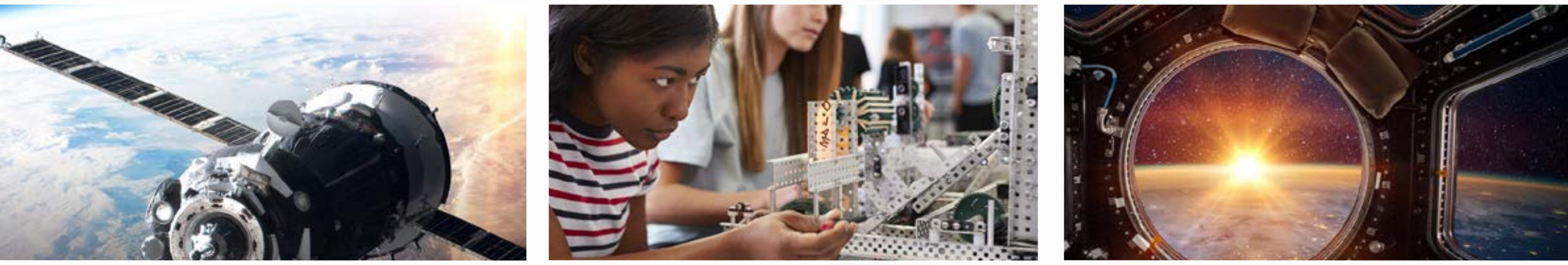
UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT
UNCTAD

EXPLORING SPACE TECHNOLOGIES FOR SUSTAINABLE DEVELOPMENT



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NOTE

UNCTAD is the lead entity within the United Nations Secretariat for matters related to science and technology as part of its work on the integrated treatment of trade and development, investment and finance. The current UNCTAD work programme is based on the mandates set at quadrennial conferences, as well as on the decisions of the General Assembly of the United Nations and the Economic and Social Council that draw upon the recommendations of the United Nations Commission on Science and Technology for Development, which is served by the UNCTAD secretariat. The UNCTAD work programme is built on its three pillars of research analysis, consensus-building and technical cooperation and is carried out through intergovernmental deliberations, research and analysis, technical assistance activities, seminars, workshops and conferences.

This series of publications seeks to contribute to exploring current issues in science, technology and innovation, with particular emphasis on their impact on developing countries.

The term “dollars” ($) refers to United States dollars unless otherwise specified.

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I. INTRODUCTION

The United Nations has a long history of promoting greater international collaboration in outer space and the use of space technologies for sustainable development. The United Nations Office for Outer Space Affairs was created in 1958 and in 2019 the international community celebrated the fiftieth anniversary of the first United Nations Conference on the Exploration and Peaceful Uses of Outer Space. In recent years, there has been increasing interest among countries in the use of space applications for sustainable development, especially to achieve the Sustainable Development Goals. In this context, in May 2019, the United Nations Commission on Science and Technology for Development selected as one of its priority themes for its twenty-third session the topic of exploring space technologies for sustainable development and the benefits of international research collaboration in this context.

Space science, technology and data have the potential to contribute in direct or indirect ways to all of the Sustainable Development Goals.[1] Space science incorporates scientific disciplines involved in space exploration and the study of outer space natural phenomena and physical bodies, and often includes disciplines such as astronomy, aerospace engineering, space medicine and astrobiology. Space technologies often refer to satellite Earth observation, satellite communication and satellite positioning. Technologies like weather forecasting, remote sensing, global positioning systems, satellite television and communications systems, as well as wider scientific fields such as astronomy and Earth sciences, all rely on space science and technology. They support policy decisions by providing real-time information as well as time-series data from any central or remote location and they are essential in monitoring progress on key Goals indicators (United Nations Office for Outer Space Affairs, 2019).

These applications already benefit countries at various income levels and regardless of whether they have their own space agencies and space programmes. Some of the least developed countries like Bangladesh, Bhutan and the Lao People's Democratic Republic have recently launched their own satellites (Union of Concerned Scientists Satellite Database, 2019). Furthermore, research in space technologies can have spillover effects in other areas: space technologies designed for space operations can be redesigned for applications on Earth, while investing in space research and education can contribute to bringing scientific knowledge to more people, as well as creating new opportunities for innovation and infrastructure (Wood and Stober, 2018).

This report highlights the potential opportunities of space-enabled technologies for delivering on the Sustainable Development Goals and proposes science, technology and innovation policy options for harnessing space technology for sustainable development. The report also discusses the role of regional and international research collaboration to support such efforts. The achievement of ambitious global goals in widely differing local contexts requires the combination of space capabilities with detailed local knowledge. Global research collaboration offers great potential to contribute to this process, providing opportunities to both create new knowledge and increase the impact of research by diffusing existing knowledge.

The report comprises six main sections that are structured as follows: chapter II reviews the different applications of space technologies for sustainable development, including in ensuring food security, health applications, access to telecommunications, reducing disaster risks, preventing humanitarian crises, monitoring natural resources and reducing poverty. Chapter III highlights recent technological developments in space technologies and examines the bottlenecks in the use of space technologies for sustainable development in developing countries and in an international context. Chapter IV identifies effective forms and areas of international scientific research in space technologies by highlighting case studies of various collaborative research and development-focused initiatives. Finally, chapter V highlights successful policies and strategies at the national, regional and international levels that can promote harnessing space technologies for the Sustainable Development Goals.

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[1] "Space science is the study of everything above and beyond the surface of the Earth, from Earth's atmosphere to the very edges of the universe. Space technology refers to the technology in the satellites and ground systems used by space scientists to study the universe (looking up) and the Earth (looking down), or to deliver services to users on the ground" (South Africa, 2008).

II. SPACE TECHNOLOGIES FOR THE SUSTAINABLE DEVELOPMENT GOALS

A. FOOD AND AGRICULTURE

Space technologies can be vital for agricultural innovation, modern agriculture and precision agriculture. Space-based technology is of value to farmers, agronomists, food manufacturers and agricultural policymakers who wish to simultaneously enhance production and profitability. Remote-sensing satellites provide key data for monitoring the soil, snow cover and drought and crop development. Rainfall assessments from satellites, for example, help farmers plan the timing and amount of irrigation needed for crops. Accurate information and analysis can also help predict a region's agricultural output well in advance and can be critical in anticipating and mitigating the effects of food shortages and famines.[2]

The use of space technologies for farming and natural resource management used to be limited largely to developed countries, due in part to high costs. In recent years, open access to geospatial data, data products and services and the lower cost of geospatial information technology facilities have stimulated its adoption across the world and particularly in developing countries through initiatives such as Open Data Cube. Emerging priorities for international collaborations in this field include the development of agricultural geospatial data infrastructure, agricultural geospatial knowledge platforms, standards and protocols enabling interoperation and data-sharing, analysis-ready agricultural thematic geospatial data products and the sharing of relevant software applications.[3] Another initiative expanding access to space technology is the crop monitoring system in China known as Crop Watch, which has played an important role in preparing international stakeholders for global crop market fluctuations and disruptions in food supply. It has encouraged national, regional and global adoption of space technology using remote-sensing data.

Space-enabled agricultural products and services can support farmers, national agricultural ministries and departments and international organizations. For example, in Canada, the remote-sensing Earth observation satellite programme Radarsat provides data to support farmers in assessing soil moisture and irrigation needs. The global positioning system technology supports innovative precision farming techniques. This helps farmers better manage risks and improve planning to boost the quality and productivity of their crops.[4] The World Meteorological Organization provides weather and draught forecasting services to farmers, herders and fishers in order to promote sustainable agricultural development, increase agricultural productivity and contribute to food security through its Agricultural Meteorology Programme (United Nations General Assembly, 2018). Afri Scout is an application that supplies pastoralists in Ethiopia, Kenya and the United Republic of Tanzania with data on water and vegetation in potential grazing areas so that they can make informed decisions about where to take their herds. Some private sector firms (e.g. Harvesting Inc., Farm Drive, Grid and Apollo Agriculture) use remote sensing and machine learning as a tool to help assign credit ratings for farmers in developing countries, allowing many to obtain loans that would otherwise not have been securable.[5] Furthermore, the Hassas-2 precision farming initiative in Turkey produces fertilization maps and applications and disseminates satellite images and analysis data to farmers over the Internet.[6]

At the national level, space applications can support the monitoring of crops from space using publicly available sources of satellite data as well as algorithms for land use and land cover.[7] The Asian Institute of Technology, the Government of Cambodia Agriculture Department and the University of Tokyo collaboratively developed an algorithm to predict rice yield at the time of harvest using Modis data.[8] This analysis was piloted in three provinces but later expanded to the national level. The geospatial agency of Bangladesh used Earth observation data to estimate the production of its two major crops, boro and aman rice.[9] Statistics Canada has used remote-sensing data since the early 1980s for applications such as census and survey validation, crop mapping and area estimation and support programme development. In 2016, Statistics Canada became the

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[2] Contribution of South Africa.

[3] Contribution of the Food and Agriculture Organization of the United Nations.

[4] Contribution of Canada.

[5] Contribution of the United States.

[6] Contribution of Turkey.

[7] The examples from Bangladesh and Cambodia were shared at Commission on Science and Technology for Development regional consultations at the United Nations Economic and Social Commission for Asia and the Pacific in August 2019.

[8] See https://modis.gsfc.nasa.gov/.

[9] See http://sparrso.gov.bd/.

first national statistical office to replace a farm survey with an approach based on a remote-sensing model for crop yield estimates.[10]

In addition to efforts targeted at farmers and national Governments, Earth observation data can support regional and international efforts to target those with the highest food insecurity risk. In agriculture, the use of remotely sensed data by the Food and Agriculture Organization of the United Nations is a key component in the effective monitoring of agricultural production. The Organization implements its mandate to assist and empower countries with knowledge, tools and methodologies to enable them to undertake reliable assessments by fostering the use of medium-resolution and high-resolution Earth observation data, combined with in situ observations, to provide reliable information to support decision-making in agriculture. In that regard, the global agroecological zones data portal and the integrated land resources information management system are used in key activities of the Organization (United Nations General Assembly, 2016).

The main objective of the World Food Programme support to global humanitarian risk mapping project was the evaluation of global humanitarian risk layers based on medium-resolution satellite data. The project ran from March 2017 to January 2018 and used several types of satellites (Landsat and Sentinel), including satellites that took a daily image of the Earth with a resolution of 300–500 m, as well as satellites that showed field structures with a higher resolution of 10–20 m, weekly or biweekly. The project supported preventive measures conducted by the World Food Programme through regional assessments of humanitarian risk. It delivered an improved assessment of spatial and temporal risk dynamics and patterns related to food insecurity and disaster risk.[11]

Furthermore, the Group on Earth Observations global agricultural monitoring initiative has been leading global cooperation in crop monitoring and market assessments to ensure transparency in crop markets.[12]

Several countries are also supporting international assessments and forecasts based on space applications, either directly through their national efforts or in partnership with other international efforts. The United States Department of Agriculture report on world agriculture supply and demand estimates is prepared monthly and includes forecasts for United States and world wheat, rice and coarse grains (corn, barley, sorghum and oats), oilseeds (soybeans, rapeseed and palm) and cotton. The global agricultural and disaster assessment system, also supported by the United States Department of Agriculture, is a web-based geographic information system for the analysis of global crop conditions and the analysis of the impacts of disasters on agriculture. The famine early warning systems network, created by the United States Agency for International Development in 1985, provides early warning and analysis on acute food insecurity in 28 countries. Along with these assessments, the systems provide reports on weather and climate, markets and trade, agricultural production, livelihoods, nutrition and food assistance.[13]

B. HEALTH APPLICATIONS

In recent years, space-based technologies have played a growing role in furthering global health objectives. In the public and global health domains, space science, technology and applications, including Earth observation and remote sensing; telecommunications, positioning and tracking; and space-based research, play a crucial role in supporting decision-making, improved care, education and early warning measures (United Nations General Assembly, 2018).

