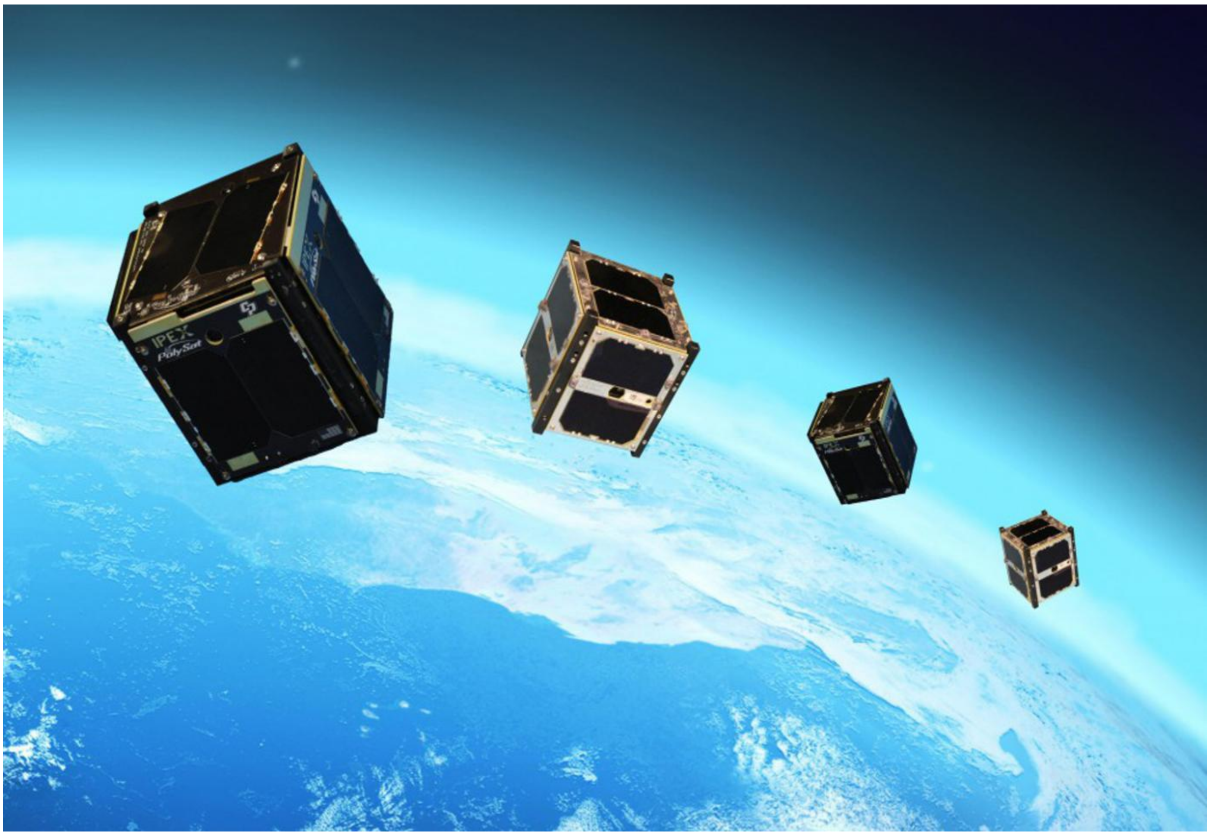
Growing the Space Economy:
The Downstream Segment as a Driver



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This report has been reviewed by Mr Michael Davis (Space Industry Association of Australia)

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EXECUTIVE SUMMARY

The space economy encompasses a much broader concept than the mere production and launch of spacecraft into the outer space. It includes the full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilizing space. This means that to all intents and purposes space-related products and services, such as space-enabled applications, are to be considered as part of the space economy.

The space economy consists of two segments: the upstream and the downstream segment. The upstream segment includes all activities that focus on the design, manufacture, assembly, launch, functioning, maintenance, monitoring and repair of spacecraft destined to be sent out to space as well as the products and services related to them; whereas downstream segment refers to all activities that employ data and knowledge that are derived from the space for Earth-related objectives as well as the products and services that support them. In other words, the upstream segment can be seen as the provision of space technology, whereas the downstream segment can be seen as the exploitation of space technology.

In 2016, the global space economy was estimated to be worth more than US$329 billion in terms of turnover. Commercial space activities captured more than three quarters of this figure in 2016. We attribute around US$77.22 billion (23.45%) to the upstream segment and around US$176.66 billion (53.34%) to the downstream segment. The remaining 23.21% is instead to be attributed to government spending, nearly half of which dedicated to defence and national security.

This paper focuses on the downstream segment. In particular, we consider the three broad categories of the downstream segment: Earth Observation, Global Navigation Satellite System and Satellite Communications. For each of these categories, we provide an overview in terms of size and functioning principle and, most importantly, of the manifold space-derived applications they enable.

Earth observation can be defined as the acquisition, collection, analysis and presentation of data on Earth's physical, chemical and biological systems from satellite-based observations. We estimate that in 2016 it captured approximately 1.65% of the total turnover generated by the downstream segment. It allows for an array of applications in different areas, such as agriculture, disaster management, intelligence, urban and regional planning, business intelligence, energy and mining, environment and climate change, mapping, weather forecasts, transport and insurance.

Global Navigation Satellite System is the infrastructure that allows users with a compatible device to determine their position, velocity and time by processing signals from satellites. We estimate that in 2016 in accounted for 27.92% of the overall revenues produced by the downstream segment. Examples of applications include surveying and mapping, navigation and route planning for pedestrians, road, maritime rail and air vehicles, public transportation, taxis and car sharing, unmanned vehicles, logistics, agriculture, marketing, location-based applets, sports and insurance.

Satellite communication refers to those activities that rely on satellites as a means of communication between two or more parties on Earth. It represents by far the largest category of the downstream, capturing a share of more than 70% in 2016, according to our computations. Broadcasting, telephony and internet access enabled by satellites turn out to be particular useful for aviation, maritime, rail machine-to-machine communications, as well as for defence, disaster management, education, health and electronic payments purposes.

Many of these applications were not economically viable until the emergence of a new paradigm known as Space 2.0. The new space era sees constellations of smaller and lighter satellites with respect to “old generation” ones. Nanosatellites weigh between one and ten kilograms each, to be compared to satellites such as the IKONOS for earth observation satellite (817 kg) the GeoEye-1 imaging satellite (1955 kg) and the Inmarsat-4 F3 communications satellite (5960kg). They are quicker and cheaper to produce and launch. Including the launch, the cost range can go down to US$150,000-US$1 million, rather than US$200 million-US$1 billion. They usually have a shorter expected lifecycle, but a different conception and acceptance of risk seems to have emerged on the demand side. Moreover, the enhancements in miniaturization and integration techniques and the new materials used are reducing the traditional trade-off between size and functionality. This means that an increasingly large number of actors can now gain access to space.

Space 2.0 deeply affects the downstream segment as well. In fact, innovations such as the increased accuracy in position and the improved resolution in satellite images, and the lower access costs to space technologies, together with the advancements in other technologies such as big data, artificial intelligence and the Internet of Things, open the door to myriad applications.

However, one more step needs to be taken. There is still a lack of understating of the potential benefits of space-derived applications, especially by those firms that belong to industries traditionally considered completely extraneous to space, such as agriculture or financial services. Operators involved in the downstream segment need to raise awareness on the importance of space technologies and provide high quality, affordable and user-friendly services.

Once this gap is filled, businesses will be able to take full advantage of the many opportunities space has to offer, thus stimulating the downstream segment to expand and improve its range of products and services and its understanding of the market. In turn, this will prompt demand and investments in the upstream segment, which will in turn result in further investments and enhancements of space technology, thus establishing a virtuous circle and perhaps producing new disruptive technologies that might open the way to a whole new set of application we cannot even imagine today.

Starting from the Australian Bureau of Statistics database, previous literature suggests that there are more than 1,400,000 companies in Australia that operate in industries that could benefit from the downstream segment for their activities. However, at present, the Australian space economy is considered to have unfulfilled potential. This represents a strong opportunity. The adoption of space-enabled products and services by a larger number of actors among these 1,400,000 companies represents could indeed substantially boost growth in the space economy.

Morgan Stanley expects the space economy to hit US$1.1 trillion by 2040, while Bank of America Merrill Lynch estimates that it will grow eight times bigger in the next thirty years, reaching US$2.7 trillion in 2045. Australia intends not to miss this opportunity, as the recent efforts and investments for the establishment of a national space agency demonstrate.

South Australia, on the other hand, boasts a vibrant space ecosystem, with more than sixty organizations active in the space economy, an estimated turnover of more than US$300 million a year and over 800 full time equivalents employed. This paper concludes by identifying some of the main downstream players based in South Australia.

INTRODUCTION

Non est ad astra mollis e terris via
(There is no easy way from the earth to the stars)

Seneca the Younger – Hercules Furens

While humans have dreamed about space exploration since ancient times, it was not until the Sixties that it became reality, and it wasn't until the end of the millennium that space became a business opportunity available even to small businesses. The first artificial satellite was sent to space on 4th October 1957 by the Soviet Union. Launched from the Baikonur Cosmodrome in Kazakhstan, the Sputnik 1 marked the beginning of a new era[1]. According to the data provided by the United Nations Office for Outer Space Affairs (UNOOSA), since then a total of 8,130 objects have been launched into space, 4,813 of which are active[2].

In addition to the sharp increase in the early Sixties, a consequence of a space race between the United States and the Soviet Union[3,] we observe a peak in the number of objects launched in the last years. The number of launches went from 222 in 2016 to 453 in 2017[4]. However, this is not the aftermath of any space race among nations, but rather the result of a new paradigm known as Space 2.0. The recent technological improvements are indeed making the production of satellites substantially quicker and cheaper. These satellites are smaller with respect to “old-generation” ones, nanosatellites being approximately the size of a shoebox. They usually have a shorter expected lifecycle, but a different conception and acceptance of risk seems to have emerged on the demand side. Moreover, the enhancements in miniaturization and integration techniques and the new materials used are reducing the traditional trade-off between size and functionality. This means that an increasingly large number of actors can now gain access to space. The way from the earth to the stars is starting to become easier.

In this paper, however, we are more interested in the way from the stars to Earth. To distinguish the two ways, we refer to the former as the upstream segment and to the latter as the downstream segment. The upstream segment can be seen as the provision of space technology, whereas the downstream segment as the exploitation of space technology.

Naturally, Space 2.0 deeply affects the downstream segment as well. In fact, innovations such as the increased accuracy in position and the improved resolution in satellite images, and the lower access costs to space technologies, together with the advancements in other technologies such as big data, artificial intelligence and the Internet of Things, open the door to a plethora of applications which were not economically viable or even possible before. Whether we realize it or not, space is already pervasive in our everyday lives. Navigation systems, maps, weather forecasts, urban planning, sports,

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[1] National Aeronautics and Space Administration, (2017). Oct. 4, 1957 - Sputnik, the Dawn of the Space Age [website]. Accessed March 2018. https://www.nasa.gov/image-feature/oct-4-1957-sputnik-the-dawn-of-the-space-age.

[2] United Nations Office for Outer Space Affairs, Online Index of Objects Launched into Outer Space.

[3] Howell E., (2012). Sputnik: The Space Race's Opening Shot. Space.com [website]. Accessed March 2018. https://www.space.com/17563-sputnik.html.

[4] United Nations Office for Outer Space Affairs, Online Index of Objects Launched into Outer Space.

insurance, unmanned vehicles business intelligence and logistics are but a few examples of space-enabled applications that this paper analyses extensively.

In 2016, the global space economy was estimated to be worth more than US$329 billion in terms of turnover[5], over a half of which estimated to be generated by the downstream segment (not including 24% of government budgets). Some foresee a huge growth in the next years. The Bank of America Merrill Lynch estimates that the space economy will grow eight times bigger in the next thirty years, reaching US$2.7 trillion in 2045[6]. As government involvement in space is gradually decreasing, investment by commercial entities is gradually increasing, we argue that a further sustainable development of the space economy is to be driven be the downstream segment, which needs to be able to understand existing market forces to attract demand. Such demand is to be satisfied by providing a wide range of value-added services for the terrestrial economy. This would stimulate the upstream to invest in and develop new technologies and to increase its efficiency and its response time.

Australia intends grasp this opportunity. In May 2018 the Government announced it will provide AU$41.0 million over four years, commencing in 2018-19, to grow the Australian space industry, including by establishing the Australian Space Agency[7].

Previous literature suggests that there are more than 1,400,000 companies in Australia that operate in industries that could benefit from the downstream segment for their activities[8]. However, at present, the Australian space economy is considered a case of unfulfilled potential.[9] South Australia, on the other hand, presents a vibrant space ecosystem, with more than sixty organizations active in the space economy, with an estimated turnover of more than US$300 million a year and over 800 full time equivalent employees.

While public authorities are making the effort to ensure the best possible environment to operate in, as it emerges also from the recently published Australian Government Response to the Review of Australia's Space Industry Capability, the challenge is now for the downstream actors to raise awareness among businesses on the potential benefits of downstream applications and to attract demand through high quality, affordable and user-friendly services.

Section 1 of this paper gives an overview of the space economy. It starts with the delicate task of providing a definition, clarifying the difference between the space economy, the space sector and the space industry. Then, a taxonomy of the space economy is proposed, with particular attention to the upstream and the downstream segment classification. Having clearly identified what we are trying to measure, we proceed by reviewing some estimates of the size of the space economy at a global and national level and we assess its size in South Australia. Finally, we discuss the evolution of the space economy in a historical perspective and its future, introducing the concept of Space 2.0.

Section 2 enters the core of our analysis. We first assess the relative share of the downstream segment and explore the link with the upstream segment. We then focus on three broad categories of the downstream: Earth Observation, Global Navigation Satellite System and Satellite Communications. For

[5] Space Foundation, (2017). The Space Report 2017, The Authoritative Guide to Global Space Activity.

[6] Tran F., Nahal S., Ma B., Epstein R. and Heelan B., (2017). *To Infinity And Beyond – Global Space Primer*. Thematic Investing, Bank of America Merrill Lynch.

[7] CommsDay and the Australasia Satellite Forum, (2018). *Budget pledges $300m for satellite positioning, imaging, space investment*. Space and Satellite AU Newsletter. Decisive Publishing.

[8] Lazzari E., (2017). *A Study of the Economic Potential of the Local Space Sector*. South Australian Space Industry Centre.

[9] Lazzari E., (2017). *A Study of the Economic Potential of the Local Space Sector*. South Australian Space Industry Centre.

each of these categories, we provide an overview in terms of size and functioning principle, so to be able to better understand the many applications later identified.

Section 3 focuses on South Australia. After having introduced the South Australian ecosystem, we provide a list of selected South Australian companies active in the downstream segment and we relate them to the analyses carried out in the previous section.

1. THE SPACE ECONOMY: AN OVERVIEW

1.1 Defining the space economy

The idea of space has fascinated humankind for millennia. However, the concept of space itself is still not well defined. A common measure includes everything that lies beyond the Karman Line, i.e. 100 kilometres (62 miles) above the Earth's sea level[10]. This is the definition used by the Fédération Aéronautique Internationale (FAI) to compile astronautics records[11], yet other definitions do exist. For example, the U.S. Air Force sets 80 kilometres (50 miles) as a threshold[12], while the National Aeronautics and Space Administration (NASA) uses 122 kilometres (76 miles) as a re-entry altitude[13].

If defining the concept of space may seem problematic, even more confusion may arise around terms such as *space sector*, *space economy* and *space industry*. Before proceeding to the core of our analysis some clarification is deemed necessary.

According to the *OECD Handbook on Measuring the Space Economy*, the space sector can be defined as:

" […] all actors involved in the systematic application of engineering and scientific discipline to the exploration and utilization of outer space, an area which extends beyond the earth's atmosphere." [14]

The space sector is hence inclusive only of those agents that are directly involved in the development, manufacture, launch, operation and maintenance of objects that go in-orbit and in the exploration of space.

In the same report the authors themselves recognize how restrictive this definition can be. For this reason they introduce the concept of space economy:

> *"The Space Economy is the full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilising space. Hence, it includes all public and private actors involved in developing, providing and using space-related products and services, ranging from research and development, the manufacture and use of space infrastructure (ground stations, launch vehicles and satellites) to space-enabled applications (navigation equipment, satellite phones, meteorological services, etc.) and the scientific knowledge generated by such activities. It follows that the Space Economy goes well beyond the space sector itself, since it also comprises*

[10] Institute of Physics, (2010). A brief history of space. Institute of Physics Archive [website]. Accessed March 2018. http://www.iop.org/resources/topic/archive/space/.
[11] De Córdoba S., unknown date of publication. 100 Km Altitude Boundary for Astronautics. Fédération Aéronautique Internationale Astronautics Records Commission (ICARE) [website]. Accessed March 2018. https://www.fai.org/page/icare-boundary.
[12] Wong W. and Fergusson J., (2010). *Military space power: a guide to the issues*. Greenwood Publishing Group.
[13] Institute of Physics, (2010). A brief history of space. Institute of Physics Archive [website]. Accessed March 2018. http://www.iop.org/resources/topic/archive/space/.
[14] OECD, (2012). *OECD Handbook on Measuring the Space Economy*. OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264169166-en.

the increasingly pervasive and continually changing impacts (both quantitative and qualitative) of space-derived products, services and knowledge on economy and society." [15]

Some key features of the characterization of the space economy with respect to that of the space sector are worth noticing:

- The use of resources that create and provide value and benefits to human beings: in line with the basic economic problem of allocating scarce resources to maximize the utility functions of the agents involved.

- The management of space is considered. This could include a vast range of activities such as:

  - legal regulation: a number of international treaties exist (such as the *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* better known as the *Outer Space Treaty,* or the *Convention on Registration of Objects Launched into Outer Space* better known as the *Registration Convention*) as well as national regulations (such as the *Space Activities Regulation 2001* in Australia, or the 2015 *35 USC Chapter 10, Sect. 105, Inventions in outer space* in the U.S.);

  - tracking and management of space debris (also known as "space junk"): space debris is the mass of non-functional artificial objects, such as old satellites, in Earth orbit or re-entering Earth's atmosphere. They constitute a danger for all space vehicles and especially for spacecraft with astronauts aboard, as they travel at speeds up to 28,000 km/h (17,500 mph).[16] The first step is identifying and tracking such objects. This is done mainly using the space surveillance system of the U.S. and Russian governments, which are able to track objects larger than 5-10 cm in low orbit and of 0.3-1.0 metres at geostationary orbit altitudes. The European Space Agency (ESA) estimates 29,000 pieces larger than 10 cm and 750,000 pieces from 1 cm to 10 cm.[17] The next step is removing the debris. Currently some projects, such as *RemoveDebris*, are under evaluation.[18]

- Both public and private actors are mentioned: as will be examined in more detail later in this section, today private agents play an increasingly important role.

- Space-related products and services, including space-enabled applications and the scientific knowledge generated by space activities are considered: not only those agents that are directly involved in the development, manufacture, launch, operation and maintenance of objects that go in-orbit and in the exploration of space are considered, as in the definition of the space sector, but also space-enabled applications, which will be analysed extensively, and

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[15] OECD, (2012). *OECD Handbook on Measuring the Space Economy*. OECD Publishing, Paris.
http://dx.doi.org/10.1787/9789264169166-en.
http://dx.doi.org/10.1787/9789264169166-en.
[16] Garcia M. (2013). Space Debris and Human *Spacecraft*. NASA [website]. Accessed March 2018.
https://www.nasa.gov/mission_pages/station/news/orbital_debris.html.
[17] ESA, (2017). Space Debris by the Numbers [website]. Accessed March 2018.
http://www.esa.int/Our_Activities/Operations/Space_Debris/Space_debris_by_the_numbers.
[18] Morelle R., (2017). RemoveDebris: Space junk mission prepares for launch. BBC News [website]. Accessed March 2018.
http://www.bbc.com/news/science-environment-41973646.

scientific knowledge generated by space activities and its applications. It is not uncommon indeed for technology developed primarily for space activities to be applied in other fields. A notable example is that of *NeuroArm*: a remotely guided robot arm used in very precise microsurgery that was developed after some prototypes inspired by *Candaram2* and the *Special Purpose Dexterous Manipulator* (Dextre), two robot arms used for maintenance and repairs on the International Space Station. Neuroarm has already helped patients receive better quality surgery and is now undergoing further enhancements. [19] Another interesting example looks at German wind turbines. *Darwin* emerged a proposal of satellite constellation for planet search. It did not pass the European Space Agency study state. Nevertheless, the technology designed to eliminate vibrations on satellites as part of this project was readily adapted to silent wind turbines is some German regions, where residents were experiencing vibration-induced breathing and sleeping issues.[20]

It is apparent that the space economy encompasses a much broader concept than that of the historical definition of the space sector. The reader with an economic mindset might have already identified the existence of a trade-off when defining these concepts: the more inclusive we are, the more blurry the boundaries become. Therefore, it might be difficult sometimes to establish whether an agent is to be considered part of the space industry or not. As a general rule, the minimum requirement posed is the possession and application of some space related expertise. For example, mobile phone retailers would not be considered as part of the space industry simply because they are selling a product that enables satellite location and tracking functions. On the other hand, an applet providing navigation services based on the traffic conditions estimated using data coming from satellites would certainly be included in the space economy.

Finally, the **space industry** can be regarded as the set of companies active in the space economy. The difference between *space economy* and *space industry* lies in the fact that while the former refers to a set of activities, the latter refers to a set of organizations. The two expressions will often be used interchangeably throughout this paper. It will be clear from the context whether we are referring to actors or to their activities.

1.2 A taxonomy of the space economy

Outlining a taxonomy of the space economy is an extremely difficult and delicate task, as any attempt would inevitably be over-simplification of a much more complex reality. Nevertheless, in order to carry out an analysis, more often than not, it is necessary to organize activities and actors into classes and subclasses; the criteria to be applied depends on the objectives of the study. The reader should not be surprised to learn that a universally accepted segmentation does not exist.

For the purposes of this paper we consider two different streams of the space industry:

- upstream segment: includes all activities that focus on the design, manufacture, assembly, launch, functioning, maintenance, monitoring and repair of spacecraft destined to be sent out to space as well as the products and services related to them;

[19] Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*.
[20] Space Foundation, (2016). *The Space Report 2016, The Authoritative Guide to Global Space Activity*.

- downstream segment: refers to all activities that employ data and knowledge that are derived from the space for Earth-related objectives as well as the products and services that support them.

The upstream segment can be seen as the *provision* of space technology, whereas the downstream segment can be seen as the *exploitation* of space technology.

Table 1 shows a list of activities that fall into either one of the two segments. It is important to highlight that this list is not meant to be exhaustive, given the rapidly changing nature intrinsic in the space economy, nor it meant to be categorical, as many actors carry out a complex mix of activities that often give rise to overlaps and that is hard to separate; it is rather meant to provide the reader with a more concrete idea of what this segmentation tries to capture.

Table 1 Taxonomy of the space economy

UPSTREAM	Space Systems	Component and Material Supply Prime/System Integration Satellite Ownership and Operation Space Qualified Testing and Facilities Space Subsystem Supply System Engineering and Technical Support
	Launch Activities	Component and Subsystem Manufacturing Launch Services Launch Support Services Launch Vehicle Manufacturing and Assembly
	Ground Systems	Antenna and Ground Station Component and Material Supply Ground Segment Prime and System Integration Ground Segment Subsystem and Equipment Supply Ground Station Ownership and Operation System Engineering and Technical Support Teleport Ownership and Operation Tracking, Telemetry and Command Operations
	Related Activities	Basic and Applied Research Consultancy Services
DOWNSTREAM	Space Enabled Services	Earth Observation Services and Applications Satellite Broadcast Service Provision Satellite Communications Service Provision Satellite Navigation and Geolocation Services and Applications User Equipment Manufacturer User Equipment Supply
	Support Activities	Applied Research Consultancy Services Financial Services Insurance Services Legal Services Technical Support Services
	Other Activities	Space knowledge derived applications

As aforementioned, there is no universal classification and alternative segmentations have been presented in other papers. Therefore, for completeness, Table 2 shows the versions proposed by three important pieces of literature: The Size and Health of the UK Space Industry 2014 by London Economics, The Space Economy at a Glance by the OECD and The Space Report by The Space Foundation.

