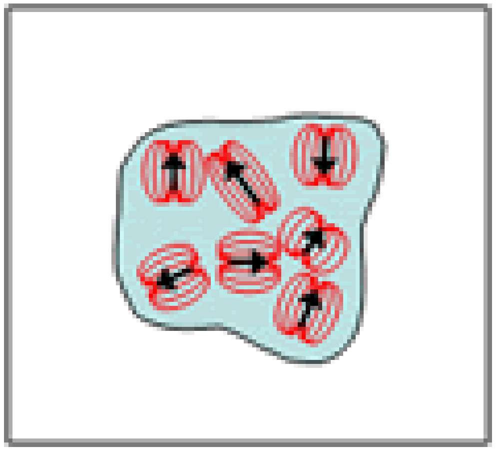
From last time

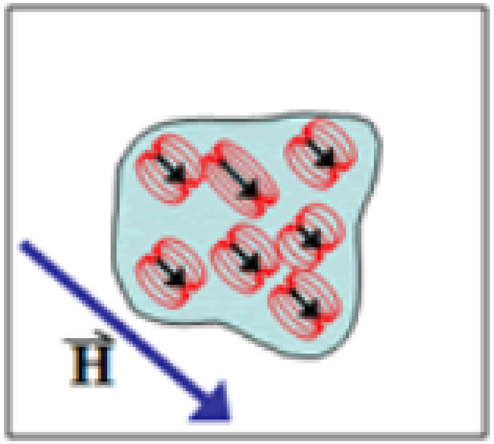
- Earth materials contain magnetic domains that behave like magnetic dipoles



- Magnetization is the total dipole moment per unit volume

$$\vec{M} = \frac{\Sigma \vec{m}_i}{Volume}$$

- Magnetic dipoles will re-orient along the direction of an inducing field

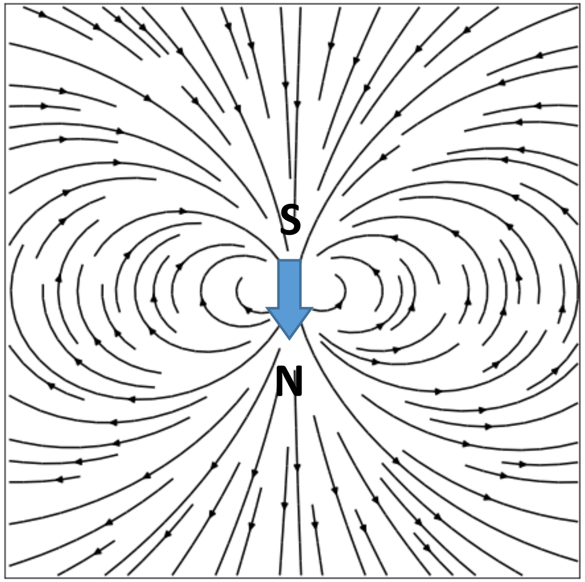


- The strength of induced magnetization is defined by the magnetic susceptibility

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

From last time

- Magnetization produces a magnetic field
- Field lines got from North to South pole
- All together:



Inducing field

Induced magnetization

Remanent magnetization

$$\begin{aligned}\vec{B} &= \mu_0(\vec{H} + \vec{M}) \\ &= \mu_0(\vec{H} + \vec{M}_I + \vec{M}_R) \\ &= \mu_0(1 + \kappa)\vec{H} + \mu_0\vec{M}_R \\ &= \mu\vec{H} + \mu_0\vec{M}_R\end{aligned}$$

Inside susceptible material

Inducing field

Anomalous field (due to magnetization)

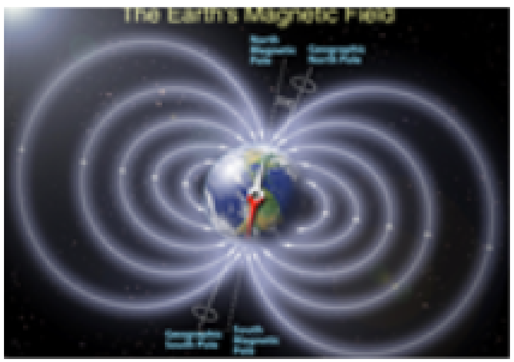
$$\begin{aligned}\vec{B} &= \mu_0(\vec{H} + \vec{H}_A) \\ &= \vec{B}_0 + \vec{B}_A\end{aligned}$$

Outside susceptible material

From last time

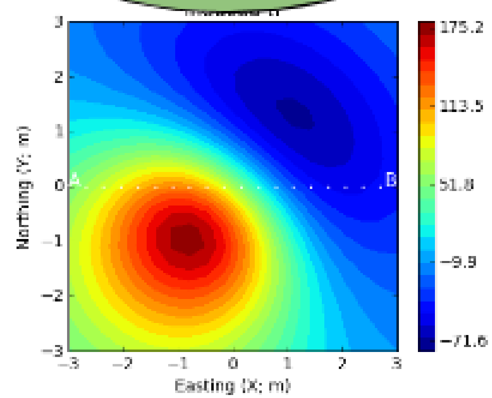
Source

Data



Input energy

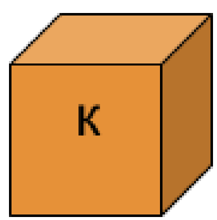
Measured response

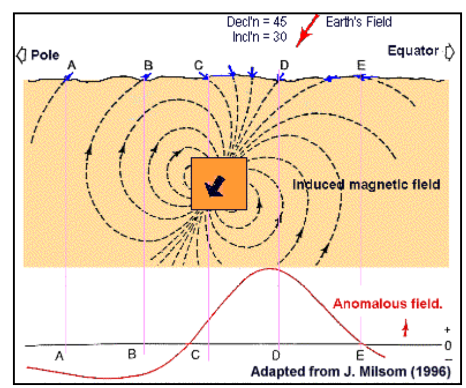


Subsurface

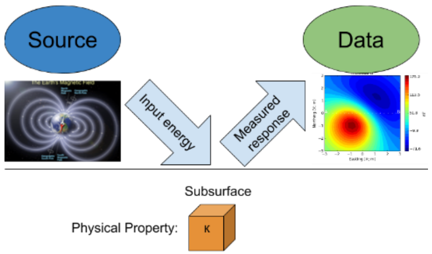
Physical Property:

Magnetic susceptibility

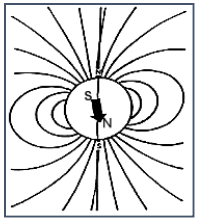




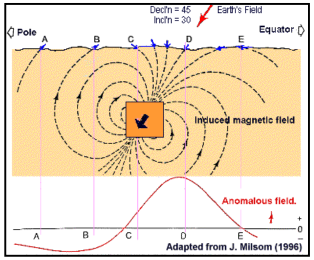
From last time



- Earth's magnetic field, $B_{0,}$ is the source:

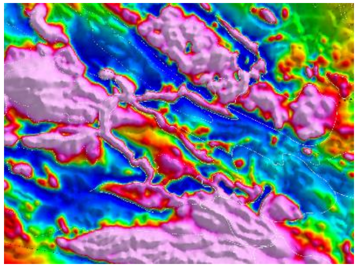


- Induces magnetization
  (may also have remanence):
  → Creates anomalous field B_A



- Measure total magnetic field

$$B = B_0 + B_A$$



Today’s topics

- Basic principles
    - The source
    - Magnetization of Earth materials
    - Anomalous field

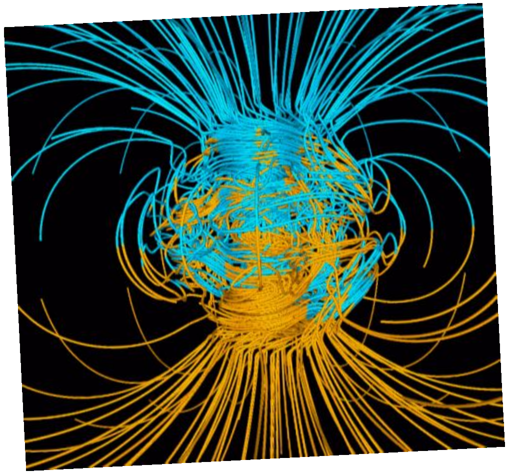
Basic principles (Source)

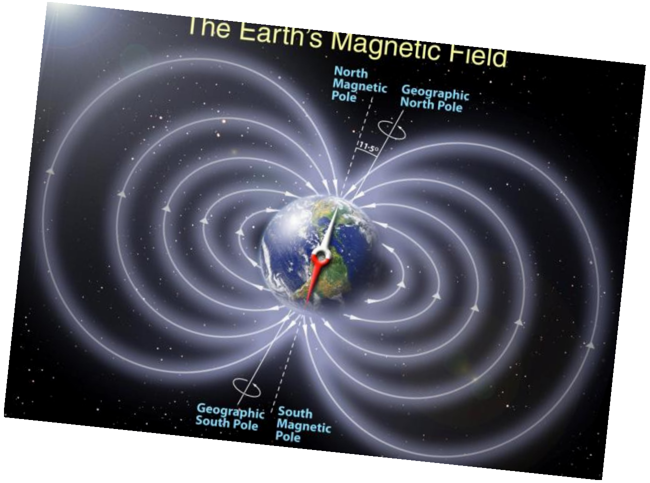
Reading on the GPG:

https://gpg.geosci.xyz/content/magnetics/magnetics_basic_principles.html#basic-principles

