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Exploring space technologies for sustainable development and the benefits of international research collaboration in this context

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Contents

Table of figures

Table of boxes

I. Introduction

The United Nations has a long history in promoting greater international collaboration in outer space as well as the use of space technologies for sustainable development. The United Nations Office for Outer Space Affairs (UNOOSA) was initially created in 1958, while the international community celebrated last year the 50th anniversary of the first United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE). In recent years, there has been an increasing interest from Member States to use space applications for sustainable development, especially to achieve the Sustainable Development Goals (SDGs). In this context, the United Nations Commission on Science and Technology for Development (CSTD) selected the topic of "Exploring space technologies for sustainable development and the benefits of international research collaboration in this context" in May 2019 as one of its priority themes for its twenty-third session.

Space science[2], technologies, and data have the potential to contribute in direct or indirect ways to all SDGs. 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 (EO), satellite communication, as well as satellite positioning. Technologies like weather forecasting, remote sensing, Global Positioning Systems (GPS), 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 in key SDG indicators (UNOOSA, 2019).

These applications already benefit countries at various income levels and regardless of whether they have their own space agencies and space programs. Some least developed countries (LDCs) like Bangladesh, Bhutan and the Lao People's Democratic Republic have recently launched their own satellites (UCS 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 the 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).

The current issues paper highlights the potential opportunities of space-enabled technologies for delivering on the SDGs, and proposes science, technology and innovation (STI) policy options for harnessing space technology for sustainable development. The paper 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 both to create new knowledge and to increase the impact of research by diffusing existing knowledge. The issues paper comprises six main sections that are structured as follows.

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[2] "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..." Source: Republic of South Africa. (2008) "Space Science and Technology for Sustainable Development" National Working Group on Space Science and Technology, Department of Trade and Industry. URL: http://www.sacsa.gov.za/policy/Space%20Brocure%20upgrade%202Sept08%20p1-10.pdf

Chapter II reviews the different applications of space technologies for sustainable development, including in ensuring food security, health applications, telecommunications, reducing disaster risks, preventing humanitarian crises, monitoring natural resources, and reducing poverty. Chapter III highlights recent technological development in space technologies and examines the bottlenecks in the use of space technologies for sustainable development for developing countries and in an international context. Chapter IV identifies the effective forms and areas of international scientific research in space technologies through highlighting case studies on various collaborative research and development-focused initiatives. Chapter V highlights successful policies and strategies at the national, regional and international level that can promote harnessing space technologies for the SDGs. Finally, Chapter VI includes some key questions for discussion.

II. Space technologies for the Sustainable Development Goals

1. Food security 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 soil, snow cover, and drought and crop development. Rainfall assessments from satellites, for example, help farmers plan the timing and amount of irrigation they will need for their 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.[3]

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, services, and the lower cost of geospatial IT facilities have stimulated its adoption across the world and particularly in developing countries through initiatives such as Open Data Cube. Emerging priorities for the international collaborations in this field include the development of the 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.[4]

Space-enabled agricultural products and services can support farmers, national agricultural ministries and departments, and international organizations. For example, Canada’s remote sensing Earth observation satellite program, RADARSAT, provides data to support farmers in assessing soil moisture and irrigation needs. The GPS technology supports innovative precision farming techniques. This helps farmers better manage risks and improve planning to boost the quality and productivity of their crops.[5] The World Meteorological Organization (WMO) provides weather and draught forecasting services to farmers, herders and fishermen in order to promote sustainable agricultural development, increase agricultural productivity and contribute to food security through its Agricultural Meteorology Programme (UNGA, 2018). AfriScout is an application that supplies pastoralists in Ethiopia, Kenya, and 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., FarmDrive, GRID, and Apollo Agriculture) use remote sensing and machine learning as a tool to help assign credit ratings for farmers in the developing world, allowing many to get loans that would otherwise not have

[3] Contribution from the Government of South Africa.
[4] Contribution from the Food and Agriculture Organization.
[5] Contribution from the Government of Canada.

been securable.[6] 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.[7]

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.[8] The Asian Institute of Technology, the Cambodian Government Agriculture Department, and the University of Tokyo collaboratively developed an algorithm to predict rice yield at the time of harvest using MODIS data.[9] This analysis was piloted in three provinces but later expanded to the national level. Bangladesh's geospatial agency used EO data to estimate the production of its two major crops, Boro and Aman rice.[10] 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 program development. In 2016, Statistics Canada became the first National Statistical Office (NSO) to replace a farm survey with a remote sensing model-based approach for crop yield estimates.[11]

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 by the Food and Agriculture Organization (FAO) of remotely sensed data is a key component in the effective monitoring of agricultural production. FAO implements its mandate to assist and empower countries with knowledge, tools and methodology to enable them to undertake reliable assessments by fostering the use of medium- 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 Agro-Ecological Zones data portal and the integrated Land Resources Information Management System are used in key FAO activities (UNGA, 2016). The World Food Programme's (WFP) Support to Global Humanitarian Risk Mapping (SpaRC) project's main objective was the evaluation of global humanitarian risk layers based on medium resolution satellite data. The project that run from March 2017 to January 2018 used several types of satellites (Landsat and Sentinel), including satellites that take a daily image of the Earth with a resolution of 300 to 500 meters, as well as satellites that show field structures with a higher resolution of 10-20 meters, weekly or bi-weekly. The project supported preventive measures conducted by the WFP 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.[12] Furthermore, the Group on Earth Observations Global Agricultural Monitoring Initiative (GEOGLAM) initiative has been leading global cooperation in crop monitoring and market assessments to ensure transparency in crop markets.[13]

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 (USDA) World Agriculture Supply and Demand Estimates (WASDE) report is prepared monthly and includes forecasts for US and world wheat, rice, and coarse grains (corn, barley, sorghum, and oats), oilseeds (soybeans, rapeseed, palm), and cotton.

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6 Contribution from the Government of the United States of America.
7 Contribution from the Government of Turkey.
8 Cambodian and Bangladeshi examples were shared in CSTD regional consultation at ESCAP in August 2019.
9 See: https://modis.gsfc.nasa.gov/
10 See: http://sparrso.gov.bd/
11 Contribution from the Government of Canada. For details on the methodology, please see section 4.8 of the following publication: https://unstats.un.org/bigdata/taskteams/satellite/UNGWG_Satellite_Task_Team_Report_WhiteCover.pdf.
12 Contribution from the World Food Programme.
13 See: http://earthobservations.org/geoglam.php

GADAS (Global Agricultural and Disaster Assessment System), also supported by USDA, is a web-based GIS 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 USAID in 1985, provides early warning and analysis on acute food insecurity in 28 countries. Along with these assessments, they provide reports on weather and climate, markets and trade, agricultural production, livelihoods, nutrition, and food assistance.[14]

