ON THE MOVE

EARTH'S MAGNETIC NORTH POLE HAS RECENTLY MOVED AT UNPRECEDENTED RATES. CIARÁN BEGGAN DISCUSSES WHERE IT MAY MOVE NEXT, AND THE IMPLICATIONS OF SUCH MOVEMENT FOR OUR NAVIGATION SYSTEMS AND RESEARCH

WHILE EARTH'S geographic north pole is fixed, the magnetic north pole moves in tandem with Earth's constantly shifting magnetic field. Depending on where on Earth you are, the magnetic field moves a relatively small distance across the globe in any given year, usually between 5 and 50 km. However, over the past few decades, the rates of movement have been extraordinary, accelerating to record speeds of 55 km per year in the 2000s, before dramatically slowing to 35 km per year over the past five years.

Whether small or large, such changes in the location of magnetic north accumulate over time, so maps of Earth's magnetic field require updates every five years to ensure accuracy. These maps are used for many purposes, whether in everyday use through your mobile phone's navigation app or for scientific use, where they aid exploration and space-weather forecasts.

Here I discuss efforts by the British Geological Survey (BGS), together with the international geomagnetic community, to update our maps of Earth's magnetic field. I explore what the most recent updates tell us about the current behaviour of magnetic north, the predictions for where it will be in the future and why the recent movement is something that has never been observed before.

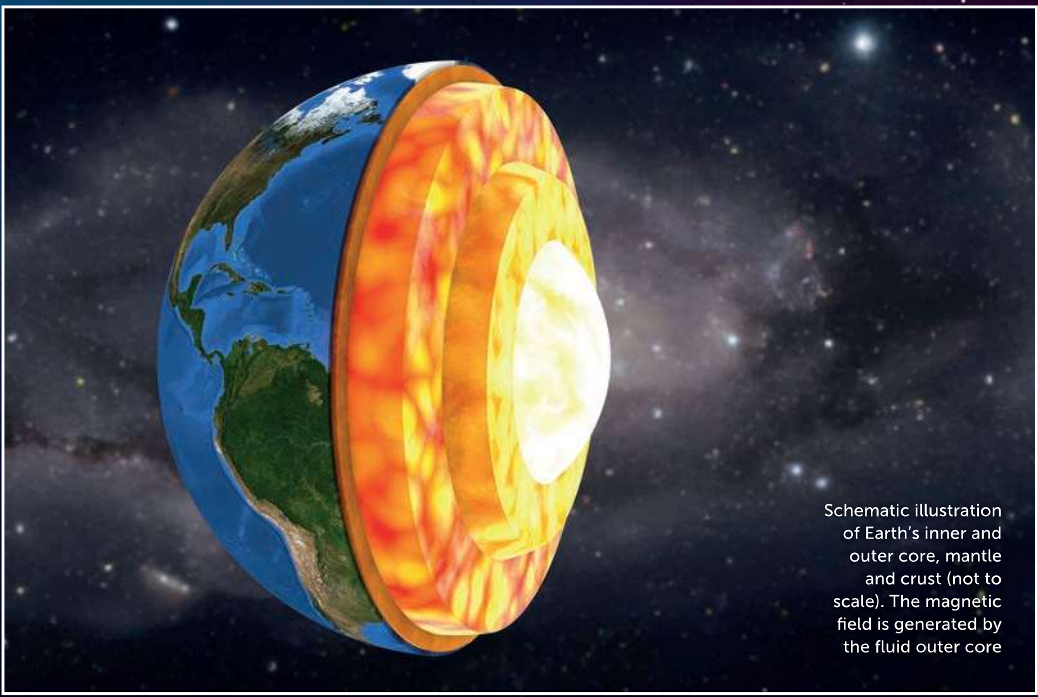
Earth's outer core

Three thousand kilometres below Earth's surface lies the outer core, a vast sphere of liquid metal (largely iron and nickel). The core is under enormous pressure from the weight of the overlying mantle, but the fluid is extremely hot, which overcomes the tendency to solidify. The outer core has a remarkably low viscosity, similar to that of a cup of tea. Although it is completely confined, rotation and convection causes the outer core to flow slowly on large scales of thousands of kilometres at around 20 km per year. On smaller scales – tens of kilometres – the flow is invisible to surface observers but is likely more turbulent and chaotic, meaning it is impossible to predict on long timescales.

