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Committee on the Peaceful Uses of Outer Space

Report on the United Nations/Germany workshop on the International Space Weather Initiative: Preparing for the Solar Maximum

(Neustrelitz, Germany, 10–14 June 2024)

I. Introduction

1. Space weather is becoming a central topic that requires improved and sustained international coordination to respond to severe space weather events, including improved international data-sharing. There is also a need for more advanced space weather models and forecast tools in support of user requirements and for the coordinated sharing and dissemination of space weather model outputs and forecasts.

2. The International Space Weather Initiative, launched in 2009, has enabled scientists to use global navigation satellite system (GNSS) data in studies of space weather. These data have brought together scientists from various disciplines (such as seismology and the study of the ionosphere and the atmosphere) to work in the field of space weather and have made it possible to apply the fundamental physics of Sun-Earth relations to applications in everyday life, which is of great importance to policymakers.

3. The International Committee on Global Navigation Satellite Systems (ICG), established in 2005, has played an important role in the Initiative's work, as geomagnetic storms, solar flares and ionospheric irregularities can result in the deterioration of the positioning, navigation and timing accuracy of global navigation satellite systems. At the same time, existing data from GNSS stations are valuable for evaluating aspects of the response of the ionosphere to magnetic storms and other effects of space weather.

4. Information on all the achievements resulting from international cooperation and coordination under the Initiative, including in relation to instrumentation, data analysis, modelling, education, training and public outreach, is made available through the Initiative's electronic newsletter and its website (www.iswi-secretariat.org).

5. The United Nations workshop on the International Space Weather Initiative: Preparing for the Solar Maximum was organized by the Office for Outer Space Affairs with the support of the German Aerospace Centre (DLR). It was held in Neustrelitz, Germany, from 10 to 14 June 2024. The workshop was co-sponsored by ICG.

6. The present report sets out the background, objectives and programme of the workshop and provides a summary of the observations made and conclusions reached

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by participants. It has been prepared for submission to the Committee on the Peaceful Uses of Outer Space at its sixty-eighth session and for consideration by the Scientific and Technical Subcommittee at its sixty-second session, both to be held in 2025.

A. Objectives

7. In line with the consideration by the Scientific and Technical Subcommittee of the agenda item entitled "Space weather" (see A/AC.105/1307, paras. 132–143), the objectives of the workshop were to (a) focus on the deployment of new instruments, particularly in developing countries; (b) discuss methods for analysing data on space weather and interpretation of data; (c) focus on new research results and findings; and (d) strengthen international coordination and cooperation on space weather products and services.

8. The discussions at the workshop were also linked to the 2030 Agenda for Sustainable Development and the targets set out in the Sustainable Development Goals. The topics of discussion and the related Goals were as follows:

(a) Continuation of the efforts in space weather education in order to better define and characterize severe space weather events and their probability of occurrence and assess their impacts on technological systems (Goal 4: quality education);

(b) Space weather research helps to promote sustainable development through the prevention of catastrophic disruptions of both ground- and space-based critical infrastructure as well as space-based services, especially during severe space weather events (Goal 9: industry, innovation and infrastructure);

(c) International coordination of operational space weather services, including monitoring, forecasting and awareness-raising, with the overall goal of protecting life, property and critical infrastructure (Goal 17: partnerships for the Goals).

B. Programme

9. At the opening of the workshop, welcoming remarks were delivered by the Director of the Office for Outer Space Affairs, the representatives of the state authority for science and research of Mecklenburg-Vorpommern of Germany, DLR and the National Aeronautics and Space Administration (NASA) of the United States of America, as well as the mayor of Neustrelitz, Germany.

10. A keynote presentation on "Solar activity and ionospheric weather", delivered by the representative of Germany, focused on the coupling between solar activity and the Earth's ionosphere, as well as the impact of solar activity on radio wave propagation, a topic that had been explored in Neustrelitz for more than 100 years. It was noted that ionospheric processes were an essential part of the complex field of space weather and that understanding those processes and modelling them were important for mitigating the impact of space weather on modern technological infrastructures. It was emphasized that the International Space Weather Initiative, the follow-up activity to the International Heliophysical Year, created new opportunities for a better understanding of solar-terrestrial relationships and the impact of space weather on day-to-day lives.

