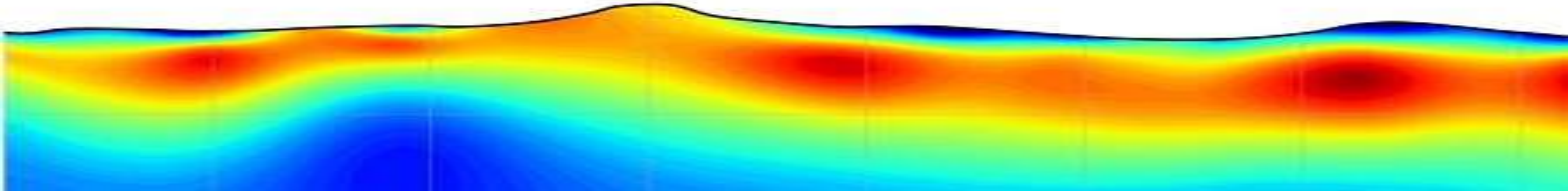
ESS302 Applied Geophysics II

Gravity, Magnetic, Electrical, Electromagnetic and Well Logging

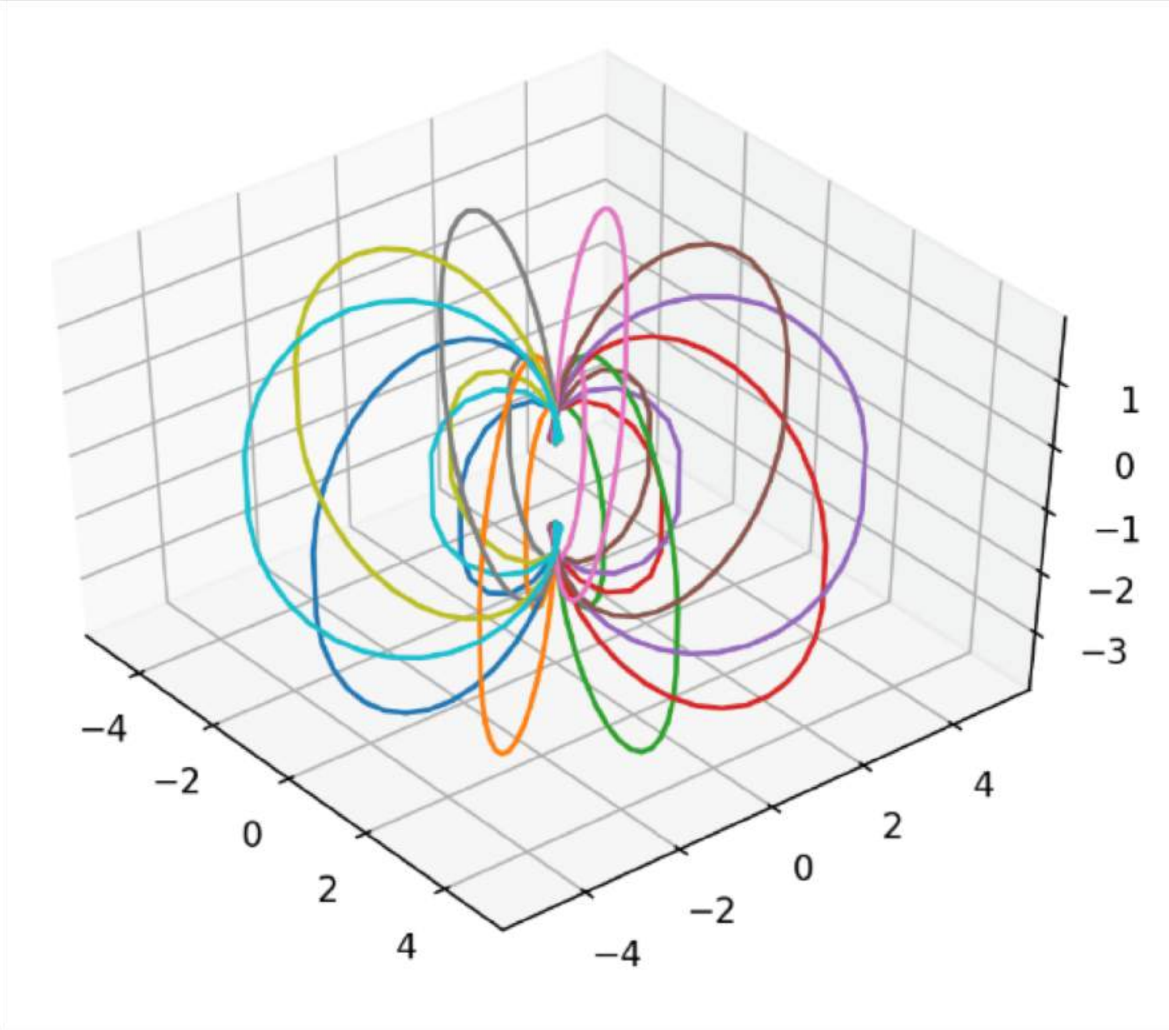
Magnetic 2: Survey and Data

Instructor: Dikun Yang Feb – May, 2019

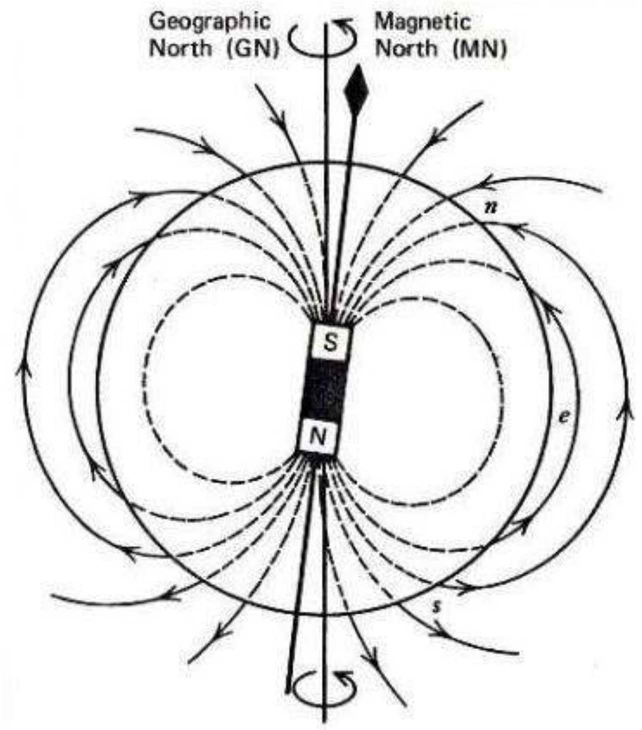


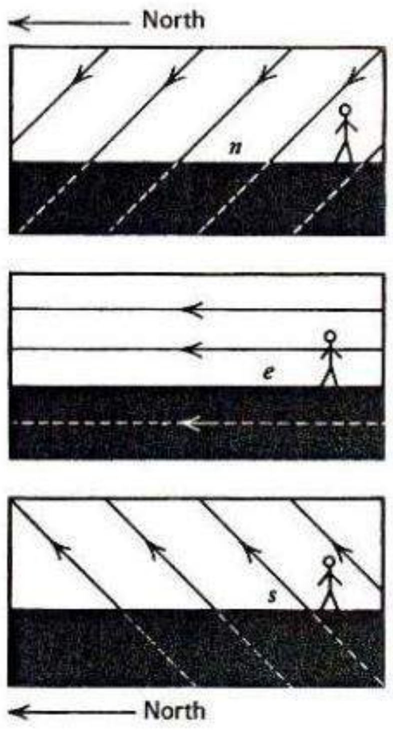
Contents

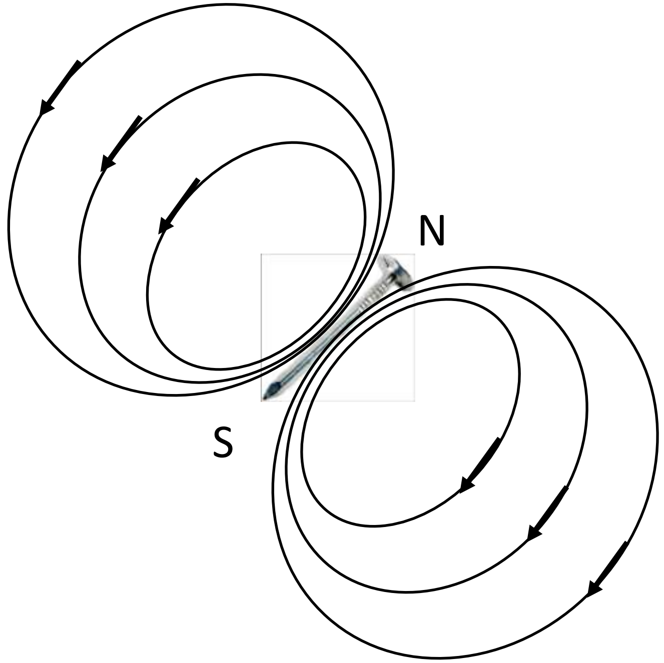
- Magnetic dipole field
- Types of magnetization
  - Remanent
  - Induced
- Magnetic data measurement
- Magnetic data corrections



