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Committee on the Peaceful Uses of Outer Space

Report on the United Nations/Costa Rica/Prince Sultan bin Abdulaziz International Prize for Water Sixth Conference on the Use of Space Technology for Water Management

(San José and online, 7–10 May 2024, with on-site training on 11 May 2024)

I. Introduction

1. The Office for Outer Space Affairs, the Government of Costa Rica and the Prince Sultan bin Abdulaziz International Prize for Water organized the United Nations/Costa Rica/Prince Sultan bin Abdulaziz International Prize for Water Sixth Conference on the Use of Space Technology for Water Management from 7 to 10 May 2024. The Sixth Conference, which was held in a hybrid format, was hosted and supported by the Inter-American Institute for Cooperation on Agriculture. In addition, two training courses were offered for on-site participants on 11 May 2024.

2. The present report provides a description of the objectives of the Conference, details of attendance and a summary of the presentations, discussions and interactive sessions held during the Conference, and includes recommendations, a summary of feedback from participants and the conclusions emerging from the Conference.

II. Background and objectives

3. The conference series on the use of space technology for water management, the first edition of which was hosted in Riyadh in 2008, is now covered under an area of cooperation in the memorandum of understanding between the Prince Sultan Bin Abdulaziz International Prize for Water and the Office for Outer Space Affairs, which was signed on 31 December 2020. The other pillars of the Space4Water project covered under that agreement include a web portal and a community of practice for the exchange of knowledge on the use of space technology and data to address issues relating to water management. The community of practice consists of stakeholders (Governments, intergovernmental organizations, academia and civil society, as well as the private sector and industry), professionals, young professionals and Indigenous voices and now has more than 150 members.

4. In order to feed a growing population while maintaining access to clean drinking water and sanitation and ensuring that the water needs of healthy ecosystems are met, humanity needs to change the way in which water is used in food production. Agriculture already consumes 70 per cent of freshwater resources worldwide; at the

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same time, the World Bank estimates that 70 per cent higher output from agricultural production will be needed by 2050 to nourish the world's population.

5. The Conference enabled an active exchange on how space technologies and data can support assessment, monitoring, research and reporting on topics related to water resource management within the context of the water-food nexus, hydrology and ecosystem preservation. It also offered an opportunity for experts and representatives of governmental agencies to exchange knowledge on the themes of the Conference, which were as follows:

(a) *Theme 1*. Water scarcity: space technologies to adapt agriculture to climate variabilities;

(b) *Theme 2*. Space technology and data for water quality monitoring and sustainable agriculture;

(c) *Theme 3*. Satellite communication: a facilitator for Internet of Things-supported water applications;

(d) *Theme 4*. Space technologies for monitoring forests, agroforestry, watersheds and their interplay;

(e) *Theme 5*. Space technology and data for glacier monitoring.

6. The objectives of the Conference were:

(a) To raise awareness of and expand the use of space technologies and space-based data for better application in water resource management within the context of the water-food nexus, hydrology and aquatic ecosystem preservation;

(b) To further the active exchange of knowledge between governmental authorities, technical experts and academia, the private sector and civil society through technical presentations, panel discussions and networking opportunities;

(c) To demonstrate how projects using space applications have successfully informed decision-making and policy;

(d) To demonstrate space-related activities, services and cooperation programmes among different user groups, in particular government officials, the diplomatic community, United Nations entities and international agencies, as well as non-governmental organizations;

(e) To build capacity on topics relevant to Latin America and the Caribbean;

(f) To exchange knowledge on and co-develop solutions for pressing water challenges;

(g) To report to the Committee on the Peaceful Uses of Outer Space through its Scientific and Technical Subcommittee.

7. The programme of the Sixth Conference included technical presentations and "lightning talks", selected through a call for abstracts; a panel discussion with representatives of governmental institutions on space-based services for governmental institutions in water management; and a field trip to a community-based water treatment facility. Following the Conference, on 11 May 2024, two training courses were offered to on-site participants.

III. Attendance

8. A total of 436 individuals registered for the Conference, 141 of whom were women (32 per cent). Among the 92 on-site participants in the meeting, 38 (41 per cent) were women.

9. Online attendance fluctuated depending on time zones around the world. In total, 124 distinct participants from 40 countries took part in the online sessions

throughout the week. Information on the gender of the online participants was not available.

10. The following 52 countries were represented at the Conference, online and on site: Algeria, Argentina, Austria, Bahrain, Bolivia (Plurinational State of), Canada, China, Colombia, Costa Rica, Côte d'Ivoire, Democratic Republic of the Congo, Egypt, El Salvador, France, Gambia, Germany, Ghana, Guatemala, Honduras, India, Italy, Kenya, Lao People's Democratic Republic, Luxembourg, Malawi, Mexico, Morocco, Nepal, Nicaragua, Nigeria, Oman, Pakistan, Peru, Philippines, Qatar, Russian Federation, Saint Lucia, Saudi Arabia, South Africa, Spain, Switzerland, Syrian Arab Republic, Tunisia, Türkiye, United Kingdom of Great Britain and Northern Ireland, United Republic of Tanzania, United States of America, Uzbekistan, Venezuela (Bolivarian Republic of), Yemen, Zambia and Zimbabwe.

11. At least 20 individuals, including 9 women, attended the two training courses offered on 11 May.

12. Among the training participants, the following 11 countries were represented: Argentina, Bolivia (Plurinational State of), Brazil, Colombia, Costa Rica, Gambia, Kenya, Mexico, Nepal, Pakistan and Peru. The majority of the participants were from governmental organizations in Costa Rica.

