Estimating the geomagnetic field as a reference for wellbore surveys: accounting for all sources and uncertainties

Ellen Clarke

32nd ISCWSA Meeting, Florence, 23rd September 2010

The Earth's magnetic field

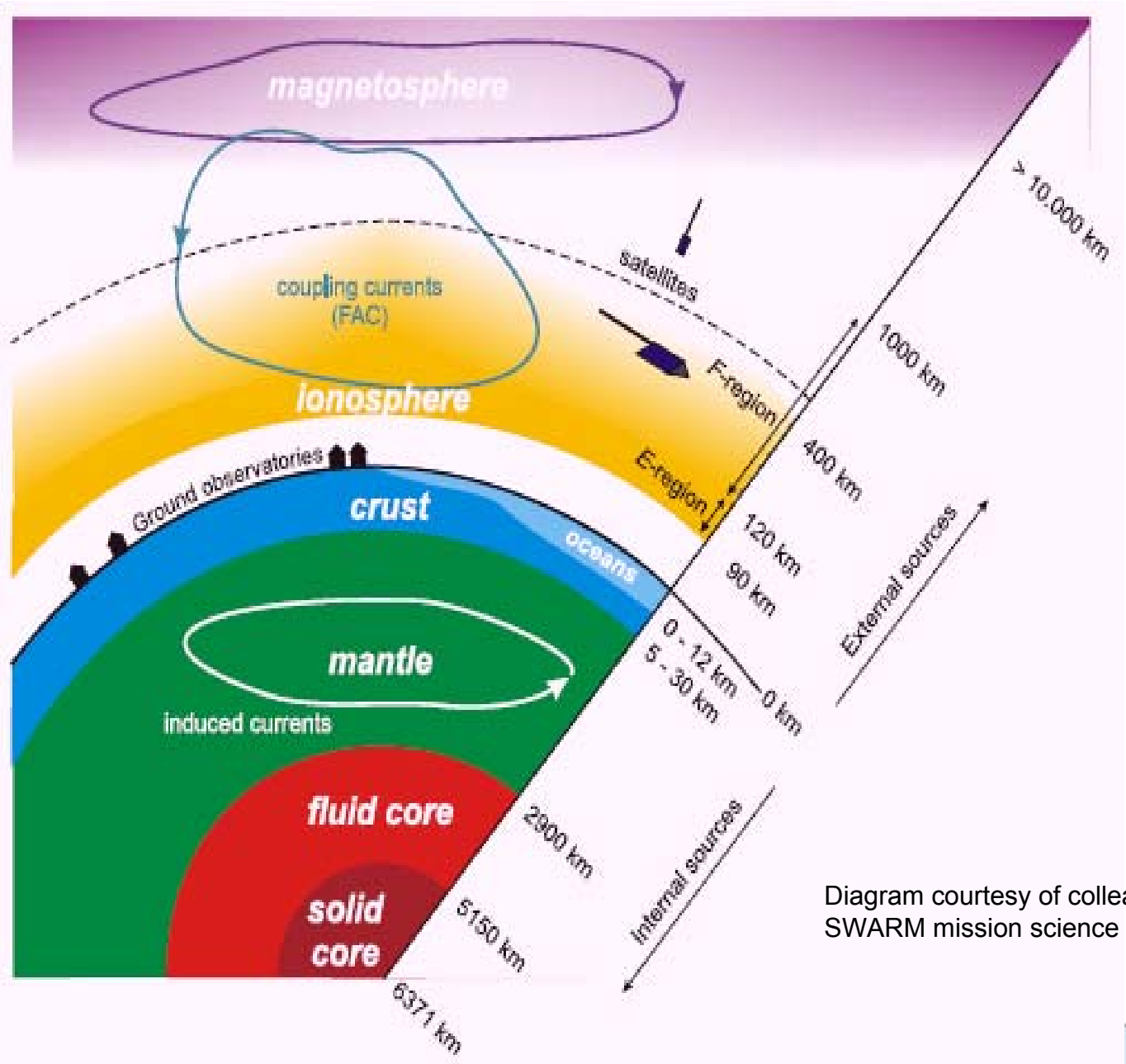
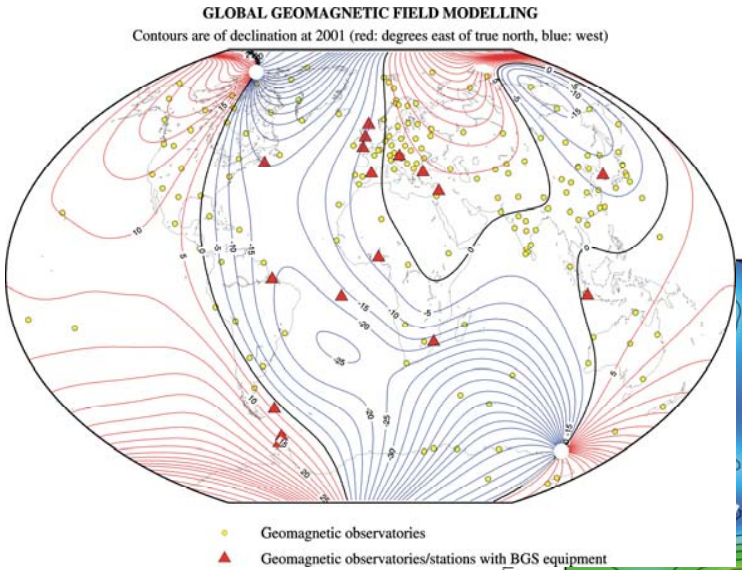


Diagram courtesy of colleagues in the SWARM mission science team

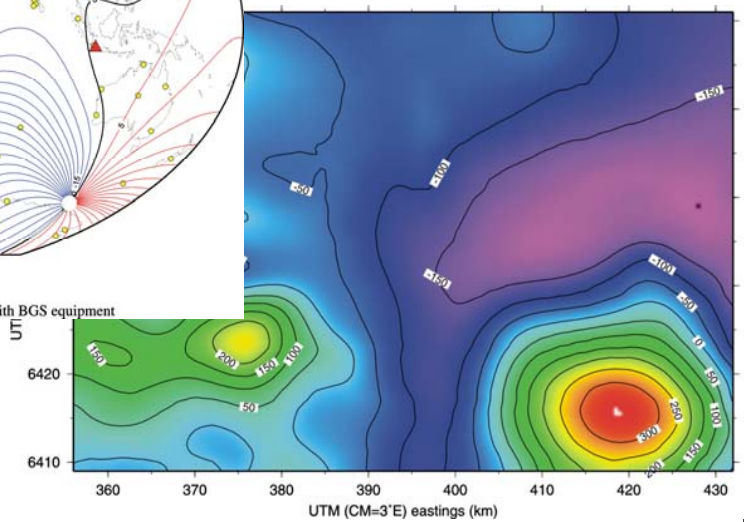
The Earth's magnetic field

- Most of the field is from the Earth's core
  - varies slowly with time (months to years)
- Local fields from magnetized rocks in Earth's crust
  - relatively stable with time
- Fields due to currents in the ionosphere and the magnetosphere
  - variations from seconds to years

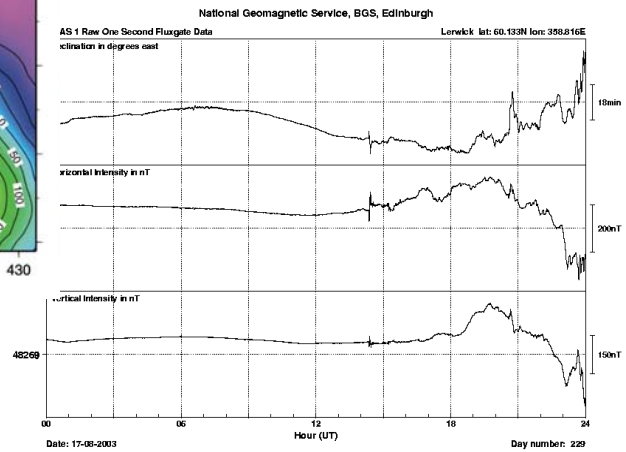
Geomagnetic field sources …



Core Field

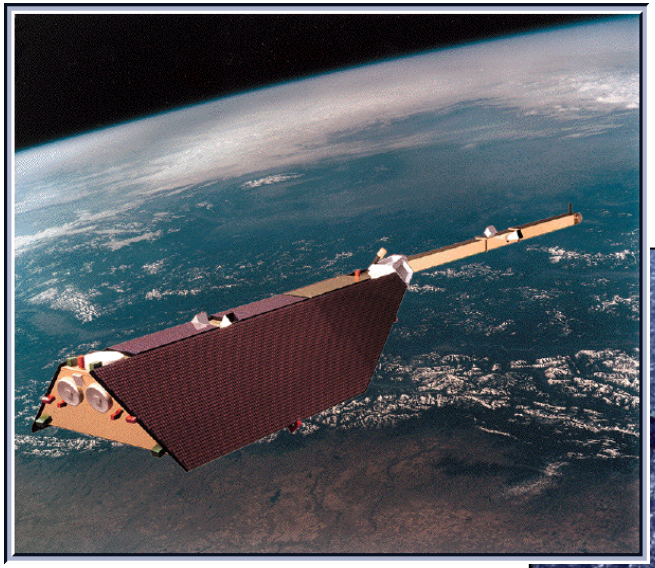


Crustal Field



External Fields

… and how they are measured



Magnetic survey satellite

Aeromagnetic survey

Magnetic Observatory

Directional reference and uncertainty

Reference direction for drilling $\rightarrow D + \varepsilon$

1. Ideally, account for all sources

$$D_1 = D_{core} + D_{crust} + D_{external}$$

$$\varepsilon_1 = \varepsilon_{core} + \varepsilon_{crust} + \varepsilon_{external}$$

2. When external fields are ignored

$$D_2 = D_{core} + D_{crust} + 0$$

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3. When crustal and external fields are ignored

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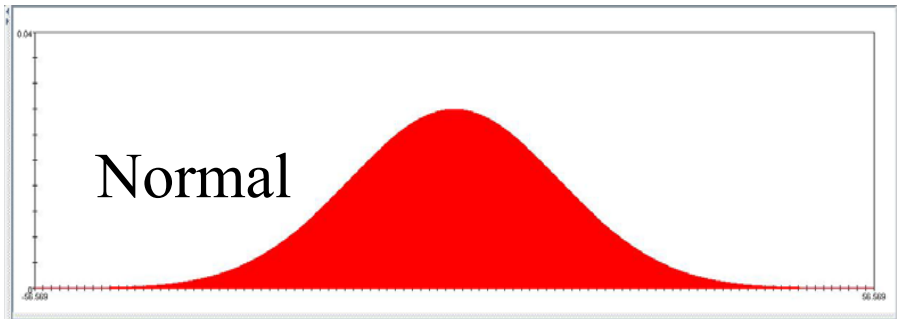
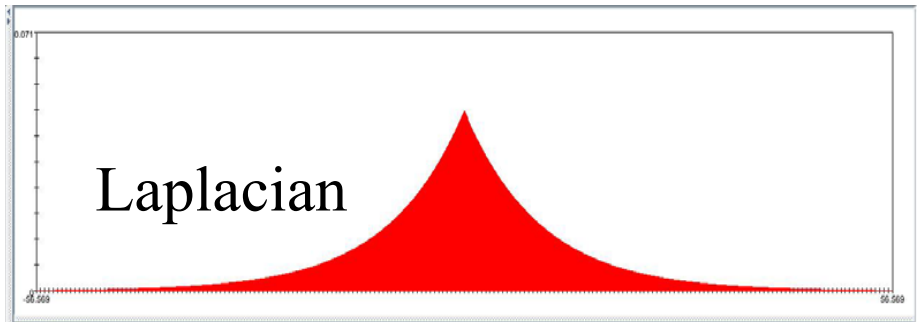
Confidence levels