Table 2 Alternative taxonomies of the space industry

Size and Health	Space Economy at a Glance	The Space Report
Upstream ■ Space Transportation □ Launch Service Provider □ Prime/system integrator □ Subsystem supplier □ Component/material supplier ■ Ground segment □ Prime/system integrator □ Subsystem supplier □ Component/material supplier ■ Satellite/payload manufacturing □ Prime/system integrator □ Subsystem supplier □ Component/material supplier ■ Spacecraft (non-satellite) manufacturing ■ Research and Consultancy (public, private) **Downstream** ■ Satellite owner/operator/service provider ■ User equipment supplier ■ Value-added service provider ■ Financial Services □ Insurers (and re-insurers) of space assets □ Investors ■ Others □ In-space communications □ Support products and services □ Consultancy – applied research **Wider space economy** ■ Broadcasting ■ Communications ■ Earth Observation ■ Defence ■ Navigation ■ Scientific ■ Integrated applications	**Space manufacturing (incl. launch services)** ■ Primes (Space systems Integrators / full systems supplier) □ Complete satellites / orbital systems □ Launch vehicles (and launch services provision in some cases) □ Control centres and ground stations ■ Tiers One and Two (Designer and manufacturer of space equipment and subsystems) □ Electronic equipment and software for space and ground systems □ Spacecraft / satellite platform structure and data handling subsystem □ Guidance, navigation and control subsystems, and actuators □ Power subsystems □ Communications subsystems □ Propulsion subsystems □ Other satellite payload's specific subsystems ■ Tiers Three and Four □ Scientific and engineering consulting (Research and development services; Engineering services) □ Material and components suppliers **Services from satellite operators** ■ Space and ground systems operators □ Launch services provision □ Satellite operations, including lease or sale of satellite capacity □ Provision of control centres services to third parties **Consumer services (Downstream)** ■ Devices and equipment supporting the consumer markets □ Chipset manufacturers □ Satnav and telecom equipment and connectivity devices vendors ■ Services and products for consumers using satellite capacity □ Direct-to-home providers □ Very Small Aperture Terminal (VSAT) network providers □ Location-based signals services providers	**Commercial Infrastructure and support industries** ■ Launch industry ■ Satellite manufacturing ■ Space Stations ■ Ground stations and equipment ■ Commercial human spaceflight (suborbital and orbital) ■ Independent Research & Development ■ Infrastructure support activities (incl. Insurance premiums) **Commercial space products and services** ■ Direct-to-Home television / Broadcasting ■ Satellite communications ■ Satellite radio ■ Earth Observation ■ Geo-location and navigation **U.S. government space budgets** ■ Department of Defense (DoD) ■ National Aeronautics and Space Administration (NASA) ■ National Oceanic and Atmospheric Administration (NOAA) ■ National Science Foundation (NSF) ■ United States Geological Survey (USGS) ■ Department of Energy (DOE) ■ Federal Aviation Administration (FAA) ■ Federal Communications Commission (FCC) **Non-U.S. government budgets** ■ Non-U.S. military space ■ European Space Agency (ESA) ■ European Union ■ EUMETSAT ■ Individual countries and national agencies

Source: London Economics (2015) The Case For Space 2015; original sources: London Economics (2014) The Size and Health of the UK Space Industry 2014; OECD (2014) The Space Economy at a Glance; The Space Foundation (2014) The Space Report

London Economics makes an interesting distinction among commercial applications and use of space services that is worth mentioning. They categorize these services based on the role of space activities in the provision of the service and their revenue generating capability. They distinguish:

- Application (with revenue generating capability):
    - enabled: product or service that would not have been possible without space capabilities (e.g. maritime broadband)
    - enhanced: product or service that uses space capability as a differentiating feature (e.g. location-based service on a mobile phone)
    - alternative: product or service using space as an alternative delivery channel (e.g. terrestrial fixed broadband)
- Use (without revenue generating capability):
    - operations: space capability is employed for organizational operations (e.g. infrastructure maintenance).[21]

1.3 The space economy in perspective

1.3.1. Premise

Unfortunately, for several reasons the economic data available on the space economy has always been of very poor quality, as other authors have noted.[22]

First of all, data collection on the space economy has systematically been underfunded. This can be ascribed to the composition of the workforce of the majority of space agencies: scientists and engineers. Economists are hardly ever consulted, unless reports for supporting expenses are required. Space managers' performance is evaluated on the results of space missions, not on the cost sustained for collecting high quality economic data for analysis.

Second, the space industry doesn't have its own category in national and international standards of industrial classification. It follows that the space economy is split and accounted for in an array of different sectors, such as transportation, software and navigation equipment or it is aggregated in much broader categories such as aerospace and electronic equipment.

Third, there is a difficulty in carrying out international comparisons, as most national statistics vary in definition, coverage and methodology.

Fourth, investment in the space industry undertaken for military and security purposes, by their very nature sensitive and/or classified, and hence not available for analysis.

Fifth, commercial firms may be reluctant to disclose information on their business. In addition to that, it is difficult to account correctly for the space economy share in final products, especially when a

[21] Sadlier G., Flytkjær R., Halterbeck M., Peycheva V. and Koch L., (2015). *The Case for Space 2015, The impact of space on the UK economy*. London Economics.

[22] Herzfeld H., (2013). *The State of Space Economic Analyses: Real Questions, Questionable Result*. Mary Ann Liebert, Inc. Publishers. and Bruston J., (2014). *Space: the Last Frontier for Socio-economic Impacts Evaluation?* in: Al-Ekabi C., Baranes B., Hulsroj P., Lahcen A. (eds) *Yearbook on Space Policy 2011/2012*. Yearbook on Space Policy. Springer, Vienna.

space element in embedded in a more complex integrated system. For instance, GPS chips in mobile phones are often not statistically classified into the space economy at all in the U.S.

Sixth, a considerable fraction of space investments are for research and development purposes. It is typically hard to track the nature of R&D investments as data available at firm level are primarily for accounting purposes. Moreover, an increasing share of companies, particularly those engaged in the downstream segment, are relatively small and exempt from statuary reporting. Even for those which are not exempt, there is usually a one year lag in publication. The lag becomes even more significant if the analysis does not use data coming from firms directly, but re-elaboration by organizations such as the OECD or The Space Foundation.

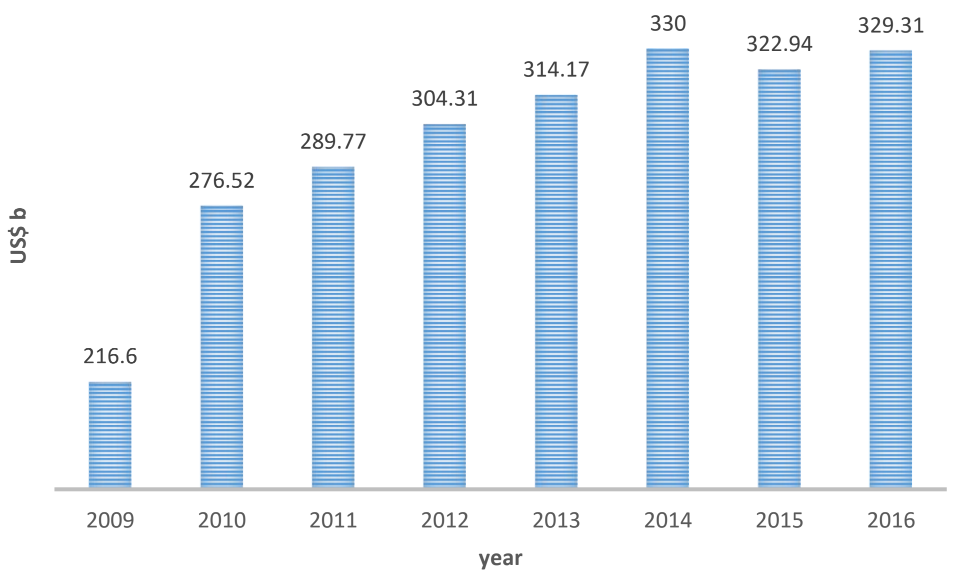
Apart from the OECD and The Space Foundation, some other organizations produce data on the space economy, yet the price of access to this data is typically very high. Some other organizations produce data hyper specific for their members, such as the Satellite Industry Association.

For the reasons exposed above, figures provided by different organization may differ, sometimes even significantly.

1.3.2 The global space economy

Figure 1 shows the global turnover generated by the space economy from 2009 to 2016 in billions of US dollars, based on the data provided by The Space Foundation.

Figure 1 Global turnover of the space economy (current prices)



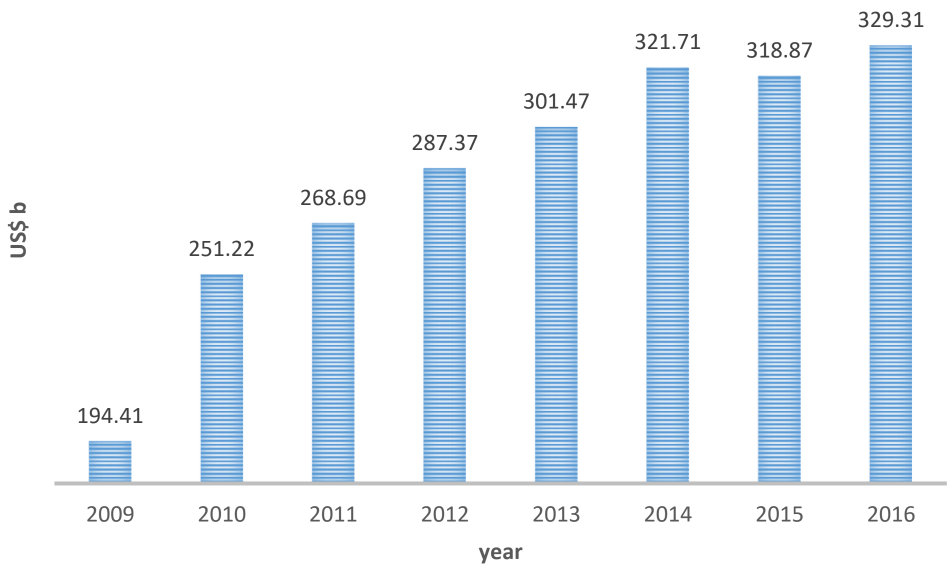
Source: Re-produced from The Space Report; multiple editions

In 2016 the global space economy was worth more than US$329 billion in terms of turnover, an increase of almost 2% on the previous year and of more than 52% with respect to 2009. The compound annual growth rate since 2009 exceeds 6.16%. To put these figures in perspective, consider that the world GDP in 2016 was around US$75,847.76 billion, an increase of 1.45% with respect to 2015, of 26.06% with respect to 2009 and an annual compound growth rate of 3.36% starting from 2009.[23]

Perhaps surprisingly, we observe a decline in the estimated revenues generated by the space economy between 2014 and 2015, shrinking by 2.12% from US$330 billion to US$322.94 billion. At least part of this fluctuation is attributable to the increasing level of activity outside the U.S. together with the large shifts in exchange rates, which resulted in a stronger U.S. dollar. The same logic applies for the years 2015 and2016, making the growth rate estimation more conservative, even if this impact was substantially less relevant.[24]

Notice that the figures presented above are in nominal terms, i.e. they are expressed in adjusted prices. To ensure better comparability across different time periods, we adjust for inflation, taking 2016 as a reference year. Figure 2 shows the global turnover generated by the space economy in billions of 2016 U.S. dollars from 2009 to 2016, based on the data in nominal terms provided by The Space Foundation.

Figure 2 Global turnover of the space economy (2016 prices)



Source: Re-produced from The Space Report; multiple editions

The increase from 2015 to 2016 amounts to US$10.44 billion, i.e. 3.27%, to be compared to 1.97% in nominal terms; from 2009 to 2016 to US$134.9 billion, i.e. 69.39% to be compared to 52.04% in

[23] Re-elaborations and computations from data source: *World Development Indicators*, World Bank.
[24] Space Foundation, (2017, 2016). *The Space Report 2017, The Authoritative Guide to Global Space Activity* and *The Space Report 2016, The Authoritative Guide to Global Space Activity*.

nominal terms; while the annual compound growth rate since 2009 hits 7.82%, 1.65 percentage points higher than the nominal figure.

Even if lower, there is still an apparent decrease in the size of the global space economy from 2014 to 2015, yet what was said for the figures in nominal terms still applies.

A technical note: we used U.S. GDP deflator, computed starting from the World Development Indicator database by the World Bank to convert revenues from years other than 2016 to 2016 prices as all the figures are expressed in U.S. dollars, hence the only inflation we need to correct for is that of the U.S.

Detailed information on absolute values and growth rates of the global space economy can be found in Table 3.

Table 3 The global space economy in numbers

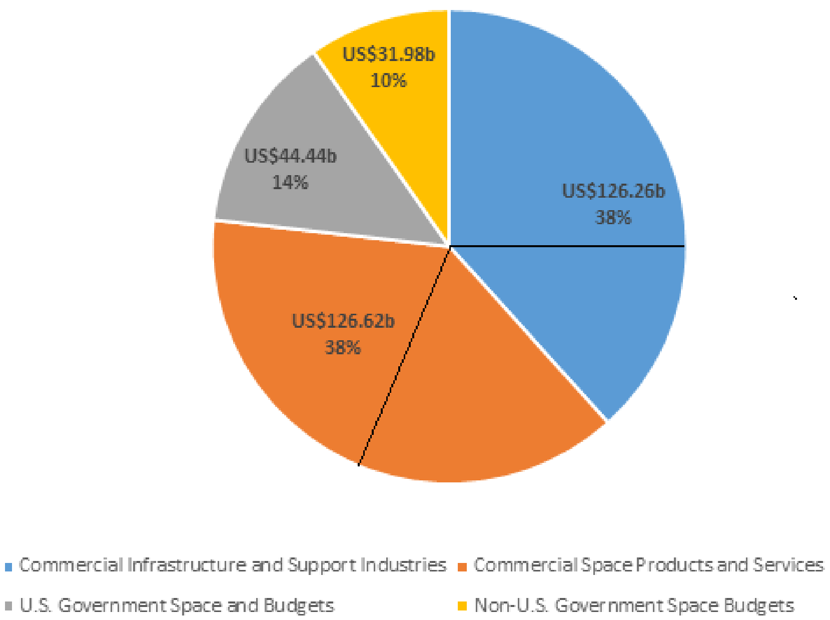
Year	Turnover in current prices (US$ b)	Growth rate with respect to previous year	Growth rate with respect to 2009	Compound annual growth rate since 2009	GDP deflator (base year: 2016)
2009	216.6	-	-	-	0.897537523
2010	276.52	27.66%	27.66%	27.66%	0.908499592
2011	289.77	4.79%	33.78%	15.66%	0.927256724
2012	304.31	5.02%	40.49%	12.00%	0.944337271
2013	314.17	3.24%	45.05%	9.74%	0.959588384
2014	330	5.04%	52.35%	8.79%	0.974875825
2015	322.94	-2.14%	49.10%	6.88%	0.987402716
2016	329.31	1.97%	52.04%	6.17%	1

Year	Turnover in 2016 prices (US$ b)	Growth rate with respect to previous year	Growth rate with respect to 2009	Compound annual growth rate since 2009
2009	194.41	-	-	-
2010	251.22	29.22%	29.22%	29.22%
2011	268.69	6.96%	38.21%	17.56%
2012	287.37	6.95%	47.82%	13.91%
2013	301.47	4.91%	55.07%	11.59%
2014	321.71	6.71%	65.48%	10.60%
2015	318.87	-0.88%	64.02%	8.60%
2016	329.31	3.27%	69.39%	7.82%

Source: Turnover in current prices: The Space Foundation; GDP deflator: computed from World Development Indicators database, the World Bank.

Analysing the space economy turnover by segment reveals substantial differences in size. Consider the segmentation proposed in *The Space Report* displayed in Figure 3. You will note that in the following figures government spending on products and services provided by commercial organizations has been accounted for in government budgets only, thus avoiding duplication of the same activity and making figures with respect to the commercial sector more conservative.

Figure 3 Space economy turnover by segment, 2016



Source: The Space Report 2017; note: numbers may not add up to total due to rounding

In the collective imagination, the space industry is typically associated with massive government funded missions. Projects such as the launch of Sputnik in 1957, the Moon landings in the Sixties and in the Seventies, the International Space Station, the famous Space Shuttle, the Rosetta Mission and the Hubble Space Telescope are but a few examples. However, they constitute just a minor share of the much broader spectrum of space activities, with private actors playing an increasingly important role and reduction in the role played by public actors, as mentioned in section 1.1. Figure 3 demonstrates this, showing that of the total spending of US$329 billion in 2016, only US$76.43 billion (23.21%) can be attributed to government activities, a decline of 0.3% with respect to the previous year US$76.69 billion and of 0.5 percentage points in terms of total. The scene is dominated by the

U.S. Government, accounting for more than 58% of government activities (nearly half of which for defence purposes).[25]

On the other hand, the turnover generated by commercial sectors in 2016 accounted for almost 77% of the total, totalling US$252.88 billion, an increase of US$6.46 billion (2.62%) with respect to the previous year. In 2016 this figure splits almost evenly across commercial space products and services, and in commercial infrastructure and support industries. The former accounted for US$126.62 billion (US$126.35 billion in 2015, a 0.2% increase), whereas the latter was US$126.26 billion (US$119.92 billion in 2015, a 5.3% increase).[26]

Commercial space products and services (included in the downstream segment in our proposed classification) will be analysed extensively further in this paper.

As for commercial infrastructure and support industries, as outlined in Table 2, these include hardware and services needed for the design, manufacture, assembly, launch, functioning, maintenance, monitoring and repair of spacecraft and related activities (upstream segment). Ground stations and equipment bring the largest contribution to this class of activities: 94% (US$118.75 billion) in 2016. Among these, Global Navigation Satellite Systems (GNSS) ground equipment reached US$89.9 billion, an increase by 7.9% over the previous year figure (notice that here we are reviewing the classification and the figures proposed in The Space Report, more information about our own classification with consequently adjusted figures can be found in the next section). The market for launches is often believed to be a major source of revenues for the upstream segment. However, Eurospace estimates a turnover of US$7.372 billion 2016 (around 2.24% of the overall space economy), to be compared to US$8.010 billion in 2015, that is an 8% decrease. Moreover, of this US$7.372 billion, US$2.05 billion were for commercial launches. In 2016 out of 85 launches, 21 (25%) were commercial, in 2017 33 out of 90 (37%)[27].[28]

Another interesting distinction is that between the satellite and the non-satellite space industry. Unfortunately, data from the same dataset is not available, hence we use data from the Satellite Industry Association. As mentioned in subsection 1.3.1., different organizations may provide different figures for the same variables of interest. Our qualitative results, however, appear to be robust with respect to this different data source.

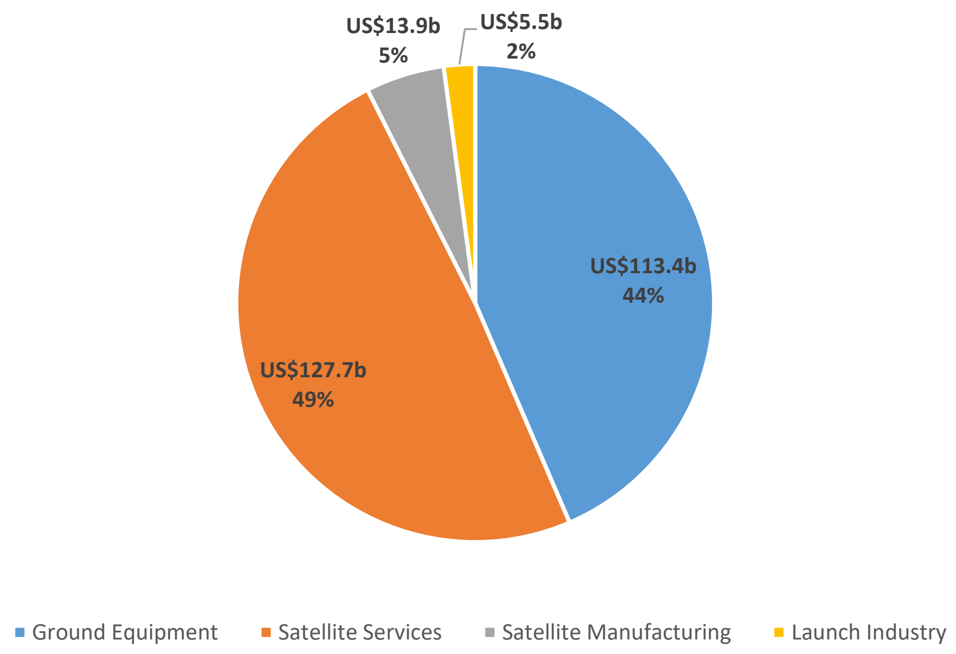
The Satellite Industry Association estimates the size of the global space economy to be US$339.1 in 2016: US$78.6 billion in the non-satellite industry (23.18%) and US$260.5 in the satellite industry (76.82%).[29] These values are to be compared with an estimated overall size of the global space economy in 2015 of US$335.3 billion, of which US$127 billion in the non-satellite industry (37.88%) and US$208.3 billion in the satellite industry (62.12%).[30] This implies that the satellite industry is responsible for a US$52.2 billion increase (25%) that more than compensates the decrease in the non-

[25] Figures retrieved from: Space Foundation, (2017, 2016). *The Space Report 2017, The Authoritative Guide to Global Space Activity* and *The Space Report 2016, The Authoritative Guide to Global Space Activity*.
[26] Figures retrieved from: Space Foundation, (2017, 2016). *The Space Report 2017, The Authoritative Guide to Global Space Activity* and *The Space Report 2016, The Authoritative Guide to Global Space Activity*.
[27] Figures retrieved from: Federal Aviation Administration, (2017, 2018). *The Annual Compendium of Commercial Space Transportation: 2017* and *The Annual Compendium of Commercial Space Transportation: 2018.*
[28] Figures retrieved from: Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*.
[29] Satellite Industry Association, (2017). *State of the Satellite Industry Report*.
[30] Satellite Industry Association, (2016). *State of the Satellite Industry Report*.

satellite industry by US$48.4 billion (-38.11%), leading to an overall US$3.8 billion increase from 2015 to 2016.

Figure 4 shows the composition of revenues generated in 2016 by the satellite industry according to the data provided by Satellite Industry Association.

Figure 4 Global satellite industry turnover break-up, 2016



Source: State of the Satellite Industry Report 2017

Consistently with the estimates of *The Space Foundation*, the launch industry represents a small fraction, with a value of US$5.5 billion in 2016 and of US$5.4 in 2015. Also satellite manufacturing accounts for a small share of the industry: 5%, reaching US$13.9 billion in 2016, a decrease by 16.27% with respect to the previous year value of US$16.6 billion. Still in line with *The Space Foundation* findings, ground equipment accounts for a significant share of the industry: 44%, hitting US$113.4 billion in 2016, US$54.5 more than the previous year, an increase by 92.53%. Finally, the largest share both in 2016 (49%) and in 2015 (61.16%) is the broad category of satellite services (included in the downstream segment), with values of US$127.7 billion and US$127.4 billion respectively.[31]

[31] Figures retrieved from: Satellite Industry Association, (2017, 2016). *State of the Satellite Industry Report*.

1.3.3 The Australian and South Australian space economy

Information about the size of the Australian space economy is even less accurate, as the attention on this important part of the economy has only emerged in recent years. Consider that as recently as 25th September 2017 the Australian Government announced its intention to establish an Australian space agency.[32]

Asia Pacific Aerospace Consultants provides an estimation of turnover in 2015 in the region of AUD 3-4 billion. This means that only approximately 0.8% of the global space economy in 2015 was generated by Australia, while the figure for the general economy was around 1.8%. Moreover, only 8.4% of space revenue is derived from exports. Estimates about the workforce employed in space in Australia for the same year range between 9,500 and 11,500 full time equivalents. [33]

There is a huge lack of data on the South Australian space economy. Estimates on the size of the industry in the state are not available in any publication, hence we produce our own. Having insufficient data for a more accurate analysis, we employ a very simple estimation method. We assess the number of employees employed in the space industry in South Australia. Then, we compute an index for the turnover per employee in other economies. Finally, we multiply the index from the previous step by the number of employees to obtain estimated turnover. It is clear that this procedure relies on the strong assumption that the composition of the workforce for our reference economies is similar to that of South Australia, or that there is not too much variation across different categories of jobs, or at least that, if positive to this variation, it is compensated for among the different types of employees. In order to increase the likelihood that such an assumption is satisfied we choose only similar economies as suggested by literature, at the expense of sample size. Despite all the limitations this method presents, we believe it is important to provide an idea of the size of the space economy in South Australia. The reader, on the other hand, should bear in mind that such an estimate is merely an approximation.

- **STEP 1**: <u>assessing the size of the workforce employed in the space industry in South Australia</u>

In *A Study of the Economic Potential of the Local Space Sector*[34], E. Lazzari carried out a survey (South Australian Space Companies Survey 2017) and combined the results with the data provided in the *South Australian Space Capability Directory*[35] to estimate 794 employees as the total workforce employed in the space industry in South Australia. We updated the survey and conservatively estimate 800 employees.

[32] Australian Government, Department of Industry, Innovation and Science, (2017). Australian Civil Space [website]. Accessed April 2018. https://www.industry.gov.au/INDUSTRY/IndustrySectors/SPACE/Pages/default.aspx.

[33] Asia Pacific Aerospace Consultants, (2015). *A Selective Review of Australian Space Capabilities: Growth Opportunities in Global Supply Chains and Space Enabled Services*.

[34] Lazzari E., (2017). *A Study of the Economic Potential of the Local Space Sector*. South Australian Space Industry Centre.

[35] South Australian Space Industry Centre, (2017). *South Australian Space Capability Directory*.

- **STEP 2:** computing the turnover per employee index

Previous literature[36] suggests that Canada and the UK can be used for comparison. With a turnover of US$5.37 billion an 9,784 employees in 2013[37], we obtain US$0.5489 million per employee in Canada, whereas we get US$0.4583 million per employee in the UK, having a turnover of US$17,654 billion and a workforce of 38,522 persons in 2015.[38] Even though South Australia seems to be more active in the space industry than the rest of the country[39], we still decided to include the index for Australia, to take into account national characteristics (e.g. regulation, the absence of an Australia space agency): around US$0.3810 million per employee. Averaging out these three values we obtain an index of US$0.4627 million per employee, which we will use for South Australia.

- **STEP 3:** computing turnover generated by the South Australian space economy:

We multiply the index computed in STEP 2 by the number of employees in STEP 1 to obtain a result around US$370 million a year.

1.4 The evolution of the global space economy

1.4.1 The phases of the global space economy evolution[40]

In order to understand how the space economy is evolving today, a historical perspective might be useful. In some way, we could compare the evolution of space activities to that of other disruptive discoveries and openings, such as the discovery of America in the fifteenth century, undersee exploration or the development of aviation. The space is not intrinsically different in the evolutionary paradigm it followed. Three different phases can be recognized: exploration, experimentation and exploitation. Of course, the boundaries might be hard to establish precisely, as we move on a continuum rather than on a discrete environment and some features might overlap and coexist.

The exploration phase is characterised by a lack of, or extremely limited, knowledge of the new environment and of the technology that opens it. The focus is on trying to acquire as much information as possible and assessing the potential of the new domain, proceeding by attempts and revising the strategy as issues arise. Typically, this involve a high level of risk associated with very high costs and little, if none, opportunities for returns at least in the short to the medium run. For this reason, private agents are usually not willing to fund activities at this stage and public intervention is required. The

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[36] Piva A., (2017). *Societal and Economic Benefits of a Dedicated National Space Agency for Australia*. South Australian Space Industry Centre.

