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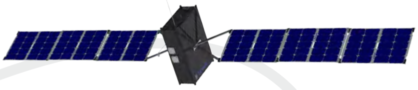
SMALL SATS BIG SHIFT

RECOMMENDATIONS FOR THE GLOBAL SOUTH

2017
White Paper
Southern Hemisphere
Space Studies Program

ACKNOWLEDGEMENTS



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PREFACE

Faculty's Preface

As we write this preface at the end of the five-week Southern Hemisphere Space Studies Program, we have seen how a group of 39 participants representing five continents has bonded into a team of promising space sector professionals. They have accomplished the challenging mission of publishing this White Paper and are set to promote it through conferences and communication channels around the world.

Participants were requested to research and report on the potential implications of the small satellite revolution for the countries of the Global South. How can developing space nations take advantage of this dramatic change to maximize the social and economic benefits for their citizens? Starting with a pre-arrival assignment on the topic, and through on-site lectures, workshops, individual research, brainstorming sessions, many group discussions followed by long writing and editing hours, and a peer review, the team has produced what we see as a comprehensive report with sensible recommendations targeted for a variety of decision makers.

We believe that the paper will have a positive influence on thinking; we are very satisfied with the "revolution" that has happened on the Mawson Lakes campus of the University of South Australia; all program participants will return to their homes as ambassadors of the vision set out by the founders of the International Space University in 1987: a peaceful, prosperous and boundless future through the study, exploration and development of space for the benefit of all humanity.

Author's Preface

The Small Satellite Revolution will be a historic landmark due to its widespread impact on almost every aspect of human life: work, education, health, security, and communication. It offers the possibility for a better and more sustainable life for us all.

Small Sats, Big Shift is a comprehensive and thought provoking White Paper that discusses the benefits that small satellites can offer to the Global South. The White Paper was prepared by a dedicated and multidisciplinary team of participants with diverse academic, professional, and cultural backgrounds. This White Paper was the result of long hours of intensive research and discussions, with the goal of producing an extensive overview of the small satellite landscape in order to aid decision makers in socio-economic and policy matters. Local, regional and national governments, private companies, non-government organizations, universities, and entrepreneurs are invited to use this White Paper as a reference for future projects and studies.

This White Paper was made possible through the dedication and support of our program faculty, staff, teaching associates, host university, and sponsors. We are very grateful to you all.

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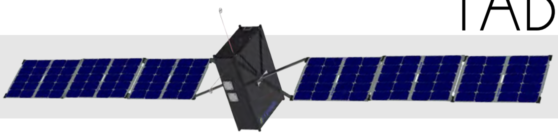


Mission Statement

To demonstrate how nations of the Global South can leverage the Small Satellite Revolution for socio-economic benefit.

The last two decades have seen a rapid increase in the popularity of small satellites. In the next five years, potentially 3000 small satellites will be launched to replace or augment existing satellite operations (Facchinetti *et al.*, 2016). The low cost and capacity for mass production of small satellites make them an ideal platform for emerging space nations to build their capabilities in the space industry. The versatility in small satellite applications paves the way for improvements in education, health, communications, agriculture, and disaster management.

Small Sats, Big Shift addresses the potential of small satellites to shape the socio-economic environment of the Global South. The goal of this White Paper is to inform decision makers of the benefits of harnessing this small satellite revolution. Through the lens of the Global South the issues of national security, crisis management, telecommunications, and resource management have been identified as key socio-economic targets for small satellite applications in this region.

Why Small Satellites?

The development of small satellites represents a shift in the traditional space industry model. Compared to conventional large satellites, small satellites are manufactured at a lower cost and within a shorter time period. They provide not only comparable services but also new functions that larger satellites cannot perform. They carry less risk per launch and can be updated and replaced at a much quicker rate. Small satellites also offer the opportunity to test new technologies. Their rapid development cycle enables operators to keep the latest technology in orbit for a fraction of the cost of launching larger satellites. These cycles allow the pace of innovation to accelerate, and for new and useful technologies to be developed more cheaply. Low capital requirements also allow owners and operators access to alternative forms of financing (Whitesides, 2015). Consequently, small satellites are an ideal platform for emerging space nations, capable of delivering services similar to larger satellites at a lower price and allowing nations of the Global South access to space. While there is no widely agreed upon definition for 'small satellite', for the purposes of this White Paper, our definition is: any satellite with a mass of less than 500 kilograms as per Facchinetti *et al.*, (2016). This definition encompasses a variety of small satellite categories, as outlined in Figure 1.

The Global South

In the context of this paper, the nations of the Global South are defined as countries lying on or below the Tropic of Cancer, covering the four major regions of the Southern Hemisphere: Africa, Asia, Oceania, and Central and South America. Many of these nations are considered emerging economies and would benefit greatly from small satellite industry services.

To encourage the nations of the Global South to invest in the small satellite industry, this White Paper provides real-world examples of how players from the industry, government and education sectors have successfully leveraged the exponential growth of this technology. The paper recommends courses of action for members of academia, governments, and private companies across a range of budgets. Recommendations are focused on promoting actions that may result in socio-economic benefits, such as the creation of jobs and businesses, enabling innovation, supporting economic growth, and promoting Science, Technology, Engineering, and Mathematics (STEM) education.

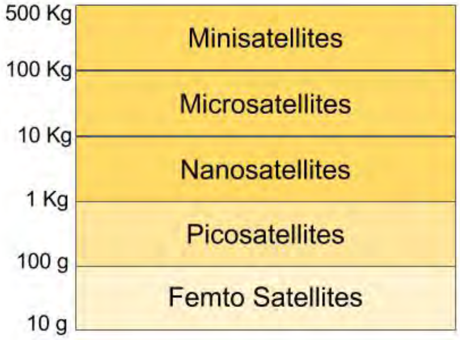


Figure 1. The different classes of small satellites.

SMALL SATS, BIG REVOLUTION

The small satellite industry is experiencing rapid and accelerated development across ground, space, and launch segments; a phenomenon that is being called the Small Satellite Revolution (White House, 2016). This revolution has seen 28 micro and nanosatellites launched in 2008, 141 in 2014, and 3000 are predicted to launch between 2016 and 2021. Since the 1990s the traditional space paradigm of large, expensive satellite projects, backed by government investment, has shifted with the rise of commercial companies making access to space cheaper and easier. While the number of large satellites (>500kg) being launched each year has remained relatively constant, small satellite interest has increased with small satellites constituting 48% of the 262 spacecraft that were launched in 2015 (Facchinetti *et al.*, 2016). No longer is space purely the domain of governments and large space agencies. Off-the-shelf and miniaturized technologies have made it possible for small satellites to be used by emerging space countries with modest financial resources or little satellite expertise (Sandau, 2010).

The Small Satellite Revolution is being driven by several key trends across the various segments:

- At the **ground segment,** there is greater involvement between industry and governmental agencies as well as development of small ground station networks connected by rapid data distribution methods.
- In the **space segment**, miniaturization of electronic components and the development of what is considered standard, off-the-shelf components, are allowing technologies traditionally limited to large satellites to be flown on small satellites for a fraction of the cost. Consequently, there is a shift from large satellites carrying multiple scientific instruments for multi-purpose missions to targeted small satellite missions focused on a single application or scientific mission.
- Within the **launching segment,** increased commercialization of space is resulting in the emergence of cheaper, smaller launching options for small satellites (Sandau, 2010) as illustrated in Figure 2.

Small satellites are typically launched into Low Earth Orbit (LEO), an orbit which places the satellites in a region of space susceptible to atmospheric drag (Kingsbury, 2015). As a result, small satellite orbits decay quickly and this short lifespan drives rapid development and replacement cycles. This generates continual demand for cheaper satellites and launch vehicles, as well as ensuring the technology operating in orbit is up-to-date (Whitesides, 2015). The small satellite industry is seeing unprecedented investment, with development, launch, and operation of small satellites rapidly increasing. Commercial space is helping to redefine the industry and the increasing market is allowing mass reductions in unit costs while improving the reliability and innovation of small satellite technology (Sandau, 2010).

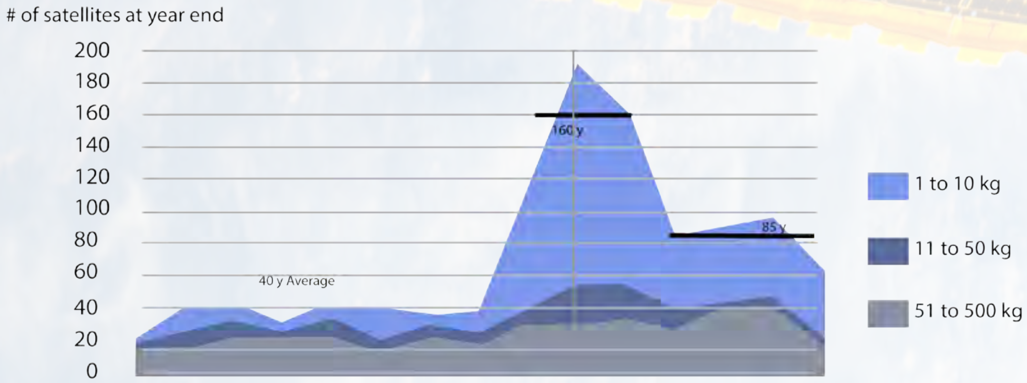
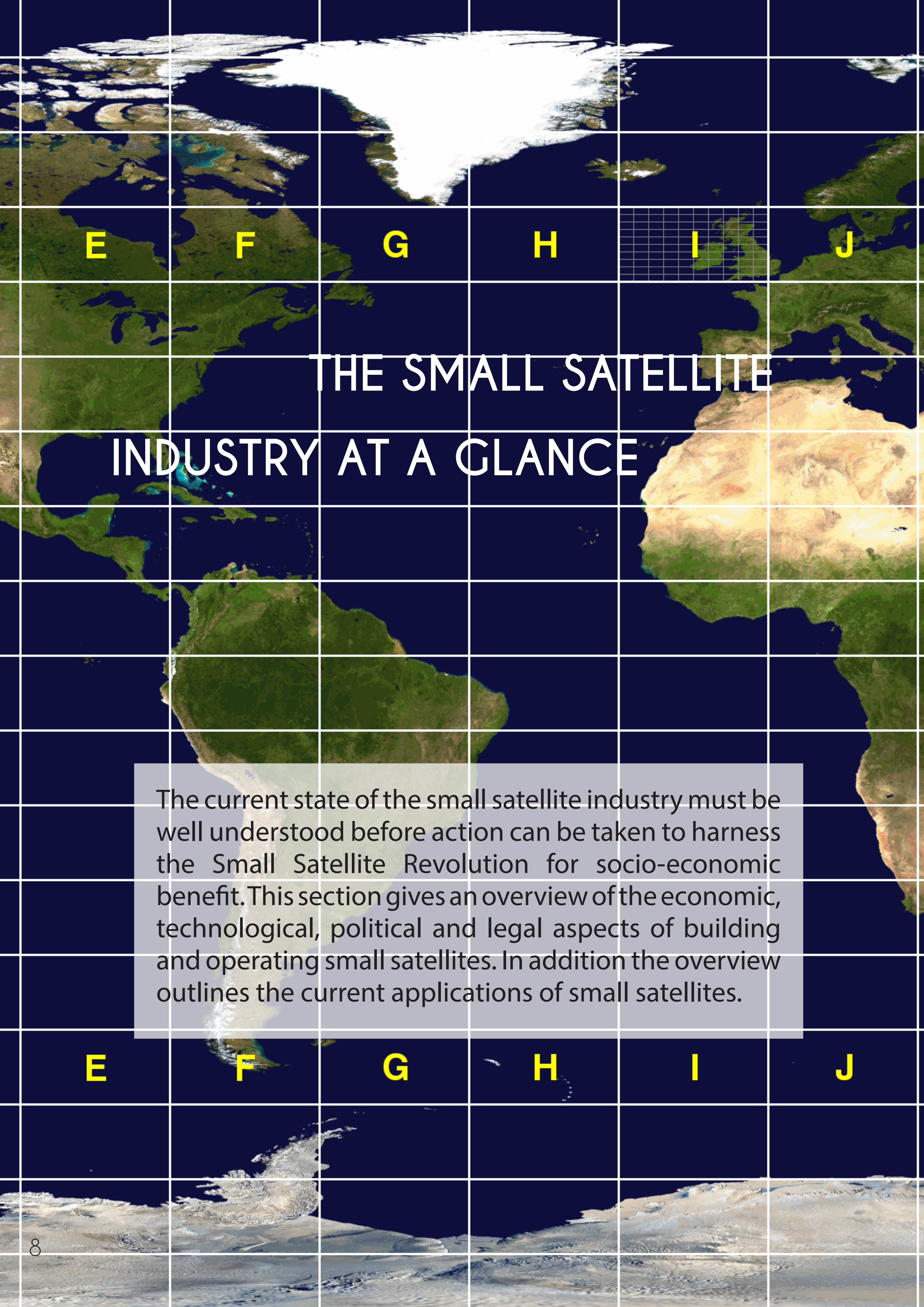


Figure 2. Number of satellites currently in orbit and predicted to be in orbit by 2019 (Pham et al. 2015)



THE SMALL SATELLITE INDUSTRY AT A GLANCE

The current state of the small satellite industry must be well understood before action can be taken to harness the Small Satellite Revolution for socio-economic benefit. This section gives an overview of the economic, technological, political and legal aspects of building and operating small satellites. In addition the overview outlines the current applications of small satellites.