- Error distributions are not usually normal



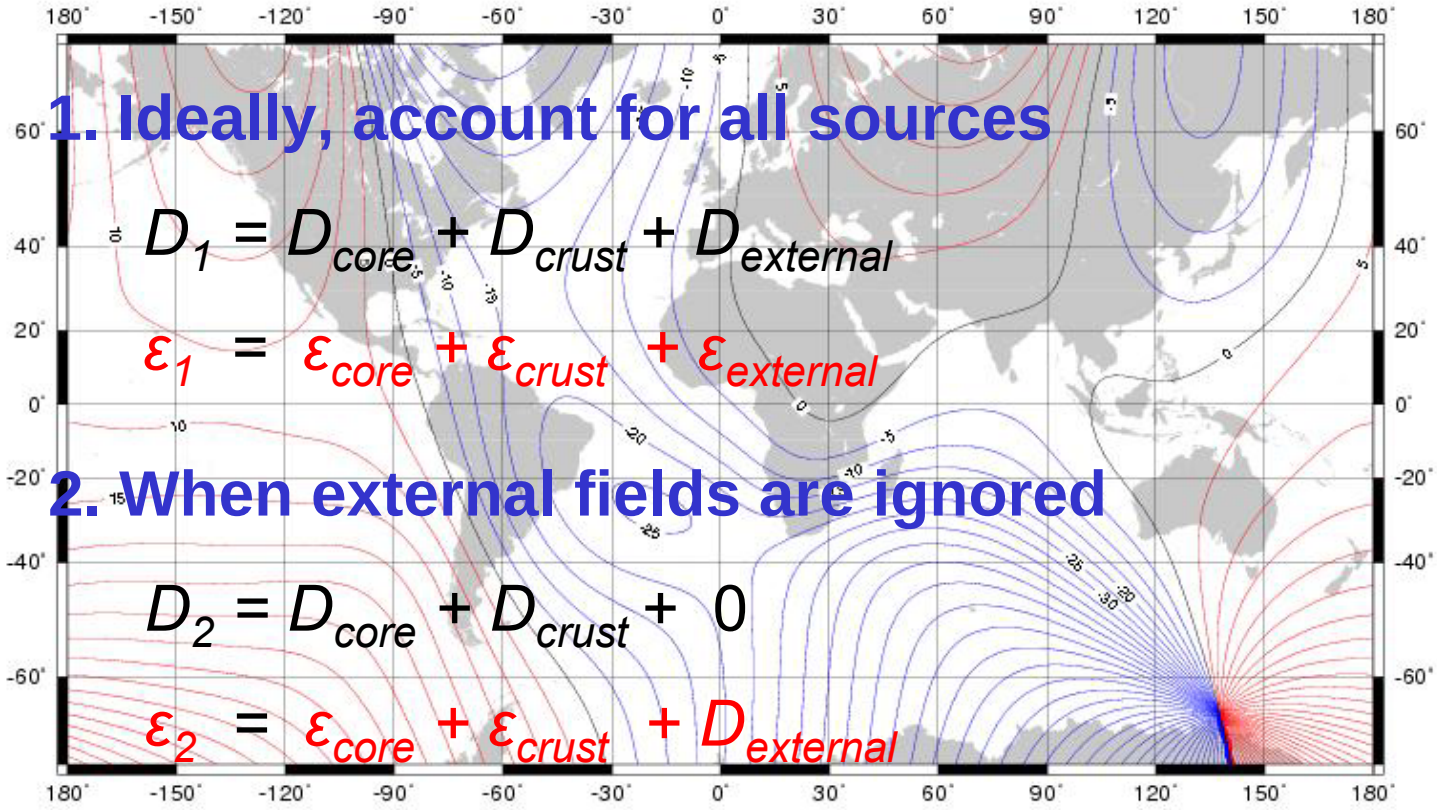


- Should not use multiples of σ and assume same confidence as with a normal distribution

- Confidence levels relevant for any error distribution

- Uncertainties presented as limits for confidence levels…
  - 68.3% (equivalent to 1σ if normal)
  - 95.4% (equivalent to 2σ if normal)
  - 99.7% (equivalent to 3σ if normal)

Directional reference and uncertainty



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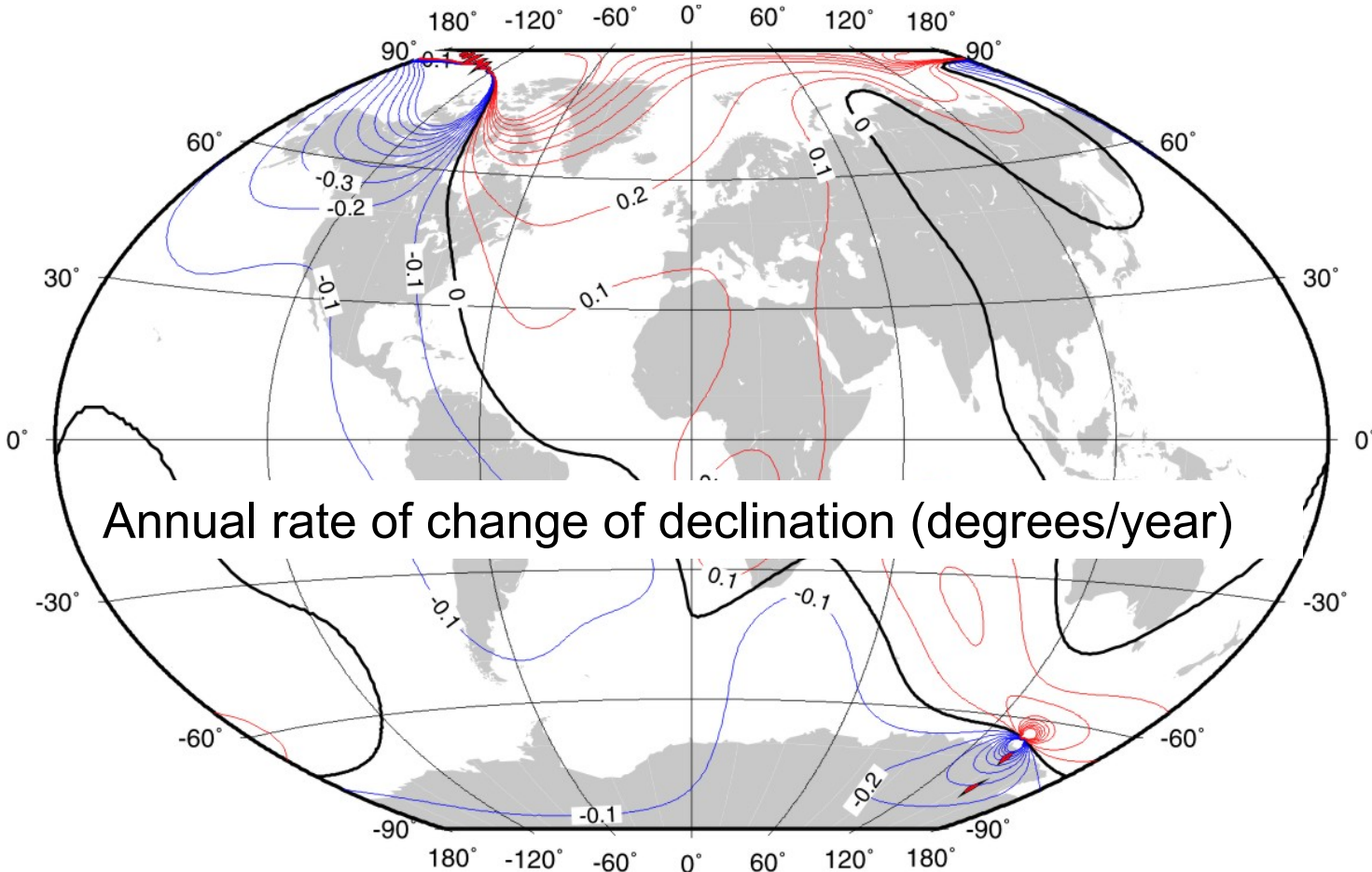
Global magnetic field models

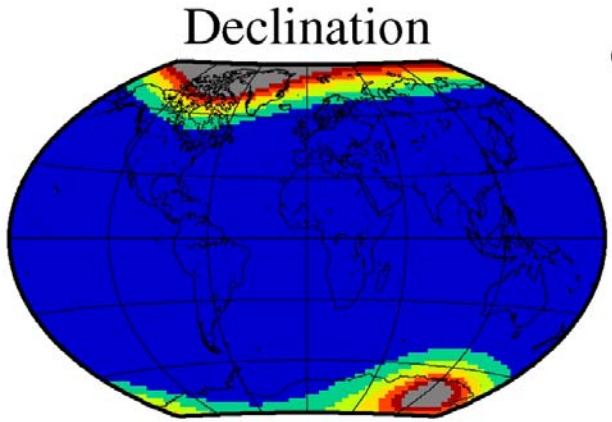
- Spherical harmonic model of the core field and the long wavelength crustal field
- Uses selected satellite and ground based observatory data
- Prediction into future

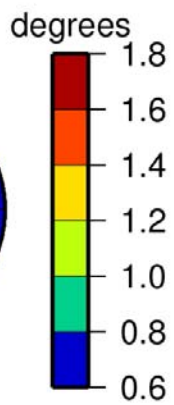


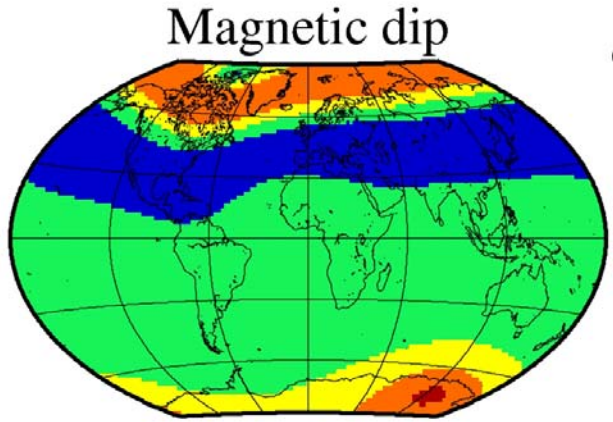
Annual rate of change of declination (degrees/year)

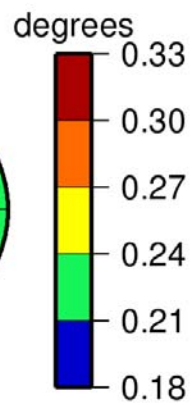
Global field model uncertainties

95.4% confidence limits



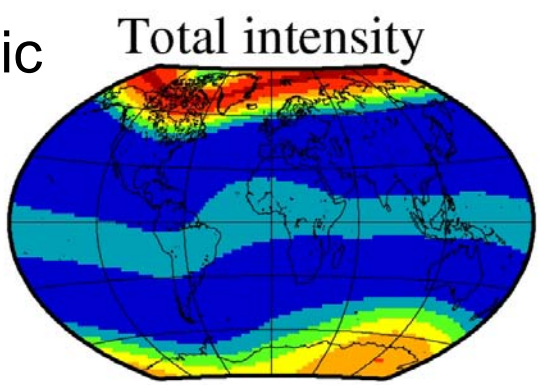


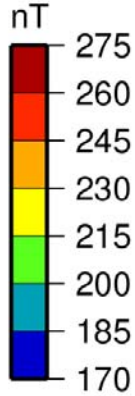




Varies with geomagnetic

- latitude; and
- activity levels

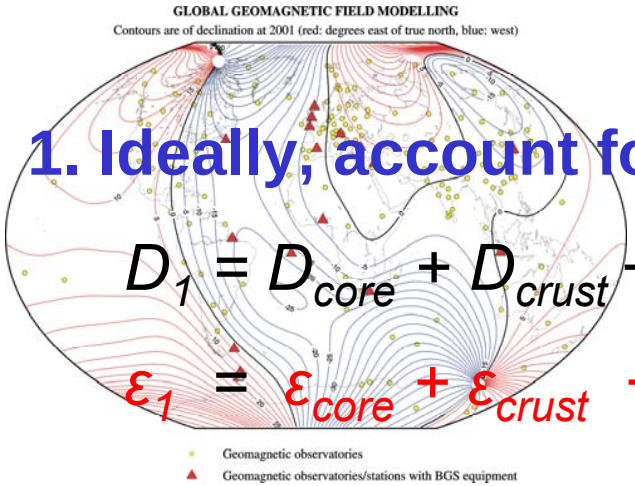


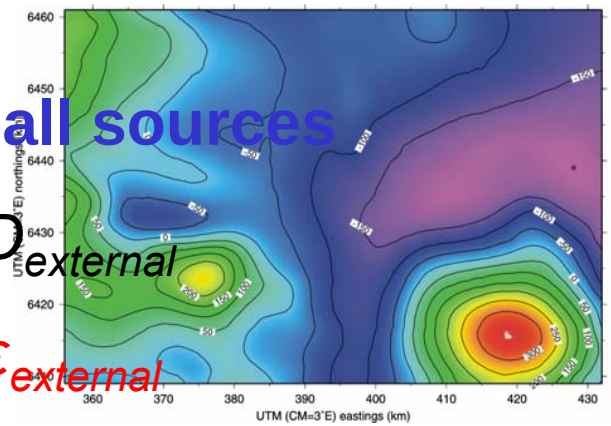


From Macmillan and Grindrod, 2010 (SPE paper 119851)