[37] Euroconsult for the Canadian Space Agency, (2015*). Comprehensive Socio-Economic Impact Assessment of the Canadian Space Sector*.

[38] Sadlier G., Flytkjær R., Halterbeck M. and Sabri F., (2016). *The Size & Health of the UK Space Industry*. London Economics.

[39] Lazzari E., (2017). *A Study of the Economic Potential of the Local Space Sector*. South Australian Space Industry Centre.

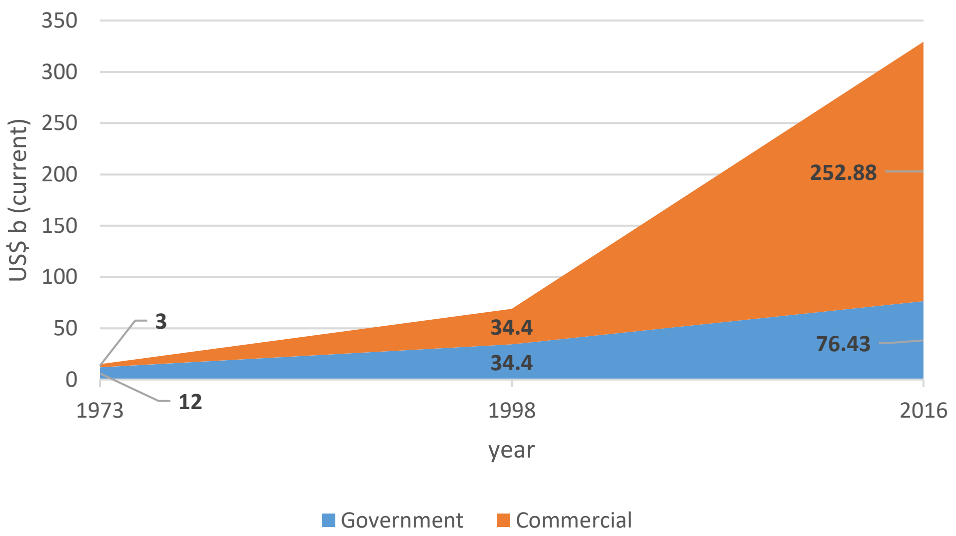
[40] The author wishes to acknowledge the work of Hamill D. in "*Hamill D., Kearney M. (2000) Transitioning to Commercial Exploitation of Space*. In: Haskell G., Rycroft M. (eds) International Space Station. Space Studies, vol 4. Springer, Dordrecht and of the authors of *A Selective Review of Australian Space Capabilities: Growth Opportunities in Global Supply Chains and Space Enabled Services*, of which the qualitative part of this subsection is a revision.

role of business is limited to the provision of tools and ancillary services as requested by governments, which are often driven by military, national security or even national prestige motivations. This applies to the space economy from the Forties to the Sixties.

In the Seventies the space economy entered the so-called experimentation phase. At this point, the fundamentals of the environment are generally understood and hence risk is reduced. The focus is now on expanding the knowledge gained throughout the preceding phase and on learning how to move more effectively and more efficiently in the new domain, also by incremental development and enhancements of the new equipment. Costs, however, do not experience the same decrease as risk does. Although, as a general rule, public actors remain the key players in the field, setting the agenda and being the main funders, private agents, in addition to the role played in the exploration phase, begin to evaluate the possibility of entering new markets. The space economy remained in this phase until the Nineties.

The approach of the new millennium marked a new chapter for the space economy: the exploitation phase. At this stage, the environment and the technology needed to operate in it are well understood. In this phase risk is typically low, costs are decreasing substantially and the focus is on further cost cutting and developing new applications that respond to the newly generated demand in the market economy. The possibility for (often very high) returns is recognized. Investment is generated from private companies replace rather than government, with massive investments injected into the new industry, either by acquiring existing infrastructure or by building new infrastructure. As they observe the positive performance of the first entrants, new actors wish to enter the market, often sustained by a large availability of funds provided by an excited capital market. As the level of activity in the environment is overheating, new ideas for business and efficiency gains come in succession at an ever-increasing pace.

Figure 5 Government and commercial space economy turnover



Source: Euroconsult World Space Industry Survey 1999 and The Space Report 2017

Figure 5 is quite illustrative of the phases the space economy went through. The choice of plotting discrete data points rather than continuous serves the purpose of highlighting the different roles played by private and public actors throughout the evolution of the industry. Hence it is not actual fluctuations that are represented, but rather linear trends. Also, notice that figures are expressed in current currency. This does not constitute a problem in this case, as we are interested in the relative trend. Correcting for inflation would have left unchanged the government and commercial shares, having an impact on absolute values only.

1973 can be set as the year in which the exploitation phase gave way to the experimentation phase. When Apollo 17 left the Moon in December 1972, it was the last time that human presence on the Moon was recorded, at least up to now. At the same time, both the Soviet and the U.S. governments were setting their space stations in low orbit with the aim of assessing the possibility of working and living in space. Moreover, early signs typical of the experimentation phase emerged: Telesat Canada launched *Anik A1* in November 1972, the first domestic communications satellite in the geostationary orbit[41], followed by *Westar 1* by Western Union in April 1974, the first U.S. communications satellite[42]. Nevertheless, despite this initial level of activity by private companies, the largest share of the space economy still belonged to government, the U.S. in particular.

As it is clearly shown in Figure 5, 1998 is of particular interest: for the first time revenues generated by commercial activities equalled government budgets. We can consider this as the end of the experimentation phase and the beginning of the exploitation phase. Since then, the share of commercial activities grew from 50% to more than 76% today.

Table 4 provides detailed information on the value of government and commercial operations in 1973, 1998 and 2016. Notice that this time we included real values, as we wish to compare figures across time and assess the growth rate net of inflation. Especially for such long periods, such a correction is essential: as the column GDP deflator tells us one U.S. dollar in 1973 is worth only 0.2364 U.S. dollars in 2016, whereas one U.S. dollar in 1998 is worth 0.7078 dollars in 2016.

From 1973 to 2016 the real compounded annual growth rate of the global space economy had been 11.11%. More specifically, commercial activities grew at an annual compound growth rate of 14.64%, while government budgets of 7.96%. Moreover, from 1973 to 1998 commercial space activities show an annual compound growth rate of 15.19%, whereas government activities is 8.98%. Turning our attention to the period from 1998 to 2016, we observe an annual compound of growth rate of 13.89% for private operations and of 6.56% for public operations.

[41] IEEE Canada, unknown date of publication. Satellite Model Anik A [website]. Accessed April 2018. https://www.ieee.ca/millennium/anik/anik_model.html.
[42] Boeing, unknown date of publication. First U.S. Domestic Synchronous Satellite System [website]. http://web.archive.org/web/20100101213052/http://www.boeing.com:80/defense-space/space/bss/factsheets/376/westar/westar.html.

Table 4 Commercial and government space activities: absolute values and growth rates in nominal and real terms, 1973, 1998, 2016

Year	Commercial - nominal (US$ b)	Government - nominal (US$ b)	Total - nominal (US$ b)
1973	3	12	15
1998	34.4	34.4	68.8
2016	252.88	76.43	329.31

Year	Commercial Share	Government Share	Compound annual growth rate since 1973 (commercial) - nominal
1973	20.00%	80.00%	-
1998	50.00%	50.00%	10.25%
2016	76.79%	23.21%	10.86%

Year	Compound annual growth rate since 1973 (government) - nominal	Compound annual growth rate since 1973 (total) - nominal	Compound Annual growth rate since previous record (commercial) - nominal
1973	-	-	-
1998	4.30%	6.28%	10.25%
2016	4.40%	7.45%	11.72%

Year	Compound Annual growth rate since previous record (government) - nominal	Compound Annual growth rate since previous record (total) - nominal	GDP deflator
1973	-	-	0.236385747
1998	4.30%	6.28%	0.707786389
2016	4.53%	9.09%	1

Year	Commercial - real (US$ b)	Government - real (US$ b)	Total - real (US$ b)
1973	0.709157241	2.836628963	3.545786203
1998	24.34785177	24.34785177	48.69570354
2016	252.88	76.43	329.31

Year	Compound annual growth rate since 1973 (commercial) - real	Compound annual growth rate since 1973 (government) - real	Compound annual growth rate since 1973 (total) - real
1973	-	-	-
1998	15.19%	8.98%	11.05%
2016	14.64%	7.96%	11.11%

Year	Compound Annual growth rate since previous record (commercial) - real	Compound Annual growth rate since previous record (government) - real	Compound Annual growth rate since previous record (total) - real
1973	-	-	-
1998	15.19%	8.98%	11.05%
2016	13.89%	6.56%	11.20%

Source: data in nominal terms: Euroconsult World Space Industry Survey 1999 and The Space Report 2017; data used to compute GDP deflator: World Development Indicators database, the World Bank.

1.4.2 Space 2.0

Being in the exploitation phase does not mean that the economy has reached its potential and that there is no room for growth. On the contrary, this phase is rich in innovation and new opportunities, as the interest for the new domain keeps growing and the number of entrants increases, stimulating competition. Indeed, the market is witnessing an important trend with notable consequences: increasingly smaller satellites.

On the supply side, small satellites are in fact benefitting both from lower development costs and shorter production times. A trade-off between size and functionality has always existed, yet it is now becoming less relevant, thanks to the improvements in miniaturization and integration technologies. Also, more standardized and commercial of the shelf (COTS) parts are becoming more popular in the construction of spacecraft.[43] On the demand side, a new acceptance for risk has emerged: the focus in more than ever on satellites that might have a shorter life-cycle, but that are cheaper.[44]

According to SpaceWorks[45] small satellites can be classified in the following categories, based on their weight:

- PICOSATELLITES: weight < 1 kg
- NANOSATELLITES: 1 ≤ weight < 10 kg
- MICROSATELLITES: 10 kg ≤ weight < 100 kg
- SMALL/MEDIUM SATELLITE: 100 kg ≤ weight < 1,000 kg

Nanosatellites weight between one and ten kilograms, to be compared to satellites such as the IKONOS-2 for earth observation (817 kg[46]) the GeoEye-1 imaging satellite (1955 kg[47]) and the Inmarsat I4 F3 communications satellite (5960kg[48]). It is hard to provide a precise point estimate of the production and launch cost of a satellite, as it depends greatly on the specific case. Broad estimates range in the US$150,000-US$1 million interval, including the launch, rather than US$200 million-US$1 billion for old generation satellites[49].

Nano and microsatellites in the 1 – 50 kg range in particular have captured considerable attention in recent years. More than 300 of these were launched last year, a 205% increase over 2016 and significantly surpassing the 182 launches forecast from the previous year made by Spaceworks.[50]Figure 6 shows the number of launches of satellites in this range from 2013 to 2017, in addition to market forecasts and the full market potential from 2018 to 2022.

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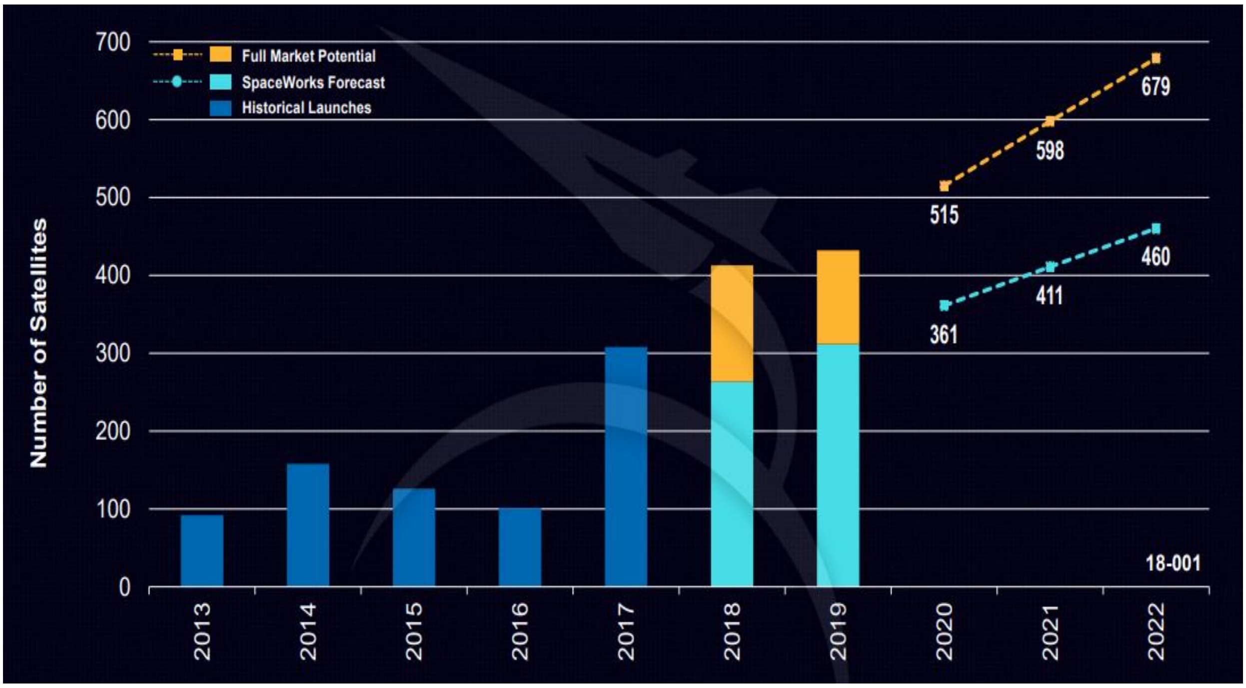
[43] OECD (2014), The Space Economy at a Glance 2014, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264217294-en.
[44] Asia Pacific Aerospace Consultants, (2015). *A Selective Review of Australian Space Capabilities: Growth Opportunities in Global Supply Chains and Space Enabled Services*.
[45] SpaceWorks, (2018). *Nano/Microsatellite Market Forecast, 8th Edition*.
[46] European Space Agency eoPortal Directory – Iknonos-2 [website]. Accessed May 2018. https://directory.eoportal.org/web/eoportal/satellite-missions/i/ikonos-2.
[47] Satellite Imaging Corporation website. GeoEye-1 Satellite Sensor [website]. Accessed May 2018. https://www.satimagingcorp.com/satellite-sensors/geoeye-1/.
[48] Gunter's Space Page, *Inmarsat-4 F1, 2, 3* [website]. Accessed May 2018. http://space.skyrocket.de/doc_sdat/inmarsat-4.htm.
[49] The Economist, (2014). *Nanosats are go!*. Technology Quarterly: Q2 2014. Print edition 7th June 2014.
[50] SpaceWorks, (2018). *Nano/Microsatellite Market Forecast, 8th Edition*.

Such a high growth is to be attributed for a substantial part to a single company: Planet. However, in 2017 they reached enough capacity to map the entire Earth's surface once a day using 1.5 million images, so they declared that their focus is now on building analytics capabilities.[51] Future growth is hence a role for other operators.

This perspective of cheaper and more readily available satellites is bound to bring about a huge impact for the space economy as a whole. In the upstream segment further enhancements to respond to the rising level of competition in the market are expected, starting from research and development and manufacture in order to reach even higher efficiency, to launch activities that will have to serve increasing demand for ancillary services.

Figure 6 Nano and Microsatellites in the 1 - 50 kg range Launch History and Market Forecast, 2018



Source: Figure taken from 2018 Nano/Microsatellite Market Forecast, 8th Edition, SpaceWorks (2018), page 8, "Nano/Microsatellite Launch History & Market Forecast (1-50 kg)".

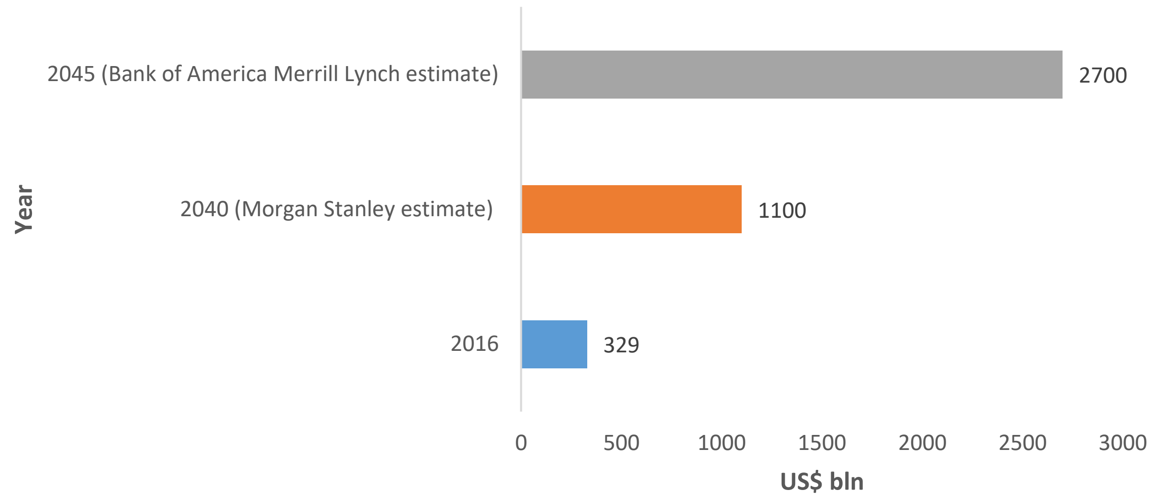
On the other hand, the downstream segment will benefit for an enormous range of the products and service we cannot even imagine today, made possible and profitable by innovation and the decreasing costs in the upstream segment. The real expansion possibilities depend largely on how the actors involved in the downstream segment will be able to bring on the market applications that will help businesses on Earth to make smarter and more informed decisions to generate added value. The

[51] Planet, Official Website Homepage [video]. Accessed May 2018. https://storage.googleapis.com/planet-videos/Planet_PlatformForAnalytics_1080p_Web.mp4.

success in doing so would in turn increase demand and competition on the upstream segment, giving rise to a so-called 'virtuous circle'.

Morgan Stanley expects the space economy to hit US$1.1 trillion by 2040[52], while Bank of America Merrill Lynch estimates that the space economy will grow eight times bigger in the next thirty years, reaching US$2.7 trillion in 2045: "*we are entering an exciting era in Space where we expect more advances in the next few decades than throughout human history*".[53] Welcome to Space 2.0.

Figure 7 Bank of America Merrill Lynch space economy size estimate for 2045



Source: Bank of America Merrill Lynch, Morgan Stanley

[52] Morgan Stanley, (2017). Space: Investing in the Final Frontier. Research [website]. Accessed May 2018. https://www.morganstanley.com/ideas/investing-in-space.

[53] Tran F., Nahal S., Ma B., Epstein R. and Heelan B., (2017). *To Infinity And Beyond – Global Space Primer*. Thematic Investing, Bank of America Merrill Lynch.

2. THE DOWNSTREAM SEGMENT

2.1 The size of the downstream segment

As was clarified in Section 1, the downstream segment refers to all activities that employ data and knowledge that are derived from the space for Earth-related objectives as well as the products and services that support them, as opposed to the upstream segment, inclusive of all activities that focus on the design, manufacture, assembly, launch, functioning, maintenance, monitoring and repair of spacecraft destined to be sent out to space and the products and services related to them.

We have seen the classification of the space economy with the associated figures in the previous section. Now we wish to assess the size of the downstream segment as opposed to the upstream. This turns out to be a delicate task at least for two reasons. First, for integrated services it is sometimes hard in practice to establish the share of revenues to attribute to each of the segment. Even more problematic is the way available data is presented. We use the figures available in the Space Report, yet we aggregate them using our own classification. In this processes some adjustments have to be made.

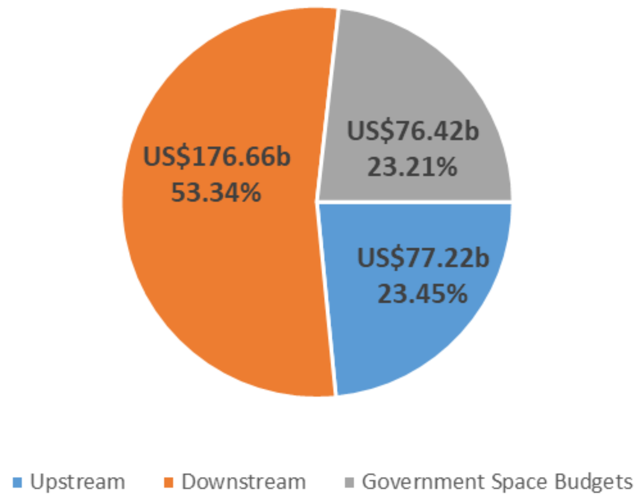
We include in our definition of the downstream what the Space Report classifies as: *broadcasting*, *satellite communications* and *earth observation*. Notice that they do not include a downstream share of what they call *geolocation and navigation* when computing the size of commercial space products and services, which is instead entirely accounted for in ground stations and equipment. However, not all the revenues generated in *geolocation and navigation* actually belong to that class. Hence we include US$49.04 billion coming from *geolocation and navigation* in our estimate for the downstream (more information of how this is done can be found in the subsection 2.3.2). This leads to an estimate of US$175.66 billion in 2016 in terms of turnover for the downstream.

We include in the upstream what the Space Report defines as *commercial infrastructure and support industries*. However, we need to subtract the US$49.04 billion we attributed to the downstream coming from *geolocation and navigation*. This leads us to estimating the size of the upstream segment in 2016 to be US$77.22 billion in terms of turnover.

From these figures, it is clear that the downstream segment enjoys a larger share in the space economy than the upstream, with more than half of the total turnover of the global space economy in 2016, while the upstream not even one fourth.

We would like to show the reader the historical evolution of the shares of the segments, however unfortunately the data we used for our classification is not consistently available for past years. Our explanation of the evolutionary phases of the space economy in the previous section suggests that the downstream enjoys an increasingly larger share over the years. Estimates from the Satellite Industry Association seem to corroborate this intuition. However, also those present some issues in the adaptation to our classification and hence we chose not to report them.

Figure 8 Downstream and upstream shares of the space economy, 2016



2.2 The link between the upstream and the downstream segment

The two segments are indissolubly interconnected, being the downstream exploitation of space technology provided by the upstream. There is a number of channels through which the downstream can benefit from the upstream if the relationship between the two is adequately managed, such as[54]:

- risk reduction: knowledge from the upstream can help actors operating in the downstream to enter new markets that exploit innovations in technology, hence with substantial potential for growth, without having to bear the full risk usually associated with such actions since part of that risk was already dealt with in the upstream;
- human capital: the downstream can benefit from skilled workforce coming from that part of the upstream previously involved in the development of the technologies exploited;
- economies of scale and scope: the downstream can use the same technology developed by the upstream to produce an array of different goods and services (economies of scope), also allowing for larger volumes, especially if at least part of the supply chain is common (economies of scale);
- collaboration: organizations from the two segments can collaborate to produce goods and services that could not be produced without close cooperation;

[54] For a more detailed discussion see *The Case for Space: The Impact of Space Derived Services and Data, (2009). London Economics*.

- ready response to market needs: the upstream can adapt its capacity to accommodate the downstream needs as they result from consumer demand.

The upstream segment, on the other hand, can benefit from a healthy downstream which provides demand for its products. We claim that a further sustainable development of the space economy is possible only through a closer cooperation and integration between the two segments, driven by a downstream able to understand existing market forces to attract demand. Such demand is to be satisfied by providing a wide range of value-added services for the terrestrial economy. This would stimulate the upstream to invest in and develop new technologies and to increase its efficiency and its response time. This can be achieved either with vertical integration between actors in the two segments, causing a reinvestment loop, or with the application of market prices by the upstream on the downstream in a competitive setting.

2.3 The different categories of the downstream segment

The downstream segment can be categorized in three main groups, on the basis of the technologies used and their application. These groups are[55]:

- Earth observation
- Global Navigation Satellite System
- Satellite communication

The three subsections that follow will provide detailed analysis on each of these groups.

[55] Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*.

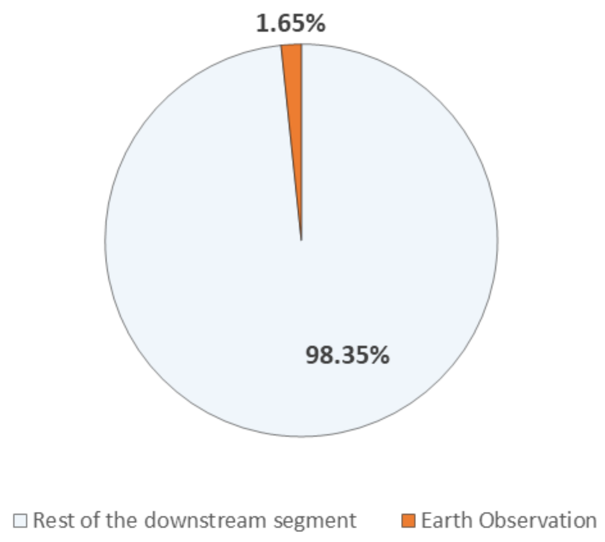
2.3.1 Earth observation

In general terms, Earth observation can be defined as the acquisition, collection, analysis and presentation of data on Earth's physical, chemical and biological systems from aerial or satellite-based observations. A more strict characterization, popular in Europe, includes only satellite-based observation.[56] This is the one we use in this paper. A few characteristics of this definition are worth noticing:

- not only the acquisition and the collection of information are included, but also its analysis and presentation;
- only observation of Earth objects is part of Earth observation, the observation of space is hence excluded;
- not only physical, but also chemical and biological features of the objects of study are considered.

According to the data provided by *Northern Sky Research*, in 2016 commercial Earth observation size was estimated at US$2.90 billion in terms of turnover[57], representing around 1.65% of the overall size of the downstream segment.

Figure 9 Share of Earth Observation on the overall downstream segment, 2016



Source: Northern Sky Research

[56] Tiwari P., Shaikh A., Afsha S. and Bajpai A., (2018). *Responsive Earth Observation & Space Museum Application*. International Research Journal of Engineering and Technology.

