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Report on the United Nations/Mongolia workshop on the applications of global navigation satellite systems

(Ulaanbaatar, 25–29 October 2021)

I. Introduction

1. Global navigation satellite system (GNSS) is a general term describing any satellite constellation that provides positioning, navigation and timing services on a global and regional basis and whose data are used for a broad range of applications. Current GNSS include the following global and regional constellations: the Global Positioning System (GPS) of the United States of America, the Global Navigation Satellite System (GLONASS) of the Russian Federation, the BeiDou Navigation Satellite System (BDS) of China, the European satellite navigation system, Galileo, of the European Union, the Navigation with Indian Constellation (NavIC) system of India and the Quasi-Zenith Satellite System (QZSS) of Japan. The performance of GNSS can be improved through satellite-based augmentation systems to provide greater accuracy, integrity and availability for professional use and applications in critical sectors involving safety of life, for example, the aviation sector, which requires high-performance integrity verification.

2. The International Committee on Global Navigation Satellite Systems (ICG) is an important platform for communication and cooperation in the field of GNSS. The United Nations Office for Outer Space Affairs, in its capacity as the executive secretariat of ICG, supports progress in achieving compatibility and interoperability between all satellite navigation systems. As new systems emerge, signal compatibility and interoperability among GNSS systems and transparency in the provision of open civil services are key factors for ensuring that civil users around the world receive the maximum benefit from GNSS and its applications.

3. The Office for Outer Space Affairs and ICG work together to raise awareness of the important role of GNSS in our societies and to promote international collaboration in this field. Specific areas of interest to ICG and its working groups include systems, signals and services (Working Group S); the enhancement of GNSS performance, new services and capabilities (Working Group B); information dissemination and capacity-building (Working Group C); and timing and geodetic reference frames (Working Group D). More detailed information is available at www.unoosa.org/oosa/en/ourwork/icg/icg.html.

4. The United Nations/Mongolia workshop on the applications of GNSS was organized by the Office for Outer Space Affairs in cooperation with the Mongolian

Geospatial Association and the Agency for Land Administration and Management, Geodesy and Cartography of Mongolia. The workshop was held online from 25 to 29 October 2021. It was supported by ICG.

5. The present report contains a description of the background, objectives and programme of the workshop, as well as an overview of the highlights of each technical session and observations made at the workshop. It has been prepared for submission to the Committee on the Peaceful Uses of Outer Space at its sixty-fifth session, to be held in 2022, and to its subcommittees.

A. Background and objectives

6. The main objectives of the workshop were to reinforce the exchange of information between countries and scale up capacities in the region for pursuing the application of GNSS solutions; share information on national, regional and global projects and initiatives, which could benefit regions; and enhance cross-fertilization among those projects and initiatives.

7. The specific objectives of the workshop were to introduce GNSS-based technology and its applications; promote the greater exchange of actual experiences with specific applications; and focus on appropriate GNSS applications projects at the national and/or regional levels.

B. Programme

8. At the opening of the workshop, introductory and welcoming statements were made by the State Secretary of the Foreign Affairs Ministry of the Government of Mongolia, the General Deputy of the Agency of the Land Management, Geodesy and Cartography and the representative of MonMap LLC. The first Mongolian cosmonaut also addressed the workshop. The representative of the United Nations Office for Outer Space Affairs made opening remarks.

9. The workshop included the following technical sessions covering a wide range of topics related to GNSS-based technology and its applications: (a) an update on GNSS and GNSS-based applications; (b) space weather; (c) high-precision GNSS positioning; (d) timing, frequency and applications; (e) Geodetic reference networks; (f) national GNSS programmes and projects; (g) case studies; and (h) reports from the ICG Working Group B Application Subgroup. In total, 48 presentations were made during the five-day workshop. Speakers were selected on the basis of their scientific or engineering background, the quality of the abstracts of their proposed presentations and their experience in programmes and projects using GNSS-based technology and its applications.

10. In accordance with its workplan, on 26 and 27 October 2021, the experts of the Task Force on Interference Detection and Mitigation of ICG Working Group S conducted a seminar on GNSS spectrum protection and interference detection and mitigation. The purpose of the seminar was to describe the importance of GNSS spectrum protection at the national level and to explain how to reap the benefits of GNSS. The seminar lecture notes are available at www.unoosa.org/oosa/en/ourwork/psa/schedule/2021/2021-seminar_IDM_-presentations.html.

11. The programme of the workshop was developed by the Office for Outer Space Affairs and the Mongolian Geospatial Association in cooperation with ICG working groups.

12. The presentations made at the workshop, abstracts of the papers presented and the programme of the workshop are available on the website of the Office for Outer Space Affairs (www.unoosa.org).