$$\varepsilon_3 = \varepsilon_{core} + D_{crust} + D_{external}$$

Directional reference and uncertainty





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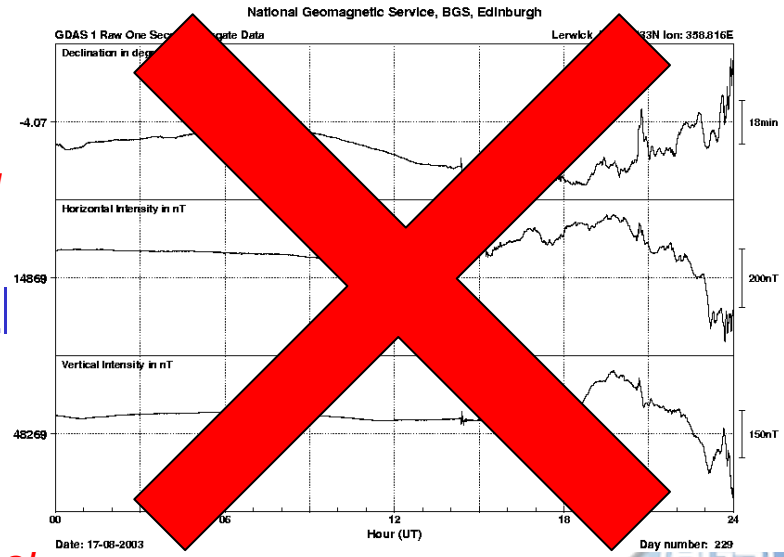
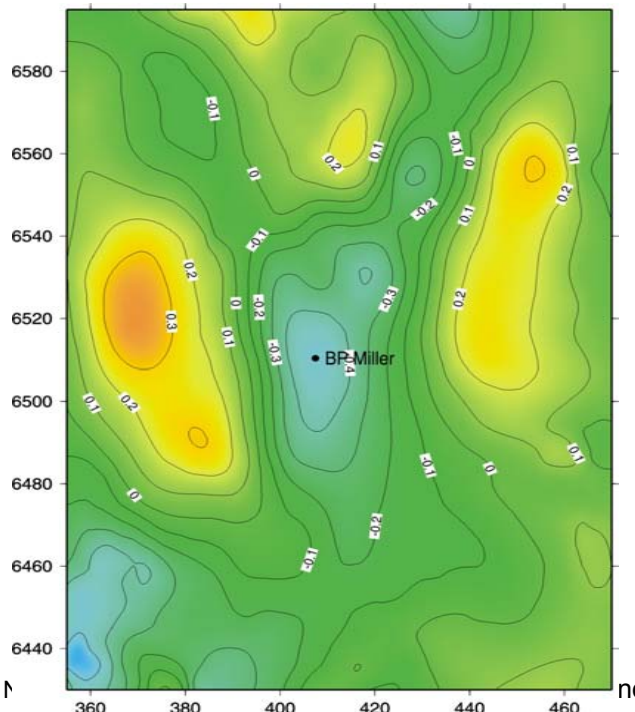
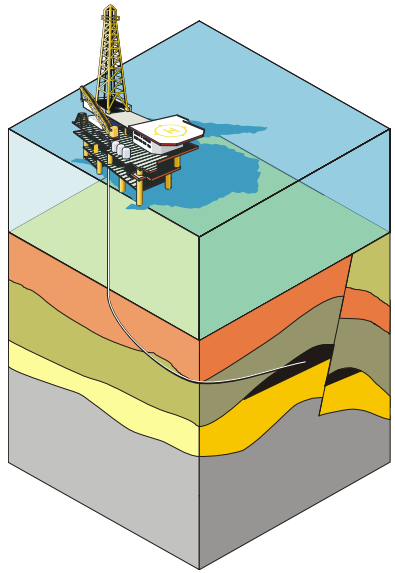


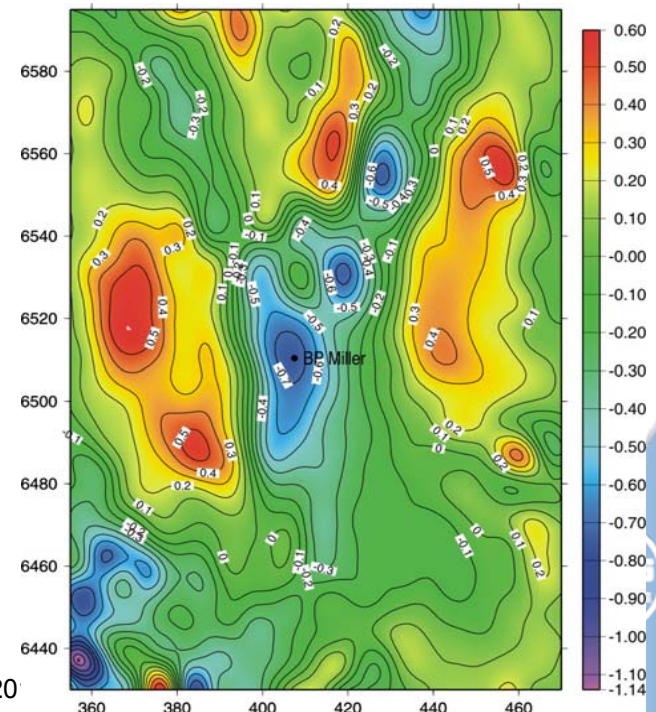
Methods to determine the crustal field

There are three main methods

- Direct measurements of the vector field
- Physical modelling of the magnetic sources
- Transformation of scalar data that exploits the physical properties of magnetic data at or near Earth's surface







Direct measurements

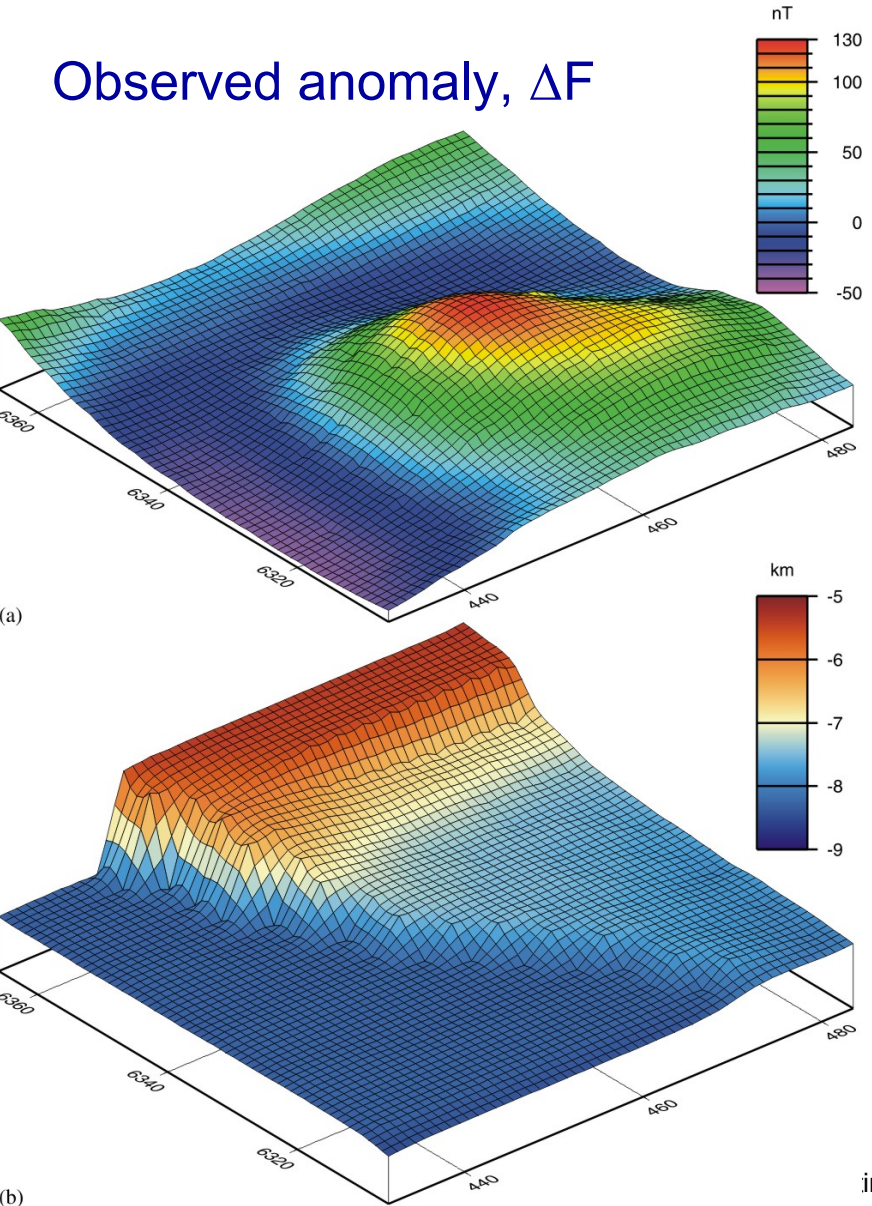
Instruments:

Vector and scalar magnetometers

Ring-laser gyro and GPS

Solving for sources

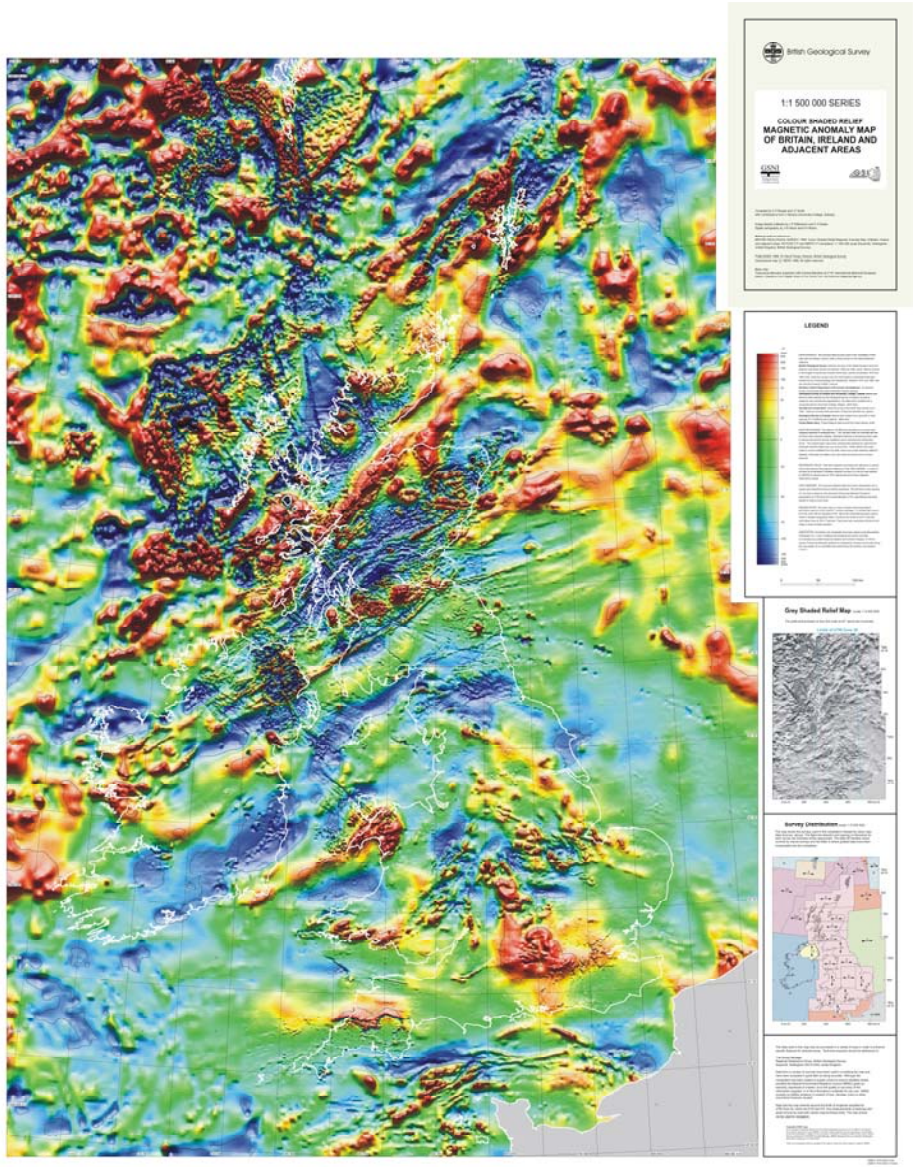
Observed anomaly, ΔF



- Assume magnetisation induced by main field
- Assume magnetisation does not vary with depth

