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Editorial

Ionospheric Monitoring and Modelling for Space Weather: An Introduction to the Special Issue

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Over the last decades, our scientific understanding and user's community appreciation of the ionospheric space weather and its impacts on Earth's environment, and some of the technological systems and human beings' priority areas, have changed considerably. Space weather comprises a set of naturally occurring phenomena that have the potential to affect the functioning of technological systems, their assets, and operations in space and on Earth.

Particularly severe weather events have the real potential to temporarily disrupt, or permanently damage, key services such as electric power, communications, navigation, water supply, healthcare, finance, transportation (aviation, rail), and agriculture, among other important infrastructure, e.g., the operation of nuclear power systems [1].

Large eruptions of X-rays and extreme ultraviolet radiation from the Sun can degrade communication signals that transit Earth's atmosphere. Coronal mass ejections, occasionally launching a billion tons of solar plasma towards Earth, can create geomagnetic and associated ionospheric storms that could last for several days. These disturbances can cause widespread disruption to the electric power grid, resulting in large-scale blackouts. Solar radiation storms, which produce elevated levels of energetic particles, can be dangerous for humans in space and may pose a risk to passengers and crew in aircraft.

All of them can damage electronics in exposed systems, including satellites that are critical for communications, global navigation, national security missions, remote sensing, and a number of other applications [2].

Probably, the two best known examples of such happenings are: (i) the space weather event in March 1989, resulting in an electric power blackout in Canada, and damage to some of the electric power transformers and other grid components in Canada and the United States. (ii) A series of space weather events in October 2003, disrupting infrastructure functions and technological systems across the globe, causing commercial airlines flights at high latitudes to be rerouted and electric power blackouts in Sweden. For a 15-h period on 29 October 2003 and an 11-hour period on 30 October 2003, the ionosphere was so disturbed that the GPS-based Wide Area Augmentation System (WAAS) was severely affected [3,4].

Hence, monitoring, modelling and proper understanding the Earth's ionosphere conditions during space weather events are important for solar-terrestrial science, economy, national and homeland security, private sector operations, infrastructure services, remote sensing, space exploration, and technology innovations that rely on communications systems and the Global Navigation Satellite System (GNSS) for positioning, navigation, and timing (PNT) services. As the interaction of radio signals, whether natural or manmade, with space environments is all the way through the Earth's ionosphere and magnetosphere, new studies are required in these domains on the improvement of synoptic observational capabilities; efficient forecasting and mitigation techniques; deployment of innovative research platforms in space and on the ground; and expansion, testing and verification of prediction and forecast to conduct a socio-economic analysis of the potential consequences of severe ionospheric space weather events and their mitigation [5].

Citation: Cander, L.R.; Zolesi, B. Ionospheric Monitoring and Modelling for Space Weather: An Introduction to the Special Issue. *Atmosphere* **2022**, *13*, 477. https://doi.org/10.3390/atmos13030477

Received: 7 March 2022
Accepted: 13 March 2022
Published: 15 March 2022

This Special Issue focuses on monitoring, and current and future programs for space and ground-based observations of the Earth's ionosphere proposing some innovative ideas. It also presents results and findings in the world-wide international domain that need additional examination and development in ionospheric weather mapping and modelling. These include selected review and featured papers on: (i) general monitoring and modelling related topics; (ii) geophysical conditions for enhanced hazard in ionospheric space weather; and (iii) physics and dynamics of the Earth's ionosphere at different latitudes.

In particular, the scientific subject of the Special Issue 'Ionospheric Monitoring and Modelling for Space Weather' met the deep interest of a large number of competent scientists across the world that during the last two years submitted twelve valid articles covering several aspects of the proposed thematic.

A philosophical article that gives a general overview of the ionospheric research and its strategic importance in the framework of Space Weather science in the future may be considered the overture of this volume [6].

The recent description of the Global Monitoring of Ionospheric Weather by GIRO and GNSS Data Fusion that gives an accurate imaging of the ionosphere fits exactly the aim of the Special Issue, still underlying the importance of classical ionospheric vertical sounding integrated with other modern measurements and models [7].

Furthermore, ionospheric monitoring based on ionosonde measurements is also the base of studies concerning the comparison between the IRI (International Reference Ionosphere) and IRTAM (IRI Real Time Assimilative Mapping), or to analyze a global climatology of sporadic E occurrence [8,9].

Satellite observations like Swarm C satellite data and the GNSS receiver's network are used for the evaluation of empirical atmospheric models, long-term studies of medium scale travelling ionospheric disturbances, and to improve CCIR maps for local ionospheric models, as well as global ionospheric TEC derivation with multi-source data in modip latitude [10–13].

Solar physics is present in this Special Issue with an analysis of the effects of solar storms on the ionosphere or fluctuation of lower ionosphere associated to electron precipitation, and with an evaluation of 10.7, sunspot number and photon flux by using a learning machine technique [14–16].

The lithosphere–ionosphere coupling subject is finally covered by analyzing the co-seismic effect and ionospheric disturbance during the strong earthquake that occurred in Alaska on 23 January 2018 [17].

