MSc Program
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CubeSats and Space Diplomacy: Accelerating Development by Utilizing the International Space Station for Earth Observation Satellite Deployment

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 15.06.2016

Affidavit

I, **BORIS BRKOVIĆ**, hereby declare

1. that I am the sole author of the present Master's Thesis, "CUBESATS AND SPACE DIPLOMACY: ACCELERATING DEVELOPMENT BY UTILIZING THE INTERNATIONAL SPACE STATION FOR EARTH OBSERVATION SATELLITE DEPLOYMENT", 131 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

Satellite technology, especially satellite Earth observation, can be a central tool to foster the achievement of the Sustainable Development Goals (SDGs). As the SDGs are aspiring to create change on a global level a reliable global network is necessary to support it. This thesis argues that a suitable network, when considering satellite technology, already exists and that it can be found in the global diplomatic network in general and within the United Nations Office for Outer Space Affairs (UNOOSA) in particular. To operationalize the full potential of UNOOSA to act as a mediator of diplomatic efforts of its Member States this thesis draws on the concept of science diplomacy. Building on the concept, the term space diplomacy and its three elements- space in diplomacy, diplomacy for space, and space for diplomacy- are defined. By analysing the Japan-UNOOSA experience and putting it in relation to the development of space technology in Ethiopia the thesis concludes that UNOOSA, together with its initiatives, can be utilized as a mediator of space diplomacy efforts of its Member States ranging from basic space science to small satellite deployment.

In light of the JAXA/UNOOSA KiboCUBE programme, this thesis analyses the current technology level and Earth observation applications of CubeSats and identifies trends in the global development and growth of such projects. To this end a survey is performed including all known CubeSats which were deployed form the International Space Station (ISS) since the first deployment in October 2012 until early 2016. One of the central findings is that the subsystem technologies used are rather advanced, while some progress is still necessary in the arias of attitude control systems. The current capabilities of CubeSats with respect to potential employment in Earth observation missions with a focus on vegetation measurements are assessed. Evaluating the possibilities of CubeSats to cope with the requirements set for such measurements leads to the conclusion that constellations of 3Unit CubeSats are developing into powerful tools for monitoring global, regional and local vegetation phenomena, with the central promise of combining the temporal resolution of GEO missions with the spatial resolution of LEO missions.

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List of Abbreviations

AAAS	American Association for the Advancement of Science
ADCS	Attitude determination and control system
ARVI	Atmospherically Resistant Vegetation Index
ASUSSR	Soviet Academy of Sciences
BCT	Blue Canyon Technologies
BPSP	Basic Plan on Space Policy
BSSI	Basic Space Science Initiative
BSTI	Basic Space Technology Initiative
CISAC	Committees on International Security and Arms Control
COPUOS	Committee on the Peaceful Uses of Outer Space
CSTP	Council for Science and Technology Policy
DLR	German Aerospace Center
DropTES	Drop tower experiment series
EAAS	East African Astronomical Society
EORC	Entoto Space Observatory and Research Centre
EPIC	Earth Photosynthesis Imaging Constellation
ESA	European Space Agency
FDRE	Federal Democratic Republic of Ethiopia
FVC	Fractional Vegetation Cover
GA	United Nations General Assembly
GPP	Gross primary production
GTP II	Second Growth and Transformation Plan (Ethiopia)
GVI	Green Vegetation Index
HSTI	Human Space Technology Initiative
IAA	International Academy of Astronautics
IAU	International Astronomical Union
ISRO	Indian Space Research Organisation
ISS	International Space Station
ISU	International Space University
ISWI	International Space Weather Initiative
ITER	International Thermonuclear Experimental Reactor
IUSSTF	Indo-US Science and Technology Forum

IVIS	Integrated Vegetation Interferometer Spectrometer
J-SSOD	Japanese Experiment Module Small Satellite orbital Deployer
JAXA	Japan Aerospace Exploration Agency
JICA	Japanese International Cooperation Agency
JST	Japan Science and Technology Agency
KACST	King Abdulaziz city of Science and Technology
KIT	Kyushu Institute of Technology
LAI	Leaf Area Index
LDCs	Least Developed Countries
METI	Ministry of Economy, Trade and Industry (Japan)
MEXT	Ministry of Education, Culture, Sports, Science and Technology (Japan)
MoA	Ministry of Agriculture (Ethiopia)
MOFA	Ministry of Foreign Affairs (Japan)
MOST	Ministry of Science and Technology (Ethiopia)
NAS	US National Academy of Sciences
NASA	National Aeronautics and Space Administration
NATO	North Atlantic treaty Organisation
NDVI	Normalized Differential Vegetation Index
NRCSD	NanoRacks CubeSat Deployer
OAD	Office of Astronomy for Development
ODA	Official Development Assistance
PNST	Post-graduate study on Nano-Satellite Technology
PRI	Photochemical reflectance index
PS0	Planet Scope 0
PS1	Planet Scope 1
PS2	Planet Scope 2
Roscosmos	Roscosmos State Corporation for Space Activities
SATREPS	Science and Technology Research Partnership for Sustainable Development program
SAVI	Soil-adjusted vegetation index
SDGs	Sustainable Development Goals
SKA	Square Kilometre Array
SNR	Signal-to-Noise Ratio

SSTL	Surrey Satellite Technology Ltd
STSG	Space Technology and Science Group
SWIR	Shortwave infrared
TAQNIA	Technology Development and Investment Company
TCARI	Transformed chlorophyll absorption reflectance index
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
UNECA	United Nations Economic Commission for Africa
UNECLA	United Nations Economic Commission for Latin America and the Caribbean
UNESCAP	United Nations Economic Commission for Asia and the Pacific
UNESCWA	United Nations Economic Commission for Western Asia
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation
UNOOSA	United Nations Office for Outer Space Affairs
VARIgreen	Variable Atmospherically Resistant Index
VNIR	Visible and near-infrared
ZARM	Center of Applied Space Technology and Microgravity
ZGIP	Zero-gravity instrument project

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It is hard to express the gratitude I feel towards Mr. Lorant Czaran, Dr. Werner Balogh, and Mr. Niklas Hedman. These UNOOSA officials have awaken my passion for space and have supported my research on the topic for the past three years. Their insightful comments and constructive criticisms throughout different stages of my studies were thought provoking and helped me focus my approach. I am grateful to them for holding a high standard for this and my previous research, forcing me to do my best. They have been a constant source of inspiration and motivation and one of the main reasons I truly believe in the organization they represent.

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1. Introduction

1.1. Space technology in support of sustainable development

In the early 19th century French author Marcel Proust wrote:

> *"A pair of wings, a different respiratory system, which enabled us to travel through space, would in no way help us, for if we visited Mars or Venus while keeping the same senses, they would clothe everything we could see in the same aspect as the things of the Earth. The only true voyage, the only bath in the fountain of youth, would be not to visit strange lands but to possess other eyes, to see the universe through the eyes of another."*

Light and radio waves are electromagnetic energy that make up a part of the electromagnetic spectrum. Visible light is only a small part of this spectrum ranging from about 400 to slightly over 700 nanometres (see Appendix 1). The author, at that time, could not have imagined how right he would be in regards to the possibilities that science and technology have brought to humankind. Today the voyage of discovery does not only consist of seeking new lands, but in having new eyes. Through space based satellite technology, we have gained wings in form of solar panels, our respiratory system consists of the storage and downlink capacities, while our new eyes are advanced sensing instruments allowing us to see beyond the physical limitations of our senses.

Since August 14th 1959 and the first image taken by Explorer 6 we have "new eyes" but what seems to be missing is a vision. In today's multipolar world, humankind is faced with *wicked* problems, and such a problem *cuts* in all directions. In other words, a wicked problem is Crosscutting, Unresolved, Transnational, and Science-based (Copeland, 2015). In the globalisation era in which *"the most profound challenges to human survival- public heath, food security, alternative energy sources, to name a few- are rooted in science and driven by technology"* (Copeland, 2009) the United Nations and its Member States have set out on defining a new set of goals and international agreements which will counter the volatility, uncertainty, complexity and ambiguity of the problems we are faced with. In 2015 the international community witnessed three landmark events which have established this 15-year framework: Sendai Framework for Disaster Risk Reduction, the Sustainable Development Goals (SDGs), and the Paris

Agreement. Through these three initiatives we have entered a new era, the Post-2015 development era.

The SDGs form an intergovernmental development blueprint consisting of 17 goals (see Appendix 2) and 169 targets. From the eradication of poverty and hunger, gender equality, to the fight against climate change and the mitigation of disasters these goals *"seek to build on the Millennium Development Goals and complement what they did not achieve."* (UN doc. A/RES/70/1, p. 1) These goals being a result of a General Assembly resolution have been accepted by all countries and stakeholders and are intended to stimulate action, through collaborative partnership, over the next 15 years in areas crucial for humanity and our planet.

The Sendai Framework is a result of three years of negotiations and consultations between UN Member States, civil society and other stakeholders. Ten years after the adoption of the Hyogo Framework for Action the document agreed upon in Sendai builds on its predecessor and aims to achieve *"the substantial reduction of disaster risk and losses of lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries."* (Sendai Framework, p. 12) To achieve such a result there has to come to a substantial reduction in- global disaster mortality; the number of people effected globally; direct economic loss in relation to global gross domestic product (GDP); damage to crucial infrastructure and basic services- and extensive increase and enhancement of- the number of countries with local and national disaster risk reduction strategies; the availability of and access to multi-hazard early warning systems and disaster risk information and assessment to people; international cooperation with developing countries to complement their implementation of the framework (ibid).

Under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC) the Paris Agreement was adopted and is intended to govern greenhouse gas emissions, adaptation and mitigation efforts, and finance. According to Article 2 of the Agreement the joint efforts aim to strengthen the global response to the threat of climate change, in the context of sustainable development, by preventing the increase of global average temperatures of 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1,5°C above pre-industrial levels. Furthermore, humankind's ability to adapt to the adverse impacts of climate change is to be increased and climate resilience and low greenhouse gas emissions development is to be fostered, in a manner that does not threaten food production (UN doc. FCCC/CP2015/L.9/Rev.1).

The post-2015 development agenda, cohesive in its content and universal in form, will require effective, improved and innovative tools to support its implementation. Among those tools are the ones offered by space science and technology, which could act as both an enabler and a catalyst for the efforts of countries with regard to progressing towards the internationally agreed Sustainable Development Goals (UN doc. A/AC.105/1063). Advancing international cooperation in the peaceful uses of space science and technology and increasing the use of space-derived data and information are at the core of international efforts for harnessing the benefits of outer space for development in the post-2015 framework (ibid).

The Committee on the Peaceful Uses of Outer Space (COPUOS), the primary United Nations body for coordinating and achieving international cooperation in space activities, in its contribution to the United Nations Conference on Sustainable Development, emphasized the value and the significance of space-derived information and recognized that space-derived geospatial data formed a resource that could be used to support sustainable development policies at local, national, regional and global levels, especially through the establishment of dedicated spatial data infrastructure (ibid). This is far from the only recognition of the importance of space-based technologies in the sustainable development agenda by the UN framework. At the United Nations Conference for Sustainable Development, better known as RIO +20, paragraph 274 of the outcome document "The future we want" states:

"We recognize the importance of space-technology-based data, in situ monitoring, and reliable geospatial information for sustainable development policy-making, programming and project operations. In this context, we note the relevance of global mapping and recognize the efforts in developing global environmental observing systems… We recognize the need to support developing countries in their efforts to collect environmental data." (UN doc. A/CONF.216/16)

Additionally, in its resolution 68/75 the General Assembly:

"Emphasizes that regional and interregional cooperation in the field of space activities is essential to strengthen the peaceful uses of outer space, assist States in the

development of their space capabilities and contribute to the achievement of the goals of the United Nations Millennium Declaration…"

1.2. Space based technology, UNOOSA and the SDGs

The post-2015 agenda has been set by the United Nations and its Member States, therefore this thesis is focusing on the role of the United Nations Office for Outer Space Affairs (UNOOSA) as it is the only General Assembly body dealing exclusively with international cooperation in the peaceful uses of outer space.[1] As it will be presented in Chapter 3, UNOOSA is facilitating the access and capacities to use composite geospatial analysis and disaggregated layers, focusing on thematic clusters such as water, agriculture, infrastructure, human settlement, health or employment, biodiversity and ecosystems. The paragraphs bellow will provide a brief overview on how space technology, UNOOSA's work and promotion of Earth observation is directly and indirectly linked to the achievement of the 17 SDGs.[2]

The Office's thematic activities and its national capacity building efforts on topics that include remote sensing, satellite navigation, satellite meteorology, tele-education and basic space science for the benefit of developing countries are activities that complement *SDG 1- ending poverty in all its form everywhere*.

The focus of SDG 2 is to *end hunger, achieve food security and improve nutrition, and promote sustainable agriculture*. UNOOSA works jointly with UN entities not only to promote the use of space-based information and resources, but to develop capacities and tools for the active and sustainable participation of Member States in this process. The special report of the Inter-Agency Meeting on Outer Space Activities entitled "Space for agriculture development and food security" (A/AC.105/1042) discusses remote sensing and other space-based applications for weather monitoring and forecasting, monitoring agricultural production, desertification, irrigation, new methods of soil management, especially precision agriculture, addressing droughts and floods and other

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[1] This focus is not intended to undermine the importance of other intergovernmental bodies, such as GEO, CEOS, Eyes on Earth etc. which have space related mandates and are of curtail importance for integrating space based applications for the achievement of the SDGs.

[2] The discussion in this Subchapter are based on the author's interpretation of the information gained during his participation in a series of meetings between the Academic Council on the United Nations System and UNOOSA in preparation of the "Vienna Vision: Peaceful, Prosperous and Sustainable World" and reports A/AC.105/1042, A/AC.105/1091, and A/AC.105/1063.

adverse conditions. Additionally, the Office is engaged in capacity building activities in this area.

In attaining SDG 3- *ensure healthy lives and promote well-being for all at all ages*- space technology has provided its usefulness in a sectorial context, with public health being a prime example of a sector in which the use of satellite communications and remote sensing is both a reality and a need. The UN-Space report A/AC.105/1091 had a focus on Space for Global Health. The report presented tools provided by space science and technology that can assist public health stakeholders in planning, research, prevention, early warning, alerts and health care delivery. Additionally, information gained from Earth observation satellites has increasingly been used to study disease epidemiology, enabling increased use of spatial analysis to identify the ecological, environmental, climatic and other factors that can have a negative effect on public health or can contribute to the spread of diseases. The ISS also serves as a platform for health studies.

For SDG 4- *ensure inclusive and equitable quality education and promote long lifelong learning opportunities for all*- UNOOSA, through its United Nations Programme on Space Applications (see Chapter 3.3.), organises workshops and meetings providing unique opportunities for bringing together experts in space science and technology, decision makers and practitioners to share their experiences and knowledge with the aim of having space-based data used for sustainable development as widely as possible. Capacity-building through long-term education is specifically provided by the regional centres for space science and technology education.

UNOOSA strives to achieve SDG 5- *gender equality and empower all women and girls*- by encouraging increased participation of women in the capacity-building missions and other activities organised by the Office.

Remote sensing applications for water management are crucial for the achievement of *SDG 6- ensure availability and sustainable management of water and sanitation for all.* From space optical and radar instruments can identify any changes in area, while spectrometers can measure water quality. Applying various algorithms to the water colour we can decipher the complex mixture of pollutants, suspended sediments and living and decomposing phytoplankton contributing to it. Measurements of soil moisture through microwave satellite technology can be used in various applications in agriculture, climate research, environmental science etc. These are only some of the many water related applications of satellite remote sensing. Through UN-SPIDER (see Chapter 3.2.), the Office assists countries in drought monitoring through the use of space technologies.

Earth observation satellites enable the mapping of available solar radiation by monitoring the spatially and temporally highly variable clouds and aerosols that impact it. Solar power mapping allows continuous assessment of Earth's solar resources through which appropriate locations for photovoltaics can be identified. In a similar fashion, information gained by satellite Earth observation can be used for the selection of right locations for wind farms. It is evident that these applications can contribute to SDG 7- *ensure access to affordable, reliable sustainable and modern energy for all.*

In most developing countries, the economic sector relies on the primary sector of the economy, such as agriculture, fishing, and extraction of resources (mining), rather than on the tertiary sector (service sector) as is the case in many western economies. To achieve SDG 8- *promote inclusive and sustainable economic growth and decent work for all*- new and innovated methods for making the most of the primary sector, while at the same time developing the secondary and tertiary sectors of the economy, need to be implemented. As can be seen in the examples for the other SDGs, satellite-based remote sensing can provide many of these sectors with the information needed to increase their productivity and use the resources more efficiently.

Space science has led to the creation of numerous scientific developments and discoveries many of which are technologies originally developed for space exploration purposes but are now used in common daily life on Earth. Solar refrigerators (which can be used to preserve life-saving vaccines), miniaturised portable sensors for monitoring metabolic health, portable water purifiers for remote locations, scratch resistant lenses, and temper foam are only some examples of so called spin-off technologies. Next to being a $330 billion industry (Space Foundation, 2015), through such spinoffs the space sector is in line with SDG 9- *build resilient infrastructure, promote industrialization an foster infrastructure*. Concerning the sustainability of the space environment and thereby space industry and other industries rallying on space technology, COPUOS has established a Working Group on the Long-term Sustainability of Outer Space Activities.

UNOOSA fosters international cooperation for increased use of space derived data and information for planning and decision-making, as well as facilitates cooperation among developed and developing countries. The activities of the Office in general contribute SDG 10- *reduce inequality within and among nations.*

Through remote sensing tools we can measure and monitor patterns of land use, its change, and development. By applying models, projections about future trends in human settlements and urbanization can be made. This information is central for city planners, architects, landscape architects, engineers, policy makers and many other stakeholders. In 2013, UNOOSA has organised an open Information Session on the topic "Space and Disaster Risk Reduction: Planning for Resilient Human Settlements", thereby presenting the benefits of space based information to what is now SDG 11- *make cities and human settlements inclusive, safe, resilient and sustainable.*

In the context of SDG 12- *ensure sustainable consumption and production patterns*- Earth observation has proven to be a reliable tool for resource management. Remote sensing is broadly used for the development of various maps: land cover, vegetation maps, soil maps, geology maps. Furthermore, the data can be applied to watershed management, biodiversity management, to combat desertification, and many other areas.

The effects of climate change have threatened the achievement of the MDGs. To ensure environmental sustainability, UNOOSA, in the implementation of SDG 13- *take urgent action to combat climate change and its impacts*- enhances capacities to employ space-derived data to monitor processes and trends on a global scale for informed decision-making within their respective mandates, and jointly coordinate Earth observation through global climate, ocean and terrestrial observing systems.

Given the scale of world oceans, satellite Earth observations proves to be the most cost-effective, comprehensive and continuous solutions for marine and ocean monitoring. Such observations yield regular systematic reference information on the state of the oceans and seas that is indispensable for the achievement of SDG 14- *conserve and sustainably use the oceans, seas and marine resources for sustainable development.*

Earth observation can help evaluate the nature and extent of illegal logging and mining or of wildlife crime, enabling repeated observation of large areas. Therefore, space-based technologies are also of significant importance for attaining SDG 15- *protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.*

As the Secretariat of COPUOS, UNOOSA works to ensure long-term sustainability of outer space activities and fosters the inter-relationship and dialogue among major space-faring nations and emerging space nations relating to increased use of space science and technology for the benefit of developing countries. The Office contributes to the enhancement of global governance and institutional development of international mechanisms in addressing the evolving space agenda thereby contributing to SDG 16- *promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective accountable and inclusive institutions at all levels.*

As argued by UNOOSA officials regarding SDG 17- *strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development-* the contributions of space technology are two-fold. Firstly, data and information from space informs behavioural changes and policy- and decision-making in support of sustainable development, and, secondly, data and information from space allow us to assess the progress in achieving the targets established for reaching the SDGs. UNOOSA promotes international cooperation for increased use of space-derived data and information in the planning and decision-making process; works to enhance regional and international knowledge sharing in fields of space technology; and assists developing countries in building capacities to use space-based data and technologies.

1.3. Problem statement

Although space technology enjoys broad recognition it is yet to market itself as the useful tool it truly is and expand its reach to those most affected, the developing and least developed countries (LDCs) (see Appendix 3). While there is a general understanding that space should be used for the benefits of all humankind, we can see that its use is unequal and only a fraction of countries is utilizing it effectively. During the past decade an increasing number of emerging countries have expressed their interest in developing indigenous space hardware. Through the advancement of microelectronics and the introduction of Commercial-Off-The-Shelf (COTS) equipment these countries have been brought closer to their goal as both the development time and the overall cost of developing very small satellites, such as CubeSats, have been substantially reduced. Therefore, this thesis sets out to explore opportunities, which have become possible through the introduction of CubeSats (see Chapter 4), for developing and integrating, into the decision-making process, indigenous Earth observation data in low-income countries. However, despite the positive technological advances, a developing country aspiring to venture into space is still faced with numerous challenges, which can in many cases only be overcome through international cooperation.

The Government of Japan together with UNOOSA has launched the "United Nations/Japan Cooperation Programme on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module (Kibo)" (short "KiboCUBE"). The intention of the programme is to utilize the ISS Kibo for the world by providing developing countries with the opportunity to deploy, from the ISS Kibo, CubeSasts, which they develop, manufacture and operate (UNOOSA, 2016). In light of the establishment of the KiboCUBE programme, this thesis will study, through a highly interdisciplinary approach, possibilities for cooperation between developed space faring nations and LDCs based on the concept of science diplomacy (see Chapter 2). The research question of this thesis will be the following: Can the mandate and existing initiatives of the United Nations Office for Outer Space Affairs (UNOOSA) be utilised as a platform for science diplomacy/space diplomacy efforts of its Member States? The research question is pursued in the context of operationalizing space technology for contributing to the achievement of the SDGs in general and through CubeSat deployment in particular.

The World Development Report on "Agriculture for Development" recognised agriculture as being one of the central factors for achieving the Millennium Development Goals of poverty reduction and environmental sustainability (Naik et al., 2013) and today agriculture remains a key element for the achievement of the SDGs (1, 2, 3, 6, 10 and 13) and is encompassed in both the Paris Agreement (Article 2b) and the Sendai Framework (para. 28b). With this in mind the projections that arable land is to decline even further, with an increasing food grain, while the number of people in rural areas will decrease, are of a great concern. New, more productive ways of agriculture needed to contra-weight these changes. One of the methods to achieve this is seen in the use of Earth observation data. Therefore, the secondary element of this thesis will be to assess the capabilities and limitations of CubeSats for Earth observation missions in general and vegetation monitoring in particular. The significant role of spatial imagery in improving crop management, especially in developing countries, and the quality of agricultural data will be highlighted and the application of CubeSat derived data underlined. However, in developing countries farmers, crop consultants, extension agents and other stakeholders are not aware of what is available, how to extract information from imagery, nor of its economic value. Consequently, this thesis argues that the indigenous development of basic space technology can foster both the integration of such data into the decision-making process and the bridging of the gap between the various stakeholders.

The thesis will build on previous CubeSat surveys (Bowmeester & Guo, 2010; Wollert et al., 2011; Selva & Krejci, 2012) by reviewing all CubeSats which were deployed from the ISS since the first deployment in 2012 until early 2016. The detailed investigation will be limited to CubeSats carrying an optical Earth observation payload. The Committee on Earth Observation Satellites (CEOS) identifies 29 measurements relevant to Earth observation missions, this thesis will focus on the nine measurements of the subcategory “vegetation”. Given that CubeSats carrying optical Earth observation instruments will be considered, the analysis of the individual measurements will be restricted to such instruments. The ongoing open debate regarding freely available vs. commercial satellite data will not be a part of the discussion, rather the benefits of merging the two will be explored.

1.4. Methodology

In order to answer the open questions and reach the aspects of this thesis the qualitative method of literature research analysis and quantitative method of technological surveying is applied throughout the work. To be able to reach a comprehensive illustration of the state-of-the-art, the basis for argumentation is excerpted from specialist journals, monographs, newspapers, scientific online sources, legal documents, UN documents, and other sources. Given the interdisciplinary nature of the thesis, expert interviews have been conducted with relevant stakeholders active in these fields. Consequently, the thesis entails both primary and secondary sources. Furthermore, a research visit to Addis Ababa, Ethiopia, has been conducted and will serve as a case study in this thesis. The scientific fields taken into consideration range from natural science, technology, politics, diplomacy, law, to economics. The scientific added value is that the findings of various disciplines are combined in a praxis oriented manner. This thesis aims to re-combine the inputs from the wide range of sources and disciplines mentioned above leading to a new set of possibilities for international scientific, diplomatic, and development cooperation.

1.4.1. Interviews

The following expert interviews have been conducted for the purposes of this thesis:

- Dr. Werner Balog, Programme Officer, UNOOSA (04.02.2016)
- Mr. Lorant Czaran, Program Officer, UN-SPIDER (16.03.2016)
- Dr. Yasushi Horikawa, former Executive Director, Space Applications Mission Directorate, JAXA (24.02.2016)
- Ms. Mika Ochiai, International Affairs Division, JAXA (24.02.2016)
- Mr. Ueta Atsushi, Adviser/Researcher, Permanent Mission of Japan to the International Organizations in Vienna (24.02.2016)
- Mr. Darly Copeland, author of "Guerrilla Diplomacy" and former Director of Strategic Communications, Department of Foreign Affairs and International Trade (Canada) (12.04.2016)
- Mr. Asegid Adane Mebratu, Project Manager, UNIDO Ethiopia (15.04.2016)
- Mr. Haileyesus Belay, Researcher at Water Resource and Irrigation Engineering Department, Addis Ababa Institute of Technology (15.04.2016)
- Dr. Tulu Besha, Head of Earth Observation Division, Entoto Observatory and Research Center (19.04.2016)
- Dr. Kumar Navulur, Senior Director of Global Strategic Programmes, Digital Globe (22.04.2016)
- Mr. Ghion Ashenafi, Electrical Engineer, Entoto Observatory and Research Center (23.04.2016)
- Dr. Rene Griesbach, Project Manager, Planet Labs (02.05.2016)

1.5. Outline

The body of this thesis will be structured into four chapters which will discuss the underlying theoretical, political and technical aspects and create the basis for linking and re-combining these concepts in chapter 6.

Chapter 2 will comprehensively analyse the dominant academic understanding of the concept of science diplomacy. Firstly, the historical presence of the concept will be reviewed depicting its development, decay and recant revival in governmental institutions and strategies. Following this introduction, the three main dimensions of the concept will be highlighted and elaborated: 1) Science in Diplomacy; 2) Diplomacy for Science; 3) Science for Diplomacy. Lastly, the current science and technology diplomacy policies and Basic Space Policy of the Government of Japan will be reflected on. International cooperation in outer space activities which can be traced back to science diplomacy engagements will be used as case examples throughout the chapter showing that the importance of space has placed it in a central role of such diplomatic endeavours.

Chapter 3 will contain detailed description of the role of UNOOSA within the UN system and determine the borders of its mandate. UNOOSA's activities from the previous years will be taken into account to exhibit how, knowingly or not, these are overlapping with the elements of science diplomacy. This chapter will encompass a detailed assessment of UNOOSA's Programme for Space Applications and its three initiatives: Basic Space Science Initiative (BSSI), Basic Space Technology Initiative (BSTI) and Human Space Technology Initiative (HSTI). The chapter will be concluded by comprehensively presenting the KiboCUBE programme and its dimensions.

In the forth chapter the potentials and limitations of state-of-the art CubeSat mission architectures will be explored while at the same time assessing the current capabilities of CubeSats with respect to potential employment in Earth observation missions. The possibilities of CubeSats to conduct certain Earth observation measurements will be investigated and limited to the CEOS measurement subcategories for "vegetation" and these are: chlorophyll from vegetation on land, land cover, Leaf Area Index (LAI), Normalized Differential Vegetation Index (NDVI), soil type, vegetation canopy cover, vegetation canopy height, vegetation cover, and vegetation type. The chapter will build on previous CubeSat surveys (Bowmeester & Guo, 2010; Wollert et al., 2011; Selva & Krejci, 2012) and analyse satellites, carrying an Earth observation payload, that were deployed from the ISS. To this end, a comprehensive survey of all satellites that have been deployed from the ISS since 04.10.2012 to 10.05.2016 has been conducted.

The fifth chapter will discuss the Ethiopian case study. The goal is to assess the country's space related activities in regards to public awareness, the participation in international space related organisations, educational opportunities and human capital, the integration of Earth observation into the governmental decision making process, the gaps between scientists and the government, the existing ground based space hardware, and the country's aspirations and technical possibilities for indigenously creating space-based hardware. The role and potential of CubeSat development and the data gained from CubeSat constellations will also be explored. To be able to categorise the space activities in Ethiopia the Space Participation Metric and Space Technology Ladder will be applied to the various space related activities currently undertaken in the country. Furthermore, the chapter will briefly outline how these activities and those that are planed can benefit from UNOOSA's initiatives.

Lastly, the sixth chapter will bring together the seemingly different elements discussed throughout the thesis and propose a framework for *space diplomacy*, which is to be understood as a subset of science diplomacy. By observing the Ethiopian case the potential of such a concept to foster the development of basic space technology and bridge the existing gaps while at the same time neutering and improving international relations will be exhibited. The demonstration of potential direct and indirect benefits of the ISS and CubeSat technology in regards to the SDGs will be both technical and political, national and international.

2. Science Diplomacy

2.1. Science diplomacy: a renaissance for humanity

The term 'science diplomacy' is relatively new and embodies the synthesis of two, when isolated, distinct elements (Turkian et al., 2015). Scientists are in the business of establishing truth, while as a 17th century ambassador, Sir Henry Wotton, memorably defined a diplomat as *"an honest man sent to lie abroad for the good of his country."* (The Royal Society 2010, p.1)

On the one hand, we have *science* which is an evidence-based form of knowledge acquisition with inherent values- honesty, uncertainty, respect for evidence, transparency and candidness, meritocracy, liability, open-mindedness and regard for opposing views- it is ideally neither political nor ideological (Dehgan & Willian, 2012). Turkian et al. (2015, p.4) describe the scientific ethos very well when stating that: *"it promotes merit (through peer review); openness (through publication); and civic values and citizen empowerment (through the encouragement of respect for diverse perspectives)."*

On the other hand, traditional *diplomacy* encompasses state representatives transcending the business of government among and between themselves (Copeland, 2011). This non-violent approach to the management of international relations is characterised by dialogue, negotiations, compromise, it involves the skill of dealing with people in a tactful and delicate way (Turkian et al., 2015).

The values of science can be linked to political goals, such as sustainable development, improved governance, transparency, the rule of law. At the same time, it must be clear that science diplomacy differs from international scientific cooperation due to the virtue of its direct relationship to government interests and objectives. The global nature of science and the universal right of its practice regardless of a country's economic or technological status (Quevedo, 2013) provides diplomats with an opportunity to leverage science as a tool of *soft power*. The concept is founded upon mutuality and common cause, with the relationship being a central motivator for the cooperation. Dehgan and Willian (2012, p. 2) rightly noted that: *"Science diplomacy is not the relationship itself, but provides the scaffolding essential for the relationship to thrive."*

The concept behind this fairly new term ‘science diplomacy’ could be followed back to 1723 when the Royal Society appointed Philip Zollman as Foreign Secretary with a role to maintain regular correspondence with scientists overseas to ensure that the fellows remained up-to-date with the latest ideas and findings. However, something big had to happen for science diplomacy to cross into the mainstream of foreign relations (The Royal Society, 2010). World War II was the milestone in the integration of science and foreign policy. In 1941, Sir Charles Galton Darwin was made Director of the Central Scientific Office in Washington thereby becoming the UK’s first accredited scientific representative abroad. Only one year later, Joseph Needham was appointed Head of the British Scientific Mission in China (Turekian et al., 2015).

Next to Great Britain the United States also has a long history of scientific appointments to the government. The first entity that was created in light of the militarisation of nuclear technology was the CIA’s Office of Scientific Intelligence in 1949 and the Office of Science Adviser and Special Assistant to the Secretary of State in 1950 (Pincus, 2014). In 1958 Switzerland sent its first science attaché to the United States whose central task it was to observe and report on the development and potential use of nuclear technology (Schlegel, 2014). For the Federal republic of Germany, the dispatching of scientists cleared the road towards the international arena and scientific endeavours were one of the key ingredients for the improvement of inter-state relations (Fähnrich, 2013).