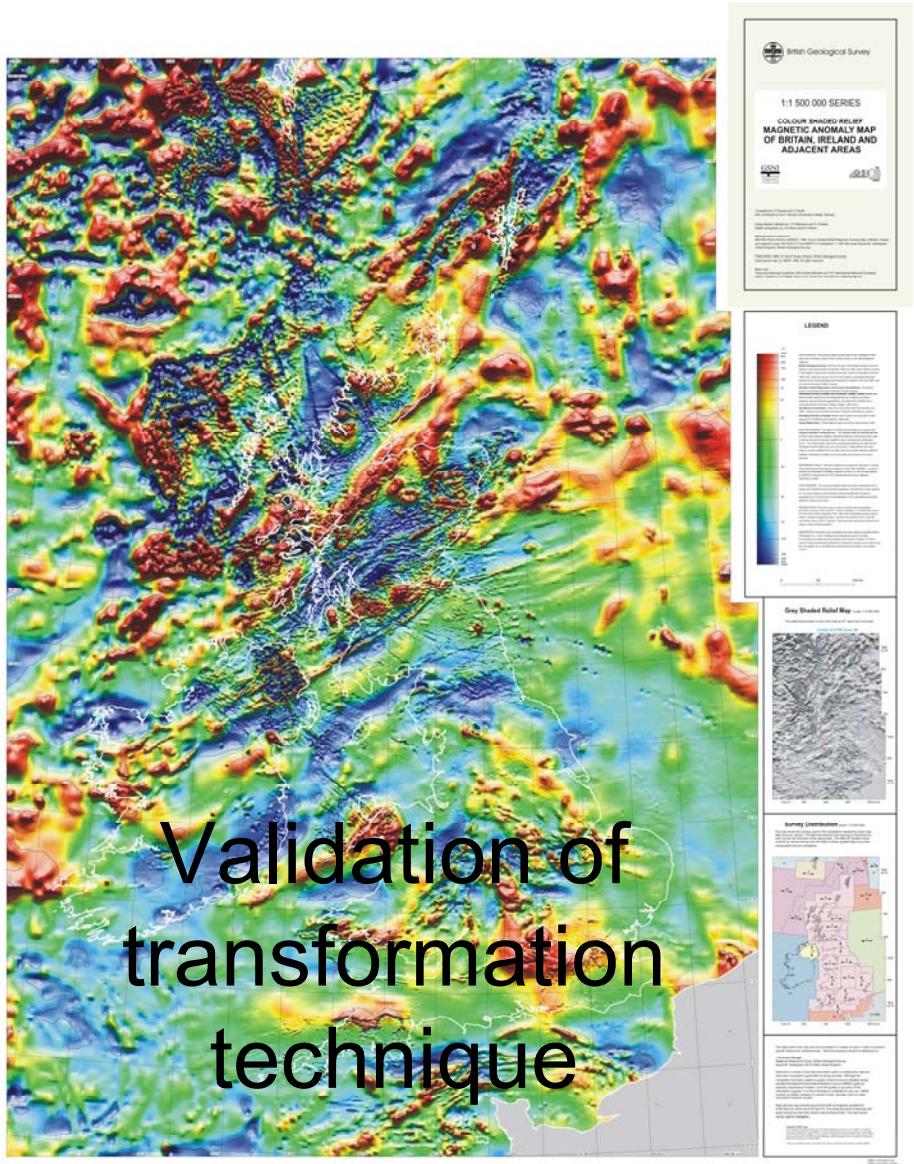
Seismically-determined depth to magnetic basement

Vector from scalar

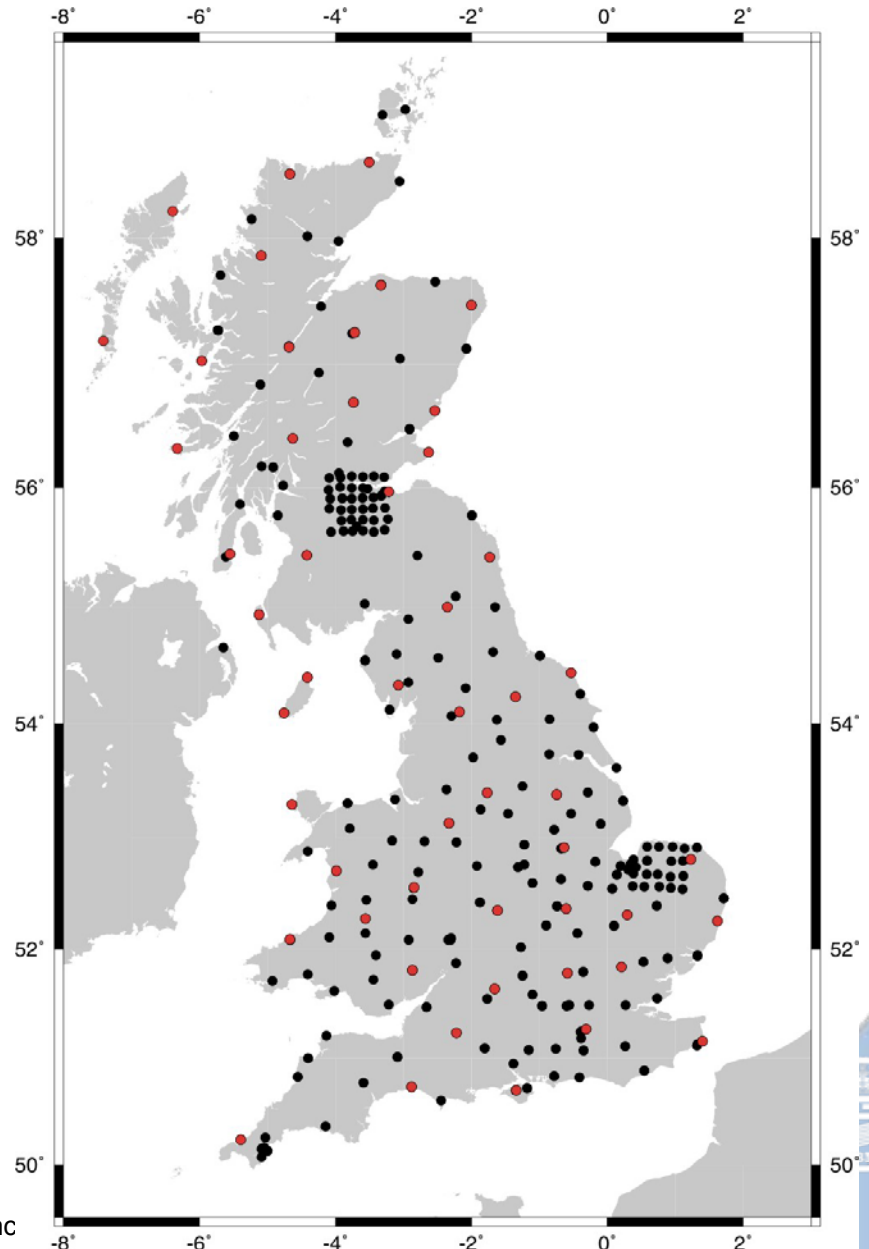


- Assume data collected in source-free region
- Assume constant main field over the area

