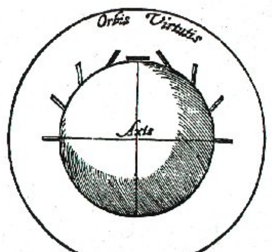
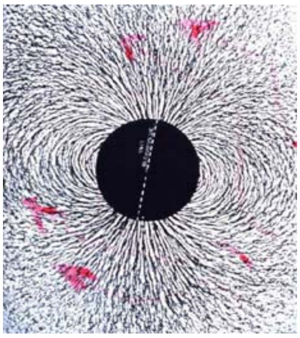
<u>**D3.1 The internal component of the Earth's magnetic field**</u>

Spatial variations of the magnetic field



Variety in the declinations of iron spikes at various latitudes of a terrella.

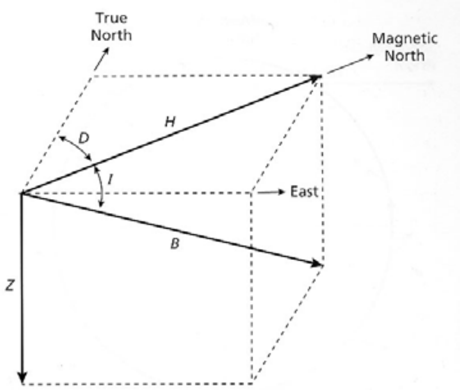
- The dipole nature of the field was described by William Gilbert in the 1600's



- The dipole accounts for about **80%** of the observed magnetic field. The axis of the dipole is inclined at 11.5 degrees to the Earth's rotation axis.

  Dipole moment = 7.94 x 10^{22} Am^2 in 2000.

- At any point the field is defined by the magnetic elements



F = total field strength

Z = vertical component of F

H = horizontal component of F

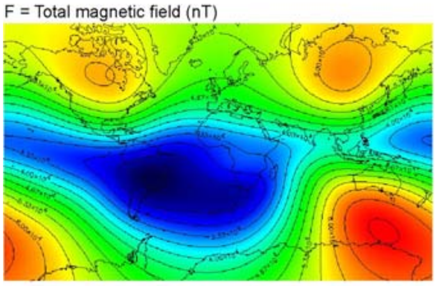
i = inclination (angle between F and surface)

d = declination (angle between H and geog. north)

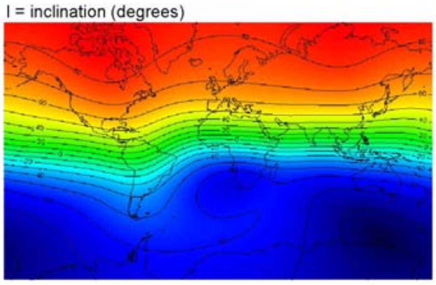
- The field is described by the International Geomagnetic Reference Field (IGRF). This is shown on the following page for 2000. Note the departures from a pure dipole field, especially the 4 regions of high Z in high latitudes.

The International geomagnetic Reference Field (IGRF) in 2000

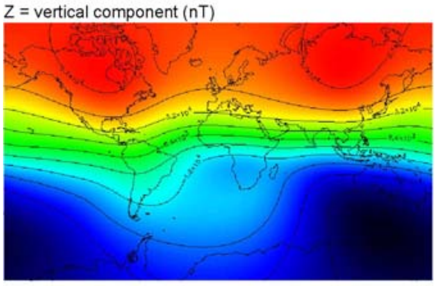
F = Total magnetic field (nT)



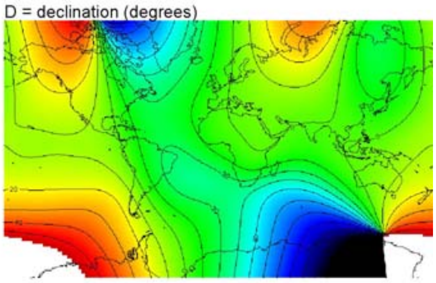
I = inclination (degrees)



Z = vertical component (nT)



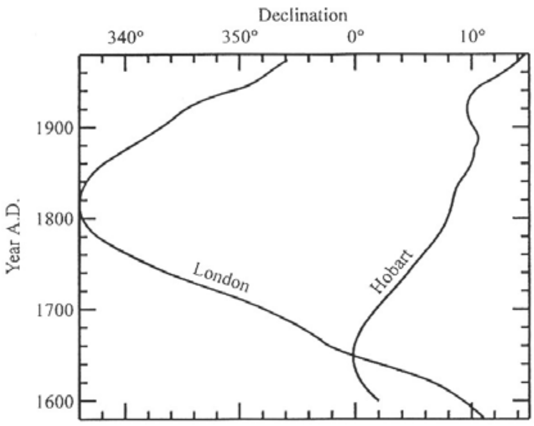
D = declination (degrees)