The Small Satellite Market

Market research projects the small satellite industry will grow at a compound annual growth rate of 19.1% from 2016 to 2021. Revenues are expected to more than double from US$2.2 billion to US$5.3 billion in the same period (Markets and Markets, 2016). 3000 micro- and nanosatellites are predicted to launch between 2016 and 2022. This will drive industry growth (Facchinetti *et al.*, 2016). Figure 3. demonstrates the segmentation of the space economy and displays the many sectors that will benefit from this growth.

Small Satellite Technology

Small satellites do not uniformly use standard technology given their variations in size and applications (see *Applications of Small Satellites*). Typically, small satellites use either miniaturized technology derived from larger monolithic satellites or standard off-the-shelf components (Sandau, 2010). However, this White Paper focuses on launching technologies, standardization, and application of satellite constellations rather than the specific technologies used in-orbit to inform its case studies and recommendations.

Launches

Small satellites are typically launched as secondary payloads on large satellite launch vehicles (LV), using auxiliary payload adapters (Sandau, 2010). One example is Spaceflight Launch Services, which offers rideshares into LEO for small satellites for a cost of $35K/kg for a 50kg satellite (Facchinetti *et al.*, 2016). However, the increase in demand of small satellite launches is beginning to outpace supply of free payload space onboard LVs. In response, companies are beginning to design dedicated launch services for small satellites (Selinger, 2016). While these do not significantly reduce the cost-per-kilogram of launch (these range from $20K/kg to $60K/kg), they do allow a faster launch cycle (Doncaster, 2016; Facchinetti *et al.*, 2016).

CubeSat Standardization

An important small satellite class to understand is the CubeSat. Developed by California Polytechnic State University (Cal Poly), the CubeSat standardization provides design guidance for small satellites to “reduce cost and development time, increase accessibility to space, and sustain frequent launches” (Cal Poly, 2014, p. 5). This standard applies only to picosatellite class, with dimensions of a 10cm cube, and a mass up to 1.33 kg. Standardization of this type is important to not only satellite design and manufacture, but to the decision making for support services, such as launch vehicles.

Constellations

While cheaper to develop and launch, the reduced size and mass of small satellites means that they cannot support the sophisticated and often multi-instrument payloads of larger satellites (Zhang and Anvar, 2011). However, their reduced size and cost makes them ideal for constellation flight. Constellation flight means a set of simultaneously orbiting satellites all assisting the completion of a common mission. The lower cost of small satellites makes constellations economically viable and opens up capabilities not available to larger satellites for a comparable budget.

Small satellite constellations have a number of benefits over single, larger satellites. The temporal resolution of imaging satellites directly increases with the number of satellites in the constellation. While the observing time for an imaging satellite in LEO is only a small fraction of the orbital time, utilizing a constellation of numerous satellites can produce continuous imaging capabilities. Constellations of small satellites are also more resilient. If a single member of the fleet is damaged it can be cheaply and easily replaced. Additionally, failure in one satellite does not significantly impact the entire mission performance (Sandau, 2010).

Policies Relating to Small Satellites

Policies are a nation's framework for action. They state precisely what must be done to realize a solution and assign responsibility for the action to a particular individual or group. The generation of good policy is crucial as it allows for efficient administration and provides a clear direction towards a given goal (University of Sydney, 2016). Policy is therefore a key component when decision-makers consider the small satellite industry and how best to use it for socio-economic gain.

Policies that address small satellites tend to be implicitly defined by other, broader policies, rather than explicitly in their own policies. The Australian Space Utilisation Policy, for example, stated that it "recognise[d] the opportunities presented by small satellites" but did not give specific guidance towards their use (Commonwealth of Australia, 2013, p.11).

Legal Considerations

International Laws and Treaties

International law is a set of rules that govern the relations between different states (United Nations, n.d.). Regarding the use of space, there exist four treaties that may affect small satellites activities:

- The 1967 Outer Space Treaty (OST)
- The 1968 Return and Rescue Agreement
- The 1972 Liability Convention
- The 1976 Registration Convention

The International Telecommunication Union (ITU) and the United Nations Office on Outer Space Affairs (UNOOSA) has produced guidelines for small satellite operators to ensure that international obligations are met by new entrants into the space industry UNOOSA, 2015, p. 2).

According to the Outer Space Treaty, a launching state will bear liability for any damage caused internationally by the space object launched under their jurisdiction (UNOOSA, 2015, p. 3). A launching state is defined as a state who launches or procures the launch of a space object, as well as the state from whose territory or facility a space object is launched (OST, Article VII, 1967, Liability Convention, Article I, 1971). Due to their need to share capabilities, small satellite launches are often international in nature and so there is often more than one state that can be considered the launching state. For these launches, the launching states should decide which country shall be the state that registers the launched

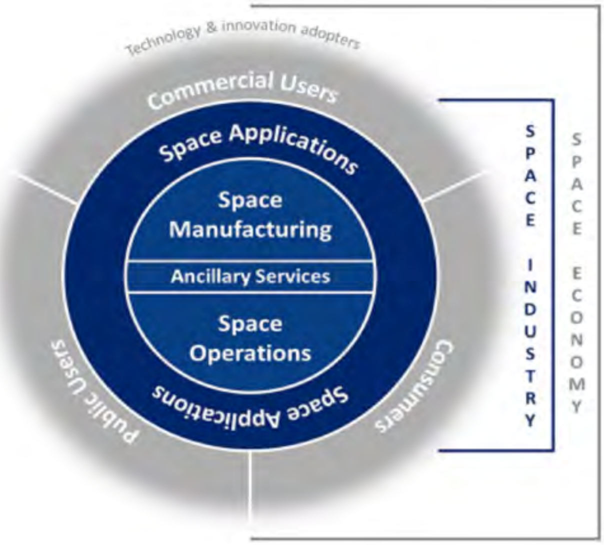


Figure 3. Segmentation of the Space Economy (Sadlier et al., 2016)

object with the UN. Launching states will be liable for the physical damage caused by their space objects (OST Art. VI, Liability Convention Art. II)

The International Telecommunication Union (ITU) regulations regarding frequency coordination must be followed in order to prevent interference with other operators. The ITU suggests that this is normally managed by a national frequency regulatory agency (UNOOSA, 2015, p.11).

Domestic Law

Domestic law should be implemented in a manner that ensures both government and non-government space activities meet all the state's international obligations under international law. Carefully defined and effective domestic law also gives reassurance to other states in collaborative projects that rigid and transparent procedures are in place (Johnson, 2014, p. 16).

Other Considerations

Launch insurance is an important consideration for any party interested in using space. Before acquiring a launch license, many states require that insurance be obtained to “indemnify the state in case international liability is incurred” (Johnson, 2017; p 74). The Third Party Liability Amount is the maximum insurable amount provided by the policy. A minimum amount is required before a launch license is granted by a particular nation, and this amount varies from state to state. (p. 75).

The United Nations (UN) also has Remote Sensing (RS) Principles that provide recommendations relevant to small satellites with Earth Observation (EO) applications. These include recommending that sensing activities of a foreign nation not be used to the detriment of that state, and that data obtained of a foreign state must be made available to that state on a “non-discriminatory basis and on reasonable cost terms” (Johnson, 2014; UNOOSA, 2017).

Applications of Small Satellites

Telecommunications

The Satellite Telecommunications industry is one that has been best serviced by large satellites placed in geostationary orbits. Telecommunications operators provide coverage predominantly to areas of high demand to generate the best profit (ITU and Mehrotra, 2012).

Implementation of telecommunications using small satellites is now shifting this business model. Start-ups and large companies, such as Fleet and OneWeb, are looking to provide global telecommunications solutions with socio-economic benefit.

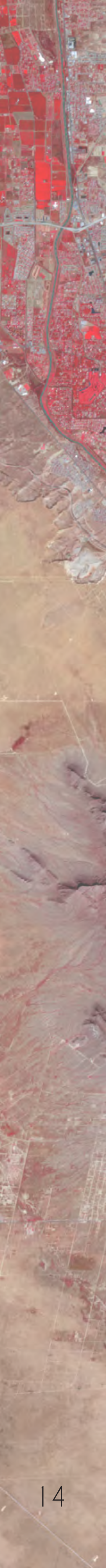
Emerging applications of global telecommunications are directed at the Internet of Things (IoT), Tele-Health and remote education. The IoT is the interconnection of sensors, which produce data and transmit from various locations and devices, via the internet. The goal of this is to provide easy access to data, reducing disadvantages associated with geographic location. Tele-health and remote education have similar objectives, but will achieve them by providing educational and health resources.

Earth Observation and Remote Sensing

EO and RS are generally used for urban planning, disaster and coastline monitoring, topographic mapping, mineral exploration, measurements of ocean dynamics, atmospherics and weather, and land and crop management. The National Aeronautics and Space Administration (NASA) are currently at the forefront of scientific EO using small satellites, with five missions planned to launch in 2017. Each mission is based on the approach of using low-cost, miniaturized instruments, while debuting new measurement methods for EO (Sandau, 2008).

CURRENT ISSUES IN THE GLOBAL SOUTH

Nations of the Global South share common challenges that reflect their geographical make-up and location. With numerous islands and large bodies of water, these nations are confronted with challenges in national security, telecommunications, crisis management, and resource management. More developed countries have addressed these issues with large satellite systems, however such systems are not generally accessible to most developing nations in the Global South. High manufacturing and operating costs serve as barriers to accessing these technologies and the capabilities that they provide. Small satellites present an alternative method of addressing such issues. Through extensive research and consultation with relevant stakeholders in the Global South, the following issues have been identified as key socio-economic areas which can be addressed by small satellites.



National Security

The term 'security' has many definitions, one of which is "the preservation of the norms, rules, institutions, and values of society" (Makinda, 1998). Many states in the Global South share common security challenges that directly impact their development. Border protection and irregular human migration are two of the most challenging issues we have identified in this region. These issues have negative economic and social implications and more importantly can lead to putting lives at risk as a consequence of those impacts (Isacson, 2014).

Border protection is crucial for national stability and security. Inefficient border protection allows criminals to traffic drugs and arms for paramilitary activities, guerrilla warfare, and large scale drug trafficking operations. Table 1 shows that in 2014, the International Organization for Migration (IOM) reported the following estimates of border-related deaths for regions in the Global South (p.6).

Irregular migration, the uncontrolled border crossing to migrate from or to a country, presents a difficult challenge for nations, as the number of migrants and related human rights violations continue to increase. In a 2013 report, the United Nations Department of Economic and Social Affairs (UNDESA) stated that such migrants are "in danger of being exploited by crime organizations involved in human trafficking and migrant smuggling." Refugees and asylum seekers are also vulnerable to this danger.

Small satellites can serve as a key element in addressing these security issues, as relevant authorities and intelligence departments can use them in addition to conventional systems to retrieve information more frequently. This can help nations in executing their strategy of national security by providing accurate and recent information. The use of small satellites would be even more effective if the relevant nations cooperated on a system of satellites that allowed shared access to regional data.

Region	*No.of deaths*	*Period*	*Source*
Sahara	*1,790*	*1996 - 2013*	*Fortress Europe*
US-Mexico border	*6,029*	*1998 - 2013*	*US Border Patrol*
Australian waters	*1,495*	*2000 - 2014*	*Australian Border Deaths Database*
Horn of Africa	*3,104*	*2006 - 2014*	*UNHCR; IOM for 2014*
Bay of Bengal	*1,500 - 2,000*	*2012 - 2014*	*UNHCR; Arakan Project*
Caribbean	*188*	*2012 - 2014*	*UNHCR; IOM for 2014*

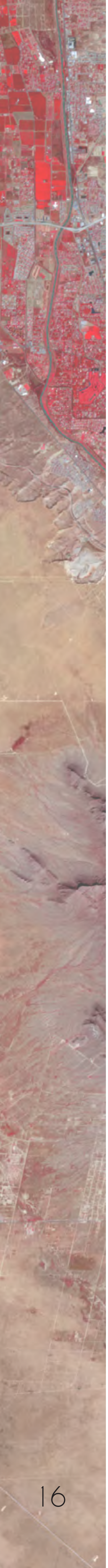
Table 1. Global South regional estimates of migrant border-related deaths as compiled by various sources. (IOM, 2014, p.6)

Crisis Management

Natural disasters such as floods, earthquakes, wild-fires, and typhoons cause significant economic and social damage in the Global South region. They devastate infrastructure such as roads and buildings, as well as farmlands and other agricultural sites. More importantly, these disasters lead to numerous human deaths and injuries and affect the productivity and welfare of societies (Ono, 2015). According to the International Federation of Red Cross, natural disasters affected around 107 million people in 94 countries in 2014 (IFRC, 2015).

