Small Satellites and the U. N. Sustainable Development Goals

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> "There can be no Plan B because there is no planet B."
> – Former U. N. Secretary General Ban Ki-Moon. 2016

The Origins of Shared Global Development Goals

The phrase "sustainable development" is now a part of the common lexicon of politicians and civil society. Although one can trace the roots of this concept (at least in the West) to ideas developed in Europe concerning forest management as far back as the 17th century, it is only in the latter half of the 20th century that it became a key theme of the environmental movement, with the realization that economic systems need to fit into a common global ecological system that contains a limited pool of resources. One of the earliest modern expressions of the concept dates to the famous 1972 Club of Rome report entitled *The Limits to Growth* [1]. This study addressed the question of how long it would take to reach the limits of growth on Earth if the growth trends in world population, industrialization, pollution, food production, and resource depletion continued unchanged. For such a scenario the authors predicted a global collapse within a century. However, they also believed that it would be possible to avoid such a catastrophe by marrying economic and environmental concerns:

> *It is possible to alter these growth trends and to establish a condition of ecological and economic stability that is sustainable far into the future. The state of global equilibrium could be designed so that the basic material needs of each person on earth are satisfied and each person has an equal opportunity to realize his individual human potential.*

The same year that *The Limits to Growth* study was published, the U. N. Conference on the Human Environment was convened in Stockholm, Sweden, to consider questions concerning the environment and economic and human development. The concept of sustainable development, as it is most widely understood today, derives from the definition contained in the report *Our Common*

S. Madry et al., *Innovative Design, Manufacturing and Testing of Small Satellites*, Springer Praxis Books, https://doi.org/10.1007/978-3-319-75094-1_5

Future, commonly called the Brundtland Report, which was released by the U. N. World Commission on Environment and Development in 1987 [2].

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:*
>
> - *The concept of 'needs', in particular, the essential needs of the world's poor, to which overriding priority should be given; and*
> - *The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.*
>
> –World Commission on Environment and Development, *Our Common Future* (1987)

This definition of sustainability goes beyond environmental concerns, to a more socially inclusive and intergenerational perspective on environmentally sustainable economic growth. Indeed there are now evolving concepts of law that involve the idea of intergenerational rights.

In 1992 the first U. N. Conference on Environment and Development was held in Rio. The main outcome of this conference was "Agenda 21," a non-binding, voluntary action plan for the United Nations and other multilateral organizations and individual governments around the world that can be executed at local, national, and global levels.

On September 8, 2000, following a three-day Millennium Summit of world leaders at the headquarters of the United Nations, the General Assembly adopted the Millennium Declaration [3]. This declaration contained several political commitments that were subsequently expressed as the Millennium Development Goals, a series of eight goals with twenty-one targets to be achieved by 2015 [4]. Progress towards meeting these goals was uneven, and the international community revisited the global goals in 2015.

On September 25, 2015, the 194 countries of the U. N. General Assembly adopted the 2030 Development Agenda, entitled *Transforming Our World: The 2030 Agenda for Sustainable Development* [5], which has five pillars: people, planet, prosperity, peace, and partnerships. The agenda contains 17 Sustainable Development Goals (SDGs) and 169 targets associated with those goals. The 17 SDGs are designed to "transform our world through ending poverty, protecting the planet and ensuring prosperity for all." The goals, which must be achieved by 2030, include: eradicating poverty and hunger; promoting good health, quality education and gender equality; clean water and affordable energy; decent work and economic growth; sustainable cities and economies; climate action; peace, justice and strong institutions; and strengthening the global partnership for sustainable development. Fig. 5.1 illustrates the SDGs.

The United Nations, Space, and Sustainable Development

From the earliest days of the Space Age, the United Nations has been at the forefront of utilizing space for development.

