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**THESIS**

# Greece: Space capabilities, needs and way forward


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**ΑΘΗΝΑ**

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# ABSTRACT

The space domain is rapidly evolving, presenting both challenges and opportunities for countries like Greece that aim to bolster their space capabilities. This thesis provides a comprehensive historical overview of Greece's space endeavors, offering valuable context to understand the current state of affairs and identify the imminent challenges and potential opportunities. An analysis of Greek national needs from space is then presented. The next chapter examines the present space capabilities of Greece, built so far to cover its needs, emphasizing both the public and private sectors, while concurrently pinpointing the country's current space programme implementations in the areas of Earth Observation, communications, navigation and more. Furthermore, the thesis delves into the potential of the on-board satellite high-performance data processing technology and how it can answer national needs. In conclusion, the thesis advocates for a forward-looking approach to Greece's involvement in the space arena. It underscores the imperative need for the formulation of a national space policy to provide strategic guidance for the development of space capabilities and the fulfillment of national space requirements.



**SUBJECT AREA:** The space sector in Greece

**KEYWORDS:** Space in Greece, Greek space capabilities, Hellenic Space Center, Greek needs from space, Greek space strategy, ESA member state, on board data processing, high-performance data processing

# ΠΕΡΙΛΗΨΗ

Ο τομέας του διαστήματος εξελίσσεται ραγδαία, παρουσιάζοντας προκλήσεις και ευκαιρίες για χώρες όπως η Ελλάδα που στοχεύουν στην ενίσχυση των διαστημικών τους δυνατοτήτων. Η παρούσα εργασία παρέχει μια ιστορική επισκόπηση των διαστημικών προσπαθειών της Ελλάδας, προσφέροντας ένα πλαίσιο για την κατανόηση της τρέχουσας κατάστασης και τον εντοπισμό των επικείμενων προκλήσεων και των πιθανών ευκαιριών. Στη συνέχεια παρουσιάζεται μία ανάλυση των ελληνικών εθνικών αναγκών από το διάστημα. Το επόμενο κεφάλαιο εξετάζει τις σημερινές διαστημικές δυνατότητες της Ελλάδας, οι οποίες έχουν αναπτυχθεί μέχρι στιγμής για να καλύψουν τις ανάγκες της, δίνοντας έμφαση τόσο στον δημόσιο όσο και στον ιδιωτικό τομέα, ενώ ταυτόχρονα εντοπίζονται οι τρέχουσες υλοποιήσεις του διαστημικού προγράμματος της χώρας που σχετίζονται με την παρατήρηση της Γης, την επικοινωνία, την πλοήγηση κ.α. Επιπλέον, η διπλωματική εργασία εμβαθύνει στις δυνατότητες της τεχνολογίας επεξεργασίας δεδομένων υψηλών επιδόσεων πάνω στους δορυφόρους και πώς η τεχνολογία αυτή μπορεί να απαντήσει σε εθνικές ανάγκες. Εν κατακλείδι, η διατριβή υποστηρίζει μια εμπροσθοβαρή προσέγγιση για την εμπλοκή της Ελλάδας στον διαστημικό στίβο. Υπογραμμίζει την επιτακτική ανάγκη για τη διαμόρφωση μιας εθνικής διαστημικής πολιτικής που θα παρέχει στρατηγική καθοδήγηση για την ανάπτυξη των διαστημικών δυνατοτήτων και την κάλυψη των εθνικών διαστημικών αναγκών.

**ΘΕΜΑΤΙΚΗ ΠΕΡΙΟΧΗ:** Ο τομέας του διαστήματος στην Ελλάδα

**ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ:** Διάστημα στην Ελλάδα, δυνατότητες της Ελλάδας στον διαστημικό τομέα, Ελληνικό Κέντρο Διαστήματος, ανάγκες της Ελλάδας από το διάστημα, ελληνική διαστημική στρατηγική, κράτος μέλος του Ε.Ο.Δ., επεξεργασία δεδομένων εν τροχιά, επεξεργασία δεδομένων υψηλής απόδοσης

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# PREFACE

The thesis titled “Greece: Space Capabilities, Needs and Way Forward”, was conducted in the context of the Interinstitutional postgraduate studies programme “Space Technologies, Applications and Services” (STAR), provided by the Informatics and Telecommunications Department of the National and Kapodistrian University of Athens.

It was carried out under academic supervision by the Associate Professor Alexandros Kolovos and as part of the research conducted for its materialization it also introduces elements of high-performance on-board data processing, relevant to the author’s work at OHB Hellas, the Greek subsidiary of the OHB SE group.

The purpose of this thesis is to accumulate knowledge related to the Greek Space Ecosystem, analyze the current status of Greece regarding the matters related to space and draw conclusions, contributing, even if modestly, to the development of space in the country.

# 1. INTRODUCTION AND HISTORICAL OVERVIEW

Greece has been involved in space activities for decades. These activities are characterized by a focus on services from space, answering military and governmental needs. The main domains of interest have traditionally been telecommunications and Earth Observation (EO). In recent years, there has been a spur of activities regarding developing the space sector in the country, culminating in the issuing of a competition regarding the design and deployment of a national satellite system in 2023.

To create a solid base for the analysis to follow in the next chapters, it is important to provide a historical context, describing the highlights of the country's earliest space history, regarding different aspects of the space domain and the initial space programmes implemented. It is highlighted that the description of the current space programme implementations will be provided in chapter 3.3.

## 1.1 Space Governance

Space governance refers to the laws, rules, norms and institutions that structure interactions in space, as well as mechanisms that are used to establish and enforce those. Greece's first official body regarding the space domain was the National Center for Space Research (Εθνικό Κέντρο Διαστημικών Ερευνών – Ε.Κ.Δ.Ε) which was founded in 1977 as part of the Hellenic Air Force [1]. Its role was to support national defense and economy through space. In 1981 the first digital image processing system was installed in the Center, which was used for processing Landsat images. In 1995 the Center was transformed, with its name changing into "National Center for Space Applications" (Εθνικό Κέντρο Διαστημικών Εφαρμογών) and its role shifting solely to support of national defense – and not economy. With its new form, the Center was responsible for updating the Hellenic National Defence General Staff and the other Branches for space activities related to Earth Observation, for supporting the operations of the Greek Armed Forces and other national bodies with the management of satellite imagery and for representing the country in satellite monitoring – related committees in the Western European Union, United Nations and NATO (North Atlantic Treaty Organization) [2]. Moreover, it introduced to the Council of Chiefs of Staff (Συμβούλιο Αρχηγών Γενικών Επιτελείων – ΣΑΓΕ) a space policy for national security in 1995, which was adopted by the Greek Ministry of Defence. The policy was updated in 2007 and the Ministry of national Defense is up to the current date the only Ministry with a documented space policy.

In 2007 it was decided that the National Center for Space Applications was to be dissolved once the Helios 2 ground station would be operational. The ground station started its operation receiving and analysing Helios –II imagery in 2010 in the 114th Combat Wing in Tanagra.

In 1991, Greece established the Space Committee (Διαστημική Επιτροπή) under the general Secretariat of Research and Technology (Γενική Γραμματεία Έρευνας και Τεχνολογίας – ΓΓΕΤ) of the then-named Ministry of Industry research and Technology. The committee had an advisory and coordinating role. In 1995, the committee initiated a plan for the creation of the Greek Committee for Space (Ελληνική Επιτροπή Διαστήματος – ΕΕΔ), which was envisaged to be a public agency for the peaceful uses of space. The agency would not be related to national defense. However, the creation of the agency did not move forward, and the Space Committee ceased operating in 1998. In June 2005, the creation of the Space Office for space policy and programme was established in the Ministry of National

Defence. The office operates under the General Directorate of National Defence Policy and International Relations (Γενική Διεύθυνση Πολιτικής Εθνικής Άμυνας και Διεθνών Σχέσεων)

In 2017 the first Greek space agency, the “Hellenic Space Agency” (Ελληνικός Διαστημικός Οργανισμός – ΕΛΔΟ) was founded with headquarters in Athens [3]. It was functioning under the Ministry of Digital Governance and its goal was to coordinate and handle national space policy and national projects in space technologies. In August of 2019 it was dissolved and it was succeeded by the Hellenic Space Center.

## 1.2 International Organizations

Greece is a member of the ITU (International Telecommunications Union) since 1865. Moreover, Greece is a part of EUTELSAT IGO (European Telecommunications Satellite Organization), INMARSAT (International Mobile Satellite Organization), COPUOS (Committee on the Peaceful Uses of Outer Space) and EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites). Greece also participates in the SATCEN (European Union Satellite Center) and the EUSPA (European Union Space Program Agency) activities.

### 1.2.1 European Space Agency

In 1994 Greece signed its first cooperation agreement with the European Space Agency (ESA) [4]. This led to knowledge exchange and mutual cooperation in studies and projects. Greece submitted a formal application to join ESA in 2003 and became the 16$^{th}$ member state of the Agency on the 9$^{th}$ of March, 2005. Following, a table that captures the Greek contributions to the ESA budget for the last few years is presented:

**Table 1: Greek contribution to the ESA budget for 2012 to 2023**

| Year | Greek Contribution in EURO | Percentage of total ESA budget |
|---|---|---|
| 2012 | 8.6 M | 0.3 % |
| 2013 | 15.1 M | 0.5 % |
| 2014 | 14.5 M | 0.4 % |
| 2015 | 12.1 M | 0.4 % |
| 2016 | 11.9 M | 0.3 % |
| 2017 | 14.6 M | 0.4 % |
| 2018 | 10.5 M | 0.3 % |
| 2019 | 10.5 M | 0.3 % |

| | | |
|---|---|---|
| 2020 | 20.6 M | 0.4 % |
| 2021 | 19.9 M | 0.4 % |
| 2022 | 20 M | 0.4 % |
| 2023 | 21 M | 0.4 % |

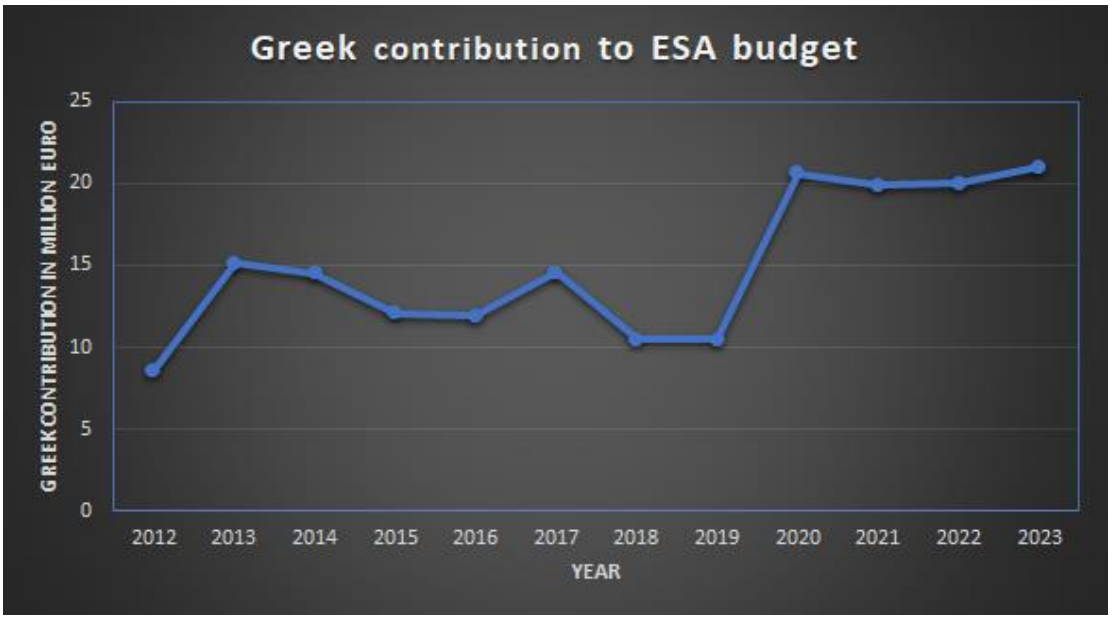


**Figure 1: Greek contribution to the ESA budget for 2012 to 2023 in absolute values**

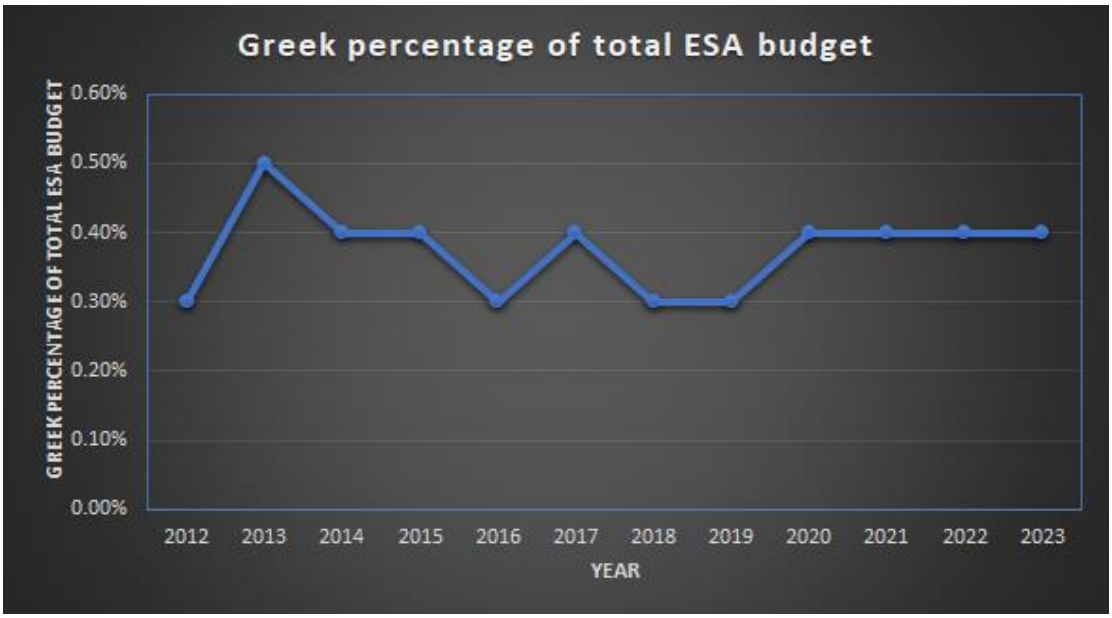


**Figure 2: Greek contribution to the ESA budget for 2012 to 2023 – percentages**

### 1.3 National Observatory of Athens - Dedicated Space Research Centre

The National Observatory of Athens - NOA (Εθνικό Αστεροσκοπείο Αθηνών) was founded in 1842 [5] and is Greece's oldest space related institution and in general its oldest research

foundation. It operates in four locations, namely the main branch in Thiseio, the Penteli Astronomical Station in Mount Penteli, the Kryoneri Astronomical station in the Corinthia Regional Unit and the Helmos Observatory in Mount Helmos which is its largest infrastructure. NOA is composed since 2012 of three institutes: Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing - IAASARS (Ινστιτούτο Αστρονομίας, Αστροφυσικής, Διαστημικών Εφαρμογών και Τηλεπισκόπησης – ΙΑΑΔΕΤ) Institute for Environmental Research and Sustainable Development (Ινστιτούτο Ερευνών Περιβάλλοντος και Βιώσιμης Ανάπτυξης) and Institute of Geodynamics (Γεωδυναμικό Ινστιτούτο). The two former are located in the premises of the Penteli Observatory while the latter is located in the central premises in Thiseio. IAASARS, with its many operational units, is active in the fields of Remote Sensing, X-Ray and infrared astrophysics, solar physics, space weather and ionospheric physics [6]. The Institute is supervised and receives support by the General Secretariat of Research and Technology, which runs under the Ministry of Development and Investments. The infrastructure and capabilities of NOA will be described with further detail in chapter 3.

### 1.4 Industry

In terms of industrial actors, there is a multitude of companies active in the space domain. In 2008, the Hellenic Association of Space Industry - HASI (Ένωση Ελληνικών Βιομηχανιών Διαστημικής Τεχνολογίας & Εφαρμογών – Ε.ΒΙ.ΔΙ.ΤΕ) was founded as a coordinated effort from the Greek space industry. Additionally, the si-cluster was founded by HASI and the Corallia unit of the Athena Research Center in 2013, to foster academic and industrial cooperation in space. Greek industrial actors active in space will be documented thoroughly in chapter 3.

A recent development took place in 2021, in the 85th Thessaloniki International Fair, when a statement of strategic intent between si-cluster, the General Secretariat of Telecommunications and Post, the Greek Ministry of Digital Governance, the grnet (Εθνικό Δίκτυο Υποδομών Τεχνολογίας και Έρευνας - ΕΔΥΤΕ) and Amazon Web Services was announced [7]. The agreement foresees the creation of an innovative and competitive space hub in Greece. The two main actions of the space hub will be the creation of specialization and training programmes for aerospace professionals as well as the collection and distribution of space data. Amazon Web Services is set to contribute with technical and financial means to startups and young professionals, with the initiatives relevant to the statement being the Greece/AWS Space Collaboration for the Economy & Development (G/ASCEnD) and the AWS Open Data Sponsorship Program.

### 1.5 Initial Space Programmes

#### 1.5.1 Earth Observation

Greece has used from the 1970’s imagery from the commercial Earth Observation satellite Landsat to cover its national needs. Also, since 2006, Greece had been a participant in the multi-national satellite program Helios-2, which ceased in 2022, with a percentage of 2,5% [8]. It was financed at 90% by France, and the rest of the participating countries apart from

Greece were Belgium, Spain and Italy with a 2.5% investment each. The Helios-2 system consists of 2 Earth Observation satellites, Helios 2A and Helios 2B [9]. The two satellites carry a high-resolution imaging instrument which is built by Thales that operates in the visible and thermal infrared wavelengths with a 35 cm spatial resolution [10]. The satellites are also equipped with a medium resolution instrument built by Airbus. In 2010, a ground station for acquiring satellite images from the Helios system became operational in Tanagra [11].

### 1.5.2 Communications

In 1970, a satellite antenna belonging to the Greek Telecommunications Organization (Οργανισμός Τηλεπικοινωνιών Ελλάδας – O.T.E), named THE-01 began its operation in Thermopylae, Greece, providing telecommunication services and interconnecting Greece with the UK, Canada and the U.S.A [12]. In 1972 the THE-02 antenna began its operation to connect with the countries of the Indian Ocean, Australia, Japan and the Far East, while in 1982 the THE-03 antenna provided greater capacity for communications with the U.S.A. The antennas belong to OTE's Center of Satellite Communication (Κέντρο Δορυφορικών Επικοινωνιών) of Thermopylae. In 1985, an Inmarsat ground station officially commenced operations in Thermopylae as well, to provide land to ship and ship to land communications via satellite. In 1994, a second Satellite Communication Center was established in Nemea by OTE, hosting over 40 satellite dishes. OTE manages the ground stations (Thermopylae and Nemea) and administers Greece's participation to INTELSAT, INMARSAT and EUTELSAT.

Additionally, in 2002, the Greek company HellasSat leased from Deutsche Telekom the DFS-Kopernikus 3 satellite, renaming it into Hellas Sat 1, thus marking the first Greek owned satellite in space, while Hellas Sat 2 was launched in 2003 [13].

### 1.5.3 Meteorology

The Hellenic National Meteorological Service (Εθνική Μετεωρολογική Υπηρεσία – E.M.Y.) is responsible for supporting the Greek national defense and economy with information relevant to meteorology. Since the decade of 1970, the Service has been using NOAA and Meteosat images, initially in analog format [1]. In 1994, the ground station "Proteus" was installed in Greece, in order to enable acquisition and processing of digital meteorological satellite images.

### 1.5.4 PNT (Position, Navigation and Timing)

A Greek infrastructure related to PNT is the Dionysos Satellite Observatory, which is situated at Penteli Mountain, roughly 25 km from the center of Athens and at an altitude of 480 m [14]. The observatory is affiliated with the Laboratory of Geodesy - School of Rural and Surveying Engineering of the National Technical University of Athens (NTUA) and is utilized for research as well as educational purposes. Dionysos Satellite Observatory has been involved in GPS campaigns and processing since the middle of the 1990s, especially with Differential GPS (DGPS) services, which can be used by various users including ships, aircraft, and land vehicles.

# 2. GREECE: NEEDS FROM SPACE

Greece is a country that can benefit greatly by utilizing space assets to address needs that stem from its geographic position, its climate and its major economic sectors. This chapter aims to define various national Greek needs that can be answered from space. In the beginning of the chapter, a general outline of the country's needs will be given, based on multiple characteristics of the climate, economy and geographical location, amongst others. Subsequently, a table of the country's needs will follow in an attempt to map them thoroughly.

## 2.1 General Outline of Greek Needs from Space

### 2.1.1 Connectivity

Greek territory includes 6000 islands and islets, of which 227 are inhabited [15]. Satellite networks can become an efficient means of connectivity for many of the islands where terrestrial networks are difficult to be implemented. This solution also applies to any remote areas where terrestrial communication networks can become unavailable, as well as for provision of connectivity to platforms such as ships and aircraft.

### 2.1.2 Culture

There are numerous cultural and archaeological sites located in the Greek territory, with 18 being registered in the UNESCO World Heritage List. Archaeological sites are subject to erosion from pollutants that are present in the atmosphere. The reaction that takes place when calcite marbles, such as those present in the Ancient Olympia archaeological site [16], are exposed to sulfur dioxide, which is a common pollutant, produces calcium sulfate hemihydrate and gypsum. The latter forms a crust and when exposed to rain dissolves, thus accelerating the deterioration of monuments [17]. Therefore, a need for pollution monitoring to protect the cultural heritage sites is needed, which can be provided by remote sensing applications.

### 2.1.3 Economy

In terms of economic development, Greece has an active agriculture and rural development sector that is contributing to the national economy and employs 11% of the total workforce (2021) [18] [19], while its commercial maritime activities are one of the main assets of its economic activity, offering a significant contribution to the country's GDP, that can range from €13 billion to €19 billion annually [20] [21]. Also, Greek ship owners control a significant portion of the world's merchant fleet (21% in 2019 [22]). A variety of applications can exploit space assets to benefit the aforementioned economic sectors.

### 2.1.4 Environmental Monitoring

In 2020, the reported forest area of Greece was 30.3% [23], a significant percentage, which indicates the need to monitor and preserve the natural resources. Additionally, the country is experiencing intense droughts and is prone to desertification [24], thus monitoring natural resources such as water reserves is crucial. The need for environmental resources monitoring can be addressed with remote sensing applications.

### 2.1.5 National Defense

Greece has extended maritime borders and its maritime territory is often disputed [25]. The country is characterized by a sensitive geographical position with an active and challenging neighbor, Turkey. Upheavals are frequently taking place, introducing the need to monitor the Greek territory and its vicinity, sea and land, at all times, for national defense purposes. It is imperative to implement measures for deterrence and tactical reconnaissance and solutions can be provided from space for that aspect. Also, with the threat of ballistic missiles [26], space assets should be leveraged to provide early warning and deterrence capabilities. Odin's Eye, an EDF (European Defense Fund) funded space-based missile early warning system, has Greek participation in the Consortium that manages the project [27].

Space is a decisive factor in modern warfare. In 2019, it was recognised as a new operational domain by NATO, a military alliance of North American and European countries that Greece is part of, along with air, maritime, land and cyberspace [28]. During Project Convergence of the U.S. Army (2020), an experimentation exercise, commercial and governmental satellites were used to capture images and telecommunications satellites, including commercial constellations, were used to relay target information. The process resulted in a reported sensor to shooter time reduction from 20 minutes to 20 seconds [29].

The prominent example of the recent conflict in Ukraine pointed out further the role of remote sensing in times of conflict with the use of MAXAR, PLANET Labs systems or ICEYE's SAR constellation by the country to answer its intelligence needs from space [30].

Moreover, the need for secure communication and data exchange in times of crisis is also present, with satellite systems being a decisive factor in that aspect. A malicious attack took place targeting Viasat satcom modems, an hour before the Russian invasion in Ukraine and reduced the Ukrainian communication capacity. One of the most prominent publicly disclosed examples of strikes on space systems, this cyber attack adds a new dimension in modern warfare and indicates the importance of satellite communications in that context [31]. Additionally, the use of Starlink is speculated as being used in military operations by Ukraine for encrypted point to point e-mail exchange as well as target acquisition, sending target information to the appropriate units without using ground infrastructure in the country [32].

Finally, GNSS services are crucial for military operations, as they enable the operational effectiveness of ground, air and sea assets. In the Ukrainian conflict, GPS jamming attempts have been made, although they might have had a major impact mainly in civilian GPS use such as aviation.

### 2.1.6 Natural Disasters

Greece is periodically ravaged by catastrophic natural disasters. In the Attica region in 2021, where the capital city Athens is located, the total area burned by wildfires was 79,334 acres [33], with almost 247,105 acres burnt in just two weeks in Greece in general that summer [34]. In 2023, a destructive wildfire in Greece, dubbed as one of the largest to take place in EU soil, burned more than 200,000 acres in the Evros area [35]. The country is prone to this disastrous phenomenon, along with floods [36] Another active phenomenon to which the country is prone is earthquakes [37]. These disasters introduce implications to human lives, as well as environmental and economic impacts. Solutions from space, such as remote sensing and satellite communications, can aid in preventing, detecting, managing and monitoring natural disasters. Fast response and deployment of emergency services can be ensured as well.

### 2.1.7 Urban Life

For 2021, Greek population living in urban areas amounted to 80% [38]. In addition, the reported illegal infrastructures in general for 2021 were 1.16 Million [39]. Given these statistics, the country can benefit from earth observation services for urban planning and illegal infrastructures monitoring.

## 2.2 National Needs Table

The following table attempts to identify the Greek national needs from space and is mostly based on the general outline of needs documented in the previous chapter. Other sources include the Greek RFI for microsatellites [40] and the military needs from space (“Modern Challenges for Air Forces in Space” chapter) as well as the national needs table ("Space Solutions to National Needs through Selected Projects in Greece” chapter), both from the Hellenic Airforce Review - Issue 127 [2]. The data is comprised by needs that are of great importance for Greece. Indicative satellite payloads for relative satellite systems that answer the needs are provided as well, with literature sources that connect them to the respective application.

Finally, the needs that are characterized by high time criticality are annotated as such. High time criticality in the context of this thesis refers to the need for data delivery related to the phenomenon with low latency, i.e. in terms of seconds to minutes, in order to mitigate risks. Finally, it is noted that some needs belong to more than one category, although for simplicity only one instance of them is provided.

