Lecture 4

- Things we might want to know about the geomagnetic field
- Components of the geomagnetic field
- The geomagnetic reference field
- All sorts of magnetic poles
- observables

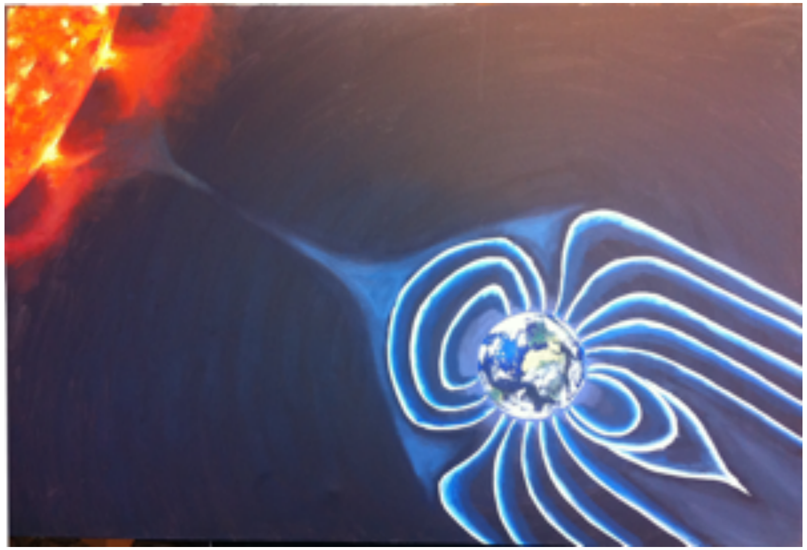
Things we might want to know

- Where does the field come from?

- How long has it existed?

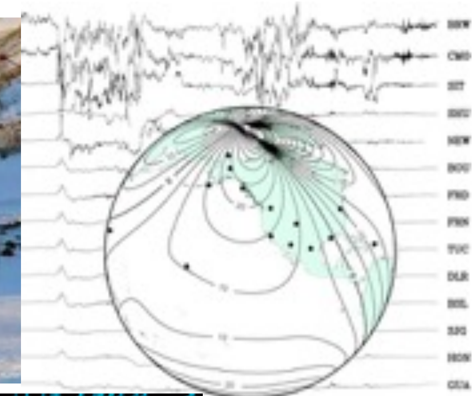
- What is its average strength and how does it vary?

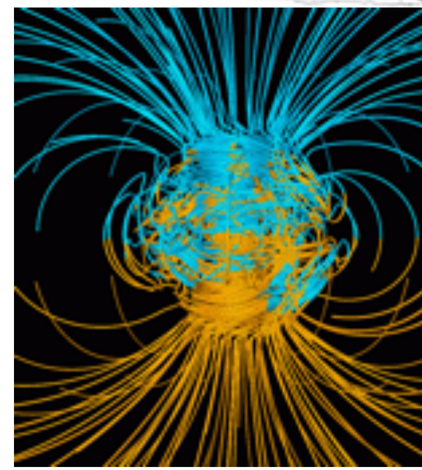
- What can it tell us about processes in the deep Earth?



How can we study the magnetic field?

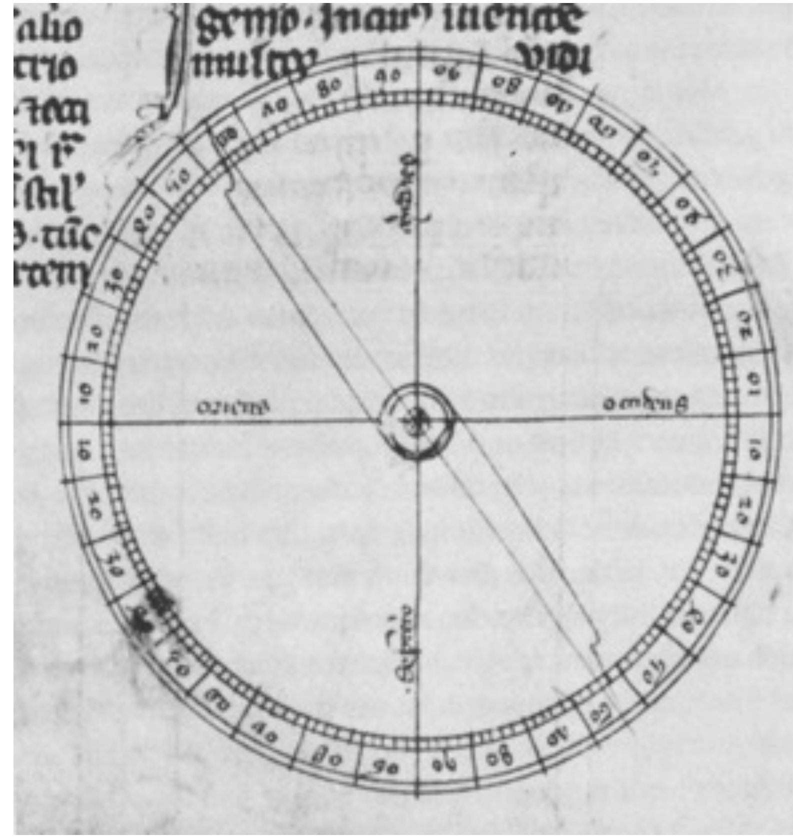
- Direct observations (satellites, ground based observatories, other human measurements [captain's logs…])
- Numerical simulation (e.g., Glatzmaier & Roberts, 1995) and laboratory dynamos (e.g., Aurnou and friends)
- Indirect records (archaeological and geological)



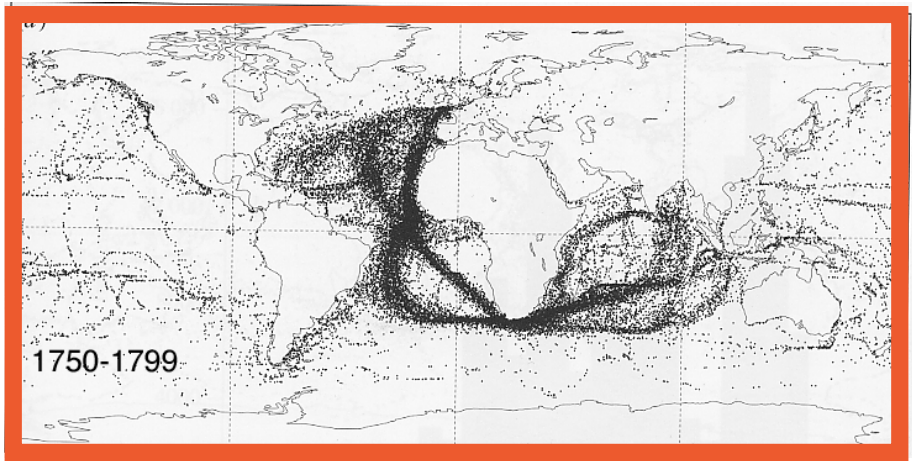


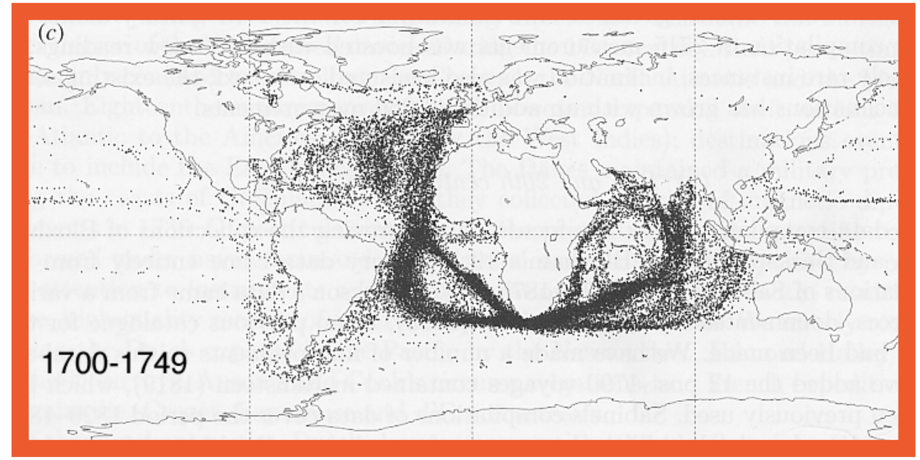
1st century CE????

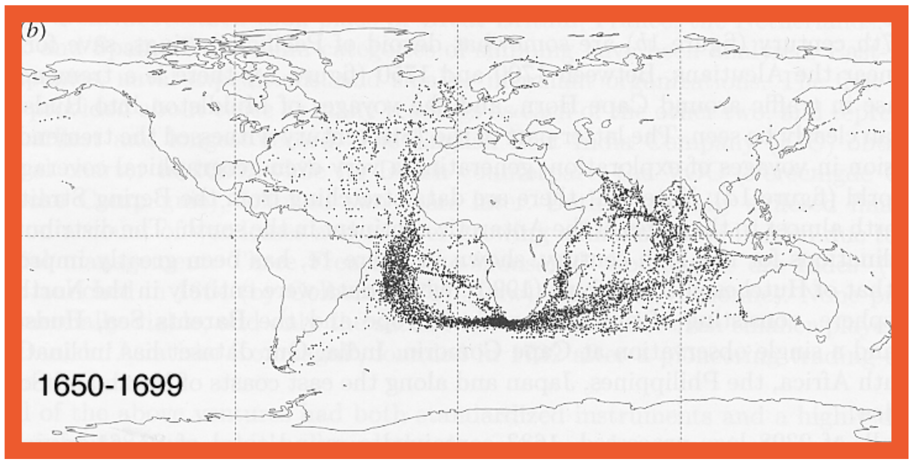
Perigrinus 1269 CE

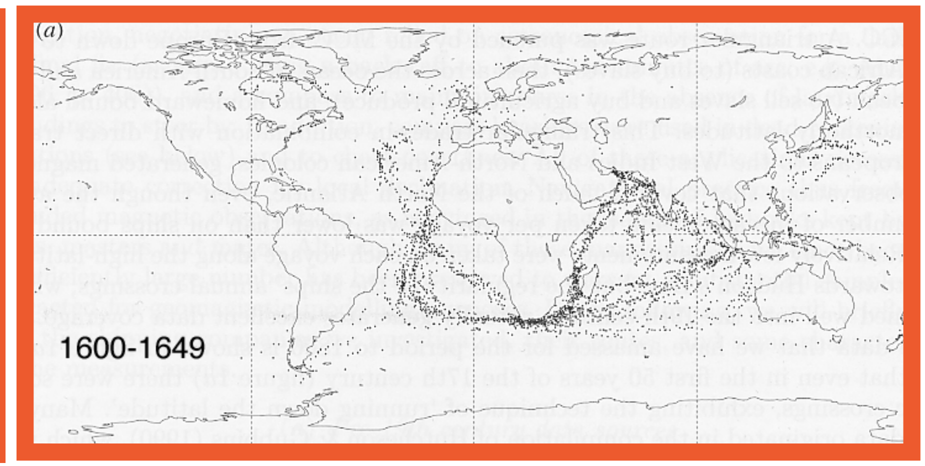


Direct observations go back a long way!


