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The use of space-based assets for enhancing EU's security: An analysis of the role of satellites in detecting internal security threats

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ΕΘΝΙΚΟ ΚΑΙ ΚΑΠΟΔΙΣΤΡΙΑΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ

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ΑΘΗΝΑ

ΑΠΡΙΛΙΟΣ 2025

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ABSTRACT

The European Union (EU) has acknowledged the growing significance of space-based assets (SBAs) in the identification and combat of diverse internal security threats. EU authorities use satellites to get accurate and timely information for early warning systems. This means the EU uses satellite technology to gather precise and prompt data for systems that warn about potential threats or emergencies, such as border crossings, ship movements, and natural disasters, helping to reduce threats effectively.

Additionally, satellite-based communication networks can offer a reliable method for transmitting critical information regarding a variety of threats, such as terrorism, organized crime and cyberattacks. Furthermore, in emergency scenarios, where disruptions to terrestrial networks may occur, satellite-based communication networks can offer a reliable alternative.

However, using SBAs for internal security purposes presents several legal, ethical, and technical challenges, including issues with interoperability, sustainability, privacy, and data protection. To investigate the effective use of SBAs and their alignment with the values and principles of the EU and its authorities, interviews were conducted.

The interviews were focused on professionals from relevant Authorities, such as Security Agency Operators, Humanitarian Aid Providers and Fire Fighters that engage in border control activities and natural disasters. The interview results raised issues of timely information, cost effectiveness and access to technology, rather than the need for more technological advancements. Issues were also raised on the incorporation of SBAs on ground operations, the ethical use of SBAs and their use to cover malicious activities.

The coupling and combination of SBAs has the potential to provide a variety of information to field operators that can significantly contribute to the identification, monitoring and management of internal security threats. The nature of an internal security threat, the technical capabilities of SBAs and the availability of resources in the field are explored in this thesis to identify best practices and solutions that could improve response times.

SUBJECT AREA: Security and Space-Based Assets.

KEYWORDS: space-based assets, internal security, satellite surveillance, border control, disaster response

ΠΕΡΙΛΗΨΗ

Η Ευρωπαϊκή Ένωση (ΕΕ) έχει αναγνωρίσει τη αυξανόμενη σημασία των διαστημικών πόρων (SBAs) στην αναγνώριση και αντιμετώπιση διαφόρων εσωτερικών απειλών ασφαλείας. Οι αρχές της ΕΕ χρησιμοποιούν δορυφόρους για να αποκτήσουν ακριβείς και έγκαιρες πληροφορίες για συστήματα έγκαιρης προειδοποίησης. Αυτό σημαίνει ότι η ΕΕ χρησιμοποιεί δορυφορική τεχνολογία για να συλλέξει ακριβή και άμεση δεδομένα για συστήματα που προειδοποιούν για πιθανές απειλές ή έκτακτες ανάγκες, όπως διασυνοριακές διελεύσεις, κινήσεις πλοίων και φυσικές καταστροφές, βοηθώντας στην αποτελεσματική μείωση των απειλών.

Επιπλέον, τα δορυφορικά δίκτυα επικοινωνίας μπορούν να προσφέρουν μια αξιόπιστη μέθοδο για τη μετάδοση κρίσιμων πληροφοριών σχετικά με ένα εύρος απειλών, όπως η τρομοκρατία, το οργανωμένο έγκλημα και οι κυβερνοεπιθέσεις. Επίσης, σε καταστάσεις έκτακτης ανάγκης, όπου ενδέχεται να διακοπούν τα επίγεια δίκτυα, τα δορυφορικά δίκτυα επικοινωνίας μπορούν να παρέχουν μια αξιόπιστη εναλλακτική λύση.