**Table 2: Identification of Greek national needs from space**

| Sector | National need from space | Solution | Indicative Payload | Highly time critical |
|---|---|---|---|---|
| Precision agriculture | Agricultural land cover classification | Earth observation satellite system or | Multispectral [41] | No |

| | | | | |
|---|---|---|---|---|
| | | services | | |
| | Soil moisture monitoring | Earth observation satellite system or services | Moderate Resolution Imaging Spectroradiometer, SAR [42] | No |
| | Weather monitoring | Weather monitoring satellites or services | Radiometer (Visible Imaging, Infrared), Radar [43] | Yes |
| | Crop growth monitoring | Earth observation satellite system or services | Multispectral / Hyperspectral [44] | No |
| | Plant disease monitoring | Earth observation satellite system or services | Multispectral [45] | No |
| | Nutrient management for crops | Earth observation satellite system or services | Multispectral [46] | No |
| | Crop yield estimation | Earth observation satellite system or services | Multispectral [47] | No |
| | Crop health and stress monitoring | Earth observation satellite system or services | Multispectral [48] | No |
| Transport | Public transport fleet management | GNSS services | - | - |

| | | | | |
|---|---|---|---|---|
| | Logistics fleet management | GNSS services | - | - |
| | Navigation for aviation | GNSS, EGNOS services | - | - |
| Civil security | Forest fire risk assessment and mapping | Earth observation satellite system or services | Multispectral, SAR [49] | Yes |
| | Fire detection | Earth observation satellite system or services | Infrared Sensors, Lidar Data, C-SAR, Moderate Resolution Imaging Spectroradiometer [50] | Yes |
| | Active Fire Monitoring | Earth observation satellite system or services | Infrared Sensors, Lidar Data, C-SAR, Moderate Resolution Imaging Spectroradiometer [51] | Yes |
| | Post fire assessment (NBR - Normalized Burn Ratio, burned area classification) | Earth observation satellite system or services | Multispectral (NIR, SWIR) [52] | Yes |
| | Flood detection | Earth observation satellite system or services | SAR [53] | Yes |
| | Earthquake building damage assessment | Earth observation satellite system or services | SAR [54] | Yes |

| | | | | |
|---|---|---|---|---|
| | Landslide detection and monitoring | Earth observation satellite system or services | SAR [55] | Yes |
| | Land degradation monitoring | Earth observation satellite system or services | Multispectral [56] | Yes |
| | Land Surface Temperature monitoring (heat waves) | Earth observation satellite system or services | Moderate Resolution Imaging Spectroradiometer [57] | Yes |
| | Human trafficking monitoring and prevention | Earth observation satellite system or services | Video / Visible Imaging [58] | Yes |
| Connectivity | Internet connectivity for remote areas | Satellite or satellite constellation for connectivity or related services | Ku band transponders [59] | - |
| | Emergency response, search and rescue | COSPAS - SARSAT services [60] | 406 MHz Beacons (Emergency Locator Transmitters, Emergency Position Indicating Radio Beacons and Personal Locator Beacons | - |
| Environmental Monitoring | Environmental resources monitoring (e.g. NDVI for forests, ecosystem mapping) | Earth observation satellite system or | Multispectral [61] | No |

| | | | | |
|---|---|---|---|---|
| | | services | | |
| | Pollution monitoring | Earth observation satellite system or services | Radiometer (Visible Imaging, Infrared), optical spectrometer [62] | Yes |
| | Hazardous material detection (asbestos etc) | Earth observation satellite system or services | Multispectral [63] | No |
| | Water quality monitoring | Earth observation satellite system or services | Multispectral [64] | No |
| | Drought Monitoring | Earth observation satellite system or services | Multispectral radiometer [65] | Yes |
| Urban Life | Urban planning | Earth observation satellite system or services | Visible Imaging [66] | No |
| | Infrastructure Monitoring (e.g. power grids) | Earth observation satellite system or services | Visible Imaging, SAR [67] | No |
| | Topographic mapping | Earth observation satellite system or services | Radar altimeter [68] | No |
| | Traffic monitoring | Earth observation | Visible Imaging [69] | No |

| | | | | |
|---|---|---|---|---|
| | | satellite system or services | | |
| | Illegal infrastructure monitoring (e.g. based on change detection) | Earth observation satellite system or services | Visible Imaging [70] | No |
| Culture | Archaeological sites monitoring (pollutants) | Earth observation satellite system or services | Moderate Resolution Imaging Spectroradiometer, LiDAR [71] | No |
| | Archaeological sites location identification | Earth observation satellite system or services | SAR [72] | No |
| Energy | Mineral resources mapping | Earth observation satellite system or services | Hyperspectral, Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) [73] | No |
| | Offshore wind farms management [74] | Earth observation satellite system or services | SAR, radar altimeter [75] | No |
| Maritime | Dark vessel detection / monitoring | Earth observation satellite system or services | AIS (Automatic Identification System), SAR [76] | Yes |
| | Port management | Earth observation satellite system or | Multispectral, SAR [77] | Yes |

| | | | | |
|---|---|---|---|---|
| | | services | | |
| | Ship tracking in coastal areas | Earth observation satellite system or services | AIS, SAR [78] | Yes |
| | Coastal zone management (erosion of shoreline) | Earth observation satellite system or services | Multispectral, SAR [79] | No |
| | Sea level monitoring | Earth observation satellite system or services | Radar altimeter [80] | No |
| | Oil spill detection | Earth observation satellite system or services | SAR [81] | Yes |
| | Fishing vessels monitoring | Earth observation satellite system or services | AIS, SAR | Yes |
| | Fishing resources management | Earth observation satellite system or services | Multispectral, Moderate Resolution Imaging Spectroradiometer [82] | No |
| | Marine ecosystem monitoring (invasive species) | Earth observation satellite system or services | Multispectral [83] | No |
| | Maritime border monitoring | Earth observation satellite | Visible Imaging, AIS, SAR [84] | Yes |

| | | | | |
|---|---|---|---|---|
| | | system or services | | |
| | Retrieval of sea surface currents | Earth observation satellite system or services | Radar altimeter [85] | No |
| | Sea surface temperature monitoring | Earth observation satellite system or services | Thermal Infrared [86] | No |
| National Defense | Land border monitoring | Earth observation satellite system or services | Visible Imaging and SAR [87] | Yes |
| | Human movement tracking | Earth observation satellite system or services | Video / Visible Imaging, SAR [58] | Yes |
| | Secure, continuous and low latency satellite telecommunications for governmental and military users | Connectivity satellite or governmental payload hosted on satellite of third party, secure governmental satcom network for satellite communications (GreeCom already in place) | X-Band, Mil-Ka band, UHF transponders [88] with encrypted channels | - |
| | Persistent monitoring of land / battlefield | Satellite constellation with high revisit times | Multispectral / SAR [89], target recognition on-board software | Yes |

| | | | | |
|---|---|---|---|---|
| | Missile and Unmanned Aerial Systems early warning | Satellites for detection of ballistic threats | Infrared (IR) sensors [90] | Yes |
| | Space situational awareness and monitoring of higher atmosphere (20-100 km) | Space situational awareness infrastructure (Already on track with EU SST and the national ground segment infrastructure) | - | - |
| | Electronic reconnaissance | Satellite or constellation with electronic signal capabilities or related services | SIGINT / ELINT | - |
| | Navigation for military purposes | GNSS services | - | - |
| | Communication Intelligence | Satellite or constellation with communication eavesdropping signal capabilities | SIGINT / COMINT | - |

## 2.3 Conclusion

The compiled table indicates that most Greek national needs from space that were identified can be answered with Earth Observation applications, with telecommunications / connectivity and GNSS services constituting solutions as well. In total, 58 instances where solutions from space can answer national needs were identified. Out of the 48 documented needs that can be answered with Earth Observation applications, 23 are characterized by high time criticality, requiring delivery of data with low latency for fast response to mitigate the impact of the addressed phenomena.

# 3. GREECE'S SPACE ECOSYSTEM: ADDRESSING NATIONAL NEEDS

The term “space ecosystem” is used in this thesis to describe the complex of integrated stakeholders, laws, policies, procedures and systems that contribute to and benefit from space exploitation. The space ecosystem is a complex and interconnected system as it includes all of the different actors and organizations that are involved in the development and use of space like governments, businesses, academic institutions, non-governmental organizations (NGOs) and the public. The different actors and organizations work together to develop and use space technologies, and they all benefit from the results of this work.

## 3.1 Current Space Governance

The political entity responsible for the space matters in Greece is the Ministry of Digital Governance. The delegation of Greece to ESA (European Space Agency) is run by the Ministry of Digital Governance and specifically the General Secretariat of Telecommunications and Post [91].

Complementing the Ministry of Digital Governance, the Hellenic Space Center serves as a government body tasked with the coordination of public and private entities involved in Greece's space initiatives and the formation of an action plan for the space domain of the country [92].

Among its objectives are the management and development of projects and programmes, promotion and communication of Greece's space strategy, representation in international space-related forums and groups, as well as the design and operation of space systems. The organization also offers training to students, researchers, and officials on space-related matters and provides advisory services to the Ministry of Digital Governance. Finally, the Hellenic Space Center’s goals include the exploitation of Greece's rights to space assets of any kind.

The Ministry of National Defence is responsible for space programmes and applications that address national defense needs. The Ministry develops its own directives regarding space autonomously and has signed a memorandum with the Hellenic Space Center in 2019. The Ministry has the right to participate in the HSC board of directors if national defense matters are discussed, after invitation and without having the right to vote. The two main bodies responsible for space within the Ministry of National Defense are the Space Directorate in the National Defense General Staff (Διεύθυνση Διαστήματος - ΓΕΕΘΑ) [93] and the Space Office in the General Directorate of National Defense Policy and International Relations. The Ministry of National Defense has signed a programmatic agreement with the Ministry of Digital Governance to coordinate and develop as well as implement space technologies.

Two main laws that contribute to the organization of space activities in Greece are presented in the following. Law 4508/2017 (coded with Law 4643/2019) [94] defines the framework for the licensing of space assets, the supervision of space activities and the responsibilities in case of damages caused by them, as well as the creation of a national registry for space assets. The law addresses activities taking place in the Greek territory, activities taking place abroad if personnel, infrastructure, movable or immovable property that belong to or are under the jurisdiction of the Greek state and activities taking place anywhere if performed by natural persons holding the Greek nationality or legal persons based in Greece and only if this is foreseen by an international agreement or treaty. Finally, the law concerns activities

performed by natural or legal persons, foreign or Greek, in Greek territory or abroad, for which personnel, infrastructure, movable or immovable property that belong to or are under the jurisdiction of the Greek state as “launching state” are used.

In parallel, Law 4727/2020 (coded with Law 5039/2023) Article 119 - paragraph 9 [95], dictates that the Ministry of Digital Governance is responsible for the deposit and management of any national contributions to ESA’s optional and mandatory programmes. It dictates that the purposes of the Greek participation in ESA activities are a) the strengthening of national security and defense, especially through the development of space infrastructure, ensuring autonomy b) the development of the Greek space industry, c) the exploitation of space data and the development of relevant applications and d) the support of research and development in the space sector. The General Secretariat of Telecommunications and Post is the representative of Greece to ESA and regulates the activities related to the Greek participation in ESA programmes. The secretariat is also responsible for the assessment and support of the participation of Greek entities in ESA activities. All Greek entities are automatically entitled to letters of support by the Minister of Digital Governance for ESA competitive invitations to tender.

In addition, the law specifies that the Minister of Digital Governance has the decision power to assemble a 7 - member committee with a 3 year tenure, that proposes the amount and the distribution of the Greek contribution to ESA, the participation of Greece in ESA programmes, projects and activities and informs the Minister of Digital Governance relative to the issuing of letters of support for ESA activities, regarding non-competitive invitations to tenders. Presiding in the committee is the Director General of Telecommunications and Post, with two other members from the Secretariat of Telecommunications and Post, one member from the Ministry of National Defence, one member from the General Secretariat of Research and Technology and members from, or proposed by, the Hellenic Space Center. Finally, the aforementioned law also dictates that the orbital slots and the relevant frequencies that have been assigned to Greece are valuable national resources and the state is responsible for their management. Orbital slots and frequencies are assigned by the state in competitions issued by the Ministry of Digital Governance.

## 3.2 Institutional Framework

### 3.2.1 National Space Policy

Greece lacks a formal national space policy, typically institutionalized within a nation, to define its goals. Thus, the relevant Ministries should develop their own policies according to their specific needs. So far, only the Hellenic Ministry of Defence has established its own space policy.

The Hellenic Space Center’s proposition in 2021 for a national space policy to the Ministry of Digital Governance [96], is the following, based on 7 main pillars:

1) Reinforcement of national defense and civil security
2) Reinforcement of the national economy

3) Pursuit of the UN (United Nations) goals for sustainable growth and promotion of the use of space to benefit humanity

4) Reinforcement of scientific excellence and contribution to scientific research and technological development

5) Provision of support to the state in governance issues and operations of public administration. Provision of high quality satellite services to citizens and businesses

6) Development of national capabilities and prevention of brain-drain

7) Reinforcement of the outreach and of the international presence of Greece

The generic strategic action plan, to be elaborated in a later stage, proposed by the Hellenic Space Center to implement a future national space policy includes the following main elements, amongst others:

1) Design, development and implementation of a national programme for presence in space through a launch on demand scheme and creation of a ground segment which will not only cover national needs, but will be offered for international cooperation and exploitation as well. This action concerns all 7 main pillars of the national policy.

2) Development of ground segment infrastructure in universities in connection with space study programmes. The specific action concerns pillars 4 and 6 of the national policy.

3) Space qualification for Greek space systems and subsystems and promotion of the aforementioned assets to be accepted in European space missions. The specific action concerns pillars 2 and 4 of the national policy.

4) Targeted use of advanced satellite technologies / services and development of new, innovative technologies. This action mainly refers to pillars 1, 2 and 5 of the national space policy.

5) Support and boost of competitiveness and extroversion of the Greek companies active in space and fostering of conditions that support startups. The specific action refers to pillars 2 and 6.

6) Pursuit of cooperation with space companies that are active abroad in order to found branches in Greece, in coordination with local companies to design, manufacture and test satellite systems and subsystems (pillars 2, 6 and 7).

7) Support of the synergy between industry and academia. This action refers to pillars 2, 4 and 6.

8) Identification of niche areas that will provide an opportunity for Greek companies to enter the space market. This action concerns pillars 2, 6 and 7.

9) Personnel additions, upgrade and exploitation of existing infrastructure and development of new infrastructure in universities and research centers that are active in the domain of space and connection with tertiary education (pillars 4, 5 and 6).

10) Development of a national business architecture that will include space technology. Founding of National Industrial Policy committee for space, with participation from the HSC, the Ministry of Digital Governance, the Ministry of Development and Investments and industry representatives (pillars 2, 6 and 7).

### 3.2.2 Space Technologies and Services as Part of the Greek Digital Transformation Plan

Elements related to space are documented in the Digital Transformation Bible of 2020-2025 [97] of the Ministry of Digital Governance. The Bible was published in December 2020 and it constitutes a digital transformation plan for Greece. The directives captured in the "Connectivity" section of the document are mainly related to telecommunications and can be summarized as follows:

- National Microsatellites Programme

The programme foresees the development of a national microsatellites constellation to address national needs with Earth Observation and Telecommunications capabilities. The constellation is envisaged to use the Fiber in the Sky and EuroQCI infrastructure. Further, the microsatellites are foreseen to support applications and services for search and rescue, border monitoring, national security, civil protection, connectivity and the protection of the environment. The programme is considered as a part of the EU GovSatCom, EuroQCI and European Secure Connectivity initiatives.

- Upgrade of the Hellenic Copernicus Collaborative Ground Segment

Development of infrastructure to manage and process large amounts of Earth Observation data that will be open to use, targeting to create an operational system that covers the Southeast Mediterranean, the Balkans and the Black Sea region. The initiative foresees the integration of ESA and National (e.g. civil security) services to the system. The relevant existing service is under the management of NOA and grnet (ΕΔΥΤΕ), that provides the high speed connection services.

- GOVSATCOM - GreeCom

GreeCom is a governmental satellite communications service that is able to transmit voice and data between Greek decision making centers even in times of crisis. The stated goal is to expand GreeCom and complement it with the Fiber in the Sky and the national microsatellite project developments.

- Fiber in the sky and ground infrastructure

The development of the Fiber in the Sky initiative has been secured to take place in the Helmos Observatory in collaboration with ESA through the ARTES ScyLight (Secure and Laser communication technology) programme. This initiative is connected in the document with EuroQCI (European Quantum Communication Infrastructure.) Greece is set to participate in the next generation of secure, quantum telecommunications through its ground segment (Helmos, Skinakas, Cholomondas). The Greek minister of Digital Governance signed the Euro QCI (European Quantum Communication Infrastructure) declaration in December 2019.

The implementation of the directives captured in the Digital Transformation Bible which are relevant to space are carried out with the following actions [2]:

- Implementation of the national microsatellites programme - autonomously answering national needs and boosting of the Greek space industry competitiveness.
- Flight heritage - promotion of the in-orbit validation of components, subsystems or systems that have been developed and tested in Greece. This is achieved through participation in ESA, EU (European Union) and national programmes.
- Ground segment infrastructure - utilization and further development of existing private - or public- owned ground infrastructure such as radar, laser stations and telescopes.
- Alignment between ministries - support of the development, application and monitoring of policies for space in different domains (telecommunications, transport, maritime, agriculture, energy, environment, security.)

The main space programmes that Greece develops to achieve the objectives above are:

- EuroQCI (Optical ground stations upgrades).
- GOVSATCOM (Greece is part of EUSPA's ENTRUSTED programme and has access to GreeCom, its own governmental, secure satellite network).
- National microsatellites programme.
- EU SST (European Space Surveillance and Tracking) – part of the SSA (Space Situational Awareness) component of the EU space programme.
- Copernicus Ground Segment Upgrade.

### 3.3 Current Space Programmes

In the following, current implementations of space technologies and services that cover the main areas of Earth Observation, Communications, Meteorology, Search and Rescue, PNT and Space Surveillance are presented.

#### 3.3.1 Earth Observation

In 2010, Greece initialized its participation in the MUSIS (MUltinational Space-based Imaging System) programme [11]. The participating countries were the same as in the Helios 2 programme with the addition of Poland. The goal of MUSIS was to interconnect optical and SAR (Synthetic Aperture Radar) satellite systems through a common ground infrastructure. The MUSIS programme materialized into the CSO (Composante Spatiale Optique) military observation satellite system. In 2022 Helios-2 programme ceased its operation and the Greek MoD is negotiating its access to the new CSO programme. CSO utilizes technology that is a product of the Airbus Pleiades system and it will consist of 3 satellites that offer visible and infrared imaging capabilities [98]. CSO-1 provides images with 35 cm spatial resolution from a 800 km orbit and CSO-2 provides imagery with a resolution of 20 cm while orbiting at 480 km. CSO-3 is planned to be launched next, to offer better revisit times [99]. It is estimated that Greece has a higher participation percentage in CSO than in the Helios-2 programme.

Also, the BEYOND Unit of the National Observatory of Athens has access to satellite data and offers services that have been utilized by a variety of institutional authorities and

international organizations, including but not limited to the European Forest Fires Information System (EFFIS), the Global Fire Monitoring Unit-GFMC, Copernicus EMS, Civil Protection Authorities across various regions including the EU, Africa, Latin America, and Asia, as well as Fire Brigade authorities, Forestry Departments, Directorates for the Protection of Forests and Natural Ecosystems, Environmental Agencies, Ministerial Bodies, and Rehabilitation Services [100]. Copernicus satellite data toolkits of BEYOND can be found in the following address: https://sentinels.space.noa.gr/ while its fire detection platform can be found in the following address: http://195.251.203.238/seviri/.

### 3.3.2 Communications

Hellas Sat 3 and 4, communications satellites of the company Hellas Sat, which are currently operational, were launched in 2017 and 2019 respectively. More details for the satellites are given in chapter 3.4.2.1.

The publication of the Digital Transformation Strategy 2020-2025 in December 2020 outlined Greece's intention to utilize space as a catalyst for digital transformation. The strategy includes the National Micro-Satellites Project, which aims to design and build a national constellation of microsatellites for answering national needs while being part of the EU GovSatcom, EuroQCI and EU Secure Connectivity directives. In 2021, the “Outline concept for end to end small satellites multipurpose solutions in response to national and European needs” Request for Information (RFI) was issued by the Greek Ministry of Digital Governance. In May 2023, the “Telecomsat Greek Connectivity Programme ITT” [101] was issued, an invitation to tendering for the materialization of the Greek national satellite program, following the RFI. The competition called for the implementation of a national satellite system for secure telecommunications, requiring an X-band payload and 24/7 provision of governmental services, with a budget of €130 million, defining a target of Greek entities participation in the 35% of the total value excluding launch costs. However, the competition was eventually cancelled.

Inmarsat has established a station in the Center of Satellite Communication of Nemea to serve EAN (European Aviation Network). Its testing and validation was completed in 2017 [102]. Kongsberg Satellite Services installed the world’s first commercially available optical ground station in the Nemea satellite center in January 2021, as part of the ESA - ESOC (European Space Operations Centre) Optical Nucleus Network [103]. In March of the same year, it was announced that the Thermopylae satellite center of OTE group was chosen by SES as a gateway for the O3b mPOWER program [104].

In the 7th of December 2019, Greece signed the European Quantum Communication Infrastructure (EuroQCI) Declaration, and three of its ground observatories, Skinakas, Holomon and Helmos were chosen to be upgraded and become part of the ground segment of the initiative. The upgrades are made as part of the ScyLight programme, with the Helmos observatory selected to be the first overall participant in 2020 [105]. The Skinakas, Holomon and Helmos observatories are set to be -further- upgraded for optical and quantum communications, as a relevant ITT under the name “Greek Connectivity Optical Ground Stations” was announced in April 2023 [106].

### 3.3.3 Meteorology

The EUMETSAT satellite ground station of the Hellenic National Meteorological Service is located in Kavouri, Athens. The station is capable of receiving data from satellites in polar orbits when they pass over Central and Southern Europe, North Africa and the Middle East. It can receive data from satellites METOP-A, METOP-B, METOP-C (EUMETSAT), NOAA-18, NOAA-19, NOAA-20, Suomi-NPP (NOAA/NASA) and the FY-3C, FY-3D satellites (CNSA). In 2018 was upgraded in order to be able to receive images from Meteosat second generation satellites [107]. Indicatively, outputs that can be produced by the station are:

- Measurements of the radiation output of Earth in more than 20 spectral channels, with a spatial resolution ranging from 350m to 1 km.
- Measurements of the wind intensity and direction over the surface of the sea.
- Measurements of radiation that are used in numerical atmospheric weather prediction models.
- Measurements for the creation of temperature and humidity profiles.
- Microwave measurements of the atmosphere for the identification of gases such as ozone and $CO_2$.

In parallel, IAASARS (The Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing of NOA) is equipped with a ground station for receiving images of the MSG-Seviri system maintained by EUMETSAT and operates it on a daily basis. The system helps in the detection, monitoring and mapping of wildfires with a 5 minute update period for the whole span of the Greek territory. The ground segment has been expanded to receive data in the L- and X- bands from satellites like Aqua and Terra, NPP, NOAA, NPOESS, FY, METOP and the Sentinels [108].

### 3.3.4 Search and Rescue

Since 2008, Greece has been a ground segment provider in the COSPAS-SARSAT (Search and rescue Satellite-aided Tracking) system through the GRMCC (GReek Mission Control Center / Εθνικό Κέντρο Ελέγχου Αποστολών / E.K.E.A [109]). The GRMCC makes Greece autonomous in handling distress signals from airplanes, ships and persons in its area of responsibility (Search and Rescue Region). The infrastructure of the GRMCC was upgraded in 2021 with 1 GEOSAR antenna, 1 LEOSAR antenna, 6 MEOSAR antennas, 3 Rescue Control Systems (RCs) and related supporting equipment [110].

### 3.3.5 PNT

Greece is hosting an EGNOS (European Geostationary Navigation Overlay Service) RIMS (Ranging Integrity Monitoring Station) in Athens since 2010. In 2022 it was announced that it will continue hosting EGNOS services with an EGNOS Version 3 infrastructure [111]. EGNOS is a Satellite Based Augmentation System (SBAS) that improves GNSS signals and is designed to provide safety of life navigation services for aviation, maritime and land users. Its main function is to receive signals from GNSS satellites using a network of reference ground stations and transfer the errors of those signals to a centralized computing infrastructure where corrections are performed. The enhanced information is then retransmitted to the appropriate area through GEO satellites [112]. RIMS stations are a component of the ground segment of EGNOS that collect measurements from GPS satellite signals and transmit the data to Mission Control Centres every second [113]. The Athens

EGNOS station will be upgraded into version 3, which will allow it to also handle Galileo signals.

Moreover, the Dionysos Satellite Observatory (DSO) at the National Technical University of Athens has created an automated processing system for daily analysis of all operational GNSS (Global Navigation Satellite System) stations across Greece [14]. This daily analysis process has been in operation for the past years, providing valuable insights into the intricate tectonic conditions within Greece. Furthermore, the outcomes of this analysis are shared with the EUREF Densification Project, which aims to generate a high-density velocity field for Europe. The key areas of focus of the observatory are: Continuous GNSS stations - beacons that are used for the observation of satellites, study of crustal deformation with the use of ground and satellite geodetic techniques, applications of GNSS and SAR on control networks and the estimation of deformation and velocity fields, applications of GNSS techniques on control networks, topography and altimetry, gravity data collection and analysis for determining the size and shape of Earth and GPS applications on maritime geodesy and navigation. Its infrastructure includes a continuous GNSS station (GPS, GALLILEO, GLONASS, SBAS) - Trimble Net R9-Trimble choke ring 5800, a continuous GPS station Trimble 4000ssi-Dorne Margolin, a continuous GPS station Trimble 5700-Zephyr, a DORIS Geodetic Satellite System Beacon, a Platform for LASER portable measuring system, a Magnetometer (in collaboration with NOA) and the STS-2/PS6-SC Seismograph in collaboration with NOA. Antique equipment includes a Baker-Nunn artificial satellite tracking camera and a LASER distance measurement system for artificial satellites.

### 3.3.6 Space Surveillance

In August 2021, the Ministry of Digital Governance signed a Space Situational Agreement with the U.S. Space Command [2]. Additionally, Greece is officially a member of the EU SST (European Space Situational Awareness) partnership since 2022 [114], with NOA envisaged to act as its national point of contact. In February 2023, an ESA invitation to tendering was announced called “Tracking Radar for LEO Space Debris Tracking in Greece (HSTR)” [115]. The specific ITT targets the design and implementation of a ground based space debris tracking radar in Greece. Lastly, in March of the same year it was made publicly known that the national space situational awareness capacity of the country would be complemented by software offered by the Spanish multinational company GMV [116].

