NEWS & VIEWS

GEOPHYSICS

A new turn for Earth's rotation

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Earth's spin rate varies with time. A six-year periodic signal in the planet's core is partly responsible, and increases the interior magnetic-field strength to much higher levels than previously thought.

The conservation of angular momentum is a powerful factor on a planet such as Earth. We can demonstrate the constant interchange of angular momentum between component parts, such as the liquid core, ocean, atmosphere and Moon, on a wide range of timescales. The interchange manifests itself to an observer on Earth's surface as tiny variations in Earth's rotation, or spin rate. At the two extremes of the measurable time periods — centuries and days — the oceanic tides and atmospheric winds, respectively, are the processes clearly mediating the interchange of angular momentum. However, on some medium timescales outstanding questions remain. Not least is the origin of a strange peak in the spectrum of spin-rate variations at around 5–8 years[1] — a feature that cannot be accounted for by atmospheric motions or by the ocean.

An explanation of this signal is now presented by Gillet *et al.*[2] (page 74 of this issue), and it involves intercommunication of angular momentum between Earth's deep interior (the fluid core) and the overlying solid mantle. By identifying this process, the authors are able to go on to determine a value for the strength of the magnetic field in the core that is much higher than previously thought.

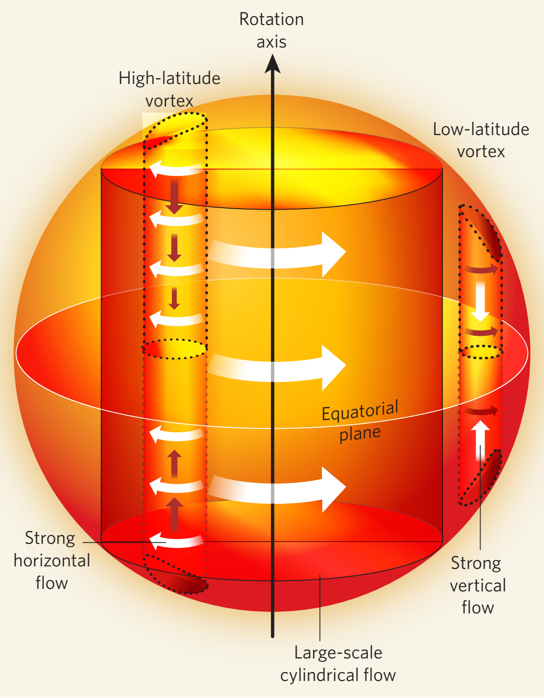

Figure 1 | The quasi-geostrophic model of Earth's core. Under this theory, there is a kind of 'rigidity' along the rotation axis of Earth's core, so that horizontal fluid motions are invariant along the rotation axis (identical regardless of their vertical height within the core) on timescales of 5–8 years. Shown here are a large-scale cylindrical motion (purely in the horizontal plane) and two arbitrary representative vortices. The vortex at high latitude has weak vertical flow, whereas the vortex near the equator has a stronger vertical flow. The rate at which the cylindrical flow propagates out from the inner core (not shown, but about one third of the whole core size) to the equator is dictated by the magnetic field strength in the core, and is the basis of Gillet and colleagues' calculation[2].

On Earth, the twice-daily tides raised by the Moon serve to slow down the planet. This effect is so pervasive that the length of the day on Earth was 25% shorter about a billion years ago. As a result, the solid Earth loses angular momentum, and this is duly taken up by the Moon receding from Earth (by about 3 centimetres per year) — an effect we can measure and verify. On the timescale of hours to days, we have one of the great triumphs of twentieth-century meteorology and geophysics, namely the demonstration of the intercommunication of angular momentum between the solid Earth and the atmosphere. As winds press on Earth's surface, they can create a torque that can alter by minute amounts — several parts in one hundred million — Earth's rotation rate (and thus its angular momentum). Amazingly, by measuring wind speeds, this exchange of angular momentum can also be verified.