11. The workshop programme consisted of 11 technical sessions and discussions of observations and conclusions, followed by closing remarks by the co-organizers and participants. Eighteen posters were presented, and 52 presentations were given at the technical sessions, which covered the topics of solar eruptions and their sources at the Sun and impact on geospace (magnetosphere, ionosphere, atmosphere and ground); flares and their impact on the ionosphere/atmosphere; the relationship between solar flares and coronal mass ejections; space weather extreme events; tools and methods for space weather education and outreach; coronal holes and high-speed streams associated with stream interaction regions; solar energetic particles and the associated

phenomena such as coronal and interplanetary radio bursts; ionospheric irregularities and their impact on GNSS, and spacecraft anomalies; geomagnetic storms and radiation belt variability due to coronal mass ejections and stream-interaction regions; space weather prediction using various techniques, including machine learning; space weather instrumentation; and operational use of space weather.

12. Poster and discussion sessions provided participants with an opportunity to discuss specific problems and projects related to space weather, in particular instrument arrays and their status of operation and coordination, and operational use of space weather data.

13. An informative technical tour of the technology museum was organized for workshop participants.

14. The programme of the workshop was developed by the Office for Outer Space Affairs, DLR and NASA in cooperation with an international scientific organizing committee. The Chairs and rapporteurs assigned to the technical sessions provided their comments and notes as input for the preparation of the present report.

15. The presentations given at the workshop, abstracts of the papers submitted, the workshop's programme and background materials are available on the website of the Office for Outer Space Affairs (www.unoosa.org).

C. Attendance

16. Scientists, engineers and educators from developing and industrialized countries in all regions were invited by the Office for Outer Space Affairs to participate in and contribute to the workshop. Participants were selected on the basis of their scientific, engineering and educational backgrounds and their experiences in implementing programmes and projects in which the Initiative played a leading role.

17. Funds provided by the United Nations and ICG were used to cover the travel, accommodation and other costs of 23 participants from 20 countries. A total of 80 experts were invited to attend the workshop.

18. The following 31 Member States were represented in person or online at the workshop: Argentina, Austria, Brazil, Canada, China, Côte d'Ivoire, Czechia, Finland, France, Germany, Ghana, Greece, India, Indonesia, Italy, Japan, Kenya, Nepal, Nigeria, Norway, Pakistan, Republic of Korea, Rwanda, Serbia, South Africa, Sri Lanka, Thailand, Türkiye, Ukraine, United Kingdom of Great Britain and Northern Ireland and United States of America. Representatives of the Office for Outer Space Affairs also attended the workshop.

II. Observations and conclusions

19. The workshop participants noted that coronal mass ejections were vast expulsions of magnetized plasma from the lower solar atmosphere into interplanetary space. Together with the often accompanying flares, they were the largest energy-release processes in the solar system and the main driver of space weather disturbances on Earth and other planets. Accordingly, coronal mass ejections were known to cause the most severe space weather effects, such as geomagnetic storms that could induce electric currents in power lines, potentially leading to widespread electrical grid failures and damage to infrastructure. Geomagnetic storms could also modify the signals of global navigation satellite systems, causing degraded accuracy. Intensive research to better understand the physical processes in the complex and interdisciplinary area of space weather was therefore essential for safeguarding technology, infrastructure and human activities both in space and on Earth.

20. The workshop observed that forecasting the impact of coronal mass ejections remained challenging owing to their complex and variable nature and the lack of accurate measurements of the background solar wind itself. Advanced coronal and

heliospheric models incorporating real-time solar wind data and detailed magnetic field measurements were essential for improving predictions. Also, data gathered on missions, such as on the NASA Parker Solar Probe and the European Space Agency (ESA) Solar Orbiter, would provide detailed information on the near-Sun environment, enhancing understanding of the coronal mass ejection processes of initiation and interaction with the solar wind.

21. The workshop noted that sunspots were temporary dark areas observed on the surface of the Sun, owing their dark appearance to their temperature which was cooler than the surroundings area, and that these structures were indicative of a strong magnetic field. The relationship between sunspot activity and flare activity, as well as the physical principles underlying solar flares, had become a significant issue because of the space weather effects of those active phenomena. Understanding solar flares and associated activities was important because such understanding provided a tool for predicting space weather, which affected interplanetary space and the Earth's upper atmosphere and thus the weather system.