[57] Figure retrieved from: Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*, original source: Northern Sky Research, (2017).

This corresponds to an increase by US$0.22 billion with respect to the previous year's absolute value of US$2.68 billion (+8.21%) (note that the 2017 edition *The Space Report* reports a value of US$2.68 billion for 2015, while the 2016 edition of US$2.47 billion for the same year. With this second option, we obtain an increase of US$0.43 billion, i.e. 17.41%).[58]

Figure 10 Composition of Earth Observation Revenues, 2011-2016

Source: figure taken from The Space Report 2017: original source Northern Sky Research

Figure 10 shows the absolute values and the composition of revenues generated by Earth observation activities from 2011 to 2016. We see that data and information products captured the largest fraction throughout all the years considered, the former being the first responsible for the growth experienced. A minority, but still significant share, is to be attributed to value added services. Finally, in 2015 and 2016 we notice the emergence of big data as a new revenue-generating category. Despite playing a secondary role in terms of turnover, this is a novelty that should not be neglected. More attention to big data in the context of Earth Observation will be dedicated later on.

Earth observation is based on remoted sensing, i.e. collecting information on an object of interest from a distance. Five main types can be identified[59]:

- Optical: it detects the solar radiation reflected by the object of study using near infrared and short-wave infrared sensors to form an image, exploiting the fact that different materials absorb and reflect sunlight at different wavelengths[60];
- Infra-red: it detects infrared radiation coming from the object of interest using middle-wave (MWIR) and long-wave (LWIR) infrared sensors emitted by warm objects[61];

[58] Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*.
Space Foundation, (2016). *The Space Report 2016, The Authoritative Guide to Global Space Activity*.

[59] Busswell G., Green N. and Postema R., (2010). *Downstream Applications and Services of Earth Observation, Satellite Navigation and Telecommunication*. Logica.

[60] Centre for Remote Imaging, Sensing and Processing, unknown date of publication. *Optical Remote Sensing* [website]. Accessed April 2018. https://crisp.nus.edu.sg/~research/tutorial/optical.htm.

[61] Centre for Remote Imaging, Sensing and Processing, unknown date of publication. *Infrared Remote Sensing* [website]. Accessed April 2018. https://crisp.nus.edu.sg/~research/tutorial/infrared.htm.

- Atmospheric: it detects optical and infrared solar radiation of the object of interest reflected from the atmosphere[62];
- Radar Altimetry: two steps are required: first the distance between the satellite and the surface is measured using the travel time of microwave pulses emitted from the satellite and reflected back; second, tracking systems are used in order to calculate the satellite position with respect to a fixed Earth coordinate reference system[63];
- Synthetic Aperture Radar: the functioning principle is similar to that of radar altimetry, yet it combines many pulses reflected in sequence[64].

The usage of these technologies brings many advantages, such as:

- wider spatial coverage: satellites are able to cover larger areas than what would be possible using aerial images acquisition in a given time frame;[65]
- higher frequency: from the point of view of the satellite, revisit time is defined as the time needed for it to retrace its path and pass over the same point on the Earth's surface. The user is probably more interested in the time necessary to observe a specific area, regardless of the position of the satellite. This is an alternative definition of revisit time. An effective strategy to minimize the user revisit time is using constellations of satellites. As mentioned in subsection 1.4.2, with its constellation, the multinational company Planet reached enough capacity to map the entire Earth's surface once a day using 1.5 million images[66]. Notice that satellites in Geostationary Earth Orbit (GEO), having a one-day orbital period, always observe the same area and hence the revisit time is virtually zero. However, due to the high altitude of these satellites the trade-off in terms of resolution is considerable;[67]
- reduced marginal costs: once the fixed costs of making the satellite operational have been sustained, the variable cost of acquiring an image is much less than what it would be using other means such as aerial platforms, which require chartering a plane and paying for pilots and technicians[68].
- more ready response to customers' needs: once a satellite is operational, it usually requires less time to acquire an image of a specific area than preparing an aeroplane;

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[62] The University of Augsburg, Institute of Physics. Atmospheric Remote Sensing [website]. Accessed April 2018. http://www.physik.uni-augsburg.de/de/lehrstuehle/afe/.
[63] Cheney R.E., (2008). *Satellite Altimetry* in 1st edition of Encyclopedia of Ocean Sciences, volume 5, pp 2504–2510, Elsevier Ltd.
[64] European Space Agency, unknown date of publication. Radar Course 2, Synthetic Aperture Radar (SAR) [website]. Accessed April 2018. https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/ers/instruments/sar/applications/radar-courses/content-2/-/asset_publisher/qIBc6NYRXfnG/content/radar-course-2-synthetic-aperture-radar.
[65] Busswell G., Green N. and Postema R., (2010). *Downstream Applications and Services of Earth Observation, Satellite Navigation and Telecommunication*. Logica.
[66] Planet, Official Website Homepage [video]. Accessed May 2018. https://storage.googleapis.com/planet-videos/Planet_PlatformForAnalytics_1080p_Web.mp4.
[67] European Space Agency, unknown date of publication. Newcomers Earth Observation Guide. Business Applications [website]. Accessed April 2018. https://business.esa.int/newcomers-earth-observation-guide.
[68] European Space Agency, unknown date of publication. Newcomers Earth Observation Guide. Business Applications [website]. Accessed April 2018. https://business.esa.int/newcomers-earth-observation-guide.

- access to remote areas: satellites are able to acquire images of remote areas, such as Antarctica, which would be difficultly accessible otherwise[69];
- observation possible even in the dark and with clouds: Earth observations techniques can be divided in passive and active imagery. In the former, sensors limit themselves to detecting emissions from the ground level or from the atmosphere. This implies that electromagnetic emissions have to be locally produced or be generated by sunlight reflection. It follows that the dark and clouds can limit observation. On the other hand, in active imagery the satellite emits specific electromagnetic signals and then measures reflection or scattering by the object of study, thus eliminating the limitations of passive imagery;[70]
- reduced interaction with object of study: in comparison with in situ observation, satellite observation reduces the interaction with the object of study, hence minimizing the disturbance. This is particularly true for passive imagery;[71]

However, satellite imaging also presents some disadvantages. Monitoring a small area becomes extremely expensive when measured by average costs per unit of surface because of the high fixed costs. Moreover, specialized training is needed.

In terms of resolution, the issue is more complex than it might appear at first. In general, we can say that the resolution achievable via aeroplanes and drones is preferable to that of satellites[72], yet enhancements in technology are reducing this gap. The most used measure for resolution is the so-called Ground Sample Distance (GSD), which is defined as the distance between two consecutive pixel centres measured on the ground. Having pixel centres closer to one another means higher definition, hence the lower the value of GSD the better. The following categorization is commonly accepted:

- GSD > 300 metres: low resolution
- 300 metres ≤ GSD < 30 metres: medium resolution
- 30 metres ≤ GSD < 5 metres: high resolution
- 5 metres ≤ GSD < 1 metre: very high resolution
- GSD ≤ 1 metre: extremely high resolution.[73]

To provide an idea of what different values of GDS imply in terms of visual impact a few examples follow. The reader should bear in mind that evaluating the quality of an acquisition goes far beyond simple naked eye inspection.

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[69] Houses of Parliament, Parliamentary Office for Science and Technology (UK), (2017). *Environmental Earth Observation*. Postnote number 566 November 2017.

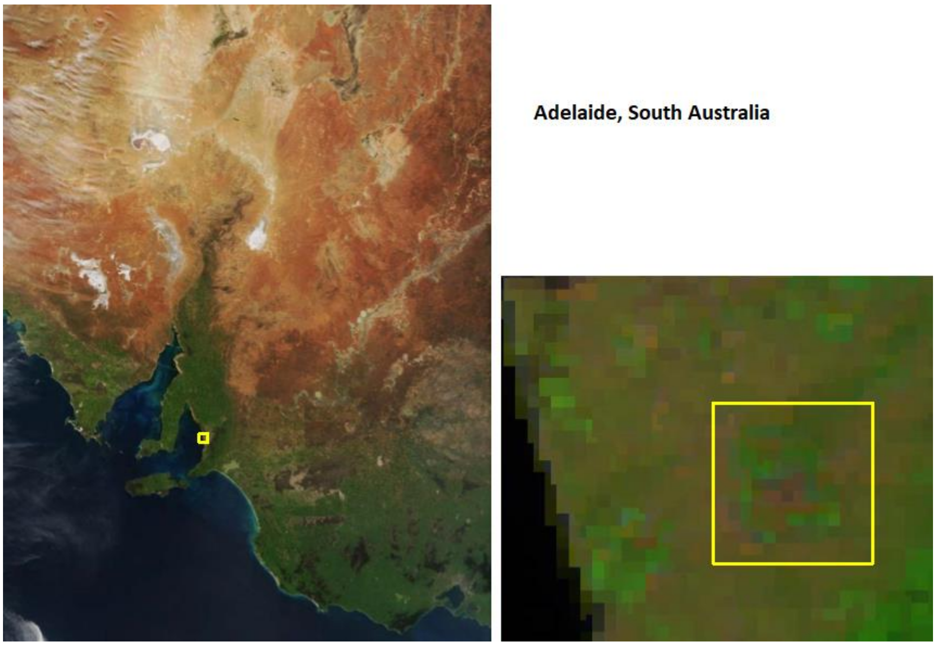
[70] European Space Agency, unknown date of publication. Newcomers Earth Observation Guide. Business Applications [website]. Accessed April 2018. https://business.esa.int/newcomers-earth-observation-guide.

[71] Tatem, A., Goetz, S. and Hay, S. (2008). *Fifty Years of Earth-observation Satellites: Views from space have led to countless advances on the ground in both scientific knowledge and daily life*. American Scientist, 96(5), 390-398.

[72] Busswell G., Green N. and Postema R., (2010). *Downstream Applications and Services of Earth Observation, Satellite Navigation and Telecommunication*. Logica.

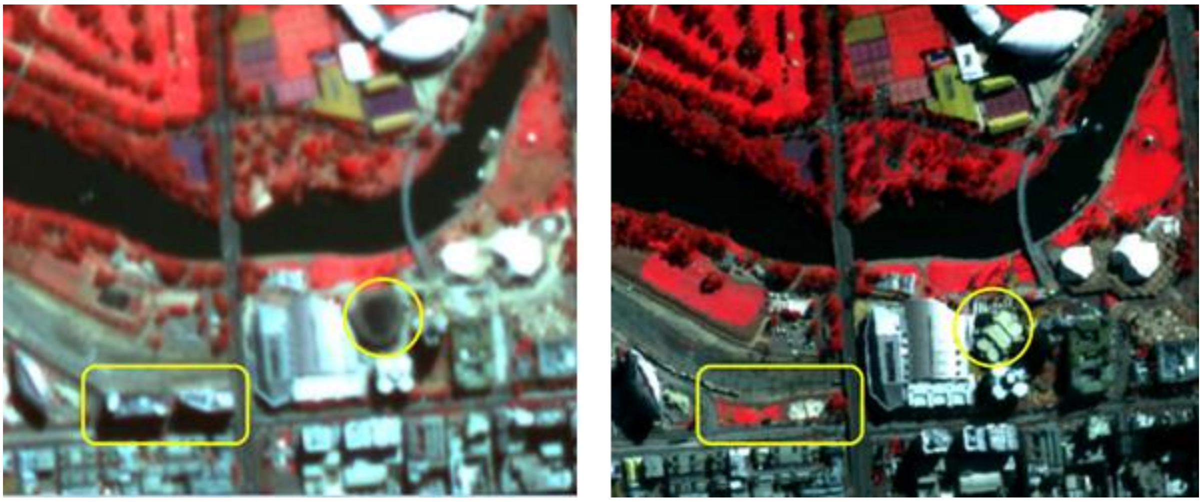
[73] European Space Agency, unknown date of publication. Newcomers Earth Observation Guide. Business Applications [website]. Accessed April 2018. https://business.esa.int/newcomers-earth-observation-guide.

Figure 11 Example of image with 250 m GSD



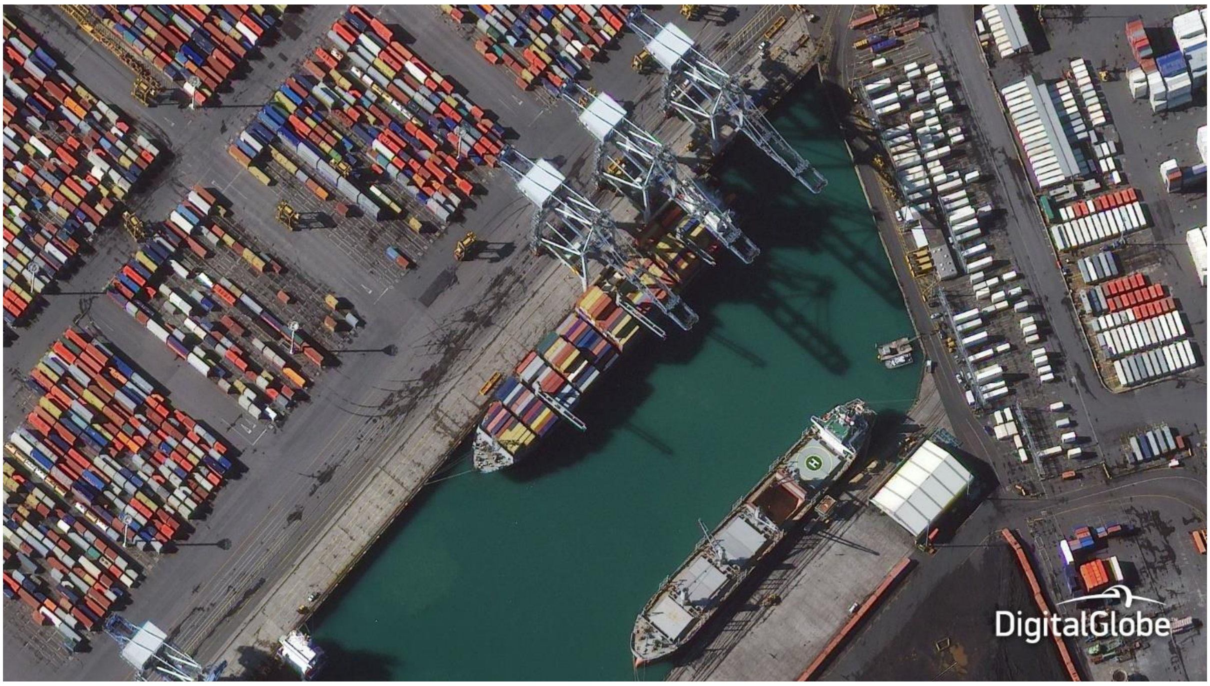
Source: image retrieved from Sensor resolutions from space: the tension between temporal, spectral, spatial and swath presentation slides prepared by Bruce D for the GeoSmart Asia and Locate Conference 2018

Figure 12 Example of image with 3 m (on the left) and 2 m (on the right) GSD



Source: image retrieved from Sensor resolutions from space: the tension between temporal, spectral, spatial and swath presentation slides prepared by Bruce D for the GeoSmart Asia and Locate Conference 2018

Figure 13 Example of image with 30 cm GSD



Source: DigitalGlobe

The National Imagery Interpretability Rating Scales (NIIRS) is a standard measurement on a scale from 0 to 9 for the interpretability or usefulness of imagery. It is not based simply on the GSD, but rather on the different tasks one can carry out with an image, yet with some level of approximation, it is possible to draw a correspondence, as shown in Table 5.[74]

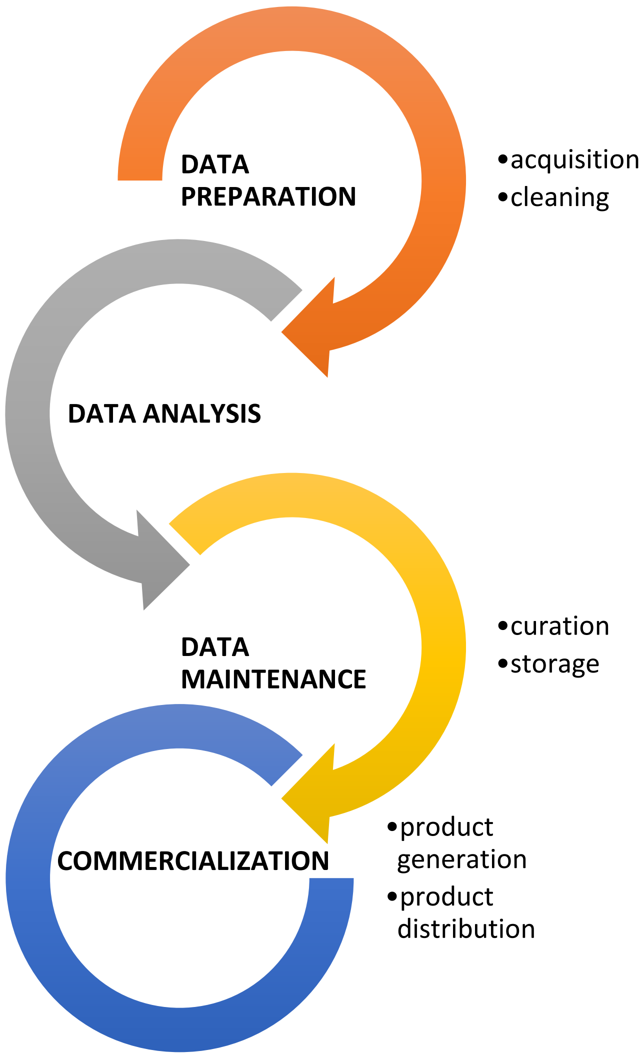
Table 5 NIIRS and GSD scores

NIIRS Scale	GSD (approx.)	Visible	Radar	Multispectral
1	> 4.5 m	Distinguish between taxi-ways and runways at a large airfield	Detect a large cleared swath in a densely wooded area	Distinguish between urban and rural areas
2	2.25 - 4.5 m	Detect large buildings (e.g., hospitals, factories)	Detect road pattern, fence, and hardstand configuration	Detect timber clear-cutting
3	1.25 - 2.25 m	Identify a large surface ship in port by type	Detect medium-sized aircraft	Identify major street patterns in urban areas
4	0.6 - 1.25 m	Identify individual tracks, rail pairs, control towers	Detect all rail/road bridges	Detect small boats(15-20 feet in length) in open water
5	0.37 - 0.6 m	Identify radar as vehicle-mounted or trailer-mounted	Count all medium helicopters	Detect ditch irrigation of beet fields
6	0.20 - 0.37 m	Identify the spare tire on a medium-sized truck	Distinguish between variable and fixed-wing fighter aircraft	Detect foot trail through tall grass
7	0.10 - 0.20 m	Identify individual rail ties	Detect road/street lamps in an urban residential area	Distinguish individual rows of crops
8	0.05 - 0.10 m	Identify the rivet lines on bomber aircraft.	Identify the dome/vent pattern on rail tank cars	
9	< 0.05 m	Identify vehicle registration numbers (VRN) on trucks.	Identify trucks as cab-over-engine or engine-in-front	

Source: European Space Agency

[74] Irvine J.M., (1997). *National imagery interpretability rating scales (NIIRS): overview and methodology*, Proc. SPIE 3128, Airborne Reconnaissance XXI.

Figure 14 The supply chain of Earth Observation products



The simple acquisition of an image is rarely of any use unless more steps are taken. The supply chain of Earth observation services can be broadly schematised as follows:

- data acquisition: images firstly need to be acquired;
- data cleaning: images have to gathered, filtered and cleaned before being stored for analysis. This might include activities such as radiometric corrections (sensor irregularities correction, defective pixels identification, etc.), atmospheric corrections, scene classification, land/water masks generation, dynamic range adjustment (adjust contrast and brightness in the image), ortho-rectification (remove sensor/satellite motion and terrain-related geometric distortions to obtain map-suitable images)[75];

[75] European Space Agency, unknown date of publication. Newcomers Earth Observation Guide. Business Applications [website]. Accessed April 2018. https://business.esa.int/newcomers-earth-observation-guide.

- data analysis: once the images have been cleaned they are ready to be analysed. The data analysis process is not unique as it depends on the objective of the analysis and requires knowledge specific to the issue under investigation;
- data curation: involves the active management of data over its entire life-cycle to deal with the increasing quantity, diversity and flow of data from a variety of sources[76];
- data storage: the final version of the data obtained as a result of the previous steps has to be stored appropriately, so that it ready available when needed;
- product generation: data has to be converted to a business products or services to support decision making processes. This could include activities such as the production of a report or of tool such as end-user applets or web portals;
- product distribution: the product realised in the preceding phase has to be made available to customers.

The European Commission highlights the problem that most of the players involved in the supply chain operate independently from one another[77]. However, some platforms that aim at connecting the different players, providing a unique and easily accessible service, are emerging. One example is the German company Cloudeo: "*We team up with world-leading content and software providers to offer geo-infrastructure, bringing together data, software and processing power. Cloudeo is dedicated to generating a greater value and a unique way to easily access geodata by bringing together all those who create, interpret and use it*[78]".

There is an array of ways in which a product can be disseminated. Based on the needs of the customer and the availability of data we can distinguish images and their derivatives in:

- archive images: given the large number of operational satellites in orbit, there is often excess capacity, so that images are acquired even in the absence of specific requests. This allows the construction of archives, which also turns out to be particularly useful in understanding the evolution of many phenomena. Customers can be granted access to different periods. This is often the most economical choice[79];
- automated browsing: when the customer does not have a pre-determined area, but is rather interested in learning where a particular phenomenon has taken or is taking place, service providers can browse their data to satisfy the request.

When instead the images for an area of interest are not available or they do not correspond to the desired characteristics (e.g. acquisition date, resolution, clouds, etc.) new images can be ordered, usually at a higher price (on-demand orders). Options include:

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[76] European Commission, Business Innovation Observatory, (2016). *Big Data in Earth Observation*. Space tech and services, Case study 64.

[77] European Commission, Business Innovation Observatory, (2016). *Big Data in Earth Observation*. Space tech and services, Case study 64.

[78] Cloudeo website, home page [website]. Accessed April 2018. https://www.cloudeo-ag.com/.

[79] European Space Agency, unknown date of publication. Newcomers Earth Observation Guide. Business Applications [website]. Accessed April 2018. https://business.esa.int/newcomers-earth-observation-guide.

- one-shot: a single or a number of images can be taken according to the specified features of the order. This can have high or low priority;
- routine: data on the area of interest is to be delivered periodically at scheduled intervals.

If an already existing image is to be purchased, a low-resolution preview is usually available to check for cloud cover, whereas if new images are to be ordered, it is often possible to specify a maximum cloud cover tolerance. The service provider would typically communicate an estimated timeframe for the acquisition, after which, if it was not possible to respect the upper limit required, a new timeframe or the acceptance of the images taken can be proposed.[80]

To deliver these services a variety of business models are possible, the most popular being[81]:

- pay-per-product: customer is required payment for a pre-determined number of images plus accessory services;
- pay-per region: payment is related to the size of the surface to be analysed;
- pay-per-target constraint: this scheme relates to the automated browsing. The customer is required to make payment in accordance with the research;
- subscription: the customer is required to make a fixed payment for a package of services. This is commonly used for routine observations.

Moreover, it is important to mention the presence of operators providing free of charge access to data. Since these are typically public organizations, restrictions on the nationality of who requires access and the intended use might apply. Further limitations may concern the amount and quality of data accessible. Examples include the European Space Agency with its famous Copernicus and other systems[82] as well as NASA[83] and the Indian Space Research Organization of the Department of Space[84].

Different needs in terms of volume, quality and type of data, as well as the availability to pay and the additional services required, are extremely dependent on the final use for which it is intended. Earth Observation products and services can indeed be applied to a wide range of sectors, such as:

- <u>AGRICULTURE</u>:

As agriculture was one the first beneficiaries of Earth Observation, the applications in this field are manifold[85].

The most basic is crop location mapping, which consists of identifying cultivated land as opposed to non-cultivated land. The analysis can be carried out at different levels of spatial coverage, such as global, national or regional. Temporal variation in vegetation greenness and in land (growth, field clearance, sowing, harvesting, etc.) are exploited. This allows the identification of trends over time

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[80] European Space Agency, unknown date of publication. Newcomers Earth Observation Guide. Business Applications [website]. Accessed April 2018. https://business.esa.int/newcomers-earth-observation-guide.

[81] Busswell G., Green N. and Postema R., (2010). *Downstream Applications and Services of Earth Observation, Satellite Navigation and Telecommunication*. Logica.

[82] https://earth.esa.int/web/guest/data-access/how-to-access-esa-data [accessed April 2018].

[83] https://earthdata.nasa.gov [accessed April 2018].

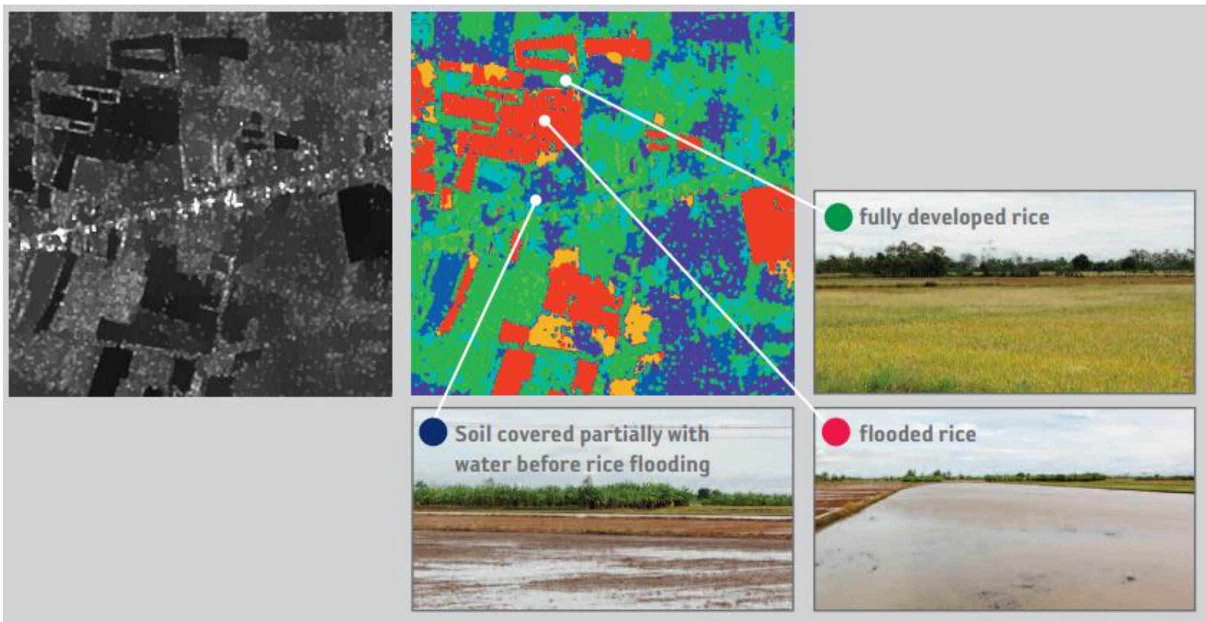
[84] http://bhuvan.nrsc.gov.in/bhuvan_links.php [accessed April 2018].