## 3.4 Greek Space Entities

The text that follows is dedicated to the documentation and analysis of the multitude of private entities, research centers and academic institutes in Greece that are dedicated to space activities, include space as a core component in their operations or have existing heritage in space activities. The chapter covers at minimum the most prominent entities in the country and does not claim to include all local individuals that are involved in space. Finally, it is clarified that the documentation and analysis concerns entities related to space technologies and services and not astronomy. Therefore, the term “Greek Space Entities” refers to the above description.

On a high level, the entries are divided in universities, research centers and industry. All entries are subsequently classified based on the ESA Generic Product Tree [117] up to system level, depending on their main products and project heritage related to space. This classification attempt aims to cluster the entities and provide a good grasp of their main

capabilities. It is noted that the TRLs [118] for the different products are various and are not included. Furthermore, entities such as student teams and entities involved in space-relevant dissemination, as well as national space assets that were not covered in chapter 3.3, are included in separate chapters but are not classified. Except from attempting to just document the various Greek space entities, the author envisages this chapter to act as a bridge between the different organizations that are active in the space domain, domestic and international, as visibility is important for potential collaborations. Moreover, the reasoning behind the layout of this chapter is that identifying the local capabilities can act as a basis for justifying the potential for a specific sub-domain to thrive within the overall Greek, European and international scheme. It can also act as a map of this part of the Greek ecosystem with key information for each entity, with further details accessible in the provided relevant websites.

The chapter ends with statistics stemming from the classification performed and the conclusions that can be made based on the compiled data.

### 3.4.1 Academia and Research

#### 3.4.1.1 Universities

In Greece, two educational programmes are dedicated to space technologies and both are offered by the National Kapodistrian of Athens. There are many university laboratories and research teams that are active in the domain, while various student teams are also participating in national and international space and aerospace competitions. An attempt to the documentation of the capacity of the country related to space with respect to academia follows.

##### 3.4.1.1.1 Study Programmes

**Bachelor's Degree, Aerospace Science and Technology - NKUA (National & Kapodistrian University of Athens)** (Central Greece - http://www.aerospace.uoa.gr/): The Aerospace Science and Technology Department belongs to the Faculty of Science of the National & Kapodistrian University of Athens and offers a bachelor's degree in the respective disciplines, aiming to create qualified graduates in the domain.

**Master's Degree - Space Technologies, Applications & Services (STAR) - NKUA** (Attica Region - http://star.uoa.gr/index_english.php): The "STAR" Master's degree is an interinstitutional programme between NKUA and the University of Patras and is offered at the premises of the Department of Informatics and Telecommunications of NKUA. It aims to create highly qualified graduates that can provide expertise in space-related jobs and research activities.

##### 3.4.1.1.2 Laboratories and Research Teams

**Applied Mechanics and Vibrations Laboratory (AMVL Lab) - University of Patras** (Western Greece - http://www.aml.mech.upatras.gr/en/):

Segment: Satellites and Probes, System: Structures

AML belongs to the department of Mechanical Engineering of the University of Patras. It has the ISO/EN 17020 and the ISO/EN 17025 certifications for mechanical testing and audits. Services provided by the lab are: mechanical and NDI testing, physical characterization, nano-particles fabrication, composite manufacturing, 3D printing, vibration and modal analysis, environmental testing and conditioning, micro-characterization and numerical analysis. Key projects include but are not limited to: Nano-modified fiber reinforced polymers in terms of mechanical, electrical and thermal properties (NANO) (ESA/ESTEC cooperation), Design, development, manufacturing and process monitoring for structures of nano-modified multifunctional materials targeting near term space applications (NANO2) (NANO) (ESA/ESTEC cooperation), Nano-enabled fiber reinforced plastics (NEFELI) (ESA/ESTEC cooperation) and Nanotube reinforced structural materials for spacecraft applications (NAREMA) (ESA/ESTEC & HPS cooperation). AMVL was also involved in the development of UPSat, the first open source satellite that was launched as part of the European QB50 Project.

**Athens Cosmic Rays Group - A.Ne.Mo.S (Athens Neutron Monitoring Station) - Dept. of Physics, Nuclear and Particle Physics Section, NKUA** (Attica Region - http://cosray.phys.uoa.gr/ ):

Segment: Ground Segment, System: User Operations

The Cosmic Ray Group is capable of providing GLE (Ground Level Enhancement) alerts and Multi-station data as federated products on behalf of all neutron monitor stations worldwide to the Space Radiation Expert Service Centre (R-ESC) through A.Ne.Mo.S. The group also offers the Dynamic Atmospheric Shower Tracking Interactive Model Application (DYASTIMA) tool.

**Computer & Communications Systems Laboratory - University of the Aegean** (North Aegean - https://icsdweb.aegean.gr/ccsl/):

Segment: Ground Segment, System: User Operations

CCSL performs research in various technological fields, including wireless and mobile telecommunications, optical communications through free space and fiber-based methods, network communications, design of digital circuits and systems design, as well as internet - worldwide web technologies. Selected projects include: SMART (Satellite Management Resources Tool - ESA) and DEGREES (Development and Evolution of the GREEk Governmental Satcom - ESA ARTES 4S).

**Control Systems Lab - NTUA** (Attica Region - https://csl-ep.mech.ntua.gr/):

Segment: Satellites and Probes, System: GNC

NTUA’s Dept. of Mechanical Engineering Control Systems Laboratory is active in the research areas of Legged Robots, Robotic Fish, Haptics, Microrobotics, Smart Piezomechanics, Unmanned Aerial Vehicles, Electrohydraulic Servosytems, Biped Robotics, Bio-Mechatronics, Soft Robotics and most importantly, Space Robotics. Key projects include: Autonomous Servicing of On-Orbit Space Systems from Robotic Systems (funded by the National Strategic Reference Framework), Identification and Assessment of Existing Terrestrial Micro-systems and Micro-technologies for Space Robotics (ESA) and

Obsidian – On-Board System Identification for Uncertainty Modelling & Characterization (ESA).

**Depend Research Team - AUTh (Aristotle University of Thessaloniki)** (Central Macedonia - https://depend.csd.auth.gr/):

Segment: Satellites and Probes, System: System Engineering Software

Depend belongs to the Computer Science Department of AUTh and has been involved in software engineering research for space applications. Indicative publication: Bozzano, M., Cimatti, A., Katoen, J.-P., Katsaros, P., Mokos, K., Nguyen, V. Y., Noll, T., Postma, B., & Roveri, M. (2014). Spacecraft early design validation using formal methods. In Reliability Engineering & System Safety (Vol. 132, pp. 20–35). Elsevier BV. https://doi.org/10.1016/j.ress.2014.07.003.

**Digital Systems and Computer Architecture Laboratory (DSCAL) - NKUA** (Attica Region - http://dscal.di.uoa.gr/):

Segment: Satellites and Probes, System: On-Board Data Management

DSCAL is part of the Department of Informatics & Telecommunications of the National and Kapodistrian university of Athens. The lab has heritage in fault tolerant computing, dependable computer architecture, on-line defect detection, fault tolerance and design validation of processors and processor-based System-on-Chips. DSCAL also focuses in space systems design and specifically on-board data handling systems, providing IP cores for image/data compression, channel coding and encryption. DSCAL was involved in the development of the ESA PROBA-3 Coronagraph System and specifically the ASPIICS Payload and the Hi-SIDE (High-Speed Integrated Satellite Data Systems For Leading EU IndustrY) - H2020 project, amongst others.

**Embedded Systems Laboratory (ESLab) - University of Piraeus** (Attica Region, Greece - http://eslab.cs.unipi.gr/):

Segment: Satellites and Probes, System: On-Board Data Management

The research focus of ESLab lies in developing testing, reliability, and security methodologies for embedded systems. This expertise is primarily centered around embedded processors and Field Programmable Gate Arrays (FPGAs), encompassing both hardware and software aspects. For example, the lab focuses on the characterisation of COTS (Commercial Off The Shelf) FPGAs and microprocessors with radiation and fault injection experiments, as well as studies of embedded systems and ICs (integrated CIrcuits) side-channel & fault-injection attacks. ESLab has been involved in ESA projects such as the Greek Cubesats In orbit Validation Projects [119], where it will develop and validate a Fault Detection, Isolation and Repair (FDIR) Strategy for the FPGA Accelerators of a CubeSat Payload and in the OSIP project Lockstep-SoC (2021-2023 Lockstep-based SEE mitigation approach for COTS SoC FPGAs).

**EO.Lab - Department of Geology - AUTh** (Central Macedonia - https://eolab.geo.auth.gr/):

Segment: Ground Segment, System: User Operations

EO.Lab focuses on research and education in the domains of Earth Observation and Geospatial Applications and Services. Key projects include: Earth Observation for Education (EO4Edu - Erasmus+ Project) and Copernicus for environmental law enforcement support (EnviroLENS - H2020).

**Internetworked Systems Lab - DUTh (Democritus University of Thrace)** (Eastern Macedonia and Thrace - http://www.intersys-lab.org/):

Segment: Satellites and Probes, System: On-Board SW

The InterSys Lab's research interests encompass various networking layers, such as transport, network, link, and middleware. Their research covers a wide range of topics, including the Next Generation Internet, Delay-tolerant Networking (DTN), Information-Centric Networking, Blockchains, the design and evaluation of transport protocols, routing and transport for disruptive networks, mechanisms for quality of service, congestion control, and reliability. Additionally, the Lab is interested in exploring security, algorithms, programming languages, and information retrieval. The research efforts of the Lab have potential applications in areas such as the Internet of Things, energy-saving protocols, and mobile devices, multimedia communications, space communications, Cloud and Web Computing, High Performance Internetworked Systems, and the Internet. Space related projects are: Extending Internet into Space - Phase 3: ESA/ESOC DTN/IP Testbed Deployment and Optimization, DISCOS: Distributed Information Storage and Communication in Outer Space (ESA), Space-Data Routers (FP-7 Project co-funded by the European Commission) and the establishment of the Space Internetworking Center (http://www.spice-center.org/).

**Lab of Electromagnetic Theory - DUTh (Democritus University of Thrace)** (Eastern Macedonia and Thrace - https://www.ee.duth.gr/en/instructor/sarris-theodoros/):

Segment: Satellites and Probes, System: Payloads / Instruments

The Lab of E/M theory of the Electrical and Computer Engineering department, Democritus University of Thrace, has extended heritage in space research and projects. These include but are not limited to Daedalus (proposed to ESA as for the EO programme's 10th Earth Explorer) and ReTiMo - Space weather monitoring nanosatellite: feasibility study (ESA). The lab has developed DUTHSat that was launched as part of the European QB50 Project and has participated in the development of the PEP instrument for the JUICE spacecraft.

**Laboratory of Forest Monitoring and Remote Sensing - AUTh** (Central Macedonia - https://fmrs.web.auth.gr/):

Segment: Ground Segment, System: User Operations

The FMRS laboratory of the School of Forestry & Natural Environment - AUTh, has conducted research in various areas including environmental resource management, monitoring vegetation dryness, modeling desertification, mapping soil erosion, assessing environmental degradation, studying landscape ecology, modeling forest fires, and monitoring biodiversity. This research has utilized Geographic Information Systems (GIS), Remote Sensing (RS), and Decision Support Systems (DSS). Key projects include: GIS and Remote Sensing for Sustainable Forestry and Ecology (SUFOGIS - Co-funded by the EU Erasmus + programme) and Forest Fire Daily Forecast (nationally funded).

**Laboratory of Remote Sensing - Dept. of Geophysics and Geothermics - NKUA** (Attica Region - http://www.remsenslab.geol.uoa.gr/index.html):

Segment: Ground Segment, System: User Operations

The Laboratory of Remote Sensing of the Department of Geophysics and Geothermics is involved in GPS measurements and Radar Interferometry, InSAR (PS and Stacking),

including satellite imaging analysis (LANDSAT, ASTER, IKONOS, QUICKBIRD) and Orthorectification. Key research projects include TERRAFIRMA - 3 : Pan-European Ground Motion Hazard Information Service (ESA and EU) and “Development of a state-of-the-art surveillance system for real-time monitoring of oil pollution” (Bilateral cooperation Greece-Germany, General Secretariat of Research and Technology, 2008-2009).

**Laboratory of Remote Sensing and GIS - University of the Aegean** (North Aegean - http://www2.env.aegean.gr/labs/Remote_sensing/EnglishBlock/Remote_sensing2.htm):

Segment: Ground Segment, System: User Operations

The Remote Sensing Laboratory of the Department of Environment - University of the Aegean, conducts research on environmental applications and has knowledge in the fields of topographic mapping, remote sensing, geographic information systems (GIS), GPS, Photogrammetry with UAS (Unmanned Aerial Systems), cartography, and new technologies, LIDAR and IFSAR UAS.

**Laboratory of Remote Sensing Spectroscopy and Geographic Information Systems (GIS) - AUTh** (Central Macedonia - https://labrsgis.web.auth.gr/en/):

Segment: Ground Segment, System: User Operations

The lab belongs to the Department of Hydraulics, Soil Science and Agricultural Engineering - School of Agriculture of AUTh and is dedicated to educational and research activities through the use of earthly, aerial and remote sensing methods for the production of EO data. Projects include: Development of a common intraregional monitoring system for the environmental protection and preservation of the Black Sea- ECO-Satellite (CBC Black Sea 2007-2013) and Merging Hydrologic models and EO data for reliable information on water - MyWater (FP7-SPA.2010.1.1.-04).

**Laboratory of Robotics and Automation - DUTh** (Eastern Macedonia and Thrace - https://robotics.pme.duth.gr/):

Segment: Satellites and Probes, System: GNC

The Laboratory of Robotics and automation belongs to the Production and Management Engineering department of Democritus University of Thrace. The lab performs research in the fields of robotics for industrial and service applications as well as industrial automation. Key projects include: “Novelty Or Anomaly HUNTER (NOAH)” - 2016, ESA and “Methods to Refine the Self-Localization of Planetary Rovers Using Orbital Imaging” - 2013, ESA.

**Marine Remote Sensing Group - University of the Aegean** (North Aegean - https://mrsg.aegean.gr/):

Segment: Ground Segment, System: User Operations

MRSG belongs to the Department of Marine Sciences - University of the Aegean. The group focuses on research regarding marine applications through the utilization of satellite and UAV data. Key projects include: SPOTS - Spectral properties of submerged and biofouled litter (ESA / 2020-2023), PLP - Plastic Litter Project (ESA / 2020-2022) and ARIA3 - ATLANTIC CITIES: smart, sustainable and secure ports and protecting the ocean (ESA / 2020-2023).

**Micro and Nano Technology Laboratory (MNTL Lab) - Department of Electrical and Computer Engineering - DUTh** (Eastern Macedonia and Thrace - https://mntlab.ee.duth.gr/en/ ):

Segment: Satellites and Probes, System: Power

MNTL performs teaching and research activities in the domains of Thin Film Technology, energy storage technology and microsensors technology. It occupies an area of 240 square meters and is in possession of equipment for: material fabrication, layers and device characterization, electrochemical cell manufacturing and characterization. Key ESA projects include: “High Specific Energy Lithium Cells for Space Exploration”(2014-2015) and “Future Lithium-ion technology: Development of advanced materials & Lithium-ion cells of space batteries”(2017-2019).

**Microprocessors Laboratory (Micro Lab) - NTUA (National Technical University of Athens)** (Attica Region - https://microlab.ntua.gr/):

Segment: Satellites and Probes, System: On-Board Data Management

Microlab is the microprocessors and digital systems laboratory of the Electrical and Computer Engineering Department - NTUA. Microlab performs research in the fields of reliability and fault-tolerance at the transistor, interconnect, circuit and system level, among others. The lab has extended heritage with activities targeting space applications. Key projects include QUEENS 1 and 2 ( “Quality Evaluation of European New SW for BRAVE FPGA”), and CAIRS21(““COTS AI Accelerators in Mixed-Criticality High-Performance Avionics for Reconfigurable Satellites: TPU versus Prominent Embedded Devices, Mitigation Techniques, SW Frameworks and AI/ML Model Uploading”), all funded by ESA.

**Optical Communications and Photonics Technology Laboratory (Optcomm Lab) - Dept. of Informatics and Telecommunications - NKUA** (Attica Region - http://www.optcomm2.di.uoa.gr/ ):

Segment: Satellites and Probes, System: Optical Communication

The Optcomm lab performs research in the domain of optical communications. In the year 2000 the Laboratory was certified with the ISO 9002 certificate for optical power and spectral measurements as well as OTDR (Optical Time-Domain Reflectometer) calibration. The research activities of the Laboratory cover the following areas: Photonic Devices and Integrated Circuits, Fiber Optics and High Speed Communication Systems, Optical Networks and Techno-economic Evaluation of Telecommunication Systems. The lab’s nvolvement in ESA projects includes the SAT4NET (satellite / terrestrial network integration - ESA) and Ultra-stable Frequency Reference Dissemination Across Commercially Deployed Fiber Networks.

**Radio & Satellite Communications Group - NTUA** (Attica Region - https://www.ece.ntua.gr/en/staff/176):

Segment: Ground Segment, System: Ground Station

The Radio & Satellite COmmunications Group of NTUA’s Dept. of Electrical and Computer Engineering performs research in the field of telecommunications. A key project is ALPHASAT: KA/Q band radio propagation measurements collection from European sites using the TDP5 Propagation Beacon (ESA).

**Remote Sensing and Image Processing Group - Department of Physics of NKUA** (Attica Region - http://en.env.phys.uoa.gr/fileadmin/env.phys.uoa.gr/uploads/Remote_Sensing.pdf):

Segment: Ground Segment, System: User Operations

The research group focuses in the study of climate change and meteorology through satellite remote sensing, environmental applications for urban environments and archaeological sites as well as environmental education. Key projects include but are not limited to: CLIMASCAPE (protection of archaeological sites from climate change through prevention, detection and management) and MASS (Motivate and Attract Students to Science). Finally, the group has been a national coordinator of the GLOBE (Global Learning and Observations to Benefit the Environment) programme.

**Remote Sensing Laboratory - NTUA** (Attica Region - https://www.survey.ntua.gr/en/departments/topo/topo-labs/rslab):

Segment: Ground Segment, System: User Operations

RS Lab belongs to the Department of Rural, Survey and Geoinformatics Engineering of NTUA and conducts research in applications of photo-interpretation and remote sensing including observing and monitoring Earth, conducting integrated surveys of the natural and socioeconomic environment and developing integrated cadastral land information systems. Key projects include: GERANIIUM: Generative Artificial Intelligence and Deep Learning for High Performing Inversion Models, ESA AO/1-9783/19/NL/AF, 2019-2022, BiCUBES: Analysis-Ready Geospatial Big Data Cubes and Cloud-based Analytics for Monitoring Efficiently our Land & Water, Hellenic Foundation for Research and Innovation, 2021-2024 and eOSD: An Intelligent Early-Warning Oil Spill Detection and Prediction System for the Arabian Gulf and the Red Sea, KAUST, 2020-2022.

**Remote Sensing Team - Department of Geography of HUA (Harokopio University of Athens)** (Attica Region - https://huaremotesensingteam.wordpress.com/):

Segment: Ground Segment, System: User Operations

The RS team of HUA belongs to the Department of Geology and focuses on research in the area of Earth Observation applications. Key projects are: High resolution SAR Interferometry for monitoring the Rio-Antirio Bridge (Western Greece) : a case study in the frame of Terrafirma-X project (German Aerospace Center - DLR 2010-2011), Ground Deformation Studies in the Central Ionian Islands (Greece) using Time Series Interferometry - ESA, 2010-2012, and Novel methodologies for the assessment of risk of ground displacement, bilateral project Greece-China, General Secretariat of Research and Technology, 2012-2015.

**SenseLab - Technical University of Crete** (Crete - http://senselab.tuc.gr/):

Segment: Ground Segment, System: User Operations

SenseLab belongs to the Dept. of Mineral Resources Engineering, Technical University of Crete. SenseLab's research focuses in the domains of Geographic Information Systems, Remote Sensing and Unmanned Aerial Vehicles. Key projects include: Monitoring ground subsidence due to ground and underground mining activities in Northern Greece, 2012 (ESA), Drones2GNSS (High precision position measurement in urban environment through development of special algorithms and drones / nationally co- funded) and RescueNET (a

mobile app that integrates EO and social data for better management in emergency situations through collaborative environments).

**Space Physics Group - Department of Physics of NKUA** (Attica Region - http://www.space.phys.uoa.gr/):

Segment: Ground Segment, System: User Operations

The space physics group of NKUA conducts research in domains such as space weather, magnetospheric, solar and Interplanetary physics. Additionally, it aims to train students in the above topics. Selected projects include: Safespace - Radiation Belt Environmental Indicators for the Safety of Space Assets (2020-2022) /H2020, HERMES - Hellenic Evolution of Radiation data processing and Modelling of the Environment in Space (2015-2018) / ESA and MAARBLE - Monitoring, Analyzing and Assessing Radiation Belt Loss and Energization (2012-2014) /FP7-Collaborative project.

#### 3.4.1.1.3 Student teams

**Aristotle Space & Aeronautics Team (ASAT) - AUTh** (Central Macedonia - https://asat.gr/): ASAT is a student team originating from the Aristotle University of Thessaloniki and its goal is making the aerospace discipline known to academia and general public. The team conducts research through two departments - Aeronautics and Rocketry, through which it created UAVs and Rockets respectively. It has participated in competitions such as Spaceport America Cup 2021 Virtual, European Rocketry Challenge 2021, Spaceport America Cup 2022 and the Air Cargo Challenge 2022 where it has achieved high ranking positions.

**ASPiRE - University of West Macedonia** (Western Macedonia - https://aspire.uowm.gr/en/): ASPiRE is an aerospace engineering team that belongs to the University of West Macedonia. The team has developed rocket and UAV technology. It has competed in CanSat Greece 2019, CanSat Greece 2020 and Spaceport America Cup 2021 Virtual.

**Beyond Earth Aristotle Missions (BEAM) - AUTh** (Central Macedonia - https://beamproject.gr/): BEAM is a student team from Aristotle University of Thessaloniki that is active in space research and the first Greek student team to be selected for a REXUS/BEXUS programme. Selected projects from BEAM include: DROPSTAR (study of oil droplet coalescence events that take place in an emulsion, in microgravity conditions - REXUS / BEXUS), ASTRO – Aristotle Student Telescope for Radioastronomy Observations, SHADE (SDR Helix Antenna Deployment Experiment - REXUS / BEXUS), LIGHT (Lunar Navigation Helmet - INGLUNA Programme) and ECOWISE (Ecological COmputations WIth low-coSt sEt-up - REXUS / BEXUS).

**Spacedot - AUTh** (Central Macedonia - https://spacedot.gr/): Spacedot is a team that belongs to Aristotle University of Thessaloniki that develops AcubeSAT, as part of ESA's "Fly Your Satellite! 3" initiative. ACUBEsat is a nanosatellite that will include a pressurized vessel built in-house. This vessel will contain a microscopic assay and a lab-on-a-chip, which will enable the growth of the yeast Saccharomyces Cerevisiae. The purpose of this experiment is to investigate how radiation and microgravity conditions in low Earth orbit affect the growth of the yeast.

**SpaceGates - NKUA** (Attica Region - https://spacegates.wordpress.com/): SpaceGates is a student team from the Department of Physics - NKUA, whose goal is the dissemination and popularization of Space and Astrophysics.

**White Noise - NTUA** (Attica Region - https://whitenoiserocketry.gr/): White Noise is an aerospace engineering team that belongs to the National Technical University of Athens. Projects of the team include CRONOS, a hybrid-fueled sounding rocket and ICARUS, a low-cost and self-sufficient probe that can gather and transmit information about the conditions on an unexplored planet (oxygen, moisture, and carbon dioxide), as well as generate a 3D map of the planet's surface to provide a comprehensive view of its topography. ICARUS won the 2nd place in CanSat Greece 2019.

### 3.4.2 Research Centers

Various research centers are operating in Greece, with a significant number of these institutions involved with space activities or having heritage with research projects that are relevant to the domain. The aforementioned entities are introduced in the following list.

**Advanced Ceramics and Components Laboratory (ACCL) - Institute of Nanoscience and Nanotechnology - National Center for Scientific Research (NCSR) Demokritos** (Attica Region - http://accl.inn.demokritos.gr/):

Segment: Orbital Transportation and Re-entry Vehicles, System: Structures

ACCL is part of the NCSR Demokritos and one of its areas of focus is space technologies. Over the past few years, the laboratory has been highly engaged in space technology research, thanks to European funding, with the overarching goal of creating innovative technologies to aid in space exploration. Its primary focus lies in researching and developing novel materials and systems that can provide thermal protection for robotic exploration craft during their entry into planetary atmospheres. Key projects are HYDRA (FP7/Space-2011-1/283797 "Hybrid ablative development for re-entry in planetary atmospheric thermal protection") and IRENA (IRENA "International Re-Entry demoNstrator Action" - Horizon 2020).

**Atmospheric Chemistry and Physics Group (APCG)** - **Institute for Environmental Research and Sustainable Development (IERSD) - National Observatory of Athens** (Attica Region - https://www.iersd.noa.gr/en/groups/atmospheric-chemistry-and-physics-group-apcg/ ):

Segment: Ground Segment, System: User Operations

APCG's main scientific directions are air quality research, earth system processes and climate, environment and health as well as Earth Observation, policy and urban perspectives. APCG has been involved in studies such as ESA's QA4EO – Quality Assurance for Earth Observation and ESA's GAUSS – Generating Advanced Usage of Earth Observation for Smart Statistics.

**BEYOND unit - centre of EO research and satellite remote sensing - IASAARS** (Attica Region - http://beyond-eocenter.eu/ ):

Segment: Ground Segment, System: User Operations

Within IASAARS operates the BEYOND unit. The unit provides disaster management services based on EO products addressing needs in Europe, the Mediterranean region, North Africa, the Middle East and the Balkans. It is compliant to European Copernicus and ESA standards. The BEYOND Unit's main focus lies in providing emergency response and support services during times of crisis, as well as promoting preparedness and recovery in accordance with Copernicus EMS standards. Additionally, the unit works towards safeguarding the sea and atmospheric environment, as well as addressing various advanced issues such as agriculture and food security, access to renewable energy and climate resilience and adaptation.

**Laboratory of Geophysics - Satellite Remote Sensing & Archaeoenvironment (GeoSat ReSeArch Lab) - Institute of Mediterranean Studies (IMS) - Foundation for Research and Technology Hellas (FORTH)** (Crete - https://www.ims.forth.gr/en/department/view?id=7):

Segment: Ground Segment, System: User Operations

The GeoSat ReSearch Lab performs research in the field of geoinformatics, targeting cultural and natural environment topics. Key projects include: KRIPIS-POLITEIA II (Politismos-Technologia, New Technologies in the Research, Study, Documentation and Access to the Information for Cultural Heritage Objects and Monuments II), KRIPIS-PERAN and Archaeo-FormoSat.