Flow of molten iron and nickel, which are electrically conducting, within Earth's existing magnetic field generates electric currents. The currents in turn create a magnetic field, and the Coriolis effect, caused by Earth's rotation, helps organise the currents into a bar-magnet-like shape, thereby reinforcing the existing magnetic field in a self-sustaining cycle known as the geodynamo.

However, the cartoon bar-magnet image of the geomagnetic field really only applies at large distances above Earth's surface. In truth, because flow within the core varies in both space and time, the strength and shape of the magnetic field is complicated and changes through time. It therefore has to be measured and mapped regularly in detail to be useful for navigation and scientific research.

For navigation purposes, a compass will point towards the closest magnetic pole, the point where the field lines 'dip' into the surface at right angles. →



Schematic illustration of Earth's inner and outer core, mantle and crust (not to scale). The magnetic field is generated by the fluid outer core

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Main image: Earth's magnetosphere. Computer artwork showing the interaction of the solar wind with Earth's magnetic field (not to scale). The solar wind is made up of charged particles emitted by the Sun (right). Earth's magnetic field deflects these particles, forming a wake-like pattern of field lines that is compressed on the sunward side and trails over a million kilometres away from the Sun on the other side of Earth – the so-called magnetotail *© Getty*

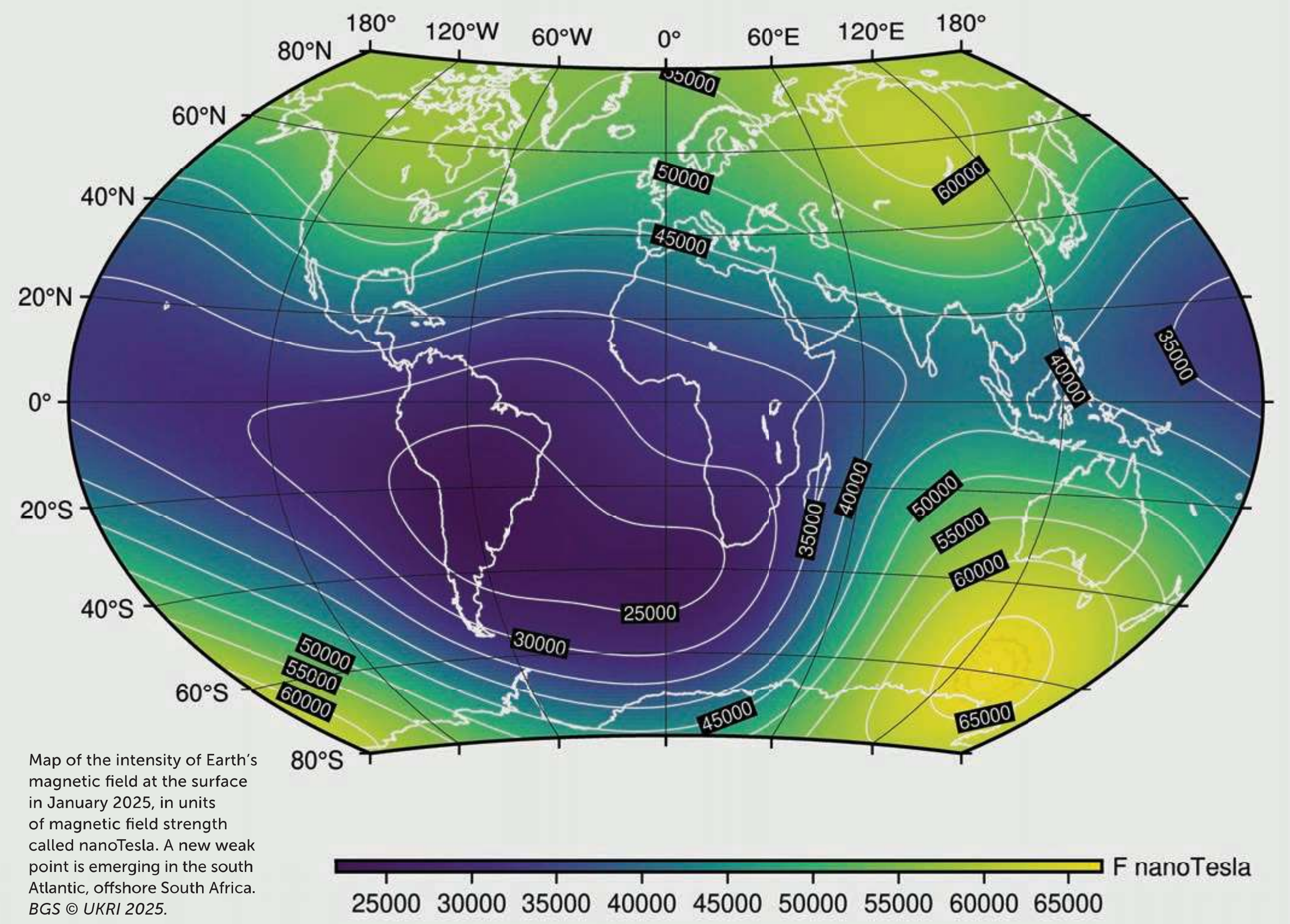
“By referring to these snapshots of the magnetic field, geophysicists can estimate how it will change over the next five years”