[85] See European Space Agency, (2013). *Earth Observation for Green Growth. An overview of European and Canadian Industrial Capability* for a more complete discussion.

and of specific characteristics of favourable conditions for cultivation. In some countries, especially in Africa, this technique often represents the only means to collect information on the size of cultivated land.

Given an area of interest, it is possible to use Earth Observation to map crop type and status. This is particularly useful to identify the different growth paths of crops across time and under a variety of conditions.

Figure 15 Example of crop type and status mapping



Source: Cosmo-SkyMed data ASI, distributed by e-GEOS and processed by sarmap.

It is also possible to gain an insight on the health of plantations with high frequency to have early warnings in case of negative conditions in order to plan an intervention and for ordinary management. For this purpose, different indicators can be computed such as the Vegetation Productivity Indicator (VPI), the Normalized Difference Vegetation Index (NDVI) and the fraction of Absorbed Photosynthetically Active Radiation (fAPAR). Moreover, there are services that provide farmers with suggestion for precision agriculture that often see the integration of Earth Observation derived data with in situ observation. The former is of particular use in identifying inadequate cultivation practices and irrigation.

Earth Observation has also proven to be useful in the identification of a set of indicators characteristic of organic as opposed to traditional crops (e.g. spatial heterogeneity, nitrogen content, detection of tractor traces in fields, etc.).

- DISASTER MANAGEMENT:

In the unfortunate case of a disaster, it can be extremely helpful to have maps and images of the area of interest before and after its occurrence. Some sites might become inaccessible and so satellites might represent the only way to gain such an insight in a short time. Information about the extent of active fires, floods, volcanic eruptions, storms, hurricanes, tsunamis and earthquakes, and on the status of rivers, roads, buildings and other infrastructure are but a few examples of a knowledge that can become essential in understanding the severity and evolution of a disaster and thus to plan, organize and carry out appropriate interventions. The International Charter Space & Major Disasters is an international cooperation aims to provide data in the case of natural or man-made disasters to help mitigate the effects on human life and property[86]. Among its members, one can find the European Space Agency, the Canadian Space Agency and companies such as Airbus Defence and Space or DigitalGlobe[87].

Currently, the main focus of Earth Observation activities in disaster management is on the immediate response. However, other activities such as historical and current precise mapping of terrain deformations and volcanic hazard monitoring can also be very important.

- INTELLIGENCE

The opportunities for Earth Observation technology to gather intelligence are of the most diverse. Governments are the most immediate consumer of intelligence services for defence and homeland security purposes; yet this data is increasingly becoming available to the public[88]. Very high resolution is often needed. Examples include the Indonesian Government detecting illegal fishing in its water supported by the company Spire, which provides hourly updates on the identity and position of vessels[89] and the monitoring of North Korean Government activities for the Committee for Human Rights in North Korea by AllSource Analysis[90], which offers expertise in analysing images acquired by other operators such as Planet, Spire, DigitalGlobe and Airbus to organizations, businesses and private citizens[91].

- URBAN AND REGIONAL PLANNING

Earth Observation is a powerful tool for urban areas as well. These present significant spatial heterogeneity, which makes them difficult to study from the ground level, and sets of different materials with their own spectral signature. Applications include mapping and monitoring of land surfaces, monitoring expansions and population distribution, the construction of 3D city models, monitoring soil sealing and identifying urban heat islands.

[86] International Charter Space & Major Disasters website, Homepage [website]. Accessed April 2018. https://disasterscharter.org/web/guest/home;jsessionid=F38143137D6FDFDFC467889E078AD849.jvm1.

[87] International Charter Space & Major Disasters website, About the Charter, Charter Members [website]. Accessed April 2018. https://disasterscharter.org/web/guest/charter-members.

[88] Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*.

[89] Spire, (2016). Spire website, News, Spire & Indonesian Ministry of Marine Affairs & Fisheries Sign a Memorandum of Understanding [website]. Accessed April 2018. https://spire.com/company/insights/news/spire-indonesian-ministry-marine-affairs-fisheries/ and
Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*.

[90] Space Foundation, (2016). *The Space Report 2016, The Authoritative Guide to Global Space Activity*.

[91] AllSource Analysis website, homepage [website]. Accessed April 2018. https://allsourceanalysis.com/.

Figure 16 Russian Activity in the Arctic, Kotelny Island, Example of Image before and after AllSource Analysis Analysis

Source: AllSource Analysis

- BUSINESS INTELLIGENCE:

Earth Observation can be used for business intelligence as well. A good example is that of the Californian company Orbital Insight, which can count the number of vehicles parked in the parking lots of stores and other businesses to better understand consumer behaviour. "*Counting cars at big box retailers, such as Target and K-Mart, gives an indication of how many customers visited the stores during a quarter, and could give an early sign on whether company earnings will go up or down*" (The Wall Street Journal).[92] Another interesting case sees the start-up company Ursa Space Systems employing Synthetic Aperture Radar technology to provide its customers with information about oil storage, might it be in oil tank depots, oil businesses' parking lots or in harbors. Such a knowledge can reveal itself to be particularly relevant for oil market investors, especially when data is scarce, such as for China. Ursa Space System also offers reports on the crude oil market, based on the intelligence acquired via its satellite observation.[93]

- ENERGY AND MINING:

Earth Observation services can be of great use in identifying new mineral deposits, for planning and designing more efficient seismic surveys and for monitoring the impact of fossil fuel extraction and mining on measures such as air, soil and water quality, presence of site rehabilitation and land use change. In addition to that, Earth observation enables remote monitoring of oil, gas and biofuel pipelines. Advantages with respect to in situ inspections include increased frequency and accuracy, early detection of stresses and leaks, encroachment monitoring and enhanced network performance and safety, route planning and ground motion monitoring.

Earth Observation can assist also in staying in line with the global trends on the energy market, which put more and more attention on renewable energy. First, the contributions to agriculture can help in the production of biofuel. Second, it can play an important role in resource assessment and exploration support for renewable energy, thanks to the huge amount of data on irradiation, cloud cover, wind velocity, wind direction, wind shear, air temperature, relative humidity, topography and elevation, surface roughness, wave height and many more indicators that can be collected.

- ENVIRONMENT AND CLIMATE CHANGE [94]:

The role of Earth Observation in monitoring the environment and climate change is huge. The greatest challenge is gaining an understanding of the complex set of variables involved and the absence of measuring stations in many remote areas that often makes satellites the only means to collect information in a timely fashion and to capture time trends.

As for inner land study, Earth Observation techniques can be used to assess the composition of the land, map individual minerals, measure ground temperatures, assess the density and health of water content and stage of development of flora and much more. All of this is useful for instance in delineating the evolution of deserts and forests, the erosion of coastlines and the movements of tectonic plates. Moreover, it is possible to compute the flow of rivers and lakes to observe millimetre-

[92] Orbital Insight website, Products, Consumer [website]. Accessed April 2018. https://orbitalinsight.com/products/consumer/#slider-1.

[93] Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*.

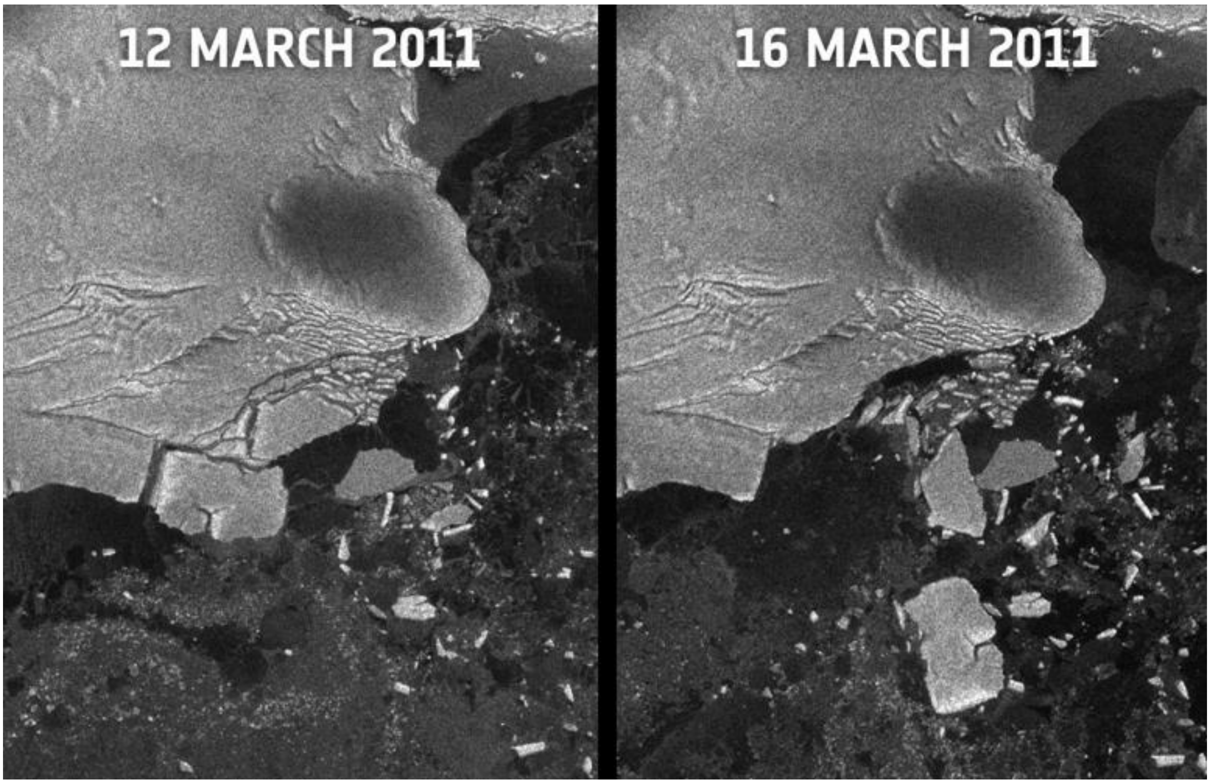
[94] The author wishes to acknowledge the European Space Agency work on the role of space on climate change in *Space for our Climate*, of which this part is a review and data is retrieved. [website]. Accessed April 2018. https://www.esa.int/Our_Activities/Observing_the_Earth/Space_for_our_climate/Space_in_climate_change.

scale land shifts above aquifers, thus allowing to infer changes in groundwater levels, besides identifying subsurface aquifer locations by measuring local variations in Earth's gravity field. Satellites can also be used to assess the risk of and to forecast volcano eruptions and once the eruption has occurred measure lava flows, mudslides, ground fissures and earthquakes, while atmospheric sensors can identify the gases and aerosols released.

Earth Observation is of great use also in observing oceans, spanning from measuring water temperature with an accuracy of a fraction of a Celsius degree and tracking currents and water flows to measuring water surface height and the level of salinity. Furthermore, by detecting chlorophyll pigments in seawater, scientists can monitor global phytoplankton distribution, which helps to enhance the accuracy of climate change models. Besides being a fundamental element of the food chain, phytoplankton also mitigates the greenhouse effect by absorbing carbon dioxide. Satellites are also used to measure wind and waves strength and direction, hence improving safety in navigation (considering that about 90% of global trade passes though the ocean) this is a significant contributor to safety.

Another important application of Earth Observation for the environment is cryosphere mapping. Satellites are able to monitor ice on Earth not only in terms of size and location, but also in terms of elevation from seawater, albedo (reflectivity), thickness, density and hardness. Having such information in time series is crucial in understanding climate change processes.

Figure 17 Example of Synthetic Aperture Radar for monitoring Icebergs



Source: European Space Agency

Satellites can produce a three-dimensional map of the atmosphere, detecting the presence of an array of different chemical substances, dust particles and clouds composition. They can identify holes in the layer, aerosols and pollutants as well as aeroplanes exhaust trails. An interesting application is the measurement of carbon dioxide emission by single plants and by individual countries, thus facilitating the enforcement of international treaties imposing upper bounds on emissions, which are often self-reported estimates.

- MAPPING:

One immediate application of Earth Observation is the creation of maps. Images of the Earth are taken from space and are then elaborated using different procedures according to the type of maps that one wishes to realize. Of course, depending on the spatial coverage and the level of detail of the maps, different levels of resolution might be needed. Also, as aforementioned, both the natural environment and the urban settings are in constant evolution, in addition to the changes that might occur due to natural disasters. It follows that for accurate mapping an adequate level of frequency in image acquisition is required.

- WEATHER FORECAST:

Thanks to some of these capabilities, information on the conditions of the Earth obtained from satellites can be combined with data from other sources in the production of weather forecasts through very complex algorithms. Consider that around 75% of the data used in numerical weather prediction models comes from satellites[95]. This data is collected both from satellites dedicated specifically to weather forecast and from satellites that have other environmental uses.

There are many advantages of using satellites for weather forecasts, such as the possibility of having a synoptic view of wide areas and higher frequency in observations, the averaging of which is more accurate than the point in situ observations. Also, they can collect information that would not be otherwise available (sea surface, temperature, sea surface wind stress, sea level, cloud liquid water content, radiation balance, aerosol, etc.) This information is combined for an improved prediction and better understanding of the underlying processes. Moreover, they can cover inaccessible and/or remote areas and the oceans.[96]

Traditionally, the global meteorological satellite community has adopted a free data sharing philosophy, with data collected mainly by public organizations. Despite the large number of weather and environmental satellites in orbit, funding issues in several OECD countries threaten the sustainability of the provision of essential long-term data series on climate[97]. Perhaps for this reason, we are recently witnessing private companies entering the market, such as Spire, which claimed: "*We*

[95] *OECD, (2014). The Space Economy at a Glance 2014*. OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264217294-en.

[96] *Kalsi S.R., (2018). Satellite Based Weather Forecasting.*

[97] *OECD, (2014). The Space Economy at a Glance 2014*. OECD Publishing, Paris. http://dx.doi.org/10.1787/9789264217294-en.

are going to provide a lot more observations for less money, and that is how weather forecasts get better"[98].

- TRANSPORT:

Earth Observation can be applied to achieve improvements in efficiency. Satellite derived information can be used to divert planes around opposing winds or adverse weather conditions, hence minimize fuel consumption, or to reduce the impact on the environment by avoiding colder air masses where ice particles contrails are more likely to form from fuel exhaust. The *Tropospheric Emission Monitoring Internet Service* (TEMIS) by ESA assisted in the rerouting of aeroplanes to avoid passing through harmful clouds of volcanic ash and sulphur dioxide.[99] The same concept is applicable to ship route planning, avoiding adverse sea conditions and dangerous ice fields. Moreover, thanks to the high level of detail in observing landscapes enabled by satellites, Earth Observation also helps in the planning of new roads and rail links, both in urban and non-urban areas.

- INSURANCE:

The insurance sector can benefit from Earth Observation derived applications to support risk modelling, for hazard and damage assessment and for claim management. In particular, archived data, can help in risk prediction and assessment activities as well as in providing evidence for claims verification (e.g. pre and post-accident images), whereas real time data can contribute to limiting losses and in planning for immediate responses.

The applications related to Earth Observation span a really diverse range of activities and are cross-sectional to many sectors. However, there is a set of technology drivers that they share:

- Big data analytics: as the number of active satellites and their capability keeps increasing and as a result the amount and variety of images they produce also increases, traditional software will no longer be able to store and process the enormous amount of information collected. For instance, it is estimated that by 2019 the European Space Agency spacecraft Sentinel will have acquired 25 petabytes of Earth Observation data[100] (1 petabyte = 1,000,000 gigabytes). Not many entities possess the ability to manage such a large amount of data, even though storage costs are decreasing and analytical tools are becoming increasingly powerful. It follows that if Earth Observation operators wish to expand their market penetration they need to develop such a capability in order to be competitive and they need to offer their customer

[98] Tollefson J., (2017). Race to provide commercial weather data heats up - A movement to privatize Earth-observing satellites is gaining ground. Nature, International weekly journal of science [website]. Accessed April 2018. https://www.nature.com/news/race-to-provide-commercial-weather-data-heats-up-1.21399.
[99] European Space Agency website, Our Activities, Observing the Earth, Benefiting our Economy [website]. Accessed March 2018. https://www.esa.int/Our_Activities/Observing_the_Earth/Benefiting_Our_Economy/Overview.
[100] Di Meglio A., Gaillard M. and Purcell A., (2014). CERN Openlab Whitepaper on Future IT Challenges in Scientific Research.

some sort of cloud based service which enables them to work without having to download the data and use their own processing capability;[101]

- Cloud computing: strictly linked with the previous point, cloud computing represents the means through which even small sized customers who do not have infrastructure nor the expertise needed to handle big data can access Earth Observation services;
- Artificial Intelligence: even if data can be adequately stored and accessed, it remains of little use if it cannot be analysed. Together with the ability to store and access information, that of being able to analyse it to gain useful insight has to be developed and the practical solution to such a challenge is artificial intelligence. This will enable the building of the necessary capabilities to analyse huge amounts of data in a timely fashion.

Despite the unquestionable utility that can be derived from Earth Observation application, we saw at the beginning of this subsection that it accounts for a mere 1.65% of the entire downstream segment. This is due to some obstacles in adoption. Foremost, because of the highly technical aspect of the applications developed, there is lack of awareness and understanding of these innovations. Such a situation causes potential customers to underestimate the potential benefits of investments in Earth Observation products and services, ultimately leading to a lack visibility on the market.[102] Also, as we already mentioned, cooperation among the different participants in the supply chain is not yet fully developed, although there are indications of this happening. Moreover, there is a high dependence on public sector consumers. This often imposes a substantial amount of administrative work that can discourage small innovative companies that do not have sufficient or appropriate resources[103] and expose companies to variable political agendas. Nevertheless, the growth rates Earth Observation experienced in recent years provides reassuring signs that these challenges are being tackled effectively.

[101] European Commission, Business Innovation Observatory, (2016). *Big Data in Earth Observation*. Space tech and services, Case study 64.
[102] European Commission, Business Innovation Observatory, (2016). *Big Data in Earth Observation*. Space tech and services, Case study 64.
[103] European Commission, Business Innovation Observatory, (2016). *Applications related to Earth Observation*, Case study 63.

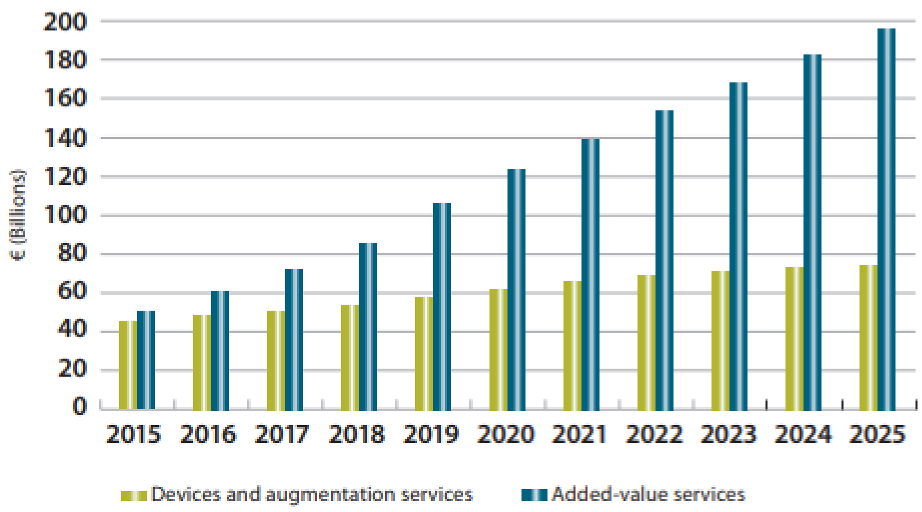
2.3.2 Global Navigation Satellite System

Global Navigation Satellite System is defined as *the infrastructure that allows users with a compatible device to determine their position, velocity and time by processing signals from satellites*[104].

Defining the scope of this market is not an easy task. In line with the European Global Satellite Systems Agency (GSA), we define the GNSS downstream market as all the activities where GNSS based position, navigation and timing is a significant enabler of functionality. The main difference between the classification of this paper and that of the GSA lies in the fact that they consider devices and augmentation services and added-value services as part of the downstream segment, while we consider only added-value services in the downstream and we include devices and augmentation services in the upstream ground equipment. We highlight the fact that in their figures, the GSA includes revenues generated from devices, from augmentation services and other necessary software solutions and content and from added-value services only for the part directly attributable to GNSS. For example, for smartphones, only the value of the GNSS chipset, for search and rescue devices only the price differential between GNSS and non-GNSS devices are included.

According to the data provided by the GSA, in 2016 the downstream market for GNSS, based on their definition, was worth around €110 billion (around US$122 billion) in terms of turnover, an increase of more than 15% with respect to the previous year figure. Around €50 billion is attributed to devices and augmentation services, while around €60 billion to added-value services, as shown in Figure 18. It would therefore follow that the size of the downstream market for GNSS in 2016 was €60 billion (around US$66.43 billion[105]) based on our definition.

Figure 18 GNSS downstream market turnover, 2015 – 2025



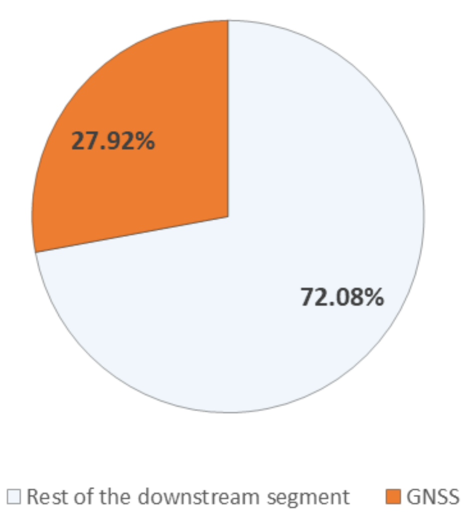
Source: GNSS Market Report, Issue 5, copyright © European GNSS Agency, 2017

[104] European Global Navigation Satellite Systems Agency, (2017). *GNSS Market Report, Issue 5*.
[105] We use the exchange rate €1 = US$1.10714285714 used in the Space Report 2017 to ensure comparability with the other categories.

It should be noted that, as aforementioned, the Space Report 2017 includes revenues generated by GNSS entirely in commercial infrastructure and support industries, for a value of €81.2 billion (US$89.9 billion). They retrieved such a figure from the European Global Navigation Satellite Systems Agency, referencing the GNSS Market Report Issue 4, which was published in 2015.[106] We chose to use this figure too in our computations for the overall size of the global space economy in order to ensure comparability with other studies. Unfortunately, Issue 4 does not provide a distinction between added-value services and devices and augmentation services. We approach this methodological issue by computing the proportion of these two parts on the most recently available total figure of €110 billion and then we apply these shares to the Issue 4 figure. This gives us a result of €44.29 billion (US$49.04 billion), which is exactly the figure we used to compute the size of the downstream segment at the beginning of this section. This means that in 2016 GNSS enjoyed a share of almost 28% on the overall size of the downstream segment in terms of turnover.

Figure 18 also provides the GSA projections up until 2025. We see that a significant expansion the revenues generated by added-value services is expected. Between 2015 and 2020 they are foreseen to grow at a rate of around 20% annually, gradually slowing to an average 9.6% through 2025[107].

Figure 19 Share of GNSS on the overall downstream segment, 2016

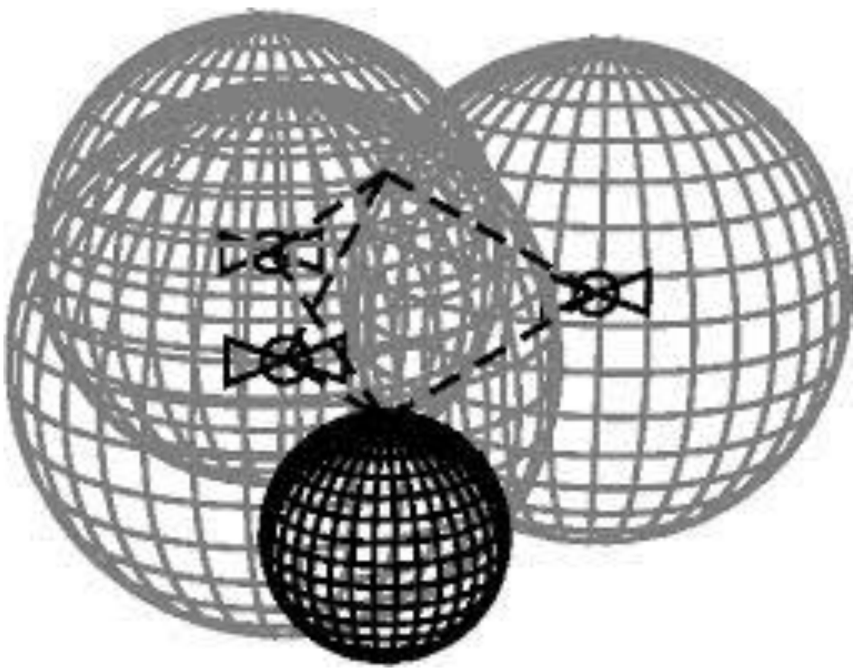


We now explain briefly the functioning principle behind Global Navigation Satellite Systems. The basic elements are a constellation of satellites and a receiver. The satellites emit electromagnetic waves towards the Earth, containing information about the position of the satellite and the time they were emitted (enabled by an atomic clock in the satellite). Once these waves reach the antenna of the

[106] Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*.
[107] European Global Navigation Satellite Systems Agency, (2017). *GNSS Market Report, Issue 5*.

receiver, the processing unit elaborates the information received to determine its position relative to the coordinate system of reference (e.g. Inertial, Earth-centred, World Geodedic). The receiver can compute its distance from the satellite generating the wave by multiplying the timeframe between the moment the wave was emitted and the moment it reached the antenna by the travel speed of the wave, i.e. speed of light. Knowing the distance from the satellite allows for the definition of a set of points equidistant from the satellite, namely a sphere with the satellite as a centre and the distance as a radius. Using a second satellite with a different position from the first one and crossing-checking the data, we know the receiver must be located both on the sphere with the first satellite as a centre and on that with the second one as a centre, i.e. the receiver must be located on the portion of the plane which results from the intersection of the two spheres. In theory, adding a third satellite with different position with respect to the other two would allow the receiver to determine its position. Indeed, the intersection between three spheres can result in a maximum of two points, of which only one will be close enough to Earth to be the position of the receiver (it is an analogous concept to introducing Earth surface as a fourth sphere).

