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Report on the workshop on the International Space Weather Initiative

(Trieste, Italy, 20–24 May 2019)

I. Introduction

1. The International Space Weather Initiative, established in 2009, has its roots in the successful International Heliophysical Year 2007 (A/64/20, para. 155). The programme of the Initiative has proved to provide a framework for collaboration among teams of scientists, serving as an example of remarkable international work in instrument operation, data collection and analysis and the publication of scientific results. The Initiative has established a platform for a bottom-up approach in order to produce space weather-literate communities, in particular in developing countries, work together as a network for sharing ideas, information and data, and develop joint projects.

2. The Initiative continues to expand and deploy new and existing instrument arrays. There are currently 19 worldwide instrument arrays with close to 1,045 deployments recording data on solar-terrestrial interaction, from coronal mass ejections to variations in the total electron content in the ionosphere. Detailed information on various networks can be found on the Initiative website (www.iswi-secretariat.org). Instruments are provided to hosting institutions by entities in Armenia, Brazil, France, Germany, Israel, Japan, Switzerland and the United States of America. In general, the lead scientist or principal investigator of an Initiative project provides the instrumentation and data. The host country provides the human resources, facilities and operational support for the operation of the instrument project, typically at a local university. Host scientists become part of the science team, and all data and data analysis results are shared within the team and made accessible to all users.

3. The Steering Committee of the Initiative, with the support of the secretariat of the Initiative, which is located in the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center, in the United States, coordinates workshops, training sessions and education and outreach activities around the globe. The secretariat liaises with the Office for Outer Space Affairs in the conduct of its activities.

4. The activities of the Initiative are aimed at facilitating collaboration among research scientists in locations of scientific interest and at promoting researches in countries with expertise in building scientific instrumentation. Developing and

merging scientific insights helps in understanding the science behind, as well as in reconstructing and forecasting near-Earth space weather.

5. The annual meetings of the Initiative Steering Committee are held on the margins of the sessions of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space. Participants in the meetings discuss the status of operation and coordination of various Initiative instrument arrays and the operational use of space weather data.

6. A periodic Initiative newsletter is published by the International Centre for Space Weather Science and Education of Kyushu University, in Japan, while the Initiative website is maintained by the Bulgarian Academy of Sciences.

7. To review the results of the operation of the Initiative instrument arrays and discuss ways and means to continue space weather research and education, an Initiative workshop was held at the Abdus Salam International Centre for Theoretical Physics, in Trieste, Italy, from 20 to 24 May 2019. The workshop was jointly organized by the International Centre, NASA, Boston College and the International Committee on Global Navigation Satellite Systems. It was supported and sponsored by the Office for Outer Space Affairs, the European Space Agency, the Scientific Committee on Solar Terrestrial Physics, Boston College and the Institute of Navigation, the European Union and the United States, through the International Committee, the International Union of Geodesy and Geophysics and the Centre for Atmospheric Research of the National Space Research and Development Agency of Nigeria.

8. The present report contains a description of 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-third session and to its Scientific and Technical Subcommittee at its fifty-seventh session, both to be held in 2020.

A. Background and objectives

9. Over the past decade, space weather, caused by solar variability and its impact on the climate, atmosphere and space environment of the Earth, has been the subject of international attention, although the effort started during the International Geophysical Year, in 1957. The open data policies of space agencies and international cooperation in space missions have been extremely beneficial to the making of significant scientific progress in the field of solar-terrestrial physics.

10. The International Committee on Global Navigation Satellite Systems has played an important role in the Initiative programme, as global navigation satellite systems (GNSS) receivers are important to better comprehend the dynamical processes happening in the Earth’s atmosphere caused by extreme space weather and solar-terrestrial interaction and their effects on satellites.

11. In line with the discussions on space weather of the Scientific and Technical Subcommittee (A/AC.105/1202, paras. 191–209), 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, in particular in developing countries; (c) discuss methods for analysing space weather data; (d) focus on new research results and findings; and (e) encourage greater cooperation in developing partnerships among Initiative instrument arrays.

B. Programme

12. At the opening of the workshop, welcome remarks and keynote speeches were delivered by the director of the Abdus Salam International Centre for Theoretical Physics and the representative of NASA. The representative of the Office for Outer Space Affairs also made opening remarks and delivered a keynote presentation.

13. The workshop programme was broad and varied, with one major talk at the start of each technical session, followed by presentations. The technical presentation sessions covered a broad range of topics in the areas of: (a) space weather instrumentations and data; (b) space weather modelling; (c) regional space weather studies; (d) solar physics; (e) magnetosphere-ionosphere-thermosphere coupling; (f) space weather effects; (g) activities of international agencies in the field of space weather; (h) outreach and education; and (i) national space weather programmes. A poster session was also organized as part of the workshop. Overall, 62 presentations were given, and 36 scientific posters were presented.

14. The programme was developed by the Office for Outer Space Affairs and the Abdus Salam International Centre for Theoretical Physics, in cooperation with NASA and Boston College.

