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Report on the United Nations/Azerbaijan workshop on the International Space Weather Initiative: the Sun, Space Weather and Geosphere

(Baku, 31 October–4 November 2022)

I. Introduction

1. Space weather is an inherently international matter. Solar and magnetic storms affect large regions of the Earth simultaneously and equatorial ionospheric disturbances occur routinely around the world. It is therefore appropriate for the United Nations to promote improvements in space weather modelling and forecasting for the benefit of all nations.

2. The International Space Weather Initiative was launched in 2009 and has developed research capacities in the scientific disciplines of sun-Earth relations and space weather in many countries around the world. The Initiative has established a platform that takes a bottom-up approach in order to produce space weather-literate communities, in particular in developing countries, enabling those communities to work together as a network to share ideas, information and data and to develop joint projects.

3. Although the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space formally concluded the agenda item entitled "International Space Weather Initiative" in 2012, the Initiative's activities have continued under the agenda item entitled "Space weather" (see A/AC.105/1001, para. 226).

4. The Initiative continues to expand existing instrument arrays and develop new ones. There are currently 19 instrument arrays worldwide, with close to 1,045 such instruments deployed that record data on solar-terrestrial interaction, from coronal mass ejections to variations in the total electron content of the ionosphere. The website of the Initiative is available at www.iswi-secretariat.org.

5. The Initiative has enabled scientists to use global navigation satellite system data in studies on space weather. These data have brought together scientists from various disciplines (such as seismology, 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 everyday life, which is of great importance to policymakers.

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6. The Initiative is governed by a steering committee, which meets once a year on the margins of the sessions of the Scientific and Technical Subcommittee. Participants in the steering committee's meeting discuss the status of the operation and coordination of various instrument arrays, space weather data analytics and the activities of the Initiative. Annual reports submitted by the national coordinators and instrument operators are presented at the meeting and published in the Initiative's newsletter.

7. The United Nations/Azerbaijan workshop on the International Space Weather Initiative: the Sun, Space Weather and Geosphere was held in order to review the results of the operation of the Initiative's instrument arrays and discuss means of continuing to carry out space weather research and education activities. The workshop was organized jointly by the Office for Outer Space Affairs and Baku State University on behalf of the Government of Azerbaijan, and it was co-organized and co-sponsored by the International Committee on Global Navigation Satellite Systems. The workshop was hosted by Baku State University and was held in a hybrid format in Baku, from 31 October to 4 November 2022.

8. The present report sets out the background, objectives and programme of the workshop and provides a summary of the observations and recommendations made by the participants. It has been prepared for submission to the Committee on the Peaceful Uses of Outer Space at its sixty-sixth session and to the Scientific and Technical Subcommittee at its sixtieth session, both to be held in 2023.

A. Background and objectives

9. The Initiative consists of three elements: (a) the instrument array programme to operate and deploy space weather instruments; (b) the data coordination and analysis programme to develop predictive models using Initiative data; and (c) training, education and public outreach programmes.

10. As the scientific community and society increasingly recognize the impact of space weather on the infrastructure of the global economy, research efforts under the Initiative must be globally concerted, given that such efforts will ultimately contribute to an improved understanding of solar conditions and conditions in the solar wind, the magnetosphere, the ionosphere and the thermosphere that could influence the performance and reliability of space- and ground-based technological systems and could endanger human life and health.

11. The International Committee on Global Navigation Satellite Systems has played an important role in the Initiative's work, as global navigation satellite system receivers are used to better comprehend the dynamic processes in the Earth's atmosphere caused by extreme space weather and solar-terrestrial interaction and the effects of those processes on satellites.