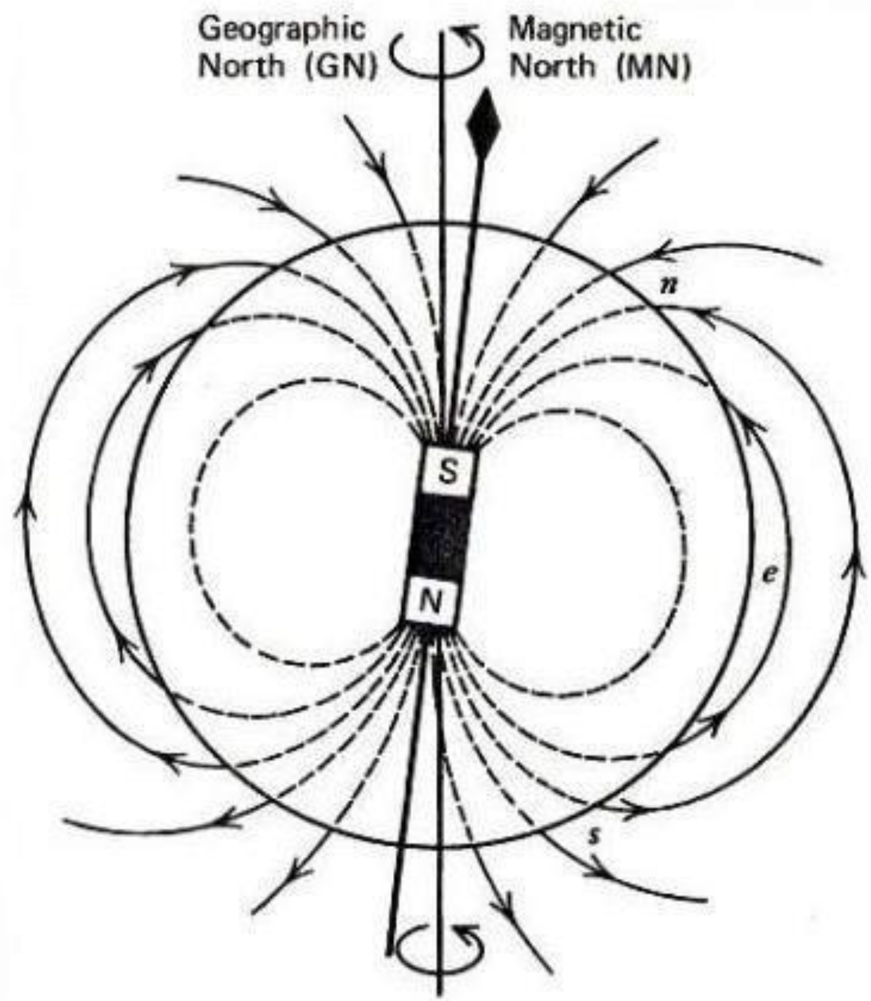
Earth’s Magnetic field

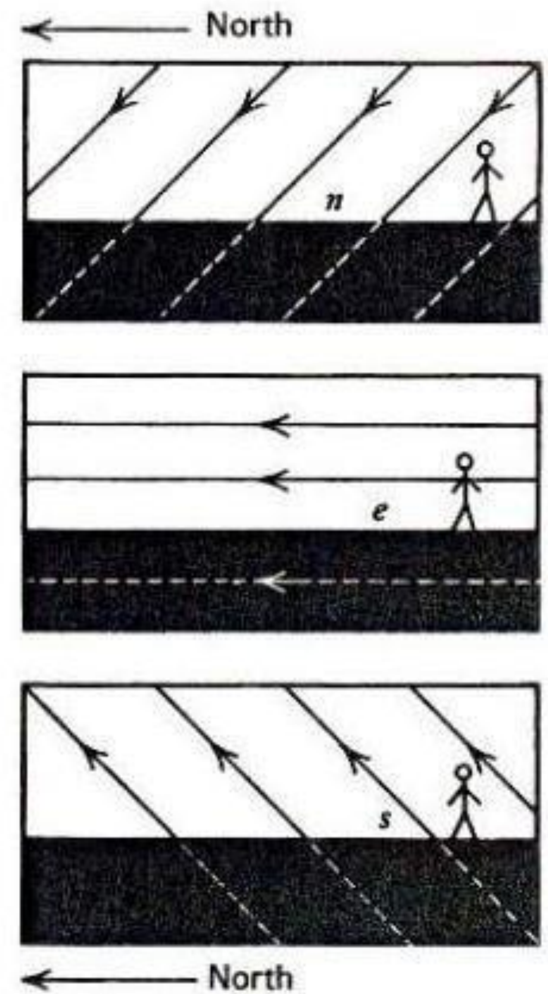
- Geomagnetic dynamo
- Complicated inside the earth near the core
- Outside the earth it looks like a magnetic field due to a dipole





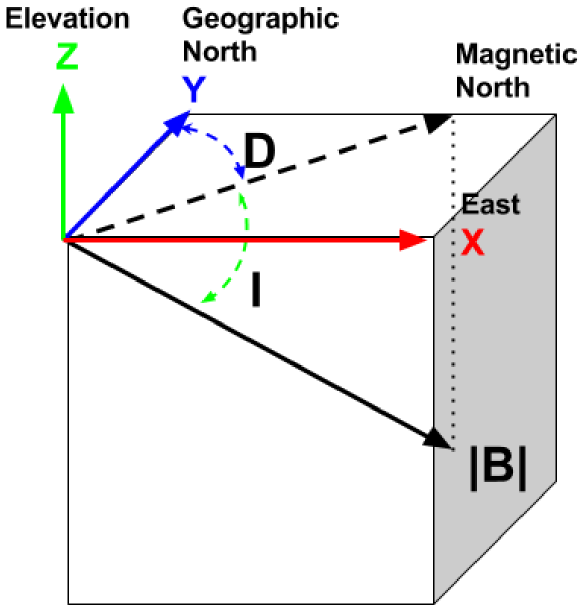
Magnetic vs Geographic North

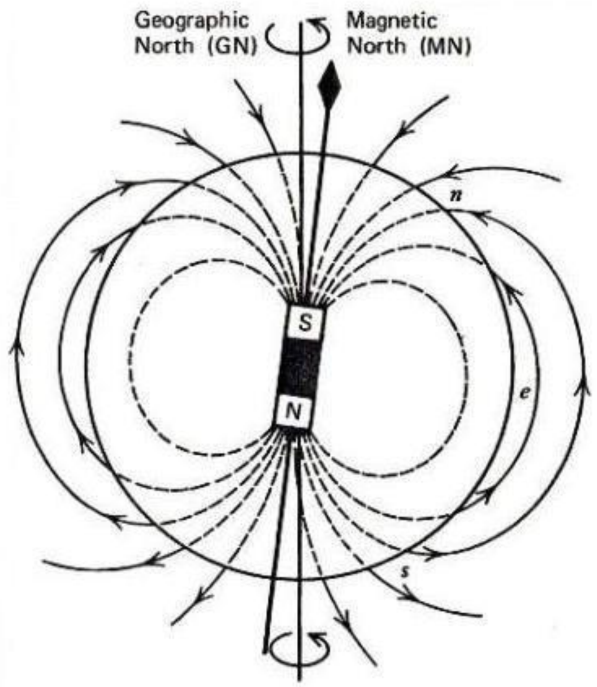


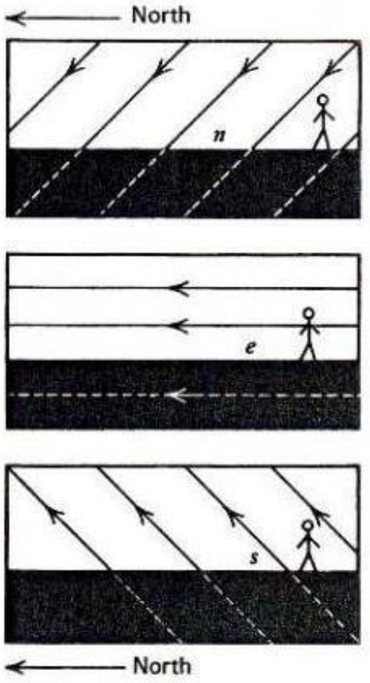


Defining Earth’s Field on Surface

- A vector field
- How is the field described anywhere?
  - Orthogonal decomposition: X, Y, Z
  - Inclination, Declination, Magnitude

