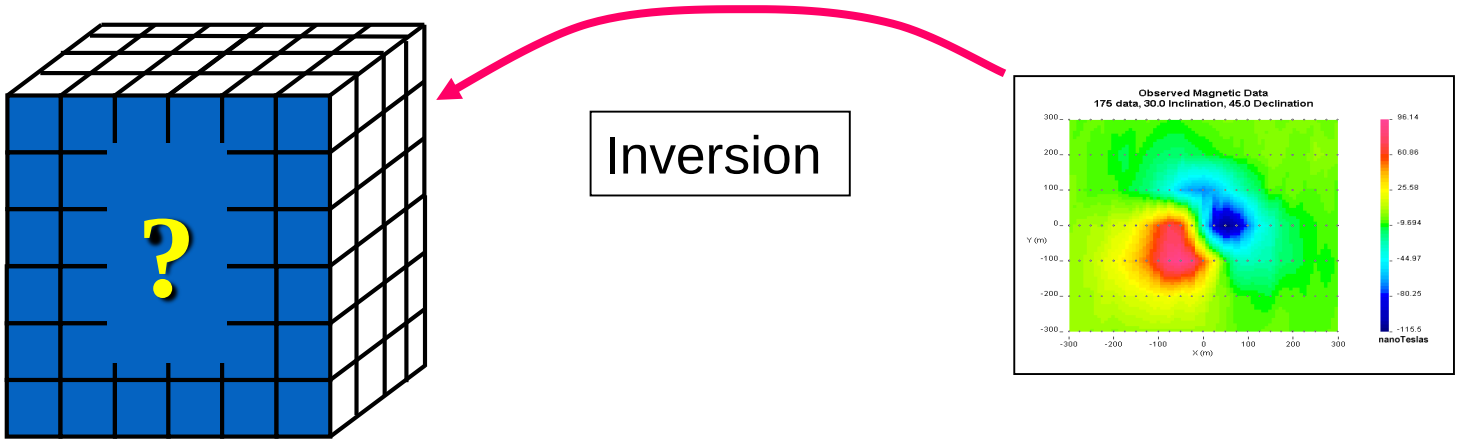
Keep data set size within reason.

Digitized the Earth – up to 10^6 cells.

Processing: Geophysical Inversion

Finding a physical property model that:

- Explains the data
- Is geologically reasonable

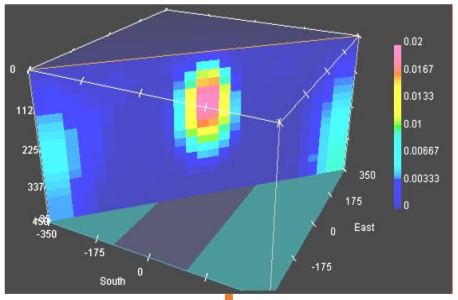


Divide the earth into many cells of constant but unknown susceptibility

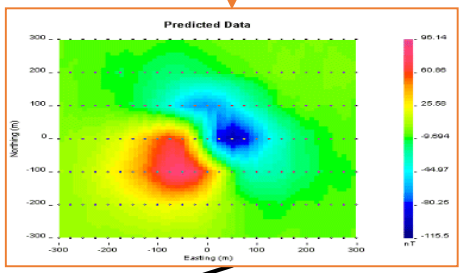
Solve the large inverse problem to estimate the value of each cell