2. 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; telecommunication, positioning and tracking; and space-based research play a crucial role in supporting decision-making, improved care, education and early warning measures. (UNGA, 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.[15] The Malaria Early Warning System (MEWS), based on geospatial data, was responsible for 500,000 fewer new malaria cases across 28 countries (Juma et al. 2017; NASA, 2012). A priority for the Public Health Agency of Canada (PHAC) is responding to emerging infectious diseases, and the PHAC's National Microbiology Laboratory (NML) undertakes research and risk assessment to inform the development of programs to combat these diseases. The NML uses EO technologies, including RADARSAT data, in their research and risk assessment activities, and products are used widely in disease surveillance and disease outbreak management (i.e. mosquito-borne diseases, tick-borne diseases, chronic diseases, water-borne disease, vulnerable human populations, and potential epidemics such as Ebola). In 2018, data from the US National Aeronautics and Space Administration (NASA) satellites were used for cholera forecasting in Yemen, which worked with 92 per cent accuracy. Thanks to space data and tools, future health and development workers will be both more efficient and effective in their campaigns against disease outbreaks.[16] The Japan Aerospace Exploration Agency (JAXA) uses Digital Elevation Models (DEMs) to map areas that are difficult to access, in order to implement efficient measures for infectious diseases (e.g., polio in Niger).[17]

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 (UNGA, 2016). Beyond monitoring infectious diseases or supporting access to medical care in remote locations, space can enable medical research that would otherwise be difficult to conduct in a terrestrial environment.[18] The microgravity environment on the International Space Station (ISS) allows the growing of larger versions of an important protein, LRRK2, implicated in Parkinson's disease. This will help scientists to better

[14] Contribution from the Government of the United States of America. These survey results and data products are freely available to all.
[15] Contribution from the Government of South Africa.
[16] Contribution from the Government of the United States of America.
[17] Contribution from the Government of Japan. Elevation data is widely used in mapping infectious diseases in part because of the influence of elevation on rainfall, temperature and humidity (Hay et. al. 2006).
[18] "Advances in telemedicine, disease models, psychological stress response systems, nutrition, cell behavior and environmental health are just a few examples of benefits that have been gained from the unique space station microgravity environment." Source: https://www.nasa.gov/mission_pages/station/research/benefits/human_health.html.

understand the pathology of Parkinson's and aid in the development of therapies directed to alleviate this disease and its effects. Thus, this pioneering research aboard the space station may end up helping 7 to 10 million people worldwide currently affected by this disease.[19] More broadly, high quality protein crystals grown in a micro-gravity environment can support new drug design for infectious diseases, cancer, and lifestyle-related diseases.[20]

3. 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 — populations are less dense, further from main networks, and have lower purchasing power. Instead of the traditional network infrastructure used for broadband connectivity (i.e., 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, Bangladesh's recently launched telecommunications satellite Bangabandhu-1 is also already broadcasting TV and radio programs and will soon provide internet, telemedicine, and distance learning facilities for people in remote areas.[21]

New and emerging technologies may shape the evolution of telecommunications access, including low/medium altitude satellites, other aerial devices, and innovative use of unused portions of the radio frequency spectrum (Buluswar, 2018).[22] For example, the development and future deployment of non-Geostationary Orbit Satellite (non-GSO) fixed satellite service (FSS) systems have the potential to increase access to broadband infrastructure and bridge the digital divide, especially for the populations living in rural areas. Furthermore, Amazon's Project Kuiper, SpaceX's Starlink constellation, Google's Project Loon, and others are planning 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 far 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 intelligent transport systems, e-government, tele-education, e-health, e-logistics, smart energy, smart agriculture), in both developed and developing countries. These technologies are also facilitating advances in sustainability, banking, and diverse government services.[23]

4. 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 (UNDRR), between 1998 and 2017, disasters killed 1.3 million people globally, while they displaced, injured, left homeless or in need of emergency assistance further 4.4 billion (UNDRR and CRED, 2018).

Space-enabled technology applications have become an important element of regional, national and local disaster risk reduction strategies. Globally, the Sendai Framework for Disaster Risk Reduction

[19] Contribution from the Government of the United States of America.
[20] Contribution from the Government of Japan.
[21] See: https://en.wikipedia.org/wiki/Bangabandhu-1
[22] Contribution from the Government of South Africa.
[23] Contribution from the International Telecommunication Union.

2015-2030[24] 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. The framework recognizes the role of space technologies in supporting risk-informed decision making especially in the understanding of disaster risk (Priority 1 of the Sendai Framework).

EO, involving remote-sensing satellite images (provided by satellites such as the United States Landsat satellites and the Sentinel satellites of the European Copernicus Earth observation programme) and increasingly high-tech in-situ instruments (i.e. 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) help to detect and monitor disaster risks, especially natural hazards, and exposure to vulnerability. Volcano hazard, for example, can be observed through land deformation due to tectonic forces. Drought hazard can be monitored by observing soil moisture, precipitation and vegetation indices. EO 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 on satellite images (Global Partnership Using Space-based Technology Applications for Disaster Risk Reduction, 2019).

To give some examples, Natural Resources Canada (NRCAN) has been acquiring time-series EO 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 provincial, territorial and regional governments' civil security operations and are available to the public. Data is critical to monitoring ice conditions in the Arctic. Because of the extent, remoteness, and isolation of these regions, EO is often the only cost effective and technically feasible means of obtaining information. Furthermore, for over a decade, Polar View has used EO 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 Canadian Arctic. The service allows 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 the international research collaboration, the service has proven to be an exemplary case for the use of EO 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. [25]

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 ICT 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).

Accurate weather forecasts and improved communication have helped to manage evacuations and save lives during the devastating 2017 Atlantic hurricane season (WMO, 2017). Countries like Bangladesh and India, vulnerable to cyclone risks, have been also investing in modern meteorological services, improving early warning systems as well as cyclone shelters and embankments. At the

[24] See: https://www.unisdr.org/files/43291_sendaiframeworkfordrren.pdf.
[25] Contribution from the Government of Canada.

passing of the Tropical Cyclone Fani in May 2019, that killed at least 89 people and caused over $1.8 billion in damages, India evacuated one million people, while Bangladesh a further 1.6 million (Finneran, 2016; Reliefweb, 2019). As these examples show, space technologies are also crucial for communication to monitor disasters, set up and feed data into early warning systems, and share alerting messages through multiple ICT platforms. These examples also show the need for appropriate policies and mechanisms that build on the effective use of space technologies.

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, which when combined with GPS data can be exploited to populate land-use databases as well as assessments of disasters such as flood or earthquake damage. **Box *1*** below shows an example of how drones have been used recently to develop maps for the Oruchinga Refugee Settlement in Uganda. Drones may also be used for rapid mapping in case of emergencies, for example, when used with crowdsourcing platforms that tag live footage from aerial vehicles flown during disasters.

Box 1: Developing maps with drones to build refugee resilience in Uganda

In 2016, the United Nations Development Programme (UNDP) in collaboration with the United Nations High Commissioner for Refugees (UNHCR) 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 that refugees and their host communities live in. The maps showed where hazards are, 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 photo-mosaic, 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 ortho-photomosaic 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 the nearby reservoirs. It also showed the 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: United Nations Development Programme et al. 2016; and contribution from the UN Office for Disaster Risk Reduction.

5. Natural resource and environment management

There has been an exponential growth in the availability of satellite data and signals produced for observing our planet. As of September 2019, there are 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 (i.e. European Space Agency), private companies (i.e. Planet, Twenty First Century Aerospace Technology), as well as universities and research institutes (i.e. Korea Aerospace Research Institute, 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.

