**////Title: Mapping Flows at Earth’s Core–Mantle Boundary**

**////Standfirst:**

The magnetic field that enshrouds Earth is generated by processes deep within the planet’s interior, which geologists still don’t fully understand. Among the effects that remain poorly studied are brief variations in the strength of the magnetic field, which occur over timescales of several decades. Through detailed mathematical analysis, Dr Klaudio Peqini and Professor Bejo Duka, both at the University of Tirana in Albania, explore how these variations could arise from changes in the flows of material at the boundary between Earth’s core, and its thick layer of mantle.

**////Main text:**

Earth’s inner structure is fascinating and complex, being composed of a double-layer core, a large layer known as the mantle and an uppermost solid layer called the crust.

The outer layer of the core is a giant spherical shell that begins 1,200 kilometres from the Earth’s centre and extends for an additional 2,263 kilometres. The outer core is composed mainly of liquid iron and nickel, mixed with lighter elements. The liquid in the outer core is electrically conductive, due to the presence of these metallic elements. This conductivity leads to electrical currents, giving rise to Earth’s magnetic field.

Although the complex dynamics of this magnetic field aren’t fully understood, a solid theory, known as magnetohydrodynamics, describes the crucial mechanisms by which the outer core generates and maintains Earth’s magnetic field, which first arose several billions of years ago. The electrical currents within Earth’s molten outer core are themselves driven by the convective currents generated as heat escapes from the core to the mantle, which are influenced by Earth’s rotation, among other factors.

The magnetic field lines generated in the core spear through the mantle, which is relatively solid and non-conducting. They make their way up to the Earth’s surface and extend into outer space up to several planetary radii away.

Scientists have been measuring the properties of Earth’s magnetic field since 1832. Since then, a myriad of measuring techniques and devices have been developed, ranging from fixed geomagnetic observatories and satellite swarms. These technologies provide a wide and extensive picture of Earth’s magnetic field, its evolution in time and space, and much more.

Through a better understanding of how Earth’s magnetic field behaves and how it is influenced by the outer core, researchers can gain new insights into an intriguing array of processes, including the shielding effects of the magnetic field and its interaction with dangerous charged particles originating from the Sun. Such interactions occasionally lead to violent geomagnetic storms, which can negatively impact our navigation systems and electrical grids.

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The layer that separates the mantle from the liquid outer core, known as the Core–Mantle Boundary, represents a rough transition between two media with different magnetic properties. This region exerts an important influence on the magnetic field lines passing through the Core–Mantle Boundary on their way to interplanetary space. The outer core, Core–Mantle Boundary and mantle cause variations in the strength of Earth’s magnetic field, which unfold over timescales ranging from just a few decades, to centuries, or even millennia.

According to the latest theories, longer-term variations are likely driven by large-scale motions taking place in the molten outer core. Since these changes occur over such a wide array of different timescales, some previous studies have proposed that a variety of different mechanisms may be responsible for driving them.

In their study, Dr Klaudio Peqini and Professor Bejo Duka explored how these variations may be driven by flows that occur at the boundary between the molten outer core, and the semi-molten mantle above it. Since both layers interact with each other directly at this boundary, each of their flow patterns are likely being driven to match each other more closely.

As a result, the research team suggests that flow patterns could emerge with unique, time-varying velocities. As these flows interact with magnetic field lines passing through them, they may be directly responsible for shorter-scale variations in Earth’s magnetic field.

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To map these velocities, and examine their subsequent influence on Earth’s magnetic field, Peqini and Duka used a model that incorporates four centuries of historical observations. In particular, they focused on a century of monthly measurements taken between 1850 and 1990 – when more stringent observational requirements produced particularly reliable sets of magnetic field measurements, spanning the entire globe.

From these surface measurements, the researchers calculated the corresponding strength of the field at the Core–Mantle Boundary – which they treated mathematically as a thin spherical shell surrounding the core. Through a series of derivations, they then produced a set of equations to describe the time-varying velocity of fluid at the Core–Mantle Boundary throughout this period. Finally, the team generated a world map of these flow velocities, allowing them to clearly visualise any shorter-scale changes.

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The resulting maps clearly revealed a global picture of Core–Mantle Boundary flow velocities which varied on the order of decades, rather than centuries. In their paper, Peqini and Duka presented a snapshot of these velocities from January 1923. That month, the map shows that material at the boundary was shifting by as much as 25 kilometres per year beneath the central Pacific, and increasing in speed by as much as 2.6 kilometres per year.

When visualising the changes that occurred over the century-long period they studied, the researchers noticed persistent features in the flow velocities underneath particular regions of Earth’s surface, including the South Atlantic, and the Indonesian archipelago. Conversely, very few changes occurred underneath either of Earth’s Polar regions. The fluid under these regions appeared to rotate almost rigidly with the planet itself.

Altogether, the team’s results agree closely with the estimates made in previous studies – but not in all cases. In some other studies, velocity maps were noticeably different due to researchers introducing physical constraints on the flow velocities allowed at the Core–Mantle Boundary, which Peqini and Duka chose not to include. They propose that this decision could account for some areas in their maps where flow velocities appear unusually high. This widely occurred in smaller-scale regions in which the rate of acceleration of Core–Mantle Boundary material was itself increasing.

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In their future studies, Peqini and Duka now hope to examine these effects in more detail – potentially leading to new sets of equations, which can map the time-varying behaviour of the Core–Mantle Boundary more accurately. Already, their results are bringing researchers a step closer to understanding why the strength of Earth’s magnetic field changes over time – especially over shorter, decades-long timescales.

Through this improved understanding, researchers could soon be able to better predict the complex behaviours of Earth’s magnetic field as a whole, as much as possible. In turn, this may shed new light on an intriguing array of processes, including its interaction with dangerous charged particles originating from the Sun, generating geomagnetic storms in more dramatic cases. Elsewhere, it could help researchers to better understand the limitations of navigation systems which rely on measuring Earth’s magnetic field – found in areas ranging from satellite technologies, to migrating birds and insects.

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This SciPod is a summary of the paper ‘Small-scale velocity field at the Core-Mantle Boundary constructed from the gufm1 global model’, from AIP Conference Proceedings. <https://doi.org/10.1063/1.5135405>

For further information, you can connect with Dr Klaudio Peqini at [klaudio.peqini@fshn.edu.al](mailto:klaudio.peqini@fshn.edu.al)