

# *Magnetometer*

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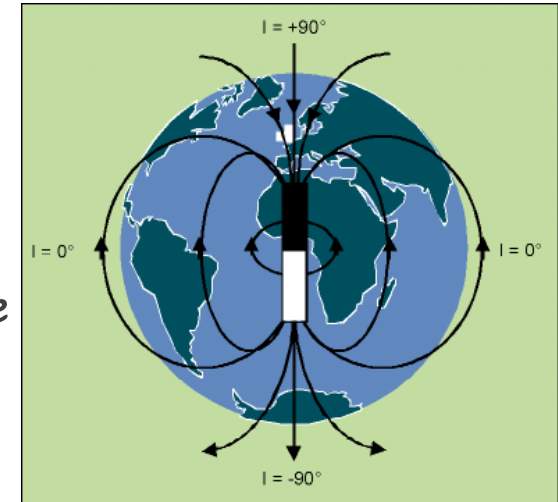
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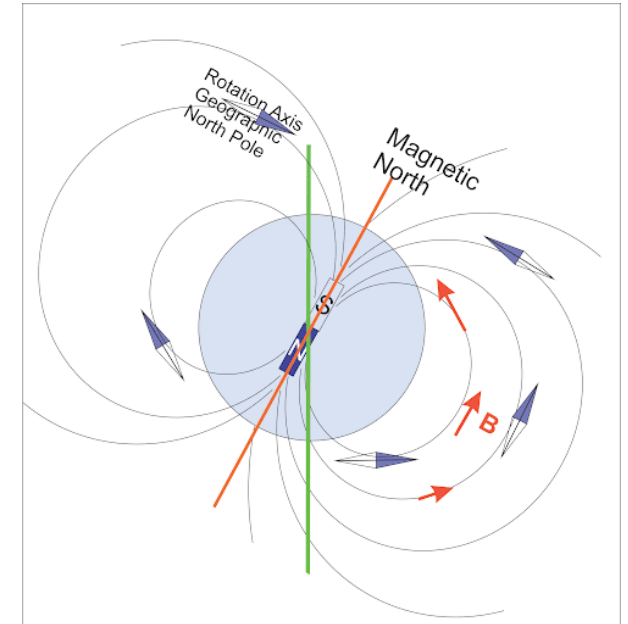
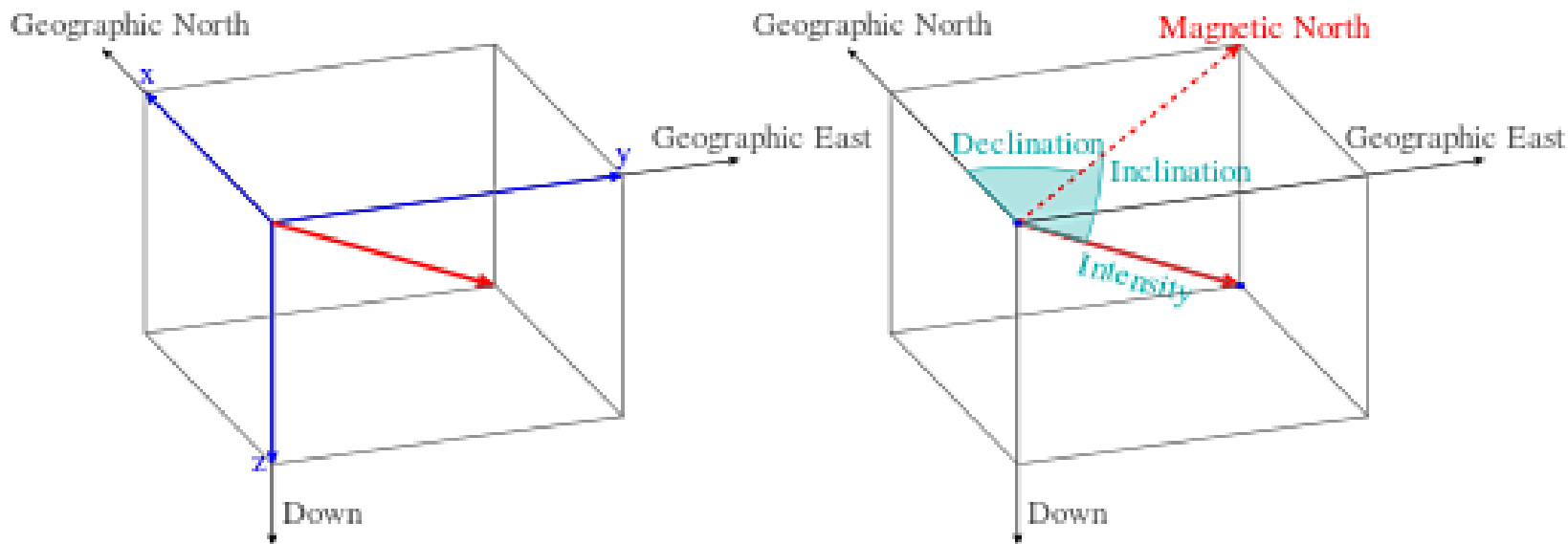
# Earth magnetic field