EO is an essential tool for managing natural resources and the environment. It is highly relevant for both monitoring and achieving the SDGs (Anderson et al., 2017; Wood and Stober, 2018). It provides information to support agricultural production, fisheries, freshwater and forestry management, while 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.[26]

EO data from satellites are also used to overcome various challenges such as water management, air pollution, and forest preservation. One example is the observation of precipitation, which is useful for tackling water related disasters such as flood, typhoon, and landslide. JAXA has developed a precipitation monitoring system known as GSMaP, which offers global rainfall maps using satellite data such as the Global Precipitation Measurement (GPM) mission and the Global Change Observation Mission (GCOM-W). In cooperation with international partners such as the Asian Development Bank and UNESCO, Japan contributes to the reduction of damage from water related disasters. Japan is also supporting atmospheric observation such as greenhouse gas (GHG) and aerosol to learn about climate change issues. The Ministry of the Environment (MOE), the National Institute for Environmental Studies (NIES) and JAXA have launched the Greenhouse Gases Observing Satellite (GOSAT) series (GOSAT) in 2009 as the world's first satellite, dedicated to monitoring greenhouse gases such as carbon dioxide (CO2) and methane (CH4). GOSAT-2 was launched last year with an enhanced capability of observing carbon monoxide in addition to CO2 and CH4 for the try of the anthropogenic emission estimation. Another example is the monitoring of forests for environmental protection and effective forest governance. JAXA is cooperating with the Japan International Cooperation Agency (JICA) and has initiated the forest monitoring system, called JJ-FAST, by using satellite data from ALOS-2. JJ-FAST is now monitoring the forests of more than 70 countries. Last year, JJ-FAST has contributed to detecting illegal deforestation in Brazil in cooperation with local authorities.[27]

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 changes on coastlines and monitor coastal erosion. The satellite images will also help to rapidly identify, in combination with signals from the automatic identification system, the vessels navigating Canadian waters and to detect those engaging in illegal fishing.[28]

Brazil monitors forests using satellites images collected by the National Institute of Space Research (INPE), although the size of the area observed represents a great challenge. The BiomeSAT project is a specific initiative that monitors forest health in the Amazon using nanosatellite technologies.[29] The collected data showed that deforestation rates peaked in the late 1990's and early 2000's. However, changes in forest and agricultural land management helped to cut annual deforestation rate by 2012 to around 80 per cent lower than the average rate between 1995 and 2006. Recent hike in forest fires in the Amazon have raised concerns about newly increasing levels of deforestation in the region (Borunda, 2019).

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[26] Contribution during CSTD side event at the Intergovernmental Consultative Committee on Regional Space Applications Programme for Sustainable Development, 28 August 2019, Bangkok, Thailand.
[27] Contribution from the Government of Japan.
[28] Contribution from the Government of Canada.
[29] Contribution from the Government of Brazil.

The geospatial agency of Bangladesh is planning a project to create a geospatial information system of the 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 this country which is particularly vulnerable to floods.[30]

EO is a powerful tool to monitor illegal mining activities. Remote sensing can be used to monitor natural variations in sand flux in rivers, and therefore, illegal sand mining. Satellite data from the NASA's Gravity Recovery and Climate Experiment (GRACE), for example, can reveal sediment discharge rates at river outlets, while the European Union's Raw Materials and Copernicus Earth observation project (RawMatCop Programme) also uses satellite images to help monitor and manage natural resources and the raw materials sector. Small satellites, such as CubeSats and SmallSats, can also produce high-resolution images at low cost to monitor mining (Bendixen et al., 2019). Companies such as ORBCOMM are using constellations of satellites in low-Earth orbit to gather Automatic Identification System signals about vessels across the ocean. 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.[31]

In addition to the applications mentioned above, EO can be also used to monitor country-specific environmental conditions and challenges, such as snow, ice and glacier monitoring. With financial support of the European Union's Horizon 2020 programme, an Austrian company called ENVEO[32] led the efforts to develop and implement the European standard service on snow and land ice monitoring as a downstream service for the Copernicus programme. The service provides geospatial products on the seasonal snow cover, glaciers and lake and river ice derived from EO satellite data (in particular Sentinel 1) in response to user needs. Some products became part of Copernicus Global Land.[33] The other near-real time information products on snow and land ice are also available free of charge.[34][35]

6. Other applications

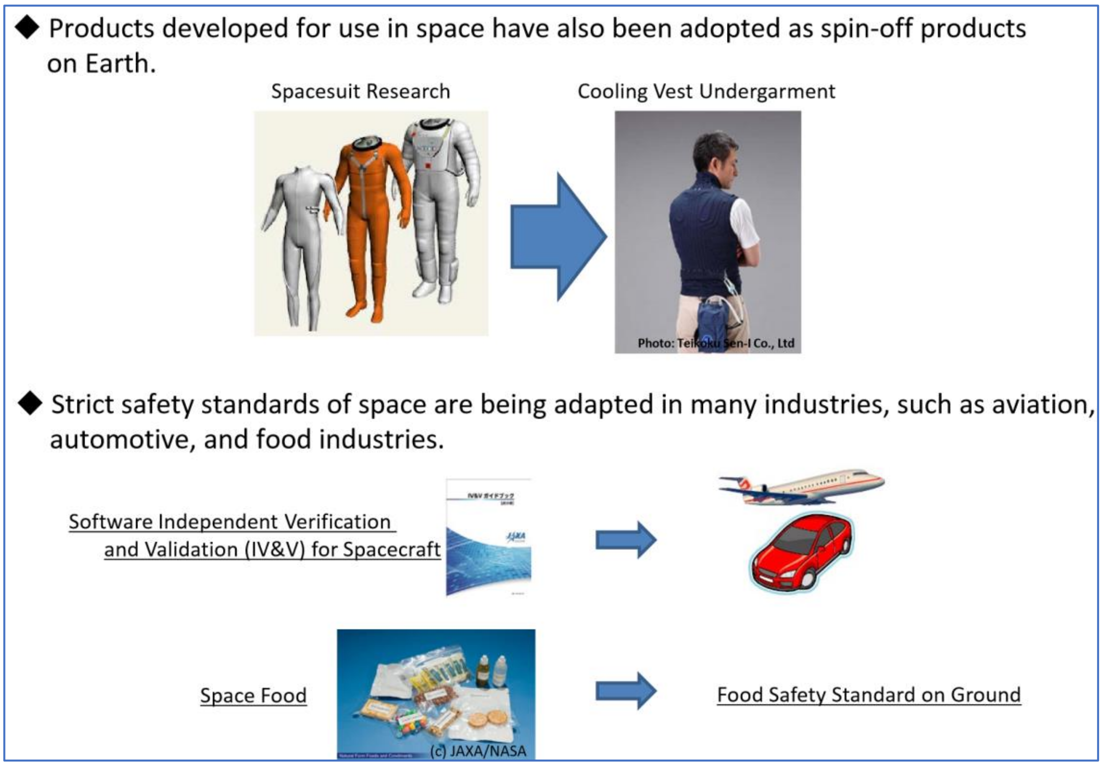
Recent studies have validated the potential of satellite imagery and machine learning to predict poverty, using publicly available and non-proprietary data (Jean et al., 2016). For example, the World Bank conducted a study to predict poverty rates, using convolutional neural networks along with high 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; Stark, 2018; Schmitt et al., 2018). However, it remains to be seen whether these 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).

