SUSTech Southern University of Science and Technology

南方科技大学 SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY

地球与空间科学系 DEPARTMENT OF EARTH AND SPACE SCIENCES

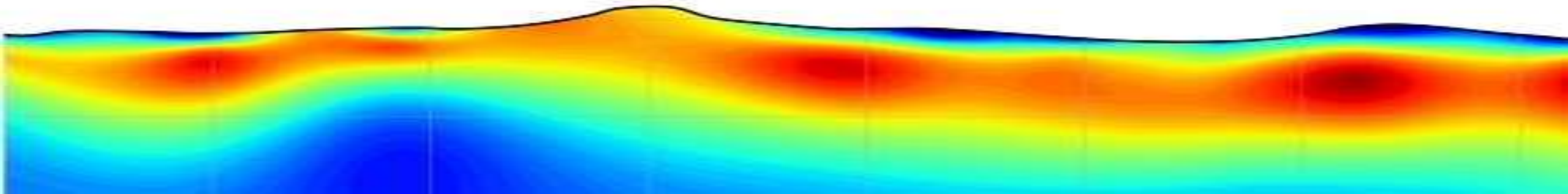
ESS302 Applied Geophysics II

Gravity, Magnetic, Electrical, Electromagnetic and Well Logging

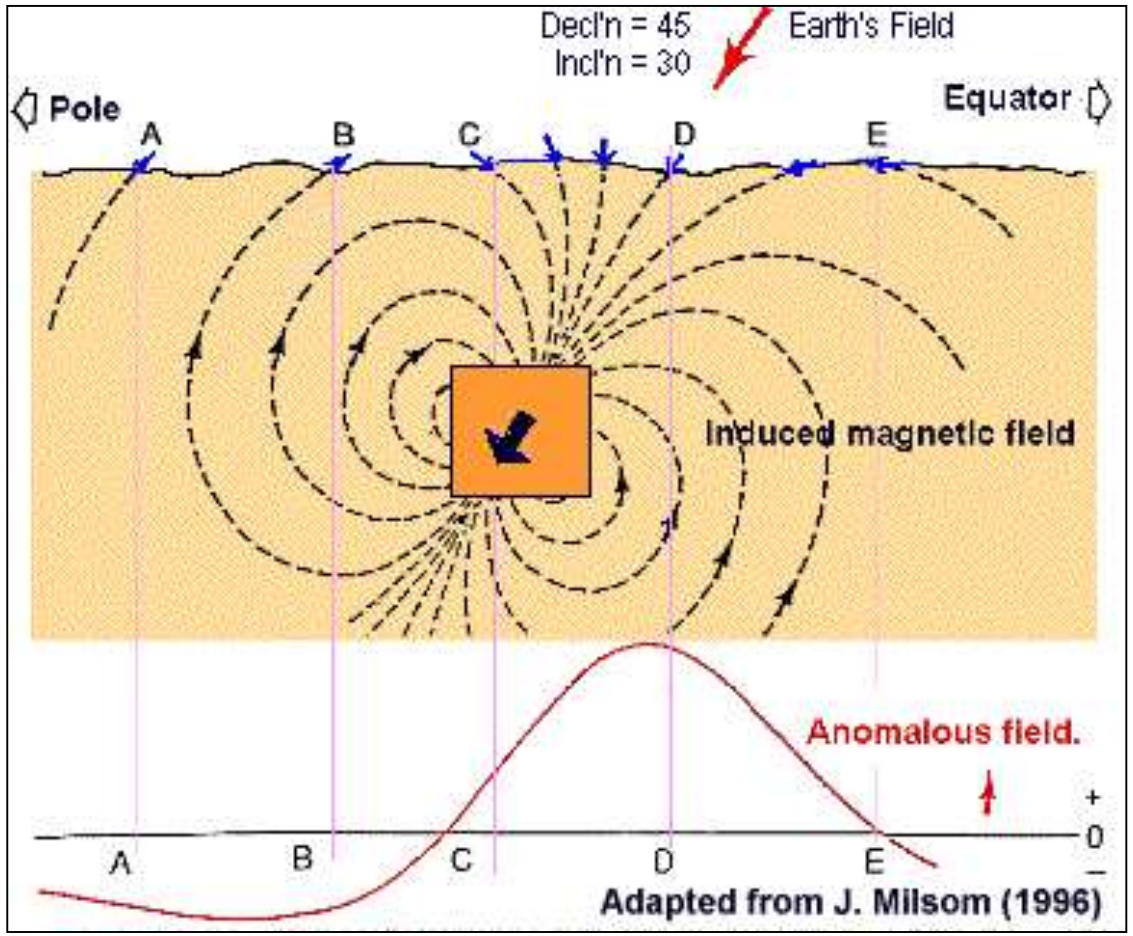
Magnetic 3: Applications

Instructor: Dikun Yang

Feb – May, 2019



Quiz



Draw a diagram similar to the figure on the left but with different inclinations

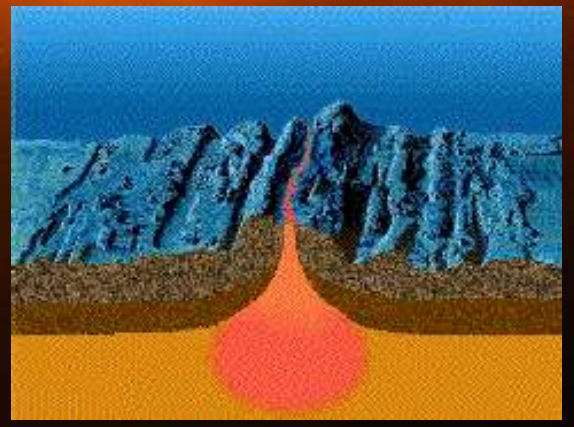
Option 1: inc = 80°

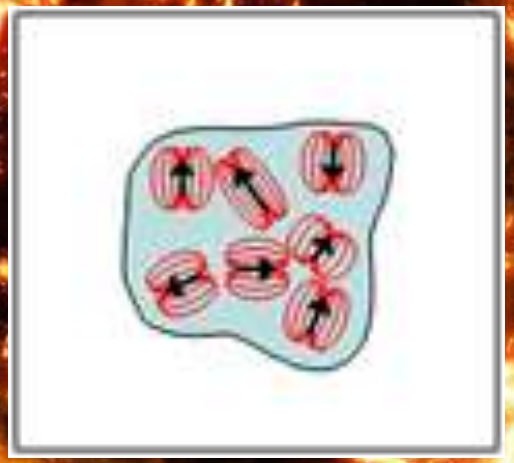
Option 2: inc = 0°

Option 3: inc = -70°

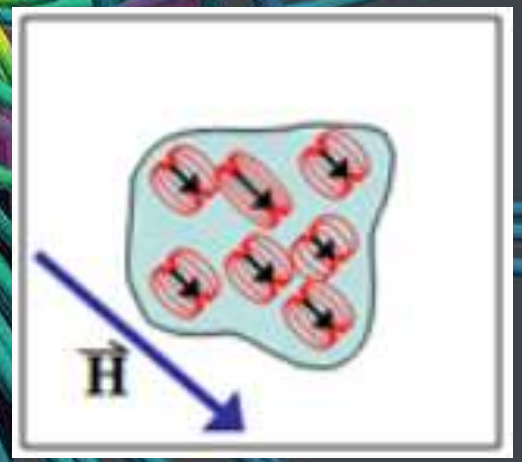
Option 4: inc = -90°