- Magnetic fields are **vector quantities** characterized by both strength and direction. The strength of a magnetic field is measured in unit's of (tesla).
- Measurements of the Earth's magnetic field are often quoted in units of **nanotesla (nT)**, the Earth's magnetic field can vary from 20,000 to 80,000 nT depending on location.
- Magnetometers used to study the Earth's magnetic field may express the vector components of the field in terms of **declination** (the angle between the horizontal component of the field vector and magnetic north) and the **inclination** (the angle between the field vector and the horizontal surface).
- At any location, the Earth's magnetic field can be represented by a three-dimensional vector. A typical procedure for measuring its direction is to use a compass (Magnetometer) to determine the direction of magnetic North.



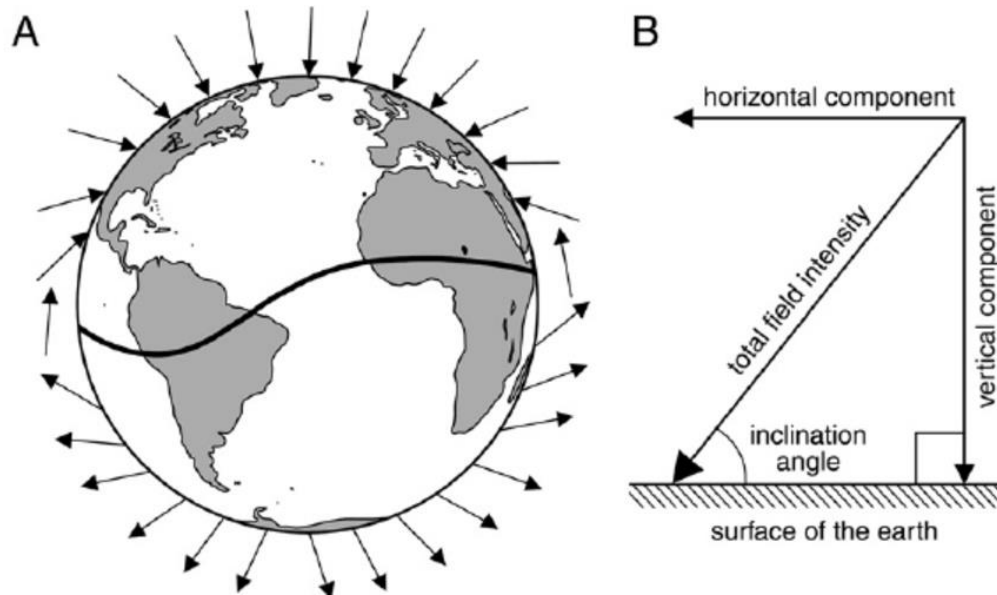
# Earth magnetic field

- Its angle relative to true North is the *declination ( $D$ )* or *variation*. Facing magnetic North, the angle the field makes with the horizontal is the *inclination ( $I$ )*.
- The *intensity ( $F$ )* of the field is proportional to the force it exerts on a magnet. Another common representation is in  $X$  (North),  $Y$  (East) and  $Z$  (Down) coordinates.



# Earth magnetic field components

- Magnetic field is calculated using the most recent [World Magnetic Model \(WMM\)](#) or the [International Geomagnetic Reference Field \(IGRF\)](#) model

