frontiers | Frontiers in Astronomy and Space Sciences

TYPE Editorial
PUBLISHED 17 June 2024
DOI 10.3389/fspas.2024.1430813

OPEN ACCESS

EDITED AND REVIEWED BY
Joseph E. Borovsky,
Space Science Institute (SSI), United States

*CORRESPONDENCE
John C. Dorelli,
john.dorelli@nasa.gov

RECEIVED 10 May 2024
ACCEPTED 14 May 2024
PUBLISHED 17 June 2024

CITATION
Dorelli JC, Connor H, Petrinec S and Murphy K (2024), Editorial: Ionospheric signatures of magnetic reconnection in Earth's magnetosphere.
Front. Astron. Space Sci. 11:1430813.
doi: 10.3389/fspas.2024.1430813

Editorial: Ionospheric signatures of magnetic reconnection in Earth's magnetosphere

John C. Dorelli[1]*, Hyunju Connor[1], Steve Petrinec[2] and Kyle Murphy[3]

[1]Geospace Physics Laboratory, NASA-GSFC, Greenbelt, MD, United States, [2]Solar and Astrophysics Laboratory, Lockheed Martin, Palo Alto, CA, United States, [3]Independent Contractor, Thunder Bay, ON, Canada

KEYWORDS

magnetic reconnection, aurora, ionospheric precipitation, global magnetosphere simulations, field aligned currents

Editorial on the Research Topic
Ionospheric signatures of magnetic reconnection in Earth's magnetosphere

Magnetic reconnection is the primary mode by which the solar wind couples to Earth's magnetosphere, resulting in large scale dissipation of magnetic energy in the form of geomagnetic storms. Over the last several decades, advances in spacecraft observations and plasma simulations have resulted in the emergence of a "standard model" of magnetic reconnection describing the conversion of magnetic energy into plasma energy at spatially localized diffusion regions (e.g., see the review by (Hesse and Cassak, 2019)). Such diffusion regions have now been studied in detail thanks to the unprecedented spatial and temporal resolution provided by the instruments on NASA's Magnetospheric Multiscale (MMS) mission, confirming many aspects of the standard model. However, despite this significant advance in our understanding of the local physics of reconnection, we lack a quantitative understanding of how reconnection couples to Earth's ionosphere on a global scale. Understanding ionospheric signatures of magnetic reconnection is important for at least two reasons. First, we do not yet have an adequate understanding of how magnetic reconnection works in three dimensions. It is clear that we cannot simply import ideas from two-dimensional reconnection theory, without significant qualitative modification, to more complex three-dimensional systems. Unfortunately, constraining three-dimensional reconnection theory with local spacecraft observations (like MMS) has proven challenging. Developing global models of the magnetosphere that are able to connect three-dimensional reconnection physics to ionospheric observables could provide more global information to constrain theory.

Another more practical motivation for understanding the connection between magnetic reconnection and the ionosphere is that reconnection generates ionospheric field-aligned current (FAC) and particle precipitation that involve kinetic scale particle transport and wave propagation not captured by global MHD models. Hence global MHD models miss a significant fraction of the energy input into the ionosphere during periods of high geomagnetic activity. This energy input can be observed by ground imagers in the form of auroral emission, by ground radar in the form of ionospheric convection, or by direct observation of precipitating particles by Low Earth Orbiting (LEO) spacecraft. In this Research Topic, we will see examples of all three types of observation, showing how ground and LEO observations can help quantify the contribution of magnetic reconnection to energy input into Earth's upper atmosphere.

The first paper in our Research Topic, by (Fasel et al.), presents evidence that Poleward Moving Auroral Forms (PMAF) are the ionospheric signature of open magnetic field lines convecting over the polar cap as a consequence of subsolar magnetic reconnection under southward Interplanetary Magnetic Field (IMF) conditions. Using both Meridian Scanning Photometer (MSP) and an All-Sky Camera (ASC)—both located at the Kjell Henrisksen Observatory in Longyearbyen, Svalbard–they compute the rate of change of the elevation angle of the PMAF, as observed by the MSP, with respect to time: the PMAF-SLOPE. The PMAF-SLOPE is then plotted as a function of both the solar wind speed and the X (GSE) component of the solar wind velocity vector, showing a very strong correlation in both cases. This strongly suggests that the PMAF is a set of open field lines that maintains a connection to the reconnection source for some period of time as it is convected Earthward over the polar cap by the solar wind. More observations such as these, in which multiple ionospheric signatures are correlated with solar wind parameters, will be needed to constrain global MHD models of three-dimensional magnetopause reconnection. Further, predicting the auroral emission associated with PMAF will require extending MHD models to incorporate particle precipitation from the reconnection sites to the ionosphere.

