Space Physics and Aeronomy Perspectives on Integrated, Coordinated, Open, Networked (ICON) Science

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Key Points:

- Brief introduction of Space Physics and Aeronomy section is provided, highlighting some unanswered questions
- Examples are shown how ICON science can provide solutions to those questions
- Limitations in Space Physics and Aeronomy section are described and some ICON based solutions are suggested

Abstract

This article is a commentary about the state of Integrated, Coordinated, Open, and Networked (ICON) principles (Goldman et al., 2021) in Space Physics and Aeronomy and a discussion on several scopes and limitations to implementing them. The commentary focuses on the basic introduction and brief literature survey (Section 1); possibilities of implementation of ICON in Space Physics and Aeronomy (Section 2) and limitations or challenges in this field with possible solutions using ICON principles (Section 3). The Space Physics and Aeronomy section of the American Geophysical Union (AGU) comprises the interactions between solar wind, Interplanetary Magnetic Field (IMF) and different planetary magnetospheres and ionospheres. The section also deals with solar physics, mechanisms behind existence of solar magnetic fields, and evaluations of high and low speed solar winds. This field is a collection of different interdisciplinary subtopics, making this an excellent example of integrated research. Similar and transparent methodologies are adopted to solve problems all over the world which shows a coordinated approach of research. Freely available data from different space agencies and universities are also great assets for this domain which supports open research. The scopes of possible networked research with mutual benefits are also highlighted. Examples of ICON-based international collaborations and support mechanisms towards young scientists are elaborated which are helpful to mitigate limitations in this domain.

Plain Language Summary

The Space Physics and Aeronomy section is very interesting as well as challenging. Despite a vast amount of research in this field, many unanswered questions remain. Interdisciplinary and integrated research can help solve those unanswered questions. Examples of coordinated research in this domain are shown in terms of similar methodologies followed to obtain different geophysical parameters all over the world. Examples of several free data resources are given which are helpful for scientists all over the world for their independent research. The domain is also bolstered by collaborative and networked research with mutual benefits. Specific examples of these collaborative research opportunities are provided. In Space Physics and Aeronomy section, feedbacks and suggestions from global scientific communities are used by space agencies to identify the future mission objectives. This domain has a lot of potentials for the young researchers. Training and guidance are often provided to young researchers by eminent scientists through different workshops and seminars with possible financial support. The paper also provides some ICON-based solutions to the challenges present in this domain.

1 Introduction

The Space Physics and Aeronomy section deals with the electrodynamics of the Sun and different planetary atmospheres. The section describes the interactions between solar wind, Interplanetary Magnetic Field (IMF) and planetary magnetospheres including the Earth. Corresponding effects on planetary ionosphere and thermosphere are also analyzed. For example, the morphologies of the Earth's low, mid and high latitude ionospheres are different from each other. The low latitude or equatorial ionosphere exhibits steep temporal and spatial electron density gradients and seasonal variabilities (Rastogi and Klobuchar, 1990) due to the presence of Equatorial Ionization Anomaly (EIA). High latitude ionization is susceptible to space weather events originating from solar wind and IMF. Study of the effects of these space weather events on Total Electron Density (TEC) of ionosphere is crucial as TEC causes attenuations to any transionospheric radio signals such as Global Navigation Satellite Systems (GNSS). Intense space weather events can also affect artificial satellites. For example, geomagnetic storm and solar flares during October 29-31, 2003 damaged Solar and Heliospheric Observatory (SOHO) and Advanced Composition Explorer (ACE) satellites (www.nasa.gov/topics/solarsystem/features/halloween_storms.html).

The presence of the Earth's ionosphere was established by Edward V. Appleton (Appleton and Barnett, 1925; Appleton, 1946). Some of the outstanding works related to the background physics of Earth's ionosphere are Rishbeth (1977), Fejer and Scherliess (1995); Rishbeth (1997); Fejer et al. (1999) and Borovsky and Denton (2006). Reviews on magnetospheres and upper atmospheres of other planetary bodies are available in Brice and Ioannidis (1970), Russell (1993), Shinagawa (2000) and Haider et al. (2011). Morphologies of solar physics are also available in the literature (Temmer, 2006; Gopalswamy, 2007; Vidotto, 2021).