Heat and Disorientation

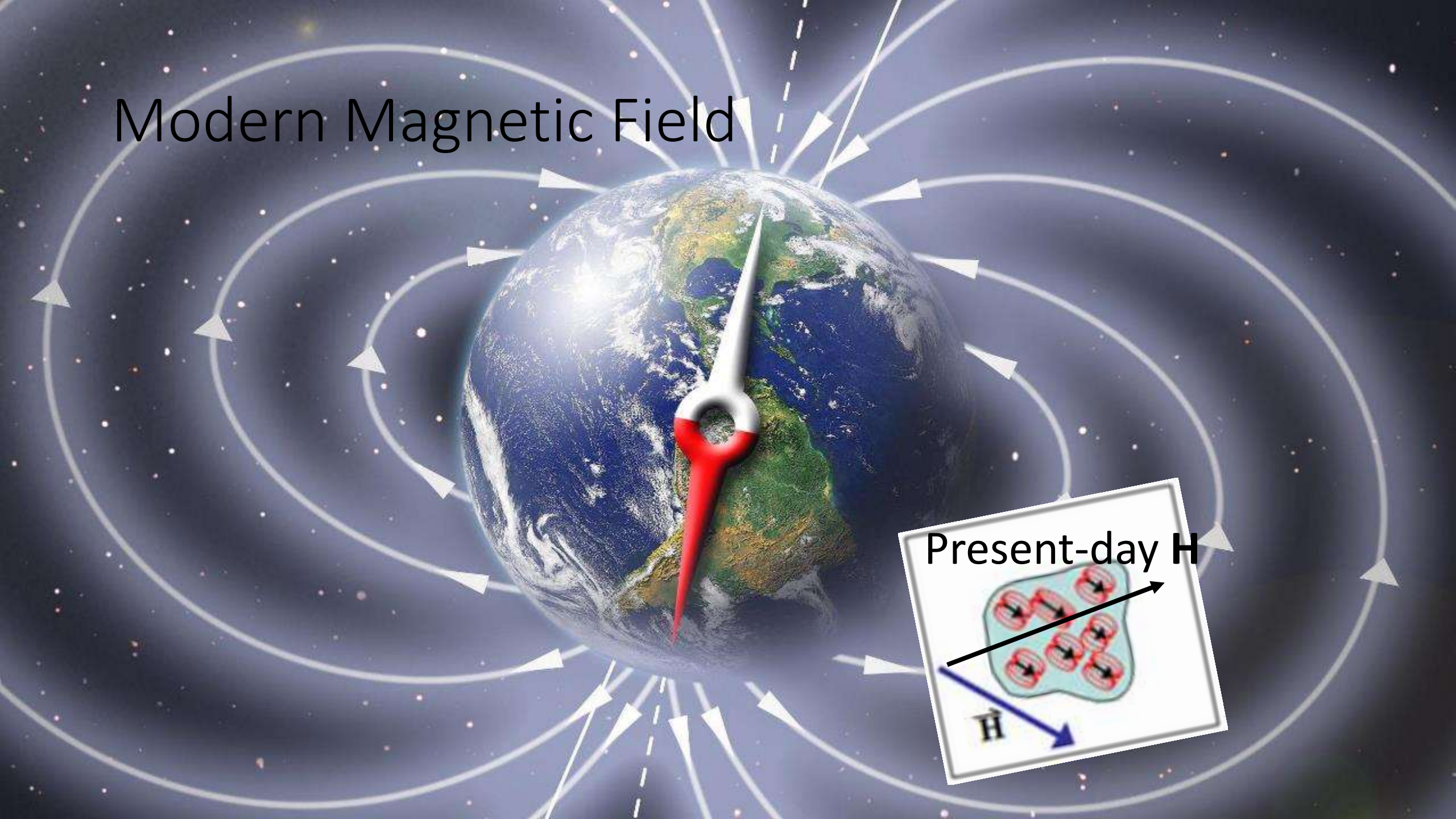




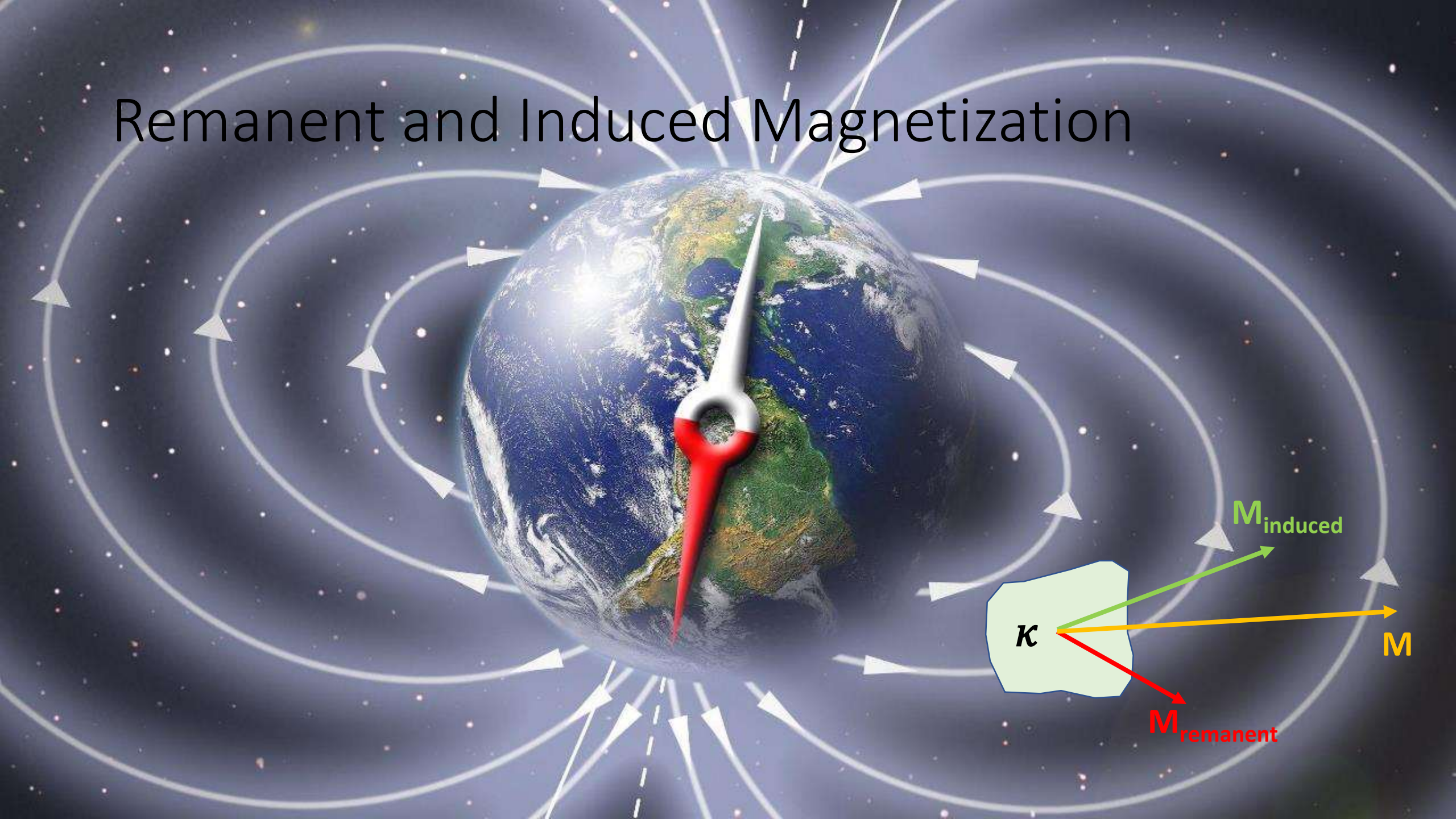
Ancient Magnetic Field



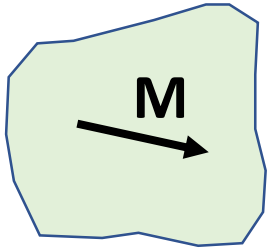
Modern Magnetic Field

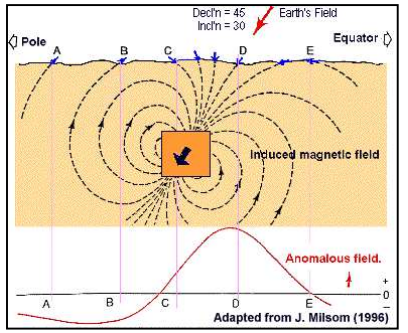


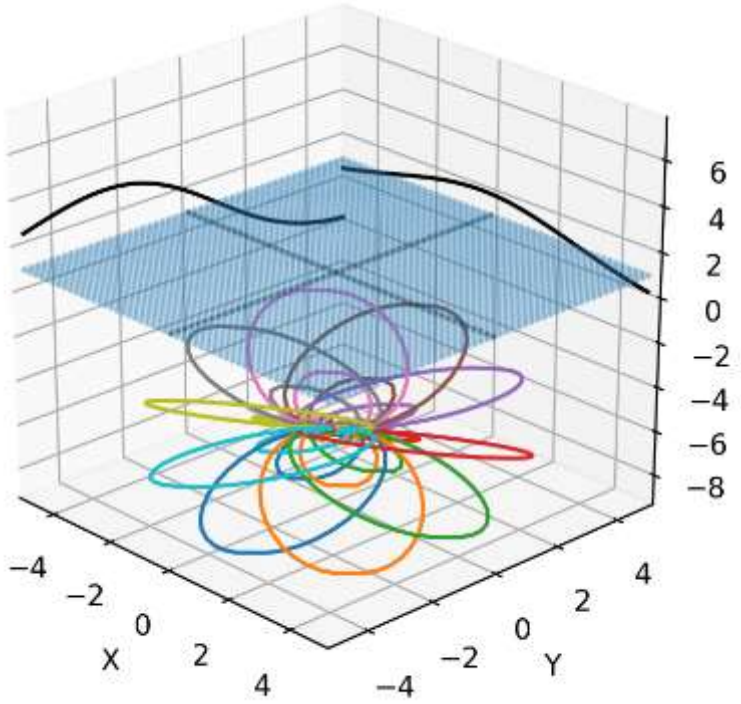
Remanent and Induced Magnetization



Magnetic Anomaly – Magnetized Objects



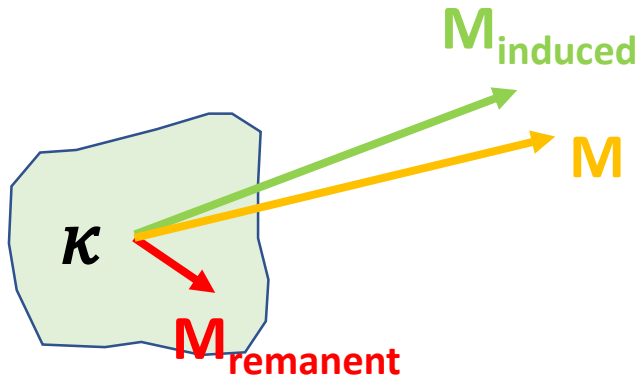




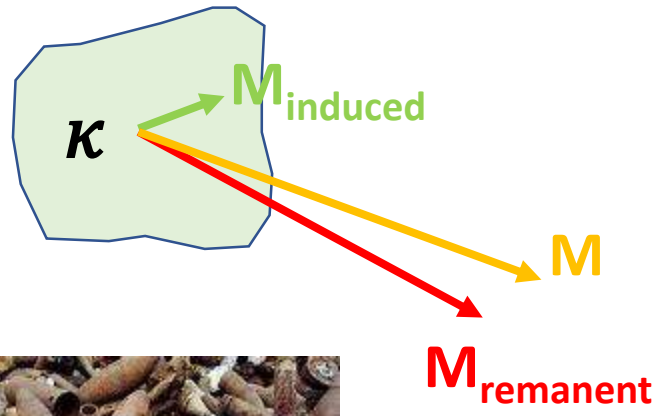
Total-field anomaly

$$|\triangle\vec{B}| = |\vec{B}_0 + \vec{B}_A| - |\vec{B}_0|$$
$$\simeq \vec{B}_A \cdot \hat{B}_0$$
$$= |\vec{B}_A| cos\theta$$

Sources of Magnetization



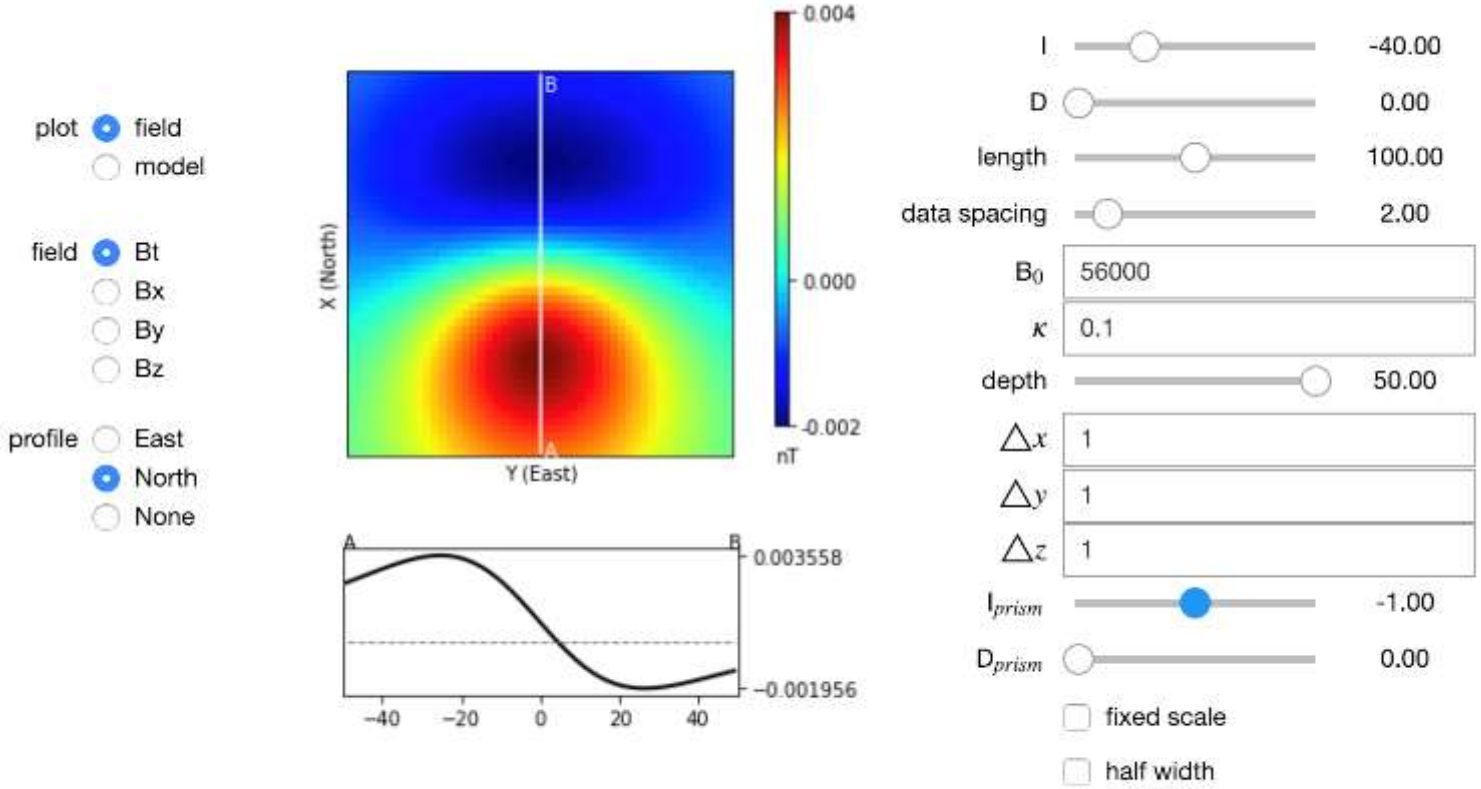
Susceptibility (magnetite)