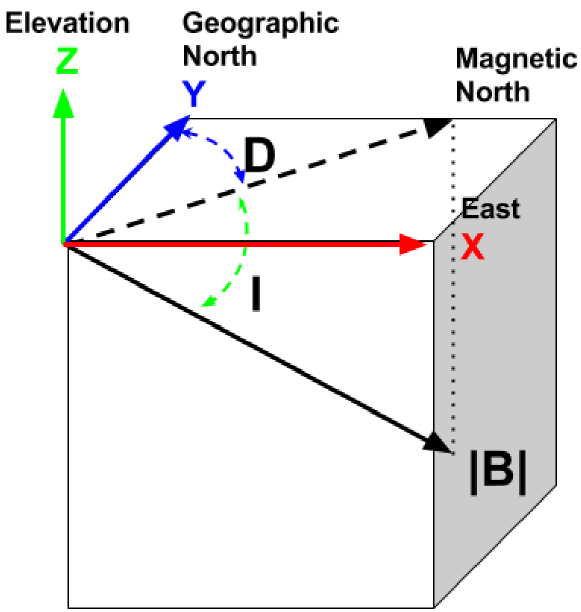


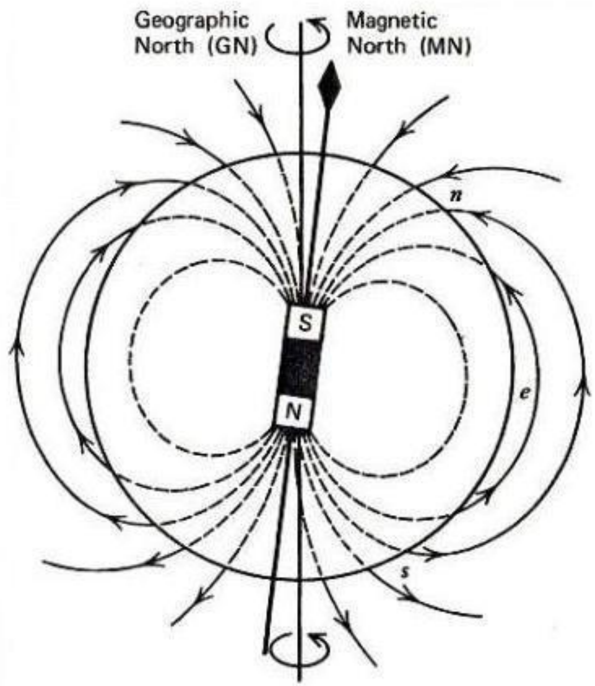


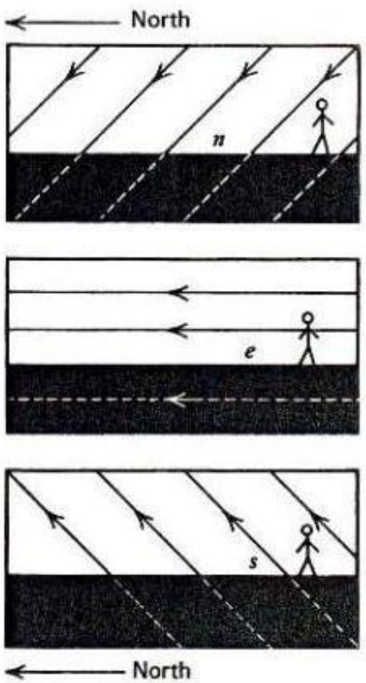


Defining Earth's Field on Surface

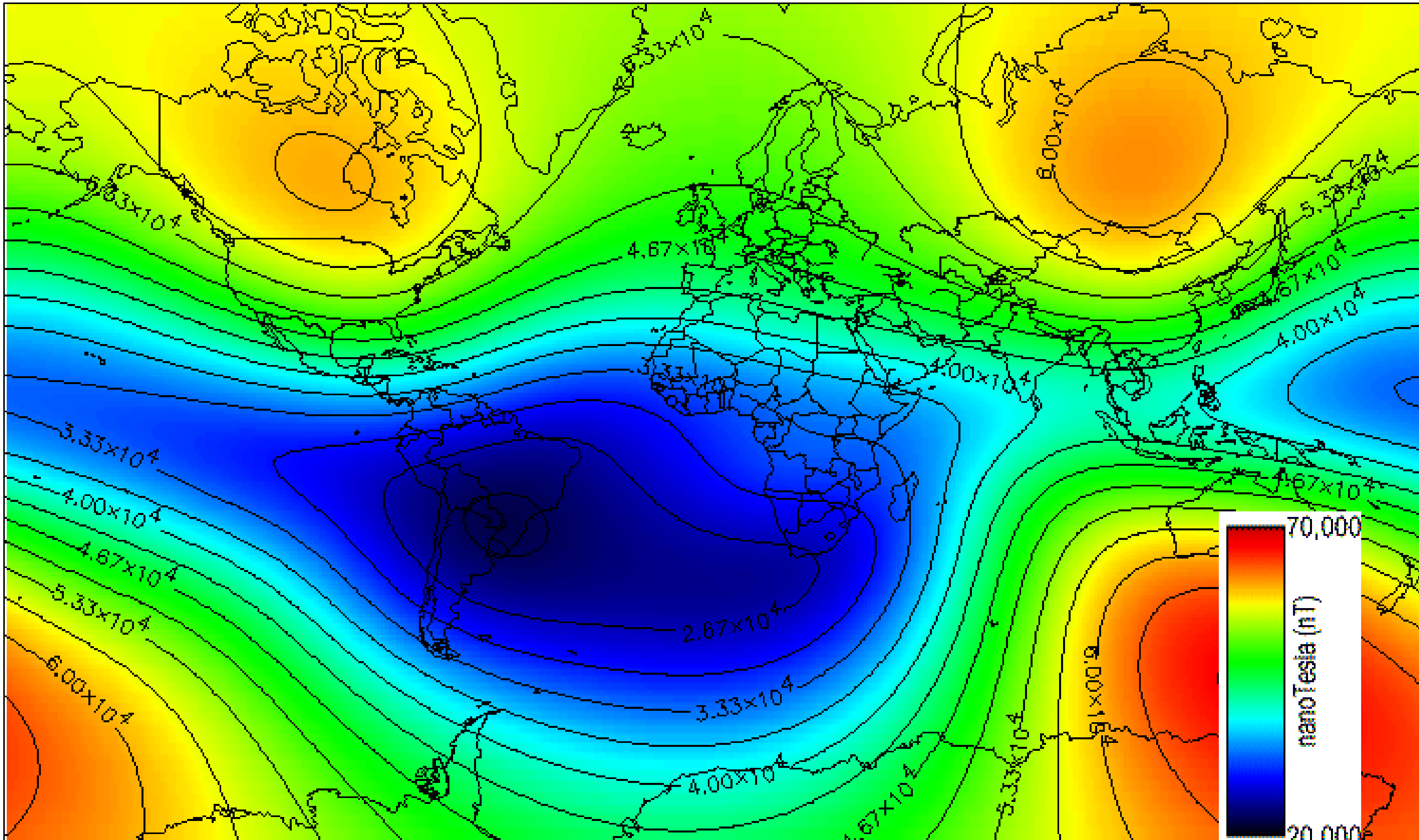
- Declination: CW degree angle from geographic North
- Inclination: Degree angle from horizontal (+ve down)
- Amplitude: Magnetic flux in units nT



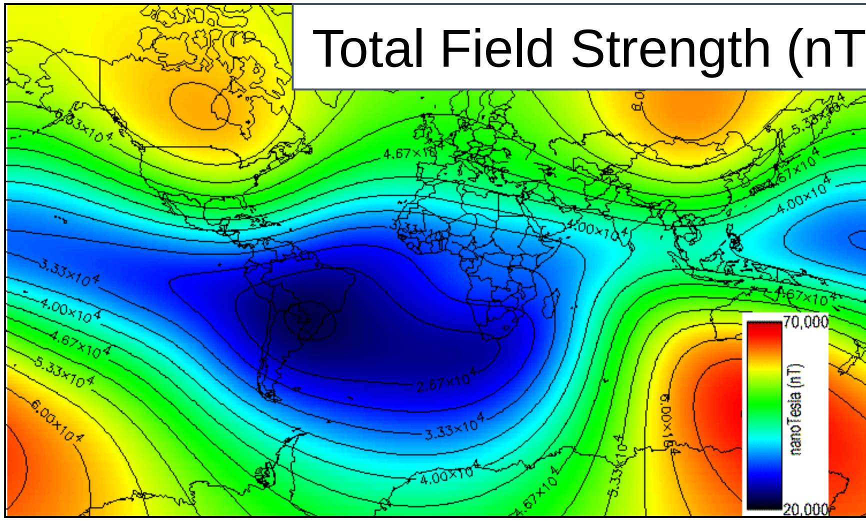


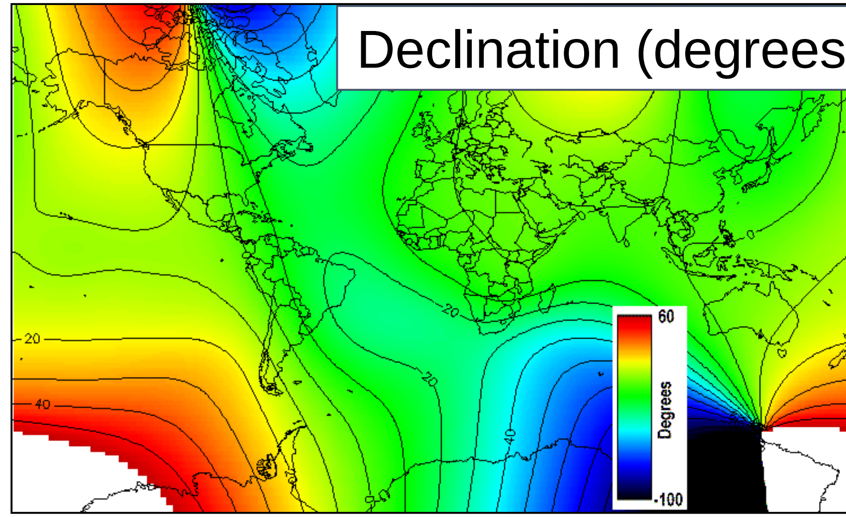


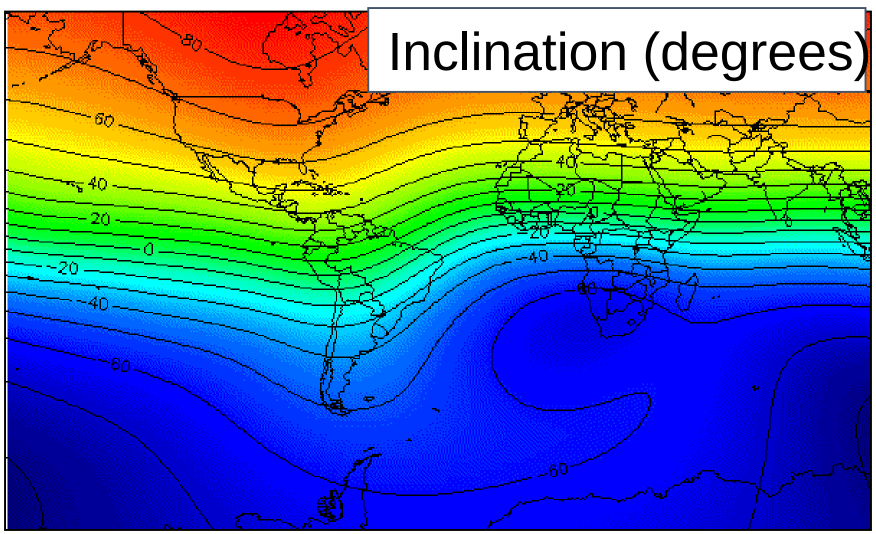
Earth’s Magnetic Field Amplitude



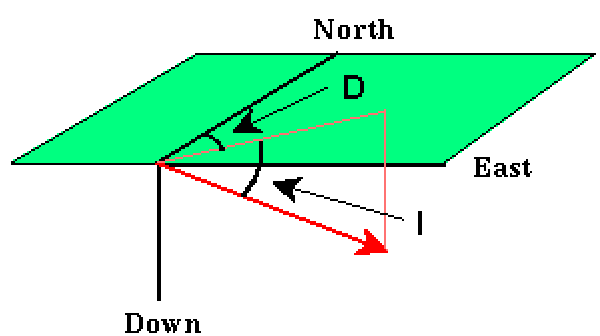
Earth's magnetic field: Strength |B| Inclination I Declination D