The inter-relations between the solar input parameters (solar wind, IMF, solar activity level) and Earth's magnetospheric-ionospheric output parameters are very complex. Efforts have been given to design models to describe these relations. Some of the standard models are International Reference Ionosphere (IRI) (Rawer and Bilitza, 1989; Bilitza et al., 2011), NeQuick (Nava et al., 2008) and Thermosphere Ionosphere Electrodynamics General Circulation (TIEGCM) (Dickinson et al., 1981; Richmond et al., 1992). Models are also designed at localized latitudinal and longitudinal swaths (Sur et al., 2017).

Though the section is enriched with a lot of past research works, still many unanswered questions remain. The nature of the interactions between solar wind, IMF, Earth's magnetosphere and ionosphere are not yet fully understood during different intensities of the geomagnetic storm. The day-to-day variabilities of low latitude TEC and the uncertainties related to post-sunset ionospheric density irregularities are some of the outstanding issues towards satellite-based navigation and spacecraft control. Electrodynamics of the Sun and the other planetary magnetosphere-ionosphere systems are yet to be fully understood and subject to the newer space missions (Parker, Juno, etc.). The outstanding questions in this section are challenging to address, and progress towards answering these questions can be facilitated by greater use of Integrated, Coordinated, Open, and Networked (ICON) principles. Doing so can help bring the community together to collectively address the major challenges. The main objective of ICON science is to enhance synthesis, increase resource efficiency, and create transferable knowledge (Goldman et al., 2021). The present article is a commentary covering Space Physics and Aeronomy on the state and the future of ICON science.

2.1. Integrated research in Space Physics and Aeronomy

Space Physics and Aeronomy is an excellent example of integrated research. The section is a blend of elementary physics, chemistry and mathematics. Some scientists work on the effects of solar wind, IMF on the Earth's magnetosphere. Others work on these space-weather effects on the Auroral Electrojet (AE) and the atmospheric Joule heating. They also observe the effects on the global neutral wind and the ionizations from different longitudes. Study of the ionosphere also needs proper understanding of the effects coming from the lower atmosphere. The coupled Whole Atmosphere Model (WAM) Ionosphere Plasmasphere Electrodynamics (IPE) model designed by NOAA CIRES and SWPC is an example of integrated research of the effects from upper as well as lower atmosphere to the ionosphere (Akmaev, 2011; Sun et al., 2015). Scientists involved in working on the equatorial ionization have to address the sharp ionospheric variabilities mainly due to EIA. The study of ionospheric density irregularities is also a very challenging section. Solar physics scientists analyze the morphologies of the Sun including solar wind, solar magnetic field, Coronal Mass Ejection (CME), sunspot cycles, etc. Other planetary magnetospheres and ionospheres are also emerging fields in this domain. In this regard, multi-disciplinary conferences and workshops are very crucial as they provide excellent platforms where scientists can learn the advancements of research in other domains and can interact with each other which may lead to possible future collaborative research using interoperable data. During the recent Covid pandemic, most conferences are being conducted virtually which helps increase participation as no transport and accommodation charges are required. The registration fees are also reduced in many conferences. This reduces financial burdens of the participants and increases possibilities of further integrated research across the world.

2.2. Coordinated research in Space Physics and Aeronomy

Space Physics and Aeronomy also use a coordinated research approach. The methodologies followed for any study are almost consistent throughout the world. For example, the identification of cycle slips due to ionospheric irregularities and multipath error correction techniques for TEC are similar. Some of the procedures may not be the same, however. For example, there are several methodologies present for TEC calibration (Abe et al., 2017). Efficiencies of different methodologies vary in different latitude-longitude sectors. In these cases, users must be aware of these differences and should apply that mechanism that provides better TEC representation in that region. The scripts/codes of the ionospheric and magnetospheric prediction models are stored in institutional websites or Github accounts and shared with global users with proper acknowledgements to the developers. The Community Coordinated Modeling Center (CCMC), NASA provides excellent tools to global users to simulate and visualize the model outputs. These efforts are examples of both open and coordinated research.

2.3. Open research in Space Physics and Aeronomy

This section also supports open data sharing. The data, models, methodologies and formulae in any scholarly articles must be provided in the data or acknowledgement section or as supplementary materials so that any reader can replicate the experiment. This is in correspondence with Findable, Accessible, Interoperable, and Reusable (FAIR) data policies (Wilkinson et al., 2016) used by American Geophysical Union (AGU). If the readers still face difficulties interpreting the data (for example: high frequency 50Hz GNSS data), they may contact the authors or the data providers.