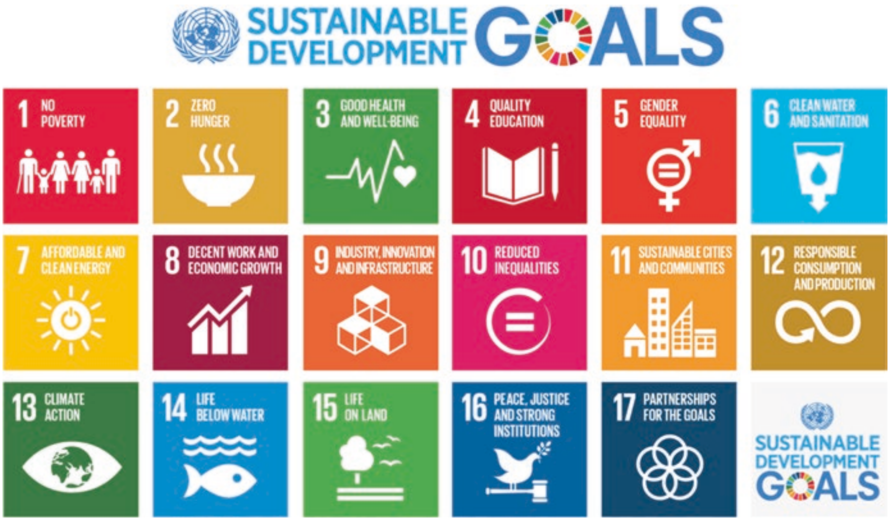

Fig. 5.1 Sustainable Development Goals (SDGs) adopted by the United Nations in September 2015

The Space Age had its origins in the midst of the Cold War, and there was an appreciation by the international community that the intense rivalries between the superpowers could either be extended to the space domain with grave risks for humanity, or that the exploration and use of outer space could be carried out for the benefit of all humankind.

In 1958, just one year after the launching of the first artificial satellite, the U. N. General Assembly in its resolution 1348 (XIII) established an ad hoc Committee on the Peaceful Uses of Outer Space (COPUOS), comprising 18 member States, to consider questions relating to the peaceful uses of outer space, organizational arrangements to facilitate international cooperation in this field within the framework of the United Nations, and deal with legal problems that might arise in the exploration and use of outer space. In 1959, the General Assembly established COPUOS (whose membership had by then grown to 24 member States) as a permanent body and reaffirmed its mandate in resolution 1472 (XIV). Since then, COPUOS has been the principal international body dealing with matters of international cooperation in the peaceful exploration and use of outer space. Since its establishment in 1959, the membership of COPUOS has grown at a steady pace, and it currently stands at 84 members. This large and growing membership strengthens COPUOS' role as the preeminent multilateral body for discussions on space cooperation, and this is particularly pertinent in the area of sustainable development, which requires concerted global action to meet the SDGs.

Throughout its almost 60-year existence, COPUOS has addressed applications of space relevant to sustainable development and the SDGs. It has done so through the medium of technical presentations by member States as a means of information exchange, through the organization of workshops and conferences, through the organization of training programs and internship programs, and multiple other activities falling under the U. N. Program on Space Applications, which has been operational since 1971. One of the key outputs of this program for developing nations has been a set of educational curriculum resources, developed by the U. N. Office for Outer Space Affairs in cooperation with the U. N.-affiliated Regional Centers for Space Science and Technology Education [6]. These curricula cover: Remote Sensing and Geographical Information Systems; Satellite Communications; Satellite Meteorology and Global Climate; Space and Atmospheric Sciences; Space Law; and GNSS. A curriculum on Basic Space Technology is currently under development.

In recent years, the U. N. Basic Space Technology initiative (UN-BSTI) has been promoting capacity building in the field of small satellites through a series of workshops that have been held in developing countries around the world [7]. The United Nations has also brokered internships and launch opportunities with leading space agencies for developing nations to become space actors through building and operating small satellites. The goal of the U. N.-BSTI is to assist developing countries to establish indigenous capacities in space science and technology. It also promotes international cooperation among various actors in the small satellite community, the use of standards, and adherence to international regulatory frameworks.