Ωστόσο, η χρήση των SBAs για σκοπούς εσωτερικής ασφάλειας παρουσιάζει αρκετές νομικές, ηθικές και τεχνικές προκλήσεις, συμπεριλαμβανομένων ζητημάτων διαλειτουργικότητας, βιωσιμότητας, ιδιωτικότητας και προστασίας δεδομένων. Προκειμένου να διερευνηθεί η αποτελεσματική χρήση των SBAs και η ευθυγράμμισή τους με τις αξίες και τις αρχές της ΕΕ και των Αρχών της, πραγματοποιήθηκαν συνεντεύξεις.

Οι συνεντεύξεις επικεντρώθηκαν σε επαγγελματίες από σχετικές Υπηρεσίες, όπως παρόχους ασφάλειας, ανθρωπιστικής βοήθειας και πυροσβέστες, που ασχολούνται με τον έλεγχο συνόρων και με φυσικές καταστροφές. Τα αποτελέσματα των συνεντεύξεων ανέδειξαν ζητήματα έγκαιρης πληροφόρησης, αποδοτικότητας κόστους και πρόσβασης στην τεχνολογία, και λιγότερο στην ανάγκη για περαιτέρω τεχνολογικές εξελίξεις. Επισημάνθηκαν επίσης ζητήματα σχετικά με την ενσωμάτωση των SBAs στις επίγειες επιχειρήσεις, τη δεοντολογική χρήση τους και την πιθανή αξιοποίησή τους για την κάλυψη κακόβουλων δραστηριοτήτων.

Ο συνδυασμός και η σύζευξη των SBAs έχουν τη δυνατότητα να παρέχουν ποικίλες πληροφορίες στους επιχειρησιακούς φορείς πεδίου, συμβάλλοντας σημαντικά στην ταυτοποίηση, την παρακολούθηση και τη διαχείριση των απειλών εσωτερικής ασφάλειας. Η φύση μιας απειλής εσωτερικής ασφάλειας, οι τεχνικές δυνατότητες των SBAs και η διαθεσιμότητα πόρων στο πεδίο διερευνώνται σε αυτήν την εργασία, με στόχο τον εντοπισμό βέλτιστων πρακτικών και λύσεων που θα μπορούσαν να βελτιώσουν τους χρόνους ανταπόκρισης.

ΘΕΜΑΤΙΚΗ ΠΕΡΙΟΧΗ: Ασφάλεια και Διαστημικές Τεχνολογίες

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: διαστημικά μέσα, εσωτερική ασφάλεια, δορυφορική επιτήρηση, έλεγχος συνόρων, αντιμετώπιση καταστροφών

To all the dreamers who look up at the stars and see infinite possibilities.

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1 Introduction

When considering the European Union (EU) security agenda the focus is on external affairs, starting with foreign and security policy and extending into trade and development issues, as part of a coherent plan of action towards improving security and stability [1]. However, for the last 30 years it is prominent that the EU's external security capacity is interconnected with internal factors, such as economic performance, regulatory presence and political cohesion. In addition, boundary-spanning security concerns create uncertain limits between internal and external security threats [2]. Hence, the EU attempts to address potential threats at home and abroad by forming holistic approaches applicable inside and outside its territory [3].

1.1 Background & context of the research

Space-Based Assets (SBAs) are widely used in local, national as well as international security. Security refers to the condition of being protected against threats, risks, or harm to individuals, institutions, or nations. It encompasses measures taken to safeguard assets, ensure stability, and promote resilience across various domains such as economic, environmental, and political systems [4]. Internal security is aimed at protecting a nation's sovereignty, state stability, and citizens from threats originating from within the country, including terrorism, criminal activity, computer hackers, and disasters [5]. It focuses on cooperation between police forces and intelligence services to achieve adequate threat control and prevent any crises. In the EU context, internal security is about safeguarding the lives of citizens and the values of liberty and democracy to enable the EU citizens to go about their ordinary business without fear [6]. EU as stated in the European Security Strategy common internal security threats include in any form of terrorism, organized crime, cybercrime, cross border crime, violence, natural and man-made disasters and transport accidents [7].

