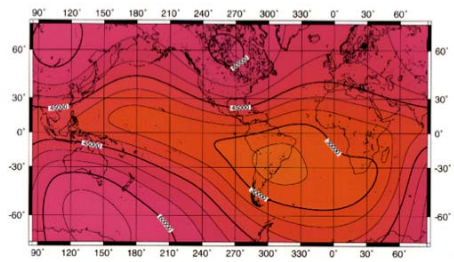
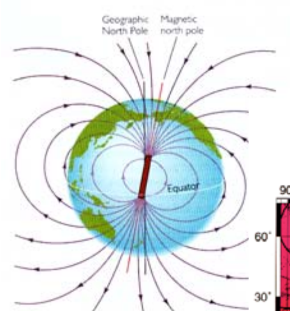


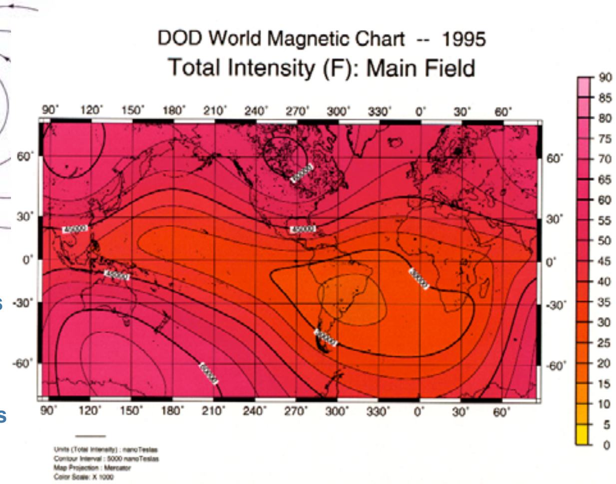
The Earth's magnetic field

Reading: Fowler Ch 3, p43-51 (and Appendix 1)

The Earth's magnetic field

…almost a dipole

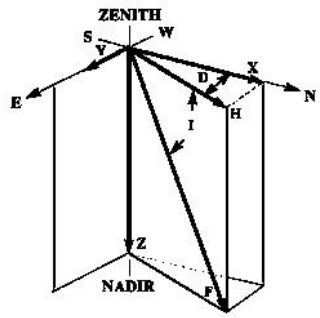


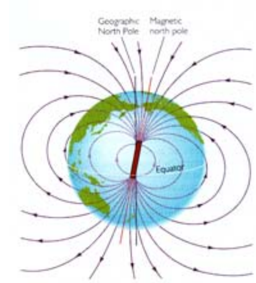


Field would be
- **vertical at the poles**
- **horizontal at the equator**

But is oriented 11.5° from the rotation axis (which is geographical north)

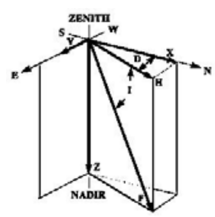
Describing the field

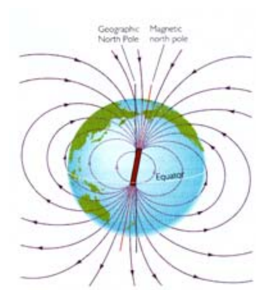


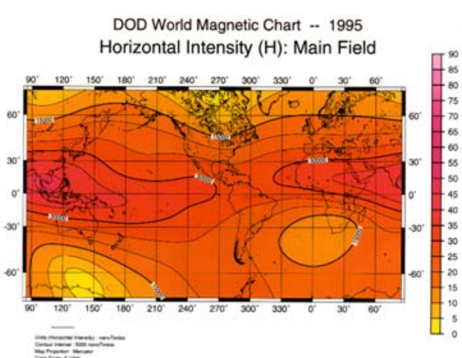


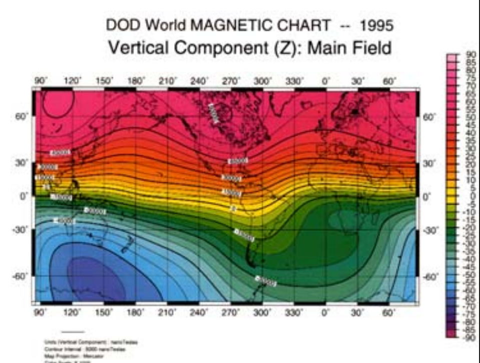
Declination (D)
Inclination (I)
Horizontal Intensity (H)
Vertical Intensity (Z)
North-South Intensity (X)
East-West Intensity (Y)
Total Intensity (F)

