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Editorial: Particle precipitation in the earth and other planetary systems: sources and impacts

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Editorial on the Research Topic
Particle precipitation in the earth and other planetary systems: sources and impacts

Particle precipitation is an important energy input to the planets' upper atmospheres, causing atmospheric heating, ionization, and emission. It also perturbs the planetary ionospheres and thermosphere, altering the compositions and conductivity, and thus influencing the dynamics in the magnetosphere (Miyoshi et al., 2021; Gabrielse et al., 2022; Yu et al., 2022). Particle precipitation can arise from various physical processes, such as diffusive wave-particle interactions (Thorne, 2010; Wang et al., 2019), parallel electric field acceleration (Lyons et al., 1979), or field line curvature scattering (Zhu et al., 2021). With the increased availability of *in-situ* data from both the Earth and other planets in the solar system, our knowledge of the complex coupling of processes that lead to the energization of particles and their effects on planets' upper atmosphere is growing every day. Therefore, studying the impacts of precipitating particles on planets' upper atmosphere as well as their origins is crucial for unravelling the underlying physics and ultimately for advancing the knowledge of our solar system.

This Research Topic aimed to bring together studies revealing the sources, characteristics, and processes responsible for particle precipitation, and consequent impacts on planets' thermosphere and ionosphere. It collected 7 research articles and 1 review article with participation from 52 authors. These published papers have covered a wide range of Research Topic, including the driving conditions of different types of particle precipitation, characteristics of localized or global-scale particle precipitation, as well responses in the ionosphere/thermosphere.

In addressing the driving conditions of high-energy particle precipitation, Salice et al. investigated electron precipitating flux at the high-energy tail (300 keV) observed by POES/Metop satellites from 2004–2014. The study aimed to parameterize of the full energy range of precipitation with respect to solar wind drivers, which could benefit the accurate modeling of chemistry-climate responses. It was found that the solar wind coupling function and geomagnetic indices, like Dst and Kp*10 indices, together are capable of determining the occurrence of strong high-energy tail precipitation.

Momberg et al. further explored the role of substorms in driving radiation belt electron precipitation and pulsating auroral emissions. The study used a forward time projection for the substorm injected electrons following their drift motion The authors found that the ground-based cameras, located where the projected precipitation is expected, capture the initiation or enhancement of pulsating aurora, directly linking the substorm-injected electrons with subsequent precipitation and pulsating auroras.

Aside from these global-wide precipitation studies, Wing et al. reviewed a complex, localized dayside particle precipitation event observed during the passage of a solar wind rotation discontinuity, where the dayside ionosphere experiences precipitation from double cusps, corresponding to both high-and low-latitude reconnections. The dayside particle precipitation shows both low-energy and high-energy ions from different regions (mantle and magnetosphere). The global MHD simulations further confirmed the double reconnection scenario at high and low latitudes.

On the other hand, da Silva et al. focused on statistical analysis of overlapping double ion energy dispersion events occurring in the cusp region, which are associated with particle precipitation originated from multiple reconnections on the dayside magnetosphere when interaction with solar wind persists. This study found the occurrence of such events is higher in the northern summer months and favors solar wind conditions with positive IMF By. These results shed light on the driving conditions that could lead to different characteristics of particle precipitation, and also suggested that the particle precipitation can serve as a proxy for revealing the solar wind and magnetosphere interactions.

While auroral emission can be used as a proxy for particle precipitation, the evolution of polar cap arc can reflect the magnetospheric dynamics and is closely connected to larger scale convection during substorms, suggesting a way of energy deposition. Lyons et al. examined the evolution of a nightside polar cap arc as it moved duskward over a ~2 h period while connecting to the auroral oval, as well as flow channels adjacent to the arc. They found the interaction between the flow channel and the auroral oval triggered two separate substorms, controlling the onset and subsequent development of substorm activity within the oval. This study highlighted the importance of polar cap flow channels in controlling the time, location, and duration of space weather activity and associated energy deposition to the ionosphere and thermosphere.