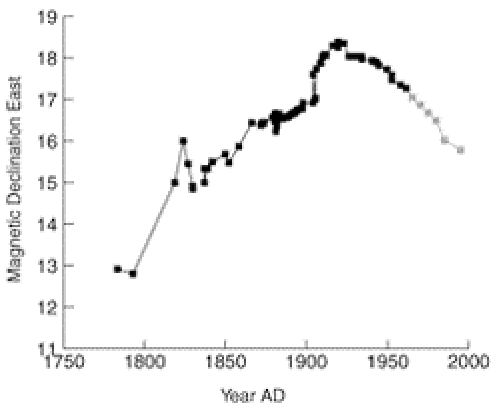


Temporal variations in the internal magnetic field

The compass was invented in China, but was used for geomancy rather than navigation in early years. Ancient texts record the variation of declination in Peking (Beijing) from at least AD720.

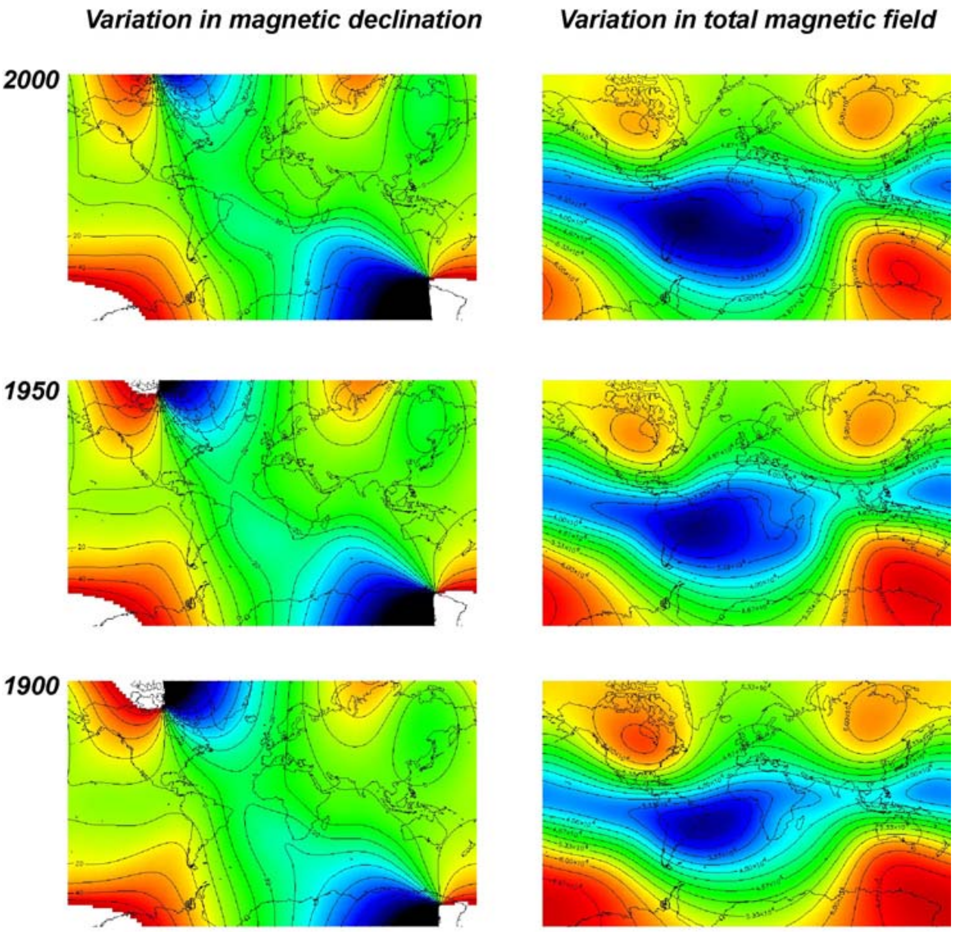
It took a while for Europeans to catch on, and the first record of temporal changes was in 1635 when Gellibrand noted that declination varies with time. The declination in London was found to vary significantly over the period 1600-2000. Figure on right shows declination in San Francisco for the last 250 years.