Shortly after the end of WWII official diplomatic relations stagnated in course of the Cold War and scientific collaboration became one of the few means of international discussions and a constant thread of communication. Essentially scientists were talking while diplomats were silent. The concept of science diplomacy seemed very promising and was supported by both the US and SSSR. This could be seen in president Reagan’s address to the nation in 1985: *“We can find, as yet undiscovered avenues where American and Soviet citizens can cooperate fruitfully for the benefit of mankind… In science and technology, we could launch new joint space ventures and establish joint medical research project.”* For this thesis it is worthy pointing out that the theme of space ventures was explicitly mentioned in this historic speech. Regan’s speech was based on facts, as previous successful collaboration in the Apollo-Soyuz Test Project (see Fig. 1) has proven that the US and Soviet Union can fruitfully cooperate in outer space activities even during times of tense relations between the two countries. In the Apollo-Soyuz Test Project astronauts from both sides learned the foreign language, astronaut Thomas Stanford said that he wanted to talk with his Russian colleagues in their mother tongue: *"When I added up the hours later, I found that I spent more time studying Russian than doing any other type of training for Apollo-Soyuz."* (Howell, 2014) This is not an isolated example of outer space activities bridging the Cold War divide. The signing of a bilateral Soviet-French agreement on space studies in 1966 made the implementation of dozens of projects possible, culminating in a series of joint space flights in 1982 (Sokolov et al., 2014). More recently after some years of strained relations the Indo-US Science and Technology Forum (IUSSTF) was established in 2000 by the two countries (Neureiter & Cheetham, 2013). It paved the way for renewed collaboration between NASA and ISRO enabling two U.S. payloads to be included on India's Chandrayaan mission. However, it must be noted that not all science diplomacy is devoted to the achievement of a greater good. Covert operations involving Pakistan, Iran, China, North Korea, and Libya on missile-propulsion technologies would be one of the negative examples (Copeland, 2011).

Fig. 1, 15.07.1975 Astronauts Donald Slayton (USA) and Aleksej Leonov (SSSR)

Other organisations which have been of particular importance for the development of science diplomacy were the North Atlantic treaty Organisation (NATO) that set up a science programme in 1957, the US National Academy of Sciences (NAS) and the Soviet Academy of Sciences (ASUSSR), these two institutions were the ones which ran parallel Committees on International Security and Arms Control (CISAC) throughout the 1980s (The Royal Society, 2010). The communication established and nurtured between these scientists laid the fundament for dialogue between President Reagan and Gorbachev.

After several years of radio silence in the official practice of science diplomacy, following the end of the Cold War, recently a renewed interest could be observed within multiple governments- especially in the United States, the UK and Japan. Posts that go in line with the concept have been re-establishing and integrated in international strategies. Former US Secretary of State, Hillary Clinton, said that: *"Science diplomacy and science and technology cooperation…is one of our most effective ways of influencing and assisting other nations and creating real bridges between the United States and* *counterparts."* (Clinton, 2009) The US government created, or re-created, the post of Science and Technology Adviser to the US Secretary of State back in 2000. The UK government followed this lead and set up a Science and Innovation Network (SIN) in 2001 aiming at linking science more directly to its foreign policy priorities. The staff of SIN, in the first eight years of its existence, has been active in forty cities in twenty-five countries, and worked alongside other diplomats and representatives of the UK. Finally, Japan has integrated science diplomacy through formal policy on the subject in 2007, to which I will come back in greater detail in Chapter 2.4. (The Royal Society, 2010).

2.2. Practice to theory - theory to practice

Dr. Nina Federoff (ibid, p. 2), former Science and Technology Adviser to the US Secretary of State, views science diplomacy as *"the use of scientific interactions among nations to address the common problems facing humanity and to build constructive, knowledge based international partnerships."* In light of these recent developments the American Association for the Advancement of Science (AAAS) in collaboration with the Royal Society set out to bring together experts from the international scientific and foreign policy community to discuss the role of science as a source of *soft power* in foreign policy. This thesis will use the findings of the AAAS discussions and the compilation of Davis' and Patman's (eds. 2015) "Science Diplomacy: New Day or False Dawn?" to define the scope of science diplomacy. The just mentioned book reaffirmed the finding of the AAAS meeting where the concept was broken down into three useful elements. To establish the connection with the theme of this thesis I will use the three stages of the International Space Station (ISS) Agreement as an example for the practical operationalization of the three elements of science diplomacy.

2.2.1. Science in diplomacy

Science in diplomacy has a priority of ensuring the effective uptake of high quality scientific advice by policy makers. It is the provision or application of scientific knowledge expertise and findings into the policy and decision making process from the inside (Copeland, 2015). In this element the scientific community should provide policymakers with the most recent information on the dynamics of the Earth's natural and socio-economic system, while pointing out the existing uncertainties in the evidence base, to secure that informed decisions are made at the national and the international level (The Royal Society, 2010).

The increasingly complex S&T-related issues and demands the world is facing in the 21st century cannot be fully addressed without*:*

"1) understanding the science driving the challenge; 2) developing the technical institutions to disseminate information and knowledge about the challenge; and 3) engaging with technical experts. As such decision makers need access to both highly qualified people and timely and relevant information." (Turekian et al. 2015, p.15)

The weight does not rest purely on the shoulders of the scientific community which is required to communicate their work in an accessible way and with sensibility to the wide political and policy context, international policy makers are supposed to meet the scientific community half way and acquire a certain amount of scientific literacy. This in itself opens up the possibility to practice science diplomacy as the improvement of the scientific literacy of delegations from developing countries is particularly important when such highly technical issues that the world is facing today are being discussed (The Royal Society, 2010).

The mechanisms of science in diplomacy can be observer on the example of the ISS. With the fall of the Soviet Union both the USA and the Russian Federation were quick to sign the 1992 agreement Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes, which also included an agreement to have their astronauts fly on-board each other's vehicles. Shortly after this bilateral agreement was formed, negotiations started on including Russia in the plans of building an international space station. They were invited to sign the ISS agreement in 1993 which set out three phases. The first phase relates both to the element of *science for diplomacy* and *diplomacy for science* as it was designed so that the United States could learn from the experience of Russian long-duration spaceflights, as the Russian Federation already had a space station named "Mir" (in English "Peace"), which would additionally enable the US diplomats to integrate the newly available information into further negotiations. The US Space Shuttle Atlantis was fitted with a Russian docking mechanism and everything was setup for nine shuttle flights to Mir between 1995 and 1998 (Payette, 2012). The basis of further negotiations depended on the scientific input the respective governments received during phase one of the ISS agreement.

2.2.2. Diplomacy for science

Diplomacy for science "seeks to facilitate international cooperation whether in pursuit of top-down strategic priorities for research or bottom-up collaboration between individual scientists and researchers." (The Royal Society 2010, p.9) The interaction between scientists and diplomats can be central to the advancement of the scientific enterprise. The first dimension of this area is of particular importance when it comes to large flagship projects that are far outside the budgetary possibilities of one single state. Examples for such investments would be the already mentioned International Space Station (ISS), the Large Hadron Collider at CERN, the Square Kilometre Array (SKA), International Thermonuclear Experimental Reactor (ITER) (Holt, 2015; Turekian et al., 2015). To reach such milestones the cumulative knowledge of the scientific community must be brought together, and here diplomatic engagement can speed up and ease the process (O'Reilly 2014).

In the second dimension diplomacy for science can be implemented in smaller projects when negotiations to reassure or justify the scientific engagement are needed. Bottom-up collaboration between various institutions and individuals are happening on a daily basis and the results of the strengthening of personal and professional relationships at this level is proving to be essential in driving S&T research and innovation (Turekian et al., 2015). If a German biologist studies biodiversity in the Brazilian rainforest, he/she must get permits from Brazil. If a French archaeologist wants to collect and analyse ethnographic material from a foreign country, he/she must get the approval of the country in question. If a Cuban medical team visits a country for testing a new drug created for the needs of that region it must get the clearance for multi-country trials. Good diplomats are necessary to get the exchanges approved, facilitate immigration, sponsor international conferences, grant visas etc. (Nichols, 2015). In a real life example NASA's SAFARI 2000 programme, which gathered a large amount of satellite imagery of South Africa, created high-level political interest which almost led to the termination of the project during a governmental debate. In the case of SAFARI 2000 diplomatic engagement by US diplomats prevented the project from being terminated (Annegarn & Swap, 2014).

Coming back to the ISS, the second phase of the agreement began in 1998 when the ISS partners (Canadian Space Agency, European Space Agency, Italian Space Agency, Japan Aerospace Exploration Agency, NASA, and Roscosmos) formalized their plans by signing a series of intergovernmental agreements and memoranda of understanding. These documents were created as a part of a series of multilateral negotiations. The international framework agreement which was created made it possible for the space agencies to tap into the potential of scientific cooperation as a unifying tool (Payette, 2012). As Julie Payette (2012, p.1), a former astronaut who flew tow space missions aboard the Space Shuttle for the construction of the ISS, fittingly wrote: *"The building of a scientific laboratory in the harsh environment of lower Earth orbit- is as much a foreign policy and human achievement as it is a technical one."*

2.2.3. Science for diplomacy

Science for diplomacy is *"the use of science to help build and improve international relations, especially where there may be strain or tension in the official relationship."* (Turekian et al. 2015, p.17) The attractiveness and influence of science as a national asset and a universal activity transcending national interests is used as a form of soft power. Here non-governmental scientists and academics play a key role in diplomacy and international policy by fostering the development of trust and agreement between nations in the absence of formal government to government relations (ibid). Scientists can build genuine contacts and through the achievement of concrete results mutual trust grows among them and through this the scientists can reassure wary political leaders of the value of their close relations (Nichols, 2015). During the Cold War while international relations between the two blocks were strained and diplomatic discussions non-existent, scientists continued to collaborate, there was a cultural exchange, a line of communication, American and Russian scientists shared the Antarctic ice station, they were working together on arms control etc.

The different types of science for diplomacy include: *) Science cooperation agreements; *) New institutions; *) Educational scholarships; *) 'Track two' diplomacy- is used to attract those working outside official negotiations; *) Science festivals and exhibitions (The Royal Society, 2010).

At present during the new low in US-Russia relations the third element of science diplomacy can be observed within the third phase of the ISS agreement- its operation. The official languages of the Space Station are English and Russian (the US and Russian astronauts learn the foreign language as part of their training), and it is controlled from the ground by two main mission control centres, one at NASA Johnson Space Centre in

Houston, and one operated by the Russian Space Agency in Korolev. There are additional control centres in Japan, Germany, and Canada. That the ISS is a model of science for diplomacy can be seen by considering that despite political tensions, that have reached a new peak since the Cold War, the ISS starting from the construction, the 24/7 operation of the station, over the manned missions that take place 365 days a year, has remained an area which has not had an on-board scuffle or major international incident (Payette, 2012).

2.2.4. The paradox of Science Diplomacy

Science and Technology, and with it science diplomacy, can be interpreted as a powerful two-edged sword. The paradox lays in the conception that on the one hand it can provide the solutions to so many tenacious problems, while on the other it can be used for control and military supremacy. It can both foster security and development, and insecurity and underdevelopment (Copeland, 2015). For example, while satellite Earth observation has been used to spot violations of arms agreements or to stop early massing of troops, at the same time it has been use for gathering critical intelligence for destructive military purposes. Dependent on its use S&T can be a vector of hard power or a vector of soft power. Joseph Nye (2004) famously recognises soft power and its importance when referring to soft power as the ability to assert an influence through attraction rather than through means of hard power that uses military and economic resources to effect the actions of other nations. The starting point of S&T is positive as science is generally viewed as a vector of soft power. Still, technology, as a tool in the hands of mankind, is related more closely to the possession and use of power, than science (Copeland, 2010a). Through the nature of the argument one can claim that the way the technology is implemented will decide which one of the two blades will cut.

As many R&D breakthroughs have emerged from military programmes or as spinoffs of military technology the foundation of these technologies are based on hard power. From the paragraph above it should be clear that for science diplomacy to be successfully practiced a transformative pattern of the strategic purpose of various technologies in areas of soft power should be followed.

2.3. Japan’s S&T diplomacy and space policy

2.3.1. Mainstreaming of Japan’s S&T diplomacy policy

Being among the pioneers of the revitalization of science diplomacy the Government of Japan is the first one to integrate it as a policy. It was perceived as so significant that the task did not fall on the Ministry of Foreign Affairs (MOFA), which usually formulates and implements diplomatic policy, but it was presided by the Prime Minister. The Prime Minister’s Council for Science and Technology drew up the policy while closely cooperating with MOFA (Yakushiji, 2009).

Japan’s aspiration towards contributing top-class science and technology capabilities in Asia and Africa can be seen as a strategy to affirm its technological development as a soft power diplomatic resource (Yakushiji, 2009). However, there is another bias to these actions. The government has become aware that it will not be able to hold on to its leadership position when it comes to R&D. Through the rise of the BRICS[3] and the growing research capabilities in these and other countries it is highly likely that Japan’s relative strength in technology will decrease in the globalized world (Sunami, Ganacgum & Kitaba, 2013). It is to work against this backdrop, where the increased interest in science and technology diplomacy is rooted. The policy makers in Japan have identified the growing science base that lays beyond its own borders and have therefore demarcated the primary objectives of S&T diplomacy as a mechanism to tap into this growing science base (Sunami, Ganacgum & Kitaba, 2015).

The S&T policy cannot be discussed without considering a broader strategy of Prime Minister Abe’s office. The overarching governmental priority is the reasserting of Japan’s industrial competitiveness through innovation. The growth strategy has three themes: 1) Reconstruction of Industry- encouraging start-ups through innovation and S&T; 2) Creation of Strategic Markets- emphasising the role of innovation in the areas of life science and energy; and 3) Global Strategy- engage Japan in the dynamics of the global economy (ibid).

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[3] BRICS refers to the association of five nations: Brazil, Russia, India, China and South Africa. These are all developing or newly developed countries distinguished by their significant influence on regional affairs and sometimes fast-growing economies.

The predecessors to the S&T diplomacy policy were the government's science and technology basic plans which were revisited every five years since 1996. Already in the first Basic Plan, effective from 1996 to 2000, space activities had a significant importance as engaging in international joint R&D regarding the International Space Station Program was one of the top priorities of the first Basic Plan (ibid). In general, the first as well as the second Basic Plan referred to Asian countries as the main target for international cooperation.

Yakushiji (2009) identifies three essential starting point regarding S&T diplomacy in Japan. Firstly, the premium is placed on mutual benefits for Japan and partner nations. Secondly, the synergy effect between diplomacy and science shall be demonstrated. Thirdly, Japan should support the foundations of science and technology in new regions of Asia and Africa through the use of Official Development Assistance (ODA).

The culmination of these developments lead the government of Japan to make the concept of science and technology diplomacy official in 2008 through the Council for Science and Technology Policy's (CSTP) report, "Towards the Reinforcement of Science and Technology Diplomacy." The policy defines science and technology diplomacy as *"any steps taken to link science and technology with foreign policy so as to achieve their mutual development…to utilize diplomacy for the further development of science and technology and promote efforts to utilize science and technology for diplomatic purpose."* (ibid, p.3) The document also describes the basic policies for promoting science and technology diplomacy (Sunami, Ganacgum and Kitaba, 2015):

1) The system should be set up in a way in which Japan and it counterparts can enjoy mutual benefits.
2) Synergies between S&T and diplomacy should be developed in light of the global issues facing mankind.
3) Developing "human resources" that sustain S&T diplomacy.
4) Increasing Japan's international presence.

There has been a noticeable development and broadening of the focus of science diplomacy engagement that came with the new policy. It can be seen in the fact that the focus is now not only set on Asian countries and technologically advanced nations, but that the newly adopted policy requires the country's science diplomacy to strengthen S&T

cooperation with developing countries for resolving global issues as well as developing human resources in these countries. The cooperation should utilise Japan's advanced S&T capacities as a basis for promoting S&T diplomacy. This is a well calculated step made in the midst of the accelerating growth of emerging economies, and given that global issues are the centre peace of these collaboration efforts Japan is utilising its S&T as a soft power (Yakushiji, 2009). In addition to this the Working Group behind the policy identified cooperation with developing countries to be valuable to the revitalization of Japan's science community, it is thought that activities in such dynamic nation can stimulate Japanese researchers and can have a positive influence on the wider R&D sector (Sunami, Ganacgum & Kitaba, 2013). This marks a new era as Japan is advancing from just transferring technologies overseas to strategically using S&T for diplomacy while at the same time presuming an international development agenda and domestic strengthening of the S&T infrastructure (Sunami, Ganacgum & Kitaba, 2015).

2.3.2. From ODA to development cooperation

Japan is the 2nd largest aid donor in the world. The government of Japan has provided over $200 billion to development in the last 30 years through its official assistance program. (The World Bank, n.d. a) Through Official Development Assistance Japan has assisted developing countries and contributed to the improvement of social development and the welfare of people in these countries. Although Japanese S&T researchers were dispatched to the countries in question, people in the S&T sphere gave little consideration to diplomacy when they collaborated on international projects (Yakushiji, 2009; Sunami, Ganacgum & Kitaba, 2015). Equally, Japan's diplomats have not thought of using Japan's S&T as a diplomatic tool. For decades a gap between these two actors existed without them being strategically linked together.

To make the most of its ODA contributions and bridge the existing gaps the government of Japan moved towards *development cooperation* which it defines as: *"international cooperation of the government and its affiliated agencies including official development assistance, for the main purpose of development in developing countries and regions."* (MOFA, 2015) The development cooperation should reflect Japan's principles: 1) extending cooperation based on a whole-of-a-nation approach, including the private sector and local government communities; 2) extending the scope of cooperation not limited to that of past ODA; 3) building mutually beneficial relations through equal partnerships with developing countries (ibid).

Following the emphasis on S&T diplomacy policy on cooperation with developing countries accelerated by the move towards development cooperation through ODA, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and MOFA launched a new program named *Science and Technology Cooperation on Global Issues* in 2008. The program consists of two subprograms: The Dispatch of Science and Technology Researchers program and the Science and Technology Research Partnership for Sustainable Development (SATREPS) program (Sunami, Ganacgum and Kitaba, 2013).

The Dispatch programme revolves around the needs of a partner country and the most suitable researchers in Japan are dispatched to developing countries as experts of the Japanese International Cooperation Agency (JICA) to engage in joint research projects previously selected by MEXT and the Japan Society for the Promotion of Science (JSPS). The main aim of the program is to make substantial international contributions through joint research that is expected to develop new technologies and the research capacity of Japan and its counterpart countries (JSPS, n.d.).

The procedure works as follows, the MOFA and JICA are the recipients of a request from developing countries for the ‘Dispatch of S&T Researchers’. Together with the MEXT the request is reviewed, after approval the dispatch procedure is started. The targeted countries are all countries which are listed as Japanese ODA recipients (see Appendix 4). Additionally, while dispatched researchers may apply for intellectual property rights on the results of the joint research the application may not disadvantage the research institution in the host country. Similarly, researchers may publish the results of their joint research and copyright their papers for the purpose of promoting scientific advancement in Japan and the counterpart country (ibid). These procedures reassure the parties involved of the objective of mutual benefits.

Next to the dispatch of S&T researchers, SATREPS is the second program that promotes joint research with developing countries. The starting point of the program is that global issues humanity faces today- climate change, infectious diseases, natural disasters etc. - cannot be tackled by one country alone. Developing countries are in many cases most vulnerable to such issues and have a need for research and development based on local requirements to enhance their own capacity to handle these issues (SATREPS, n.d.).

In SATREPS, the Japan Science and Technology Agency (JST) and JICA work together, while collaborating with ODA, to achieve the following aims: 1) International Cooperation- the goal is to enhance international cooperation between Japan and developing countries; 2) Addressing Global Issues and Advancing Science- creating innovations by acquiring new knowledge and technology aimed at resolving global issues; 3) Capacity Development- advancing independent R&D capacity in developing countries, training future human resources in developing countries, creating networks between researchers, and constructing sustainable research systems (ibid).

2.3.3. Japan's Basic Space Policy

Japan can be credited with *"more than five decades of achievements in human spaceflight…and produces sophisticated launchers, satellites and robotic devices to equal the world's best."* (Moltz, cited in Peoples 2013, p.1) After four years of planning, in 2012 Japan restructured its administrative organs related to the development and use of space. The purpose of such an administrative reform was to make space policy a whole of government strategy (Anan, 2013). Furthermore, Japan's space development should promote the use of space as a diplomatic and foreign policy tool (Kallender-Umezu, 2013). The paragraphs below will outline Japan's Basic Space Policy and the latest Basic Plan on Space Policy (BPSP). As the essence of this thesis revolves around satellite Earth observation in developing countries and science diplomacy special attention will be dedicated to elements considering these topics.

Three focal points of Japan's space policy have been designated through the 2012 reform:

1) *The Cabinet Office* is in command of the whole of government space policy herby replacing MEXT as the main policy planer (Anan, 2013). The Office has the authority to coordinate all other space-related government organs (Kallender-Umezu, 2013).

2) *The Committee on National Space Policy* drafts the Basic Space Plan and disseminates budgetary prioritization to the ministries. The amendments allow the

Committee to get involved in the maintenance and management of satellites and equipment (Anan, 2013).

3) *Japan Aerospace Exploration Agency* (JAXA) is the core space agency supporting the development and use of space. The law instructs that the programs of the space agency should now be aimed at applications that reflect user needs (Kallender-Umezu, 2013). MEXT continues to work as the competent ministry of JAXA and holds responsibility for the finances and personnel of the space agency. Through the amendment the Cabinet Office has gained authority to partake in the jurisdiction of JAXA. The Cabinet Office can oversee JAXA through the Prime Minister who has become one of the competent ministers of the space agency (Anan, 2013). The Ministry of Economy, Trade and Industry (METI) has also gained significant input and program jurisdiction through the reform and is now able to promote its own programs using JAXA's extensive engineering talent. From an operational point of view, the amendment allows JAXA to go beyond its previous R&D limitations and assist and advise on new projects initiated by the private sector. JAXA can now work flexibly for each ministry's administrative purposes (Kallender-Umezu, 2013).

The latest Basic Plan on Space Policy (BPSP) was established on January 25th 2013 by the Strategic Headquarters for Space Policy and is placed at the most fundamental level for Japan's development and utilization of space. The Basic Plan covers a 5 year period starting from fiscal year 2013. JAXA's Mid-Term Goal is based on the BPSP. In the Basic Plan (2013, p. 5) it is stated that:

> *"Space utilization should be promoted hereafter in fields of critical importance to the industry and human life…for this purpose, government-supported research and development should be conducted in a manner that outcomes of such research and technology contribute to sophistication and improve efficiency of the industry, administration and people's lives."*

Six basic pillars for Japan's development and utilization of space formulated in the Basic Space Law are reaffirmed in Article 2.4. of the BPSP:

1) *Peaceful use of space*- Before the revision in 2012 Japan's space policy has interpreted the idea of peaceful purposes much more restrictively and has not

allowed passive military uses of space. This was argued to keep Japan's space policy not only in line with the Outer Space Treaties but with Article 9 of the Japanese Constitution which is also known as the "peace constitution". (Peoples, 2013) *"Japan has used the Basic Space Law to move from a policy of exclusively non-military uses of space to one of non-aggressive uses of space that can include military components."* (ibid, p. 137)

2) *Improvement of people's lives*- Space activities have already become an indispensable basis for everyday life. By exploiting the maximum potential of outer space activities a positive effect on people's lives is to be expected.

3) *Development of industry*- The number of employees in the Japanese space industry has dropped by 30% in comparison with the latter half of the 1990s. The sales have also experienced a decline from over 350 billion yen (≈$3,1 billion) in the 1990s to about 260 billion yen (≈$2,3 billion) at the time the BPSP was written. The satellite market is dominated by the U.S and European companies, while the rocket launching services are led by Europe and Russia followed by China and India.

4) *Prosperity of human society*- Advances in R&D will prompt new technological breakthroughs contributing to a better lifestyle and dynamic future.

5) *Promotion of international cooperation*- Japan's recognition stemming from the significant contributions on the international level should be utilized as a diplomatic asset in order to conduct *space diplomacy*. In the BPSP it is pointed out that the joint operation of satellites and data sharing can establish a harmonious relationship beneficial to both Japan and a partner. The government is urged to learn the needs in other countries by taking the following measures: bilateral cooperation agreements, export financing, trade insurance, financial aid through Official Development Assistance, and activities via diplomatic activities abroad.

6) *Consideration for the environment*- It is recognised that the utilization of space offers potential for solving global energy and environmental problems. In the same time the activities leading to the utilization of space should be environmentally friendly including that of outer space.

When looking at satellite remote sensing the BPSP recognises the market size of satellite data which is approximately 100 billion yen (≈$900 million) globally and 10 billion yen (≈$90 million) in Japan. The foreign demand to be acquired includes earth observation satellites which are currently in *"growing demand particularly in emerging countries"*. (ibid, p. 31) The demand, especially in emerging countries, is characterised by an increasing need for not only the provision of satellites but also human resource development, technology transfer and other services which are supposed to be supplied as a total package (ibid).

The long term goal of Japan is to provide continuous data acquisition using the same (or same type) of sensor and to improve the frequency of imaging and to thereby expand the application of remote sensing in broader fields. The government will also support industry, administrative bodies, universities, etc. to perform empirical research that can lead to new applications of satellite data. At present MEXT is working on the development of large satellites for research while METI is working on small commercial satellites. The BPSP advises the ministries to employ ultra-small satellites to streamline their system to provide images and cut costs (ibid). Moreover, in the articles concerning the strategic development and utilization of space the BPSP identifies the decrease of the size of satellites, including ultra-small satellites, as a measure to be taken to expand the range of users. This development is interesting for the purpose of this thesis since further utilization of CubeSat technology is suggested in the BPSP.

Concerning the promotion of space diplomacy, the BPSP recognises that for the improvement, expansion and deepening of multinational communication and cooperation the United Nations should be utilized. Negotiations relevant to diplomacy will be handled by the Cabined Office and the MOFA (Anan, 2013). In response to the rapidly increasing needs of developing countries for space infrastructure it is necessary to operationalize Japan's space system and world class know-how as a tool for diplomacy with special consideration to the specific needs of individual countries. In order to meet these needs the BPSP advises that JAXA, JICA and the relevant ministries and agencies should provide support for human resource development, technology transfer, and space agency establishment by the central government of the recipient country in addition to supplying of satellites in the form of the above mentioned *total package* (BPSP, 2013). Additionally, it is advised for the government to support the overseas business expansion by taking effective approaches including the employment of ODA. By using most of the diplomatic establishments abroad and JAXA overseas liaison offices close contact with foreign research institutions, persons of significance, and international organizations shall be maintained (ibid).

Japan has put its policies to practice. SATREPS, since its formation in 2008, has implemented 99 projects in 43 countries and 44 joint research projects in 26 countries are currently in progress. The country has promoted joint research with developing countries, by including state-of-the-art S&T cooperation as part of ODA, providing them with capacity building needed to answer present global issues, they have cooperated on the basis of equal partnership with East Asian countries in the context of the East Asian Science and Innovation Area (Sunami, Ganacgum & Kitaba, 2013), with developing countries through SATREPS and the Dispatch of S&T Researchers program, and have entered into research cooperation in cutting-edge technology with technologically advanced countries. Furthermore, Japan has managed to effectively utilize the international structure set up within UNOOSA and facilitate international cooperation in space science and technology, this will be further elaborated on in the following chapter.

3. UNOOSA and the road to Low Earth Orbit Satellites

3.1. UNCOPUOS and the Secretariat

Before humankind began exploring the near earth orbit and the vastness of the universe, theoretically according to the *usque ad sidera* principle, every state was allowed to have sovereign rights over its own portion of outer space. However, as soon as Sputnik 1 penetrated the atmosphere of the Earth on October 4th 1957, the theoretical right crumbled. As Caseese (2005) argues, the technological and military supremacy of the two superpowers, USSR and USA, trumped the principle mentioned above and as a consequence outer space was seen as free to explore and open to everybody. The transition from *usque ad sidera* to *res communis ominum* could have happened in those 90 minutes that were necessary to ensure that the satellite, Sputnik 1, has orbited the Earth.

Realising that by these actions an entire new area has become operational the United Nations were quick to react and in 1959 the General Assembly set up the Committee on the Peaceful Uses of Outer Space (COPUOS) to review the extent of international cooperation in the peaceful uses of outer space, to devise programmes in this field to be commenced under United Nations auspices, to support continued research and dissemination of space-related information, and to consider legal issues resulting from the exploration of outer space (Lala, 1998). Put in shorter terms COPUOS (hereinafter "Committee") is to govern the exploration and use of space for the benefit of all humanity: for peace, security and development. At its establishment the Committee had 24 members, today it has grown to be one of the largest Committees in the United Nations with 83 Member States, and a large number of relevant international organizations which have an observer status with the Committee (UNOOSA, n.d. a). The Committee has two sub-committees: Scientific and Technical Subcommittee (STSC) and Legal Subcommittee (LSC).

The formation of international space law begun with the 1963 Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space which consequently led to the consideration, negotiation and adoption of five major multilateral treaties, which, one could claim, are the most significant developments undertaken by the Committee: 1) 1966 Treaty on Principles governing the Activities of

States, Including the Moon and Other Celestial Bodies, known as the Outer Space Treaty formed the fundament for all the following treaties; 2) 1968 the Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (Rescue Agreement); 3) 1972 convention on Liability for Damage Caused by Objects Launched into Outer Space (Liability Convention)- the success of this convention is that it is, next to the Outer Space Treaty, the only treaty in international law that calls on state liability, on *absolute* state liability for damage caused by a space object on the surface of the Earth or to aircraft in flight, this also encompasses the state's liability for actions of private entities; 4) 1974 Convention on Registration of Objects Launched into Outer Space (Registration convention)- according to which states and international intergovernmental organisations that agree to abide the Convention are required to establish their own national registries and provide information on their space objects to the Secretary-General for inclusion in the United Nations Register; 5) 1979 Agreement Governing the Activities of States on the Moon and Other Celestial Bodies (Moon Treaty)- the treaty provides that the Moon and its natural resources are the *common heritage of mankind*. Next to the five treaties, four sets of legal principles have been formulated: 1) 1963 Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space; 2) 1982 Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting; 3) 1986 Principles Relating to Remote Sensing of the Earth from Outer Space; 4) 1992 Principles Relevant to the Use of Nuclear Power Sources in Outer Space.

The decisions of the General Assembly concerning the peaceful uses of outer space and those of the Committee are implemented by the United Nations Office for Outer Space Affairs (UNOOSA). One of the central reasons for establishing UNOOSA in 1962 was the coordination of mankind´s space activities at international level. Its role is to support the work of the Committee and to implement a multifaceted programme that covers the legal, scientific and political aspects of space-related activities. The Office works closely with national space agencies, international space organisations, the private sector, non-governmental organisations and media (UNOOSA, 2011). For over 50 years UNOOSA has provided practical assistance on the use of space technology for peaceful purposes throughout the world, through its workshops, initiatives, fellowships and regional centres. Given the rapid advances in space technology and the constant evolution of the space agenda each of the Subcommittees, as well as COPUOS, meet annually under the administrative arm of the Committee, UNOOSA, to monitor and discuss these developments.

Several United Nations entities routinely use space-derived geospatial data, which constitute a vital source of essential information for a wide range of mandated activities (Brkovic & Kristof, 2015). During the contract period between 2008 and 2013, the Department of Field Support, the Department of Peacekeeping Operations, the Department of Political Affairs and their field missions collectively spent $12 million on system contracts, while other entities of the United Nations system spent approximately $3 million (United Nations, 2014). Processed data and information are shared among United Nations entities and made available through websites such as *ReliefWeb*, a global hub for time-critical humanitarian information on complex emergencies and natural disasters, the *Global Disaster Alert and Coordination System*, *UNITAR/UNOSAT*, the *Inter-Agency Standing Committee's Common and Fundamental Operational Datasets Registry* and the UN-SPIDER operated *Knowledge portal* (UN doc. A/AC.105/1063).