[30] Contribution during CSTD side event at the Intergovernmental Consultative Committee on Regional Space Applications Programme for Sustainable Development, 28 August 2019, Bangkok, Thailand.
[31] Contribution from the Government of the United States of America.
[32] See http://www.enveo.at/euprojects/89-cryoland.
[33] See https://land.copernicus.eu/.
[34] See http://neso1.cryoland.enveo.at/cryoclient/.
[35] Contribution from the Government of Austria.

Space applications can also support education. E-education initiatives, for example, can benefit from satellite telecommunications, while UNICEF supports the mapping of schools using satellite imagery and machine learning.[36]

Scientific, technological, and innovative research and development for space may also yield practical SDG-relevant applications (see **Figure *1***). For example, battery storage capabilities have become more robust due to US government-funded research for space applications. With more efficient batteries, overall energy efficiency increases and 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. And though more futuristic, the rise of the commercial space transportation industry, including the increased frequency of suborbital launches, has created the possibility of a suborbital Earth-to-Earth transportation market emerging (UNGA, 2016).

Figure 1: How space research and development leads to terrestrial products



Source: Government of Japan.

III. Rapid technological change and bottlenecks in space science and technology

1. 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 will enable new SDG-relevant applications. Aerial platforms like

[36] Over 130,000 schools have been mapped in over 9 countries. See: http://unicefstories.org/magicbox/schoolmapping/

drones may serve a complementary role to satellite-based Earth observation. And crowdsourcing is expanding the collaboration opportunities between citizens and space agencies, programs, and initiatives in both developed and least developing countries to fill data gaps for a range of applications (e.g., weather, climate change, air quality monitoring, and vector-borne disease monitoring).

Artificial intelligence and cloud computing

Artificial intelligence (AI) and machine learning (ML) can enable users to analyse vast amounts of EO 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, EO data could be analysed in real-time, minimizing the time and effort needed of human analysts. There are several global developments to more effectively harness machine learning for the SDGs. For example, the CGIAR 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.[37] However, machine learning models are only as good as the data they are trained on, and the quality of the data can determine the suitability of the model for accurate and robust prediction.[38]

Increasingly, the application of AI and ML to EO data is occurring on cloud computing platforms. The cloud computing model is becoming the prevailing mode of work for most medium- and large-scale global data sets, including Earth observation (EO) 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 EO 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 JRC 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 is ingested (some include pre-loaded data, which reduces the effort on the part of the user) to scripting language (which is used for the 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.[39]

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 SDGs. There are promising examples for future satellite positioning technology applications. First, data from continuous recording GPS reference stations 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 US to use data from continuously recording GPS stations to monitor the passage of tsunamis across ocean basins, due to its 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 EO platforms are developing capabilities to monitor global wireless spectrum, with applications for monitoring digital divides, wireless penetration (e.g., LTE towers in Kenya), and economic indicators in developing countries.[40]

[37] Contribution from the Government of the United States of America.
[38] Contribution from ITU.
[39] Contribution from UNDRR.
[40] Personal communication with Hawkeye 360.

Drones can serve as an alternative, relatively cheap source of EO data compared to satellites and are increasingly being used in crop prediction and food security applications.[41] While drones can be built for several thousand US dollars and travel over 100 km on one battery, 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 EO data.

Crowdsourcing

Crowdsourcing, enabled through digital, mobile, and social networking tools, can support efforts to more effectively harness space technologies for sustainable development. Crowdsourced image labelling is used by several aid-NGOs to manually identify patterns of affected areas by a natural disaster that can be automated with machine learning (International Environmental Policy Consultancy, 2018). Data Collaboratives for Local Impact (DCLI), a partnership between the US President's Emergency Plan for AIDS Relief (PEPFAR) and the Millennium Challenge Corporation (MCC), is working in Africa to build the enabling environment for data-driven decision-making to end the AIDS epidemic, improve health outcomes, reduce gender inequality, and support economic opportunity for vulnerable youth. A key focus of PEPFAR is citizen mapping of high HIV-prevalent areas, in partnership with Humanitarian OpenStreetMap Team (HOT) and others, to identify HIV hot spots, health facilities and pharmacies, and improve allocation of program resources. DCLI's Innovation Challenge produced over 40 data innovations that support improved health systems, reduce HIV risks for adolescent girls and young women, and promote economic opportunity.[42]

2. Bottlenecks in the use of space technologies

Despite 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 lack of financial resources to develop space programs, especially in developing countries; technology and skill gaps to develop, use and adapt space technologies; challenges with respect to user needs, 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 public can 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 the European Space Agency, for example, there may be a lack of understanding among policy makers 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 programs in developing countries tend to point to other priorities and concerns that should be addressed before investment into space technologies. The launch of Bangladesh's first satellite had a cost of around 0.5 per cent of the country's annual budget. In an LDC, where most people are not well informed about the advantages and disadvantages of satellite technology,

[41] See: https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/Pages/Events/2018/Drones-in-agriculture/asptraining.aspx
[42] Contribution from the Government of the United States of America.

investments of 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.

At the moment, only eight African countries have launched their own satellites (Algeria, Angola, Egypt, Ghana, Kenya, Morocco, Nigeria and South Africa), with more than half of the satellites being launched in the last five years (Space in Africa, 2018). 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 (MIT News, 2011).

Lack of financial resources

The lack of domestic and international financial resources is another obstacle for investing in space programs in developing countries. Governments worldwide invested around $ 75 billion in space programs in 2017. In comparison, Nigeria and South Africa, the two African countries with the largest space budgets spent $ 29 million and $ 23 million in the same year, respectively (OECD, 2019).

According to the OECD (2019), official development aid (ODA) directed to space-related projects is relatively modest, amounting to a total of $ 607 million for the whole period between 2000 and 2016. For comparison, total ODA commitments in 2016 alone amounted to $ 188 billion. Top donor countries include those with well-established space programs (i.e. European Union, Japan, United States of America) and countries with special programs to use space technologies for development aid (i.e. United Kingdom). The priority areas of ODA flows during this period were environmental management, forestry management and telecommunication.

In developing regions, it is particularly difficult to develop the private sector in the space industry or attract private funding. In much of the Asia-Pacific region, as opposed to Europe, Canada, America, and Australia, there are few opportunities to commercialize geospatial research and development activities and technologies from space applications. As a result, SDG-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.[43]

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). EO data has been increasing exponentially in recent years. It is estimated that around 200 million EO data sets are available in total (Anderson, 2017). This can be overwhelming for countries and researchers who are new to space-enabled data applications, and they can struggle to decide what data is needed and where to find it. Processing this amount of data, and modelling for forecasting models require huge computing capacities and appropriate skills in machine learning and AI.

There is also an absence of a critical number of personnel who have 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 government agencies and private sector firms who could be potential users of the technology.[44]

[43] Contribution during CSTD side event at the Intergovernmental Consultative Committee on Regional Space Applications Programme for Sustainable Development, 28 August 2019, Bangkok, Thailand.
[44] Contribution during CSTD side event at the Intergovernmental Consultative Committee on Regional Space Applications Programme for Sustainable Development, 28 August 2019, Bangkok, Thailand.

Data challenges: data access, standardization, data 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, 2019).

Many environmental satellite images and data produced by governments and multinational agencies are provided free of charge (i.e. images by NASA's Landsat and the European Space Agency's Copernicus satellites). Other national agencies provide only part of their data free of charge (i.e. Brazil, China, India, Japan, South Korea). The market of commercial satellite EO 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 the SDGs, remains a great challenge. This is amplified when EO data is aimed to be used in support of the SDG indicators combined with official statistics, as methodologies for standardization are currently in development on the international scene. Furthermore, processing the vast amount of satellite data requires high computing and storage needs, including machine learning and AI capabilities.