1750-1799


(c)
1700-1749


(b)
1650-1699


(a)
1600-1649

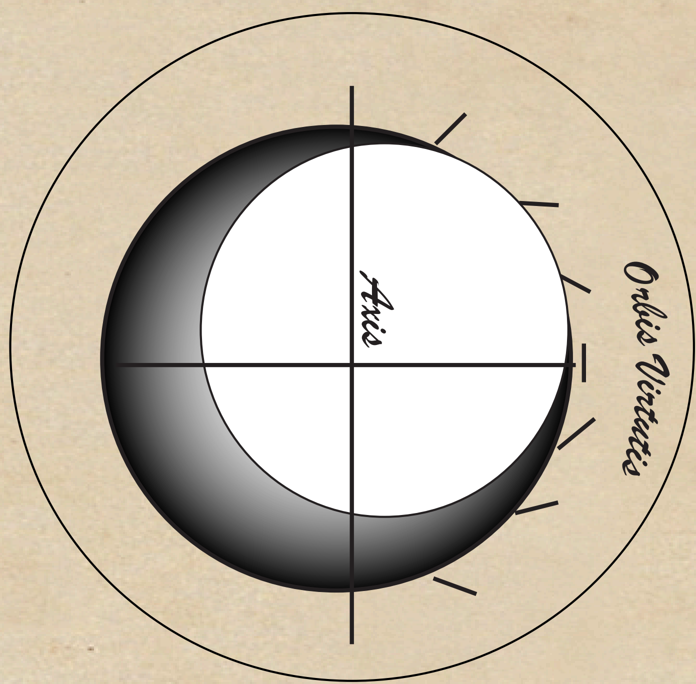
Gilbert (1544- 1603)

Physician to Queen Elizabeth

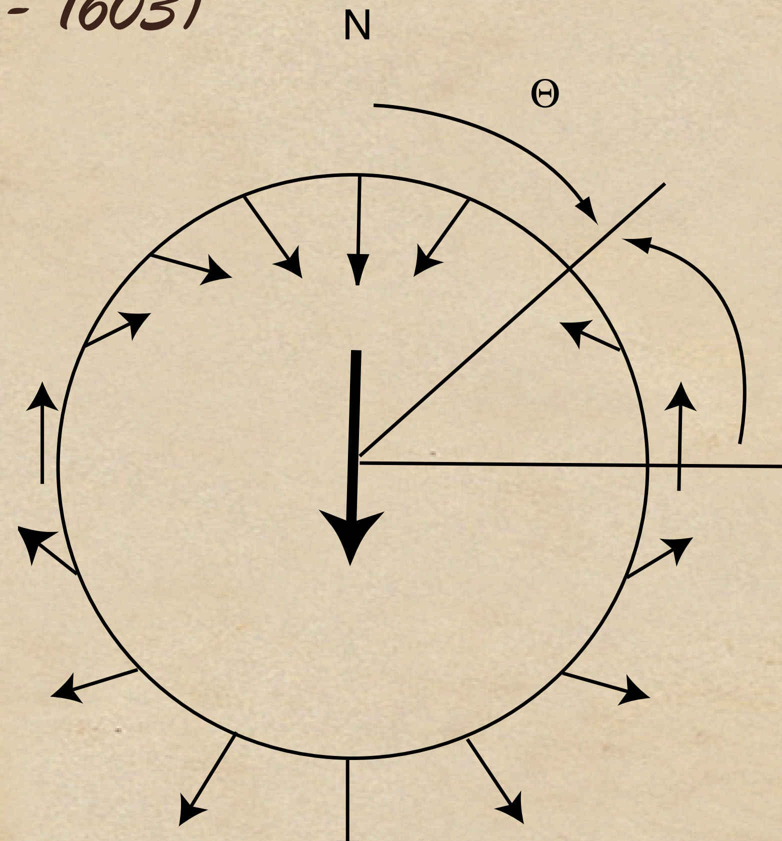
Studied magnetism of the earth and magnetic materials

Studies of a lodestone ball or "terrella"

Gilbert (1544- 1603)



The field of a magnetic dipole



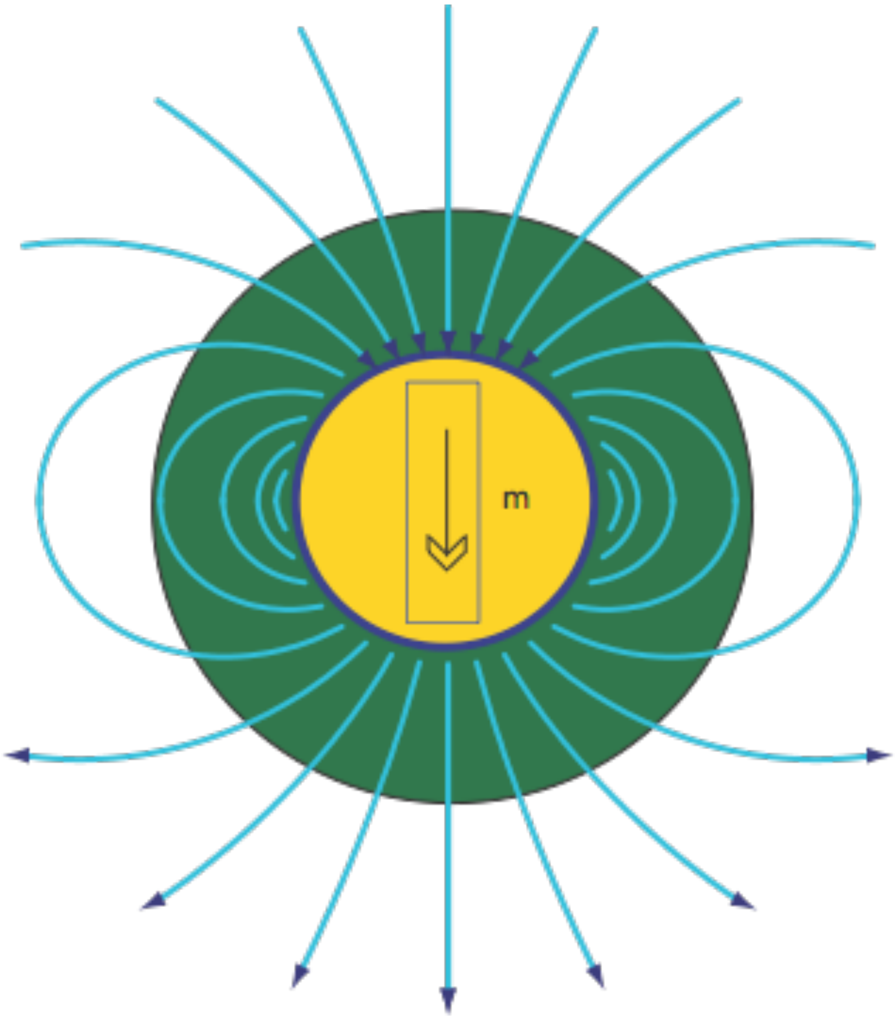
The Earth itself is a great magnet!

"We may see how far from unproductive magnetick philosophy is, how agreeable, how helpful, how divine! Sailors when tossed about on the waves with continuous cloudy weather, and unable by means of the celestial luminaries to learn anything about the place or the region in which they are, with a very slight effort and with a small instrument are comforted, and learn the latitude of the place."

Gilbert 1600

Uses of the “bar magnet” hypothesis

- Sailors can “learn their latitudes” (not very accurately) by measuring dip of the field.
- Geologists can “learn the latitude” of rocks at their birth and track the movements of the continents through time.
- example is: shallow dip in sea-level glacial deposits used to support “snow ball earth” hypothesis.



Geocentric Axial Dipole (GAD); D=0

The intensity of the field is twice as strong in the polar than in the equator

The inclination varies as a function of latitude from 0- at equator to vertical at poles