Magnetic Dipole Field at Different Scales

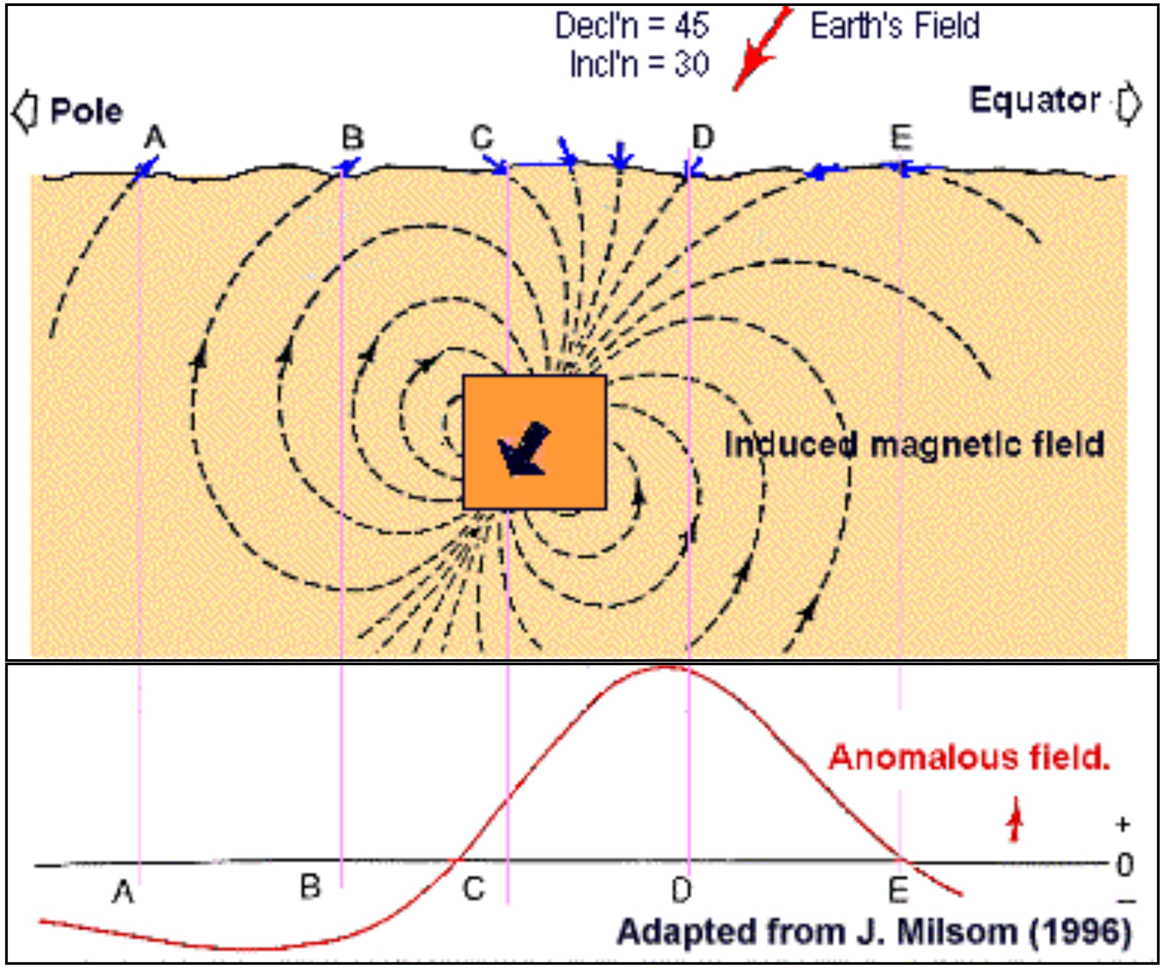






$$\mathbf{B}(\mathbf{r}) = \nabla \times \mathbf{A} = \frac{\mu_0}{4\pi}\left(\frac{3\mathbf{r}(\mathbf{m}\cdot\mathbf{r})}{r^5} - \frac{\mathbf{m}}{r^3}\right).$$