Information from remote-sensing technologies is used to monitor disease patterns, understand environmental triggers for the spread of diseases, predict risk areas and define regions that require disease-control planning.[14] In the context of the ongoing coronavirus disease of 2019 (COVID-19) pandemic, using geographic information system data, various institutions have been able to publish information on confirmed infections and deaths, which has been useful in epidemiological studies of the virus. [15] The South African National Space Agency, for example, has been using geographic information system data to locate informal settlements and monitor potential pandemic hotspots.[16] The malaria early warning system, based on geospatial data, was responsible for 500,000 fewer new malaria cases across 28 countries (Juma et al., 2017; National Aeronautics and Space Administration (NASA), 2012). A priority for the Public Health Agency of

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[10] Contribution of Canada. For details on the methodology, see section 4.8 of the publication available at https://unstats.un.org/bigdata/taskteams/satellite/UNGWG_Satellite_Task_Team_Report_WhiteCover.pdf.

[11] Contribution of the World Food Programme.

[12] See http://earthobservations.org/geoglam.php.

[13] Contribution of the United States. The survey results and data products are freely accessible.

[14] Contribution of South Africa.

[15] Contribution of the United Nations Office for Outer Space Affairs.

[16] Contribution South Africa.

Canada is responding to emerging infectious diseases and its national microbiology laboratory undertakes research and risk assessment to inform the development of programmes to combat these diseases. The laboratory uses Earth observation technologies, including Radarsat data, in research and risk assessment activities, and products are used widely in disease surveillance and disease outbreak management (e.g. vulnerable human populations, mosquito-borne diseases, tick-borne diseases, chronic diseases, water-borne diseases and potential epidemics such as of Ebola virus disease). In 2018, data from NASA satellites were used for cholera forecasting in Yemen, which worked with a 92 per cent accuracy rate. Thanks to space data and tools, future health and development workers may be both more efficient and effective in their campaigns against disease outbreaks.[17] The Japan Aerospace Exploration Agency uses digital elevation models to map areas that are difficult to access, in order to implement efficient measures for infectious diseases (e.g. polio in the Niger).[18] The German Aerospace Centre has collaborated with the World Bank on research related to the pandemic using geospatial analytics from satellite measurements, in situ data and computer modelling. This research has been helpful in providing empirical evidence on air quality during the ongoing global health crisis.[19]

Public health is a prime example of a sector in which the use of satellite communications and remote sensing is vital. Satellite communications are an integral part of the overall health information infrastructure. Key applications of satellite technology in this field include telemedicine, tele-health, disease surveillance systems and health mapping (United Nations General Assembly, 2016). During the COVID-19 pandemic, the use of satellite communications technologies and information and communications technologies has enabled the exchange of medical expertise while minimizing in-person contact as medical professionals meet, examine and diagnose patients virtually. Sila Health is an example of a communications technology that virtually connects users to medical professionals after screening symptoms with the platform's chatbot service, while also providing local governments with an avenue to share pandemic-related updates with citizens through short message services, Whatsapp and Facebook Messenger. This low-cost solution has had great success in Bulawayo, Zimbabwe, providing affordable health care to economically vulnerable communities (Sila Health, 2020). In addition, there are also numerous contact tracing mobile applications, many of which use geolocation to provide a better picture of the spread of the virus as well as early warning of future waves. Such applications have been developed by several Governments across the world. However, a caveat to be considered is that many of these applications store personal data, which may potentially lead to concerns about privacy.

Beyond monitoring infectious diseases or supporting access to medical care in remote locations, the use of space can enable medical research that would otherwise be difficult to conduct in a terrestrial environment.[20] The microgravity environment on the International Space Station allows for the growth of larger versions of an important protein, LRRK2, implicated in Parkinson's disease. This can help scientists to better understand the pathology of Parkinson's disease and aid in the development of therapies directed to alleviate the disease and its effects. The pioneering research on the Space Station may help 7–10 million people worldwide currently affected by the disease.[21] More broadly, high quality protein crystals grown in a microgravity environment can support new drug design for infectious diseases, cancers and lifestyle-related diseases.[22]

C. ACCESS TO TELECOMMUNICATIONS

Access to terrestrial networks is limited or non-existent in many parts of the world, particularly in sparsely populated rural or remote areas. Satellite technologies are well-placed for the delivery of broadband services in those areas, either on their own or in combination with other technologies. Expanding access to rural areas is challenging, as populations are less dense, further from main networks and have less purchasing power. Instead of the traditional network infrastructure used for broadband connectivity (that is, blanket coverage with many adjacent cells each supported by a base station), a new set of network technologies can often reduce infrastructure requirements and offer more cost-effective service delivery options. For example, the telecommunications satellite Bangabandhu-1 recently launched by Bangladesh also broadcasts television and

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[17] Contribution of the United States.

[18] Contribution of Japan. Elevation data are widely used in mapping infectious diseases in part because of the influence of elevation on rainfall, temperature and humidity (Hay et al., 2006).

[19] Contribution of Germany.

[20] "Advances in telemedicine, disease models, psychological stress response systems, nutrition, cell behaviour and environmental health are just a few examples of benefits that have been gained from the unique space station microgravity environment" (https://www.nasa.gov/mission_pages/station/research/benefits/human_health.html).

[21] Contribution of the United States.

[22] Contribution of Japan.

radio programmes and will soon provide for Internet, telemedicine and distance learning facilities for people in remote areas.[23]

New and emerging technologies may shape the evolution of telecommunications access, including low-altitude and medium-altitude satellites, other aerial devices and innovative uses of unused portions of the radio frequency spectrum (Buluswar, 2018).[24] For example, the development and future deployment of non-geostationary orbit satellite fixed-satellite service systems have the potential to increase access to broadband infrastructure and bridge the digital divide, especially for populations living in rural areas. Egypt has launched a series of communications and broadcasting satellites under its Nile Sat umbrella, with coverage across North Africa. The Tiba Sat satellite in this series is expected to ensure access to broadband and Internet connectivity nationwide.[25] Furthermore, Project Kuiper (Amazon), Starlink Constellation (Space X), Project Loon (Google) and others plan to provide global Internet access through nanosatellite constellations and high-altitude balloons.

Although satellites are key to delivering broadband Internet access to unserved areas (part of Goal 9), their impacts go beyond that, including applications in urban and already-connected areas, which are important to the aviation, maritime, energy and other sectors, enabling new capabilities and applications in areas already connected to the global network and helping drive down costs for many people. Space-based connectivity is helping make smart societies a reality (including with regard to intelligent transport systems, electronic government (e-government), tele-education, e-health, e-logistics, smart energy and smart agriculture), in both developed and developing countries. These technologies are also facilitating advances in sustainability, banking and diverse government services.[26]

D. DISASTER RISK REDUCTION AND HUMANITARIAN CRISES

Disasters cause important loss of lives and assets around the world. According to the United Nations Office for Disaster Risk Reduction, between 1998 and 2017, disasters killed 1.3 million people globally, while they displaced, injured, left homeless or in need of emergency assistance a further 4.4 billion people (United Nations Office for Disaster Risk Reduction and Centre for Research on the Epidemiology of Disasters, 2018).

Space-enabled technology applications have become an important element of local, national and regional disaster risk reduction strategies. Globally, the Sendai Framework for Disaster Risk Reduction 2015–2030 calls for the promotion and enhanced use of space and in situ information through geospatial and space-based technologies, as well as Earth and climate observations enabled by remote sensing to enhance measurement tools and the collection, analysis and dissemination of data.[27] The framework recognizes the role of space technologies in supporting risk-informed decision-making especially in the understanding of disaster risk (priority 1).

Earth observation, involving remote-sensing satellite images (provided by satellites such as the United States Landsat satellites and the Sentinel satellites of the European Union Copernicus Earth observation programme) and increasingly high-technology in situ instruments (e.g. floating buoys to monitor ocean currents, temperature and salinity; land stations to record air quality and rainwater trends; sonars and radars to observe fish and bird populations; seismic stations to monitor earthquakes; and environmental satellites to scan the Earth from space) helps to detect and monitor disaster risks, especially natural hazards, and exposure to vulnerability. Volcano hazards, for example, can be observed through land deformation due to tectonic forces. Drought hazards can be monitored by observing soil moisture, precipitation and vegetation indices. Earth observation can also be used to map urban and rural areas that have been impacted by natural, technological and biological disasters, as well as to assess damages and losses. Flooding and tsunami impacts can be directly measured based on the size of the flooded areas visible in satellite images (Global Partnership Using Space-based Technology Applications for Disaster Risk Reduction, 2019).

For example, Natural Resources Canada has been acquiring time-series Earth observation data, including from Radarsat, in order to provide critical, near real-time information to public safety authorities before, during and after river ice jams and break-up and flood events. The Radarsat flood products are also integrated into and used by the civil security operations of provincial, territorial and regional governments and are available to the public. Data are critical to monitoring ice conditions in the Arctic. Because of the extent, remoteness and

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[23] See https://en.wikipedia.org/wiki/Bangabandhu-1.

[24] Contribution of South Africa.

[25] Contribution of Egypt.

[26] Contribution of the International Telecommunication Union.

[27] See https://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf.

isolation of these regions, Earth observation is often the only cost effective and technically feasible means of obtaining information. Furthermore, for over a decade, Polar View has used Earth observation satellites from Radarsat and Sentinel 1 in providing a community ice service that decreases the risk associated with travelling over coastal sea ice in the Arctic. The service allows for the selection of the shortest route around ice ridges and open water, helping to minimize travel time, fuel costs and equipment wear, while maximizing safety. Thanks to international research collaboration, the service has proven to be an exemplary case of the use of Earth observation to support traditional ways of life in the Arctic, to help northern communities adapt to climate change and to improve the safety of northern residents and visitors. [28]

Satellite-enabled meteorological tools help to understand the Earth's atmosphere and oceans and support weather forecasting. In recent years, significant technological progress in space observation technologies has resulted in an increasing amount of data. This has been combined with progress in the scientific understanding of dynamic and physical processes in the atmosphere and their interactions with the oceans, and powerful computer and information and communications technology facilities. Thanks to these factors, scientists have made significant progress in predicting, monitoring and managing climate and weather-related disasters through advanced meteorological tools (Guo, 2010; Zeng, 2018).