Figure 20 Intersection of three spheres



Source: Royal Observatory of Belgium

However, this measurement might not be accurate enough. If we accept that the speed of light is about 299,792,458 m/s, even with a one-millisecond error in timing we could get an error in distance measurement in the order of 300 kilometres. To prevent this the clock in the receiver would need to be exactly synchronised with the clocks in the satellites, which is possible only in theory. Hence, we need at least four satellites to ensure accuracy. In practice, more than four satellites are generally used, depending on the environment. Differences in clocks may cause errors of around ± 2.5 metres. In addition to this, there are many other possible sources of error, such as:

- Ionosphere effect: ionosphere is the layer of atmosphere between 80 kilometres and 600 kilometres above the sea level. The high concentration of ions in the ionosphere can delay the satellite signal and can cause a position error of ± 5 metres;
- Troposphere effect: tropospheric delays originate from the changing humidity, temperature and atmospheric pressure typical of this layer of the atmosphere. The error is estimated to be around ± 0.5 metres;
- Receiver Noise: caused by the receiver hardware and software, around ± 1 meter;
- Multipath distortion: it occurs when the signal is reflected off an object (e.g. the ground or the wall of a building) to the antenna, hence artificially increasing the distance and the delay, causing an error of ± 1 metre;
- Orbital error: since the orbits in which satellites travel vary by small amounts, the position of the satellite is not perfectly estimated, causing an error of ± 2.5 metres.[108]

There may be some obstacles that impede the correct functioning of GNSS. For instance, buildings, bridges, tunnels or trees might block completely the signal before it reaches the receiver. Moreover, there may be disturbance produced by other devices that use the same frequency. Denial of service can also be intentional. When a disturbance is generated deliberately it is referred to as "jamming". "Spoofing" occurs when an action induces the receiver to report an incorrect location, or introduces a false signal created by a signal generator, or rebroadcasting an actual GNSS signal from some other location. Anti-jamming systems and encrypted signals can be effective ways to protect oneself against this sort of attack.[109]

In order to improve the performance of GNSS, multiple support and augmentation of signal techniques have been developed.

First, using different frequencies allows for a significant reduction in the ionospheric error and lowers the chances of disturbances and jamming.

Second, receivers that can connect to more than one constellation of satellites benefit from shorter signal acquisition time, enhanced position and time accuracy and a reduction of problems associated with signal obstruction. There are currently three main fully functional GNSS systems: Global Positioning System (GPS), Global Navigation Satellite System (GLONASS) and BeiDou Navigation Satellite System (BDS). GPS is operated by the United States' Air Force. The Department of Defence launched the first satellite in 1978, yet it was not until 1983 that it was allowed for civilian use. In 1993 the 24 satellites it is composed of today became operational[110]. Although the U.S. Government spent more than US$900 million in fiscal year 2017, the service is provided free of direct user charges[111].

[108] NovAtel, (2015). *An Introduction to GNSS*, Chapter 4 - *GNSS Error Sources*.

[109] NovAtel, (2015). *An Introduction to GNSS*, Chapter 7 - *GNSS Denial*.

[110] NASA, (2012). Global Positioning System History [website]. Accessed March 2018. https://www.nasa.gov/directorates/heo/scan/communications/policy/GPS_History.html.
NovAtel, (2015). *An Introduction to GNSS*, Chapter 3 – *Satellite Systems*

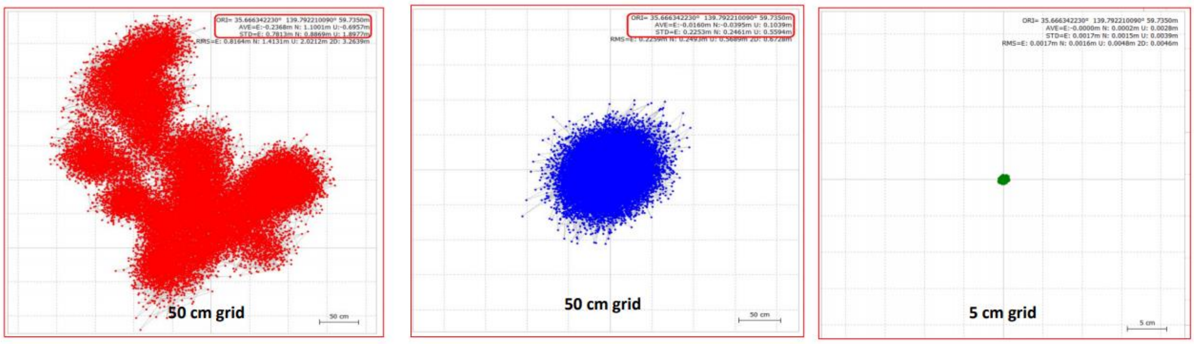
[111] U.S. Air Force, National Coordination Office for Space-Based Positioning, Navigation, and Timing, GPS.gov, Governance, Program Funding [website]. Accessed April 2018. https://www.gps.gov/policy/funding/.

GLONASS is the Russian counterpart to GPS, operated by the Russian Space Forces. The constellation was declared operational in 1996, but due to poor maintenance it started to degrade, so that by the end of 2011 only seven satellites out of the 24 previously launched were functional. However today, as a result of stronger financial and political support, the network offers 24 active satellites. Use for civilian purposes was opened in 1999.[112] BeiDou is the Chinese GNSS infrastructure. It became operational in December 2012, making China the third nation in the world to have its own system. However, its coverage is in the Asia Pacific region only, compared to GPS and GLONASS, which have a global coverage. The operations leading to global coverage are expected to be completed by 2020.[113] Besides the three aforementioned systems, there are a few under construction, such as the European Galileo (already partially operational and expected to be finished in 2020), the Indian Regional Navigation Satellite System (IRNSS) and the Japanese Quasi-Zenith Satellite System (QZSS).

Third, it is possible to use differential techniques. The idea is that two receivers close to one another should experience the same errors more or less (apart from the receiver noise). If the location of one receiver (the base station) is precisely known, one can compare it with the position calculated using GNSS, compute the differential and use this as a correction factor for the receiver whose location is unknown (the rover). The integrated system is often referred to as Differential Global Navigation System (DGNSS). The information about the correction factor either can be sent to the receiver though satellites (Satellite Based Augmentation System) or through terrestrial radio messages (Ground Based Augmentation System).

Moreover, there are also more advanced techniques that can provide even more accuracy, such as Real Time Kinematic (RTK) and Precise Point Positioning (PPP), which can reach accuracy levels in the order of 1 cm and 3 cm respectively. [114]

Figure 21 Accuracy of GNSS technologies



SPP (Single Point Position) DGPS (Differential GPS) RTK (Real Time Kinematic)

Source: Center for Spatial Information Science, The University of Tokyo

[112] Deployment of the GLONASS constellation [website]. Accessed April 2018. http://www.russianspaceweb.com/glonass_deployment.html.
NovAtel, (2015). An Introduction to GNSS, Chapter 3 – Satellite Systems.

[113] NovAtel, (2015). *An Introduction to GNSS*, Chapter 3 – *Satellite Systems.*

[114] NovAtel, (2015). *An Introduction to GNSS*, Chapter 5 – *Resolving Errors.*

Not surprisingly, there is a trade-off between accuracy and price of GNSS receivers[115]. Nevertheless, we are already witnessing a significant reduction in prices on the market, a reduction that is expected to unfold even more in the next years. Consider for example dual frequency receivers, which traditionally cost around US$5000. Companies such as SwiftNav now offer them for around US$600 and ABI Research estimates that by 2021 the price will drop to US$50. The Polish start-up ChipCraft is working hard with the objective of offering a multi-constellation dual-frequency system with an integrated antenna for US$10.[116]

The enhancements in accuracy and the reduction in costs are two aspects of the GNSS market that appear to be quite promising in extending even further the plethora of space-enabled commercial opportunities, which already include[117]:

- <u>SURVEYING AND MAPPING:</u>

As we have seen, Earth Observation techniques are used in surveying and in the creation of maps. However, in order to be have a geometrically correct representation, one may need to record the position of some fixed points in the images acquired. Moreover, the large diffusion of GNSS enabled devices allows users to participate in the creation of maps, a process some call the *democratization of digital mapping*, for which knowing users' location is essential.

Of course, this brings benefits to a number of fields, such a mining, urban planning, agriculture or cadastral surveying for example.

- <u>NAVIGATION AND ROUTE PLANNING:</u>

Navigation is the field of study that focuses on the process of monitoring and controlling the movement from one place to another. It is not enough to know our own position, we need to know the position of the place we intend to travel to and the possible ways to reach it, made possible by maps. This can be used for route planning for pedestrians, road (e.g. cars, bicycles, trucks, etc.), air, rail and maritime vehicles.

- <u>ROAD MOBILITY:</u>

Navigation profoundly changed the way drivers of different vehicles can move from one place to another. The most immediate benefit is the possibility of having access to reliable and updated directions in real time. The real time dimension is a crucial aspect what would not have been possible without the advent of GNSS. When this process is integrated with other technologies, benefits in terms of time saving, safety, efficiency and environmental impact can be huge. For example, by monitoring real time traffic conditions on the road (e.g. by combing data on position and speed of users collected in conjunction with Earth Observation techniques and/or other devices) rerouting of vehicles is made

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[115] Busswell G., Green N. and Postema R., (2010). *Downstream Applications and Services of Earth Observation, Satellite Navigation and Telecommunication*. Logica.

[116] Mellon C. and Graglia M., (2017). The Price of Precision: How Autonomous Vehicles Will Drive Down the Cost of Dual-Frequency Satellite Receivers. New America [website]. https://www.newamerica.org/international-security/future-property-rights/blog/price-precision-dual-frequency/.

[117] notice that given the multidimensional nature of the classification, the classes described are not meant to be mutually exclusive, rather they often complement each other for the supply of products and services to final consumers.

possible, hence reducing travel time, fuel consumption, the risk for incidents and emissions. Also, users can update in real time events such as accidents and road closures to enhance the service. User provided information combined with street-view techniques can also help to anticipate street signs and other authorities' directions that might otherwise have been discovered too late for efficient route planning. In their 2010 study, Ganti et al. found that taking the "greenest route" resulted in 10% saving on fuel consumption (conservative estimate)[118].

Such a knowledge can also be exploited by public authorities for more efficient urban planning (e.g. when planning the construction of new streets or additional lanes or when setting traffic lights or street signs) and for support in road enforcement (e.g. fines, spots where to set speed cameras, tolls, etc.).

- AIR MOBILITY:

First, we find the optimization of enroute flight. If road route planning suffers from the physical limitations imposed by existing infrastructure (i.e. one can usually not drive though a building or a lake), aeroplanes do not. Once again, Earth Observation techniques can help in monitoring factors such as winds and weather conditions that can be taken into account when computing the best route. This process can take three different forms: flexible track systems, user-preferred routes (UPR) and dynamic airborne reroute procedure (DARP). In the first case the optimal route is computed once and updated seasonally; the second case is similar to the first one, but the computation is made on a single flight basis. DARP instead sees the optimization during the flight, making use of Earth Observation for updates on wind and weather conditions and subsequently of GNSS for navigation.[119]

Second, GNSS can assist in departure and landing, both for navigation within the airport and for designing the optimal paths.

Third, GNSS allows aeroplanes to report their position to air traffic controllers on the ground and to other aeroplanes, via a technology called Automatic Dependent Surveillance – Broadcast (ADS-B).

Fourth, GNSS enables infringement alarms, notifying the pilot if getting too close to restricted areas.

- MARITIME MOBILITY:

GNSS technology can be applied to maritime (inclusive of both sea and inner waterways) mobility as well. GNSS enabled positioning helps ships to navigate, and, as is the case for road and air mobility, it can be used for route planning to improve efficiency and safety and to save time and fuel. In particular, integration with Earth Observation can contribute in the estimation and forecast of winds, waves, currents and propelling. The latter is by far the first responsible among meteorological factors to cause increased consumption of fuel (around 80% of additional fuel usage is generated by propelling)[120].

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[118] Ganti R,K., Pham N., Ahmadi H., Nangia S. and Abdelzaher T. F., (2010). *GreenGPS: A Participatory Sensing Fuel-Efficient Maps Application*. Proceedings of the 8th International Conference on Mobile Systems, Applications, and Services. New York: Association for Computing Machinery.

[119] Enge P., Enge N., Walter T. and Eldredge L., (2014). *Aviation Benefits from Satellite Navigation*. Original Paper, Mary Ann Liebert.

[120] Riva F., unknown date of publication. *GNSS applications for the maritime navigation*.

Moreover, GNSS allows vessels to report their position for safety, security and traffic control purposes thanks to systems such as the Automatic Identification System (AIS) and the Long-Range Identification and Tracking, which may be legally mandatory depending on the type of vessel.

Finally, GNSS is a key enabler of functionality in systems for port operations, such as transit progress, docking and loading and unloading operations.

- RAIL MOBILITY:

Knowing the position of a train is essential for the safety of passengers and workers and for an efficient use of the infrastructure. Traditionally, a train position is determined using hardware that is installed as part of the railway infrastructure along the tracks, which is costly to install and to maintain. GNSS technology is more cost efficient, provides the desired level of accuracy and can be more reliable, as it is less subject to breakdowns.[121]

This allows train drivers and controllers to operate trains and learn about the position of other trains on the same tracks, so as to optimize operations, especially in high traffic areas.

Besides that, GNSS technology can be used for more accurate scheduling and to give passengers and other users information about the location of the train and expected time of arrival.

- PEDESTRIAN AND URBAN PUBLIC TRANSPORT:

GNSS enabled navigation for pedestrian use presents some peculiarities. First, either for physical or legal/administrative reasons pedestrians can walk where vehicles cannot access and vice versa. Creating the need to provide navigation instructions specific to pedestrians, which also requires the construction of specific maps (e.g. pathways and alleys in a park might be included as well).

A second peculiarity is that, especially in urban settings, pedestrian movement takes place indoors or in places where the surrounding environment (e.g. construction or vegetation) limit or even block GNSS satellite signals (light indoor environments). The integration of GNSS with other technology can help alleviate this problem. Assisted Global Positioning System (A-GPS) can improve the performance of devices connected to a cellular network by combining data from satellites and the cellular network, while inertial micro-electromechanical systems (inertial MEMS) utilize sensors to be placed on the human body to better understand a person’s movements. The advent of Galileo is also expected to bring about significant improvements in the availability and accuracy of GNSS signal in the urban context[122].

Moreover, as for railway transportation, GNSS can be used to provide users with information about the location and the expected waiting time, and time of arrival of city public transportation (e.g. buses or trams). Service providers can also monitor the location, route and speed of their vehicles in order to optimize lines and scheduling.

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[121] GSA, (2017). *GNSS for RAIL 2017* [video]. Accessed April 2018. Available at: https://www.youtube.com/watch?v=8qEsMlujCC4.

[122] Hunaiti Z., Rahman A., Denideni M. and Balachandran W., (2006). *The Impact of Galileo on Pedestrians Navigation Systems*, 16th International Conference on Electronics, Communications and Computers (CONIELECOMP'06).

Finally, it possible to combine pedestrian navigation with the information about public transport services with the view of an increasingly integrated system that can provide users with information on the most efficient way to reach a place, or the time they need to depart in order to arrive on time.

- TAXIS AND CAR SHARING:

GNSS is also used to track taxis so that when customers require a ride they can be informed about the waiting time. Moreover, the taxi company can keep track of its vehicles.

City car sharing is increasingly popular, as the relatively newly introduced sharing economy paradigm confirms its role in the market. GNSS enables firms to track their cars and follow the route of their customers, so they can charge the correct fare and to ensure the car is not driven outside a predetermined geographical area.

- UNMANNED VEHICLES:

GNSS technologies can be exploited for positioning and navigation of autonomous vehicles, of course combined with other complex technologies, which are beyond the scope of this paper. This includes Unmanned Ground Vehicles (UGVs), Unmanned Aerial Vehicles (UAVs), Unmanned Surface Vehicles (USVs) and Unmanned Underwater Vehicles (UUVs).

- LOGISTICS:

Logistic activities can benefit hugely from GNSS technology. Indeed, as we have just seen, it can be used to design optimal routes for the means of transport of goods, to track their way and even for shipments via unmanned vehicles.

Besides tracking the entire vehicle, it is also possible to track individual containers using GNSS receivers installed directly in the container which then transmit their location to learn about the container’s current position, its route, how long it remained in a place and any unauthorized movement. When accurate enough, these are also able to notify any opening and closing of the container’s door.

In addition, shipment companies can keep their customers updated on the status of the shipment by allowing them to access such information or by sending notifications.

- AGRICULTURE:

The discussion on the applications of Earth Observation techniques to agriculture in the previous subsection should already have given the reader a sense of the important role the space can play in supporting the development of smart precision agriculture. GNSS technology is a critical enabler of functionality in this market too, with a wide array of applications. However, in the vast majority of cases, GNSS technology alone is not sufficient and the integration with other technologies is fundamental. The combination of GNSS and Earth Observation in particular can turn out to be extremely fruitful in the new paradigm that sees the figure of the farmer less and less as a mere performer of operative tasks, but rather as a decision maker for both operational needs and strategic planning. Other non-space related technologies such as drones and grounds sensors complete the picture of an integrated system for the maximum informative capacity.

Examples include the measuring of areas and their perimeters, including agricultural fields (field definition). Monitoring spatial variability is a first step in implementing site-specific crop management. Precise information about position is crucial, making required accuracy at a sub-metre or at least metre level.

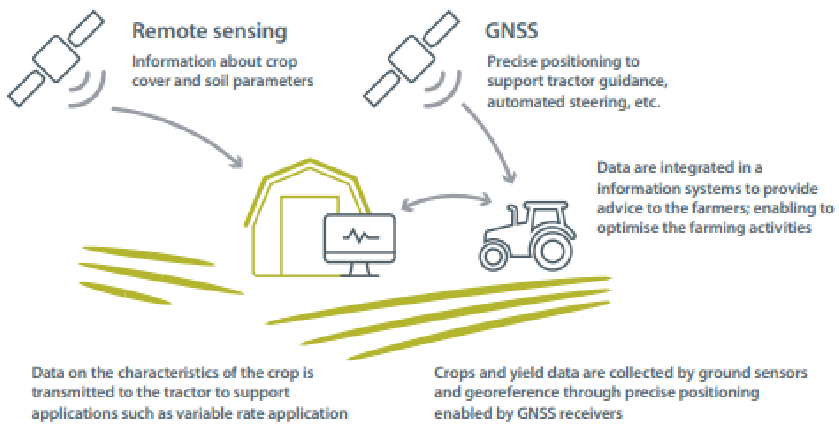
In addition, GNSS technologies can assist in the operation of machinery such as tractors. For instance, they can help the driver to follow the optimal path, hence minimizing costly overlaps (farm machinery guidance), or the driver could be completely replaced by automatic navigation supported by GNSS (automatic steering).

Moreover, GNSS helps in the precise planting of seeds and distribution of the right amounts of agrichemicals (e.g. pesticides) in the correct location in order to improve productivity, reduce costs and minimize the impact on the environment.

Finally, information about location can contribute in monitoring the spatial evolution of phenomena such as epidemics among plantation or parasites.

In addition, it is possible to track animals to know where they are, and when and where they move. For instance, one could learn where livestock grazes to understand its eating patterns.

Figure 22 Example of integrated system in agriculture



Source: GNSS Market Report, Issue 5, copyright © European GNSS Agency, 2017

- <u>MARKETING:</u>

Information about the location and movements of actual and potential customers, also combined with other data, can be exploited for more accurate profiling and targeting of consumers. For example, one could better understand shopping behaviours or send notifications with advertisement of nearby businesses.

- LOCATION BASED APPLETS:

The incorporation of GNSS technology in smartphones that support applets has led to the generation of a plethora of apps that rely on location, often in combination with other technologies, to offer their services.

The most immediate are apps that provide navigation services, such as the famous Google Maps or Baidu Maps. These apps typically do not limit themselves to giving directions to travel from one place to another, but rather offer access to a more complete system that provides information about places and transportation means (e.g. business hours, busy hours, reviews from other users, public transportation schedules, etc.).

Other examples include apps that allow users to save the location where they parked their car so to find it more easily, location based games, cameras that record the location a photo was taken in, social networks and instant messaging apps that allow users to share their position, dating apps that identify other users within a given distance or in a chosen area, tracking of other people and training apps (e.g. monitor track, compute distance run and average speed when jogging).

- SPORTS:

The applications of GNSS to sports are not limited to applets. For example, as part of its business incubation program, the European Space Agency supported the start-up Johan in the development of a device soccer players keep on during the game that, thanks to GNSS, measures their speed, distance, position and acceleration. At the end of the match, the data collected is uploaded to a dedicated internet platform. Players and coaches can then analyse the information available to improve performance.[123]

- INSURANCE:

Insurance institutions can benefit from GNSS too. For example, GNSS can help alleviate moral hazard in the car insurance market when agreements establish the payment of a premium based on the total distance driven in a given time period. By using GNSS, the insurance company can monitor the distance travelled by the insured to charge the correct premium.

As we have described, the applications related to Global Navigation Satellite System span an incredibly diverse range of activities. Many of them rely on the integration with Earth Observation, yet there are also other technologies that present key opportunities, when coupled with GNSS, in the future. These include:

- Internet of Things (IoT): the Internet of Things is a key companion to GNSS technology. Indeed, GNSS itself "simply" allows the receiver to learn its location with respect to a given coordinate system. Nevertheless, as we have seen, for full functionality of many services it is essential that the position of some objects is communicated to an integrated system. For example, in

[123] Space Foundation, (2016). *The Space Report 2016, The Authoritative Guide to Global Space Activity.*

car sharing services an available car needs to be able to communicate its position so that user can find it when searching for the closest vehicle to use. This service would not be possible without the integration of the two technologies;

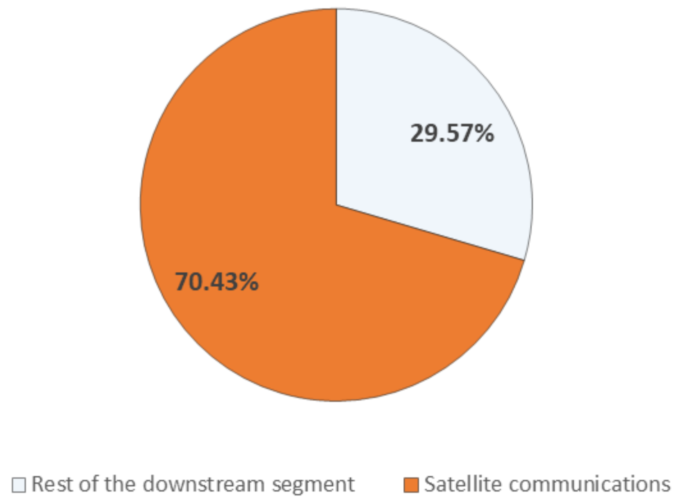
- Big data analytics: once again big data analytics is a major enabler of spaced-derived applications, as the volume of data collected is constantly on the increase. Without the capability to process it, the data is not meaningful and therefore it cannot be converted into valuable knowledge.

2.3.3 Satellite communications

Satellite communication refers to those activities that rely on satellites as a means of communication between two or more parties on Earth. This includes both one-way (e.g. broadcasting of entertainment content) or two-way/multi-way (e.g. voice or conference calls) communications.

According to the estimates provided by the Space Foundation in The Space Report, the downstream segment of the market for satellite communication was worth US$123.72 billion in 2016 in terms of turnover[124], essentially unchanged with respect to the US$123.86 billion figure[125]. This means that satellite communications enjoy a share of more than 70% of the overall size of the downstream segment. Satellite television is by far the major contributor to this category, having generated around US$97.7 billion of revenues in 2016, almost 79% of the overall turnover of this category.