The United Nations has also played a leading role in promoting international cooperation in the use of space technology to address humanitarian and environmental concerns. The major space powers and large commercial entities have availed their assets on orbit to support such activities many times in the past. Normally these have involved conventional (i.e., "large") satellites, but the growing capability of small satellites is now making it possible to augment, in a meaningful way, space systems that support sustainable development. These capabilities have been discussed elsewhere in this book, but some pertinent and specific examples are useful to note here.

When Hurricane Katrina made landfall in New Orleans on August 29, 2005, it wrought devastation on a huge scale. To get an overview of the damage, disaster response coordinators needed satellite imagery, and the first picture received was from the Nigerian satellite NigeriaSat-1 [8], a 100-kg satellite built by Surrey Satellite Technology Ltd. in the UK, and operated as part of the Disaster Monitoring Constellation. This anecdote highlights three points: (i) small satellites are now capable enough to address real developmental issues; (ii) this technology is now in the hands of a growing number of developing nations; and (iii) the private sector is playing a key role in rolling out this technology to new space actors.

Although the cost per kilogram of launching a satellite into space has not changed greatly over the past two decades, the capability per kilogram launched into orbit has grown tremendously. This increase in capability is due to advances in electronics, sensors, IT, and data analytics. As noted earlier it has led to a game-changing revolution in geospatial technology applications, and the next breakthrough area now pending appears to be with small constellations providing networking and digital telecommunications services. Yet other applications will undoubtedly follow. This means that small satellites are now able to support some of the objectives of the SDGs, and developing countries may be able to leverage off of this capability to meet their own national SDG implementation plans. This does not mean that small satellites will be able to do everything in space, but their supplemental role is growing. And ironically, there are environmental and sustainability concerns about the proliferation of small satellites in space in terms of orbital space debris. These caveats must be born in mind as consideration is given to the possible role that small satellites can play in supporting the SDGs.

The U. N. Sustainable Development Goals (SDGs)

Goals 1 and 2: Ending Poverty and Hunger

Approximately 900 million people in developing countries live on $1.90 a day or less. In the two decades following 1990, the number of people living in poverty was reduced by almost half, but food price increases could swiftly reverse these gains. Poverty, food prices, and hunger are inextricably linked. Not every poor person is hungry, but almost all hungry or malnourished people are poor. Hunger is the most severe and critical manifestation of poverty. Millions of people live with hunger and malnourishment because they simply cannot afford to buy enough food, cannot afford nutritious foods, cannot afford farming supplies to grow their own food, or live in areas where severe environmental conditions – often driven by climate change – limit agricultural production.

Globally, 1 in 9 people are undernourished [9], and the vast majority of these people live in developing countries. Poor nutrition causes 45% of deaths in children under five – approximately 3.1 million children die each year. Addressing SDG Goal 2 to end hunger also indirectly addresses Goal 1 (ending poverty), because agriculture is still the single largest employer in the world, providing livelihoods for 40 percent of the world's population. It is the largest source of income and jobs for poor rural households.

The world's agricultural land comprises 49 million $km,^2$ about 37.5% of the total land surface of Earth. Satellites can provide timely and reliable information on the development and condition of crops and help to improve crop yields by allowing farmers to make better-informed decisions about when to water, fertilize, and harvest their crops.

Already, small satellites developed by Planet are providing rapidly repeating images of agricultural regions and providing rapid access to these data, see Fig. 5.2 below. So the data to support agriculture is much more readily available. The challenge is now to develop affordable access to the data and applications to provide useful information to farmers on the ground, especially in developing countries.