There is both a south and a north magnetic pole. Unlike ‘geographic north’ or ‘true north’, which is the fixed point around which the rotation axis of Earth spins, ‘magnetic north’ is constantly moving, so forecasting its movement is crucial for accurate navigation. However, to use a compass, we must convert the measurement to a known orientation (shown on a map). The correction of the angle between true north and magnetic north is called ‘declination’. The global field maps, which are updated every five years, provide that correction everywhere on and above Earth’s surface.

Magnetic-field maps

Two magnetic-field maps (or models) have recently been updated to incorporate the movement of magnetic north. The first, the World Magnetic Model (WMM), which was updated in December 2024, is used in a variety of devices including aircraft, shipping and submarine navigation. The second, the International Geomagnetic Reference Field (IGRF), which was updated in January 2025, is a complementary model and is used globally as a standard reference for geophysical research and applied science. For example, the IGRF is used in subsurface exploration (such as archaeological and aeromagnetic studies) to remove the background magnetic field and detect any magnetic anomalies.

Both models comprise a series of magnetic-field maps that track and forecast changes in the magnetic field.



Map of the intensity of Earth’s magnetic field at the surface in January 2025, in units of magnetic field strength called nanoTesla. A new weak point is emerging in the south Atlantic, offshore South Africa. *BGS © UKRI 2025.*