The Earth's magnetic field

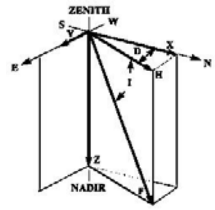


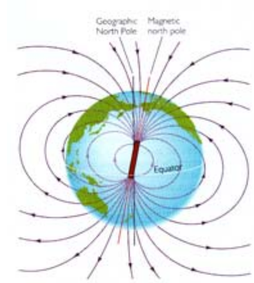


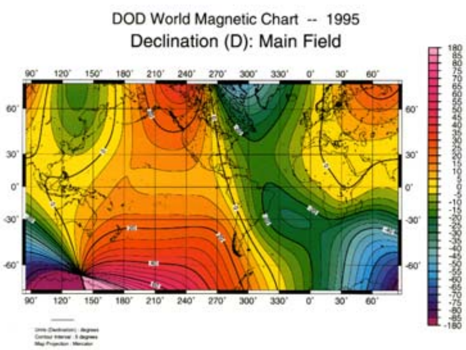


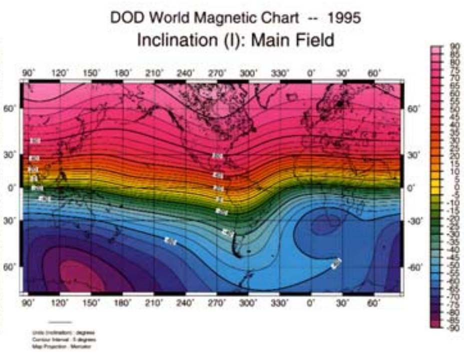


The Earth's magnetic field







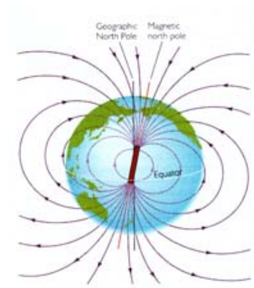


EPS 122: Lecture 5 – Earth's magnetic field

Describing the Earth's field

the best fit dipole

This first order simple model/description of the field allows use of paleomagnetic observations to determine past plate motions



Magnetic potential

$$V(\mathbf{r}) = \frac{1}{4\pi r^3}\mathbf{m}\cdot\mathbf{r}$$

The Earth's best fit dipole moment, m = 7.94×10^{22} Am^2

Magnetic field is the derivative of the potential

$$\mathbf{B}(\mathbf{r}) = -\mu_0 \nabla V(\mathbf{r})$$

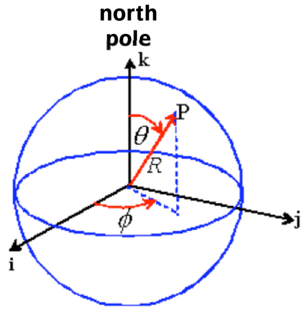
given the magnetic permeability of free space,
$\mu_0 = 4\pi \times 10^{-7}$ kg m A^{-2} s^{-2}

dot or scalar product

$$\mathbf{m}\cdot\mathbf{r} = mr\cos\theta$$

EPS 122: Lecture 5 – Earth's magnetic field

Spherical polar coordinates



- **R** **radius**
- **θ** **colatitude, 0 to pi**
  (degrees from north pole)
- **Φ** **longitude, 0 to 2pi**

Conversion from / to Cartesian coordinates

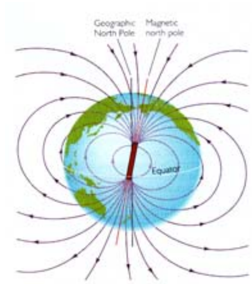
$$R = \sqrt{x^2 + y^2 + z^2} \qquad x = R\sin\theta\cos\phi$$
$$\theta = \cos^{-1} z/R \qquad y = R\sin\theta\sin\phi$$
$$\phi = \tan^{-1} y/x \qquad z = R\cos\theta$$

Gradient operator

$$\nabla f = \left(\frac{\partial f}{\partial r}, \frac{1}{r}\frac{\partial f}{\partial \theta}, \frac{1}{r\sin\theta}\frac{\partial f}{\partial \phi}\right)$$

Describing the Earth's field

the best fit dipole



Magnetic field in spherical polar coordinates

$$\mathbf{B}(\mathbf{r}) = (B_r, B_\theta, B_\phi)$$

the radial, southerly, easterly components

If the Earth's magnetic dipole moment is aligned along the z-axis:

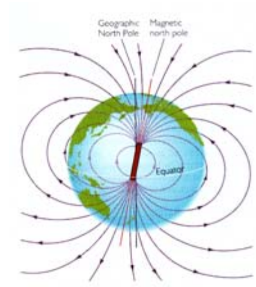
$$V(\mathbf{r}) = \frac{1}{4\pi r^3}\mathbf{m}\cdot\mathbf{r}$$

$$= \frac{mr\cos\theta}{4\pi r^3} = \frac{m\cos\theta}{4\pi r^2}$$

we can calculate the magnetic field at any point....

