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Editorial: Coupling Processes in Terrestrial and Planetary Atmospheres

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Editorial on the Research Topic

Coupling Processes in Terrestrial and Planetary Atmospheres

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Welcome to the Research Topic "Coupling Processes in Terrestrial and Planetary Atmospheres" in Frontiers in Astronomy and Space Sciences. This research topic has been motivated by the recent developments in modeling and observation of interaction processes in the atmospheres of Earth and other Solar System planets. The atmosphere-ionosphere system on Earth and also on other studied planets is controlled by lower atmospheric effects, e.g., by upward propagating waves of various spatiotemporal scales from below (e.g., Forbes et al., 2006; Chau et al., 2012; Yiğit and Medvedev, 2015; Vadas and Becker, 2018), and by space weather effects from above (e.g., Yiğit et al., 2016). The nature of these effects is highly variable, which makes studying vertical coupling in the atmosphere-ionosphere a challenging endeavor. An increasing number of numerical studies demonstrate a significant amount of thermospheric and ionospheric effects of small-scale waves of the lower atmospheric origin (e.g., Heale et al., 2014; Miyoshi et al., 2014; Hickey et al., 2015; Yiğit and Medvedev, 2017; Yu et al., 2017; Gavrilov et al., 2020). Waves are routinely observed in the terrestrial atmosphere, for example, by ground-based lidars (e.g., Yang et al., 2008; Baumgarten et al., 2015), radars (e.g., Pramitha et al., 2019), airglow imagers (e.g., Pautet et al., 2019; Vargas et al., 2021), space-borne instruments (Park et al., 2014), and balloon flights (Hertzog et al., 2008). Satellite observations on Mars demonstrate that the Martian thermosphere is continuously populated by waves of the lower atmospheric origin (e.g., Jesch et al., 2019; Siddle et al., 2019; Yiğit et al., 2021b). The influence of these waves is increasingly appreciated in planetary atmospheres as well (e.g., Medvedev and Yiğit, 2019, and the references therein).

In order to better understand the structure and evolution of the middle and upper atmospheres, coupling processes both from below and above should be taken into account (Ward et al., 2021). Our Research Topic includes contributions from topics on various processes spanning a wide altitude range from the lower atmosphere to the thermosphere-ionosphere, especially regarding multi-scale wave coupling phenomena. Utilized methods of analysis include three-dimensional general circulation models (GCMs), TEC data from GNSS receivers, magnetometers, Doppler sounding systems, satellites, and ionosondes.

After an extensive review process, six papers contributed in total by 30 authors from six different countries have been accepted to this Research Topic. Lilienthal et al. present simulations of the middle atmosphere dynamics using the MUAM GCM, in which they implement for the first time the whole atmosphere gravity wave parameterization (Yiğit et al., 2008). They confirm that small-scale gravity waves (GWs) can penetrate into the thermosphere, as has been shown by a number of previous GCM simulations. Additionally, they study the effects of GWs on the terdiurnal tide. They find that, compared to the Lindzen-type GW scheme used in the earlier version of the GCM, the nonlinear wave-wave interactions in the whole atmosphere scheme lead to breaking levels lower in the atmosphere with smaller zonal GW drag, which is a more realistic feature of the mesosphere and the lower thermosphere (MLT). Their simulations show that the MLT wind reversals are sensitive to the initial GW momentum flux assumed in the lower atmosphere. Overall it is concluded that subgrid-scale GWs play a crucial role for circulation patterns and temperature distribution as well as for the terdiurnal tidal amplitude and phases.