As seen in Figure 4, a significant majority of the disasters that occurred in the last decade happened in the Global South. More than two-thirds of workers and more than half of the region's total income come from the agricultural sector (Milkias, 2010). Agriculture is highly sensitive to natural disasters, as these could destroy crops and farmlands in a short period of time, leading to food deficiencies and widespread hunger. Through remote sensing, satellite radio, and geographic information systems (GIS), small satellites can play a significant role in transmitting early natural hazard evidence with higher frequency than conventional systems. The relevant disaster management authorities would be able to detect warning signs earlier, conduct near to real time monitoring, and deliver more efficient post-recovery services in a less costly and more flexible manner.

Figure 4: Number of disasters by continent (2005-2014) (IFRC, 2015)



Telecommunications

Telecommunication networks like the Internet offer several social and economic opportunities. They provide connectivity that enables nations to transition from being resource-based economies to knowledge-based (Deloitte, 2014). Yet, according to the International Telecommunication Union (ITU) (2016), around half of the world's population lacks Internet access, as shown by Figure 6. Emerging nations are particularly affected, as they do not enjoy the stable Internet connections available to more developed countries.

The Internet is the primary enabling technology of the connected age. It is pervasive and ubiquitous in almost all areas of life - including business, social, science and research, and politics. Although internet access is a staple in some parts of the world, it remains a luxury for many and is virtually non-existent for others.

Low internet access is highly correlated to low family income, disability, remoteness, and long term unemployment (Vinson and Rawsthorne, 2015). Further, digital exclusion is likely to worsen the trend towards greater inequality, both domestically and internationally. A 2016 report by the Australian Council of Social Service (ACOSS) stated that with the rapid and continuous development of digital technology, the ability to understand and take advantage of these innovations is essential in sustaining social and economic engagement (Walton *et al*., 2013 cited in ACOSS, 2016).

Non-terrestrial telecommunication services for remote areas are typically provided by large satellite systems, which most emerging nations in the Global South do not possess. These countries are forced to depend on international space players, both governmental and private, for data requirements and satellite applications. Advancements in small satellites and their constellations can offer these emerging countries access to cheaper but equally reliable telecommunication solutions.

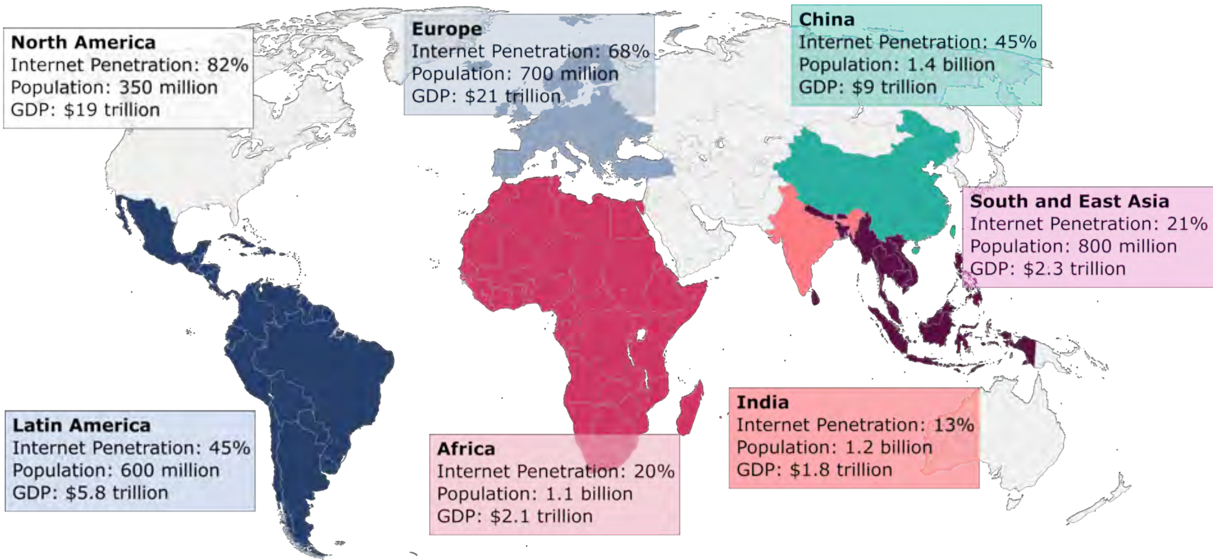


Figure 5: Estimates of Internet penetration by region (Deloitte, 2014)

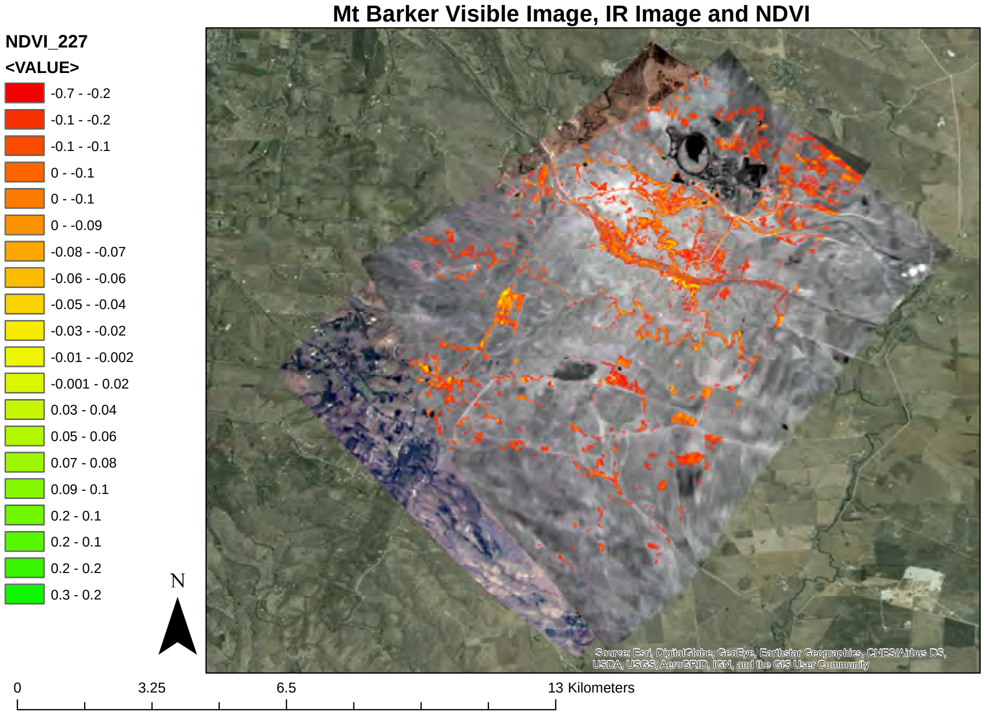
Resource Management

Current estimates state that approximately 15 million square kilometers of the Earth's surface is covered by cultivated land, one of the most prevalent types of land cover (Licker et al., 2007). Feeding a rapidly increasing population in the Global South poses a major challenge to agricultural production, food processing and distribution, and food security.

Effective agricultural management must address issues such as soil erosion and drought. In Australia, the Queensland State Government has highlighted the importance of considering the impacts of erosion. Soil erosion reduces the ability of soil to accumulate the water and nutrients needed to grow crops, and this in turn reduces farmland productivity (Queensland Government, 2016). In a study conducted in rural Australia, approximately 40% of farmers and farm managers interviewed reported that drought had decreased their output to significantly lower levels and in some cases, completely eliminated it (Edwards *et al.*, 2008).

Land-based agricultural areas, forests, and fisheries are three major resources available in the Global South. The misuse of these will result in hunger for the local population and reinforce poverty, especially in times of natural disasters. These would negatively affect the economy as the production and consumption of goods decrease. In addition, poor resource management will lead to the redirection of public funds from other national priorities towards relief efforts.

Humans depend on the Earth's natural resources for survival and we must therefore properly manage these assets. Small satellite applications should be used to monitor vegetation health and help identify preventive measures to save crops, see Figure 7. Small satellites offer cost-effective solutions for resource management to countries of the Global South that are highly dependent on agriculture.

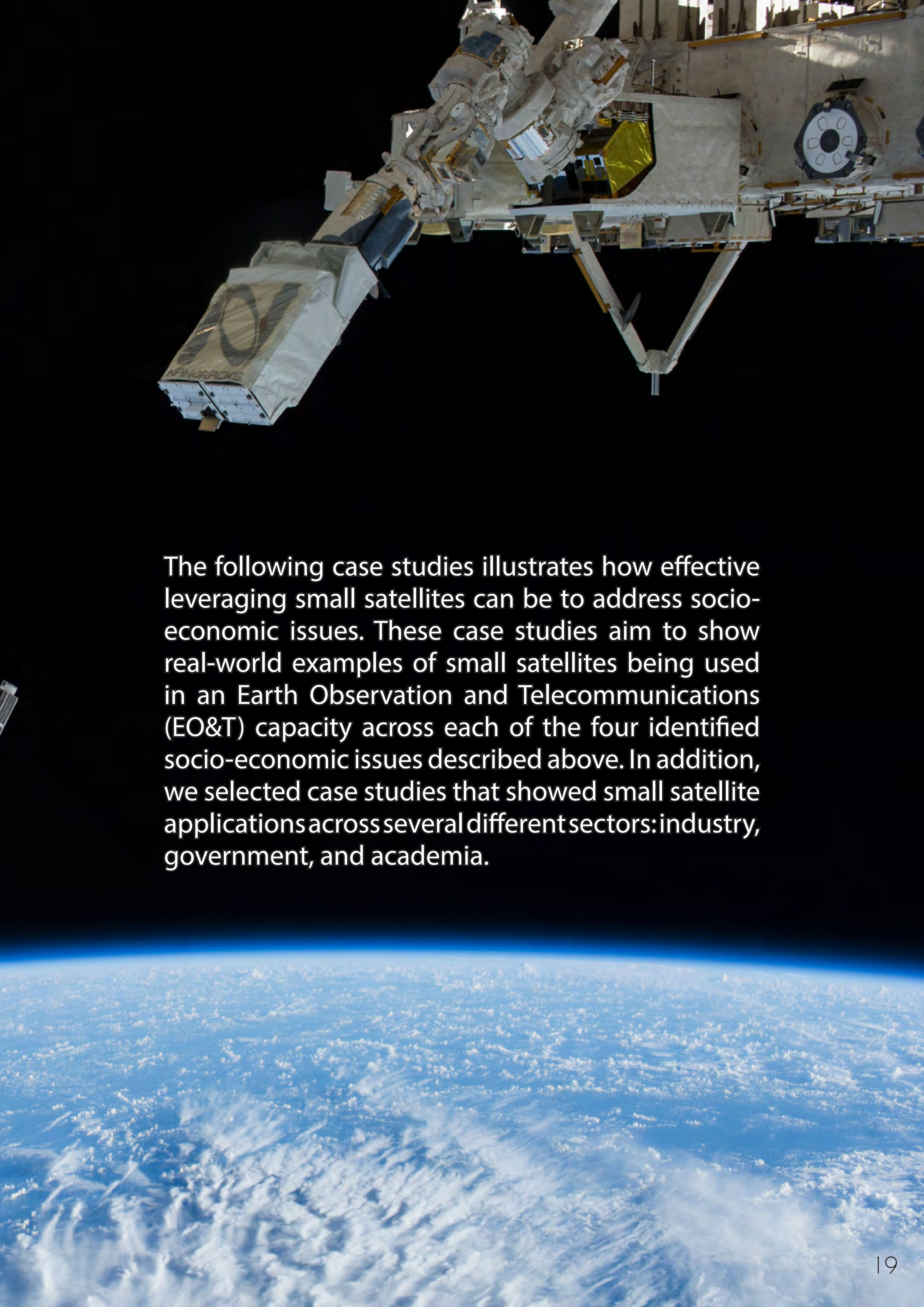


Mt Barker Visible Image, IR Image and NDVI

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 6: Image captured by SH-SSP17 payload, launched from Mount Barker, Australia, 22nd January 2017

CASE STUDIES



The following case studies illustrates how effective leveraging small satellites can be to address socio-economic issues. These case studies aim to show real-world examples of small satellites being used in an Earth Observation and Telecommunications (EO&T) capacity across each of the four identified socio-economic issues described above. In addition, we selected case studies that showed small satellite applications across several different sectors: industry, government, and academia.