Space technologies like Earth observation satellites have enabled Sentinel Asia to provide speedy and accurate early warning data and improved disaster preparedness through Internet dissemination methods and web-based geographic information system mapping tools.[29] Similarly, accurate weather forecasts and improved communications helped to manage evacuations and save lives during the 2017 Atlantic hurricane season (World Meteorological Organization, 2017). Countries vulnerable to cyclone risks, such as Bangladesh and India, have been also investing in modern meteorological services and improving early warning systems, as well as cyclone shelters and embankments. Tropical Cyclone Fani in May 2019 killed at least 89 people and caused over $1.8 billion in damages; Bangladesh evacuated 1.6 million people and India evacuated 1 million people (Finneran, 2016; Reliefweb, 2019).

As these examples show, space technologies are also crucial for communications, to monitor disasters, set up and feed data into early warning systems and share alert messages through multiple information and communications technology platforms. These examples also show the need for appropriate policies and mechanisms that build on the effective use of space technologies.

Box 1

Uganda: Developing maps with drones to build refugee resilience

In 2016, the United Nations Development Programme in collaboration with the United Nations High Commissioner for Refugees and in support of the Office of the Prime Minister of Uganda, launched a project to develop base maps for the Oruchinga Refugee Settlement. The settlement covers an area of approximately 8 km^2 and has a population of around 6,300 refugees. The aim of the project was to support refugee settlement planning and management through a better understanding of the environment in which refugees and their host communities live. The maps showed the location of hazards, helped to identify risks to livelihoods and provided information on sand encroachment, environmental conditions and soil fertility.

The maps were based on a high-resolution aerial photomosaic, produced using a lightweight camera-bearing drone. The mapping exercise covered 17 km^2, resulting in more than 1,200 individual aerial photographs covering the settlement and surrounding areas. The individual photographs were stitched together to derive a single georeferenced orthophoto of the settlement. A three-dimensional digital surface model was derived from the overlapping aerial photographs using photogrammetry.

Analysing the data enabled soil analysis that enhanced the mapping of flood and soil erosion risk, as well as irrigation potential from nearby reservoirs. It also showed accessibility to basic services such as health care and primary and secondary schools. The maps and data generated through the project were used to inform the community and its stakeholders in planning and resource management.

Sources: Contribution of United Nations Office for Disaster Risk Reduction; United Nations Development Programme et al., 2016.

Recent UNCTAD research shows that drones can offer a low-cost approach to remote sensing, especially in developing countries and in emergency situations (UNCTAD, 2019a). They transmit images of the Earth's surface in real time that, when combined with global positioning system data, can be exploited to populate land-use databases as well as assessments of disasters such as flood or earthquake damage. For example, drones have been used recently to develop maps for the Oruchinga Refugee Settlement in Uganda (box 1). Drones may also be used for rapid mapping in the event of emergencies, for example, when used with crowdsourcing platforms that tag live footage from aerial vehicles flown during disasters.

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[28] Contribution of Canada.

[29] Contribution of Japan.

E. NATURAL RESOURCE AND ENVIRONMENT MANAGEMENT

There has been an exponential growth in the availability of satellite data and signals produced for observing the Earth. As at September 2019, there were 170 Earth observation satellites in operation, including around 30 weather satellites, by 62 different operating agencies (Committee on Earth Observation Satellites, 2019). Satellites can be operated by national Governments, multinational agencies (e.g. the European Space Agency (ESA)), private companies (e.g. Planet and Twenty-First Century Aerospace Technology) and universities and research institutes (e.g. Republic of Korea Aerospace Research Institute and University Corporation for Atmospheric Research). Most of the environmental satellite images and data owned by Governments and multinational agencies are provided free of charge to users around the world.

Earth observation is an essential tool for managing natural resources and the environment. It is highly relevant for both monitoring and achieving the Sustainable Development Goals (Anderson et al., 2017; Wood and Stober, 2018). It provides information to support agricultural production, fisheries, freshwater and forestry management, and it can also help to monitor activities that are harmful for the environment, such as illegal logging, mining, poaching and fires. For example, Australia is also using satellite observations to monitor drought conditions and illegal water diversions in the Murray-Darling Basin.[30]

Earth observation data from satellites are also used to overcome various challenges such as in water management, air pollution and forest preservation. One example is the observation of precipitation, which is useful for addressing water-related disasters such as floods, typhoons and landslides. The Japan Aerospace Exploration Agency has developed a precipitation monitoring system known as Gsmap, which offers global rainfall maps using satellite data such as the global precipitation measurement mission and the global change observation mission. In cooperation with international partners such as the Asian Development Bank and the United Nations Educational, Scientific and Cultural Organization, Japan contributes to the reduction of damage from water-related disasters. Japan is also supporting atmospheric observation such as of greenhouse gases and aerosols to learn about climate change issues. The Ministry of the Environment, the National Institute for Environmental Studies and the Japan Aerospace Exploration Agency launched the greenhouse gases observing satellite series in 2009 as the world's first satellite dedicated to monitoring greenhouse gases such as carbon dioxide and methane. Greenhouse Gases Observing Satellite 2 was launched in 2018 with an enhanced capability of observing carbon monoxide in addition to carbon dioxide and methane to estimate anthropogenic emissions. Another example is the monitoring of forests for environmental protection and effective forest governance. The Japan Aerospace Exploration Agency is cooperating with the Japan International Cooperation Agency and has initiated a forest monitoring system called the Japan International Cooperation Agency and Japan Aerospace Exploration Agency Forest Early Warning System in the Tropics, by using satellite data from Alos-2. The system is now monitoring forests in more than 70 countries and, as at April 2020, had detected 308,353 points of concern. Last year, the early warning system contributed to detecting illegal deforestation in Brazil in cooperation with local authorities.[31]

By surveying the various marine and coastal ecosystems of Canada, the recently launched Radarsat constellation mission will assess the impact of human activity and climate change on coastlines and monitor coastal erosion. Satellite images will also help to rapidly identify, in combination with signals from the automatic identification system, vessels navigating Canadian waters and detect those engaging in illegal fishing.[32]

Brazil monitors forests using satellites images collected by the National Institute of Space Research, although the size of the area to be observed represents a great challenge. The Biome Sat project is an initiative that monitors forest health in the Amazon using nanosatellite technologies.[33] The collected data show that deforestation rates peaked in the late 1990s and early 2000s. However, changes in forest and agricultural land management helped to cut the annual deforestation rate by 2012 to around 80 per cent lower than the average rate between 1995 and 2006. Recent increases in forest fires in the Amazon have raised concerns about newly increasing levels of deforestation in the region (Borunda, 2019).

The geospatial agency of Bangladesh is planning a project to create a geospatial information system of the

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[30] Contribution made during Commission on Science and Technology for Development side event at Intergovernmental Consultative Committee on Regional Space Applications Programme for Sustainable Development, 28 August 2019, Bangkok.

[31] Contribution of Japan.

[32] Contribution of Canada.

[33] Contribution of Brazil.

coastal regions and identify potential fishing areas in the Bay of Bengal. The country is also using geospatial technologies to monitor the river network to identify changes in the coastline and erosion of the river system. This river monitoring system will potentially help minimize loss of life and property in Bangladesh, which is particularly vulnerable to floods.[34]

Earth observation is a powerful tool with which to monitor illegal mining activities. Remote sensing can be used to monitor natural variations in sand flux in rivers and, thereby, illegal sand mining. Satellite data from the NASA gravity recovery and climate experiment, for example, can reveal sediment discharge rates at river outlets, and the European Union raw materials and Copernicus Earth observation programme also uses satellite images to help monitor and manage natural resources and the raw materials sector. Small satellites, such as cube sats and small sats, can also produce high-resolution images at low cost, to monitor mining (Bendixen et al., 2019). Companies such as Orbcomm use constellations of satellites in low Earth orbit to gather automatic identification system signals about vessels across oceans. With this technology tracking all compliant vessels, law enforcement can more easily identify vessels that are not in compliance and are more likely to be used in human trafficking.[35]

In addition to the applications mentioned above, Earth observation can also be used to monitor country-specific environmental conditions and challenges, such as snow, ice and glacier monitoring. With financial support from the European Union Horizon 2020 programme, the company Enveo in Austria led efforts to develop and implement a European standard service on snow and land ice monitoring as a downstream service for the Copernicus programme.[36] The service provides geospatial products on seasonal snow cover, glaciers and lake and river ice derived from Earth observation satellite data (in particular Sentinel 1) in response to user needs. Some products have become part of Copernicus global land.[37] The nearly real-time information products on snow and land ice are available free of charge.[38]

F. REDUCTION OF POVERTY

Recent studies have validated the potential of satellite imagery and machine learning to predict poverty, using publicly available and non-proprietary data (Jean et al., 2016). For example, the World Bank has conducted a study to predict poverty rates using convolutional neural networks along with high-resolution satellite imagery (Engstrom et al., 2017). These methods can also help developing countries estimate measures of urban poverty, including the proportion of the urban population living in slums and informal settlements and access to basic services and infrastructure. The use of machine learning to detect informal settlements is an emerging area of research (Kuffer et al., 2016; Schmitt et al., 2018; Stark, 2018). However, it remains to be seen whether such big data-derived indicators will continue to be as accurate as research and pilot projects suggest. While there are opportunities for big data to augment the evidence base for developing countries, in which traditional statistics are scarce, some algorithms may increasingly develop out of sync with the underlying socioeconomic reality over time (Lazer et al., 2014).

Space applications can also support education. E-education initiatives, for example, can benefit from satellite telecommunications, and the United Nations Children's Fund supports the mapping of schools using satellite imagery and machine learning.[39]

Scientific, technological and innovative research and development for space may also yield practical Goals-relevant applications. For example, battery storage capabilities have become more robust due to research for space applications funded by the United States Government. With more efficient batteries, overall energy efficiency increases and the use of renewable energy sources becomes more feasible. A welding technique developed for assembling rocket fuel tanks can provide stronger, safer, more environmentally friendly and less power-intensive welds for any type of metal infrastructure. In addition, the rise of the commercial space transportation industry, including the increased frequency of suborbital launches, has created the possibility of the emergence of a suborbital Earth-to-Earth transportation market (United Nations General Assembly, 2016).

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[34] Contribution made during Commission on Science and Technology for Development side event at Intergovernmental Consultative Committee on Regional Space Applications Programme for Sustainable Development, 28 August 2019, Bangkok.

[35] Contribution of the United States.

[36] See http://www.enveo.at/euprojects/89-cryoland.

[37] See https://land.copernicus.eu/.

[38] Contribution of Austria. See http://neso1.cryoland.enveo.at/cryoclient/.

[39] Over 130,000 schools have been mapped in over nine countries. See http://unicefstories.org/magicbox/schoolmapping/.