There is also a challenge related to the data quality. At the global level, the Working Group on Geospatial Information of the Inter-agency and Expert Group on SDG Indicators requires that the satellite data used for monitoring the SDGs needs to be, among others, consistent, reliable, transparent, relevant, and open and free. Data also needs to be accurate and be 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 case of the European Union's Copernicus Programme, user needs are assessed via several channels (i.e. consultations, workshops, expert groups, 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 users' every-day workflow and complement in-situ data acquisition systems.[45] Data availability and the modelling approach can be very different in developing countries, where often not many in-situ data is available. Although in-situ data is highly relevant, space data sometimes becomes the only reliable source.

Geographical constraints

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

Regulations and governance of space commons

[45] Contribution from the Government of Austria.

The 1967 Outer Space Treaty[46] is the basic framework on international space law that sets the principles governing space activities. According to the Treaty, the exploration and use of outer space should 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 and 2019b). One of the most urgent issues is the increasing number of space debris in orbit around the Earth. According to the European Space Agency, 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, they might even fall back on Earth in an uncontrolled manner (OECD, 2019). Only international cooperation, guidelines and mitigation measures will be able to address the sustainability of human space expansion.

Furthermore, with the development of technologies like drones, Light Detection and Ranging (LIDAR) sensing, and machine learning and AI algorithms applied to EO 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 EO data, regulation against their use in many countries will likely favour satellite based EO data and programs.[47]

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 SDGs, 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 is 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.[48]

IV. International scientific research in space for the Sustainable Development Goals

1. International Space Station

The world's largest international cooperation programme in science and technology is the International Space Station (ISS), which has been operating continuously since 1998. It is a collaboration between the space agencies of Canada (CSA), Europe (ESA), Japan (JAXA), the Russian Federation (Roscosmos) and the United States of America (NASA), who developed the project together and are now jointly operating and using the ISS. The Station itself is an extraordinary technological and engineering achievement, as its elements were launched from different countries and continents, and they were assembled in space once they had reached orbit. It has three laboratory modules: the US Destiny laboratory module (2001), the European Columbus laboratory (2008), and Japan's Kibo laboratory (2008). These laboratories are furnished with research equipment, while the external platforms support experiments and applications in space science, EO and technology. Scientific and research activities on the Station include experiments on micro-organisms, cells, tissue cultures and even small plants and insects; research on aging and the effects of long-duration

[46] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, see: http://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html.
[47] Contribution during CSTD side event at the Intergovernmental Consultative Committee on Regional Space Applications Programme for Sustainable Development, 28 August 2019, Bangkok, Thailand.
[48] Contribution from the International Telecommunication Union.

spaceflight on the human body; physics experiments with different materials, such as on the behaviour of liquids in microgravity; and high-tech experiments with remote operations, energy efficiency and maritime surveillance.

Research and discoveries on the Station are supported by thousands of researchers, engineers and technical personal from Earth. They also feed into the work of scientists, universities and private companies, who in this way can benefit from the 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 (i.e. commercial spaceflight; commercial capsules; commercial robotics services; commercial services for collecting, processing, analyzing data on space debris). Agencies like the European Space Agency (ESA), JAXA and NASA are all considering new types of public-private partnerships (OECD, 2018).

2. Regional cooperation on scientific research for space

A very effective form of long-term international research cooperation in space is the case of the European Space Agency, established in 1975. ESA is managing 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.[49] The organization is truly international, with its headquarters in Paris and different sites across Europe. ESA is funded by financial contributions from its members. It is pulling together scientists, engineers, and information technology specialists coming from all Member States.

ESA's Earth-orbiting space science missions, several of them part of international collaborations, are dedicated to observing the universe, the solar system, and fundamental physics.[50] Currently operational missions observing the universe include the Hubble Space Telescope, a joint project of ESA and NASA launched in 1990. It is considered as 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.[51] Inspired by this success, NASA, ESA and the Canadian Space Agency (CSA) are collaborating to launch the highly anticipated James Webb Space Telescope in 2021, that is expected to have a similar impact on astrophysics as did its predecessor. Another notable ESA mission is Gaia, which has produced the richest star catalogue to date, contributing to understanding the history of our Galaxy. The data collected by Gaia has also contributed to 800 publications in 2018 only.[52]

ESA also has several operational missions that contribute to our knowledge about the Sun and the solar system. For example, the Solar and Heliospheric Observatory (SOHO), launched in 1995 together with NASA, contributes to discoveries about the Sun's interior, its visible surface and atmosphere, and

[49] ESA Member States include Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom, while Slovenia is an Associate Member. Furthermore, Bulgaria, Croatia, Cyprus, Malta, Latvia, Lithuania, Slovakia, as well as Canada have cooperation agreements with ESA.
[50] For the complete list of legacy, ongoing and upcoming missions see: https://www.esa.int/ESA/Our_Missions/(sort)/date.
[51] See: http://www.esa.int/Our_Activities/Space_Science/Hubble_overview.
[52] See: http://m.esa.int/Our_Activities/Space_Science/Gaia/Gaia_creates_richest_star_map_of_our_Galaxy_and_beyond

the solar wind.[53] Furthermore, ESA has successfully run robotic space missions in the past, such as Rosetta/Philae mission (2004-2016) that resulted in a robot landing on an asteroid.

ESA is the main technical partner of the European Union's two flagship space projects: the European Global Navigation Satellite System (also 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 of the dedicated Sentinel satellites (UNOOSA, 2018). **Box *2*** below shows how the European Union is supporting the uptake of EO services in neighbouring regions.

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 EO stakeholders and activities across eleven countries in North Africa, the Middle East, and the Balkans to expand the region's collective EO capacity. The aim of the three year project that run from 2016 to 2018 was to support the effective integration of existing EO capacities; provide an interface for the engagement of all EO stakeholders; promote the uptake of EO services and data in response to regional needs; and contribute to the improved implementation of and participation in the Group on Earth Observations (GEO), the Global Earth Observation System of Systems (GEOSS), and Copernicus in the region.

The project started with needs assessments, gap analyses and EO maturity assessments to capture participating countries' EO capacities, cooperation and national uptake and awareness. To showcase specific ways in which EO services could help tackle 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[54] providing access to regionally specific information with millions of datasets, 45 regional portals and sites, to encourage the long-term uptake of EO activities. Around 40 scientific publications were produced during the course of the project, which is now part of GEO's initiatives.

Sources: Contribution from the Government of Turkey; European Commission (2019); GEO-CRADLE (2019).

3. International scientific research for drought monitoring from space

Building resilience to drought in Southeast Asia has become a pressing need with the increased frequency of droughts in region.[55] 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. Asia-Pacific regional cooperation platforms and networks related to space technology applications and disaster risk management, including the Regional Space Applications Programme for Sustainable Development (RESAP), have extended their spheres to address global sustainable development challenges beyond disaster risk reduction like drought monitoring.

[53] See: http://www.esa.int/Our_Activities/Space_Science/SOHO_overview2.
[54] See: http://datahub.geocradle.eu/.
[55] This section is based on inputs from ESCAP, United Nations General Assembly (2018), and United Nations (2018).