UNOOSA´s role is in fact more in coordination, promotion and enhancement of the cooperation among Member States and different UN agencies. Therefore, one of the goals of UNOOSA is standardisation and better coordination of usage of space data. One such initiative is *UN-Space*, which is an inter-agency meeting on outer space activities, with the aim of promoting synergies and preventing duplication of effort related to the use of space technology and applications in the work of United Nations entities (ibid). The main concern of UNOOSA is to bring experts together, who will afterwards create networks of their own. Additionally, UNOOSA can offer managerial assistance to help build a national chain: data gathering – interpretation – decision –reaction - reflexion.

Through UNOOSA the United Nations provides a forum for countries, international organisations and non-governmental organisations to discuss issues related to the peaceful uses and exploration of outer space (UNOOSA, 2006). The UN Programme on Space Applications has been introduced in 1971 to enhance the understanding and subsequent use of space technology for peaceful purposes in general, and to promote greater cooperation and exchange of actual experiences in space science and technology between industrialized and developing countries as well as among developing countries. The following subchapters will analyse the United Nations Platform for Space-based Information for Disaster Management and Emergency

Response (UN-SPIDER) and the Programme on Space Applications with its three initiatives- 1) Basic Space Science Initiative (BSSI); 2) Basic Space Technology Initiative (BSTI); 3) Human Space Technology Initiative (HSTI). Although in-depth the exploration of the programmes and initiatives will be limited to the extent relevant for the purpose of this thesis.

3.2. UN-SPIDER

Most satellites point inwards towards Earth's surface, rather than outwards towards the vastness of outer space, understanding this the United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) was created to *"ensure that all countries, international and regional organisations have access to and develop the capacity to use all types of space based information"* (UN-SPIDER, n.d.). Earth observation from space is one of the most important sources of information for decision makers that have to react to challenges such as global environment changes and security issues. This information has to be of practical use, it has to be fast and accessible at low cost and be available for their users.

UN-SPIDER was created based on a 2006 GA Resolution to support the full disaster management cycle, to connect the disaster management and space communities while being a facilitator of capacity-building and institutional strengthening, in particular for developing countries (UN doc. A/RES/61/110). The General Assembly was concerned about the devastating impact of disasters (natural or technological), causing the loss of lives and property, displacing people from their homes and destroying their livelihoods, and causing tremendous damage to societies around the world. The General Assembly decided that the programme should work closely with regional and national centres of expertise and to be offered, by Member States, particularly by developing countries (ibid).

Since its establishment in 2006, UN-SPIDER has devoted considerable efforts to building its network of Regional Support Offices (RSOs). The network of RSOs works in close collaboration with UN-SPIDER offices in Beijing, Bonn and Vienna. Joint activities are cross-cutting in UN-SPIDER´s pillar of work: Technical Advisory Missions, training activities and other capacity building measures, ad-hoc emergency support and bridging knowledge gaps in the use of space technologies in disaster risk reduction or emergency response. For example, the RSOs use their expertise to develop tailor-made training material and to conduct one-week training courses with the aim of strengthening the skills of staff in government agencies on the use of specific software applications to process satellite imagery (UN-SPIDER, 2014).

UN-SPIDER aims to bridge the gap between science and practice by promoting useful and operational methodologies on the use of space technologies for disaster risk management. The recommended practices are intuitively accessible in a user-friendly way on the UN-SPIDER *Knowledge Portal*. In addition to the recommended practices, multiple RSOs have elaborated booklets on lessons learnt in using space technologies. Furthermore, UN-SPIDER has been actively working with specific government agencies as a way to promote the incorporation of specific texts in the post-2015 framework, highlighting the use of Earth observations and space-based technologies (ibid). UN-SPIDER also aims to disseminate information for non-specialists. They are often sending out teams for the assessment of a country´s usage of geospatial data and they are helping with implementations of adjustments (Czaran 2016, pers. comm.).

The web-based Knowledge Portal of UN-SPIDER is now a well-established source of information for many practitioners in disaster risk reduction and emergency response (St-Pierre, 2014). The portal provides databases on open source satellite data, derived products and software, as well as compilations of all relevant maps and resources for selected major disasters. Furthermore, management practices are promoted at this portal. They are giving guidance on the use of archived and up-to-date imagery to derive information for disaster risk reduction and emergency response (flood-plain delineation, flood mapping, vegetation monitoring etc.). UN-SPIDER is also strengthening its network of 16 regional support offices (UN doc. A/AC.105/1063).

3.3. Program on Space Applications

Following the recommendation of the first United Nations Conference on Exploration and Peaceful uses of Outer Space (UNISPACE) held in Vienna, Austria, in 1968 the United Nations Programme on Space Applications (hereinafter "Programme") was established. The Programme subsequently became operational in 1971 and is implemented by UNOOSA under the guidance of the United Nations Expert on Space Applications, a special expert position created for this purpose. During UNISPACE II held in 1982 UNOOSA was given a mandate for implementing the Programme. The mandate given by GA resolution 37/90 in 1982 was further broadened and strengthened during in a second GA resolution 54/68 following UNISPACE III in 1999. The, for this thesis, relevant aspects of the mandate are summarised in the subsequent paragraphs.

The Programme has the mandate to support international space cooperation and exchange of actual experiences in space science and technology between industrialised and developing countries as well as among developing countries or industrialised countries. It should assist Member States with capacity building in space science, technology and its applications. Such activities should stimulate the growth of indigenous centres and an autonomous technological base in space technology in developing countries. The Programme is also mandated to disseminate information on space-related activities and to provide so-called technical advisory services, on different aspects of space science and technology and related applications, upon request from Member States. The mandate also encompasses the promotion of cooperation in space applications projects between government establishments, universities and research institutions and private industry (UNOOSA, n.d. b). The Programme is implemented through the organization of conferences, workshops, training courses and other events on advanced space applications and new system developments on a wide range of aspects of space science and technology applications (UN res. 37/90; UN res. 54/ 68). These activities are linked to the Programme's thematic priorities in the fields of: *biodiversity*, *climate change*, *disaster risk reduction*, *global health*, *environmental monitoring and natural resource management*, *global navigation satellite systems*, and *satellite communications* (UNOOSA, n.d. b).

Since it became operational, the Programme has organized approximately 300 training courses, workshops, seminars and conferences and has provided funding support to more than 18000 participants, mainly from developing countries. The Programme also cooperates with academic institutions to offer long-term fellowship programmes (see Chapter 3.4.4.) and provides support to the Regional Centres for Space Science and Technology Education affiliated with the United Nations (UNOOSA, 2012). Through the Programme six Regional Centres for Space Science and Technology Education were established. The Centres are located in the regions that correspond to the United Nations Economic Commissions for Africa (Morocco, Nigeria), Asia and the Pacific (India and China), Latin America and the Caribbean (Brazil and Mexico), and Western Asia (Jordan). To ensure a common standard of teaching at the Centres, the Programme has developed standardized education curricula in the major fields of space applications which are followed in each of the Centres (ibid).

The Programme also implements the already mentioned three initiatives: 1) the Basic Space Science Initiative (BSSI), as space science is the basis for the practical use of space technology applications; 2) the Basic Space Technology Initiative (BSTI), focussing on capacity building in space technology development, particularly in the field of small satellite development- UNOOSA has identified a increasing number of countries that have the capability to develop small satellites and today there are roughly 60 to 80 such countries, with a growing number interested in such activities; 3) the Human Space Technology Initiative (HSTI), that aims to assist countries interested in human exploration of outer space and in the utilisation of space-based research platforms such as the International Space Station.

3.4. Basic Space Science Initiative

Education and research related to the space environment such as astronomy and astrophysics are considered to be one of the first steps towards the establishment of indigenous capacities for the development and use of space technology and its applications (Balogh et al., 2010; UNOOSA, 2012). On this basis in 1991 the Programme on Space Applications launched a long-term effort for the development of basic space science and for international and regional cooperation in this field in form of the BSSI.

The Initiative began by organising a series of workshops in Africa, Asia and the Pacific, Latin America and the Caribbean, and Western Asia from 1991 to 2004. One of the central recommendations from the workshops was that small astronomical facilities should be established in developing countries to facilitate and assist hands-on research and education at the university level (Haubold & Balogh, 2009). Following these recommendations BSSI contributed to the inauguration of small astronomical facilities in developing countries and has developed educational materials for teaching and observing programmes using small optical telescopes in the established facilities (Balogh et al., 2006; Haubold & Balogh, 2009).

The resources for such activities were found in the Japanese Cultural Grant Aid. Since 1982 the government of Japan started providing educational and scientific equipment to developing nations though this Aid programme. As part of the country’s ODA, the Cultural Grant Aid provided reflector telescopes and accessories to Singapore

(1987), Indonesia (1988) and Thailand (1989). Starting with 1991 the donation of the telescopes was facilitated by the BSSI and resulted in the establishment of observatories in Sri Lanka (1995), Paraguay (1999), the Philippines (2000) and Chile (2001). Next to the reflector telescopes, 20 planetaria were donated to countries around the world between 1986 and 2008 (Kitamura, 2004; Haubold & Balogh, 2009).

To guarantee that the equipment is being used efficiently, the government of Japan provided follow-up assistance programmes. As part of the follow-up programme Japanese engineers and scientists spend time in the recipient country to provide training to the staff. Staff members from the receiving institutions also had the opportunity to participate in six-month training courses held in Japan (Kitamura, 2004).

The workshops from 2005 to 2009 were focused on activities related to the International Heliographic Year 2007 (IHY 2007) and the International Year of Astronomy 2009 (IYA 2009). In this period the Programme on Space Applications, through the BSSI, contributed to the establishment of several worldwide ground-based instrument networks (Haubold & Balogh, 2009).

From 2010 to 2012, the workshops focused on the International Space Weather Initiative (ISWI). Numerous space weather instrument arrays have been established through ISWI. These arrays collect data for use in research and education, required for the better understanding of the impact of solar activity on our planet. ISWI led to the establishment of the International Centre for Space Weather science and education in Japan (UNOOSA, 2012).

Currently the BSSI continues to provide support to operators of planetariums, astronomical telescopes, and ISWI instruments (UNOOSA, n.d. c).

3.5. Basic Space Technology Initiative

The workshop on the theme “Small satellites at the service of developing countries”, organized by UNOOSA in cooperation with the International Academy of Astronautics (IAA) was held in the forefront to UNISPACE III. Representatives taking part in the workshop concluded that small satellites are valuable tools for the development of space infrastructure and application programmes. Furthermore, it was recognised that small satellites *“offered and would continue to offer opportunities for international cooperation.”* (UN.doc. A/CONF.184/C.2/L7 1999, p. 1)

There have been a total of 12 UNOOSA/IAA workshops focusing on small satellites at the service of developing countries. More than 750 participants have taken part in these workshops and financial support was provided to participants from developing countries. After analysing the 11 reports (UN doc. A/RES/54/68; A/AC.105/745, 772, 799, 813, 835, 855, 884, 897, 971, 1016) 9 of which were published prior to the establishment of the BSSI the conclusions of the workshops can be summarised as follows:

- The Workshops highlighted the importance of earth observation programmes for developing countries and the benefits of international cooperative efforts.
- All the reports have emphasized the need for greater awareness among the public and decision makers of the potential benefits of space technology applications. The importance of incorporating space into education had a central position in the reports.
- The workshops identified the importance of international collaboration across regions, technology transfer, and on the job training. The benefits for African countries having access to space system development were underlined.
- An increasing number of countries, including developing countries, have established or were in the process of establishing national space programmes during the 9 years observed. This trend was reflected in the reports and it has been recognised that small satellite platforms open the door for developing countries and countries with limited space budgets to participate in such activities and tailor the technology in question to their specific needs.
- An emphasis was set on the technical abilities that can be acquired especially in the areas of microelectronics, micro/manufacturing and miniaturisation. Additionally, the experienced gained can be productively implemented in a variety of other industries.
- The reports reflected on the increasing public availability of the information about space technology and its know-how, specifically also relating to the development of standardized platforms and interfaces such as the CubeSat platforms.
- The development of small satellites has been perceived as feasible even for entities and organisations with comparatively small budgets and modest

infrastructure requirements. The contributions of students and role of universities for developing space assets in developing countries was stressed.

- Small satellite development was recognised as being a steppingstone for enhancing a country's space capacity as the experience gained is in many cases directly linked to the development of larger satellites.
- Small satellites provide new opportunities for international space cooperation. Furthermore, such cooperation can be equal and fully beneficial to all parties involved, whether new entries or established players, as each partner is more likely to be able to offer indigenous capabilities and knowledge given the relatively quick technology innovation cycles of small satellite programmes.

Following these events capacity building in space technology development came increasingly into the focus of the United Nations Programme on Space Applications (Balogh & Haubold, 2009). Therefore, in 2009 UNOOSA distributed a questionnaire and engaged in informal discussions with stakeholders in preparation of creating a basic space technology initiative. One of the questions was *"Which activities should be at the focus of a space technology initiative?"* (ibid, p. 1848) to which replies indicated a strong interest in the development and operation of small satellites.

This trend of countries that have previously been mainly users of space applications to establish basic capacities in space technology development and their growing interest in small satellites, especially CubeSats, has been substantially increased by the miniaturization of consumer-electronic components which started to replace more costly and sometimes less capable space-qualified components resulting in a further reduction of the cost of space technology development. In response to this growing interest in nano- and small-satellite platforms, in line with the mandate of the Programme on Space Applications, UNOOSA launched the Basic Space Technology Initiative in 2009 (Balogh, 2011).

The word *basic* in BSTI came out of the reason that the initiative is not talking about cutting edge high-tech space innovation. When interviewed Mr. Balogh (04.02.2016), Programme Officer for space science and technology in the Space Applications Section of UNOOSA, pointed out that this was done with a background that the results of the BSTI *"could not be mobilised for any military purposes"*, as is perceived to be possible from a space technology initiative. He further elaborated that one should not underestimate the technical capabilities of the matter discussed in this initiative, as many of the components in CubeSats are the most advanced micro technology the market has to offer. Mr. Balogh argued that such a deliberate setting is to be interpreted as a buffer between the two spheres- peaceful use and military application.

The mission of the BSTI is to increase access to and use of space applications in support of policy and decision making for sustainable development by supporting building capacity in basic space technology development, with a focus on the development of nano and small satellites and their applications considering potential contributions to internationally agreed development goals. (UNOOSA, 2009; UN doc. A./AC. 105/983). The initiative has the underlying objectives (UN doc. A/AC.105/2011/CRP.14):

a) Act on the interest of many countries aspiring to establish indigenous capacity in basic space technology development.
b) Address the upward role of small satellites for education, basic space science and operational applications.
c) Assist countries with their efforts to ensure compliance with the legal and regulatory framework and promote the use of appropriate standards where relevant.
d) Promote international cooperation and information exchange in capacity building in basic space technology.

3.5.1. Foundations

The first activities mandated to the BSTI were to conduct a series of international conferences on small satellite programmes for sustainable development. From 2009-2011 the Office for Outer Space Affairs organised three symposiums on this topic in cooperation with the Government of Austria and the European Space Agency (ESA). The role of the symposia was to enhance access to space applications tools for sustainable development by building indigenous institutional capabilities in basic space technology and small satellite technology, and to assist in defining the overall direction of the BSTI (UN doc. A/AC.105/2011/CRP.14; UN doc. A./AC.105/966).

During the first symposium in 2009 participants considered the issues related to small satellite mission planning and implementation. The topic of the second symposium, held in 2010 considered scientific and engineering issues and participants received training in payload, instrument and sensor design. At the final symposium, held in 2011, the focus was set on operational and regulatory issues (UN doc. A./AC.105/966; UN doc. A./AC.105/983, UN doc. A./AC.105/1005).

3.5.2. International Space Technology Conferences

In cooperation with UN Member States, BSTI has organised regional conferences which correspond to the United Nations Economic Commission for Africa (UNECA), Asia and the Pacific (UNESCAP), Latin America and the Caribbean (UNECLA), and Western Asia (UNESCWA). To date three such conferences have taken place, attended by more than 600 professionals, one in each country representing the Regional Centre: Japan, United Arab Emirates, and Mexico.

The symposium in Japan was attended by 290 professionals from 43 countries who have discussed and received training on the topic of the changing architecture, payloads and players regarding nano-satellite[4] technology (UN doc. A./AC.105/1032). At the conference the participants argued that nano-satellites opened up new opportunities with end-user driven applications limited only by the laws of physics. The participants noted that the collaboration with universities was very fruitful and that by these activities the engagement of subcontractors can be limited thereby simplifying programme mission complexity (ibid).

At the UN/United Arab Emirates symposium “Small-Satellite Missions for Developing Space Nations” in 2013 it was emphasized that the International Space Station (ISS) has been used as a launch platform for small satellites. This address created a link between small-satellite development and human space exploration activities (UN doc. A/AC.105/1052).

The participants in the UN/Mexico symposium reflected on the speed at which developments were happening in the field of small-satellite activities and the growing number of operational small satellite missions. Therefore it was also noted that small satellites are space objects in the legal sense and that compliance with national and international space law should be fulfilled especially in regards with relevant GA

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[4] Nano-satellites are very small satellites of total mass between 1-10kg.

resolutions such as resolution 62/101[5] and resolution 68/74[6] (UN doc. A/AC.105/1086).

3.5.3. Space Technology Education Curriculum

As already mentioned above following UNISPACE'82 a network of Regional Centres for Space Science and Technology Education were established. To add to the existing curriculums the BSTI was mandated to develop an education curriculum in aerospace engineering and small satellite development. The regional conferences talked about in subsection 3.4.2. had an additional purpose and this was to provide a setting for educators engaged in the development of the curriculum in question to meet and work on its further formulation. Under the BSTI a survey of world-wide academic programmes in aerospace engineering and small satellite development was conducted and it is anticipated that educators from several institutions listed in that survey (more than 50 institutions from 18 countries) will contribute to the education curriculum (UNOOSA, 2010). The work on the curriculum began in 2012 during the UN/Japan symposium and is planned to be finalized in 2016 (UN doc. A/AC.105/2015/CRP.11).

3.5.4. Long-term Fellowship Programme

The BSTI has, in cooperation with interested academic institutions, established a long-term fellowship programme in aerospace engineering and small-satellite development (Balogh, 2011). In 2011 UNOOSA together with the government of Japan and in cooperation with the Kyushu Institute of Technology (KIT) established the UN/Japan long-term fellowship programme 'Post-graduate study on Nano-Satellite Technology' (PNST) for nationals from developing countries and non-space fairing nations.

Since 2013 the programme has started to accept both doctoral and master degree students with full support through a scholarship covering housing, food, transport and other expenses is provided by the MEXT of Japan (UNOOSA, n.d. d). During the 2015 application round more than 155 potential applicants registered through the PNST website. Presently there are 15 doctorate degree students and 6 master degree students studying at KIT under this fellowship scheme (UN doc.A/AC.105/2015/CRP.11).

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[5] GA res. 62/101 "Recommendations on enhancing the practice of States and international intergovernmental organizations in registering space objects".

[6] GA res. 68/74 "Recommendations on national legislation relevant to the peaceful exploration and use of outer space".

3.5.5. Projects

In its mandate, the BSTI is offered with a framework to support the implementation of regional and international projects related to capacity building in space technology. Currently two projects are being perused, while one was concluded in 2011.

Together with the International Space University (ISU) the Office for Outer Space Affairs developed the elements for a best practice guidebook for small satellite development for organizations and institutions that was subsequently made available and distributed through the BSTI (UNOOSA, n.d. e).

The BSTI is involved and supports the HUMSAT project led by the University of Vigo, Spain. The system is intended to provide a communications service known as “storage and forward”, and the different users of the system will be expected to develop and define their own applications. The space segment of the HUMSAT system is composed of a constellation of 1U CubeSats. The aim of the project is to develop, through the participation of organizations from many countries, a constellation of such satellites to collect data from globally distributed sensor networks (Balogh, 2011; HUMSAT, n.d. a; HUMSAT, n.d. b).

Lastly, in 2015 the government of Japan, JAXA and UNOOSA launched a new project. The cooperation project named “United Nations/Japan Cooperation Programme on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module (Kibo)” (short “KiboCUBE”) intends to utilize the ISS Kibo for the world. The project is a part of both the BSTI and HSTI and is discussed in detail in chapter 3.6.3.

3.6. Human Space Technology Initiative

In 2011, the UN General Assembly declared the 12th of April as the International Day of Human Space flight.

“I am confident that the International Day of Human Space flight will remind us of our common humanity and our need to work together to concur common challenges. I hope it will inspire young people in particular to pursue their dreams and move the world towards new frontiers of knowledge and understanding.” (Ban Ki-moon, 2012)

The year marked the fiftieth anniversary of humankind’s first flight into outer space when Yuri Gagarin opened up a new era of human activity crossing the boundary of Earth's surface and atmosphere. The commemoration within COPUOS resulted in the adoption of the *Declaration on the Fiftieth Anniversary of Human Space Flight*. On the Fiftieth Anniversary of the Committee on the Peaceful Uses of Outer Space, UN Member States emphasized the need to look more closely into how advanced space research, exploration systems and technologies could further contribute to meeting challenges, such as those imposed by global climate change, food security and global health, and endeavour to assess how the outcomes and spin-offs of scientific research in human space flight could increase the benefits, in particular for developing countries (Ochiai et al., 2014).

To make space exploration a truly international effort the HSTI aims to promote the increase of the use of space applications and spin-off technologies in emerging and developing countries as well as to provide a platform to foster collaboration between spacefaring and non-spacefaring countries (UNOOSA, 2015). The activities of the Initiative are based on three pillars: outreach, capacity building, international cooperation.

3.6.1. Outreach

When it comes to the outreach dimension the initiative organizes annual expert meetings and workshops with the goal to raise awareness on the current state-of-the-art of space exploration activities and the benefits of operationalising human space technology and its applications. During the first annual meeting, held in Malaysia in 2011, it was recommended that the Initiative should take action to raise awareness among stakeholders ranging from decision makers in both the public and private sectors, to the researchers and students (UN doc. A/AC.105/1017).

3.6.2. Capacity building

The Capacity Building efforts focus on the fact that the unique environment of microgravity and making use of it through scientific research can provide us with insights into certain phenomena and processes. HSTI is fostering scientific activities aimed at promoting education and research under microgravity conditions around the world and particularly in developing countries. To initiate its capacity building activities HSTI introduced two projects: zero-gravity instrument project (ZGIP) and the drop tower experiment series (DropTES) (UNOOSA, n.d. f).

Through ZGIP microgravity simulation instruments, called *clinostats,* are provided to schools, universities, research centres and institutes around the world free of charge. This is done to motivate research institutes and create a global network of participating institutions in the field of space and microgravity research (Ochiai et al., 2014).

Together with the Center of Applied Space Technology and Microgravity (ZARM) and the German Aerospace Center (DLR), UNOOSA has established the DropTES fellowship programme that allows a selected group of students to conduct their own microgravity experiments at the Bremen Drop Tower. The 146m drop tube enables students to conduct experiments in various fields such as fluid physics, combustion, thermodynamics, material science and biotechnology (Ochiai et al., 2014; UNOOSA, n.d. g).

3.6.3. International cooperation and the KiboCUBE programme

Under the auspices of UNOOSA and its HSTI in 2012 for the first time UN organisations and all five ISS partner agencies jointly discussed how to utilize the ISS for the benefits of humanity (UN doc. A/AC.105/1024). The partners recognised that the ISS, as one of humankind's most remarkable technological achievements, provides unique cooperative opportunities for both scientific and engineering projects (UNOOSA, 2015). HSTI has since continued to bring together and connects various partners from the international community and other UN entities to explore how the largest permanent crewed research facility in space can benefit humanity.

On October 4th 2012, which marked the 55th anniversary of the first satellite launch, Sputnik 1, a new possibility for international utilization of the ISS became active. On this day the first set of CubeSats was deployed from the Small Satellite Orbital Deployer (SSOD) attached to the Japanese Kibo module's robotic arm at the ISS. Space station commander Sunita Williams of NASA described the event as follows: *"Fifty-five years ago we launched the first satellite from Earth. Today we launch them from a spacecraft... Fifty years from now, I wonder where we'll be launching them from."* (Howell, 2012)

Three years after this ISS landmark event, in his address during the 58th session of COPUOS, Japanese Minister-Counsellor Mr. Fukuichiro Tanaka (2015) announced the cooperation programme "United Nations/Japan Cooperation programme on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module (Kibo)" or short "KiboCUBE" programme. In his statement, Mr. Tanaka said that: *"Through this programme, Japan hopes to broaden space activities and applications more equitably for peaceful purposes and facilitate the development of human resources."*

While interviewing JAXA's Dr. Horikawa[7] (24.02.2016), one of the main actors behind the establishment of KiboCUBE, he explained the background of the programme:

"We [Japan] have the capability to deploy a satellite from the ISS and why shouldn't we use this capability to its fullest? We should provide such an opportunity to everybody. The background of starting such an idea comes from the fact that we have many experiments at the ISS- biological, earth observation, astronomic observation, and many others- we invested a lot of funds on the development and operation of the space station. When you spend such an amount of money you have to create certain achievements and outcomes of such an investment and we are looking for various opportunities to utilize the ISS and Kibo is one of these."

Through the KiboCUBE programme UNOOSA and JAXA jointly aim to utilize the ISS Kibo for the world (UNOOSA, n.d. h). At present Kibo is the only option for deploying CubeSats from the ISS.[8] Kibo's exclusive capacity is comprised of an airlock system and a robotic arm. Till date (10.05.2016) 122 CubeSats from numerous countries around the world have been successfully deployed from the ISS. This has significantly contributed to the broadening of space activities and applications and to capacity building in space science and technology. Out of this reason both UNOOSA- in line with the mission and objectives of the BSTI and HSTI- and JAXA along with the Government of Japan are demonstrating their commitments to promote space science and technology in developing countries and raise awareness of the role these technologies play in promoting sustainable development (UNOOSA, 2015).

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[7] Dr. Yasushi Horikawa is a former Executive Director of the Space Application Mission Directorate of JAXA. In 1998 he became a program manager for the Japanese Experimental Module Kibo and in 2002 he was assigned as a space advisor to the president.

[8] Currently there are two deployment devices that rely on the Japanese Kibo module: 1) the Japanese Experiment Module Small Satellite orbital Deployer (J-SSOD), 2) NanoRacks CubeSat Deployer (NRCSD)

3.6.3.1. ISS deployment vs. piggyback launches

Such an initiative provides developing countries with the unique opportunity to design, manufacture and operate their own satellite and thereby build national capacity in spacecraft engineering, design, construction and operation. JAXA on the other hand will launch the CubeSat to the ISS and deploy it from Kibo thereby substantially reducing the cost of such an endeavour to the recipient country. Such an opportunity has additional benefits for the recipient country. Prior to the operationaliztion of the Japanese Experiment Module Small Satellite orbital Deployer (J-SSOD) small satellites of the CubeSat class could only be deployed by rockets as piggyback satellites. What this means is that the small satellites would 'hitch' a ride with the main payload and it would be thrown into orbit after the main satellite is successfully deployed (NASA 2015).

For a satellite to be included as a piggyback payload, it must pass space environment tests, which proves that the satellite in question will be able to survive the harsh environment during launch and its operation in space. One of the tests is the vibration test that simulates vibrations experienced during launch. For the small satellite to be able to share the space with the larger and far more valuable main payload it is required to pass the scrupulous vibration test which simulates vibrations experienced during launch and subject the small satellite to rigorous levels of agitation. An additional hurdle when it comes to piggyback launches is that even after passing the space environment test there is an uncertainty whether or not the satellite is in working order after enduring the vibration of the actual launch (ibid). For countries hoping to lose their 'space virginity' the relaxation of the vibration condition can be game-changing as many entities located in developing countries cannot afford to use expensive aerospace-rated electric parts to pass such a vibration test.

The benefits of a deployment from the ISS are plentiful. Starting from the launch, the piggyback opportunities are limited to launches that have extra weight available other than their main satellite. The advantage provided by the space station is that there are regularly scheduled cargo resupply flights by Japanese, American, Russian and French cargo ships, on which CubeSats can travel more frequently. The main benefit of such a cargo spacecraft is that the small satellite is kept in a soft bag and is buffered with packing material thus significantly reducing vibration levels in comparison to the piggyback launches. This allows engineers and designers to choose considerably cheaper electric components that do not have established space ratings, which in turn will lower the total cost of satellite development. In contrast to not knowing the condition of the spacecraft after the launch, space station deployment allows astronauts aboard the ISS to perform quality checks on the hardware and ensure that the small satellite is not damaged prior to its deployment into space. Furthermore, given that on a piggyback launch the small satellite's ejection is directly affected by the main satellite's timing, the launch via the space station's robotic arm has the advantage of being able to choose the best timing for the small satellite's ejection (ibid).

3.6.3.2. Eligibility

The KiboCUBE programme is open for research institutes, universities, and other public organizations located in developing countries that are Member Sates of the UN and have no means to transport artificial satellites into space and place them into orbit (UNOOSA, 2015). Through the programme, UNOOSA and JAXA will make an "Announcement of Opportunity" (herein after "Oportunity"). Per Opportunity one 1 unit (1U) CubeSat (see Chapter 4.1.) will be selected and the partners undertake to provide its deployment from Kibo. JAXA will bear the costs of launch of the CubeSat to the ISS and deployment from Kibo. In an interview with Ms. Ochiai (24.02.2016) from the International Affairs Division of JAXA, she said that there is an ambition to steadily increase the number of Opportunities they will be able to provide in the near future. Furthermore, Ms. Ochiai pointed out that the limitation of opportunities is additionally influenced by the fact that this programme is presently financed exclusively by JAXA's contributions derived from its budget.

Entities applying for an Opportunity are responsible for the complete development of their 1U CubeSat including the design, manufacturing, test and verification of their CubeSat, as well as its operation and utilization after deployment (UNOOSA, 2015). As Dr. Horikawa elaborated (24.02.2016), the indigenous development of such a 1U CubeSat is *"mainly about providing technological incentives and the process of making a satellite- the powering components, communications and control."* He stressed that such 1U cubic satellites do not have many application functions and that people's lives could hardly be improved through applications they provide, however the *"testing phase can be very satisfying for the interests of new actors in space, such as developing countries...this is a new entrance and an introduction to space activities."*

Given that the recipient entity is to develop the CubeSat, the entity has to fulfil certain eligibility criteria. As written in the first Announcement of Opportunity (UNOOSA, 2015) applying entities must have sufficient capability in the following areas:

- CubeSat development and testing
- Ability to transport the CubeSat to JAXA
- Submission of safety assessment reports
- Coordination of the CubeSat’s radio frequency
- Ability to obtain a license of radio stations
- Development of the ground station facility

During an interview for this thesis Dr. Werner Balogh (04.02.2016), Programme Officer at UNOOSA, highlighted that the BSTI’s focus on education and technology transfer can be additionally mobilised for the purposes of the KiboCUBE programme if the selected entity were to officially request a certain form of assistance. Additionally, technical coordination between JAXA and the selected entity will exist throughout the process.

UNOOSA, together with the Government of Japan and JAXA, has managed to offer through UN-SPIDER, the Programme on Space Applications and its three initiatives an array of opportunities for countries aspiring to enter the space arena. The activities start from awareness raising, followed by capacity building in both the human resource and technological dimension and have now, with the introduction of the KiboCUBE programme, culminated in the opportunity to deploy and operate an indigenously built small satellite.

4. CubeSats and Earth Observation

4.1. Introduction to satellite-based remote sensing

The essence of the principle behind remote sensing is the recording of information about an object without being in direct contact with that object. According to this abstract definition most of us have practiced a form of remote sensing as any photo that we have taken is composed of different colours which are derived from electromagnetic radiation and those colours represent specific ranges of the electromagnetic spectrum. Moreover, we can determine spatial relationships by simply looking at such a photo and determining whether an object is in front of or behind the other, even such a simple action is turning data, the photo, into information, the spatial relationships (Gibbons, 2000).