Goal 3 Good Health and Well-Being

Many of the world's people living in rural areas do not have local access to high-quality health. A visit to a

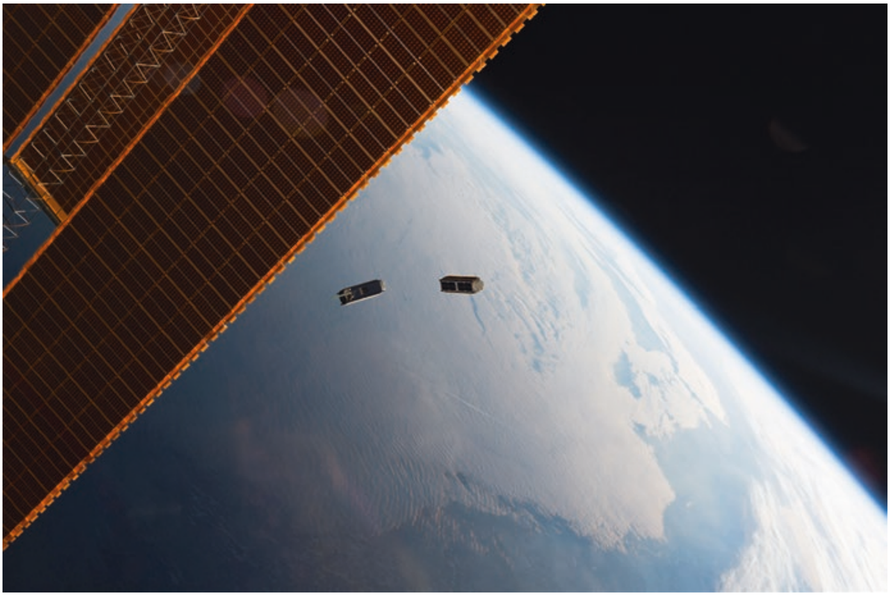

Fig. 5.2 Two of Planet's 3-unit Dove satellites shortly after deployment from the NanoRacks Cubesat Deployer on the International Space Station on May 17, 2016. (Image courtesy of NASA. Source: https://www.nasa.gov/image-feature/cubesats-deployed-from-the-international-space-station)

specialist requires a lengthy and costly journey to a city that the patient may simply not be financially or physically capable of undertaking.

Small satellite constellations, such as those envisaged by OneWeb, could expand the availability and cost-effective delivery of telemedicine services to remote locations. Such capability could greatly broaden patient access to medical expertise normally only available in tertiary hospitals. Also, by allowing specialists to support rural doctors to treat their patients in situ, small satellite constellations could relieve pressure on the tertiary hospitals in the main cities. In should be noted, however, that new high throughput satellites of larger size might be able to provide similar capabilities.

These expanded satellite capabilities as well as new ground systems – such as those that use metamaterials to create electronic beams that track non-Geo satellites at low cost – could create many new telemedicine services. This might include, for instance, live video teleconsultations, supported in real time with clinical data. Medical information and alerts could also be distributed more rapidly to remote clinics and hospitals. Patient record keeping could also benefit from improved communications provided by small satellite constellations. Such new space capabilities would enable the establishment of national systems of managing patient medical records. These new space-based capabilities might even include inventory control in remote clinics for more rational and efficient delivery of medical supplies, or for monitoring fluctuations in demand for certain medicines in an area. Such capabilities could provide early warning of the spread of certain diseases.

Goal 4: Quality Education

The 2nd Millennium Development Goal was the attainment of universal primary education by 2015. Indeed, significant progress was made to improve education access during the 2000s, specifically at the primary school level, for both boys and girls. However, access to schools does not imply anything about the quality of education, or completion of primary schooling. Many developing countries face challenges with regard to the provision of quality education to learners, especially in rural areas that find it difficult to attract and retain the best educators.

The promise of satellites to support education was already realized many years ago, but the technological support requirements on the ground posed a challenge in terms of implementation. During the 2000s India demonstrated a very successful, large-scale roll-out of tele-education to thousands of schools with its geostationary EduSat program. China, through its national television university that began with demonstration projects in 1987 using Intelsat satellites that were transferred to the Chinasat to service some 90,000 villages, has also been quite successful. Similar success in Indonesia, Thailand, Malaysia, Nigeria, and many other countries have proven that tele-education via satellite networks can be successful.