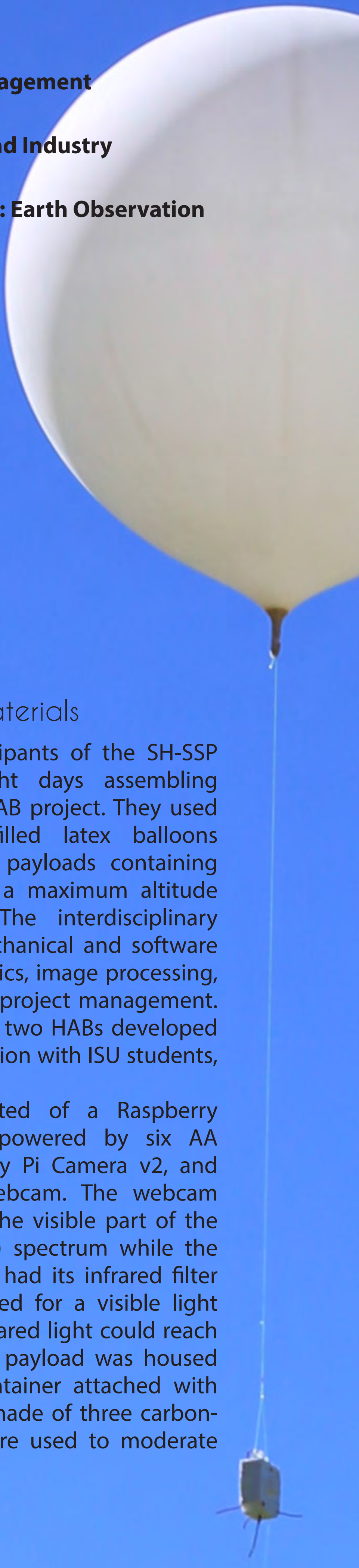
Case Study:

High Altitude Balloon - A Small Satellite Project for Students

Issue: Resource Management

Sector: University and Industry

Satellite Application: Earth Observation



Background

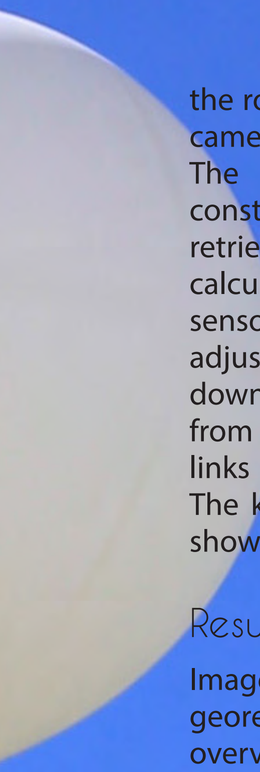
The High Altitude Balloon (HAB) project was conducted by the participants of the Southern Hemisphere - Space Studies Program (SH-SSP) 2017 of the International Space University (ISU) in cooperation with the Amateur Radio Experimenters Group (AREG). Two balloons were designed and launched in South Australia on the 22nd of January 2017. The first was launched from McLaren Vale and the other simultaneously from Mount Barker.

The HAB design and launch experiment demonstrated the possible socio-economic benefits of real-time agricultural monitoring using constellations of small satellites. The main purpose of this project was to illustrate how advanced crop monitoring technology could help address common agricultural challenges such as floods, droughts, increased food demand, and poor harvest. By equipping payloads with optical or hyper-spectral sensors, HABs and small satellites can provide spectral information about crops and help farmers reduce losses and maximize profitability.

Methods and Materials

A team of 36 participants of the SH-SSP program spent eight days assembling and executing the HAB project. They used two large helium-filled latex balloons capable of carrying payloads containing scientific sensors to a maximum altitude of 40 kilometers. The interdisciplinary project spanned mechanical and software engineering, electronics, image processing, communication, and project management. This project included two HABs developed by AREG in collaboration with ISU students, faculty, and staff.

The payload consisted of a Raspberry Pi micro-computer powered by six AA batteries, a Raspberry Pi Camera v2, and a Logitech C920 webcam. The webcam recorded images in the visible part of the electromagnetic (EM) spectrum while the Raspberry Pi camera had its infrared filter removed and switched for a visible light filter so that only infrared light could reach the sensor chip. The payload was housed in a polystyrene container attached with a balancing system made of three carbon-fibre rods, which were used to moderate



the rotation of the payload and prevent the camera from taking blurry pictures.

The experiment involved payload construction, programing, launching, retrieval, weather monitoring, flight path calculation, and image processing. The sensors and camera focus were calibrated, adjusted, and synchronized pre-launch. The downlink data was transmitted in real time from the HABs over the Wenet telemetry links with a speed of 115 kilobits/second. The key parameters of this experiment are shown in Table 2.

Results

Images tools were used to mosaic and georectify the image data to produce an overview of vegetation growth in the Murray River region. The resulting map clearly shows the irrigated region around the Murray River and the northern coast of Lake Alexandrina. Individual differences between plots of the same species can be used to determine the health of the crops.

Conclusion

Our HAB project illustrates the potential of small satellite applications for resource monitoring and management. It provided us with an understanding of how to design, launch, and operate a balloon and laid a solid foundation to better understand small satellite assembly, integration, launching, and operation.

This project illustrated the significance of small satellite technology for agricultural monitoring. At present, there is a lack of adequate data that provides farmers with high spatial, spectral, and temporal resolution information for early detection of changes in vegetation. Small satellite technology is a broad, largely untapped market with great potential that can serve as a promising tool to tackle these problems more effectively.

Flight Designation	Horus 41 – SHS #1	Horus 42 – SHS #2
Launch Date	21/1/2017 23:44:50 UTC	21/1/2017 23:45:14 UTC
Landing Date	22/1/2017 02:36:40 UTC	22/1/2017 02:37:54 UTC
Flight Duration	2 Hours 51 Minutes	2 Hours 52 Minutes
Launch Site	-35.2202° 138.5561°	-35.07628° 138.85695°
Landing Site	-35.3094° 138.9002°	-35.14061° 139.0276°
Distance Traveled	32.7 km	17.1 km
Maximum Altitude	34,136 m	36,059 m

Table 2. Key parameters of HAB flights

Case Study:
Fleet - A Small Satellite Startup

Issue: Telecommunication

Organisation Level: Industry

Satellite Application: Telecommunications

Background

Even in the 21st century, the lack of access to communication is still prevalent in rural areas where the vast majority of agricultural production is located. With a predicted increase in the human population to 9.6 billion by 2050 (UN News Centre, 2013), and a finite amount of arable land that is already nearing complete use, the agricultural sector needs to increase its efficiency (Sali, 2012). To sustain the growing population new technology needs to provide detailed, near-real time information to farmers to allow them to more effectively manage their land. Linking these areas via the traditional means such as cable or fiber would be prohibitively expensive. An affordable way of tackling these issues is by applying the opportunities presented by the Internet of Things (IoT) coupled with the aid of the Small Satellite Revolution. IoT is a trend that is shaping the digital revolution by connecting everyday objects with two-way data transmission (Miorandi, *et al*., 2012). While most of the developed world is already extensively covered with cellular mobile networks, Wi-Fi and Bluetooth, that level of coverage has not been established in the majority of areas in the countries of the Global South, as demonstrated by Figure 9.

Proposed Solution and Business Plan

Fleet, an Australian space technology startup, made it their mission to provide "Free Global Satellite Connectivity for the Internet of Things", identifying the lack of telecommunications coverage, and determining the availability of the necessary commercial off-the-shelf sensors (Fleet, 2016). The business plan is to fill the coverage gap with 100 nano satellites, each weighing 24 kilograms (Nardini, 2017). These satellites will provide Machine-to-Machine links to make the IoT available to remote areas (Appendix A).

Nanosatellites are the medium of choice because they are low cost, scalable, agile, and have quick production times (Fleet, 2016). In the case of Fleet's satellites, they will each take 3 months to construct, each cost approximately $1.5 million AUD to produce, and provide 4.5 million square kilometers of coverage. (Nardini, 2017). Though the service is free to the end-user, Fleet's business model is to collect royalties from front-end licensing, meaning that the company producing the sensors and selling them to the user pays a fee to Fleet to allow their sensors to use the satellite-provided data link. For example, already existing technologies such as Amazon Dash may be integrated into agricultural practices. Amazon Dash is a Wi-Fi connected device that, with a push of a button, reorders products. This data is instantly transmitted to the supplier and may be delivered to the purchaser, allowing the individual to dedicate more time to their production responsibilities (Adamczyk, 2015).

One of the targeted markets for Fleet is precision agriculture. Data from the sensor will enable farmers to identify variations in the land to take necessary management steps (Zhang and Kovacs, 2012). Countries in the Global South rely strongly on agriculture. For example, almost half of Australia's landmass is used for farming (Australian Bureau of Statistics, 2016). This provides a large potential market for Fleet, as agricultural areas tend to be remote and often lack digital connections. Currently, data collection in these areas is still very reliant on the work of humans instead of leveraging technology that already exists. Other potential markets are the mining and the defense industry (Appendix A).

Similar to other countries in the Global South, Australia does not have a space agency. However more and more entrepreneurs are breaking into the space sector, inspired and encouraged by the Small Satellite Revolution. The Australian government provides subsidies to companies that are "international from day one, digital, scalable, following massive trends, and they want to see a great team" (Appendix A). Fleet received 50,000 AUD from the South Australian government under the South Australian Micro-Finance Fund (SAMFF) and raised further funds from venture capitalists (Appendix A).

Flavia Tata Nardini is one of the co-founders of Fleet. Through networking within the tight-knit space community in Australia, Flavia was able to raise close to 5 million AUD within a week. Fleet was chosen as an example of the enthusiasm within the space industry and the accessibility of space technologies to relative newcomers. Space entrepreneurship is a growing field and, with the support of government and financial investors, many new jobs can be created, directly stimulating the economy. As with Fleet, their workforce currently consists of three employees but seeks to grow to 100 by the time that more than half of their satellites will be deployed (Appendix A).

Access to small satellite technologies may be harnessed to fill gaps in telecommunications for many purposes, including agriculture. This will directly sustain and stimulate the economy of the host nation. The cheaper costs of small satellites means that more entrepreneurs may break into the space industry to create their own companies, providing cheap access to vasts amounts of data, stimulating the economy through increasing the efficiency of remote work sectors and generating new jobs.

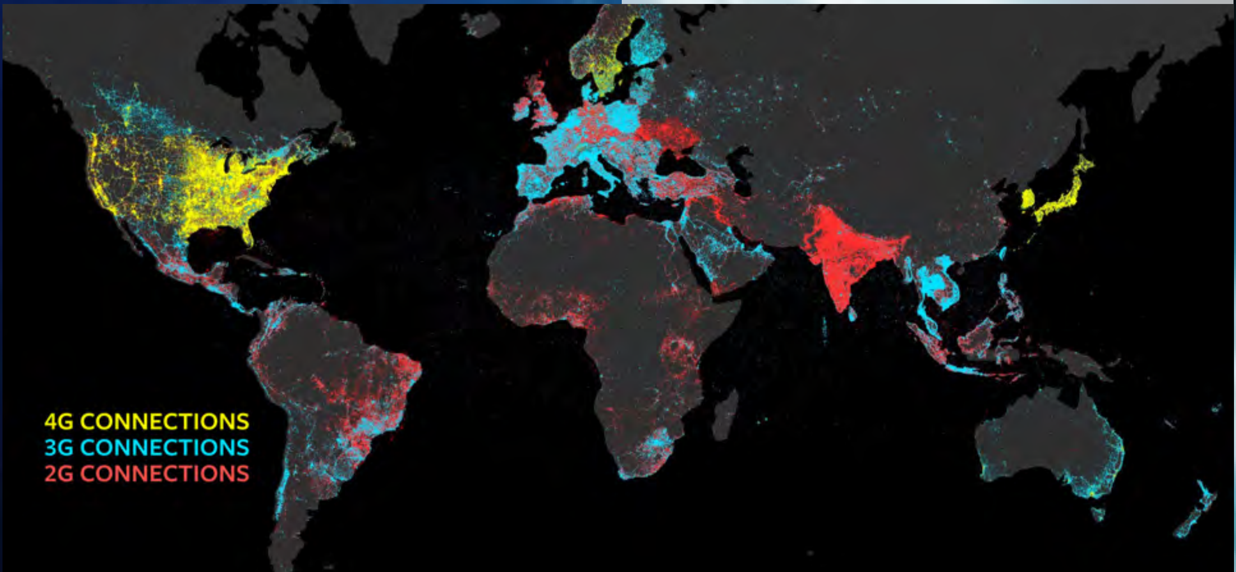


Figure 7. Geographical coverage of mobile data 2G, 3G and 4G. (MyBroadband, 2016)

Case Study: Mexico - An Emerging Space Nation

Issue: Resource Management

Organization Level: Government, Industry and University

Satellite Application: Interorganizational Cooperation

Background

Development of space technology may not seem like the highest priority for many developing countries seeking to supply primary needs such as nutrition and housing for their people, and to manage their resources efficiently. For the case of Mexico, this factor resulted in a lack of interest in having its own space program and therefore an absence of policies, enterprise, or educational programs directed towards the space sector, let alone an agency solely dedicated to the development of the sector.

Efforts made in small satellite technology by educational institutions such as the National Autonomous University of Mexico (UNAM) in coordination with the government, other educational institutions, and private industry, laid the foundations for the creation of the Mexican Space Agency in 2010 (Mexican Space Agency, 2012a). Small satellites have been the key technology for space research and development in Mexico because of lower cost, development advantages, and simple manufacturing. As a result, several projects for remote sensing, natural resource management, volcanic observations, climate monitoring, and pollution measurement are currently in development.

