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

(Helsinki, 23–26 October 2023)

I. Introduction

1. The term "global navigation satellite system" (GNSS) refers collectively to the satellite navigation systems in operation or being developed around the world, including 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 and the European satellite navigation system (Galileo) of the European Union. These systems are supplemented by space- or ground-based augmentation systems. Examples of space-based augmentation systems are the United States Wide Area Augmentation System, the Russian System for Differential Correction and Monitoring, the European Geostationary Navigation Overlay Service, the Indian Global Positioning System Aided Geo Augmented Navigation system and the Japanese Michibiki satellite-based augmentation system. The use of several or all GNSS in orbit typically increases productivity and accuracy compared with the use of only one of such systems.

2. The growing number of GNSS and their economic, social and scientific benefits for humankind led to the establishment of the International Committee on Global Navigation Satellite Systems (ICG) in 2005 under the umbrella of the United Nations. The 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 the various GNSS 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 such systems and their applications. More detailed information is available on the ICG information portal (www.unoosa.org/oosa/en/ourwork/icg/icg.html).

3. The United Nations/Finland workshop on the applications of global navigation satellite systems was organized by the Office for Outer Space Affairs in cooperation with the National Land Survey of Finland on behalf of the Government of Finland. The workshop was held in Helsinki from 23 to 26 October 2023. It was co-organized and co-sponsored by ICG, the Finish Meteorological Institute, the University of Vaasa, the Nordic Institute of Navigation and u-blox. The workshop was supported by the City of Helsinki.

4. The present report describes the background, objectives and programme of the workshop and provides an overview of the highlights of each session and the observations made by the participants. It has been prepared for submission to the Committee on the Peaceful Uses of Outer Space at its sixty-seventh session and for consideration by the Scientific and Technical Subcommittee at its sixty-first session, both to be held in 2024.

A. Background and objectives

5. Since 2001, the Office for Outer Space Affairs has been organizing regional workshops to demonstrate the value of GNSS to the global community and to encourage the integration of GNSS technology into the basic infrastructure of developed and developing countries. The Committee on the Peaceful Uses of Outer Space adopted the topic "Recent developments in global navigation satellite systems" as a regular item on its agenda in 2007. Under the item, the Committee and its Scientific and Technical Subcommittee review issues related to the latest developments in the field of GNSS and new GNSS applications.

6. In line with the consideration by the Scientific and Technical Subcommittee at its sixtieth session of the agenda item entitled "Recent developments in global navigation satellite systems" (see A/AC.105/1279, paras. 129–151), the main objectives of the workshop were as follows: (a) to reinforce the exchange of information between countries and scale up capacities in the region for pursuing the application of GNSS solutions; (b) to share information on national, regional and global projects and initiatives that could benefit regions; and (c) to enhance cross-fertilization among those projects and initiatives. The discussions at the workshop were also linked to the Sustainable Development Goals.

B. Programme

7. At the opening of the workshop, introductory and welcoming statements were made by the representatives of the National Land Survey of Finland and the University of Vaasa. The representative of the Office for Outer Space Affairs also made opening remarks.

8. The workshop included the following technical sessions covering a wide range of topics related to GNSS-based technology and its applications: (a) current and planned GNSS and satellite-based augmentation systems; (b) applications of GNSS: case studies; (c) GNSS-based data; (d) low Earth orbit positioning, navigation and timing; (e) resilient positioning, navigation and timing; (f) national GNSS programmes and projects; (g) GNSS technology; (h) national experiences in the use of GNSS; (i) the impact of space weather on GNSS navigation and related services; and (j) GNSS in service of space weather monitoring and research. In total, 61 presentations were made during the four-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.

9. A technical tour to the Metsähovi Geodetic Research Station was organized by the Finnish Geospatial Research Institute of the National Land Survey of Finland for the workshop participants. The Metsähovi Station is one of the northernmost geodetic stations in the core network of the Global Geodetic Observing System of the International Association of Geodesy, located at 60 degrees north latitude.

10. The programme of the workshop was developed by the Office for Outer Space Affairs, the National Land Survey of Finland and the University of Vaasa.

11. 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

12. A total of 118 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.

13. Funds provided by the United Nations, ICG and the National Land Survey of Finland were used to defray the costs of air travel and the daily subsistence allowance for 24 participants.