12. In line with the consideration by the Scientific and Technical Subcommittee of the agenda item entitled "Space weather" (see A/AC.105/1258, paras. 158–172), the purpose of the workshop was to (a) raise awareness among Member States of the impact of space weather; (b) focus on the deployment of new instruments, particularly in developing countries; (c) discuss methods for analysing data on space weather; (d) focus on new research results and findings; and (e) encourage greater cooperation in developing partnerships between instrument providers and instrument hosts. The discussions at the workshop were also linked to the 2030 Agenda for Sustainable Development and to Sustainable Development Goals 4, 9 and 17.

B. Programme

13. At the opening of the workshop, welcoming remarks were made by the Rector of Baku State University, the Minister of Science and Education of Azerbaijan, the Deputy Minister of Youth and Sport of Azerbaijan, the Chairman of the Board of the

Azerbaijan Space Agency “Azercosmos”, the Director of Nasiraddin Tusi Shamakhy Astrophysical Observatory, a professor emeritus of Maryland University and the representative of the National Aeronautics and Space Administration (NASA). The representatives of the Office for Outer Space Affairs and the Executive Secretariat of the International Committee on Global Navigation Satellite Systems made opening remarks. Keynote speeches were delivered by the professor emeritus of Maryland University and the representative of NASA.

14. The workshop programme consisted of eight technical sessions and discussions on observations and recommendations, followed by closing remarks by the co-organizers. A total of 57 presentations were given at the technical sessions, which covered topics in the areas of: (a) space weather instrumentation and data; (b) space weather modelling; (c) space weather research; (d) solar physics; (e) magnetosphere-ionosphere-thermosphere coupling; (f) space weather effects; (g) national and regional space weather programmes; and (h) space weather case studies, outreach and education.

15. Each technical session included a discussion focusing on the key challenges and issues raised in the presentations. The results of the discussions were summarized and presented at the closing session, at which a final exchange of views was held and the conclusions and recommendations were adopted.

16. An informative technical tour of Azercosmos was also organized for workshop participants.

17. The programme was developed by the Office for Outer Space Affairs and Baku State University, in cooperation with the 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.

18. 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

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

20. Funds provided by the United Nations, the Government of Azerbaijan and the International Committee on Global Navigation Satellite Systems were used to cover the travel, accommodation and other costs of 25 participants from 23 countries. A total of 281 experts were invited to attend the workshop.

21. The following 65 Member States were represented in person and online at the workshop: Algeria, Austria, Azerbaijan, Bahrain, Bangladesh, Belgium, Brazil, Burkina Faso, Cameroon, Chile, China, Colombia, Congo, Côte d’Ivoire, Croatia, Democratic Republic of the Congo, Egypt, Estonia, Ethiopia, Gabon, Germany, Ghana, Guinea, Haiti, India, Indonesia, Iran (Islamic Republic of), Iraq, Italy, Japan, Kazakhstan, Kenya, Kuwait, Lao People’s Democratic Republic, Latvia, Lebanon, Malaysia, Malta, Mexico, Mongolia, Morocco, Myanmar, Nepal, Nigeria, Pakistan, Peru, Philippines, Poland, Republic of Korea, Russian Federation, Senegal, Serbia, Slovakia, Somalia, Spain, Sri Lanka, Sudan, Tajikistan, Türkiye, Uganda, United Kingdom of Great Britain and Northern Ireland, United States of America, Venezuela (Bolivarian Republic of), Yemen and Zambia. Representatives of the Office for Outer Space Affairs also attended the workshop.

II. Observations and recommendations

22. The participants expressed the view that research activities on space weather served as one of the first steps in implementing a broader programme of measures designed to protect the Earth from the dangers posed by space. A discussion was held on means of dealing with potential threats, including extreme space weather events and events such as celestial superflares and asteroid impacts that had a low probability of occurring but that, if they did occur, would have serious consequences.

23. The participants noted that the frequency of spacecraft anomalies typically peaked a few days after the onset of a solar energetic particle event in near-Earth space or the sudden commencement of a solar storm. In both cases, energetic protons and electrons in the space environment interacted with spacecraft components, causing their degradation or loss.