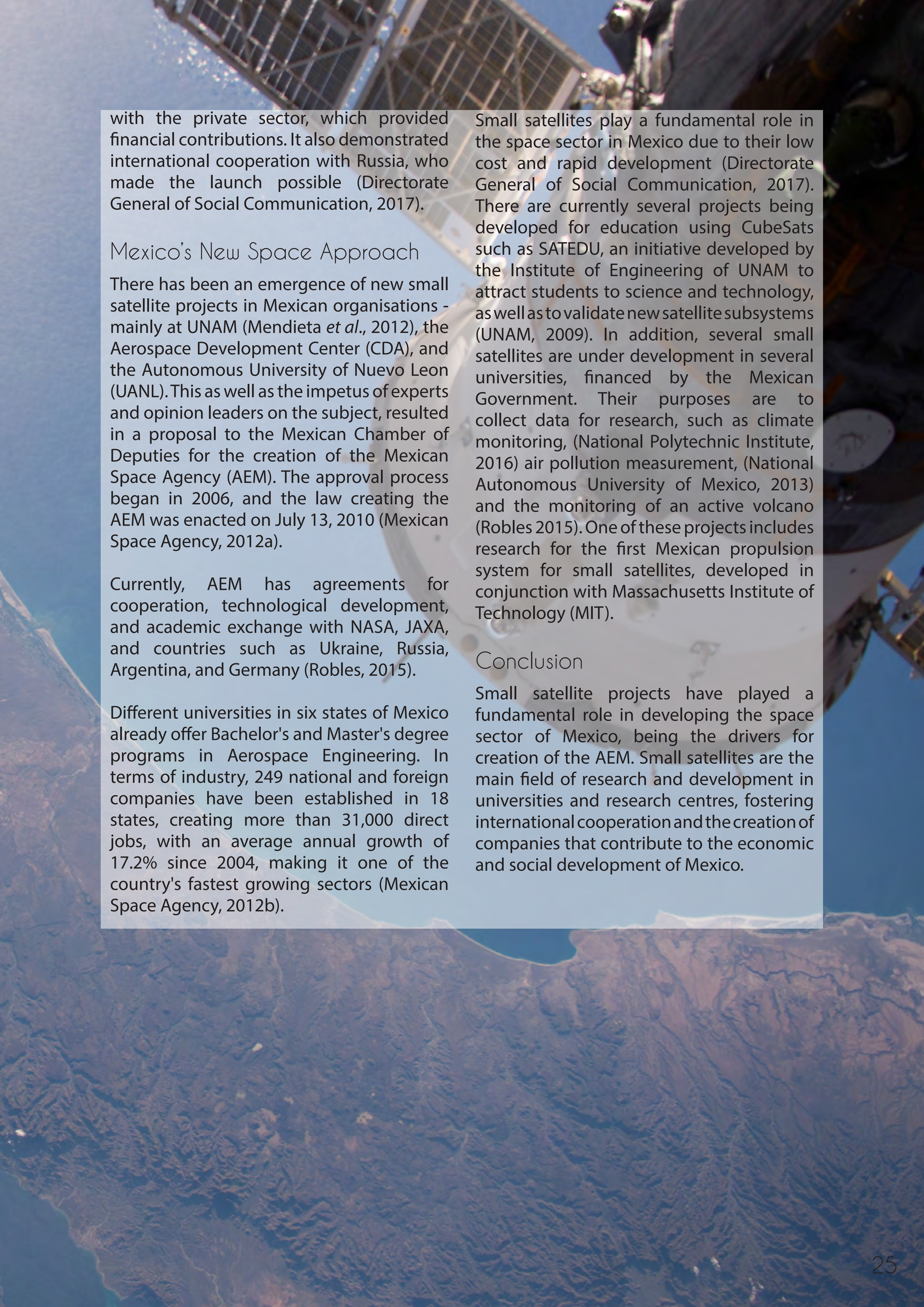
The Mexican Space Industry

Mexico created the National Outer Space Commission in 1962 by Presidential Decree, and made two successful rocket launches to obtain atmospheric data and test propulsion systems. Because of the country's political, economic, and social situation, along with the government's disinterest in science and technology, the Commission was closed in 1977 (Montaño, 2015). The Commission's personnel and resources were reassigned to several different institutions that continued their previous lines of work, mainly in the areas of remote sensing and meteorology. Over time, the expertise in rocket and space technology was dispersed and lost (Pacheco *et al.*, 2009).

This loss of experience and knowledge among decision makers and academics in Mexico was a key reason for Mexico's late reentry into space development. For over five decades, universities and other groups made several attempts to implement educational or science and technology programs, however the lack of economic support prevented successful growth of Mexican space development and ultimately resulted in the cancellation of these programs (Pacheco *et al.*, 2009).

Despite the circumstances, there were several different efforts in Mexico to use satellite technology. The first satellites owned by the Mexican Government were purchased from Hughes Aircraft Company and launched into orbit from the United States in 1985. Up until that year the telecommunications capabilities available in Mexico were rented from foreign companies, meaning that it was technologically dependent on other nations (Robles, 2015).

The first indigenous development of Mexican satellites was carried out by the National Autonomous University of Mexico (UNAM), which produced the UNAMSAT-A and UNAMSAT-B microsatellites. The first satellite was lost at launch however, the second was put into orbit on September 5, 1996. Although contact with the satellite was lost the mission demonstrated cooperation



with the private sector, which provided financial contributions. It also demonstrated international cooperation with Russia, who made the launch possible (Directorate General of Social Communication, 2017).

Mexico's New Space Approach

There has been an emergence of new small satellite projects in Mexican organisations - mainly at UNAM (Mendieta *et al*., 2012), the Aerospace Development Center (CDA), and the Autonomous University of Nuevo Leon (UANL). This as well as the impetus of experts and opinion leaders on the subject, resulted in a proposal to the Mexican Chamber of Deputies for the creation of the Mexican Space Agency (AEM). The approval process began in 2006, and the law creating the AEM was enacted on July 13, 2010 (Mexican Space Agency, 2012a).

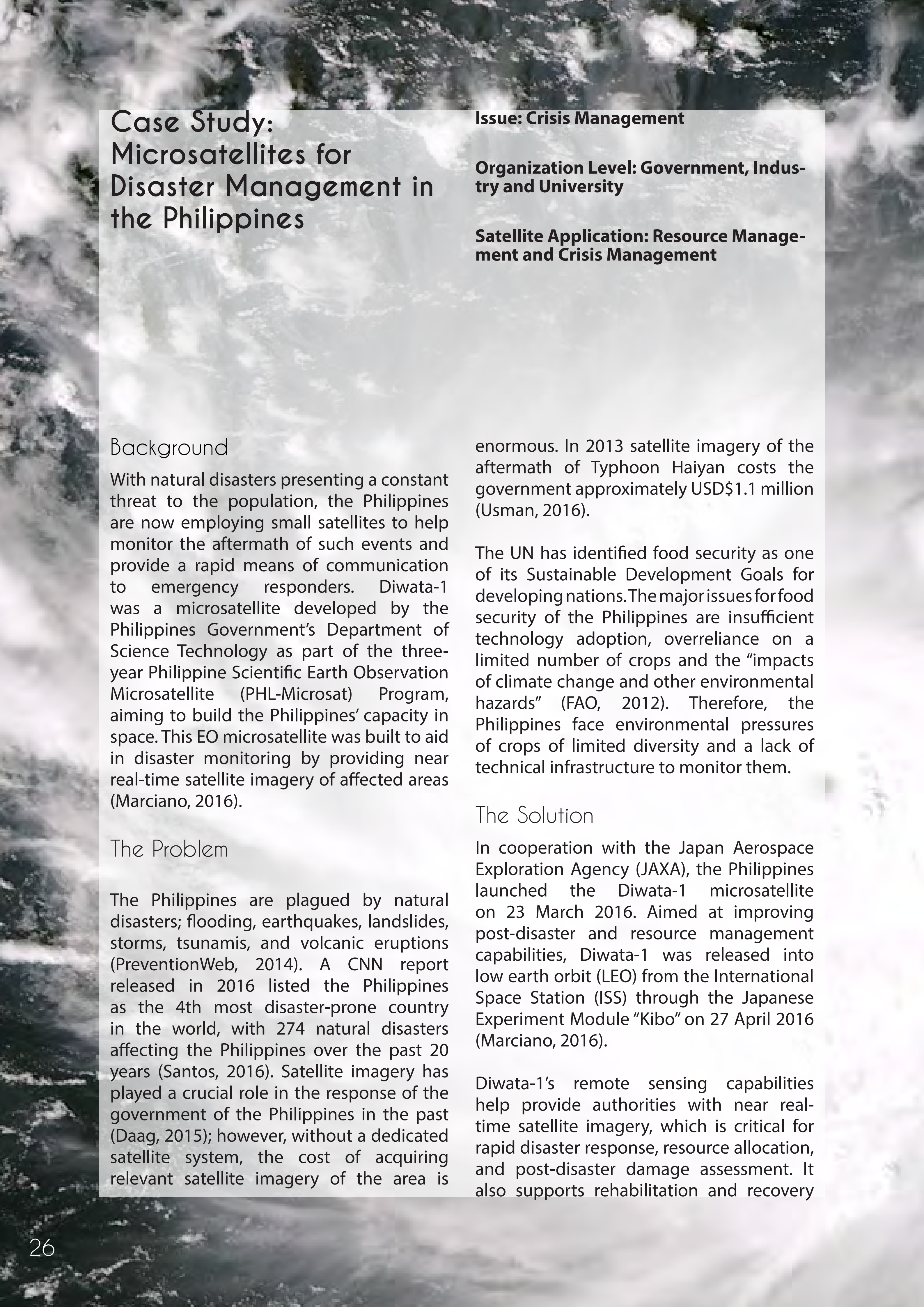
Currently, AEM has agreements for cooperation, technological development, and academic exchange with NASA, JAXA, and countries such as Ukraine, Russia, Argentina, and Germany (Robles, 2015).

Different universities in six states of Mexico already offer Bachelor's and Master's degree programs in Aerospace Engineering. In terms of industry, 249 national and foreign companies have been established in 18 states, creating more than 31,000 direct jobs, with an average annual growth of 17.2% since 2004, making it one of the country's fastest growing sectors (Mexican Space Agency, 2012b).

Small satellites play a fundamental role in the space sector in Mexico due to their low cost and rapid development (Directorate General of Social Communication, 2017). There are currently several projects being developed for education using CubeSats such as SATEDU, an initiative developed by the Institute of Engineering of UNAM to attract students to science and technology, as well as to validate new satellite subsystems (UNAM, 2009). In addition, several small satellites are under development in several universities, financed by the Mexican Government. Their purposes are to collect data for research, such as climate monitoring, (National Polytechnic Institute, 2016) air pollution measurement, (National Autonomous University of Mexico, 2013) and the monitoring of an active volcano (Robles 2015). One of these projects includes research for the first Mexican propulsion system for small satellites, developed in conjunction with Massachusetts Institute of Technology (MIT).

Conclusion

Small satellite projects have played a fundamental role in developing the space sector of Mexico, being the drivers for creation of the AEM. Small satellites are the main field of research and development in universities and research centres, fostering international cooperation and the creation of companies that contribute to the economic and social development of Mexico.



Case Study: Microsatellites for Disaster Management in the Philippines

Issue: Crisis Management

Organization Level: Government, Industry and University

Satellite Application: Resource Management and Crisis Management

Background

With natural disasters presenting a constant threat to the population, the Philippines are now employing small satellites to help monitor the aftermath of such events and provide a rapid means of communication to emergency responders. Diwata-1 was a microsatellite developed by the Philippines Government's Department of Science Technology as part of the three-year Philippine Scientific Earth Observation Microsatellite (PHL-Microsat) Program, aiming to build the Philippines' capacity in space. This EO microsatellite was built to aid in disaster monitoring by providing near real-time satellite imagery of affected areas (Marciano, 2016).

The Problem

The Philippines are plagued by natural disasters; flooding, earthquakes, landslides, storms, tsunamis, and volcanic eruptions (PreventionWeb, 2014). A CNN report released in 2016 listed the Philippines as the 4th most disaster-prone country in the world, with 274 natural disasters affecting the Philippines over the past 20 years (Santos, 2016). Satellite imagery has played a crucial role in the response of the government of the Philippines in the past (Daag, 2015); however, without a dedicated satellite system, the cost of acquiring relevant satellite imagery of the area is enormous. In 2013 satellite imagery of the aftermath of Typhoon Haiyan costs the government approximately USD$1.1 million (Usman, 2016).

The UN has identified food security as one of its Sustainable Development Goals for developing nations. The major issues for food security of the Philippines are insufficient technology adoption, overreliance on a limited number of crops and the "impacts of climate change and other environmental hazards" (FAO, 2012). Therefore, the Philippines face environmental pressures of crops of limited diversity and a lack of technical infrastructure to monitor them.

The Solution

In cooperation with the Japan Aerospace Exploration Agency (JAXA), the Philippines launched the Diwata-1 microsatellite on 23 March 2016. Aimed at improving post-disaster and resource management capabilities, Diwata-1 was released into low earth orbit (LEO) from the International Space Station (ISS) through the Japanese Experiment Module "Kibo" on 27 April 2016 (Marciano, 2016).

Diwata-1's remote sensing capabilities help provide authorities with near real-time satellite imagery, which is critical for rapid disaster response, resource allocation, and post-disaster damage assessment. It also supports rehabilitation and recovery programs. A second satellite Diwata-2, to be launched in 2018 will provide a way for emergency responders and people from affected areas to communicate during disasters when infrastructure get damaged or destroyed (Marciano, 2016).

Benefits

The Diwata-1 satellite has already succeeded in capturing images of the Philippines that will aid in forestry, agriculture management, and disaster monitoring. The provision of resource management will allow the government to better manage agriculture and reduce the effects of climate change on food security. The use of images will allow government and emergency services to better monitor and manage disasters, resulting in the reduction in human casualties and a quicker disaster response.