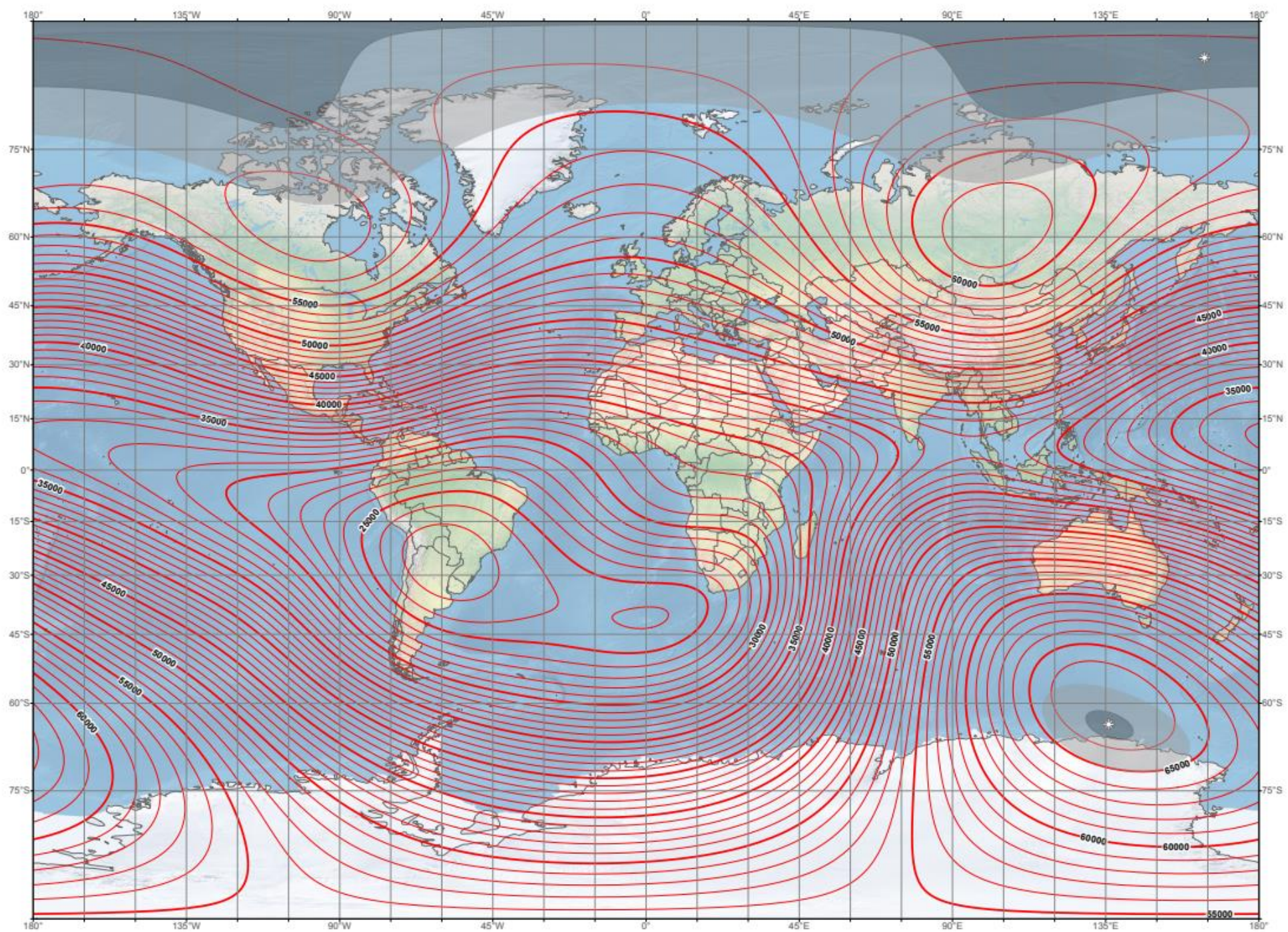


Horizontal comp = total field intensity  $\times \cos$  (inclination angle)

Vertical comp = total field intensity  $\times \sin$  (inclination angle)



[https://www.ngdc.noaa.gov/geomag/WMM/data/WMM2020/WMM2020\\_F\\_BoZ\\_MILL.pdf](https://www.ngdc.noaa.gov/geomag/WMM/data/WMM2020/WMM2020_F_BoZ_MILL.pdf)



*World  
Magnetic  
Model -  
Epoch  
2020.0  
Main Field  
Total  
Intensity  
(F)*



### Calculate Magnetic Field

Latitude:  ☐ S ☒ N

Longitude:  ☐ W ☒ E

Elevation: ☐ GPS ☒ Mean sea level

Kilometers ▼

Model: ☒ WMM (2019-2024) ☐ IGRF (1590-2024)

☐ EMM (2000-2019)

Start Date: Year  Month  Day

End Date: Year  Month  Day

Step size:

Result format: ☒ HTML ☐ XML ☐ CSV ☐ JSON

Calculate

### Lookup Latitude / Longitude

Enter a street address, street name, or street intersection. For best results, include as much location information as possible with the street address in your search, such as city, state, zip code.