C. Attendance

13. A total of 324 specialists representing national space agencies, academia, research institutions, international organizations and industry from developing and developed countries concerned with the development and use of GNSS for practical applications and scientific exploration were invited to participate in the workshop.

14. The following 61 Member States were represented at the workshop: Algeria, Australia, Azerbaijan, Bahrain, Bangladesh, Brazil, Burkina Faso, Cambodia, Canada, Chile, China, Côte d'Ivoire, Croatia, Cuba, Ecuador, El Salvador, Ethiopia, Fiji, Finland, France, Gabon, Germany, India, Indonesia, Iran (Islamic Republic of), Japan, Kenya, Kiribati, Lao People's Democratic Republic, Lesotho, Malaysia, Maldives, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Nepal, Nigeria, Oman, Pakistan, Peru, Philippines, Portugal, Russian Federation, Rwanda, Saudi Arabia, Sri Lanka, Tajikistan, Thailand, Togo, Tonga, Tunisia, Turkey, Uganda, United Arab Emirates, United States of America, Uzbekistan, Venezuela (Bolivarian Republic of), Zambia and Zimbabwe. The European Commission was also represented. Representatives of the Office for Outer Space Affairs and the International Telecommunication Union also participated.

II. Summary of discussions and observations

15. Through the presentations and the exchange of views that took place during the workshop, participants raised awareness of issues and opportunities in the use of GNSS for various applications that could provide sustainable social and economic benefits, for developing nations in particular. Each of the technical sessions included a discussion of the key challenges and issues presented.

16. The workshop noted that the field of GNSS was developing in a way that enabled satellite operators responsible for current and planned systems and their augmentation systems to cooperate at the international level with each other and the user community. It was noted that ICG had become an important platform for communication and cooperation in the field of GNSS and that the Office for Outer Space Affairs continued to support progress towards achieving compatibility and interoperability among global and regional space-based navigation systems. It was also noted that ICG, as a multilateral coordination mechanism, had allowed GNSS technology to evolve over time while still providing the structure necessary to achieve efficient interaction in one of the most important fields of space applications.

17. The workshop noted that space weather was a major factor limiting the precision and reliability of positioning, navigation and timing services provided by GNSS. It was noted that geomagnetic storms and substorms, solar flares and ionospheric irregularities could result in the deterioration of those services. Case studies of the impacts of space weather on GNSS highlighted the different approaches to mitigating the influences of space weather on single-frequency, dual-frequency, real-time kinematic and precise point positioning. Another focus of presentations delivered at the workshop was the evaluation of the characteristics of the different ionospheric models used in single-frequency operations during space weather events.

18. The workshop noted that a number of training activities focusing on ionospheric physics and space weather science had been planned by the Office for Outer Space Affairs in cooperation with the Abdus Salam International Centre for Theoretical Physics, Italy, Boston College of the United States and ICG, to be held in 2022.

19. A seminar conducted by the Task Force on Interference Detection and Mitigation of ICG Working Group S introduced spectrum management for radio-navigation satellite services (RNSS) and the mitigation of radio frequency interference, collectively referred to as "spectrum protection". Experts with experience in the development, operation and use of RNSS discussed regulatory, technical, operational and policy aspects of RNSS spectrum protection. It was noted that there were an almost limitless

number of GNSS applications and that GNSS was of crucial importance for national and global economies.

20. With respect to GNSS vulnerability and threats, it was noted that the satellite signals received by GNSS receivers were much weaker than the radio signals typically used by ground-based systems such as television stations or mobile phone networks, and consequently, it was essential to keep the frequencies used by terrestrial services well separated from those used in GNSS. There were many potential interference sources that could degrade GNSS performance and prevent the use of GNSS.

21. Participants in the workshop were therefore encouraged to engage with spectrum regulators and decision makers in their respective countries to ensure that there was a solid understanding of the processes and the organizations involved in the regulation of the GNSS spectrum and that the GNSS spectrum was adequately protected. Only by ensuring that the GNSS spectrum was kept clean and free of interference could GNSS be used to maximum benefit.

22. It was noted that GNSS systems, using a standard GNSS receiver, could provide positioning accuracy of about 10 metres. However, that level of accuracy could be improved using error correction techniques. GNSS measurements were affected by satellite clock errors, orbit errors (ephemeris errors), ionospheric effects, tropospheric effects, receiver circuit errors and multipath distortion. All those effects, with the exception of multipath distortion which remained a major source of error, could be removed or reduced by using special signal observation methods and signal-processing techniques. One such method was differential observation, in which a reference station, installed at a known position location, enabled exact measurement errors to be computed, thus providing accuracy to a few centimetres – a process known as real-time kinematic processing. Another method took into account satellite-related error data (clock and orbit data) from the satellite itself using a separate signal or link. At the workshop, a presentation was made on a simple methodology to design and implement a low-cost GNSS software-defined radio receiver. It was noted that the availability of reliable and flexible receivers was a priority for many applications, including research.