Describing the Earth's field

the best fit dipole



Three components

$$B_r(r,\theta,\phi) = -\frac{2\mu_0 m\cos\theta}{4\pi r^3}$$

$$B_\theta(r,\theta,\phi) = -\frac{\mu_0 m\sin\theta}{4\pi r^3}$$

$$B_\phi(r,\theta,\phi) = 0$$

Total field

$$B(r,\theta,\phi) = \sqrt{B_r^2 + B_\theta^2 + B_\phi^2 +} = \frac{\mu_0 m}{4\pi r^3}\sqrt{1+3\cos^2\theta}$$

At the north pole

$$B_r(r,0,\phi) = -\frac{\mu_0 m}{2\pi r^3}$$

$$B_\theta(r,0,\phi) = 0$$

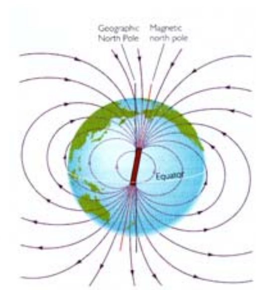
At the equator

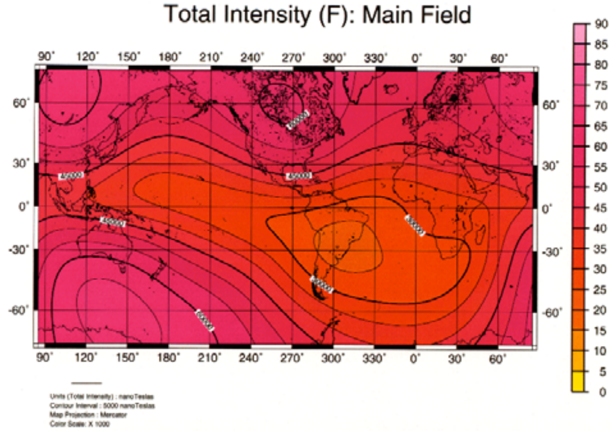
$$B_r(r,90,\phi) = 0$$

$$B_\theta(r,90,\phi) = -\frac{\mu_0 m}{4\pi r^3}$$

Magnitude of the total field at the pole is twice as strong as at the equator

Describing the Earth's field





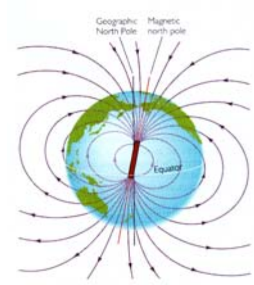
← **6 x 10^{-5} T or 6000 nT at the poles**

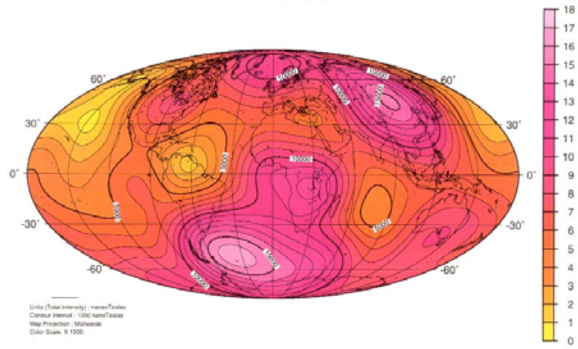
← **3 x 10^{-5} T or 3000 nT at the equator**