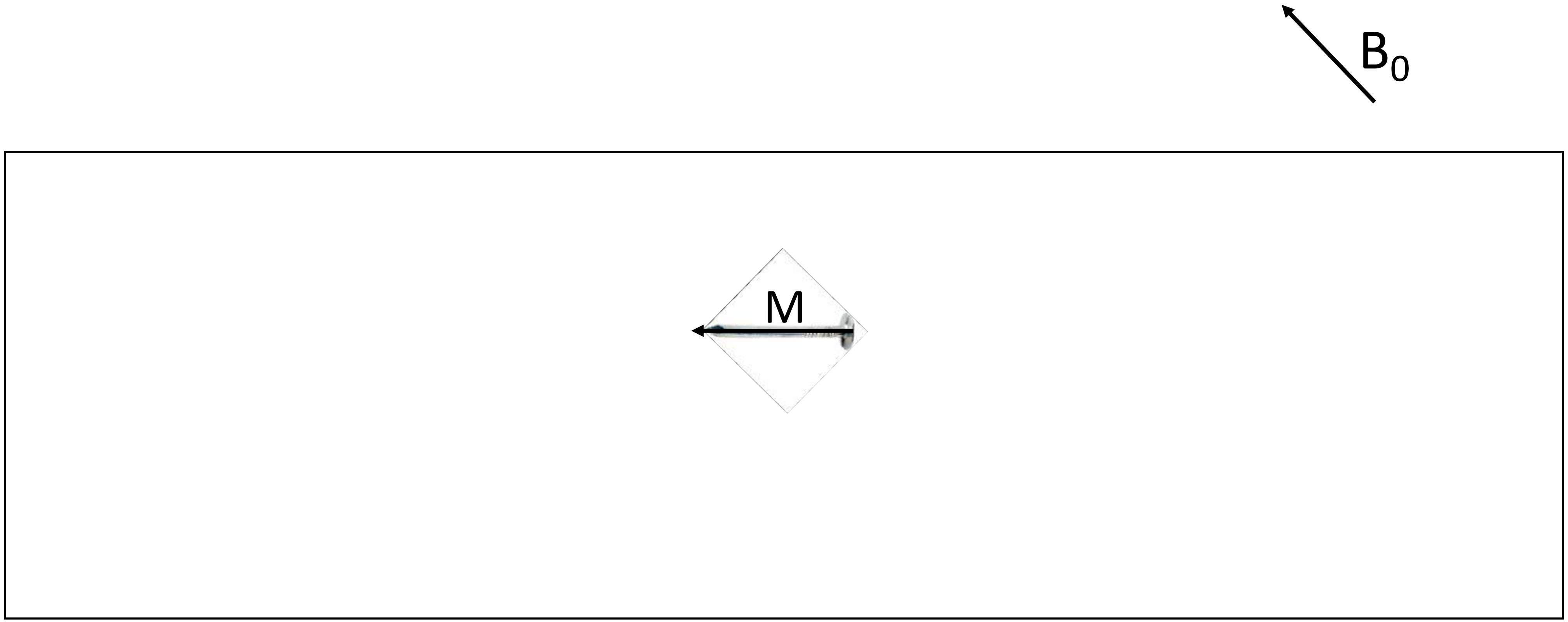
Composite Field



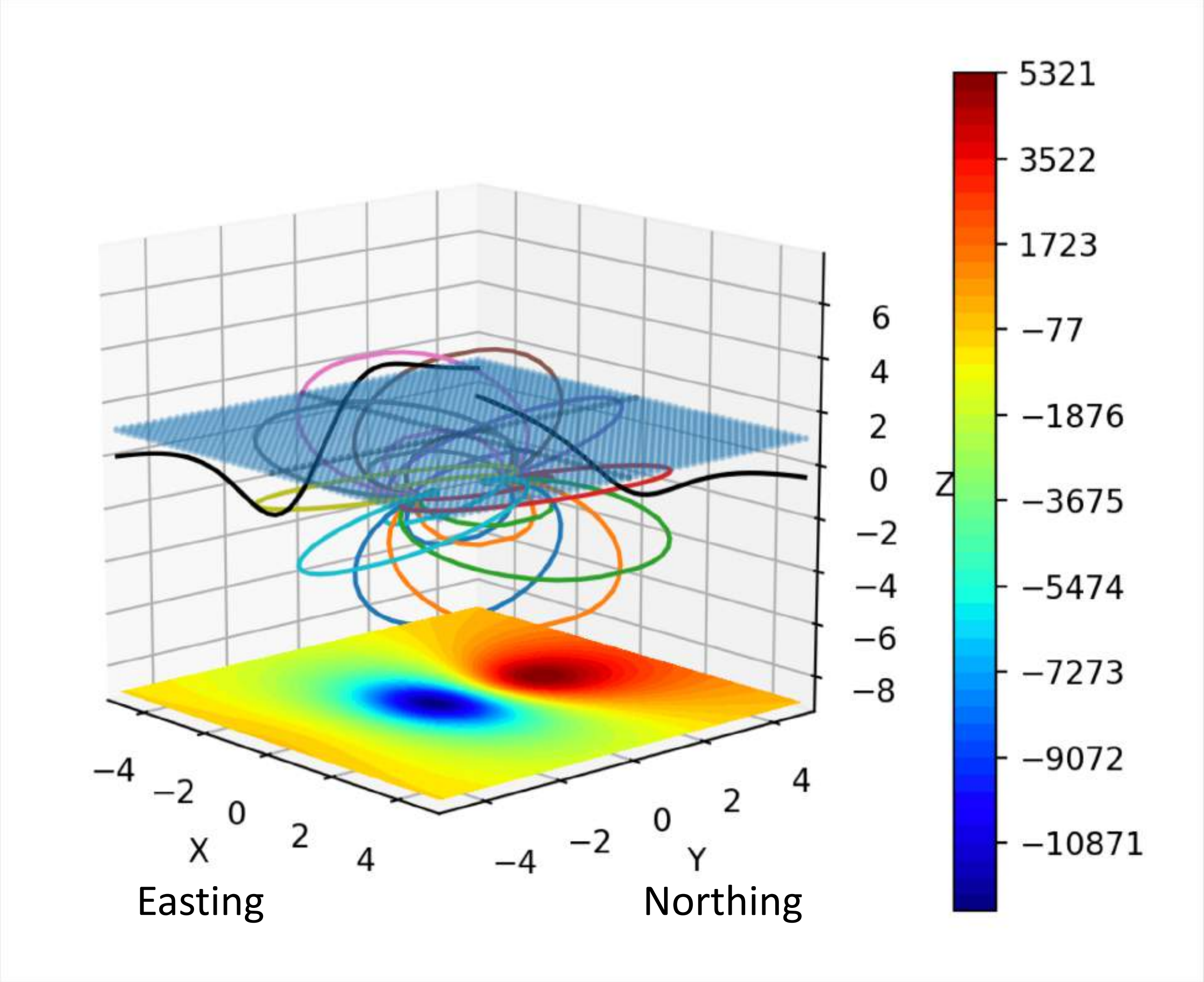
Can you:

- Draw field lines for B_A from a buried dipole
- Draw the inducing field B_0 on the surface
- Draw the total field $|B| = |B_0 + B_A|$ on the surface

Composite Field (BYO)



Arbitrary Magnetic Dipole Applet



https://github.com/yangdikun/magLab
MagDipole.ipynb

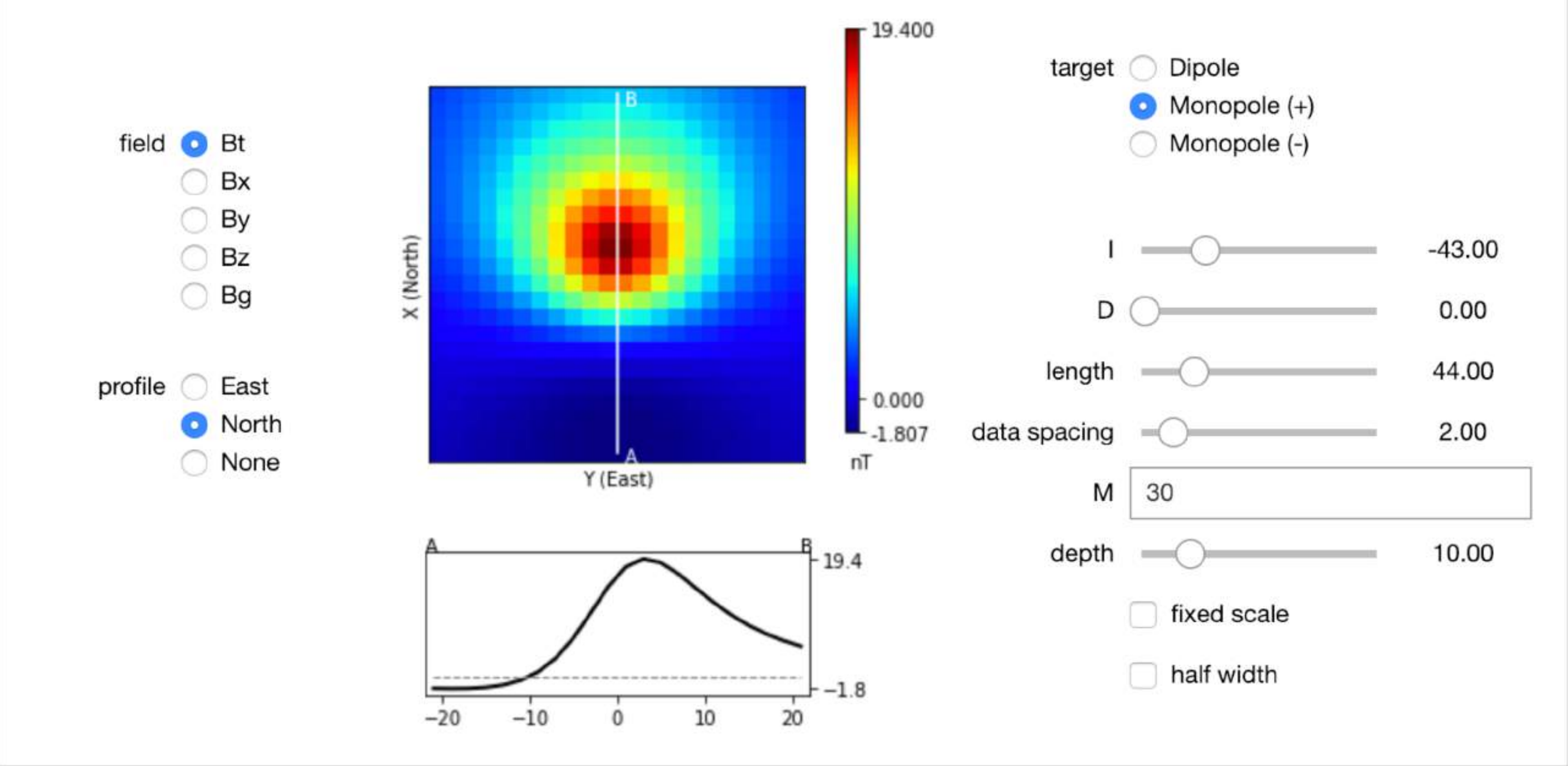
```
# define a dipole
dipoleloc = (0.,0.,-1.)
dipoleL = 2.
dipoledec, dipoleinc = 0., 0.
dipolemoment = 1e13
```

```
# geomagnetic field in Tesla, degree, degree
B0, Binc, Bdec = 53600e-9, -45., 0.
```