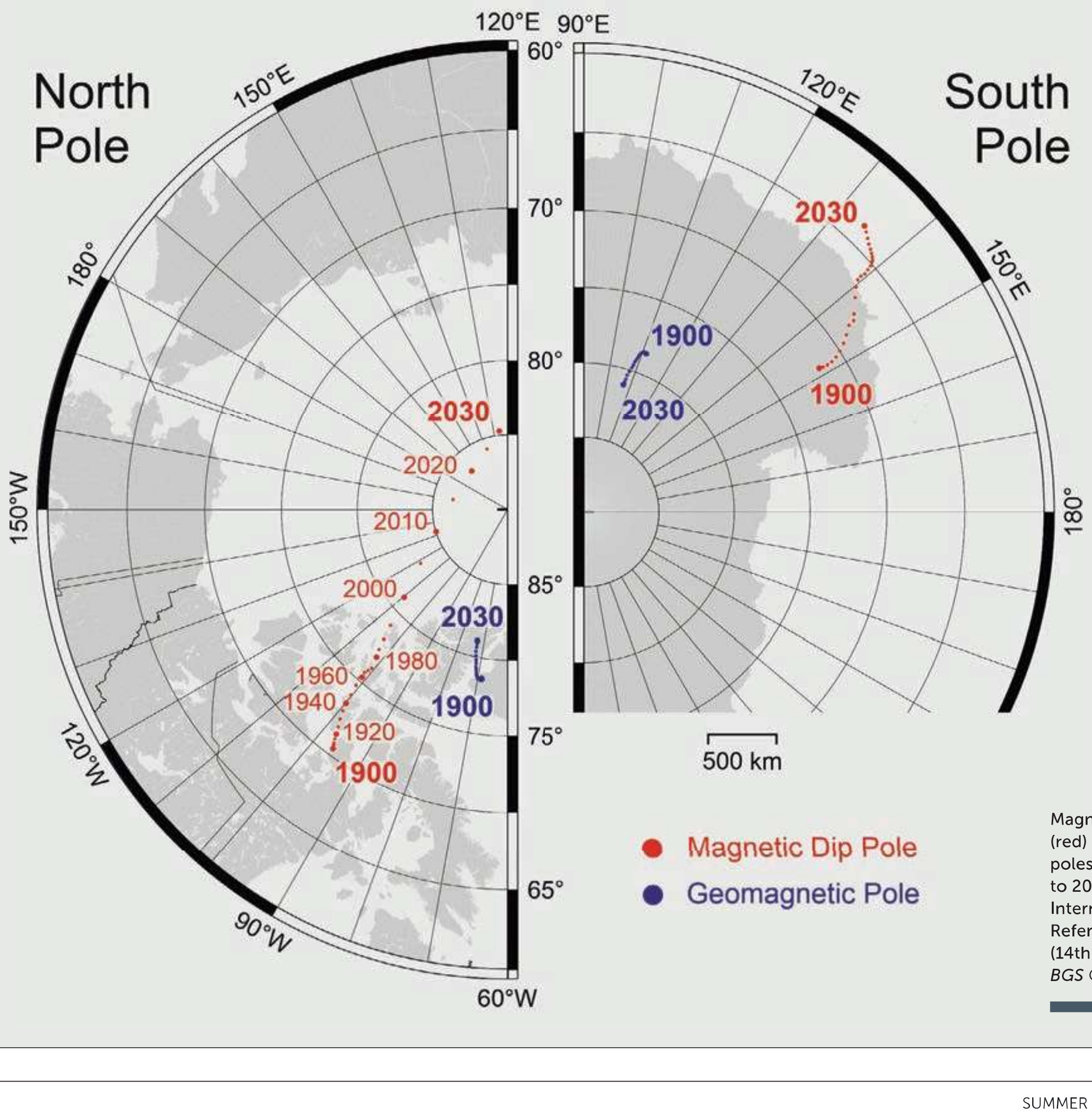
Measurements of the magnetic field are made at geomagnetic observatories on the ground and by dedicated satellites that orbit around 500 km above Earth's surface. Data from hundreds of magnetic observatories around the world are used, including nine operated by the BGS.
To make the maps, tens of millions of measurements are collected and checked for errors, before sophisticated computer programs process the data to extract the core field signals.

The computer programs create two snapshots of the magnetic field: one five years in the past and the other slightly into the future. By referring to these snapshots, geophysicists can also estimate how the magnetic field will change over the next five years. Currently, predictions run until 2030; in 2030, the process will be repeated for the next update, to forecast the field in 2035 and so on.