As the particle precipitation deposits energy to the upper atmosphere, the atmosphere is disturbed in terms of composition, density, and velocities at various altitudes. With tens of keV electrons precipitating downward, E/F-regions are often observed to experience ionization, depending on the energy of particle precipitation. But whether the steeping F-region density spectra are interlinked to the precipitation is not well known. Ivarsen et al. therefore explored the correlation between dissipating F-region irregularities and the particle precipitation and found that the E region conductance enhancement plays an important role in generating the dissipation of F-region irregularities.

The auroral conductance, as a direct consequence of auroral particle precipitation due to the magnetosphere-ionosphere coupling. While chorus waves are often considered to be one main driver of diffusive auroral precipitation and subsequently the conductance, the impact of chorus waves on precipitation and conductance over a global sense requires investigation, particularly under different geomagnetic activity conditions. Gillespie et al., by combining chorus wave statistics observed from the THEMIS mission and simulations, derived the precipitation energy spectrum, calculated their impact on the conductance, and further revealed the relative contribution of both upper and lower-band chorus. These conductance profiles, categorized by the AE index, would be a useful tool to be applied in global models.

Besides the drivers, characteristics, and impacts of particle precipitation mentioned above, one article in this Research Topic theoretically explored particle precipitation initiated by nonlinear wave-particle interaction processes. Unlike quasi-linear regimes, the nonlinear interactions of whistler-mode waves with energetic electrons change the way that electrons precipitate at the loss cone boundary. Gan et al. found that anomalous scattering transports electrons away from the loss cone while the phase bunching process directly leads to particle precipitation. These combined nonlinear processes lead to a smaller precipitation-to-trapped flux ratio than what is expected from quasi-linear theory. This study expands the knowledge of mechanisms responsible for particle precipitation and would be essential for understanding real-world physical processes like microbursts.

Overall, the Research Topic gathered diverse contributions investigating the complex particle precipitation mechanisms and their effects across the coupled magnetosphere-ionosphere-thermosphere systems. With new observations, models, and analysis techniques, these perspectives will help advance our understanding of particle precipitation on Earth and other planets.

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Conflict of interest

The 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.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

References

Gabrielse, C., Kaeppler, S. R., Lu, G., Wang, C.-P., and Y, Y. (2022). "Chapter 4 - nergetic particle dynamics, precipitation, and conductivity," in *Cross-scale coupling and energy in the magnetosphere-ionosphere-thermosphere system*. Editors Y. Nishimura, O. Verkhoglyadova, Y. Deng, and S.-R. Zhang (Elsevier), 217–300. 9780128213667. doi:10.1016/B978-0-12-821366-7.00002-0

Lyons, L. R., Evans, D. S., and Lundin, R. (1979). An observed relation between magnetic field aligned electric fields and downward electron energy fluxes in the vicinity of auroral forms. *J. Geophys. Res.* 84 (A2), 457–461. doi:10.1029/JA084iA02p00457

Miyoshi, Y., Hosokawa, K., Kurita, S. e. a., Oyama, S. I., Ogawa, Y., Saito, S., et al. (2021). Penetration of MeV electrons into the mesosphere accompanying pulsating aurorae. *Sci. Rep.* 11 (1), 13724. doi:10.1038/s41598-021-92611-3

Thorne, R. M. (2010). Radiation belt dynamics: he importance of wave-particle interactions. *Geophys. Res. Lett.* 37, L22107. doi:10.1029/2010GL044990

Wang, D., Shprits, Y. Y., Zhelavskaya, I. S., Agapitov, O. V., Drozdov, A. Y., and Aseev, N. A. (2019). Analytical chorus wave model derived from Van Allen Probe observations. *J. ofGeophysical Res. Space Phys.* 124, 1063–1084. doi:10.1029/2018JA026183

Yu, Y., Cao, J., Pu, Z., Jordanova, V. K., and Ridley, A. (2022). Meso-cale lectrodynamic oupling of the Earth agnetosphere-onosphere ystem. *Space Sci. Rev.* 218, 74. doi:10.1007/s11214-022-00940-0

Zhu, M., Yu, Y., Tian, X., Shreedevi, P. R., and Jordanova, V. K. (2021). On the ion precipitation due to field line curvature (FLC) and EMIC wave scattering and their subsequent impact on ionospheric electrodynamics. *J. Geophys. Res. Space Phys.* 126, e2020JA028812. doi:10.1029/2020JA028812