14. The following 31 Member States were represented at the workshop: Algeria, Belgium, Canada, Chile, China, Colombia, Côte d'Ivoire, Croatia, Cyprus, Czechia, Egypt, Ethiopia, Finland, France, Germany, India, Indonesia, Kenya, Lao People's Democratic Republic, Mexico, Mongolia, Nepal, Nigeria, Norway, Philippines, Poland, Republic of Korea, Spain, Sudan, Thailand and United States. Representatives of the Office for Outer Space Affairs also participated.

II. Summary of discussions, observations and concluding remarks

15. Through the presentations made and the exchange of views 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, in particular for developing nations. Each of the technical sessions included a discussion of the key challenges and issues presented. Discussions at the workshop confirmed that the use of a combination of multiple systems could significantly improve many applications, as the use of more satellites strengthened the orbit geometry, resulting in higher accuracy and wider coverage of GNSS signals.

16. Participants in the workshop noted that L1C, a signal in the L1 band, was designed specifically to enable interoperability between the global positioning system and other GNSS and allowed greater cooperation between GNSS providers worldwide. The L2C signal, when combined with L1 coarse acquisition code in a dual-frequency receiver, enabled ionospheric correction, which could increase the accuracy of GPS. Lastly, the L5 signal would be used for safety-of-life transportation and other high-performance applications such as aviation. When used in combination with L1C and L2C, L5 would provide a highly robust service, and enable sub-meter accuracy without augmentations and very long-range operations with augmentations. It was further noted that the provision of a signal offering coarse acquisition in Galileo, the E5a signal, and in GPS, the L5 signal, could be a distinguishing feature of Galileo with respect to all other constellations that could further improve capability to acquire the E5 signal at low complexity. It was also noted that high-positioning and emerging applications of BDS were also being realized and exploited together with other GNSS, as well as several space-based augmentation systems.

17. Participants in the workshop noted that the growing reliance on GNSS had generated increased interest in its authentication, validity and security, which was challenging because of external interference. It was noted that at present, none of the GNSS open signals or civilian signals were protected from spoofing. The signals were not designed from the viewpoint of anti-spoofing capabilities. It was further noted that methodologies had been developed to authenticate the Quasi-Zenith Satellite System (QZSS) signals, as well as the GPS and Galileo signals by using QZSS. This methodology could also be implemented for other GNSS open signals such as those of BDS. The methodology was based on broadcasting the digital signature embedded in one of the QZSS signals for the authentication of the GPS and Galileo signals so that anti-spoofing capabilities for open signals could be implemented.

18. Participants in the workshop learned that the availability of Navigation with Indian Constellation (NavIC) signals in three bands (L5, S, L1) would aid in the

improved diversity of observations and better modelling of ionospheric phenomenon. The possibility of using space-borne NavIC L5 satellite signals transmitted from the geostationary and inclined geosynchronous satellites to perform land surface monitoring using a space-borne or airborne NavIC reflectometry receiver was also demonstrated.

19. Participants were also informed about the Korean Positioning System development programme and the Korea Augmentation Satellite System, designed to provide GNSS signals for users in the Korean Peninsula and the surrounding region and to be used for a wide range of applications, including transportation, navigation and surveying.

20. Participants in the workshop noted that in response to the rapid development of space-based augmentation systems around the world, several space-based augmentation system initiatives were being developed in Africa with the goal of having a single African system. A flagship project entitled “Satellite-based augmentation system-Africa” was paving a way towards an operational space-based augmentation system service, which would bring benefits to many sectors, including maritime navigation, precision agriculture and aviation.

21. Participants noted projects focused on characterizing the quality of and patterns in Automatic Dependent Surveillance – Broadcast data and identifying any errors or anomalies coming from potential failure modes. A demonstration was given of the GNSS-based trajectory reconstruction and analysis results as a case of machine learning-based inference of the relevance of contribution to signal processing in air navigation, air traffic management, surface navigation, logistics and strategic developments.