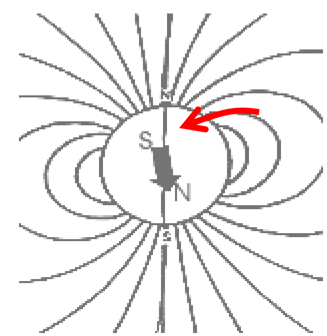






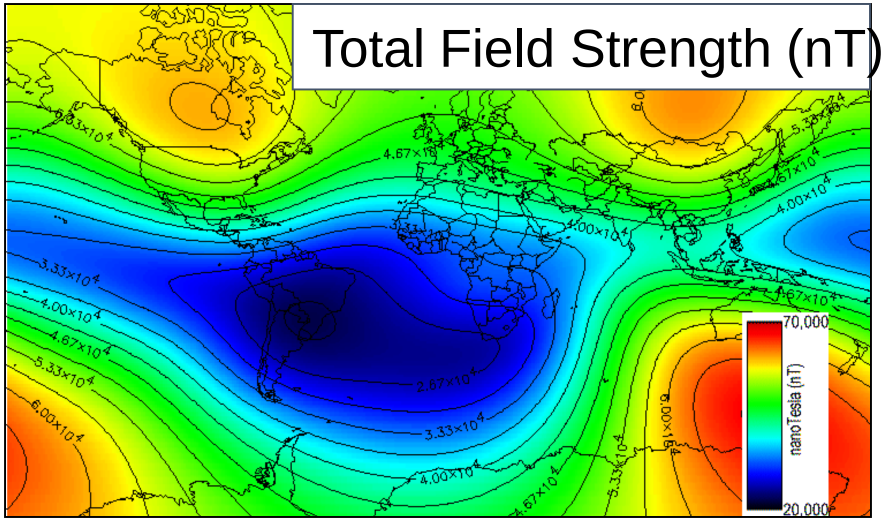
B_{max} = 70,000 nT H_{max} = 55.7A/m
B_{min} = 20,000 nT H_{min} = 15.9A/m

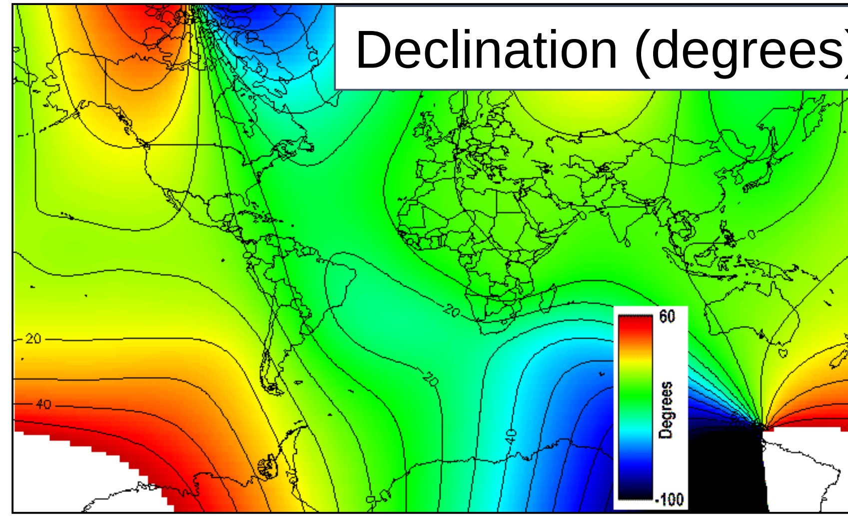


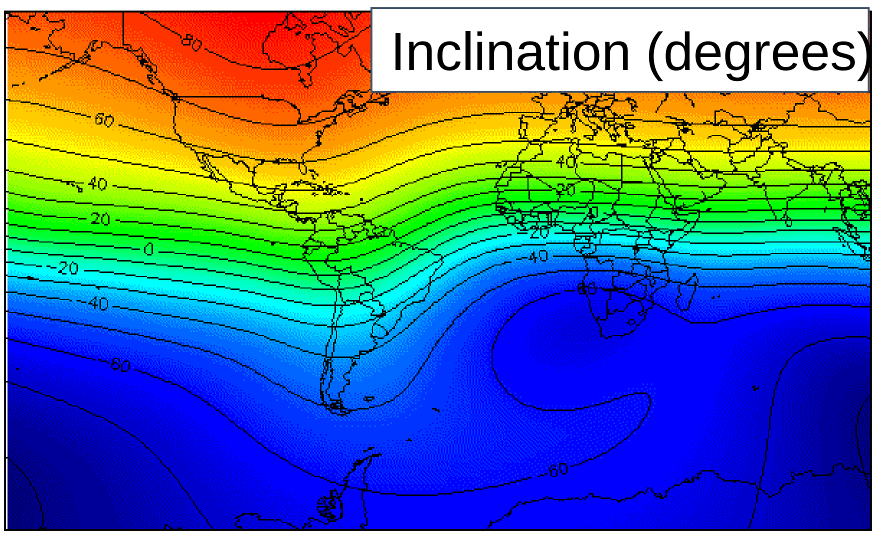


http://www.ngdc.noaa.gov/cgi-bin/seg/gmag/igrfpg.pl

Earth's magnetic field: Strength |B| Inclination I Declination D







VANCOUVER

Latitude: 49° 15' 0" N
Longitude: 123° 7' 60" W
Magnetic declination: +16° 19'
Declination is POSITIVE (EAST)
Inclination: 70° 11'
Magnetic field strength: 54197.1 nT

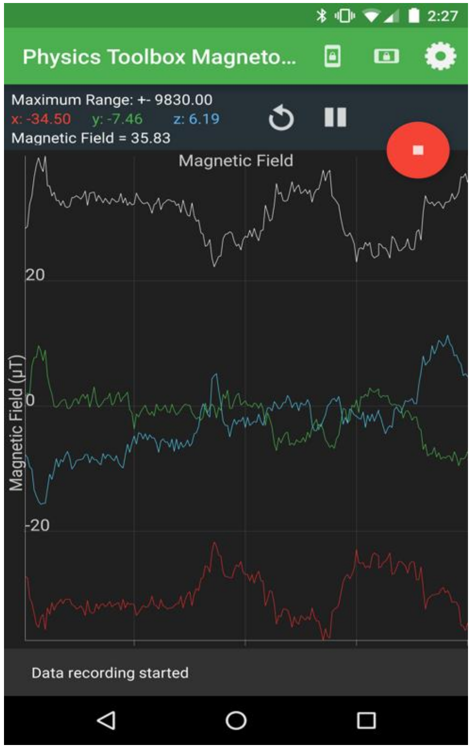
http://www.ngdc.noaa.gov/cgi-bin/seg/gmag/igrfpg.pl

Demo: Magnetometer on Cell Phones

Physics toolbox

- Compass: magnetic N and S

Magnetometer on Cell Phones



Physics toolbox

- Compass: magnetic N and S
- 3-axis magnetometer: Total, X, Y, Z
- Verify the total field and inclination in Vancouver

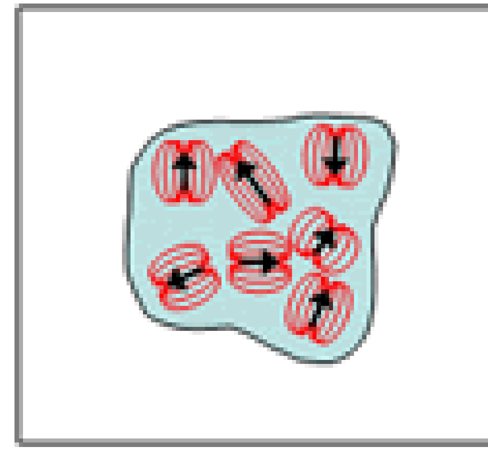
Basic principles (Magnetization)

Reading on the GPG:

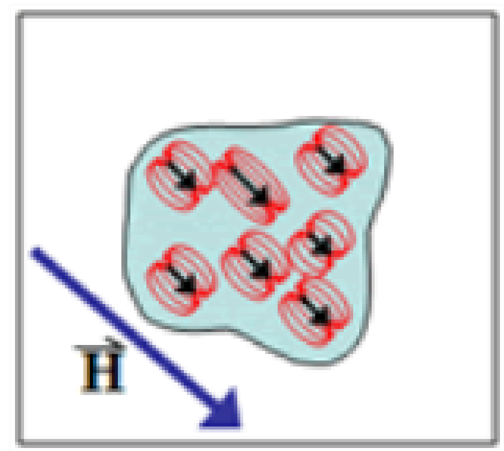
https://gpg.geosci.xyz/content/magnetics/magnetics_basic_principles.html#basic-principles