UXO

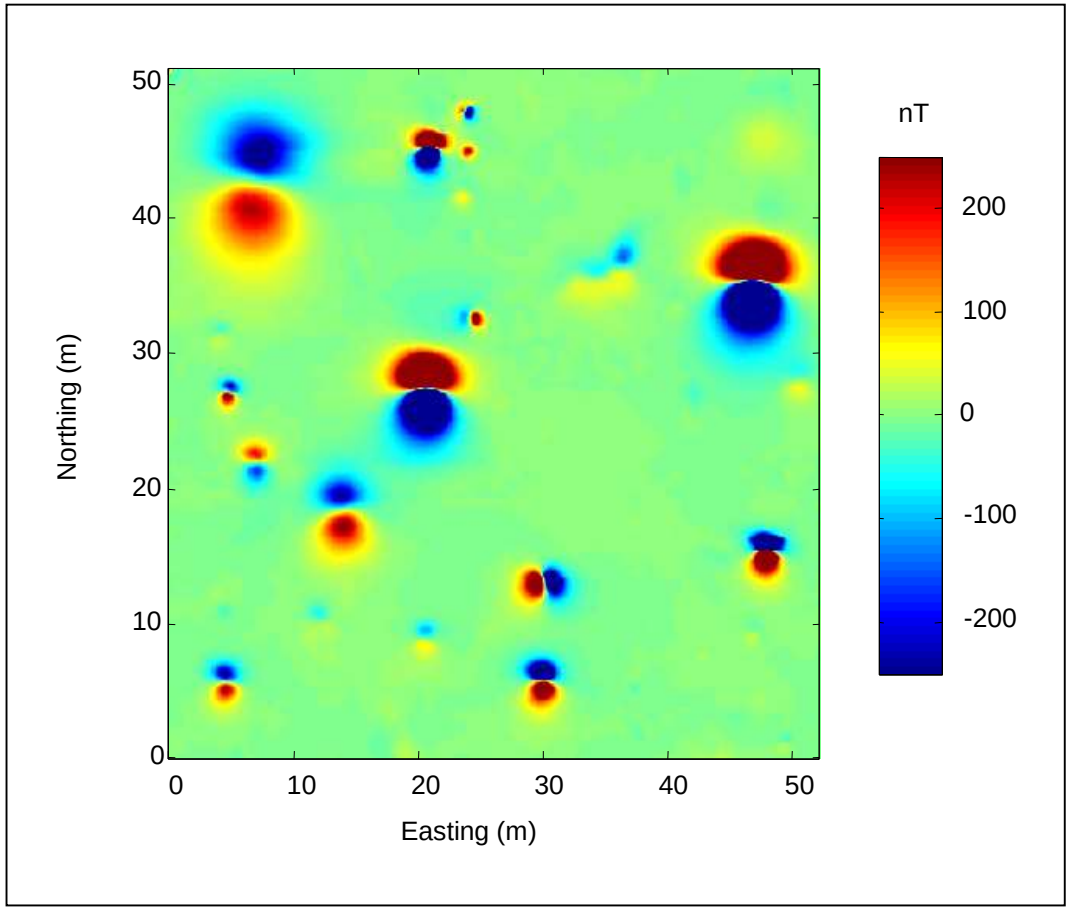
- depth: top boundary of the prism (meter)
- I_{prism}: inclination of the prism (reference is north direction)
- D_{prism}: declination of the prism (reference is north direction)

In [2]:
```
mag = MagneticDipoleApp()
mag.interact_plot_model_prism()
```



UXO (Unexploded Ordnance)

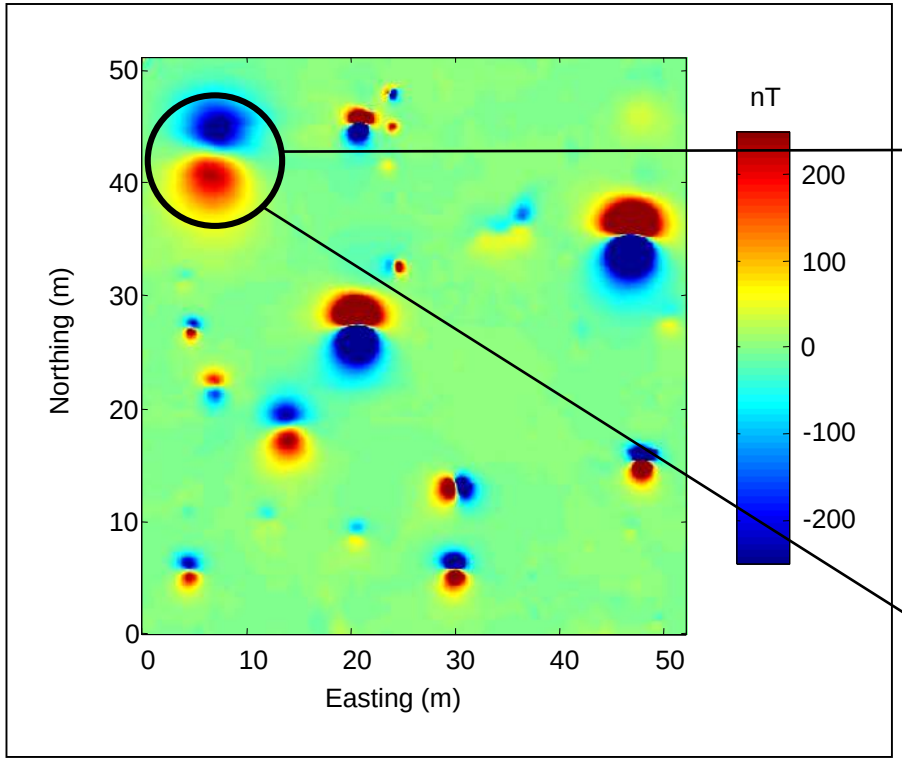
Magnetic Survey

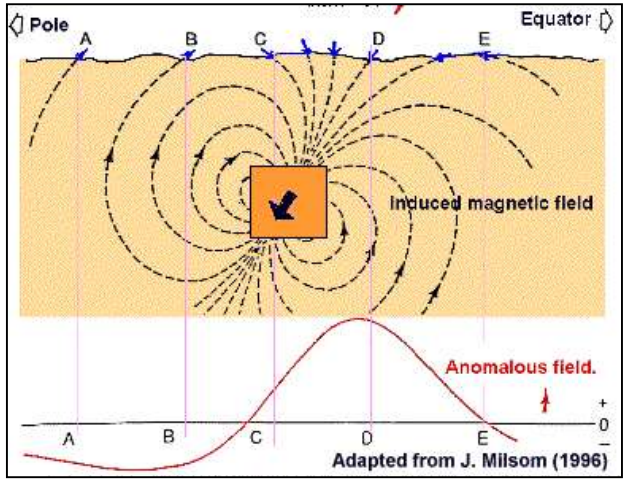


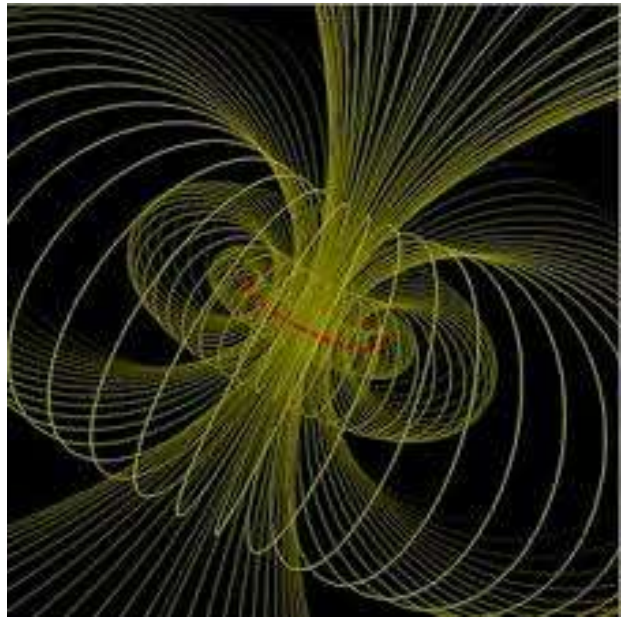
Induced or Remanent?

A UXO anomaly map:

- Dipole field on the surface
- Induced or remanent?
- How can we tell it's a UXO?



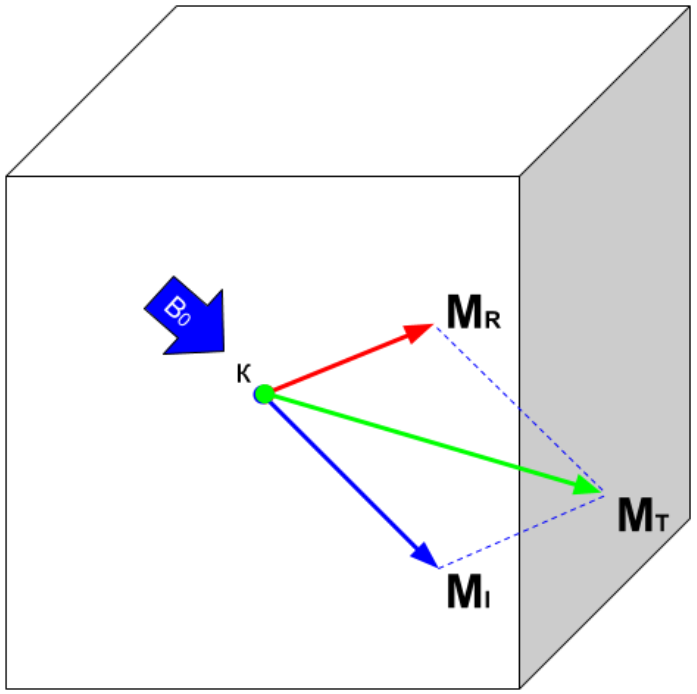


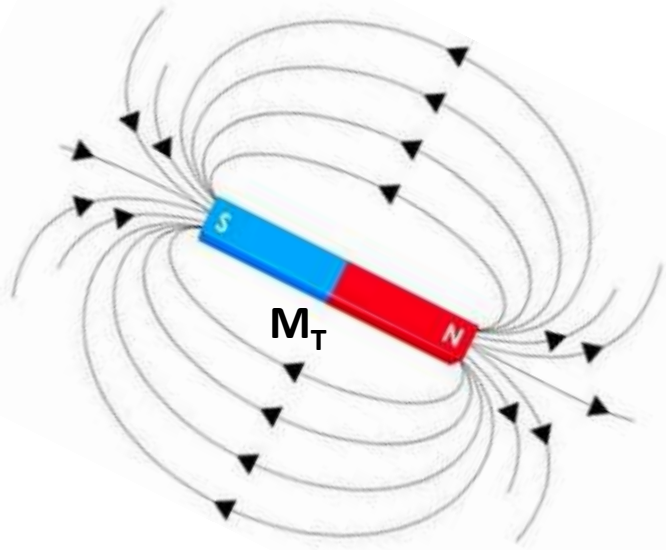


Parameterization

Following parameters uniquely define a dipole:

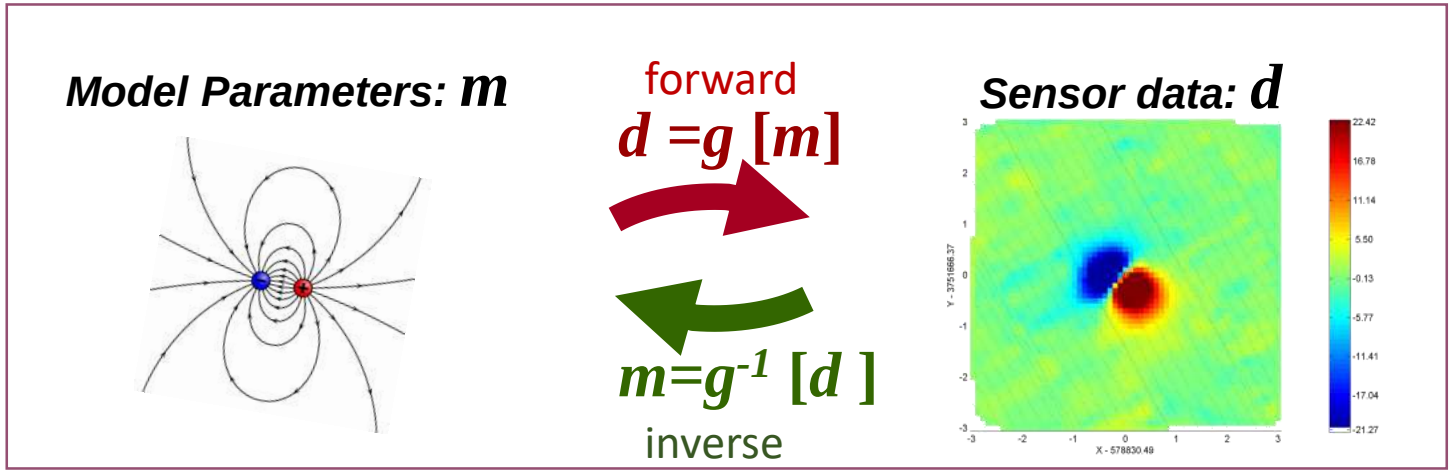
- Position (X, Y, Z)
- Total dipole moment vector (M_T) from induced and remanent (Mx, My, Mz)

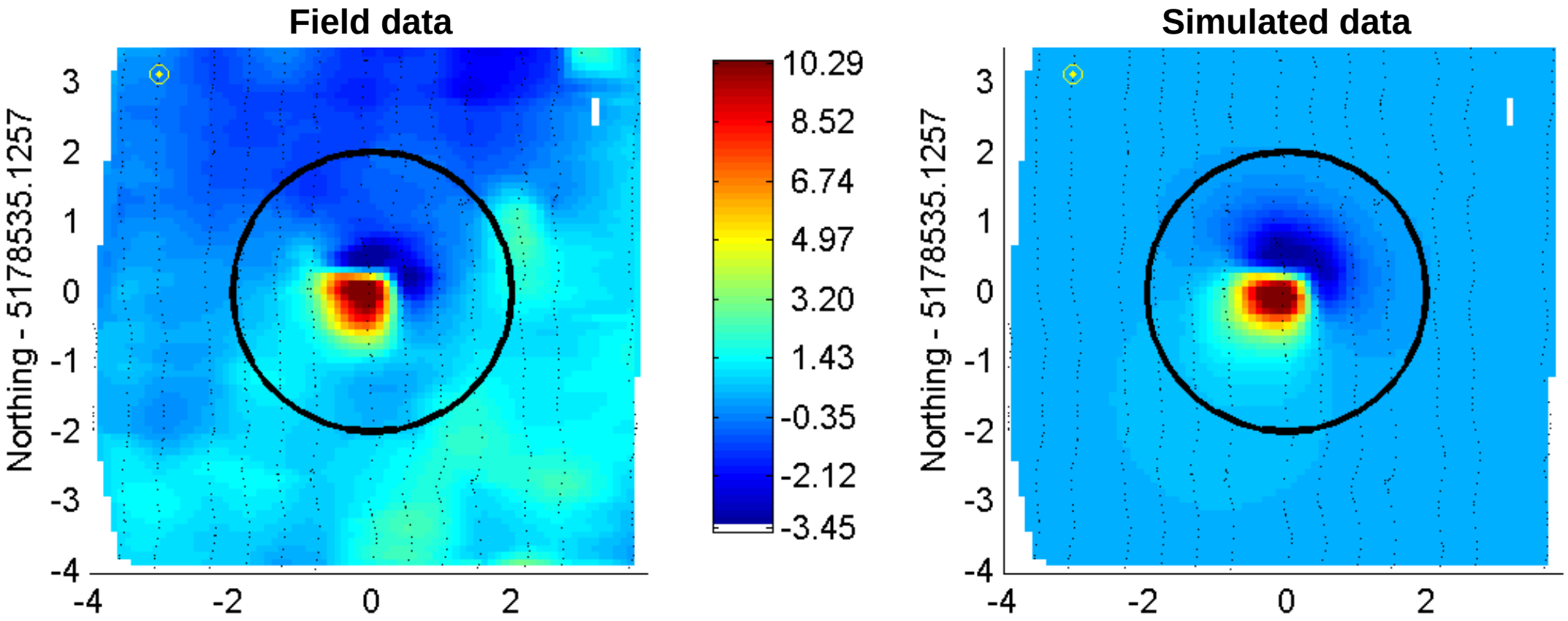




Dipole Model Inversion

- Six parameters *m* = [X, Y, Z, Mx, My, Mz]
- Data inversion: search the parameter space to find a particular combination of [X, Y, Z, Mx, My, Mz] that reproduces the dipole pattern on the map
- Automatic search or manual data fitting