22. Participants also noted that the exploitation of signals from low Earth orbit satellites for positioning, navigation and timing services had become a major trend for space-based positioning, navigation and timing systems owing to the potential benefits that low Earth orbits could bring to GNSS. It was further noted that under the FutureNAV Low Earth Orbit – Positioning, Navigation and Timing programme of the European Space Agency, an in-orbit end-to-end demonstration would be developed with the objective of demonstrating the benefits of the programme to end users in terms of performances and new added-value services. Information was provided on the INdoor navigation from CUBesAt TEchnology (INCUBATE) project, aimed at promoting the exploitation of low Earth orbit small satellites for precise position, navigation and timing information in challenging conditions and investigating how these could be obtained in indoor environments. Information was also provided on the CentiSpace low earth orbit augmentation system for the establishment of global integrity monitoring and GNSS signal augmentation.

23. Another focus of presentations delivered at the workshop was resilient positioning, navigation and timing, and the convergence of positioning, navigation and timing technology with non-traditional and emerging technology to improve the reliability, performance and safety of mission-critical applications in the air, on land, at sea and in space. The participants learned about advanced machine learning for anomaly detection and jammer localization, approaches for making accurate fibre-optic time signals available to a larger number of remote users, as well as how to improve the accuracy of remote, low-frequency radio time broadcasts. The evolution of state-of-the-art jamming signal structures was also described.

24. The session on case studies and national programmes gave participants an additional opportunity to share their experiences in the use and applications of GNSS.

25. Participants in the workshop noted that the vulnerabilities of GNSS were well categorized, and it was understood that space weather was the largest contributor to single-frequency GNSS errors. Primary space weather effects on GNSS included range errors and loss of signal reception. The GNSS industry was facing several scientific and engineering challenges in keeping pace with increasingly complex user needs, including developing receivers that were resistant to scintillation and

improving the prediction of the state of the ionosphere. With GNSS modernization, the use of additional signals was expected to reduce errors caused by the ionosphere.

26. Participants learned about the European Space Agency Space Weather System, its objectives and current development status, and how the system was designed to support the mitigation of the effects of space weather on the infrastructure and services that were critically dependent on space-based assets. More detailed information is available on the European Space Agency Space Weather Service Network website (https://swe.ssa.esa.int/).

27. Presentations on the impact of space weather on the operation of critical infrastructure facilitating everyday life highlighted that GNSS observations were widely used in space weather services to monitor the spatio-temporal evolution of ionospheric disturbances, although such systems could themselves occasionally be affected by geomagnetic storms. With the approach of the next solar activity maximum – expected in early 2024 according to current estimates – it was not just increased storm activity that would challenge GNSS performance. It was noted that gradual changes in ionospheric background conditions over the longer term might also challenge some solutions developed and tested during years of lower solar activity. Besides the challenges and risks, the participants also discussed the means of mitigating them, with a focus on the portfolio of space weather monitoring and forecast services.

28. Participants noted that the performance of low-cost GNSS receiver systems in the area of high-accuracy positioning had improved to a level comparable with high-end GNSS receivers. Dual- and triple-frequency GNSS receivers, including the antenna, were available for less than $1000. It was noted that in order to evaluate the performance of low-cost GNSS receiver systems in the computation of total electron content (TEC) and rate of TEC index (ROTI), observations were made from four different GNSS receiver systems (both high-end and low-cost). Data were logged for several days and analysed using two different types of software independently. The results from both processing outputs had shown that low-cost GNSS receiver systems provided results that were in line with the outputs of the high-end GNSS receiver systems. It was noted that further studies would be carried out by logging data using different types of antennas, adding additional receivers and using different types of software.

29. Participants in the workshop noted the proposal of the Subcommission on Emerging Positioning Technologies and GNSS Augmentations of the International Association of Geodesy to create a new working group under the Subcommission that would focus on low-cost GNSS receiver systems for high-accuracy positioning, navigation and timing and associated applications. It was noted that the total cost of such receiver systems should be a few hundred dollars, including all necessary components, and that they should be easy to use in the field without requiring expert knowledge. This type of system would further enhance capacity-building and the development of new applications on a large scale. It was further noted that the proposed working group would cooperate with the project team on space weather monitoring using low-cost GNSS receiver systems of the ICG Working Group on Information Dissemination and Capacity-building, and would also promote the Working Group's project developments at International Association of Geodesy events and support the development of prototype receiver systems for base-station and rover units.

30. 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. Participants provided positive feedback on the workshop, stating that the topics addressed met their professional needs and expectations.

31. Participants expressed their appreciation to the United Nations, the Government of Finland and the co-organizers for both the excellent organization and the substance of the workshop.