Guest editors acknowledge all the authors of the published articles for their relevant contributions, are grateful to the Editorial Office of *Atmosphere* for the care and assistance given to the success of this Special Issue, and to *Atmosphere* for the offered opportunity.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zolesi, B.; Cander, L.R. *Ionospheric Prediction and Forecasting*; Springer: Berlin/Heidelberg, Germany, 2014.
2. Hapgood, M.A. Technological Impacts of Space Weather. In *Geomagnetism, Aeronomy and Space Weather: A Journey from the Earth's Core to the Sun*; Cambridge University Press: Cambridge, UK, 2019. [CrossRef]
3. Ruiyuan, L.; Shunlin, L.; Bo, W.; Changfa, L. Ionospheric Effects of the March 13, 1989 Magnetic Storm at Sub-Auroral Region. *Geomag. Geoelectr.* **1996**, *48*, 85–90.
4. Weaver, M.W.; Murtagh, W.; Balch, C.; Biesecker, D.; Combs, L.; Crown, M.; Doggett, K.; Kunches, J.; Singer, H.; Zezula, D. *Halloween Space Weather Storms of 2003*; Rep.NOAA Technical Memorandum OAR SEC-88; NOAA: Boulder, CO, USA, 2004.
5. Cander, L.R. *Ionospheric Space Weather*; Springer Nature: Cham, Switzerland, 2019.
6. Hapgood, M. Ionospheric Science: An Example of the Importance of Diversity in Approaches to Scientific Research. *Atmosphere* **2022**, *13*, 394. [CrossRef]
7. Galkin, I.; Froń, A.; Reinisch, B.; Hernández-Pajares, M.; Krankowski, A.; Nava, B.; Bilitza, D.; Kotulak, K.; Flisek, P.; Li, Z.; et al. sGlobal Monitoring of Ionospheric Weather by GIRO and GNSS Data Fusion. *Atmosphere* **2022**, *13*, 371. [CrossRef]
8. Pignalberi, A.; Pietrella, M.; Pezzopane, M. Towards a Real-Time Description of the Ionosphere: A Comparison between International Reference Ionosphere (IRI) and IRI Real-Time Assimilative Mapping (IRTAM) Models. *Atmosphere* **2021**, *12*, 1003. [CrossRef]

9. Merriman, D.K.; Nava, O.A.; Dao, E.V.; Emmons, D.J. Comparison of Seasonal foEs and fbEs Occurrence Rates Derived from Global Digisonde Measurements. *Atmosphere* **2021**, *12*, 1558. [CrossRef]
10. Yin, L.; Wang, L.; Zheng, W.; Ge, L.; Tian, J.; Liu, Y.; Yang, B.; Liu, S. Evaluation of Empirical Atmospheric Models Using Swarm-C Satellite Data. *Atmosphere* **2022**, *13*, 294. [CrossRef]
11. Essien, P.; Oliveira Barros Figueiredo, C.A.; Takahashi, H.; Wrasse, C.M.; Barros, D.; Browne Klutse, N.A.; Otoo Lomotey, S.; Ayorinde, T.T.; Gobbi, D.; Bilibio, A.V. Long-Term Study on Medium-Scale Traveling Ionospheric Disturbances Observed over the South American Equatorial Region. *Atmosphere* **2021**, *12*, 1409. [CrossRef]
12. Haralambous, H.; Leontiou, T.; Petrou, V.; Singh, A.K.; Charalambides, M.; Lithoxopoulos, N.; Agisilaou, A. Adjusting CCIR Maps to Improve Local Behaviour of Ionospheric Models. *Atmosphere* **2021**, *12*, 691. [CrossRef]
13. Fu, W.; Ma, G.; Lu, W.; Maruyama, T.; Li, J.; Wan, Q.; Fan, J.; Wang, X. Improvement of Global Ionospheric TEC Derivation with Multi-Source Data in Modip Latitude. *Atmosphere* **2021**, *12*, 434. [CrossRef]
14. Schmölter, E.; Berdermann, J. Predicting the Effects of Solar Storms on the Ionosphere Based on a Comparison of Real-Time Solar Wind Data with the Best-Fitting Historical Storm Event. *Atmosphere* **2021**, *12*, 1684. [CrossRef]
15. Fu, T.; Wu, Z.; Hu, P.; Zhang, X. Fluctuation of Lower Ionosphere Associated with Energetic Electron Precipitations during a Substorm. *Atmosphere* **2021**, *12*, 573. [CrossRef]
16. Machado da Silva Benoit, A.G.; Petry, A. Evaluation of F10.7, Sunspot Number and Photon Flux Data for Ionosphere TEC Modeling and Prediction Using Machine Learning Techniques. *Atmosphere* **2021**, *12*, 1202. [CrossRef]
17. Zhang, Y.; Liu, X.; Guo, J.; Shi, K.; Zhou, M.; Wang, F. Co-Seismic Ionospheric Disturbance with Alaska Strike-Slip Mw7.9 Earthquake on 23 January 2018 Monitored by GPS. *Atmosphere* **2021**, *12*, 83. [CrossRef]