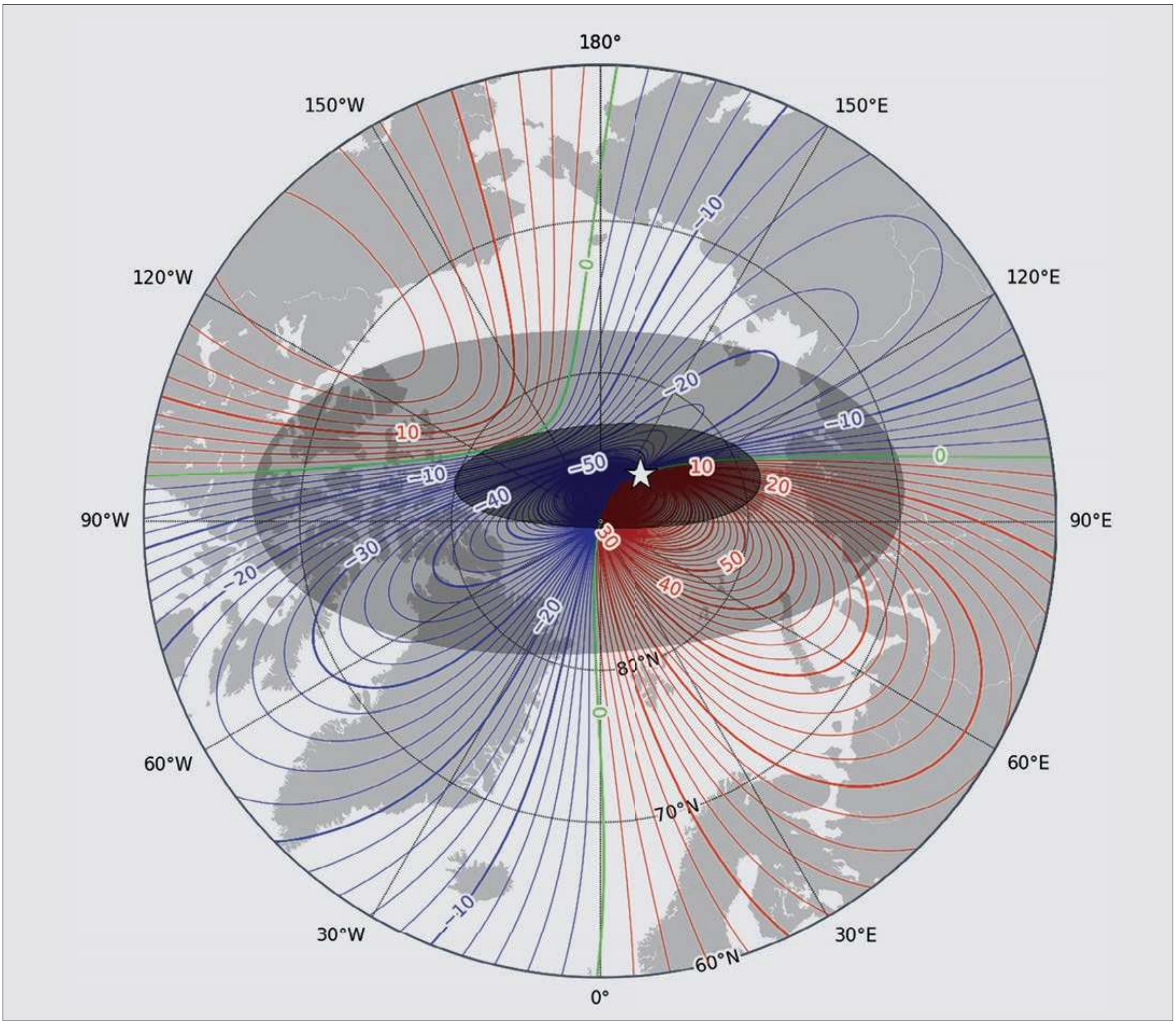
Scientific impact

The IGRF map is a collaborative effort and is updated with the support of the international geomagnetic community. The January 2025 release saw the model's fourteenth update, led by BGS alongside 18 other institutions from four continents. As the IGRF represents a consensus from international scientists, it is an agreed standard reference against which other scientific research may be checked. It is created for the public good and ensures that scientists across the world can continue with their forecasts and explorations.

The map is of particular use to those requiring extremely accurate magnetic-field values, including aeromagnetic studies, mining, oil and gas exploration, ionospheric modelling, space weather forecasting and spacecraft orientation, as well as magnetic correction for compass users. Without the IGRF updates every five years, there would be significant economic loss and inefficiency. In fact, without a regular update, directions in mapping applications would become incorrect in some parts of the world like South →



Magnetic pole locations (red) and ideal geomagnetic poles (blue) from 1900 to 2030. From the International Geomagnetic Reference Field (14th release). *BGS © UKRI 2025.*



Declination (magnetic variation) in the region of the north pole at 2025.0 from the World Magnetic Model (WMM) 2025. Red: positive (east); blue: negative (west); green: zero (agonic line). Dashed red and blue lines have 180° declination. Contour interval is 2°, white star is the location of the north magnetic pole, and the projection is polar stereographic. The black [grey] shaded regions around the poles correspond to the blackout zones [caution zones], the regions where the horizontal component of the magnetic field H < 2000nT [H < 6000nT]. *BGS © UKRI 2025.*

America. Errors in scientific comparisons in areas of North America, where the rate of change is largest, could rise to 5% after a few decades.

Historical context

The first published magnetic declination chart was of the Atlantic (Halley's Magnetic Chart) in 1700; the first modern Hydrographic Office (Admiralty) series dates from 1858. In a sense, the practicalities are the same today as ever: measure the magnetic field in as many locations as possible, through time, to track the shape of the field and how it changes.