Easting = -0.13 m; Northing = 0.16 m

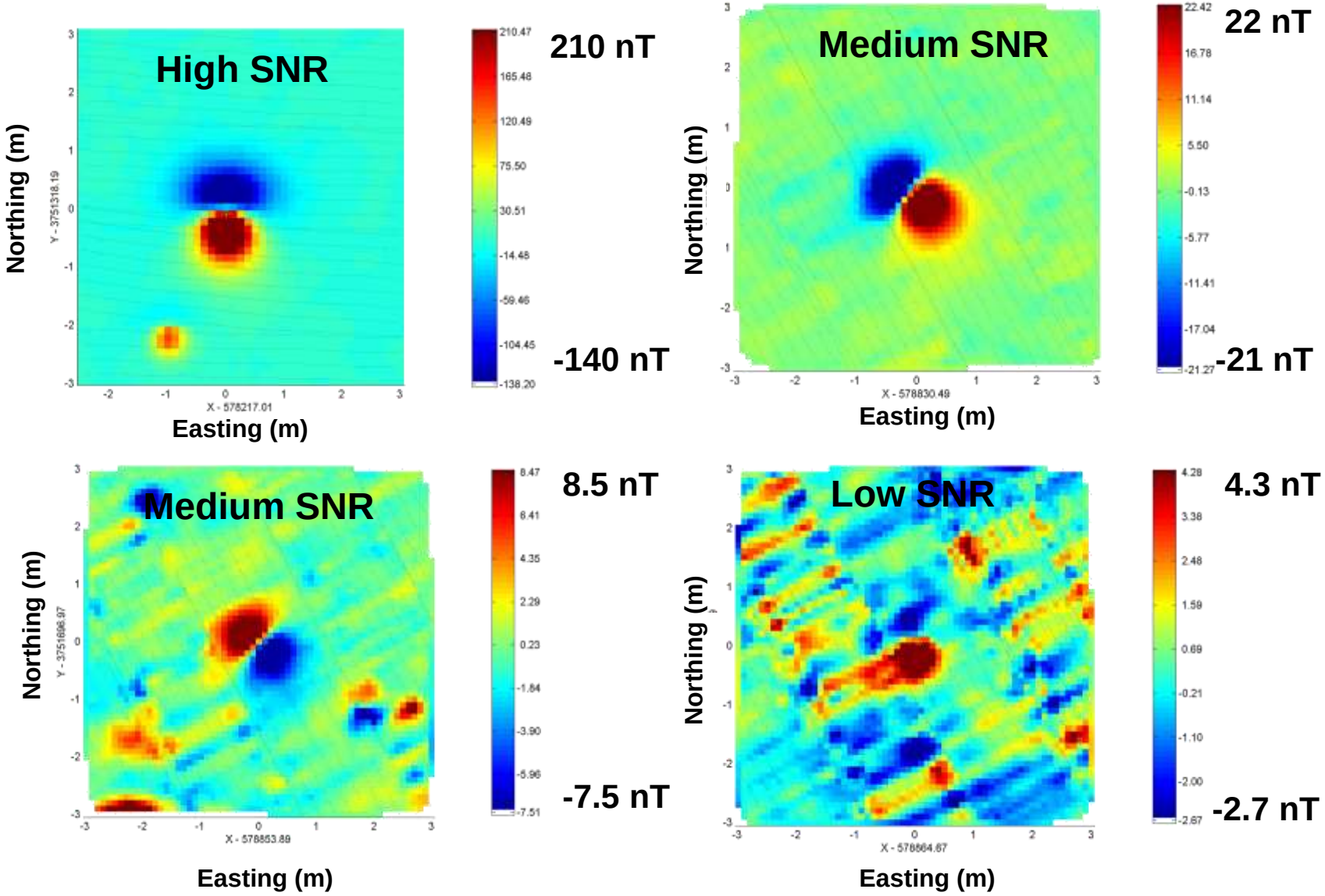
Depth = 0.26 m; Moment = 0.0226 Am^2

Azimuth = 37^o ; Dip = 28.8^o

Fit quality = 0.95

Use the recovered dipole parameters to identify UXO

Practical Issues

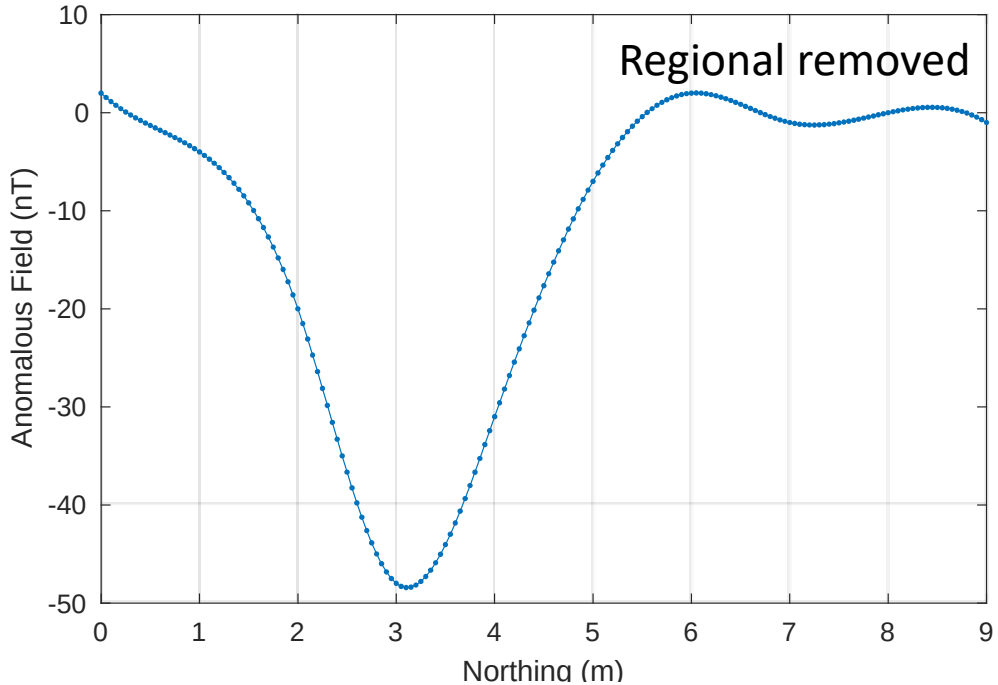


The Lost Re-bar

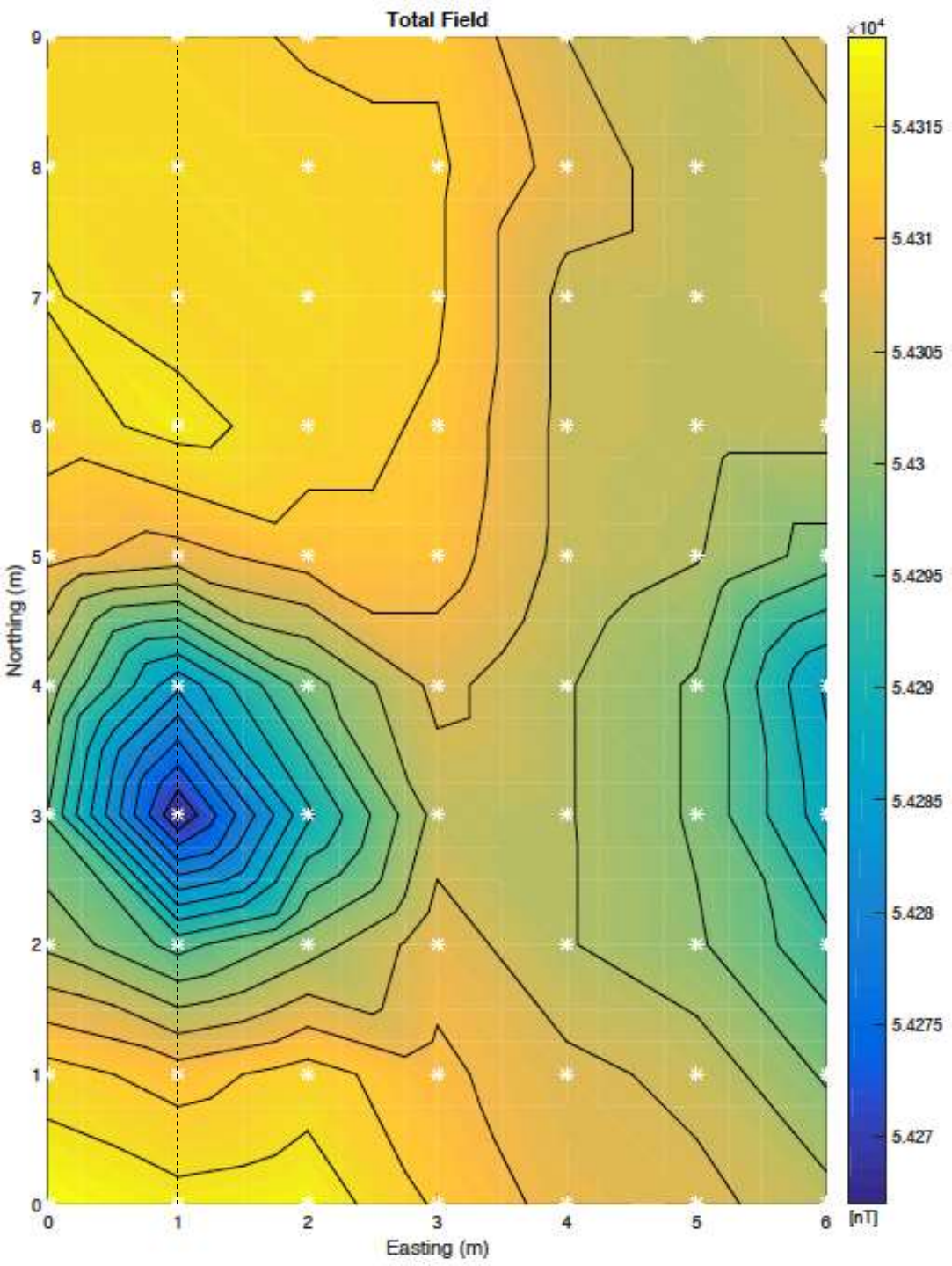
A long re-bar was buried somewhere on a beach in Canada.
It was hazardous so students need to locate it.

Digging in sand is exhausting…

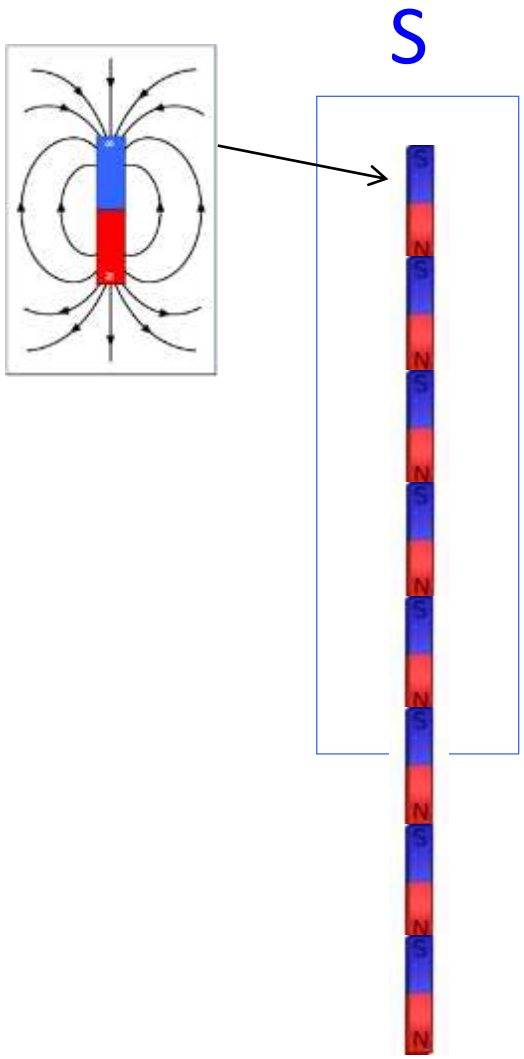
Magnetic Anomaly

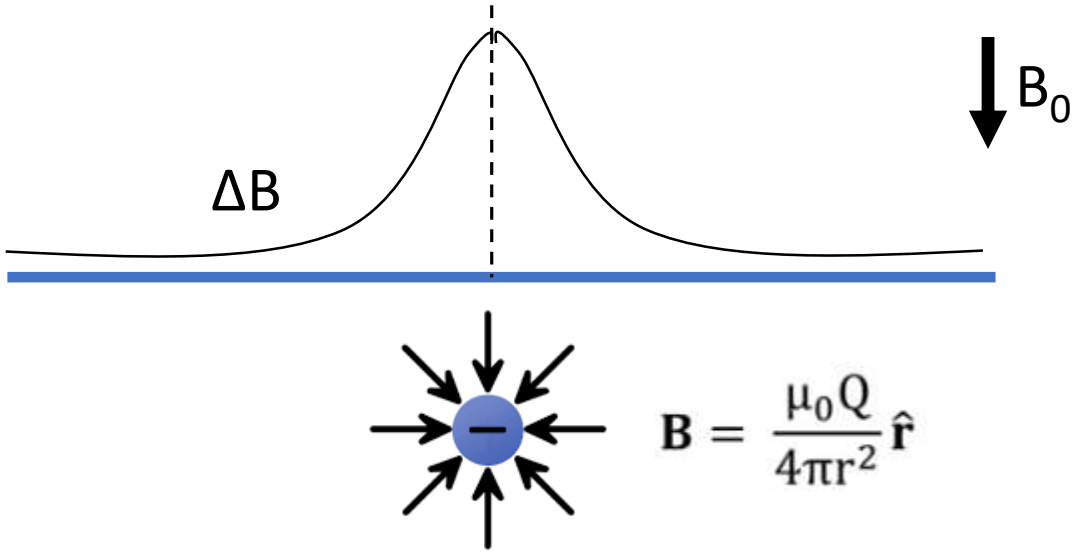


- **Digging**: 4+ hours, 60 (sweating) people, failed!
- **Magnetic**: 1 hour, 2 people, recovered the lost re-bar!
- Why single peak without sign changes?



Build a Long Rod using Dipoles

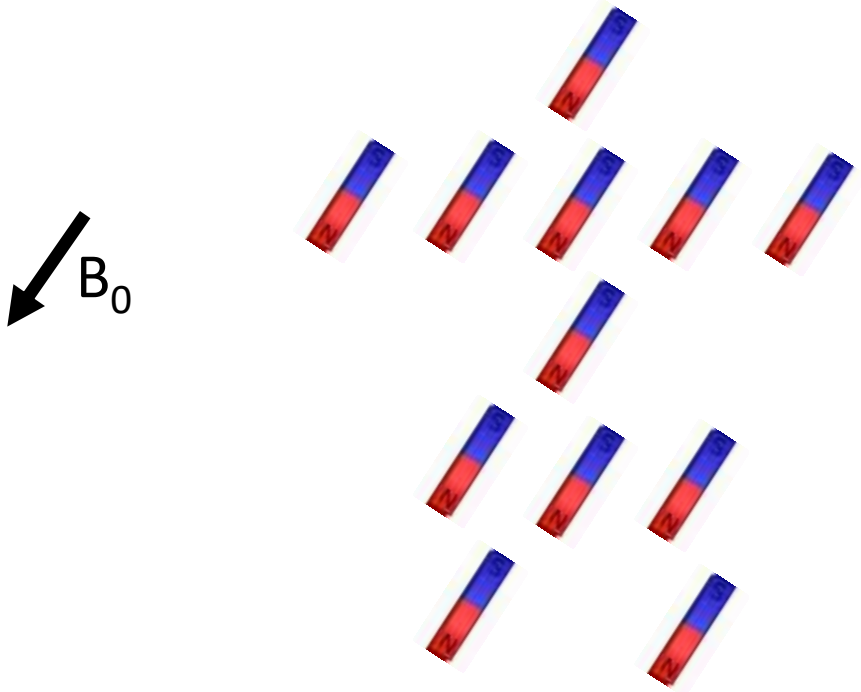


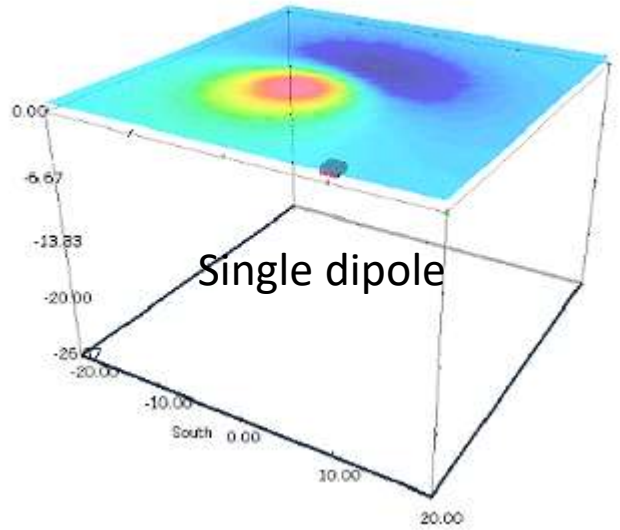


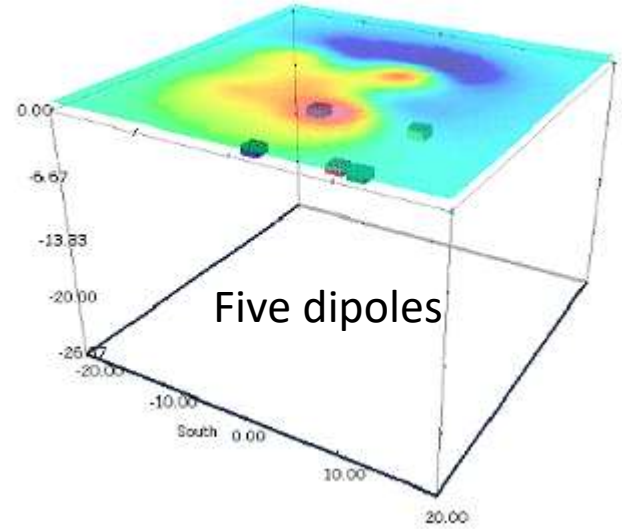
$$\mathbf{B} = \frac{\mu_0 Q}{4\pi r^2}\hat{\mathbf{r}}$$

- N and S inside the rod cancel out
- Net negative and positive charge at two ends
- Only “see” one change if the rod is vertical and long
- A **monopole** anomaly (field lines determined by a single magnetic charge)
- What if the remanence makes the magnetization not uniform inside the pipe?