Data sharing is an essential part of global research. The Space Physics and Aeronomy section is enriched with free data resources from different space agencies and universities which is the key to the advancement of research in this domain. For example, geophysical data related to heliophysics studies can easily be obtained from NASA's Space Physics Data Facility (SPDF), at the website omniweb.gsfc.nasa.gov. The data is obtained from different satellite missions and ground-based measurements. Some of the examples are solar wind speed, flow pressure, IMF (from ACE, WIND, IMP 8, Geotail), proton fluxes (NOAA Geostationary Operational Environmental Satellite (GOES)), AE, Dst (World Data Center for Geomagnetism (WDC), Kyoto and all its data supplier stations), Polar Cap North (PCN) from Thule (Technical University of Denmark (DTU), Denmark). The data can be available in one minute as well as in hourly/daily resolutions. Geophysical data are also available from the website of WDC (wdc.kugi.kyoto-u.ac.jp) and NOAA's National Center for Environmental Information (NCEI) (www.ngdc.noaa.gov/stp/GEOMAG/kp_ap.html). Global TEC data are available from GNSS receivers, ionosondes, etc. These are a few examples of free data resources to help global independent research. Geophysical data from other planetary observations and new space missions are also available from the websites of different space agencies and universities. This increases the scope of research on emerging topics. Apart from data sharing, NASA and other space agencies also provide free study materials to every space enthusiast.

Information on data calibration and corresponding sensing instruments are also freely available at websites. For example, details of instruments used in NASA's Living with a Star (LWS) Parker Solar Probe (PSP) are available at the website of Johns Hopkins University, Applied Physics Laboratory (parkersolarprobe.jhuapl.edu/Spacecraft/index.php#Instruments) and at www.nasa.gov/content/goddard/parker-solar-probe-instruments). The details of NASA's Solar Probe Plus (SPP) mission FIELD instrument is available in Bale et al. (2016). The same from PSP is available in Diaz-Aguado et al. (2021a, 2021b).

Workshops are being organized for contributing to decadal surveys, white papers, etc. through slack channels and Google documents. The author had a chance to participate in similar workshop (Heliophysics 2050 Workshop by Lunar and Planetary Institute and Universities Space Research Association) in 2021 where efforts have been given for international collaboration to summarize the present understandings in space physics and enlist necessary future plans. These are some good examples for both open and networked research.

2.4. Networked research in Space Physics and Aeronomy

Networking is an important aspect towards the growth of any field of science. Networking helps sharing ideas, creating possible collaborations and helps young researchers to learn from eminent scientists around the world. Networking can be conducted in the form of workshops, conferences, seminars, collaborations with mutual benefits, etc. The author has participated in the International Reference Ionosphere workshop conducted by the Committee on Space Research (COSPAR) at National Central University, Taiwan in 2017 and the Workshop on Space Weather Effects on GNSS Operations at Low Latitudes at Abdus Salam International Centre for Theoretical Physics (ICTP), Italy in 2018 with financial supports. Financial support is crucial for young scientists, especially from developing countries. In those mentioned workshops, the author had the chance to interact and learn from the eminent scientists in this field. All young participants were divided into several groups to work on certain scientific objectives during the workshops. The works were presented at the end of the workshops when the eminent scientists provided their valuable feedback. The author also had a chance to be involved in an International Space Science Institute (ISSI) project as a young scientist. ISSI provides an excellent platform for collaborative research by various international teams. The author also participated in several multidisciplinary conferences and meetings during the last five years such as AGU fall meeting, European Geosciences Union (EGU) fall meeting, International Union of Radio Science (URSI) General Assembly, COSPAR General Assembly and Beacon Satellite Symposium. These experiences provided him with good platforms for interactions and possible collaborations. The recent Covid pandemic definitely slows down the progress of research all over the world. But even during this uncertain period, collaborative research has been increased due to numerous virtual meetings. As there is no need to join physically, no financial burdens are associated which facilitate broader participation. In these meetings, participants can interact with each other for further discussions in a more focused manner. Different slack channels are provided for these focused discussions and possible collaborative research. The author is currently involved in working in two focused groups (i) COSPAR International Space Weather Action Team (ISWAT) and (ii) Center for the Unified Study of Interhemispheric Asymmetries (CUSIA) under Dr. Daniel T. Welling, University of Texas at Arlington. In these groups, global scientists can contribute alongside the team leaders and principal investigators for their mutual benefits. Science missions by different space agencies have co-investigators from different universities. Students working under those investigators can also contribute to these missions as necessary "people-power" to analyze and interpret data which benefits both sides. SCOSTEP Visiting Scholar (SVS) program assists young scientists to work in eminent research institutes to their space program objectives. This is another example of mutual benefits (for the young scientist and the corresponding institute). CCMC GEM Modeling Challenge, CEDAR Electrodynamics Thermosphere Ionosphere (CETI) Challenge were conducted to simulate certain space weather events and validate the performances of the existing models. Scientists can submit their model runs which get published in reputed journals and conferences and provide important information regarding the efficiencies of existing models in adverse space-weather conditions. NASA citizen scientist program is an excellent way to involve any space enthusiasts in space related observations. Some of the programs related to this section are Junocam (www.missionjuno.swri.edu/junocam) and Aurorasaurus (www.aurorasaurus.org). In 2021, the NASA heliophysics division LWS Architecture Committee (LWSAC) requested the space science community to provide feedback on the Strategic Science Areas (SSA) Focused Mission Topics. The author has also provided some feedback. These are excellent examples of networked research with mutual benefits.