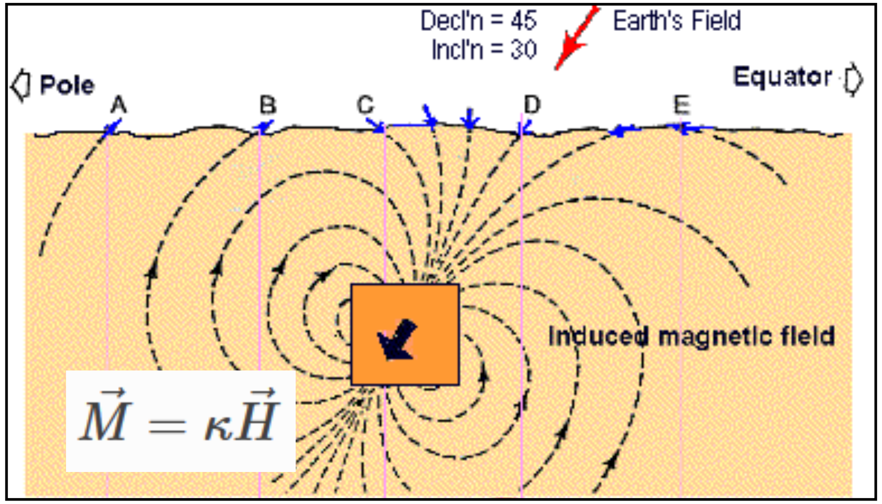
Induced Magnetic Dipole Applet

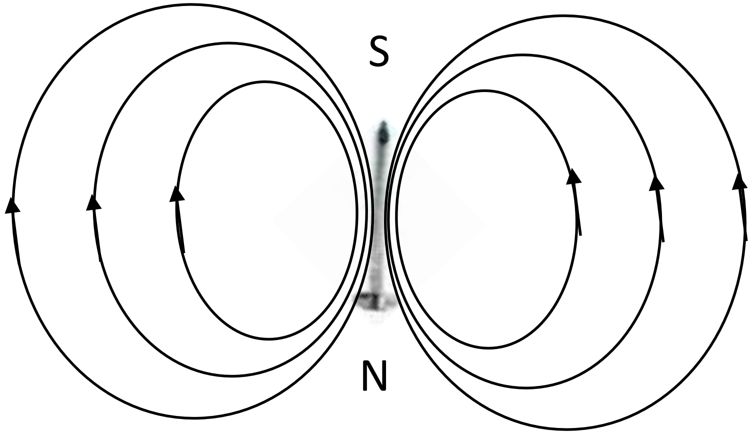
geosci-labs/
MagneticDipoleApplet.ipynb

```
mag = MagneticDipoleApp()
mag.interact_plot_model_dipole()
```



Types of Magnetization



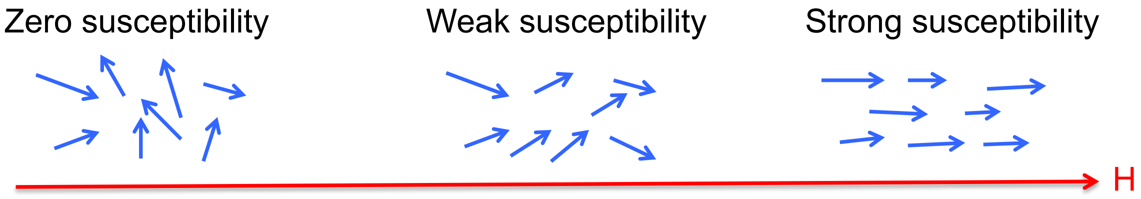


Induced:

- Same direction as B_0
- Depend on inducing field and susceptibility

Remanent :

- Memorize external field direction when cooled down



Magnetic field: B or H?

$\vec{B}$: Magnetic Flux Density $(Wb/m^2 = \text{Tesla})$
$\vec{H}$: Magnetic Field (A/m)

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

$$\boxed{\vec{B} = \mu \vec{H} = \mu_0 (1+\kappa) \vec{H} = \mu_0 (\underset{\text{inducing}}{\vec{H}} + \underset{\text{induced}}{\vec{M}})}$$

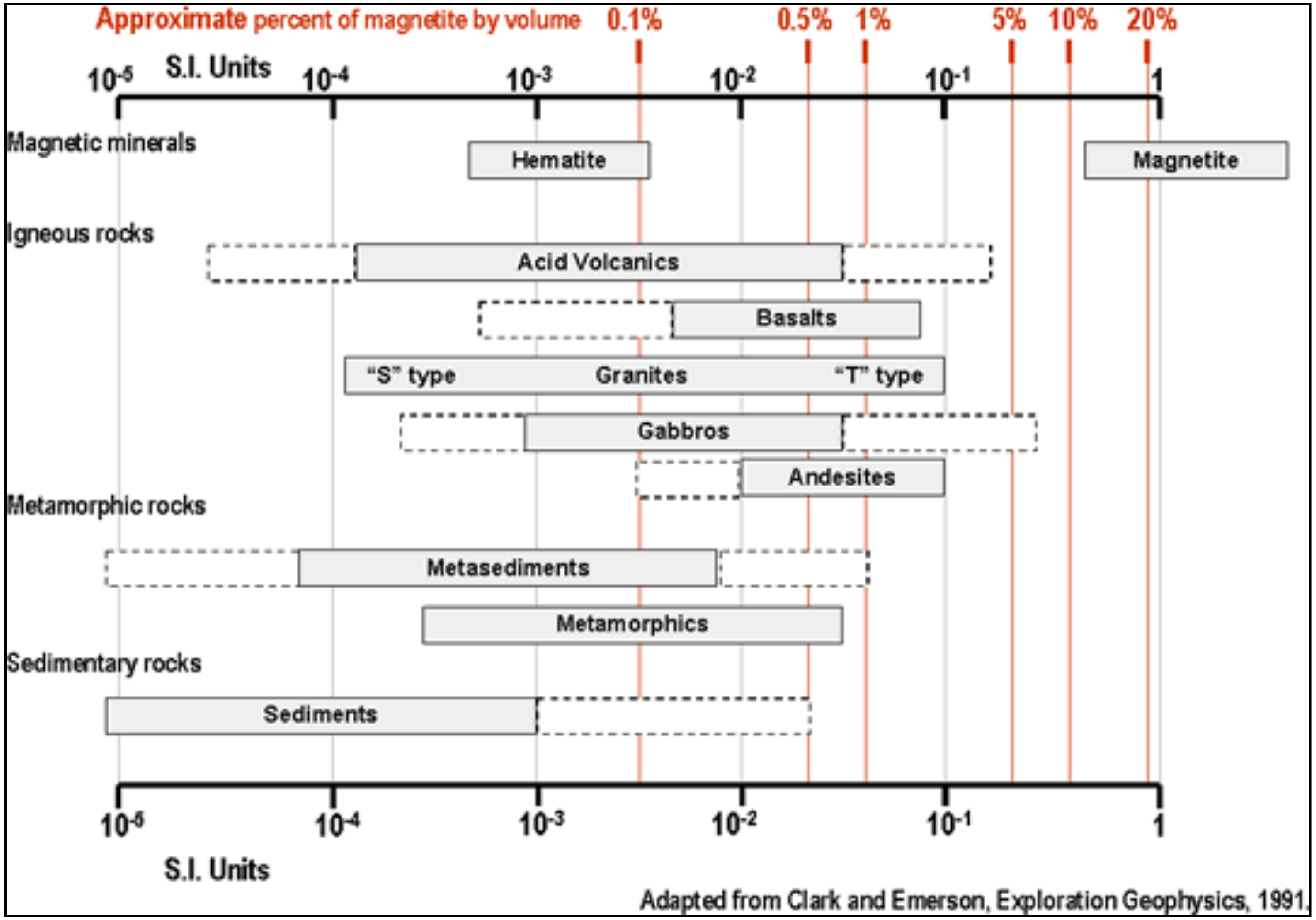
μ = magnetic permeability
$\mu = \mu_0 (1+\kappa)$

Magnetic permeability of free space:
$\mu_0 = 4\pi \times 10^{-7}$

Susceptibility is a convenient indicator of material's magnetic property: zero for non-magnetic and a positive value for magnetic.