That experience was successful because of the investment in the educational infrastructure on the ground and the close integration of the space and educational communities. The technological barriers have been considerably lowered in the past ten years, making it now much easier to implement satellite-aided tele-education in the classroom, as well as self-learning supported by Internet access. In short, Internet based tele-education programs via small satellite constellations, which have been optimized for data networking in rural and remote areas, offers many new opportunities.

The envisaged LEO communications satellite constellations could potentially be used to make excellent quality educational materials accessible to every child in a country, no matter where that child lives, or his or her socioeconomic level. Such programs could potentially raise the general educational level of rural communities in the sense that education is not confined to school-age children, but can also take the form of an adult education program that could be delivered through schools, community centers, and libraries (see Fig. 5.3 below).

Addressing the provision of quality education also addresses an important aspect of Goal 1 (ending poverty) because poor education is one of the factors that can lead to being trapped in a cycle of poverty.

Goal 5: Gender Equality

Women and girls represent half of the world's population and therefore also half of its potential. It has been proven, time and again, that empowering women and girls has a multiplier effect that helps drive economic growth and development across the board. Therefore addressing gender inequality is crucial to accelerating sustainable development.

The inspirational power of space to attract young people into science, engineering and technology careers is well known. Girls and young women are just as inspired by space as their male counterparts, but they often lack access to

Fig. 5.3 A ground-station for OneWeb satellites pictured on the roof of a rural school. (Image courtesy of OneWeb)

opportunities or they do not receive encouragement from role models that they can relate to. In some places girls are even actively discouraged from taking mathematical subjects in high school, which excludes them from many career options in science and engineering.

A fact sheet on Women in Science published by the UNESCO Institute of Statistics in 2017 [10] showed that women accounted for less than a third (28.8%) of those employed in scientific research and development careers across the world. This imbalance is greatly exacerbated in developing countries.

Small satellite activities bring the exciting realm of space science and technology within reach of non-governmental organizations that promote greater participation of girls and women in science and technology. One such example is the South African NGO MEDO that specializes in STEM education for school-age girls. This organization has taken advantage of the ready availability of commercial off-the-shelf cubesat components to support a team of young female high-school students to build a cubesat. Students who graduate from the MEDO program are inspired by their encounter with space to consider scientific and technical careers. The following quote by one of their graduates, now studying electrical engineering, is telling: “I feel inspired. I never imagined a girl from a township doing these big and amazing things, learning from world-renowned astronomers.” See Fig. 5.4 below [11].

Goal 6: Clean Water

The aim of Goal 6 is to mitigate urban water challenges, ensure access to basic safe and affordable potable water and

Fig. 5.4 Schoolgirls learning to solder electronic components in one of MEDO's STEM programs. (Image courtesy of MEDO)

sanitation services, and to improve the treatment of waste water. In water-stressed regions, the objectives of Goal 6 can become contentious political issues. Inadequate access to clean water can affect public health, undermine economic performance, and even lead to conflict over access to limited water resources. Small satellites can introduce transparency and public accountability in the area of water resource management. They also provide an affordable means for developing nations to monitor water quality over very wide areas.

There are two ways in which small satellites can support Goal 6. The first is through remote sensing of water bodies, and the second is through relaying in-situ measurements from remote sampling locations.

Remote sensing with satellites enables broad and efficient monitoring of reservoir water levels, providing early warning of shortages and uniform data across different countries that share water sources, and increasing transparency and consistency in water delivery. Earlier in this chapter the point was stressed that the capability per kilogram on orbit has increased dramatically in recent years. The 2-unit cubesat mission called SWEET (Sweet Water Earth Education Technologies) has been proposed by the Technical University of Munich. This small satellite would take advantage of developments in the miniaturization of sensor technology to address the question of whether water quality measurements using a hyperspectral camera might be possible with a cubesat [12]. The objective of SWEET is to monitor 62 freshwater lakes in Africa, which are a source of drinking water to millions of people, with an average revisit time of 3.5 days. The precursor mission, envisaged to be launched from the ISS, could validate the mission concept and technology. An operational system would need a constellation of four satellites placed in a

Sun-synchronous orbit with an initial altitude of around 650 km.