Build a Complex Body





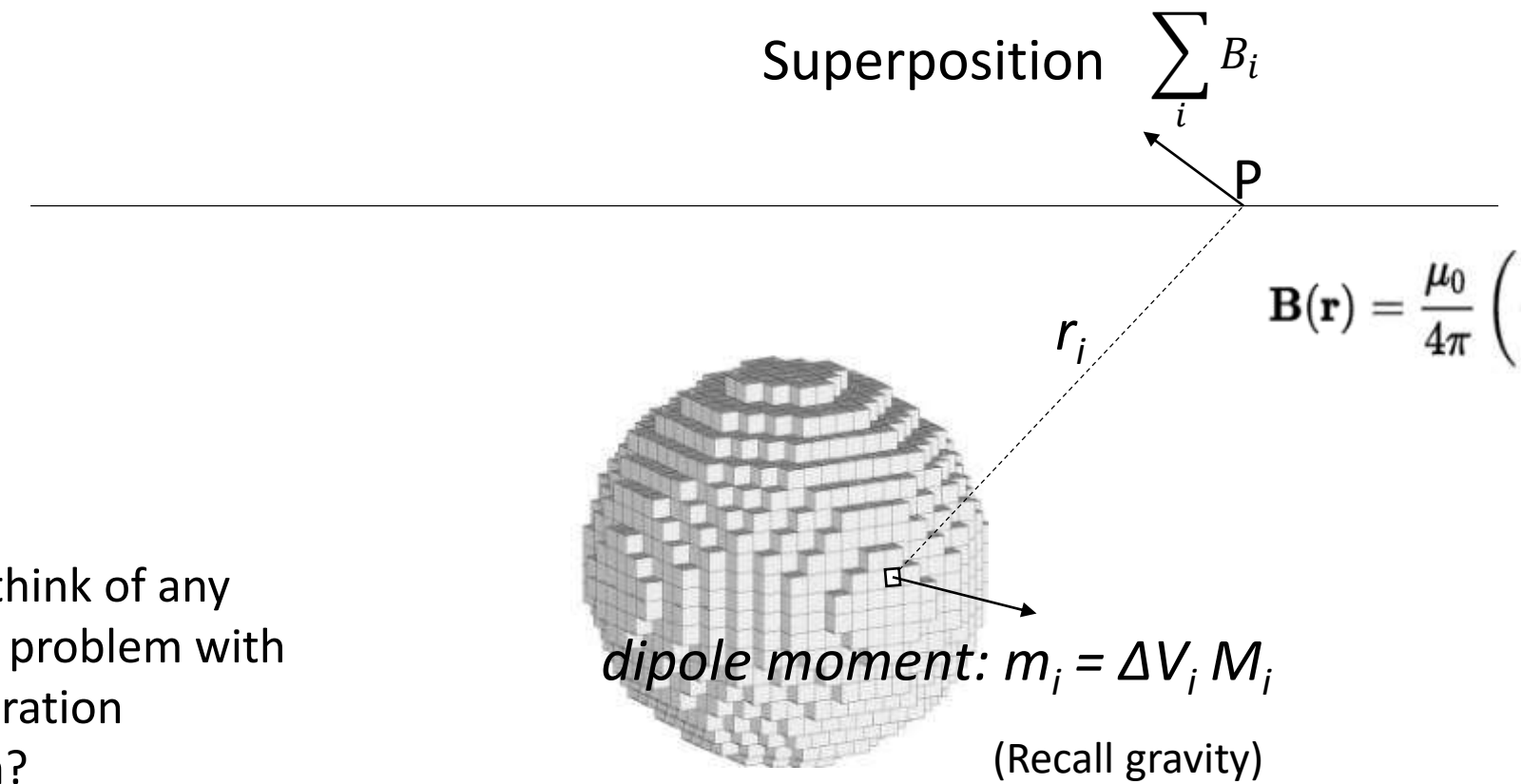


Superposition: Sum up contribution from each dipole

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\left(\frac{3\mathbf{r}(\mathbf{m}\cdot\mathbf{r})}{r^5} - \frac{\mathbf{m}}{r^3}\right)$$

Arbitrarily Shaped Objects

Superposition $\sum_i B_i$



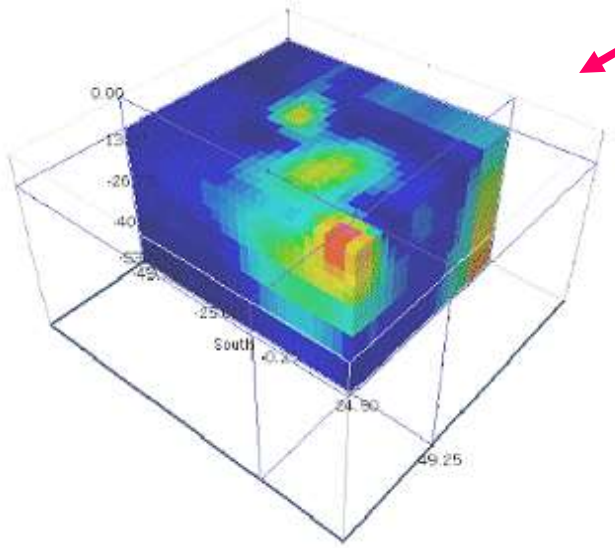
$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\left(\frac{3\mathbf{r}(\mathbf{m}\cdot\mathbf{r})}{r^5} - \frac{\mathbf{m}}{r^3}\right)$$

(Recall gravity)

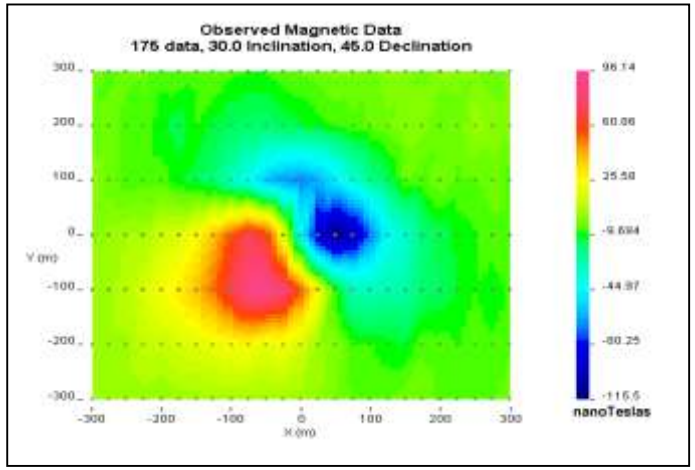
Can you think of any potential problem with this integration approach?

Arbitrary Magnetic Dipole Applet

A complicated earth model of κ
(Induced magnetization)