III. RAPID TECHNOLOGICAL CHANGE AND BOTTLENECKS IN SPACE SCIENCE AND TECHNOLOGY

A. RECENT TECHNOLOGICAL DEVELOPMENTS

New technological developments are driving down the costs to use, adopt and adapt space science and technology. Machine learning, big data and cloud computing make it possible to derive automated insights from satellite imagery for poverty monitoring and agricultural applications. Emerging satellite functionalities can enable new Goals-relevant applications. Aerial platforms like drones may serve a complementary role to satellite-based Earth observation. In addition, crowdsourcing is expanding collaboration opportunities between citizens and space agencies, programmes and initiatives in both developed countries and the least developing countries, to fill data gaps for a range of applications (e.g. related to weather, climate change, air quality monitoring and vector-borne disease monitoring).

Artificial intelligence and cloud computing

Artificial intelligence and machine learning can enable users to analyse vast amounts of Earth observation data in a faster and more efficient manner. With appropriate in situ observations, convolutional neural networks, a deep learning method, may be used to automate image recognition and classification tasks on remote-sensing imagery. As a result, Earth observation data could be analysed in real time, minimizing the time and effort needed by human analysts. There are several global developments to more effectively harness machine learning for the Sustainable Development Goals. For example, the CGIAR [Consultative Group on International Agricultural Research] Platform for Big Data in Agriculture coordinates efforts to apply machine learning, precision agriculture and other novel techniques to solve agricultural challenges across the world.[40] However, machine learning models are only as good as the data on which they are trained and the quality of the data can determine the suitability of the model for accurate and robust prediction.[41]

Increasingly, the application of artificial intelligence and machine learning to Earth observation data is occurring on cloud computing platforms. The cloud computing model is becoming the prevailing mode of work for most medium-scale and large-scale global data sets, including Earth observation applications. This is due to the ability of cloud services to archive large satellite-generated data sets and provide the computing facilities to process them. As cloud computing services are being more widely used, the technology is maturing rapidly. Taking the example of Earth observation analysis as a use case, there are many different platforms and applications available for the risk community to use. These include the Open Data Cube, Copernicus Data and Information Access Services, Earth on Amazon Web Services, Google Earth Engine, the Joint Research Centre Earth Observation Data and Processing Platform, NASA Earth Exchange and the European Centre for Medium Range Weather Forecasts Climate Data Store. Each of these cloud computing services has different benefits. These range from the way the data are ingested (some include pre-loaded data, which reduces the effort on the part of the user) to scripting language (which is used for processing). One of the main disadvantages of using cloud services is their lack of interoperability. This means that for users, there must be a trade-off between flexibility and ease of use.[42]

Emerging satellite and aerial platforms

There are several developments with respect to satellite positioning technologies and aerial platforms that could positively impact the achievement of the Sustainable Development Goals. There are promising examples for future satellite positioning technology applications. First, data from continuous recording reference stations for global positioning systems can be used to extract information on atmospheric and tropospheric water content which can be fed into operational weather forecasts and improve forecasts in areas with heavy rainstorms. Second, experiments are underway in the United States to use data from continuously recording stations for global positioning systems, to monitor the passage of tsunamis across ocean basins, due to the impact on the ionosphere. If a tsunami is detected, its source, likely passage across ocean basins and potential impact can be predicted 24 hours in advance. Furthermore, satellite Earth observation platforms are developing capabilities to monitor the global wireless spectrum, with applications for monitoring digital divides, wireless penetration (e.g. long-term evolution

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[40] Contribution of the United States.

[41] Contribution of the International Telecommunication Union.

[42] Contribution of the United Nations Office for Disaster Risk Reduction.

towers in Kenya) and economic indicators in developing countries.[43]

Drones can serve as an alternative relatively cheap source of Earth observation data compared with satellites and are increasingly being used in crop prediction and food security applications.[44] For example, in Cape Town, South Africa, the platform Aeroview uses drones to produce infrared imagery of farming land. This aerial mapping approach helps farmers to quickly detect problem areas in crops and prevent crop failure (Abardazzou, 2017).

Drones can be built for several thousands of dollars and travel over 100 km on one battery. However, their use tends to be regulated by law in many countries. Thus, despite the relatively higher cost of satellite data, it will likely continue to be used in place of lower-cost drones as a source of Earth observation data.

Crowdsourcing

Crowdsourcing, enabled through digital, mobile and social networking tools, can support efforts to more effectively harness space technologies for sustainable development. Crowdsourcing platforms like Ushahidi may help to contextualize information gathered from space technologies using data provided by civil society on the ground. Ushahidi crowdsourcing has had success in the domains of election monitoring, human rights activism, crisis response to natural disasters and recently in mapping responses to the COVID-19 pandemic, which has been helpful in coordinating humanitarian initiatives (Lungati, 2020). Similarly, crowdsourced image labelling is used by several aid-related non-governmental organizations to manually identify patterns of areas affected by a natural disaster that can be automated with machine learning (International Environmental Policy Consultancy, 2018). Data Collaboratives for Local Impact, a partnership between the United States President's Emergency Plan for AIDS Relief and the Millennium Challenge Corporation, is working in Africa to build an enabling environment for data-driven decision-making to end the AIDS epidemic, improve health outcomes, reduce gender inequality and support economic opportunities for vulnerable youth. A key focus of the United States President's Emergency Plan for AIDS Relief is citizen mapping of high HIV-prevalent areas, in partnership with Humanitarian Open Street Map Team and others, to identify HIV hot spots, health facilities and pharmacies and improve the allocation of programme resources. The Data Collaboratives for Local Impact Innovation Challenge has produced over 40 data innovations that support improved health systems, reduce HIV risks for adolescent girls and young women and promote economic opportunities.[45]

B. BOTTLENECKS IN THE USE OF SPACE TECHNOLOGIES

Despite the decreasing costs of some space technologies and the increasing availability of open-source data, there are some bottlenecks that hinder their application in certain fields and their use in some regions of the world. These bottlenecks include the lack of awareness concerning the benefits of space technologies; high costs and the lack of financial resources to develop space programmes, especially in developing countries; technology and skill gaps to develop, use and adapt space technologies; challenges with respect to user needs and access to and compatibility of the available data sets; geographical constraints for developing space launch facilities and conducting astronomical research; emerging issues concerning regulations and the international governance of space commons; and some of the risks of using space technologies.

Lack of awareness concerning the benefits of space technologies

Space-related technologies tend to develop at a much faster rate than policymakers and the general public may easily understand. Lack of awareness concerning the benefits of space technologies for sustainable development can prevent developing countries from harnessing these technologies. In the experience of ESA, for example, there may be a lack of understanding among policymakers of what information satellite technology can deliver, a lack of understanding of costs and benefits and a lack of experience of how satellite information can be used in development activities (Caribou Space, 2018).

Critics of space programmes in developing countries tend to point to other priorities and concerns that should be addressed before investment in space technologies. The launch of the first satellite by Bangladesh cost around 0.5 per cent of the annual national budget. In a least developed country, where most people are not well informed about the advantages and disadvantages of satellite technology, investment on such scale can fuel political debates (Shamrat, 2018). Raising awareness about the benefits of space technologies and equally distributing benefits among the population is key.

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[43] UNCTAD communications with Hawkeye 360.

[44] See https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Pages/Events/2018/Drones-in-agriculture/asptraining.aspx.

[45] Contribution of the United States.

At present, 11 countries in Africa have launched satellites (Algeria, Angola, Egypt, Ethiopia, Ghana, Kenya, Morocco, Nigeria, Rwanda, South Africa and the Sudan), with 41 satellite launches cumulatively (Space in Africa, 2020). As more and more developing countries consider using space technologies, it is important that they make the right technical, social and political decisions recognizing their needs and priorities (Massachusetts Institute of Technology News, 2011).

Lack of financial resources

The lack of domestic and international financial resources is another obstacle to investing in space programmes in developing countries. Governments worldwide invested around $75 billion in space programmes in 2017. In comparison, Nigeria and South Africa, the two countries in Africa with the largest space budgets, spent $29 million and $23 million in the same year, respectively (Organization for Economic Cooperation and Development, 2020).

According to the Organization for Economic Cooperation and Development (2020), official development assistance directed to space-related projects is relatively modest, amounting to $1.28 billion for the entire period between 2000 and 2018. Leading donor countries include those with well-established space programmes (e.g. Japan, the United States and the European Union) and countries with special programmes to use space technologies for development aid (e.g. the United Kingdom). The priority areas of official development assistance flows during this period were environmental management, forestry management and telecommunications.

In developing regions, it is particularly difficult to develop the private sector in the space industry or to attract private funding. In much of the Asia and the Pacific, compared with in Australia, Canada and the United States of America, as well as Europe, there are few opportunities to commercialize geospatial research and development activities and technologies from space applications. As a result, Goals-relevant applications cannot attract investments that sustain the participation of experts and scientists or the projects that are often developed with geospatial and space-related agencies.[46]

Technology and skills gaps

In many developing countries, the lack of capability and expertise to produce satellite information with local resources and to provide user support can be a barrier to expanding the use of satellite technologies (Caribou Space, 2018). Earth observation data has been increasing exponentially in recent years. It is estimated that around 200 million Earth observation data sets are available in total (Anderson et al., 2017). This can be overwhelming for countries and researchers new to space-enabled data applications and they may struggle to decide what data are needed and where to find them. Processing this amount of data and modelling for forecasting models require significant computing capacities and appropriate skills in machine learning and artificial intelligence.

There is also an absence of a critical number of personnel with the capacity to generate downstream applications of space technologies. In developing countries, losing even a single expert within an organization can jeopardize efforts within government agencies. This absence of critical mass applies not only to institutions developing space applications but also to government agencies and private sector firms that could be potential users of the technology.[47]

Data challenges: Access, standardization, quality and user needs

Obstacles to the wider use of satellite technologies include restrictive data access, lack of standardization, data that are not fit enough for purpose, lack of analysis of ready data and insufficient frequency of observations (International Telecommunication Union, 2018).

Many environmental satellite images and data produced by Governments and multinational agencies are provided free of charge (e.g. images by the NASA Landsat and ESA Copernicus satellites). Other national agencies provide only part of their data free of charge (e.g. Brazil, China, India, Japan and the Republic of Korea). The market of commercial satellite Earth observation is still evolving, but for-profit companies generally charge a fee for their data and services (Wood and Stober, 2018).

Deriving statistics from satellite data and integrating geospatial information into different national and international monitoring and reporting processes, including the monitoring of progress on the Sustainable Development Goals, remains a great challenge. This is amplified when Earth observation data are aimed to be used in support of the Goals indicators combined with official statistics, as methodologies for standardization

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[46] Contribution made during Commission on Science and Technology for Development side event at Intergovernmental Consultative Committee on Regional Space Applications Programme for Sustainable Development, 28 August 2019, Bangkok.

[47] Contribution made during Commission on Science and Technology for Development side event at Intergovernmental Consultative Committee on Regional Space Applications Programme for Sustainable Development, 28 August 2019, Bangkok.

are currently in development on the international scene. Furthermore, processing the vast amount of satellite data requires high levels of computing and storage, including machine learning and artificial intelligence capabilities.