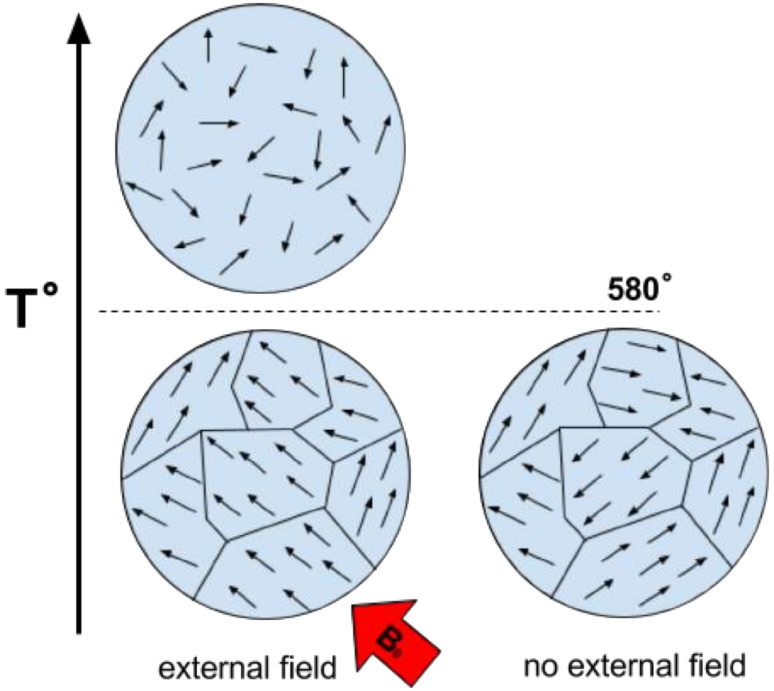
Magnetic Susceptibility (S.I. Units)

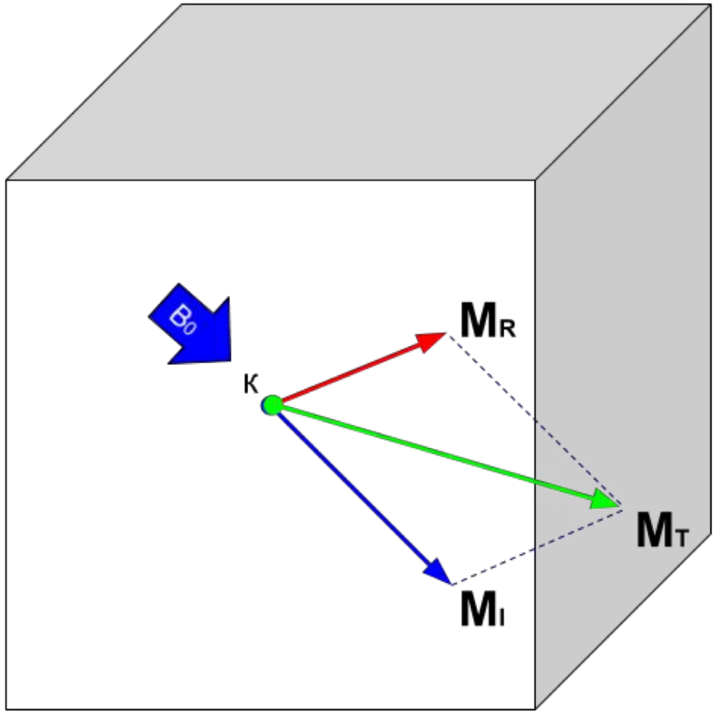
Magnifier of H



Remanent Magnetization

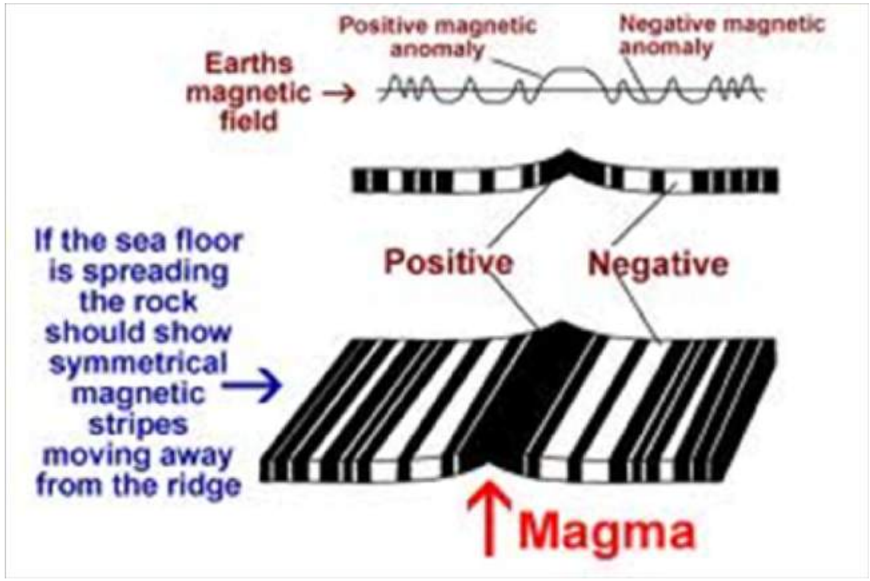
- Magnetic material cooling through Curie temperature (~550 C) acquires a magnetic field in the direction of the earth's field.
- Final magnetization sum of induced and remnant magnetization: $\vec{m} = \vec{m}_I + \vec{m}_R$

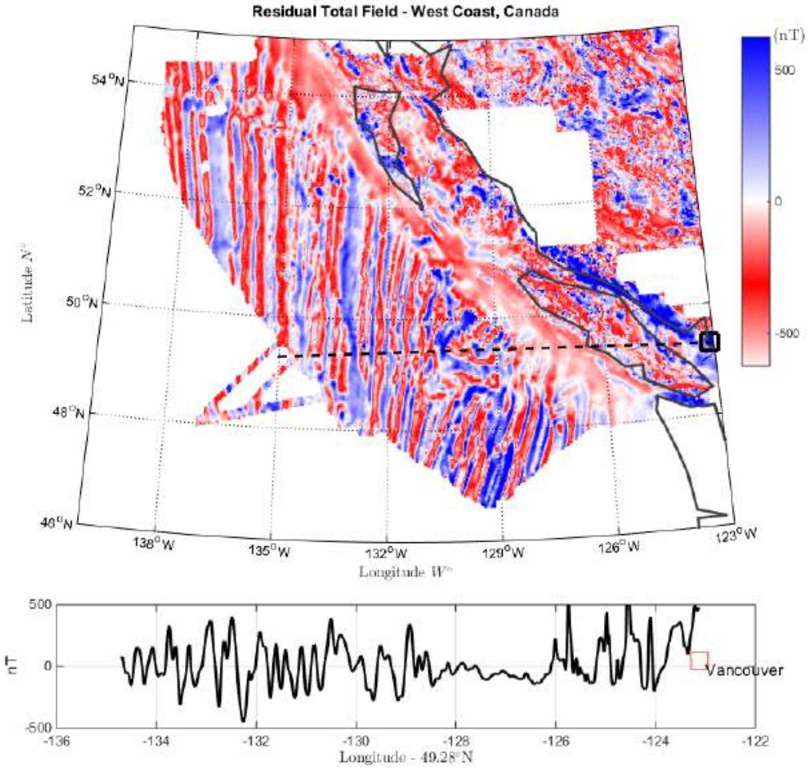




Remanent Magnetism

- Small scale: UXO, rebar, drums
- Large scale: geologic units.
  Sea floor spreading



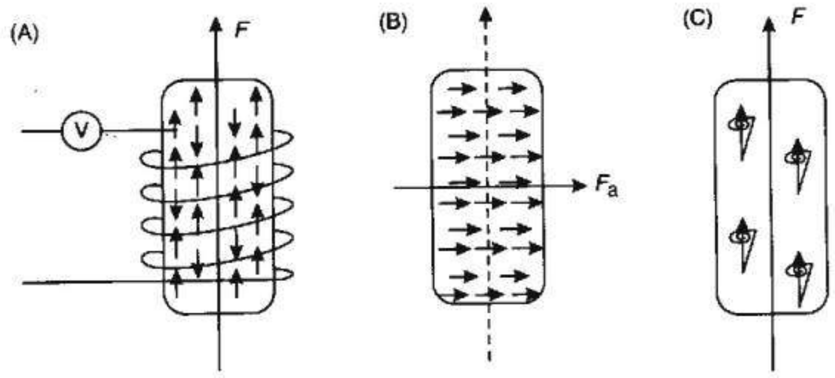


Three Ingredients

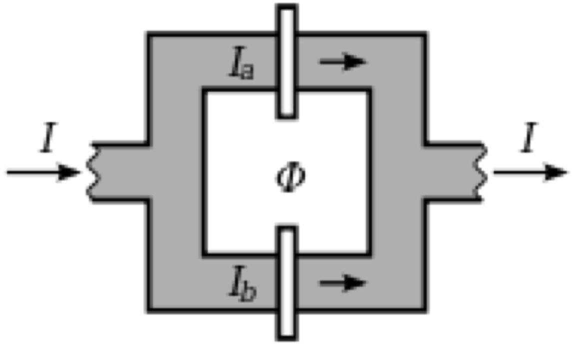
- Inducing field (B_0)
  - Uniform and strong
- Induced field
  - From present-day magnetization
  - Small object behaves like a dipole
  - Induced magnetization in the same direction as B_0
  - Field (usually small) proportional to B_0
  - A linear relation - susceptibility
- Remanent field
  - From ancient magnetization
  - Independent of B_0 (can be large)