24. The participants also noted that phenomena produced by solar activity, such as flares and coronal mass ejections, could have a severe impact on the terrestrial environment. In studies of coronal mass ejections and energetic electrons that cause radio bursts, joint observations with a radio interferometer, the Low-Frequency Array and space-based radio receivers provided an extensive picture of various aspects of flare characteristics and contributed to estimates of the impact of such flares on the Earth. It was highlighted that microwave observations of the Sun remained one of the most significant trends in solar radio astronomy and solar physics. Participants were informed about spectral polarimetric observations of the Sun made by the RT-32 radio telescope at the Ventspils International Radio Astronomy Centre. The results were shown of a study on disturbances in the D region of the ionosphere, conducted using the very low frequency receiver of the Atmospheric Weather Electromagnetic System for Observation, Modelling and Education.

25. The participants observed that space weather forecasting was a complex issue that involved modelling solar plasma from the solar corona to the Earth's atmosphere. Therefore, coronal, heliospheric, ionospheric and magnetospheric models were needed to simulate the transfer of energy from the Sun to the Earth. In order to bring together and connect all those models on a virtual, interactive space weather modelling platform, the Virtual Space Weather Modelling Centre, which would bring together 19 separate models, was being developed. The participants noted the modelling of a coronal mass ejection event using a new heliospheric model called Icarus and the modelling of the total electron content over Africa using satellites of the Constellation Observing System for Meteorology, Ionosphere and Climate.

26. The participants also noted the less sophisticated but faster models, such as the European Heliospheric Forecast Information Asset and a 3D coronal magnetohydrodynamics model called COCONUT, which were used by operational space weather services to forecast the solar wind and the propagation of coronal mass ejections in the inner heliosphere and their possible propagation to Earth. It was further noted that the Gorgon magnetohydrodynamics model had been adapted to simulate the global magnetosphere faster than in real time, allowing for modelled and measured solar wind to produce continuous forecasting of geomagnetic conditions.

27. The participants learned about the NeQuick2 ionospheric electron density model, designed for trans-ionospheric propagation applications to reproduce the median behaviour ("climate") of the ionosphere and to estimate the 3D electron density of the ionosphere for current conditions ("weather"). The NeQuick2 web model website is available at https://t-ict4d.ictp.it/nequick2/nequick-2-web-model.

28. The participants also learned about the development of the Monitors for Alaskan and Canadian Auroral Weather in Space network to fill gaps in space weather data. The network is a sensor web network that provides real-time and historical global navigation satellite system total electron content, differential total electron content and scintillation data products. All data are entered into the Madrigal database and made available for near real-time processing. It was noted that vertical total electron content maps had been produced from approximately 6,000 global navigation satellite

system dual-frequency receivers worldwide. The data on total electron content had been available online as of 2000 and a new product, line-of-sight total electron content data files, had been available for the last three years. Those data files provide total electron content for every satellite and every receiver, every 30 seconds. The website of the Madrigal database is available at http://cedar.openmadrigal.org.

29. The participants noted that huge amounts of data were produced by ground- and space-based instrumentation that was designed to monitor the Sun-Earth system. In addition to increasing computing capability, those data sets were used to produce forecasting models and space weather products. It was noted that the machine learning approach could be used to identify functions that could approximate space weather processes and forecast their manifestation in the Earth's magnetic field and the ionosphere.

30. With regard to the applications of space weather research, it was noted that technological systems and the activities of modern civilization could be affected by changing space weather conditions. The study of everything from the dynamics of the Sun and the solar atmosphere to the particles and magnetic fields in the space surrounding the Earth helped to increase understanding of the physical processes driving the space environment, which in turn helped to create better simulations and predictive models of that complex system, and ultimately better protect technology, as well as provide early warnings to spacecraft operators of the hazards presented by increased space weather activity.