13. Remote participants were invited to use the online platform to ask questions in the chat box during discussions, and the organizers used the same interface to provide complementary information. Furthermore, a form was made available in order to enable both online and on-site participants to post questions that they could not ask during the sessions.

IV. Programme

A. Overview

14. The programme comprised presentation sessions, a panel discussion, lightning talks and training courses.

15. The display of posters with QR codes supported the delivery of a poster session in hybrid format and increased the number of initiatives and research projects presented during the Conference.

16. The total duration of the event was approximately 40 hours (not including lunch breaks) over a five-day period. It involved seven speeches (two by women), 45 technical presentations (16 by women) and 25 lightning talks (11 by women). The programme comprised 13 sessions, including a high-level opening ceremony, a technical opening session with keynote addresses, four lightning talk sessions and 10 technical presentation sessions on the following topics:

(a) Water scarcity: space technologies to monitor precipitation, soil moisture and drought;

(b) Informed decision-making for agricultural interventions and irrigation decisions;

(c) Space technologies and their relevance for groundwater monitoring;

(d) Space technologies for monitoring flood risk and impact, and relevant climate change adaptations in agriculture;

(e) Space technology and data for water quality monitoring (and sustainable agriculture);

(f) Satellite communication: a facilitator for Internet of Things-supported water applications;

(g) Space technologies for monitoring forests, agroforestry, watersheds and their interplay (parts 1 and 2);

(h) Space technology and data for glacier monitoring.

17. The panel discussion on space-based services for governmental institutions in water management was the most interactive session of the event. A technical closing session enabled the moderators to contribute observations, conclusions, a gap assessment and recommendations. The ensuing training courses covered two topics: streamflow modelling using European Centre for Medium-Range Weather Forecasts (ECMWF) streamflow services, and Earth observation data for water quality assessment.

18. All of the presentations delivered during the Conference have been made available on the Office for Outer Space Affairs website,[1] the Office for Outer Space Affairs YouTube channel[2] and the Space4Water portal.[3] They are also linked on the individual profile pages of those speakers who are represented in the Space4Water community as stakeholders, young professionals or Indigenous voices and have their own profile pages.

B. High-level opening session

19. The Sixth Conference was formally opened by the Director of the Inter-American Institute for Cooperation on Agriculture, followed by opening remarks by the Deputy Director of the Office for Outer Space Affairs and a pre-recorded opening speech by a representative of the Prince Sultan bin Abdulaziz International Prize for Water, as well as opening remarks by the United Nations Resident Coordinator in Costa Rica and the Vice-Chancellor of the Ministry of Foreign Affairs and Worship of Costa Rica.

20. The Director of the Inter-American Institute for Cooperation on Agriculture highlighted that his organization, which worked on technical cooperation and was recognized for its resilience, had faced numerous crises. He underlined the urgent need to create a new future for agriculture, considering that farms currently received only 14 per cent of the final sale price of their products, as well as the need to be more concerned about all farming inputs, especially water. The importance of technology in transforming agriculture could not be overstated, in particular because the growing population would require more food. The future of agriculture should be closely linked with water science, through a platform that integrated agriculture with various allies. He concluded by pointing to the need for networks and strategic alliances.

21. The Deputy Director of the Office for Outer Space Affairs expressed gratitude to the host country, to the Prince Sultan bin Abdulaziz International Prize for Water and to the Inter-American Institute for Cooperation on Agriculture for their hospitality, support and contributions to organizing a conference at that level, as well as to all the experts and speakers. He addressed the critical juncture at which humanity stood, with unprecedented levels of water stress resulting from climate change, urbanization and population growth. Population growth in particular brought about an increased need for agricultural production, which currently already consumed 70 per cent of freshwater resources. The impact of water not only on the survival of humankind but also on the achievement of the Sustainable Development Goals was profound. He also highlighted the importance of space technology and space-based data for water management and mentioned that conferences on the subject had played a critical role in promoting effective water management strategies. Through the Conference, he added, the Office for Outer Space Affairs aimed to bring together a diverse group of actors, including technical experts, academics, local communities and decision makers, to enhance

[1] www.unoosa.org/oosa/en/ourwork/psa/schedule/2024/united-nations-costa-rica-psipw---sixth-conference-on-the-use-of-space-technology-for-water-management-draft-programme.html.

[2] https://youtube.com/playlist?list=PLaOqa4cng0GEBaC-rb7X-z-mIO7VrtHz_&si=jsA8uw9Gmoi89YNI.

[3] Space4Water portal, available at http://www.space4water.org.

diplomatic engagement among countries and improve operational cooperation, which facilitated the integration of efforts. Recognizing the performance of space technology in building capacities and reducing gaps, the Conference was positioned as a cornerstone for future development, involving stakeholders from cooperative organizations, academia and the private sector.

22. In a pre-recorded speech, a representative of the Prince Sultan bin Abdulaziz International Prize for Water delivered opening remarks and highlighted that the four specialized prizes, which covered the entire water research landscape, had been awarded every two years since 2002. The representative acknowledged his organization's long-standing relationship with the Office for Outer Space Affairs, which dated back to the first international conference on the use of space technology for water management in 2008, as well as the Office's work in implementing the Space4Water project. A memorandum of understanding setting up their cooperation on the Space4Water portal and project had been signed in 2016 and renewed in 2021. The twelfth Prize for Water, to be awarded in 2026, would focus on the management of water resources and encouraged innovative approaches.

23. The United Nations Resident Coordinator in Costa Rica drew attention to the current challenges faced by Costa Rica, such as electricity and water rationing and declining water quality. She highlighted the importance of the Conference and of exploring how space-based solutions could be utilized to address those issues, with a focus on monitoring water quality and predicting and managing the future of water quality through a global platform aimed at fostering collaboration. She stressed the need to develop suitable technology to meet specific water needs and the necessity of enhancing capabilities and facilitating the transfer of water technology with the aim of concrete actions for sustainable water management in the future.