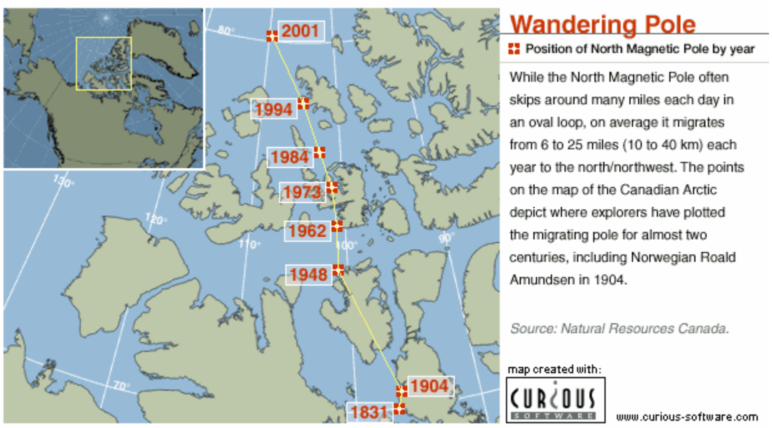




● The **secular variation** in the Earth's magnetic field occurs on many timescales including:

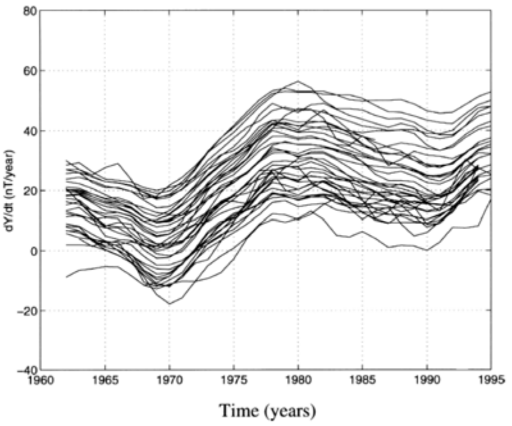
(a) Westward drift: patterns in the IGRF field can be seen to move west over the last century.





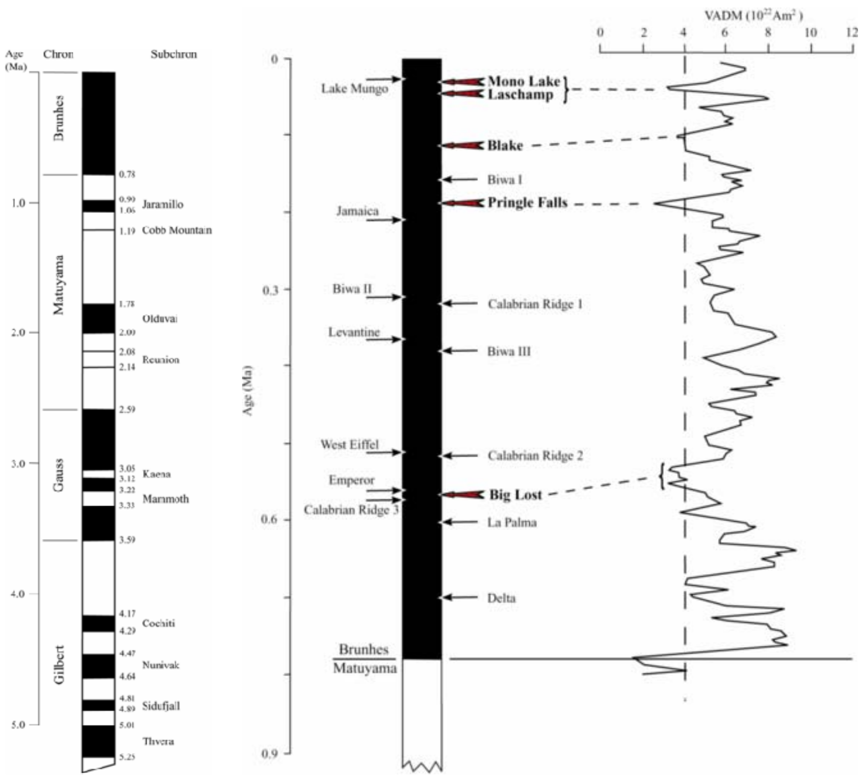
(b) Investigations of historical records from early navigators and explorers has extended these records back to the 1600's (Jackson et al., 2000) and are displayed as movies at http://geomag.usgs.gov/movies/.

(c) Short term **geomagnetic jerks** occur on time scales of a decade. The figure below shows time derivative of the eastward field component at 37 geomagnetic observatories across Europe. Jerks may be related to changes of flow in the inner core, and may also be related to changes in the length-of-day.