The United Nations Economic and Social Commission for Asia and the Pacific's (ESCAP) Regional Cooperative Mechanism for Drought Monitoring and Early Warning (Regional Drought Mechanism) 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 typically are 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 been providing technical support in Cambodia and Myanmar through training, validation and installation of drought monitoring systems. The operationalization of the drought monitoring system in Myanmar with technical support from India has significantly improved the former's monitoring capability. The system provides agricultural drought information in terms of prevalence, severity and persistence using moderate resolution data, multiple indices for drought assessment and augmentation of ground data bases.

Replicating these best practices will also depend on ground in-situ data and on the governments' 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, as well as providing policymakers with information that will enable them to make evidence-based decisions on how and when to prepare for drought. In addition, the regional drought 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, Myanmar has prioritized drought risk management for improving disaster and climate resilience in the agriculture sector, while Cambodia's National Action Plan for Disaster Risk Reduction (NAP-DRR) 2014–2018 highlighted the need to enhance drought early warning capabilities with a focus on improved technologies and community-based dissemination mechanisms.

4. Space-enabled research cooperation for disasters 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 (UN-SPIDER) 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 Member States to use those benefits effectively. Combining regional and global approaches, UN-SPIDER organizes technical advisory missions, conferences, workshops, discovery days and thematic expert meetings. Such events enable Member States to exchange knowledge and experiences and learn about innovative methods, best practices and opportunities to access satellite-derived resources. The UN-SPIDER 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 UN-SPIDER 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 (UNGA 2018).

Processed data and information are shared among United Nations entities and made available through websites such as ReliefWeb[56], a global hub for time-critical humanitarian information on complex

[56] See: www.reliefweb.int.

emergencies and natural disasters, the Global Disaster Alert and Coordination System[57], UNITAR/UNOSAT[58], the Inter-Agency Standing Committee's Common and Fundamental Operational Datasets Registry[59] and the UN-SPIDER knowledge portal[60] (UNGA, 2016).

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

5. International scientific cooperation to enhance access to space

Several international efforts are promoting access to space, especially for developing and emerging countries. UNOOSA and JAXA's cooperation programme known as "KiboCUBE," offers developing countries the opportunity to deploy CubeSats from the Japanese Kibo laboratory of the ISS. 1KUNS-PF, selected as the first KiboCUBE and developed by a team from the University of Nairobi, was successfully deployed from Kibo laboratory in 2018. This CubeSat is also the first satellite of of Kenya, and it is a good example of how international collaboration contributes to access to space. Through the activity of KiboCUBE, JAXA hopes to further contribute to opening new gateway for the developing and emerging countries to access space. Similarly, the Asia-Pacific Space Cooperation Organization (APSCO) supports satellite development by training students and academicians, supporting the development of radiometric calibration capabilities of APSCO countries, and developing small satellites through its Joint Small Multi-Mission Satellite Constellation Program. In a UK-funded global partnership to improve fire detection rates in South Africa, capacity-building will be provided by Strathclyde University to students at Cape Peninsula University of Technology for the development of the ZACube-2 CubeSat platform.

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 UK companies are providing services – either commercial or in-kind – to support the SDGs 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, UK small satellite manufacturing firm Surrey Satellite has a contract with the Philippines Department of Science and Technology (DOST) to provide one-tenth of the capacity of the Novasar radar satellite for monitoring Philippine territorial waters and help protect its marine resources and fisheries. This contract is part of a Memorandum of Understanding (MoU) signed between the UK and the Philippines in July 2019 to strengthen science and technology partnership 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

[57] See: www.gdacs.org.
[58] See: www.unitar.org/unosat.
[59] See: cod.humanitarianresponse.info.
[60] See: www.un-spider.org.

UK's 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), exchange of scientists, and collaboration between institutions and organizations in both countries.[61]

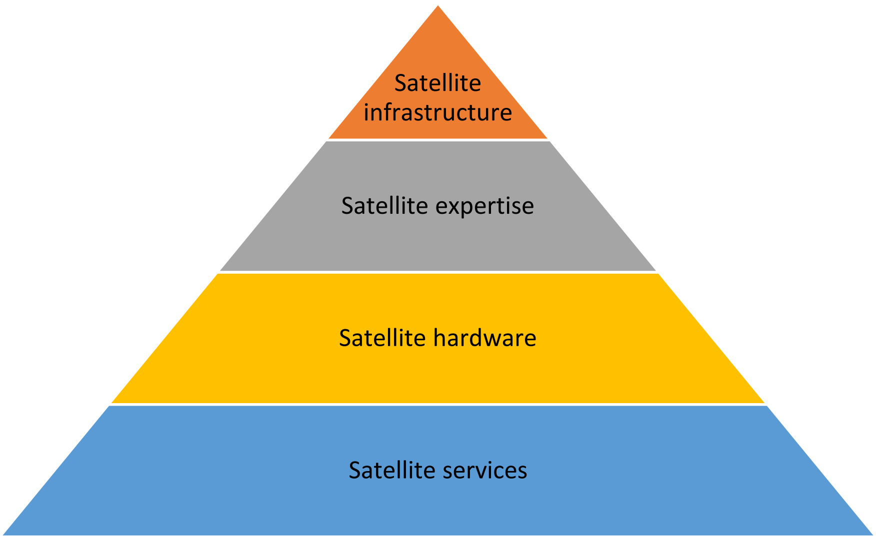
V. Policies and strategies

1. National policies and strategies

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

As illustrated by **Figure 2**, space already benefits all countries as they use satellite services let it be in the form of communications, remote sensing, positioning or space science (Wood, 2012). But as we move up on the steps of 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 and limitations to engage at different levels of space related activities (see **Figure 3**).

Figure 2: Countries by use of satellite services, investment in hardware, expertise and infrastructure



Source: Wood, 2012.

Figure 3: Potential motivations for developing countries to invest in space technologies and expertise

Investment area	**Satellite service:** using satellite services in Earth observation, communication, navigation and science	**Satellite hardware:** owning and operating a spacecraft and supporting ground system	**Satellite expertise:** training personnel in satellite engineering	**Satellite infrastructure:** establishing local facilities to fabricate satellites

[61] Contribution from the Government of the United Kingdom.

Short term motivation	Address time sensitive national needs for information	Meet unique, local requirements for information with specific temporal frequency, spatial resolution, 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 operations 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.

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 severity of drought, predict crop harvest and changes in agricultural patterns. Space technologies are also used for mining and safety, such as 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 mitigate the impact of climate change. Although Botswana is using satellite services, it is lacking specialised space infrastructure and enough people who are well trained in space technologies. Ongoing collaborations with regional and international partners (i.e. Angola, Kenya, South Africa, as well as African Union, Southern African Development Community) could help to build technical capacity, receive and process space science data, and learn best practices in engaging with local communities.[62]

On the other hand, another developing country, South Africa (see **Box 3** below), had a national interest in making larger investments in space technologies. Running its own satellite program has several benefits for South Africa, including becoming less dependent on foreign partners, getting more customized satellite services and data, and providing local human resources an opportunity to understand satellite operations.

Harnessing space for the SDGs requires not necessarily experts in space science but geospatial technologists and engineers who can transform satellite-generated data into SDG 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 who can develop applications in pursuit of the SDGs. 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.