The two basic methods of conducting remote sensing operations involve on the one hand airspace governed by air law, and the near Earth orbit where air law does not have the attention it otherwise enjoys (Diederiks-Verschoor & Kopal, 2008). From the many definitions of remote sensing the one most relevant to the topic of this thesis[9] can be found in Principle 1 (para. 1) of the "Principles Relating to Remote Sensing of the Earth from Outer Space" which states:

> *"The term "remote sensing" means the sensing of the Earth's surface from space by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resources management, land use and the protection of the environment."*

Remote sensing is a tool that uses sophisticated sensors to measure the amount of electromagnetic energy exiting an object or geographic area. The data is transformed into information by using mathematically and statistically based algorithms (Jansen, 2007). Distinguishing objects through remote sensing methods can entail the consideration of texture information of features on the Earth. Pixels that have the same texture are grouped together, and such a group is considered an object that can represent physical features on Earth. (Benz et al., 2004) Additionally, through remote sensing we can expand the concept of object identification and analyse non-physical features. Such measurements

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[9] The principles set by resolution A/Res/41/65 by the UN General Assembly in 1986, although non-binding, are the only set of principles relating to remote sensing that encompasses all 193 members of the United Nations.

have geographic information but do not represent physical features on Earth (Huang, Jiang & Li, 2001). These techniques draw information from the relevant wavelengths. For example, spectral bands covering frequencies in the near-infrared (NIR) wavelength emphasize vegetation health, while shortwave infrared (SWIR) regions are responsive to moisture content in vegetation, forest canopy and soil (The World Bank, n.d. b). Thus, remote sensing science can provide us with fundamental new information. As Jansen (2007, p.7) elaborates:

> *"(...) remote sensing science is much like surveying, providing fundamental information that other sciences can use when conducting scientific investigations... remote sensing derived information is now critical to the successful modelling of numerous natural (e.g., water-supply estimation; eutrophication studies; non-point source pollution) and cultural (e.g., land-use conversion at the urban fringe; water-demand estimation; population-estimation) processes."*

As this thesis is limited to optical remote sensing it is important to note that optical remote sensing makes use of visible (400-700nm), near-infrared (700-1400nm) and shortwave infrared (1400-3000nm) to form images of the surface. Optical remote sensing depends on the Sun as the only source of illumination who's solar irradiation spectrum, after passing through the atmosphere, has significant remaining energy within the wavelength range from 2,5-3µm. When the solar radiation hits a target it can be transmitted, absorbed or reflected. *"The reflectance spectrum of a material is a plot of a fraction of radiation reflected as a function of the incident wavelength and serves as a unique signature for that material."* (CRISP, n.d.) Each material reflects and absorbs differently at specific wavelengths, in principle this means that we can identify a material from its spectral reflectance signature. Such identification is dependant on the sensor's *spectral resolution* which is the ability to resolve spectral features and bands into their individual components (HORIBA, n.d.). Depending on the number of spectral bands optical remote sensing systems are classified into four types (CRISP, n.d.):

- Panchromatic imaging system: consists of a single channel detector sensitive to radiation within a broad wavelength range. The physical quality which is being measured is the apparent brightness.
- Multispectral imaging system: the sensor has multiple channels each of which is sensitive to radiation within a narrow wavelength band. The multilayer image

which is created contains information on both the brightness and spectral information (colour) of the observed objects.

- Superspectral imaging system: such an imaging system typically has more than 10 channels. As the bands on such a detector are narrower than those on a multispectral imaging system, it enables us to measure finer spectral characteristics of the observed target.
- Hyperspectral imaging system: are also known as imaging spectrometers and acquire images in approximately 100 or more adjoining spectral bands. This precise spectral information allows for even better characterisation and identification of the observed objects.

As elaborated above different surfaces such as water, vegetation or soil reflect radiation differently and therefore have a different spectral signature (see Figure 2). In the case of vegetation, the spectral reflectance curve of healthy green vegetation has a significant minimum of reflection in the visible portion, while it increases in the near infrared portion of the electromagnetic spectrum. The role of chlorophyll is central for this spectral signature. Chlorophyll absorbs light at wavelengths of about 0,45 and 0,67μm and strongly reflects green light. The internal structure of plant leaves cause the high reflectance between 0,7 and 1,3μm. Sensors that measure the reflected energy in the visible and near-infrared region of the spectrum will record, in the case of healthy green vegetation, a week signal in the blue and red region due to the absorption by chlorophyll for photosynthesis, somewhat stronger in the green and very strong in the NIR region due to the cellular structure in the leaves. Stressed vegetation can be identified as the reflectance in NIR is significantly lower than it would be under normal conditions. As the internal structure varies between different types of vegetation the characteristic spectral signature allows us to differentiate between these types. However, this is easier said than done as such variations can be marginal and dependant on many variables. Nevertheless, through hyperspectral imaging systems such measurements have become possible. Additionally, measurements in shortwave infrared (SWIR) allow for additional varying depending on the type of plant and the plant's water content. As water has strong absorption bands around 1,45, 1,95 and 2,50μm, reflectance of leaves in the SWIR region generally increases when leaf liquid water content decreases. This property can be used for the identification of tree types and plant conditions (CRISP, n.d.). The unique characteristics that can be measured by optical remote sensing can provide environmental scientists, agronomists, farmers, crop managers, and other relevant stakeholders with fundamental information regarding the condition of the observed vegetation which should ultimately lead to better decision-making be it increasing yield and achieving food security, protecting biodiversity and our environment, or any other related cause.

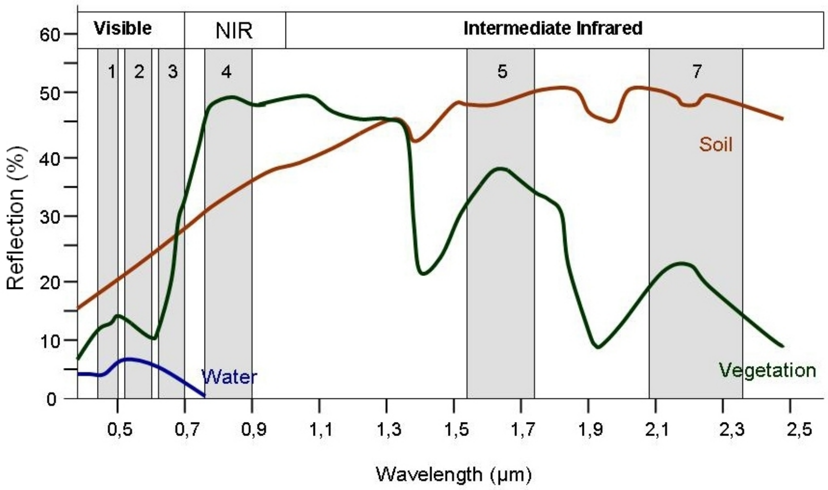

Fig. 2, Spectral signatures of soil, water and vegetation, and spectral bands of Landsat 7 (SESO, n.d.)

When considering satellite-based Earth observation the first question that should be answered is why do we want to step beyond Earth's boundaries and into outer space to observe phenomena that happen in the atmosphere, at the Earth surface, or even below the surface? Firstly, satellite-based remote sensing allows us to see the state of the world as it is. We can acquire data systematically over very large geographic areas. Having the ability to use one single sensor to distinguish a vast spatial domain or a long time interval bring major advantages to science and the decision-making process. Secondly, space-borne observation allows us to frequently observe the entire Earth. Many features on earth are variable across many different timescales: short term (hours or days), mid-term (weeks or months), and long-term (years or decades). Remote sensing, especially when satellite-based, can provide continuous datasets that can be used for a broad array of applications. With the significant increases in temporal resolution we can revisit the same place on Earth more often.

Remote sensing provides information (spectral, spatial, and temporal), which is of value and should be effective and economical. However, we should be aware that remote sensing has its limitations. It will not provide us with all the necessary information to conduct physical, biological, or social science (Jansen, 2007). It has been acknowledged that remote sensing has often been oversold in the past and that this consequently led to the scepticism towards such data as it could not deliver what it promised. Dr. Navulur, Digital Globe's senior director for global strategic programmes, very well described the way the gained information should be interpreted on the example of agriculture during an interview (22.04.2016) for this thesis:

"When you look at remote sensing and agriculture, this is very similar to a human going to a doctor. A lot of the tests a doctor does are based on the difference in temperature, skin colour, and based on this you have the diagnostics. Even if you have multiple spectral bands you are only able to detect the features of something going on in a field and you still need the doctor, in this case the agronomist, who can diagnose what the problem is."

What this means is that remote sensing itself does not provide a stakeholder with an answer. One must understand that the remote sensing process, as most scientific processes, consists of 4 central steps: 1) statement of the problem; 2) data collection; 3) data-to-information conversion; and 4) information presentation (Jansen, 2007). Traditionally, several operational indices are based on data gained by remote sensing instruments. However, the results of these indices are often unclear, uncertain, and difficult to interpret for decision-makers. Nevertheless, remote sensing remains a central information-gathering tool, which can enable stakeholders to make smarter decisions. A farmer can get better yields from his crops, an engineer can map available solar radiation, governments and companies can carefully monitor logging and mining activities etc. Remote sensing systems on-board satellites provide us with high quality and relatively inexpensive data per km^2. Today cloud-computing resources allow for working with big datasets from which new information can be extracted. When we look at the system as a whole and combine the new sensors, deeper archives, and better computing abilities, we can draw information from satellite imagery that is more sophisticated than ever before.

The obstacle that remains is making this data and information available to everyone, and providing those countries that aspire to develop indigenous Earth observation capacities with the opportunity to do so. CubeSats can be a part of the solution. These low-cost spacecraft have evolved from purely educational tools to a platform for technology demonstration and scientific instrumentation. Therefore, the technological capabilities and limitations of CubeSats in relation to the possibility of conducting Earth observation measurements will be explored in the subchapters bellow.

4.2. The CubeSat Standard

Commercial Earth observation satellites tend to have a wet mass[10] above 1000kg. Developments of micro-technologies for sensors and instruments allow for the design of dedicated well-focused Earth observation missions. This has allowed satellites of the Smallsat class (see Table 1) to become true competitors to larger spacecraft. It has been claimed that with Smallsats similar performance can be achieved at a fraction of the mission cost of large satellites (Konency, 2004). The introduction of Commercial-Off-The-Shelf (COTS) equipment have substantially decreased the development time and reduced the overall cost. Given their short development time CubeSats can truly fly state-of-the-art instruments which is not the case with large satellites.

Table 1, Satellite Classification (NASA, n.d. a; Konecny, 2004)

Classification	Wet Mass	
Large Satellite	>1000kg	
Medium Sized Satellite	500-1000kg	
Mini Satellite (Minisat)	100-500kg	Small Satellites (Smalsats)
Micro Satellite	10-100kg	
Nano Satellite (Nanosat)	1-10kg	
Pico Satellite (Picosat)	0,1-1 kg	
Femto Satellite (Femtosat)	<100g	

According to the classification presented above CubeSats fall into the Pico (for 1U CubeSat) or Nano-satellite (for 2U and above) class. In light of the miniaturisation of satellite technology the CubeSat standard was created by Professor Jordi Puig-Suari at cal Poly and Professor Bob Twiggs at Stanford. The purpose of their project was and still remains: *"to provide a standard for design of picosatellites to reduce cost and development time, increase accessibility to space, and sustain frequent launches."* (CubeSat n.d., p. 5) According to the now generally accepted standard a 1 Unit (1U)

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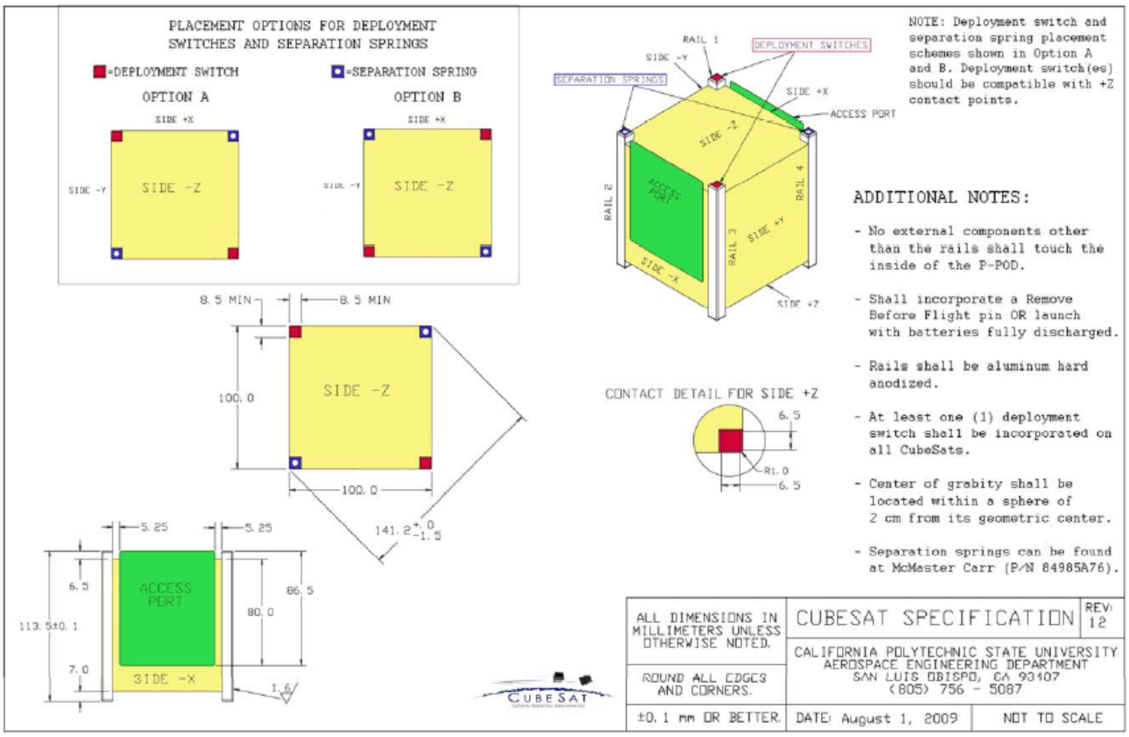
[10] The mass of a satellite including fuel

CubeSat shall measure 10x10x10cm^3 (see Fig. 3) and should weigh no more than 1,33kg. In this thesis 1U, 2U (see Appendix 5) and 3U (see Appendix 6) are considered.[11] CubSats composed of 2U measure ≈ 10x10x20cm^3, while a 3U CubeSat measures ≈10x10x30cm^3, as we can see it is the z axis which differs between these three types of CubeSats. Both the 2U and 3U standard do not have strict mass constraints.



NOTE: Deployment switch and separation spring placement schemes shown in Option A and B. Deployment switch(es) should be compatible with +Z contact points.

ADDITIONAL NOTES:

- No external components other than the rails shall touch the inside of the P-POD.
- Shall incorporate a Remove Before Flight pin OR launch with batteries fully discharged.
- Rails shall be aluminum hard anodized.
- At least one (1) deployment switch shall be incorporated on all CubeSats.
- Center of grabity shall be located within a sphere of 2 cm from its geometric center.
- Separation springs can be found at McMaster Carr (P/N 84985A76).

ALL DIMENSIONS IN MILLIMETERS UNLESS OTHERWISE NOTED.	CUBESAT SPECIFICATION	REV: 12
ROUND ALL EDGES AND CORNERS.	CALIFORNIA POLYTECHNIC STATE UNIVERSITY AEROSPACE ENGINEERING DEPARTMENT SAN LUIS OBISPO, CA 93407 (805) 756 - 5087	
±0.1 mm OR BETTER.	DATE: August 1, 2009	NOT TO SCALE

Fig. 3, 1U CubeSat Specifications, California Polytechnic State University (CubeSat, n.d.)

The CubeSat standard also identifies certain testing requirements which must be performed to meet the launch provider requirements. The test includes random vibration, thermal vacuum bakeout, visual inspection, qualification, protoflight. The launch vehicle provider outlines the exact test requirements the CubeSat is suppose to pass. As argued in chapter 3.6.2.1., ISS deployment is favourable for new space actors as the testing requirements, particularly the vibration test, are not as rigorous for cargo spacecraft destined to dock with the space station, as those set for launch vehicles offering "piggyback" deployments. The technical capabilities and limitations of these very small satellites, derived from the CubeSat survey (see Appendix 7) and literature review of previous similar satellite surveys, will be discussed in the paragraphs bellow.

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[11] CubeSats of up to 6U have been successfully deployed. There are considerations for 12U or 27U CubeSats.

4.3. Technological capabilities and limitations of CubeSats

4.3.1 Dimensional constraints

In general spacecraft comprise of a payload which is to execute a measurement, experiment, or other task, and a bus which includes the critical support functions necessary to operate the spacecraft such as: communications, command and control, power generation, energy storage, data buffering and storage, de-orbit mechanism etc. The 2U and 3U Cubesats frequently dedicate 1U to the bus and the other(s) to the payload (Woellert et al., 2011).

As seen above the CubeSat standard constrains the satellite's mass (1,33kg for 1U) and its volume (10x10x10 cm^3). It is the volume which presents the limiting factor in regards to the payloads, as the dimension constrains are the most stringent ones and payload performance is often correlated to their dimension (Selva & Krejci, 2012). In regards to optical Earth observation one of the most obvious aspects to consider is the optical system, the aperture of the system directly determines its diffraction-limited angular resolution and therefore the ground spatial resolution (ibid):

$$\Delta x \approx h \cdot \Delta\theta = h \cdot 2.44 \frac{\lambda}{D}$$

Δx stands for the ground spatial resolution, $\Delta\theta$ is the diffraction limited angular resolution, h is the orbit altitude, λ is the wavelength and D is the instrument aperture. Following this simple calculation we can see that physics dictate the following limitations in ground spatial resolution for a CubeSat with a diameter of 10cm in a 350-400km initial orbit[12] (common for CubeSats deployed from the ISS) using a nadir-looking passive optical instrument:

Table 2, Limitations in ground spatial resolution

Λ	D	≈ Δx (max)
400-700 nm (visible light)	400km (350 km)	3.9-6.8 m (3,4-6m)
650 nm (red)	400km (350 km)	6,3 (5,5m)
0.75-1.4 μm (near infrared)	400km (350 km)	7.3-13.6 m (6,4-12m)

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[12] There are 4 circular orbits in which satellites are placed: Low Earth Orbit (200-1200km), Medium Earth Orbit (1200-35790km), Geosynchronous Orbit (35790km), Geostationary Orbit (35790km). At a 350-400km orbit and latitudes within 52 degrees of the equator, a CubeSat can cover the majority of the world's populated areas and agricultural regions. However, the low orbit means that the satellites will have a short lifetime, as they will be de-orbited faster due to the higher atmospheric drag at these low altitudes when compared with altitudes in which larger satellites are functioning.

In the same way the diameter of an RF antenna determines its gain and therefore affects signal-to-noise ratio (SNR):

$$G \approx \eta \cdot \left(\frac{\pi \cdot D}{\lambda}\right)^2$$

By applying this formula Selva and Krejci (2012) derived that the frequency or bandwidth of the antenna or sensing system will be limited to 3 GHz which corresponds to C-band. Out of this reason lower bands which are used in remote sensing cannot be considered for CubeSats with the exception of deployable mechanisms which can be introduced but increase the risk, complexity, power, mass and the cost of the CubeSat.

When conducting their survey in 2011 Selva and Krejci (2012) found that high-resolution optical imagers were infeasible given the state-of-the-art of CubeSat technology at that time. Today such measurements have been flight proven and they will be further discussed in chapter 4.4.1.

4.3.2. Attitude determination and control system, and geolocation

Attitude determination and control system (ADCS) measures the orientation of the satellite and maintains or adjusts the orientation as fitting for mission requirements. There are passive and active ADCSs. For optical remote sensing active ADCS is required (Woellert et al., 2011). For CubeSat-based missions the problem of *attitude determination* still persists, although accuracies of less than 2° have been achieved and with the integration and further development of miniaturised star trackers accuracies of well below 1° can be expected.

Attitude control has experienced improvements with suppliers stating that the accuracy is at a level below 1°. Blue Canyon Technologies (BCT) had an objective to design, develop and fabricate an all-in-one ADCS with a pointing accuracy of +/- 0,2°, with half of 1U volume for a 3U CubeSat. BCT has successfully developed the XACT ADCS and a Nano Star Tracker (BCT, n.d.; Air Force SBIR/STTR, 2014). In conclusion overall accuracies of below 1° are readily available for CubeSat developers around the world.

It is essential to be able to determine the satellite's attitude at time of measurement and this has a direct impact on the quality of the measurement. It is the factor that determines the precision with which a scene is *geolocated*. If we are considering CubeSat constellations this already important factor becomes even more crucial in the case of cross-registered measurements. In this case, and in the case of marrying the CubeSat measurements with those of larger satellites, the ability to align the individual measurements can heavily affect the quality of the outcoming data. With an attitude uncertainty of 2° we are already talking about a spatial uncertainty on ground of multiple kilometres (Selva & Krejci, 2012). Attitude control is also indirectly limiting satellite-ground communication data rates (Bouwmeester & Guo, 2010).

Attitude control performance still remains the bottleneck of CubeSat technology even though the technology has improved since the surveys conducted by Bouwmeester and Guo (2010), Woellert et al. (2011), and Selva and Krejci (2012), which identified that these small satellites mostly relied on sun sensors and magnetometers. The situation has been improved through the integration of three-axis control including sun sensors, star gazers, magnetometer, magnetorquers, momentum wheels, propulsion systems. The trade-offs in integrating more advanced ADCSs when it comes to CubeSats remain the same- complexity, size, mass, and cost.

4.3.3. Power supply

Most CubeSats use solar arrays which are either mounted directly to the body of the satellite or are integrated as deployable solar arrays. For body mounted solar arrays the average power generation and consumption for CubeSats ranges from 1 to 7 W for a 1-3U Cubesat respectively. When it comes to deployable solar arrays much greater power generation can be achieved- this comes with the risk of increased complexity and deployment failure. Battery storage is needed given that the typical orbit of a CubeSat (90-105min) will expose the satellite to the Sun for about 2/3 of the time. Lithium-ion battery technology is well suited for this task as they are the most energetic rechargeable batteries available:

- They are generally much lighter than other types of rechargeable batteries of the same size.
- They hold their charge.
- They have no memory effect, which means that they do not have to be completely discharged before recharging.

- They have higher power and higher energy density compared to traditional types.

The lack of power is one of the central reasons because of which CubeSats remain to be viewed as toys or university student training devices (Boshuizen et al., 2014). Out of the power limitation CubeSats are incompatible with high energy instruments such as imaging radars, lidars, thermal sensors, radar altimeters, scatterometers, and instruments requiring an active illumination source.

4.3.4. Communications

Transmitter technology for small satellites in LEO are UHF/VHF transmitters- maximum data transfer rate of approximately 38 kbps- and S-band transmitters-maximum data transfer rate of around 10Mbps. Most CubeSats use UHF band and transmit their data with a digital form of modulation. Again 2U or 3U CubeSats can accommodate more sophisticated communications subsystems and have had BHF beacons, VHF band, high-data-rate S-band transmitter and full amateur radio transmitters integrated in a single 3U CubeSat. Through recent advances in the cell phone industry regarding X-band transmitters with data transfer rates of around 100Mbps which were thought to be unreasonable for nano-satellite integration have now been integrated into the 3U Dove satellite (Boshuizen et al., 2014).

An additional complexity arises because of the short window of visibility of a CubeSat in LEO. The pass over the ground station typically lasts only a few minutes. Countries just entering the space arena often lack the infrastructure and can afford one or two ground stations with small antennas limiting uplink and downlinking of data. Communication capabilities between CubeSats and the ground are primarily limited due to the link budget rather than the technology, as micro-electronics for high data rates are available. Furthermore, the communication subsystems can consume more than 50% of the total available power budget during the few minutes per day when the satellite is transmitting while in line of sight of the ground station (Wollert et al., 2011).

When it comes to on-board data handling, in their CubeSat survey Selva and Krejci (2012) found that the limitations are to be found in the data rates and not data storage.

4.3.5. Thermal control

Thermal control is usually passive with heat sinks and optical tape on the outer structure, keeping the structure (not including the solar panels) in a range of -15°C and 40°C (ibid).

As highlighted by Selva and Krejci in their 2012 survey, the dependence of noise on temperature together with the limited cooling capabilities on Cubesats makes measurements in the short-wave and mid-infrared regions practically challenging.

4.3.6. Propulsion

There are a number of propulsion systems which are implemented in or are under consideration for CubeSat missions: electrocynetic pumping and catalytic decomposition of liquid anhydrous hydrazine; pulsed-plasma thrusters; liquid-SF_6-fuelled cold gas propulsion system; solidified nitrogen storage gas thrusters; vacuum arc thrusters.

Many propulsion technologies are still in the development and testing phase, some have been successfully flown aboard CubeSats and it is fair to conclude that formation flying is a feasible option for CubeSat constellations which has also been flight proven (Planet Labs Dove constellation).

The concept of formation flying is one of the greatest opportunities when it comes to CubeSats as it opens up new possibilities for operational missions.

4.4. Utilizing the ISS for deploying Earth observation satellites

In the scope of this thesis a survey was conducted which encompassed all CubeSat which were deployed from the ISS since the first deployment on 04.10.2012 until the 10.05.2016 (see Appendix 7).

In less than 4 years 17- 1U, 3- 2U, and 103- 3U CubeSats, amounting to 122 CubeSats have been deployed from the space station, and more than 30 CubeSats have been successfully delivered to the ISS in 2015 and 2016 which are now awaiting deployment.

From the 122 satellites, 1 CubeSat was deployed by an astronaut during a space walk, 17 have been deployed by the J-SSOD, while the rest were deployed by the NRCSD. It is important to note that all the 3U deployments from the ISS have successfully transmitted signals to the ground. No signal has been received from 30% of the 1U and 50% of the 2U CubeSats that have been deployed (see Fig. 4).

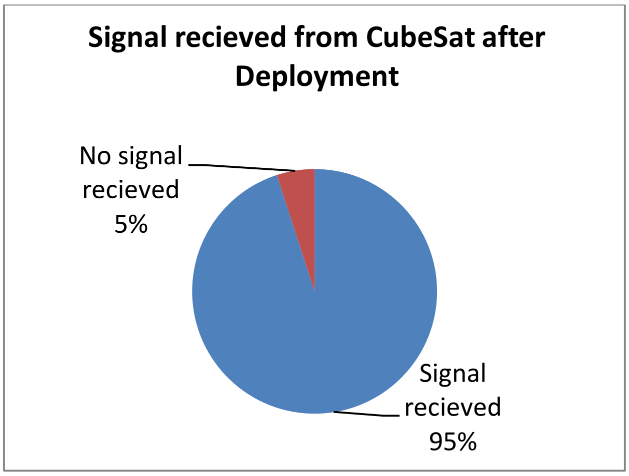

Fig. 4, Signals received from CubeSat after ISS deployment

When looking at launch success a total of 42 CubeSats destined for ISS deployment were lost in launch failure (see Fig. 5). However this figure is highly influenced due to the loss of 40 Dove satellites produced by Planet Labs, meaning that a total of only 3 satellite developers have lost their satellites in 2 launch failures (Antares-130 on the 28.10.2014 and the Falcon 9 launch on the 28.06.2015) of the 15 separate launches, considered in this survey, of spacecraft destined to dock with the ISS (see Fig. 5).

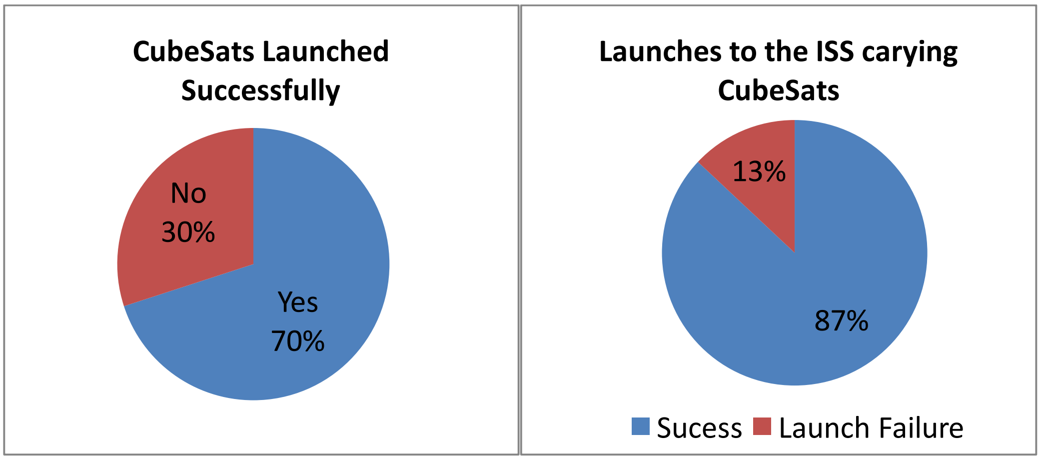

Fig. 5, CubeSat launches

The UN Inter-Agency Space Debris Coordination Committee has adopted guidelines to harmonize major space-faring nations, the central principle behind the guidelines is that satellites are to either actively or passively deorbit within 25 years after launch (IADC, 2007). CubeSats deployed from the ISS are in line with the UN guidelines as those observed have de-orbited in 3-9 months.

From all the CubeSats deployed from the ISS, 91 have carried an optical Earth imaging instrument(s) either as their primary or secondary payload (see Table 3). This number is once again influenced by the Planet Labs constellation deployments amounting to 80- 3U earth imaging CubeSats (with another 32 currently in the ISS).

Table 3, CubeSats deployed from the ISS carrying an imaging instrument[13]

Satellite	Class	Organisation	Payload
ArduSat 1	1U	NanoSatisfi	Technology CubeSat for amateur and student experiments carrying a 1.3 megapixel optical CMOS camera and onboard sensors: photolux sensor, IR temperature, PCB temperature, 3-axis magnetometer, Geiger counter, 6-DOF IMU and MEMS gyros
ArduSat X	1U	NanoSatisfi	Technology CubeSat for amateur and student experiments identical to ArduSat 1
Chasqui 1	1U	Universidad Nacional de Ingeniería del Perú	camera: RGB + NIR (no signals received)
F1	1U	FPT University	Student built technology cubesat with low-resolution camera, temperature sensors, 3-axis magnetometer (no signal received)
LitSat 1	1U	Lietuvos Kosmoso Asociacija	Technology CubeSat carrying VGA camera, GPS receiver
LituanicaSAT 1	1U	Vilnius University	Technology CubeSat carrying VGA camera, GPS receiver, telemetry beacon and 150 mW V/U FM voice transponder
PicoDragon	1U	VNSC	Technology CubeSat taking low resolution Earth images to test on-board systems
SkyCube	1U	Southern Stars Group LLC	Technology cubesat for Earth imaging- VGA camera (no signal received)
STMSat 1	1U	St. Thomas More Cathedral School	Earth imaging payload, payload contains a crucifix blessed by Pope Francis. First satellite to be design and built entirely by *elementary school* students
WE WISH	1U	Meisei Electric Co.	Technology CubeSat carrying ultrasmall thermal infrared camera

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[13] *In red are satellites from which no signals were received after deployment.*

Raiko	2U	Wakayama Univiersity, Tohoku University	Technology CubeSat carrying three cameras: colour CMOS, colour CCD, high-sensitive CCD sensor
Flock 1-1 to 1-28	3U	Planet Labs	28 earth imaging CubeSats; CCD imaging system capable of RGB
Flock 1b-1 to 1b-28	3U	Planet Labs	28 earth imaging CubeSats (6 were not deployed) ;CCD imaging system capable of RGB
Flock 1d'-1 to 1d'-2	3U	Planet Labs	2 earth imaging CubeSats; CCD imaging system capable of RGB
Flock 1e-1 to 1e-14	3U	Planet Labs	14 earth imaging CubeSats; CCD imaging system capable of RGB
Flock 2b-1 to 2b-14	3U	Planet Labs	14 earth imaging CubeSats; CCD imaging system capable of RGB
Flock 2e-1 to 2e-12	3U	Planet Labs	12 earth imaging CubeSats (to be deployed); CCD imaging system capable of RGB and NIR
Flock 2e'-1 to 2e'-20	3U	Planet Labs	20 earth imaging CubeSats (to be deployed) ; CCD imaging system capable of RGB and NIR

From the table above we can see that 1U CubeSats are carrying simple low-resolution imaging instruments, mostly VGA or CMOS cameras. We Wish has carried a ultrasmall thermal infrared camera and the Peruvian Chasqui-1 (1U) satellite had 4 bands integrated in its payload, however no signals were received after it was deployed by an astronaut during a spacewalk and the intended experiment of imaging land and distinguishing between fertile and uncultivated areas could not be undertaken. Nevertheless, this shows the potential of even the smallest CubeSats to undertake certain vegetation measurements.