SBAs are used for the prevention, monitoring, evaluation and handling of potential or existing threats. Threats are identified as the situational conditions under which an incident or a series of actions can escalate to threats such as illegal migration and trafficking, natural disasters, terrorist attacks, organized crime or cyberattacks. SBAs support the prevention or the handling of critical threats by providing Intelligence, Surveillance and Reconnaissance (ISR) tools, communications and real-time data in situations that require early warning and real time data for decision making in the field of operations [8].

SBAs typically consist of three key components: an operational space segment, an operational ground segment, and an operational user segment. These are often referred to as the uplink, downlink, and crosslink, which transmit and receive telemetry data [9]. The data received provides critical information through various products—such as space imagery and weather maps—or services, including satellite communications, positioning, and navigation.

SBAs provide critical support to information and data transmission. Satellites transmit information via radio signals to ground stations, while ground stations send operating instructions to satellites. Satellites provide services, which are used in both civilian and military operations. Despite the vast advantages in the use of SBAs, they are vulnerable to unintentional damage and disruption, and to deliberate attacks [10].

ISR tools from SBAs, are utilized by Authorities that are responsible for civil response, protection, and resilience. Earth Observation (EO) satellites are already used to a certain extent in the support of the action of first responders in case of major disasters. The coordinated utilization of satellites is needed to provide timely delivery of images and geospatial information of an incident and the concerned area. In addition, civil protection utilizes SBAs to identify all necessary aspects for the identification and combat of threats. Also, the use of satellites and communication networks can be used as ISR tools to border and maritime control as well as in natural disasters.

1.2 Problem statement

The utilisation of satellite technologies in Intelligence, Surveillance, and Reconnaissance systems and communication networks is steadily increasing. Specific technical capabilities of Space-Based Assets are already employed by civil response agencies, supporting both the monitoring of threats and the coordination of responses. Innovative initiatives also showcase current technological advancements, such as improvements in signal processing, which offer potential benefits for civil response operations. Existing case studies—within EU territory and in neighbouring countries—demonstrate the use of SBAs, highlighting best practices and identifying technical challenges that could be addressed in the future.

However, the deployment of SBAs is accompanied by several technical limitations. Firstly, interoperability poses a challenge, as SBAs are typically integrated with other digital tools used by various authorities for both ISR and communication purposes. Secondly, sustainability is a concern, given that SBAs demand substantial financial, material, and energy resources. Thirdly, questions arise regarding whether the spatial resolution and revisit times of SBAs are sufficient to deliver timely and valuable information for incident monitoring and response coordination. Fourthly, privacy is an issue, as SBAs can capture sensitive information that may infringe upon personal data rights. Fifthly, cybersecurity and data protection present significant risks.

The enhanced capabilities of SBAs are increasingly linked to emerging technologies, such as artificial intelligence (AI) and the Internet of Things (IoT). The advanced algorithms employed by AI and IoT rely on vast quantities of data, necessitating robust measures to ensure data integrity and protection against cyber threats. Thus, while the future of SBAs is challenged by these issues, it is also driven by the pressing need for more effective and efficient civil response systems, encompassing both ISR and communication functions

1.3 Research question

This thesis seeks to address the following questions: Are existing Space-Based Assets capable of delivering accurate and timely information to specific authorities for effective field operations in civil response, including both ISR and communication functions? To what extent are interoperability and technological advancements required to enhance the integration and adoption of SBAs in civil response systems?

1.4 Objectives & Scope

This thesis examines the capabilities and challenges of Space-Based Assets in civil response, proposing future improvements in both Intelligence, Surveillance, and Reconnaissance tools and communication systems. The focus is on the utilisation of satellite technologies by ground and field services to enhance monitoring of threats and coordination of responses. It is evident that escalating threats necessitate immediate prevention and response actions, where space technologies offer significant benefits.