Misfit: Comparing predictions to measurements

Once a model is estimated …

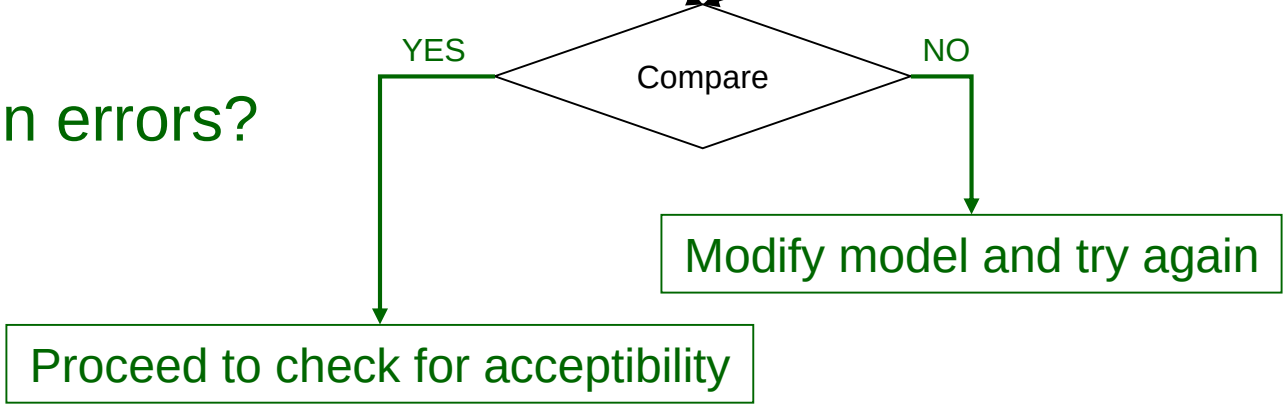


Calculate data caused by that model.



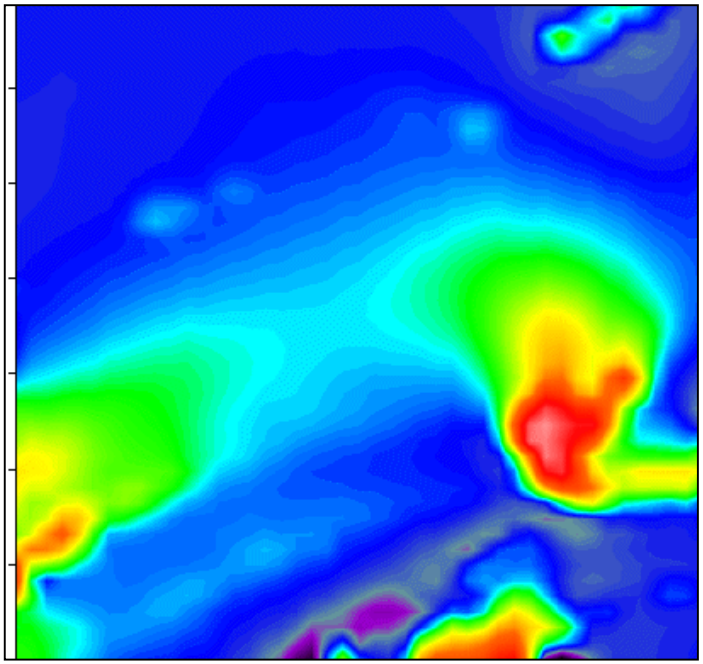
Compare predictions to these measurements.

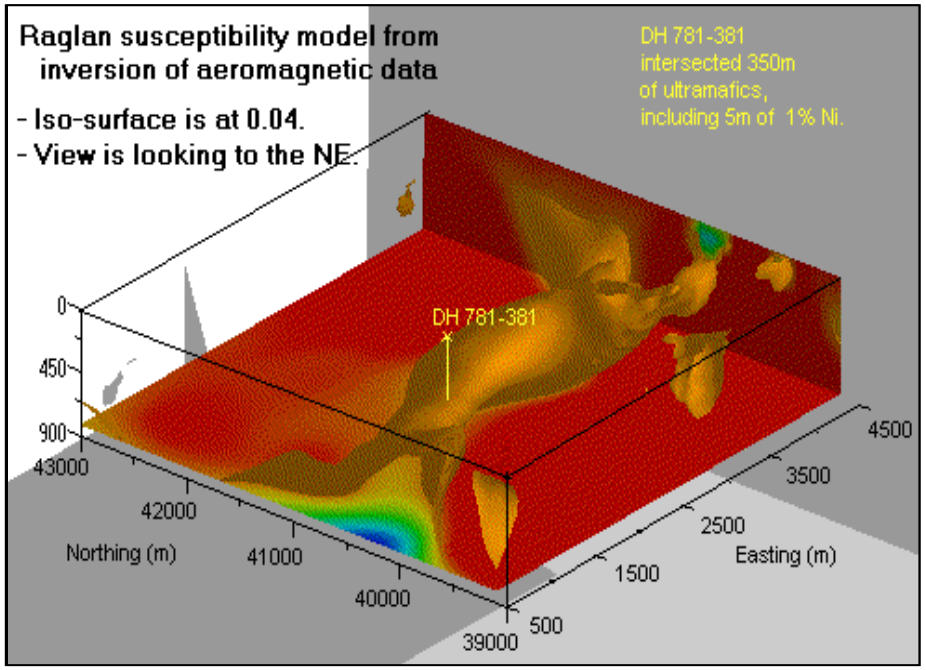
Is comparison within errors?