Remote sensing is extremely useful but should be complemented with in situ measurements, especially for determining water quality. Water quality monitoring by water management agencies using conventional ground-based methods is labor intensive and costly, limiting sample collection over temporal and spatial scales. Even for well-resourced agencies, water collection stations may represent only a small percentage of the spatial extent of the water bodies under their management. Samples taken on any given day may not adequately represent the water quality of that location over a week, month, or season. This is where continuous monitoring becomes helpful. One such system, proposed for Tunisia, combines in situ water quality sensors placed in waterways and water bodies with cubesats being used as store-and-forward data relays [13].

Goal 12: Responsible Consumption and Production

Decoupling economic growth from the use of non-renewable natural resources is fundamental to sustainable development. Consumption of non-renewable resources is also directly linked to greater air, soil, and water pollution, which diminishes the capacity of Earth to sustain its growing population. Goal 12 is about ensuring sustainable consumption and production practices.

This goal is linked to a number of other SDGs, and much of what is written about the applications of small satellites to those goals applies here as well. The proliferation of small Earth observation satellites has two effects that pertain to Goal 12, namely making it much harder to conceal irresponsible production and consumption behaviors, and making it much cheaper to monitor large areas to find and document irresponsible consumption and production practices. For example, in arid regions, satellites can be used to expose violations of water quotas by water users.

In April 2016, the U.N. Food and Agriculture Organization (FAO) and Google entered into an agreement to cooperate on using satellite imagery to better manage the world's agricultural resources. In February 2017, Planet acquired Terra Bella from Google. Under the terms of this acquisition agreement, Planet now operates the seven Skysat high-resolution (<1-m) microsatellites, in addition to its own in-house developed fleet of 150-odd medium-resolution (3-5m) Dove satellites. This has created a powerful and unprecedented capability to support the objectives of Goal 12 with small satellites.

Goal 14: Life Below Water

Earth's oceans are under threat from pollution, overfishing, and the effects of global climate change. Billions of people on Earth are dependent on the oceans for their livelihoods and nutrition. Therefore any threat to the Oceans is a direct threat to sustainable development. Sustainable Development Goal 14, *Conserve and sustainably use the oceans, seas and marine resources,* addresses these threats.

Small satellites are playing a significant role in addressing aspects of Goal 14. One key area is that of maritime domain awareness. Many developing countries face the problem of illegal, unreported, and unregulated fishing within their exclusive economic zones by foreign commercial entities that can "out-fish" the locals, because of their superior vessels and technology.

As many of these illegal fishing activities occur far from coastal waters, they are invisible to maritime surveillance capabilities based along coasts. However, few countries have the resources to patrol and investigate suspicious activities over very large expanses of ocean. These gaps in surveillance allow such illegal activities to proceed unchecked, with grave humanitarian and environmental consequences. It is estimated by the FAO that illegal, unreported, and unregulated (IUU) fishing represents a theft of around 26 million tons, or close to $24 billion value of seafood a year. However, IUU fishing has broader social, economic, and security impacts as well. Illegal trawling off the Horn of Africa for decades has been identified as a significant contributing factor to the emergence of piracy in Somalia.