Induced Magnetization

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



- Induced magnetization **parallel to** inducing field



- The strength of induced magnetization depends on susceptibility and strength of inducing field

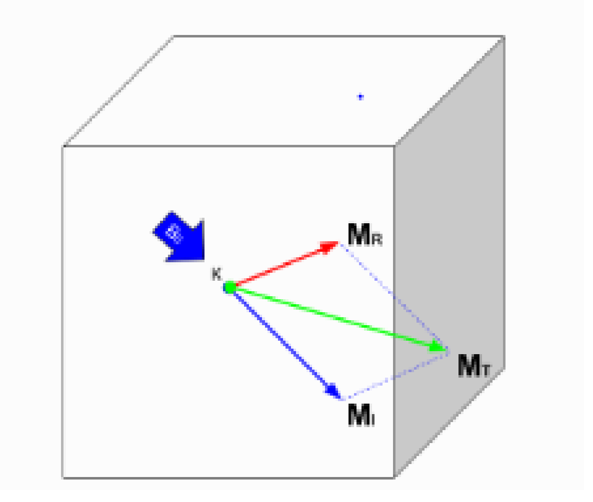
Remanent Magnetization

- A permanent magnetization contribution which is **not** supported by an external field

- Total magnetization is vector sum:

$$\overrightarrow{\boldsymbol{M}}_{\boldsymbol{T}} = \overrightarrow{\boldsymbol{M}}_{\boldsymbol{I}} + \overrightarrow{\boldsymbol{M}}_{\boldsymbol{R}}$$

- Only significant in ferromagnetic materials (magnetite, steel etc…) so typically can be ignored

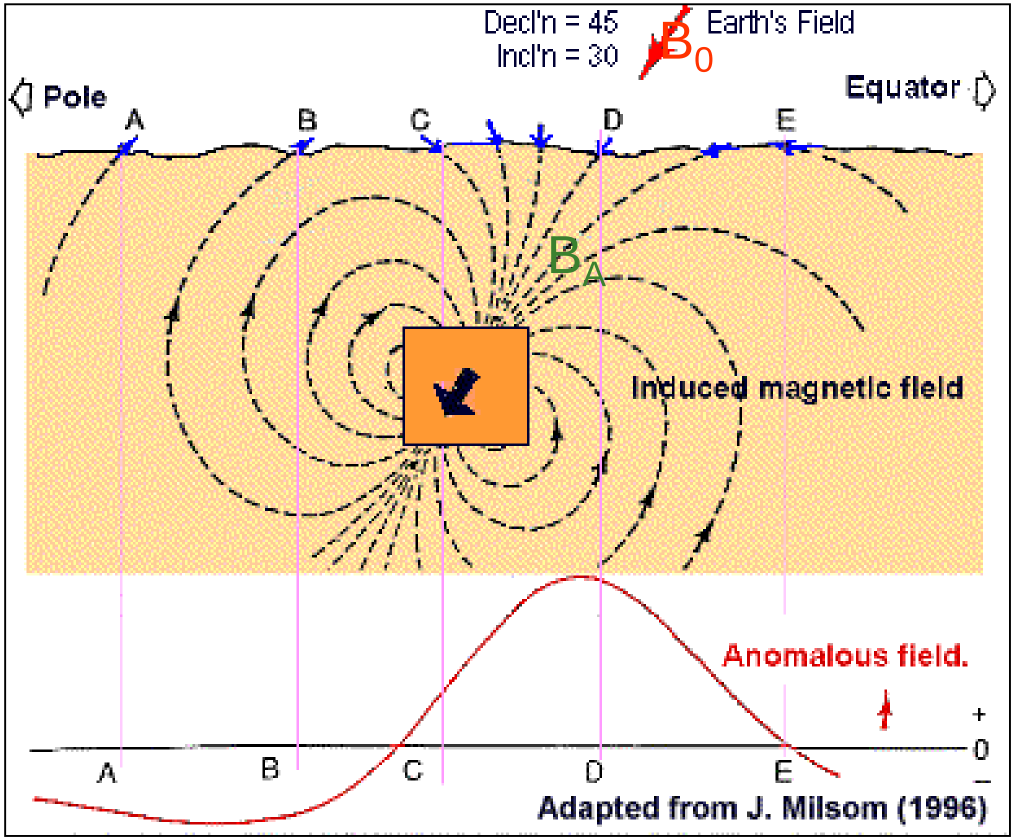


Anomalous fields
(no remanence)

Reading on the GPG:

https://gpg.geosci.xyz/content/magnetics/magnetics_basic_principles.html#basic-principles

The composite field



Composite field:

$$B = B_0 + B_A$$

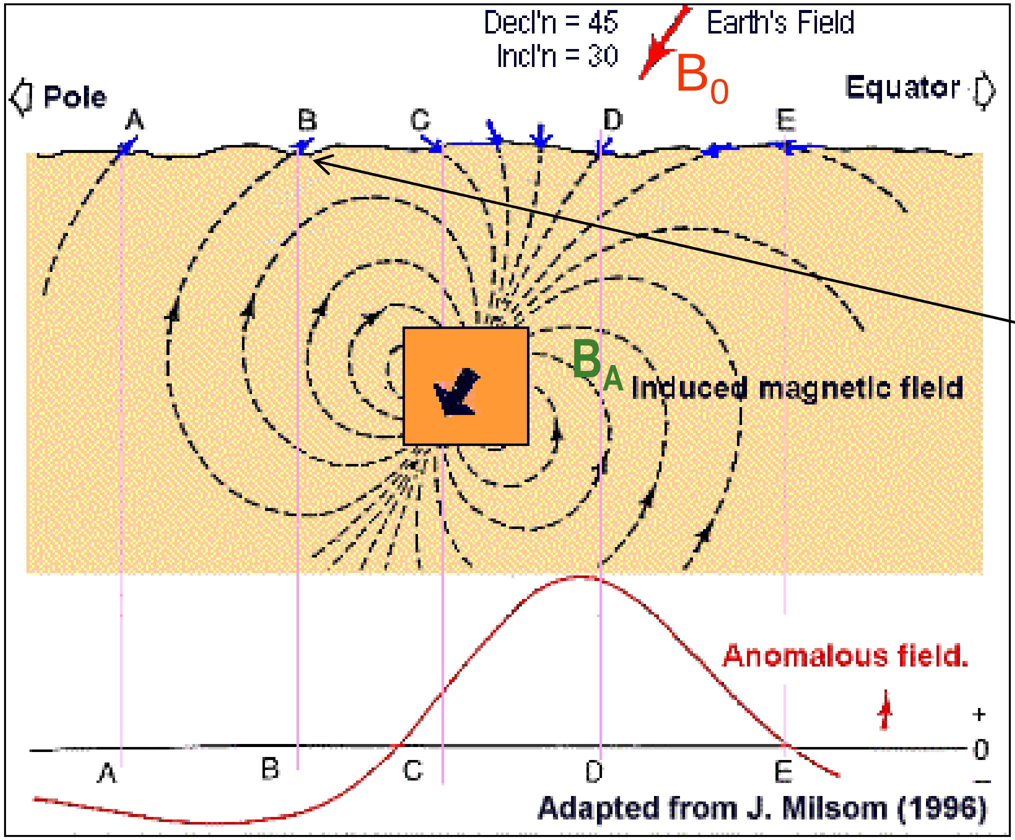
B is a vector:

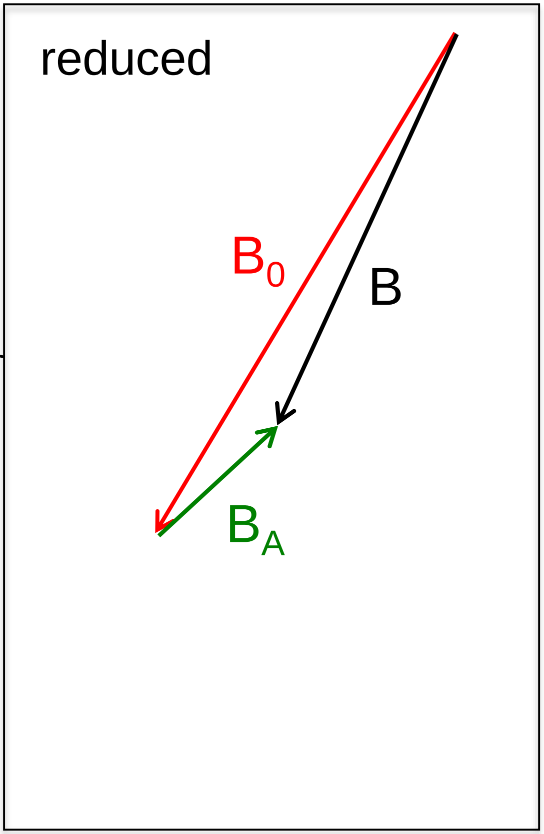
$$B = \{B_x, B_y, B_z\}$$

Total field:

$$|B| = |B_0 + B_A|$$

The composite field





Composite field:

$$B = B_0 + B_A$$

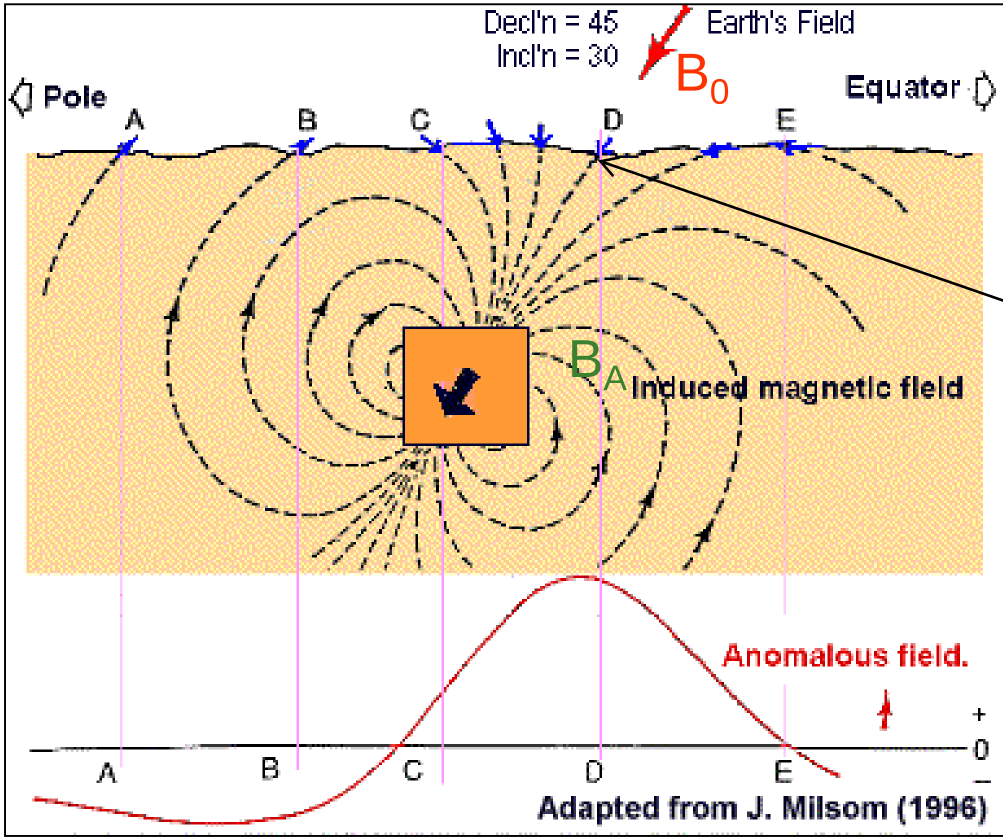
B is a vector:

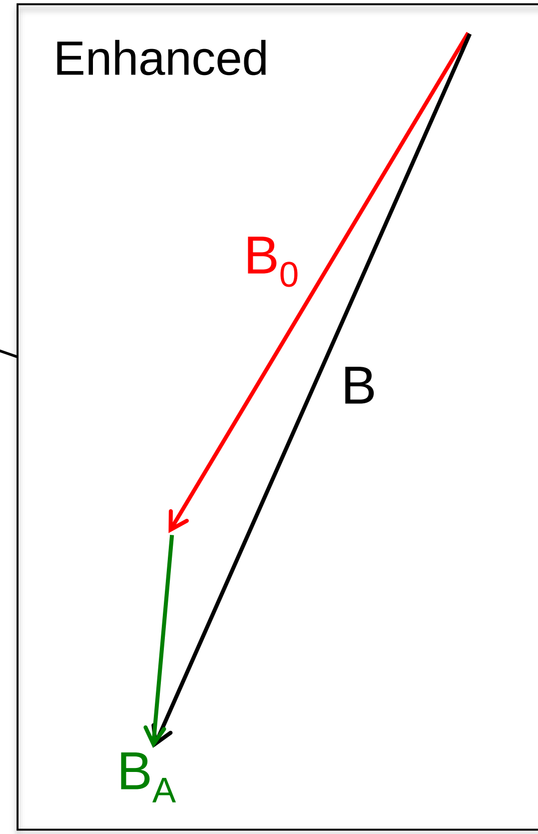
$$B = \{B_x, B_y, B_z\}$$

Total field:

$$|B| = |B_0 + B_A|$$

The composite field





Composite field:

$B = B_0 + B_A$

B is a vector:

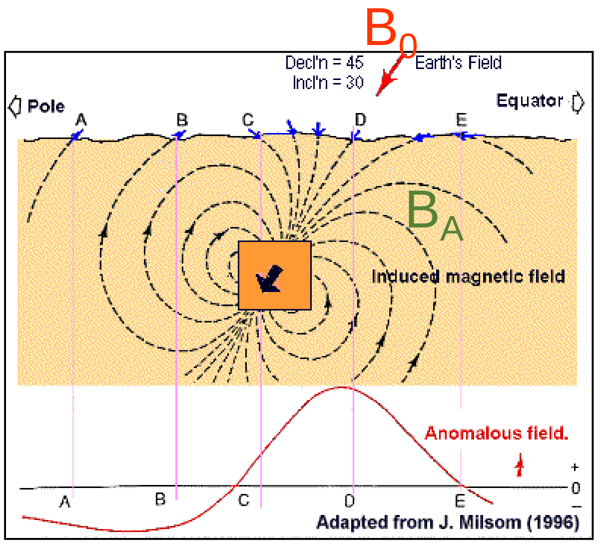
$B = \{B_x, B_y, B_z\}$

Total field:

$|B| = |B_0 + B_A|$

The anomalous field

Measured field B = $B_0 + B_A$



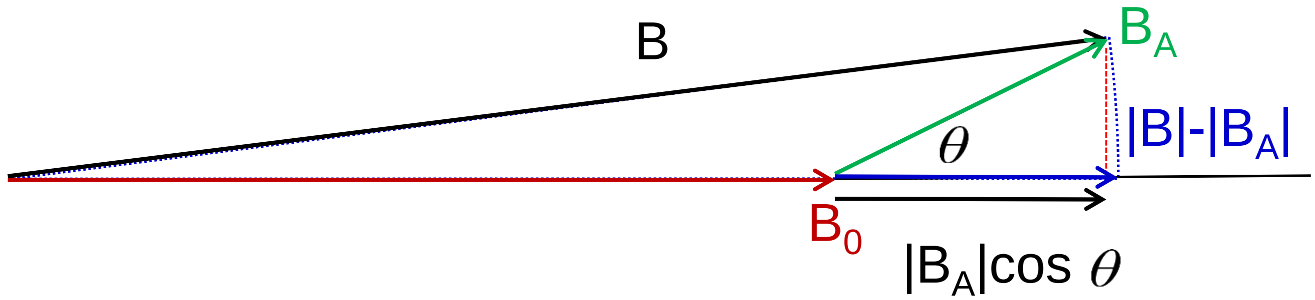
Link to GPG

- The total field anomaly: $\Delta B = |B| - |B_0|$
- If $|B_A| \ll |B_0|$ then
- That is, total field anomaly ΔB is the projection of the anomalous field onto the direction of the inducing field.

$$\triangle\vec{B} \simeq \vec{B}_A \cdot \hat{B}_0$$

Why is the total field anomaly: $\triangle\vec{B} \simeq \vec{B}_A \cdot \hat{B}_0$

- Vector Diagram

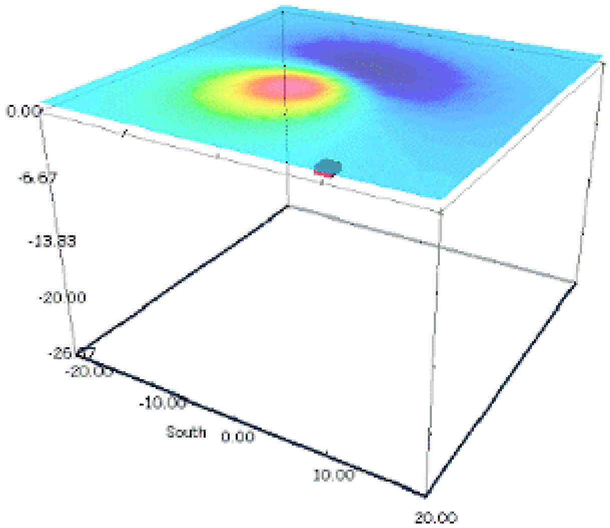


$$|\triangle\vec{B}| = |\vec{B}_0 + \vec{B}_A| - |\vec{B}_0|$$
$$\simeq \vec{B}_A \cdot \hat{B}_0$$
$$= |\vec{B}_A| cos\theta$$

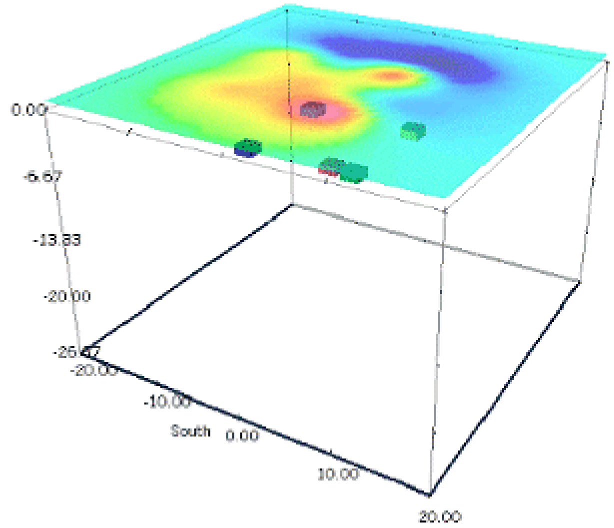
Often call this B_t: total field anomaly; also referred to as TMI data