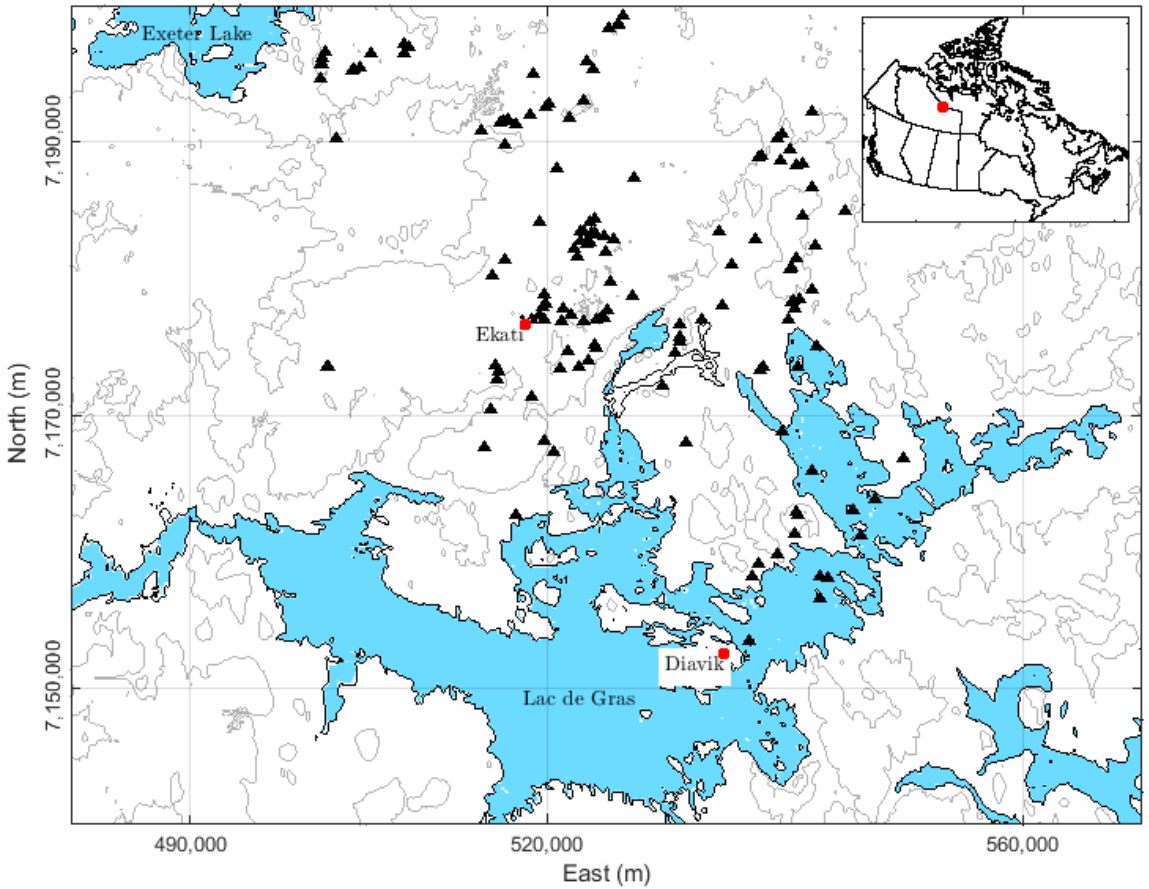
Inversion

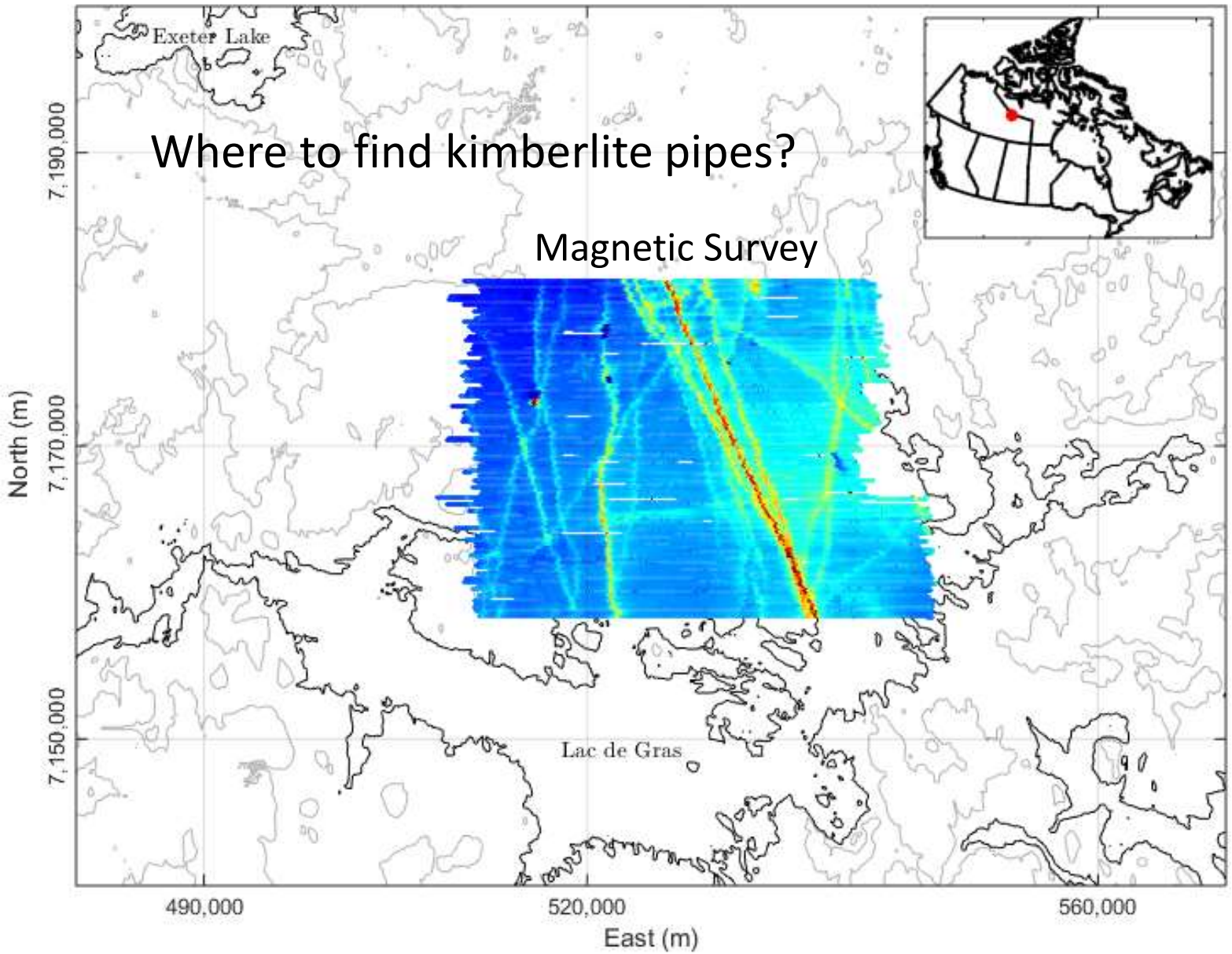


Divide the earth into many cells that contribute to the data on surface

- Each cell has a constant but unknown susceptibility (induced magnetization only)
- Each cell has an unknown magnetization vector (induced and/or remanent magnetization)

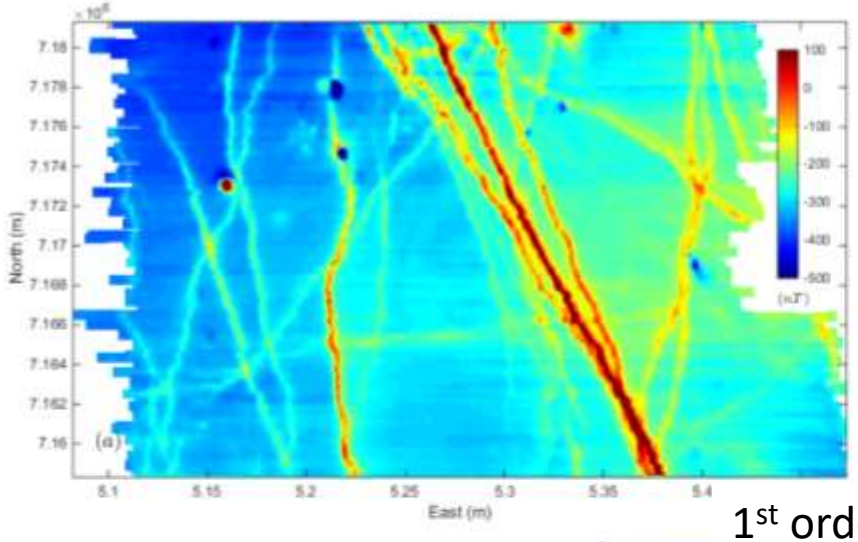
Ekati Diamond Property, Northwest Territories



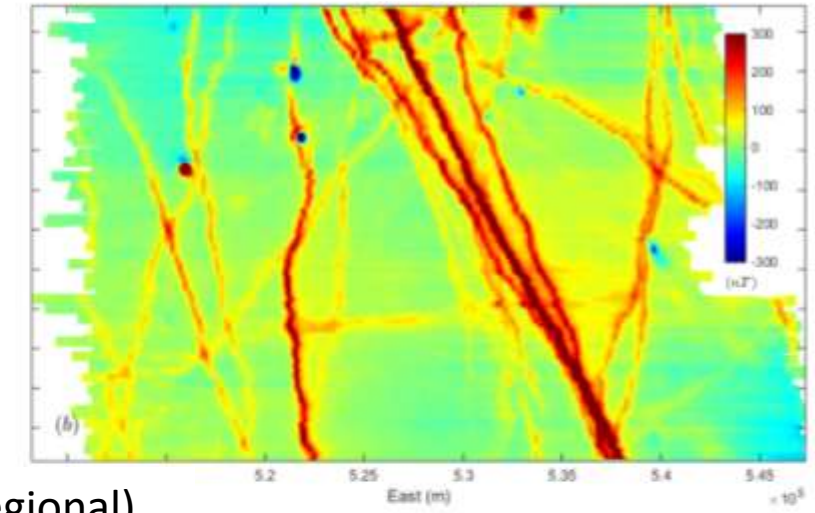

Where to find kimberlite pipes?
Magnetic Survey
Exeter Lake
Lac de Gras
North (m)
7,190,000
7,170,000
7,150,000
490,000
520,000
560,000
East (m)

Data Processing: Regional Removal

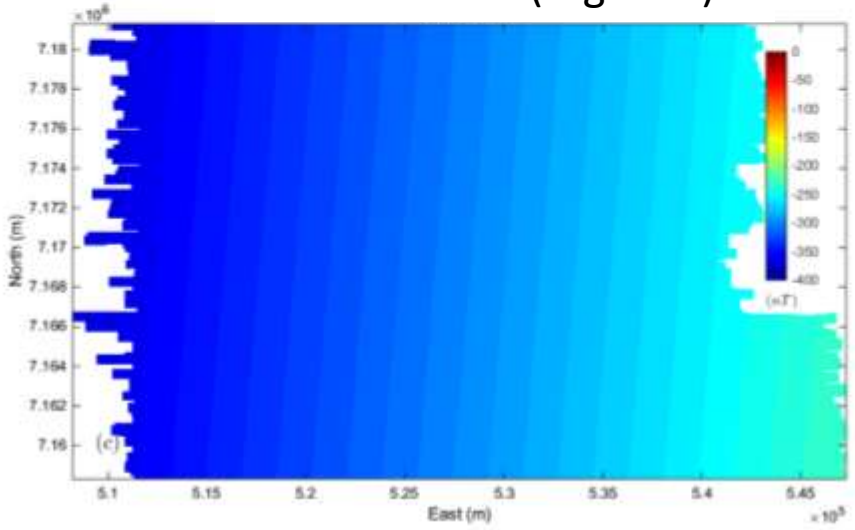
Original data



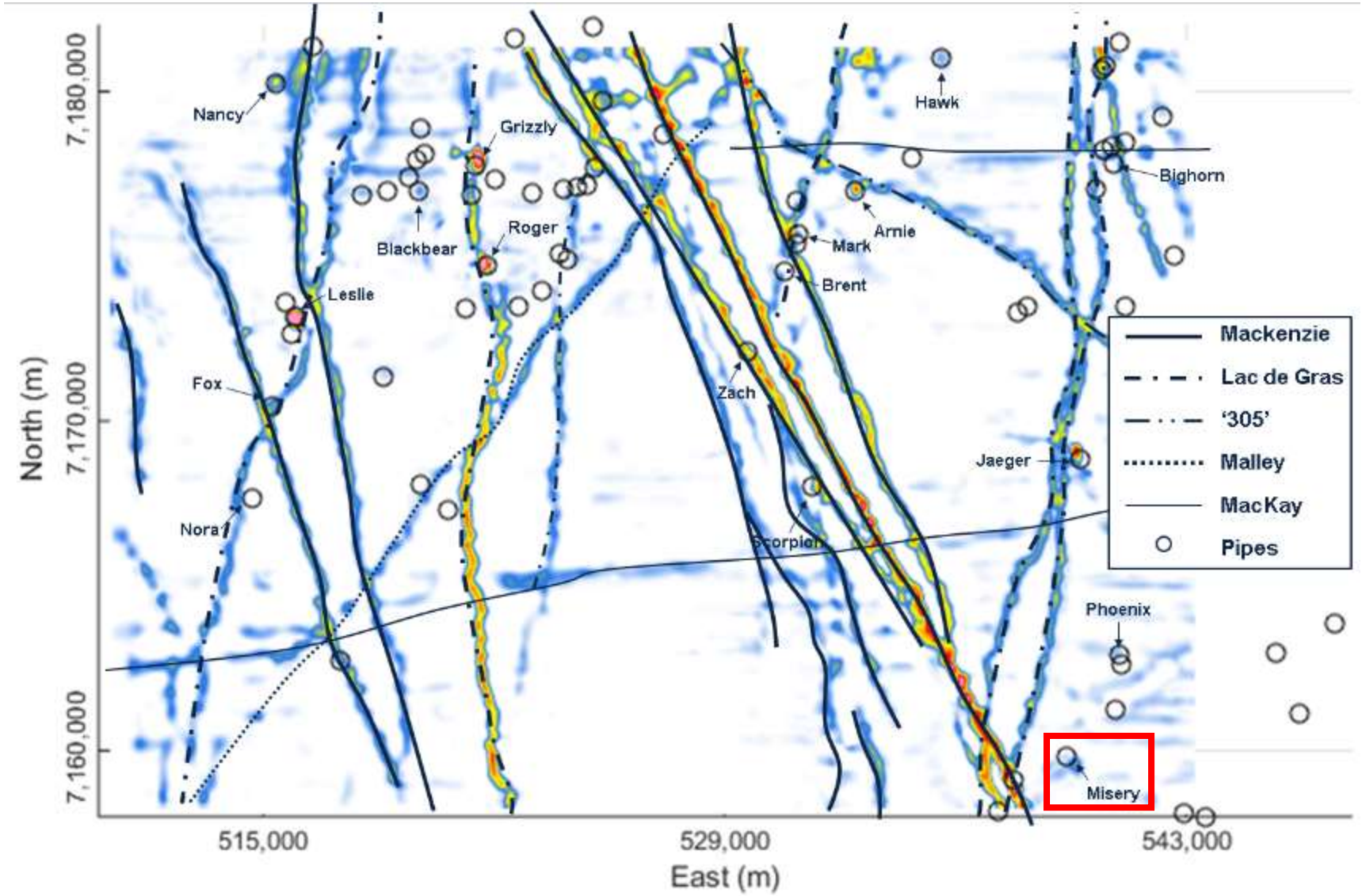
After regional removal



1st order trend (regional)