(d) Continuous reduction of dipole field since 1600
($P = 9.4 \times 10^{22}$ Am^2 in 1600, $P = 7.94 \times 10^{22}$ Am^2 today)

(e)Complex sequence of magnetic field **reversals** over the observed geological record. During a reversal the whole field switches north and south poles. Between reversals there is evidence that the magnetic dipole axis and the Earth's rotation axis are approximately parallel.



The sequence of reversals appears to be **chaotic** with no regular frequency.

The present normal polarity (Brunhes chron) has lasted for 780,000 years.

Periods without a reversal for 10^7-10^8 years are called **superchrons**.

Cretaceous normal superchron	118-83 Ma
Permo-Carboniferous (Kiaman) reverse superchron	312-262 Ma

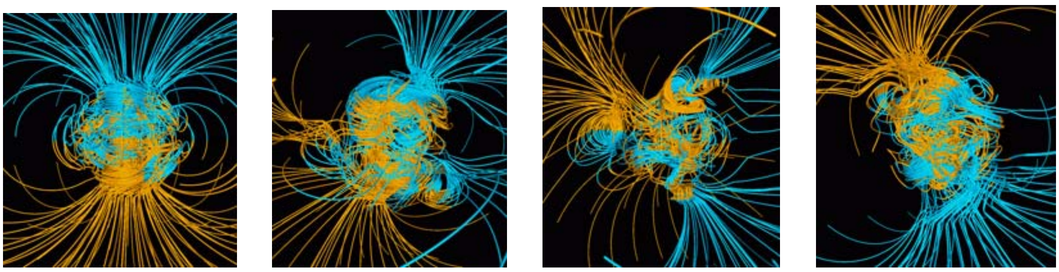
The reduction in the main field over the last 400 years could indicate we are approaching a reversal. How might reversals affect life on Earth?

Origin of the internal magnetic field

- High temperatures inside the Earth (well above Curie temperature) exclude the possibility of remnant magnetization generating the magnetic field.

- The secular variation, and alignment of dipole with rotation axis, suggest that the magnetic field originates in the relatively rapid fluid motion in a part of the Earth with a high electrical conductivity. This only leaves the outer core (composed of liquid iron) as the place where the field must be generated.

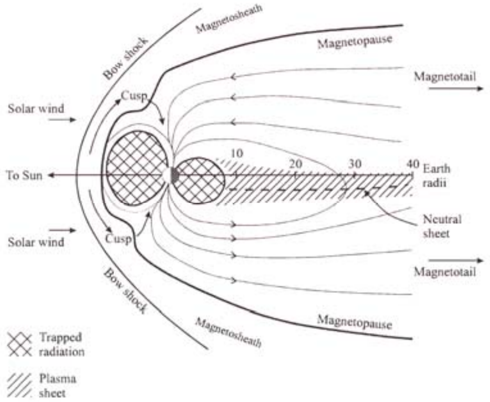
- A complex fluid motion is believed to act as a self sustaining dynamo. Computer simulations of the **geodynamo** can partially explain the observed spatial and secular field variations, including reversals. These models include convection, Coriolis forces and magnetohydrodynamics. However many details remain unanswered.



Computer simulation of a geomagnetic reversal (Glatzmaier and Roberts, 1995)

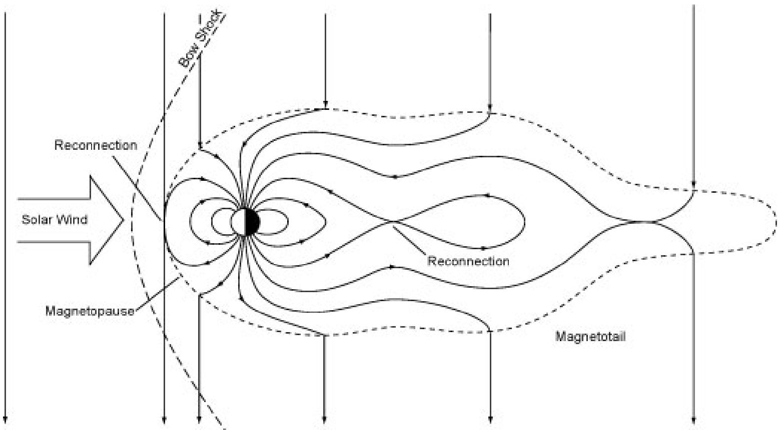
D3.2 External component of the Earth's magnetic field

The magnetic field measured at the surface of the Earth is due to sources **inside** and **outside** the Earth. The external component is generated in the atmosphere and magnetosphere.



●The solar wind (a stream of *H* and *He* ions) is deflected by the Earths internal magnetic field to create the magnetosphere.

●The interactions between the solar wind and the Earth's magnetic field are very complex. Temporal changes in the solar wind, due to sunspots, solar flares and coronal mass ejections can produce a change in the magnetic field at the surface of the Earth.