24. The Vice-Chancellor of the Ministry of Foreign Affairs and Worship of Costa Rica began by highlighting the need to improve water resource management to ensure its availability starting at the local level, while demanding political commitment at all levels. With reference to the Conference programme, he continued by stressing the importance of global efforts to achieve universal health. Threats such as pollution and climate change must be managed holistically. The Vice-Chancellor provided some contextual information on Costa Rica, which spans an area of more than 54,000 km^2 and boasts diverse geography, and highlighted the country's deep commitment to the stewardship of water and natural resources. That commitment had made the country's use of space solutions for water management essential. He added that Costa Rica recognized the importance of space-based innovations and that the State ensured that access to water was upheld, acknowledging the integral role of water in empowering women, securing food and advancing human development. The Conference was a means of taking advantage of opportunities related to water management, as was the meeting hosted by Costa Rica in June 2024 on the United Nations Conference to Support the Implementation of Sustainable Development Goal 14: Conserve and sustainably use the oceans, seas and marine resources for sustainable development, to demonstrate the country's commitment to the health of the oceans. He concluded by stating that the water diplomacy and policies of Costa Rica were designed to benefit future generations, reflecting his country's enduring commitment to those critical resources.

C. Technical opening session

25. The technical opening session started with a keynote address delivered by the Deputy Director of the Office for Outer Space Affairs, who provided an overview of the use of space-based data and technology to address water and food security in times of climate change. He began with water and climate challenges and then turned to technological innovations, after which he spoke of the role of space technology in addressing challenges and improving water management practices. He also shed light on the operational use of space technologies to address water issues and contributions to the achievement of the Sustainable Development Goals, such as precision farming

using satellite data for field management, crop and soil monitoring, drought management and conservation in rice farming. He recalled the pressing challenges related to water and warned that the gross domestic product could diminish by 6 per cent in regions affected by water scarcity. Furthermore, he pointed to the overexploitation of fresh water and its pollution by industrial waste and urban sewage, leading to ecosystem degradation and health issues. In addition, he mentioned other pressures, including population growth, urbanization, and ageing and inadequate infrastructure, sometimes owing to economic and financial constraints. He also mentioned social and cultural challenges relating to disparities in access to water, and noted that transboundary water management and conflicts over shared resources posed legal and political challenges that complicated the situation. He also addressed the technical divide between developed and developing countries and, lastly, highlighted the four pillars of integrated water management:

(a) Data collection, management and continuous observation;

(b) Technology and innovation: advancement in satellite communication, Earth observation and geographic information systems;

(c) Education and capacity-building: educating communities and policymakers was considered fundamental, as they must take ownership of water management;

(d) Policy and governance.

26. The Deputy Director added that the strategic and economic significance of space technologies and their applications lay in the ability to communicate, observe and locate. He concluded his address by recalling various programmes of the Office for Outer Space Affairs relating to the matter and the role of the regional education centres and the Committee on the Peaceful Uses of Outer Space.

27. A speaker from the University of Costa Rica and representative of the World Meteorological Organization (WMO) delivered a keynote address that provided an overview of the existing space-based data products related to water and a user needs assessment for capacity-building and data in Latin America. The speaker gave an introduction to the WMO mandate as the specialized agency of the United Nations for weather, climate and water, and mentioned its regional associations. He continued by explaining the WMO space programme, which provided access to satellite data and products; awareness-raising and training; and coordination in the thematic areas of space technology, water and transmission frequencies, and in regional activities. The speaker presented the space-based Observing Systems Capability Analysis and Review (OSCAR/Space) tool, a register of satellites with information from Member States on each instrument's frequencies, points of contact and other information. Finally, he explained the role of virtual laboratories, the training centres of excellence through which WMO ran hundreds of satellite courses each year. He spoke about the role of the regional focus groups of WMO and of the Coordination Group on Satellite Data Requirements, noting that the latter connected institutions, countries and other users to space agencies. He concluded by mentioning the regional surveys conducted by WMO to assess user and capacity-building needs.

28. A speaker from the Water Directorate of the Ministry of Environment and Energy of Costa Rica delivered a keynote address on the Costa Rica case study that was structured in three parts: regulatory framework, creation of data and future steps. As for the regulatory framework, the speaker noted that the Water Act of 1942 determined the management of water resources, with certain limitations. Structured in general regulations, economic regulations and technical ones, the Act provided a legal framework for the management of water resources, allowances and regulations on water use, including instruments to regulate the nexus of technical and legal questions, such as drilling or inadequate water use. It also included a classification of watersheds and chemical, physical and biological water indices. In Costa Rica, activities included the collection of data on institutional operations, groundwater maps (e.g. water levels) and the water-energy nexus, the modelling of watersheds and

the monitoring of wells (using time series), as well as the remote sensing of groundwater potential and of the depth of aquifers. Water quality was monitored at 135 sites throughout the country through field data collection and laboratory analysis. Future steps in the country's activities included an update to the legislation on water, the integration of efforts and activities, as well as the recovery of good water quality in watersheds. Better management of hydrological resources was also needed.

29. Lastly, a representative of the Office for Outer Space Affairs gave a presentation on the Space4Water project, providing an overview of its history and objectives and its three pillars, namely, the conference series, the portal and community-building. Since the beginning of the conference series in 2008, the project had brought together more than 600 people from over 140 countries at five conferences. Launched in 2018, the Space4Water portal was being developed continuously. A few key features of the portal were highlighted, and statistics on portal content and users were shared, including on the Space4Water community, which consisted of 104 stakeholders, 20 professionals, 26 young professionals and seven Indigenous voices.