Box 3: South Africa's Satellite Development Programme

South Africa, much like other countries around the globe, relies incalculably on space- and ground-based data for information relating 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 regards to the country's resources. Much of the space-based data is obtained from affiliating countries that are technologically more independent in terms of space-based

[62] Contribution from the Government of Botswana.

applications and hence, can 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 that 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-tech 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 (ARMC) with the nano-satellite programme being 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 (R 1.5 billion) to ensure that South Africa's leadership position in space science and technology is maintained in the African continent, as the country continues to develop critical skills, modernise existing facilities and build the requisite space infrastructure.

Source: Contribution from the Government of South Africa

<u>Collaborate with technical and academic communities and the civil society to drive progress on the SDGs</u>

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 (NSDI), geo-information, and other space-related policies. Some countries, like the Lao People's Democratic Republic, do not have a forum within which geospatial practitioners can discuss space technologies with their managers or politicians. Responding to this gap, Lao NGUM (National Geographic Utilization and Management) was formed. In Nepal, its GIS society provided capacity-building in remote sensing as well as promoted policies on its national spatial data infrastructure.[63] 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 has been a challenge. In Bhutan, its science-driven virtual GIS platform created a geospatial information structure without official government support. The informal platforms of geospatial experts in these countries many times drive the creation of NSDI, space policy, and geo-information policies that are eventually adopted by government. One exception is Sri Lanka and its Disaster Management Center, where government drove efforts to develop geospatial and NSDI policies.[64]

<u>Continue to share data for development and adapt open data and open science policies and frameworks</u>

National governments and their respective space agencies or geospatial departments can proactively share data with bilateral and multilateral organizations to support the SDGs. Such open data and open science collaborations have a long history in Europe. The SPOT VEGETATION programme started in the 1990's 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 SPOT VEGETATION programme delivered from 2001 onwards free of charge datasets to the entire user community, and

[63] See: https://www.negiss.org.np/.
[64] See: http://www.dmc.gov.lk/index.php?lang=en.

so became the real precursor for 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.[65]

In carrying out its mandate of research and space exploration, NASA has entered into more than 3,000 agreements with more than 120 nations and international organizations since its establishment. NASA's global partnerships are represented today 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 South Africa's Council for Scientific and Industrial Research, allowing them to develop useful models using satellite data and build capacity in data analysis. Furthermore, all Earth science data from NASA, NOAA, and USGS satellites is made available under a policy of free, full and open, under a non-discriminatory principle "where all users will be treated equally." This allows countries who may not have the capability to operate satellites to benefit from globally relevant datasets.[66]

2. 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. In 2016, the African Union Heads of State and Government during their Twenty-Sixth Ordinary Session on 31 January 2016 in Addis Ababa adopted the African Space Policy and Strategy as the first of the concrete steps towards realizing an African Outer Space Programme that was identified as one of the flagship programmes of the AU Agenda 2063.[67] 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 (UNGA 2016, UNGA 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 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 ESCAP's Regional Road Map for the Implementation of the 2030 Agenda.[68]

The creation of a South American Space Agency was proposed in 2011 during the meeting of Defence Council of the Union of South American Nations (UNASUR), including Argentina, Bolivia, Brazil, Chile,

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[65] Contribution from the Government of Belgium.

[66] Contribution from the Government of the United States of America.

[67] 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." More information on the African Space Policy and Strategy, respectively, can be found here: 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.

[68] Contribution from ESCAP. For more information: https://www.unescap.org/resources/asia-pacific-plan-action-space-applications-sustainable-development-20182030

Colombia, Ecuador, Paraguay, Peru, Surinam, Uruguay and Venezuela. Although a regional agency could reduce costs and contribute to build capabilities in space technologies for the members, there has been no concrete moves ever since for the realization of the project, as countries do not seem to agree on the support and funding of such an agency.

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

Several regions have extensive collaboration on technical and capacity-building initiatives to support space for the SDGs. In Latin America, there is some international collaboration in space technologies in the region, mainly led by Argentina, Brazil, Chile and more recently Mexico (see **Box 4** below). These collaborations are often with more capable space nations 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, who has a long history of space-related scientific activities, worked with US, Brazilian and European organizations on its scientific and EO satellites. Brazil, the other South American country with large investments in its space program, worked with China on the China-Brazil Earth Resources Satellite, as well as with the Russian Federation and Ukraine on rocket projects. Chile 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, like Bolivia and Venezuela launched their communication and remote sensing satellites in collaboration with China. Regarding international cooperation in the region, the Argentinian-Brazilian SABIA-Mar mission is a dual satellite EO mission, which will support research on ocean ecosystems, marine habitats, seashores, and will help to map water hazards. These collaborations and partnerships are contributing to knowledge transfer and building technological capabilities in aerospace and STI in the region. In the Asia-Pacific region, ESCAP (through its RESAP network) shared more than 400 satellite images and products for drought, cyclone, earthquake and flood to disaster-affected countries in 2017-18 as a 24/7 service with free data and support from RESAP member countries (United Nations, 2018).[69]

Box 4: Selected international space cooperation projects of Mexico

Climate change is increasingly affecting sectors like agriculture, farming and fisheries. Space technologies help fight the vulnerabilities within these sectors, providing technologies that allow information sharing. One of the projects implemented by Mexico is a cooperation between the Mexican Space Agency (AEM), the Agro-food and Fisheries Information System (SIAP) and the European Space Agency, to develop space technological tools in order to boost the fisheries sector and promote sustainable aquaculture.

Mexico has been also cooperating with ESA, through the *Globbiomass* project, to produce a biomass map of the Yucatan 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 was covering 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 about the biomass resources of other countries in the region too, such as Costa Rica, the Dominican Republic, El Salvador, Guatemala, Honduras, Nicaragua, and Panama.

Sources: Contribution from the Government of Mexico; Globbiomass (2019).

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

3. Multi-stakeholder initiatives

Encourage multi-stakeholder actors to continue to share EO digital public goods

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

For example, DigitalGlobe releases open imagery for select major crisis events (including pre-event imagery, post-event imagery, and crowdsourced damage assessment) into the public domain under a Creative Commons 4.0 license.[70] Planet, another private sector provider of EO data, directly supports the International Space Charter and Major Disasters, making its imagery available to humanitarian organizations, volunteers and the public.[71] 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 openly licensed satellite data as well as models and algorithms for processing remote sensing data. OpenAerialMap provides tools for searching, sharing, and using openly licensed satellite and drone imagery.[72] 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.[73]

Build space for SDG-focused global and public-private partnerships

Multi-stakeholder entities can forge global and public-private partnerships to more effectively harness space for the SDGs. The United States, through PEPFAR, is a founding member of the Global Partnership for Sustainable Development Data (GPSDD), which is working to convene, connect and catalyze partnerships to build demand, political will and capacity for data-driven decision-making to advance sustainable development challenges. GPSDD partnered with NASA, the Group on Earth Observations (GEO), the Committee on Earth Observation Satellites (CEOS), and others to launch the Africa Regional Data Cube (ARDC), which is building capacity in Kenya, Tanzania, Ghana, Senegal and Sierra Leone for using time-series satellite images and other geospatial data to improve environmental management, adaptation to climate change, and agricultural productivity. ARDC, which will feature regional Landsat data, will serve as a platform for scale-up of a continent-wide Digital Earth Africa geospatial capability.[74]

Public-private partnerships, whether global or domestic, can also support space for the SDGs. The Partnership for Resilience and Preparedness Initiative is a public-private alliance hosted by the World Resources Institute (WRI), which seeks to improve access to data, including space-based Earth

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[70] See: https://www.digitalglobe.com/ecosystem/open-data. Note that DigitalGlobe has an MoU with UNOOSA 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 (UNGA 2018).