T is the teslas

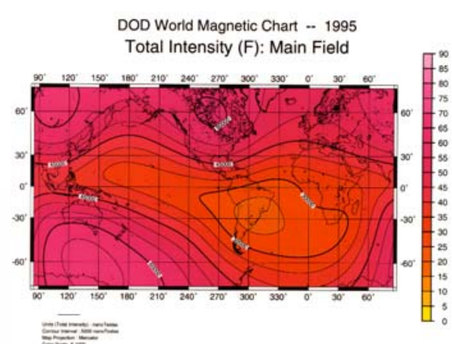
The Earth's magnetic field

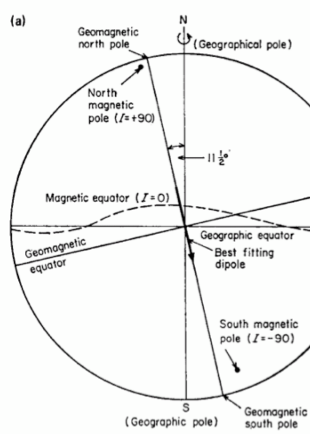
...non-dipole field





The Earth's magnetic field



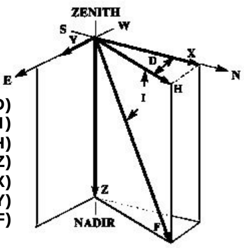


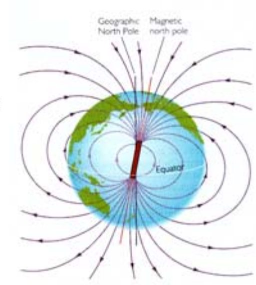
Best-fit dipole currently 11.5° from geographic north pole

But this has varied with time

A few definitions
for surface measurements

Declination (D)
Inclination (I)
Horizontal Intensity (H)
Vertical Intensity (Z)
North-South Intensity (X)
East-West Intensity (Y)
Total Intensity (F)





$$Z(R,\theta,\phi) = -B_r(R,\theta,\phi)$$

$$H(R,\theta,\phi) = |B_\theta(R,\theta,\phi)|$$

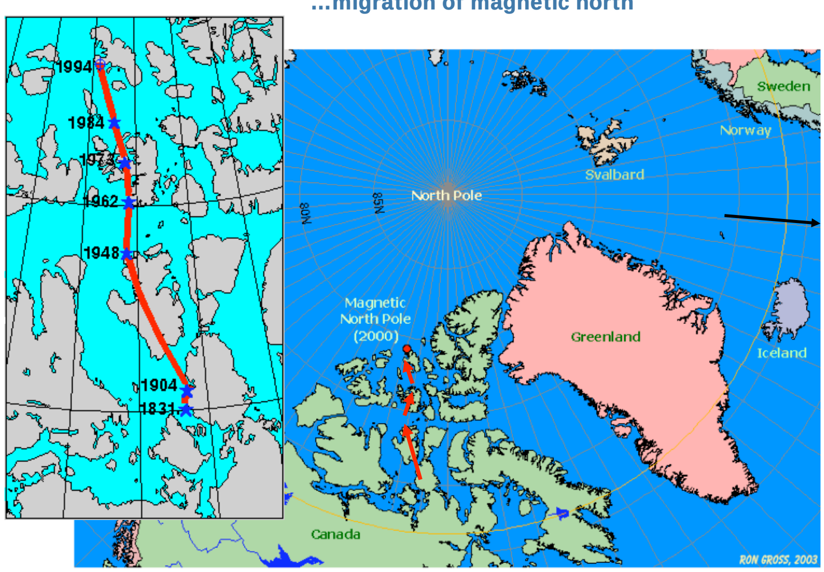
magnetic inclination

$$\tan I = \frac{Z}{H} = \frac{2\cos\theta}{\sin\theta} = 2\cot\theta = 2\tan\lambda$$

where λ is the magnetic latitude (λ = 90 – θ)