Small satellites are playing a huge role in supporting maritime domain awareness by serving as platforms for Automatic Ship Identification (AIS) systems that allow information to be gathered about vessels and their patterns of activity. Space-based AIS was pioneered in the mid-2000s, initially with microsatellites, such as those built by Orbcom and Aprize Satellite, but with time the technology has been ported to smaller and smaller platforms. The AISSat-1 was a 6-kg satellite developed for the Norwegian Space Center in 2010 as a development project that subsequently entered into operations for the Norwegian coastal management authorities [14]. In 2014 the satellite was supplemented with AISSat-2 and from 2015 by AISSat-3. A more recent entrant in the satellite AIS domain is Spire Global, a private company that was established in 2012 and which to date has launched some 50 of its Lemur series of 3-unit cubesats that now form a constellation providing access to over 1 million AIS messages per day, see Fig. 5.5 below.

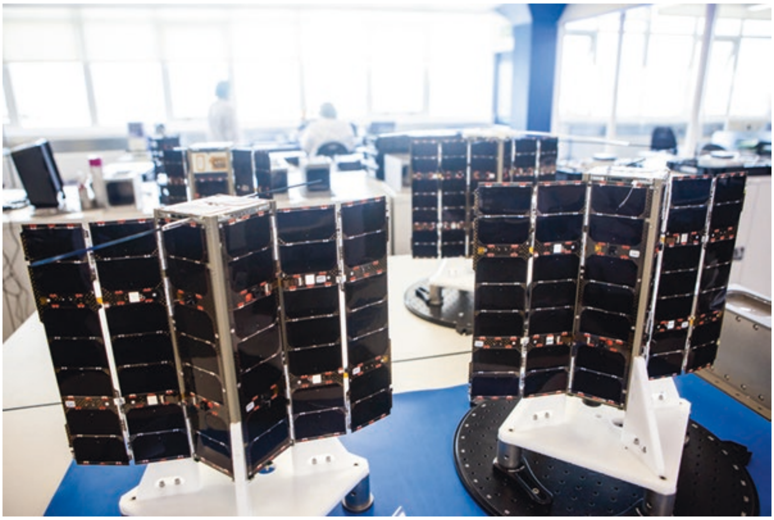

Fig. 5.5 A group of Spire's Lemur satellites undergoing testing. (Image courtesy of Spire)

Small satellites are also being used to monitor ocean color, which can reveal the presence of suspended particulate matter, plankton concentrations, and pollution. For example, observations acquired with the Algerian microsatellite AlSat-1 have been used to model suspended particulate matter along the Algerian coast [15].

The SPectral Ocean Color (SPOC) Small Satellite Mission is a 3-unit cubesat under development at the University of Georgia. The primary mission objective of the SPOC satellite is to acquire moderate resolution imagery in several spectral bands ranging from 400 to 900 nm to monitor coastal wetland status, estuarine water quality, and near-coastal ocean productivity. The SPOC satellite was selected by NASA's Undergraduate Student Instrument Project and its Cubesat Launch Initiative to be built in 2016-2018 and launched in the 2018-2020 timeframe [16].

Goal 13: Climate Action

One of the predicted consequences of global climate change is that extreme weather events will become more frequent and more intense. Goal 13 encourages the world to take urgent action to combat climate change and its impacts. As the world faces the possibility of having to deal with more disasters, satellites will increasingly contribute to supporting disaster management.

There are many examples of the use of small satellites to support disaster management. As already stated NigeriaSat-1 was the first satellite to image New Orleans after Hurricane Katrina struck in 2005. That satellite was operated as part of the Disaster Monitoring Constellation for International Imaging (DMCii). The overall constellation comprises a number of remote sensing satellites constructed by the British company Surrey Satellite Technology Ltd. (SSTL) and operated for the Algerian, British, Chinese, Nigerian, Spanish, and Turkish governments by DMC International Imaging (DMCii). The DMC is a private sector member of the International Charter for Space and Major Disasters, under which it contributes imagery free of charge to disaster-affected countries.

Currently in its second generation, the DMC satellites have a 650-km-wide swath with a 22-m GSD. The multiple satellites in the constellation give DMCii the ability to image any point in the world on a daily basis. The DMC illustrates nicely how a constellation of small satellites can collectively provide capabilities that complement those of larger, more expensive satellites. The DMC satellites have also served as a springboard for several countries to start their own national space programs.

