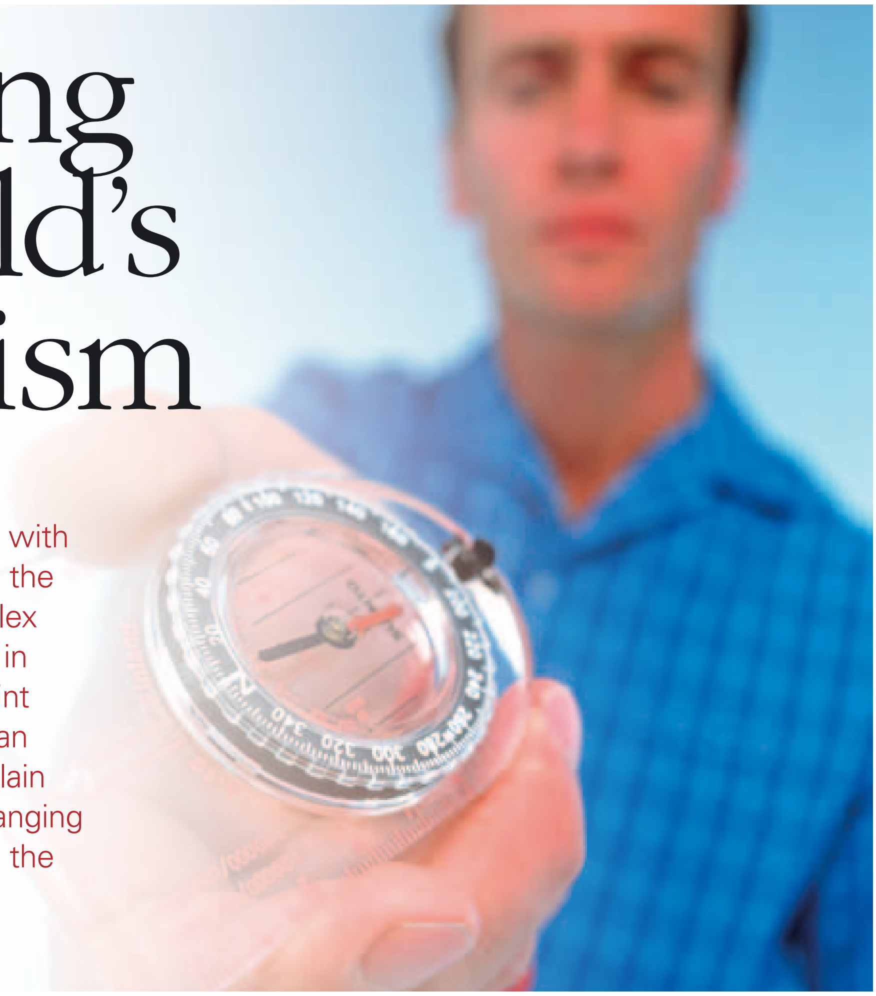
# Modelling the world's magnetism

People have been finding their way with compasses for many centuries, but the Earth's magnetism is a more complex business than you might think, and in most places a compass doesn't point exactly towards the North Pole. Brian Hamilton and Susan Macmillan explain how understanding our planet's changing magnetic field helps keep us facing the right direction.



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In late 2009 the British Geological Survey (BGS) released the latest revision of the World Magnetic Model (WMM) in collaboration with the National Geophysical Data Center (NGDC) in the USA. The model aims to provide a reliable estimate of the magnetic field's strength and direction on or near the Earth's surface. It also predicts how the field will change over the next five years, meaning it continues to be accurate until it is next updated, in 2014.

The WMM is an easy-to-implement and reliable tool that lets you work out the direction you are facing relative to True North from anywhere on Earth, using a compass or magnetometer (a device for measuring the magnetic field). True North is the direction towards the geographic North Pole, around which the Earth rotates. In our everyday lives we are surrounded by familiar streets and landmarks, so finding our orientation relative to True North is not an issue. But these reference points are not always available in, for example, wilderness areas or at sea. After all, it's not much use having a map unless you know which way you're facing.