Magnetometers

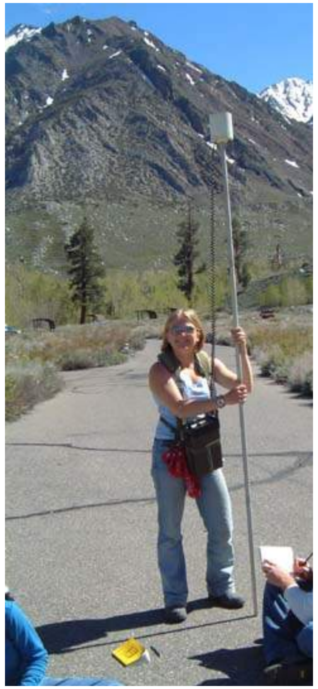
- Total field |B|
  - Proton precession (NMR)
  - Cesium vapour magnetometer



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

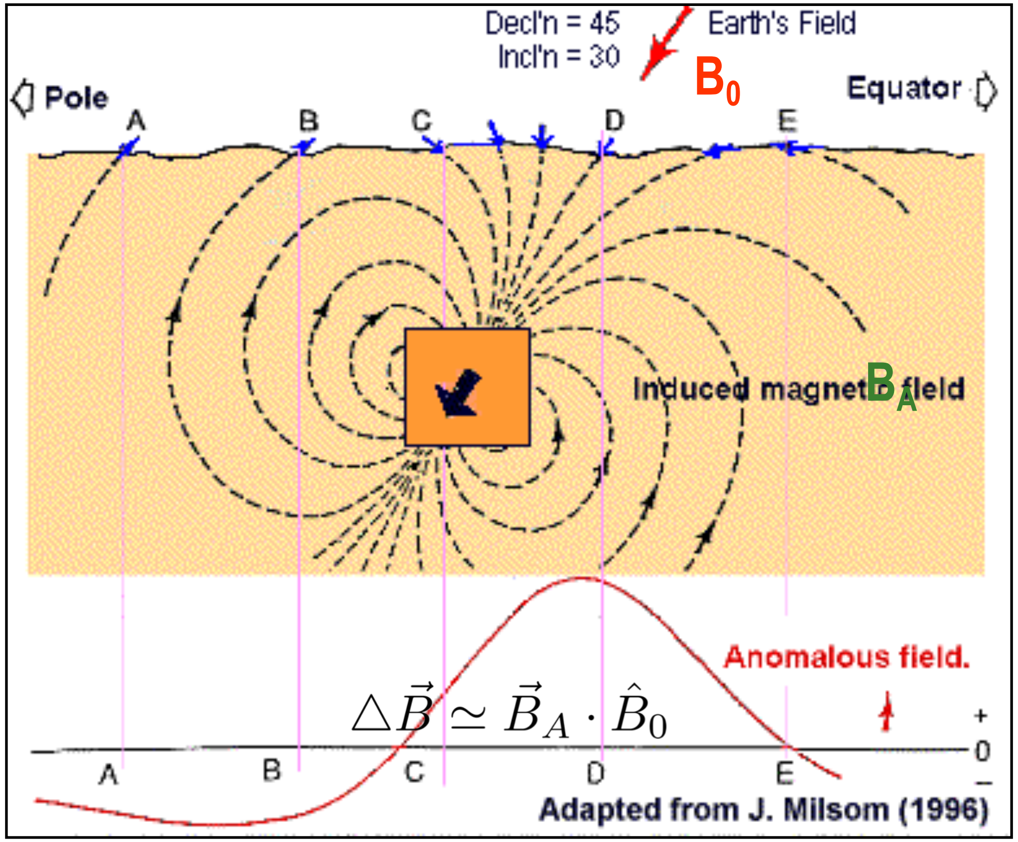


Magnetic sensors to acquire data



Multi-scale Nature of Magnetic Field

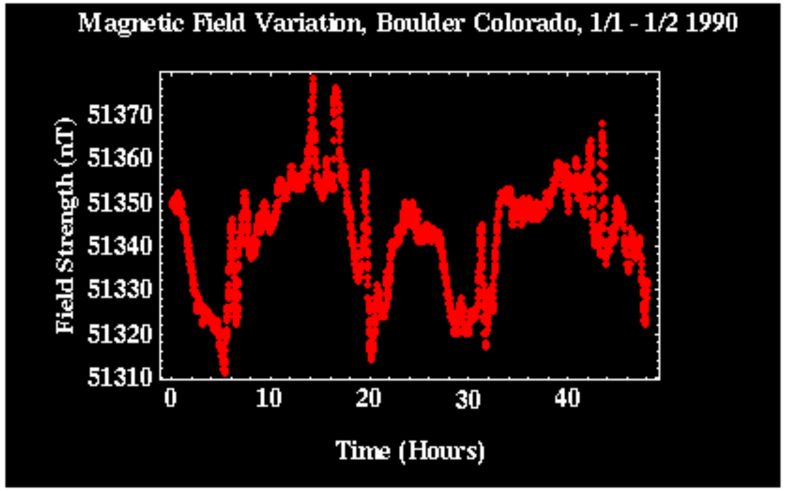
- Assumptions used in this conceptual model?

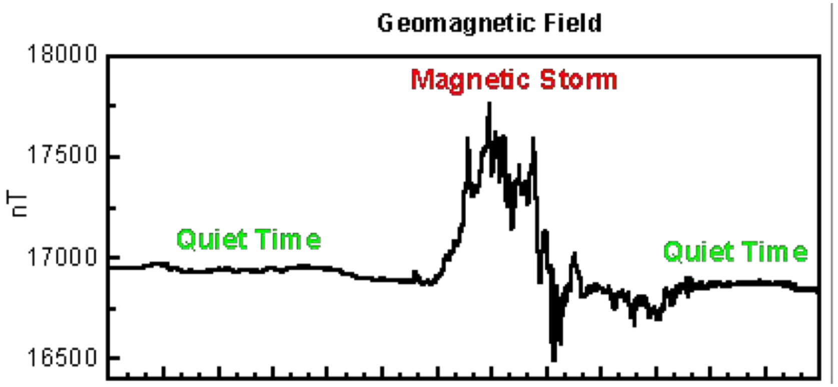


- B_0 is constant in space
- B_0 is constant in time
- A single magnetized body sufficiently small for dipole approximation
- Non-magnetic outside of the body

Time Variations of the Earth's Field

- 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 – millions of years)