15. The presentations made at the workshop, as well as abstracts of the papers submitted, the workshop programme and background materials, are available on the websites of the Office for Outer Space Affairs (www.unoosa.org) and the International Centre (http://indico.ictp.it/event/8682/).

C. Attendance

16. Scientists, engineers and educators from developing and industrialized countries from all economic regions were invited by the Office for Outer Space Affairs, the Abdus Salam International Centre for Theoretical Physics, NASA and Boston College 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. Preparations for the workshop were carried out by an international scientific organizing committee and a local organizing committee.

17. Funds provided by the Office for Outer Space Affairs, the International Centre and co-sponsors were used to cover the travel, accommodation and other costs of 44 participants from 31 countries. A total of 115 experts attended the workshop.

18. The following 47 Member States were represented at the workshop: Algeria, Argentina, Azerbaijan, Bangladesh, Bosnia and Herzegovina, Brazil, Bulgaria, Burkina Faso, Chile, China, Colombia, Costa Rica, Côte d'Ivoire, Croatia, Egypt, Ethiopia, Fiji, France, Georgia, Germany, Ghana, Hungary, India, Indonesia, Iran (Islamic Republic of), Italy, Japan, Kazakhstan, Kenya, Malaysia, Nepal, Nigeria, Norway, Pakistan, Peru, Russian Federation, Rwanda, Slovenia, Spain, Sri Lanka, Sudan, Turkey, Uganda, Ukraine, United Kingdom of Great Britain and Northern Ireland, United States and Zambia. Representatives of the Office for Outer Space Affairs, the European Space Agency and the Scientific Committee on Solar Terrestrial Physics also attended the workshop.

II. Observations and recommendations

19. The participants noted the current status and prospects of numerous distributed networks for monitoring space weather. It was observed that adverse space weather was one of the principal threats to technological systems. Coronal mass ejections, large solar flares and high-speed solar wind streams often led to sequences of damaging disturbances within the Earth's magnetosphere, in the atmosphere and even on the Earth's surface.

20. The participants recalled that the Scintillation Network Decision Aid was a real time, data-driven communication outage forecast and alert system. It was noted that the Network needed capability restoration (for updating existing global positioning and very high frequency sensors) and consistent data acquisition (real-time data to be made available to the network participants or through collaboration with principal

investigators). Additional training and education in the next phase of the Network for better system site support would be a good opportunity for the Initiative community.

21. The participants observed that very low frequency measurements provided valuable information on the ionospheric response to solar X-ray flares and that the educational project “Solar flares detected by ionospheric effects” and the space weather monitoring system “Global ionospheric flare detection system” monitored the lower ionosphere by means of such measurements to provide information on solar flare effects. It was noted that participation in the aforementioned project was open to all interested educational and research institutions and that very low frequency technique should be used for detecting and analysing particle precipitation effects.

22. The participants recalled that the Continuous H-alpha Imaging Network instrument array was an observational network with ground-based solar flare monitoring telescopes. It was noted that solar spectroscopes would be added to the Network instruments in order to improve the measurement of physical quantities of solar active phenomena and that capacity-building activities would be organized to build skills in data analysis, including that of new spectroscopic data.

23. The participants learned about the development of the Monitors for Alaska and Canadian Auroral Weather in Space network to fill gaps in space weather data. This network is a sensor web network that provides both real-time and historical GNSS total electron content, differential total electron content and scintillation data products. All data are to be input into the Madrigal database and made available for near real-time processing.

24. The participants also learned that compact multicolour imaging cameras used interference filters to select the optical emission features. Owing to their low cost and minimal resource requirements, they would be a strong candidate for deployment across the globe for ground-based and suborbital observations, as well as for inclusion in small satellites. It was highlighted that those cameras would contribute to building capacity for state-of-the-art optical instrument development, data collection, processing, analysis and interpretation of space weather parameters and international cooperation.

25. With regard to future space weather monitoring instruments, the capabilities and development of a new coronagraph sensor to be carried on the forthcoming Solar Orbiter mission were described, as well as the scientific and operational potential for corona observations near the solar disk, both in terms of quality and added lead time for predicting the impacts of coronal mass on Earth. The ensuing discussions shifted the focus from the space-based optical domain to ground-based radio wave observations. The importance of both radio emissions and their polarization for understanding the heliosphere and the impacts of radio bursts on human-made systems was stressed.

26. The participants noted the sensitive observations of ionospheric ultraviolet emissions made by the International Space Station. The intensity of those emissions was proportional to the square of the electron density and thus provided a sensitive measure of plasma density in the upper atmosphere. Numerous results from morphological features to observations of vertical structure were shared and summarized with the message that there was still much to be learned from this rich, unique data set.

27. The participants also noted the use of GNSS sensor networks in West African countries and the relative merits of the available data. Despite the progress shown in terms of number of sensors, it was underlined that the availability of data from some sources was relatively poor. It was stressed that a network that primarily used airports for sensor locations provided the most consistent data by virtue of more reliable power and communications than other facilities. Those were therefore important reflections to be considered for future sensor installations.