Raglan aeromagnetic data

- Estimate a model for the distribution of subsurface magnetic material.
- Model will be “smooth”, and close to pre-defined reference.
- Display result as cross sections and as isosurfaces.



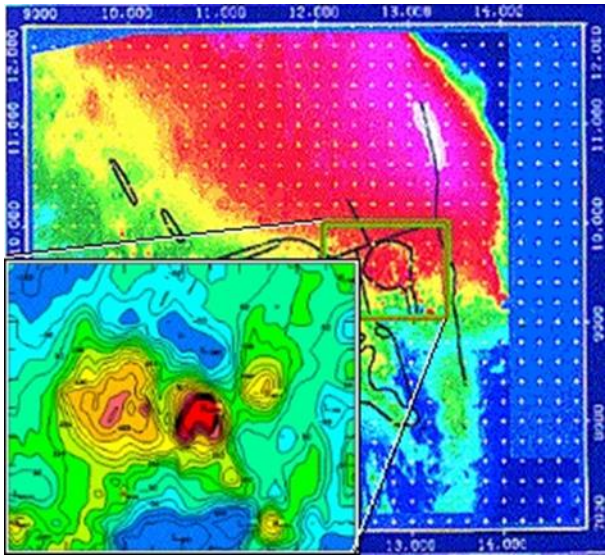


- Are “sills” connected at depth? Inversion result supports this idea.
- It helped justify a 1050m drill hole.
- 330m of peridotite intersected at 650m 10m were ore grade.
- Image shows all material which has k > 0.04 SI.

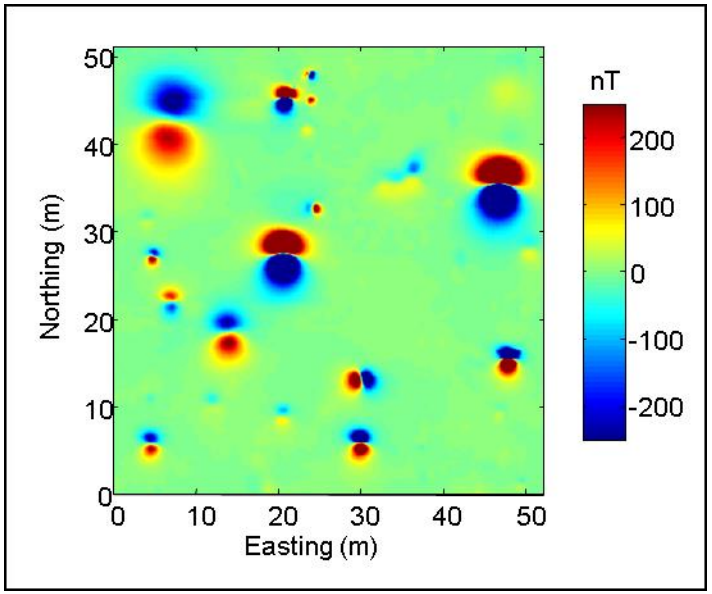
Recap

- Sensors measure total field or sometimes vector components
- Surveys on small or large scale
- Ground, air and borehole surveys
- Optimum spacing determined by size of anomalies