Figure 23 Share of Satellite communications on the overall downstream segment, 2016

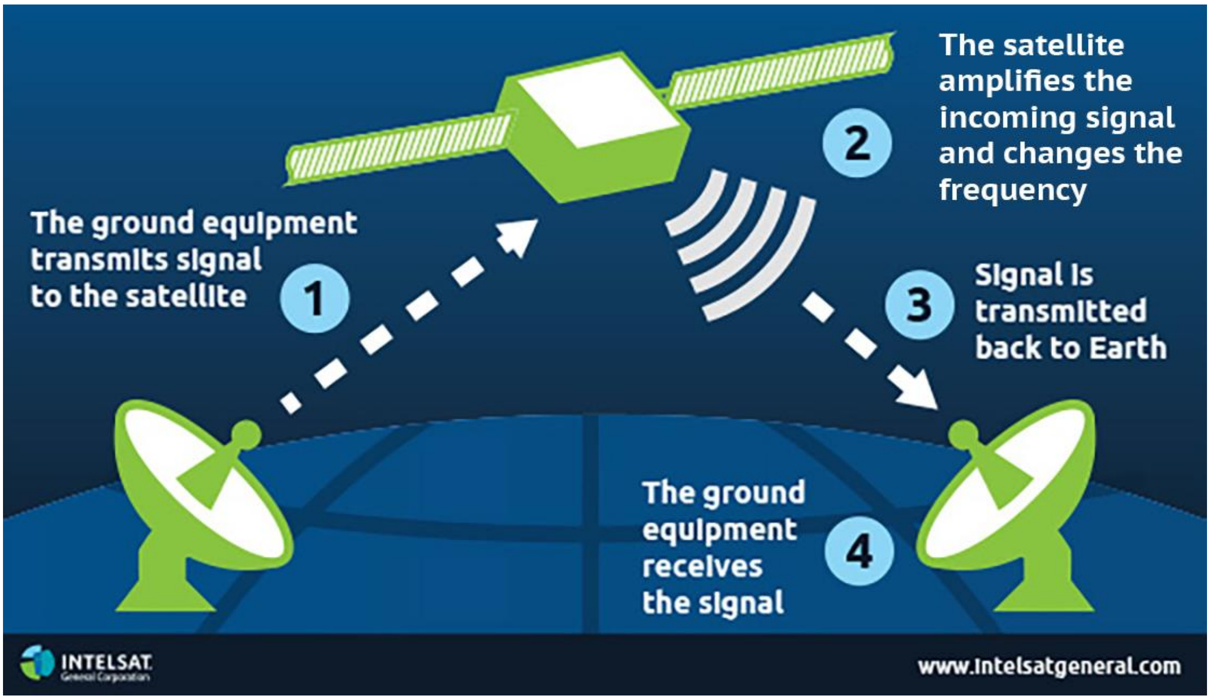


Source: Space Foundation

[124] Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*.
[125] Space Foundation, (2016). *The Space Report 2016, The Authoritative Guide to Global Space Activity*.

The basic functioning principle of satellite communication is illustrated in Figure 24.

Figure 24 Basic architecture of satellite communications network



Source: INTELSAT General Corporation

As can be seen in the picture, four main steps are involved. First, an earth station or other ground equipment, either fixed or in motion, transmits the data to the satellite using radio frequencies. This is called the uplink. Second, the satellite receives the signal, amplifies it and changes the frequency. Third, the satellite transmits the amplified and modified signal back to Earth. Finally, a second earth station or other ground equipment, either fixed or in motion, receives the signal.

Naturally, one satellite is not sufficient to manage all the traffic. Additional capacity can be obtained using several satellites on different bands, or by physically separating them apart from one another, so that the beamwidth of the antenna can distinguish between different satellites.

It is also possible to gather different signals into a main uplink transmission (e.g. multiple telephone calls or television signals). This is what typically happens, as this is significantly more efficient than having a large number of individual ground stations or other equipment.

The employment of satellites in communication activities presents various advantages, such as:

- wide coverage: while there are still areas of the world that are not reached by cellular signal, satellite systems cover particularly large areas and some of them, such as Iridium[126], have full global coverage (including the poles). This means that satellites enable communications in areas that would be extremely difficult to reach, such as oceans, the sky or remote areas, or where it would not be economically viable, such as sparsely populated areas, hence providing service to remote users and reliability to users who need to be sure they will be able to communicate wherever they are. Furthermore, this also allows use of the system internationally, without having to incur in roaming charges;

Figure 25 Australia 2G, 3G and 4G network coverage map

Source: OpenSignal

- flexibility: flexibility can have different connotations when referring to satellite communications. First, one could refer to spatial flexibility, meaning that even if the system is not designed to have full global coverage, it is always possible to change the areas covered, even if the satellites are already operational. Second, one could refer to flexibility as in terms

[126] Global Telesat Communications [webstite]. Accessed April 2018. https://www.globaltelesat.co.uk/coverage#tabscoverage1.

of content, i.e. the satellite infrastructure itself does not need changing if there are changes to the mix of service provided or upgrades to the radio network. Alternatively, one could refer to flexibility in how the satellite capacity is exploited, that is the possibility of modulating the capacity allocated to the different applications as needed. For example, in case of natural disasters, one could temporarily assign priority to rescue operations at the expense of other services. Another possibility, still underexplored, is that of storing content on the satellite to broadcast on-demand services, so to upload it in periods of less intense demand; [127]

- no limit in the number of receivers: downlink satellite reception is by its nature a non-rival good, since it can serve a potentially infinite number of users with no impact on the quality of the content broadcast, as long as they are within its reach[128];
- no need for investments in high cost ground infrastructure: building a new terrestrial network can be extremely expensive. Especially when the area considered is remote and sparsely populated the per capita costs can be prohibitive;
- network independence: in spite of the increasing integration of satellite and terrestrial systems, they remain autonomous with respect to one another in their functionality. This implies that if, for any reason such as natural disasters, terrorist attacks, hacking, political and governmental limitations, the terrestrial network is compromised, the satellite network can work as a back-up system.

However, it also presents some disadvantages, such as:

- latency: latency can be split into propagation delay and processing delay. Propagation delay is the time it takes a radio wave to travel the uplink to the satellite and then the downlink back to Earth. For satellites in geostationary orbit, considering that the radio waves travel at the speed of light, the propagation delay can be approximately a 239-278 millisecond interval. Of course, in two-way communications the total propagation delay estimate needs to be doubled. A possible solution is to use satellites in Low Earth Orbit, reducing the altitude of the satellite, the distance travelled by the signal and consequently the delay. This has been observed to vary between 4.3 and 7.8 milliseconds, depending on the altitude of the satellite[129]. However, satellites in these orbits do not maintain a fixed position in the sky relative to Earth. It follows that the signal has to be managed by other satellites once the previous one falls beyond direct view[130]. Processing delay is instead the delay caused by the time taken by each device the signal goes through to process it;

[127] Busswell G., Green N. and Postema R., (2010). *Downstream Applications and Services of Earth Observation, Satellite Navigation and Telecommunication*. Logica.
[128] European Satellite Operators Association, unknown date of publication. *Entering the Hybrid Age*.
[129] Berlocher G., (2009). Minimizing Latency in Satellite Networks. ViaSatellite [website]. Accessed April 2018. https://www.satellitetoday.com/telecom/2009/09/01/minimizing-latency-in-satellite-networks/.
[130] INTELSAT General Corporation, unknown date of publication. Satellite Basics [website]. Accessed April 2018. https://www.intelsatgeneral.com/satellite-basics/.

- limited speed: satellite-enabled connections have reached quite respectable speeds. For instance, Viasat announced they would reach 100 mgps in 2018 with Viasat-2[131], yet terrestrial technologies such as fibre still enjoy a significant advantage;
- specialized satellites terminals required: in order to be able to receive the signal from satellites, devices must be specifically designed for this purpose.

The features of satellite communication technology just seen make it suitable for a wide range of applications. These can virtually include any circumstance where there is a need for communication. However, empirical evidence shows satellites are often employed for communications purposes when terrestrial options are not viable, available or reliable, thus remaining a second or a back-up choice, yet still very frequent. The main reasons for this can be found in the limitations just seen and in the higher cost generally charged for satellite connections with respect to terrestrial ones. Moreover, notice that the recent trends show an increasing integration between satellite and terrestrial technology, rather than a fierce competition. The former can indeed be used as a link to the latter or they can coexist for improved reliability. Furthermore, the relationships with Earth Observation and GNSS are clear. As for Earth Observation, through the uplink the satellite receives information about what it should observe and through the downlink it transmits data back to Earth. This cannot be classified exactly as satellite communications given the definition we provided at the beginning of this subsection, as an element of elaboration and activity by the satellite itself is present, yet it is a relationship worth highlighting. As for GNSS, as we have seen in the previous subsection, many applications require that the location of the receiver is shared with other devices or becomes part of an integrated system. Of course, satellite communications can serve for this purpose. That being the premise, satellite communication has a direct application in:

- <u>BROADCASTING</u>:

Satellites can be used to broadcast content from service providers to the general public. According to the International Telecommunication Union (ITU) indeed, *broadcasting-satellite service* can be defined as "*A radiocommunication service in which signals transmitted or retransmitted by space stations are intended for direct reception by the general public*"[132]. We are hence referring to one-way communications, including television and radio. The wide spatial coverage advantage turns out to be useful in at least two situations. On one side, for live news stories and events occurring in places where there is no terrestrial reception as well. Consider for example a news reporter in an area hit by war where terrestrial infrastructure has been destroyed. Thanks to satellite communication technologies, it is possible to live broadcast these stories. On the other side, consumers located in areas with poor terrestrial signals can benefit from satellite wide coverage. However, even users with the possibility of connecting to a terrestrial network watch satellite television. In fact, satellite

Figure 26 Satellite dish

[131] Sheetz M., (2018). One of the few publicly traded space companies unveils its high-speed internet satellite network. CNBC [website]. Accessed April 2018. https://www.cnbc.com/2018/02/27/viasat-2-high-speed-internet-satellite-network-comes-online.html.

[132] International Telecommunication Union, (2016*). Radio regulations, Articles, Edition of 2016* – Article 1.39.

television providers have often developed additional and different content, thus inducing a separate demand. Moreover, the use of compression techniques such as the H.265/HEVC format allows for high quality audio and video. Furthermore, thanks to satellite television it is possible to access channels from all over the world, hence there are no longer geographical limitations. The main drawback is the need for a so-called *satellite dish*, which some users dislike[133] and which is costly to install.

- <u>SATELLITE PHONES:</u>

Probably the most immediate application of satellite communications, satellite phones allow users to make and receive voice and video calls and text messages and to connect to the internet. They can be extremely useful in remote areas where cellular networks are not available. Since they are designed to be used also in extreme conditions (e.g. deserts or glaciers), they are usually more resistant to shocks than ordinary cell phones (e.g. extreme temperatures, water, etc.). On the other hand, they are typically much more expensive. Naturally, the price depends substantially on the features of the phone, usually starting from US$600. Data use is also generally quite expensive when compared to traditional connections, with different options and plans offered by different network operators. Recently, adaptors for smartphones that enable the use of use satellite connections are appearing on the market. For example, the Thuraya SatSleeve is a satellite communication enabler to be placed at the back of a smartphone, to which then connects via Wi-Fi[134].

Figure 27 Thuraya SatSleeve

Source: Optus

Besides being used in circumstances where there is limited cellular reception, satellites phones are used in situations where there is a need for privacy and/or anonymity. For instance, to avoid wiretapping and censorship imposed by some governments. This led some countries such as Cuba to ban satellites phones[135].

Naturally, in order for a satellite phone to work properly, it is necessary that it can receive the satellite signal, which can become difficult if indoors. However antennas placed on rooftops, which then amplify the signal in the indoor environment, can be used to overcome this issue.

- <u>INTERNET ACCESS:</u>

Similarly to what happens for internet access using mobile phones, it is possible to use satellites to provide internet access to households and businesses. As we have already seen, high fixed costs of terrestrial infrastructure make it a non-economically viable option in sparsely populated areas. Digging

[133] Papathanassopoulos S., (2009). *Satellite Television*. The International Encyclopedia of Communication. Donsbach, Wolfgang (Ed). Blackwell Publishing.
[134] Thuraya [website]. Accessed May 2018. http://www.thuraya.com/satsleeve-plus.
[135] Visit Cuba [website]. Accessed May 2018. http://www.visitcuba.com/travel-guide/travel-tips/faqs/#9.

trenches and laying ducting to the door of each property costs more than US$53/m[136]. Satellites infrastructure has high fixed costs too, yet, thanks to the wide spatial coverage it allows, they are split on a larger number of users. Consider that approximately 46% of the world population used to live in rural areas in 2016 according to the World Bank estimates[137]. It is true that many governments around the world are working for the reduction of the so-called *digital divide*, often subsidizing the construction of terrestrial infrastructure, yet such a process can take a long time and not every area can be covered. Satellites can help close this gap. Moreover, as we already mentioned, satellite-enabled connections have reached quite satisfactory speeds.

The three aforementioned applications, internet access in particular, enable a plethora of derived applications. Examples include:

- <u>AVIATION:</u>

Traditionally, aeroplanes have been tracked using radar when flying over land or coastal areas, with flight paths being negotiated by radio. Yet, when flying over oceans and other remote areas, even High Frequency (HF) radio systems struggle to provide the same level of reliability that satellite communication systems can offer. The European Space Agency is currently developing IRIS, a satellite-based air–ground communication system for safer Air Traffic Management (ATM). The system is already partially operational and it is expected to be completed by 2028[138].

Figure 28 Aeroplane Satellite Antenna

Source: WLAN

The same issue arises for communication needs other than those of flight paths tracking and determination, such as the need to communicate medical emergencies or in-flight credit card sales on commercial flights. In fact, the traditional system that sees the connection to subsequent towers on the ground becomes unreliable in remote areas. Instead, satellite systems prove to be more reliable. It is sufficient to install an antenna on the top of the aircraft to connect to the satellite. Notice however that this increases drag and hence fuel consumption. Furthermore, it is also possible to offer passengers internet connectivity while flying: "*Over half of the world's aircraft will be equipped for in-flight Wi-Fi within the next six years. […]It is set to become a billion-dollar revenue sector by 2020*" claims Inmarsat[139].

[136] Agnelli S., (2016). *SATELLITE INTERNET Eutelsat – Future Ready?*. Eutelsat presentation 29th November 2016. Exchange rate: average spot inter-bank average spot inter-bank Euro-U.S. Dollar average exchange rate on the day of the presentation.

[137] The World Bank, *World Development Indicators database.*

[138] European Space Agency website, Our Activities, Telecommunications & Integrated Applications, Satellite Communications for Air Traffic Management (IRIS) [website]. Accessed May 2018. https://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/Satellite_Communication_for_Air_Traffic_Management_Iris.

[139] Plush H., (2017). *How does Wi-Fi work at 35,000 feet and why don't all airlines offer it?*. The Telegraph [website]. Accessed May 2018. https://www.telegraph.co.uk/travel/travel-truths/how-does-inflight-wi-fi-work/.

- MARITIME:

Similar to aircraft, vessels experience connectivity issues when navigating. Satellite systems provide solutions for those at sea, from recreational boaters to marine transport and fishing companies, needs reliable communication systems. Naturally, those need depend on the purpose of journey. Recreational boaters might need to able to communicate in case of emergency, but satellite systems can be used for providing internet access and telephony services on board ships or cruises, to receive weather and oceanographic updates and alerts for improved safety and more efficient fishing. Moreover, as we mentioned in the previous subsection, sharing one's vessel position might be legally mandatory depending on the type of vessel. Of course, satellite communication systems can serve this purpose as well.

- RAIL:

As in aviation and maritime, rail transport can also benefit from satellite communication systems to share trains' location, perhaps obtained using GNSS, and for on-board connectivity when travelling in remote areas.

- MACHINE-TO-MACHINE:

Machine-to-machine (M2M) applications encompass all those applications that exploit satellite communications to support automatic monitoring and control of remote assets. This includea a wide array of applications, such as communications for unmanned vehicles, security cameras, industrial processes and sensors for the monitoring of the environment, and gas and oil pipelines.

- DEFENCE:

Defence operations take place in all environments and the ability to communicate in a continuous, reliable and secure way, enabled by satellites, is an essential factor for the success of such operations.

- DISASTER MANAGEMENT:

Once again, space-enabled technologies prove to be extremely useful in disaster management operations. Indeed, as a consequence of the disaster, terrestrial infrastructure can be severely damaged, hence making communications unreliable, limited or even unavailable. However, these situations usually require continuous and up-to-date flows of information between staff, volunteers on the spot, affected population and external sources to better organize rescue activities. Moreover, even after the emergency is dealt with, it often takes a long time to repair old infrastructure or build new, so that satellites might represent the only option for the continuity of service.

- EDUCATION:

Satellite-enabled communications can be used to provide education services for students who live in remote areas both for distance learning (e.g. video lectures) and as means to provide connectivity to schools that would not otherwise have any. For example, Project iMlango is a project started in Kenya that aims to improve children school attendance and learning outcomes through high-speed satellite internet connectivity for individual e-learning, continuous training and support to teachers to use best practice to integrate ICT into schools' learning processes and Electronic attendance monitoring with digital semi-conditional payments to incentivise families to send their kids to school[140].

- HEALTH:

Satellite communication systems can prove themselves useful also in providing telemedicine services to patients who live in remote areas with limited access to healthcare facilities and to other means of connection. In fact, it is possible to allow these patients or other medical staff to interact with doctors from a distance for video or voice consultations, which might help in treatment of the patients or might identify that further investigation is required. Furthermore, it also possible to connect medical appliances that collect medical information and transmit the data directly to physicians.

- ELECTRONIC PAYMENTS:

According to the World Payments Report 2017 by Capgemini and BNP Paribas, in 2015 global non-cash, transactions hit 433.1 billion and they project high growth rates for this figure[141]. These type of transactions require connectivity to the respective systems and this could become an issue for some remote geographical areas. Satellite communications can help in connections to the payment system. Once again, the Indonesian experience provides an interesting example. Bank Rakyat Indonesia is one of the largest commercial banks in Indonesia and the country's largest lender by assets[142]. As its customer base is spread over a large number of islands terrestrial internet connection can be hard to establish. Therefore, the bank experienced problems in ensuring the success of transactions[143]. On 20th June 2016 Bank Rakyat Indonesia became the first bank in the world to own and operate a satellite: the BRIsat[144].

As we have seen in the beginning of this subsection, television broadcasting represents by far the major contributor to satellite communications. The recent trends observed in the demand for entertainment content might legitimately cast some doubts on the future of this market. Specifically, these trends see increased expectations in terms of:

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140 iMlango website – About – Our story [website]. Accessed May 2018. https://www.imlango.com/our-story/.

141 Capgemini and BNP Paribas, (2017). *World Payments Report 2017*.

142 Indonesia-Investments, Bank Rakyat Indonesia [website]. Accessed May 2018. https://www.indonesia-investments.com/business/indonesian-companies/bank-rakyat-indonesia/item209.

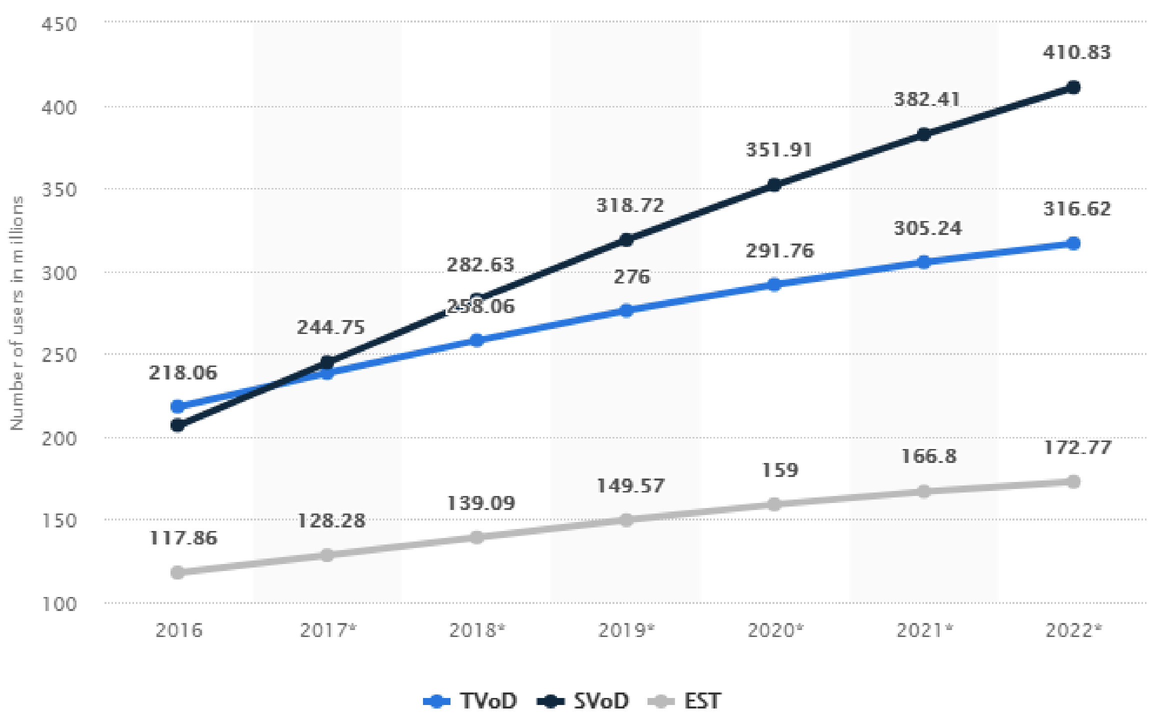
143 Space Foundation, (2017). *The Space Report 2017, The Authoritative Guide to Global Space Activity*.

144 Indonesia-Investments, Bank Rakyat Indonesia Finally Sees Launch of BRIsat [website]. Accessed May 2018. https://www.indonesia-investments.com/news/news-columns/bank-rakyat-indonesia-finally-sees-launch-of-brisat/item6940?searchstring=satellite.

- personalized choice of content: users expect to watch content of their choice to be chosen for a wide and quality catalogue;
- personalized timing: viewers expect to watch content whenever they want and to be able to pause or interrupt the video to resume watching when they choose to;
- ability to switch easily across devices: whether it is a television screen, a tablet, a computer or a smartphone, users expect to be able to watch content on any device of their choice and to be able to switch easily across these devices;
- smooth reproduction: users expect smooth reproduction of content, with fast buffering and no interruptions
- image and sound quality: viewers expect to able to watch content of their choice, at a time of their choice, on the device of their choice, with smooth reproduction and high image and sound quality.

The cumbersomeness in the last point should well conceive the idea of the increasing expectations of users. The question is therefore what role satellites can have in this new paradigm. Incumbents and new entrants on the market such as YouTube and Netflix are addressing these trends through the internet. Traditional television broadcasters are responding by making the content they broadcast on the so-called *linear television* available online *on demand* as well.

Figure 29 Number of digital video users worldwide, 2016-2022



Source: © Statista 2018

Figure 29 shows the number of digital video users worldwide in 2016 and projections up until 2022, segmented in Transactional-Video-on-Demand (TVoD) (also called Pay-per-View), Subscription-based-Video-on-Demand (SVoD) and Electronic-Sell-Through (EST) services. For their computations, Satista uses the following definitions[145]:

- TVoD: *time-limited access to premium video content that requires a usage-based one-time payment. Content includes movies, TV shows or series and can be downloaded or streamed to various devices for a pre-determined period of time. Top vendors of TVoD services are, for example, iTunes, Google Play or Amazon Instant Video*;
- SVoD: *Subscription-based-Video-on-Demand services, e.g. Netflix and Amazon Prime Instant Video, offer unlimited access to their content libraries for a monthly subscription-fee. Movies and TV series can be streamed to various supported connected devices. The SVoD market does not include ad-supported services, pay-per-view offerings or services that require a pay-TV subscription (e.g. HBO Go)*;
- EST: *premium digital video content that is purchased in a one-time transaction and is permanently accessible as a digital video file through cloud-based or offline storage. Top vendors of EST services are, for example, iTunes, Google Play or Amazon Instant Video*.

It is clear that these estimates support our claim. Yet, our original question on the role of satellites remains unanswered. More insight can perhaps be gained by looking at Table 6, showing estimated consumption of data for content delivery.

Table 6 Data consumption for content delivery through the internet, 2016-2021

	2016	2017	2018	2019	2020	2021	CAGR 2016–2021
By Geography (PB per Month)							
North America	17,696	24,545	32,795	42,976	53,141	63,519	38%
Asia Pacific	10,259	14,715	20,416	28,415	38,831	55,306	53%
Western Europe	7,155	9,869	13,035	17,049	21,750	27,760	40%
Central and Eastern Europe	1,589	2,257	3,025	4,093	5,565	7,650	50%
Latin America	1,245	1,799	2,453	3,226	4,414	6,569	52%
Middle East and Africa	396	702	1,168	1,877	3,092	4,848	84%
Total (PB per Month)							
CDN Internet traffic	38,340	53,888	72,893	97,636	126,793	165,651	44%

Source: Cisco VNI, 2017

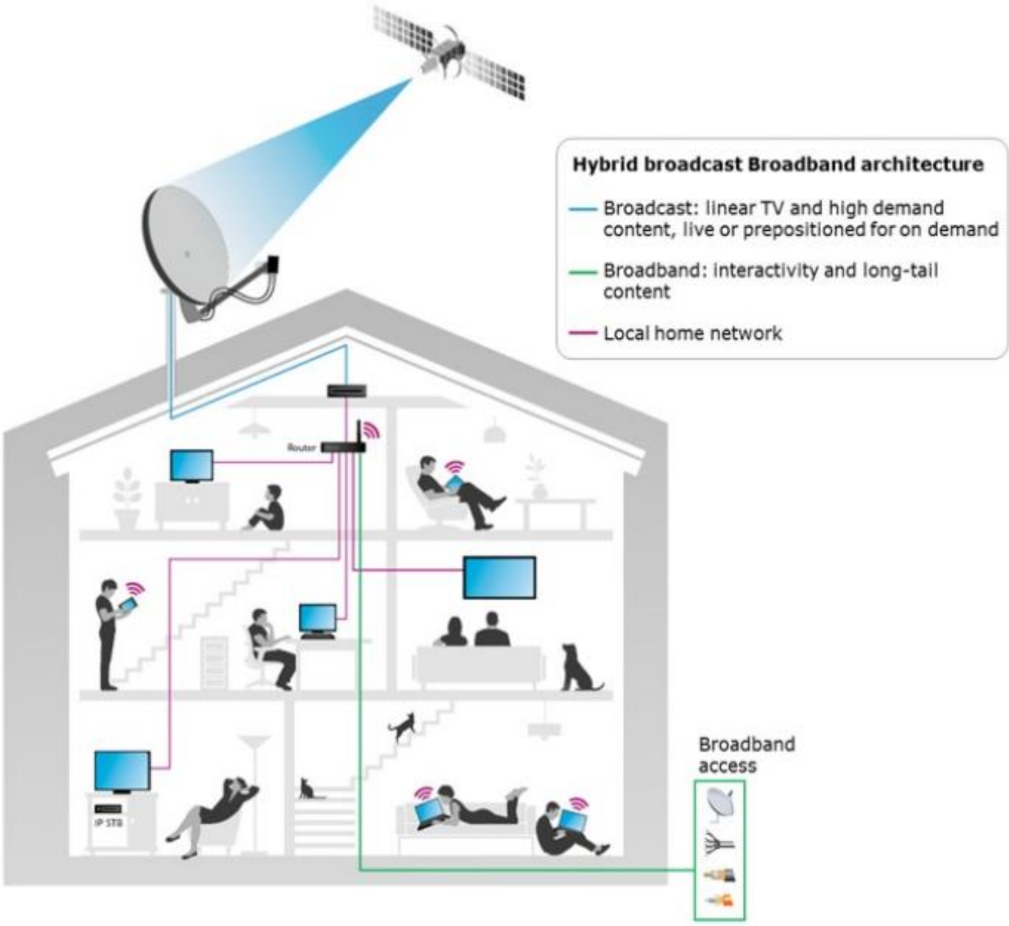
[145] Statista, (2018). Number of digital video users worldwide from 2016 to 2022, by type (in millions) – More information – Market definition [website]. Accessed May 2018. Restricted area.