Superposition of Magnetic Anomalies

Magnetic field for one prism
Prism own dipole-like field

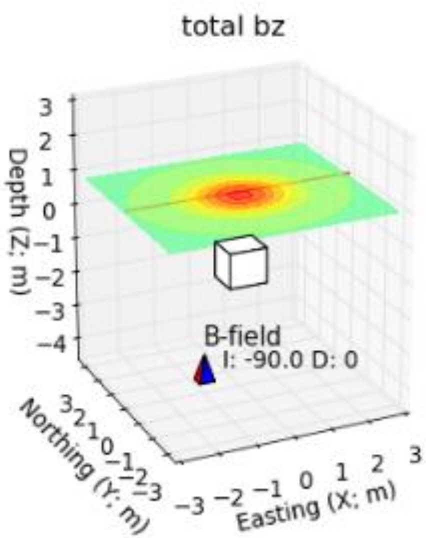


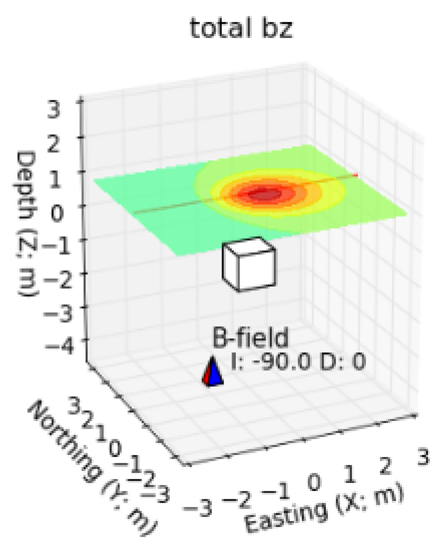
Magnetic field for 5 prisms
Superposition

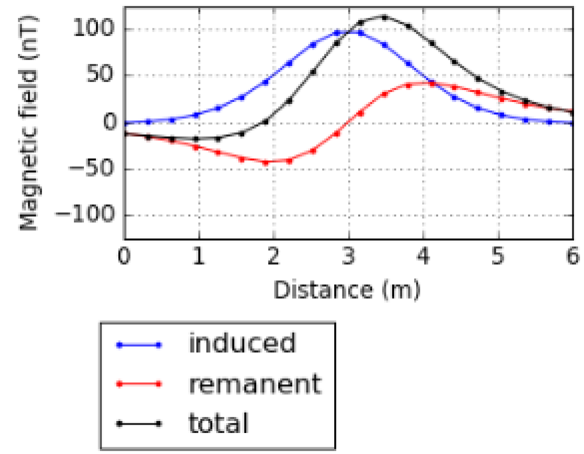


What if there is significant remanence?

No remanence **Remanence along x**





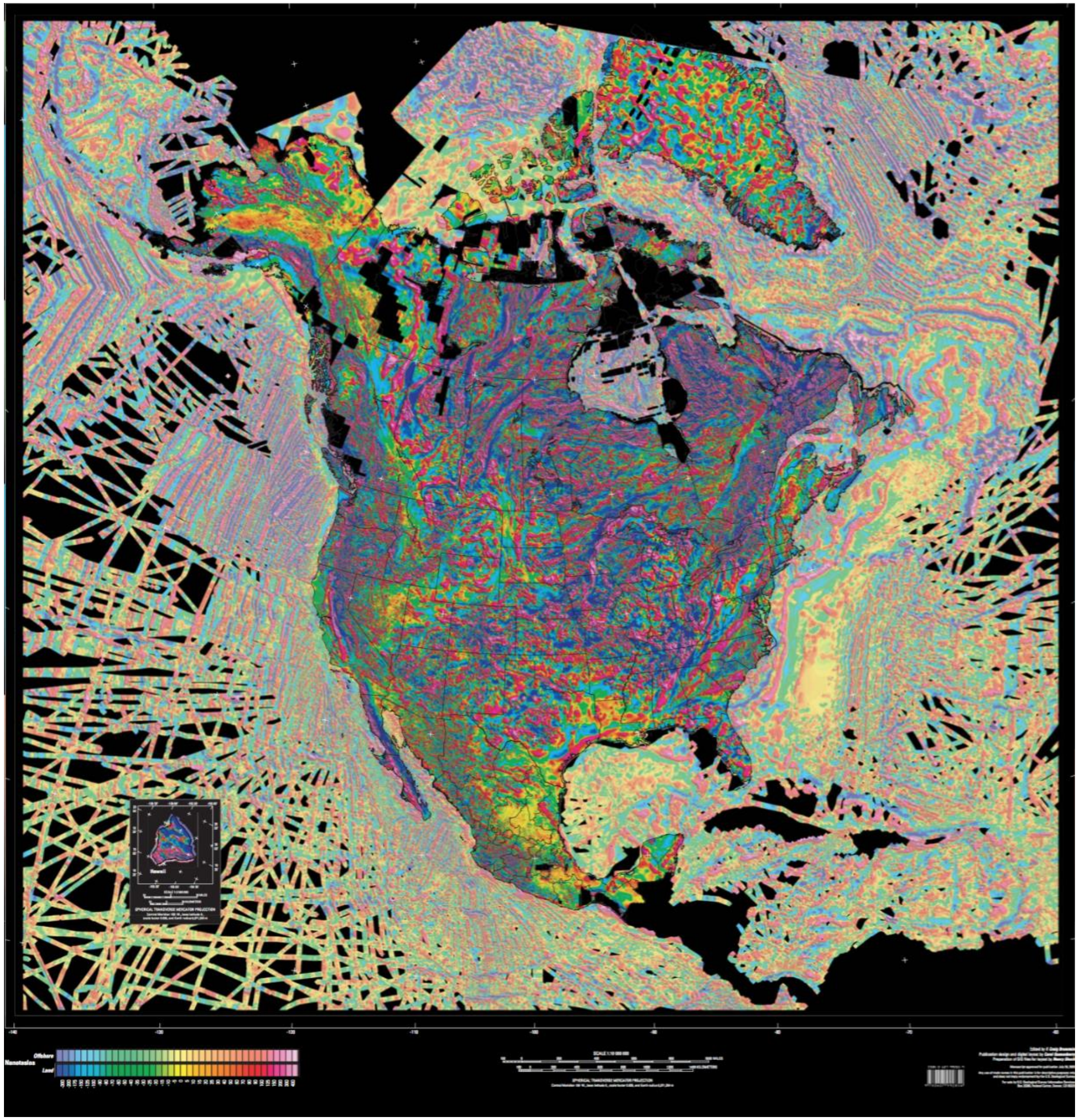


- Affects total magnetization of the block
  → Changes strength and orientation of anomalous B-field
  → Changes shape and location of TMI anomaly