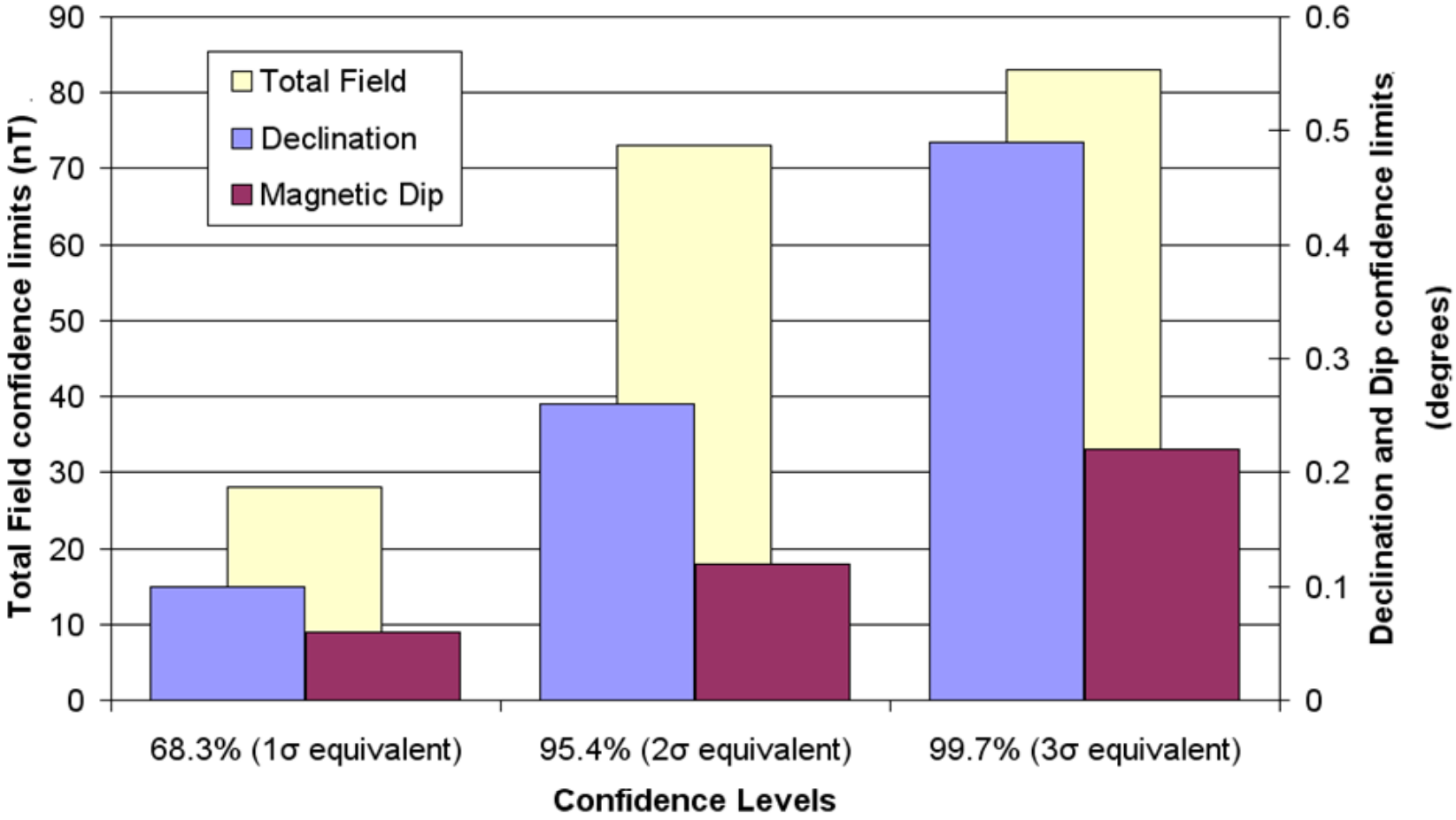
Crustal (and core) field uncertainties



Validation of transformation technique



Crustal (and core) field uncertainties



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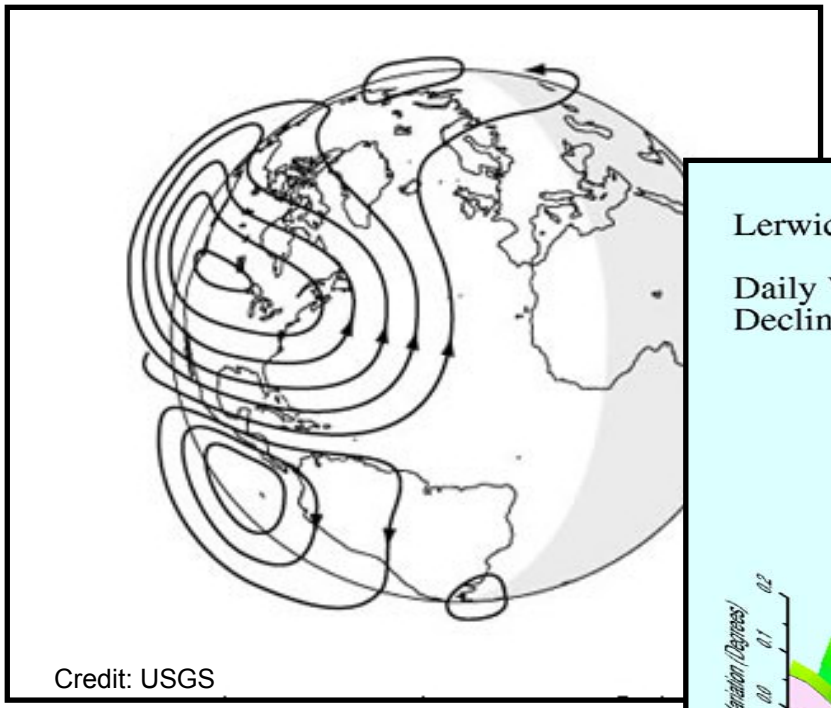
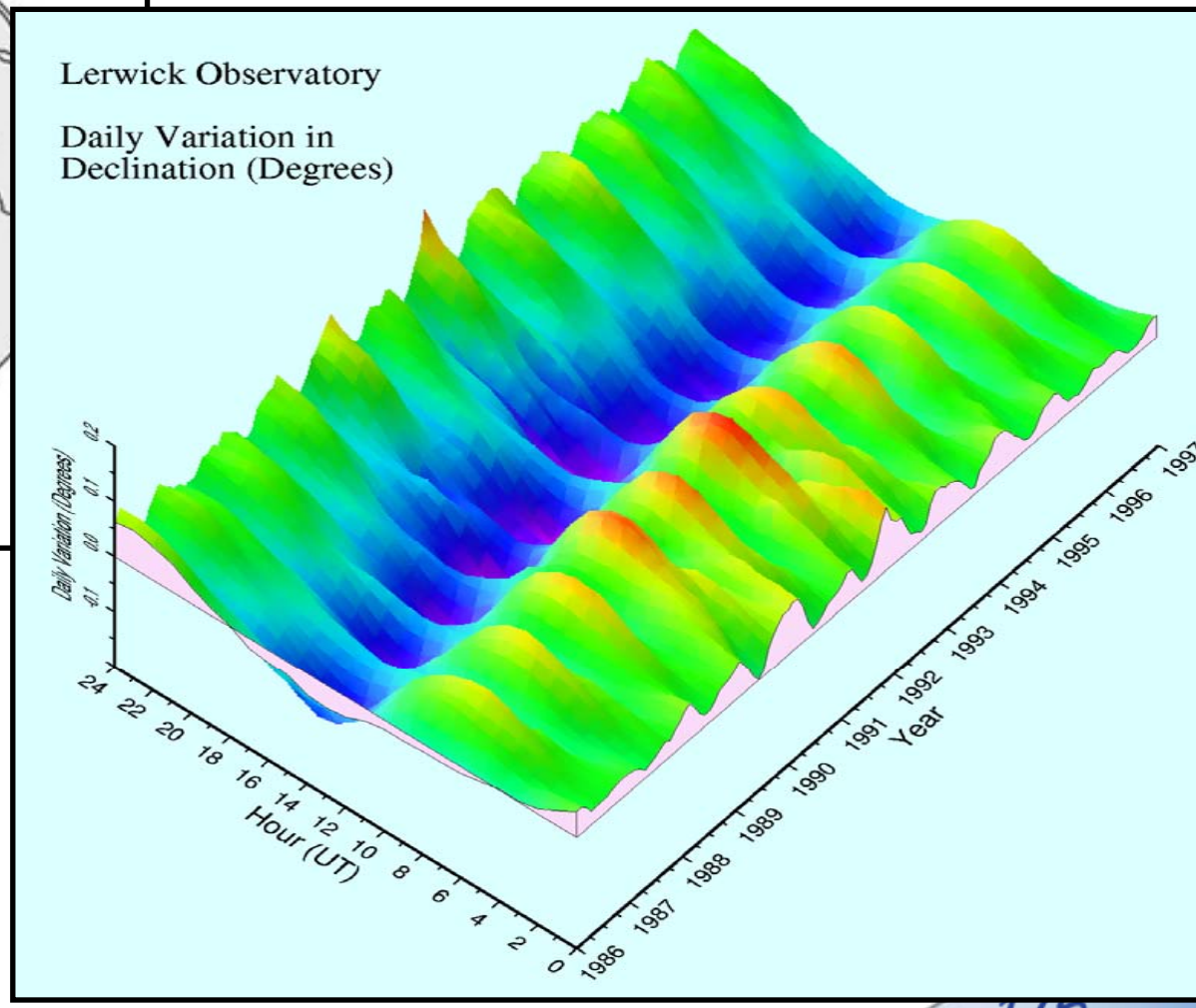
External fields: ‘regular’ disturbances