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

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

[73] Contribution from the Government of the United States of America. More information at: https://www.radiant.earth/

[74] Contribution from the Government of the United States of America.

observations, to empower communities and business to better plan for and build climate resilience.[75] In a domestic context, NorthStar Earth & Space Inc. (NorthStar), a Canadian information company, is developing an Earth and Space monitoring and information delivery service and infrastructure. NorthStar is currently collaborating with the Québec and the Canadian Governments as well as private clients to demonstrate and co-create products by undertaking aerial campaigns with a hyperspectral sensor. These campaigns allow NorthStar to simulate future services that would be derived from its space infrastructure related to forestry, oil and gas monitoring, maritime domain awareness and the management of coastal ecosystems.[76]

4. International collaboration and cooperation

Invest in multilateral mechanisms and platforms for sharing EO data assets

Countries can continue to invest in multilateral mechanisms for the effective sharing of EO data, digital assets (e.g., models, 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.[77] Brazil has signed a partnership agreement with the European Union on the Copernicus program which will allow Brazilian access to images to help monitor fragile biomes, tropical forests, oil spills on the ocean and other areas.[78] A data sharing platform has been established to disseminate satellite data among the APSCO countries.[79]

Throughout the UN system, there are efforts to share data or derived data products and services with Member States. Among UNOOSA's efforts to share EO 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 young people and women, irrespective of the level of development of a country. UNOOSA's MoU with China's National Space Administration enables the provision of imagery for disaster management, monitoring the effects of climate change and supporting efforts to attain the Sustainable Development Goals. WMO, 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 WMO members. Data acquired by environmental and meteorological satellites have contributed to improving weather and climate predictions (UNGA, 2018).

Strengthen international cooperation on space-related R&D and capacity-building

The international community can continue to invest in multilateral cooperation in scientific research and 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

[75] Contribution from the Government of the United States of America.
[76] Contribution from the Government of Canada.
[77] Contribution from the Government of the United States of America.
[78] Contribution from the Government of Brazil.
[79] Contribution from the Government of Turkey.

scientific research in space, many satellite and human spaceflight missions involve a wide range of national partners. For example, NASA, the US National Oceanic and Atmospheric Administration (NOAA), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), and the French National Center for Space Studies (CNES) partnered to launch OSTM/Jason-2 and Jason-3, satellites that monitor sea-level rise and track the transport of heat throughout the Earth's oceans, which can help identify where climate change is most likely to affect coastal communities.[80]

Canada's national satellites also support international scientific cooperation through contributions to specific SDG-relevant issues and instrumentation on international satellite platforms. Measurements of Pollution in the Troposphere (MOPITT), a Canadian instrument on NASA's Terra satellite, 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 their impact of human activities. SWARM, a mission led by the European Space Agency (ESA) to which Canada contributes resources, provides a new understanding of the Earth's magnetic fields. Surface Water Ocean Topography (SWOT), a satellite led by NASA to which Canada contributes, will enable a better understanding of the aquatic ecosystems and monitor life underwater. SWOT will also contribute to Canadian water management by measuring how lakes, rivers, reservoirs and oceans change over time. Soil Moisture Active Passive (SMAP) is another NASA satellite to which Canada contributes. SMAP advances the understanding of the water and carbon cycles by producing global maps of soil moisture and the freeze-thaw state of soil both in the Canadian boreal environment and globally. Soil Moisture Ocean Salinity (SMOS) is a European Space Agency (ESA) satellite which the CSA supports through science and application development. SMOS measures ocean surface salinity and soil moisture to better understand Earth's water cycle. It provides measurements over snow and ice-covered regions. Finally, Optical Spectrograph and InfraRed Imager System (OSIRIS), an instrument on Sweden's Odin satellite, 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 programs and organizations in which Canada participates.[81]

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.[82] The WMO and Coordination Group for Meteorological Satellites (CGMS) Virtual Laboratory for Training and Education in Satellite Meteorology 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, ESCAP has been working with Pacific countries and regional institutes to develop the capacity to use space technology and geographical information systems applications as crucial elements in efforts to attain universal access to disaster early warning information. ESCAP 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 service, 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 Thailand and Indonesia (UNGA, 2018).

[80] Contribution from the Government of the United States of America.
[81] Contribution from the Government of Canada.
[82] Contribution from the Government of Canada.

Leverage intergovernmental platforms for space

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

Data is 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 EO 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 the EO data providers and communities around the world. CEOS' role is to focus its activities around being a coordination body of the Space community in order to address specific issues related to satellite data. In full alignment with the intergovernmental GEO, CEOS principal role is to support the integration of satellite observations in the SDG processes for a full realisation of the 2030 Agenda on sustainable development by all countries. A dedicated group of Space Agencies under CEOS has developed a handbook that presents the main capabilities of satellite Earth observations, their applications and a systematic overview of present and planned CEOS Earth observation satellite missions and their instruments.[83]

By 2030, GEO envisions a world in which 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 Agenda, GEO envisions that the foundation has been laid for governments and organizations to capitalize fully on the benefits Earth observations provide to monitor, plan, and report on the SDGs through 2030. One of the strategic priorities of GEO is Earth Observations for Sustainable Development Goals (EO4SDG). As part of the 2017-19 Work Programme, the EO4SDG has three goals and associated objectives to realize the vision and serve the purpose described above. The goals describe overarching, desired outcomes, and the objectives articulate specific, measurable results.

- 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 SDG.
- GOAL II: Increase skills and capabilities in uses of Earth observations for SDG activities and their broader benefits.
- GOAL III: Broaden interest, awareness, and understanding of Earth observations support to the SDGs and contributions to social, environmental, and economic benefits.[84]

VI. Key questions for discussion

- What are examples of projects and/or policies in your country aimed at using space technologies for sustainable development?

[83] Contribution from the Government of Canada.
[84] Contribution from the Government of Canada.

- What are the main challenges confronted while trying to implement space-enabled projects and/or policies in your country or region?
- How are recent technological developments – including machine learning, big data, cloud computing, CubeSats, nanosats, 3D printing – impacting the availability, accessibility, and/or cost of applying space technologies for the SDGs?
- How is increased private sector involvement in space science and technology impacting the value proposition for space exploration, Earth observation, and other space applications, particularly for developing countries?
- What are the most significant bottlenecks in the use of space technologies for developing countries? Key areas to consider include lack of awareness about potential developmental benefits, technology and skills gaps, lack of appropriate and targeted financing, national policy and governance challenges, and lack of intergovernmental and/or domestic cooperation.
- What are examples of policies, projects, and initiatives aimed at promoting international research collaboration in the area of space technologies for sustainable development? What are the main challenges confronted in implementing these projects?
- What are effective forms of bilateral and regional collaboration (e.g., data sharing arrangements, joint research, capacity-building, joint launch of satellites) that enable space applications for the SDGs and/or address application bottlenecks?
- What are the actions that the international community, including the CSTD, can take to leverage the potential of space technologies for sustainable development, including through international research collaboration in this context? Can you give any success stories in this regard from your country or region?

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