Secular variation

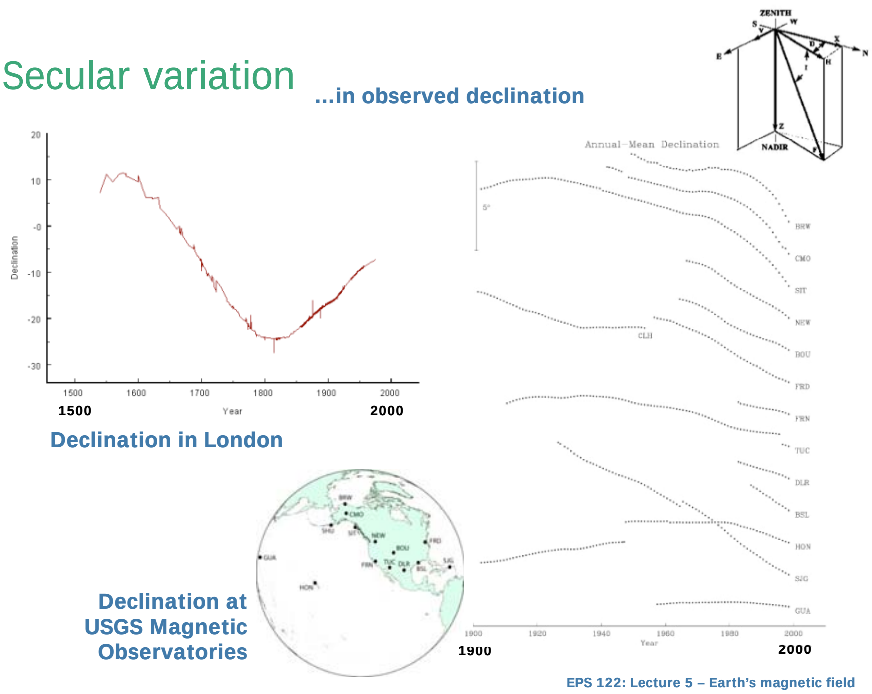
...migration of magnetic north



0°

Secular variation

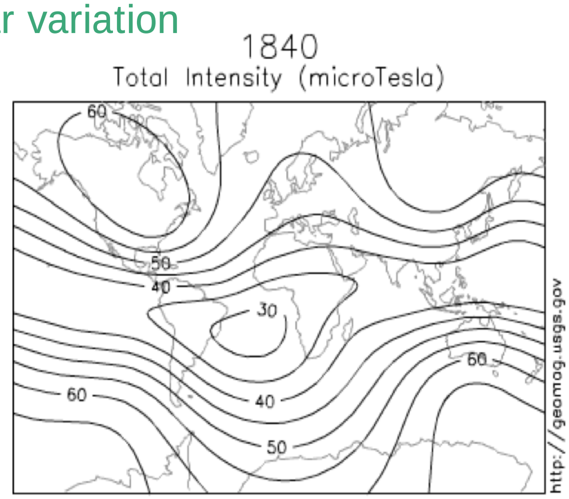
...in observed declination



Declination in London

Declination at USGS Magnetic Observatories

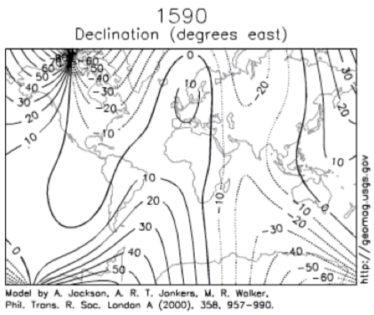
Secular variation

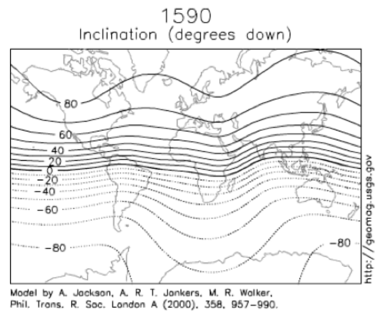


Model by A. Jackson, A. R. T. Jonkers, M. R. Walker, Phil. Trans. R. Soc. London A (2000), 358, 957–990.