An exponential expansion of CubeSat capabilities can be seen while moving from the 1U class towards the 3U CubeSats. The most advanced CubeSat to be deployed from the ISS is MicroMAS developed by the Massachusetts Institute of Technology. Although not being an optical earth observation satellite it will be discussed here because of its remarkable specifications. The 3U CubeSat (10x10x34 cm, 4.5kg) houses a passive hyperspectral microwave spectrometer operating near the 118.75-GHz oxygen absorption line. The satellite is designed to autonomously collect microwave radiometry data and transmit it thorough an RF link to a ground station. 1U of the CubeSat is used for the radiometer payload. The focus of the satellite's mission is to observe thunderstorms, tropical cyclones, and hurricanes from a near-equatorial orbit. This low-cost option is intended to prove the potential for the deployment of multiple very small satellites that can provide near-continuous views of severe weather and fill the gap of high-cost platforms (Blackwell et al., 2012; Earth Observation Portal, n.d. a).

Coming back to optical earth observation the CubeSat which has pushed the limits is the Dove satellite developed by Planet Labs. This constellation will be discussed in greater detail in the following subchapter. Two additional satellites that will be mentioned at this point are the STACEM (lost in launch failure) and CanX-2. Neither was deployed from the ISS but their payloads contain noteworthy instruments. CanX-2 (10x10x34cm, 3,5kg) was developed by University of Toronto and launched in 2008. The 3U CubeSat carried a miniature VNIR spectrometer which was capable of achieving the required spectral and spatial resolutions for Normalized Differenced Vegetation Index (NDVI) measurements like the ones done by AVHRR. Such measurements were not undertaken as they were not a part of the satellite's mission. STACEM was lost during a launch failure in 2015. This 3U CubeSat was intended to conduct optical experiments to collect imagery in the visible, near infrared (NIR) and hyperspectral range (Gunter's Space Page, n.d.; Operationally Responsive Space, n.d.). This has been the first Earth imaging CubeSat carrying such a payload of gathering information in both VNIR and hyperspectral range, which would enable a series of applications for vegetation monitoring and management.

4.5. The Dove flock

The company behind the Dove satellite, Planet Labs, was founded in 2010 by former NASA scientists who met at the UN. Since its foundation the company has launched over 100 satellites and is currently operating the largest constellation of earth imaging satellites in history (Planet Labs, n.d.). Such a constellation would be extravagantly expensive if comprised of traditional satellite elements. During his address to the UN Sustainable Development Summit, Planet Labs' CEO Will Marshal said: *"Our goal is to do something truly unprecedented, to image the entire planet every day and to make change on our planet visible, accessible and actionable."* (Marshall 2015)

Planet labs designs, builds, and operates their constellation of nano-satellites. The satellites they have created are 3U CubeSats (10x10x30cm, ≈5kg), with a payload consisting of an optical system and camera able to capture imagery at 3-5m Ground Sample Distance (GSD). The Dove satellites contain no component directly sourced from the space industry, all the components have been procured from Commercial Off-the-Shelf (COTS) suppliers. As pointed out by Boshuizen et al. (2014, p. 2): *"The same tools that perform heat transfer analysis on the latest Ford Diesel engine can also be applied to the problem of Earth observing Nanosats. The same electronic design tools used for the Playstation 4 are directly transferable to spaceflight hardware."*

The Dove satellites are deployed into two types of orbit: 1) ISS orbit at a 52° inclination and approximately 400km altitude; 2) Sun Synchronous Orbits (SSO) at 98° inclination or higher at approximately 475km altitude. Constellations, to which Planet Labs refers to as "Flocks" are operated in both orbit types. (Planet Labs, 2015a) For the purpose of this thesis the specification of the optical instruments which are flown in ISS orbit will be considered (see Table 4).

Table 4, ISS Orbit Satellite Specifications (Planet labs, 2015b)

Description	International Space Station Orbit
Inclination	52°
Expected Lifetime	1 year per satellite
Orbital Insertion Altitude	420km
Equatorial Crossing Time	Varies
Sensor Type	Bayer-masked CCD camera
Spectral Bands	Red: 610-700nm Green: 500-590 nm Blue; 420-530nm Near-infrared 770-900nm
Ground Sampling Distance (Nadir)	2.7-3.2m
Mission continuity	Maintain up to 55 satellite constellation through continual replenishing/upgrading of satellites

The satellite is powered by deployable solar arrays without cover glass which enables the spacecraft to develop significantly more power at a lower cost and mass (Boshuizen et al., 2014). Power storage is provided by Lithium-ion cells.

For attitude determination the Dove satellite uses a star camera, GPS, a photodiode array for coarse-sun sensing, and MEMS IMU. For Attitude control four reaction wheels in a tetrahedral arrangement and three air-core magnetorquers are used (Boshuizen et al., 2014; Earth Observation Portal, n.d. b). While interviewing Dr. Griesbach, project manager at Planet Labs, he further elaborated on the positioning accuracy of the Dove satellites:

> *"It is correct, that CubeSats provide limited capabilities for onboard navigation equipment, but this is not really needed, if Ground Control Points (GCP) will be used. Currently Planet Labs uses GCP derived from a worldwide LandSat mosaic, which allows positioning accuracies in the 30-40m range. For the operational constellation, which will be available next year, a new GCP base will be deployed, which allows positioning accuracy better than 10m, practically in the 7-8m range."*

The communication subsystem consists of a 2-way UHF transceiver, and high-speed X-band downlink transmitter, and S-band uplink receiver. The command and data holding is controlled by a single board computer- low-powered x86 processor with 0.5 terabytes of solid state storage (ibid).

4.5.1. Optical system

So far three versions of the optical system have been launched: Planet Scope 0 (PS0), Planet Scope 1 (PS1), and Planet Scope 2 (PS2) (Planet Labs 2015 a., p. 4). The telescope in the Dove satellite is a Maksutov-Cassegrain design with a 91mm aperture, a tube length of 20cm and it approximately takes up 2.5 U of the satellite. The optical system is paired with an industrial CCD (11-29MP) equipped with Bayer-mask filter which is placed at the very rear of the satellite. The CCD sensor converts filtered photons into electrons, which are then amplified to produce a digital number corresponding to each pixel in each band (see Fig. 6). For the detector to be able to fulfil its function there has to be a path for light to reach it. What this means is that there is very little room left for the satellite bus. The bus has ended up being placed in a total volume of roughly ¼ of a Unit. Because of the space limitations the electronics of the camera have been placed in a "tuna can" addition to the rear of the satellite (Boshuizen et al., 2014; Planet Labs, 2015a; Planet Labs, 2015b).

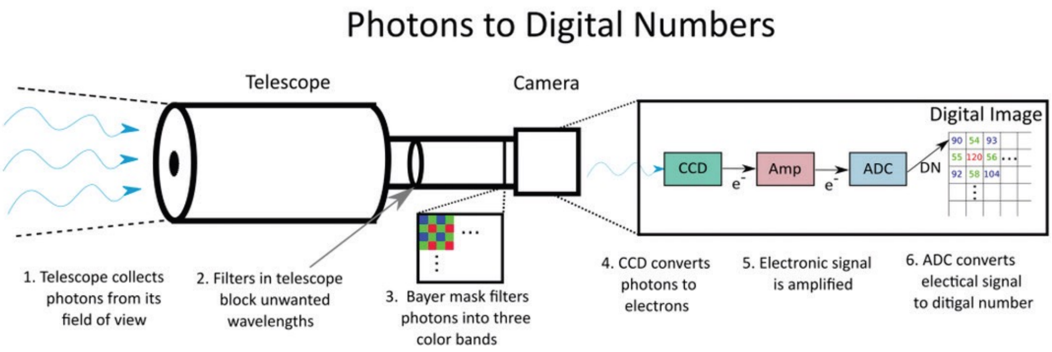

Fig. 6, Planet Labs Optical System and Camera (Planet Labs 2015a, p. 5)

Dove satellites currently in operation in the ISS orbit all carry the Planet Scope 2 optical system. PS2 features a five element optical system that provides a wider field and superior image quality compared to PS0 and PS1. This optical system is paired with a 29MP CCD detector and exhibits uniformly high pixel quality and usability over the entire sensor. The imaging system in each spacecraft currently in orbit captures red, blue and green (RGB) imagery (see Fig. 7).

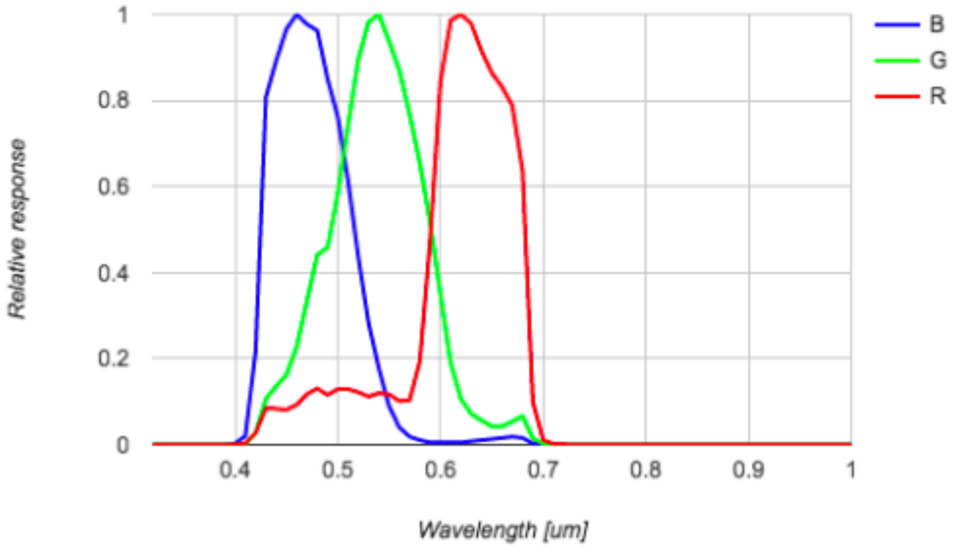

Fig. 7, RGB Spectral bands for PS2 (Planet Labs, 2015b)

The launch of the Atlas-5 launch vehicles on the 06.12.2015 and 23.03.2016 were especially important launches for Planet labs, as the spacecraft were carrying their Flock 2e Prime satellites which will increase their on-orbit collection capacity in both true-colour (RGB) and near-infrared (NIR) bands (see Fig. 8) (Holm, 2016). The first 8 satellites were deployed from the ISS on the 17.05.2016.

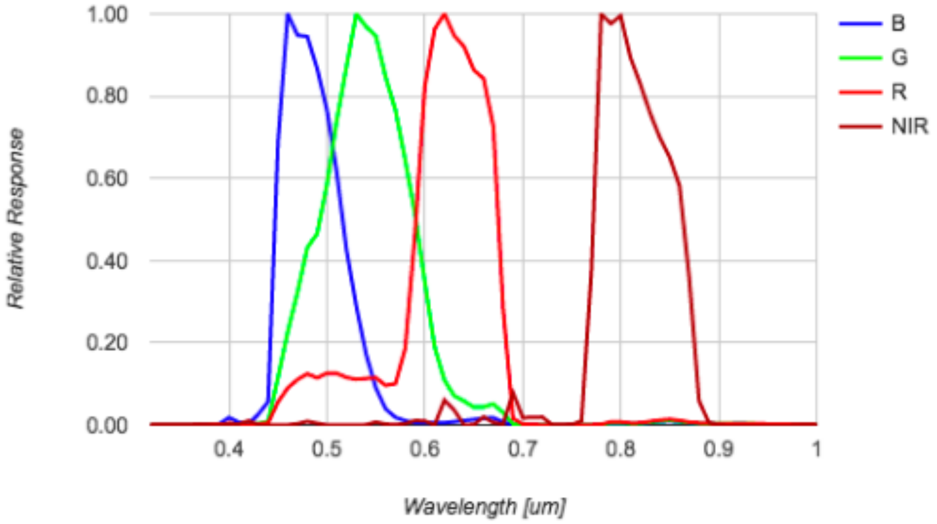

Fig. 8, Expected Spectral Response for PS2 with NIR capability (Planet Labs 2015 b.)

4.6. Looking forward- hyperspectral imaging

Hyperspectral instruments divide the light they receive in up to hundreds of narrow, adjacent wavelengths. By doing this the spectral signatures of particular features, crops or materials are revealed. The data provides us with valuable information on mineralogy, agricultural forecasting and environmental monitoring. Until recently cameras in conventional satellite missions were bulky with a mass of 100kg or more. The cost of a typical imaging spectrometer mission ranges between $200-$500 million for a single satellite, therefore potential mission design of a total cost under $1 million are a motivating factor to consider a new design. Although such instruments have not yet been flown on a CubeSat this is very likely to change in the near future as argued bellow.

The European Space Agency (ESA) has been working on a hyperspectral instrument to be carried inside the CubeSat standard. The ability to shrink this optical instrument to such an extent was made possible through the *single diamond point turning* manufacturing technique. The technological feasibility was proven by a prototype (ESA, 2014).

Under an ESA GSTP contract a European industrial consortium is developing the first smart miniaturized hyperspectral imager designed to be operated on a 3U CubeSat and larger spacecraft. The instrument is called *Hypercube* and is a pushbroom instrument equipped with an on-board data handling system. The spectral range of Hypercube is 470-900nm. To reduce the huge amount of information that such an instrument can produce to levels that can be handled by a CubeSats downlink capacity, hypercube is equipped with an on-board data handling system able to process in real time the data acquired and downlink the final data products to the ground. The applications that have been selected for the onboard implementation are the following: 1) monitoring of vegetation conditions; 2) crop water requirements; 3) fire hazard; 4) delineation of flooded areas; 5) land cover and land use change detection (Esposito & Marchi, 2015).

The possibility for such miniature mission architectures has caught the attention of NASA. Mandl et al. (2015) suggest a mission composed of a constellation of 6U CubeSats carrying a Headwall Nano-Hyperspec. The spectral bandwidth of the instrument in question ranges from 400-1000 nm, whereas large satellites have spectral bandwidths of 400-2500nm. However, even when considering other parameters such an instrument cannot quite match when compared with large satellites, the potential for daily time series and the immense reduction in cost make the CubeSat architecture compelling.

4.7. CubeSats and the CEOS measurement categories for vegetation

Approximately 70% of the Earth's land surface is covered with vegetation. Knowledge about differences in vegetation species, distribution patterns, the phonological cycles, modification in the plant physiology and morphology provide us with important insights into the climatic, edaphic, geologic, and physiographic characteristics of an area. Plants have adapted both their internal and external structure to perform photosynthesis and this structure together with its interaction with electromagnetic energy has a direct impact on how leaves and canopies appear spectrally when recorded using remote sensing instruments. Earth observation techniques can be applied to a variety of vegetated landscapes including: agriculture, forests, rangeland, wetland, manicured urban vegetation (Jensen, 2007).

In this section of the thesis a measurement-centric view is taken with the goal of analysing the possibilities of CubeSats from the perspective of measurement requirements. Building on Selva and Krejci (2012) the 2016 CEOS database was used to obtain a reference set of measurements and measurement categories. CEOS identifies 29 measurements relevant to Earth observation missions and has divided these into five categories: atmosphere; land; ocean; snow and ice; gravity and magnetic fields. For the purposes of this thesis the possibilities of obtaining measurements relevant to the "vegetation" subcategory of "land", through a CubeSat mission will be analysed. Conducting an exhaustive literature review of the state-of-the-art of satellite remote sensing for each one of the nine detailed measurements identified by CEOS in the subcategory vegetation is out of the scope of this thesis given the limited timeframe and space. Therefore, the focus lays on the possibilities of the CubeSat to meet the measurement requirements and not on the measurement itself. The preliminary assessment of the utility of CubeSat missions measuring different vegetation parameters can be seen in Table 5.

Table 5, Utility of CubeSat missions measuring different vegetation parameters

Detailed measurement	Definition (CEOS, 2016a)	Minimal Spectral Range[14]	CubeSat technology readiness (unavailable, in development, flight proven)
Chlorophyll fluorescence from Vegetation on Land	Solar induced chlorophyll fluorescence occurs during photosynthesis. It exhibits a strong linear correlation with terrestrial gross primary production (GPP). Direct global space borne observations of the fluorescence emission provide the same or better GPP estimations as those derived from traditional remotely-sensed vegetation indices using ancillary data and model assumptions.	687nm and 760nm	Unavailable
Land Cover	Processed from land surface imagery by assigning cluster(s) within a given area to specific classes of objects	400-1400nm (VNIR) 1400-3000nm (SWIR)	Flight Proven
Leaf Area Index (LAI)	One half of the total projected green leaf fractional area in the plant canopy within a given area.	400-1400nm (VNIR)	Flight proven
Normalized Differential Vegetation Index (NDVI)	Difference between maximum (in NIR) and minimum (around the Red) vegetation reflectance, normalised to the summation.	620-750nm (Red) 700-1400nm (NIR)	Flight proven
Soil type	Result of the classification of different types of soil within a vegetated area.	620-750nm (Red) 1400-3000nm (SWIR)	Unavailable

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[14] The minimum spectral requirements for the respective measurements, considering only optical remote sensing.

Vegetation Canopy (cover)	Fraction of the ground area covered by tree crowns in %.	400-1400nm (VNIR) 1400-3000nm (SWIR)	Unavailable
Vegetation Canopy (height)	Vertical projection of an area covered by tree crowns in meters.	RBG (stereotypic view)	Flight proven (Unavailable)[15]
Vegetation Cover	Fraction of vegetated land in an area.	400-1400nm (VNIR)	Flight proven
Vegetation type	Result of the classification of different types of vegetation within a vegetated area.	hyperspectral	In development

4.7.1. Terrestrial chlorophyll fluorescence

Terrestrial chlorophyll fluorescence is directly related to photosynthetic function. The information gained through measurements of chlorophyll fluorescence contributes to our understanding of the carbon cycle and about the health and stress of the plant's vegetation. The information can be useful for forestry, agriculture, and global carbon cycle modelling as we can more accurately estimate the terrestrial carbon budget. (Joiner et al., 2013) Currently only one operational instrument is recognised, by CEOS, to be able to conduct such measurements, TANSO-FTS1 flown on the GOSAT satellite. There is a second instrument TANSO-FTS2 being developed which will be flown on GOSAT 2 (CEOS, 2016b). In addition to the CEOS recognised instruments such measurements can be undertaken by the GOME-2 satellite. ESA has also announced the Fluorescene Explorer (FLEX) mission, which will map fluorescence to quantify photosynthetic activity (ESA, 2015).

In their study Greenbaum et al. (2015) propose an Earth Photosynthesis Imaging Constellation (EPIC) mission. The mission would consist of four 6U CubeSats carrying an Integrated Vegetation Interferometer Spectrometer (IVIS) instrument. The instrument in question would consist of two primary sensors: a spatial-heterodyne-spectrometer and a hyperspectral imager. Such a CubeSat with a narrow-band multispectral imager would be able to measure chlorophyll fluorescence. Furthermore, by combining the narrow band multispectral imager with a wide band multispectral imager EPIC promises to, for the first time, directly measure gross primary production (GPP) from space (ibid).

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[15] Potential for relevant measurements can be found in the use of stereographic images, however these lack behind measurements taken by SAR and lidars. Therefore, the category is viewed as "unavailable".

4.7.2. Land Cover

Land cover refers to the physical and biological cover over the surface of land. It includes water, bare soil, vegetation, and artificial structures. There are multiple drivers of land cover change and these can be socioeconomic, demographic, macroeconomic factors, global and regional climatic forces, local and proximate physical forces etc. The current pace at which humans are modifying land is far greater than ever before and these anthropogenic modifications are influencing changes in ecosystems and environmental processes at all scales- local, regional, and global (Zhu, Liang & Jiang, 2012).

> *"Traditionally crop areas are reported based on census data that cannot provide geographical distribution information. Besides, the process is tedious, time-consuming, and costly. Remote sensing has proven to be an effective tool to estimate crop distribution for a wide range of end users including government agencies, farmers and modellers." (ibid, p. 721)*

As argued by Foody (2010), the ground data used as a reference in the validation of land cover products are often degraded by error. Foody (2010) found that even small errors in the ground reference dataset may introduce large bias into the derived estimates and that there is no error-free reference data set. Thematic maps are an imperfect model of the environment, however they are widely used and the value of the map is clearly a function of the accuracy (Foody, 2002). Although land cover measurements can be undertaken with CubeSat mission given the high resolution imaging (RGB, NIR, hyperspectral), the spatial accuracy of the measurement (see 4.2.2.) plays an important factor. As argued in subchapter 4.4. Planet Labs plans to launch a new GCP base which will allow positioning accuracy better than 10m, this remains to be seen in practice. Nevertheless, constellations of CubeSats will provide a previously unprecedented temporal resolution and as highlighted by Dr. Navulur (22.04.2016): *"Given that we can map large areas precisely with big satellites, we need the very small satellites to gather the timely location intelligence which will become increasingly relevant, that is how I see the two playing together.*"

4.7.3. Leaf Area Index

The *Leaf Area Index (LAI)* is an important biological parameter. Firstly, LAI defines the area that interacts with solar radiation and this is the area which provides much of the remote sensing signal when we consider vegetation. Secondly, the surface in question is the one that is responsible for carbon absorption and exchange with the atmosphere (Jansen, 2007).

The Normalized Differential Vegetation Index (NDVI) (Rouse et al. 1974), soil-adjusted vegetation index (SAVI) (Huete, 1988), Photochemical reflectance index (PRI) (Gamon, Penuelas & Field, 1992), transformed chlorophyll absorption reflectance index (TCARI) (Haboudane et al. 2004) are all computed from a combination of a few channels in the VNIR, and such sensors have been flown on CubeSats. The Leaf Area Index (LAI) can be estimated through these indices (Price, 1993; Price & Bausch, 1995; Colombo et al., 2003).

4.7.4. Normalized Differential Vegetation Index

Since the 1970s we know that net photosynthesis is directly related to a plant's absorption of photosynthetically active radiation. What this means is that the higher the quantity of visible sunlight a plant absorbs during the growing season, the higher its productivity as it is photosynthesizing more. On the contrary, a less productive plant absorbs less sunlight. When looking at the electromagnetic spectrum, this translates to plants being able to absorb solar radiation in the photosynthetically active radiation (PAR) spectral region (400-700nm), while they reflect solar radiation in the near-infrared spectral region (Weier & Herring, 2000). To transform the raw data, gathered by the satellite's instruments, into useful information scientists have developed many vegetation indices based on modelling various variables from the remotely sensed data. The NDVI is one such vegetation measurement with a long heritage developed by Rouse et al. in 1974. It has been shown to be connected to vegetation vigour, percentage green cover, biomass etc. NDVI values can be averaged over time to establish the "normal" growing conditions for the vegetation in a given region for a given time of year (NASA, n.d b). By applying such a method we can characterize the health of the vegetation in a particular region and put it into relation to the norm. To be able to estimate the NDVI, measurements in the NIR and in the red region of visible light are required:

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

While the NDVI has proven to be useful for timely estimation of vegetation conditions, we cannot operationalize it to compare pixel location or time periods. This ability of comparing pixel values would be useful for removing seasonal vegetation changes, facilitating interpretation through the historical record and between different vegetation cover. Fortunately, scientists have managed to increase the practicality of the NDVI through a new measure that standardizes the NDVI (using t-scores) to time of year and pixel location. The probabilities, which are generated from the Standardized Vegetation Index (SVI), describe the deviation of vegetation conditions from the average based on bi-weekly/weekly/monthly/yearly NDVI values. The SVI is capable of providing a near real-time indicator of the onset, extent and duration of vegetation stress. Through this index we have the possibility of comparing vegetation conditions over relatively long periods of time at the highest spatial resolution of the satellite from which the data is gathered (University of Nebraska-Lincoln, n.d.; Peters et al., 2002).

As in the LAI example above, CubeSats carrying a VNIR instrument are capable of making the necessary measurements from with NDVI can be derived. These are very significant measurements as we can relate this band ratio to several effects on the ground.

4.7.5. Soil type

Satellite remote sensing is now in a position to provide meaningful spatial data for use in soil science investigations. The significant advances when it comes to spatial assessment of soil structure have emerged from optical remote sensing, while the soil moisture measurements have benefited from improvements in microwave systems (Anderson & Croft, 2009). While some simplified methods exist to estimate bare soil wetness from spectral channels, measurements of the categorical variables necessary to estimate, to a relevant degree, certain soil properties are currently out of the domain of CubeSat technology because of both space and power constraints. Moreover, bands in the SWIR are often necessary.

4.7.6. Vegetation canopy cover and height

The *vegetation canopy cover (density)* and *vegetation canopy height* are of particular interest when it comes to biomass calculations. State-of-the-art measurements are done through the use of SAR and lidars (Selva & Krejci, 2012). As it was pointed out in chapter 4.2.3 such instruments are out of the scope of CubeSats. However, certain potential for relevant measurements can be found in the use of stereographic images from CubeSats.

4.7.7. Fractional vegetation cover

Fractional vegetation cover (FVC) is an important parameter used to measure surface vegetation cover. Accurate estimates of this biophysical parameter are needed for research on land-surface processes, climate change, and numerical weather predictions. The applications of FVC extend to agriculture, forestry, resource and environmental management, land use, disaster risk monitoring, drought monitoring etc. FVC can be retrieved from information gained by remote sensing, there are two methods to achieve this: 1) the empirical-model method- an empirical relationship Between the NDVI and the FVC is established after which the FVC is than calculated from the NDVI; 2) the physical model method- considers the complex canopy radiative process and is difficult to calculate using this method (Yan, Mu & Liu, 2012).

Numerous studies have established that there is a linear relationship between the NDVI and the FVC (Baret & Steven, 1995; Munoz et al., 2009; Kouchi et al., 2013):

$$FVC = \frac{NDVI - NDVI_s}{NDVI_v - NDVI_s}$$

NDVIs and NDVIv stand for representative values of NDVI for bare soil (FVC=0) and vegetation (FVC=1). However, the vegetation index shows saturation problems for high vegetation covers (>60%) and the NDVI becomes almost insensitive to FVC changes. To counterweight this problem, NIR reflectance is substituted by green reflectance, consequently developing a Green Vegetation Index (GVI) (Camacho-de Coca et al., 2004):

$$GVI = \frac{\rho_{green} - \rho_{red}}{\rho_{green} + \rho_{red}}$$

The atmospheric effects can be further reduced by introducing the Atmospherically Resistant Vegetation Index (ARVI) resulting in a Variable Atmospherically Resistant Index (VARIgreen) (Carlson and Ripley 1997):

$$VARI_{green} = \frac{\rho_{green} - \rho_{red}}{\rho_{green} + \rho_{red} - \rho_{blue}}$$

All the vegetation indexes mentioned above (Munoz et al. 2009) can be derived from measurements made by instruments currently carried in various CubeSat missions thereby fulfilling the criteria for FVC measurements.

4.6.8. Vegetation type

Renowned remote sensing scientist, Dave Simonett, said “green is green is green.” This means that in the visible and NIR portion of the spectrum two different crops which have a canopy closure on the same date as when the remotely sensed data was collected would have identical spectral reflectance characteristics. (Jansen, 2007) In an interview conducted for the purpose of this thesis with Dr. Kumar Navulur (22.04.2016), said that even with the 16 bands on the World View 3 satellite only limited spectral signature separation can be done and that a hyperspectral camera is the instrument necessary, among other relevant factors such as more frequent observations and observations in the SWIR, for estimating the *vegetation type*.

The hyperspectral sensors can sample narrow portions of the spectrum. This greater spectral dimensionality allows in-depth examination which makes it possible to identify unique absorption features through which we can discriminate between one vegetation type and another with a high degree of accuracy. (Jansen, 2007) This description of Jansen refers to a simplified and ideal scenario, praxis has shown us that such precise measurements are dependant on the spectral seasonal cycles of a specific plant and other area and plant specific variables. As highlighted in subchapter 4.5. such a hyperspectral instrument small enough to fit into a CubeSat has been developed and it is fair to expect it to be flight proven in the near future.

From the case study which took all 3U CubeSats deployed from the ISS into account we can see that considering vegetation measurements identified by CEOS four of the nine measurements can be undertaken, while the hyperspectral sensor necessary for differentiating between vegetation types has been developed and tested, and is now to be flight proven. The detailed discussion follows in Chapter 6.

5. Case Study of Space Technology and its Applications in Ethiopia

5.1. The Ethiopian case and the Space Participation metric

Millennia ago, *"on the borders of the upper Nile, ... a black race of men ... organized the complicated system of the worship of the stars, considered in relation to the productions of the earth and the labours of agriculture."* This is how Volney, in his 1926 work "Ruins of Empires", describes the origin of Ethiopian astronomy. A fascination with the stars is unsurprising given the country's proximity to the equator, its extensive plateaux, rising more than 4,600 meters above sea level, and the dry weather conditions in many regions, making it one of the best places on Earth to observe the star-spangled dome above our heads.

For the purposes of this thesis a research visit to Addis Ababa, Ethiopia, was carried out with the goal of assessing the state of the space related educational system, space related ground hardware, the integration of Earth observation applications in relevant institutions dealing with agriculture, the relevance of space technology for the country's development plan, and the country's aspiration to develop indigenous satellite technology. In a later stage the findings will be put into relation with UNOOSA's activities. The justification for choosing Ethiopia as a case is twofold. Firstly, the country being among those on the list of developing countries is a potential candidate for the KiboCUBE programme and a primary target of the activities and initiatives started by UNOOSA and its Member States. Secondly, the country has clear ambitions to join the space arena. In 2015, Ethiopia has become the first country in East Africa to launch a space programme (Macdonald, 2015) which has now been taken over by the government with the hope to boost local agricultural and communication industries, and has thereby joined other African nations, including Algeria, Egypt, Nigeria, South Africa, and Tunisia which already have national space agencies.

In this case study the technology categories of the Space Participation Metric (see Table 6) will be used to assess the country's space activity.

Table 6, Categories of space activities for Space Participation Metric definition (Wood & Weigel 2012a, p. 231)

Technology category	Technical Category Definition
1) Low	Evidence of membership in international space related society, hosting of space meeting or space-related regulatory action
2) Medium low	Evidence of space related education, research, or capacity building programs
3) Medium	Evidence of ground based space hardware
4) Medium high	Evidence of space hardware or launch facilities
5) High	Evidence of human rated launch vehicles or spacecraft

The fourth category "evidence of space hardware" is defined very broadly, which allows for further layering. One approach would be to divide the category into subcategories based on the Space Technology Ladder (see Table 7). However, such an approach would need much caution, as CubeSat development was not considered in previous studies referring to the Space Technology Ladder and it is needles to argue that there is a significant difference in the local development of a LEO microsatellite and a 1U Cubesat.

Table 7, The Space Technology Ladder (Wood & Weigel 2012b, p. 17)

The Space Technology Ladder	
13	Launch Capability: Satellite to GEO
12	Launch capability: Satellite to LEO
11	GEO Satellite: Built Locally
10	GEO Satellite: Built through Mutual International Collaboration
9	GEO Satellite: Built Locally with Outside Assistance
8	GEO Satellite: Procure
7	LEO Satellite: Built Locally
6	LEO Satellite: Built through Mutual International Collaboration
5	LEO Satellite: Built Locally with Outside Assistance
4	LEO Satellite: Built with Support in Partner's Facility
3	LEO Satellite: Procure with Training Services
2	Space Agency: Establish Current Agency
1	Space Agency: Establish First National Space Office

Information on the local knowledge was collected from existing publications, web sources and by interviewing key Ethiopian experts. Through the field visit adequate information concerning the local capacity of using Earth observation tools for agricultural applications, as well as those regarding end-to-end (design, develop, manufacture, assemble, integrate and test, operate) development of basic space technology was assessed. The subchapters below will discuss the individual elements of space activities in Ethiopia to then categorise the country according to the Space Participation Metric. Furthermore, it will be shown how existing UNOOSA initiatives can contribute to the categories.