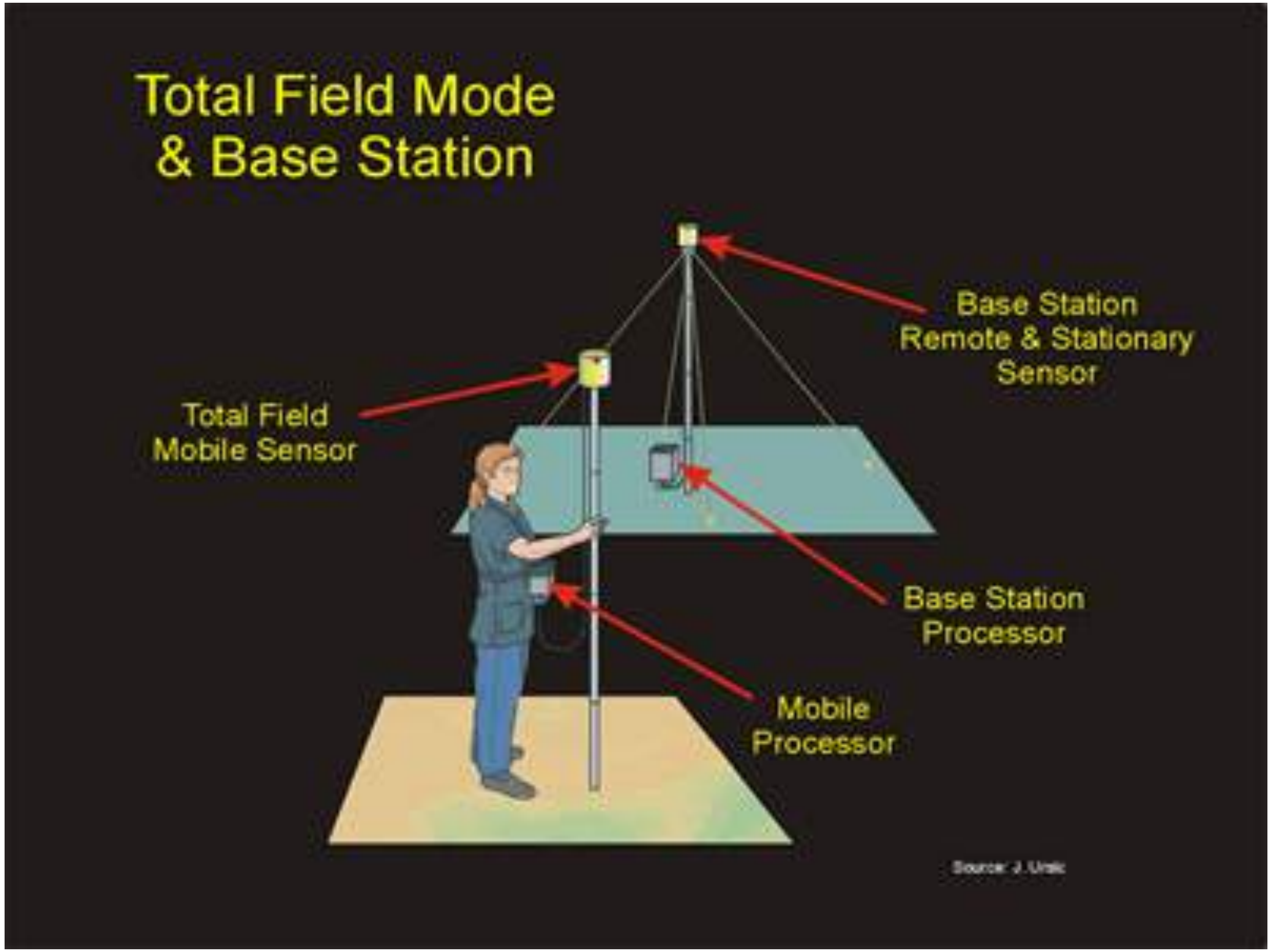
Base station correction

- 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

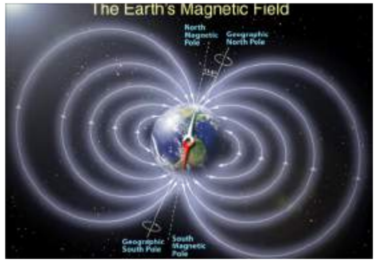
- Perform a correction by subtraction



Regional Removal

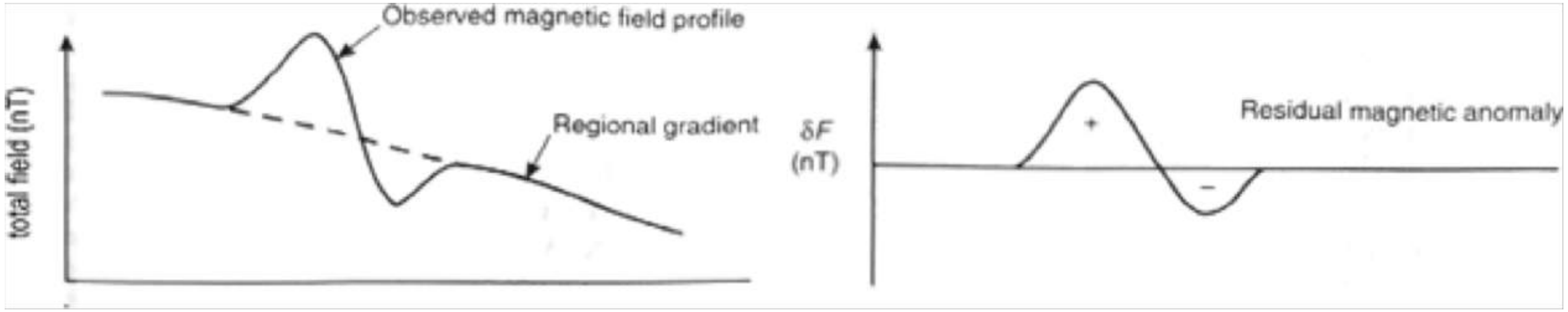
- Any magnetic measurement is superposition of fields from many objects at different scales
- Example: magnetic data for UXO could include

 +  + 

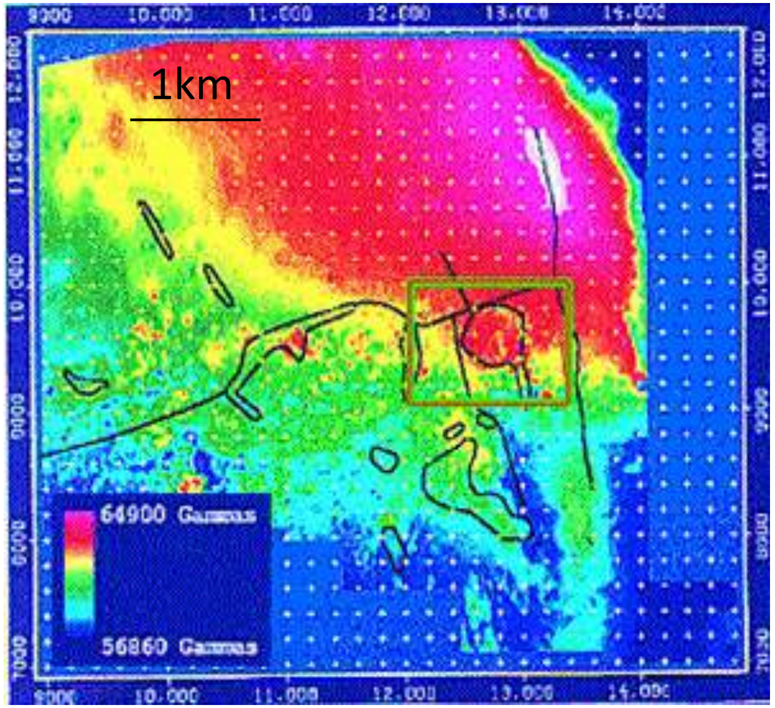
+ 

+...

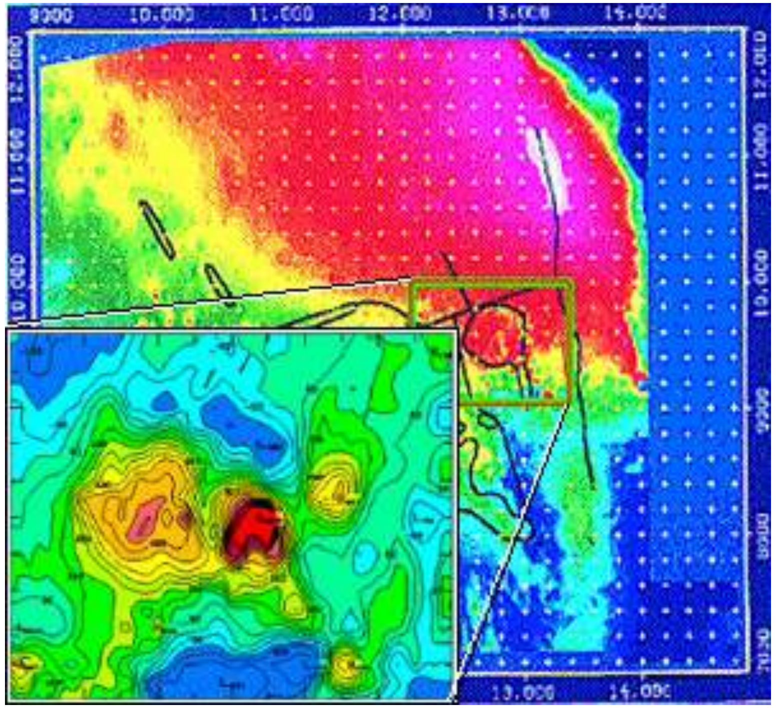
- Regional removal (assuming no magnetic objects larger than a certain length scale)