28. The participants observed the availability and distribution of data through the NASA-sponsored coordinated data analysis workshops data centre. It was highlighted

that this virtual digital instrument represented an important contribution to the space weather community and that it served as a central repository for many data types that would otherwise require users to perform multiple searches through various interfaces and data formats.

29. The participants recognized that the convenience and expediency provided by such a central standardized distribution point as the aforementioned data centre had greatly enhanced space weather product development, while the open web interface had brought those advantages to all users, expanding access freely across countries.

30. The participants noted that GNSS technology was a relatively convenient means for monitoring the activity of the ionosphere. Consequently, the aggregation and standardized reduction of such data across regions represented a goal. The participants underscored the need for consolidated, accessible standardized GNSS data archives, such as the solar data sets available through the coordinated data analysis workshops. As a matter of fact, this was the very issue that the Abdus Salam International Centre for Theoretical Physics had tackled by announcing a plan to calibrate and upload global GNSS total electron content data gathered over the past 20 years and to make it freely available to the space weather community.

31. The participants observed that a wide range of instrumentation and sensing techniques were used for probing regions that ranged from the proximity of the sun's surface to the lowest layer of the ionosphere. However, some expressed the view that it would be desirable to hold a more thematically focused workshop in the framework of the Initiative programme.

32. The participants noted the latest advances in space weather modelling, including improvements to existing codes and algorithms that addressed the broad range of space weather prediction from the sun to the Earth. They took note of regional space weather studies that had drawn on observations, data analyses and modelling to understand and ultimately predict the complex state and interactions of the sun, solar wind, magnetosphere and ionosphere and their impact on technological systems.

33. The participants learned about estimating the sizes and energy of the most extreme solar flares and coronal mass ejections on the basis of what was known about past solar events in other sunlike stars. The study of those events yielded statistical plots where the high energy tails of the distributions provided estimates of possible event energy. For example, the famous Carrington flare/coronal mass ejection suggested that a flare with the energy of 10^{33} ergs might occur every 150 years, whereas a flare of 10^{34} ergs might occur every 125,000 years.

34. The participants noted that ground-based H-alpha observations of small-scale motions in solar filaments seemed to precede several eruptive flares. Doppler-shifted signals in the red and blue wings of the H-alpha line were also observed. Those motions occurred minutes to a few hours before a flare and, thus, could be used as precursors with predictive capability for large flares and their associated coronal mass ejections.

35. The participants also noted the rates of halo coronal mass ejections over solar cycles 23 and 24. Halo coronal mass ejections arose from events near the disk centre and were well correlated with space weather on Earth. Those data originated from the coordinated data analysis workshops catalogue of coronal mass ejections observed by the Solar and Heliospheric Observatory Large Angle and Spectrometric Coronagraph. The peak rates in the two cycles were similar, although the distributions during each cycle varied. The data also included interplanetary type II radio bursts, which were indicative of energetic coronal mass ejections driving shocks.

36. The workshop provided an impromptu opportunity for students and young researchers to give a summary of their presentations during the oral session, and therefore useful practice for their presentation skills. Some participants expressed the view that, at future workshops, it might be useful to schedule time for poster summaries given by students and thus encourage young people to participate in the

Initiative activities and in projects that pushed the frontiers of research, development and experimental operations.

37. The participants recognized that space weather research benefited from effective international coordination and collaboration in 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 research advances to space weather applications.

38. The participants noted two worldwide initiatives that would benefit from coordination with the Initiative to exploit synergy: the International Space Weather Action Teams of the Committee on Space Research, and the Heliophysics Data Environment Alliance. It was noted that the International Space Weather Action Teams were open to all individuals and groups committed to active participation in their activities.

39. The participants recalled that one of the goals of the Initiative had been to encourage growth in the number of space scientists around the world. In Africa, for example, hundreds of PhD students and young scientists had been trained in space weather and imparted with the skills needed to conduct research in space weather science. Today, many national and regional teams focused on increasing capacity-building for space weather monitoring, instrumentation, education and research in their home institutions.

40. The participants noted that capacity-building and technical guidance should continue to be provided to countries that wished to be engaged in space weather science and education. This also required technicians and engineers to gain more detailed knowledge of the ground stations and instrumentation dealing with the observation of space weather. It was noted that opportunities for continued partnerships with capacity-building entities and activities within the United Nations should be further developed.

41. The activities of the Initiative were also coordinated with the Regional Centres for Space Science and Technology Education, which are affiliated with the United Nations, and the programme on GNSS applications of the International Committee on Global Navigation Satellite Systems. In this regard, the participants noted the African workshop on GNSS and space weather to be held at the African Regional Centre for Space Science and Technology Education – in French Language in Rabat, in 2020. The workshop was to be co-organized by the Office for Outer Space Affairs, the Abdus Salam International Centre for Theoretical Physics and Boston College.

42. The participants expressed their appreciation to the Office for Outer Space Affairs, the Abdus Salam International Centre for Theoretical Physics and the sponsors for the substance and excellent organization of the workshop.