New uses for directional information appear all the time. Many smart phones now contain simple magnetometers to determine the direction of the magnetic field, and hence True North. If you have used Google Maps on a smart phone you'll have seen that it shows the orientation of the phone, making the map easier to interpret. Another example is mobile applications that overlay local information on the smart phone's camera display – so-called 'augmented reality'. These can only work if the phone knows which direction the camera is pointing, so it has to calculate True North by measuring the magnetic field.

On the face of it, the magnetic field is a great way to find your direction. That's why compasses have been used since the Middle Ages as a simple but effective navigational aid. And even when other methods are available, the magnetic field is still a useful back-up. But over time, people have realised that compass directions vary from place to place and also change slowly over time. This is a problem if you want to know where you are relative to a fixed direction like True North.

The famous English astronomer Edmund Halley (after whom Halley's Comet is named) was the first person to map how compass direction varied over the globe. He published the first chart of compass variations in 1701, after two expeditions around the Atlantic making accurate measurements of the magnetic field.

The main cause of these deviations lies deep within the Earth. Most of the Earth's magnetic field is generated by the molten outer core. This is a region of liquid metal roughly 2000km thick, starting about 3000km below our feet. As this conducting, iron-rich fluid slowly moves through the Earth's magnetic field, it creates electrical currents. These currents in turn produce and sustain the Earth's magnetic field. However, the outer core does not produce a simple field like the one around a bar magnet, and the fluid movements there cause the field to evolve over time.

The latest revision of the WMM is a new description of the magnetic field and how it varies over time, sponsored by the US National Geospatial-Intelligence Agency and the UK Defence Geographic Centre. It is the standard model of the magnetic field used by the US Department of Defense, the UK Ministry of Defence, the North Atlantic Treaty Organization and the International Hydrographic Organization for navigation, and in systems that need to know which direction they are facing. It is also used widely in civilian systems – for example, it is incorporated into the Android Software Development Kit.

Mapping the Earth's magnetic field has developed considerably since Halley's day. We now use millions of measurements of the magnetic field from satellites, in particular the Danish Ørsted satellite and the German CHAMP satellite. The CHAMP mission came to an end last September, but not before providing 10 years of fantastic data.

Satellite data is great for looking at large areas of the Earth, but changes over time are better recorded by fixed magnetic observatories. We use data from 150 observatories around the world, including five run by BGS. Without the dedication and generosity of all the organisations running these observatories the WMM would not be possible.

To analyse this huge quantity of data, BGS uses high-performance computers in the Edinburgh office, home of the geomagnetism team. Our mathematical techniques and understanding of the magnetic field let us produce a model that can estimate the Earth's magnetic field, not only where the satellites and observatories measure it, but also below the surface and even out into space. We can also estimate how it will change over the coming years.

The image below shows how far a compass deviated from True North across the globe in 2010. Its contour lines show that in London you'd have found your compass needle pointed about two degrees to the west of True North, and it gets worse as you head northwest in the UK: in the Western Isles you'd have been six degrees out. In New Zealand, compasses deviate by more than 20 degrees – polar explorers could find themselves facing completely the wrong way.

*An 'augmented reality' application (Wikitude) for Android smartphones that uses the WMM in conjunction with the phone's magnetometer and location to determine its orientation relative to True North. This allows it to overlay local information onto the camera's field of view such as the location of the Royal Observatory Edinburgh from BGS's Edinburgh office.*

Ted Harris

You can also clearly make out the South Magnetic Pole, south of Australia just off the Antarctic coast. The North Magnetic Pole is off the top of the image, north of Canada – you can see it is closer to the North Geographic Pole than the South Magnetic Pole is to the South Geographic Pole.

You can also see the South Atlantic Anomaly. This is an area of especially low magnetic field strength around the South Atlantic and Brazil. It's interesting not only because it indicates large changes within the Earth's core, but also because the weaker magnetic field here allows the solar wind to penetrate closer to the Earth – something that increases the risk of electronic glitches in satellites.

The green lines – called agonic lines – show where a compass would point to True North. They pass through relatively few countries, and not through the UK. However, our modelling suggests that the agonic line currently over continental Europe is moving towards the UK at about 30km a year. If the current trend continues, it should reach southeast England in about 2017 or so. Compasses in this area will then point to True North for a short time.