Large-scale data

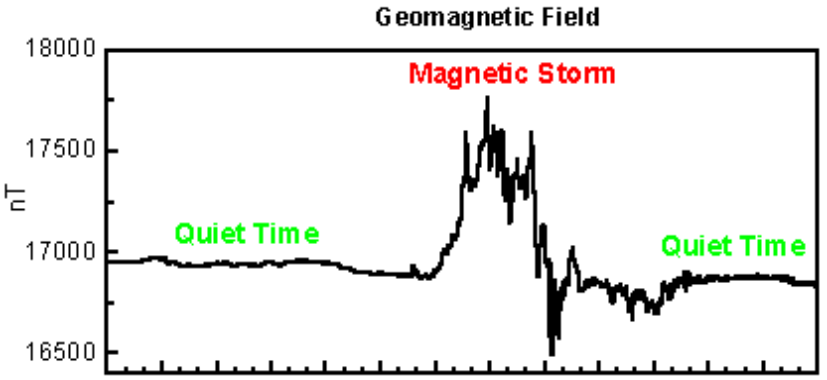


Small-scale data

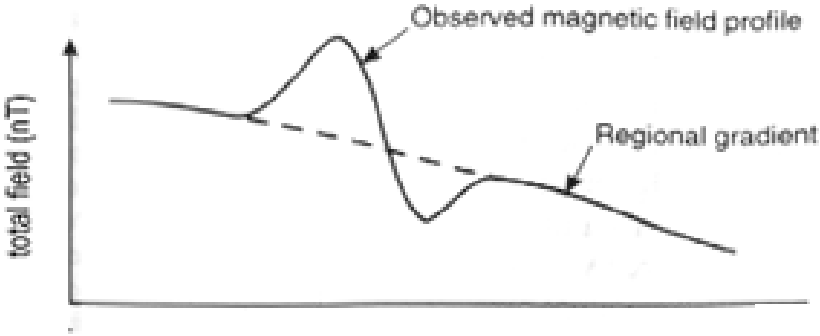


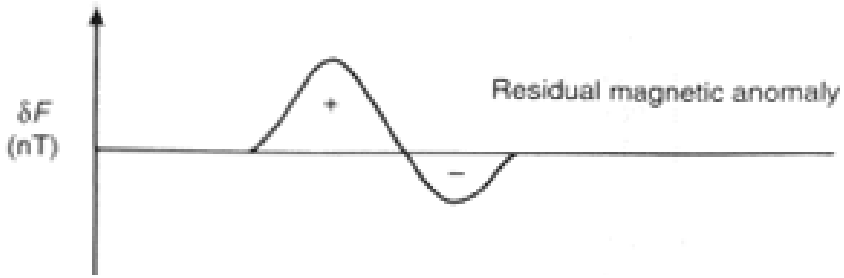
Recap

- Should remove geomagnetic field (base station)

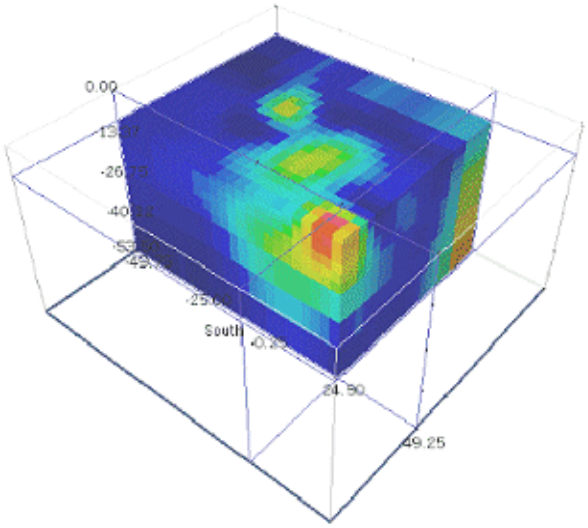


- Remove regional trends





- Other processing:
  - Upward continuation?
  - Derivatives?
  - Reduction to pole?
  - Inversion?



Unit Activities

- **Labs: (Magnetics I)**
  - Monday, September 16th
  - Tuesday, September 17th
- **Labs: (Magnetics II)**
  - Monday, September 23rd
  - Tuesday, September 24th
- **TBL:**
  - Monday, September 23rd
- **Quiz:**
  - Monday, September 23rd