There is also a challenge related to data quality. At the global level, the Working Group on Geospatial Information of the Inter-agency and Expert Group on Sustainable Development Goal Indicators requires that the satellite data used for monitoring progress on the Sustainable Development Goals need to be, among others, consistent, reliable, transparent, relevant and open and free. Data also need to be accurate and provided on a continuous basis.

Assessing user needs regarding the satellite images and data produced is a continuous challenge in the implementation of large space programmes. In the case of the European Union Copernicus programme, user needs are assessed via several channels (e.g. consultations, workshops, expert groups and task forces), but taking into account various political and technological discussions, transparency, traceability and representativeness remains a challenge. The products and solutions need be suitable for integration into the everyday workflows of users and complement in situ data acquisition systems.[48] Data availability and the modelling approach can be very different in developing countries in which, often, not much in situ data are available. Although in situ data are highly relevant, space data sometimes become the only reliable source.

Geographical constraints

Some countries face geographical constraints in developing space launch facilities and conducting astronomical research. These constraints can be bridged through international partnerships and cooperation. For example, the Lao People's Democratic Republic, in 2015, launched the Laosat 1 satellite from China (Laosat, 2019). Bangladesh, in 2018, launched the Bangabandhu-1 satellite from Florida, United States (Space X, 2018). Due to its unique atmospheric conditions, Chile hosts around 50 per cent of the world's installed capacity of astronomical observatories. Many of these are operated by international partners such as Brazil, Canada, Japan, the United States and member States of the European Union (UNCTAD, 2019b).

Regulations and governance of space commons

The 1967 Outer Space Treaty is the basic framework of international space law that sets the principles governing space activities.[49] According to the Treaty, the exploration and use of outer space "shall be the province of all mankind". Space is free for exploration and use by all States and none of them should claim sovereignty. Space exploration is intended only for peaceful purposes.

Over 50 years have passed since the text of the Outer Space Treaty was agreed, but new challenges in space exploration remain largely unaddressed (*The Economist*, 2019a; *The Economist*, 2019b). One of the most urgent issues is the increasing number of space debris in orbit around the Earth. According to ESA, there are over 23,000 debris objects in space that are tracked, with millions of small debris objects untracked. The accumulation of space debris represents a considerable risk of collision for satellites, or in some cases, debris might fall back to Earth in an uncontrolled manner (Organization for Economic Cooperation and Development, 2020). Only international cooperation, guidelines and mitigation measures can address the sustainability of human space expansion.

Furthermore, with the development of technologies like drones, light detection and range sensing and machine learning and artificial intelligence algorithms applied to Earth observation data, the gap between the technology development process and legislative process is widening. One example is the regulation of drone technologies. While drones provide relatively cheaper methods for collecting Earth observation data, regulation against their use in many countries will likely favour satellite-based Earth observation data and programmes.[50]

Risks of using space technologies

Finally, it is important to note the risks and trade-offs regarding the use of space technologies. Images and data produced by space technologies can help to achieve the Sustainable Development Goals, but they can also be used for military purposes and may create information asymmetries that can adversely affect different market actors. The same data that are used to explore and monitor natural resources, if shared unequally, can support some users of satellite data to exploit fish reserves or negotiate unfair mining contracts.[51]

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[48] Contribution of Austria.

[49] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (http://www.unoosa.org/oosa/en/our-work/spacelaw/treaties/outerspacetreaty.html).

[50] Contribution made during Commission on Science and Technology for Development side event at Intergovernmental Consultative Committee on Regional Space Applications Programme for Sustainable Development, 28 August 2019, Bangkok.

[51] Contribution of the International Telecommunication Union.

IV. INTERNATIONAL SCIENTIFIC RESEARCH IN SPACE FOR THE SUSTAINABLE DEVELOPMENT GOALS

A. INTERNATIONAL SPACE STATION

The world's largest international cooperation programme in science and technology is the International Space Station, which has been operating continuously since 1998. It is a collaboration between the space agencies of Canada (Canadian Space Agency), Japan (Japan Aerospace Exploration Agency), the Russian Federation (Roscosmos), the United States (NASA) and Europe (ESA), which developed the project together and are now jointly operating and using the Space Station. The Space Station itself is an extraordinary technological and engineering achievement, as its elements were launched from different countries and continents and assembled in space once they had reached orbit. It has three laboratory modules: the Destiny laboratory module (United States; 2001), the Kibo laboratory (Japan; 2008) and the Columbus laboratory (Europe; 2008). These laboratories are furnished with research equipment, while the external platforms support experiments and applications in space science, Earth observation and technology. Scientific and research activities on the Space Station include experiments on microorganisms, cells, tissue cultures and small plants and insects; research on ageing and the effects of long-duration spaceflight on the human body; physics experiments with different materials, such as on the behaviour of liquids in microgravity; and high-technology experiments with remote operations, energy efficiency and maritime surveillance.

Research and discoveries on the Space Station are supported by thousands of researchers, engineers and technical personnel from Earth. They also feed into the work of scientists, universities and private companies that can benefit from state-of-the-art space technologies. As space agencies are looking at cost-effective solutions, the International Space Station is also stimulating industrial activities and private sector research and development in space technologies (e.g. commercial spaceflight; commercial capsules; commercial robotics services; and commercial services for collecting, processing analysing data on space debris). Agencies such as ESA, the Japan Aerospace Exploration Agency and NASA are considering new types of public–private partnerships (Organization for Economic Cooperation and Development, 2020).

B. REGIONAL COOPERATION ON SCIENTIFIC RESEARCH FOR SPACE

An effective form of long-term international research cooperation in space is the example of ESA, established in 1975. ESA manages Europe's space programme, with an annual budget of around $6.2 billion in 2019. Its mission is to shape the development of Europe's space capability and ensure that space research benefits the citizens of Europe and the world. The organization has 22 member States.[52] The organization is international, with headquarters in Paris and different sites across Europe. ESA is funded by financial contributions from members. It brings together scientists, engineers and information technology specialists from all member States.

ESA Earth-orbiting space science missions, several of which are part of international collaborations, are dedicated to observing the universe, the solar system and fundamental physics.[53] Currently operational missions observing the universe include the Hubble Space Telescope, a joint project of ESA and NASA launched in 1990. It is considered one of the greatest scientific projects in astronomy. Looking deep into space with cameras that can see across the entire optical spectrum, from infrared to ultraviolet, Hubble has changed scientists' fundamental understanding of the universe.[54] Inspired by this success, the Canadian Space Agency, ESA and NASA are collaborating to launch the James Webb Space Telescope in 2021, which is expected to have a similar impact on astrophysics as its predecessor. Another notable ESA mission is Gaia, which has produced the richest star catalogue to date, contributing to understanding the history of the Milky Way galaxy. The data collected by Gaia contributed to 800 publications in 2018.[55]

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[52] ESA member States include Austria, Belgium, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom; Slovenia is an associate member. Furthermore, Bulgaria, Canada, Croatia, Cyprus, Latvia, Lithuania, Malta and Slovakia have cooperation agreements with ESA.

[53] For the complete list of legacy, ongoing and upcoming missions see https://www.esa.int/ESA/Our_Missions/(sort)/date.

[54] See www.esa.int/Our_Activities/Space_Science/Hubble_overview.

[55] See m.esa.int/Our_Activities/Space_Science/Gaia/Gaia_creates_richest_star_map_of_our_Galaxy_and_beyond.

ESA also has several operational missions that contribute to knowledge about the sun and the solar system. For example, the solar and heliospheric observatory, launched in 1995 together with NASA, contributes to discoveries about the sun's interior, its visible surface and atmosphere and the solar wind.[56] Furthermore, ESA has successfully run robotic space missions in the past, such as Rosetta and Philae mission (2004–2016), which resulted in a spacecraft landing on an asteroid.

Box 2
Meeting regional needs with Earth observation services and data

The Geo-Cradle project, supported by the European Union, was established to bring together Earth observation stakeholders and activities across 11 countries in North Africa, the Middle East and South-Eastern Europe to expand the region's collective Earth observation capacity. The aim of the three-year project that ran from 2016 to 2018 was to support the effective integration of existing Earth observation capacities; provide an interface for the engagement of all Earth observation stakeholders; promote the uptake of Earth observation services and data in response to regional needs; and contribute to the improved implementation of and participation in the Group on Earth Observations, the Global Earth Observation System of Systems and Copernicus in the region.

The project started with needs assessments, gap analyses and Earth observation maturity assessments to capture Earth observation capacities, cooperation and national uptake and awareness in the participating countries. To showcase specific ways in which Earth observation services could help address regional challenges, the project conducted pilots in four thematic areas, including climate change adaptation, food security and water management, raw materials and energy. The project also launched a networking platform and a regional data hub providing access to regionally specific information with millions of data sets and 45 regional portals and sites, to encourage the long-term uptake of Earth observation activities (datahub.geocradle.eu/). Around 40 scientific publications were produced during the course of the project, which is now part of Group on Earth Observations initiatives.

Sources: Contribution of Turkey; European Commission, 2019; Geo-Cradle, 2019.

ESA is the main technical partner of the two flagship space projects of the European Union: the European Global Navigation Satellite System (known as Galileo) and the Copernicus Earth observation programme. In the case of Galileo, ESA has been designing and developing the satellite systems and has been in charge of the technical development of the infrastructure. In the case of Copernicus, ESA has been entrusted with the development of the space component, including the launch and operation of the dedicated Sentinel satellites (United Nations Office for Outer Space Affairs, 2018). The European Union is supporting the uptake of Earth observation services in neighbouring regions (box 2).

C. INTERNATIONAL SCIENTIFIC RESEARCH FOR DROUGHT MONITORING FROM SPACE

Building resilience to drought in South-East Asia has become a pressing need with the increased frequency of droughts in the region.[57] Despite the available benefits of space applications, many developing countries still do not have the requisite access to such innovative technologies, human capacity or the infrastructure to effectively utilize and apply these tools. Regional cooperation platforms and networks in Asia and the Pacific related to space technology applications and disaster risk management, including the regional space applications programme for sustainable development, have extended their spheres to address global sustainable development challenges beyond disaster risk reduction like drought monitoring.

The Regional Cooperative Mechanism for Drought Monitoring and Early Warning of the United Nations Economic and Social Commission for Asia and the Pacific brings together developed and emerging countries with advanced experience in using innovative space applications with high disaster-risk countries that could use the information and tools but lack the knowledge or capacity to do so. High disaster-risk countries are typically the least developed countries and small island developing States. The mechanism has created a toolbox of products, information and services to support drought-prone developing countries in enhancing their resilience, which can be replicated and adapted to different country contexts. Through its technical service nodes in China, India and Thailand, the mechanism has provided technical support in Cambodia and Myanmar through training, validation and the installation of drought monitoring systems. The operationalization of the drought monitoring system in Myanmar with technical support from India significantly improved monitoring capability in Myanmar. The system provides agricultural drought information in terms of prevalence, severity and persistence using moderate-resolution data, multiple indices for drought assessment and the augmentation of databases. Replicating such best practices depends

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[56] See www.esa.int/Our_Activities/Space_Science/SOHO_overview2.

