A Brief Summary of

The International Space Weather Initiative Workshop on Space Weather: Science and Applications

2 - 3 November 2021, online

The 2021 ISWI workshop was jointly organized by the United Nations Office for Outer Space Affairs and the Vikram Sarabhai Space Centre of the Indian Space Research Organization, India. This follows the in-person meeting that was held at the Abdus Salam International Center for theoretical Physics (Trieste, Italy) in 2019. More than 500 applications were received but the attendance was limited to 350 persons by the conferencing system at the UN.

ISWI activities are aimed at facilitating collaboration among research scientists in locations of scientific interest and promoting research in countries with expertise in building scientific instrumentation. Developing and merging scientific insights helps in understanding the science behind, as well in adding new knowledge on space weather phenomena near Earth and interplanetary space.

The 2021 ISWI workshop consisted of four sessions that covered the solar origin and terrestrial consequences of space weather and also space weather due to variations within Earth's atmosphere. The sessions started with a welcoming remarks by K. Rajeev (SPL/VSSC Director), T. K. Pant (SP/VSSC), S. Gadimova (UNOOSA), and N. Gopalswamy (ISWI). A brief description of each session follows.

Session 1: Sun, Solar Wind and Extreme Solar Eruptions

N. Gopalswamy's topic was "Extreme solar eruptions and their space weather Consequences". He explained how 100-year and 1000-year space weather event sizes can be estimated from the tail of cumulative distributions of solar flares, coronal mass ejections, sunspot area, solar energetic particle events, and geomagnetic storms.

S. P. Rajaguru introduced helioseismology and its connection to the solar magnetic variability – the root cause of space weather. After discussing the current developments in global and local helioseismology, he pointed to a list of unsolved problems requiring helioseismology for their solution.

D. Verscharen discussed the solar wind from the Sun to Earth focusing on the multi scale plasma processes. At the end of his talk, he introduced the Solar Orbiter mission and showed how the remote-sensing and in-situ instruments provide data to address the multi scale physics of the inner heliosphere.

B. C. Joshi presented a new opportunity to study space weather using distant astronomical objects: pulsars. He detailed how the high precision measurements of dispersion measure required by Pulsar Timing Arrays (PTAs) for gravitational wave detection can be useful for space weather studies. In addition to measuring density variation in the solar wind, PTAs are capable of detecting density enhancement in transient shocks in interplanetary coronal mass ejections and/or solar wind interaction regions.

Session 2: Space Weather - Sources, Consequences, Observations and Modeling
D. Nandi's talk focused on the fundamental physics behind space weather. After introducing kinetic and magnetohydrodynamic plasma regimes, he discussed current efforts in understanding the solar activity variability that affects a wide range of phenomena including solar magnetism, solar storms, solar wind conditions, solar radiation spectrum, planetary impact of solar wind, among others.
S. Schonfeld discussed current developments in the F10.7 solar activity index. It is the microwave radio flux measured at 10.7 cm wavelength (2.8 GHz) and available for more than 70 years. It serves as EUV proxy used for atmospheric research. He detailed how the gyro-resonance and bremsstrahlung components contributing to F10.7 index can be separated and the implications for ionospheric total electron content (TEC) models.
P. Doherty summarized the space weather impacts on the society such as power grid damage, satellite damage, radiation exposure, and HF communication. She also explained how GNSS signals can be used for space weather studies and how space weather affects GNSS applications. She also pointed to the global nature of space weather and the international government level efforts supporting forecasting and mitigation of space weather.
B. Nava explained the underpinnings of the NeQuick ionospheric electron density model and how it can be used for space weather studies. He showed specific examples illustrating how NeQuick model can provide realistic "weather-like" descriptions of the 3-D electron density of the ionosphere and the storm-time space weather effects in terms of total electron content (TEC).

Session 3: Space Weather Impacts on Magnetosphere - Thermosphere - Ionosphere System
D. Chakrabarty elucidated the phenomenon of penetration electric field and the current efforts in understanding it. He focused on the field aligned currents in the ionosphere and their roles in communicating solar wind/magnetospheric electric field disturbances to the polar ionosphere and eventually to the equatorial ionosphere electric field penetration. He also provided a set of issues related to the penetration electric field that are poorly understood.
A. K. Patra summarized the current understanding of several ionospheric phenomena relevant to space weather: vertical plasma drift, equatorial plasma bubble, 150-km echoes, and E region plasma irregularities. He showed specific examples of ground and space-based observations and how they are interpreted with the current level of understanding of these phenomena.
K. Shiokawa's talk focused on the role of the Earth's inner magnetosphere in space weather. He demonstrated that the inner magnetosphere consists of multi-energy energy plasma, waves, electric, and magnetic fields collectively forming a complex system responsible for the acceleration and loss of plasma. He discussed the related phenomenon of energetic particle precipitation in the polar atmosphere that may change the atmospheric dynamics through ozone destruction.

Session 4: Space Weather Instrumentation, Data, Outreach and Education K. Sankarasubramanian reviewed the recent developments in instrumentation and space mission activities in exploring the Sun and its surroundings. He highlighted exciting results from current missions such as Parker Solar Probe and Solar Orbiter and summarized the capabilities of future missions such as India's Aditya-L1 and ESA' Lagrange L5 missions.
B. Joshi described observing facilities at the Udaipur solar observatory including the newly established CALLISTO radio telescope (part of ISWI instrument network). He showed several space weather events and how they are analyzed using data from disparate instruments from space and ground. He emphasized the need for synergy among multi wavelength observations

with magnetic field measurements, extrapolations, and simulations to make progress toward a better understanding of eruptive processes and their monitoring.
S. Gadimova outlined the activities and opportunities provided through the International Committee on Global Navigation Satellite Systems (ICG). Understanding the issues related to GNSS is vital in utilizing it toward economic and social development, including environmental preservation in each country. She also explained how UNOOSA is collaborating with entities involved in space weather capacity building activities (e.g., ICTP, Boston College, and ISWI).
G. Vichare gave a summary of geomagnetic indices, tools, techniques, and consequences of geomagnetic storms. In particular she presented several extreme storm events observed magnetic observatories of the Indian Institute of Geomagnetism (IIG) including the Ali bag observatory. She described the IIG data on the great geomagnetic storms of September 1, 1859, known as the Carrington storm.
K. Groves focused on how extreme space weather can occur under quiet solar conditions (in the absence of eruptive solar events and magnetic storms). He showed that ionospheric plasma instabilities result in small-scale irregularities that can generate strong scintillation affecting frequencies from HF to L-band. He also presented information on numerous scintillation-induced GNSS performance impact during solar maximum periods.
M. L. Mays provided information on space weather outreach activities at the Community Coordinated Modeling Centre (CCMC) of NASA's Goddard Space Flight Center. After outlining the main functions of CCMC, she explained the readily available outreach resources such as (i) Web based tools and simulation services that can be used for space weather and space science research & education, (ii) Specialized simulations, visualizations, and tutorials in support of space weather summer schools, and (iii) Interactive visualizations of simulations with OpenSpace (an open-source interactive data visualization software designed to visualize the entire known universe and portray our ongoing efforts to investigate the cosmos).

The workshop ended with concluding remarks from Tarun K. Pant (VSSC) and Sharafat Gadimova (UNOOSA) that thanked the organizers, lecturers, and participants and expressed hope toward and in-person ISWI workshop. All the presentations made during this ISWI workshop are available online at the UNOOSA web site: https://www.unoosa.org/oosa/en/ourwork/psa/schedule/2021/2021-iswi-workshop-2021-presentations.html.

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