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Guest Editorial: International Space Science Institute (ISSI) Workshop on Probing Earth's Deep Interior Using Space Observations Synergistically

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During the last two decades, the GRACE and SWARM space missions have provided a wealth of groundbreaking results about the spatio-temporally variable gravity and geomagnetic fields of the Earth. However, more can be learned about the deep Earth's structure by combining data of the Earth's gravity and magnetic fields together with Earth's rotation data routinely measured using space geodesy techniques, such as Very Long Baseline Interferometry (VLBI). The synergistic use of these three observables represents a unique way to investigate the physics of the deep Earth's interior. In addition to the well-known correlation between the Earth's rotation and magnetic field observed at the decadal time scale, recent studies have reported an unexpected correlation between spatio-temporal changes of the gravity field and of the magnetic field, also at the decadal time scale. Processes occurring in the liquid core and at the core–mantle boundary (CMB) are potentially responsible for this observation. The workshop "Probing the Deep Earth Interior by using in synergy observations of the Earth's gravity and magnetic fields, and of the Earth's rotation" held at the International Space Science Institute (ISSI, Bern) on 1–4 September 2020, gathered about 40 scientists from different horizons and expertise to discuss this novel research topic. The different sessions successively addressed the capability of the gravity and magnetic fields, and Earth rotation observations to detect deep Earth signals on interannual time scales, the current knowledge of processes occurring in the fluid outer core, at the CMB and within the lower mantle, as well as the present-day status of theoretical models describing the deep Earth structure.

This Special Issue gathers together overview articles that provide state-of-the-art knowledge on the various aspects of this emergent research area. It addresses different timescales associated with these deep Earth observed signals as well as associated modeling aspects.

The theoretical gravitational signal caused by density contrasts in the fluid outer core and at the CMB is addressed by Dumberry and Mandea (2022). The authors revisit different core processes and investigate whether gravity changes and ground deformations associated with these phenomena can be detected in the relevant observations. Based on

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our current understanding of core dynamics, the deep Earth mechanisms contributing to gravity variations and ground deformations are approximately ten times smaller than those related to mass redistributions in the surface fluid envelopes and associated crustal deformations. Extracting a signal of core origin requires the accurate removal of contributions from dynamical processes occurring in the atmosphere, oceans and hydrosphere, which remains a great challenge.

The following article by Lesur et al. (2022) is devoted to observations of the Earth's magnetic field. Evidence of fast variations of the Earth's core magnetic field is seen by both magnetic observatory and satellite records. The paper discusses how these variations have been identified from ground observations at the Earth's surface over the last centuries and in recent decades from satellite data. Their characteristics at the core–mantle boundary can be inferred through localized and global modeling processes, paying particular attention to their time scales. The paper also addresses the possible types of waves in the liquid outer core, together with their main features, that may give rise to these fast geomagnetic variations. Geomagnetic observations from satellites have highlighted interannual variations in the rate of change of the magnetic field originating from Earth's core. Downward continuation of these surface observations to the core primarily shows up in the equatorial belt. Gillet et al. (2022) first recall the main characteristics of these patterns, addressing their spatio-temporal resolution, as seen from field models. Then, they review the dynamical frameworks proposed so far to understand and model these observations. And, finally, they provide a resume of the associated main geophysical implications on core and lower mantle structure, properties, and dynamics.

Fluid dynamics processes in the outer core are addressed in the paper by Triana et al. (2022). It explores Earth rotational and fluid eigenmodes with periods ranging from nearly diurnal to multi-decadal as well as their dependence on diverse factors, such as magnetic effects, density stratification, fluid instabilities or turbulence. Rekier et al. (2022) discuss decadal and interannual fluctuations of the Earth's rotation (or equivalently the Length-of-Day) and their relation with the Earth's deep interior, in particular motions in the outer core and torques at the core–mantle boundary.

The paper by Breuer et al. (2022) is devoted to the interiors of other bodies of the Solar System. It shows how planetary exploration in recent years and decades has led to an incredible harvest of new results on the internal structure of the inner planets Mercury and Mars, as well as the Moon, and Ganymede and Enceladus, satellites of Jupiter and Saturn, respectively.

The paper by Le Bars et al. (2022) presents fluid dynamics experiments developed to better understand flows in the fluid core of the Earth and their signatures in geomagnetic field, gravity and rotation observations. They also show that these laboratory experiments are fully complementary to numerical simulations of core motions. Current knowledge on the physical, chemical and mineralogical structure of the Earth's mantle and core is the subject of the paper by Dehant et al. (2022) and is the basis for all the other papers. The authors also discuss the various coupling mechanisms occurring between the Earth's liquid core and the mantle.

Observations of the Earth's gravity field are addressed in Chen et al. (2022). This paper discusses observations of the GRACE space gravimetry mission launched in 2002 to study mass redistributions in the surface fluid envelopes of the Earth related to climate change and variability. It also discusses other solid Earth processes such as Glacial Isostatic Adjustment (GIA) and seismic deformations of the Earth's crust which are clearly visible in GRACE data. It also explores the capability of this data set to detect gravitational signals related to the Earth's deep interior.

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