Location:

Get & Add Lat / Lon

### Magnetic Field

Model Used: WMM-2020							
Latitude: 32° 3' 42" N							
Longitude: 36° 5' 5" E							
Elevation: 0.0 km Mean Sea Level							
Date	Declination ( + E   - W )	Inclination ( + D   - U )	Horizontal Intensity	North Comp ( + N   - S )	East Comp ( + E   - W )	Vertical Comp ( + D   - U )	Total Field
2020-04-05	4° 50' 36"	48° 31' 22"	29,916.7 nT	29,809.9 nT	2,525.9 nT	33,841.8 nT	45,169.4 nT
Change/year	0° 3' 42"/yr	0° 3' 34"/yr	8.8 nT/yr	6.1 nT/yr	32.8 nT/yr	80.7 nT/yr	66.3 nT/yr
Uncertainty	0° 19'	0° 13'	128 nT	131 nT	94 nT	157 nT	145 nT

Magnetic  
Field  
Calculators

# Magnetometer

A magnetometer is an instrument that measures magnetism—either magnetization of magnetic material like a ferrimagnet, or the strength and, in some cases, direction of the magnetic field at a point in space.

- There are two basic types of magnetometer measurement. Vector magnetometers measure the vector components of a magnetic field. Total field magnetometers or scalar magnetometers measure the magnitude of the vector magnetic field.



# Magnetometer applications:

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- They are used for navigational purposes in airplanes and multicopters within the IMU.
- They are used in anti-lock braking systems in vehicles.
- Magnetometers have been used in space missions for magnetic field measurements.
- Magnetometers are used for mineral exploration; it is used to search world-class deposits of gold, silver, iron copper, etc.
- They are used in many defense applications; UAVs, submarines, etc.
- Magnetometers have found usages in smart phones which have applications that serve as compasses.

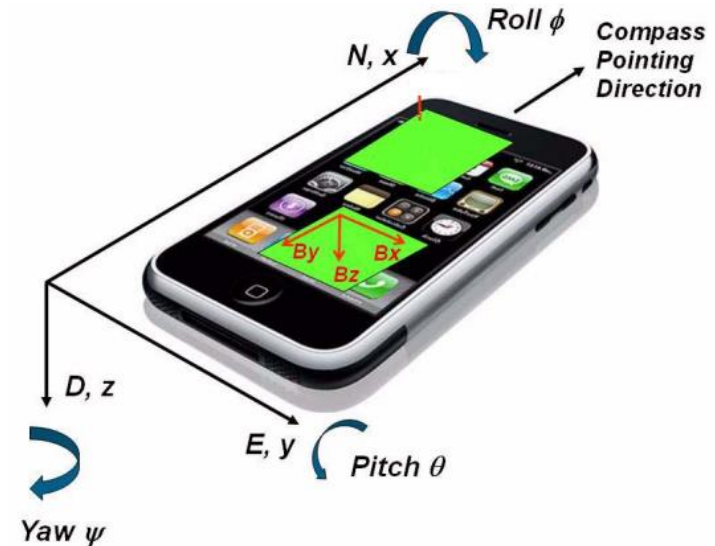
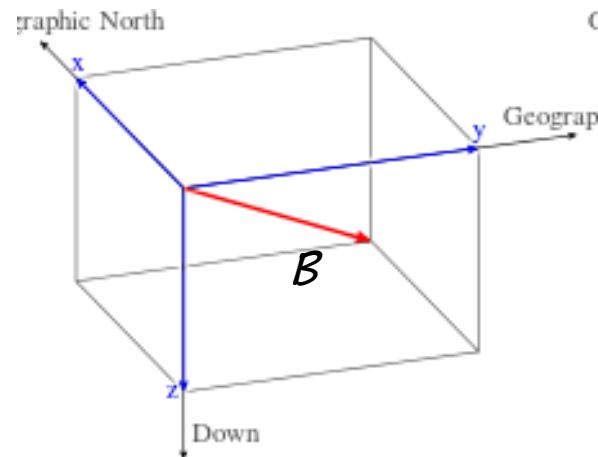


# Heading angle by a magnetometer

A three-axis magnetometer measures the components of earth's magnetic field (the geomagnetic field).

