CSQ-40

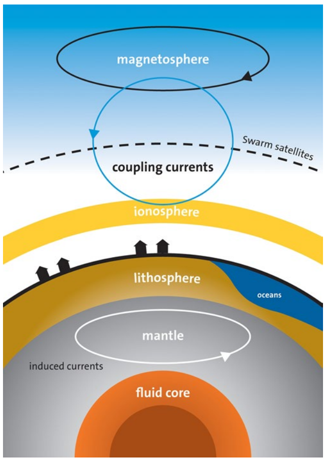
Question	Knowledge Advancement Objectives	Geophysical Observables	Measurement Requirement	Tools & Models	Policies / Benefits
What is the dynamics of the fluid outer core at short timescales, and how is it coupled with the mantle ?	A) Improve the separation of the internal and external sources of the magnetic field measured by satellites. In particular, separate core signals from those generated by electrical currents in the ionosphere, and from induced secondary fields in the conducting mantle, at high spatial and temporal resolutions.	. Magnetic field measured by satellites ● Ground Magnetic data from observatories and variation stations	● High temporal resolutions (including 1s data from ground stations) ● Global coverage ● Multi-satellite missions with orbits inclination choice to cover efficiently local times (e.g. combination of polar orbits with orbit with large inclination ~60°)	Theoretical magnetic models of ionosphere, magnetosphere, FAC contributions at low altitudes. Ground observatories are needed to separate core field from ionospheric field and separate magnetosphere contribution Models of mantle conductivity Models for induced fields Dynamo models	Forecast the evolution of the geomagnetic field Production of accurate reference field models Improved understanding of deep Earth processes (core dynamics, core-mantle coupling, deep mantle properties…), governing how energy flows from the core to the surface. Improved knowledge of spaceweather
	B) Quantify the screening effect of the conducting mantle on core field signals measured by satellites, from the mapping of the 3D variations of the electrical conductivity of the mantle.	• Magnetic field measured by satellites ● Ground Magnetic data from variation stations (Magneto-telluric data to constrain the lithosphere and upper mantle) ● Combination of geophysical observables to constrain the 3D		As above Surface conductivity models Mantle composition models Methods for joint inversions of various	

		electrical conductivity of the mantle: geomagnetic data, gravity data, seismology, mineral physics.		geophysical observables (needed to improve mantle composition models)	
	C) Resolve the geomagnetic signatures of periodic motions at sub-decadal timescales in the core flows, and constrain the corresponding rapid core dynamics.	• Magnetic field measured by satellites ● Ground Magnetic data from variation stations	• Multi-satellite missions with orbits inclination choice to cover efficiently local times (e.g. combination of polar orbits with orbit with large inclination ~60°) • High temporal resolution and high spatial resolution, globally	Theoretical magnetic models of ionosphere, magnetosphere, FAC contributions at low altitudes. Ground observatories are needed to separate core field from ionospheric field and separate magnetosphere contribution Mantle conductivity models to separate core and induced fields Geodynamo models able to describe rapid variations; geomagnetic data assimilation in these models	
	D) Assess whether and where the regions near the core-mantle boundary are stably stratified or not, and the impact on the core flows.	. Observations of the core field to constrain flow velocities at the top of the core • Seismic data (constraining the stratification)	● Multi-satellite missions with orbits inclination choice to cover efficiently local times (e.g. combination of polar orbits with	As above plus: Constraints on the heat flow, models of mantle flow velocity (seismological & geodynamic models of	

			orbit with large inclination ~60°)	the top of the core and the bottom of the mantle). Dynamo models able to handle stratification	
	E) Assess the impact on core flows due to mantle heterogeneity and spatial or spatio-temporal variations in core-mantle boundary topography.	• Gravity and seismology to constrain core-mantle boundary topography variations • Earth's rotation (angular momentum) • Mineral physics • Observations of the magnetic field to constrain flow velocities at the top of the core (see above)		As above plus: Models of gravito-visco-elastic deformations of the Earth's mantle able to handle 3D variations in structure (not only radial). Models of mantle conductivity (3D) Models of core-mantle coupling Continuous models of core flows based on satellite and ground data Dynamo models able to handle the considered boundary conditions	

Solid Earth 8: Narrative

Convection in the fluid core is considered a primary source of the geodynamo, at the origin of the Earth's main magnetic field. Constraining the space-time evolution of the geodynamo and forecasting the evolution of the geomagnetic field thus requires to improve our knowledge of the fluid core motions. This is also needed in order to understand the origin of large interannual changes in the observed geomagnetic field. Great progress have been made in recent years in modelling the flow dynamics, as we are now able to build geodynamo models approaching Earth's like conditions (Aubert & Gillet 2021). However, the dynamics of the flows is not well constrained on timescales shorter than a couple of years by the current geomagnetic observations, due to unmodelled ionospheric and magnetospheric signals (Lesur et al., 2022). Periodic structures have been recently detected at timescales of a few years, but their temporal frequencies are still unperfectly resolved from satellite data covering a limited time-span (Gillet et al, 2022, Ropp & Lesur, 2023). Exploring and understanding these transient wave-like motions is a possible avenue to decipher the dynamo field inside Earth's core. This calls for long-lived satellite coverage, continuing after the Swarm mission of ESA.



Internal and external sources of the magnetic field (@ESA).

Another challenge is to assess the impact of a non-spherical core-mantle boundary, which can be significant even for a small deformation of the boundary (Mandea et al., 2015 ; Vidal & Cebron, 2020, 2021). This last point raises the question of the interactions with the mantle. The core-mantle coupling involves e.g. redistributions of mass at the core-mantle boundary, a possible gravitational torque between a non-spherical inner core and mass anomalies in the mantle, or forces generated by electrical currents in the lowermost mantle (Buffett, 2015). Finally, we still struggle to understand whether the regions near the core-mantle boundary are stably stratified or not (Irving et al, 2018), and the impacts of such stratification on the flows is potentially large (Mound et al, 2019). This key issue has important consequences regarding the Earth's thermal history. To answer these questions, geomagnetic data provide a major observational constraint.

The core field is the main contributor to the observed magnetic field at the Earth's surface, which also includes contributions from the lithosphere and from external sources: the ionosphere and the magnetosphere. Thus, satellite observations of the space-time variations of the Earth's magnetic field provide an indirect sensor on the space-time patterns of the core flows, provided that they can be separated from the other sources (Lesur et al., 2022). It requires observations from ground observatories, in addition to geomagnetic satellite data at high temporal resolution. Signals from the core are also overprinted by induced secondary fields in the electrically conducting mantle, and filtered out by the conductive mantle. This screening effect is not well estimated, stressing the need for a better knowledge of the 3D mantle conductivity (see also Question 7). Conversely, mapping and understanding the transient motions in the core opens a possible way to sample the electrical properties of the deep mantle, because the core dynamics is sensitive to the electrical condition (conducting or insulating) at the top of the core (Schaeffer & Jault, 2016). Improving the separation of the internal and external sources of the magnetic field measured by satellites, at the highest possible spatial and temporal resolutions, is crucial and would benefit from improved knowledge in particular of the electrical currents in the ionosphere.

Aubert, J. & Gillet, N. (2021). The interplay of fast waves and slow convection in geodynamo simulations nearing Earth's core conditions, *Geophysical Journal International*, 225(3), 1854–1873.

Buffett, B. (2015). Core-mantle interactions, In: Gerald Schubert (editor-in-chief) Treatise on Geophysics, 2nd edition, Vol 8, 213-224, Oxford: Elsevier.