D. Technical presentations on water scarcity: space technologies to adapt agriculture to climate variabilities

1. Water scarcity: space technologies to monitor precipitation, soil moisture and drought

30. Moderated by a representative of the Food and Agriculture Organization of the United Nations (FAO), the session included research presentations on the urgency of implementing sustainable water management strategies to address escalating water scarcity challenges. The representative noted that climate variability phenomena such as El Niño and its increasingly strong effects required a thorough analysis of drought processes.

31. Growing interest in measuring and monitoring precipitation, soil moisture and drought in intermediate and local-scale projects was a common pattern throughout the work presented. Numerous methodologies and sources of information for measuring and monitoring those phenomena were presented. Examples included data from the Standardized Precipitation-Evapotranspiration Index Global Drought Monitor and the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), Soil Moisture Active Passive (SMAP) global soil moisture data, the Vegetation Condition Index and the Standardized Precipitation Index. The studies presented had been carried out in the Andes Region, the Amazon Region, the Oranie Region (western Algeria), and regions affected by meteorological drought in the Gambia. Many of the studies included an examination of variability and possible adaption under changing climatic conditions and projections.

32. One key interest of local governments was to identify droughts both faster and more cost-effectively through risk monitoring platforms. Moreover, the presented analyses identified potential optimizations of agricultural productivity with drought-resistant seeds, especially in drought-prone regions. The use of the Google Earth Engine platform to provide effective monitoring of soil moisture in a time series from 2015 to 2022 through the SMAP global soil moisture data sets was highlighted.

2. Informed decision-making for agricultural interventions and irrigation decisions

33. During the session, experts from international, regional and national organizations shared their insights and experiences from various perspectives on how satellite data were used to monitor water productivity and how to leverage remote sensing for efficient irrigation practices. The aim of the session was to explore how technology and data could help to tackle some of the most pressing challenges in agriculture today. Examples included achieving food security while ensuring sustainable water use, monitoring water use in agriculture effectively to increase productivity, and providing governmental authorities and local actors with precise,

accurate and timely information for policy implementation, decision-making and operational monitoring.

34. Presentations were given on the "Water productivity through open access of remotely sensed derived data" (WaPOR) portal, developed by FAO, and its implementation in the Lower Limpopo River Basin in Mozambique to assess irrigation performance; on operational irrigation management based on Landsat data and the Surface Energy Balance Algorithm for Land (SEBAL) module, leading to the development of the SAT'IRR platform to assist farmers by providing guidance in irrigation decisions and enhancing water use efficiency in Morocco; and on a space-based approach to irrigation scheduling with a 1 km resolution using the leaf area index along with water balance monitoring, including evapotranspiration projections, integrating remote sensing data with modelling to optimize water use and reduce production costs. It was noted that the innovation related to irrigation scheduling was applicable globally and could benefit farmers, policymakers and environmental sustainability efforts in general.

3. Space technologies and their relevance for groundwater monitoring

35. Presentations during the session on the relevance of space technologies for groundwater monitoring covered topics such as assessing vulnerability and co-designing climate-resilient water management strategies for rural communities using geospatial data sets; remote sensing for the management of transboundary aquifers; cloud computing and remote sensing data for potential groundwater recharge estimation; and groundwater vulnerability mapping and the assessment of interactions between land use, land change and groundwater recharge under urban heat islands in North Africa and in Bolivia (Plurinational State of), Ghana, Mexico and Pakistan.

36. Participants noted that space technologies offered a powerful toolbox for monitoring groundwater resources around the world. They provided data on factors influencing groundwater recharge, such as vegetation cover, soil moisture and changes in land use. Geographic information systems made it possible to integrate various data sources for comprehensive groundwater resource analysis. The Global Positioning System (GPS) of the United States enabled precise location tracking for well monitoring and aquifer mapping. Large-scale monitoring became feasible because space data covered vast areas, which was particularly valuable for regional aquifers, while offering a cost-effective approach, reducing but not replacing expensive, ground-based methods for data collection. Another benefit of space-based monitoring was timely data acquisition to enable regular monitoring and rapid response to changes in groundwater levels.

37. Participants also noted that gaps in space-based groundwater monitoring included limited data access and quality, a lack of technical expertise in some regions, and gaps in the integration of data from diverse sources. Training and capacity-building for the effective use of technology and robust infrastructure, such as national spatial data infrastructure, were suggested as means of addressing those gaps.

4. Space technologies for monitoring flood risk and impact, and relevant climate change adaptations in agriculture

38. The presentations during the session on flood risk and impact highlighted floods as the most severe hazard, affecting millions of people worldwide, and as the deadliest hazard globally. It was noted that compounding events were becoming a major challenge: floods, droughts, landslides and glacier melting, to name just a few. Applications and tools such as the Flash Flood Guidance System, artificial intelligence and machine learning using impact-based monitoring to improve early warning systems were considered helpful, as were Earth observations, as they filled in existing data gaps regarding precipitation, flood modelling and inundation mapping. Speakers referred to data sources such as the Global Precipitation Measurement Mission and the Sentinel missions.

39. Speakers mentioned the importance of outscaling and upscaling methodology and documenting lessons learned. Crop damage estimation, for example during floods, could rely on geographic information systems to understand risks and vulnerabilities and to develop sensitivity analyses to support decision-making. Early warning systems were regarded as a prerequisite for preparing communities for minimizing losses and enhancing their adaptive capacity. Space technology provided support for estimating the impacts, damage and losses caused by extreme events, including for crop areas. Speakers highlighted that, in order to enable all stakeholders to apply the technology with a view to managing floods better, long-lasting capacity-building was essential, as were training and education in satellite meteorology.