**Laboratory of Process Systems Design and Implementation (PSDI) - Chemical Process Engineering and Energy Resources Institute (CPERI) - Centre for Research and Technology - Hellas (CERTH)** (Central Macedonia - https://psdi.cperi.certh.gr/):

Segment: Satellites and Probes, System: Power

The PSDI lab focuses on research in the area of modeling, design, optimization and control of chemical and energy conversion processes. PSDI has participated and developed infrastructure and technology in the following domains: design and construction of process systems, modeling, control and optimization of systems and processes, development of electrochemical process systems, development of thermochemical and catalytic processes for energy, fuels and chemicals production, BTL processes and hydrogen production from RES. Key projects are: “Development of a closed loop regenerative HT-PEM Fuel Cell System” (ESA), “Regenerative fuel cells for Mars exploration“ (ESA), “Feasibility of Regenerative PEM Fuel Cell (RPEMFC) for space applications”(ESA).

**Industrial Systems Institute - Athena Research and Innovation Center** (Western Greece - https://www.isi.gr/):

Segment: Ground Segment, System: User Operations

ISI is the institute of the Athena Research center that focuses in conducting research on Information and Communications Technology (ICT) for the Greek as well as for the European industry. Its research areas include intelligent systems and robotics, cyber-physical and networked embedded systems, manufacturing systems and processes and enterprise information systems, autonomous interactive systems and machine intelligence, security and protection of systems, networks and infrastructure and advanced materials and structures. Key projects that ISI has been involved in include ESA DISCOS, which is about security in delay-tolerant networks and MENELAOS (Micro Sensor Technologies for

Navigation Space Applications), a si-cluster project targeting the development of a navigation system for satellites and spacecraft that is based in an inertial measurement unit.

**Information Technologies Institute - CERTH** (Central Macedonia - https://www.iti.gr/iti/en/home/):

Segment: Ground Segment, System: User Operations

ITI is active in research in the fields of informatics, telematics and telecommunications. Its research sectors are comprised by the Computational Perception and Interaction Sector and the Multimedia, Networks and E-services sector. Its infrastructure includes an additive manufacturing research unit and a smart home research infrastructure. Key projects that ITI has been involved in are: WQeMS — Copernicus Assisted Lake Water Quality Emergency Monitoring Service (H2020), CALLISTO — Copernicus Artificial Intelligence Services and data fusion with other distributed data sources and processing at the edge to support DIAS and HPC infrastructures (H2020), PestNu — Field -testing and demonstration of digital and space based technologies with agro-ecological and organic practices in systemic innovation (H2020), EOTiST — Earth Observation Training in Science and Technology at the Space Research Centre of the Polish Academy of Sciences (H2020), SnapEarth — Fostering Earth Observation market uptake thanks to natural and holistic access to added value data generated through cutting-edge Artificial Intelligence technologies (H2020) and 7SHIELD — Safety and Security Standards of Space Systems, ground segments and Satellite data assets, via prevention, detection, response and mitigation of physical and cyber threats (H2020).

**Institute of Chemical Engineering Sciences (ICEHT) - FORTH** (Western Greece - https://www.iceht.forth.gr/):

Segment: Satellites and Probes, System: Power

ICEHT's research and development fields are Nanotechnology - Advanced Materials, Energy - Environment and Biosciences - Biotechnology. In the domain of Energy - Environment, it has developed a 1 kW High Pressure Electrolyser for space applications in the context of the ESA project "Development of a Closed Loop Regenerative HT PEM Fuel Cell System".

**Institute of Computer Science (ICS) - FORTH** (Crete - https://www.ics.forth.gr/):

Segment: Satellites and Probes, System: On-Board SW

ICS is one of FORTH's institutes and focuses on research revolving around the Information Society, aiming to advance it in national and European level. Its laboratories and facilities include: the computer architecture and VLSI systems laboratory, the Computational BioMedicine Laboratory, the Computational Vision and Robotics Laboratory, the Distributed Computing Systems and Cybersecurity laboratory, the Human Computer Interaction laboratory, the Information Systems Laboratory, the Telecommunications and Networks lab and the Signal Processing Laboratory. Other important features of ICS are the ambient intelligence programme that aims to provide human centric AmL technologies and smart environments, the registry of .gr domain names and the Department of Systems and Networks. Indicative key projects in which ICS FORTH has been involved in are the ESA Multi Frame Super Resolution Experiments, the ESA Cognitive Cloud Dual Camera, CALCHAS (Computational Intelligence for Multi-Source Remote Sensing Data Analytics -

H2020) and PHySIS (project about developing, testing and evaluating novel signal processing technologies for real-time processing of hyperspectral data cubes - H2020).

**Institute of Electronic Structure and Laser (IESL) - FORTH** (Crete - https://www.iesl.forth.gr/):

Segment: Satellites and Probes, System: Optical Communication

IESL since its founding in 1983 has been performing research and training in the fields of Laser Science, Micro/nano-electronics, Polymer Science, Materials Science and Astrophysics. Its research divisions are the following: Applied Photonics & Light-Matter Interactions, Soft Matter, Fundamental Photonics and NanoElectronics, Photonic and Quantum Materials. Key projects include SIDLOC in collaboration with the Libre Space Foundation and the collaboration with ESA for the development of solutions for beam steering on compact optical breadboards.

**Institute of Informatics & Telecommunications (IIT) - National Centre for Scientific Research "Demokritos"** (Attica Region - https://www.iit.demokritos.gr/):

Segment: Satellites and Probes, System: RF / Microwave Communication (Platform and Payloads)

IIT is active in the research areas of artificial intelligence and telecommunications. Its two divisions are the Division of Telecommunications and Networks which includes the Media Networks Lab (MNL), the Telecommunications Network Lab (NeL) as well as the Wireless Communications Lab (WiCom) and the Division of Intelligent Information Systems which includes the Software Engineering Lab (SKEL The AI Lab) and the Computational Intelligence Lab (CIL). Key projects in which IIT has been involved in are the Horizon AI4Copernicus (Reinforcing the AI4EU Platform by Advancing Earth Observation Intelligence, Innovation and Adoption) and the ESA DELHILA (Deployable high gain antenna structure for small spacecraft science mission).

**Ionospheric Group - IASAARS** (Attica Region - http://www.iono.noa.gr/):

Segment: Ground Segment, System: User Operations

The ionospheric group of IASAARS provides academic and operational users with data and products for monitoring, specifying, forecasting, and making long-term predictions about ionospheric conditions over Europe. Key projects include: Space Weather Precursor Services Operations (SN-IV3) European Ionosonde and Neutron Monitor Network - ESA, Warning and Mitigation Technologies for Travelling Ionospheric Disturbances Effects (TechTIDE) - European Commission and Plasmasphere Ionosphere Thermosphere Integrated Research Environment and Access services: a Network of Research Facilities (PITHIA-NRF) - European Commission.

**Office of Space Research and Technology, Academy of Athens** (Attica Region - http://www.academyofathens.gr/en/research/office/space):

Segment: Ground Segment, System: User Operations

The Office engages in research and public outreach activities related to Space and Magnetospheric Physics, Planetary Physics and Plasma Physics. The team analyzes data provided by ongoing space missions, collaborates with institutions such as the Applied Physics Laboratory (APL) of the Johns Hopkins University in the U.S.A., the Max Planck Institut für Sonnensystemforschung in Germany, and the Centre d' Etude Spatiale des

Rayonnements in France. The Office publishes their research through articles in refereed international scientific journals, books, and contributions in international scientific conferences worldwide. Additionally, the Office organizes scientific meetings, seminars, and presentations for the scientific community (seminars of the Academy of Athens, lectures at Educational Institutes of Greece) and the public (open talks, interviews with the media). Its members also supervise graduate students in Space Physics-related subjects.

**Orion Lab Research Group - IASAARS** (Attica Region - https://orionlab.space.noa.gr/):

Segment: Ground Segment, System: User Operations

The Orion Lab research group operates within IASAARS and performs research on AI for EO data. Key projects include but are not limited to: Deepcube - explainable AI pipelines for Big Copernicus Data (H2020) and SeasFire (Earth System Deep Learning for Seasonal Fire Forecasting in Europe - ESA).

**Remote Sensing Laboratory - Institute of Applied and Computational Mathematics - FORTH** (Crete - http://rslab.gr/):

Segment: Ground Segment, System: User Operations

RS Lab's main focus lies within the climate change and urbanization areas of application, and the research performed addresses both urban as well as natural environments. RS Lab also provides remote sensing services to public organizations and institutions. Key projects include: H2020 Harmonia (development of platform with tools to predict climate change effects), BLENDED (ESA project investigating the application of technologies that enable the secure, valuable and efficient collaboration of data and algorithms) and EO4UTEMP (ESA-funded Living Planet Fellowship, development of a novel Urban Surface Temperature - UST algorithm exploiting Earth Observation data).

**Research Center for Astronomy and Applied Mathematics, Academy of Athens (RCAAM)** (Attica Region - http://astro.academyofathens.gr/index.html ):

Segment: Ground Segment, System: User Operations

The Research Center for Astronomy and Applied Mathematics (RCAAM), is part of the Academy of Athens. Its core competencies include Galactic Dynamics and Galactic Morphology, Nonlinear Dynamics and Chaos Theory, Solar Physics, Magnetohydrodynamics, Cosmology and Gravitation. Key projects include the Athens Effective Solar Flare Forecasting for ESA's SSA SWE segment and FLARECAST (Flare Likelihood And Region Eruption Forecasting - H2020).

**Space Programmes Unit - Athena Research and Innovation Centre** (Attica Region - https://www.athena-spu.gr/ ):

Segment: Satellites and Probes, System: Other

The SPU of the Athena Research and Innovation Center is a not-for-profit, non-civil service unit, that aims to promote involvement of the Greek space ecosystem in space activities. It is organized into three areas, the Systems Engineering, the Program Management and the Strategic Cooperation with Industry and Other Organizations domains. The Athena SPU has been involved in multiple ESA projects, such as Daedalus, a low flying spacecraft for the exploration of the Earth's upper atmosphere and GLEME (Global Lidar Exploration of the MEsosphere) mission concept.

**Space Weather Operational Unit - IASAARS** (Attica Region- https://www.astro.noa.gr/en/operational-services/monada-diastimikoy-kairoy/ ):

Segment: Ground Segment, System: User Operations

IAASARS hosts the Space Weather Operational Unit. The unit operates tools such as HESPERIA REleASE that provides prediction of 30-50 MeV solar energetic protons in geospace and the HESPERIA UMASEP-500 that provides ground detection of events in real-time for high energy protons, with energies ranging above 500 MeV. The forecasts are available through the website http://www.hesperia.astro.noa.gr. NASA has designated the HESPERIA tools as a high priority for global inclusion in the simulation of crewed missions to the Moon and Mars. The tools were developed as part of the H2020 “High Energy Solar Particle Events foRecastIng and Analysis” project with NOA coordinating the consortium.

### 3.4.3 Observatories

The observatories in Greece are an important part of the Greek space strategy. Greece participates in programmes that involve optical telescopes, such as EU SST and EuroQCI. In addition, the Helmos, Holomon and Skinakas observatories infrastructure has been chosen to be upgraded for optical and quantum communications through the ESA ScyLight programme and the Greek Connectivity Optical Ground Stations initiative. The following list captures Greece’s ground segment assets.

**Eudoxos Astronomy Complex** (Ionian Islands - https://astro-eudoxos.org/): Research Foundation of Kefallinia (RFK) Eudoxos administers the Eudoxos Astronomy Complex, which is made up of two main components: the "Ainos Astronomy Base" and its Satellite Space Station “G. Lykoudis." It is placed around the Ainos mountain plateau at an altitude of 1070 m. Its 3 main telescopes are the TCC 1.4 m Cassegrain telescope, the TAM 0.6 m Cassegrain telescope and the TVD 0.51 m Ritchey-Chrétien telescope.

**Holomon Astronomical Station** (Central Macedonia - https://www.astro.auth.gr/n/?p=holomon_station): The Holomon observatory is located near the village of Taxiarchis, Chalkidiki at an altitude of about 850m. It hosts a 40 cm CDK / “L - mount” telescope [120]. The observatory is used for research, outreach and training of students. It is set to be upgraded for optical communications and quantum key reception through ESA - ScyLight [121] and through the Greek Connectivity Optical Ground stations programme. The Holomon site is one of the three sites of observatories for AUTh, with the other two located in Thermi, Greece and Prodromos, Cyprus respectively.

**Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing - National Observatory of Athens (IAASARS) infrastructure** (Based in Attica Region - https://www.astro.noa.gr/en/): IAASARS is a major research institute for space related topics in Greece and focuses in observational astrophysics - cosmology, solar & terrestrial environment - space physics as well as remote sensing and machine learning for signal / image processing. Its available infrastructure includes:

- Helmos Observatory - Aristarchos 2.3 m lens Ritchey-Chrétien optical telescope. It is located in one of the darkest areas of continental Europe, 2430 m above sea level in Mt. Helmos. It is used for the observation of astronomical objects. The Aristarchos telescope was the first ground station chosen by ESA for the ScyLight programme,

with the equipment for optical communications with satellites installed in 2021. It is also foreseen for the observatory to be further upgraded through the Greek Connectivity Optical Ground Stations ESA programme.

- Kryoneri Observatory - 1.2 m Cassegrain reflector telescope located at the top of Mt. Killini at about 900m altitude. Upgraded in 2016 through the ESA NELIOTA program, to monitor the surface if the Moon for NEO (Near Earth Objects) impacts.
- Newall Telescope - 62.5 cm lens refractor telescope located at NOA facilities in Penteli. It is used for public outreach purposes.
- Doridis Telescope - Pefractor with double achromatic lenses of 40cm diameter and a focal length of 5m. Used for public outreach purposes. Located in Athens, Greece.
- Meteosat 2nd generation Ground station - Receives images from the MSG - SEVIRI system. Used for detecting, monitoring and mapping wildfires with a 5 minutes latency.
- X/L band satellite acquisition station - reception, acquisition, and processing of signals from satellites including the EOS Aqua & Terra (MODIS – Moderate Resolution Imaging Spectroradiometer), the NPP (VIIRS, ATMS, etc), the NPOESS, the NOAA, the FYI, and the MetOP satellites. The system can be used for geo-hazard activity monitoring, urban heat island mapping, smoke dispersion forecasts, aerosol pollution indices assessment, issuing of volcanic ash and dust alerts as well as wildfire detection and monitoring.
- Geomagnetic array ENIGMA (HellENIc GeoMagnetic Array) - ENIGMA collects data for the examination of geomagnetic pulsations caused by the connection between the solar wind and magnetosphere, utilizing a trio of ground-based magnetometer stations located in Greece's Trikala (Klokotos), Attiki (Dionysos), and Lakonia (Velies).
- Athens Digisonde portable sounder - Utilized for remote sensing of the Earth's ionosphere, the Digisonde is a digital portable sounder, equipped with four receiving antennas (DPS-4) positioned at a distance of approximately one wavelength from one another.
- Atmospheric remote sensing station - IAASARS has been utilizing a ground-based Atmospheric Remote Sensing Station (ARSS) to monitor aerosol pollution and ground solar radiation levels within the Athens city area. Positioned at an altitude of 130 m above sea level on the roof of the Biomedical Research Foundation of the Academy of Athens (located at 37.9 N, 23.8 E), the ARSS site is situated in proximity to the city center and approximately 10 km away from the sea. The ARSS station is furnished with a CIMEL CE318-NEDPS9 solar photometer, which enables the retrieval of aerosol optical depth at eight different wavelengths spanning from 340 to 1640 nm, including polarization observations. The CIMEL instrument is an element of NASA's AERONET (Aerosol Robotic Network). The data generated from ARSS are processed daily and can be accessed on AERONET's website, including aerosol inversion retrievals that are beneficial for characterizing aerosols, such as Saharan dust advection, smoke, or volcanic ash episodes. Additionally, the ARSS has a UV-MFR instrument for measuring radiation in the UV spectral region.

- PANGEA (PANhellenic GEophysical observatory of Antikythera). It is a sustainable climate observatory at the island of Antikythera (35.861N, 23.310E, 110m a.s.l). The system meets the ACTRIS RI's optimal specifications and includes a multi-wavelength lidar, which operates continuously at Antikythera, a NASA-AERONET sunphotometer, a UV-MFR (Ultraviolet Multi-filter Radiometer), a Direct-sun Solar Polarimeter (SolPol), and a Field Mill Electrometer (JCI 131 FM).
- Wall-E and EVE LIDARs for atmospheric measurement.
- Connectivity infrastructure - Connected to the internet via the Greek Research and Technology network, with a speed of 1 Gbps. The Helmos Observatory connects to the wide area network through optical fiber, backed up by a wireless antenna connection.

**Mythodea Observatory** (Western Greece): The Mythodea Observatory belongs to the University of Patras, has a 0.35 m telescope [122] and it is used for scientific research.

**Skinakas Observatory** (Crete - https://skinakas.physics.uoc.gr/en/): Skinakas is a research facility operated jointly by the Institute of Astrophysics - FORTH and the Dept. of Physics - University of Crete. The observatory hosts a 1.3m modified Ritchey–Chrétien telescope, a 0.6m robotic Cassegrain telescope and a 0.3m Schmidt-Cassegrain telescope. It is located at an altitude of 1750m in Mount Ida, Crete. The main goal of the observatory is to perform basic investigations in astrophysics and encourage astronomy among the general public and students in Greece. The observatory will be upgraded for optical and quantum communications through ESA via the ScyLight programme [123] and through the Greek Connectivity Optical Ground Stations programme as well.

### 3.4.4 Other

**Corallia** (Attica Region - https://corallia.org/): Corallia is a think tank foundation, part of the Athena Research center, that drives innovation ecosystems in national and regional level in Greece. It focuses on the management of clusters, incubators and entrepreneurship programmes. Corallia has founded the si-cluster (Space Technologies and Applications Cluster) which aims to promote innovation in the space domain and foster industry and academic cooperation and coordination.

**ESA Business Incubation Center (BIC) Greece** (Attica Region - https://www.esa-bic.gr/): ESA BIC Greece is responsible for providing support to startups involved in space activities. Some of the benefits that ESA BIC offers are financial support, office spaces, training, infrastructure and equipment, networking and technical and business support.

**ESA Permanent Facility for Altimetry Calibration (PFAC) validation station** (Crete - https://www.esa.int/ESA_Multimedia/Images/2020/11/Crete_Greece?TB_iframe=true&width=370.8&height=658.8): A station dedicated to the calibration of radar altimeter data, situated in the island of Gavdos, south of Crete. Western Crete has the advantage of unique positioning of the Copernicus Sentinel - 3 and Sentinel - 6 crossing points. The station is complemented by a calibration/validation site in the Cretan mountains.

**Hellenic Aerospace Industry** (Attica Region, Greece - https://www.haicorp.com/en/):

The Hellenic Aerospace Industry was founded in 1975 and is responsible for maintenance and research & development programmes related to military applications. In the recent years

the intention to boost local space upstream capabilities concluded in the “Greek CubeSats in Orbit Validation Projects” and the “Upgrade to HAI (Hellenic Aerospace Industries) Assembly, Integration and Testing (HAIT) Facilities” ITTs [124]. The former mentions explicitly the need to use as much as possible the HAI facilities during the CubeSat assembly, integration and testing phase. The latter involves an upgrade to the HAI facilities to further boost upstream capabilities, targeting assembly, integration and testing of satellites.

**Hellenic Space Center (HSC)** (Attica Region - https://hsc.gov.gr/en/): Hellenic Space center is a governmental organization responsible of coordinating public and private entities in Greece regarding the country’s space activities. Further, its goals include design as well as management of projects and programs, promotion and dissemination of the Greek space strategy and representation in space-related international fora and groups, design and operation of space systems, provision of training to students, researchers and officials for space-related issues, advisory function to the Ministry of Digital Governance, the de facto responsible entity for space in Greece, regarding space issues as well as exploitation of the country’s rights in space assets of any kind.

**Satellite Ground Station in Tanagra** (Central Greece): A ground station for receiving Helios 2 data is located in Tanagra - 114th Combat Wing.

### 3.4.5 Industry

Numerous companies that are dedicated to or include space activities in their operations are located in Greece. A prominent organization in the private sector is the Hellenic Association of Space Industry, which aims to foster collaboration between the space technology and applications industrial entities domestically and internationally. Moreover, the Association targets the promotion of European and international collaboration for space activities and the optimization of the Greek industry participation in national and European space activities. Finally, HASI aims to contribute to the promotion of research and development activities in the space sector. As of 13 August 2023, HASI was consisted of the most prominent and active private entities in the Greek space industry, with the total members amounting to 56 [125].

#### 3.4.5.1 Industrial Entities

Following is a compilation of private entities that undertake space activities in Greece, in alphabetic order.

**Adamant Composites** (Western Greece - https://space.adamant-composites.com/):

Segment: Satellites and Probes, System: Structures

Adamant Composites specializes in advanced materials and structures. Its main activities focus on composites manufacturing, deployable technologies, novel materials and processes, mechanical ground support equipment and engineering support (design & analysis). Some of the main products of the company are CFRP (carbon fiber-reinforced plastic) sandwich panels, lightweight stable large deployable truss, Nano-enabled prepreg for improved CFRP structures, CFRP struts, deployable antenna for small satellites and Nano-enabled adhesives.

**Advent Technologies S.A.** (Attica Region - https://www.advent.energy/):

Segment: Satellites and Probes, System: Power

Advent Technologies belongs to the Advent Holdings Inc. Group which has an international presence. The group focuses on producing fuel cells and addresses the power generation, automotive, aviation, defense, oil & gas and marine markets. Key products are the M-ZERO, SERENEU and Honey Badger 50 fuel cells. Advent has been involved in projects such as: “Development of a closed loop regenerative HT-PEM Fuel Cell System” - delivery of a high-temperature proton exchange membrane (“HT-PEM”) stack to ESA and the ESA “Regenerative PEM Fuel Cells” project.

**ADVEOS** (Attica Region - https://adveos.com/):

Segment: Satellites and Probes, System: RF / Microwave Communication (Platform and Payloads)

ADVEOS implements wireless and satcom communication systems. The company is involved in analog IC design, Digital IC design, System engineering, embedded firmware and research. Its key products are ADV361 (Bluetooth low energy locator) and ADV6231 (Wi-Fi 6E & Bluetooth / Ble SoC).

**Akronic** (Attica Region - https://www.akronic.com/ ):

Segment: Satellites and Probes, System: On-Board Data Management

Akronic designs RF/mmWave and analog/mixed-signals custom integrated circuits in CMOS and BiCMOS technologies. Their stated services can target applications from DC to up to 100 GHz and include aerospace industry as part of their customer base. Other industries addressed are telecom, automotive and internet of things (IoT). Their end to end services can start from system definition to complete chip development and any of the steps in between. Specifically, the stated services are: Schematic-level design of a block (e.g. Low-Noise Amplifiers, Low Pass Filters, Voltage Controlled Oscillators, Received Signal Strength Indicators etc.) or sub-system (e.g. transmitter, receiver, Phase Locked Loop, Analog to Digital Converter, etc.), physical implementation (layout), chip top-level integration and verification and packaging selection and design of chip-to-PCB transition for operation at mm-Wave frequencies.

**Alma Technologies** (Attica Region - https://www.alma-technologies.com/**):**

Segment: Satellites and Probes, System: On-Board Data Management

The company is involved in IP cores for FPGA development and ASIC design. Its key products are image and video compression IP cores, cryptographic function, SPI bus and flash memory controller IP cores. An Alma Technologies JPEG encoder IP core was used on board the Mars Curiosity Rover Malin Space Science Systems (MSSS) camera system. Another key product is the CCSDS 122.0-B-1 IP core encoder, that is used for data compression in space applications.

**AlongRoute** [ESA BIC Greece] (Central Macedonia - https://alongroute.com/):

Segment: Ground Segment, System: User Operations

AlongRoute delivers highly precise marine forecasts for weather routing solutions through AI implementation to lead to a more sustainable and safer maritime scheme. Currently, the

company offers high resolution forecasts with a period of one hour regarding waves, winds and sea currents.

**Attisat S.A.** (Attica Region):

Segment: Ground Segment, System: Ground Station

Attisat is active in the field of satellite communications and specifically ground station components. The company has also been involved in the CRETIAS project for ESA's Secure Satcom for Safety & Security (4S) [126].

**BitRezus** [ESA BIC Greece] (Attica Region - https://bitrezus.com/):

Segment: Satellites and Probes, System: On-Board SW

BitRezus implements blockchain technologies to secure space assets and space operations. A key project of the company is Astropledge, a layer to prevent and monitor cyber attacks on satellites by using smart contracts and blockchain.

**Caius** [ESA BIC Greece] (Epirus Region - https://www.caius.gr/):

Segment: Ground Segment, System: User Operations

Caius develops EO products using AI techniques and computational methods. A key product of the startup is Caius Paths, an application that aims to map out the paths in nature for different areas of Greece using AI and satellite data.

**Circuits Integrated Hellas** [ESA BIC Greece] (Attica Region - https://www.circuitsintegrated.com/):

Segment: Satellites and Probes, System: RF / Microwave Communication (Platform and payloads)

CI offers innovative solutions for the Satcom, 5G and IoT industries. Its designs include analog, digital, mixed signal, RF and mm Wave ICs. The company has designed 10+ IP products including phase shifters, VCOs and a chipset for analog beam forming. One of IC's key products is the next generation and proprietary Monolithic Microwave Integrated Circuit (MMIC) that targets satcom on the move applications, among others.

**Cloud Signals** [ESA BIC Greece] (Attica Region - https://cloudsignals.eu/):

Segment: Ground Segment, System: User Operations

Cloud Signals targets the development of state-of-the art digital technologies inspired by space to anticipate market demand and create innovative solutions. Key projects in which Cloud Signals has been involved in are 5G backhaul network as a service and the ESA 4S project "Development and evolution of the Greek satcom network". Their key product is Network as a Service (NaaS) 5G Cellular backhaul on GEO and LEO satellites that can be combined with cloud based services and virtualizations.

**Consortis** (Central Macedonia - https://www.consortis.gr/en):

Segment: Ground Segment, System: User Operations

Consortis focuses on land engineering surveys and consultancy services. The company also provides related applications. Consortis offers geospatial services such as GIS application development, spatial data management and 3D analysis, EO services and cadastre-land administration. The company's key applications include but are not limited to:

development of a recording and management geoinformation system for road networks - MOBIROAD, Real Estate Management - LANDIFY and MAPtheYA - Water and Sewer Network Management Application.

