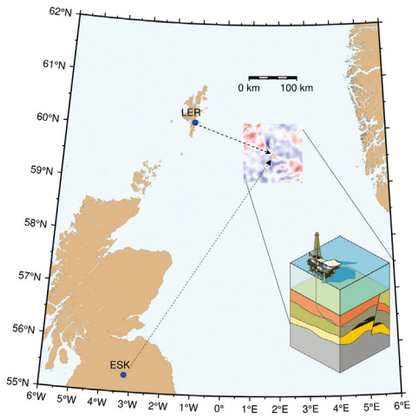
At mid-latitude, the daily range of the magnetic field direction often exceeds the desired threshold accuracy of 0.1° for the magnetic declination. They can also experience much greater variations, due to solar activity-driven geomagnetic storms, during which declination can change by several degrees in less than 20 minutes.

Combining the IFR1 results with $\boldsymbol{B}_{external,}$ as measured at nearby magnetic observatories or calibrated variometer stations, accounts for all sources. IFR2 provides accurate estimates of the magnetic field for quality control and correction of borehole surveys, either in real time or retrospectively.

Figure 2 Geomagnetic observatories around the globe. BGS © UKRI 2025.

Figure 3 Measurements from geomagnetic observatories (Figure 2) combined with IFR1 provide a 'virtual' observatory at the drilling location. BGS © UKRI 2025.



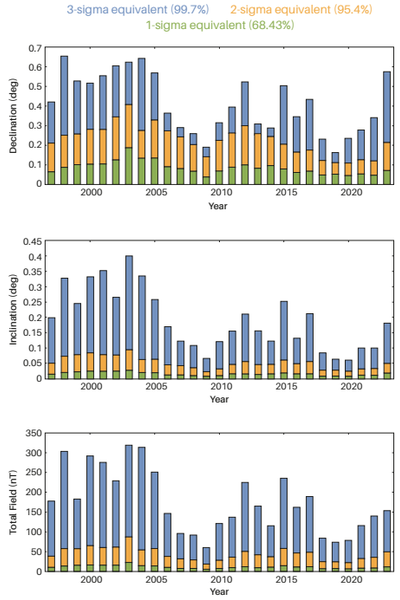


Figure 4 Example of solar cycle dependence of uncertainties in the North Sea associated with the external field; that is, using IFR1 only. Analysis of this type and results specific to the region are provided in the written reports. BGS © UKRI 2025.

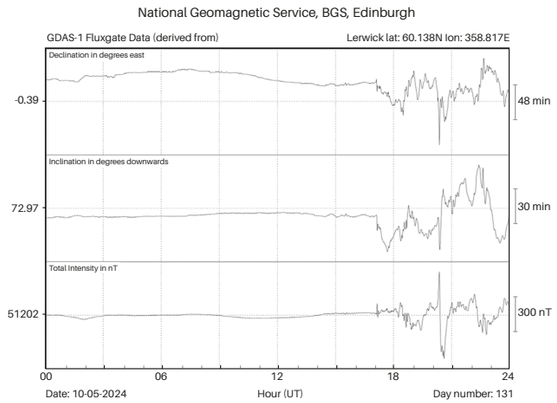
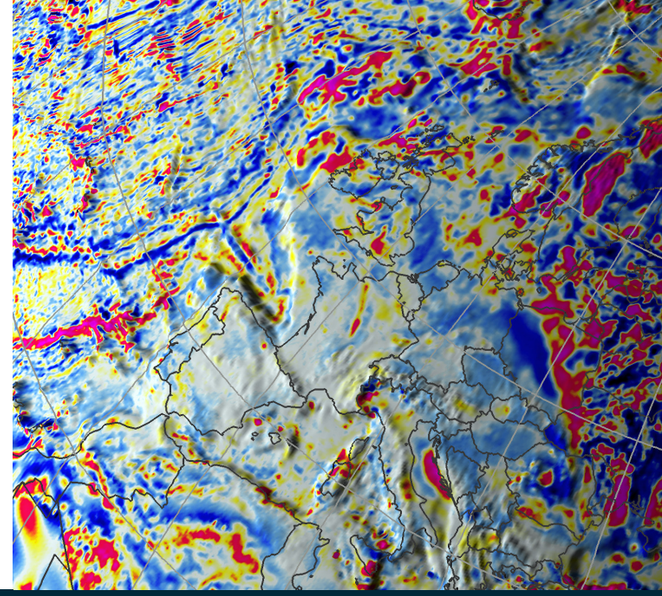


Figure 5 Lerwick observatory (LER) magnetogram showing declination (top panel), dip (middle) and total field intensity (bottom) variation. A geomagnetic storm starts at 17:00 UT. BGS © UKRI 2025.

