Earth, Planets and Space

PREFACE

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Special issue "DynamicEarth: Earth's interior, surface, ocean, atmosphere, and near space interactions"

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The near-Earth's gravity and magnetic fields are most important to enable terrestrial life. The role of the gravity field is obvious, it reflects the mass distribution of the Earth's interior and determines, e.g., the flow of water. The role of the geomagnetic field is more indirect. It protects our atmosphere from severe solar and cosmic radiation. Mankind's capability to measure the gravity and geomagnetic fields has been fundamentally important to advance societal development since hundreds of years (e.g., navigation) and it has brought scientific breakthroughs in several disciplines of geosciences recently (e.g., response of ground water tables to natural climate variability and anthropogenic water use, characteristics of solar–terrestrial interactions in the magnetosphere and space weather).

Variations in Earth's interior, atmosphere, oceans, and near-Earth space manifest in the gravity and Earth's magnetic fields and their changes. Understanding the spatial and temporal characteristics of these potential fields requires knowledge of the all these Earth's components. In turn, observations of the geomagnetic and the gravitational fields provide a wealth of information about them. An interdisciplinary approach is thus most effective to best exploit new observations and advanced modelling capabilities. The Priority Programme 1788 "DynamicEarth" funded by the German Research Foundation (DFG) between 2015 and 2021 has established an international research framework for gravity, geomagnetism, space and atmospheric sciences to tackle the interdisciplinary questions. This special issue collects contributions that exploit data from recent dedicated satellites in low Earth orbit, such as ESA's Swarm mission launched in 2013 and the US/German GRACE-FO mission launched in 2018, among others. It also addresses studies based on ground-based observations and on empirical and numerical models which concerns one or more of these geoscientific research areas.

A global geomagnetic field model derived from data of several satellites, as well as ground, airborne and ship data is provided by Baerenzung et al. (2022). At well covered regions, the model reaches resolutions up to spherical harmonic degree and order 1000, and temporally down to 3 h. It thus emphasises on the representation of the lithospheric field. Another model advancement lies in the joint estimation of the magnetospheric fields and those induced in the mantle and crust. Oceanic magnetic signals are expected to provide valuable information on climatological trends in the ocean. Their extraction from geomagnetic measurements requires, however, high-precision estimates from other magnetic field sources. Petereit et al. (2022) used 10 years of geomagnetic ground-based observations to investigate the

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seasonal variations and long-term trends of oceanic lunar tide. An increased specification of errors in estimating oceanic tidal signals by applying the model infrastructure described in Baerenzung et al. (2022) from this special issue is discussed in Saynisch-Wagner et al. (2021). Differently to oceanic tides, signals from ocean circulation are very challenging to detect in magnetic observations due to their long-term variability combined with their low amplitude, but still could provide an approach towards better understanding ocean climate evolution. To this aim, Hornschild et al. (2022) evaluated a new algorithm for detecting magnetic signals of ocean circulation on a synthetic data set.

Space- and ground-based geomagnetic observations combined with, e.g, electric field, plasma density and drift, and solar wind data are crucial to investigate the magnetosphere–ionosphere interactions and, in addition, are essential in characterising signal properties from magnetospheric sources. To complement the Swarm data base of magnetic measurements, Michaelis et al. (2022) and Styp-Rekowski et al. (2022) presented calibrated magnetic data from non-dedicated instruments onboard ESA's GOCE satellite mission by an analytical and by a Machine Learning technique, respectively. Their results demonstrate the high value and quality of the data from this low-flying satellite (about 260 km altitude) by successful applications in imaging magnetic signatures of the lithospheric field and deciphering the local time dependence of magnetospheric ring current signals. Xiong et al. (2021) exploited recently non-dedicated calibrated magnetometer data of the GRACE-FO twin satellite mission which flies in a string-of-pearls constellation. They derived characteristic correlations lengths of magnetic disturbances due to auroral field-aligned currents. By the combination of solar wind, geomagnetic, and ionospheric data and indices, Rout et al. (2022) identified a global magnetosphere–ionosphere quasi-resonant mode of oscillation during long-duration auroral geomagnetic activity.