**Draxis** (Central Macedonia - https://draxis.gr/):

Segment: Ground Segment, System: User Operations

Draxis develops environmental ICT products and services. A key product of the company is envi4all, a mobile application that informs about current, forecasted and historical air pollution levels. They have contributed in a number of EO-related projects, which include but are not limited to: H2020 EIFFEL (Revealing the role of GEOSS as the default digital portal for building climate change adaptation and mitigation applications), H2020 CALLISTO (Copernicus Artificial Intelligence Services and data fusion with other distributed data sources and processing at the edge to support DIAS and HPC infrastructures) and H2020 ENVISION (Monitoring of Environmental Practices for Sustainable Agriculture Supported by Earth Observation) and H2020 APOLLO (Advisory platform for small farms based on earth observation).

**ELFON LTD** (Attica Region - https://www.elfon.gr/):

Segment: Satellites and Probes, System: Electronics

ELFON develops wiring harnesses and electromechanical assembly. The company provides end to end services: product design, component specification and procurement, tooling design, construction and verification, manufacturing, testing, packaging and delivery, on-board installation and product documentation. Key product manufacturing includes: power harnesses, signal harnesses, fiberoptic assemblies and spacewire assemblies. ELFON is responsible for delivering the harnessing for the 26 digital cameras of the PLATO spacecraft.

**EMTECH SPACE** (Attica Region - https://emtech.global/space/):

Segment: Satellites and Probes, System: System Engineering Software

EMTECH focuses on software engineering for space applications, using ECSS standards. The services provided by EMTECH include spacecraft simulators, ground segment software and software verification and validation. One key product of the company is the SimBridge, an application that extends the capabilities of ESA's SMP2 simulator with assets such as numerical computing environments, 3D graphics & VR tools and high-level programming languages scripting.

**Epsilon Group** (Attica Region - http://www.epsilon.gr/):

Segment: Ground Segment, System: User Operations

Epsilon group is active in many domains, including Geoinformatics. The company has developed proprietary products and is involved in different R&D projects. Key products include: ArcFIRE, DIGITAL GREECE, ECOMAPS, HERMES and Enviducation.

**European Sensor Systems (ES Systems)** (Attica Region - https://esenssys.com/):

Segment: Satellites and Probes, System: Propulsion

ESS is involved in the development of sensors for medical, industrial, HVAC (Heating, Ventilation and Air-Conditioning) and aerospace applications. The company's developments

include pressure sensors and transducers that can be used in space applications such as in electric propulsion systems. A key product is the ESCP-SAPT pressure transmitter.

**FEAC Engineering** (Attica Region - https://feacomp.com/):

Segment: Satellites and Probes, System: Structures

A company that specializes in simulation driven product development. FEAC provides simulation services (Finite Element Analysis, Computational Fluid Dynamics, Boundary Element Method, System Simulation, Real-Time Digital Twin and Structural Health Monitoring Services), distribution of Siemens products as well as the proprietary PITHIA Boundary Element Method (BEM) solution.

**Geoapikonisis S.A.** (Attica Region - https://www.geoapikonisis.gr/en/):

Segment: Ground Segment, System: User Operations

Geoapikonisis is a geoinformatics solutions provider. The company is divided in Sector A - management resources management & finances, quality management, IT technological support and Sector B that focuses in the domains of digital image processing, geoinformatics systems, solutions and data, transports and environment, cadastre and surveying as well as project management. The company's applications include WebGis Editing, Telektima, Telearsis and TripMentor. Their services include land use / land cover mapping and surveying & topography. Geoapikonisis also offers thematic services in many domains including but not limited to Agriculture, Security, Climate Change and Hydraulics and has heritage in developing information systems.

**Geomatics** (Attica Region - https://www.geomatics.gr/en/):

Segment: Ground Segment, System: User Operations

Geomatics focuses on geoinformatics applications, aerial surveying and mapping and cadastral surveys. Key services offered are: Aerial photography with digital and analog sensors, photogrammetric mapping, digital terrain models and digital orthophotos, GIS applications, cadastral surveys and Land Information Systems, LIDAR surveys, land surveys and GPS applications, production of geographical data, precision and archeological surveys and 3D laser scanning applications.

**Geospatial Enabling Technologies (GET)** (Attica Region - https://www.getmap.eu/?lang=en):

Segment: Ground Segment, System: User Operations

GET is a company providing location related data and information management. The company is developing central spatial data infrastructures that can be accessed via web services and utilizes free and open source software and tools. The company's key solutions offered are in the areas of geoinformatics, open data solutions, data for digital twins, business intelligence, Earth Observation and environment. One key product is GETOpenData, a subscription-based service for EO data acquisition by end users.

**Geosystems Hellas S.A.** (Attica Region - https://www.geosystems-hellas.gr/):

Segment: Ground Segment, System: User Operations

Geosystems Hellas is involved in Earth Observation applications. It is the authorized reseller for Hexagon Geospatial and Hexagon Airborne Solutions as well as for Leica Geosystems

sensors in Greece and Cyprus. Its key products include Remote sensing, photogrammetry and GIS management with Hexagon products, Leica Geosystems sensors (aerial, lidar, scanners, related software) and the reselling of satellite data (partnership with Planet, Skywatch and COSMOSkymed). The company is involved in R&D activities (ESA, Horizon, National and more) related to health and urban resilience, climate change and environment, energy & ICT as well as cultural heritage. An R&D project of the company is the BLENDED (Synergetic use of Blockchain and Deep Learning for Space Data) project funded by ESA.

**Geotopos** (Attica Region - https://geotopos.gr/):

Segment: Ground Segment, System: User Operations

Geotopos is an engineering services company that is developing remote sensing and GNSS applications, among others. Geotopos has developed many projects, mostly nationally funded, that include remote sensing and GNSS. Key projects include the nationally funded Geo-Guide and the European IST funded Eye in the Sky project.

**Greek Biotope / Wetland Centre** (Central Macedonia - https://www.ekby.gr/ekby/en/EKBY_home_en.html):

Segment: Ground Segment, System: User Operations

The GBWC (Ελληνικό Κέντρο Βιοτόπων Υγροτόπων - EKBY) promotes sustainable management of renewable natural resources in Greece, the Mediterranean and the European continent. Its activities include leveraging EO data. GBWC is part of the partnership that developed the ESA Globwetland II Information system.

**Hellas Sat** (Attica Region - https://www.hellas-sat.net/):

Segment: Ground Segment, System: Mission Operations

Hellas Sat is the company that owned the first Greek satellite and has been designated through the law 4506/2017 as a “national operator” for Greece. There are imposed restrictions in the company’s operation, regarding the nationality of the personnel, the location of its operation centers and ground stations (Greece and Cyprus) and the responsibility to provide backup for national defense satellite communication services in a 24/7 basis [2]. Hellas Sat owns and operates the Hellas Sat 3 and 4 satellites that are currently in orbit, offering direct to home and connectivity solutions. The latter, address civilian customers and range from cellular backhauling as well as trunking to mobility solutions in land, air and water. Hellas Sat’s governmental connectivity solutions include fixed governmental networks and mobility solutions.

Hellas Sat 3 was launched on 26 of June 2017 with an Ariane 5 launch vehicle and was placed in GEO at 39° East. It is based in the Thales Alenia Space Spacebus-4000C4 platform, weighs 5780 kg and is equipped with an S-band payload, 44 Ku-band transponders and 1 Ka-band transponder [127]. Hellas Sat 4 was launched in 2019 with an Ariane 5 rocket and was positioned in GEO at 39° East as well. It is based on the Lockeed Martin A2100 platform and weighs 6495 kg (wet mass). It is equipped with Ku and Ka band transponders [128]. The national rights for the orbital position of 39° East and the relative radio frequencies are exclusively licensed to Hellas Sat by the Greek and the Cypriot republic until the year 2041.

The company owns two teleports, one located in Koropi, Greece and the other in Kofinou, Cyprus and offers hosting services, satellite uplink and downlink services, video content

aggregation and distribution, satellite control and operations as well as disaster recovery. The Koropi station is located at 37°93'N, 23°88'E at an elevation of 114m. Its viewable arc is 95°E to 47°W and its total surface amounts to 20,000 sq. meters. The 5 antennas support the Ku and Ka bands. The teleport in Kofinou is located at 34°51'N, 33°23'E at an elevation of 217 m. Its viewable arc is 105°E to 37°W. The antennas are more than 30, are in a total area of 30,000 sq. meters and the bands supported are C, Ku and Ka.

Hellas Sat offers connectivity between Greek governmental entities through GreeCom (Greek Governmental SatCom / ΚΛΕΙ.Δ.ΔΙ - Κλειστό Δορυφορικό Δίκτυο), the Greek governmental satcom network. The GreeCom distribution center is operated by the Ministry of National Defense Staff within its premises. It is noted that Hellas Sat is owned by the Arabsat organization since 2013.

**Hellenic Technology of Robotics (HTR)** (Attica Region - http://htr.gr/wordpress/):

Segment: Satellites and Probes, System: Electronics

HTR develops robotic platforms, autonomous and tele-presence-based. Their solutions include outdoor surveillance and intervention robots, hazardous environment remediation and dismantling systems complemented by virtual reality environments and all terrain robot platforms as well as autonomous legged robots for remote surveillance and intervention. The company's know-how involves structural mechanics, mechatronics, motorisation and digital servo systems, wireless networks and power electronics. Also, the company operates real time dynamics and control simulation tools running on Linux RT platforms, to validate multiple degrees of freedom systems while taking into account environmental inputs. Involved in European Joint research projects, the company owns several patents in the fields of sensor design, shape memory-alloy micro actuators and remote powering and monitoring of micro-actuator systems. HTR key products are: autonomous robotic platforms using solar power that aims to achieve energy-autonomous surveillance missions for long time spans and a satellite docking station. HTR has secured the use of its rover wheels for the Cube Rover missions of Astrobotic, inc on the Moon.

**HERADO** (Attica Region - https://www.herado.eu/):

Segment: Satellites and Probes, System: Payloads / Instruments

HERADO is the proprietary developer of ALMAR, a multiple-types of radiation personal dosimeter, that connects to a cloud platform and can monitor radiation levels. The product is implemented leveraging know-how from space technology.

**Heron Engineering** (Attica Region - https://www.heron-engineering.gr/):

Segment: Satellites and Probes, System: Structures

Heron Engineering provides mechanical engineering services that address the aerospace domain, between others. Their offered services include structural and decompression analysis, optimization of components, test results interpretation and documentation. Their software tools include CAD (Siemens NX) and CAE (MSC Patran/Nastran) suites. Key projects that Heron Engineering has been involved in include Design Concept and Requirements Study for the HERACLES Interface Elements for ESA and "Recovery and Return To Base" involving the MESO micro-launcher (H2020).

**INASCO HELLAS** (Attica Region - https://inasco.com/):

Segment: Satellites and Probes, System: Structures

INASCO HELLAS designs and manufactures high-performance CFRP composites and metallic structures that target aerospace applications. Their key products include spacecraft structures, structural panels and parts, mechanical ground support equipment and aeronautical structures. The company contributes in ESA missions such as JUICE, PLATO, enVision and TRUTHS.

**Industrial Services & Technologies (IST) S.A.** (Western Greece - https://www.ist-eng.com/):

Segment: Launchers, System: Structures

IST offers mechanical engineering services and has been involved in aerospace projects. Their services include design of industrial products using SOLIDWORKS, simulations with FEA using COSMOS M, creation of functional prototypes, product validation, market research and evaluation of suppliers and subcontractors, mechanical endurance tests and cooling performance tests. IST was involved in the “Development of test tools for thrust launcher measurement including concrete support for LP10 demonstrator Ariane 6” project.

**insigh.io** [ESA BIC Greece] (Attica Region - https://insigh.io/):

Segment: Ground Segment, System: User Operations

Insigh.io is an end-to-end IoT solution provider that offers IoT hardware and firmware, an IoT platform for management of the devices and measurements as well as implementation planning for IoT projects. The company’s solutions include satellite connectivity integration. The end-to-end system is open with documentation available online.

**Integrated Systems Development (ISD) S.A.** (Attica Region - https://www.isd.gr/):

Segment: Satellites and Probes, System: On-Board Data Management

ISD is an electronics manufacturer and integrator. The company’s activities involve software development for embedded and general purpose platforms, digital, analog and RF integrated circuit design, PCB design, memory design, telemedicine, digital signal processing and system integration. Some of the company’s key products are: rad - hard analog mixed-signal IP blocks and the SpaceFibre demonstrator kit. ISD has also been involved in the development of a high performance data processor with Airbus D & S [129].

**Interbalkan Environment Center** (Central Macedonia - https://i-bec.org/):

Segment: Ground Segment, System: User Operations

I-BEC is a non-profit international organization that focuses on environmental research and addresses sustainable management of natural resources. Its services include Remote Sensing and GIS, with applications such as Vegetation Dryness Monitoring, Assessment of Soil Erosion Risk and Water Quality Parameters in Selected Water Bodies. I-BEC’s key projects include : Riveralert - Decision Support System for flood risks alert in Strymon/Struma River Basin (Co-financed Greece - Bulgaria 2013), Autonest - Automated Telemetric applications for operational monitoring in Nestos River Basin (Co-financed Greece - Bulgaria 2013) and e-highway - Environmental Highway Observatory (contracted by Egnatia Odos S.A).

**Intracom Defense (IDE)** (Attica Region - https://www.intracomdefense.com/):

Segment: Ground Segment, System: Ground Station

Intracom Defense is a leading provider of electronics, communications and hybrid energy systems in the defense and security areas. The company focuses on providing tactical communications systems, hybrid power systems, security solutions and customized defense electronics. IDE has manufacturing plants spanning a total floor space of 7500 $m^2$. The company's manufacturing capabilities include printed board assemblies, cable and harness assembly, magnetic manufacturing, mechanical and electromechanical products, a number of special processes including but not limited to micro-blasting and molding, Clean Rooms of ISO 7 and 8, and system integration and test facilities equipped with a 10 tons overhead crane. Last but not least, IDE has automatic test and inspection equipment, for processes such as X-Ray 2D inspection, electrical and functional testing and environmental test screening. IDE also offers support and laboratory services. The company participates in ESA and European projects and has established a Space Programmes Division. A key project that IDE is involved in is Odin's Eye, an EDF -funded project for ballistic missile early warning from space, contributing in the state of the art technologies in secure communications and cybersecurity for satellite systems. Another project that IDE has been involved in is the implementation of the RF unit for ESA's Ku-band SPARK microwave transponder.

**LEO Space Photonics** (Attica Region - https://leo-sprd.eu/):

Segment: Satellites and Probes, System: Optical Communication

LEO Space Photonics designs electronic and photonic transceivers as well as analog/mixed signal and photonic integrated circuits for satellite communications applications. Their products target intra-satellite optical connections as well as high-speed optical inter-satellite links. Key products are the VCSEL transceivers and the coherent optical transceivers.

**Libre Space Foundation (LSF)** (Attica Region - https://libre.space/):

Segment: Satellites and Probes, System: Other

Libre Space Foundation is a non -profit organization, active in many space-related domains. LSF creates open-source software and hardware solutions as well as integrated systems for space applications. They have built and operated the Qubik-1, 2, 3 and 4 picosatellites as well as the PICOBUS PocketQube deployer. The first 2 satellites and the deployer were launched in 2021 as part of the DREAMS payload program in the inaugural Firefly Alpha launch of Firefly Aerospace. The Qubik-3 and 4 satellites were launched with Firefly Aerospace's Flight 2 #ToTheBlack in October 1, 2022. Other LSF key projects and products include SatNOGS, a worldwide open source satellite ground station network, SIDLOC (Spacecraft Identification and Localization) a proposed standard for the identification and localization of spacecraft which has been selected to fly on board the Ariane 6 maiden flight and UPSat, the first open source satellite, that was launched in 2017.

**Loctio** [ESA BIC Greece] (Attica Region - https://www.loctio.com/):

Segment: Ground Segment, System: User Operations

Loctio aims to democratize and optimize IoT-based location services offering low-power accurate positioning through processing GNSS, LEO satellite signals assisted by 5G on the cloud or on the edge in a location-as-a service scheme.

**Map** (Attica Region - http://map4u.gr/):

Segment: Ground Segment, System: User Operations

Map is active in the field of geoinformatics. The company's services include Satellite and aerial imagery, UAV mapping, geospatial data production, 3D city models, DTM (Digital Terrain Model) and DSM (Digital Surface Model) creation and remote sensing applications in which the company leverages satellite, aerial images and lidar data. The remote sensing solutions may address protection of the environment, precision agriculture, as well as phenomena and disaster monitoring.

**NEUROPUBLIC S.A.** (Attica Region - https://www.neuropublic.gr/):

Segment: Ground Segment, System: User Operations

NEUROPUBLIC is a company that has developed products and services that aim to innovate and help in the agricultural sector. One of the company's key products is gaiasense, a system that is made up by thousands of IoT sensors installed in land across Greece and Europe that also leverages satellite data and can benefit agricultural production. Another product of NEUROPUBLIC is the EarthInsight Engine, an in-house developed and end to end processing software capable of real-time analysis of optical and radar data.

**Noesis Technologies** (Western Greece - https://noesis-tech.com/):

Segment: Satellites and Probes, System: On-Board Data Management

Noesis Technologies develops IP cores and provides ASIC and FPGA design services for the telecom domain. The areas that their IP cores design target are: forward error correction, voice and data compression, security. telecom digital signal processing, networking and baseband PHYs. Their development tools include C-Cubed and ComLab. Their customer list includes NASA.

**OHB Hellas MON E.P.E.** (Attica Region - https://www.ohb-hellas.gr/):

Segment: Satellites and Probes, System: Other

OHB Hellas is the Greek subsidiary of the aerospace technology group OHB SE and was established in 2018 in Marousi, Greece. The company focuses on the development of high performance data processing solutions on board satellites. OHB Hellas has been involved in a multitude of projects related to high performance data processing, some of which are MFSR (Greek - developed AI application executed on-board the OPS-SAT satellite in 2022 - ESA), Cognitive Cloud Dual Camera (two - satellite earth observation system with on-board decision making capabilities - ESA) and CAIRS21 (COTS AI Accelerators in Mixed-Criticality High-Performance Avionics for Reconfigurable Satellites: TPU versus Prominent Embedded Devices, Mitigation Techniques, SW Frameworks and AI/ML Model Uploading - ESA).

The OHB SE group is involved in many large satellite development projects, including the development of the Meteosat Third generation satellites, the SARah and SARlupe programmes, as well as the PLATO and the EnMap missions. OHB subsidiaries also provide their own microsatellite solutions, such as OHB Sweden with the Innosat and OHB Luxspace with the Triton-X platforms.

**Omikron Environmental Consultants** (Central Macedonia - https://omikron-sa.gr/en/):

Segment: Ground Segment, System: User Operations

Omikron Environmental Consultants is a company that provides environmental consultancy services. The company leverages Earth Observation data for its operation and two of its key products are Ofire+, an early detection system against dangerous natural phenomena such

as wildfires and SeaLoc, a platform addressing the needs of marine users by providing marine forecasting or observation products and other services.

**OTE Group of Companies** (Attica Region - https://www.cosmote.gr/cs/otegroup/en/corp_homepage.html):

Segment: Ground Segment, System: Ground Station

OTE group is the biggest technology enterprise in Greece. Through its subsidiaries, the group is active in mobile and landline telephony, broadband services, ICT solutions, satellite communications, real estate and professional training. OTE owns two satellite centers, one in Thermopylae and one in Nemea. The Satellite Communications Center in Thermopylae hosts the THE-01, THE-02 and THE-03 antennas that were mentioned in chapter 2. One of the antennas will be used by the Hellenic Open University and the department of Electronic Engineering of the T.E.I of Central Greece (Τμήμα Ηλεκτρονικών Μηχανικών Τ.Ε. - Τ.Ε.Ι Στερεάς Ελλάδας) for educational purposes and will be turned to a radiotelescope. The Satellite Communications Center in Nemea hosts multiple antennas and is an international gateway for connectivity services. The Nemea site reportedly offers clear skies with a 95% probability in the summer months [130]. The key features and services offered by the two teleports in Thermopylae and Nemea are summarized as follows: Independent GEO/MEO/LEO satellite fleet operations, orbit control missions/telemetry and tracking facilities, uplink/downlink operations in C-Ku-Ka-S-L frequency bands, gateway teleport hosting for satellite broadband services, broadcast solutions/ direct-to-home, video contribution, earth observation / geo-information content delivery, disaster services, sites mirroring, geo-redundancy, satellite teleport infrastructure-as-a-service, data center facilities, power autonomy, physical and cybersecurity operations and global geo-diverse connectivity over fiber to global PoPs [131].

**Otesat-Maritel** (Attica Region - https://www.otesat-maritel.com/):

Segment: Ground Segment, System: Ground Station

Otesat-Maritel belongs to the OTE group of companies, is active in the field of satellite communications being a major player in the Greek maritime market and provides Inmarsat, Iridium and VSAT connectivity solutions. Additionally, the company provides integrated telecom services that fuse satellite and terrestrial data networks. Key products of Otesat-Maritel are: Inmarsat solutions, such as Inmarsat Fleet Xpress, Inmarsat Fleet Broadband and Inmarsat ISATPhone 2, Iridium products such as Openport, Certus, Legacy and Extreme, Government satcom solutions for aeronautical, land and maritime services and the VSAT Ku Band service. Furthermore, other Otesat-maritel solutions include but are not limited to s@tgate, mailonboard, IRIS Cyber Security and ICT solution and Point to Point services. The company provides marine electronics for communication, navigation and safety & security and is also qualified to perform surveys such as the GMDSS radio survey and the VDR/S-VDR APT survey. Lastly, the company provides services such as gyro compass overhauling and electronic charts.

**OQ Technology** (Attica Region - https://www.oqtec.space/):

Segment: Satellites and Probes, System: Ground Station

OQ Technology is a multinational company that offers 5G IoT services and satellite connectivity through LEO and GEO satellites. OQ's hybrid satellite-cellular terminal can be used for controlling and monitoring assets in maritime, transportation, oil & gas, agriculture

as well as other types of applications and supports GSM/LTE-M/NB-IoT networks and satellite links for both uplink and downlink. OQ Technology has a branch in Greece.

**Planetek Hellas** (Attica Region - https://www.planetek.gr/):

Segment: Ground Segment, System: User Operations

Planetek Hellas was founded in 2006 and is a member of the Planetek Group. The company provides services in the field of Geomatics, including the leverage of EO data and systems for critical infrastructure monitoring, urban planning, civil protection and security. Projects of the company include Coastal Water Attribute Monitoring using Satellite data (European Space Imaging) and Copernicus Land which involves the development of European coastal zone thematic mapping (EEA - European Environment Agency). Finally, the company has been developing the SpaceOP3C project, which targets the industrialization of software / hardware for hyperspectral data on-board processing.

Planetek Group has many developments, such as the rheticus platform, which is a cloud solution for automatic, cloud-based geoinformatics services. It has also been involved in space missions, such as the ASI PRISMA satellite mission - Earth Observation Hyperspectral Precursor System, for example.

**Pleione Energy S.A.** (Athens, Greece - https://www.pleione-energy.com/):

Segment: Satellites and Probes, System: Power

Pleione Energy is a joint venture between Adamant Composites and the German company OMNIDEA-RTG Gmbh. The company focuses on developing innovative solutions that can be applied in the energy and space sectors. The company is involved in projects such as GRACE II (ESA), which is about the development of a breadboard for a bank of supercapacitors. Other key projects are COORAGE (ESA), which is about the development of graphene-based lithium battery cells with extended life cycle and GADGET (ESA), which is about the selection, manufacturing, testing and benchmarking of graphene-based energy storage components with enhanced energy and power density.

**Prisma Electronics** (Eastern Macedonia and Thrace - https://www.prismaelectronics.eu/index.php/en/):

Segment: Satellites and Probes, System: Electronics

Prisma Electronics is involved in the design, the development and manufacturing of IT, smart-grid and wireless solutions, as well as integrated electronics components. Their targeted application domains include space. The company is also involved in R&D activities. Regarding the space domain, the company offers the following services: PCB design and assembly, cables and harnessing design and assembly, device & system MAIT, on-site support services, EGSE design and manufacturing. Specialized services include isolation and continuity tests, bake-out tests and burn-in tests. Its infrastructure includes an ISO 7 clean room and a TVAC chamber. Prisma has participated in multiple ESA projects. One of them was the Solar Orbiter, where Prisma was responsible for the development of complex harnessing and equipment. Another was project MEPS, where as subcontractor of SITAEL Italy the company was responsible for the manufacturing of Hall effect thrusters PPUs for microsatellites.

**Promilist** [ESA BIC Greece] (Attica Region - https://www.promilist.com/#/):

Segment: Ground Segment, System: User Operations

Promilist aims to provide optimized shipping routes by implementing AI techniques and leveraging EO data, in order to cut on fuel consumption and thus voyage costs and $CO_2$ emissions.

**Raymetrics** (Attica Region - https://raymetrics.com/):

Segment: Satellites and Probes, System: Payloads / Instruments

Raymetrics is a company with global presence in the field of atmospheric Lidars. Raymetrics' proprietary solutions implement AI and machine learning algorithms to tackle complex challenges. They address environmental problems such as smart cities applications, marine applications, industrial emissions, the agricultural industry, climate projections and seasonal forecasts. Also, the company's products can apply to meteorology, for targeted functions in weather prediction nowcasting, temperature and humidity profiling, planetary boundary layer studies and help in aviation with cloud base prediction, visibility measurements and PBL measurements. Furthermore, Raymetrics solutions can apply in early warning systems such as for desert dust, wildfires and volcanic ash. Finally, the company is involved in research for state of the art remote sensors and advanced ground based sensors and space technologies. Key products include the Wall-E lidar, the eVe lidar, the α-lidar, the ozone lidar, the QOMA laser, 3D ceilometers, dust detectors and VA, WF detectors.

**Satways** (Attica Region - https://www.satways.net/):

Segment: Ground Segment, System: User Operations

Satways focuses on creating comprehensive Geospatial command and control solutions for a variety of security and public safety applications. These solutions are designed to support the needs of organizations such as the police, coast guard, emergency medical services, civil protection and fire and rescue operations, as well as critical public infrastructure protection, transportation security, and border monitoring. They provide software and hardware solutions, some of which are (software): Atlantis, a 3D Geographical Information System, AutoTrack, an automatic resource location system and ENGAGE IMS/CAD (Incident Management & Computer Aided Dispatch).

**SITAEL Hellas** (Central Macedonia - http://www.sitael-hellas.com/):

Segment: Satellites and Probes, System: Propulsion

SITAEL Hellas is the subsidiary of SITAEL, an Italian, privately-owned company active in the space sector. SITAEL Hellas is able to cover all the processes needed for the design and test of electronic equipment and focuses in the development of space propulsion systems. SITAEL Hellas key activities include involvement in the ESA MEPS project, which is about the design of a hall effect thruster for microsatellites and in the EU CHEOPS project, which is about the development of three Hall Effect Thruster based propulsion systems - for LEO, GEO and space exploration applications.