Lecture 4

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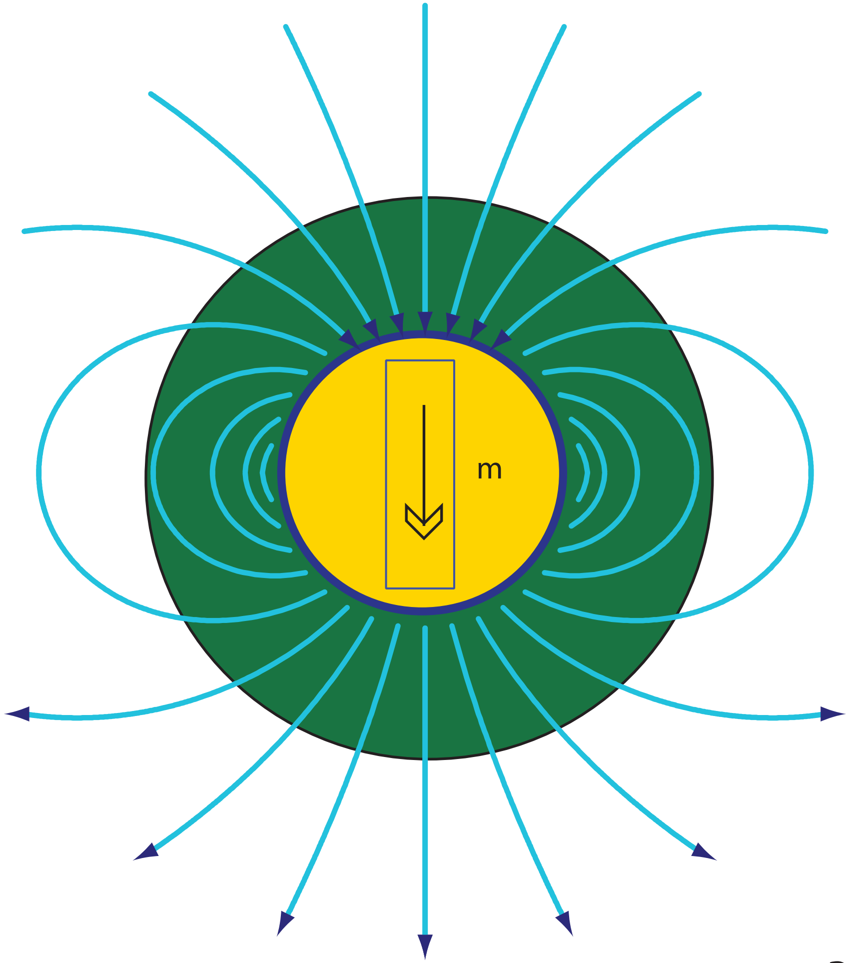
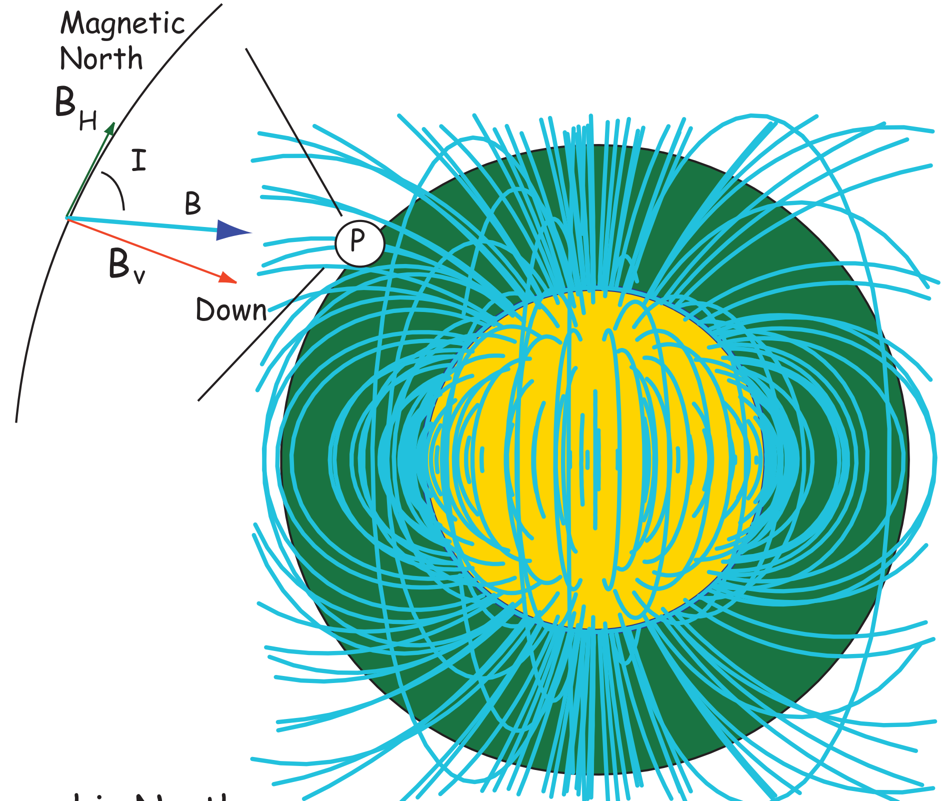
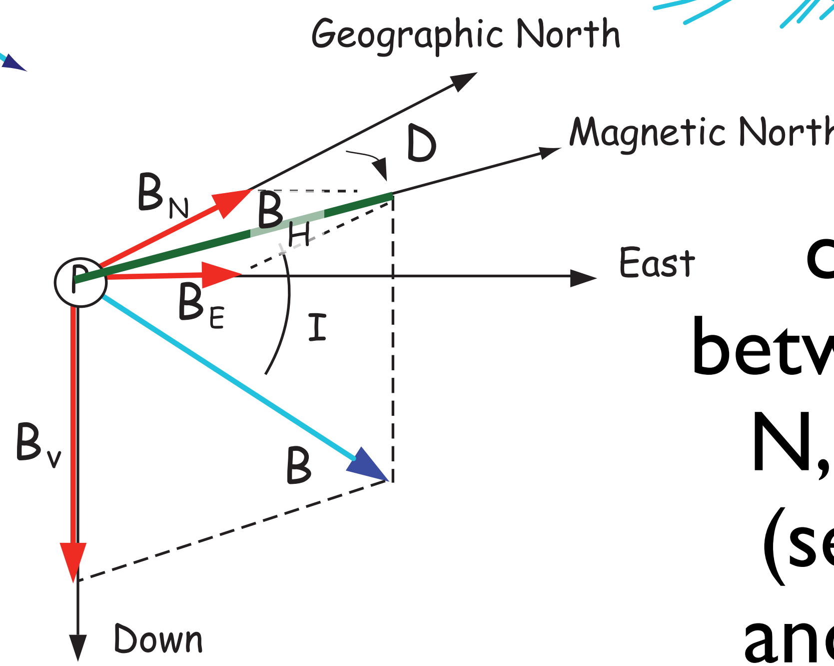
But the field is more complicated than that







can convert between D,I B and N,E,V with trig (see Lecture 3 and Chapter 2)

Recall from the last lecture:

A magnetic field (**H**) is the gradient of a magnetic potential:

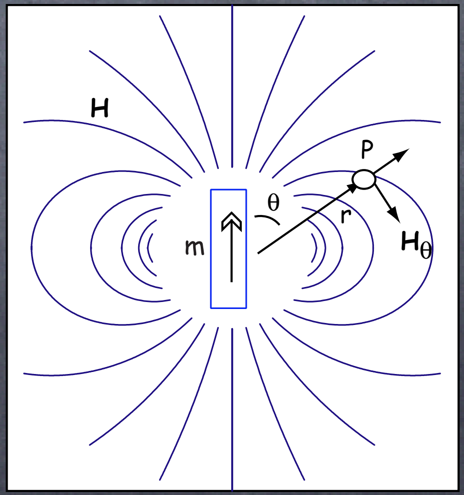
$$\mathbf{H} = -\nabla \psi_m$$

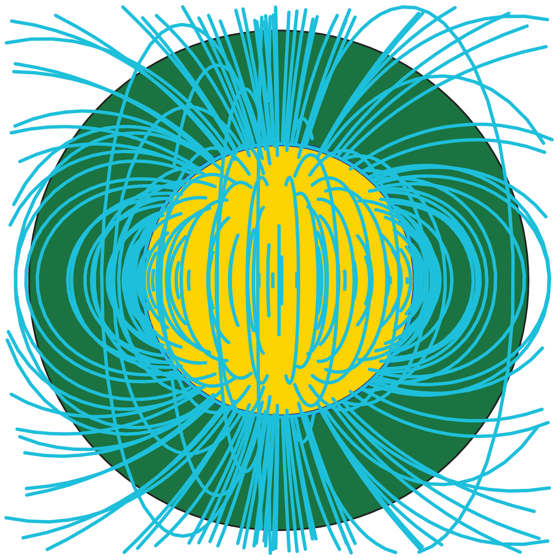
simplest case: $$\psi_m = \frac{\mathbf{m} \cdot \mathbf{r}}{4\pi r^3} = \frac{m \cos\theta}{4\pi r^2}$$

So, knowing m, we can evaluate **H** anywhere and vice versa

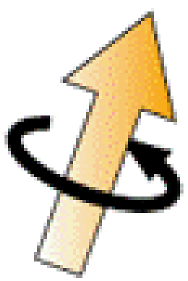
$$H_r = -\frac{\partial \psi_m}{\partial r} = \frac{1}{4\pi} \frac{2m\cos\theta}{r^3}$$

$$H_\theta = -\frac{1}{r}\frac{\partial \psi_m}{\partial \theta} = \frac{m \sin\theta}{4\pi r^3}$$

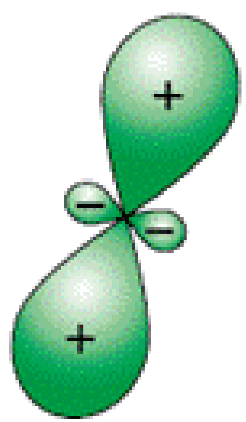




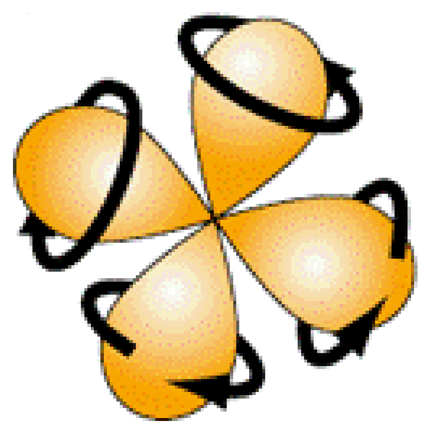
The “real” field is sum of dipole plus a lot of more complicated fields:



dipole



quadrupole



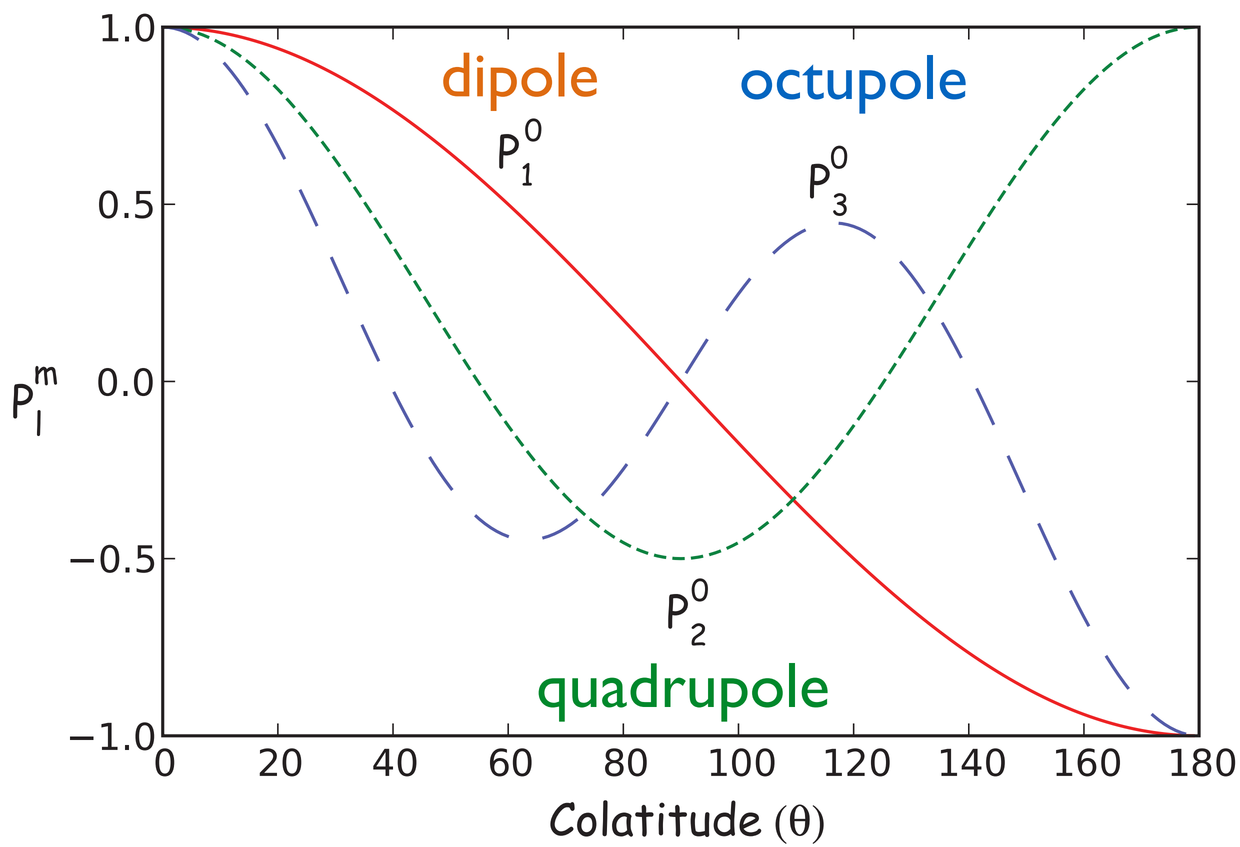
octupole

dipole potential: $$\psi_m = \frac{\mathbf{m}\cdot\mathbf{r}}{4\pi r^3} = \frac{m\cos\theta}{4\pi r^2}$$

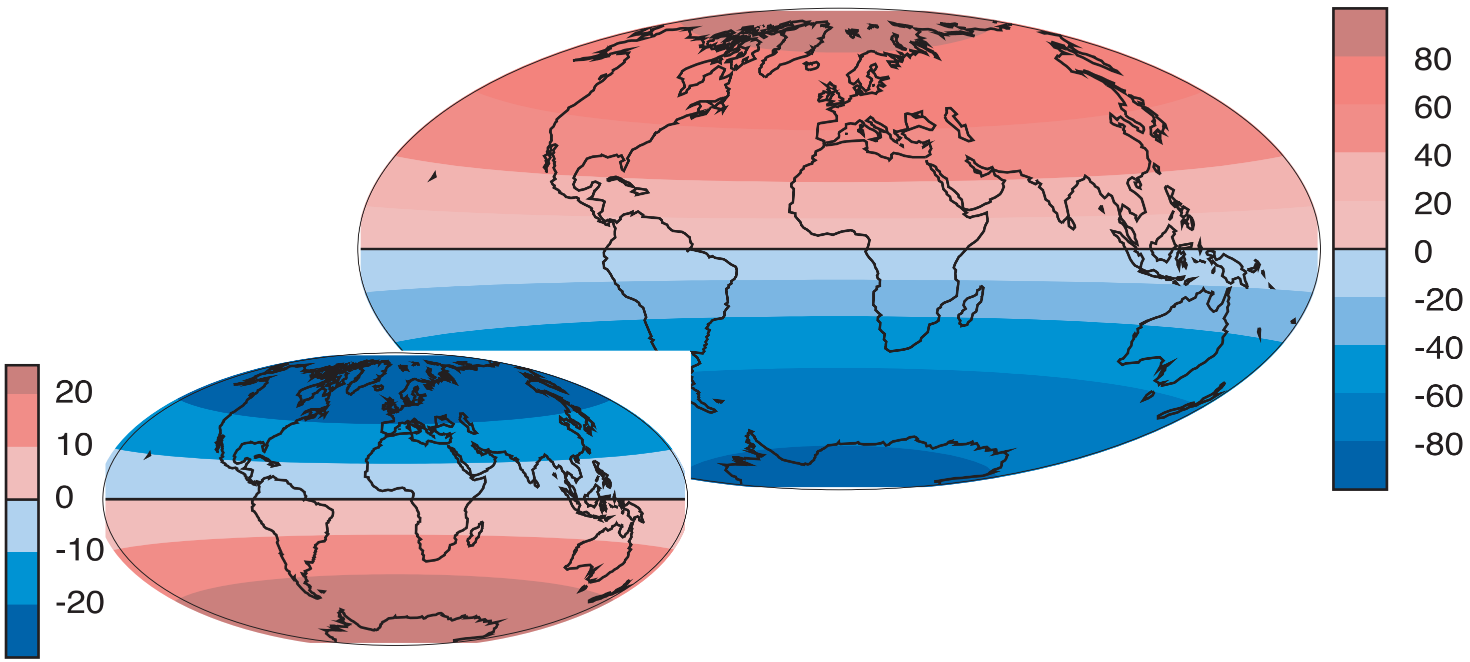
more general case:

$$\psi_m(r,\theta,\phi) = \frac{a}{\mu_o}\sum_{l=1}^{\infty}\sum_{m=0}^{l}\left(\frac{a}{r}\right)^{l+1} P_l^m(\cos\theta)\left(g_l^m\cos m\phi + h_l^m \sin m\phi\right)$$

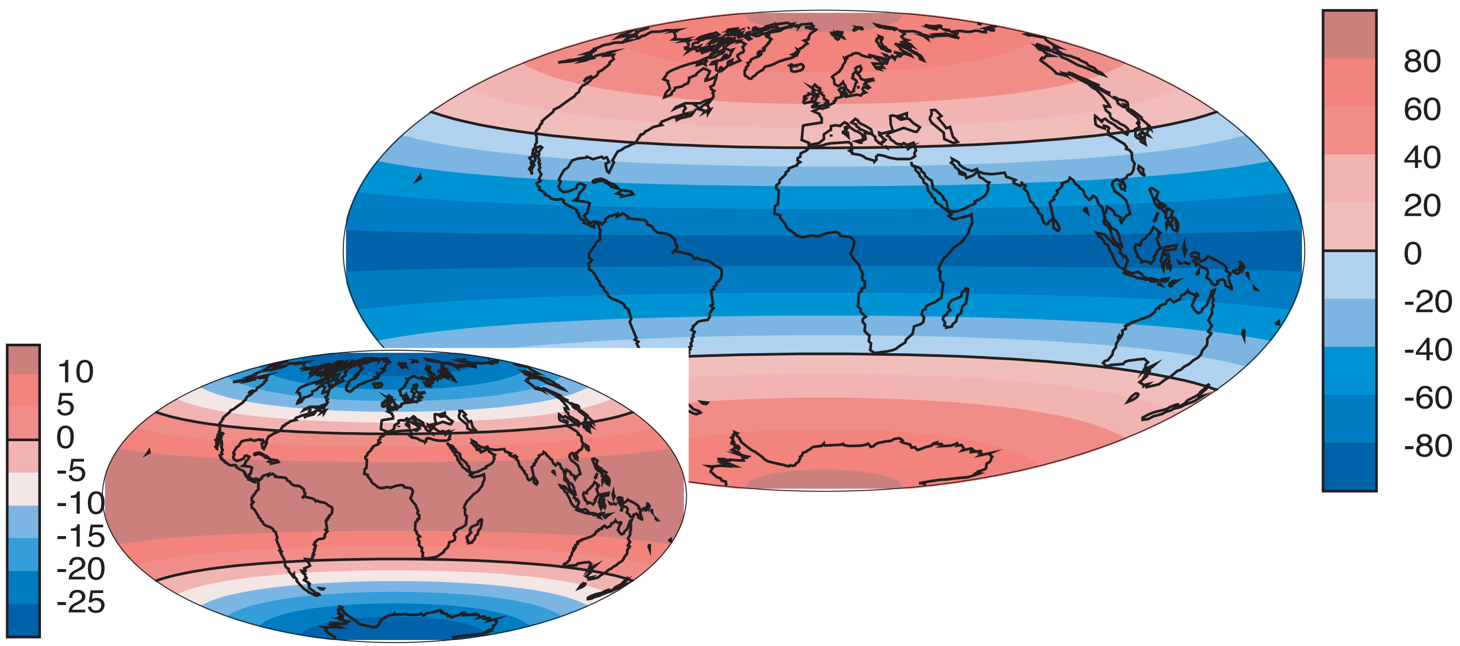
$$P_1^0 = \cos\theta,\ P_2^0 = \frac{1}{2}(3\cos^2\theta - 1),\ \text{and}\ P_3^0 = \frac{1}{2}\cos\theta(5\cos^3\theta - 3\cos\theta)$$