In 2014, the WMM will be due for its next revision to keep up with these gradual changes in the magnetic field. The scientific discipline of magnetic field modelling is constantly improving, and we hope to apply new and better techniques to the job. Nor does data collection stand still; the European Space Agency will soon launch its SWARM satellite mission. This is a three-spacecraft mission that will measure the Earth's magnetic field in more detail than ever before. Together, these will ensure that future revisions of the WMM will continue to provide accurate orientation for those who depend on it. ■

## MORE INFORMATION

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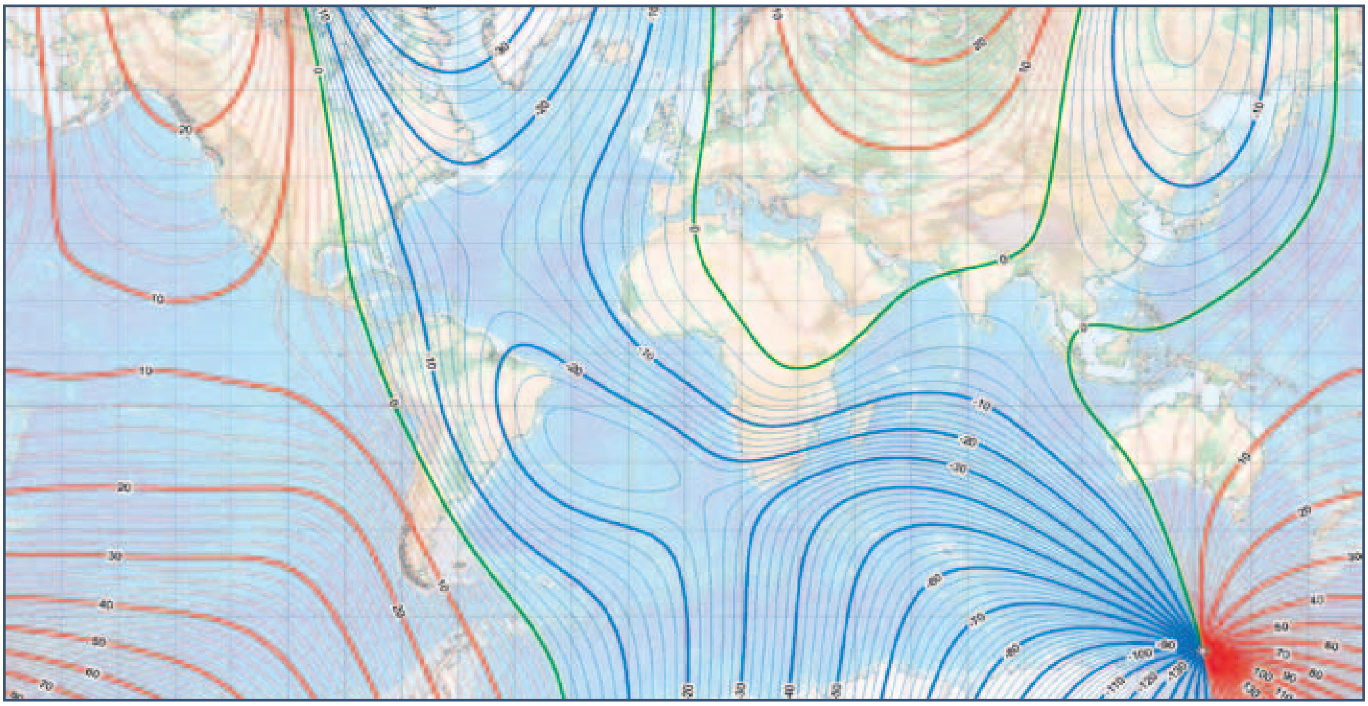
Magnetic field values can be calculated on the BGS website: **www.geomag.bgs.ac.uk/data_service/models/wmm_calc.html**



*Map of compass variation from the WMM for January 2010: variation of compass needle from True North is shown in degrees clockwise (red/positive) or anti-clockwise (blue/negative).*