31. The participants recognized that space weather research benefited from effective international coordination and collaboration with regard to the sharing and use of available observations; the assessment of space weather forecasting and analysis capabilities; the advancement of knowledge, theory and modelling; and the application of advances in research to space weather-related applications.

32. The participants learned about a study on the temporal and periodic variations of the monthly flare index and selected geomagnetic activity parameters, such as the simple global geomagnetic activity index and the disturbance storm time index for solar cycles 21 to 24 (from 1976 to 2019). The results demonstrated that all parameters were highly correlated with the 11-year solar activity period and that flare index variations were one of the main drivers of geomagnetic activity.

33. The participants also learned about rare events, such as the well-known Carrington event of 1859, and hypothetical superflares that tend to occur in solar-like stars with large spot areas (more than an order of magnitude larger than the largest sunspot areas).

34. The participants noted that plasmas in the solar corona and the solar wind were known to be structured across the magnetic field, suggesting that uniturbulence might play a role in those regions. It was noted that a research project on novel 3D numerical simulations of propagating transverse waves was being carried out to better understand the physics of turbulence, and that the results would be verified with the relevant observational data.

35. The participants recognized that the mechanism of large-scale stellar magnetic field formation, including the Sun's 11-year variable cycle, was generally understood. However, the balance of hydrodynamic and magnetic helicity and its transport along the spectrum remained to be studied. In that regard, the view was expressed that the shell approach could be used for the future study of small-scale energy transport along the spectrum and to address the problem of the stabilization of large-scale stellar dynamo processes.

36. The participants noted the activities carried out in the framework of the International Committee on Global Navigation Satellite Systems. It was noted that the Committee's working groups were considering the challenging aspects of space weather phenomena, their impact on users of global navigation satellite systems, the variability of those impacts and the actions that might mitigate their effects. The activities of the working group on information dissemination and capacity-building

and its project team on space weather monitoring using low-cost global navigation satellite system receiver systems was highlighted. The participants noted that the project would develop protype systems to explore the possibilities of using low-cost receiver systems for space weather monitoring.

37. The participants further noted that the three major areas of future work of the project team were: (a) to explore low-cost global navigation satellite system receivers that could be used to compute total electron content-related parameters; (b) to explore software that could be used to process data from low-cost global navigation satellite system receivers in order to compute total electron content; and (c) to design a prototype low-cost global navigation satellite system receiver for space weather-related applications. It was highlighted that the project team was open to all individuals and groups committed to active participation in its activities. Several workshop participants expressed an interest in contributing to those efforts.

38. The participants observed that a wide range of instrumentation and sensing techniques were used to investigate regions that ranged from the area close to the Sun's surface to the lowest layer of the ionosphere. Some participants expressed the view that it would be desirable to include more case studies of space weather events in future workshops.

39. The view was expressed that hands-on workshops with tutorial materials and exercises on specific space weather-related disciplines should be organized before the holding of future workshops on the International Space Weather Initiative. The importance of follow-up training for the purposes of continuous learning and of sustainably maintaining core competencies was also emphasized.

40. The participants recommended that capacity-building and technical guidance should continue to be provided to countries that wished to be engaged in space weather-related science and education. Technicians and engineers also needed to gain more detailed knowledge of the ground stations and instrumentation involved in the observation of space weather. The view was expressed that opportunities for continued partnerships with capacity-building entities and activities within the United Nations should be further developed.

41. It was noted that the Initiative's activities were also coordinated with the United Nations-affiliated regional centres for space science and technology education and with the programme on global navigation satellite system applications of the International Committee on Global Navigation Satellite Systems.

42. The participants were informed that the journal *Sun and Geosphere* would publish a special issue on solar influences on the magnetosphere, ionosphere and atmosphere by the end of 2022. The participants were invited to submit their research results on space weather and solar terrestrial physics to the journal.

43. The participants expressed their appreciation to the United Nations, the Government of Azerbaijan, Baku State University and the co-sponsors for the substance, excellent organization and successful conclusion of the workshop.