[57] This section is based on inputs from the United Nations Economic and Social Commission for Asia and the Pacific, United Nations General Assembly (2018) and United Nations (2018).

on ground data and Government commitment to operationalizing the system to improve the lives of vulnerable communities. In this respect, the mechanism has provided continued support in capacity-building to member States through various thematic training sessions and provided policymakers with information that will enable them to make evidence-based decisions on how and when to prepare for droughts. In addition, the mechanism provides support to drought-prone countries in forging strong institutional partnerships between line ministries through capacity-building, knowledge and information-sharing and integrating drought risk reduction into policy, planning and implementation. For example, the Cambodia National Action Plan for Disaster Risk Reduction 2014–2018 highlighted the need to enhance drought early warning capabilities with a focus on improved technologies and community-based dissemination mechanisms and Myanmar has prioritized drought risk management for improving disaster and climate resilience in the agriculture sector.

D. SPACE-ENABLED RESEARCH COOPERATION FOR DISASTER RESPONSE AND HUMANITARIAN RELIEF

Space technology facilitates data collection and transmission, smooth and expedient communications and tracking and tracing efforts during and after natural disasters and in complex humanitarian emergencies. The United Nations Platform for Space-based Information for Disaster Management and Emergency Response promotes the use of space-based information in disaster management, disaster risk reduction and emergency response operations by raising awareness of the benefits of space technologies for disaster management and building the capacities of States to use those benefits effectively. Combining regional and global approaches, the United Nations Platform organizes technical advisory missions, conferences, workshops, discovery days and thematic expert meetings. Such events enable States to exchange knowledge and experiences and learn about innovative methods, best practices and opportunities to access satellite-derived resources. The United Nations Platform knowledge portal contains databases made up of freely available satellite data, derived products and software and compilations of all relevant maps and resources for selected major disasters. The Office for Outer Space Affairs is strengthening the United Nations Platform network of regional support offices, which currently has 21 members, to ensure that recommended practices and other references, tools and services are shared more widely (United Nations General Assembly, 2018). Processed data and information are shared among United Nations entities and made available through websites such as Relief Web,[58] a global hub for time-critical humanitarian information on complex emergencies and natural disasters, the Global Disaster Alert and Coordination System,[59] United Nations Institute for Training and Research and its Operational Satellite Applications Programme,[60] the Inter-Agency Standing Committee's common and fundamental operational data sets registry[61] and the United Nations Platform knowledge portal[62] (United Nations General Assembly, 2016).

Some countries with the requisite space capabilities, technologies and data are also contributing to international efforts for disaster response and humanitarian relief. The Landsat series of satellites, developed by NASA and operated by the United States Geological Survey, provide data used by Servir, a development initiative of NASA and the United States Agency for International Development. Servir uses Landsat and other United States satellite data to make maps used in disaster relief and support sustainable land use planning by developing countries. The NASA and United States Agency for International Development partnership on the Servir network provides data, information and methods combining Earth observation and geospatial data for decision-making and visualizations to address environmental problems including deforestation, pollution, flooding, drought and biodiversity loss. Currently there are Servir nodes in Africa (Kenya and the Niger), the Americas (Panama and Peru) and Asia (Nepal and Thailand). United Kingdom-based Inmarsat has donated satellite telecommunications and connectivity equipment to the Philippines Department of Social Welfare and Development for natural disasters and emergencies (Business Mirror, 2019).

E. INTERNATIONAL SCIENTIFIC COOPERATION TO ENHANCE ACCESS TO SPACE

Several international efforts are promoting access to space, especially for developing and emerging countries. The cooperation programme of the Japan Aerospace Exploration Agency and the United Nations Office for Outer Space Affairs, known as Kibo Cube, offers developing countries the opportunity to deploy cube

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[58] See www.reliefweb.int.

[59] See www.gdacs.org.

[60] See www.unitar.org/unosat.

[61] See cod.humanitarianresponse.info.

[62] See www.un-spider.org.

sats from the Kibo laboratory of the International Space Station. 1KUNS-PF [first Kenyan University nanosatellite precursor flight], selected as the first Kibo cube and developed by a team from the University of Nairobi, was successfully deployed from the Kibo laboratory in 2018. This cube sat is also the first satellite to emanate from Kenya and is a good example of how international collaboration contributes to access to space. Through the activity of Kibo Cube, the Japan Aerospace Exploration Agency hopes to further contribute to opening new gateways for developing and emerging countries to access space. Similarly, the Asia-Pacific Space Cooperation Organization supports satellite development by training students and academicians, supporting the development of radiometric calibration capabilities of member countries of the organization and developing small satellites through its joint small multi-mission satellite constellation programme. Another example of international scientific cooperation is seen in a United Kingdom-funded global partnership to improve fire detection rates in South Africa, for which capacity-building will be provided by Strathclyde University to students at Cape Peninsula University of Technology for the development of the cube sat platform. Further examples of international scientific cooperation in space research include that of the Russian Federation and several collaborators in the Spectrum Roentgen Gamma and Sirius projects. These projects involve several countries and stakeholders, recognizing the benefits of collaborative research in expanding access to space.[63]

Bilateral agreements can support science and technology partnerships involving both public and private sector actors through donations of equipment, capacity-building and access to satellite capacity. For example, two United Kingdom companies are providing services, either commercial or in-kind, to support the Sustainable Development Goals in the Philippines. The bilateral agreement includes capacity-building activities not only to build and use space technologies but also to establish a new space agency. In another example, United Kingdom small satellite manufacturing firm Surrey Satellite has a contract with the Philippines Department of Science and Technology to provide one tenth of the capacity of the Novasar radar satellite for monitoring territorial waters of the Philippines and helping protect its marine resources and fisheries. This contract is part of a memorandum of understanding signed between the Philippines and the United Kingdom in July 2019 to strengthen science and technology partnerships for sustainable development, including through the Newton Agham Programme, by implementing research and development and capacity-building activities, as well as collaboration on the establishment of the Philippine Space Agency. The United Kingdom Newton Fund, established in 2014, supports science and technology innovation partnerships through joint research and development work, postgraduate scholarships, capacity-building activities (e.g. conferences, joint training, workshops and other events), exchanges of scientists and collaborations between institutions and organizations in both countries.[64]

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[63] Contribution of the Russian Federation.

[64] Contribution of the United Kingdom.

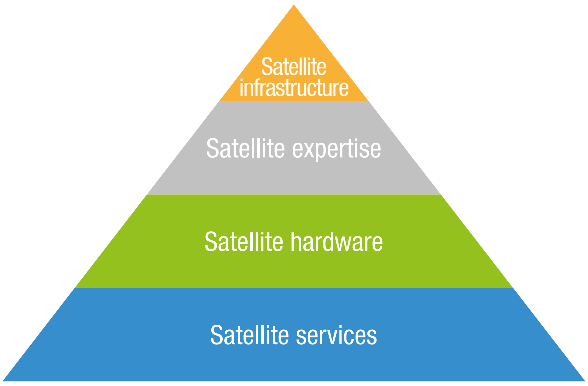
V. POLICIES AND STRATEGIES

A. NATIONAL POLICIES AND STRATEGIES

Harness scientific research and technology applications in space to build capabilities, improve infrastructure and increase public awareness

As illustrated in figure 1, space already benefits all countries as they use satellite services, whether in the form of communications, remote sensing, positioning or space science (Wood, 2012). Yet moving up the pyramid, fewer countries invest in owning satellite hardware, build local space expertise or build and operate satellites. The promotion of national space policies is highly dependent on the socioeconomic and political context of countries. Governments in developing countries may have different motivations to engage and limitations at different levels of space-related activities (figure 2).

Figure 1
All countries use satellite services, but fewer invest in local space hardware, expertise and infrastructure



Source: Wood, 2012.

Botswana, for example, is using satellite services for different applications to support the work of the Government by enabling informed regional planning and enhancing infrastructure. In agriculture, space technologies are used to predict the severity of droughts and predict crop harvests and changes in agricultural patterns. Space technologies are also used for mining and safety, such as in mineral prospecting and disaster management (e.g. detecting earth tremors and giving caution to those in affected areas). Botswana uses space technologies to make and revise maps, to monitor natural resources and to mitigate the effects of climate change. Although Botswana is using satellite services, it is lacking

Figure 2
Potential motivations for developing countries to invest in space technologies and expertise

Investment area	Satellite services: Using satellite services in Earth observation, communications, navigation and science	Satellite hardware: owning and operating a spacecraft and supporting ground systems	Satellite expertise: training personnel in satellite engineering	Satellite infrastructure: establishing local facilities to fabricate satellites
Short-term motivation	Address time-sensitive national needs for information	Meet unique local requirements for information with specific temporal frequency, spatial resolution and spectral coverage	Develop knowledge to be an informed consumer of satellite services	Increase technical involvement of local personnel in satellite activities
Long-term motivation	Enable informed regional planning Enhance infrastructure and industry	Gain operational experience Decrease dependence on uncertain technology sources Ensure service continuity	Inspire young scholars Enhance education and research opportunities Build up industrial capability	Use infrastructure to facilitate long-term series of satellite projects

Source: Wood, 2012.

specialized space infrastructure and enough people who are well trained in space technologies. Ongoing collaborations with regional and international partners (e.g. Angola, Kenya, South Africa, the African Union and the Southern African Development Community) could help to build technical capacity, receive and process space science data and learn about best practices in engaging with local communities.[65]

Box 3
South Africa: Satellite development programme

South Africa relies incalculably on space-based and ground-based data for information related to various interconnected thematic areas. This information is used to provide direction for maintenance, development and security measures to be taken by the Government with regard to the country's resources. Much of the space-based data are obtained from affiliated countries that are technologically more independent in terms of space-based applications and that can therefore distribute their information to other countries. By investing in and managing its own satellite programme, South Africa can ensure that the information it receives is more reliable and locally specific to whichever area requires attention. The opportunity cost of not investing in the satellite programme would result in (i) South Africa lagging behind in its global space capability and its leading position on the African continent; (ii) the erosion of a solid skills and technology base; (iii) the degradation of high-technology infrastructure and facilities; (v) over-reliance on foreign parties for space applications, including national security; (vi) and an inability to seize opportunities offered by a rapidly growing space market.

A solid base has now been established to initiate a vibrant satellite building programme called African Resource and Environmental Management Constellation with the nanosatellite programme used as a technology platform to respond to immediate challenges, such as Operation Phakisa. These new initiatives will require an investment of around $100 million (R1.5 billion) to ensure that the leadership position of South Africa in space science and technology is maintained on the African continent, as the country continues to develop critical skills, modernize existing facilities and build the requisite space infrastructure.

Source: Contribution of South Africa.