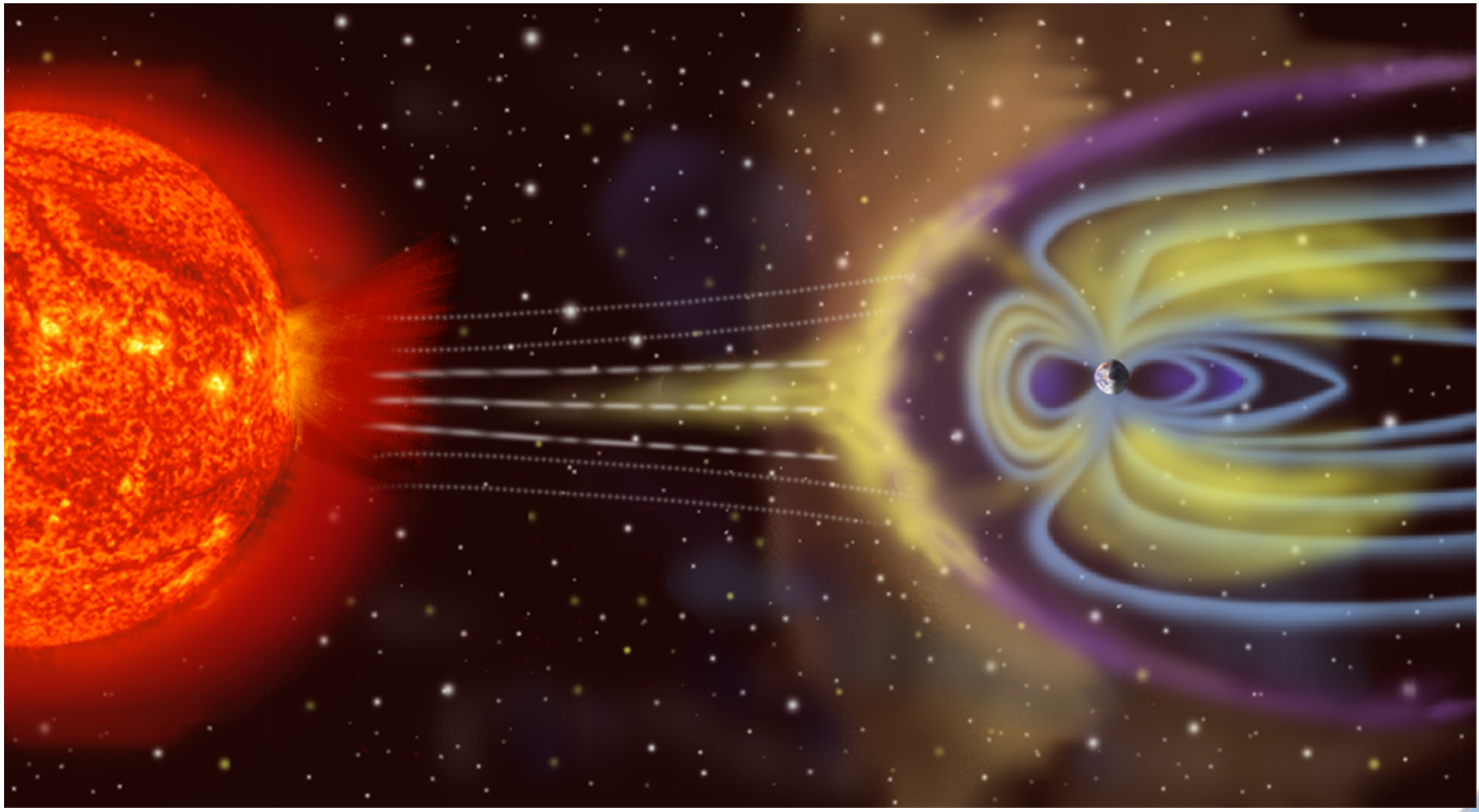
Credit: USGS

ionospheric currents



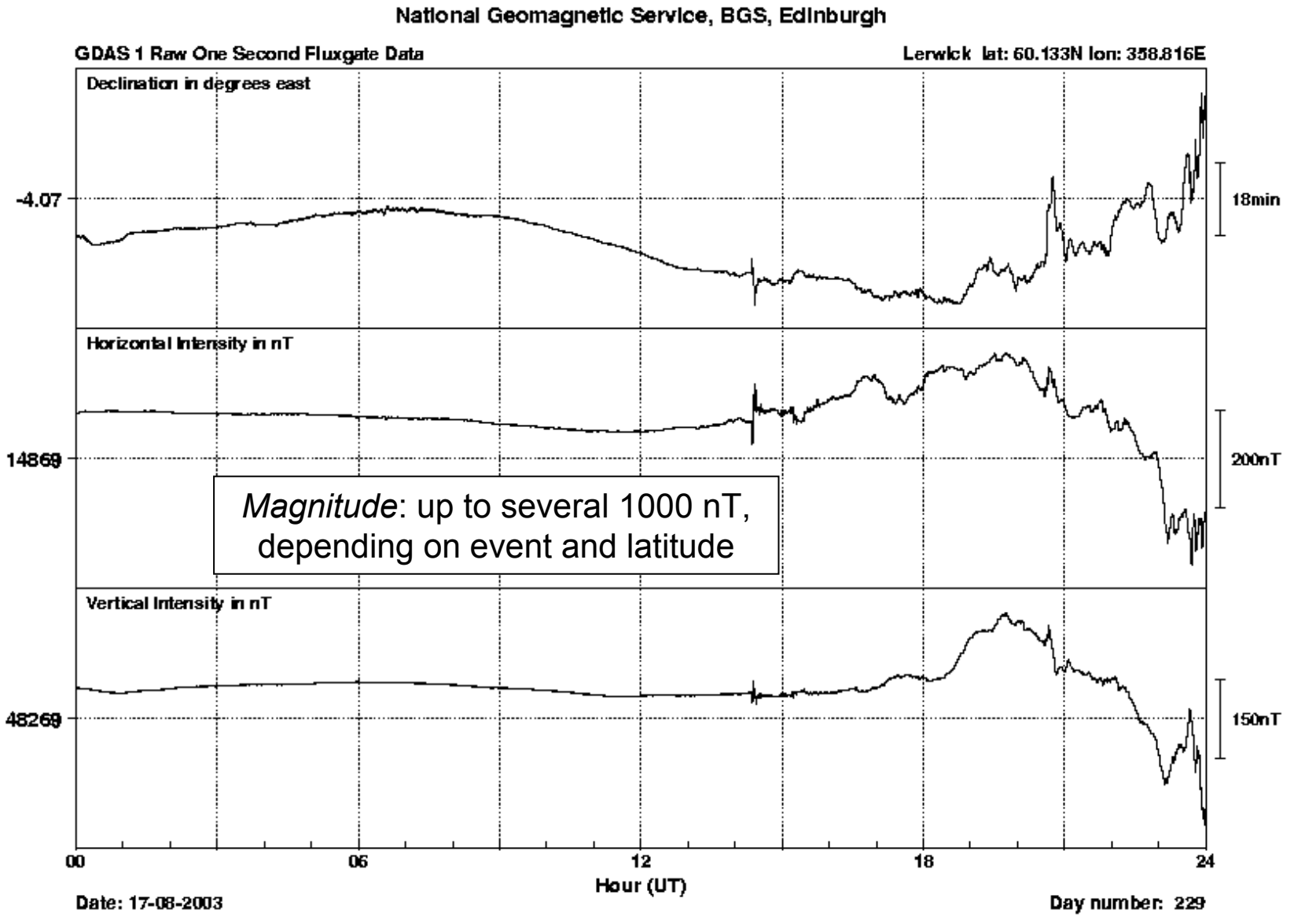
diurnal variation

External fields: irregular disturbances



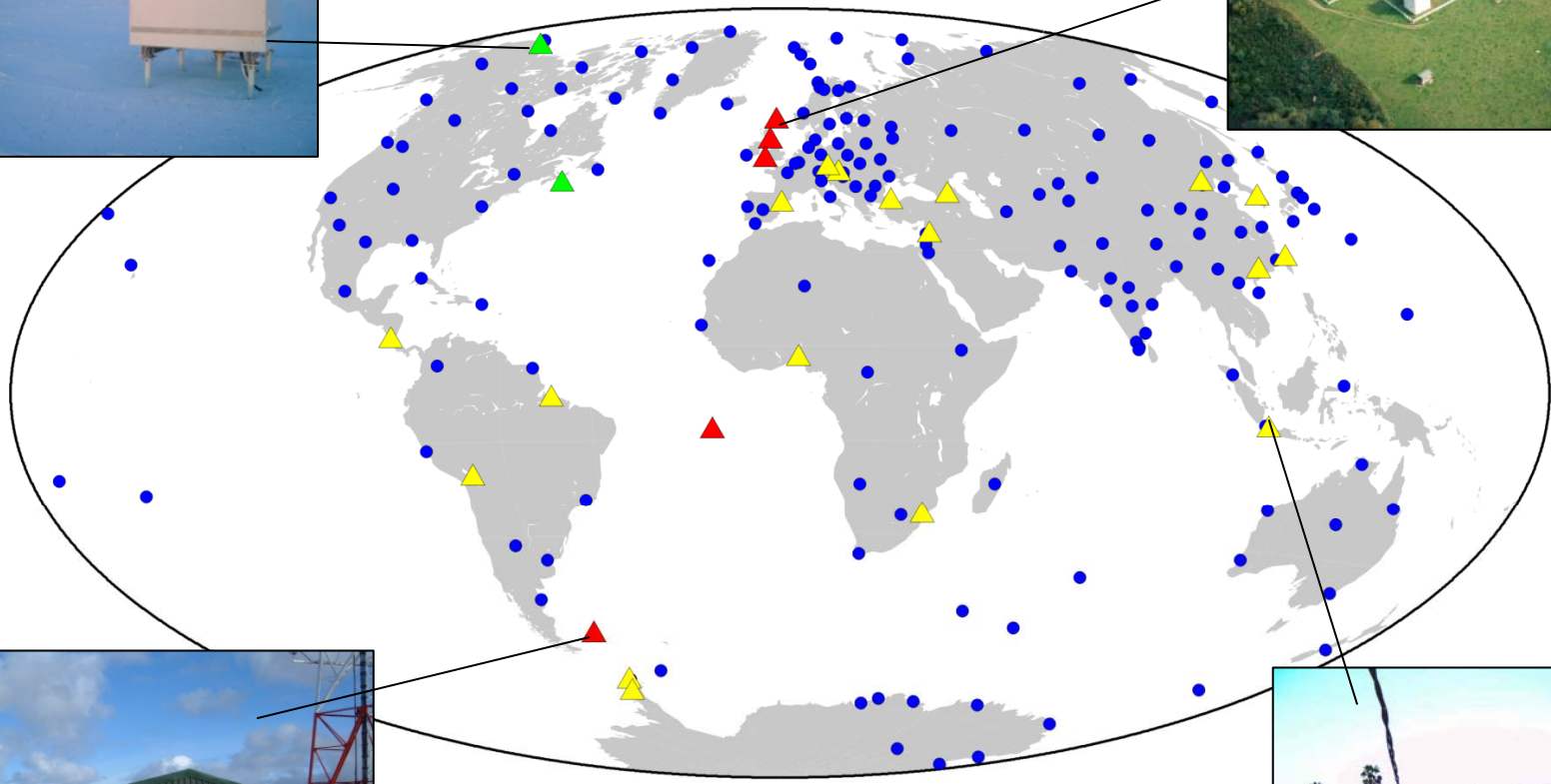
Solar wind speed 300 to 1000 km/s
(1 - 4 days to travel to the Earth)

External fields: irregular disturbances



Magnitude: up to several 1000 nT, depending on event and latitude

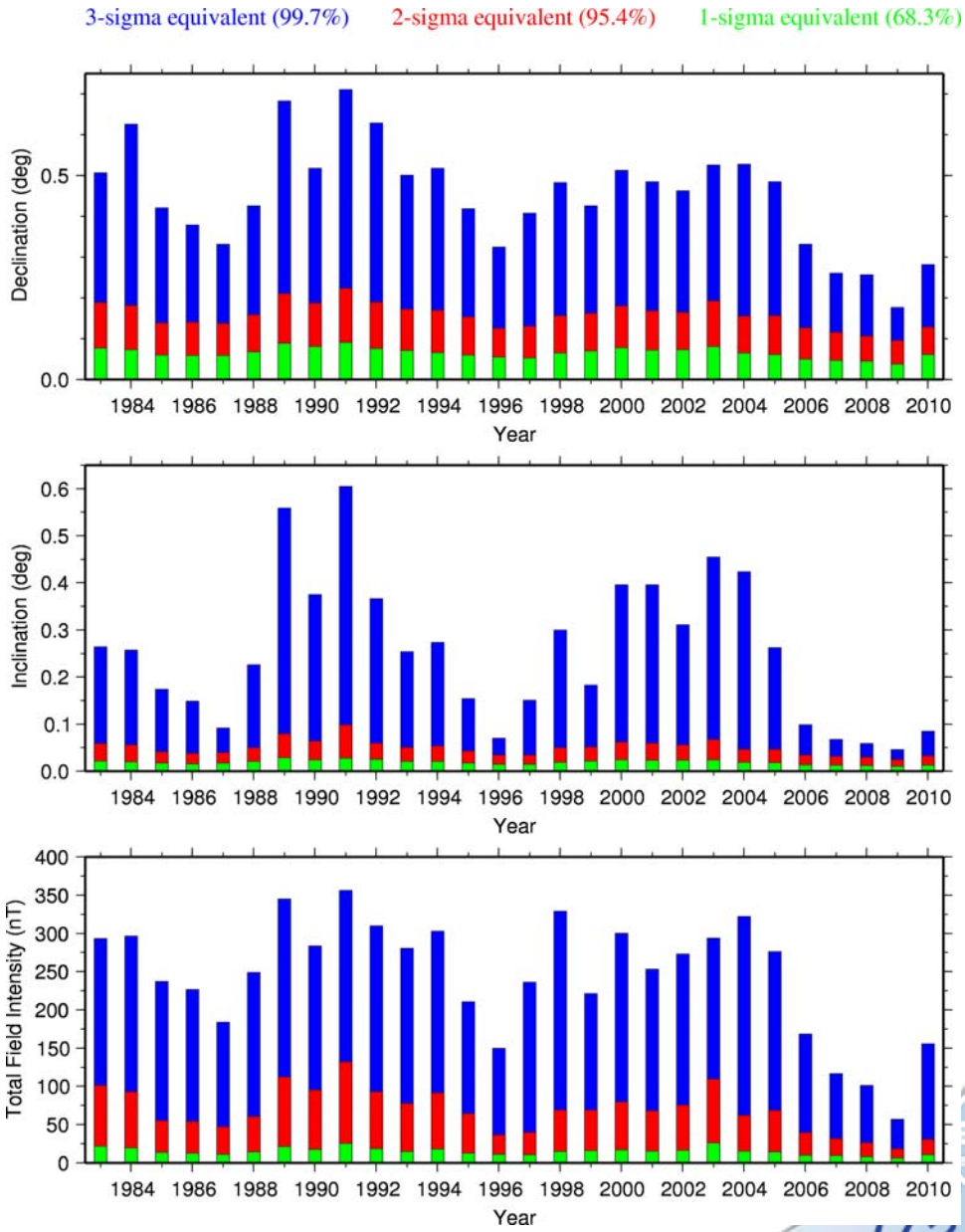
Geomagnetic Observatories



Crustal (and core) field uncertainties

... due to signal from external fields

variations by **year** (at Lerwick)



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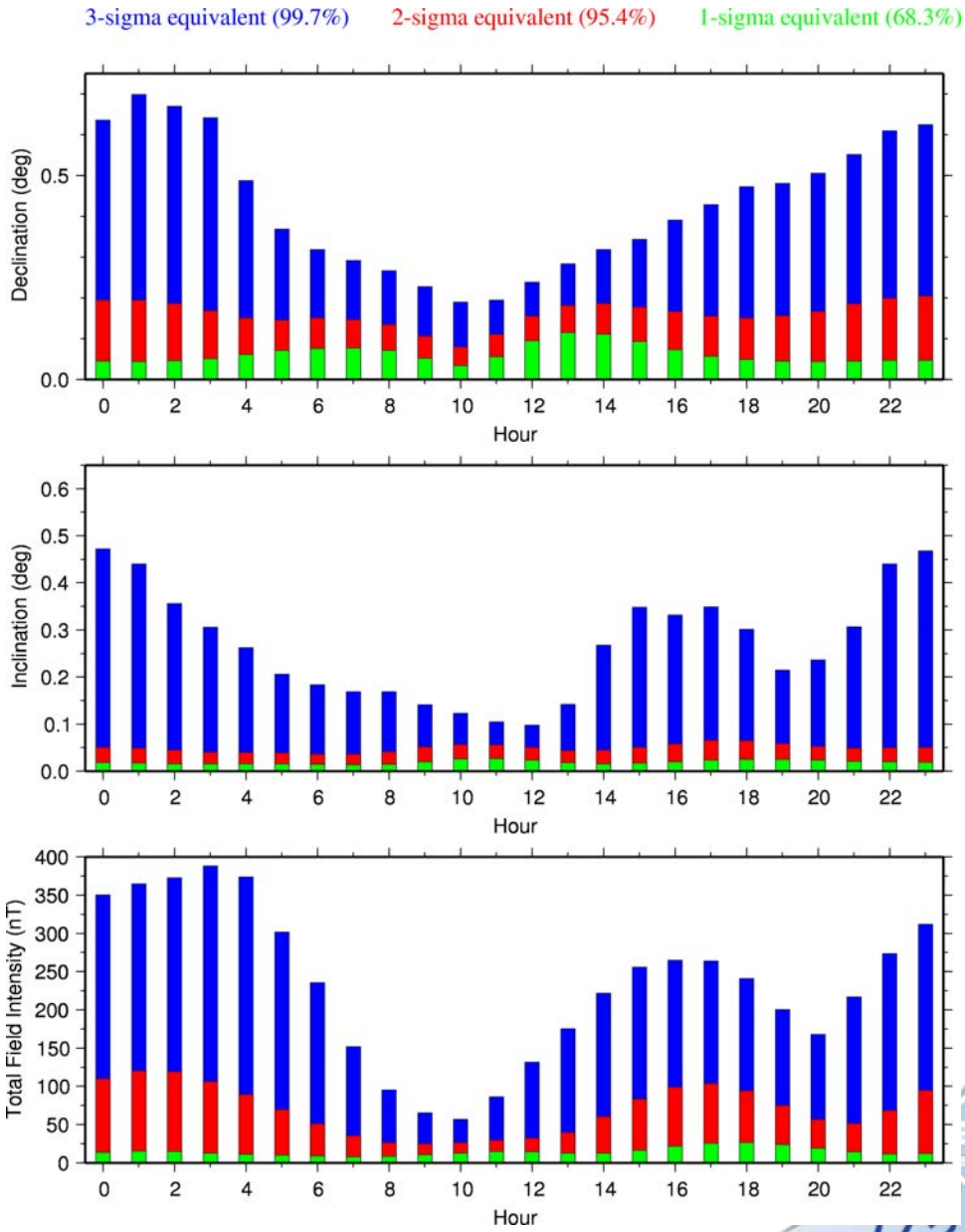
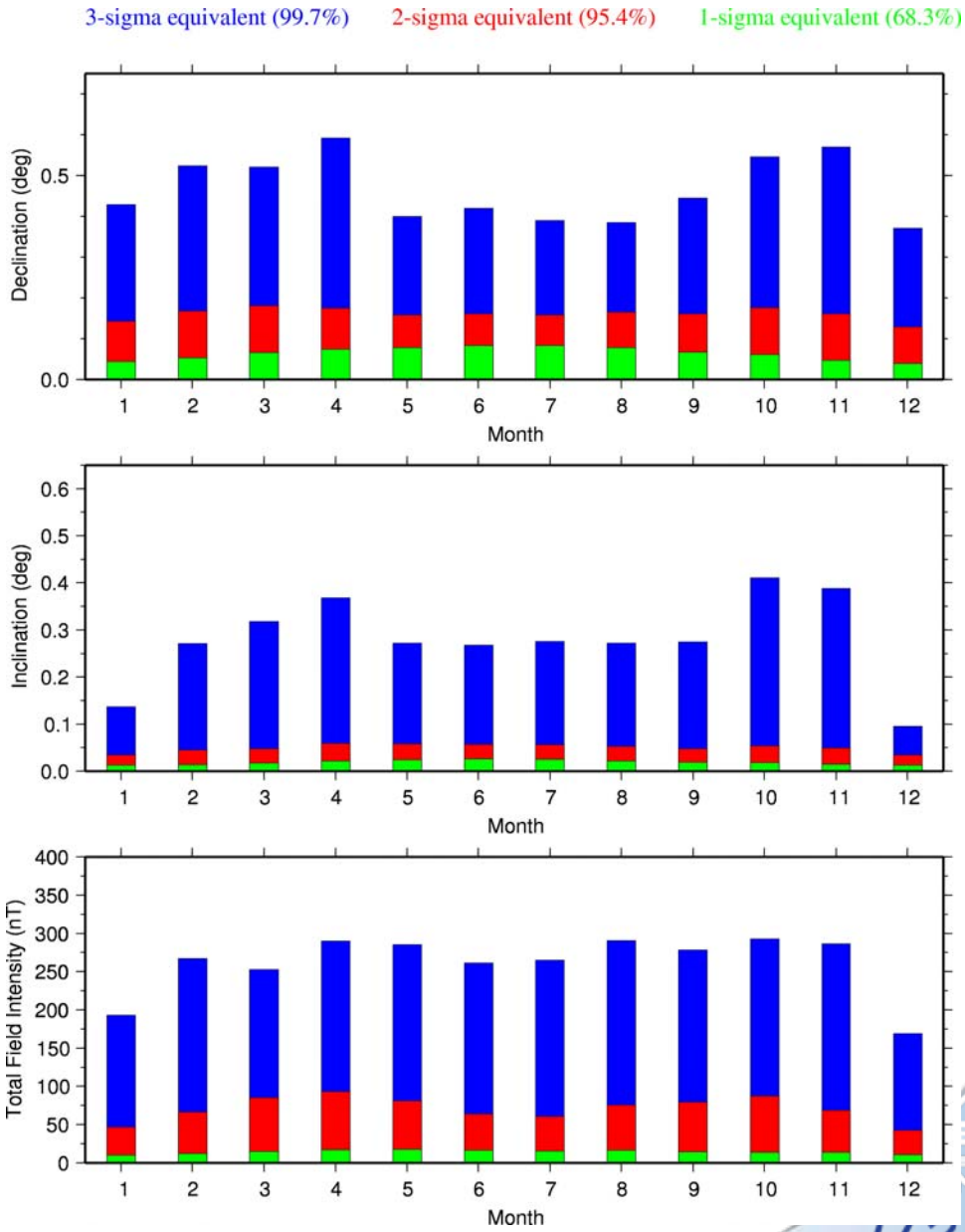