A secondary beneficial outcome of the program was the partnership developed between the various governmental and academic institutions of both Japan and the Philippines. This enabled Filipino university students to undertake small satellite test and evaluation courses at both the Kyushu Institute and Tohoku University (National Research and Development Agency, 2016). This partnership led to building international relations and upskilling the Filipino workforce. In addition, the USA was involved in the launch, furthering the collaboration. Another result of the collaboration is the co-development of small satellite related tertiary courses, which will help build the capability of the Filipino space industry. This will allow the Philippines a more diverse workforce, which, for developing countries, is the “driving force of economic development” (Kaulich, 2012).

Conclusion

The PHL-Microsat program is an example of an emerging space nation using satellites to foster regional cooperation, encourage local workforce growth, and address resource and crisis management.

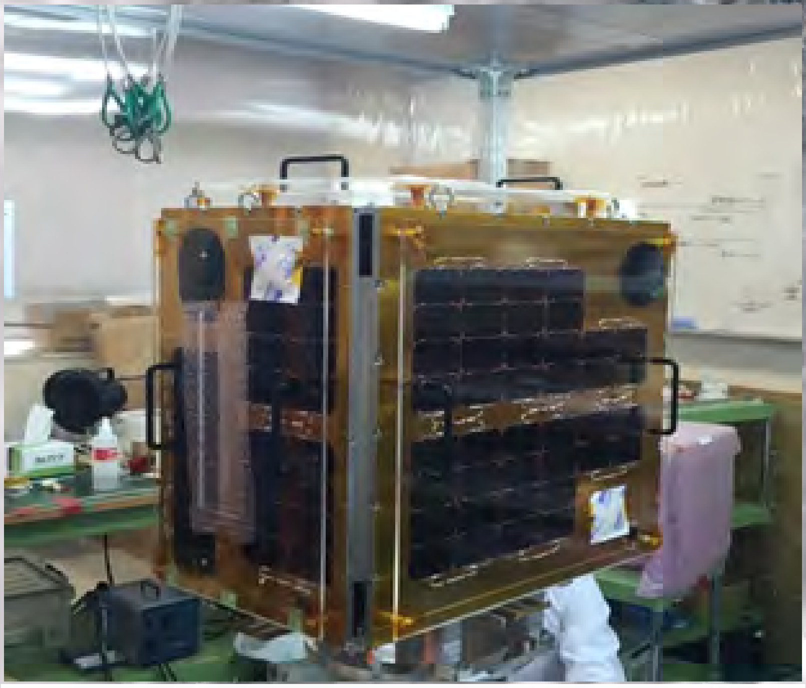
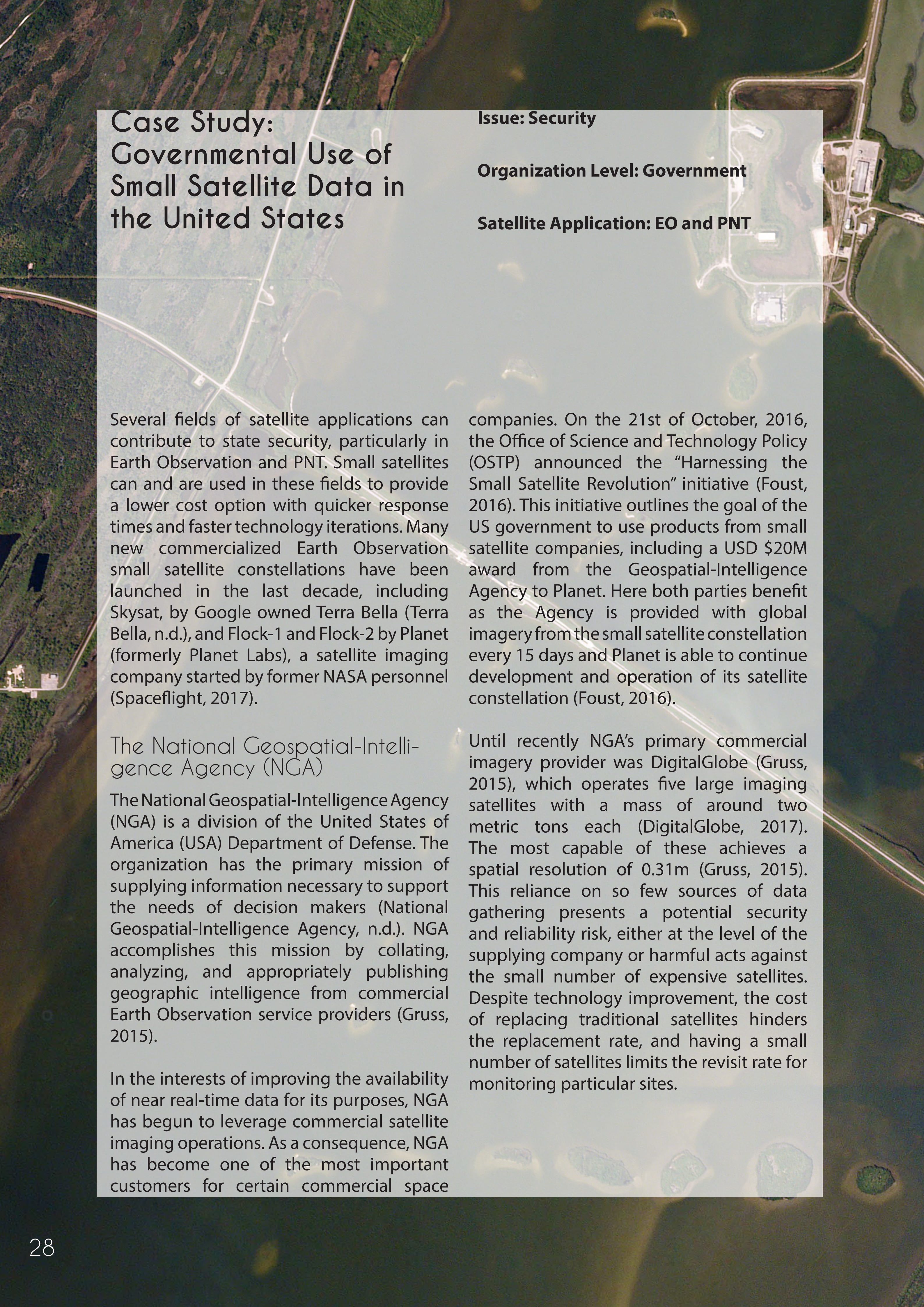


Figure 8: Diwata-1 microsatellite (Marciano, 2016)



Case Study: Governmental Use of Small Satellite Data in the United States

Issue: Security

Organization Level: Government

Satellite Application: EO and PNT

Several fields of satellite applications can contribute to state security, particularly in Earth Observation and PNT. Small satellites can and are used in these fields to provide a lower cost option with quicker response times and faster technology iterations. Many new commercialized Earth Observation small satellite constellations have been launched in the last decade, including Skysat, by Google owned Terra Bella (Terra Bella, n.d.), and Flock-1 and Flock-2 by Planet (formerly Planet Labs), a satellite imaging company started by former NASA personnel (Spaceflight, 2017).

The National Geospatial-Intelligence Agency (NGA)

The National Geospatial-Intelligence Agency (NGA) is a division of the United States of America (USA) Department of Defense. The organization has the primary mission of supplying information necessary to support the needs of decision makers (National Geospatial-Intelligence Agency, n.d.). NGA accomplishes this mission by collating, analyzing, and appropriately publishing geographic intelligence from commercial Earth Observation service providers (Gruss, 2015).

In the interests of improving the availability of near real-time data for its purposes, NGA has begun to leverage commercial satellite imaging operations. As a consequence, NGA has become one of the most important customers for certain commercial space companies. On the 21st of October, 2016, the Office of Science and Technology Policy (OSTP) announced the “Harnessing the Small Satellite Revolution” initiative (Foust, 2016). This initiative outlines the goal of the US government to use products from small satellite companies, including a USD $20M award from the Geospatial-Intelligence Agency to Planet. Here both parties benefit as the Agency is provided with global imagery from the small satellite constellation every 15 days and Planet is able to continue development and operation of its satellite constellation (Foust, 2016).

Until recently NGA’s primary commercial imagery provider was DigitalGlobe (Gruss, 2015), which operates five large imaging satellites with a mass of around two metric tons each (DigitalGlobe, 2017). The most capable of these achieves a spatial resolution of 0.31m (Gruss, 2015). This reliance on so few sources of data gathering presents a potential security and reliability risk, either at the level of the supplying company or harmful acts against the small number of expensive satellites. Despite technology improvement, the cost of replacing traditional satellites hinders the replacement rate, and having a small number of satellites limits the revisit rate for monitoring particular sites.

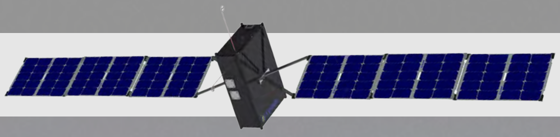
The Use of Small Satellites

Recently, NGA has begun to purchase data from small satellite providers including Terra Bella, which currently operates seven small satellites in orbit and has planned more (Terra Bella, n.d.), Planet Labs with a flock of 63 satellites (Erwin, 2017) and BlackSky, who plans to have six small satellites in orbit by the end of 2017 (BlackSky, 2016). This is a combined result of the mentioned initiative on small satellites (Foust, 2016) and the aspirations of the new Director of the agency, Robert Cardillo, who has said of small satellites: "The skies — really space — will darken with hundreds of small sats to be launched by Skybox, Planet Labs, BlackSky and others" and has appropriately involved the agency in operations with small satellites providers (Gruss, 2015).

Small satellites offer a number of benefits to NGA's mission and, by proxy to the USA. The increased prominence and low cost of small satellites, nanosatellites in particular, has enabled a significant number of small companies to enter the field with a relatively small initial investment (Dillow, 2015). The presence of governmental agencies as potential customers of small satellites companies greatly increases the addressable market and present a considerable business opportunity. Additionally, the potential of and tendency for large constellations of small satellites - offered by various companies and in various orbits - provides an unmatched capacity for redundancy and reliability. These large constellations allow for rapid revisit, potentially permitting a daily update of changes to a site (Planet) and even rarely interrupted real-time video (Terra Bella) (Gruss, 2015).

With their recent branching into both supporting, and relying on the small satellite industry, NGA has recognized the value that small satellites provide to national security.

Recommendations



To properly harness the Small Satellite Revolution, decision-makers must consider effective strategies to implement for the Global South. Following consultations with relevant stakeholders regarding issues in the Global South, the White Paper Team developed a series of recommendations for decision makers in the education, government, and private sectors. These recommendations aim to facilitate taking advantage of the Small Satellite Revolution for socio-economic benefit in the Global South, considering both the current state and future trends of the small satellite industry. We considered the outcomes of the case studies of small satellite usage explored earlier in this White Paper to support these recommendations.

To support these recommendations, we describe a value chain for the small satellite industry, following small satellite development from initial design through to final implementation. The value chain is used to pair budget and capability requirements with appropriate entry points into the small satellite industry for education, government, and private sector stakeholders.

For each recommendation below, we will assign an entry point on the value chain. This will help decision-makers understand the relative level of budget and capability required to realize the ideas presented.

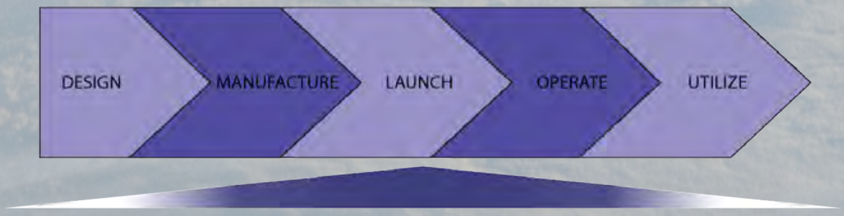


Figure 9. The small satellite value chain

Policy Recommendations

In this section, we propose a framework for changes to policy pertaining to small satellites. We consider policy holistically before addressing specific recommendations in the subsequent sections. This is to highlight the importance of careful policy implementation that will ensure the controlled and sustained development of the small satellite industry.

Domestic Legal Frameworks

Emerging and established space nations must consider the domestic implications of the international policies described in Section 2.5. Each emerging space nation should:

A - Consider becoming a signatory to all relevant UN treaties on space, thus demonstrating their intention to be a responsible user of space.

B - Establish several domestic regulations for space use. We recommend that each nation implement:

- A national space policy to provide clear direction and assign responsibility for proposed space utilization, with specific mention of intended small satellite use.
- A domestic register of space launches, to allow state jurisdiction and control over small satellites
- A domestic frequency coordination agency to provide the interface between the ITU and the small satellite industry

Tax Breaks and Financial Incentives

Investment in the space industry “requires thriving in a challenging environment” (Gurtuna, 2013) and government financial incentives should be introduced to reduce the risk that industry carries.

C - States should implement a national policy regarding insurance, that scales the Minimum Third Party Liability amount depending on the size of the launch. This will mean that small satellite launches will not require the same insurance requirements as larger satellite launches. Alternatively, the state could provide subsidies or indemnities to small satellite operators to reduce liability to third parties in the case of fault.