5.2. The Ethiopian Space Science Society

Space science and technology are not necessarily the first words that jump to mind when one considers a country that has weathered extreme periods of economic, social, and political hardship and is still trying to find its way up the ladder to prosperity. Despite the many daunting tasks that lie ahead, the Ethiopian Space Science Society (ESSS) was founded in 2004 by a group of visionaries with the mission *"to build a society with a highly developed scientific culture that enables Ethiopia to reap the benefits accruing from space science and technology."* (The Japanese Times, 2015)

The Society's establishment attracted criticism early on, due to the fact that the country's people were poverty-stricken and battling malnutrition with memories of ravaging famine ever-present. It did not take long for the ESSS to become known as the "crazy people's club", as many believed that the effort and resources dedicated to space science would be better spent elsewhere (Besha 2016, pers. comm.). As Solomon Belay, director of the Entoto Space Observatory and Research Centre (EORC), relates in an interview for The Japan Times (2015): *"People said we were crazy, the attention of the government was to secure food security, not to start a space and technology program. Our idea was contrary to that."*

Over the past decade, a handful of space science enthusiasts have overcome these adversities and managed to change the perceptions of many people, both in the government and among the wider public. Today, the society comprises some 15,000 members, with nineteen branch offices located in different universities across the country and more than fifty clubs in schools intended to inspire the youth. The Society works tirelessly to increase the number of its clubs and branches in order to promote the use of space science, tailored to suit the needs of the Ethiopian environment, with the ultimate goal of supporting the economy, social services, land resource management, and the protection of the environment.

In 2012 the Society has managed to reach one of its first major milestones. With the support of the Government of Ethiopia, the Society was chosen to represent the country within the International Astronomical Union (IAU) to which membership was granted in 2012. When looking at the technology categories of the Space Participation Metric, this resembles the fulfilment of the first category. Furthermore, in February 2011, Ethiopia has laid the foundations for the establishment of the East African Astronomical Society (EAAS). Following the IAU's Announcement of Opportunity, through the support of EAAS members, Ethiopia was chosen to host the East African Regional Office of Astronomy for Development, which is the first regional node to be established on the African continent. At the signing ceremony, Director of the Office of Astronomy for Development (OAD) commented:

"We are very excited about this collaboration with our Ethiopian colleagues, not only because of the visionary leadership shown within the country in terms of science and technology but also because of the exemplary projects they have embarked on such as the Entoto Observatory and Space Science Research Centre. We have worked closely with the region for several years now and this agreement is a significant milestone for the growth and development of astronomy in East Africa." (IAU, 2014)

Coming back to the national level the next step envisaged by ESSS, regarding the promotion and awareness rising on space science, is the establishment of a planetarium in the capital city, Addis Ababa. These developments in Ethiopia very well reflect the understanding of UNOOSA and its BSSI, that activities and research related to the space environment such as astronomy and astrophysics are considered to be one of the first steps towards the establishment of indigenous capacities for the development and use of space technology and its applications. The dimension of awareness raising is generally an important aspect in this process, when considering a country with 10 million people at risk of famine (Stallard, 2016) this element gains even greater significance. With existing governmental support and a building notion of space science being essential for the country's development, this thesis acknowledges that there is great potential for achieving this next milestone through the existing international cooperation mechanisms within

UNOOSA. Through Japans Cultural Development Aid and the BSSI such a step could be made by the construction of a planetarium in Addis Ababa. the benefits of which, from a diplomatic standpoint, will be discussed in Chapter 6.

5.3. The Entoto Space Observatory and Research Center

Against a picturesque backdrop with herdsman on horseback and farmers leading oxen dragging plows, high above the crowded streets of Addis Ababa, lays the result of the Society's hard work in form of the $2.5 million Entoto Space Observatory and Research Center (EORC), financed by Mohammed Almoudi, an Ethiopian-Saudi businessman, without resorting to the use of government funds and international aid.

5.3.1. Curriculum development

The EORC project encompassed 32 public and one private university, thereby providing the ground work for launching a postgraduate programme which is affiliated with the Addis Ababa University.

The postgraduate programme is initiated to motivate young Ethiopians to join aerospace disciplines and create a possibility for them to advance in the fields of: astronomy, astrophysics, space science, remote sensing and geodesy (see Table 8). In 2015 more than 200 students applied to the 24 places open for the PhD program in astronomy (Stallard, 2016).

Table 8, Postgraduate Programmes at EORC

Postgraduate Programmes at EORC	
PhD Programmes	**MSc Programmes**
Doctor of Philosophy in Astronomy and Astrophisics	Master of Science in Astronomy and Astrophysics
Doctor of Philosophy in Space Science	Master of Science in Space Science
Doctor of Philosophy in remote sensing	Master of Science in Remote sensing
Doctor of Philosophy in Geodesy	

During an interview with Dr. Tulu Besha (19.04.2016), one of the founding members of ESSS and Head of the Earth Observation Division at EORC, he further elaborated on the curriculum development. Reflecting on the curricula developed by UNOOSA, Dr. Besha states that those developed by ESSS are similar, but still not the same, as they are focused on the fields mentioned above and the context of the country. Talking about the division he is heading, and thereby the focus of this thesis, Dr. Besha discussed on the know-how of his students:

"We have an MSc and PhD programme in remote sensing and our curriculum gives our students the capability to use remote sensing for a wide array of applications: precision agriculture, drought monitoring, monitoring climatic variability, resource monitoring, precipitation. They can integrate all remote sensing applications from thermal to radar sensors. We will continue producing young graduates and in a reasonable time we can raze the capacity of Ethiopia to a significant level. In geodesy, we use GPS for different national mapping initiatives. We are also modernising the surveying techniques that rely on satellite services and the monitoring of Earth's gravitational field. We use INSAR techniques to monitor the Ethiopian rift and the plate tectonics. Mostly our students tailor their research to validate satellite data against in-situ data. This is a technically very strong field. Mostly we are trying to calibrate the satellite data with in-situ measurement to give confidence to those not as familiar with the field."

Through the establishment of the EORC and the postgraduate programmes ESSS has managed to reach the second category of the Space Participation Metric. As the official mission of EORC is to *"satisfy all space science and technology needs, especially to meet satellite science and technology needs of the country by 2025"* (Mamo 2016a, p. 13) the next step in their development will be to establish a satellite science and technology division, which will entail its own curriculum and MSc programme. Dr. Besha noted that there is a great interest to collaborate with UNOOSA in the development of a curriculum in satellite technology and satellite science disciplines, as well as in information communication. This falls in line with the existing project of the BSTI to develop an education curriculum on space engineering (ECSE) which is expected to be finalised in 2017 (see Chapter 3.5.3.).

5.3.2. Space observatory

On top of the 3,200 meter tall Mount Entoto, next to the research centre lay the two dome house telescopes. During the visit to the observatory Mr. Ghion Ashenafi, electrical engineer at EORC, explained the details of the telescope. The facilities have two identical telescopes of a photometric and spectroscopic type, with a Schmidt-Cassegrain reflector.

The diameter of the telescope is 1m and the focal length 8m. Mr. Ashanafi described how the observatory is becoming one of the prime places to view Orion's belt as it appears larger and more pronounced here than from other parts of the northern hemisphere. This is the first observatory in East Africa and represents the first piece of ground based space science infrastructure in Ethiopia. Putting this in relation with the Space Participation Metric, with the establishment of EORC Ethiopia has stepped into the "medium" technology category.

The Entoto Observatory is only the beginning of space observation in Ethiopia. ESSS, together with four universities, has performed a feasibility study for the Lalibela Optical Astronomical Project. As the current observatory has its limitations due to the high humidity, relatively high cloud cover in comparison with other regions in the country, and close proximity to the night-lights of Addis Ababa, the new location promises to take full advantage of the opportunities related to space observations in the equatorial country. The plan is to build a far larger telescope in this northern part of the country on the Lalibela mountain range at an altitude greater than 4000m.

These positive developments were observed and recognised by the Ethiopian government which led to the transfer of EORC together with its entire staff to the Ministry of Science and Technology (MOST) on March 5th 2016. This transfer was a deliberate move to secure:

> *"(...) the sustainable development of the Entoto Observatory and Research Center's research and training in recognition of the crucial contributions of the space exploration and Earth observation programs for the emerging Ethiopian economy, social services, environmental protection and management, climate change, as well as for building national pride..."* (Mamo, 2016b.)

Through this transfer the first national space office was established and by this Ethiopia has climbed the first step of the Space Technology Ladder.

5.4. Space technology and the Second Growth and Transformation Plan

The government of the Federal Democratic Republic of Ethiopia (FDRE) has created a five-year development plan with the goal of achieving a gross domestic product (GDP) growth of 11-15% per year from 2016-2020/21. The Second Growth and Transformation

Plan (GTP II) can be considered as the country's development scheme in which the objectives and targets the government expects to achieve are outlined.

This thesis will consider two aspects of Ethiopia's GTP II, and these are science and technology development, and agriculture. GTP II has not yet been made official, however, a draft version of the document has been published (National Planning Commission, 2015).

5.4.1. Science and technology development

The objective of the Ethiopian government when it comes to science and technology development is to formulate a framework in order to *"facilitate import of foreign technologies, apply for technological transfer for improved productivity, and accelerate the technological transfer through implementing various science and technology packages and reform programs."* (National Planning Commission 2015, p. 43) This shall be achieved by following a strategy which encompasses the identification, compilation and analysis of the relevant value adding technological information and databases and their follow-up technological duplication and adaptation (ibid).

In light of the second GTP in 2015 the Government of FDRE requested the ESSS to develop a 5 years Space Science Strategy Plan that could be included in the second national GTP. Now the government and the Ministry of Science and Technology (MOST), as a part of the mission on science and technology, have included the Space Science Strategic Plan in the 5-year development plan which once approved will become the focus area of the government. As stated by H.E. Abiy Ahmed, minister of MOST:

"The government is fully aware of the fact that Space Science, Education and research is not anymore a luxurious activity to be left to the industrialized nations. The world with no exception is prone to an extreme form of space science which can have significant effects on many sophisticated ground and space based technological systems. In this context, the Ethiopian government renewed its commitment to strengthen, expand and popularize science, technology innovation, education and research all over our country in line with the Growth and Transformation Plan GTP II." (Mamo 2016a, p.8)

Next to developing the Space Science Strategy Plan, the ESSS in collaboration with the Finish Space Technology and Science Group (STSG) has completed a feasibility study encompassing both the ground and space segments of satellite development, which in currently being processed by the government and awaiting approval. This study goes in line with the governments ambitions to have an Ethiopian satellite for the monitoring of farmland (The Japan Times, 2015).

5.4.2. Space technology and agriculture in Ethiopia

Agriculture is the foundation of Ethiopian economy, it accounts for more than half of the gross domestic product (GDP) and 80% of the total employment. It is important to note that only 20% of farmers in the country use modern agricultural practice[16]. The general goal of the Ethiopian government to continue having double-digit growth can only be achieved by enhancing the agriculture sector (Mebratu 2016, pers. comm.). It is fair to argue that there is a need of using space born satellite technology in the country to transform traditional agriculture to modern agriculture and achieve the SDGs (Baley & Bedadam, 2014).

GTP II recognises that smallholder agriculture will continue to be the basis of the country's agriculture sector. Therefore, a scaling up strategy shall be implemented leading to cluster based agriculture development intended to solve problems such as mixed- and inter-cropping. The overarching goal of the government is to modernise agricultural production and build production capacity so that the sector plays a key role in stabilizing the macro economy of the country. As stated in the draft of the GTP II (National Planning Commission, p. 27): *"These objectives will be ensured through increasing productivity of the sector."*

During an interview with Mr. Haileyesus Belay Lakew (15.04.2016), a member of the earth2observe project[17], he pointed out that there is a big distrust in forecasting among Ethiopian farmers: *"The farmer, as the end user, does not trust the (satellite) data from the institutes, mostly because they cannot understand it."* During the research visit it has quickly become clear that it would be premature to view the farmer as a direct user of the information gained by satellite Earth observation. This was concluded given the technological standing of the agricultural sector in general, the difficulties to

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[16] Although there is no generally accepted definition of modern agricultural practice, for the purpose of this thesis it is understood as the use of state-of-the-art farming technology and mechanization, and innovative practices and growing techniques.

[17] The earth2observe project is a collaborative four-year project with the overall objective to contribute to the assessment of global water resources through the use of new Earth observation datasets and techniques. It will integrate available global earth observation, in-situ datasets and models and will construct a global water resource re-analysis dataset of significant length (several decades).

communicate the data and information from the centres where it is gathered to the various remote regions of the country, and the overall distrust of such data from the side of the farmers. This has led to the decision to focus on the government as a user of satellite data.

Baley and Bedada (2014), in their need assessment survey, examined the incorporation of Earth observation within the Ethiopian Ministry of Agriculture (MoA). MoA is responsible for the management of agricultural and rural development at the national level. The ministry's activities range from policy development, water use and small-scale irrigation, monitoring events affecting agricultural development, rural agriculture technology training, food security, to the conservation and use of forests and wildlife resources. During their 2014 study, the researchers found that there were no remote sensing experts as primary users at national level in the sector, but only secondary users who have taken courses in related fields. The study identified a significant lack in skilled labour due to which MoA undertook no active remote sensing related developmental and scientific research.

Today the situation has slightly improved as the Ministry has set both short and long term plans to use remote sensing technology more efficiently. According to these plans, the agricultural sector will employ more than 150 remote sensing experts at national level over the next 25 years. In the two years since Baley and Badada's study MoA had also conducted a programme in collaborations with the Netherlands intended to monitor crop health for yield prediction by using mostly MODIS data and deriving the NDVI. Furthermore, from a recent personal experience Dr. Griesbach (2016, pers. comm.) noted: *"I know a number of well-educated specialists in different African countries, but the overall number is far too low... A recent example in Ethiopia showed, that the educational base is good and young specialists can perform well in their countries."*

One of the questions that surfaced during the research visit was related to the use of freely available satellite data to which Dr. Besha gave his inputs:

"We cannot say that there is enough freely available data. It is adequate for developing the skills and knowledge. For practical application the ideal scenario would be if globally we would have a constellation of satellites. For example, a constellation of CubeSats for agriculture, with good geometry, to provide information for precision

agriculture. That kind of initiative might be very helpful. I believe that agriculture is a global issue which can be tackled jointly by the global community."

The local researchers were well aware of the freely available data and have routinely used such datasets in their training and research. Having a constellation which would enable higher repetition times, for this region which is often covered by clouds during the growing season, would allow for more measurements to be taken during this crucial time. Through very high temporal resolution, made possible by CubeSat constellations, it would be possible to detect deviations from the normal growing pattern early on, which would ideally translate into adequate localised action and more accurate yield prediction.

When considering research and academic institutes it became clear that these have been using satellite data, especially concerning pre-drought warning. However, here another problem arises. As pointed out by Mr. Belay; *"There is a lack of coordination between the researchers and this leads to contradicting research results being delivered to the ministry. Different institutes apply different datasets and get different results."* He continues in elaborating how in 2015 three separate research institutes predicted the shortage of rainfall for the next 6 months, but that these results were not taken into account: *"There is a gap between the educated experts and the politicians."*

Although ESSS has achieved an impressive relationship with the government though awareness building programmes, the organisation of different stakeholder meetings, organising workshops and public programmes and outreach programs via television and radio, there is still a noticeable gap. This is also reflected in the following comment of Mr. Belay:

"Even our earth2observe products will possibly not reach the end users, although it is useful for designers, project coordinators and indirectly the farmer. If we would produce indigenous high quality satellite data it might not be used. The matter is not the quality of data, it is the gap between the government and academia, the government and the farmers, the academia and the farmers. All three levels must be bridged to utilize the data."

It is yet to be seen how the recent transfer of EORC to MOST will influence the bridging of this gap. During the research stay it was noticed that the EORC and members of the international earth2observe project were not aware of each other's work and the similarities of their approach, although being located in the same city. This shows that there is still work to be done on bridging the gap between academic institutions themselves. The EORC strives to become a centre of excellence both locally and regionally when it comes to the fields it studies. Now that the center has been merged with MOST the research suggests that EORC could take on a role of a data congregation centre, where the inputs from the various institutes could undergo a form of peer review by selected scientists to than be forwarded to the relevant ministries. The necessity of bridging the gaps is exemplified by the notion that the institutes currently lack a method of getting the information out of the centre of the country, Addis Ababa, to the regions that need it. Governmental institutions can play a central role in bridging this divide as the country has multiple administrative layers (see Fig. 9): regions, zones, woreda (districts), and kabele (wards).

Fig.9, Administrative zones of Ethiopia

In the figure above, the dark lines represent the regions, the lighter ones the zones, and the white lines the woredas. Individual kebale are distributed within the woredas and are the smallest administrative layer. An organised line of communication exists spanning from the central government to the kebale. Local research on the utilization of the existing administrative setup for data and information dissemination relating to Earth observation should be encouraged in the country.

5.5. Future of space technology in Ethiopia

The ambitions of Ethiopian space development are clear, the country wants to bridge the "stratospheric divide" (Leloglu, 2004) and enter the medium-high category of space applications in the Space Participation Metric.

When asked what would it mean for the country and its stakeholders if Ethiopia would have an indigenous spacecraft in Earth's orbit, Dr. Besha replied:

"The first thing is national pride. National pride is a part of our mission. The second element is the definite need for Earth observation technologies. The applications could focus on precision agriculture as that is where our national GDP is. Tackling our national issues would be a strong plus for our stakeholders and the government. This is to be perceived in combination with national pride, it is a synergy. National pride and national capacities are inseparable and one drives the other."

Such remarks do not come as a surprise as a study by the OSCE (2011) found that national prestige is the main motivation for developing national space programmes in the initial years of their establishment.

Dr. Besha continued to elaborate the approach which ESSS and EORC are likely to take in the initial phases of satellite development. He stated that as a developing country they would preferably start with a project that is cost effective with a minimal probability of failure. Dr. Besha stressed the importance of minimizing the risk associated especially with financing the programmes as most developing nations, which are very young in terms of space technology, prefer a technology which is cost effective. He warned that encountering initial risks or mission failure might make it very difficult to repeatedly convince the decision-makers to make the same investment. *"If something wrong happens, the necessity is to minimise the risk in these initial stages. The concept is to start with the cost effective solutions with minimal risk, which would be the CubeSat, then you go to medium scale, and at the end of the ladder you have the high scale satellites.*"

From the statement above one can see that the first step ESSS and EORC hope to achieve is a successful launch of a locally built CubeSat. The KiboCUBE programme provides the opportunity for the country to minimize such an initial risk by cutting the investment by up to 50% through the free launch and reducing the likelihood of mission failure by ISS deployment. However, as pointed out in Chapter 3.6.3.2 certain technical eligibility criteria in form of a ground station and national capacity in designing, manufacturing, testing and operating the CubeSat need to be fulfilled.

At present the country does not have any ground station facilities. However, the country's space strategy plan includes the establishment of ground stations. Dr. Horikawa (2016, pers. comm.) pointed out that for the operation of a very small satellite such as a CubeSat even amateur radio communication can be sufficient, composed of a receiver and small generator. One example for a resourceful entry-level ground station was a student project at the University of Hawaii, for which a mobile ground station was build that successfully tracked CubeSats XI-IV, Cute-1, and QuakeSat (Wollert et al., 2011). The research questions the long-term necessity for such an eligibility criterion in the KiboCUBE programme. Two evident options exist for how this initial barrier could be circumvented. ESA sponsors the global Educatonal Network for Satellite Operations (GENOS), which is a peer-to-peer client server network of ground stations interconnected via the internet (ibid). The distribution of the network allows for the increase of daily visibility of the satellite. An educational satellite project can be selected to participate in GENSO and utilize any participating ground station. Furthermore, the non-profit University Space Engineering Consortium (UNISEC) has a ground station network working group (GSN-WG) comprised of thirteen Japanese universities and four participating institutes in the US, Sweden, Taiwan, and Germany. UNISEC has standardized open-source software for ground station management and web-enabled services. The research would recommend the two establishing partners of KiboCUBE, JAXA and UNOOSA, to consider such alternative approaches as these could be connected to a potential future goal. As discussed with Dr. Navulur, many developing countries still do not have the infrastructure necessary to process large amounts of downlinked satellite data:

"If you had a global infrastructure of ground terminals you could actually process the data and the output would actually be small, there might be another way of looking at this problem, not transferring all this data to the developing nations but somewhere central where you could actually process the data and then send out the information layers which are much smaller."

When it comes to the technological criteria currently there is no existing capacity in Ethiopia to fulfil these in a practical sense. Nonetheless, certain development steps, which were discussed with Dr. Besha and Mr. Ashanafi, could lead to the achievement of the criteria. The first step would be to provide special training which would be designed for selected talented and academically strong candidates from mechanical engineering, control engineering, software engineering and other relevant disciplines. As Dr. Besha explains, the training could be completed in relatively short time and could introduce the already experienced engineers to the specific topic of end-to-end nano-satellite development. After establishing the fundamental knowledge, the next step would be to collaboratively work with external professionals from space fairing nations to build the first CubeSat. On this CubeSat academic and professional capabilities can be built, which would allow for the development of a second CubeSat within Ethiopia's own capacity. Dr. Besha and Mr. Ashanafi both highlight that for the initial phase international collaboration and consultation is needed.

This state in Ethiopia supports the findings of Wood and Weigel (2012) who recognised that individual initiative, when it comes to building local capability in satellite design, manufacture and operations, is not enough out of two reasons. Firstly, some knowledge that is required for satellite programs is tacit and must be learned by interacting with experienced practitioners. Secondly, when looking on the organization level, learning to collaborate on complex task and learning tacit knowledge and the build-up of organizational knowledge takes time. Although one can focus a team on the design aspects and another on manufacturing, however, it is necessary that both have an overview of the entire process.

Additionally, the phases mentioned by Dr. Besha and Mr. Ashanafi are nothing new. Such development paths have been described in multiple studies looking at the beginnings of satellite development in developing countries (Leloglu & Kocaoglan, 2009; Wood & Weigel, 2011; Arguon, 2012; Wood & Weigel, 2012b). The experts interviewed did not express interest in acquiring a commercial turnkey system as the benefits to local knowledge would be limited to the operation of the satellite. The goal of EORC and ESSS is to have their local engineers and scientists engaged from the very beginning of the process, ideally starting with a CubeSat.

The development and implementation of a tailored training course, such as the one mentioned above, is a central part of UNOOSA's mandate and it can be developed by the Programme on Space Applications' BSTI. However, the full cost of such a training program falls on the recipient country. When discussing this topic with Dr. Balogh (2016, pers. comm.), he pointed out that the possibility exists for a Member State of UNOOSA to take over the costs and actively contribute to the training by providing its own experts to take part in the training mission.

The case study reflected on the modern Ethiopian space journey which started with the establishment of ESSS in 2004. The development plan that the society pursued contained the elements of firstly building awareness on the benefits of space science and its applications, secondly becoming a part of an international organisation, thirdly establishing a basis for higher education on space related topics, fourthly building ground based space hardware, and lastly transferring the resources to the national administration and thereby forming a nationally run space programme and securing the long term sustainability of space related activities in the country. Under indigenous capacities, without relying on government funds, the Ethiopian Space Science Society has managed to bring the country to the third category of the Space Participation Metric ("medium") and up to the first step of the Space Technology Ladder. However, to step beyond the stratosphere additional assistance is needed and as it will be argued in the following chapter such assistance can be provided by utilizing UNOOSA as a mediator of space diplomacy efforts of space fairing nations.

6. Discussion

6.1. The Ethiopian space journey and the potentials of UNOOSA

Through the information presented in the chapter above a correlation can be drawn between the space technology development path in Ethiopia and the individual initiatives started by UNOOSA and the Government of Japan. At the initial stages, UNOOSA assists developing countries in their awareness raising activities- there has been a long tradition in donating planetariums in collaboration with Japan. Any of the 193 recognised countries by the UN can become a Member State of the main Committee and the Secretariat. UNOOSA has developed curricula on the topics of remote sensing and geographic information systems, satellite communications, satellite meteorology and global climate, and space and atmospheric sciences. Together with the government of Japan, the Office offers a fellowship program at both MSc and PhD levels. The Office can also assist Member States of the UN in their national curriculum development. Additionally, through UN-SPIDER the Office provides specialised training courses to governmental institutions on the integration of remote sensing tools for various applications. Through the joint programme with Japan, BSSI has contributed to the inauguration of small astronomical facilities in developing countries and has developed educational materials for observation programmes in the established facilities that are using the donated small optical telescopes. These activities were followed up by the visits of Japanese scientists who would train the local staff. Through the KiboCUBE programme UNOOSA and Japan now offer the opportunity to all developing countries recognised by the UN to deploy their indigenously built CubeSat.

The paragraph above shows that UNOOSA and its initiatives can support the development path of a country such as Ethiopia from the first to the fourth technology category of the Space Participation Metric, which requires the evidence of space hardware.

At present there is not a single organisation, be it national or international, for-profit or non-profit, that offers a platform which can assist any country in the world to develop technological capacity ranging from low to medium-high (according to the Space Participation Metric) thereby answering to the need of a “total package” service expressed by emerging countries. UNOOSA offers space faring nations the opportunity to utilize its initiatives for international cooperation projects with potential recipient countries, and developing countries with the possibility of direct assistance in all dimensions of space science and technology. The international community has, intentionally or not, created an organisation which can provide countries aspiring to gain access to space with cooperation opportunities to promote space science and technology, educate their human capital, build ground based space related hardware, and now through KiboCUBE manufacture, launch and operate space based hardware at a previously unprecedented low cost and risk. All these activities accelerate sustainable development in countries following this development path. The following subchapter will reflect on how the development of the technology that is at the core of this thesis, CubeSats, and the applications derived from it can assist sustainable development nationally and internationally.

6.2. CubeSats, the ISS and Sustainable Development

The British economist E.F. Schumacher coined the term “small is beautiful” which is a call to empower people through simple but appropriate technologies (Dasgupta, 2016). The use of miniaturization technology in microelectromechanical systems (MEMS) has led to a 100-fold decrees in price compared to traditional spacecraft subsystems while additionally lowering the size (100-1000×) and mass (Boshuizen et al., 2014). Because of these advances small satellites have the potential to become the “satellites for the people” (Woellert et al., 2011) as they have removed the very large obstacle of cost from the equation and can now truly allow many countries that have not yet passed the “stratospheric divide” to do so.

Mr. Atsushi and Ms. Ochia (2016, pers. comm.) identify three unique factors when it comes to small satellite development- cost, technology, opportunity. The interviewees pointed out that CubeSats can be developed and operated under reasonable cost. Secondly, the technological capacity is not too difficult to obtain and research institutes and universities are able to develop such satellites while still mirroring the multidisciplinary approach of traditional satellite development at only a fracture of the time and cost. Lastly, the opportunity for launching small satellites as a piggyback on launching vehicles and spacecraft destined for the ISS provides the interested parties with more openings to put the satellite into orbit.

The research shows that designing, manufacturing, launching and operating a 1U CubeSat can assist low-income countries in developing a workforce for indigenous technology development and provide a venue for awareness rising by tapping into the public's pride in national technology progress. Currently the 1U CubeSats do not provide Earth observation applications that would improve people's lives, as was rightly noted by Dr. Horikawa and confirmed through the research. However, this testing phase can be *"very satisfactory for the interests of new actors in space such as developing countries."* (Horikawa, 2016)

When looking at 3U CubeSats the arguments change. Considering vegetation measurements four of the nine measurements identified by CEOS have been flight proven, while the hyperspectral sensor necessary for differentiating between vegetation types has been developed and tested, and is now to be flight proven. There is no dispute in regards to CubeSats replacing bigger satellites on account of the sheer pixel resolution or possible number of bands. Nevertheless, it is realistic to reach 50% of the performance of a traditional satellite when considering this measurement category. A clear advantage would be to decrease investment vulnerability by making these small spacecraft quickly, deploying them in an ever-faster fashion and gathering the data rapidly.

Given the small size and mass of the satellite it has a very high manoeuvrability which allows format flying. To be able to enjoy the full benefits of CubeSat-based Earth observation one definitely needs a constellation. An individual CubeSat is better suited for technology demonstration than actual beneficial Earth observation applications, as the data that would be gained is already freely available (MODIS, Landsat-8, Sentinel-2 etc.). The potential for mission architectures consisting of very large constellations of CubeSats has one central promise and this is to *"combine the temporal resolution of GEO missions with the spatial resolution of LEO missions"* (Selva & Krejci 2012, p.50). We are not supposed to view small satellites as competition to larger spacecraft. Existing larger satellites, like for example RapidEye, World View 3 or Sentinel-2, provide accurate information with high spatial and spectral resolution, but with limited temporal resolution. Higher temporal information can, to a certain extent, replace higher spatial and spectral information, however the combination of high spatial, spectral and temporal resolution is where the added value is to be found: *"A combination of different satellites would therefore allow to increase the information base for decision making."* (Griesbach, 2016, pers. comm.) Through such marrying of CubeSat data with that gained from larger satellites the temporal vs. spatial resolution trade-off in mission design could be eliminated. In practical terms, taking vegetation monitoring into account, this would mean that with the current CubeSat technology we would be able to catch deviations very early. The high manoeuvrability allows us to collect from small areas. If we are looking at precision agriculture, we want to look at a few fields within a footprint of usually 3kmx3km. With a constellation of 6-8 satellites, depending on the orbit, we might get 10-20 revisits a day (Navulur, 2016, pers. comm.). Dr. Griesbach whilst referring to the high imaging frequency of CubeSat constellations, like the one Planet Labs is planning, pointed out that this allows a stable supply with satellite imagery even in the cloudiest regions of the world, amongst them a lot of developing countries: *"The availability of imagery will trigger the implementation of geospatial technologies for mapping and accounting of agriculture production."* However, to be able to integrate the information into the decision-making process, as highlighted by Dr. Navulur, we need to understand the crop's behaviour during the day:

> *"For example in a typical mid-west region in the United States, at around 9-10a.m. is when the fog lifts, meaning that there is a lot of moisture in the crops, around 2-3p.m. is when the peak of the sun comes around so there is natural moisture depletion within the canopy and then around 4-5p.m. it starts going back to normal. There is a wilting of the leaves, there is a canopy change during this period. I think it is just a matter of understanding that at different stages the plant will behave differently, but having that information and then looking for any deviations will start allowing you to diagnose problems much quicker than coming back every day or every other week."*

Traditional remote sensing has always focused on spectral signatures, and there is an inherent assumption that one is looking down at the same spot at the same time of the day. Dr. Navulur highlighted the fact that there is very little research in terms of how to model crop behaviour within a day with multiple passes. This also brings one unexpected positive externality to the limited number of bands currently flown on CubeSats as in a way having 4 bands is easy as we are only limiting the performance of CubeSats *"to identifying early problems and not anything more than that."* (Navulur, 2016) As there is no available metric for measuring the level of utilization of satellite images, one suggested measure is the number and topics of publications in the various conferences and publication journals in the field. The timely need for research on crop behaviour at such high temporal resolutions has the potential to demonstrate the utilization of CubeSat images and provides new field to explore for researchers worldwide.

From the interviews that have been conducted and the literature review, it has become evident that CubeSats are here to stay. The number of countries interested in the development is constantly growing, ESA and Roscosmos are both pioneering work on 3D printed CubeSat elements, NASA has recently opened a new clean-room exclusively for CubeSat development. If we look at the private sector UrtheCast has partnered up with Surrey Satellite Technology Ltd (SSTL) and has acquired Deimos for $76,4 million to make the most of their knowledge in low cost small satellite solutions. Digital Globe, the largest commercial satellite provider, has partnered up with Saudi Technology Development and Investment Company (TAQNIA) and King Abdulaziz city of Science and Technology (KACST) to build a small satellite constellation capacity. NanoRacks is aspiring to introduce a new service called “Stash and Deploy”, by which a variety of standard and customer-specific component will be stashed aboard a satellite deployment platform, like the ISS. This would allow satellites to be assembled in space very quickly and to the customer’s exact needs. Start-ups like Spire and BlackSky Global have gathered tens of millions in venture capital. Google has acquired Skybox Imaging for $500 million. These developments have also influence the launch providers as Rocket Labs is now taking online-bookings for CubeSats, and Virgin Galactic has already arranged contracts to place 648 microsatellites into orbit over 39 launches (Singh, 2016).