Crustal (and core) field uncertainties

... due to signal from external fields

variations by **month** (at Lerwick)



Directional reference and uncertainty

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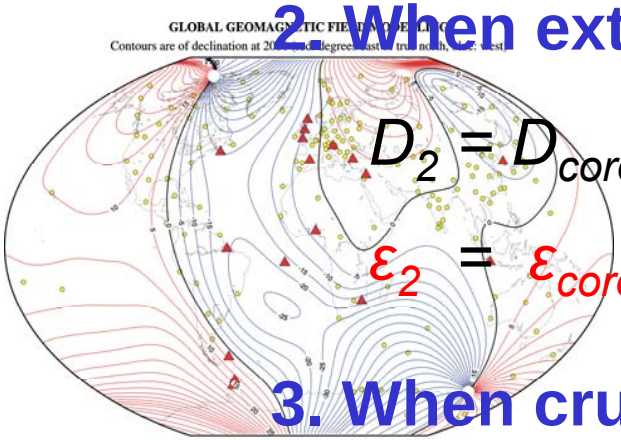

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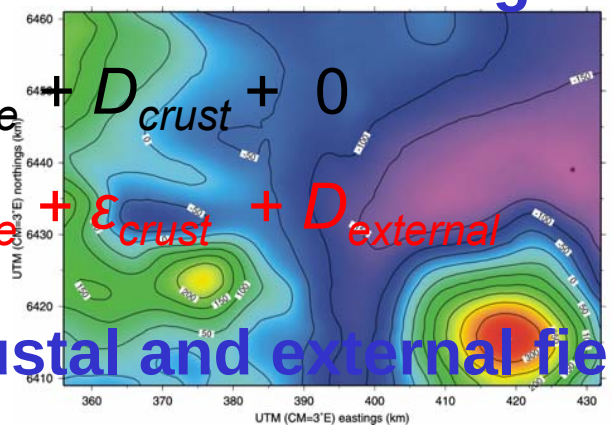

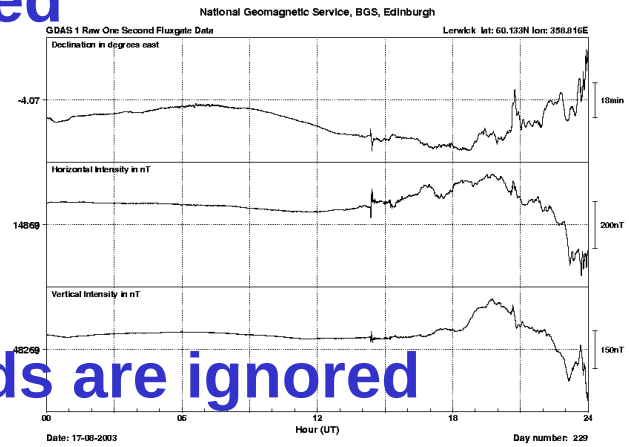

3. When crustal and external fields are ignored

$$D_3 = D_{core} + 0 + 0$$

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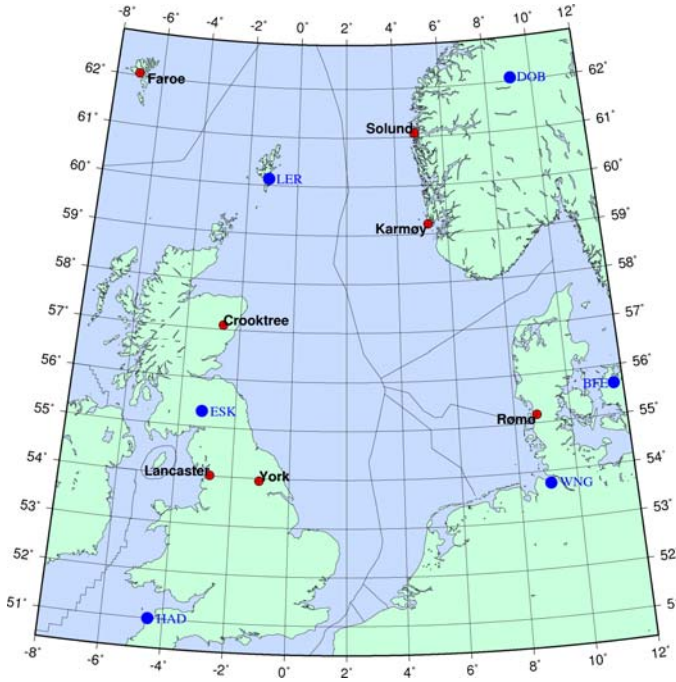
Estimating the external field at the drill site

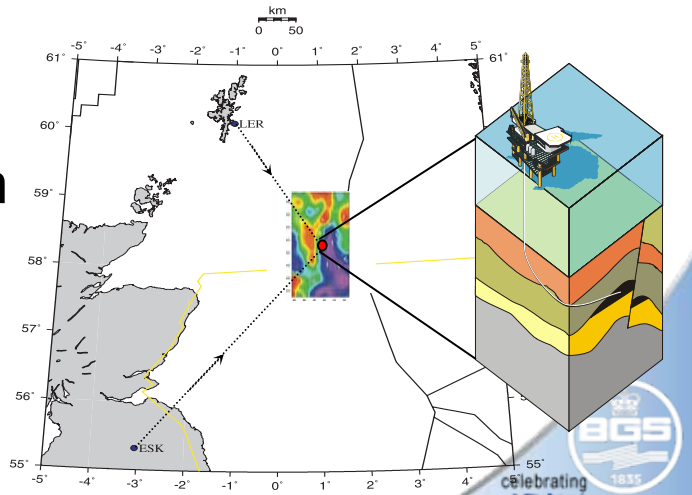
- Use data from nearby magnetic observatories (and/or calibrated variometer stations)

  - can use one or more

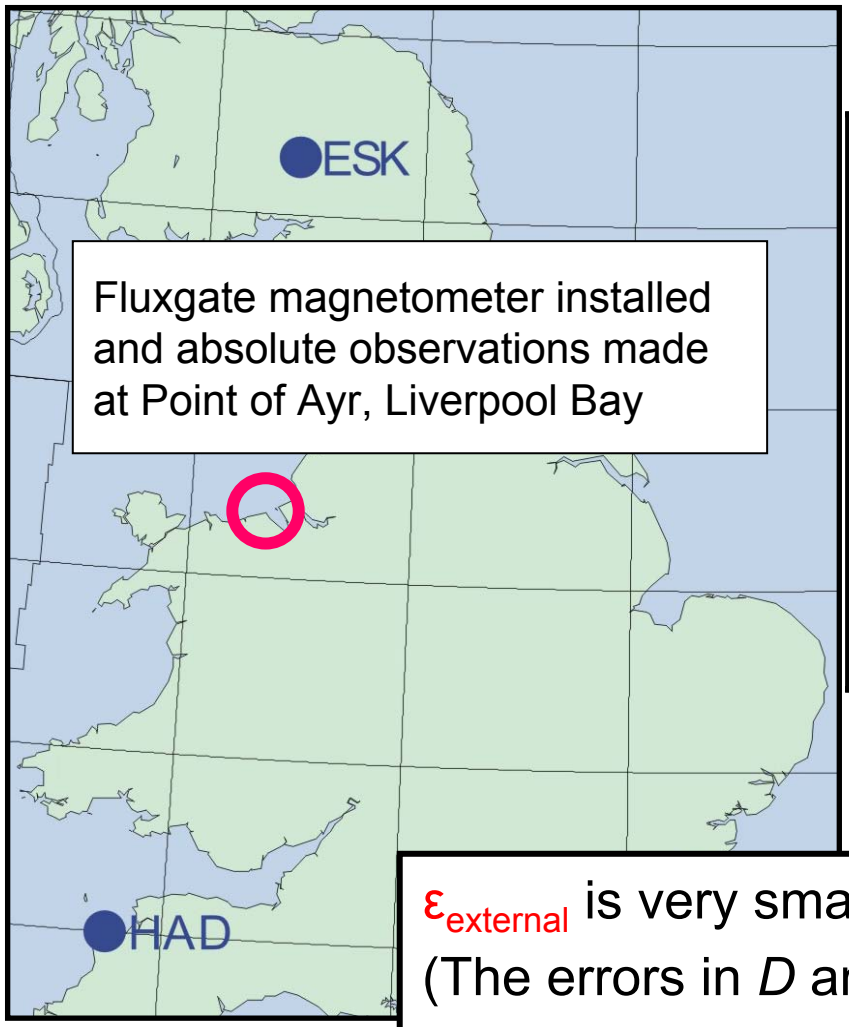
- Take advantage of observatory quality control, quasi-definitive data and real-time operations

- Use the real observatories to create a ‘virtual’ observatory at the drilling location





Liverpool Bay experiment 1994-95



Month	*D* (deg)	*I* (deg)	*F* (nT)
Oct 94	0.006	0.005	5.3
Nov 94	0.008	0.006	3.4
Dec94	0.007	0.003	5.3
Jan95	0.005	0.002	4.4

Russell, Shiells and Kerridge, (1995)

$\varepsilon_{external}$ is very small compared with the errors $\varepsilon_{core} + \varepsilon_{crust}$
(The errors in *D* and *I* are ~0.07° and ~30nT in *F.*)
At North Sea latitudes the contribution of $\varepsilon_{external}$ does not significantly affect the overall uncertainty of the technique.