Recall one petabyte is equal to one million gigabytes. We see that a compound annual growth rate of 44% is expected from 2016 to 2021 at a global level. There are noticeable differences in absolute values and growth rates depending on the geographical region. North America is already the largest consumer and is expected to remain so throughout the whole period considered, yet is the one with the lowest compound annual growth rate. Particularly interesting is the case of Middle East and Africa, with only 396 petabytes being consumed in 2016 and 4,848 petabytes estimated for 2021, a compound annual growth rate of 84%. The point hence becomes how it will be possible to provide such a large amount of data. With existing capacity, a large number of users would be left out[146]. The EMEA Satellite Operators Association estimates that in order to develop capacity to serve the entire market by 2020 using fibre, Europe alone would need to invest €150 billion. In addition to that, negative externalities of an all-streaming model on the environment are striking, given that one hour of standard definition streaming produces approximately 0.27 kilograms of equivalent carbon dioxide (CO_2e) from data centres and transmission activities only[147].

An at least partial solution to this problem proposed by the EMEA Satellite Operators Association can be found in an hybrid broadcast broadband system, that is *a solution that combines satellite for linear television and non-linear high-demand content, with terrestrial broadband for interactivity and long-tail catalogue, can deliver state-of-the-art High Definition quality TV and video content everywhere, including in geographical areas where fast broadband (viz. > 30 Mbit/sec) Internet connectivity remains limited or is unavailable*. The key idea is to locally store temporarily some content on users' devices transmitted at first via satellite broadcasting, following the observation that a significant share of content is consumed by viewers in a short timeframe (a few days). Hence, live TV and short/mid-tail on demand content would be delivered by satellite broadcasting, while long-tail on demand content by terrestrial infrastructure or using satellite-enabled internet access. [148]

[146] EMEA SATELLITE OPERATORS ASSOCIATION, (2015). *Will video break the Internet?*. Position Paper.
[147] Shehabi A., Walker B. and Masanet E., (2014). *The energy and greenhouse-gas implications of internet video streaming in the United States*. Environ. Res. Lett. 9 054007, IOP Institute of Physics Publishing.
[148] EMEA SATELLITE OPERATORS ASSOCIATION, (2015). *Will video break the Internet?*. Position Paper.

Figure 30 Hybrid broadcast Broadband architecture



Source: EMEA SATELLITE OPERATORS ASSOCIATION

3. THE SOUTH AUSTRALIAN ECOSYSTEM

As we have seen, the uses of space technologies for industry are manifold. However, as we highlighted in the previous section, especially for Earth Observation, on the demand side there is a lack of understanding, which causes potential customers to underestimate the benefits of investments in space-derived products and services. We believe there is a role for companies interested in operating in the downstream segment to overcome this obstacle by raising awareness and by providing user-friendly final products to customers - linking products to users.

In *A Study of the Economic Potential of the Local Space Sector*[149], E. Lazzari reports the following table, displaying the number of companies operating in Australia in 2016 for selected industries (according to the Australian Bureau of Statistics classification) that might benefit from the downstream segment.

Table 7 Number of organizations in selected industries, Australia 2016

Industry	**Number of organizations**
Agriculture, Forestry and Fishing	177,012
Mining	7,915
Electricity, Gas & Water Supply	6,306
Construction	358,466
Accommodation & Food Services	90,284
Transport, Postal and Warehousing	133,093
Information Media & Telecommunications	20,024
Financial & Insurance Services	193,489
Rental, Hiring and Real Estate Services	240,509
Public Administration & Safety	7,288
Education & Training	28,399
Health Care & Social Assistance	123,416
Arts & Recreation Services	26,418
TOTAL	**1,412,619**

Source: Australian Bureau of Statistics

One does not necessarily need to agree this is a good representation of the total number of organizations in Australia that operate in industries that might benefit from the downstream segment. Indeed the classification used is broad and there are other industries that might benefit from the downstream, as we have seen in the previous section. However, the key takeaway is unquestionable: there is a large number of firms in Australia that could be potential customers for space-derived products and services.

[149] Lazzari E., (2017). *A Study of the Economic Potential of the Local Space Sector*. South Australian Space Industry Centre.

At present, the Australian space economy is considered to be underdeveloped, and it represents a clear case of unfulfilled potential. In fact, the space industry in Australia contributes approximately only 0.8% to the global space economy, while Australia's share of the overall world economy is 1.8%.[150] This not only limits the space economy itself, but also makes it harder for businesses to access space technology.

Recognition of the need for action is emerging, such as the efforts for the establishment of an Australian Space Agency. In May 2018 the Australian Government announced that AU$41.0 million over four years from 2018-19 will be allocated to grow the Australian space industry. This includes funding of AU$26 million to establish the Australian Space Agency, which will set the national direction and coordinate domestic space activities for Australia. In addition, AU$15 million over three years from 2019-20 has been allocated to establish the International Space Investment project, which will provide grants to strategic space projects that generate employment and business opportunities for Australians. These resources are dedicated to partnering with international space agencies to enable Australian businesses to compete in the global space economy. The Commonwealth Government is also investing more than AU$260 million to develop world-leading core satellite infrastructure and technologies, including better GPS for Australian business and regional Australians and improved access to satellite imagery. This includes AU$160.9 million to deliver a Satellite-Based Augmentation System to improve the reliability and the accuracy of positioning data from five metres to 10 centimetres, across Australia and its maritime zone. AU$64 million is to be invested in the National Positioning Infrastructure Capability to complement Satellite-Based Augmentation System to improve GPS to an accuracy as precise as 3 centimetres in areas of Australia with access to mobile coverage. AU$36.9 million is for Digital Earth Australia, to provide governments, businesses, researchers and individuals with access, through the Digital Earth Australia program, to reliable standardized satellite data that identifies physical changes to the Australian environment.[151]

As for South Australia in particular, the South Australian Space Industry Centre (SASIC) provides a prominent platform for South Australia to promote and attract investment in the space industry in the state and to work closely with the recently announced Australian Space Agency. SASIC, with its clear industry engagement and focus, provides the foundation for an operational node of a National Space Agency in Adelaide. SASIC has developed the Space Innovation and Growth Strategy (South Australia): Action Plan 2016-2020, which details the State's vision through three pillars:

- grow South Australia's economy through space activity;
- invigorate South Australia's space innovation ecosystem by stimulating capabilities and expertise in South Australia and strengthening the commercialisation of research results in the space industry;
- engage international cooperation with lead countries by growing a network of strategic partnerships in the space sector

Part of the strategy includes strong networking between local stakeholders that gave rise to the South Australia Space Forum. This program is a series of biannual events that facilitates collaboration among participants in the South Australian space economy. The events aim to stimulate the South Australian space ecosystem by:

- encouraging the exchange of information and promoting the latest industry developments

[150] Lazzari E., (2017). *A Study of the Economic Potential of the Local Space Sector*. South Australian Space Industry Centre.
[151] CommsDay and the Australasia Satellite Forum, (2018). *Budget pledges $300m for satellite positioning, imaging, space investment*. Space and Satellite AU Newsletter. Decisive Publishing.

- showcasing South Australian capabilities to local and international investors
- assisting research organisations to identify industry needs and future areas of demand
- promoting commercial application of new research and technologies.

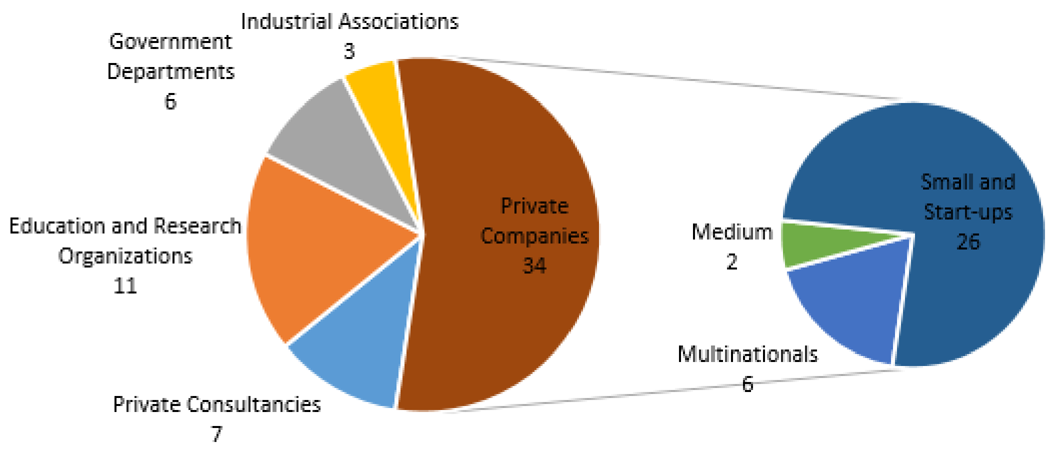
This engagement aims to promote collaboration and innovation between South Australia and members of the space industry around the globe to the mutual benefit of all parties.

Furthermore, SASIC established the South Australia Space Council, an expert panel of representatives from private companies, research organisations, universities and government who meet quarterly to inform the State Government's approach to growing the space economy.

The State Government has committed AU$4 million over 4 years to promote the development of the space industry in South Australia, specifically through the management of the Space Innovation Fund (SIF). The SIF is comprised of three distinct activities to support entrepreneurs and start-up founders: space scholarships, the Space Incubator Program and the Space Accelerator Program. These three programs work together to provide a pathway for post-graduate innovators and entrepreneurs to develop expertise and build knowledge in specialist space related fields of study (the Scholarships Program) to develop entrepreneurial ideas in order to bring them to market (provided by the Space Incubator Program), then seeking to rapidly develop their technology, build channels to market and pitch for investment by tapping into global networks of mentors, investors, and corporate partners (provided under the Space Accelerator Program).

SASIC has also published the South Australian Space Capability Directory, which identifies and maps the State's existing expertise and capabilities in space. The document highlights a vibrant local ecosystem, with more than sixty organisations active in the space economy. In section 1, we estimated that the South Australian space economy generates a turnover of approximately US$370 million a year, employing around 800 full-time equivalents.

Figure 31 Break-up of South Australian organizations active in the space economy



We now provide a brief overview of a sample of South Australian private companies that have developed capabilities related to the downstream and that are currently active in this segment. As a primary dataset, we use our South Australian Space Capability Directory. We also use the Space Industry Association of Australia (SIAA) Australian Space Capability Database, which contains information about private enterprises, consultancies, associations, research organisations, educational institutions and government departments in the whole country. We then integrate with information retrieved from companies' websites and from correspondence with some of the companies' representatives.

AEROMETREX

FIELD: EARTH OBSERVATION

HEADQUARTERS: 59 King William St, Kent Town SA 5067

COMPANY PROFILE:

Aerometrex is a mapping service company, expert in mapping from all types of imagery including satellite, large-format aerial, medium-format oblique aerial, and small-format UAV systems. The company also has LiDAR capability through its subsidiary company Atlass-Aerometrex in Queensland. Aerometrex is a sales agent for e-Geos satellite imagery including CosmoSkyMed radar satellite imagery and the full range of satellite imagery offered by Airbus-EADS.

APPLICATIONS:

They support the following applications:

- Corridor Mapping
- Engineering
- Mining Mapping
- Windfarm Mapping
- Environmental Mapping
- Disaster & Emergency Mapping
- Urban planning, property development, media and entertainment
- aero3Dpro

in fields such as Water & Environment, Infrastructure & Transport, Urban Planning and Energy & Mining. Examples of services specific to remote sensing include vegetation indexes, cut and fill volume analysis, change detection and line of sight analysis.

WEBSITE: aerometrex.com.au

AUSPACE

FIELD: SATELLITE COMMUNICATIONS

HEADQUARTERS: 27-31 London Road, Mile End South, SA 5031

COMPANY PROFILE:

Auspace is a systems integrator with a machine-to-machine communications specialisation, focused on delivering turnkey, bespoke solutions by enabling systems for the integrated management of lone workers, vehicle management systems, industrial infrastructure and assets. Auspace joined the Nova Group of companies in 2007 and in 2012 was re-purposed to focus on an in-service M2M specialisation

APPLICATIONS:

They support applications In-Field Service Management, Lone Worker Safety and Machine-to-Machine Communications. Examples of applications for the three aforementioned groups include:

In-Field Service Management:

- Driver behaviour
- Fatigue management
- In cab feedback
- Bespoke sensor and authentication integration
- Visualisation, reporting and analytics
- Decision support
- Enterprise integration
- Journey management

Lone Worker Safety:

- Duress notification
- Man down alarm
- Welfare and status reporting
- Location tracking
- Emergency management

Machine-to-Machine Communications:

- Asset and attribute monitoring
- Asset control
- Data collection
- Decision support
- Enterprise integration

WEBSITE: auspace.com.au

FLEET SPACE TECHNOLOGIES

FIELD: SATELLITE COMMUNICATIONS

HEADQUARTERS: 8A Myer Court, Beverley SA 5009

COMPANY PROFILE:

Fleet is an agile space company making it faster, simpler and cheaper to connect the world's Internet of Things devices, connecting the IoT around the world using a massive fleet of small low-cost satellites. They currently rely on the Iridium and Inmarsat networks, but they reported that by 2020 they would develop their own one hundred satellite network that will allow to connect over a billion devices every day, anywhere on the planet.

APPLICATIONS:

Fleet provides direct, global access to a secure low-cost low-bandwidth connectivity platform ideal for machine-to-machine data exchange and deploying IoT sensor networks at scale. They developed a software specifically designed to reduce satellite connection costs that works by selecting only necessary data and by compressing it before sending it over the satellite. Nano Compression combined with their Selective Analytics platform can reduce the amount of data sent over satellite by over 80%.

Moreover, starting from September 2018 the so-call *Portal* will be available. This is made of an Edge Server, a LoRaWAN gateway, a satellite modem and an antenna and it will enable users to deploy up to a hundred sensors within a 15 kilometres range.

Applications span the whole range of machine-to-machine activities that require connectivity in remote areas, yet they are particularly suited for agriculture, logistics, resources and environment.

WEBSITE: fleet.space

GEOPLEX

FIELD: EARTH OBSERVATION

HEADQUARTERS: Adelaide office: 27-31 London Road, Mile End South SA 5031 (other offices in Melbourne, Canberra, Sydney)

COMPANY PROFILE:

Part of the Nova Group since 2016, Geoplex specialises in the delivery of Enterprise geographic information system solutions and professional services. This includes the sale of geospatial data collected using satellites, via partners such as Planet Labs (Earth Observation imagery) and Spire (Satellite - Automatic Identification Systems maritime tracking). Geoplex also collaborates with the U.S. software company AGI to offer the physics modelling software Systems Tool Kit in Australia. This allows engineers and scientists to perform complex analysis of ground, sea, air, and space assets, and share results in one integrated solution.

APPLICATIONS:

Geoplex has significant expertise in analysing, interpreting and presenting a wide range of geospatial data through a variety of mediums. They design and implement conceptual models for geospatial analysis requirements to provide greater insight into data using visualisation techniques and technologies.

Applications in defence, security and intelligence have proven to be of particularly successful. However, they do not limit their activities to these fields. For example, solutions in agriculture and business intelligence have been developed as well.

WEBSITE: geoplex.com.au

GREENHOUSE GAS MONITOR AUSTRALIA

FIELD: EARTH OBSERVATION

HEADQUARTERS: 23 Stanley St, Leabrook SA 5068

COMPANY PROFILE:

Greenhouse Gas Monitor Australia Pty Ltd (GGMA) spawned from the Advanced Instrumentation Technology Centre (AITC) at Australian National University. It was formed to develop and commercialise state-of-the-art capabilities to measure, monitor and understand the behaviour of greenhouse gases in the atmosphere. GGMA's main activities focus on the development and commercialisation of novel instrumentation and methods to measure CO2 and CH4 in the atmosphere, supported by field measurements, on the development atmospheric models to attribute measurements of GHGs to sources and sinks and predict the transport of GHGs in the atmosphere and on the provision of GHG data products to industry, legislators, traders, and to the agricultural community through interpretation of Earth-based and space-based sensors.

APPLICATIONS:

Applications include better monitoring and management of the roles of agriculture, forestation and deforestation as CO2 sources and sinks, more reliable weather forecasts and more sensitive detection of climate change.

WEBSITE: rsaa.anu.edu.au/research/established-projects/greenhouse-gas-monitor

INOVOR TECHNOLOGIES

FIELD: REMOTE SENSING and EARTH OBSERVATION

HEADQUARTERS: 10 Pulteney Street, Adelaide, South Australia

COMPANY PROFILE:

Inovor Technologies builds small satellites, providing a full development service from customer needs to requirements, through design, build, integrate and test. They provide a turnkey solution for commercial, government and research clients wanting a payload flown in space. Using their novel satellite platform technology, they manufacture spacecraft for several applications.

APPLICATIONS:

Partnered with a defence prime and the University of Adelaide, Inovor has developed a nanosatellite-based space situational awareness system to monitor defence and commercial space assets from both accidental and malicious threats. Inovor is also supporting the development of a ground-based data fusion system, using multiple ground and space-based sensors, to maintain a space object catalogue

Relative to the applications we saw in Section 2, they report working on a hyperspectral AgTech application, using small satellite based remote sensing and Earth imaging data to support agriculture.

WEBSITE: inovor.com.au

IRRISCAN

FIELD: EARTH OBSERVATION

HEADQUARTERS: c/- Tennant Schulz 191 Fullarton Road, Dulwich SA 5065

COMPANY PROFILE:

Irriscan is an Adelaide based company jointly held by Australian interests with Italian investment and technical foundations provided by Ariespace, a spinoff company of University of Naples Federico II. Using satellite based information and regional meteorological data, the company has been established to deliver user-friendly and cost-effective analysis of crop development or landscape condition on a regular in-season basis.

APPLICATIONS:

Applications concern primarily agriculture and water supply, including:

- guided irrigation delivery and management of other inputs and sensors
- study of variation between and across blocks/fields to direct scouting for:
  - pest and disease issues
  - maturity assessment
  - weed or other stress
- support landscape and natural resource management

These are carried out thanks to the acquisition of images using Earth Observation techniques at high spatial and temporal resolution, combined with weather data, hence allowing for

- high resolution map classification, multi-date, multi-resolution image segmentation approach to estimate land-cover classification maps
- spatial processes analysis and land monitoring
- detection of forest extension and degradation, modelling forest biomass and its change

Results are made easily accessible to customers via a user-friendly interface system accessible directly from the website.

It was worth noticing that this approach may also be applied to larger scale landscape and sports-field irrigation and to monitoring natural resource assets across seasons

WEBSITE: irriscanaustralia.com.au

MYRIOTA

FIELD: SATELLITE COMMUNICATIONS

HEADQUARTERS: 25 Chesser St, Adelaide SA 5000

COMPANY PROFILE:

The company was born out of The University of South Australia's Global Sensor Network research program. Commencing in 2011, this three-year, AUD 12 M program was led by Myriota Founders, Dr Alex Grant and Dr David Haley, at UniSA's Institute for Telecommunications Research. Its mussion is to provide access to high value small data in remote locations at low cost.

APPLICATIONS:

Myriota's focus is on creating small, self-contained modules to connect things to the internet via satellite low prices, typically for low data applications. Myriota is making the internet of things an economic reality for a whole new range of industries and devices. Main applications include:

- resource sector asset monitoring (e.g. minerals, oil and gas)
- pumping assets (e.g. irrigation) monitoring
- horticulture monitoring
- livestock monitoring
- rain measurement

WEBSITE: myriota.com

SMALL WORLD COMMUNICATIONS

FIELD: SATELLITE COMMUNICATIONS

HEADQUARTERS: 6 First Avenue, Payneham South SA 5070

COMPANY PROFILE:

Small World Communications specialises in the design of error control encoders and decoders used in digital communications. Error control codes are used to correct errors caused by noise, interference and signal distortion. Its products consist of software cores that are used in field programmable logic arrays and application specific integrated circuits. Many of its products are designed for and used in satellite and deep space communication systems. These include encoders and decoders that are compatible with the Consultive Committee for Space Data Systems, GEO-Mobile Radio, Inmarsat and Intelsat standards as well as custom coding solutions.

APPLICATIONS:

Relative to the applications we saw in Section 2, Small World Communication's products are used in mobile phones, as well as being used in satellites and ground stations.

WEBSITE: sworld.com.au

CONCLUSION

The global space economy was worth more than US$329 billion in 2016 and it is expected to hit US$2.7 trillion by 2045. Such a huge growth is to be attributed to Space 2.0, a new paradigm that sees cheaper and faster production and launch of satellites, increasingly smaller and capable of overcoming the traditional trade-off between size and functionality thanks to enhancements in integration and miniaturization techniques. Space 2.0 also describes a new acceptance of risk on the demand side, available to invest in satellites with a shorter expected lifecycle but cheaper. This means that space is progressively becoming a more and more accessible and affordable business environment for a larger number of actors.

As governments do not represent the main investors in space technologies anymore, it follows that this expansion of the space economy must be the result of market forces. In particular, we identified the downstream segment as a main driver. Indeed, the downstream segment can benefit greatly from the lower access costs to improvements in the upstream brought about by Space 2.0, such as higher accuracy and resolution, as well as from the concurrent advancements in technologies such as big data, artificial intelligence and the Internet of Things, providing the terrestrial economy with an array of applications for final users and for businesses to improve efficiency, productivity and decision making processes. In fact, a plethora of space-derived applications which were not economically viable or even possible before can now represent the answer to a variety of issues, making space even more pervasive of our everyday life. Agriculture, disaster management, insurance, transports, logistics and business intelligence are but a few examples of the many applications we analysed in detail.

As appealing as space-derived applications might appear, there is still a lack of understanding of their potential benefits, especially by those firms that belong to industries traditionally considered completely extraneous to space. Hence, we believe that for a further sustainable development of the space economy, operators involved in the downstream segment need to raise awareness on the importance of space technologies and provide high quality, affordable and user-friendly services. Downstream companies need to explain the benefits of space technologies to farmers, insurers, couriers and others potential users and to provide them with easy-to-adopt and affordable solution specific to their businesses.

Once this gap is filled, businesses will be able to take full advantage of the many opportunities space has to offer, thus stimulating the downstream segment to expand and improve its range of products and services and its understanding of the market. In turn, this will prompt demand and investments in the upstream segment, which will in turn result in further investments and enhancements of space technology, thus establishing a virtuous circle and perhaps producing new disruptive technologies that might open the way to a whole new set of applications we cannot even imagine today.

LIST OF ABBREVIATIONS

ADS-B	Automatic Dependent Surveillance – Broadcast
A-GPS	Assisted Global Positioning System
AIS	Automatic Identification System
AITC	Advanced Instrumentation Technology Centre
ATM	Air Traffic Management
BDS	BeiDou Navigation Satellite System
COTS	Commercial off the shelf
DARP	Dynamic Airborne Reroute Procedure
DGNSS	Differential Global Navigation System
ESA	European Space Association
EST	Electronic-Sell-Through
FAI	Fédération Aéronautique Internationale
fAPAR	fraction of Absorbed Photosynthetically Active Radiation
GDS	Ground Sample Distance
GEO	Geostationary Earth Orbit
GGMA	Greenhouse Gas Monitor Australia Pty Ltd
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSA	European Global Navigation Satellite Systems Agency
IoT	Internet of Things
IRNSS	Indian Regional Navigation Satellite System
ITU	International Telecommunication Union
LEO	Low Earth Orbit
LRIT	Long-Range Identification and Tracking
LWIR	Long-Wave Infrared
M2M	Machine-to-machine
MEMS	Micro-electromechanical system
MWIR	Middle-Wave Infrared
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NIIRS	National Imagery Interpretability Rating Scales
PPP	Precise Point Positioning
QZSS	Japanese Quasi-Zenith Satellite System
RTK	Real Time Kinematic
SASIC	South Australian Space Industry Centre
SIAA	Space Industry Association of Australia
SIF	Space Innovation Fund
SVoD	Subscription-based-Video-on-Demand
TEMIS	Tropospheric Emission Monitoring Internet Service
TVoD	Transactional-Video-on-Demand
UAV	Unmanned Aerial Vehicles
UGV	Unmanned Ground Vehicle
UNOOSA	United Nations Office for Outer Space Affairs
UPR	User Preferred Route
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
VPI	Vegetation Productivity Indicator

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