Another developing country, South Africa, has a national interest in making larger investments in space technologies (box 3). Running its own satellite programme has had several benefits for South Africa, including becoming less dependent on foreign partners, obtaining more customized satellite services and data and providing local human resources an opportunity to understand satellite operations. Similarly, Egypt has made large investments in space technologies since the National Authority for Remote Sensing and Space Sciences (NARSS) developed the country's first miniaturized satellite or cube sat, called NARSS Cube 2. Fitted with a camera with a ground resolution of 100 m, the satellite was built to be able to take photographs of the territories of Egypt.[66] Nigeria has also developed a greater national interest in space technology, investing in capacity-building training and infrastructure development initiatives. Nigeria has reaped the benefits of space technologies in the areas of technical and scientific expertise, the delivery of health care through telemedicine, weather forecasting and aviation safety, as well as satellite remote sensing and resource mapping.[67]

Harnessing space for the Sustainable Development Goals does not necessarily require experts in space science but rather geospatial technologists and engineers to transform satellite-generated data into Goals-related applications. The existence of a space agency or talent for space science and engineering is not as important as scientists, engineers, technologists and geospatial experts to develop applications in pursuit of the Goals. Such experts in downstream applications, not space in particular, can transform Earth observation and other space-derived data into insights for the environment, economy and society.

Collaborate with technical and academic communities and civil society to drive progress on the Sustainable Development Goals

Every country's unique socioeconomic and political situation shapes the development of national policies on space and geospatial applications. In many cases, it is experts in downstream applications that organize in informal groups that ultimately convince Governments of the need for a national spatial data infrastructure, geoinformation and other space-related policies. Some countries do not have a forum at which geospatial practitioners can discuss space technologies with their managers or politicians. Responding to such a gap, the Lao People's Democratic Republic formed the National Geographic Utilization and Management. In Nepal, the geographic information system society provided capacity-building in remote sensing and promoted policies on national spatial data infrastructure.[68] However, because of the frequent turnover of political administrations within the country, building an infrastructure to consistently educate politicians on the importance and use of geospatial technologies for development

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[65] Contribution of Botswana.

[66] Contribution of Egypt.

[67] Contribution of Nigeria.

[68] See https://www.negiss.org.np/.

has been a challenge. In Bhutan, the science-driven virtual geographic information system platform created a geospatial information structure without official government support. The informal platforms of geospatial experts in these countries often drive the creation of a national spatial data infrastructure, space policy and geoinformation policies that are eventually adopted by the Government. One exception is Sri Lanka and its Disaster Management Centre, where the Government led efforts to develop geospatial and national spatial data infrastructure policies.[69]

Continue to share data for development and adapt open data and open science policies and frameworks

National Governments and their respective space agencies or geospatial departments can proactively share data with bilateral and multilateral organizations to support the Sustainable Development Goals. Such open data and open science collaborations have a long history in Europe. The Spot Vegetation programme started in the 1990s and was the starting point of a European Earth monitoring system that was developed jointly by Belgium, France, Italy, Sweden and the European Commission. The programme delivered, from 2001 onward, free-of-charge data sets to the user community and was the precursor to the Copernicus programme, with its free, full and open access to the Copernicus Sentinel data. The project has also been a driver for international cooperation in space technologies with tangible and observable results.[70]

In carrying out its mandate of research and space exploration, NASA has entered into more than 3,000 agreements with over 120 countries and international organizations since its establishment. NASA global partnerships are represented by more than 700 active agreements with partner entities around the world. These partnerships offer multiple benefits to NASA and its partners, from enhancing the pace of scientific progress through rapid, open access to science mission data, to sharing risks and costs while promoting discovery and advancement. For example, NASA shared data from the Terra satellite with the South Africa Council for Scientific and Industrial Research, allowing the Council to develop useful models using satellite data and to build capacity in data analysis. Furthermore, all Earth science data from satellites of NASA, the United States National Oceanic and Atmospheric Administration and the United States Geological Survey are made available under a policy of free, full and open access, under a non-discriminatory principle whereby all users are to be treated equally. This allows countries that may not have the capability to operate satellites to benefit from globally relevant data sets.[71]

B. REGIONAL COOPERATION

Promote regional awareness and consensus-building on space for sustainable development

Regional cooperation mechanisms can support the development of regional space policies, spatial data infrastructures and political consensus-building for space-focused development initiatives. The African Union Heads of State and Government, at the twenty-sixth ordinary session in Addis Ababa, on 31 January 2016, adopted the African Space Policy and Strategy as the first concrete step towards realizing an African outer space programme, identified as one of the flagship programmes of the African Union Agenda 2063.[72] Moreover, the Southern African Development Community has committed to developing a shared satellite framework. The policy framework is based on establishing regional integration in the development of satellite technology to service the continent's developmental needs. Through the dissemination of valuable satellite information and operational services, the framework will benefit areas of broadcasting, communications and navigations, among others. Furthermore, through the international steering committee of the African Geodetic Reference Frame project, the United Nations Economic Commission for Africa has continued to develop a unified geodetic reference frame to contribute to the harmonization of geographic data and statistics in Africa (United Nations General Assembly, 2016; United Nations General Assembly, 2018).

In 2018, the Asia-Pacific Plan of Action on Space Applications for Sustainable Development 2018–2030 was adopted at the third Ministerial Conference on Space Applications for Sustainable Development in Asia

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[69] See http://www.dmc.gov.lk/index.php?lang=en.

[70] Contribution of Belgium.

[71] Contribution of the United States.

[72] The two policy goals are "to create a well-coordinated and integrated African space programme that is responsive to the social, economic, political and environmental needs of the continent, as well as being globally competitive" and "to develop a regulatory framework that supports an African space programme and ensures that Africa is a responsible and peaceful user of outer space" (see https://au.int/sites/default/files/newsevents/workingdocuments/33178-wd-african_space_policy_-_st20444_e_original.pdf; https://au.int/sites/default/files/newsevents/workingdocuments/33178-wd-african_space_strategy_-_st20445_e_original.pdf).

and the Pacific. This outcome document represents the collective commitment to scale up the use of space technology and geospatial information applications in the region and will guide participating countries and organizations on policy actions and interventions to support the delivery of the United Nations Economic and Social Commission for Asia and the Pacific regional road map for the implementation of the 2030 Agenda for Sustainable Development.[73]

The creation of a South American space agency was proposed in 2011 during the meeting of the Defence Council of the Union of South American Nations, including Argentina, the Plurinational State of Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Suriname, Uruguay and the Bolivarian Republic of Venezuela. A regional agency could reduce costs and contribute to building capabilities in space technologies for members. However, concrete moves have not yet been made for the realization of the project, as agreement on support and funding for such an agency has not yet been reached.

Encourage regional space-related activities to support research and development, capacity-building and data sharing

Several regions have extensive collaboration on technical and capacity-building initiatives to support the use of space technologies for the Sustainable Development Goals. The African Very Long Baseline Interferometry Network is an example of African regional cooperation on space technology. The group exchanges knowledge and collaborates to strengthen radio astronomy capabilities in the region in order to develop the square kilometre array radio telescope planned to be built in Australia and South Africa. Once completed, it will be the world's largest radio telescope.[74] In addition, through the African Union, Botswana, among other countries in Africa, contributes to the work of Global Monitoring for Environment and Security, which aims to strengthen capacity for African policymakers to plan and design national, regional and continental policies using Earth observation data.[75] In the Americas, there is some collaboration in space technologies in the region, mainly led by Argentina, Brazil, Chile and, more recently, Mexico (box 4).

Box 4
Mexico: Selected international space cooperation projects

Climate change is increasingly affecting sectors like agriculture, farming and fisheries. Space technologies help address the vulnerabilities within these sectors, providing technologies that allow for information-sharing. One of the projects implemented by Mexico is a cooperation between the Mexican Space Agency, the Agrifood and Fisheries Information System and ESA to develop space technology tools in order to boost the fisheries sector and promote sustainable aquaculture.

Mexico has also been cooperating with ESA through the Globbiomass project to produce a biomass map of the Yucatán Peninsula and Central Mexico by using spatial data, in situ data and algorithms. The biomass map helps to estimate the potential of biomass resources, related to Goal 7 on access to affordable, reliable and sustainable energy. The map covers aboveground woody biomass in tropical and subtropical moist broadleaf forests, dry broadleaf and coniferous forests and mangroves. Mexico is supporting the creation of a geospatial platform that could provide maps of the biomass resources of other countries in the region, such as Costa Rica, the Dominican Republic, El Salvador, Guatemala, Honduras, Nicaragua and Panama.

Sources: Contribution of Mexico; Globbiomass, 2019.

Such collaborations are often with countries active in space in the form of bilateral arrangements, to build satellites and rockets, use launch facilities or provide ground support (Gocłowska-Bolek, 2017; Sarli et al., 2018; Wood, 2012). For example, Argentina, which has a long history of space-related scientific activities, has worked with organizations from Brazil, the United States and Europe on scientific and Earth observation satellites. Brazil, the other country in South America with large investments in its space programme, worked with China on the China–Brazil Earth Resources Satellite, as well as with the Russian Federation and Ukraine on rocket projects. Chile has worked with European organizations to build remote-sensing satellites. As Chile is also hosting astronomical observatories for other nations, the country is exploring opportunities to use this privileged position to develop capabilities in big data analysis and artificial intelligence capacities (UNCTAD, 2019b). Other countries have launched communications and remote-sensing satellites in collaboration with China, such as the Plurinational State of Bolivia and the Bolivarian Republic of Venezuela. With regard to international cooperation in the region, the Argentina and Brazil Sabia-Mar mission is a dual-satellite Earth observation mission, aimed at supporting research on ocean ecosystems, marine habitats and seashores and helping to map water hazards. These collaborations and partnerships are contributing to knowledge transfer

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[73] Contribution of the United Nations Economic and Social Commission for Asia and the Pacific. See https://www.unescap.org/resources/asia-pacific-plan-action-space-applications-sustainable-development-20182030.

[74] Contribution of Madagascar.

[75] Contribution of Botswana.

and building technological capabilities in aerospace and science, technology and innovation in the region. In Asia and the Pacific, the United Nations Economic and Social Commission for Asia and the Pacific, through its regional space applications programme for sustainable development network, shared more than 400 satellite images and products on droughts, cyclones, earthquakes and floods to disaster-affected countries in 2017–2018 as a 24/7 service with free data and support from the member countries of the programme (United Nations, 2018).[76]

C. MULTI-STAKEHOLDER INITIATIVES

Encourage multi-stakeholder actors to continue to share Earth observation digital public goods

As space science and technology is increasingly transformed by cloud computing, artificial intelligence and crowdsourcing, private sector firms and non-profit organizations will continue to play a role in sharing Earth observation data, models and other relevant digital resources. In addition to the efforts of national Governments, private satellite data providers release proprietary Earth observation data for humanitarian and development purposes. These initiatives need to be encouraged to share Earth observation digital public goods.