External field uncertainty revisited 2005

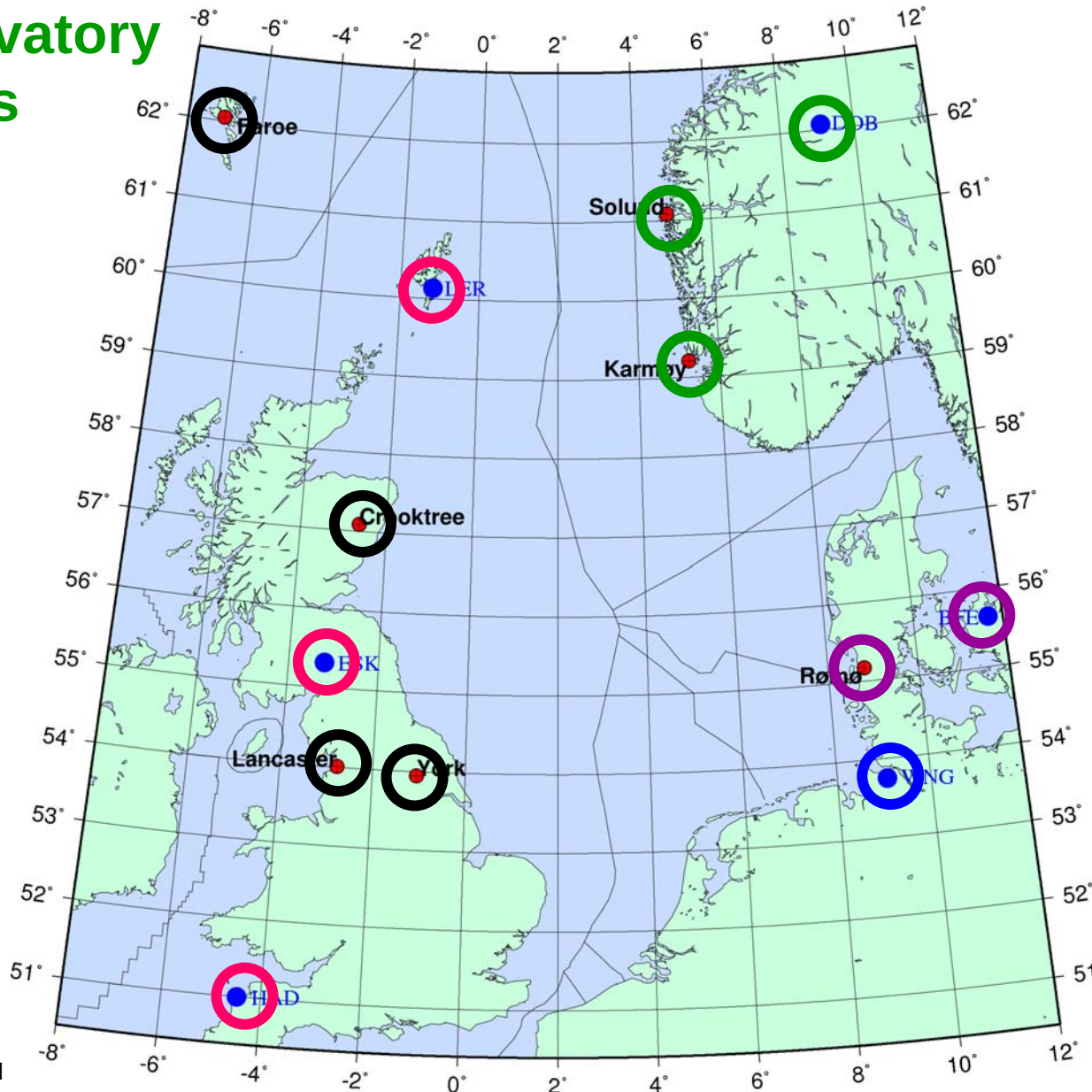
TGO (Norway) observatory & variometer stations

GFZ (Germany) observatory

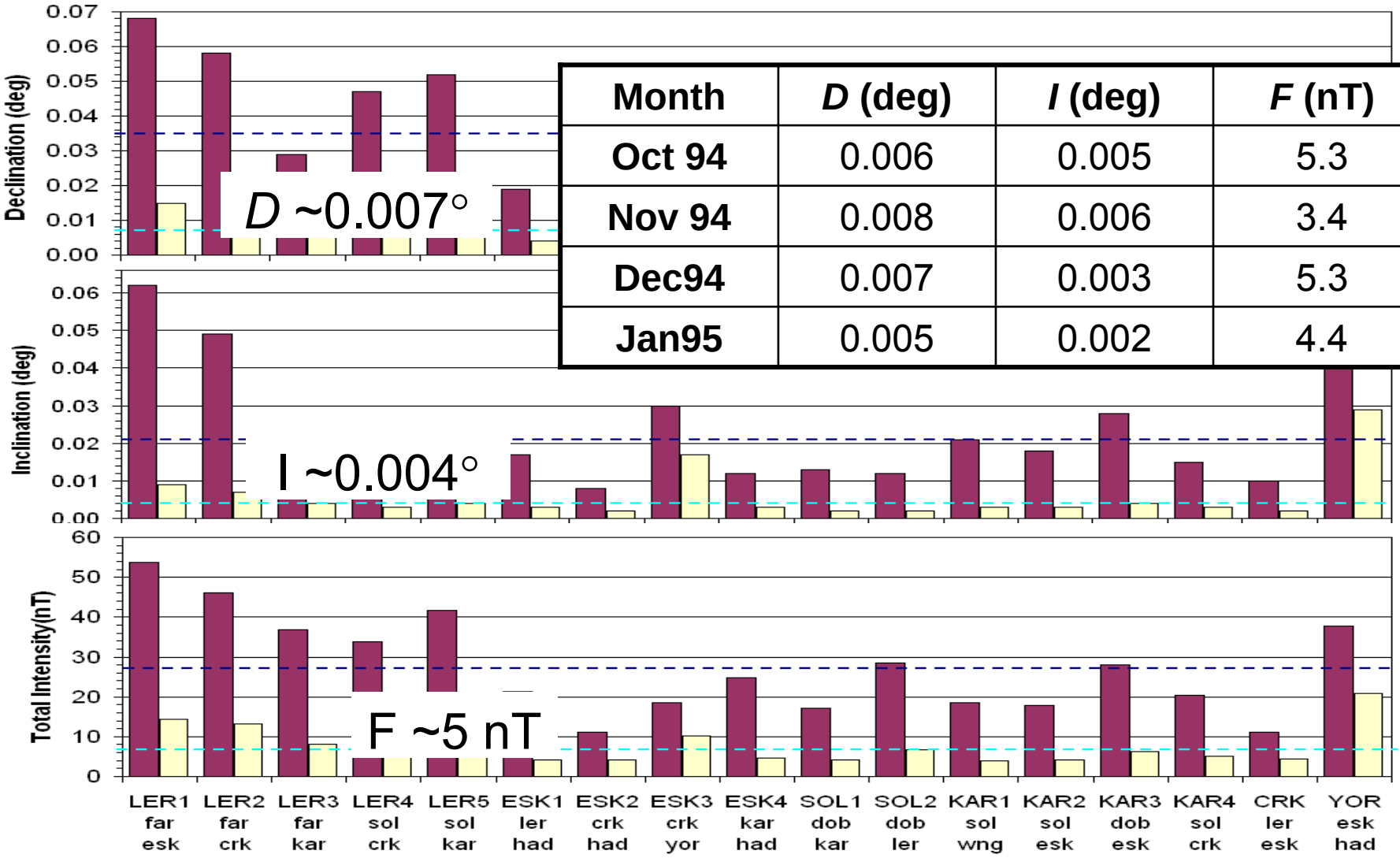
DMI (Denmark) observatory & variometer station

SAMNET (UK) variometer stations

BGS (UK) observatories



External field uncertainties ($\varepsilon_{external}$) around the North Sea



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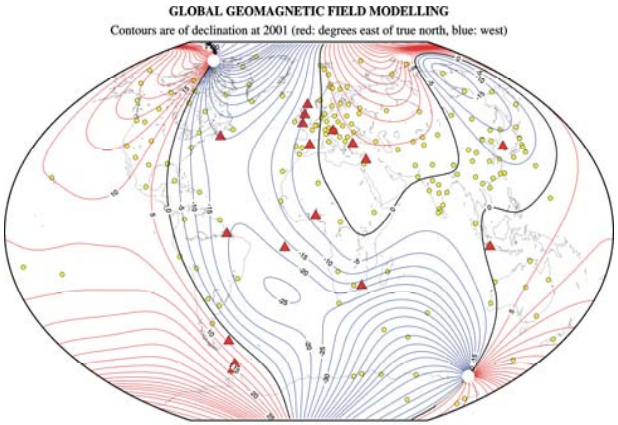
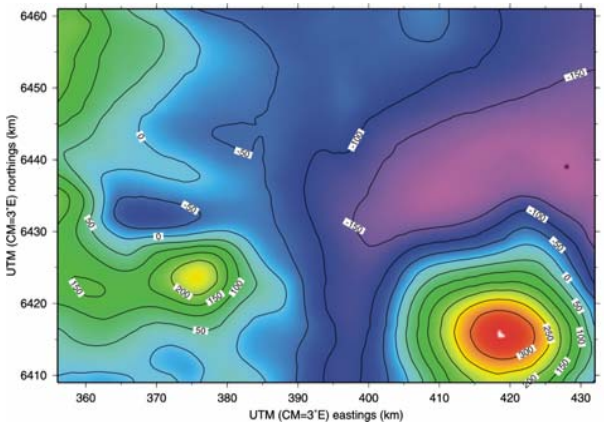
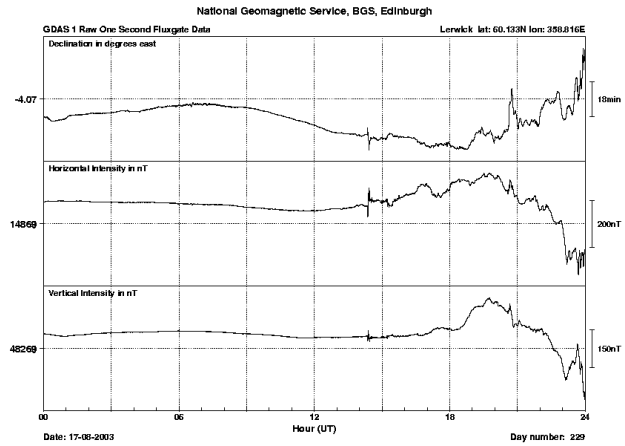






Summary and Conclusions

• Providing a single answer on the uncertainty associated with the geomagnetic reference field is hard.

• The uncertainty associated with a particular reference value, depends on

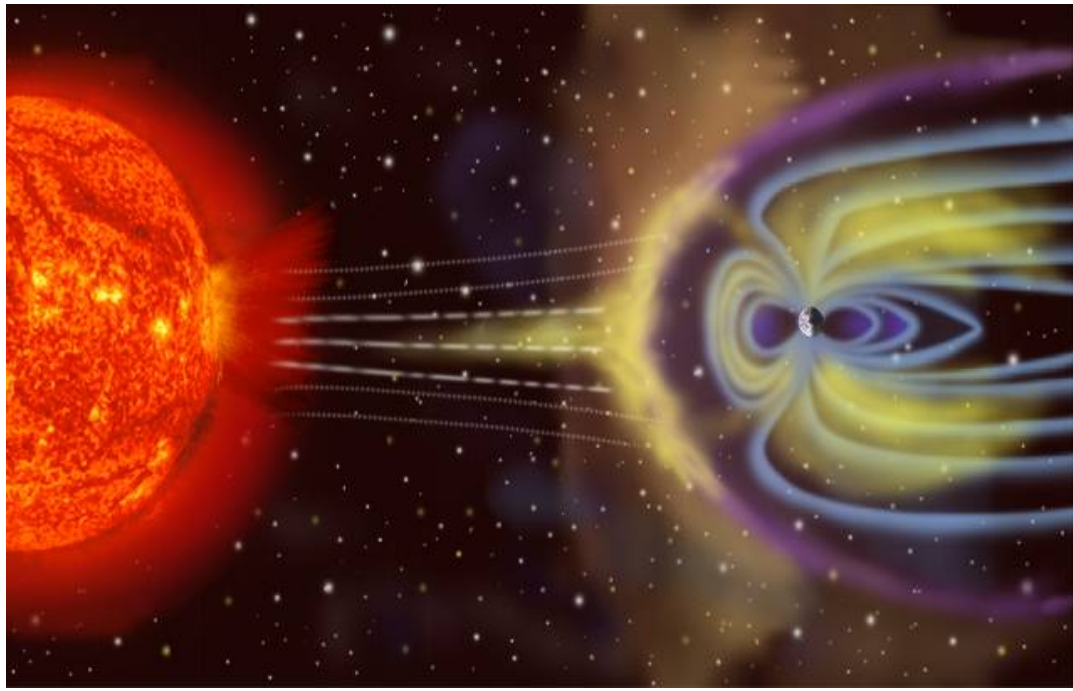
what sources are included in the estimate;
location on the earth's surface; and often on
time of day, season and solar cycle

• Including all sources will

reduce the uncertainties; and importantly,
provide a more robust estimate of the uncertainties by removing any hourly, seasonal and solar cycle variations

External field sources

- Ionospheric currents
  - from about 100 km altitude
- Magnetospheric currents
  - out to several Earth radii
- Secondary currents induced in the earth



External fields: long-term trends