One might expect reconnection generated particle precipitation to have an impact on the ionospheric conductance, which in turn will impact ionospheric currents and electric fields in an observable way. Currently, global MHD models of Earth's magnetosphere do not incorporate all the kinetic processes in the chain of events leading from magnetospheric particle precipitation and FAC to ionospheric currents and electric fields. The second paper in our Research Topic, by (James et al.), is a model validation study in which the Space Weather Modeling Framework (SWMF) (Tóth et al., 2005) is used to compare simulated and observed FAC and auroral electrojet (AE) currents in the ionosphere. Comparing FAC output from SWMF to those observed by the AMPERE constellation (Anderson et al., 2024), (James et al.) find that the simulated FAC are smaller than the observed FAC by about a factor of two. Further, the observed hemispheric asymmetries in FAC and AE currents are often not captured by the simulations, suggesting that a more accurate model of the relationship between precipitating magnetospheric particles and ionospheric conductance is needed in the simulations.

The distinctive particle precipitation signatures associated with magnetic reconnection (e.g., energy-latitude dispersion, low energy cut-offs) are observed over a wide range of magnetic local times and at all levels of geomagnetic activity. The third paper in this Research Topic, by Sotirelis et al., presents a statistical analysis of a year of DMSP (Defense Meteorological Satellite Program) observations of low-energy cutoff (LEC) ion spectra. Sotirelis et al. developed an automated method for identifying LEC, organizing the observations according to the open-closed boundary and equatorward boundary (EQB) of the aurora. The result is a map of LEC energy as a function of magnetic local time and magnetic latitude, revealing four distinct populations of ions: 1) cusp, mantle and open-LLBL ions associated with dayside magnetopause reconnection; 2) energy dispersed ions near the OCB on the nightside associated with magnetotail reconnection; 3) a duskside population near the EQB that may be associated with the onset of isotropy; and 4) a lower energy LEC, present throughout the auroral oval, that may consist of ions accelerated out of the opposite hemisphere. Global maps of LEC structure such as those presented by (Sotirelis et al.) will provide important constraints for the next-generation of global magnetosphere models.

As discussed by (Fasel et al.) in this Research Topic, PMAFs are the auroral signatures of reconnected magnetic flux tubes as they are convected over the polar cap by the solar wind. The electron precipitation that produces the auroral emission causes an enhancement of the plasma density in the F-region of the ionosphere, resulting in "polar cap patches" that emerge from the poleward edges of the PMAFs. These polar cap patches may be responsible for the HF radar backscatter identified as poleward-moving radar auroral forms (PMRAFs). The final article in this Research Topic, by (Zou et al.), makes use of the global SuperDARN radar network to investigate correlations between PMRAFs observed in opposite hemispheres. They found that PMRAFs in opposite hemispheres are highly temporally correlated. This high degree of correlation suggests that two PMRAFs propagate away from each other from a single source at the subsolar magnetopause. Nevertheless, (Zou et al.) noted significant inter-hemispheric asymmetry in the spatial structure of the PMRAFs.

In summary, the work presented in this Research Topic covers a broad range of observations of ionospheric signatures of magnetic reconnection, including auroral emission, HF radar back-scatter and *in situ* satellite observations of field-aligned currents and precipitating particles. The observations described herein will provide strong constraints on the theory of three-dimensional magnetic reconnection and guide the development of future global models of magnetosphere-ionosphere coupling.

Author contributions

JD: Writing–original draft. HC: Writing–review and editing. SP: Writing–review and editing. KM: Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

SP was employed by the company Lockheed Martin.

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.

Publisher's note

10.3389/fspas.2024.1430813

References

Anderson, B. J., Takahashi, K., and Toth, B. A. (2024). Sensing global birkeland currents with ®Iridium engineering magnetometer data. *J. Geophys. Res.* doi:10.1029/2005JA011126

Hesse, M., and Cassak, P. A. (2019). Magnetic reconnection in the space sciences: past, present and future. *J. Geophys. Res.* 125, e2018JA025935. doi:10.1029/2018JA025935

Tóth, G., Sokolov, I. V., Gombosi, T. I., Chesney, D. R., Clauer, R., Zeeuw, D. L. D., et al. (2005). Space weather modeling framework: a new tool for the space science community. *J. Geophys. Res.* 110. doi:10.1029/2005JA011126