**SoftCom (Software Competitiveness) International** (Attica Region - https://www.softcom-int.com/):

Segment: Satellites and Probes, System: System Engineering Software

SoftCom is a software engineering company that has a strong presence in Greece and cooperation with many medium and large multinational companies in Germany, Switzerland and France. One of the many domains where SoftCom is active is space, with the company focusing on ground segment software, EO and flight software and being compliant with ESA

standards. A key space project that SoftCom has been involved in is AAMS (Advanced Alarm Management System), which is about introducing intelligence to alarms generation for space system operators at ESOC and leveraging modern smartphone technology to present alarms with contextual information about the system under monitoring. Another project is Space 4.0 (a cloud-based platform that provides flexible facilities for the processing of satellite payload data - EU & nationally funded).

**Space Asics S.A.** (Attica Region - https://www.space-asics.gr/):

Segment: Satellites and Probes, System: On-Board Data Management

Space Asics is targeting the development, evaluation and commercialization of custom, low-power, radiation hardened mixed signal analog/digital ASICs to be used in space applications. The company has developed asics for ESA projects and its key products are divided in two categories: the low speed, low power, Rad-Hard, sensor data acquisition ASICs suitable for spacecraft housekeeping, propulsion system control and other functions and the medium to high speed, Rad-Had ASICs for CMOS and CCD Image Sensor data acquisition built around 12-bit to 16-bit ADC modules at 20Msps. Space Asics' products contain multiple optimized functions in the same chip and some of them are the SIF ASIC, the ETM ASIC, the 16-bit ADC ASIC and the MCI-ASIC.

**Space Hellas** (Attica Region - https://www.space.gr/en):

Segment: Ground Segment, System: User Operations

Space Hellas is a systems integrator and service provider active in the domains of telecommunications, IT and security. The company has a vast collection of competencies and participation in activities leveraging cutting edge technologies. Their involvement in the space domain includes but is not limited to, the following projects: ESA satcom pooling and sharing system, ESA CloudSat: Scenarios for Integration of Satellite Components in Future Networks and ESA φSAT: The Role of Satellite in Future Internet Services.

**Space Applications and Research Consultancy (SPARC)** (Attica Region - https://sparc.space/):

Segment: Ground Segment, System: User Operations

Sparc consists of a group of physicists and engineers and demonstrates competencies in Data, Space, Nuclear, Plasma and Material Sciences. Their activities include data services and distribution, scientific data curation and processing, data analysis, ML and AI applications, data driven physics models, simulations of energetic particle detectors, detection and forecasting of space weather events and R&D project management. Key projects that SPARC is involved in is the post-post processing and display of near-real-time plots of GOES-16 measurements of electron fluxes, SafeSpace, a project that aims to advance space weather forecasting and thus offer better protection for space assets and SREN (Space Radiation Effects Nowcast), a platform that integrates a user-friendly GUI for near-real-time assessment as well as historical event information about damages caused to spacecraft by space weather.

**Space Innovation Solutions** [ESA BIC Greece] (Attica Region - https://www.esa-bic.gr/space-innovation-solutions/):

Segment: Ground Segment, System: Ground Station

Space Innovations Solutions develops a 3D printed multi-beam antenna with the aim of offering seamless satellite handover with efficient SWaP and low costs.

**TELETEL** (Attica Region - https://www.teletel.eu/):

Segment: Ground Segment, System: Development and Construction of Space Segment

TELETEL is a company that designs and develops hardware and software solutions for spacecraft and satellite avionics and ground equipment, focusing in testing and monitoring tools for on-board data networks, EGSEs, on-board data handling hardware and software and more. They are also active in the aeronautics and defense domains. TELETEL key solutions include the iSAFT product line comprised of SpaceWire Front-End link analyser, SpaceWire PCie, SpaceFibre front-end, SpaceFibre pcie, CAN/CANOpen Front-End, MIL-STD-1553 front-end and more. In terms of electrical ground support equipment, the company provides multiple solutions such as a spacecraft interface simulator and CDMS, MMU EGSE and custom simulators/SCOEs. Their services in the latter domain include but are not limited to customisation of EGSEs and EGSE components and development of custom test SW applications and integration of COTS hardware components. TELETEL additionally offers services for on-board software development for space missions and avionics and network communication protocols, independent software verification and validation, ground software engineering services for aerospace and defense applications, as well as real-time software for radar systems, command and control applications. Also, the company has competences in designing FPGAs and digital/mixed signal PCBs and in implementing rad hard designs. Teletel's track record indicatively involves providing EGSE for the ESA LSTM mission, the ESA FLEX satellite and for the PLATO mission, amongst others. Moreover, TELETEL develops EUCLID mission application software components including thermal control, power management and more. Lastly, the company offers engineering support in the domains of operation, AIT and AIV with an indicative heritage in the EUCLID payload module AIT software support for AIRBUS DS France.

**Terra Spatium S.A.** (Attica Region - http://www.terraspatium.gr/):

Segment: Ground Segment, System: Ground Station

Terra Spatium offers geoinformatics space products and services. Additionally, the company offers private security services. Terra Spatium develops geospatial systems and customized applications from system architecture and concept of operation to software and hardware implementation. Applications include Geo-Data base, image servers and GIS projects with their respective web applications. Geoinformation solutions of Terra Spatium include Mapping & cadastral studies, environmental and physical surface management, agriculture and forestry, defense and security, maritime surveillance and land border control. Key projects of the company include industrial support to the HELIOS-II programme Greek ground segment, DIPAS (Development of Precision Apiculture Service) and Delphinion (ESA), a project about investigating the use of satcom to enhance security of future transport systems. Key products include the Θ|SAR platform, a system developed by Terra Spatium to provide accurate prediction on objects and people drifting at sea and EUGENIUS, a service that assesses the quality of habitats and the degree to which a landscape facilitates movement. The latter service is also complemented by change detection services.

**Thales Hellas** (Attica Region - https://www.thalesgroup.com/el/countries/europe/thales-greece):

Segment: Satellites and Probes, System: Other

Thales Hellas marks the presence of the Thales Group in Greece and is its 100% subsidiary. Thales Hellas mostly focuses in military and aeronautical applications, but is also active in space activities. The company was one of the 3 down-selected for the national microsatellites programme after the relevant RFI [132].

**TotalView** (Attica Region - https://www.totalview.gr/):

Segment: Ground Segment, System: User Operations

TotalView is a satellite imagery provider with competences in software development for related applications. Its products include images ranging from 30-50 cm (e.g. Worldview -3 images), 51 cm - 1 m (e.g. KazEOSat-1 images) and more than 1 m (Planet - Dove images).

**weasic** (Attica Region - https://www.weasic.com/):

Segment: Satellites and Probes, System: RF / Microwave Communication (Platform & Payloads)

Weasic designs and implements millimeter wave asics. The company's IP portfolio is extended and its solutions include analog and mixed signal IPs for automotive, radar, 5G backhaul and satellite communications applications. Some of weasic's key products from their extended range of solutions are: 10 to 15 GHz broadband microwave receiver front-end, 10GHz to 15GHz broadband wireless microwave transceiver front-end, 4.4 to 7.75 GHz low phase noise fractional-N synthesizer and the frequency multiplier 10G/20/40/80GHz LO generator.

### 3.4.5.2 Other

In this chapter, non-profit entities and entities relevant to space education and dissemination are included.

**Astronio** (https://www.astronio.gr/ , https://www.youtube.com/channel/UCYhH65nE2M8rGwMWvAlVu2A):

Astronio is a Greek youtube channel and website dedicated to the dissemination of space technologies and astrophysics subjects. It is one of the largest Greek popular science media and has cooperated with ESA for different dissemination activities.

**Beyond Orbit** (Attica Region - https://www.beyond-orbit.org/):

Beyond Orbit is a not-for-profit organization that consists of undergraduate, postgraduate and PhD students and aims to build the first Greek rover, in order to participate in the European Rover Challenge.

**ESERO (European Space Education Resource Office) Greece** (Central Macedonia - https://esero.gr/ ): ESERO aims to connect the different STEM disciplines with space and educate primary and secondary education students accordingly. Also, it aims to promote the value of space to society and economy, through educating teachers about ESA programmes as well as the different aspects of the space domain.

**Eugenides Foundation** (Attica Region - https://www.eef.edu.gr/en/): The Eugenides Foundation is a private educational institution that was founded in 1956 in Athens, Greece. It promotes science via educational venues and is also equipped with a digital planetarium in the premises. Space and astronomy topics have a prominent role in its activities.

**Greek Meteorite Museum** (Attica Region - https://www.meteoritemuseum.gr/): A private museum dedicated to meteorites showcasing and dissemination of space science.

**Greek NewSpace Society** (https://greek.nss.org/): Greek New Space society is a non-profit organization, the Greek chapter of the National Space Society and aims to promote the knowledge of NewSpace technologies. GrNSS organizes the NASA Space Apps challenge in Thessaloniki and Piraeus, Greece and the NewSpace pioneers programme, an initiative in cooperation with university laboratories where participants can conduct space research under the supervision of the GrNSS Academic Advisors. GrNSS also aims to offer participation in analog missions and hosts science communication events.

**SPIN (Space Innovation)** (Attica Region - https://space-innovation.org/): SPIN is a non-profit organization that consists mainly of university students and aims to disseminate space technologies. SPIN organizes CanSat, a Greek national competition scheme that runs in cooperation with ESA and WCRC (World CanSat & Rocketry Competition). It addresses students of secondary and tertiary education that compete in creating a soda-can sized satellite that executes a mission objective of their choice. The satellite is launched by a rocket created by SPIN in a 1 km altitude. Another project of SPIN is the creation of a reusable CanSat rocket launcher that can deploy four CanSat payloads. Last but not least, SPIN hosts STEM workshops for arduino, addressing both secondary school, high school, university students and everyone who aspires to participate in a STEM workshop.

### 3.5 Statistics

The data from the classified entries can be visualized as follows:

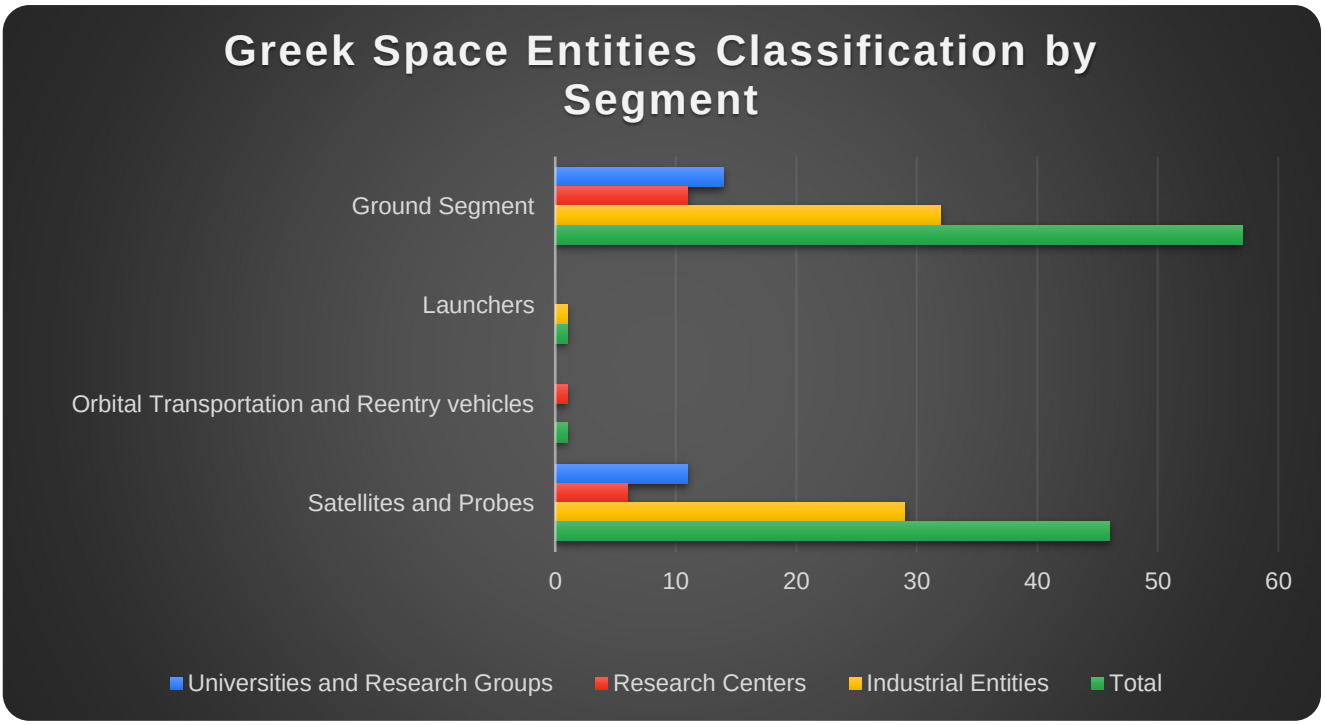


**Figure 3: Greek space entities classification by segment**

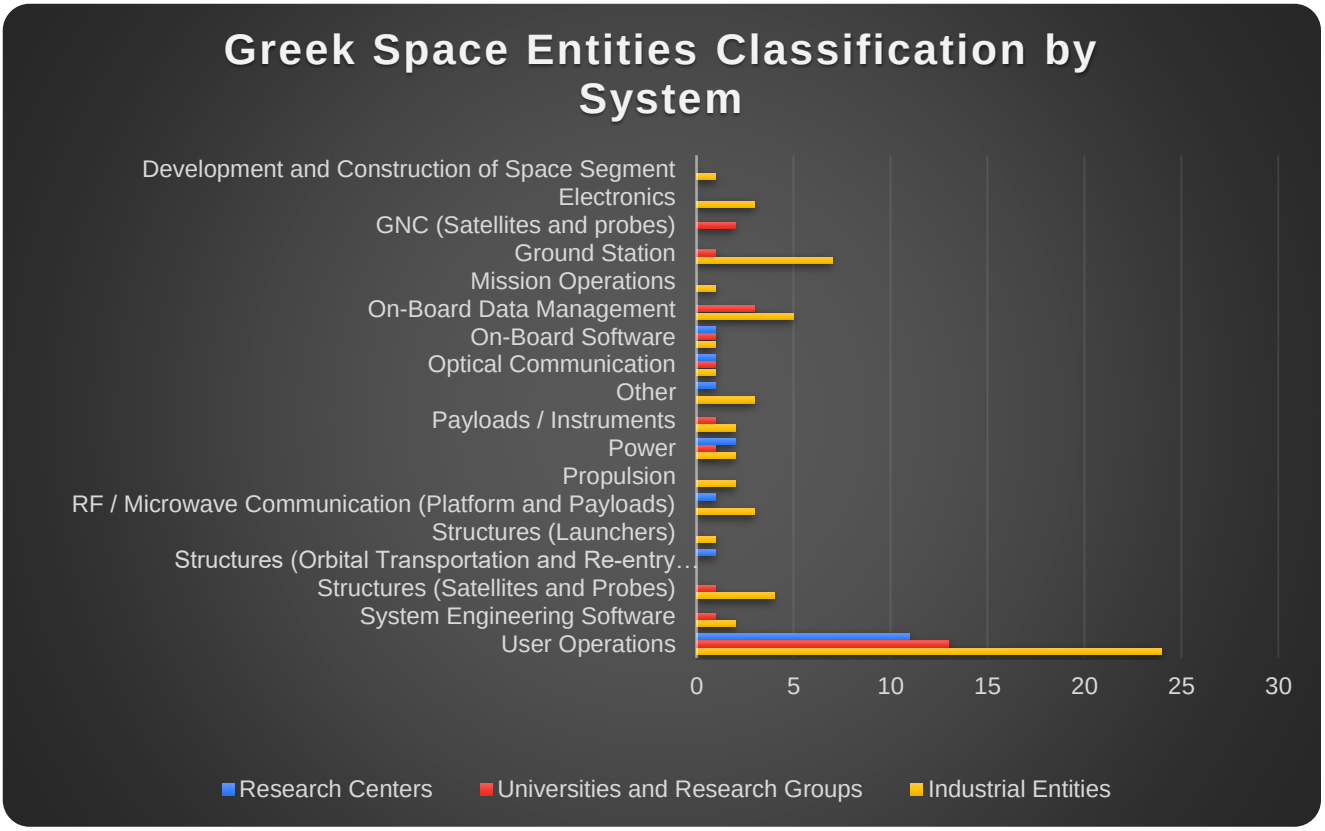


**Figure 4: Greek space entities classification by system**

It is noted that the “Other” category has been assigned to entities that can provide space systems integration.

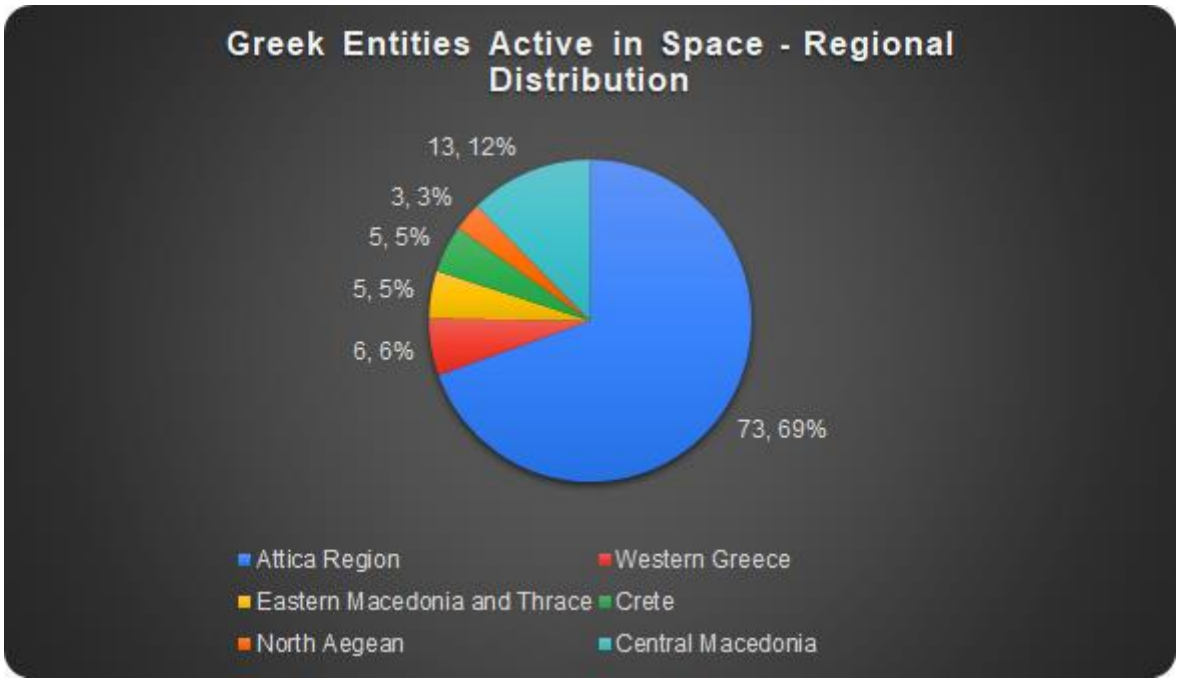


**Figure 5: Greek space entities distribution by region**

## 3.6 Conclusion

The majority of the entries are private entities (62) with university laboratories - university research groups and research centers amounting to a significant number as well (25 and 18 respectively).

From the classification of the total 105 entities, it is concluded that on segment level, the most entities belong to the ground segment, with a significant presence in the satellites and probes segment. On system level, the entities mostly belong to the user operations category, concerning downstream applications for Earth Observation with a noteworthy presence in space physics. A significant amount of entities relevant to the total number is in the system category of electronics, on-board software, on-board data management, rf / mmWave communication as well as structures (for the satellites and probes, launchers and orbital transportation / re-entry vehicles segments). Additionally, another significant cluster is the ground station category, with prominent entities such as OTE group of companies that belong in it, which is in possession of two satellite teleports. Finally, a key asset for Greece is Hellas Sat, the country's national operator and the only entity that is in the possession of a satellite in orbit. It is also notable that two industrial primes belonging in the OHB and Thales groups have a presence in Greece.

Most of the entries in this chapter are located in the Attica region of Greece, with a significant presence in Central Macedonia.

The highlight of the national space assets of Greece is its ground observatories, some of which are selected to be involved in ESA and EU programmes.

Finally, it is highlighted that HASI frequently creates a list, documenting the different entities of the Greek space ecosystem, the "Greek Space Catalogue" [223]. It contains additional prominent entities to those mentioned in the current chapter, such as Miltech Hellas and Theon Sensors.

# 4. GREECE AND HIGH – PERFORMANCE DATA PROCESSING ON-BOARD SATELLITES

The aim of this chapter is to analyze the technology of high-performance data processing on-board satellites, dubbed also as HPDP in the context of this thesis, which constitutes a cutting edge NewSpace technology domain that is being adopted by the space industry worldwide. Also, this chapter presents how this technology could benefit Greece. In general, high performance data processing on-board satellites can improve space systems in a number of ways, including:

- Increasing the amount of data that can be processed in orbit: This can lead to more timely and accurate decision-making, as well as the ability to process data that would otherwise be too large to transmit to the ground.
- Improving the performance of space-based applications: This could include applications such as Earth Observation and communications.
- Making space systems more affordable: COTS high performance computers are often less expensive than radiation-hardened computers, which can save money on the development and launch of space systems.
- Making space systems more adaptable: COTS computers can be more easily updated and upgraded than radiation-hardened computers, which can help to ensure that space systems remain up-to-date with the latest technologies.

High performance data processing is the main strategic focus of OHB Hellas, the Greek subsidiary of the aerospace multinational OHB SE group, by which the author is employed. To achieve the goals of this chapter, extensive literature review will be performed, showcasing the potential of the specific technology domain.

## 4.1 The Technology of High Performance Data Processing On-Board Satellites

High performance data processing on-board satellites involves the use of widely available, COTS computers with great computation power on-board satellites and space vehicles in general, to provide great performance, adaptability and enable the use of cutting-edge technologies in the space domain.

Modern satellite instruments often generate a vast amount of raw data that exceeds the capacity for transmission to the ground. Even the most compact hyperspectral imagers create data in the magnitude of TB per orbit [133]. Consequently, it becomes crucial to employ different methods to decrease the payload data volume [134].

Traditional radiation hardened space computers such as the LEON processors that implement the SPARC architecture [135] and the BAE Systems RAD750 [136], have been used as general purpose and payload computers for satellites. However, these architectures are falling behind in terms of processing capabilities and are not optimal solutions for the implementation of the cutting edge applications that are surfacing in the modern space domain. In a 2018 study by Lentaris et al [137], it was concluded that certain 28nm system-on-chip (SoC) devices performed faster than space-grade and embedded CPUs by 1−3 orders of magnitude, while consuming less than 10 Watts. For example, the Xilinx Zynq 7045 SoC outperformed by 1-2 orders of magnitude the rad-hard LEON4 (E698PM) processor.

New, disruptive hardware platforms, such as FPGAs, Graphic Processing Units (GPUs), SoCs and Systems-On-Module (SoMs) that are being offered as COTS solutions (space-grade and non-space grade) can address space applications and aim to bridge the apparent gap, providing computing power required to intelligently manage payload data in orbit. In general, COTS space computers offer higher performance and power efficiency, especially important for the more resource-constrained satellites that are used in LEO.

Drivers for the selection for space use of non-radiation hardened computers apart from their high performance are their radiation tolerance (e.g. Total Ionizing Dose - TID minimum requirements) and Single Event Latch-up (SEL) / Single Event Upset (SEU) / Single Event Functional Interrupt (SEFI) mitigation on system and software level, the implementation of fault-detection (such as ECC correcting codes), their packaging and power, their long term support and the availability of device lot traceability [138]. Further, other quality factors are the availability of development, verification and debugging tools, the size of the respective user community, the support for reliable real time operating systems, the access to open source APIs and drivers and the procurement lead times. These criteria when met adequately for space use are deciding factors for the use of such processors in orbit. Also, an important aspect is that many such platforms have mature inference engine tools for machine learning. Finally, it is noteworthy that COTS computing platforms that are not space grade may undergo radiation testing campaigns to be characterized for space use.

To design highly-reliable COTS computers, several steps are implemented [139]:

1) Components are chosen based on their reliability and radiation resistance
2) Local Single Event Effect mitigations such as latch-up detection and Error Detection And Correction for memories are implemented
3) System Single Event Effects such as supervisors are implemented
4) Highly reliable system architectures such as failure correcting links, redundant links and redundant functions are implemented

The trade off between different types of space computers, as presented in ESCCON 2019 (ESA) by RUAG, to provide an indicative baseline regarding these technologies, is captured in the following table [139]:

**Table 3: Trade-off between different types of space computers**

| Type | Total Dose | Performance | Life-time | Price |
|---|---|---|---|---|
| Rad-hard OBC | >100 kRAD | 70 DMIPS | 15 years in GEO | €2M |
| Constellation OBC | 50 kRAD | 1800 DMIPS | <10 years in LEO | <€200K |
| Panther Single Board Computer (SBC) | >100 kRAD | 70 DMIPS | >15 years in GEO | €500K |

| | | | | |
|---|---|---|---|---|
| Constellation SBC | 50 kRAD | 1800 DMIPS | <10 years in LEO | <€50K |

COTS on-board processing solutions targeted for space use can be OBCs with dedicated payload data processing units such as the KPLabs Antelope OBC [140] or dedicated processing platforms such as the NanoXplore NG ULTRA FPGA [141], the Ubotica Cognisat XE-1 processor [142], the KPLabs Leopard DPU [143], the Xilinx Virtex 5QV FPGA [144] and the Xiphos Q8 processor [145], amongst others.

The way these high performance processing platforms address the payload data volume issue is by enabling techniques to manage data on-board satellites more efficiently, such as data compression, reduction and extraction of critical information. To this end, Artificial Intelligence (AI) applications that run on said processors is leveraged to maximize the value of satellites, as for example AI algorithms can be implemented on-board Earth Observation satellites to extract useful information from large data sets. By transferring part of the processing pipeline on the edge and using AI, it is possible to decrease the latency of data that reaches end users. A prominent example is presented in [146], where the proposed system for the H2020 project EO Alert is able to generate and deliver alerts for extreme weather nowcasting regarding convective storms with the use of AI [147] in less than one minute, implementing an end to end emulated on-board processing and communications system. The Xilinx Zynq US+ board ZU19EG Multi-processor System-on-Chip (MPSoC) is used for data processing, while the processed data are SEVIRI optical VIS/TIR (visible / thermal infrared) data.