When we consider these developments the projections by the research firm Markets and Markets which estimate that the nano- and microsatellite market will grow from $702,4 million in 2014 to $1887,1 million in 2019, come as no surprise. Northern Sky Research revealed that Earth observation is the prime driver behind the industry’s growth and project that 40% of the nano- and microsatellites which will be launched by 2024 will have an Earth observation mission design (ibid). This is mainly due to certain data needs in many industrial verticals such as agriculture, forestry, wildlife etc. that can be filled with data from such very small satellites. As explained by Dr. Navulur (2016, pers. comm.), if one looks at the consumer they first want to carry out mapping, the second thing is reconnaissance, and thirdly surveying:

“Let’s talk about how some companies do commodity report today, what they do is they have a statistical distribution of the fields across a given country, and CubeSats

are ideal to start looking at that distribution of specific plots, so you are now inferring from a small subset of the population what the general trends of the population are. I see that kind of monitoring as being very suitable to the CubeSats in comparison to what we [Digital Globe] currently do. As we cannot come back to these locations on a regular basis as CubeSats can do. Second aspect is that 90% of people in the next 20-30 years will be moving to urban areas. That means that change is constantly happening, that 20-30min information is becoming a lot more relevant for location based businesses, location based inelegance."

Although there is a wide array of, often freely, available space data today one can argue that it is in principle not necessary to develop indigenous capabilities in space technology development to benefit from space applications. The thesis recognises that one single Earth observation CubeSat cannot contribute much to the existing open-source data, but has not entered into this open debate in full length, the research has rather explored options on how the existing data could be married with new data derived from CubeSat constellations. However, in the case of developing even a single 1U CubeSat, the mastery and good understanding of the technology fundaments of these applications are a precondition for achieving a higher level of independency (Balogh & Haubold 2009). When considering developing countries this can enable them to acquire the means to develop basic space technology and transition from being passive to becoming more active space users, for example, *"by allowing them to become providers of space-based data and information."* (ibid, p. 1848)

Through the Kibo Module the International Space Station has continued to drive the growth of space science and the robust commercial marketplace in space. The ISS provides young companies with the chance to test their products and identify the market space, and now through the KiboCUBE programme Japan and UNOOSA provide developing countries with the opportunity to gain access to space by further decreasing the cost and risk barrier. During the opening of 59th COPUOS session (08.06.2016) the Japanese delegation highlighted that throughout the first Announcement of Opportunity 13 applications from developing countries were received and that, following this initial success, the second Announcement of Opportunity for the KiboCUBE programme can be expected in the near future. The ISS and J-SSOD have reached a new milestone on the 27th April 2016 through the deployment of Philippine's 50kg class microsatellite Diwata 1. This is a demonstration of the potential for long-term partnerships when it comes to satellite development in connection with ISS deployment. Japan, through its Kibo Module and J-SSOD, can now deploy satellites ranging from a 1U CubeSat to a 50kg microsatellite. At present KiboCUBE only encompasses 1U CubeSats leaving plenty of room for future developments of the programme. To this end this thesis would recommend for the programme to make efforts to tap into the country's ODA contributions, in line with its science and technology diplomacy policy, thereby KiboCUBE would not only rely on the funds that JAXA is able to provide. The question that remains open is the one of finding an international mechanism or approach to transfer the technology in question from space faring nations to developing countries. One tool to achieve such a development and the mutual benefits of both the donor and recipient country is *space diplomacy*.

6.3. Space Diplomacy

Globalisation in the 21st century has two tendencies, it de-territorialises political space, and privatises the benefits and socialises the costs. When we look at the current state of space technology and the use of space-based Earth observation systems, which themselves operate in a legally de-territorialised region, although there is a general agreement that space should be used for the benefits of all humankind, we can see that its use is unequal and only a fraction of countries is utilizing it effectively. The Sustainable Development Goals are aspiring to create change on a global level, as argued satellite technology can be a central tool to achieving the goals, and to do so the SDGs need a reliable global network to support it. A network can only be formed if exchanges happen in a multitude of directions.

This thesis argues that a suitable network already exists and is in fact the international diplomatic network. Diplomacy is a non-violent approach, using political communications, to the management of international relations and is characterized by dialogue, negotiations, compromise. *"Diplomacy gets you from looking to seeing, from hearing to listening, from dictate to dialogue.*" (Copeland, 2016, pers. comm.) However, to get from signing (the SDGs) to implementing we need to draw on one specific feature of diplomacy and this is complex knowledge based technologically enabled problem solving through the concept of science diplomacy. In its essence science diplomacy is about practical applications which will advance the ends of security and development:

"There is no doubt that the SDGs and science diplomacy have a symbiotic type of relationship. Many if not most of the SDGs have a significant S&T component. The SDGs could be arrayed under one or the other heading of contributing to either security or development, or maybe both. Alternatively, if you are trying to make the case for science diplomacy, a more pronounced role for science and technology in diplomacy, or international policy and international relations more generally, you could use the fact that the international community has agreed on the SDGs to bolster the case for more resources into science diplomacy which is terribly under-resourced at the moment. This is a very nice two-way symbiotic relationship between science diplomacy and the SDGs." (Copeland, 2016, pers. comm.)

6.3.1. Diplomacy vs. international cooperation

The way both Japan's S&T diplomacy policy and Basic Space Policy are formulated reassures the parties that the relationship will be a transformative one, shared moral principles and equal partnerships seem to form the pillars of cooperation. Through the two policies the government of Japan redefines "diplomacy" in a sense that it should not just be the establishment of good relationships with other nations, but should also be aimed at the realization of national interests and the strengthening of industry's international competitiveness. Japanese scientists, next to being first rate scientists, are viewed as private envoys representing Japan. The researchers put down roots in local communities, friendships and networks are developed with their local colleagues, and progress in research is made (Yakushiji, 2009). To a great extent the success of space related initiatives and the penetration into emerging markets depends on *"Japan's capability to coordinate national interests among countries, that is, diplomacy."* (Sunami, Ganacgum and Kitaba 2013, p. 8)

In its many years of space activity, Japan has addressed international issues by cooperating in the group on Earth Observations (GEO), Asia-Pacific Regional Space Agency Forum (APRSAF), Sentinel Asia, Charter on Cooperation to Achieve the Coordinated Utilization of Space Facilities in the Event of Natural or Technological Disasters, United Nations Committee for the Peaceful Uses of Outer Space (UNCOPUOS), the International Space Station and a series of bilateral agreements. In general, we can see that Japan's space related international cooperation efforts developed in three directions. Firstly, Japan is cooperating with developed space faring nations such as the United States, Russia, European countries, China and India on small, medium and large-scale projects. Secondly, the country is engaged in medium scale projects with the Asia-Pacific region. Although these countries are still in the phase of developing their space capacities the foundations are there for collaborative programmes to be persuaded. Thirdly, Japan has the opportunity to cooperate bilaterally with all countries, especially with developing countries that have been vocal about their space ambitions, and this has been highlighted in both Japan's science and technology diplomacy policy and BPSP. Article 6 of Japan's Basic Space Law (2008) states that in regards to the development and use of outer space international cooperation: *"shall be carried out in order to enable Japan to play a positive role and contribute to advancing national interests in international society, through positively promoting international cooperation and diplomacy..."* In this article, Japan's policy makers have made an important and correct separation between diplomacy and international scientific cooperation.

If we are to call something diplomacy it must be connected in one way or another to the values, policies and interests of states. If a couple of NGO's or a couple of corporations, or even research institutes cooperate to advance some shared research interest that they have and if these are not connected to the values, policies and interests of states or international organisation than it is international scientific cooperation and not science diplomacy (Copeland 2016, pers. comm.). Through the SDGs states have agreed on a set of values- reflected in the individual goals-, policies- the SDGs themselves-, and interests- the achievement of the SDGs. This opens up an array of opportunities for countries to practice science diplomacy through the governmental sector, non-governmental sector and even through private corporations if their actions are in line with the values, policies and interests of the relevant state. The concept discussed in this thesis can contribute to meeting the increasing demand of emerging countries for the provision of satellite data and hardware, human resource development, technology transfer and other services which are supposed to be supplied as a total package. Coming back to Japan, one of the central questions that can be derived from the BPSP and Basic Space Law, in connection with the Science and Technology Diplomacy policy, is yet to be answered: how to promote *space diplomacy*?

6.3.2. The three elements of space diplomacy

This thesis views space diplomacy as a subset of science diplomacy focused on space science and technology. Currently the term “space diplomacy” remains undefined. Regardless of this, the term has been used many times in both academic studies and news articles. On the one hand the predominant theme in the academic literature (Whiting, 2003; Arbatov & Dvorkin eds., 2010; Betmann, 2016; Rose, 2016) in regards to space diplomacy revolve around the topics of conflict prevention and the use of space assets for diplomatic leverage as a form of hard power, thereby heavily diverging from the concept of science diplomacy. While on the other hand news coverage (Krepon, 2012; Avuthu, 2014; BBC, 2014; Gunawardene, 2014; Fernholz, 2015) uses the term when referring to international cooperation, which, as argued above, is not the same as diplomacy.

The presently most active step to change the scenario of such an open interpretation of the term is undertaken by the subject of this thesis, UNOOSA. The Office, within its activities leading up to the UNISPACE+50, is organising a series of three High Level Forums “Space as a driver for socio-economic sustainable development” to offer the collective space community the opportunity to provide guidance and recommendations for the UNISPACE+50 road map. This blueprint aims to define concrete deliverables of space for the development of a nation under the four pillars: 1) Space Economy, 2) Space Society, 3) Space Accessibility; 4) Space Diplomacy (UN doc. A/AC.105/C.1/2016/CRP.4). As we can see space diplomacy is encompassed within these four pillars and will be further elaborated on during the three High Level Forums and UNISPACE+50.

This thesis will suggest its interpretation of space diplomacy and embed it as a subset of science diplomacy which itself is essentially a form of public diplomacy and a method of utilizing a country’s *soft power* resources. As a result of the extensive research on the topics of science diplomacy, Japan’s S&T diplomacy policy and space policy, and UNOOSA’s mandate and activities throughout this thesis, as a conclusion space diplomacy and its suggested elements will be defined. The paragraphs below will also elaborate on how UNOOSA’s mandate can be utilized as a tool for space diplomacy activities of its Member States.

In its announcement of the first High Level Forum, which was to be held in November 2015, but was postponed to the second half of 2016, UNOOSA (2015c, p.6) has defined the term space diplomacy as: *"Cooperation among nations in using space technologies and applications to address common challenges facing humanity and to build constructive, knowledge based partnerships."* As we can see the definition in question is very much in line with the principles of science diplomacy. The document (ibid, p.6) continues in saying that space diplomacy embraces both *space for diplomacy*- *"cooperation in space can improve international relations"*- and *space in diplomacy*- *"the use of space for peaceful purposes for improving international relations."* While the collective research in this thesis supports the general definition, the interpretation of the elements of space diplomacy are viewed as unnecessarily limiting the potential outreach and utilization of this diplomatic asset. Therefore, an alternative interpretation of the elements of space diplomacy is suggested. In line with the concept of science diplomacy, the elements of space diplomacy are: space in diplomacy, space for diplomacy, and diplomacy for space.

6.3.2.1. Space in diplomacy

Space in diplomacy is the uptake and promotion of high quality space derived information and science advice by policy makers. Daryl Copeland, a person who does not have a technical background, but has more than 30 years of diplomatic experience, mentions satellite remote sensing in his writings (Copeland, 2010b) on the topic of science diplomacy. When interviewed (12.04.2016) and asked why this particular technology, among others, is pointed out as a potential tool for science diplomacy he replied the following:

> *"It is one of those areas where a certain degree of S&T capacity can be leveraged across a very wide span of human endeavour. Whether it is resource monitoring, arms control, tracking deforestation, water supply, desertification. (...) It seems to me as if we are looking at particular technologies, remote sensing among others, that can play a role of fundamental importance in advancing the objectives of security and development worldwide in ways that other technologies can't. This notion of leverage, of adding value, of improving performance, remote sensing plays very centrally into all of those agendas."*

Mr. Copeland is an example of a diplomat who has acquired the necessary amount of scientific knowledge to be able to understand the potential relevance of a particular technology. In the example above, satellite remote sensing is highlighted out of its applicability for a broad array of issues and its leveraging power based on soft power e.g.

an admirable space based resource from which one can provide useful services to a recipient country. Furthermore, Earth observation has been identified as a useful tool for the monitoring of international treaties (Aschbacher, 2002; Johnston, 2006; ESA, 2002). Space in diplomacy as the provision or application of space-related scientific knowledge expertise and findings into the policy and decision making process from the inside, requires two essential elements: data and trained personnel. UNOOSA promotes data sharing and implements human capital training. Through its initiatives, tailored remote sensing training courses for governmental personnel have been developed and delivered thereby fostering the uptake of quality satellite data into the decision-making process from within the governmental institutions. This in itself opens up the possibility to practice science diplomacy as the improvement of the scientific literacy of delegations from developing countries is particularly important when such highly technical issues that the world is facing today are being discussed both on the bilateral and multilateral level. There are no obstacles standing in the way of space fairing Member States to offer their experts to be a part of the training missions, as the financial hurdle of paying for the experts is still a considerable limiting factor for a low-income country.

6.3.2.2. Diplomacy for space

Diplomacy for space would be the use of the existing diplomatic relations for linking of scientific know-how with the diplomatic network and the facilitation of top-down strategic priorities for research or bottom-up collaboration between individual scientist and researchers. When asked about why Japan and JAXA have decided to work with UNOOSA on so many projects- planetariums, telescopes, fellowships, KiboCUBE- Dr. Horikawa said:

> *"The reason why we chose UNOOSA as a partner is because it has the network and the contact-base with many developing countries whom we hope to reach with these programmes. Within COPUOS it is easy to announce such an opportunity and be reassured that it has reached the right people. In addition to COPUOS, UNOOSA has an excellent network based on the BSSI, BSTI and HSTI."*

In COUPOS and its Subcommittees, STSC and LSC, an arena is created in which the relevant experts- diplomatic, legal, and technical- come together three times a year to discuss a variety of pressing space related topics. The interaction between scientists and diplomats can be central to the advancement of the scientific enterprise and UNOOSA actively- through its Programme on Space Applications- and passively- by acting as the Secretariat of COPUOS- works on achieving the most fruitful interaction of the two spheres.

6.3.2.3. Space for diplomacy

Space for diplomacy is the operationalization of space activities as diplomatic assets as a source of soft power to help build and improve international relations. As highlighted in chapter 2.2.3., the attractiveness and influence of science and technology as a national asset and a universal activity transcends national interests and can be used as a form of soft power. However, space technology is dual use, it can be used both for peaceful and non-peaceful purposes. This is best reflected in the fact that many space related components, parts and sub-systems are subject to heavy export control. What is necessary to secure that one's space diplomacy efforts are perceived as a soft power resource is a buffer between the two sides of the space technology coin. Such a buffer can be created by mediating one's activities through UNOOSA. This argument is supported by the responses of UN Member States and other space actors to a questionnaire released in 2009 (Balogh & Haubold) which indicated that UNOOSA could act as an honest and independent interlocutor, information broker and interface between stakeholders, specifically between countries and entities that already have a demonstrated experience with space technology development and countries and entities seeking to establish basic space technology capabilities.

UNOOSA offers the structure to act as a mediator in all the different types of science for diplomacy and therefore space for diplomacy: *) New institutions- UNOOSA assists in building remote sensing sectors in governmental institutions by providing tailored training; *) Educational scholarships- Japan/UNOOSA fellowship programme; *) 'Track two' diplomacy- informal and unofficial contacts and activities between groups of individuals can be formed in the committee meetings, symposia, conferences; *) Science festivals and exhibitions- various symposia organised by UNOOSA, UNOOSA/ESA "My Planet from Space: Fragility and Beauty" exhibition in New York.

The three elements of space diplomacy should have a synergetic relationship with the individual elements supporting each other through a delicate interplay and transfer of resources.

6.4. Synopsis

The SDGs as an internationally agreed development blueprint provide the international community with a previously unprecedented assortment of opportunities to practice science diplomacy. Concentrating on space-based technology, this thesis has identified that the existing concept can be slightly modified, while maintaining its core values and principles, to better fit the technology in questions. Therefore, the term space diplomacy and its three elements have been defined.

Space diplomacy should enable various actors in the space arena to either actively approach or be approached by their foreign ministries with a goal to utilize the soft power that is at the core of this discipline. Ever since the space race technological progress in space technology, especially the launch of a country's first space-based resource, has been strongly connected to national pride and prestige. To be able to tap into something as fundamental as national pride or even be a substantial part of it, such as Japan through KiboCUBE, has a great diplomatic value as it can potentially influence the public opinion and the public's attitude towards the formation and execution of foreign politics while at the same time emulating the country's values, policies and interests, and this is public diplomacy.

The paradox of space technology was underlined. Space-based technology can provide the answers to many wicked problems the world is facing today and foster security and development, but if used for the wrong purposes it can lead to insecurity and underdevelopment. Next to providing the "infrastructure" for the practice of space diplomacy, the United Nations Office for Outer Space Affairs has been identified as a buffer between the two spheres- military use and peaceful applications - as it governs the exploration and use of space for the benefit of all humanity, for peace, security and development. The three-fold significance of UNOOSA- having an established diplomatic and scientific network ranging across all countries of the world, having developed multiple initiatives through its Programme on Space Applications, and being perceived by the international community as an honest broker- showcases its potential to be utilized as a mediator of space diplomacy efforts of its Member States.

Exploring the Ethiopian case demonstrated the state-of-the-art of space related technology in this East African country. Analysing the development path of the country's progress in regards to space science and technology a common pattern could be identified and compared to studies dealing with the topic. The country's development stages, as well as those considered in research on the topic, reflected the individual categories of the Space Participation Metric. Starting form awareness rising necessary for the government's support to enter an international space related organisation, followed by space related education and research, culminating in the construction of ground based space hardware, and aspiring to achieve space-based hardware. It was noted that there is a clear trend and growing interest in developing countries in acquiring small satellites technology and benefiting from their applications, especially Earth observation. The CubeSat brings new opportunities for the international cooperation between space fairing nations and developing countries these countries and the practice of science diplomacy. With the operation of the ISS and the Japanese Kibo Module all non-space faring nations have come closer to outer space than ever before.

The relevance of the development of CubeSats to the SDGs can be found in the generation of ingenious low-cost solutions, not only in individual educational endeavours, but also in more complex government-sponsored undertakings. Within a developing country, a small satellite programme can foster good international relations through the development of partnerships, it could stimulate interest in science and technology, enhance the quality of education, promote research and development in a variety of engineering related sectors, it can lead to the establishment of new businesses, improve quality of life, the productivity of industrial sectors, and the state of the environment through its applications, and result in better linkages between government agencies, educational institutions and industrial sectors. It is this unique three-dimensional nature of basic satellite technology development and its application that directly connects it to the concept of sustainable development and its three pillars: society, economy, and environment (see Fig. 10).

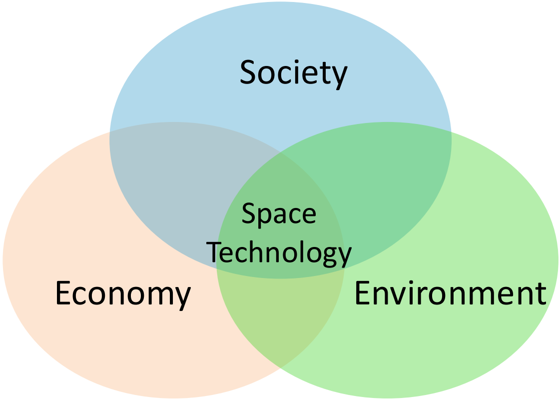

Fig. 10, The three pillars of Sustainable Development

In an international view, the SDG’s will rely on the monitoring of the state of the planet at national and global level. Satellite imagery allows us to create an accurate baseline of the current state of the planet by creating a base layer of a spatial resolution of up to 10m when considering open source data (Sentinel-2) and up to 30cm when considering data gathered by commercial providers (World View 3). Foundational information layers such as roads and transportation, population dynamics, structures and neighbourhood patterns, water bodies and their quality, biodiversity etc. can be derived from such a base layer. By introducing daily collection capacities of state-of-the-art CubeSat constellations, various organizations and governments can quantitatively map the progress of the SDG’s. *“The technology will enable the various stakeholders to do micro level analysis at a macro scale.*” (Navulur, 2016) Retirements of large satellites and the arrival of new ones can create data gaps. Single-purpose CubeSats can be deployed to prevent such data gaps from occurring until the larger satellite has been launched. Constellations of small Earth observation satellites do not only have the potential to improve the available data but can also increase the operational stability of the global observation system securing data continuity for monitoring the SDGs through 2030 and beyond. We have to bear in mind that the Outer Space Treaty states: *“the exploration and use of outer space...shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.”* The ISS, a symbol of science diplomacy, and CubeSat technology have the potential to surpass this principle by enabling all countries, irrespective of their degree of economic development, to develop space technology, enter outer space, explore and use it to defy the volatility, uncertainty, complexity and ambiguity of the problems humankind is faced with today.

7. Conclusion

This thesis has interrelated two fields: science as an evidence based form of knowledge acquisition, and diplomacy as the means of transcending the interests of governments, which at first did not seem to share many characteristics. The thesis has identified commonalities of these fields that resonate throughout the topic of the use and application of space technology for the benefits of humankind.

Chapter 2 analysed the underlying history and understanding of the concept of science diplomacy and its three elements. The paradox of S&T was highlighted as it can provide answers to many tenacious problems we are faced with today, while at the same time it can be used for dominance and supremacy. The vector of soft power was identified as an underutilized diplomatic resource. Pioneering achievements of Japanese policy makers in regards to the science diplomacy concept and the connection to its Basic Plan on Space Policy were reflected on to later show how both spheres can benefit by strategically being coupled to the country's existing initiatives with UNOOSA.

Chapter 3 has undertaken a detailed analysis of UNOOSA's mandate and initiatives. In the chapter the Office's activities have be taken into account to exhibit how these are overlapping with the elements of science diplomacy. Furthermore, the unique arena consisting of diplomatic, policy, scientific, and technical experts was recognised. The space science and technology development pathway setup by UNOOSA's initiatives, beginning with awareness razing and culminating in the development of space based hardware, reflected that of national initiatives across the globe.

In chapter 4 a comprehensive survey has been conducted consisting of 122 CubeSats that have been deployed from the ISS from 04.10.2012-10.05.2016. Both the strengths and limitations of the state-of-the-art technological capabilities of these very small satellites were assessed, which showed that for specific missions they can easily reach 50% of the performance of their larger counterparts. The unique possibility of operating large constellations was underlined. Moreover, the chapter analysed possibilities of conducting vegetation measurements with optical Earth observation instruments flown on-board CubeSats. From the extensive research it was concluded that four out of the nine vegetation measurements recognised by CEOS can currently be conducted by CubeSat-based mission, while the integration of the miniature hyperspectral sensor can be expected in the near future.

Chapter 5 discussed the Ethiopian case and assessed the country’s space related activities, from education to ground hardware, and put them into relation with the Space Participation Metric and the Space Technology Ladder. This chapter reflected on the difficulties space initiatives can face in low-income countries whose inhabitants are at times faced with existential difficulties such as food security. It became clear that although significant progress has been achieved in the past decade and that some gaps still remain between the relevant stakeholders in the country. The Ethiopian Space Science Society has managed to indigenously bring the country to the third category of the Space Participation Metric (“medium”) and up to the first step of the Space Technology Ladder. This thesis identified that for further developments in the aria of basic space technology, especially when it comes to passing the “stratospheric divide”, purely indigenous efforts will not suffice. Therefore, the reliance on international cooperation is a central element for emerging countries and their space related ambitions.

Chapter 6 merged the different elements presented throughout this thesis and proposed a framework for the concept of space diplomacy. The three elements of space diplomacy- space in diplomacy, diplomacy for space, and space for diplomacy- were identified and defined. The thesis came to the conclusion that UNOOSA together with its initiatives and as the Secretariat of COPUOS can efficiently be utilized as a mediator of science diplomacy and space diplomacy efforts of its Member States. Furthermore, it was demonstrated how efficient integration of satellite data into the Post-2015 development agenda can nurture all three pillars of sustainable development, both nationally and internationally, and bring us closer to a world such as envisaged by astronaut Michael Collins: *“Earth must become as it appears: blue and white, not rich, nor poor… blue and white, not envious or envied.”* It should not be necessary to fly beyond Earth’s boundaries to realise that our planet, which we all share, is connecting us together in a more essential way, than colour of our skin, religion, political ideology, or economic importance divide us.

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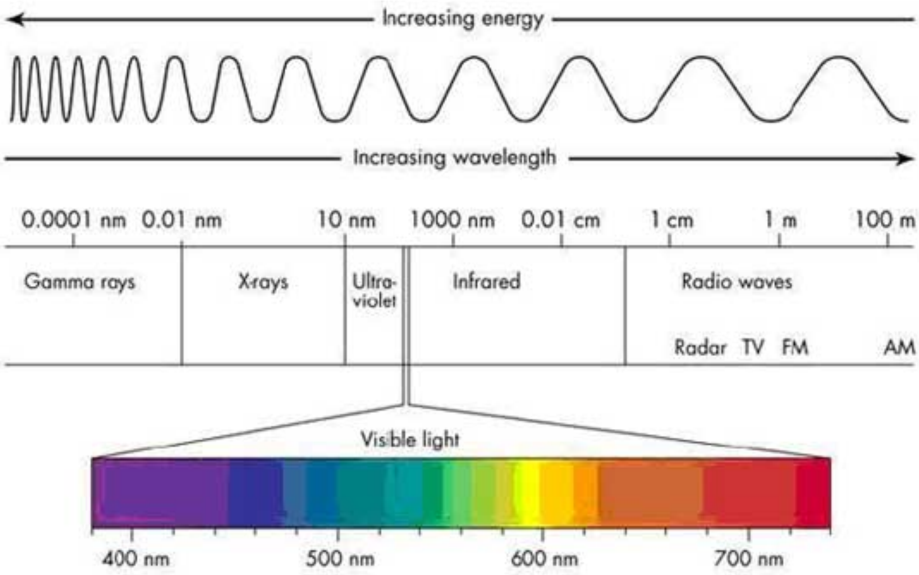
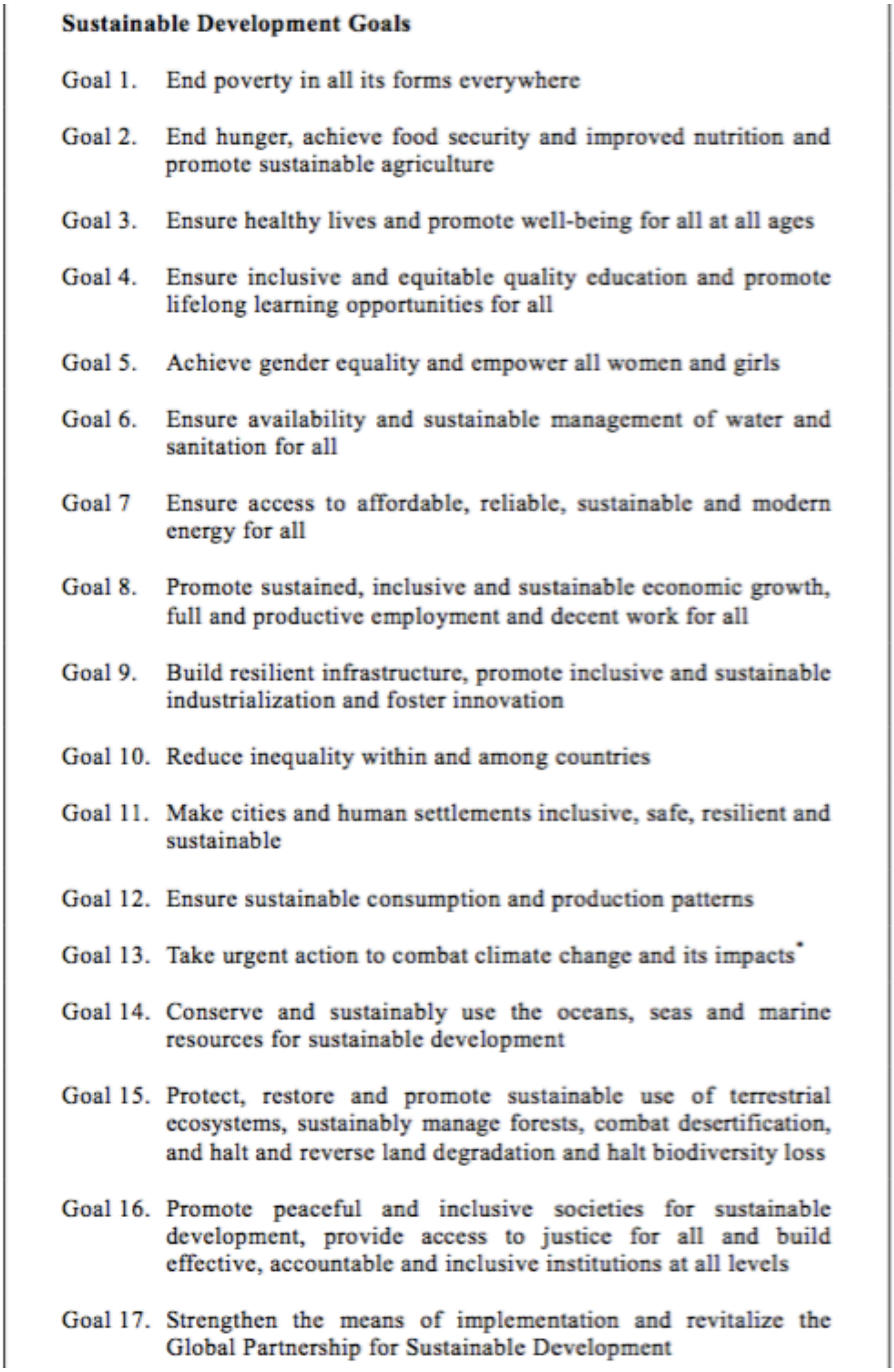
Appendices

1. *The electromagnetic spectrum,* *http://www.acecrc.sipex.aq*



2. *Sustainable Development Goals, (UN doc. A/RES/70/1)*



Sustainable Development Goals

Goal 1. End poverty in all its forms everywhere

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture

Goal 3. Ensure healthy lives and promote well-being for all at all ages

Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Goal 5. Achieve gender equality and empower all women and girls

Goal 6. Ensure availability and sustainable management of water and sanitation for all

Goal 7 Ensure access to affordable, reliable, sustainable and modern energy for all

Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

Goal 10. Reduce inequality within and among countries

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable

Goal 12. Ensure sustainable consumption and production patterns

Goal 13. Take urgent action to combat climate change and its impacts*

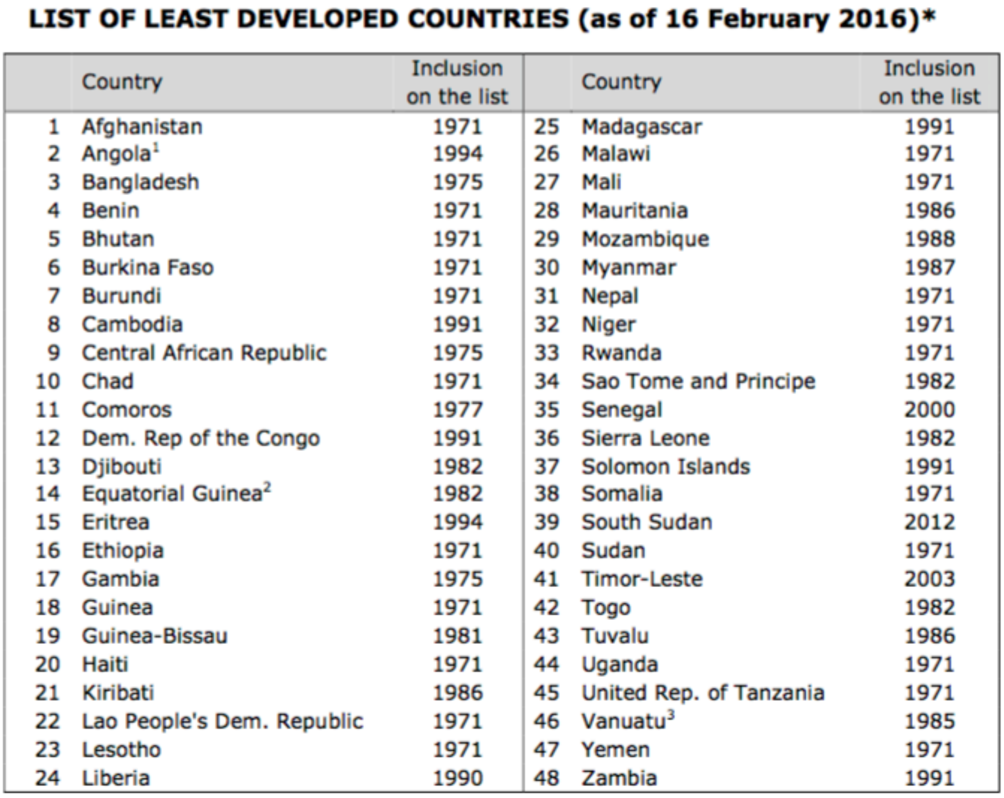
Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