At the mid- and low-latitude ionosphere, high-precision satellite-based geomagnetic observations are used to investigate ionospheric currents which result from a close interaction with neutral dynamics in the lower thermosphere and atmosphere, and with the geomagnetic field. Rodríguez-Zuluaga et al. (2022) provide the frontier letter of this special issue identifying the source of low-latitude post-sunset F region plasma irregularities to be off-equatorial which is in contrast to earlier theories suggesting equatorial sources. This observational evidence was achieved by analysing the 3-component Swarm magnetic field measurements and the derived hypothesis was verified with a local physics-based model of ionospheric irregularities. Concerning regular, periodic variability, Yamazaki (2022) provides a comprehensive study of solar and lunar daily geomagnetic variations and their equivalent ionospheric current systems in the E region including their quantification. Only available from ground-based, locally restricted data so far, this paper provides a global view on atmospheric tides in the magnetic field based on Swarm observations. Sporadic-E events are E region ionospheric irregularities and they, as well as post-sunset equatorial F region irregularities, can disturb trans-ionospheric radio waves used for navigation, such as GNSS, severely through their strong imprint in local plasma density gradients. Arras et al. (2022) discussed generation mechanisms for the rarely observed equatorial Sporadic-E events based on GPS radio occultation data from multiple satellites, while Sobhkhiz-Miandehi et al. (2022) identified tidal variations in the occurrence of mid-latitude Sporadic-E events based on GPS radio occultation of the FORMOSAT-3/COSMIC mission and compared the observations with results from a whole-atmosphere General Circulation Model (GCM).

Parameterised imaging of the regular global ionospheric plasma density is provided by Lalgudi Gopalakrishnan and Schmidt (2022). Also their work relies on electron density profiles derived from GPS observations onboard the GRACE and the FORMOSAT-3/COSMIC missions supported by in situ electron density data from several missions. Validation with independent ionosonde data revealed a correlation between observations and their parameterised images of the ionospheric F region peak height up to 90%. The variability of neutral winds and temperature in the Mesosphere–Lower Thermosphere (MLT) largely determine the variability of the entire ionosphere, e.g., by the propagation of atmospheric tides and waves. Thus, the MLT is a major link in vertical atmosphere coupling. Based on globally distributed, satellite-based neutral temperature data and results from a whole-atmosphere GCM, Siddiqui et al. (2022) described the reduction of low-latitude solar tides at the MLT during both Northern and Southern stratospheric warming events. They suggested that changes in the latitudinal shear in the MLT could explain the observed variability. Based on a synthetic data set for a network of radar stations, He (2023) reviewed existing analysis schemes and introduced a new scheme for the derivation of planetary waves in the MLT winds, as well as compared the implications of the schemes on the analysis results. Applying a spectral analysis on a data set from a radar network campaign in northern Germany, Charuvil Asokan et al. (2022) provided evidence that gravity waves with periods between 2 and 7 h dominate horizontal medium-scale structures of neutral winds in the MLT.

Several of the works in this special issue rely on a most accurate performance of GCMs of the upper atmosphere. As a step forward towards a most realistic representation of neutral and electron density in GCMs, Corbin and Kusche (2022) and Fernandez-Gomez et al. (2022) proposed data assimilation approaches of CHAMP, GRACE, and Swarm neutral density data into a GCM and could demonstrate the improvement of the model predictions of neutral and electron density, respectively.

Only a multi-disciplinary approach from disciplines in geophysics, meteorology, geodesy, and theoretical developments can reveal a better understanding of the complex variability of Earth's magnetic and gravity fields including the various sources of this variability, e.g., in the Earth's interior, oceans, magnetosphere, and atmosphere. The presented papers give valuable examples of fruitful interdisciplinary research in solar–terrestrial science and provide ground for new approaches.

Abbreviations

CHAMP	CHAllenging Minisatellite Payload
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
ESA	European Space Agency
GCM	General Circulation Model
GNSS	Global Navigation Satellite Systems
GOCE	Gravity field and steady-state OCean circulation Explorer
GPS	Global Positioning System
GRACE(-FO)	GRavity Recovery and Climate Experiment (-Follow-On)
MLT	Mesosphere–lower thermosphere

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