22. Workshop participants took note of how different types of sunspots were associated with varying levels of solar activity. Discussions covered the classification of flare intensity and its relationship with different classifications of solar activity intensity. It was noted that sunspot groups were classified in two different ways, based on their morphology and evolution (modified Zurich classification) and on the magnetic properties of sunspot groups (Mount Wilson magnetic classification). It was also noted that the Mount Wilson magnetic classification of sunspot groups could be used as the main predictor to establish a more reasonable solar flare prediction model.

23. Workshop participants observed that extreme space weather events were considered high-impact, low-probability events that began on the Sun in the form of extreme solar flares and coronal mass ejections. Participants took note of the Heliophysics Big Year, a global celebration of solar science and the Sun's influence on Earth and the entire solar system, and its activities in 2024 and 2025, which would focus on studies of Sun-to-geospace elements that could potentially trigger major to extreme space weather events.

24. Workshop participants took note of the Committee on Space Research (COSPAR) International Space Weather Action Teams (ISWAT) initiative, which was a global hub for collaborations addressing challenges across the field of space weather. One of the objectives of the ISWAT S2-01 team was to study and compare different automated coronal hole detection schemes and develop strategies to quantitatively assess the uncertainty of coronal hole boundary locations. It was also noted that a data set of coronal images was publicly available for analysis (https://iswat-cospar.org/S2-01).

25. Workshop participants learned that the Community Coordinated Modelling Center, an inter-agency partnership for research in support of the generation of advanced space science and space weather models, was providing a mechanism by which research models could be validated, tested and improved for use in space weather forecasting. The Center also provided access to a large number of state-of-the art research models. The continuously expanding model set included models in all scientific domains, from the solar corona to the Earth's upper atmosphere. This science service was provided through web access (http://ccmc.gsfc.nasa.gov).

26. The workshop participants also learned about the first results obtained from a low-cost software-defined radio (SDR)-based ionosonde in the African equatorial region. It was noted that the comparison showed that the low-cost, low-power SDR-based ionosonde had demonstrated a level of performance that was equivalent or higher than that of conventional ionosondes available in the region in terms of the reliability, flexibility and accuracy of determining the main ionospheric parameters.

27. Workshop participants observed that the eruption of prominences could have a significant influence on the solar-terrestrial environment. It was noted that data analysis showed a correlation between the prominence's increasing height and the

oscillation periods, suggesting a potential link to the subsequent eruption observed by the Solar Terrestrial Relations Observatory (STEREO) spacecraft. Hence, these findings provided new insights into prominence dynamics and might pave the way for improved eruption prediction, aiding future space weather forecasting.

28. Workshop participants noted that the primary ionospheric phenomena causing potential space weather impacts on GNSS included the introduction of large gradients in the ionospheric total electron content, ionospheric irregularities triggering rapid signal amplitude and/or phase variation (scintillation), and sudden increases in background noise or total electron content due to solar radio bursts or solar flares. These phenomena were demonstrated using GNSS total electron content observations available in the Madrigal database (http://cedar.openmadrigal.org/). Information from over 6,000 GNSS sites were now being downloaded and processed daily. This data set had been utilized to monitor the ionospheric signatures of storm-enhanced density features, solar flares, geomagnetic pulsations, auroral structures, stratospheric warmings, and the Tonga volcanic explosion.

29. In addition, the Madrigal database now incorporated scintillation observations gathered from networks of specialized scintillation GNSS receivers. Currently, scintillation data from the entirety of 2023 and 2024 was available online. This database encompassed data from various networks, including the Development of Monitors for Alaskan and Canadian Auroral Weather in Space (MACAWS), the Canadian High Arctic Ionospheric Network (CHAIN), the Low-Latitude Ionospheric Sensor Network (LISN) and the National Institute of Geophysics and Volcanology (INGV) network of Italy.