40. While data, information and tools were available, their use and applications often remained a challenge, raising questions as to their effective and efficient application. Capacity-building with regard to access to and the interpretation and use of the various data sets and tools was limited at all levels, from the regional to the national and local levels. Good practices existed, but gaps in their uptake remained a challenge to broader operational use.

E. Technical presentations on space technology and data for water quality monitoring (and sustainable agriculture)

41. Participants noted that many factors, including agricultural runoff, untreated wastewater and climate change, contributed to the degradation of water quality in many regions of the world. Although billions had been spent on satellite research and development and building satellite infrastructure, applications and technology transfer received less funding.

42. It was also noted that the science and technology of satellite remote sensing of water quality were continually evolving. It was concluded that capacities to measure and quickly disseminate information will have evolved in a decade. A common thread in the presentations given during the session was the question of how to improve confidence in the products and services generated and the notion that uncertainties were just as important as absolute values. The need to build capacity to use tools, ranging from exploring the ability to distinguish algal types to measuring pesticide applications in an agricultural context and watersheds and climatic factors influencing current and future water quantity and quality conditions, was highlighted. Harmful algal blooms were identified as an increasing global problem. Advancing the use of satellite remote sensing to better quantify such blooms and bloom ecology was considered critically important.

43. A presentation on the rural aqueduct associations of Costa Rica, in which a community-based water management approach had been taken, shed light on the work carried out by those communities, who had developed a risk management tool in which risk was defined on the basis of hazard exposure, vulnerability and capacity, and had successfully used that information to manage their basins. A discussion evolved around compiling data layers into an up-to-date, non-static comprehensive risk assessment to inform investment and to anticipate future issues.

44. Areas of interest examined by presenters during the two presentation sessions on the theme of water quality monitoring included lakes, rivers, reservoirs and mega-delta regions in Asian mega-deltas and in Argentina, Colombia, Costa Rica and the United States.

45. Conclusions on the gaps in space-based water quality monitoring included the need for a better understanding of end-user needs in relation to various water quality parameters and temporal and spatial resolutions; the need for increased awareness of (new sources of) remote sensing information within end-user communities; and the need to educate users on errors in existing methodologies to foster understanding of the challenges of traditional measurements, for example by taking only one sample in the middle of a lake. In addition, speakers noted that institutional and regulatory barriers needed to be understood and water quality limit values codified. Finally, it

was noted that there was an uneven distribution of in situ data needs globally. Optical equipment for collecting in situ data could also pose challenges, especially with regard to new satellites with higher spectral resolution, such as the Plankton, Aerosol, Cloud, ocean Ecosystem sensor (Ocean Colour Instrument) of the National Aeronautics and Space Administration of the United States, which would require more sophisticated (hyperspectral) in situ measurements. Along with in situ data needs, training opportunities remained the other nearly global and constant need.

F. Technical presentations on satellite communication: a facilitator for Internet of Things-supported water applications

46. Participants stated that the integration of advanced sensors, Internet of Things technology and satellite communication systems opened up new possibilities for real-time monitoring and data collection in remote or inaccessible areas, especially those without mobile phone network coverage. Such satellite and Internet of Things systems facilitated communication and data exchange among devices and thus made it possible to remotely track water levels, consumption patterns and agricultural dynamics with unprecedented accuracy and efficiency.

47. Examples of the work presented included Internet of Things sensors that sent data concerning water quality and issued local alerts on cyanobacteria levels. It was noted that constellations of satellites could acquire data for an entire area, enabling the identification of potential sources of contamination and projections of its overall impact. Progress was also being made not only in global connectivity and asset tracking and monitoring, but also in environmental monitoring, emergency response and precision agriculture. The observation of cacao plantations over their full growth cycle – including irrigation, fertilization, pest management, plant diseases and ecological side effects – using Internet of Things sensor technologies in remote areas was also presented. The aim of that project was to transmit the collected data by satellite.

G. Technical presentations on space technologies for monitoring forests, agroforestry, watersheds and their interplay

48. The focus of theme 4, which was addressed in two presentation sessions, was on the utilization of space technologies for monitoring and modelling forests and watersheds. Presentations covered many different applications of space technologies to develop models, primarily in defining parameters such as land use conditions and digital elevations, which were critical for watershed monitoring and modelling. Satellite technologies made it possible to monitor change over time, as was presented in the examples of mangroves and the disappearing Aral Sea. The presenters highlighted the need for robust in situ monitoring to improve bias correction and to calibrate models derived from global Earth observation systems. There was also considerable discussion on capacity development and training for stakeholders in order to be able to use and rely on those information systems for decision-making and policy formation.

49. In a keynote presentation, a speaker introduced the open, global Group on Earth Observations Global Water Sustainability (GEOGLOWS) Streamflow Model, which provided daily forecasts based on 80 years of hydrological records and meteorological forecasts as input data. Other significant technologies discussed during the session included quantitative assessment tools for land degradation and water conservation, with an emphasis on the need for innovation in agriculture and climate change adaptation, and ways to estimate crop losses in the case of floods, presented by the Space and Upper Atmosphere Research Commission; satellite and aerial imaging to monitor drought and the shrinkage of the Aral Sea, by the Centre for Space Monitoring and Geoinformation Technologies under the Space Research and Technology Agency of Uzbekistan; time series analysis of mangrove forest cover loss using satellite-based radar data, by the Ministry of Lands, Housing and Human

Settlements Development of the United Republic of Tanzania; comparative hydrological dynamics and water security in the Sundarijal watershed in Nepal, developed with the Regional Hydro-Ecologic Simulation System, a modelling approach for broadleaf and conifer forests to simulate streamflow; and hydrographic intelligence in spatial databases using PgHydro, a PostgreSQL/PostGIS extension for water resources decision-making, to analyse drainage networks, presented by the National Water and Basic Sanitation Agency of Brazil. Lastly, a speaker from the Stockholm Environment Institute Africa Centre, based in Kenya, gave a presentation on the performance of the land component of the fifth generation of European ReAnalysis (ERA5-Land) for hydrological modelling in data-scarce regions.