23. Participants noted that access to high-accuracy positioning services provided by GNSS and regional navigation satellite systems would serve as an enabler for emerging mass-market high-accuracy positioning applications, such as in autonomous systems in transportation, construction, mining, agriculture and location-based service applications. It was also noted that the ability to measure and monitor GNSS signal quality was critical to assess GNSS usability and performance.

24. The workshop noted that ICG Working Group C, led by the Office for Outer Space Affairs, and the Centre for Spatial Information Science at the University of Tokyo, Japan, organized a series of training courses from 2018 through 2020 focusing on a low-cost receiver for high-accuracy positioning and GNSS data processing using the post-processing real-time kinematic technique. The training course lecture notes were available at the ICG information portal (www.unoosa.org/oosa/en/ourwork/icg/activities.html). A new series of training programmes focusing on GNSS data processing would begin in 2022. That series would include a session for policy- and decision makers on GNSS principles and applications.

25. It was noted that GNSS satellites were equipped with atomic clocks that were accurate to within nanoseconds. While that was incredibly accurate, time measurements were necessary for the calculation of GNSS positioning. GNSS receivers could also use time measurements to provide timing accuracies of within 20 nanoseconds. The participants were shown an example of GNSS time transfer methods for remote clocks of common-view and all-in-view observations based on code measurements and the reference timescale of GNSS.

26. Participants took note of recent developments in the use of both the Integrated Geospatial Information Framework Overarching Strategic Framework and Implementation Guide for the purpose of geodetic capacity-building, including

examples from countries currently using the Framework to develop country-level action plans. There was a need for standards and procedures that were fit for purpose, including consolidated checklists that would serve to ensure consistent and sustainable use of GNSS, and related activities in the regions.

27. The workshop noted that technical seminars on reference frames in practice were being organized by the International Federation of Surveyors (FIG) Commission 5 on positioning and measurement, in cooperation with the International Association of Geodesy, the International GNSS Service and ICG Working Groups C and D. The seminars were held in conjunction with the FIG Working Week for the benefit of operational geodesists or surveyors who dealt with reference frame issues in both governmental and commercial environments.

28. Participants learned about education and training programmes on GNSS. It was noted that social and economic development in the countries of the region could be enhanced by improving the skills and knowledge of university educators and scientists through the conduct of rigorous theory, research, field exercises and pilot projects in GNSS technologies. Information on short- and long-term training courses on various aspects of GNSS, conducted at the regional centres for space science and technology education, affiliated to the United Nations, was also provided.

29. The session on case studies gave participants an additional opportunity to share their experiences in the use and applications of GNSS. Participants learned about high-accuracy positioning products that increase efficiencies and save time and input costs for the agriculture industry. A wide selection of innovative GNSS positioning products that could assist with construction and mining applications were also demonstrated.

30. Participants expressed appreciation for the various reports from the ICG Working Group B Application Subgroup on topics such as intelligent transport system applications and services, a GNSS-based emergency warning system responding to all types of hazards ranging from earthquakes to forest fires, GNSS user technology, high-precision products and services, and GNSS signal authentication applications, all of which illustrated that GNSS technology was undergoing a rapid evolution responding to the need for ubiquitous access, automation and secure positioning and showed how new developments would bring continuous accuracy, integrity and robustness to the main application domains.

31. The workshop was informed that the second edition of the publication *The Interoperable Global Navigation Satellite Systems Space Service Volume* (ST/SPACE/75/Rev.1), which had undergone a thorough review and update of all content, including the latest constellation data from all GNSS providers and adding GNSS space user flight experiences. The workshop took note of the release of the companion video. Both had been made available at www.unoosa.org/oosa/en/ourwork/icg/documents.html.

III. Concluding remarks

32. The discussion session provided guidance on how institutions could work together through regional partnerships to share and transfer knowledge and develop joint activities and project proposals. The feedback on the workshop received from participants was very positive, with participants saying that the topics addressed met their professional needs and expectations.

33. It was also emphasized that the Office would continue its work on capacity-building through the regional centres for space science and technology education, affiliated to the United Nations, and the centres of excellence, and would work further to ensure that end users benefited from the GNSS multi-constellation.

34. Participants expressed their appreciation to the United Nations, the Government of Mongolia and the ICG working groups for both the excellent organization and the substance of the workshop.