D - States should also implement policy whereby reductions in Minimum Third Party Liability amount are granted in return for risk reduction measures provided by the operator. An example of these measures could be additional orbit collision analysis, or enforcing restrictions on proximity to foreign owned critical space resources. The reductions in the insured liability amount would result in reduced insurance costs for the small satellite operator, stimulating growth in existing and emergent small satellite applications.

Recommendations to Academic Institutes

The current trend in small satellites is to provide more for less, which, in turn, has led to the "Smaller, Cheaper, Faster, Better" model (Heidt *et al.*, 2016). Thus, there is now more opportunity for the education sector to access small satellite technologies. Recommendations to the education sector are focused on engaging a wider portion of students at a variety of education levels in small satellite Earth Observation & Telecommunications (EO&T) technology. We also discuss improvement of the resources available to those students to facilitate their engagement and learning.

Recommendation 1

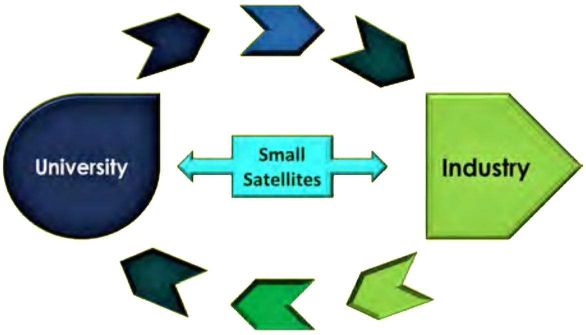
Add hands-on small satellite activities to the primary and secondary school curriculum, with a focus on EO&T.

Value Chain Entry: Design and Utilize

The technological and engineering industries are developing rapidly, and the need for sustainable STEM education is vital. Broad and inclusive STEM education provides the skills necessary to address future socio-economic issues, and small satellites could provide these services as well as act as an educational tool to build skills. We recommend that both primary and secondary institutions take advantage of small satellite technology by including it in their curriculum planning, placing an emphasis on using EO&T in applications for social good. Sandau (2010) highlights that small satellites are "natural means for education and training" because "they allow direct, hands-on experience at all stages" of the satellite development process.

There are already several initiatives in the industry to provide small satellite educational solutions. One example is *Launchbox*, a space education start-up company based in Adelaide, Australia. Their mission is to put space technology in the hands of primary and secondary school students by providing kits that allow classes to build their own model satellites and conduct real space experiments (Pearson, 2015). Launchbox also has a project called 'LIFTOFF' that eventually plans to send students' experiments into space.

The low cost of small satellites make it feasible for educational institutions to have access to space. The skills developed in these programs will assist in addressing the socio-economic problems of the future. The integration of small satellite technology and applications into school curriculums will foster interest in the community and more engagement in STEM, which has various positive social effects (Klimov *et al.*, 2005).



Recommendation 2

Develop university level courses on small satellites and their EO&T applications, with a practical focus on building small satellites.

Value Chain Entry: Design, Manufacture, and Utilize

The investigation of fundamental scientific problems is a core mission of universities (Swartwout, 1997). With advancements in technology making small spacecraft less expensive, universities are able to offer their services in the area of spacecraft design and development. Building on recommendation 1, tertiary level students should be provided with the skills needed to address the socio-economic problems of the future using small satellites.

We recommend that universities implement courses designed for small satellite and EO&T applications, with a research focus on “hands-on” projects. The practical component of the course is particularly important as open-ended, discovery based learning has proved to be more effective than lecture style presentation (Shiroma, *et al.*, 2009). Outcomes of the HAB Balloon Project and the satellite launch by UNAM have shown that this kind of education has been successful in the past and could be readily implemented by new institutions. As an outcome of their collaboration, the Philippines microsatellite program has begun to develop their own tertiary courses on small satellites.

Recommendation 3

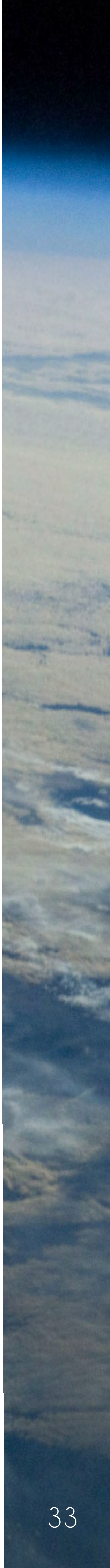
Encourage partnerships between universities and industry to develop new small satellite technology with applications towards socio-economic issues.

Value Chain Entry: Design, Manufacture, Operate, and Utilize

As small satellite technology improves and demand for their services increases (Heidt *et al.*, 2000), there will be a push for innovative solutions. This will require more collaboration between academia and industry than ever before. We recommend partnerships between universities and industry to exchange research facilities and human resources for grants and funding opportunities. Placing emphasis on EO&T will foster benefits for both parties; industry members can acquire innovative R&D that will enable them to remain competitive in the market, while also building specialist skills in the university environment.

These industry-university partnerships should establish programs that integrate the best resources of both parties, where the university provides research facilities and fellowship opportunities, and industry provides access to the necessary resources to carry out projects together. We recommend that students lead and develop viable small satellite projects with the goal to encourage students to validate new technology and gain collaboration development experiences. Industry can draw on student innovations to explore new markets. Previously, these partnerships have provided positive benefits for both parties; for example, the AREG, UniSA, and ISU collaboration allowed AREG to conduct its first ever simultaneous balloon launch and provide a test scenario for its new communications technology. In return, the ISU participants gained a wide range of skills. Such successful collaboration illustrates that projects involving small satellites can foster beneficial partnerships between industry and universities. University students gain experience within the industry environment, while industry obtains publicity and positive feedback. Supporting innovative projects created by young people fosters confidence in society, a profitable enterprise for industry.

The government sector is the key driver for harnessing the Small Satellite Revolution, through its ability to affect and implement policy. The recommendations focus on improving partnerships among government, academia, and private sectors.



Recommendations to Governments

The government sector is the key driver for harnessing the Small Satellite Revolution, through its ability to affect and implement policy. In addition to the general considerations presented earlier, this section provides recommendations for various levels and sizes of government. The recommendations focus on improving partnerships among government, academia, and private sectors.

Recommendation 4

Develop innovation programs within the State and Local Communities directed towards EO&T.

Value Chain Entry: Design

Innovation is a critical aspect to keeping the small satellite industry sustainable. The encouragement of innovation on a small government level, with a focus on the emerging small satellite industry, will ensure that EO&T technology remains cutting edge and is a viable investment for private enterprise. We recommend that at a small government level, public funding be put towards programs that nurture innovation in small satellite EO&T. While a focus on EO&T is preferable for the purposes of this paper, innovation remains a key driver of spin-in and spin-off technology, which benefits innovation.

We recommend that funding be directed into various innovation drivers such as grants or public courses to maximize productivity. Financial support should be provided to start-ups in the forms of grants or grant-matching, whereby government will match private investment in EO&T start-ups. Public courses in innovation should be introduced to engage public and private parties, thus reducing the risk of start-up failure. The case study of Fleet indicates how important innovation is for building new capabilities.

These programs are a way for lower levels of government to influence higher levels of government and position themselves to take advantage of applications of the small satellite industry. Encouraging high growth innovation creates new job areas, which has been shown to have a positive effect on the economy (Wong, Ho and Autio, 2005). With a focus on EO&T, new applications of existing technology as well as the development of new technology will occur, allowing countries to further take advantage of the Small Satellite Revolution.

Cooperate regionally to develop the Small Satellite industry, with emphasis on EO&T.

Recommendation 5

Value Chain Entry: Design, Manufacture, Launch, Operate, and Utilize

Not every state can implement its own sovereign space industry that encompasses the entirety of the small satellite value chain. Nevertheless, this should not be a factor that impedes a nation from becoming involved in the space industry and being able to take advantage of the applications that space based resources can bring. We recommend nations cooperate regionally to develop a small satellite industry, with emphasis on EO&T. Cooperation with neighbouring states has numerous benefits. It shares the cost of a potentially expensive venture across the region and can foster positive political relationships. The socio-economic issues of the region can be jointly addressed for the most effective results.

Sandau (2010) identifies that "countries taking their first steps in space need to learn relevant techniques from more experienced space users." Hence, cooperation between states should be encouraged by implementing technology, expertise, and capability sharing agreements. Governments should work together to produce policies that foster both national and regional capabilities, and that allow smaller spacefaring nations to influence the global space policy sector.

The Nigeria small satellite program (Aron, 2013) partnered with other nations and industry to launch a small satellite that assisted with resource and crisis management (James *et al*., 2013). In addition, the satellite coordinated with the Disaster Monitoring Constellation to provide crisis monitoring to the region. The collaboration between the DigitalGlobe Constellation and small satellite operators is a good example of how this recommendation can be implemented at a local level. The case study of the Filipino micro-satellite program has already generated regional cooperation, which has encouraged capability sharing. The design, development, and launch of the program involved three different nations, and the satellite has already begun to provide socio-economic benefits.

Collaboration with regional partners means that the benefits of EO&T applications can be focused on relevant regional issues, while distributing the mission costs. This results in a more specific effort that targets all the identified socio-economic issues, with greater overall benefits to the participant states.

Recommendation 6

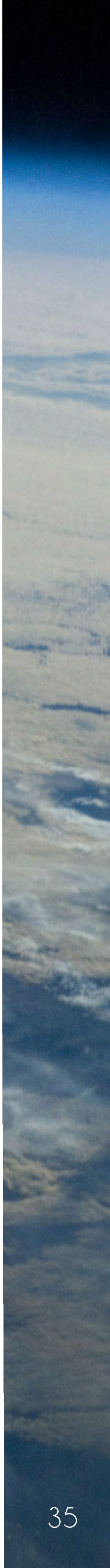
Establish a government agency that deals exclusively with small satellite EO&T, to reduce the regulatory complexity for players in the small satellite industry.

Value Chain Entry: Design, Operate, and Utilize

The key to promoting small satellite applications is to have a streamlined process for stakeholders. Existing overheads that deal with multiple levels of government increase the complexity of gaining access to space. Addressing these overheads reduces the cost of implementation for small satellite providers and users.

We recommend that governments consolidate and establish a space EO&T agency that combines the roles of multiple agencies. This should aid with all stages of the value chain, including assistance with regulatory requirements and funding.

The case study on Fleet and its CEO (Nardini, 2017) shows that meeting regulatory requirements can be complicated and expensive for a start-up. Streamlining this process would allow more money to be diverted into actualization of the start-up capability. The balloon launch case study also highlighted the difficulties of dealing with disparate stakeholders. By simplifying this process, there will be a higher level of development in the sector that will result in more innovative solutions.



Recommendations to Private Companies

In the private sector, innovation is realized and applied to provide a sustainable and profitable service. These recommendations suggest sustainable and innovative markets for business development in the small satellite industry that produce socio-economic benefits.

Recommendation 7

Develop software and provide consulting services to small EO&T satellite operators to more effectively connect their data to their customers.

Value Chain Entry: Design and Utilize

With the expansion of the small satellite industry, it is crucial to effectively connect consumers to EO&T data collected by small satellites. We recommend developing intermediary services to bridge the gap between small satellites and consumers, using both professional and publicly available software to allow users access to satellite services such as monitoring of mining, crop growth, carbon emissions, and maritime services.

These intermediary services consist of both consulting and application services. Consulting services can be used to assist customers by analyzing development trends. Application services can provide a suite of specialized EO&T applications to integrate consumer needs with the data available. These could be easily available through either web or phone applications. For example, Google has developed a Google Earth Engine API that allows a connection between geospatial data and a cloud based processor (Google, 2016).

By developing this class of technology, various stakeholders can be informed by relevant EO&T data. For example, the public can be kept abreast of emergency situations disseminated from disaster response agencies to ensure their safety. Private businesses, such as farmers, can possess specialized technology that allows them to easily manage their resources. This, in turn, leads to higher productivity and a corresponding profit increase. Other services, such as the military, can be provided with innovative solutions that help secure the borders of the countries they serve, providing a higher level of coordination and effective use of resources.

Recommendation 8

Invest in the development of small telecommunications satellites with focus on the Internet of Things and Telecommunications.

Value Chain Entry: Design, Manufacture, Operate, and Utilize

Telecommunications satellites have traditionally been owned and operated by large multinational companies, taking advantage of the most profitable sector of the satellite operation industry (The Tauri Group, 2016). This paradigm is beginning to shift because of the Small Satellite Revolution. Advances in miniaturization technology and enhanced launch capacities have made small telecommunications satellites more viable. Parties without the means to enter into this multi-billion-dollar market now have new opportunities to do so (Clark, 2006). We recommend that private entities with an interest in entering the *manufacture* and *operate* sectors of the small satellite value chain do so in the telecommunications sector. Small telecommunication satellites are beginning to emerge on the world market, with various scales and scopes. Fleet is an example of a start-up company already taking advantage of this new trend. They are getting involved in the IoT, which begins to connect our homes, cars, and jobs via the internet. There are also larger companies like O3B that are looking to use small satellite constellations to provide internet access on a global scale (Collar, 2016). Tele-health and remote education are important applications of these technologies. Tele-health has potential for significant positive impact on rural health (Gagnon, 2006) and remote education has been identified as an enabler for human capital growth (Ally, 2009 p1). O3B, as well as other developing projects such as One Web and internet.org, are pioneering larger scale internet access to connect the world.