AI on-board can also be applied in the satellite communications domain [148], where it can minimize human intervention from ground and enable real-time error detection and other beneficial applications, which are further elaborated in chapter 4.2.2. Additionally, intelligent systems that leverage AI can be utilized for deep space applications and space exploration for autonomous navigation and decision-making. In these cases, the high latency of ground control commands defines the need for increased autonomy and the power constraints for great efficiency, respectively. Finally, HPDP enables high level space mission concepts such as space-as-a-service.

Except from the AI techniques that can be implemented to manage satellite data in orbit, HPDP can potentially offer satellite adaptability in an unprecedented scale, in terms of software updating and application variability in satellites, which are traditionally inflexible platforms, thus maximizing satellite usefulness and return of investment. One such example is ESA's OPS-SAT, which uses an Altera Cyclone V SoC with an ARM dual-core Cortex-A9 MPCore and a Cyclone V FPGA [149]. OPS-SAT can receive bootable images with different applications that are executed on its hardware while in orbit. The company Exodus Orbitals also develops a software for hardware virtualization, which enables users to upload their own code in satellites [150]. The adaptability aspect that HPDP can provide will be further elaborated in the 4.3 Space-as-a-service sub-chapter.

Another cutting-edge architecture that is being explored for use in space, with ESA showing interest in it, is neuromorphic hardware [151][152][153][154]. Neuromorphic hardware is designed to mimic the architecture of the human brain, which is highly energy - efficient. It implements Spiking Neural Networks (SNNs) which can be more energy efficient than

Convolutional Neural Networks (CNNs) [155]. This is an important advantage when considering the power constraints of satellites, especially those that apply to CubeSats and Small EO satellites. However, at least in some cases, there is a trade-off to be made between energy and accuracy, as indicated in the study of Kucik and Meoni [156].

Computation in SNNs is triggered by spikes, which leads to immediate response to inputs and they can implement plasticity rules, allowing for easier adaptation to environmental changes [157]. Moreover, neuromorphic hardware is characterized by parallelism [158], that offers computational advantages and scalability [159], enabling it to be expanded to handle more complex problems.

Examples of neuromorphic hardware are the Intel Loihi 2 [160] and the Brainchip Akida [161] chips. It is notable that currently, there is a lack of space-grade neuromorphic chips.

## 4.2 Domains of Application

Main domains of application where HPDP can potentially offer significant advantages are documented in this section. Focus will be given in the capabilities enabled by AI on-board, with specific use cases for representative domains of space applications. These use cases encompass studies that review on-board AI execution, or scenarios where AI is used for applications that could potentially be adopted on-board to reap the benefits of the implementation. In parallel, it must be noted that the use of the HPDP technology can be expanded in other areas of application that are not mentioned here.

### 4.2.1 Earth Observation

LEO Earth Observation constellations are following a clear trend of rapid growth, with the prominent example of PlanetLabs and its Doves and SkySats. Planet has more than 150 satellites circling the Earth, gathering an immense amount of imagery spanning over 350 million square kilometers each day. This dataset holds an average of 1,300 images for every location on the planet's landmass [162]. Other Earth Observation constellations in LEO include the ICEYE [163], the Capella Space [164] and the Satellogic [165] fleets. In the scenario of large formations of earth observing satellites orbiting in LEO with intersatellite-link and adequate ground station availability, coupled with AI-execution on-board, critical data from anywhere in the globe can reach the decision-makers in near-real-time. This could lead to faster response and better crisis management, preventing environmental and economic damages and even human casualties.

In parallel, the EO market is predicted to sustain growth in the future, indicating the futureproof nature of edge processing for earth-observing satellites. A breakdown for the predicted growth of the different sub-domains of EO is presented in the following (source: EUSPA).

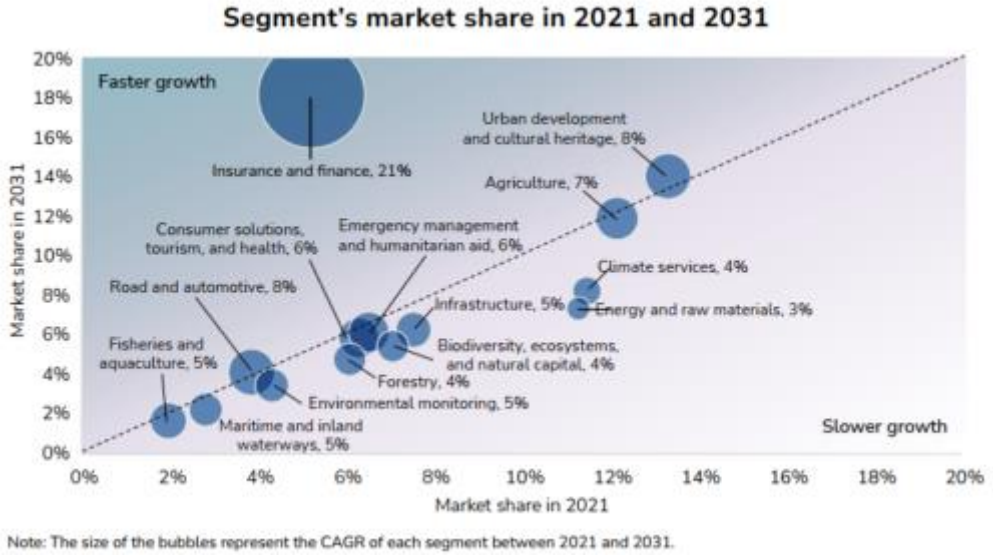


**Image 1: EO segment market share 2021 – 2031. Source: EUSPA**

HPDP enables Artificial Intelligence to be integrated into satellite systems, which offers numerous benefits to EO applications, enhancing the payload data management processes. The main advantage of on-board AI execution is the time criticality aspect. Instead of having to process the complete downloaded datasets on ground, AI algorithms extract useful features [166] that have smaller size, which can be then downlinked consuming less bandwidth [167].

Indicative latencies for state-of-the-art civil security related EO products include the Copernicus Emergency Management Service Activation Extent Mapping with a latency of about one hour [168] and the Copernicus Maritime Surveillance with a latency in the range of 20-40 minutes for the Vessel Detection Service (VDS) [169]. The European capabilities will improve with the use of the MTG third generation satellites that will be able to scan Europe in a frequency of 10 and 2.5 minutes [170] and aid in active fire detection. Lastly, the latency for NASA's FIRMS (Fire Information for Resource Management System) is specified at <1-30 minutes for products from the Terra/Aqua and Suomi NPP/NOAA-20 polar orbiting satellites, although the service only addresses US and Canada [171]. These figures serve as a comparative baseline for the potential of the HPDP-enabled EO services, an analysis of which will follow.

One key area where AI proves invaluable is in fire detection. Satellites equipped with AI algorithms can analyze high-resolution imagery in real-time, swiftly identifying and tracking wildfires across vast areas. This capability enables early detection and rapid response, aiding in the mitigation of forest fires and reducing the potential for widespread damage. By leveraging AI, satellites can continuously monitor regions prone to fires, providing timely alerts to authorities and facilitating more effective firefighting efforts. The study in [172] used CNNs trained to detect wildfires and then optimized to meet on-board processing demands, implemented in the Intel Movidius NS2, Nvidia Jetson Nano and Nvidia Jetson TX2 boards. The results validated the usefulness of Trusted Autonomous Satellite Operations implementation in future missions for disaster management. Another relevant feasibility study is the "Dual-camera satellite with on-board AI-Based decision making capabilities", that demonstrates the merits of AI on-board to enable a two-satellite EO system with wide

swath and high resolution fire detection capabilities [173] This concept proves the merits of using AI on board to have wide swath and high resolution camera synergy and low latency data delivery. The use case assessed was fire detection.

Cloud detection is an EO application significantly enhanced by AI on-board satellites. AI algorithms, integrated into satellite systems, enable automated cloud detection and classification with high accuracy and speed. By analyzing satellite imagery, AI algorithms can identify cloud cover, distinguish between different cloud types, and track cloud movements over time. This is particularly important to save bandwidth with rejection of cloudy images. In [174], the authors propose cloud detection-based image downlink prioritization for small satellites.

Moreover, AI-powered satellite systems can facilitate ship detection in vast oceanic regions. Satellite imagery combined with AI algorithms can automatically identify and track ships, enabling efficient monitoring of maritime activities, including vessel traffic, illegal fishing, and piracy. By employing AI, satellites can analyze large volumes of data and detect anomalies, such as unregistered or suspicious vessels, enhancing maritime security. This technology can assist maritime authorities in conducting timely interventions and enforcing regulations, leading to improved safety and protection of marine resources as well as enhanced national security. The proof of concept that was developed by Elecnor Deimos in the context of the H2020 project EO-Alert enabled ship detection and alert delivery typically in less than 1.5 minute, using the Xilinx Zynq US+ boards ZU19EG Multi-processor System-on-Chip (MPSoC) for data processing and an end to end communications emulator for alert transmission [146]. The researchers processed TerraSAR-X and DEIMOS-2 optical satellite data for this application. In [175], a ship detection algorithm to be implemented on-board satellites is proposed. The suggested system minimizes the amount of data that needs to be transmitted and processed on the ground, resulting in a more efficient data volume. Additionally, it greatly reduces the time required to accomplish the objective of the application. In the “Don’t try this at home” ESA study, it is demonstrated that by utilizing an end to end system that includes a space processing segment with AI execution on-board, the authorities could have been alerted for the 2022 Nord Stream sabotage [176] within 15 minutes instead of relying in the typical data processing pipeline that runs for 20-30 days for AIS and EO data collection and processing [177].

Artificial Intelligence deployed on satellites also enables flood detection in Earth Observation applications. By leveraging AI algorithms, satellites can analyze satellite imagery and SAR data to identify regions prone to flooding, monitor water levels in rivers and lakes and track the extent of flood events in real-time. This information is invaluable for early warning systems and emergency response efforts. AI-powered flood detection on satellites can enable rapid identification of at-risk areas, facilitating evacuation plans and resource allocation to minimize the impact of floods on human lives and infrastructure. In [178], a flood mapping approach is proposed via a CubeSat constellation utilizing AI on-board.

In earthquake disaster management, AI integrated into satellite systems can play a vital role in assessing and responding to seismic events. Satellites equipped with AI algorithms can analyze satellite imagery, SAR data, and other geospatial information to map and monitor areas affected by earthquakes. AI can aid in rapid damage assessment, identifying collapsed buildings, infrastructure disruptions, and potential hazards. This information is crucial for search and rescue operations, emergency response planning, and post-disaster recovery efforts. By leveraging AI, satellites provide near-real-time insights into earthquake-

affected regions, enabling effective coordination and deployment of resources to mitigate the impact of seismic events. The US DoD's AI based xView2 tool has been used for damage identification and for aid in rescue efforts in the 2023 Turkey earthquakes. By leveraging machine-learning algorithms and integrating satellite imagery sourced from other providers, it achieves a significantly accelerated process of identifying and assessing the severity of building and infrastructure damage in disaster-stricken regions by utilizing semantic segmentation, surpassing the capabilities of traditional damage assessment systems [179]. The potential transfer of this processing pipeline on-board the satellite could lead to lower latencies and faster response. In [180], a deep learning based system is proposed for change detection on-board satellites, which can aid in response to disasters such as earthquakes.

Also, satellites equipped with AI algorithms can analyze imagery and data to identify changes in the environment, detect the movement of military equipment, and track the deployment of forces. This information enables military commanders to make informed decisions, respond quickly to changing situations, and coordinate operations more effectively. AI-driven monitoring on satellites can potentially enhance battlefield awareness, reduce response times, and enhance the overall command and control capabilities in defense scenarios. Additionally, AI algorithms that run on-board satellites can inform decision makers about enemy infrastructure and assets such as aircraft and weapons, based on object detection techniques. This provides added value in the reconnaissance tactics of the military. In [181], a method to detect military targets such as aircraft from satellite images, with Deep Convolutional Neural Networks is presented.

Lastly, intelligent system architectures powered by AI can be implemented to enable Agile Earth Observation Satellites with adaptive mission planning. In this case satellites or constellations can adaptively target objectives to monitor on ground and eventually even form a priority system, maximizing their output value. Such concepts are presented in [182] and [183].

### 4.2.2 Satellite Communications

Satellite communication presents the potential for uninterrupted service in areas with limited or no coverage, widespread availability of service, and the ability to expand services as needed. Nonetheless, before these advantages can be fully realized, various obstacles need to be overcome. Resource management, network control, network security, spectrum management, and energy consumption in satellite networks pose greater difficulties compared to terrestrial networks [184].

AI integration on-board communications satellites can revolutionize the field, enhancing various aspects of the technology to improve latency, efficiency and performance. In parallel, intervention from ground control can potentially be minimized, reducing costs.

One area where AI proves invaluable is in digital beamforming. Satellites equipped with AI algorithms can dynamically adjust the beamforming patterns of their antennas, optimizing signal transmission and reception. By analyzing real-time data on signal quality, satellite positions, and user demands, AI algorithms can intelligently adapt the beamforming patterns to improve coverage, reduce interference, and enhance overall communication capacity. In

[185], the AI-controlled beamforming with on-board processing is presented and assessed, with a promising on-board applicability score.

Another significant application where AI enhances satellite communications is in beam hopping pattern reconfiguration. Beam hopping allows satellites to dynamically switch between different beam patterns to establish connections with multiple ground stations or user terminals. AI algorithms integrated into satellite systems can analyze network conditions, user demands, and traffic patterns to intelligently predict and optimize beam hopping patterns. By dynamically reconfiguring beam patterns based on AI-driven insights, satellites can efficiently allocate resources, optimize network capacity, and provide seamless connectivity to a large number of users. AI-powered beam hopping pattern reconfiguration enhances the flexibility and adaptability of satellite communications systems, ensuring efficient utilization of resources. In [186], deep reinforcement learning is proposed for dynamic beam pattern and bandwidth allocation in beam-hopping satellite systems. This implementation can offer adaptation to data traffic fluctuations due to variability in user demands, maximizing the satellite's performance.

Telemetry anomaly detection is another critical application where AI on board satellites plays a crucial role. Satellites generate telemetry data related to their operational status, health, and performance. AI algorithms can analyze this data in real-time, detecting anomalies and potential issues in satellite systems. By continuously monitoring telemetry parameters, AI can identify abnormal behavior, malfunctions, or potential failures. This enables proactive maintenance, timely intervention, and efficient troubleshooting, minimizing downtime and ensuring the reliability of satellite communications. AI-driven telemetry anomaly detection enhances the operational efficiency and longevity of satellite systems, reducing the risk of service disruptions. In [187], the performance of different machine learning algorithms that can be used for satellite telemetry anomaly detection is assessed.

LEO connectivity mega-constellations are booming, with prime examples being the Starlink constellation that counts close to 4000 satellites in orbit [188] and the OneWeb megaconstellation that counts more than 600 satellites in orbit [189]. Another example is Amazon's Project Kuiper which foresees a fleet of 3000 connectivity satellites. It is noteworthy that these constellations already implement or consider implementation of ISL (Inter-Satellite Link). For example, the SpaceX V2 satellites employ optical inter-satellite links [190], OneWeb considers the use of ISL for its next generation of satellites [191], while Project Kuiper is set to implement an ISL to connect with the US SDA (Space Development Agency) transport layer, as well as to have its own mesh network [192].

In inter-satellite link path planning, AI-powered satellite systems can optimize the communication paths between interconnected satellites. AI algorithms can analyze various parameters, such as satellite positions, link quality, traffic demands, and network topology, to intelligently plan and optimize ISL paths. AI-driven ISL path planning enhances the performance and scalability of satellite systems, enabling seamless connectivity and data exchange among satellites in complex constellation topologies. In [193], the authors propose a deep reinforcement learning method for dynamic inter-plane ISL planning optimization in LEO satellite constellations.

Additionally, AI algorithms integrated into regenerative payloads can analyze incoming signals, perform signal processing operations, and enhance the quality of the transmitted signals. By leveraging AI, regenerative payloads can mitigate induced errors, noise,

distortion, and interference, resulting in improved signal quality and reduced error rates. This capability is particularly beneficial in satellite communications, where signals can suffer from various impairments during transmission through the space environment. In [185], the use case of Forward Error Correction with AI in regenerative payloads on-board satellites is presented and assessed as having good potential for on-board applicability.

### 4.2.3 Deep Space and Space Exploration

AI can enable deep space satellites and exploration rovers to make autonomous decisions based on real-time data analysis with benefits maximized if the AI execution takes place on-board the space vehicles. AI algorithms can analyze sensor data, images, and other scientific measurements to identify interesting features, prioritize targets, and adjust mission plans accordingly. This autonomy reduces reliance on ground control commands, which come with high latency, and allows for more efficient and adaptive exploration of celestial bodies. Different AI applications can potentially be implemented in edge processing platforms to increase space vehicle autonomy and efficiency.

AI algorithms can analyze imagery and sensor data to create detailed maps and models of the terrain, enabling exploration rovers to navigate challenging landscapes with greater precision and efficiency. AI-powered terrain analysis helps in identifying obstacles, determining safe paths, and optimizing rover movements. This capability is particularly crucial in complex and uncharted environments, such as the surfaces of Mars or other celestial bodies and in the context of orbiter - rover synergy. An implementation of AI, to classify martian terrain and aid in rover navigation, is AI4Mars [194].

Additionally, AI can enhance rover path planning. AI implementation for rover navigation is presented in [195], where Sobel operators and an ML model are implemented and path ranking efficiency is assessed, in the context of the Mars Perseverance rover use case. Another AI implementation for increased rover autonomy and adaptability through the OASIS autonomous space system is presented in [196].

Deep space satellites and exploration rovers generate scientific data. AI algorithms integrated into these systems can analyze the data in real-time, helping to identify patterns, detect anomalies, extract valuable scientific insights and ultimately decide which data to transmit back to Earth. AI-powered data analysis accelerates the process of scientific discovery, enabling researchers to make informed decisions and prioritize areas of interest for further investigation. In [197], the use of machine learning for science autonomy in the context of MOMA (Mars Organic Molecule Analyzer) for the EXOMars mission is presented. NASA’s Perseverance rover uses the AEGIS (Autonomous Exploration for Gathering Increased Science) AI tool to autonomously select and target Martian rocks [198]. Regarding the scientific discovery procedures, the PIXL tool of the Perseverance rover already implements AI to determine its position [199].

In a different area of application and in parallelism with Earth-orbiting satellites, AI algorithms can monitor the health and performance of deep space satellites and exploration rovers, detecting anomalies, and potential faults. By continuously analyzing telemetry data, AI can identify deviations from normal behavior and initiate corrective actions or notify ground control. This capability enhances the reliability and longevity of the vehicles by enabling early detection of issues and proactive maintenance.

Finally, AI can play a role in efficient resource allocation for deep space missions, as for example with the implementation of reinforcement learning for communications resources management in space exploration systems, targeting an efficient, cognitive radio that was proposed in [200].

### 4.3 Space-as-a-Service

Space-as-a-service marks the transition from a product centric approach to a service centric approach in the space industry, similar to the software as a service platforms and cloud computing. End users that want to benefit from space do not have to have the expertise or the budget to carry out a space mission. Expenditures are shifted from capital (CapEx) to operations (OpEx), thus lowering the entry barrier to space. According to the categorization by Andreas Hein and Citlali Bruce Rosete [201], space-as-a-service encompasses many as-a-service categories, such as: payload, space platform, satellite, constellation, ground station, mission, space data and in-space mobility. This is a niche area and an emerging trend in space, which leads to an inevitable transformation of the industry, as underlined in [133]. The space-as-a-service concept can be enabled by HPDP, given the flexibility and reconfigurability aspects of the latter that allow new, innovative uses for satellites. In this chapter, different aspects of space-as-a service will be assessed. To host multiple applications seamlessly on-board satellites, flexible hardware platforms, and virtualization technologies, such as hypervisors (Jailhouse, XEN, Xtratum etc.) and docker container-type technologies, which are not typically implemented in traditional, radiation hardened computers, are needed. Additionally, in the case of EO product downlink and time critical services in the context of space-as-a-service, the need for HPDP on-board satellites is apparent.

A table with the main industrial actors providing space-as-a-service concepts, classified based on [201] follows:

**Table 4: Space-as-a service international scheme**

| Company | Country | Description | References |
|---|---|---|---|
| AAC Clyde Space | GB | Space data-as-a-service. Hyperspectral and weather data are offered, VDES (VHF Data Exchange System) data service is planned. | https://www.aac-clyde.space/what-we-do/space-data-as-a-service |
| Endurosat | BG | Cubesat-based satellite-as-a-service / mission-as-a-service . | https://www.endurosat.com/services/shared-satellite-service/ |

| | | | |
|---|---|---|---|
| Exodus Orbitals | CA | Space platform-as-a-service with user defined software payload. | https://www.exodusorbitals.com/ |
| Loft Orbital | US | Loft Orbital provides mission-as-a-service. | https://www.loftorbital.com/ |
| Momentus | US | Mission-as-a-service (customer payload delivery and hosted service). | https://momentus.space/services/ |
| Plan S | TR | Space-mission-as-a-service. Plan S states that it designs satellites that are software defined and can be reconfigured on orbit for new mission objectives. The satellites host customers' payloads and Plan-S is responsible for qualification, launch and operations of the satellites. | https://www.plan.space/ |
| Planet Labs | US | Space data-as-a-service for high-resolution data. | https://www.planet.com/products/hi-res-monitoring/ |
| Planetek | IT | Space platform-as-a-service. AIX, known as AI-express, establishes a testing ground to harness cutting-edge technologies within the space environment, focusing on achieving rapid response, high responsiveness, and minimal delay. This encompasses the utilization of specialized processing units for Artificial Intelligence (AI) and Blockchain. AIX presents a blended edge ecosystem utilizing a satellite platform in orbit, furnishing Earth observation payloads, readily deployable CubeSats, and a software framework foundation. This framework operationalizes services and delivers a conceptual barrier between sensors and on-board assets. | https://incubed.phi.esa.int/portfolio/aix/ |

| | | | |
|---|---|---|---|
| Satellogic | US | Satellogic offers constellation-as-a-service to its customers. In 2022, Satellogic signed a 3 year agreement with Albania to cover some of its needs from space [202] | https://satellogic.com/ |
| Serenum Space | CZ | CubeSat-based satellite-as-a-service. Serenum provides shared satellites or the option to use a whole satellite. | https://www.serenumspace.com/services/satellite-as-a-service |
| Sky and Space (SAS) | GB | CubeSat-based satellite-as-a-service. | https://skyandspace.co/index.php/satellite-service/ |
| Spacebelt | US | Data Security as a Service (DSaaS), space-based cloud data storage service. | https://spacebelt.com/ |
| Spacecom | IL | Satellite-as-a-service model based on their existing AMOS satellites. | https://amos-spacecom.com/lp/nationsat/ |
| Spacemanic | SK | CubeSat-based satellite-as-a-service, tailor made to integrate the payloads of customers. Spacemanic is a spin-off company from the Slovak Organisation for Space Activities (SOSA), which has successfully designed, developed, launched and operated skCUBE. | https://www.spacemanic.com/services/ |
| SpaceX - Starshield | US | Payload-as-a-service. Hosted payloads for governmental agency services, particularly for national security. | https://www.spacex.com/starshield/index.html |
| Spiral Blue | AU | Space platform-as-a-service. Spiral blue invites end users to run their code in space. | https://spiralblue.space/ |

| | | | |
|---|---|---|---|
| Spire | US | Constellation-as-as-a-service provider, space-to-cloud data and analytics company that specializes in the tracking of global data sets powered by a large constellation of nanosatellites. The company currently operates a constellation of more than a hundred CubeSats. | https://spire.com/space-services/ |
| Xplore | US | Xplore aims to provide space data-as-a-service, space platform-as-a-service , operations as a service and satellite-as-a-service targeting a commercial, government and non-profit customer base. | https://www.xplore.com/services/space-as-a-service.html |
| York Space Systems | US | York space systems offers mission-as-a-service. | https://www.yorkspacesystems.com/ |

The focus of this thesis lies on the satellite-as-a service, space platform-as-a-service and space data-as-a-service. In one of the four definitions for the first according to [201], users share a physical setup and various layers of the logical structure implemented in the satellite, or the satellite is used as a node in space to run end user applications. The second term, space platform-as-a-service, refers to the concept where end users can build applications for the space platform. These two terms are in fact quite similar and are enabled by high performance, flexible computing platforms. Space data-as-service refers to the provision of requested data from space to end users.

Satellite-as-a-service enables business models through which satellite owners can enlist their in-orbit platforms for renting, thus generating revenue streams from their assets. On the other hand, customers such as companies, universities, research centers and even individuals with an enthusiasm for space can build an application based on specific satellite platform specifications. Subsequently, they can validate their application in space by applying it to data generated by various satellite instruments, in orbit at a small cost. While access to space research and satellite deployment traditionally requires significant expertise and funding even for institutional organizations, satellite-as-a-service democratizes space for multiple user categories and fosters innovation.

Furthermore, the aforementioned customers can subscribe to a space-as-a-service platform to acquire specific data from satellites. In parallel, governmental entities such as ministries could enroll in a space-as-a-service solution to receive rapid civil alerts from space, enabled by HPDP, without having to invest in building satellites. In general, the space data-as-a-service can even be offered with a subscription scheme, as is AAC Clyde Space's solution [203]. Additionally, developers can create apps targeted for use in satellite systems, thus creating a marketplace, where users can benefit by buying and implementing applications that satisfy their needs.

Also, for just a fraction of the revenue from a specific commodity, e.g. agricultural production, space-as-a-service has the potential to create large turnovers due to the enhancement of services from space, in this case through precision agriculture [133]. Of course, many applications can potentially be hosted to run in parallel in a space node, maximizing the output of the system.

In addition, an important characteristic of the space-as-a-service concept is the potential it has for reducing environmental impact from space activities, as it entails less launches and less space debris.

The as-a-service concepts described can be upscaled to constellation-as-a-service, where constellations can be owned (on the whole or in a federated ownership scheme) and provide the same services to multiple end users with more versatility and most importantly, better revisit times.

## 4.4 HPDP - Benefits for Greece

### 4.4.1 High Performance Computing Platforms for On-Board Data Processing

The development of high-performance payload computers for satellites in Greece holds significant potential for benefiting the country in various ways. By developing high-performance payload computers locally, Greece could potentially establish itself as a player in the space industry. This achievement enhances national prestige and independence, as it reduces reliance on foreign technology and strengthens Greece's technological capabilities, while it creates a national product that can be used as an asset.

Greece has various entities, industrial and research oriented, that specialize in space electronics and on-board data management, as indicated in chapter 3. Such examples are DSCAL, MicroLab and ESLab, ISD, OHB Hellas, Prisma Electronics and Planetek Hellas. Leveraging existing local capabilities and expertise in electronics and on-board data management allows Greece to harness its intellectual resources and develop cutting-edge technologies within its borders. The development of high-performance payload computers requires collaboration between various stakeholders, such as government agencies, research institutions, and private companies. This collaboration fosters technology transfer, knowledge exchange, and cross-sector partnerships. It facilitates the growth of a robust ecosystem, promoting innovation and fostering synergies between different entities.