- Failure to recognize and ruin interpretation

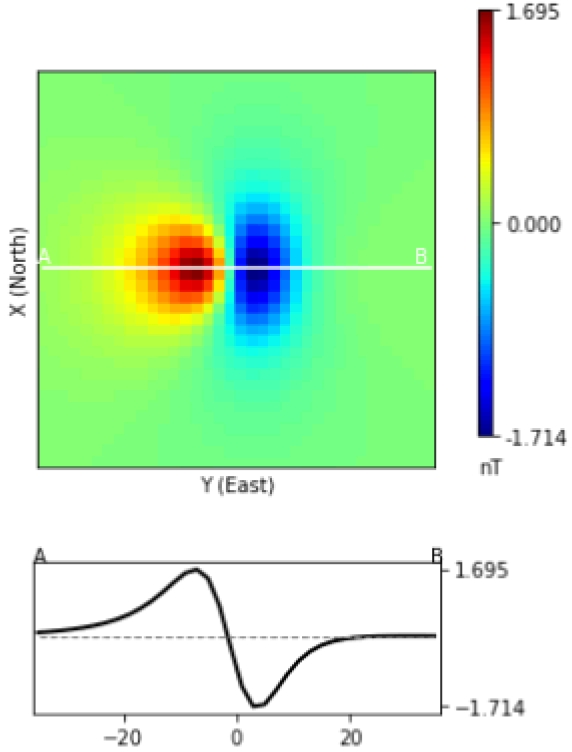
Magnetic anomaly map of North America

- http://pubs.usgs.gov/sm/mag_map/mag_s.pdf

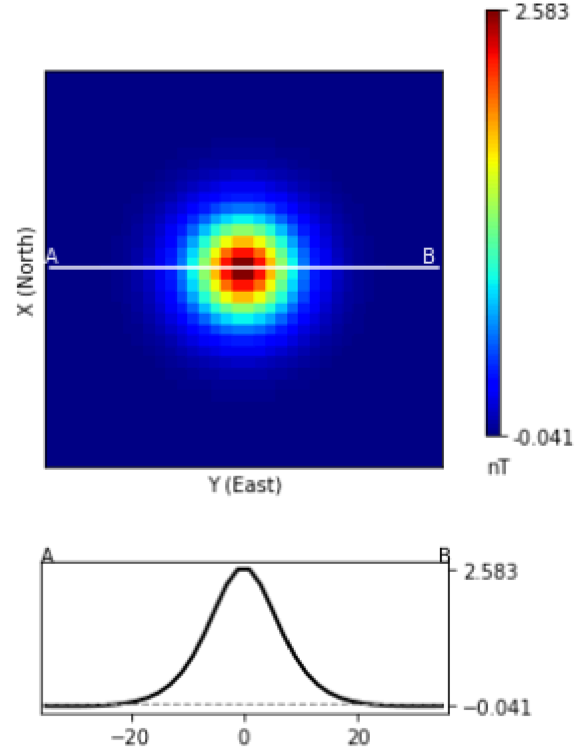


Types of anomalies

Dipole

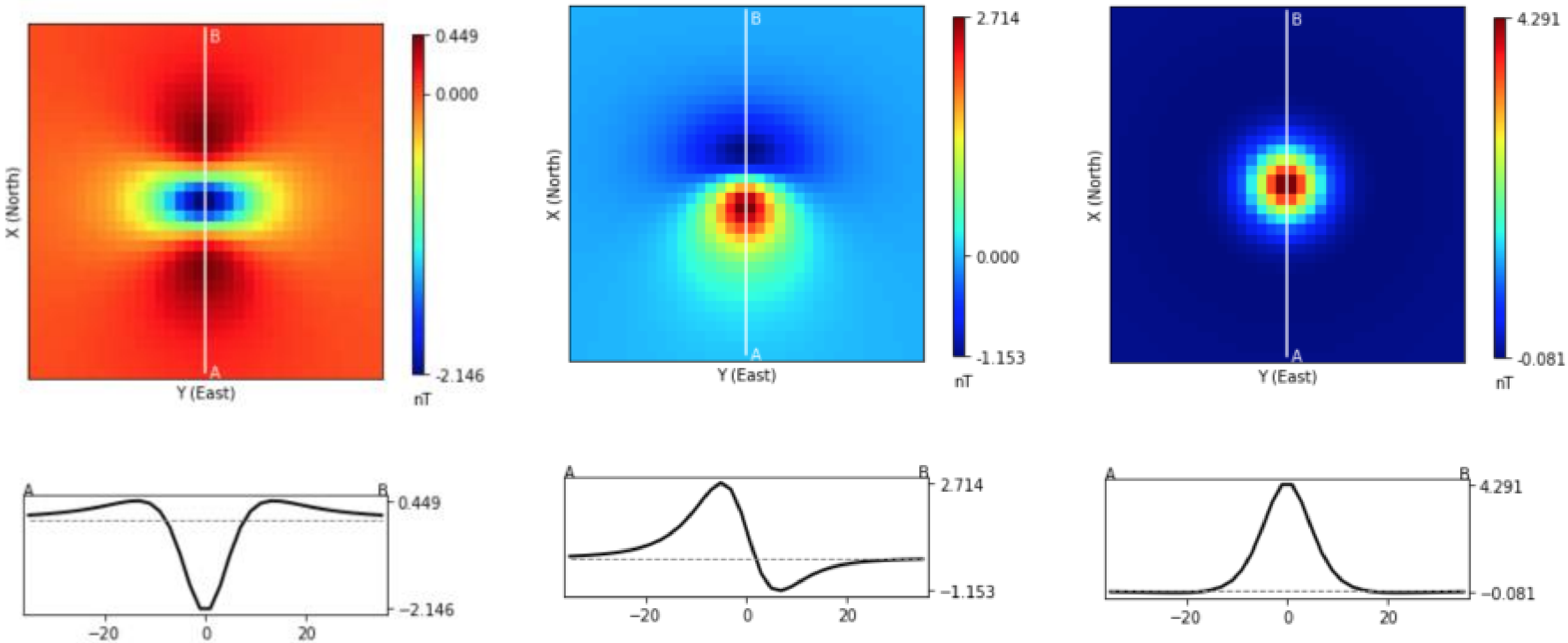


Monopole



Effects on Earth's field orientation

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



Inclination=0

Inclination=45

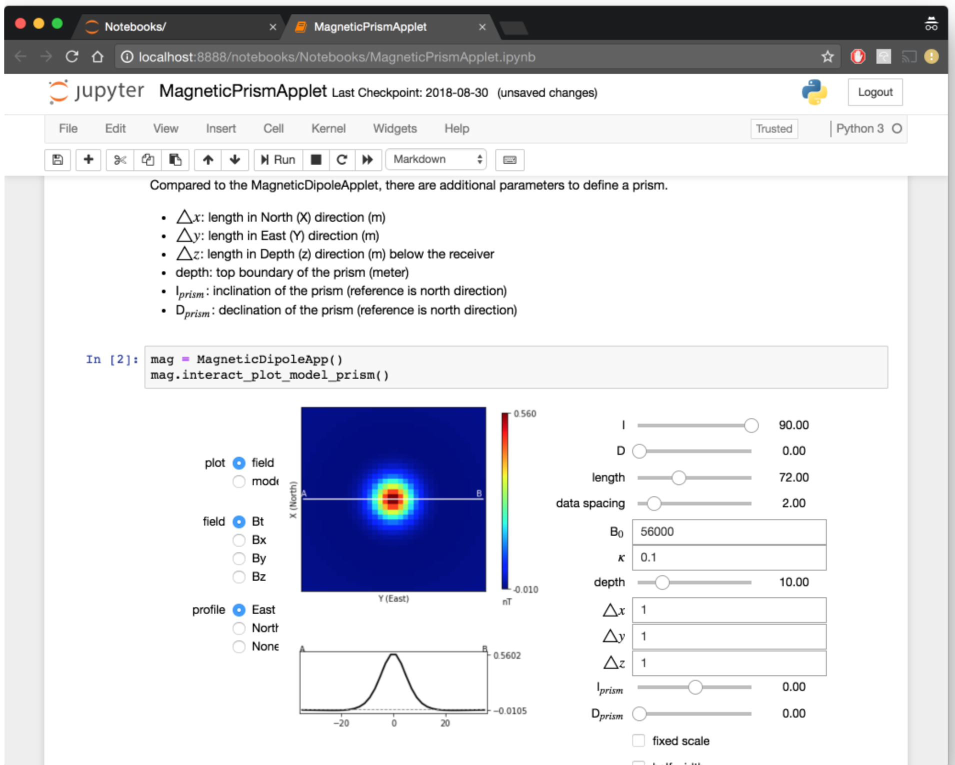
Inclination=90

Magnetic dipole app

Link to app and questions:

https://mybinder.org/v2/gh/geoscixyz/gpgLabs/master?filepath=notebooks%2FMagneticDipoleApplet.ipynb

Magnetic Prism App



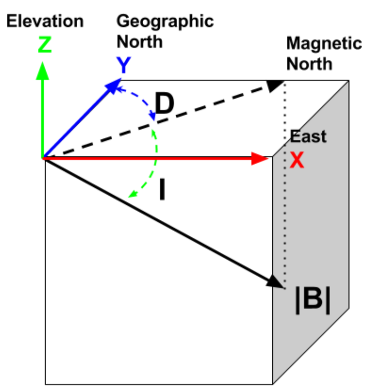
- A single prism with uniform magnetization
- Arbitrary dimensions
- Arbitrary orientation of the body
- Arbitrary strength and orientation of remanent magnetization.
- Can model cubes, rods, sheets, dykes …

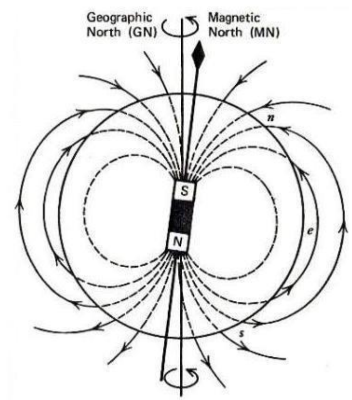
https://mybinder.org/v2/gh/geoscixyz/gpgLabs/master?filepath=notebooks%2FMagneticPrismApplet.ipynb

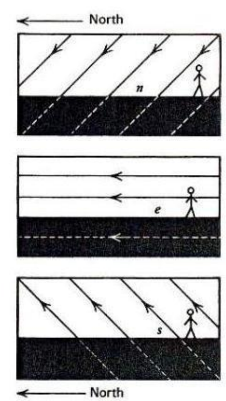
Recap

- Earth's magnetic field acts as a source

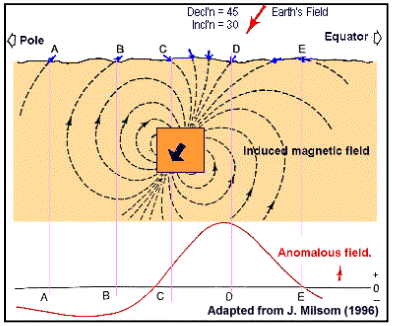
- It is defined by inclination, declination and amplitude







- The Earth's field induces magnetization in susceptible bodies



Recap

- Induces magnetization is parallel to the Earth’s field

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

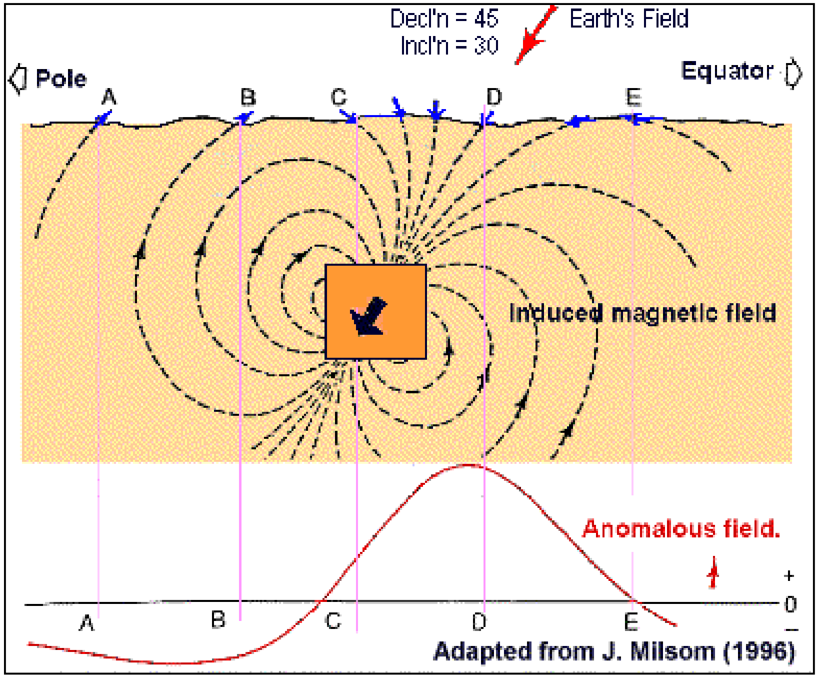
- The total magnetization is induced + remanent (if it exists)

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

- The measured field is

$$B = B_0 + B_A$$

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



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