This sector has the potential to bring the standards of living enjoyed in developed nations to some of the poorest and most remote communities in the world. The benefits to society from investment in this sector are the many improvements in quality of life that a connected world brings.

Recommendation 9

To assist with EO&T applications in the Global South, companies should engage in the creation of next generation launch vehicles, specifically designed for small satellites. New launch technology would reduce costs, improve reliability and provide a higher frequency of launch.

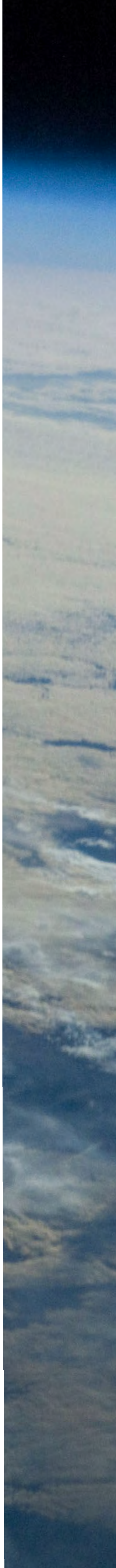
Value Chain Entry: Design, Manufacture, Launch, and Operate

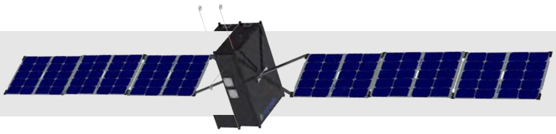
With the small satellite revolution sweeping the globe, the need for launch services is in high demand. It is necessary for the launch segment of the space industry to upgrade its capacity to accommodate the upcoming increased demand in small satellites (Doncaster, Williams and Shulman, 2017). At present, the global launch of small satellites relies mainly on traditional Launch Vehicles (LV) companies, such as Arianespace, United Launch Alliance (ULA) and Orbital ATK. With long launch cycles and high costs, this method cannot meet the burgeoning needs for small satellite launch services in the future. We recommend investment in research for the next generation launch services for small satellites from both technical and operational perspectives. Investment in this technology development is tailored most appropriately for parties interested in the Launch stage of the small satellite value chain. We make recommendations here into two separate categories, Launch Technology and Launch Operation.

With regard to Launch Technology, we recommend that LV providers use modular design to leverage the standardization of small satellite sizes. Reusable or low cost first stages should be used. To meet future demands, flexible and fast deployment methods are preferred. A potential solution could involve the use of high altitude balloons as described previously, yet on a much larger scale, to act as the first stage of the satellite launch. This would save propellant costs as well as remove the need for dedicated launch sites. Innovative launch operations could be addressed by recommending that venture capitalists and investors invest in companies developing this technology.

As for Launch Operations, the policy for launch service pricing could be changed. In this new business model, launch providers would charge according to the size of the small satellite operator's income. This would provide incentive for financing new technology, and improve demand for launch services.

Investment in these next generation technologies acts as an enabler for innovation of EO&T data in the future. This ensures that the future socio-economic needs of the Global South can be addressed quickly and effectively by emerging technology and applications.





CONCLUSION

The Small Satellite Revolution is here. Now the countries of the Global South have more opportunities to access the socioeconomic benefits that small satellites can provide.

With a lowered barrier to entry, the nations of the Global South that have been minor players in the space industry thus far now have the means to enter this market and reap the benefits that the Small Satellite Revolution can offer. The Global South has a diverse range of people, culture, and environments. Using the applications of small satellite technology, every person - from the sprawling cities of Shanghai to the sparsely populated areas of Sub Saharan Africa - can be part of The Revolution.

This White Paper has sought to bring recommendations to, and stimulate thought and discussions for, members of the Global South as to how the Small Satellite Revolution can promote socio-economic benefit. These suggestions were broken into four sections.

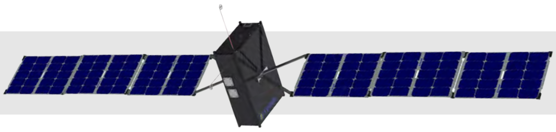
Policy Considerations: Emerging space nations need to position themselves, from a policy and governance standpoint, to maximize the engagement of their nation and region with the global space community.

Education Sector: Educational institutions are the backbone of the age of innovation and are responsible for preparing a sustainable and agile workforce to meet future challenges. Academic stakeholders need to engage students at all levels of their institution and provide the means for cutting-edge technology development.

Government Sector: A nation's government is the binding force between all stakeholders, and bears the responsibility to lead with directed and considered planning. Governments need to focus on how they can promote synergy with industry and academia for socio-economic benefit.

Private Sector: Players in the private sector are the global demonstrators of how the technologies of the modern age can be used for social and economic benefit. Private companies need to engage in markets that will stimulate the next iteration of the Small Satellite Revolution.

The issues and applications considered in this White Paper provide the foundation for countries of the Global South to harness the Small Satellite Revolution to realize effective change. The increased use of small satellites can bring the era of geographic disadvantage and inequality to an end. The time for social and economic transformation is now. The age of the Small Satellite Revolution is upon us and it is time for the Global South to take action.



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ACRONYMS

ACOSS	Australian Council of Social Service
AIAA	American Institute of Aeronautics and Astronautics
API	Application Program Interface
AREG	Amateur Radio Experimenter's Group
DESA	Department of Economic and Social Affairs
DOS	United States Department of State
EO	Earth Observation
EO&T	Earth Observations & Telecommunications
GIS	Geographic Information System
IADC	Inter-Agency Space Debris Coordination Committee
IFRC	International Federation of Red Cross
IOM	International Organization for Migration
ISU	International Space University
ITU	International Telecommunication Union
LV	Launch Vehicle
MIFR	Master International Frequency Register
NASA	National Aeronautics and Space Administration
NGA	National Geospatial-Intelligence Agency
OST	Outer Space Treaty
PNT	Position, Navigation and Timing
RS	Remote Sensing
STEM	Science, technology, engineering and mathematics
UN	United Nations
UNHCR	United Nations High Commissioner for Refugees
UniSA	The University of South Australia
UNCOPUOS	UN Committee on the Peaceful Uses of Outer Space
US	United States
USA	United States of America

SUMMARY OF LIVE INTERVIEW WITH FLAVIA TATA NARDINI

Appendix A

What are the different fields using IoT (the Internet of Things)? What is the maturity of the industry?

The IoT can be useful in almost any field. The industry is ready. There are lots of sensor available for every field. The software infrastructure is ready (Amazon, Microsoft Azure) to sort and treat the data. The communication infrastructure is ready too. Land communication infrastructure is already installed in cities dedicated to IoT communications. (SigFox, for example). Take transportation – in Australia at the moment, they track trucks on GPS, but IoT doesn't just track, it also monitors the maintenance for the whole fleet of trucks. But this infrastructure is not available in remote areas, so that is where Fleet is filling a gap. Fleet will provide communication solutions for sensors installed in remote areas with a focus on IoT.

Can you tell us more about the investment that you received so far?

The Australian government provides "Match Grants". You have to raise your own money and the government matches it, 2:1. We had to raise 25.000 AUD, and the government match it 2:1. So they gave us 50.000AUD. There are many matching grants, up to 1M$. Meaning that if you raise 1M$ the government gives you additional 2M$AUD. This constituted our seed investment.

What are VC (Venture Capitalist) firms looking at when investing in startups?

The requirements are that you have to be international from day one (same as for the government grants). They want to help you only if you have big plans. To be international you need a big vision, you need to be able to sell everywhere What is important is to build a team with complimentary skills. Investors appreciate to see a mix of expertise.

What have you learnt between you first (Launchbox) and second venture (Fleet)?

I learnt that we are usually too scared of our ideas. Start big is the way to go. Don't try to do something small to go to a big one, start with the big idea. If you start with the small ideas you lose focus on your big goal. Pitch the big goal not the roadmap. It is fine to have intermediary steps to reach your product, but one of my learning is to pitch the big idea.

How do you build your credibility as a space entrepreneur?

A space background is a plus, the space community will accept you. The more you have done the better. If you enter the industry just pretending to have space background and business background but you do not have, the community will not accept you. People from outside the space industry who are very successful in business can bring very good value to the space entrepreneurship community, and the Space community is learning to accept business people.

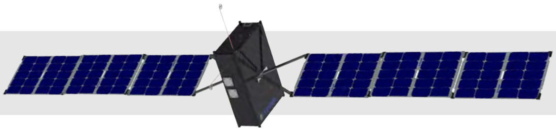
What innovation you want to see in the satellites launching segment?

The big change I want to see is if companies like Zero2infinity that provide low-cost and high frequency of launches can get funded and have an operating launcher. We need a new launcher solution in the next 3 years. They are many companies trying, and eventually one of them will succeed. We hope that they will succeed without too many failures because each failure affects our insurance costs. Therefore, reliability is a key aspect for those launcher companies.

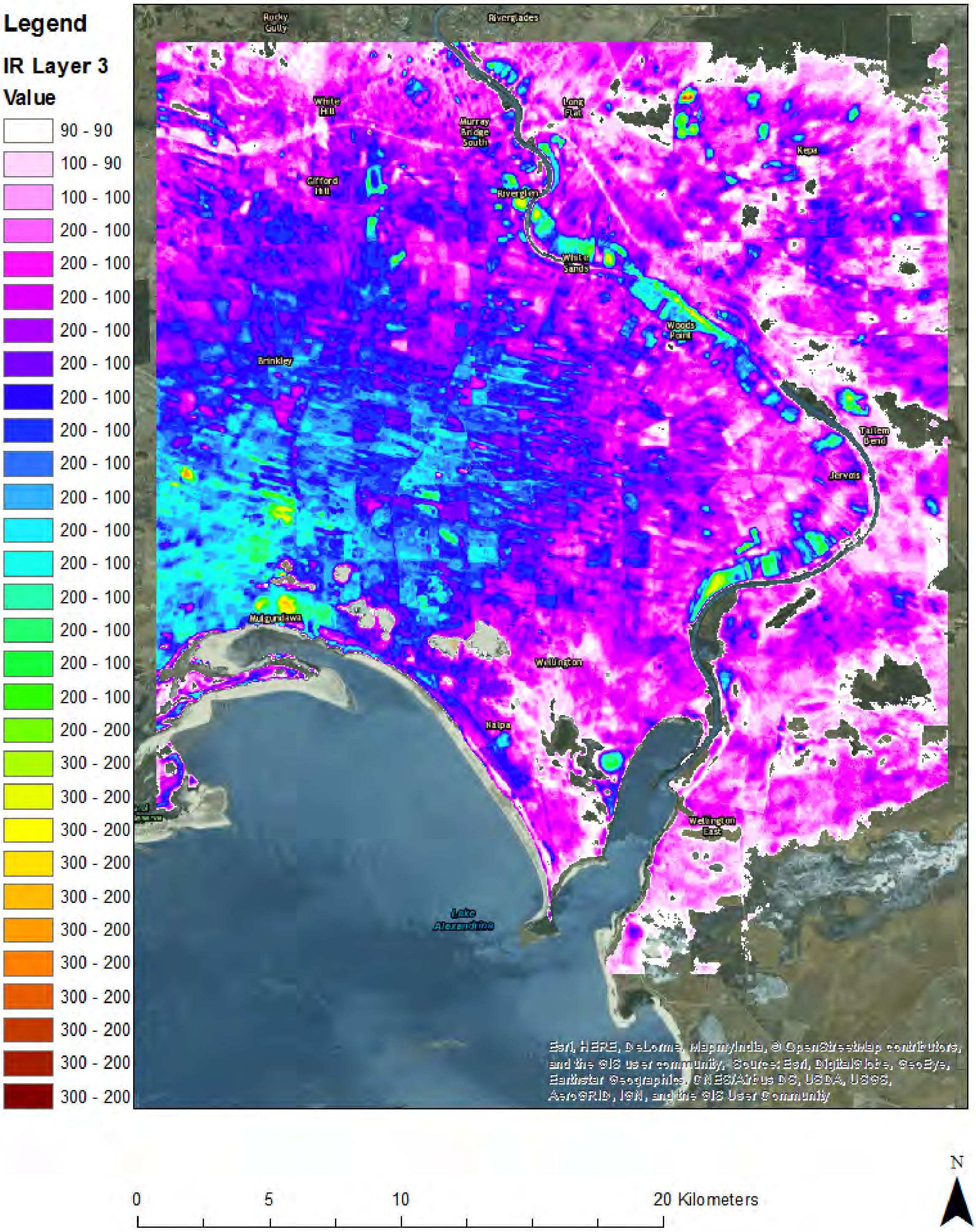
What do you think of university partnering with start-ups to give opportunities of internship in space startups?

The speed of startup is really fast. You don't want anything to slow you down. I'm open to have student for internships, but they have to be the best, hardworking, independent and fast. If the university could screen the students to make sure they have the right skills for the space start up environment it would be great.

Appendix B



Georectified IR map of the Murray-River region. Higher IR values, associated with vegetation vigor, are shown at the red end of the spectrum. (Bathgate et al., 2017).



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Participants of the Southern Hemisphere Space Studies Program Program 2017