30. Workshop participants noted that in order to provide relevant input for the evolution of the second generation of the European satellite-based augmentation system (EGNOS V3), an extensive network of globally distributed receivers was established to analyse both total electron content and scintillation data. Furthermore, an attempt had been made to record data streams of heavy scintillation events from low- and high-latitude regions. Such data streams could then be used as example scenarios for different GNSS receivers to test their robustness with respect to strong phase and amplitude scintillations.

31. Workshop participants also noted that the Initiative consisted of 19 instruments, of which Germany maintained two: the Compound Astronomical Low-Frequency Low-Cost Instrument for Spectroscopy and Transportable Observatory (CALLISTO) and the Global Ionospheric Flare Detection System (GIFDS). It was noted that DLR, at Neustrelitz, was operating several CALLISTO receivers (10–80 MHz, 100–800 MHz and 1,000–1,600 MHz), as well as GIFDS receivers for monitoring solar radio bursts and solar flares. It was highlighted that the original receivers had been further developed, in terms of hardware and software, to minimize noise and ease maintenance work so that the behaviour of different propagation paths could be observed. The results were compact receivers with a built-in screen and personal computer, forming the basis for a wide range of space weather event analysis.

32. The workshop participants observed that a number of CALLISTO spectrometers were deployed worldwide and together constituted the e-Callisto network. Data from individual instruments were automatically uploaded by file transfer protocol to the central server at the University of Applied Sciences and Arts Northwestern Switzerland and were available at (www.e-callisto.org/), together with CALLISTO technical documentation.

33. The workshop participants discussed the problem of space weather forecasting using traditional approaches, as well as the advantages of using machine learning techniques to identify and characterize phenomena that drive space weather.

34. With regard to the operational space weather, it was noted that the Space Weather Research and Technology Applications (SPARTA) Center of Excellence would use computer models to replicate space weather disturbances and use experiments, artificial intelligence and machine learning to develop solutions to help

improve the performance of satellites and other navigational technology in adverse conditions.

35. It was also noted that the ESA Space Weather service network was providing pre-operational services for spacecraft operations on the basis of a federated service provision model, providing end users with a very wide range of products and information about current and upcoming space weather conditions, along with post-event analysis support. This was provided along with the first data from the ESA Distributed Space Weather Sensor system via the ESA Space Weather Portal (https://swe.ssa.esa.int).

36. The workshop discussions helped to identify (a) any significant gaps in instrument types and coverage; (b) problems in maintaining instruments and data flow in terms of the continuity, collection, analysis and modelling of data; and (c) how to attract early-career scientists and support other ongoing international initiatives on space weather.

37. The workshop participants agreed that data from the Initiative's instrument arrays should be combined with space-based and other ground-based data through modelling and measurements to advance space weather science, thus leading to robust research output and the publication of scientific papers in international journals. It was also agreed that the space weather and global navigation satellite system communities should share data and collaborate on space weather research.

38. With the support of Member States under the umbrella of the Committee on the Peaceful Uses of Outer Space, efforts should continue in order to achieve the goal of reliable space weather prediction, involving the whole space science community in general and the space weather community in particular.

39. The following recommendations were made by the workshop participants:

(a) Capacity-building and technical guidance should continue to be provided to countries that wish to be engaged in space weather science and education;

(b) Opportunities for continued partnerships with capacity-building entities and activities within the United Nations should be further developed;

(c) Increased international cooperation should be promoted in order to meet current and future needs for space weather services, and a coordination mechanism should be established, with participation on a voluntary basis and support from the Office for Outer Space Affairs as appropriate.

40. To enable effective international coordination and collaborations in space weather research and services, there should not be any barriers to data flows and communications. To that end, an open data policy, complete with rules of operation and data standards, should be promoted at the national level.

41. The workshop was informed that proceedings of the workshop would be published by the Springer Publishing Company. Workshop proceedings would highlight the status of global space weather research, particularly in developing countries. All participants were invited to submit their research results on space weather to the editors of proceedings.

42. The workshop took note of the offer made by Nigeria to host the workshop in 2025. The interest of the Republic of Korea in hosting the workshop in 2026 was also noted.

43. The workshop participants expressed their appreciation to the United Nations, DLR, the co-sponsors and the scientific organizing committee for the substance, excellent organization and successful conclusion of the workshop.