50. Participants in the sessions underscored the role of space technologies in monitoring forests and watersheds. Despite advancements, challenges in the effective use of space technologies included limited capacity and training among stakeholders to use and trust remote sensing data, inadequate access to innovative tools and technologies for climate adaptation and food security, and the need for comprehensive in situ monitoring to enhance the accuracy of satellite-derived models. Areas of interest examined by speakers during the two presentation sessions on the theme of forests, agroforestry, watersheds and their interplay were sub-Saharan Africa, as well as Brazil, Nepal, Pakistan, the United Republic of Tanzania and Uzbekistan. The presentation on the streamflow model was based on a global perspective, with examples from Ecuador, Libya and Malawi.

51. Continued investment in scientific research, capacity-building and international cooperation was considered vital. Addressing the highlighted gaps would be crucial for sustainable environmental management and policymaking.

H. Technical presentations on space technology and data for glacier monitoring

52. Participants emphasized space technology as a highly effective way to study fragile and dynamic phenomena such as glaciers, as it provided monitoring data and input to models. Multitemporal data had proved useful in estimating the current state of and future predictions regarding the cryosphere. The assessment of climate change effects was considered critical for emergency response and the effective protection of that highly fragile system. Quantitative assessment and modelling of mass balance provided very relevant information for those interested in glacier systems.

53. Presentations delivered under theme 5 included the increasing risk of glacial lake outburst floods; the application of space technology for mass balance studies; and using remote sensing and hydrological modelling for the assessment of water resources and cascading geohazards. The presentations focused on the Hindu Kush-Himalayan Region, Patagonia and Peru.

54. Gaps identified in the field of glacier monitoring included spatio-temporal studies, the quantitative assessment of climate change, regional simulations for probabilistic and predictive mapping, structural properties of snow packing, improved in situ data, structural aspects of glaciers, studying causes and effects, glacier depletion monitoring, snowmelt and run-off modelling, and studies of atmospheric conditions of the cryosphere.

I. Panel discussion on space-based services for governmental institutions in water management

55. The panel discussion was focused on the utilization of space-based services to support governmental institutions involved in water management. Current challenges, innovative solutions, ongoing projects and the importance of international cooperation were highlighted. Participants identified several key challenges in accessing and utilizing satellite data, including the high cost of data and computational power,

technical limitations in both hardware and capabilities to operate software, and in using satellite data effectively and interpreting the data.

56. Various national space agencies that were represented on the panel had developed innovative programmes to mitigate those challenges. Examples included the provision of operational satellite image data; the development of future missions, for example to provide high-resolution imagery supporting the work of ministries and to offer Internet of Things data for diverse applications, including water management; centralizing data collection; implementing a 20-year space plan in which agricultural needs were prioritized; focusing on developing capabilities in satellite technology; and applying machine learning to satellite data to process large volumes of information.

57. Successful international collaboration was highlighted as essential for progress. Panellists mentioned cooperation efforts that were focused on the use of space technology to forecast the rainy season and feed information into early warning systems, and on establishing training centres to improve mapping capabilities.

58. During the discussion, the need for capacity-building initiatives was underscored. Examples of existing initiatives included postgraduate programmes in space technology for technical training, ad hoc training initiatives, the provision of data and training and the development of tools to aid ministries in data-sharing and Internet of Things applications. Participants mentioned ongoing and planned projects aimed at expanding the use of space technology, including the launch of new satellites, and enhancing capabilities through training programmes to improve the application of space technology in water management and other sectors.

59. The panel concluded that space technology played a crucial role in water management. Effective capacity-building and international cooperation were imperative to overcoming current challenges and maximizing the benefits of space-based services for governmental institutions.

J. Technical closing session

60. In this session, the moderators delivered concluding remarks on the presentations and some shared recommendations.

61. Nearly all moderators recommended continuing to increase international collaboration, because sharing resources and expertise could improve data access for all. Furthermore, they suggested providing training and capacity-building, especially at the institutional level (including among institutions worldwide) and in the context of communities of practice. The need to coordinate among various actors and foster in situ data-collection efforts to train and validate models based on Earth observation and remote sensing data was also highlighted.

62. Under theme 1, the moderators of the four sessions made a number of key suggestions. The moderator of the presentations on water scarcity encouraged collaborative work and the creation of networks for data management and for sharing successful experiences in the evaluation of variables such as precipitation, soil moisture and drought indicators. The moderator of the session on space technologies and their relevance for groundwater monitoring suggested training water managers in the use of space technologies to improve the monitoring of groundwater, and using standardized data protocols to establish common data formats for easier integration and analysis. The moderators of the session on flood risk and impact suggested the provision of platforms for easy access to various satellite data and information, an integrated analysis with climatic and economic data sets using space-based applications to estimate crop loss and damage, and a tool to develop flood susceptibility models with a view to reducing disaster risks. The four pillars of the Early Warnings for All initiative (risk knowledge and management; detection, observation, monitoring and forecasting; warning dissemination and communication; and preparedness and response capabilities) were highlighted as important, and artificial intelligence chatbots such as “Chato”, which was used in El Salvador, were

mentioned as a means of improving communication with users in the agricultural sector and managing risk. Finally, the moderators recommended using geospatial tools to assess vulnerability and risk with the aim of informing policy, with special attention to disaster risk reduction.