The IFR2 service includes:

- values from the IFR1 service
- derivation of time-stamped, one-minute values of declination, dip and total field intensity at well-path waypoints
- web-based, real-time data supply to customer:
  - dedicated secure pages for each site
  - magnetograms for reference
- responsive stop/start data supply as required
- real-time automated monitoring and regular quality control checks by scientists
- back-up systems at every stage of the processing chain



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British Geological Survey

Interpolated in-field referencing (IFR2) and in-field referencing (IFR1) services for improved well-bore placement accuracy enhance drilling efficiency and reduce the risk of collisions.

Geomagnetism as a tool for well-bore navigation

Navigating towards subsurface targets when drilling for oil and gas holds many challenges. With increased distances of horizontal well reach: positional certainty is hard to achieve; there is an increased risk of collision with neighbouring wells in the congested subsurface; and ever-decreasing target areas are harder to hit.

Directional drilling is a firmly established technique within the industry. Using magnetic survey instruments downhole to make measurements while drilling (MWD) can reduce drilling time and thus operational costs. Accurate, high-quality information on the Earth's magnetic field (***B***) is needed to attain the required levels of precision for MWD surveys with confidence.

In general, accuracies of 0.1° for the horizontal angle (magnetic declination), 0.05° for the vertical angle (magnetic dip) and 50 nT for total field strength are desired.

MAGNETIC FIELD CORRECTIONS

The BGS Global Magnetic Model (BGGM), in-field referencing (IFR1) and real-time interpolation in-field referencing (IFR2) enable the BGS Geomagnetism team to provide accurate estimates of:

The main field ($\boldsymbol{B}_{main}$) generated by the fluid motion in the Earth's outer core plus the large-scale crustal field.

Local crustal field ($\boldsymbol{B}_{crust}$) anomalies arising from nearby rocks.

The external field ($\boldsymbol{B}_{external}$) that results from electrical current systems in the ionosphere and magnetosphere.

BGS Global Geomagnetic Model

The BGGM is a high-definition mathematical model of the Earth's undisturbed internal field ($\boldsymbol{B}_{main}$). A new model is released every year, providing the most up-to-date and accurate global estimates. The sources included are the main magnetic field from the outer core and large-scale crustal features, providing up to 28 km spatial resolution.

In-field referencing

Local crustal anomalies are significant in directional drilling, particularly since the errors generated without including them are often systematic and grow with well total depth (TD).

IFR1 is calculated as:

$$IFR1 = BGGM + \boldsymbol{B}_{local\ crust}$$

IFR1 provides accurate geomagnetic field estimates along well paths and includes the geomagnetic sources from the Earth's core and from the Earth's crust (local rocks), providing even higher higher accuracy than the BGGM alone.

The IFR1 service includes:

- Field-specific IFR set-up
- A written report including bespoke uncertainty estimates
- Maintaining the field set-up for as long as the field is operated
- Per well and per pad requests
- IFR1 HyperCube web application

To derive crustal field anomalies, we make use of data collected from aeromagnetic surveys so the local crustal fields are mapped up close. Mathematical techniques are applied to extract the directional information from the field strength measured by the aircraft.

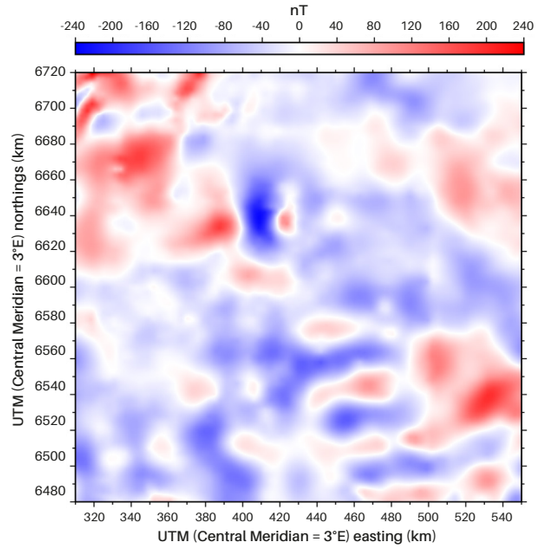

Figure 1 Crustal anomaly map for an area of the North Sea. The crustal field varies on geological timescales and can be considered as a static offset to values derived from global models. BGS © UKRI 2025.

Depth (m)	Declination (°)	Dip (°)	Total Field Intensity (nT)
0	0.196	75.524	51305.8
760	0.136	72.528	51338.0
1370	0.077	72.520	51350.0
1860	0.031	72.522	51377.5

Table 1 IFR1 derived values for a particular well in the North Sea.

Interpolation in-field referencing

IFR2 is calculated as:

$$IFR2 = IFR1 + \boldsymbol{B}_{external}$$

The Earth's magnetic field varies in time and space due to external field sources. These include regular daily variation values.