Sir James Clark Ross, a British naval officer, led the team that first surveyed the location of the magnetic north pole. Ross located it on 1 June 1831 and, between 1839 and 1843, completed an expedition to conduct magnetic observations and to reach the south magnetic pole. Since then, the north magnetic pole has only been surveyed eight more times; the last time was in 2007 when it was still in Canada. The south magnetic pole has been surveyed eight times in all; the last time was in 2000, but because it is offshore from Antarctica, it remains hard to reach.

To find the magnetic pole, a magnetic-field model is required to predict the location of the poles, accurate to within a few kilometres. However, the poles never stay still and can move up to 80 km from their expected position during a single day due to variations in magnetic activity caused by the influence of the solar wind. This makes magnetic navigation close to the pole impossible, so the WMM has clearly marked 'blackout' zones around the poles, where compass readings are not reliable.

Recent movement

The recent update to the models has highlighted that the current behaviour of magnetic north has never been observed before.

Magnetic north is estimated to have moved at about 10 km/year from 1600 to 1990. In the 2000s, it accelerated to reach a record speed of 55 km/year. The 2020 IGRF update showed magnetic north had slowed slightly, moving at around 50 km/year, continuing on its path towards Russia, having been in Canada for the last 400 years. Newly released maps have shown that the movement of magnetic north has slowed down further over the past five years to about 35 km/year, a deceleration that has not been seen before. Our prediction is that the magnetic north pole will continue to slow down its movement over the next five years, whilst still travelling towards Siberia.

In comparison, the magnetic south pole has moved very little in the past century, at around 5 to 10 km/year, and has been drifting slowly offshore of Antarctica since the 1950s. It continues to move northwards whilst the north pole is now moving southward. Interestingly, as the north pole moves towards Siberia, we predict that both the north and south pole will briefly have the same longitude, around 135°W, in early 2026, which has probably not happened in many centuries.

A weak region of the field known as the South Atlantic Anomaly has been observed for centuries, where the strength of the field is anomalously low. This often affects electronics on low-orbiting satellites, as high-energy solar particles penetrate Earth's magnetic shielding. In the past 100 years, the location of the minimum point has drifted westward from South Africa towards Brazil. However, we noticed in 2025 that there is a new second minimum developing off the coast of South Africa along with the existing area, which is currently passing over Argentina. We are unsure of how this minimum will develop in the future or the potential effects it could have on satellites.

> **"The creation of magnetic-field models like the WMM and IGRF is a truly international effort"**

A magnetic flip?

By magnetic reversal, or 'flip', we mean the process by which the north pole is transformed into a south pole and the south pole becomes a north pole. From study of reversals captured in volcanic eruption sequences, the process takes on the order of five to ten thousand years. In the past, the magnetic field has undergone an 'excursion' rather than a full reversal, whereby the field experiences a large decrease in its overall strength, but it does not reverse. Sometime later, the field regenerates itself with the same polarity; that is, north remains north and south remains south.

As a matter of geological record, Earth's magnetic field has undergone hundreds of known reversals of polarity. We can see this in the magnetic patterns found in volcanic rocks, especially those recovered from the ocean floors. On average, we have seen four or five reversals per million years in the last ten million years. But, in other periods of Earth's history, for example during the Cretaceous, there have been much longer times (40 million years) when no reversals occurred. Reversals are certainly not predictable or periodic in nature.

If we look at the trend in the global strength of the magnetic field over time since measurements began in 1832, we can see a downward trend. Indeed, projecting this forward in time would suggest zero magnetic field in about 1,500 to 1,600 years, which is when some believe we would see a reversal. However, the current strength of the magnetic field is not particularly low in terms of the range of values it has had over the last 10,000 years. Also, bearing in mind 'excursions' and knowing what we do about the properties of mathematical models of the magnetic field, it is far from clear whether we can easily conclude that a flip will take place. Our best estimates also show that past magnetic reversals have taken perhaps a few thousand years at the fastest to occur; so don't worry, it is a very slow process on human timescales and one we would likely adapt to.

The creation of magnetic-field models like the WMM and IGRF is a truly international effort and would not be possible without the contributions of thousands of observers, scientists and engineers from around the world. The maps are used by nearly everybody in some form, whether they are aware of it or not. Hopefully, you can better appreciate the enormous effort that goes into making these maps the next time you are lost and open a mapping application on your phone for guidance. G

CIARÁN BEGGAN
Geophysicist at the British Geological Survey, UK

FURTHER READING

A full list of further reading is available at geoscientist.online.

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