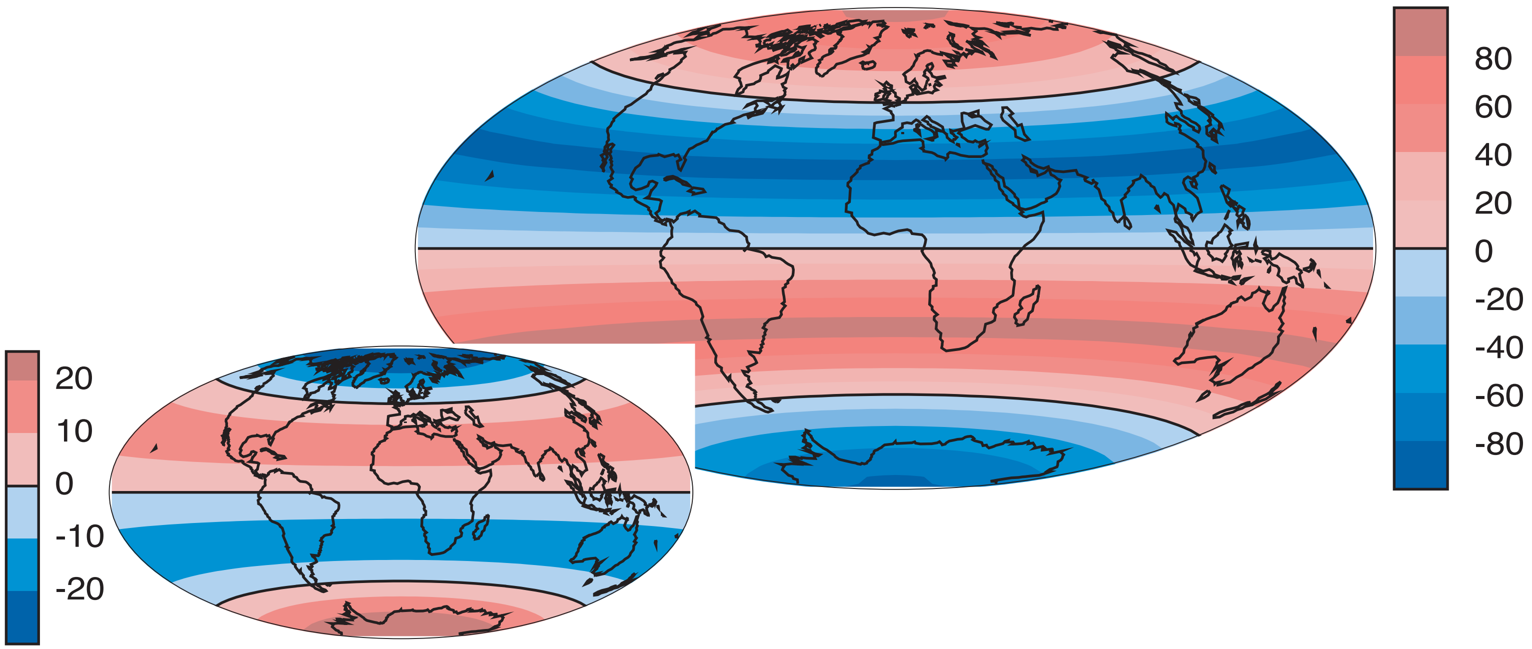
Dipolar field and potential



Quadrupolar field and potential



Octupolar field and potential



Geomagnetic potential:

$$\psi_m(r,\theta,\phi) = \frac{a}{\mu_o}\sum_{l=1}^{\infty}\sum_{m=0}^{l}\left(\frac{a}{r}\right)^{l+1} P_l^m(\cos\theta)\left(g_l^m\cos m\phi + h_l^m \sin m\phi\right)$$

So, we need a whole list of numbers g_l^m and h_l^m

(International Geomagnetic Reference Fields - IGRF)

These are best-fits from the observations for a given year.

These lists allow us to predict the geomagnetic field vector at any point outside the core

Lecture 4

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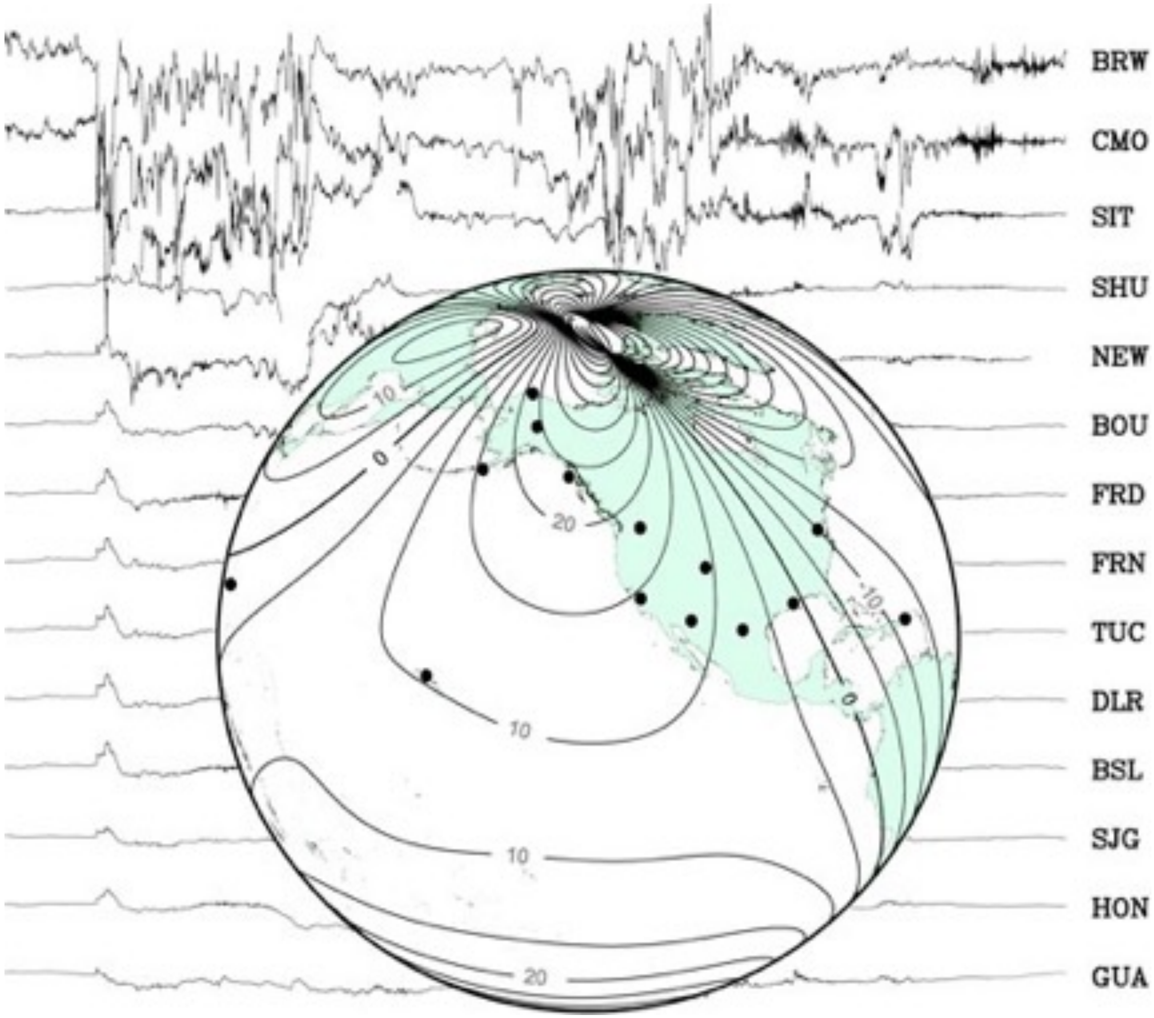
Getting a reference field model

- Make a bunch of measurements of the geomagnetic field vector all over the world
- Find the best-fit coefficients to a special equation (the geomagnetic potential equation)
- These coefficients are the international geomagnetic reference field
- Can calculate the geomagnetic field vector ANYWHERE outside the source (the core)

geomagnetic observatories and satellites



Observatories since 1800s; IGRFs since 1900

TABLE 2.1: IGRF, 10TH GENERATION (2005) TO $l = 6$.

l	m	g (nT)	h (nT)	l	m	g (nT)	h (nT)
1	0	−29556.8	0	5	0	−227.6	0
1	1	−1671.8	5080	5	1	354.4	42.7
2	0	−2340.5	0	5	2	208.8	179.8
2	1	3047	−2594.9	5	3	−136.6	−123
2	2	1656.9	−516.7	5	4	−168.3	−19.5
3	0	1335.7	0	5	5	−14.1	103.6
3	1	−2305.3	−200.4	6	0	72.9	0
3	2	1246.8	269.3	6	1	69.6	−20.2
3	3	674.4	−524.5	6	2	76.6	54.7
4	0	919.8	0	6	3	−151.1	63.7
4	1	798.2	281.4	6	4	−15	−63.4
4	2	211.5	−225.8	6	5	14.7	0
4	3	−379.5	145.7	6	6	−86.4	50.3
4	4	100.2	−304.7				