3. Limitations/Challenges in Space Physics and Aeronomy and possible solutions through ICON

3.1. Knowledge based limitations

The lack of proper understanding of basic concepts and proper training for young students can lead a meritorious aspirant to an unfulfilled career. This problem can be solved if eminent scientists can teach them online. Online courses can be designed where interested students and researchers can register free of cost or with nominal registration fees. The relevant study materials can be provided weekly/monthly to all the registered participants. End of course evaluation process with certificates can be implemented for all participants to judge their understanding. This can add to ICON open and networked research if they are assigned with some tasks including analysis of any space-weather event using openly shared data and standard models. The results can lead to publications (for the researchers' benefit) and towards a better understanding of that space-weather event to the scientific community. If no registration fees are applied to make these courses available for everyone, this will benefit the broader community and we can bring more young researchers that would have been left out without these courses.

3.2. Cultural limitations

The cultural barriers for young aspirants from different parts of the world can be a challenging aspect. These lead to a lack of communication and idea-sharing as well as an unwillingness towards collaboration. This barrier can be removed by arranging cross-cultural workshops, seminars, student meetings, mentoring schemes, etc. This will help researchers from diverse backgrounds interact and understand each other. As mentioned in subsection 2.4, efforts are being made to involve young aspirants through different programs such as SCOSTEP SVS program, CCMC challenges where they can contribute to the understanding of space-weather events. These are some of the examples of networked research with mutual benefit as the young aspirants also contribute towards the research interest of the corresponding institute during those programs. But in most cases, they remain unaware of these opportunities. It is the responsibility of their supervisors to communicate this information to them during their undergraduate tenure.

3.3. Unavailability of Data

Though a lot of freely available data are present, there are still some data that are not published freely by different agencies, universities or laboratories. They adhere to some data policies which restrict data sharing with other researchers which is not in accordance with the ICON principles. Sometimes, they only provide data to their collaborating institutes. Thus, there is a need to redesign data policies to enable open sharing while ensuring proper credit and attribution to the data generators.

3.4. Technical limitations

The lacking infrastructure is one of the major barriers for researchers; this limitation is particularly acute in developing countries. Institutes are often unable to purchase instruments for studies and observations. More funding from different agencies may solve this problem. The online freely available data and educational resources in the Space Physics and Aeronomy section help to a certain extent in absence of infrastructure investments, which is an ICON-based solution (open research).

3.5. Professional limitations/challenges

Some universities or institutions are not providing financial support to their employees for pursuing higher studies and research abroad. This can be solved partially if universities and institutes from different countries can agree to exchange students and staff for a certain period of time. These students and staff can learn from the other universities and contribute to the research interests of their visiting institute which is also in line with the mutually beneficial ICON-based networked research.

3.6. Limitations towards English Proficiency

The lack of proficiency in English is also a major problem for young scientists mainly from non-English speaking countries. These lead to communication problems in their future career. They remain skeptical towards interacting with other scientists leading them towards unclear concepts in their subjects. Overcoming language barriers is one key element that needs to be addressed to research with the broader community. ICON-based solutions provided in subsections 3.2. and 3.5. (seminars, workshops, challenges, exchange programs or any mode of interactions) can build their confidence towards presenting in English. These processes will bring out more young talented scientists who will contribute to the community with their research in the future.

4. Acknowledgements

The author thanks A.G., J.S. and other ICON leadership members for assisting him in writing this paper.

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