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Editorial: Understanding the causes of asymmetries in Earth's magnetosphere-ionosphere system

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Editorial on the Research Topic
Understanding the causes of asymmetries in Earth's magnetosphere-ionosphere system

Geomagnetic activity observed in geospace, the upper atmosphere, and on the ground results from solar-terrestrial interactions. Such interactions correspond to the coupling between the solar wind, magnetosphere, and the thermosphere-ionosphere (MIT) system (Khazanov, 2016). However, given the complexity of the whole system and its large spatial scale and long-term solar variability, effects resulting from this coupling can be asymmetric. For example, inter-hemispherical asymmetric responses can arise when a hemisphere receives more energy than the other (e.g., Knipp et al., 2021; Pakhotin et al., 2021), local time effects can take place due to the occurrence of intense dawn-dusk interplanetary electric fields (e.g., Haaland et al., 2017), and asymmetric geomagnetic field and mapping are caused by the Earth's dipole offset and tilt (e.g., Laundal et al., 2017).

The drivers that generate asymmetric MIT coupling response are generally recognized as long term: solar activity (Zhang et al., 2022) and dipole offset and tilt (Laundal et al., 2017); middle term: seasons (Lu et al., 2010); and short term: the y and z components of the interplanetary magnetic field (IMF) (Cowley, 1981; Li et al., 2011; Knipp et al., 2021). Thermospheric neutral mass density can present local time asymmetries associated with IMF B_y (Forster et al., 2017), and inter-hemispheric asymmetries can be generated by cross-hemispheric propagation of large-scale gravity waves (Bruinsma and Forbes, 2007). In addition, forcing from the mesosphere and lower thermosphere can generate inter-hemispheric neutral wind asymmetric patterns that can in turn asymmetrically impact neutral density in different hemispheres (Stober et al., 2021).

This Research Topic received 10 articles dealing with asymmetric responses of the MIT system to different types of solar wind forcing. Most articles focused on effects caused by the IMF B_y component, but there are contributions with focus on seasonal effects as well as effects on the ionosphere and upper thermosphere caused by large-scale gravity waves coming from the lower thermosphere. The articles focus on a variety of data analysis techniques, including machine learning and data assimilation, as well as numerical simulations. Data analyses include solar wind and IMF data, magnetic field in geosynchronous orbit, low-Earth orbit thermospheric neutral mass density data, ionospheric current data, and ground magnetometer data. Physics-based models and empirical models are used in the simulations.

We start with the contribution provided by Ohma et al., who performed a statistical and superposed epoch analysis study of the magnetic field in nightside geosynchronous orbit to investigate how substorms evolve in association with B_y. The authors found that $|B_y|$ in the magnetotail increases during the loading phase of substorms, i.e., prior to substorm onset. Then, $|B_y|$ reaches maximum values during the expansion phase and is significantly reduced during the remaining unloading phase. Eggington et al. conducted magnetohydrodynamic simulations of a geomagnetic storm to study the timescales over which asymmetries in the magnetotail appeared in response to variations in the IMF By component. They concluded that during strong solar wind driving, asymmetries in the magnetotail caused by IMF B_y appear after convection has communicated the information. However, during weaker driving, induced B_y effects can drive asymmetries in the 15–40 Earth radii region on shorter timescales.

Laundal et al. introduced the concept of a displacement field, a two-dimensional vector defined on a spherical shell that explains how magnetic field line footprints between both northern and southern hemispheres are displaced to one another as a result from perturbations in the geomagnetic field in the magnetosphere. By using an empirical model to account for ionospheric convection (Weimer, 2005), Laundal et al. (2018) found that inter-hemispheric asymmetries generated by the displacement field associated with the dipole tilt can sometimes surpass the asymmetric effects generated by the IMF B_y. By using an empirical model based on magnetic field measurements in low-Earth orbit, Hatch et al. found that Birkland current densities are mirrored from the northern to the southern hemispheres when the signs of IMF B_y and of the dipole tilt angle are reversed.

The effects of sudden changes in solar wind ram pressure caused by interplanetary discontinuities were investigated by Madelaire et al. The authors used 2.5 decades of ground magnetometer data to discover two interesting local time asymmetries: 1) a dawn-dusk asymmetry when IMF $B_z > 0$ in the first 30 min with stronger perturbations on the dawn side, and 2) a noon-midnight asymmetry when IMF $B_z < 0$ with stronger perturbations on the nightside. Madelaire et al. attributed the first effect to the amplification of the partial ring current, and the second effect to significant contributions by dipolarization of the near-tail geomagnetic field. Madelaire et al. used the same event list provided by Madelaire et al. to investigate the effects of dynamic pressure on the high-latitude transient geomagnetic field response. The authors found a pre-noon current vortex that moves westward, and a post-noon current vortex that does not move toward the nightside as suggested by previous numerical and experimental works.

Weygand et al. studied inter-hemispheric variations of the horizontal ground geomagnetic field recorded by southern hemisphere stations in Antarctica and the corresponding conjugate northern hemisphere stations in Canada and Iceland. The authors showed differences of onset times of the field variations associated with moderate IMF B_y (0.5–2.5 nT) occurring during summer and winter seasons.

An integrated study of inter-hemispheric asymmetries in the ionosphere-thermosphere system using experimental analysis and numerical simulations was performed by Hong et al. The authors used field-aligned currents observed by the Active Magnetosphere and Planetary Electrodynamics Response Experiment to specify the high-latitude electric potential in the Global Ionosphere and Thermosphere Model during a magnetic storm. Results show that inter-hemispheric asymmetries are highly dependent on IMF B_y, with intense asymmetries occurring around the equinox with more Joule heating associated with high-latitude electric potential in the southern hemisphere. Zhu et al. found with numerical simulations that large-scale gravity waves launched in different hemispheres with different phase speeds during an intense magnetic storm can generate asymmetric negative storm phases at the equatorial ionization anomaly peak region located in the afternoon sector of the ionosphere. Maute et al. studied the effects caused by lower atmospheric forcing on the magnetosphere-ionosphere system and the subsequent thermospheric neutral mass density during a moderate magnetic storm. Using more realistic lower boundary conditions in Whole Atmosphere Community Climate Model extended simulations, the authors showed that the northern hemisphere neutral density can be improved by up to 15% against climatological lower boundary conditions.

In summary, this Research Topic provides a good overview of asymmetric effects in the MIT system caused by several drivers, in particular the IMF B_y. These contributions result from ongoing efforts and include future perspectives, new methodologies, and new aspects concerning the combination of data analyses and numerical simulations.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

Author CG was employed by the company The Aerospace Coorporation.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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