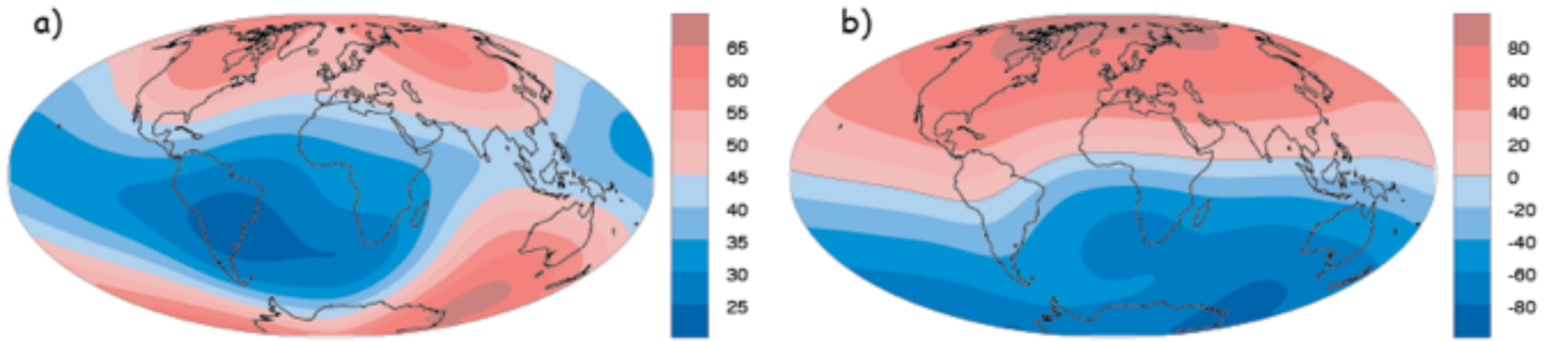
current version is IGRF-12

Thebault et al. (2015): dx.doi.org/10.1186/s40623-015-0228-9

online calculator: http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html

B

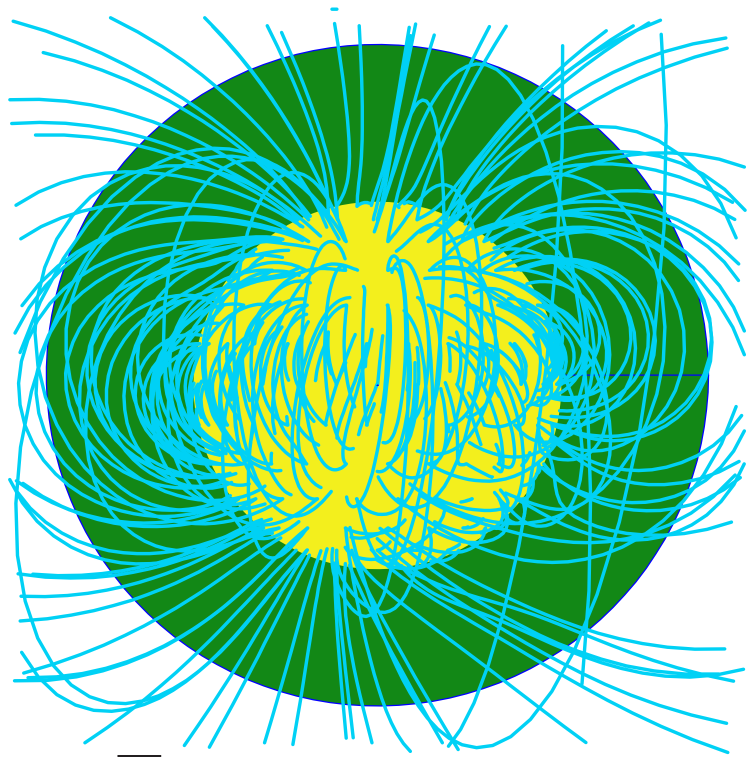
Inc



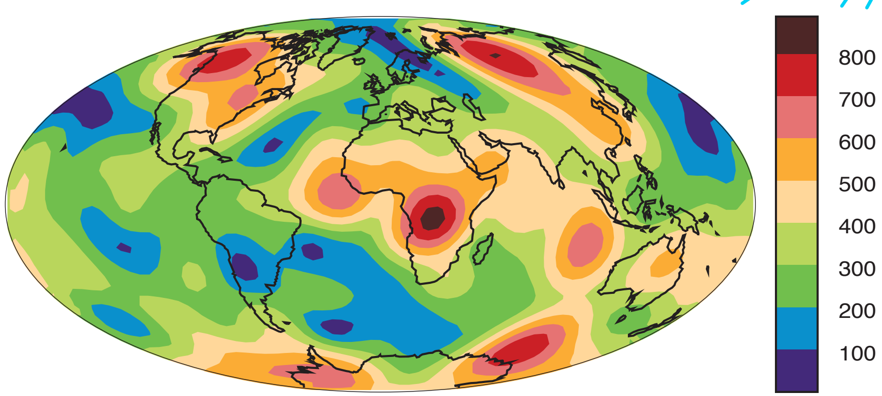
Still has increase in B towards the pole and change in inc with latitude, but more complicated

90% dipolar though!

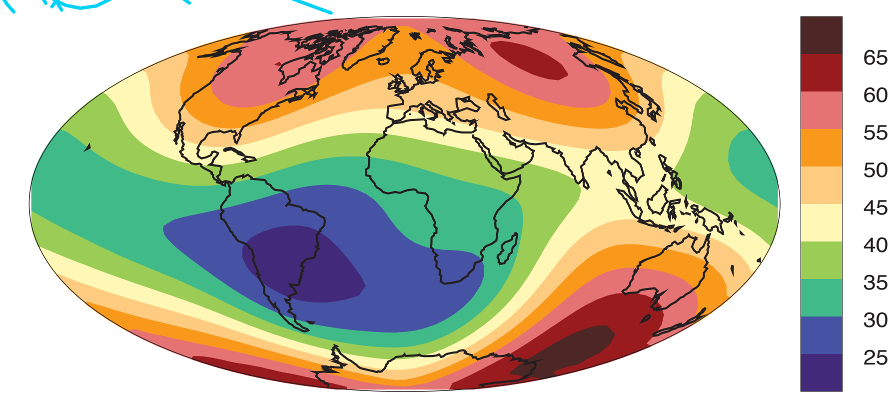
Different projections of the same thing - IGRF 2005