The influence on the upper atmosphere of the variability of GW sources is poorly explored. Yiğit et al. present simulations of subgrid-scale GWs with the Coupled Middle Atmosphere Thermosphere-2 (CMAT2) GCM, incorporating the whole atmosphere subgrid-scale GW parameterization. They use this modeling framework to study how variations of GW source activity influence the middle and upper atmosphere winds and temperature. For this, they incorporate a latitude-dependent GW source activity that resembles the one observed by TIMED/SABER observations in the lower atmosphere and explore the upper atmospheric effects of upward propagating GWs. Their study suggests that GW activity and associated dynamical and thermal effects strongly depend on the vertical structure of the horizontal momentum flux. While the GW parameterization specifies the GW activity in terms of vector fluxes and phase speeds, SABER observations provide GW activity in terms of absolute momentum fluxes, which do not include directional information. Additionally, it is noted that the various formulations of GW activity, such as temperature fluctuations, or (zonal) drag, characterize different aspects of the wave field. While the wave activity is a measure of the magnitude of harmonics in a given point, GW drag is related to their dissipation and vertical decay. Overall, they conclude the latitudinal variations of the GW source spectrum produce second-order effects in the upper thermosphere. However, the middle atmosphere is more sensitive to GW variability.

Via coupling to the ions, variations in the neutral atmosphere can influence the ionosphere (e.g., Koucká Knížová et al., 2020). Koucká Knížová et al. start their paper with a concise review of vertical coupling between the atmosphere and ionosphere, discussing the influence of the lower atmosphere on the ionosphere. Later, they provide observational evidence of how atmosphere-ionosphere coupling takes place. Their ground-based ionosonde measurements demonstrate ionospheric variability associated with meteorological processes. With the multi-point continuous Doppler Sounding analysis they detect clear GW propagation in the upper atmosphere and retrieve propagation characteristics, which suggest that the wave energy sources lie below the observational altitudes.

The global navigation satellite system (GNSS) is a constellation of satellites that have a wide range of applications: mapping, navigation, military, and atmospheric and ionospheric research. Azeem uses total electron content (TEC) data from GNSS to study traveling ionospheric disturbances (TIDs), which are ionospheric signatures of propagating atmospheric gravity waves. This study specifically focuses on GWs generated by a convective thunderstorm that took place on 28 April 2014 over North America. By analyzing the TID and the background winds simultaneously Azeem is able to characterize the behavior of the wave intrinsic frequency. In agreement with previous modeling and theoretical studies, this observational study shows that the intrinsic wave frequency increases if the wave front and the wind are in opposite directions and it decreases if they are in the same direction.

Total solar eclipses produce direct effects on the ionosphere for a short amount of time by reducing the photoionization flux due to the local shadow of the moon over the atmosphere. Meza et al. study the response of the ionosphere and the geomagnetic field to the 2020 Solar Eclipse in the South American sector. They use magnetometers and GNSS receivers to probe the atmosphere-ionosphere. They find that the Solar Eclipse produce a variation in the maximum effective vertical total electron content (VTEC) depletion up to 30%.

Sudden stratospheric warmings (SSWs) are known to influence the upper atmosphere in a variety of ways (Pancheva and Mukhtarov, 2011; Nayak and Yiğit, 2019; Goncharenko et al., 2021b; Mošna et al., 2021), producing long-range vertical coupling between the lower and upper atmosphere. Goncharenko et al. investigate the effects of the 2013 Arctic SSW on the high-latitude Southern Hemisphere, using a combination of ground-based and satellite data. Overall, they provide observational evidence that mesospheric and ionospheric anomalies observed above Antarctica can be associated with the SSW. This is indicative of the global nature of SSW effects.

These papers contribute to the ongoing efforts to characterize the upward wave fluxes, the consequences of their dissipation and the external drivers of the state of the ionosphere, and the knowledge necessary to properly understand planetary atmospheres/ionospheres. Our lack of knowledge regarding these processes is now recognized as one of the primary uncertainties impeding the development of whole atmosphere models. These papers highlight the multi-dimensionality of this effort, both in terms of the number of different phenomena involved and the range of observational techniques necessary to this investigation.

AUTHOR CONTRIBUTIONS

EY wrote the first draft of the Editorial. All authors contributed to manuscript revision, read, and approved the submitted version.

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