For example, Digital Globe releases open imagery (including pre-event imagery, post-event imagery and crowdsourced damage assessment) of select major crisis events in the public domain under a Creative Commons 4.0 licence.[77] Planet, another private sector provider of Earth observation data, directly supports the International Charter on Space and Major Disasters, making its imagery available to humanitarian organizations, volunteers and the public.[78] Cloud computing providers like Amazon Web Services and Google Cloud through Google Earth Engine host public data archives of satellite imagery and provide lower-cost or free services for research, education and non-profit use. New non-profit initiatives are emerging to share open-licence satellite data, as well as models and algorithms for processing remote-sensing data. Open Aerial Map provides tools for searching, sharing and using open-licence satellite and drone imagery.[79] Radiant Earth Foundation provides an open-source hub to share machine learning libraries and models to support global development in areas including agriculture, climate change and conservation.[80]

Build space for Goals-focused global and public–private partnerships

Multi-stakeholder entities can forge global and public–private partnerships to more effectively harness space for the Sustainable Development Goals. The United States, through the the United States President’s Emergency Plan for AIDS Relief, is a founding member of the Global Partnership for Sustainable Development Data, which is working to convene, connect and catalyse partnerships to build demand, political will and capacity for data-driven decision-making to advance sustainable development challenges. The Partnership partnered with NASA, the Group on Earth Observations, the Committee on Earth Observation Satellites and others to launch the Africa Regional Data Cube, which is building capacity in Ghana, Kenya, Sierra Leone, Senegal and the United Republic of Tanzania for using time-series satellite images and other geospatial data to improve environmental management, adaptation to climate change and agricultural productivity. Africa Regional Data Cube, which will feature regional Landsat data, will serve as a platform for the scale-up of a continent-wide digital Earth Africa geospatial capability.[81]

Public–private partnerships, whether domestic or global, can also support space for the Sustainable Development Goals. The partnership for resilience and preparedness initiative is a public–private alliance hosted by the World Resources Institute that seeks to improve access to data, including space-based Earth observations, to empower communities and businesses to better plan for and build climate resilience.[82] In a domestic context, North Star Earth and Space, an information company in Canada, is developing an Earth and space monitoring and information delivery service and infrastructure. North Star is collaborating with the Government of Canada and the government of the province of Québec, as well as private clients, to demonstrate and co-create products by undertaking aerial campaigns with a hyperspectral sensor. These campaigns allow North Star to simulate future services that could be derived from its space

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[76] These data and services are worth over $1 million.

[77] See https://www.digitalglobe.com/ecosystem/open-data. Digital Globe has a memorandum of understanding with the United Nations Office for Outer Space Affairs to increase awareness of new, very high-resolution space-based data and services within the United Nations and to promote the availability of and access to such data and the provision of open data to the United Nations system during disasters (United Nations General Assembly, 2018).

[78] See https://www.planet.com/disasterdata/.

[79] See https://openaerialmap.org/.

[80] Contribution of the United States of America. See https://www.radiant.earth/.

[81] Contribution of the United States.

[82] Contribution of the United States.

infrastructure related to forestry, oil and gas monitoring, maritime domain awareness and the management of coastal ecosystems.[83]

D. INTERNATIONAL COLLABORATION AND COOPERATION

Invest in multilateral mechanisms and platforms for sharing Earth observation data assets

Countries can continue to invest in multilateral mechanisms for the effective sharing of Earth observation data, digital assets (e.g. models and machine learning models) and derived geospatial products. These mechanisms can be supported by international charters or agencies, regional platforms and national Governments and their respective space agencies. An example of a worldwide collaboration through which satellite data are made available for the benefit of disaster management is the International Charter on Space and Major Disasters. By combining Earth observation assets from different space agencies, the Charter allows resources and expertise to be coordinated for rapid response to major disaster situations, thereby helping civil protection authorities and the international humanitarian community.[84] Brazil has signed a partnership agreement with the European Union on the Copernicus programme, which will allow Brazil access to images to help monitor fragile biomes, tropical forests, oil spills on the ocean and other areas.[85] A data-sharing platform has been established to disseminate satellite data among Asia-Pacific Space Cooperation Organization countries.[86]

Throughout the United Nations system, there are efforts to share data or derived data products and services with Member States. Among United Nations Office for Outer Space Affairs efforts to share Earth observation data, its open universe initiative in partnership with Italy is aimed at enhancing and completing the online availability and visibility of astronomical and space science data following internationally agreed standards. It is also promoting the development of software applications and educational and outreach environments for astronomy and space science to further the progress of society in terms of culture and knowledge, in particular among women and youth, irrespective of the level of development of a country. The United Nations Office for Outer Space Affairs memorandum of understanding with the National Space Administration of China enables the provision of imagery for disaster management, monitoring the effects of climate change and supporting efforts to attain the Sustainable Development Goals. The World Meteorological Organization, through its space programme, conducts a wide range of activities and acts as a bridge between satellite operators and users with the overall objective of promoting the wide availability and utilization of satellite data and products for weather, climate, water and related applications by World Meteorological Organization members. Data acquired by environmental and meteorological satellites have contributed to improving weather and climate predictions (United Nations General Assembly, 2018).

Strengthen international cooperation on space-related research and development and capacity-building

The international community can continue to invest in multilateral cooperation in scientific research and the development of space technologies, as well as collaborating in global education and capacity-building. Although the International Space Station is the most visible example of international scientific research in space, many satellite and human spaceflight missions involve a wide range of national partners. For example, the National Centre for Space Studies of France, NASA, the United States National Oceanic and Atmospheric Administration and the European Organization for the Exploitation of Meteorological Satellites partnered to launch the Ocean Surface Topography Mission Jason-2 and Jason-3 satellites that monitor sea-level rise and track the transport of heat throughout the oceans, which can help identify where climate change is most likely to affect coastal communities.[87]

The national satellites of Canada support international scientific cooperation through contributions to specific Goals-relevant issues and instrumentation on international satellite platforms. Measurements of pollution in the troposphere, a Canadian instrument on the Terra satellite of NASA, scans the Earth's atmosphere to gather important data on air pollution used to assess pollution reduction initiatives such as vehicle emission reduction standards and to understand the impact of human activities. Swarm, a mission led by ESA to which Canada contributes resources, provides a new understanding of the Earth's magnetic fields. Surface water ocean topography, a satellite led by NASA to which Canada contributes, aims to enable a better understanding of aquatic ecosystems and monitor life

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[83] Contribution of Canada.

[84] Contribution of the United States.

[85] Contribution of Brazil.

[86] Contribution of Turkey.

[87] Contribution of the United States.

underwater and also to contribute to water management in Canada by measuring how lakes, rivers, reservoirs and oceans change over time. Soil moisture active passive is another NASA satellite to which Canada contributes, which advances understanding of the water and carbon cycles by producing global maps of soil moisture and the freeze-thaw state of soil in both the boreal environment in Canada and globally. Soil moisture ocean salinity is an ESA satellite that the Canadian Space Agency supports through science and application development and which measures ocean surface salinity and soil moisture to better understand the Earth's water cycle. It provides measurements over snow and ice-covered regions. Finally, the optical spectrograph and infrared imager system, an instrument on the Odin satellite of Sweden, assists scientists to better understand the impact of human activities and natural phenomena on the environment and climate. Its data on air quality plays a key role in international programmes and organizations in which Canada participates.[88]

The International Space Exploration Coordination Group, to which Romania contributes along with 13 other space agencies, also supports international scientific cooperation through mutual research and operational efforts in space exploration.[89]

In addition to scientific collaboration, particularly on Earth observation satellite platforms, international partners can continue their efforts to build scientific and technological capacities for space science and technology. The International Student Education Board, for example, is designed to encourage global collaboration in space education among the student community worldwide.[90] The Virtual Laboratory for Training and Education in Satellite Meteorology of the World Meteorological Organization and Coordination Group for Meteorological Satellites is a global network of specialized training centres and meteorological satellite operators working together to improve the utilization of data and products from meteorological and environmental satellites. In the area of multi-hazard early warning systems, the United Nations Economic and Social Commission for Asia and the Pacific has been working with countries in the Pacific and regional institutes to develop the capacity to use space technology and geographical information system applications as crucial elements in efforts to attain universal access to disaster-related early-warning information. The United Nations Economic and Social Commission for Asia and the Pacific and its regional partners have conducted a series of intensive training courses to build capacity. They have also completed pilot projects in Fiji, the Federated States of Micronesia, Papua New Guinea, Solomon Islands and Tonga, which included technical services, tailored toolboxes and model development for weather research forecasting, ocean wave monitoring and drought early warning. The project also contributed to South–South cooperation through the sharing of expertise available in institutes in Indonesia and Thailand (United Nations General Assembly, 2018).

Leverage intergovernmental platforms for space

Among other initiatives within the international community, the United Nations Committee of Experts on Global Geospatial Information Management, the Committee on Earth Observation Satellites and the Group on Earth Observations foster collaborative efforts towards harnessing space for the Sustainable Development Goals. The United Nations Committee of Experts on Global Geospatial Information Management is the leading intergovernmental global geospatial policymaking body and has been successful in building a global architecture and regional geospatial committee architectures in Asia and the Pacific, the Americas, the Arab States, Europe and Africa. The various work programmes place a strong emphasis on integrating national information systems for measuring and monitoring progress towards the Sustainable Development Goals, capacity-building and national-level implementation (United Nations General Assembly, 2018).

Data are essential for the achievement of the 2030 Agenda. Its success will depend on the availability of high quality, timely and universally accessible data. The effective use of Earth observation data in support of national monitoring and reporting against the global indicator framework, as well as informed decision-making on development policies, will require closer collaboration among national statistical offices and Earth observation data providers and communities around the world. The role of the Committee on Earth Observation Satellites is to focus its activities on being a coordination body for the space community in order to address specific issues related to satellite data. In full alignment with the intergovernmental Group on Earth Observations, the principal role of the Committee on Earth Observation Satellites is to support the integration of satellite observations in Goals-related processes for a full realization of the 2030 Agenda by all countries. A dedicated group of space agencies under the Committee on Earth Observation Satellites has developed a handbook that presents the main capabilities of satellite Earth observations, their

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[88] Contribution of Canada.

[89] Contribution of Romania.

[90] Contribution of Canada.

applications and a systematic overview of present and planned observation satellite missions of the committee and their instruments.[91]

By 2030, the Group on Earth Observations envisions a world in which the uses of Earth observations and geospatial information to support progress on the Sustainable Development Goals are valuable, routine and customary. In the first five years of the 2030 Agenda, the Group envisioned that the foundation would be laid for Governments and organizations to capitalize fully on the benefits that Earth observation provided to monitor, plan and report on the Sustainable Development Goals through 2030. As part of the 2017–2019 work programme, the Group had three goals and associated objectives to realize the vision and serve the purpose stated above. The goals described overarching desired outcomes and the objectives articulated specific, measurable results, as follows:

- Goal I. Demonstrate how Earth observations, geospatial information and socioeconomic and other data contribute in novel and practical ways to support sustainable development efforts and the Sustainable Development Goals.
- Goal II. Increase skills and capabilities in uses of Earth observations for Goals-related activities and their broader benefits.
- Goal III. Broaden interest, awareness and understanding of Earth observation support to the Sustainable Development Goals and contributions to social, environmental and economic benefits.[92]

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[91] Contribution of Canada.

[92] Contribution of Canada.

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