Magnetic field lines



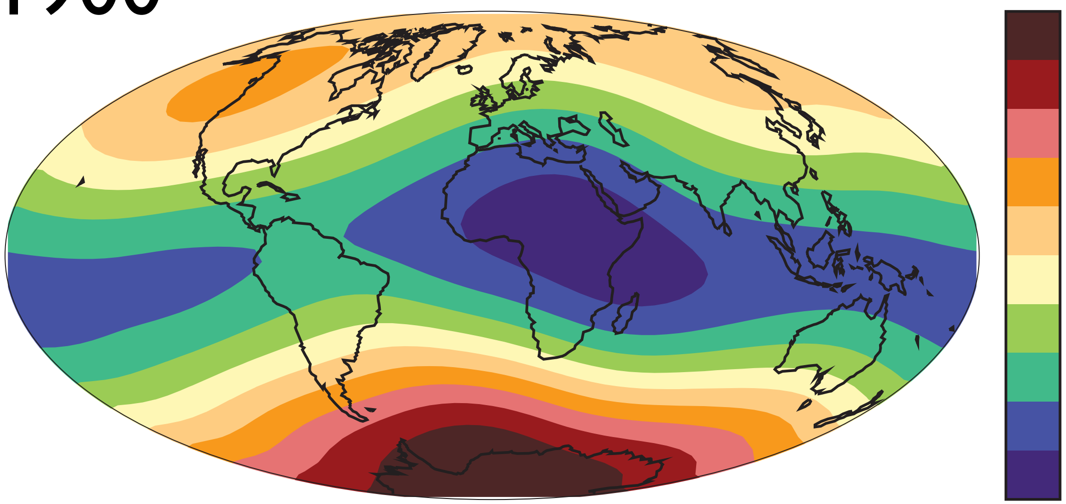
strength at the CMB



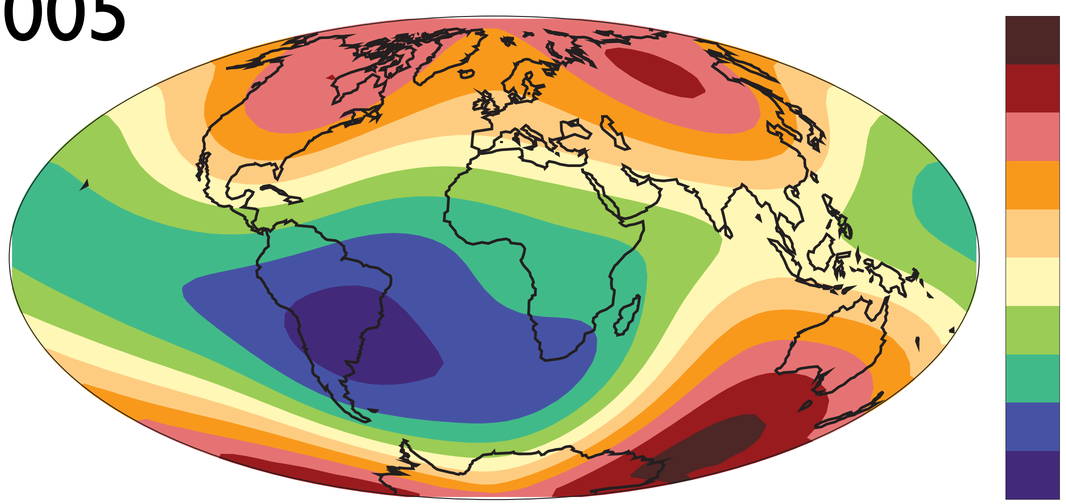
strength at the surface

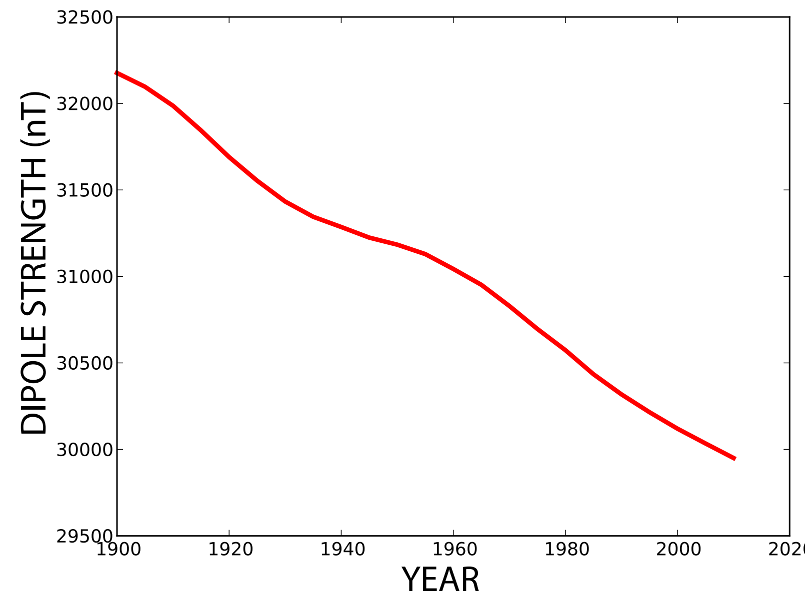
Secular variation

1900



2005





8% drop over last century

Lecture 4

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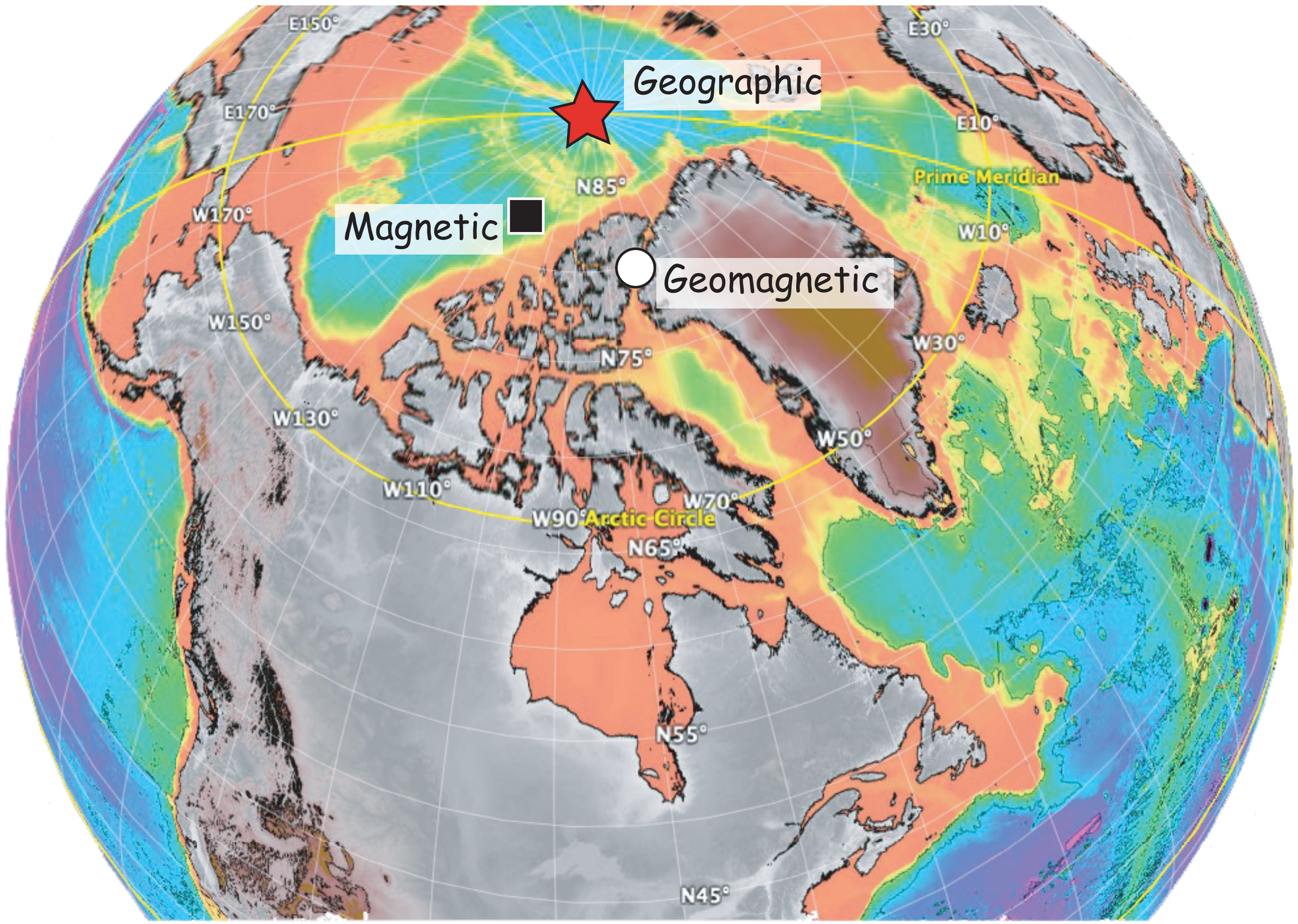
Our first three poles (more to come)



geographic: spin axis (the GAD pokes out here)
magnetic: places where field is vertical
geomagnetic: piercing points of best-fit dipole

Lecture 4

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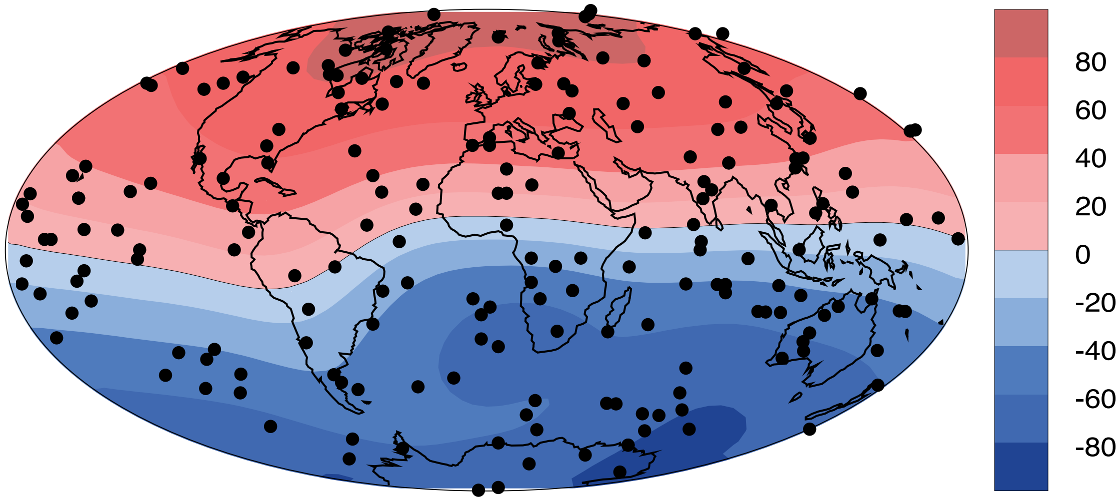
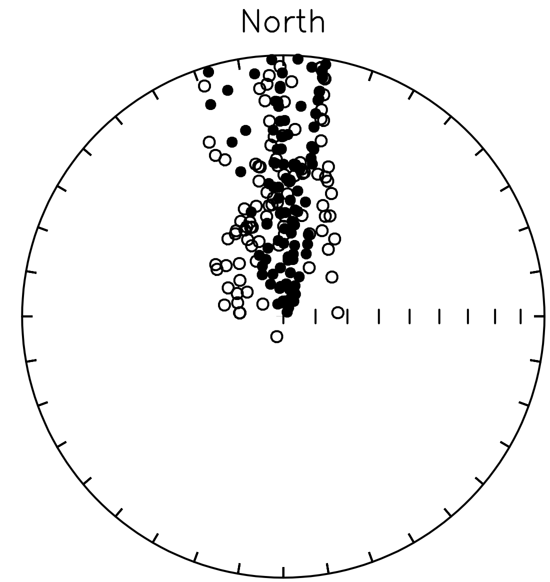
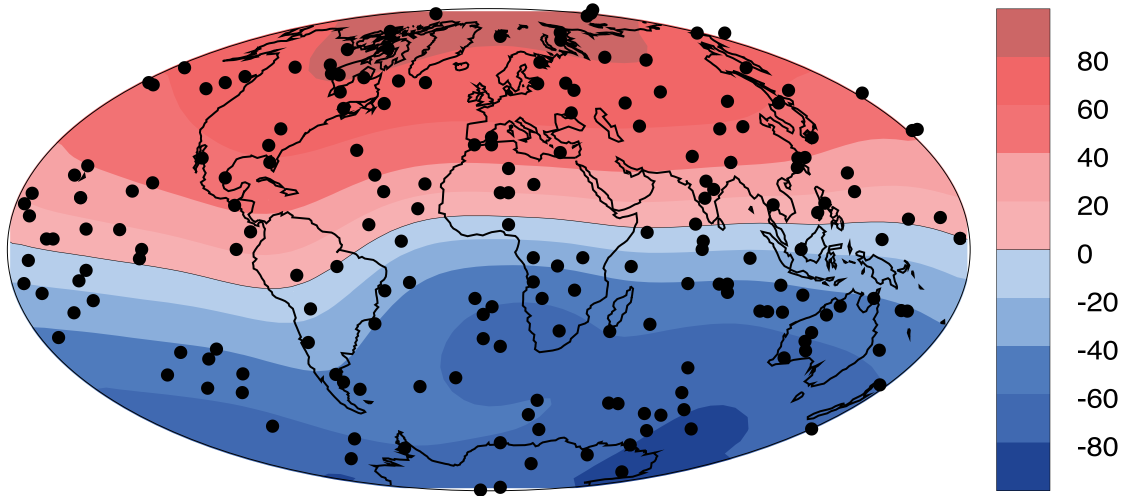
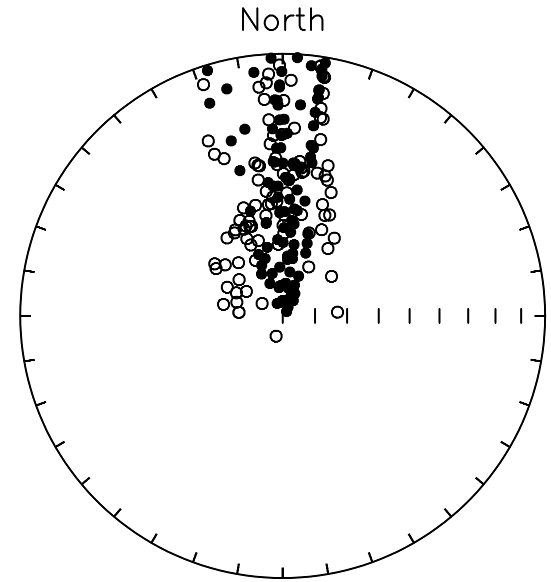