The primary objective is to assess the effectiveness of SBAs in delivering timely and accurate information for specific threat scenarios. Given the wide range of potential threats, this thesis evaluates the technical capabilities of SBAs across various categories, with a particular emphasis on cross-border crime and natural disasters. Following an extensive literature review, interviews were conducted with officials from authorities relevant to migration needs, including the Hellenic Police and Frontex, as well as humanitarian aid providers involved in cross-border migration. The interviews were extended to professionals from Fire Protection Agencies to compare SBA requirements for border control and natural disaster response.

The main scope of this thesis is to understand the way existing SBAs are used, and which SBAs are more suitable for a variety of operations, based on their technical capabilities. The thesis also explores interoperability challenges and opportunities for greater SBA utilisation in the future, enabling authorities to more effectively manage EU borders and fire incidents. The intended outcome is to identify SBA improvement requirements for civil protection authorities, focusing on early warnings, monitoring, and coordinated response.

1.5 Thesis structure

The introduction of this dissertation, in Chapter 1, identifies the main topic and the scope of work. The thesis continues with a literature review, in Chapter 2, that identifies existing practices and technologies in satellite ISR as well as the relevant technical capabilities, limitations and legal considerations. The literature review also focuses on existing case studies in EU and internationally, that provide valuable information for the use of SBAs in civil protection. The methodology, in Chapter 3, is formulated based on literature review of existing technologies and examples. The methodology focuses on the formation of a carefully structured open-end questionnaire that was addressed to top Security Officers, Humanitarian Aid Providers and Fire Fighter of national and international authorities. The data gathered from the interviews were analysed and the results of this process are presented in Chapter **Error! Reference source not found.**. Following the conducted research based on the literature review and the interviews, a discussion of the findings and for future work are presented in Chapter 6. Finally, the conclusions of the thesis are presented in Chapter 6.

1.6 Significance of the study

The utilization of SBAs for the prevention and response in threats holds immense significance in local, regional, national, EU and international affairs. In the context of migration, SBAs provide a comprehensive view of movement patterns, enhancing border ISR, supporting humanitarian efforts, and informing policy development. Real-time data on population movements enable proactive responses to potential crises, such as refugee flows or life-threatening situations. Similarly, SBAs play a vital role in civil response to natural disasters. Satellite imagery offers critical insights into environmental factors linked to climate change, which can exacerbate devastating events like floods or forest fires. The development and application of SBAs can also foster international cooperation, facilitating coordinated responses and promoting regional stability and safety.

This thesis explores the future of SBAs and how these technologies can be further integrated into civil response systems. It seeks to identify existing best practices in the deployment of SBAs across a range of potential threats. Additionally, the thesis examines technological limitations—such as timely data acquisition and interoperability across various SBA sources—and proposes new frameworks to enhance the adoption of SBAs in civil protection operations.

A key contribution of this study is a survey conducted through interviews with officers from national and international authorities, as well as NGOs, involved in migration management and fire response, including the Hellenic Police, Frontex, and Fire Protection Agencies. The survey results corroborate findings from the literature review and reinforce the arguments for improvements presented in this thesis, supporting the case for broader SBA integration into operational contexts. Finally, this study offers recommendations for leveraging diverse SBA sources to improve the timeliness and efficiency of data gathering, which is of critical importance for decision-making during operations.

2 Literature review

The literature review focuses on the concept of internal security with a special focus on EU territory. The literature review analyses the potential security threats that can be tackled by SBAs. It refers to the legislative framework of the EU for the use of SBAs and potential developments in the ethical and the legal context of operations. Moreover, the literature analyses the technical capabilities of SBAs, and the SBA technologies already used by civil response. Finally, it refers to specific case studies within the EU territory and in other countries, to identify best practices and technical challenges that could be improved in the future.

2.1 Overview of the main threats to EU's internal security

2.1.1 Internal Security

Internal security is defined as the measures taken by a state to maintain and protect its sovereignty, public order, and safety from internal threats. Domestic security involves a set of measures to counteract such threats as unauthorized crossing of borders, smuggling, terrorism, etc., and take place within the territories of a given state [5]. Internal security is more concerned with the security of national borders, protection of important infrastructures and law enforcement [6].