In addition, the development of high-performance payload computers could create opportunities for economic growth in Greece. It could lead to the establishment of research and development centers, manufacturing facilities, and specialized workforce training programs. This growth in the high-tech sector generates jobs, attracts investments and stimulates the economy.

The identification of niche areas for Greek companies to enter the space market is an element of the HSC’s proposed strategic action plan, as analysed in chapter 3.2.1. High-performance payload computers for satellites represent a niche area in the space industry. Compared to other domains, Greece may face less fierce competition in the specific one, allowing it to carve out a unique position in the market. By focusing on this specialized technology, Greece can leverage its strengths and gain a competitive edge. ESA has a keen

interest in the emerging trend of on-board data processing and AI on-board and this can be leveraged to further expand local capabilities and topple competition.

High-performance data processing on-board satellites can benefit many domains of applications in the space sector, including Earth Observation. Developing high-performance payload computers could allow Greece to enhance its capabilities in this strategic area. As indicated in chapter 2, 23 of the identified national needs in the EO category are characterized by high time criticality and can be addressed with applications enabled by HPDP. These applications could be fire detection and monitoring, flood detection and monitoring, ship detection, missile early warning and target identification on the ground, amongst others, significantly reducing the country's response time to natural disasters and events that threaten national security. A domestically developed or co-developed high performance computing subsystem, executing AI algorithms, could be implemented in a national Earth Observation satellite, thus addressing the country's needs via a programme that is developed locally.

Greece's development of high-performance payload computers could position the country to become an exporter of advanced space technologies. With a unique product in the market and growing expertise, Greek companies can seek international collaborations and partnerships, leading to the export of satellite components and technology transfer. This enhances Greece's global reputation as a high-tech hub and boosts its export revenues.

Finally, HPDP enables the Satellite-as-a-service concept, which has its own added benefits for the country, that will be described in the next chapter.

### 4.4.2 Satellite-as-a-Service

Satellite-as-a-Service (SaaS) has the potential to bring numerous benefits to Greece, leveraging different applications based on seasonal needs, facilitating collaboration between universities, research centers, and businesses, enhancing the processing of Earth Observation (EO) data products, and utilizing Greek expertise in AI and on-board data management. Following is an overview of the potential advantages. It should be noted that the arguments from chapter 4.4.1 regarding the advantages of developing HPDP, apply also in the case of satellite-as-a-service.

The integration of satellite services, such as fire and flood detection, could significantly contribute to Greece's disaster management and resilience efforts. In chapter 2, it was indicated that many of the identified needs for Greece that involve Earth Observation are highly time critical. Early detection of disasters and other time critical phenomena allows for prompt response and efficient allocation of resources, reducing the impact on human lives, infrastructure, and the environment. SaaS could enhance the effectiveness of Greece's disaster preparedness and response systems, at a lower cost (e.g. subscription in the service instead of buying a constellation). Moreover, SaaS enables Greece to optimize satellite services based on seasonal requirements. For example, during the summer, satellite-based fire detection systems can be deployed to identify and monitor forest fires, providing early warnings and facilitating efficient response measures. In autumn, flood detection systems can be utilized to monitor and assess areas prone to flooding, helping authorities take proactive steps for mitigation and response.

SaaS can act as a collaborative platform for universities, research centers, businesses and private individuals in Greece. By providing a scheme for these end users to upload and validate their applications in space, SaaS fosters innovation and research. This collaboration can lead to the development of novel applications, data analysis techniques, and scientific discoveries, enhancing Greece's technological and research capabilities.

SaaS offers multiple data sources for EO product processing businesses and research units in Greece, which are 48, as indicated in chapter 3 (category based on ESA taxonomy: User Operations). By accessing satellite data from various providers and sensors, these entities could improve their products' accuracy, resolution, and timeliness. This allows for better monitoring of natural resources, environmental changes, and agricultural activities, leading to more informed decision-making and resource management. At the same time, local needs are addressed with local capabilities, ultimately boosting the local ecosystem and economy.

With AI algorithms and data processing capabilities embedded within the satellites, real-time data analysis and decision-making can be achieved without relying solely on ground-based processing. This enhances the efficiency and responsiveness of satellite services, making them more valuable for various applications. The on-board AI asset could be provided by the local capacity, as many companies and research units are involved with AI for EO, as assessed in chapter 3.

The workshop "Satellite-based Services for Disaster Risk Management" was organized by Eurisy in collaboration with EUSPA, the Greek Ministry for Climate Crisis and Civil Protection, and the Ministry of Digital Governance. Taking place in Athens on May 25th, 2022, the event sought to foster a shared comprehension among Greek and European stakeholders regarding the benefits that satellite-based services offer throughout the disaster management process. Additionally, it aimed to explore ways to streamline the accessibility and utilization of these solutions at both national and local levels [204]. A survey was conducted by Eurisy in conjunction with the event, with a participation from 63 respondents, including small and medium-sized enterprises (SMEs), public entities and researchers engaged in a wide range of fields. These fields encompassed environmental protection, disaster risk management, urban planning, and energy, among others. The participants were all stakeholders in the disaster management domain and were using satellite applications or were interested in them. An outcome of the survey was that the main barriers in the adoption of satellite technologies were of technical and economic nature. Satellite as a service is able to tackle both of those challenges, as it overcomes those exact hurdles for access to space services.

SaaS could create economic opportunities for Greece by attracting investments and fostering the growth of the space industry. The provision of satellite services could lead to the establishment of local satellite technology companies, job creation, and technology transfer. Additionally, the availability of satellite data and services could attract international businesses and researchers to collaborate with Greek entities, further boosting the economy.

Overall, Satellite-as-a-Service could potentially bring numerous benefits to Greece, ranging from tailored seasonal applications and collaboration opportunities to enhanced data processing capabilities and economic growth. By harnessing these advantages, Greece could strengthen its technological capabilities, improve disaster management, and promote sustainable development for the benefit of its citizens and the environment.

### 4.5 HPDP - Benefits for Europe

Greece is located in Southeastern Europe, therefore the Greek needs which are covered by HPDP, are also European needs. Also, Europe can evidently benefit from satellite-based early warning in multiple scenarios. In [204], the role of satellite applications in countering climate change and related hazards is assessed, given that extreme weather effects and related phenomena will only increase in the future, due to the climate crisis. The benefit of using satellite services to mitigate disasters such as in the flood-prone Wallonia is presented. The WALOUS project is utilized by the Public Service of Wallonia to create fresh land cover and land use maps through the utilization of preexisting geographical databases, aerial photographs, and Copernicus imagery. These maps of land use and land cover enable the detection of areas susceptible to flood hazards. By evaluating regions of economic operations that could be impacted by specific flood scenarios, strategies can be suggested to mitigate risks within these zones. Another point made in this publication is the need to monitor satellite imagery for structural deformations in bridges, based on the Morandi bridge collapse in Italy on the 14th of August 2018. In these use cases, smart satellites would potentially be able to provide timely alerts and prevent or help in the disaster mitigation.

Regarding statistics for some of the similar needs, looking just at the EU, wildfires in 2022 impacted 26 of the 27 EU countries (all except Luxembourg), burning in total 2,068,795 acres [205]. It is emphasized that EO, GNSS services and satellite communications can help in mitigation of disastrous phenomena, with low latency alert delivery being a key factor.

For 2021, total insurance losses in Europe from flooding were estimated to be more than $12,000,000,000 US [206]. Flood detection and monitoring via satellites could aid in management of this disastrous phenomenon and reduce damages.

In addition, in a report by the Food and Agriculture Organization of the United Nations in 2022 for the Mediterranean and the Black Sea, it was documented that the majority of fishing stocks (73%) with confirmed assessments are still being harvested at levels that exceed ecological sustainability and the average fishing intensity remains twice as high as the threshold deemed environmentally viable [207]. Ship detection and tracking from space could aid in combating illegal fishing, for example by monitoring fisheries - restricted areas. Monitoring the European sovereign territory and its vicinity to detect and control incidents such as the Nord Stream sabotage in a timely manner, is another apparent use case where HPDP could benefit Europe.

Apart from the sovereign European needs, the potential of HPDP and the concepts it enables can also be traced in the strategic plans of the European Space Agency.

A prominent example of a programme with which HPDP is aligned is the ESA Civil Security from Space (CSS) initiative. The primary objective of the European Space Agency's Civil Security from Space Programme, is to promote the utilization of space-related advancements that contribute to the preservation of lives and livelihoods. It facilitates the rapid and effective involvement of civil security organizations in humanitarian efforts, law enforcement activities, ensuring public safety and responding to emergency situations. This initiative is designed to provide assistance at any given moment, with the overarching goal of benefiting all individuals involved [208]. The envisaged end-to-end CSS systems rely on sensors for gathering data for situational awareness, a communications infrastructure for quick and secure delivery of data and processing capacities to extract value and actionable

insights from the data. Ultimately, it is crucial to deliver the information to civil security and crisis management authorities, entrusted with the duty of undertaking suitable measures to counteract and effectively address situations that pose a threat to the safety of European citizens.

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**Image 2: ESA's Vision 2035 for a federation of systems in the context of CSS. Source: ESA**

The CSS programme can be materialized by a federated end to end system of interoperable segments, something that is largely enabled by HPDP and its characteristics.

In parallel, at least three research units affiliated with ESA are involved in the exploration of AI applications for space: the AI Special Interest Group Dedicated to Space and Related Sciences, the ESA Advanced Concepts Team and the ESA Φ-lab, which is specifically involved in the use of AI on board Earth Observation missions [209]. ESA investigates commercial use cases where AI could be applied in space activities, including data processing and transmission and autonomous navigation. The interest of the Agency for AI in space and edge computing is confirmed by multiple issued ITTs and the milestone mission of the OPS-SAT satellite that was mentioned in a previous chapter.

Further, the ESA Agenda 2025, indicates the need for Europe to upgrade its involvement in space and create new markets for space technologies that boost green and digital concepts. In the context of this directive, ESA issued in 2021 the Cognitive Cloud Computing in Space campaign, which called for the utilization of AI and edge computing to benefit space missions [210].

ESA has also launched Φ-Sat 1, a 6U CubeSat with a HyperScout-2 camera and an Intel Movidius board with an Intel Myriad II chip (VPU) that implemented cloud detection on-board to filter out captured images [211]. The follow up mission, Φ-Sat 2, also a 6U CubeSat, will be equipped with a multi-spectral optical camera and an Intel Movidius Myriad II as well. The apps that will run on-board include ship detection, cloud detection and forest monitoring [212]. Also, through AI4EO, ESA's Artificial Intelligence initiative, winners of the Orbital AI challenge will be able to run their application on board Φ-Sat 2 [213].

Moreover, in ESA's Technology Strategy 2022 Version 1.2 [214], Artificial Intelligence is identified as one of the megatrends that will widely affect the performance of space missions. COTS components are also identified as one of the technological domains of interest. The growing adoption of COTS products in the space industry, necessitates the support of technology programs to assess their suitability for use in space applications. To enable broader usage of COTS than previously anticipated, the European Space Agency (ESA) has taken measures to ensure their compatibility. This includes efforts to establish a reliable supply chain for fully space-qualified components. Given that mission scenarios are becoming more diverse and cannot be categorized solely as either COTS-based or fully-qualified components-based missions, ESA recognizes the need to address this evolving landscape.

In the same document, regarding the telecom technological needs, high performance, low power digital signal processors (e.g., reconfigurable, hybrid transparent/regenerative digital processors), systems-on-chip, software defined payloads / networks, virtualisation, beamforming and beam hopping are identified as suitable for different areas of application such as GEO flexible Ultra High Throughput satellites beyond terabit/s, (V)LEO, MEO satellites and constellations offering IoT, broadband and FSS (Fixed Satellite Services) services, satcom integration into 5G/6G, M2M (Machine to Machine) and IoT systems. In addition, power efficient signal processing addresses the green, digital satcom ecosystem and satcom in-orbit servicing areas of application. In parallel, on-board processing is explicitly identified as a driver in the instrument category with respect to commercial class EO missions and AI autonomy as a constellation enabler for commercial EO missions. Of course, these technologies can answer needs in Copernicus, Earth Explorer and Scout class missions as well. Furthermore, speed, constellation synchronization, on-board reprogrammability and flexibility are identified as needs for future EO missions, all of which can be addressed with HPDP.

The benefits of digital engineering as a domain of technology innovation are also highlighted, in terms of the added value for advanced on-board autonomy, higher system robustness and cost reduction for the operational overhead induced by the multitude of satellites in orbit. High-performance computing in space is mentioned as a potentially game-changing digital engineering technology, which may have an impact on the future competitiveness of the European space industry.

Thus, it becomes evident that the development and use of high-performance processors addresses many points of interest highlighted by the European Space Agency and boosts the European space industry competitiveness. The development of HPDP also aligns with the wider European need for digital sovereignty [215] and the EEE Space Component Sovereignty for Europe [216]. Finally, it complements other European policies, such as the Chips Act [217] which calls for boosting the competitiveness and resilience of Europe in the semiconductor manufacturing domain.

## 4.6 Conclusion

High performance data processing on-board satellites is a niche area in the space domain that has a great potential to address multiple apparent needs in Greece and in Europe in general. These needs vary and include natural disaster mitigation and digital independence, amongst others. The development of this technology or of some of its aspects can potentially

take place in Greece, harnessing existing local know-how, creating industry-academia synergies, boosting the economy and most importantly, creating national and European independence via a sovereign product in a cutting-edge technological domain.

# 5. CONCLUSIONS

## 5.1 Way Forward - National Space Policy

After citing the capabilities of Greece in space and presenting its national needs, it is evident that there is potential to be harnessed in the local space sector and this potential can be utilized to tackle the local problems at the same time. However, as was indicated throughout the thesis, there is a lack of a written, centralized national Greek space policy. In an era where space exploration and utilization hold immense potential and the economic proliferation from space activities can be substantial, with the space dubbed frequently as the next trillion dollar industry [218], the absence of a comprehensive national space policy can have far-reaching consequences. The absence of such a policy discourages investments and brain regain, diminishes the exploitation of the local ecosystem, leads to increased costs of acquiring services due to less coordination and matching of academia and industry and ultimately creates a greater dependence on foreign solutions, even for critical national needs.

The stages for the implementation of a public policy cycle can be summarized as follows [219]:

1) Identification of a problem. The creation of policy requires the identification of a problem, officially recognised in the government agenda.
2) Decision making and formulation of public policy. The problem, which is dictated by the current situation combined with the ideal requirements, leads to policy making, which defines what must be achieved and the assessment of different alternatives to that end. A prerequisite for the success of this step is good knowledge of the subject.
3) The application of the defined policy through a structured programme with specific actions, that contains elements such as which organizations will implement the programme, which are the resources and their distribution, as well as the timeline for the implementation.
4) Results. Every programme should demonstrate achieved results. Nevertheless, situations may arise where the results are delayed, the programme is wrongly implemented or blocked.
5) Evaluation of the policy’s consequences. This final step is a long-term process as the consequences of the policy will take a certain amount of time to become apparent.

A national space policy serves as a roadmap for the development and growth of the domestic space industry. Without such a policy in place, potential investors and entrepreneurs may hesitate to allocate resources to space-related ventures. The absence of clear guidelines and long-term goals can lead to uncertainty and inhibit the flow of capital, hindering the growth of domestic space enterprises.

In parallel, a well-defined national space policy provides a framework for effectively leveraging the local ecosystem and resources. Without a clear roadmap, the coordination between various stakeholders such as government agencies, research institutions, and industry becomes challenging. As a consequence, the potential for collaborative partnerships and the efficient utilization of local talent and infrastructure diminishes. This can hamper the overall growth and competitiveness of the domestic space industry, as the exploitation of local resources and expertise becomes suboptimal. At the same time, without

a national space policy that fosters coordination between academia, research centers and industry, there is a lack of alignment between research and development efforts and the needs of commercial space ventures. This mismatch leads to increased costs when acquiring services from academia or industry, as the solutions provided may not align with the specific requirements of commercial space applications. The absence of a guiding policy framework prevents academia and industry from effectively collaborating and exchanging knowledge, leading to redundancies, inefficiencies, and increased financial burdens.

Additionally, a lack of cohesive national policy can ultimately discourage scientists and engineers from returning to their home country, resulting to the hindering of the reversal of the brain drain that has impacted Greece the preceding years [220].

Moreover, a comprehensive national space policy is crucial for fostering domestic capabilities and reducing dependence on foreign solutions. Without clear objectives and support mechanisms, countries may find themselves relying heavily on technologies and services provided by other nations. This dependence not only limits a nation's sovereignty and strategic autonomy but also introduces vulnerabilities and potential geopolitical risks. A lack of a robust national space policy can impede the development of indigenous technologies and inhibit the country's ability to address its unique challenges and opportunities in space exploration and utilization. Chapter 3 provided an overview of the national capabilities regarding space, which can be harnessed and upgraded through a robust national space roadmap.

A national space policy describes the needs of a country from space and which measures should be taken to answer them. Its most critical function is that it ensures that priorities are in place, because the needs from space usually are many and the resources scarce, especially for smaller countries like Greece [221]. As described in chapter 2, there are national needs that can be answered from space, encompassing the sectors of crisis management, national defense, environmental monitoring and more. A national space policy that revolves around the addressing of these needs will establish a solid roadmap for solving the problems described, possibly leveraging local solutions to that end. An example of such an undertaking, is the creation of a centralized hub for the provision of EO data to different governmental organizations by HSC that was announced in 2023 [222]. This service will be able to centrally provide insights for natural disaster mitigation and situational awareness, through very high resolution imagery (30 cm), lowering costs for the Greek state and answering crucial needs. The contracted supplier for the provision images is TotalView, a space company located in Greece.

Moreover, through a national space policy and by leveraging ESA and European programmes, know - how that stays in the country can be created. A delegation that frequently exchanges with the local space actors can potentially leverage European programmes that align with national interests and create value for society, implementing the national space policy.

The 2021 HSC proposal for a national space policy should be updated taking into account the lessons from the Ukrainian war, the new EU Space Strategy for Security and Defence, and the abandonment of the Greek microsatellite programme which focused mainly on telecommunications.

The lessons from the Ukrainian war have shown the importance of space-based capabilities for both military and civilian applications. The EU Space Strategy for Security and Defence

has outlined a number of priorities for the EU in space, including security and surveillance, crisis management, and disaster response. The abandonment of the Greek microsatellite programme means that Greece needs to focus on other areas of space development, such as Earth observation. The updated national space policy proposal should reflect these changes in the strategic landscape.

As a final note, the Hellenic Space Center can perform the coordination between state, academia, research centers and industry [2] and contribute to the creation of a solid national space policy, orchestrating the local space activities in all levels. Further, the HSC can coordinate with the Ministry of National Defense to formulate a plan for further space integration in national defense programmes.

To conclude, there is a need for the creation of a national space policy in Greece, in order to solidify the country's goals regarding space and chart the necessary directives accordingly, offering a multitude of benefits to the local space sector and ultimately, society.

## 5.2 Specific Proposals for how Greece can Enhance its Space Capabilities

### 5.2.1 System and Subsystem Building Capacity

Another important aspect of the way forward of Greece is the need for satellite building capacity in the country. Recently, there are many developments in this direction, mainly with the Greek Cubesats In Orbit Validation Projects [119], the Upgrade to HAI (Hellenic Aerospace Industries) Assembly, Integration and Testing (HAIT) Facilities [124] and the Telecomsat Greek Connectivity [101] ESA programmes. All these initiatives target the upgrade of satellite building capacity in Greece. However, it must be ensured that these programmes are implemented in a way that economic return and technology transfer for the Greek space industry are secured.

It should also be considered that Greece could find its place within the inter-European and international space scene through expertise in specific, niche areas that combine its local strengths and can also answer the national needs. One such domain could be high-performance data processing which could play a significant role in the development of the satellite subsystem building capacity in Greece.

The responsible coordinators on a national level should exchange with the industry and academia and define such areas of opportunity and growth, all based on a solid national space policy. Whether creating a roadmap for satellite development in the country or focusing on specific subdomains of the space sector, centralized planning and a national space policy with clear targets in place are required.

### 5.2.2 Investing in Research and Development in Space Technologies

This directive includes developing new technologies and improving existing ones. To effectively invest in research and development (R&D) in space technologies, a country should embark on a well-structured journey. Firstly, it's essential to establish a clear vision and strategy, defining specific goals and objectives for space technology R&D. A national space policy could play a key role in that aspect. Next, allocating a significant budget for

these endeavors is crucial, while the formation of a dedicated national space agency or program could play a pivotal role in coordinating and overseeing all space-related activities within the country.

Encouraging public-private partnerships and fostering collaboration between government agencies, research institutions and private companies to pool resources and expertise should take place. Furthermore, funding research projects directly in space-related fields, such as propulsion systems, and materials science, is vital. Promoting innovation is equally crucial, offering incentives such as tax breaks and subsidies to companies and startups engaged in space R&D. Collaborating internationally by participating in space research partnerships and sharing knowledge and resources can help achieve common goals. Investing in infrastructure, including testing sites and research centers, is essential to support space technology development and testing as well, while fostering the commercialization of space technologies by incentivizing private companies to develop and market products and services derived from R&D efforts, can drive economic growth. Lastly, engaging the public through educational programs, outreach, and media campaigns can inspire interest and support for space R&D. This comprehensive approach to investing in space technology R&D can lead to technological advancements, economic growth, and international prestige.

### 5.2.3 Building up the Country's Expertise in Space Science and Engineering

This directive includes training and educating the next generation of space scientists and engineers. To effectively train space scientists and engineers, a structured approach that encompasses various key components should be implemented. Firstly, establishing a comprehensive educational framework is essential. This includes developing specialized academic programs and courses in space-related fields at universities and technical institutions, while investing in infrastructure and equipment for the relevant facilities. Scholarships and grants should be made available to encourage students to pursue degrees and careers in space science and engineering.

Also, facilitating practical training opportunities is important. This could be implemented by establishing internships and apprenticeship programs with space agencies, aerospace companies, and research institutions to allow students and young professionals to work on real-world space projects. Lastly, another important factor is engaging in public outreach and awareness campaigns to inspire and educate the public about space science and engineering careers.

### 5.2.4 Collaborating with Other Countries and Organizations-Companies in Space Projects

This directive includes working with other countries to share resources and expertise. Partnering with other nations provides access to a broader pool of talent, expertise, and experience. It allows countries to tap into the knowledge and skills of scientists, engineers, and space professionals from around the world, while enabling technology transfer. Finally, by creating the right conditions domestically, companies could be attracted to found subsidiaries in Greece, thus accelerating the technology and know-how transfer which could

be leveraged to serve the national space policy, while creating job positions at the same time.

# 6. ABBREVIATIONS – ACRONYMS

| | |
|---|---|
| AI | Artificial Intelligence |
| AIT | Assembly, Integration and Testing |
| ASI | Agenzia Spatiale Italiana |
| AUTh | Aristotle University of Thessaloniki |
| CAD | Computer Aided Design |
| CERTH | Centre for Research & Technology Hellas |
| CNES | Centre National d'Études Spatiales |
| COPUOS | Committee on the Peaceful Uses of Outer Space |
| COTS | Commercial Off The Shelf |
| CSO | Composante Spatiale Optique |
| CSS | Civil Security from Space |
| DLR | Deutsches Zentrum für Luft- und Raumfahrt |
| DMIPS | Dhrystone Mega Instructions Per Second |
| DPU | Data Processing Unit |
| DTN | Delay Tolerant Networking |
| DUTh | Democritus University of Thrace |
| ECSS | European Cooperation for Space Standardization |
| EDF | European Defense Fund |
| EEE | Electric, Electronic and Electromechanical |
| EGNOS | European Geostationary Navigation Overlay Service |

| | |
|---|---|
| EGSE | Electrical Ground Support Equipment |
| ELINT | Electronic Intelligence |
| EO | Earth Observation |
| ESA | European Space Agency |
| ESA BIC | European Space Agency Business Incubation Center |
| ESERO | European Space Education Resource Office |
| ESOC | European Space Operations Centre |
| EURO QCI | European Quantum Communication Infrastructure |
| EUSPA | European Union Agency for the Space Programme |
| EUTELSAT IGO | European Telecommunications Satellite Organization |
| FORTH | Foundation for Research and Technology Hellas |
| FPGA | Field Programmable Gate Array |
| FSS | Fixed Satellite Services |
| GEO | Geostationary |
| GIS | Geographic Information System |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| GRMCC | GReek Mission Control Center |
| H2020 | Horizon 2020 |
| HAI | Hellenic Aerospace Industry |

| | |
|---|---|
| HASI | Hellenic Association of Space Industry |
| HPDP | High Performance Data Processing |
| HSC | Hellenic Space Center |
| HSTR | Hellenic Space Debris Tracking Radar |
| IAASARS | Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing |
| IC | Integrated Circuit |
| ICT | Information and Telecommunications Technology |
| INMARSAT | International Mobile Satellite Organization |
| IP | Intellectual Property |
| ISA | Israel Space Agency |
| ISL | Inter-Satellite Link |
| ITT | Invitation to Tender |
| ITU | International Telecommunications Union |
| JAXA | Japan Aerospace Exploration Agency |
| LEO | Low Earth Orbit |
| M2M | Machine to Machine |
| MEO | Medium Earth Orbit |
| MGSE | Mechanical Ground Support Equipment |
| ML | Machine Learning |
| MUSIS | MUltinational Space-based Imaging System |
| NASA | National Aeronautics and Space Administration |

| | |
|---|---|
| NCSR | National Center for Scientific Research |
| NIR | Near InfraRed |
| NKUA | National and Kapodistrian University of Athens |
| NOA | National Observatory of Athens |
| OBC | On-Board Computer |
| OTE | Organismos Tilepikoinonion Ellados (Greek Telecommunications Organization) |
| PNT | Position, Navigation and Timing |
| RF | Radio Frequencies |
| RFI | Request for Information |
| RS | Remote System |
| SaaS | Satellite-as-a-Service |
| SAR | Synthetic Aperture Radar |
| SATCEN | European Union Satellite Center |
| SEE | Single Event Effect |
| SEFI | Single Event Functional Interrupt |
| SEL | Single Event Latch-up |
| SEU | Single Event Upset |
| SIGINT | Signal Intelligence |
| SoC | System-on-Chip |
| SoM | System-on-Module |
| SST | Space Situational Awareness |

| | |
|---|---|
| STEM | Science, Technology, Engineering, and Mathematics |
| SW | Software |
| SWIR | Short Wave InfraRed |
| UAS | Unmanned Aerial Systems |

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