If  $B_r = \begin{bmatrix} B_{rx} \\ B_{ry} \\ B_{rz} \end{bmatrix}$  are calibrated readings of a magnetometer in  $x$ ,  $y$ , and  $z$  direction. The magnetic field vector in inertial frame can be represented by:

$$B_r = R_x(\phi)R_y(\theta)R_z(\psi)B \begin{pmatrix} \cos \delta \\ 0 \\ \sin \delta \end{pmatrix}$$



# Heading angle by a magnetometer

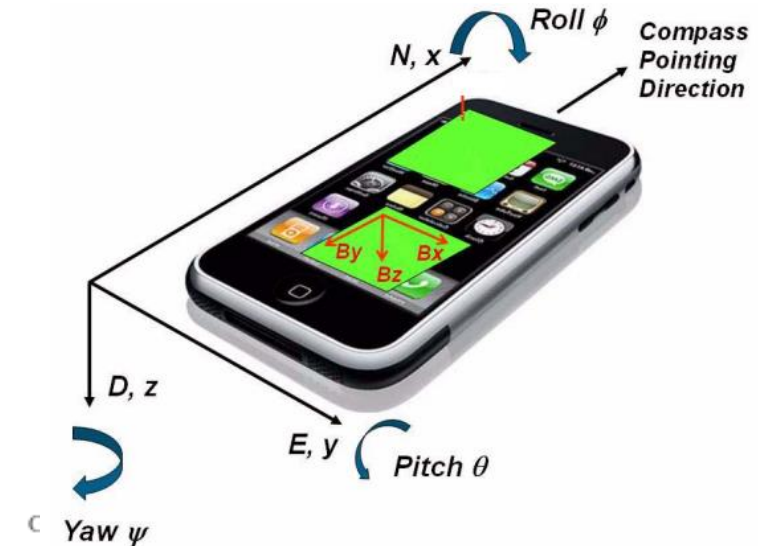
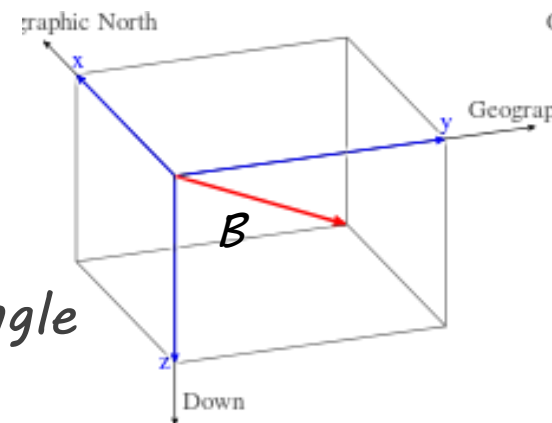
$B$  is the geomagnetic field strength which varies over the earth's surface in inertial frame, and  $R$  is the rotation matrix.

$\delta$  is the angle of inclination of the geomagnetic field measured downwards from horizontal and varies over the earth's surface (e.g.  $\delta = 48.31^\circ$  at the Hashemite university).

For Example:  $B$  vector at HU

$$B = \begin{bmatrix} 45169.4 \cos 48.31^\circ \\ 0 \\ 45169.4 \sin 48.31^\circ \end{bmatrix}$$

without considering the declination angle



# Heading angle by a magnetometer

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$$\mathbf{B}_r = \mathbf{R}_x(\phi) \mathbf{R}_y(\theta) \mathbf{R}_z(\psi) B \begin{bmatrix} \cos \delta \\ 0 \\ \sin \delta \end{bmatrix}$$

$$\begin{bmatrix} B_{rx} \\ B_{ry} \\ B_{rz} \end{bmatrix} = \begin{pmatrix} c\theta c\psi & c\theta s\psi & -s\theta \\ s\phi s\theta c\psi - c\phi s\psi & s\phi s\theta s\psi + c\phi c\psi & s\phi c\theta \\ c\phi s\theta c\psi + s\phi s\psi & c\phi s\theta s\psi - s\phi c\psi & c\phi c\theta \end{pmatrix} B \begin{bmatrix} \cos \delta \\ 0 \\ \sin \delta \end{bmatrix}$$

*If a roll angle  $\phi$  and a pitch angle  $\theta$  of a body are known, Then the tilt angle  $\psi$  from the north can be calculated using a magnetometer measurements as follow:*

$$\tan(\psi) = \frac{B_{rz} \sin \phi - B_{ry} \cos \phi}{B_{rx} \cos \theta + B_{ry} \sin \theta \sin \phi + B_{rz} \sin \theta \cos \phi} + \text{Declination Angle}$$

# Working example

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$$\tan(\psi) = \frac{B_{rz} \sin \phi - B_{ry} \cos \phi}{B_{rx} \cos \theta + B_{ry} \sin \theta \sin \phi + B_{rz} \sin \theta \cos \phi}$$

Ex: A magnetometer mounted on a rigid body, at moment its readings are  $\begin{bmatrix} 29,762 \\ 2,399 \\ 33,606 \end{bmatrix}$  nT. If  $\phi = \theta = 0$ , calculate yaw angle  $\psi$ .

- Solution:

- $\tan \psi = \frac{0 - 2399 \cos 0}{29762 \cos 0} = -4.6^\circ$