Regional Removal



Before: details about the deposit masked by the regional field

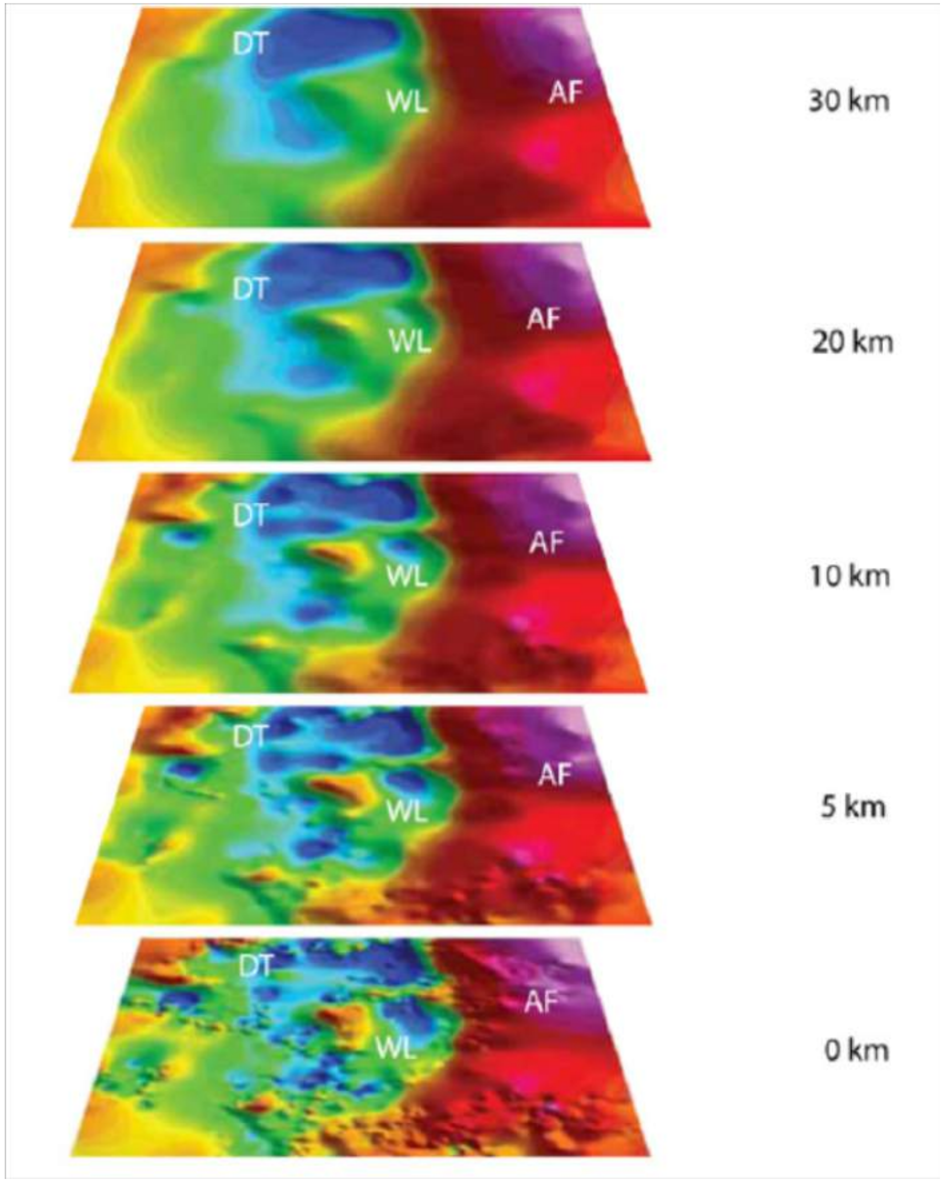


After: target of interest better revealed

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

Upward Continuation

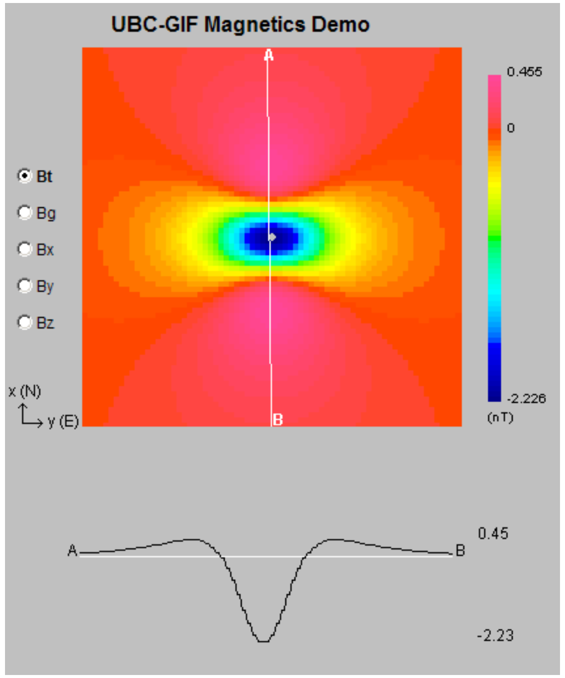
- Low-pass filter: remove short-wavelength signals from small near-surface objects
- As if data are measured at higher elevations
- Highlight regional trends



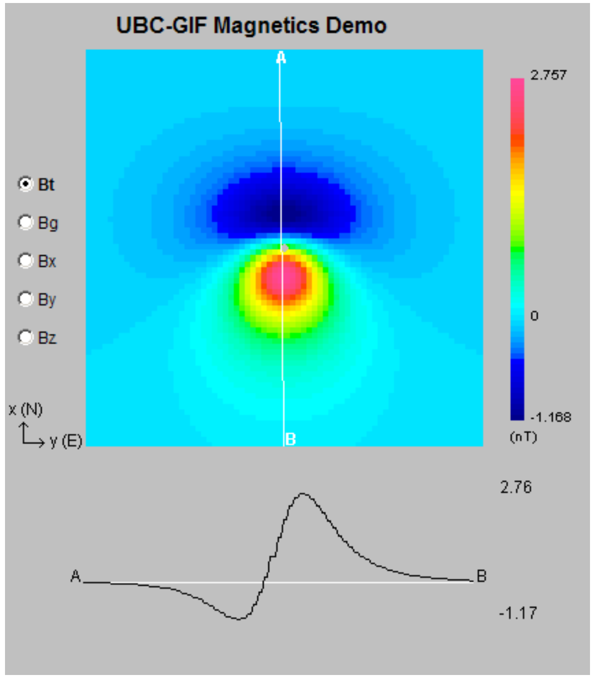
Reduction to Pole (RTP)

Experiment with:
geosci-labs/MagneticDipoleApplet.ipynb

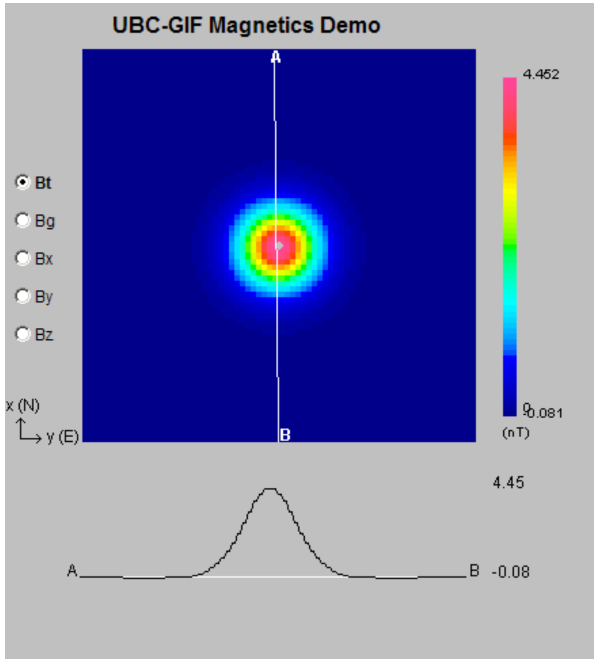
- Same object buried at the center of the map
- Inclination determines the direction of magnetization – we may observe different patterns
- RTP: process the data as if the inducing field (B_0) is purely vertical (at poles)



Inclination=0



Inclination=45



Inclination=90

Summary

- Magnetic dipole model (important!)
- Draw the composite field
- Magnetization
  - Induced: Geological Objects
  - Remanent: Iron, steel
- Data measurement and correction
  - Recall gravity…