63. The presentations, discussion and moderation regarding theme 2, on water quality monitoring, led to the following concluding recommendations in addition to the general ones provided above: improve coordination and the sharing of optical data and water quality data by data producers; build a global validation network; identify success stories; cultivate citizen science networks in order to engage local communities; and raise awareness. In addition, the co-development of products was considered to increase ownership and use, both of which were considered relevant.

64. Theme 3, on the Internet of Things, concluded with the identification of challenges such as cost, latency of data transmissions, limited bandwidth, power consumption, and signal interference and blockage. An outlook on future developments included the expansion of satellite constellations, advances in satellite technology, integration with 5G networks, the emergence of edge computing, and a focus on diverse sustainable applications. The moderator noted that regulatory considerations would become increasingly important.

65. The moderators of the sessions on space technologies for monitoring forests, agroforestry, watersheds and their interplay (theme 4) highlighted that scientists and users of space-based data needed to clearly communicate value and be honest about the limitations of findings in order to advocate effectively for the resources necessary to close the gaps in capacity-building and in situ monitoring with the aim of improving space-based data sets.

66. With regard to theme 5, recommendations to fill gaps in glacier monitoring included effective institutional arrangements, ensuring continuity in future observations, adopting and reporting climate indicators, ensuring accuracy in climate observations, arranging in situ data and sharing data and experiences from different regions.

K. Closing ceremony

67. The closing ceremony of the Sixth Conference was opened by Ambassador Carmen Isabel Claramunt, who delivered closing remarks on behalf of the Ministry of Foreign Affairs and Worship and the Government of Costa Rica. She underlined the importance of the subject matter for Costa Rica and for all, and highlighted in particular the field trip to the rural aqueduct associations and the practical experiences gained. She reiterated that it was an honour for Costa Rica to host the Conference and reminded participants of the water challenges that remained to be addressed, such as the electricity crisis caused by droughts. In addition, she mentioned the water-related risks faced by her country. She highlighted the importance for Costa Rica of implementing its drought and flood management strategies, bridging the gap between crop and water stress, and improving governance in water resource management with respect to financing, urban planning, education and ecological preservation. Long-term solutions for water management would address risks and vulnerabilities to climate hazards. She added that water-related decisions made in global assemblies, conventions and frameworks dedicated to climate resilience and the environment should be implemented, and she congratulated the participants on their relevant, innovative contributions to a more sustainable and equitable management of water. She provided a few examples of the outstanding work presented during the Conference and referred to her country's co-hosting of the third Ocean Conference, to be held in June 2025. She thanked the Office for Outer Space Affairs and the Inter-American Institute for Cooperation on Agriculture for the organization and hosting of the Sixth Conference, and expressed gratitude to the participants and trainers. She ended her speech by stating that the Conference was an excellent example of strengthening and stimulating the links between science, diplomacy and public policy for the benefit of human beings.

68. The Deputy Director of the Office for Outer Space Affairs highlighted how thoroughly the transformative potential of space technology for addressing sustainable water management had been examined, as seen in the numerous sessions in which the critical role of satellite data in optimizing irrigation practices and enhancing water productivity in agriculture had been underscored, as well as in the session on groundwater management through Earth observation data and in the sessions on the integration of machine learning and satellite imagery for flood risk assessment and climate change adaptation. Furthermore, he emphasized the importance of water quality monitoring, with notable examples from the Asian mega-deltas and Latin America demonstrating the application of satellite imagery to assess water quality and detect contaminants.

69. Participants expressed their gratitude to the Government of Costa Rica for its generous hospitality and their appreciation to the team from the Inter-American Institute for Cooperation on Agriculture, the co-sponsors and all partners for their support. Participants acknowledged the efforts, dedication and meticulous planning by the organizing teams from the Office for Outer Space Affairs, the Ministry of Foreign Affairs and Worship and the Institute, all of which had contributed to the success of the Sixth Conference. Participants and experts were thanked for their contributions, and the importance of continuing to leverage space technology for sustainable water management was stressed.

L. Field trip to visit a local community-managed aqueduct in the Orosi Basin in Costa Rica

70. A half-day field trip organized by the Inter-American Institute for Cooperation on Agriculture allowed participants to gain first-hand experience of community-based water management as carried out by rural aqueduct associations in Costa Rica. The associations are outstanding examples of community organizations, and they operate as non-profit organizations under the delegation of the Institute of Aqueducts and Sewers of Costa Rica on the basis of agreements among neighbours who jointly manage and operate community aqueducts, ensuring the supply and quality of water in their respective localities. Governed by the Associations Law of Costa Rica, the associations must adhere to strict legal, technical, administrative and financial regulations.

71. During the excursion, participants explored the water management practices implemented by the rural aqueduct association of Orosi. The use of geospatial technologies had been instrumental in making decisions regarding the sustainability and efficiency of water management in the area. Through dialogue with community members and on-site demonstrations, participants gained a deep understanding of how those tools were being applied in a local context to enhance the conservation and management of water resources.

72. The Orosi District faces the risk of landslides, in particular during the rainy season, when the area experiences heavy rainfall, which reaches levels as high as 6,000 mm per year at higher elevations. The National Emergency Commission analysed areas of potential flooding and landslides. The comprehensive risk management tool for rural aqueduct associations, which was developed in order to strengthen the capacities of those associations in communities experiencing water stress in the north of Costa Rica, is a result of a collaboration between the Institute of Aqueducts and Sewers of Costa Rica and the United Nations Development Programme, with the support of the Global Environment Facility. The risk management tool was presented during the technical presentation sessions held during the Conference.