Goal 15: Life on Land

Forests cover 30 percent of Earth's surface and are home to more than 80 percent of all terrestrial species of animals, plants, and insects. Around 1.6 billion people depend on forests for their livelihood. This includes some 70 million indigenous people. Deforestation and desertification, caused by human activities and climate change, pose major challenges to sustainable development and affect the lives and livelihoods of millions of people. Thirteen million hectares of forests are being lost every year, while the persistent degradation of dry lands has led to the desertification of 3.6 billion hectares. Deforestation and forest degradation results in the destruction of habitats for many species, soil erosion, decrease in freshwater quality, and higher carbon emissions into the atmosphere.

The objective of Goal 15 is to manage forest in a sustainable manner, combat desertification, halt and reverse land degradation, and halt biodiversity loss. Often the earliest indications of these phenomena manifest in very remote regions of the world. Earth observation satellites enable global monitoring of patterns of deforestation and desertification. It appears that the pace and scale of changes is increasing faster than in the past, so having more monitoring capability that is more widely accessible will place more information in the hands of the public, who can then influence policy makers to address these issues. The advantage of small satellites is that there are now many more "eyes in the sky," making it much harder to conceal illicit activities and easier to expose corrupt government practices that allow rapacious industrial activities to occur in forests that ought to be protected.

Already, the Planet constellation allows daily monitoring of the world's forests that enables early detection of illegal logging and allows regular assessments of the health of forests. In addition, a number of nanosat missions are under development to study forests. CaNOP (Canopy Near-IR Observing Project) is a 3-unit cubesat mission under development at Carthage University in Wisconsin, USA, to provide hyperspectral imaging of forests to study biomass production and carbon uptake in mature and harvested forests. CaNOP was selected in 2016 by NASA to be launched as part of the agency's Educational Launch of Nanosatellites (ELaNa) initiative in 2018. The Kalam mission is a 10-kg nanosat under development by students at the National Institute of Technology Rourkela in India to observe deforestation, biodiversity loss, and land damage caused by open-cast mining operations.

Goal 16: Peace, Justice, and Institutions

Corruption and poor administration have the potential to undermine sustainable development in many ways. The extent to which they actually do so depends on the strength and integrity of national and international institutions. Part of Goal 16 is about building effective, accountable, and inclusive institutions.

Because small satellites can now be accessed (and even owned) by civil society organizations, they can improve transparency and the building of strong democratic institutions by making it much, much harder to conceal human and environmental abuses.

The Eyes on Darfur project was implemented by the NGO Amnesty International in 2007 with the objective of exposing a brutal genocide in Sudan through procuring satellite data from commercial operators. Ironically, the project may actually have led to an escalation of human rights violations, as the Government of Sudan retaliated against the monitored communities in an effort to shut down the project and deter other groups from involvement in the Darfur region [17]. Although the reaction of the government was disappointing, it does show that even brutal aggressors are sensitive to open international exposure of their activities. This is a case where evidence gathered by satellites needs to be used to secure convictions in international courts of justice.

According to the Satellite Industry Association, 51% of the 126 satellites launched in 2016 were non-military Earth-observing satellites [18]. This number (down from the 2015 figure) received a huge boost with the launch of another 88 Dove satellites by Planet in February 2017. As companies such as OneWeb extend more robust broadband connectivity to the entire globe using large networks of small satellites in low Earth orbit, it will also be easier to get news and images out of remote conflict areas, such as, for example, election-related violence.

Conclusion

Despite all the challenges posed by small satellites to the long-term sustainability of the space environment, particularly with regard to the proliferation of orbital space debris, they also hold out great promise to support the attainment of the Sustainable Development Goals by 2030. The key word in both contexts is sustainable, underpinning the fact that, increasingly, human and environmental security on Earth is underpinned by safety and security in outer space.

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