3. List of Least Developed Countries, http://www.un.org/en/development/desa/policy/cdp/ldc/ldc_list.pdf



LIST OF LEAST DEVELOPED COUNTRIES (as of 16 February 2016)*

	Country	Inclusion on the list		Country	Inclusion on the list
1	Afghanistan	1971	25	Madagascar	1991
2	Angola[1]	1994	26	Malawi	1971
3	Bangladesh	1975	27	Mali	1971
4	Benin	1971	28	Mauritania	1986
5	Bhutan	1971	29	Mozambique	1988
6	Burkina Faso	1971	30	Myanmar	1987
7	Burundi	1971	31	Nepal	1971
8	Cambodia	1991	32	Niger	1971
9	Central African Republic	1975	33	Rwanda	1971
10	Chad	1971	34	Sao Tome and Principe	1982
11	Comoros	1977	35	Senegal	2000
12	Dem. Rep of the Congo	1991	36	Sierra Leone	1982
13	Djibouti	1982	37	Solomon Islands	1991
14	Equatorial Guinea[2]	1982	38	Somalia	1971
15	Eritrea	1994	39	South Sudan	2012
16	Ethiopia	1971	40	Sudan	1971
17	Gambia	1975	41	Timor-Leste	2003
18	Guinea	1971	42	Togo	1982
19	Guinea-Bissau	1981	43	Tuvalu	1986
20	Haiti	1971	44	Uganda	1971
21	Kiribati	1986	45	United Rep. of Tanzania	1971
22	Lao People's Dem. Republic	1971	46	Vanuatu[3]	1985
23	Lesotho	1971	47	Yemen	1971
24	Liberia	1990	48	Zambia	1991

4. MOFA 2011, *Japan's Official Development Assistance White Paper 2011*, Available from: http://www.mofa.go.jp/policy/oda/white/2011/html/honbun/b4/sanko3.html

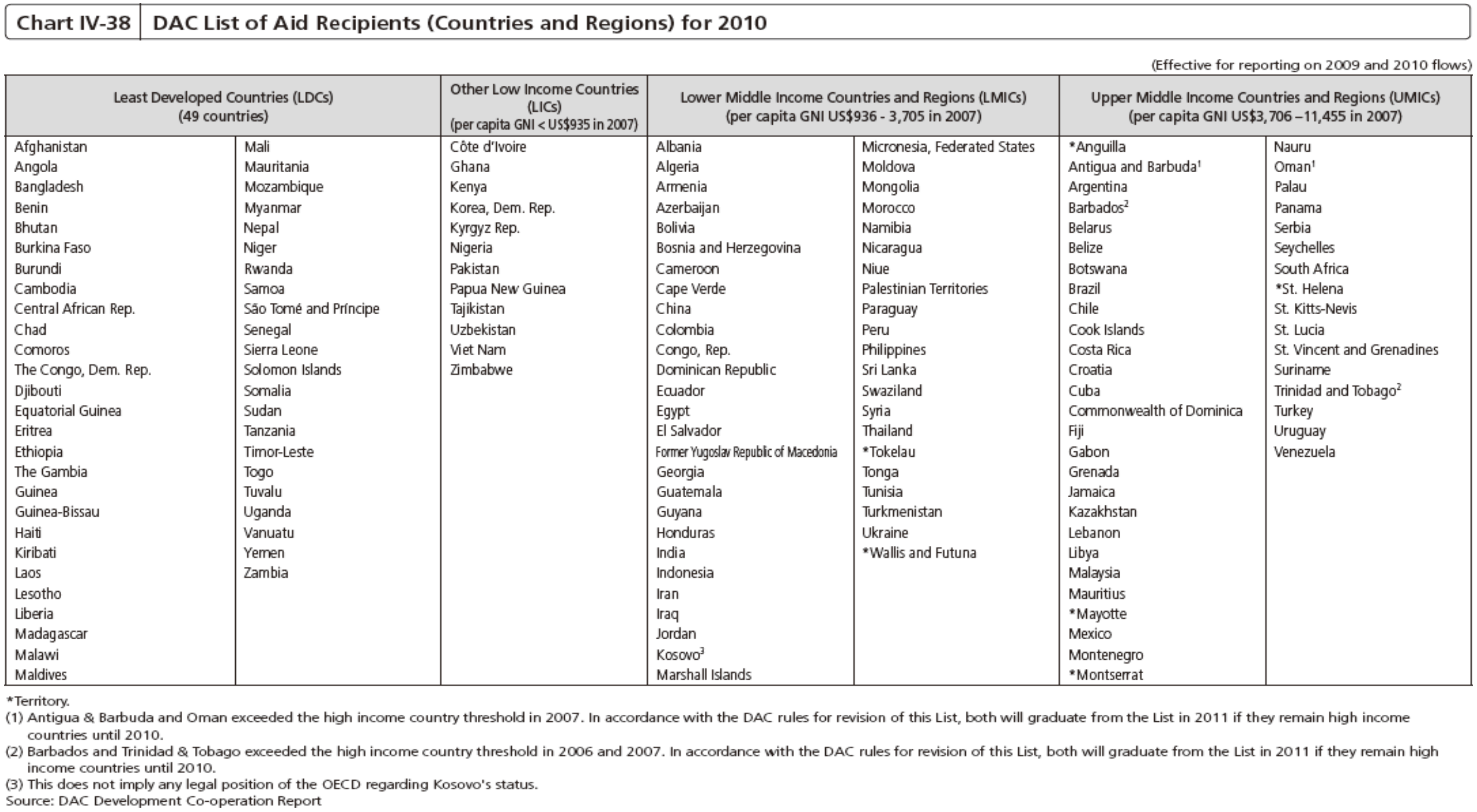


Chart IV-38 **DAC List of Aid Recipients (Countries and Regions) for 2010**

(Effective for reporting on 2009 and 2010 flows)

Least Developed Countries (LDCs) (49 countries)		Other Low Income Countries (LICs) (per capita GNI < US$935 in 2007)	Lower Middle Income Countries and Regions (LMICs) (per capita GNI US$936 - 3,705 in 2007)		Upper Middle Income Countries and Regions (UMICs) (per capita GNI US$3,706 –11,455 in 2007)	
Afghanistan	Mali	Côte d'Ivoire	Albania	Micronesia, Federated States	*Anguilla	Nauru
Angola	Mauritania	Ghana	Algeria	Moldova	Antigua and Barbuda[1]	Oman[1]
Bangladesh	Mozambique	Kenya	Armenia	Mongolia	Argentina	Palau
Benin	Myanmar	Korea, Dem. Rep.	Azerbaijan	Morocco	Barbados[2]	Panama
Bhutan	Nepal	Kyrgyz Rep.	Bolivia	Namibia	Belarus	Serbia
Burkina Faso	Niger	Nigeria	Bosnia and Herzegovina	Nicaragua	Belize	Seychelles
Burundi	Rwanda	Pakistan	Cameroon	Niue	Botswana	South Africa
Cambodia	Samoa	Papua New Guinea	Cape Verde	Palestinian Territories	Brazil	*St. Helena
Central African Rep.	São Tomé and Príncipe	Tajikistan	China	Paraguay	Chile	St. Kitts-Nevis
Chad	Senegal	Uzbekistan	Colombia	Peru	Cook Islands	St. Lucia
Comoros	Sierra Leone	Viet Nam	Congo, Rep.	Philippines	Costa Rica	St. Vincent and Grenadines
The Congo, Dem. Rep.	Solomon Islands	Zimbabwe	Dominican Republic	Sri Lanka	Croatia	Suriname
Djibouti	Somalia		Ecuador	Swaziland	Cuba	Trinidad and Tobago[2]
Equatorial Guinea	Sudan		Egypt	Syria	Commonwealth of Dominica	Turkey
Eritrea	Tanzania		El Salvador	Thailand	Fiji	Uruguay
Ethiopia	Timor-Leste		Former Yugoslav Republic of Macedonia	*Tokelau	Gabon	Venezuela
The Gambia	Togo		Georgia	Tonga	Grenada	
Guinea	Tuvalu		Guatemala	Tunisia	Jamaica	
Guinea-Bissau	Uganda		Guyana	Turkmenistan	Kazakhstan	
Haiti	Vanuatu		Honduras	Ukraine	Lebanon	
Kiribati	Yemen		India	*Wallis and Futuna	Libya	
Laos	Zambia		Indonesia		Malaysia	
Lesotho			Iran		Mauritius	
Liberia			Iraq		*Mayotte	
Madagascar			Jordan		Mexico	
Malawi			Kosovo[3]		Montenegro	
Maldives			Marshall Islands		*Montserrat	

*Territory.

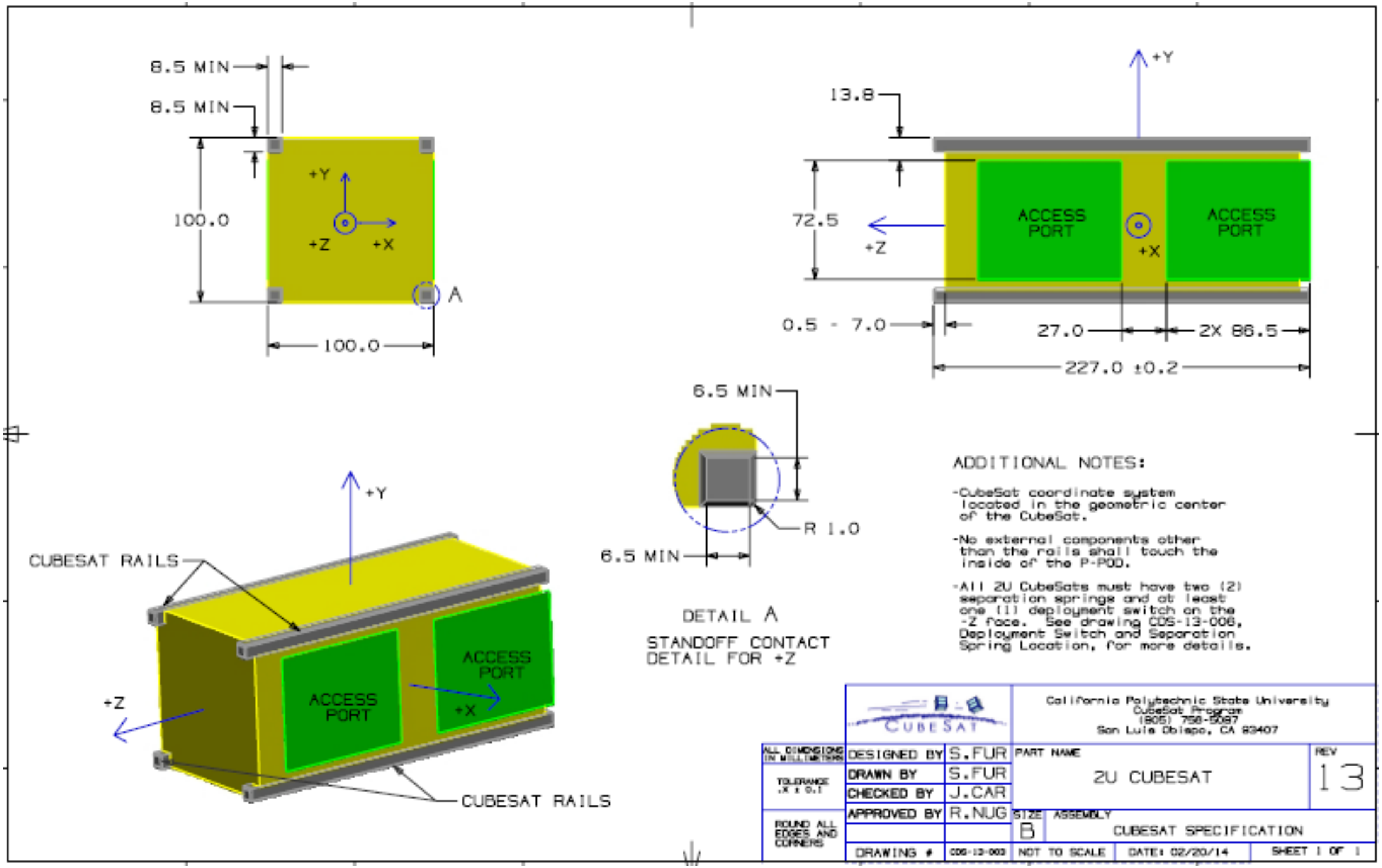
(1) Antigua & Barbuda and Oman exceeded the high income country threshold in 2007. In accordance with the DAC rules for revision of this List, both will graduate from the List in 2011 if they remain high income countries until 2010.

(2) Barbados and Trinidad & Tobago exceeded the high income country threshold in 2006 and 2007. In accordance with the DAC rules for revision of this List, both will graduate from the List in 2011 if they remain high income countries until 2010.

(3) This does not imply any legal position of the OECD regarding Kosovo's status.

Source: DAC Development Co-operation Report

5. 2U CubeSat Design Specification Drawing, California Polytechnic State University



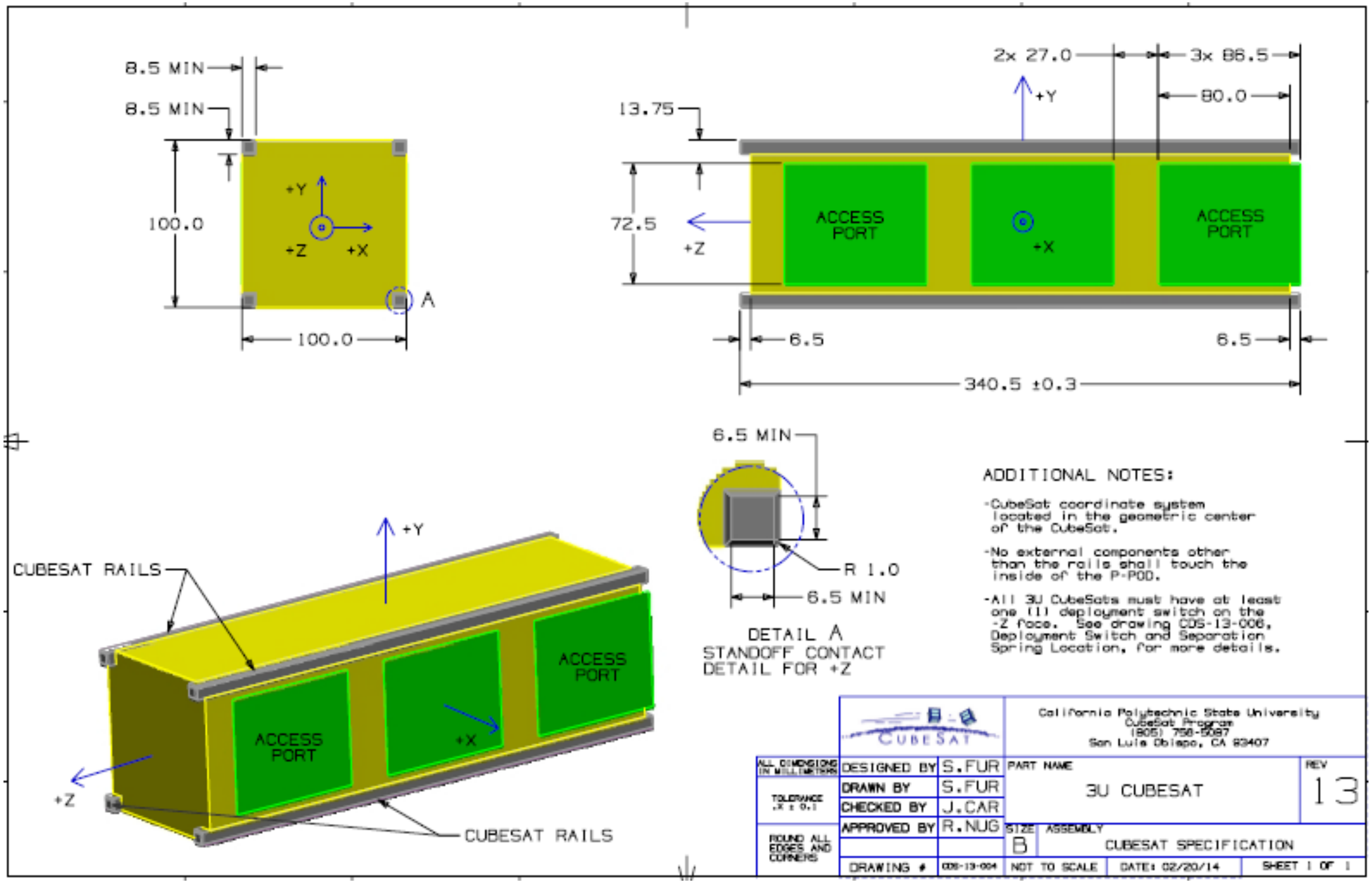
ADDITIONAL NOTES:

- CubeSat coordinate system located in the geometric center of the CubeSat.
- No external components other than the rails shall touch the inside of the P-POD.
- All 2U CubeSats must have two (2) separation springs and at least one (1) deployment switch on the -Z face. See drawing CDS-13-006, Deployment Switch and Separation Spring Location, for more details.

California Polytechnic State University
CubeSat Program
(805) 756-5087
San Luis Obispo, CA 93407

ALL DIMENSIONS IN MILLIMETERS
TOLERANCE .X ± 0.1
ROUND ALL EDGES AND CORNERS
DESIGNED BY S.FUR
DRAWN BY S.FUR
CHECKED BY J.CAR
APPROVED BY R.NUG
DRAWING # CDS-13-003
PART NAME 2U CUBESAT
REV 13
SIZE B
ASSEMBLY CUBESAT SPECIFICATION
NOT TO SCALE
DATE: 02/20/14
SHEET 1 OF 1

6. 3U CubeSat Design Specification Drawing, California Polytechnic State University



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ALL DIMENSIONS IN MILLIMETERS
TOLERANCE .X ± 0.1
ROUND ALL EDGES AND CORNERS

DESIGNED BY S.FUR
DRAWN BY S.FUR
CHECKED BY J.CAR
APPROVED BY R.NUG
DRAWING # CDS-13-004

PART NAME 3U CUBESAT
REV 13
SIZE B
ASSEMBLY CUBESAT SPECIFICATION
NOT TO SCALE
DATE: 02/20/14
SHEET 1 OF 1

CubeSat Deployment from ISS (04.10.2012-10.05.2016)

Satellite	Class	Organisation	Launch Vehicle	Deployer	Date of Deployment	Re-entree into atmosphere	Notes
1 Unit CubeSats							
AAUSAT 5	1U	Aalborg University	H-2B-304 (19.08.2015)	J-SSOD	05.10.2015		Technology cubesat receiving AIS beacons from ships
AESP-14	1U	IPA, INPE	Falcon-9 v1.1 (10.01.2015)	J-SSOD	05.02.2015		no signal received
ArduSat 1	1U	NanoSatisfi	H-2B-304 (03.08.2013)	J-SSOD	19.11.2013	15.04.2014	Technology cubesat for amateur and student experiments carrying a CMOS camera and onboard sensors: photolux sensor, IR temperature, PCB temperature, 3-axis magnetometer, Geiger counter, 6-DOF IMU and MEMS gyros
ArduSat X	1U	NanoSatisfi	H-2B-304 (03.08.2013)	J-SSOD	19.11.2013	16.04.2014	Technology cubesat for amateur and student experiments identical to ArduSat 1
Centennial 1	1U	Booz Allen Hamilton	Falcon-9 v1.1 (14.04.2015)	NRCSD	15.07.2015	06.01.2016	Technology demonstrator cubesat carrying otical sensors and a small camera
Chasqui 1	1U	Universidad Nacional de Ingeniería del Perú	Soyuz-U (05.02.2014)	Space walk	18.08.2014		CCD camera: RGB + NIR (no signals received)

F 1	1U	FPT University	H-2B-304 (21.07.2012)	J-SSOD	04.10.2012		Student built technology cubesat with low-resolution camera, temperature sensors, 3-axis magnetometer (no signal received)
FITSat 1 (Niwaka)	1U	Fukuoka Institute of Technology	H-2B-304	J-SSOD	04.10.2012	04.07.2013	Technology cubesat
Lambdasat	1U	Lambda Team	Antares-120 (13.07.2014)	NRCSD	04.03.2015	16.05.2015	Technology demonstration
LitSat 1	1U	Lietuvos Kosmoso Asociacija	Antares-120 (09.01.2014)	NRCSD	28.02.2014		Technology cubesat carrying VGA camera, GPS receiver
LituanicaSAT 1	1U	Vilnius University	Antares-120 (09.01.2014)	NRCSD	28.02.2014	28.07.2014	Technology cubesat carrying VGA camera, GPS receiver, telemetry beacon and 150 mW V/U FM voice transponder
PicoDragon	1U	VNSC	H-2B-304 (03.08.2013)	J-SSOD	19.11.2013		Technology cubesat taking low resolution Earth images to test on-board systems
SkyCube	1U	Southern Stars Group LLC	Antares-120 (09.01.2014)	NRCSD	28.02.2014	08.11.2014	Technology cubesat for Earth imaging- VGA camera (no signal received)
STMSat 1	1U	St. Thomas More Cathedral School	Atlas-5 (401) (06.12.2015)	NRCSD	to be deployed from ISS		Earth imaging payload, payload contains a crucifix blessed by Pope Francis
UAPSat 1	1U	Universidad Alas Peruanas	Antares-120 (09.01.2014)	NRCSD	28.02.2014		Technology cubesat (no signal received)
WE WISH		Meisei Electric Co.	H-2B-304 (21.07.2012)	J-SSOD	04.10.2012 (no signal recieved)	11.03.2013	Technology cubesat carrying ultrasmall thermal infrared camera
TechEdSat 1 (TES 1)	1U	SJSU, ÅAC Microtec, NASA Ames	H-2B-304 (21.07.2012)	J-SSOD	04.10.2012		Technology cubesat to evaluate Space Plug-and-play Avionics (SPA)
2 Unit CubeSats							
ArduSat 2	2U	NanoSatisfi	Antares-120 (09.01.2014)	NRCSD	28.02.2014	01.07.2014	Technology cubesat (no signals received after deployment)

GOMX 2	2U	GOMSpace	Antares-120 (28.10.2014)		lost in launch (recovered from wreckage)		Technology demostration of de-orbit system
Raiko	2U	Wakayama Univiersity, Tohoku University	H-2B-304 (21.07.2012)	J-SSOD	04.10.2012	15.07.2013 (last communication with Raiko)	Technology cubesat carrying three cameras: colour CMOS, colour CCD, high-sensitive CCD sensor
3 Unit CubeSats							
Arkyd 3-Reflight (A3R)	3U	Planetary Resources	Falcon-9 v1.1 (14.04.2015)	NRCSD	15.07.2015		Technology demonstration cubesat for future asteroid prospecting missions
CADRE	3U	University of Michigan	Atlas-5 (401) (06.12.2015)	NRCSD			Technology cubesat investigating atmospheric density response to extreme driving
Flock 1-1 to 1-28	3U	Planet Labs	Antares-120 (09.01.2014)	NRCSD	11-28.02.2014		28 earth imaging cubesats (RGB)
Flock 1b-1 to 1b-28	3U	Planet Labs	Antares-120 (13.07.2014)	NRCSD	19.08.2014		28 earth imaging cubesats (6 were not deployed) (RGB)
Flock 1d-1 to 1d-26	3U	Planet Labs	Antares-130 (28.10.2014)		lost in launch		Destroyed during launch- 26 earth imaging cubesats
Flock 1d'-1 to 1d'-2	3U	Planet Labs	Falcon-9 v1.1 (10.01.2015)	NRCSD	03.03.2015		2 earth imaging cubesats (RGB)
Flock 1e-1 to 1e-14	3U	Planet Labs	Falcon-9 v1.1 (14.04.2015)	NRCSD	13-16.07.2015		14 earth imaging cubesats (RGB)
Flock 1f-1 to 1f-14	3U	Planet Labs	Falcon-9 v1.1 (28.06.2015)		lost in launch		Destroyed during launch- 14 earth imaging cubesats
Flock 2b-1 to 2b-14	3U	Planet Labs	H-2B-304 (19.08.2015)	NRCSD	05.09.2015		14 earth imaging cubesats (RGB)
Flock 2e-1 to 2e-12	3U	Planet Labs	Atlas-5 (401) (06.12.2015)	NRCSD	to be deployed		12 earth imaging cubesats (RGB + NIR)

Flock 2e'-1 to 2e'-20	3U	Planet Labs	Atlas-5 (401) (23.03.2016)	NRCSD	to be deployed		20 earth imaging cubesats (RGB + NIR)
GOMX 3	3U	GOMSpace	H-2B-304 (19.08.2015)	J-SSOD	05.10.2015		Technology cubesats to demonstrate reception of ADS-B signals from aircraft and geostationary telecommunication satellite spot beam signal quality using L-band reconfigurable software defined radio payload
GEARRS 2	3U	NearSpace Launch, Air Force Research laboratory	Antares-120 (13.07.2014)	NRCSD	04.03.2015	08.11.2015	Technology demonstration of the Globalstar satellite communications network
MicroMAS	3U	Massachusetts Institute of Technology	Antares-120 (13.07.2014)	NRCSD	04.03.2015		Technology cubesat carrying a multispectral passive microwave radiometer that collects observations in the 118 GHz range
MinXSS	3U	University of Colorado at Boulder	Atlas-5 (401) (06.12.2015)	NRCSD			Technology cubesat miniature X-ray Solar Spectrometer
RACE (ex CHARM)	3U	JPL / CalTech / UT-Austin	Antares-120 (28.10.2014)		lost in launch		Technology cubesat to preform validation of a 183 Ghz radiometer to measure water vapour from the Earth's atmosphere
S-CUBE	3U	PERC/Chitech, Tohoku University	H-2B-304 (19.08.2015)	J-SSOD	17.09.2015		Astronomical cubesat for observing meteors from LEO
SERPENS	3U	SERPENS	H-2B-304 (19.08.2015)	J-SSOD	17.09.2015	27.03.2016	Technology cubesat to test VHF and S-band communications for store and forward messaging payload and a pulsed plasma thruster
TechEdSat 3p (TES 3p)	3U	SJSU, University of Idaho, NASA Ames	H-2B-304 (03.08.2013)	J-SSOD			Technology demonstration of an Exo-Brake passive de-orbit system

TechEdSat 4 (TES 4)	3U	SJSU, University of Idaho, NASA Ames	Antares-120 (13.07.2014)	NRCSD	04.03.2015		Technology demonstration of the Exo-Brake and frequent uplink/downlink control capabilities
Tomsk-TPU 120	3U	Tomsk TPU	Soyuz-2-1a (31.03.2016)	Space walk	to be deployed		Technology demonstration of 3D printed cubesat structure
Micro-satellite							
Diwata 1	50kg class	DOST	Atlas-5 (401)	J-SSOD	27.04.2016		Payload: high precision telescope (HPT) with a resolution of 3m; multispectral imager (SMI) with LCTF; wide field camera with 7km resolution; a middle field camera with a resolution of 185m
QB 50 project planed deployments							
14-BISAT (QB50 BR01)	2U	Instituto Federal Fluminense			2016		
Aalto 2 (QB 50 FI01)	2U	Aalto University			2014		
ANUSAT 2 (QB50 IN01)	2U	Anna University			2016		
Aoxiang 1 (QB50 CN04)	2U	Northwestern Polytechnic University			2016		
BeEagleSat (QB50 TR01)	2U	Istanbul Technical University / Air Force Academy			2016		
BUSAT 1 (QB50 CN01)	2U	Beihang University			2016		

HAVELSAT (QB50 TR02)	2U	HAVELSAN			2016		
Hoopoe (QB50 IL01)	2U	Space Laboratory of the Herzliya Science Center			2016		
i-INSPIRE 2 (QB50 AU03)	2U	University of Sydney			2016		
KPI-SAU 1 (QB50 UA01)	2U	National Technical University of Ukraine			2016		
LilacSat 2 (QB50 CN02)	2U	Herbin Institute of Technology			2016		
Link (QB50 KR01)	2U	Korea Advanced Institute of Science and Technology			2016		
NJUST 1 (QB50 CN03)	2U	Nanjing University of Science and Technology			2016		
NUDTSat (QB50 CN06)	2U	National University of Defense Technolgy (NTNU)			2016		
Pegasus (QB50 AT03)	2U	Fachhochschule Wiener Neustadt			2016		
PHOENIX (QB50 TW01)	2U	National Chung Kung University			2016		
QBITO (QB50 ES01)	2U	Universidad Politécnica de Madrid			2016		
QBUS 1 (Challenger, QB50 US01)	2U	University of Colorado Boulder			2016		
QBUS 2 (Atlantis, QB50 US02)	2U	University of Michigan			2016		

QBUS 3 (Discovery, QB50 US03)	2U	Stanford University			2016		
QBUS 4 (Columbia, QB50 US04)	2U	Inter-American University Puerto Rico			2016		
RoBiSAT 1 (QB50 RO01)	2U	Institute of Space Science and the Romanian Space Agency Research Center			2016		
RoBiSAT 2 (QB50 RO02)	2U	Institute of Space Science and the Romanian Space Agency Research Center			2016		
SamSat-QB50 (QB50 RU01)	2U	Samara State Aerospace University			2016		
SAT JP2 (QB50 FR03	2U	nstitut Superieur Des Sciences Et Technique (INSSET)			2016		
SNUSAT 1 (QB50 KR02)	2U	Seoul National University			2016		
SpaceCube (QB50 FR05)	2U	MinesParisTech			2016		
STU 1 (QB50 CN07)	2U	ShanghaiTech Universit			2016		
SUSat (QB50 AU01)	2U	The University of Adelaide			2016		
UCLSat (QB50 GB03)	2U	MSSL, University College London			2016		
QB50 AU02 (UNSW-EC0)	2U	University of New South Wales			2016		

UPSat (QB50 GR02)	2U	University of Patras			2016		
URSA MAIOR (QB50 IT02)	2U	University of Rome "LA SAPIENZA"			2016		
VZLUsat 1 (QB50 CZ02)	2U	VZLÚ			2016		
X-CubeSat (QB50 FR01)	2U	École Polytechnique			2016		
YUsend-QB50 (QB50 CA01)	2U	York University, Toronto			2016		
ZA-AeroSat (QB50 AZ01)	2U	Stellenbosch University			2016		
ZJU CubeSat (QB50 CN05)	2U	Zhejiang University			2016		
DelFFi Delta (QB50 NL01)	3U	Delft University of Technology			2016		
DelFFi Phi (QB50 NL02)	3U	Delft University of Technology			2016		
DUTH (QB50 GR01)	3U	Democritus University of Thrace / Space Research Lab			2016		
EntrySat (QB50 FR02)	3U	Institut Superieur de l'Aeronautique et de l'Espace (ISAE)			2016		
Ex-Alta 1 (QB50 CA03)	3U	University of Alberta			2016		
GAMASAT (QB50 PT01)	3U	University of Porto			2016		

LituanicaSAT 2 (QB50 LT01)	3U	Vilnius University			2016		
OGMS-SA (QB50 FR04)	3U	UPEC			2016		
QARMAN (QB50 BE05)	3U	von Karman Institute			2016		

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