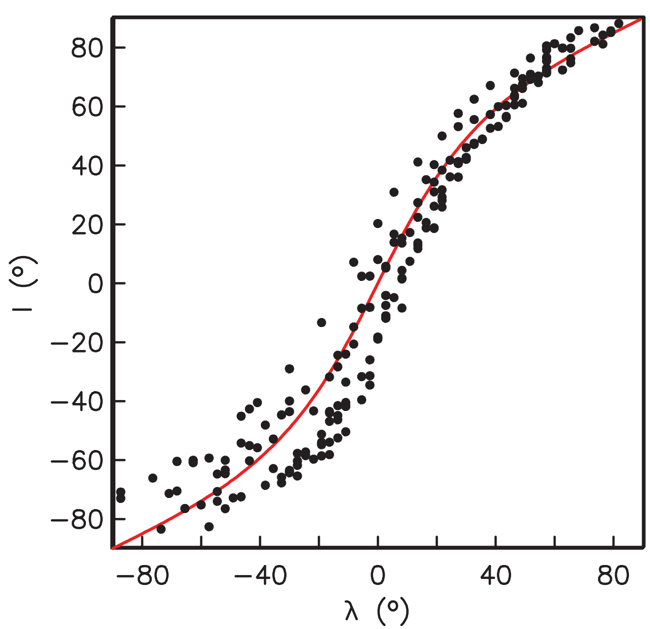
Declination and inclination observed around the globe and plotted on equal area projection

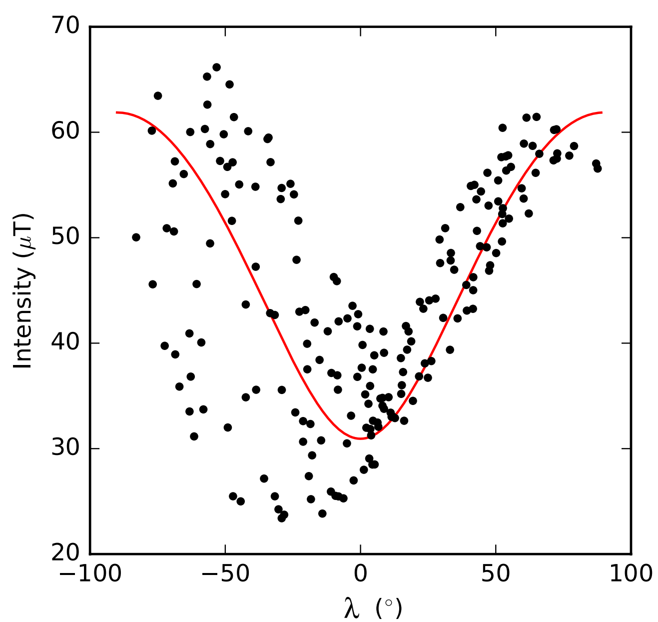
You will do something like this for problems 2.1 & 2.2 in your assignment





evaluate the field vector at these points





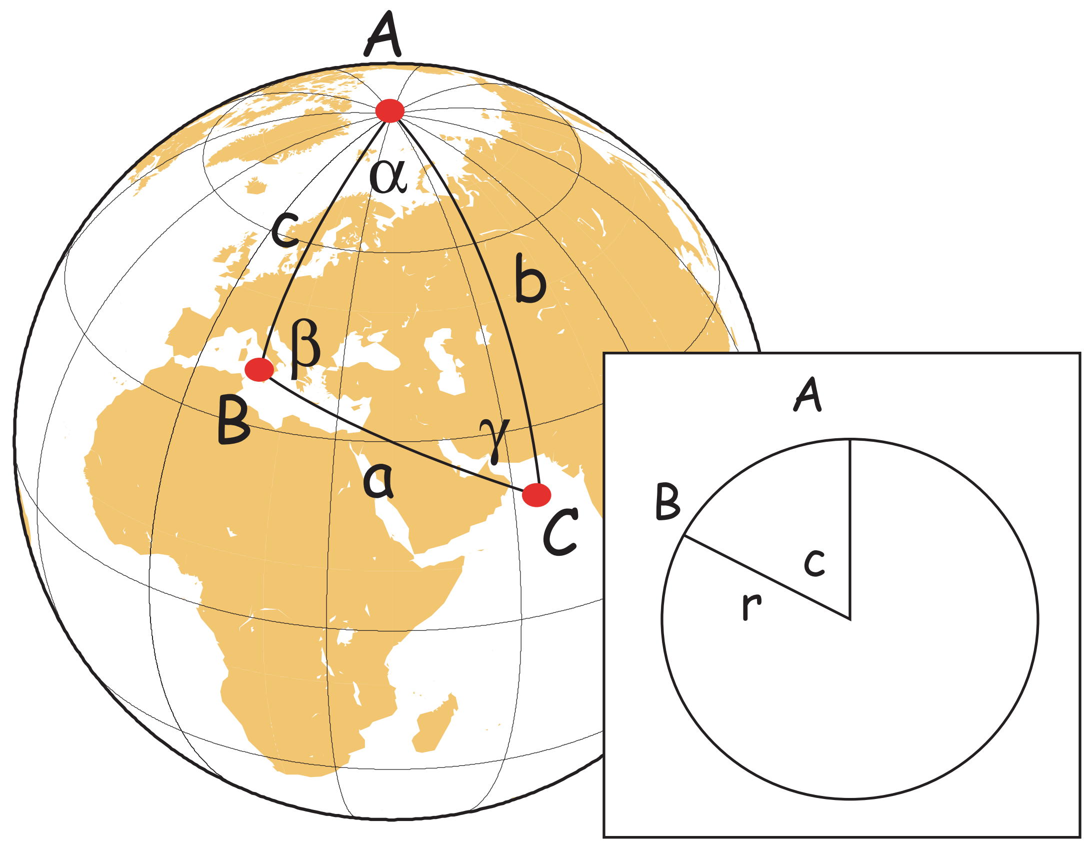
Lecture 4

- Things we might want to know about the geomagnetic field
- Components of the geomagnetic field
- The geomagnetic reference field
- All sorts of magnetic poles: 2 more!
- observables

But first: a math refresher
spherical trigonometry

law of sines:

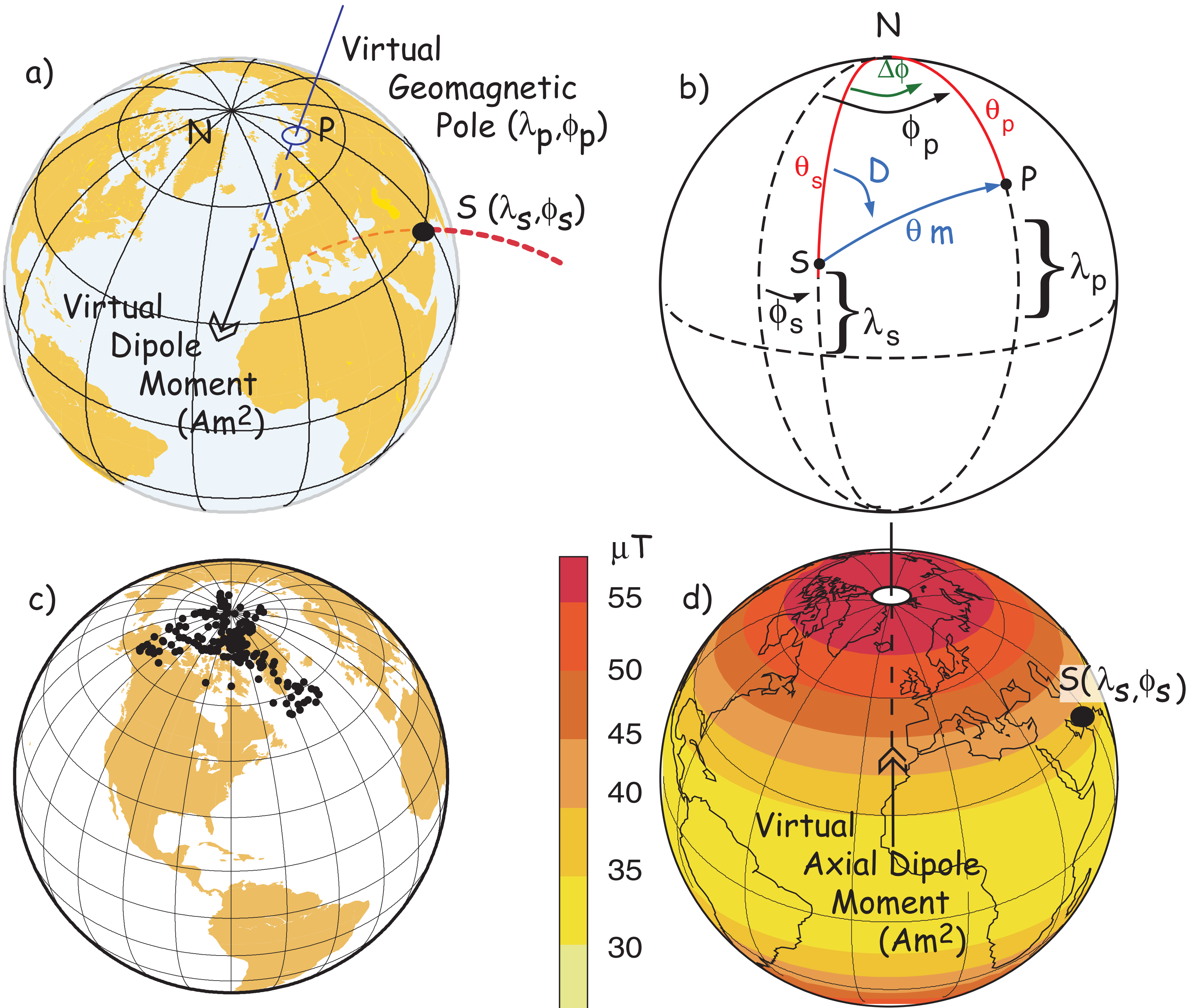
$$\frac{\sin\alpha}{\sin a} = \frac{\sin\beta}{\sin b} = \frac{\sin\gamma}{\sin c}$$



law of cosines:

$$\cos a = \cos b \cos c + \sin b \sin c \cos\alpha$$

another pole



The last pole!

- When you average a bunch of poles together (to average out secular variation), you get one more pole
- a Paleomagnetic Pole. This is assumed to be equivalent to GAD: aligned with the spin axis and centered in the earth.
- Can you these poles to calculate paleolatitude, e.g.

Assignment

- Make sure you have properly installed PmagPy (now you need it!).
- Follow the instructions in the cookbook for moving the data_files directory to your Homework folder
- Do problems 2.1 and 2.2 in the online version of the textbook.