● From 50-1500 km above the Earth's surface is the **ionosphere**, a region of plasma with high electrical conductivity. Changing magnetic fields from the magnetosphere can induce large electric currents in the ionosphere. Changes in these currents produce large changes in the magnetic field measured at the Earth's surface.

● Large currents flow in specific locations including:

-equatorial electrojet flows on magnetic equator on side facing sun

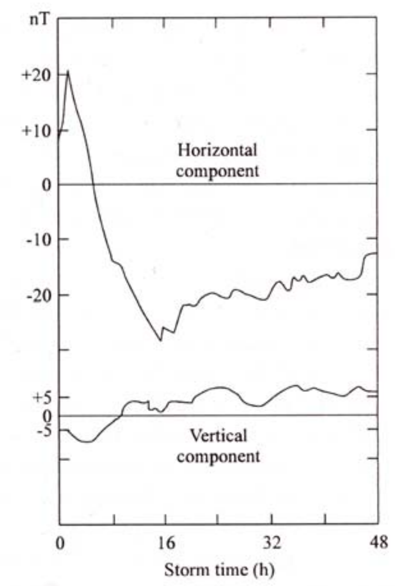
-auroral electrojet flows at high magnetic latitude

● When the solar wind is in a steady state, the Earth's magnetic field shows a daily variation that is due to the Earth turning within the current systems of the magnetosphere and ionosphere. The typical variation is called the **solar quiet day variation** (S_q). The amplitude is typical 10-20 nT and varies with latitude.

● A much smaller variation is seen every 25 days and is caused by the orbit of the moon.

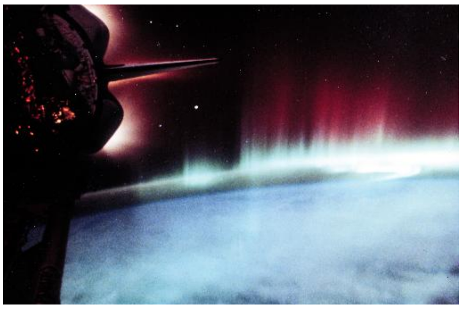
● When the solar wind is active, the Earth's magnetic field is said to be disturbed. **Magnetic storms** occur when the current systems change over a period of several days and the field at the Earth's surface can change by 100's of nanotesla. These changes are largest beneath major ionospheric current systems.

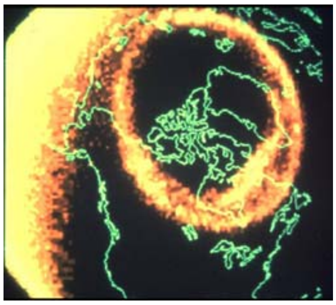
The figure shows a typical magnetic storm at low magnetic latitude.



● Smaller disturbances are classified as substorms and bays and have timescales of several hours.

● Solar activity is characterized by an **11 year cycle** and we have just passed the maximum. Maximum solar activity results in high levels of activity in the Earth's external magnetic field and frequent magnetic storms and strong auroral displays.





References

G.A. Glatzmaier and P.H. Roberts, A three-dimensional self-consistent computer simulation of a geomagnetic field reversal, Nature, 377, 203-209 (1995).

Jackson, A., Jonkers, A. R. T. & Walker, M. R., 2000. Four centuries of geomagnetic secular variation from historical records, *Phil. Trans. R. Soc. London, A* **358**, 957-990.

D3.3 Comparison of the Earth's gravitational and magnetic fields

	Gravitational field	*Magnetic field*
Overall field geometry	Approximate spherical symmetry **g** varies as $1/r^2$	80% dipole **B** varies as $1/r^3$
Direction	Down, by definition	Inclination varies from +90˚ to –90 ˚
Spatial variations	978,000 mgal at Equator 983,000 mgal at poles GRS formula simple and accounts for variation of **g** with latitude	25,000 nT at Equator 61,000 nT at high latitude IGRF is a complex series of spherical harmonics
Temporal variations with internal origin	Signal produced by plate motion and mantle convection????	Secular variation, jerks, westward drift and north-south field reversals Poles moving at ~ 15 km/yr
Temporal variations with external origin	Tidal signals (< 0.5 mgal)	Diurnal S_q variation (50 nT) Magnetic storms (100-1000nT) 11 year sunspot cycle
Latitude variation in Edmonton	~ 1 mgal km^{-1}	~3 nT km^{-1}
Elevation variation in Edmonton	~ 0.3 mgal m^{-1}	~ 0.03 nT m^{-1}

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