V. Feedback

73. Participants were encouraged to provide written feedback using a dedicated online form. The overall rating of the event was 4.7 out of 5 (94 per cent). In their

feedback, participants noted that the Conference had offered insights into remote sensing applications from various countries, including access to new data sets, methodologies, models and the latest research. Participants had had the opportunity to explore case studies and projects, which had enhanced their understanding of current issues and advancements in the field. They also stated that the Conference had attracted a diverse group of attendees from different backgrounds, disciplines and geographic locations, thus fostering a cross-pollination of ideas and encouraging interdisciplinary collaboration. That diversity had promoted a comprehensive understanding of the challenges and solutions related to space technology for water management. The discussions had offered valuable insights into recent technological advancements for agricultural water management and newly developed monitoring tools across the globe. Overall, participants indicated that the Conference had provided an understanding of various models, data analysis techniques and actions in utilizing satellite technology to improve water management practices. Eighty-one per cent of those who provided feedback noted that they had seen presentations that they considered inspiring and relevant for implementation in their respective countries. When asked about the extent to which they would be able to apply their newly gained knowledge in their work, 19 per cent of participants responded "extensively", 31 per cent "quite extensively", 38 per cent "moderately", and 12 per cent did not respond. Participants expressed a preference for the conference series to remain at the international level instead of a regional level, which had been considered for sustainability reasons and to focus on the water-related challenges faced in specific regions.

74. In their feedback, participants from institutions in Costa Rica pointed to the tremendous value of such international conferences, of learning about the methods and approaches used in other countries around the world, and, in particular, of raising awareness of available technologies. The quality of the contributions and exchanges was also highlighted.

75. Feedback on the training courses yielded an overall rating of 4.53 out of 5 points (91 per cent) for the two courses, with 87 per cent of training participants seeing opportunities to apply what they had learned about streamflow modelling or the use of Earth observations to monitor water quality in their respective home countries.

76. Participants in the training course on streamflow modelling stated that the course had been highly beneficial and had allowed them to acquire new skills related to tools for water monitoring. The course had covered the data available from the GEOGLOWS ECMWF Streamflow Model, which had proved to be highly useful for short-term forecasting for and issuing hydrological warnings. Accessing data from the Model had provided them with enhanced knowledge and a deeper understanding of the subject matter. The training had also enabled participants to gain insight into the tool and fostered potential future collaboration. The Model was praised for its quality and effectiveness. Participants expressed appreciation for the tutorial, which had been instrumental in demonstrating the process of retrieving and manipulating data for their own simulations. They had learned about flood forecasting and volume calculation techniques, and the course had also covered ways to bridge gaps in existing data, enabling participants to supplement their in situ information on river flow and historical data. They expressed confidence in their ability to fill in missing data for certain years, to obtain future measurements and to compare and calculate differences between the Model and in situ data for better estimates.

77. Participants in the training course on Earth observation data for water quality assessment highlighted that they had gained valuable insights into additional toolboxes, facilitating the generation of ideas for future water quality monitoring projects. The course had highlighted alternative data sources and online methods to display data. Participants had been introduced to new applications and resources, which had expanded their knowledge base. In their feedback, they underscored the challenge of keeping up with the continuously emerging data sources about which they had learned. In addition, they had learned about different sources of information on water quality and participatory monitoring tools, which were found to be particularly interesting

and beneficial. The training course had enabled productive discussions with colleagues, fostering potential collaboration and exposing participants to diverse perspectives and realities different from their own.

VI. Conclusions

78. The United Nations/Costa Rica/Prince Sultan bin Abdulaziz International Prize for Water Sixth Conference on the Use of Space Technology for Water enabled meaningful exchanges on the application of space technology for water security, particularly in the context of climate change. The Sixth Conference specifically focused on agriculture as the sector that consumes the largest quantity of water but is essential for ensuring food security.

79. Key conclusions drawn from the Conference include the critical importance of international collaboration and knowledge exchange. There was a strong emphasis on the need to expand and replicate capacity-building initiatives globally, with practical training designed to equip participants with the skills necessary to implement space-based water management solutions. Capacity-building at the institutional level was considered particularly important for ensuring that stakeholders could effectively utilize and benefit from advanced technologies and data. Numerous speakers highlighted the creation of networks among experts in order to tackle global environmental challenges effectively.

80. Enhancing data accessibility and integration through open data policies and platforms such as the WaPOR portal and GEOGLOWS model was deemed crucial. In addition, strengthening partnerships across Governments, the private sector, academia and civil society with a view to developing innovative financing models and policy frameworks was recommended. The Conference revealed that the integration of emerging technologies, including space-based applications combined with other sensor data, in some cases supported by the Internet of Things and machine learning, was considered to hold promise for improved monitoring, analysis and risk management. However, it was also noted that challenges such as costs, data transmission issues and regulatory considerations needed to be addressed.

81. Emphasis was also placed on engaging local communities through citizen science initiatives and co-developing products to enhance data collection, raise awareness and ensure that technological advancements were useful in practice and would be widely adopted.

82. In addition, the Conference demonstrated that the use of geospatial tools and the development of comprehensive data platforms can provide valuable insights for policymaking, especially in the fields of disaster risk reduction and environmental management. To ensure the sustainability of observation systems, it is important to address current and future challenges.

83. The importance of a multifaceted approach involving collaboration, capacity-building, technological innovation and community engagement to effectively address and manage global environmental challenges was a common thread throughout numerous sessions.