Download: http://geomag.usgs.gov/movies/

Secular variation



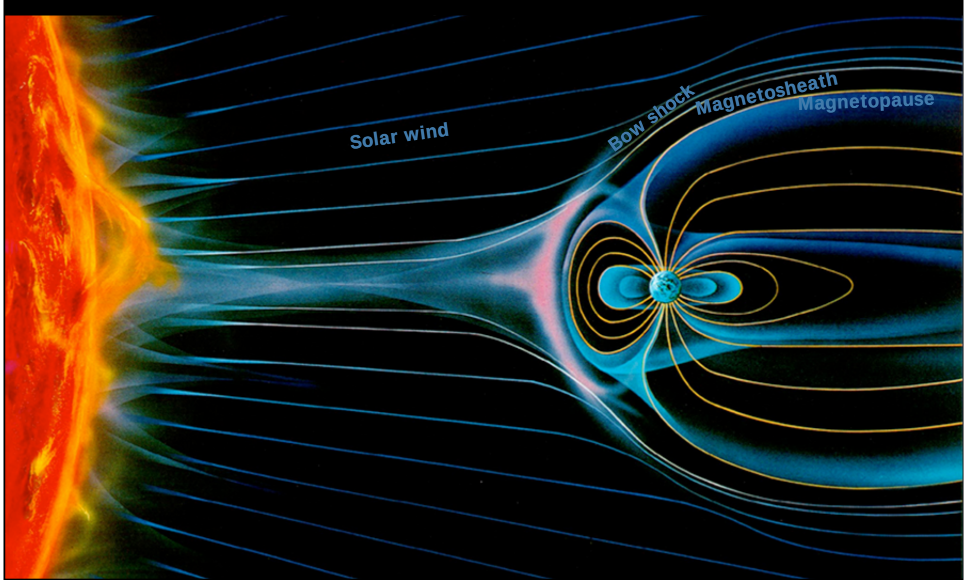


Download: http://geomag.usgs.gov/movies/

Solar wind

...and the Earth's magnetic field

The solar wind confines the Earth's magnetic field to the magnetosphere

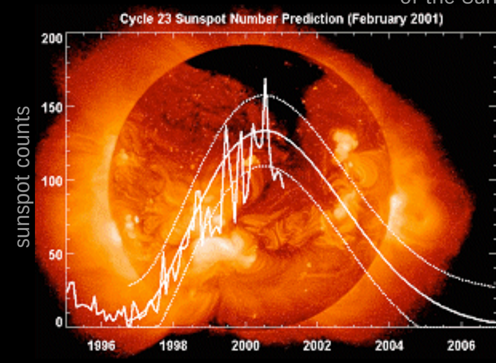


The sunspot cycle

and flips in the Sun's magnetic field

- 11 year sunspot cycle
- Sunspots are intense magnetic loops which poke out of the photosphere
- Sun's dipole flips at peak in sunspot activity
- Last peak / flip: February 2001
- The magnetic south pole is now at the geographical north pole

X-ray image of the Sun



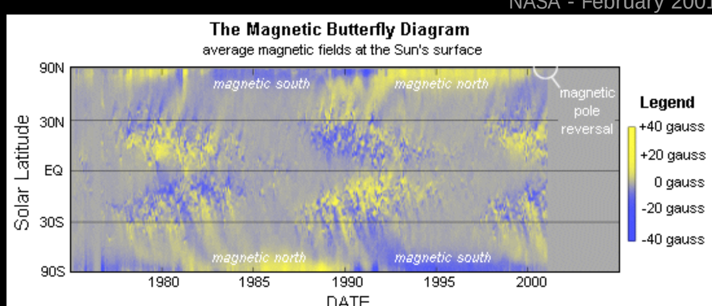
NASA - February 2001

- On Earth the field flips at intervals of ~200,000 years (5,000 to 50 mill)
- The last reversal on Earth happened 740,000 years ago

The sunspot cycle

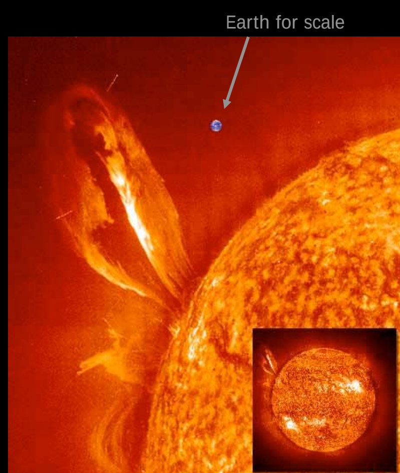
and flips in the Sun's magnetic field

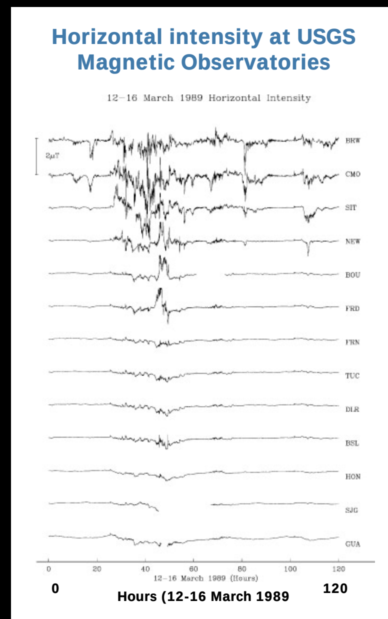
NASA - February 2001



- Meridional flows carry magnetic fields from mid-latitude sunspots to the Sun's poles
- The poles flip because south-pointing magnetic flux is transported to the north magnetic pole, and north-pointing flux to the south magnetic pole
- Do we see evidence for this migration on Earth?

Space weather
solar storms





EPS 122: Lecture 5 – Earth's magnetic field