The problem addressed by Gillet *et al.*[2] concerns the unexplained spectral peak at a period of around 6 years. To discover signals in Earth's core in the 5–8-year range, Gillet *et al.* first studied the fluid motion occurring at the core surface. Geomagnetism provides the tool for this exercise: the variations of the flow at the core surface cause small perturbations in Earth's magnetic field, because the magnetic-field lines are dragged along by the highly conducting iron that constitutes the bulk of the core. Fundamental to Gillet and colleagues' ability to properly recover these small motions was their use of a theory that ascribes enormous influence to the rotational force within Earth — the Coriolis force. As a result, provided that the timescale of the motions is sufficiently short, the horizontal part of the fluid motion is invariant in the direction of the rotation axis[3] (Fig. 1).

This quasi-geostrophic theory is used with great effect in atmospheric dynamics. But it has only recently been applied in studies of the core, because its validity in the presence of magnetic fields was, until recently, thought to be questionable. It allows extrapolation of surface velocities deep into the core's interior. With the interior fluid velocities known, the angular momentum of the core, and hence its effect on Earth's rotation, can be calculated. Such a calculation was first performed more than 20 years ago[4] on timescales of decades, and demonstrated the reasonable consistency between the angular momentum carried by the core's motions and the concomitant changes in the rotation speed of the mantle. Gillet *et al.*[2] checked this calculation for angular-momentum conservation in the 5–8-year band and found good agreement between the core's fluctuations in angular momentum and those exhibited by the mantle.

Remarkable as that is, we now come to the second part of the story: the resolution of a conundrum that has been puzzling geophysicists for decades. The core is known to support several resonant frequencies, just as a stretched violin string does. The core's frequencies are determined primarily by the strength of the magnetic field, the lines of which act as the violin strings. The stronger the magnetic field, the more the equivalent tension in the string, and the higher the note. For the core, these notes are called torsional oscillations. An influential paper[5] from 40 years ago put the fundamental (lowest) frequency at 60 years, meaning that the magnetic field in the core was about 0.2 milliteslas[6,7], coincidently similar to the value at the core surface. Gillet *et al.*[2] now revise that number to 2 milliteslas, which is roughly the strength of a refrigerator magnet.

Rather than standing waves (as in the case of a violin), Gillet and colleagues see propagation of disturbances in time across the core, from the region near the inner core to the equator, where the motions vanish — presumably a characteristic of a large loss of energy in this region, equivalent to having a large amount of friction. But the friction idea isn't supported because the viscosity of the core is very low, similar to that of water. Therefore, this remarkable disappearance of energy points to electrical conductivity in the overlying mantle, although that interpretation is not the only one.

What is not yet understood is the source of the excitation of the torsional waves and the cause of the 6-year periodicity. Because the waves propagate from the inner core boundary both inwards (towards the rotation axis) and outwards (towards the equator), it is possible that a small shaking of the inner core is responsible. How that occurs is not known. But one idea is that there is a characteristic frequency for an inner core that is shaped like an egg lying with its long axis in the equatorial plane. This frequency could correspond to a period of around 6 years, the oscillation being associated with the gravitational tug that density anomalies in the mantle impart on it[8] when it is displaced from equilibrium. In principle, many different forcing mechanisms might excite that motion, which in turn excites the torsional oscillations.

The ability of Gillet and colleagues[2] to accurately retrieve flow in the core at a period of around 6 years, and a value for the strength of the magnetic field in Earth's interior, is stunning to some of us geophysicists — there is so little signal in this period band that can be unambiguously separated from the contaminating influence of the external magnetic field originating in the magnetosphere around the Earth. This type of calculation will certainly be checked by others, and satellite missions such as the European Space Agency's Swarm mission (due to launch in 2012) will further that goal by providing data of the highest quality. The authors' resolution[2] of the interior-field strength in favour of a value about ten times higher than previously thought (2 milliteslas compared with the lower 0.2 milliteslas), is in better agreement with inferences from the damping (or energy loss) of nutations — the nodding motions of Earth's spin axis caused by the influence of bodies such as the Moon.

This result now opens up the need for a reappraisal of decadal signals in the length of a day. Because the fluid motions at this period are no longer likely to be invariant with respect to the rotation axis, the vexing mismatch between Earth's observed rotation and the predictions from geomagnetism[9] may be resolved by discovering the true axial dependence of the motions. That goal is in sight, and will provide a final check on the strength of the interior magnetic field. ■

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