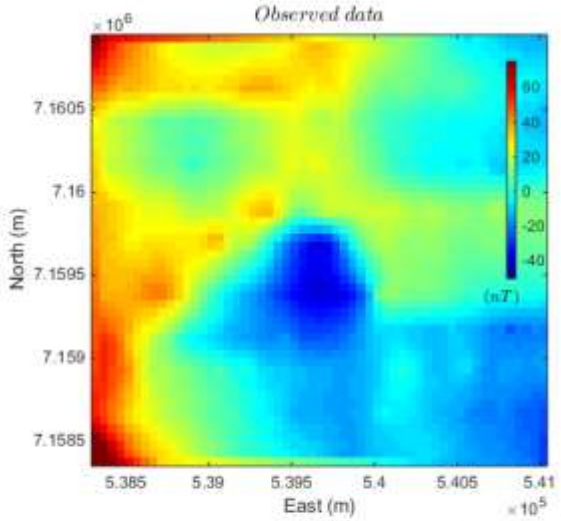


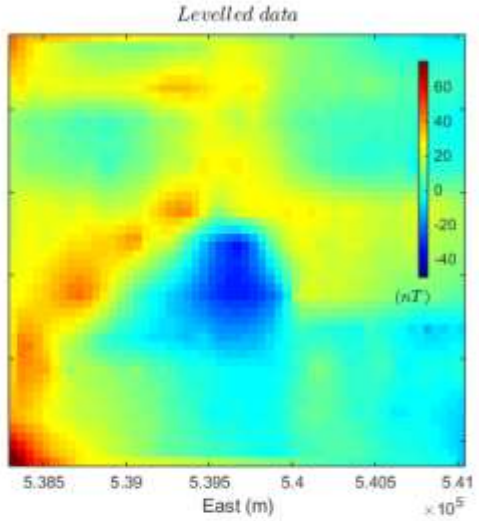
Misery Pipe


Nancy
Grizzly
Hawk
Bighorn
Blackbear
Roger
Arnie
Mark
Brent
Leslie
Fox
Zach
Jaeger
Nora
Scorpion
Phoenix
Misery
Mackenzie
Lac de Gras
'305'
Malley
MacKay
Pipes
7,180,000
7,170,000
7,160,000
North (m)
515,000
529,000
543,000
East (m)

Data Around Misery Pipe

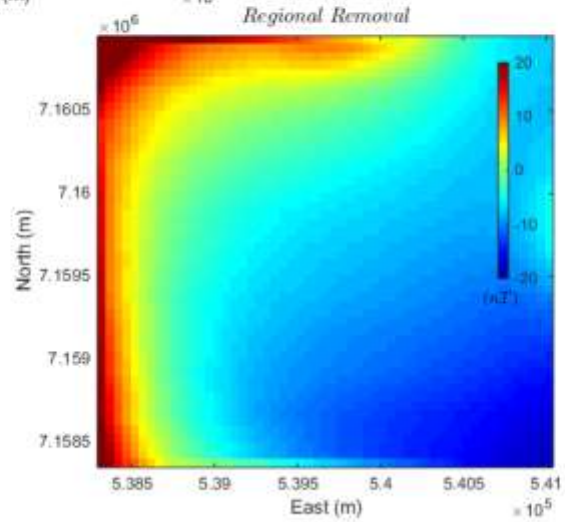
Original





After regional removal

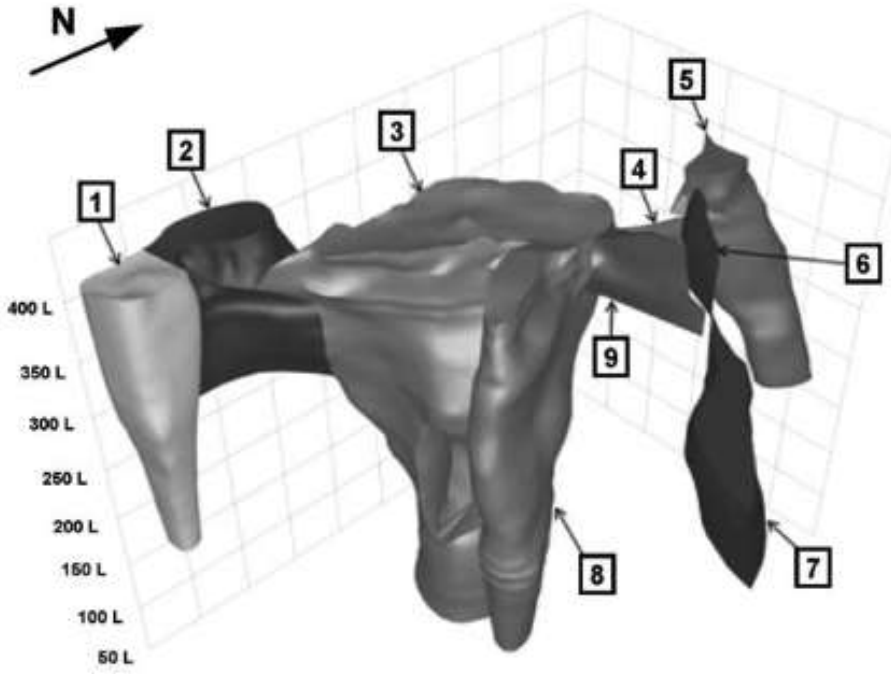
Regional



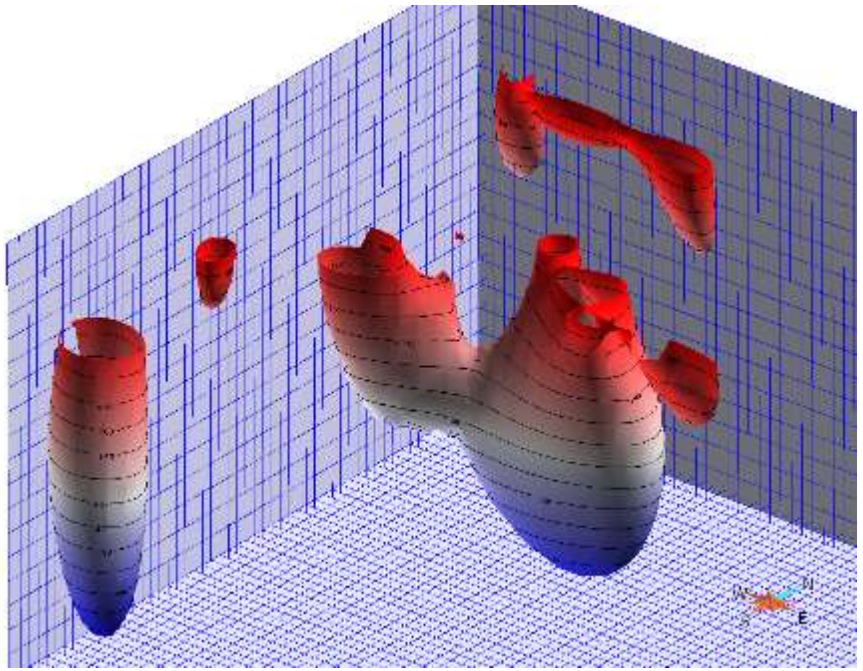
- Local anomaly showing reversely magnetized body (remanent)
- Removal of the regional field to enhance the target (ready for inversion)

Inversion Result

Geology from drilling



Inverted model

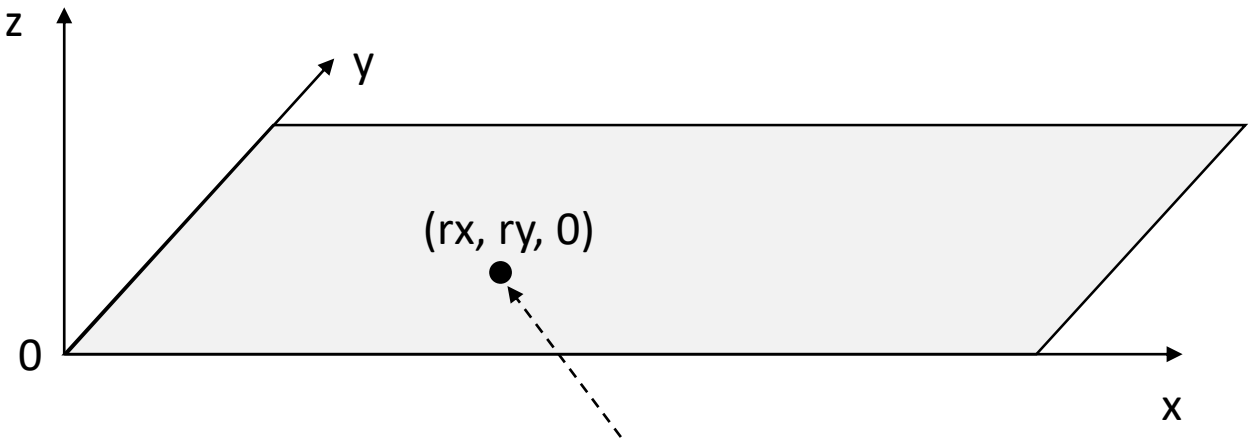


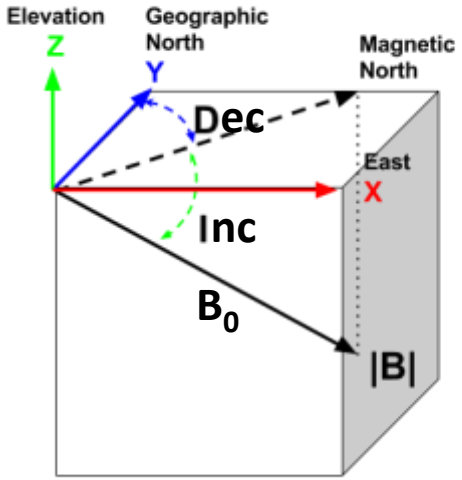
Nowicki et al. (2004)

Summary

- Two types of magnetization
- Dipole model builds everything
- UXO
- Re-bar
- Mineral (diamond) exploration

Magnetic Assignment – Block





Magnetic anomaly from a susceptible block

$$\mathbf{M} = \kappa \mathbf{H}_0 = \kappa \mathbf{B}_0 / \mu_0$$

$$\mathbf{m} = \mathbf{M}V$$

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\left(\frac{3\mathbf{r}(\mathbf{m}\cdot\mathbf{r})}{r^5} - \frac{\mathbf{m}}{r^3}\right).$$