This means that the security of an organization is achieved through constant assessment of the internal environment, to determine possible threats and how to deal with them. This includes data collection from different sources, integration of satellite imagery data to predict and possibly halt security threats. In addition, the promotion of public order, and preservation of peace and order are other goals of internal security. This includes exercise of police powers in relation to crime prevention, regulation of social gatherings, crowd control, and disaster response.

Internal security is highly dependent on border control to ensure that there is a strict control on movements of people and commodities across the border. Internal security demands cooperation between different police forces at regional, state, border and federal levels, as well as security agencies. It is possible to note that the integration of SBAs can contribute to the enhancement of the internal security processes in a rather large degree. These technologies offer clear and live pictures which are essential in the identification and management of threats. In addition, satellite-based communication systems help authorities to co-ordinate by offering real-time data and communication systems [11].

The efficient and timely application of these technologies alongside the synergy between law enforcement agencies, and constant threat analysis guarantee the solidity of internal security. This integrated approach does not only increase the chances of identifying and preventing unlawful conduct but also increases the security and soundness of a country [5].

2.1.2 Internal Security Threats

The EU is threatened by a wide range of security risks that cut across political, economic, energy, environmental, societal, and geopolitical dimensions. Mitigation disaster prevention and environmental conservation have been amongst some of the most important areas of political change in the EU.

Crime and security are two of the most prominent internal security threats. Global population mobility enhances illegal migration in the EU and exposes cultural disparities, resulting in social tensions and difficulties in assimilation. Moreover, economic exclusion and perceived unfairness can lead to radicalization of some groups in the population and render them vulnerable to extremism. This radicalization, in turn, threatens in the form of terrorism, as evidenced by various attacks in recent years. For example, in the European Agenda on Security in 2015, terrorism is determined as one of the threats to the EU and the need for the enhancement of measures to counteract terrorist acts is stated. Other risk areas include crime, which at any given time, should be handled by internal security forces [12].

Europe has already encountered emergent issues relating to climate change, including unanticipated severe wildfires and the extremely accelerated rate of loss of species and ecosystems in Europe, thus, cooperation among Member States (MS) is essential [13]. Energy security is among the critical security dimensions of the EU, especially in the wake of the Green Deal. The EU is gradually changing its demand for energy sources to natural gas and renewable energy sources, and a slow reduction in oil and coal. New natural gas fields in the territorial waters of Cyprus, Greece, and Syria are significant in EU energy security. As Europe weans itself off oil, the alternatives to petrochemical products, including plastics, must be identified.

Another important element of the EU is Economic Security. A serious challenge is the absence of a prioritized investment system under a unified legal regime. It is possible to identify the specific sectors for such investment as the first step toward achieving an ideal model of economic complementarity. Overcoming this obstacle appears to be crucial in attaining a long-term and balanced economic relationship. The failure to reduce income disparity within and between MS leads to social tension and could act as a catalyst to worsen housing costs, especially in urban areas due to high demand. The freedom of movement of persons within the territory of the EU as a principal can cause conflict in the countries of demographic increase. It can also cause problems of cultural integration as it included the European citizens but also the migrants coming from the third countries.

Thus, in addressing these multiple-faced security threats the EU is capable of improving its security and promoting more stable and beneficial relations with third countries. The application of SBAs can offer significant techniques for the avoidance or tracking of incidents, which pose a security threat.

2.2 Overview of the EU policies & strategies

“The Union supports autonomous, reliable and cost-effective access to space, especially as regards critical infrastructure and technology, public security and the security of the Union and its Member States” [14].

The EU has formed the Common Foreign and Security Policy (CFSP) and the Common Security and Defence Policy (CSDP) that serve as a flagship framework to address internal and external security threats. The CFSP is a broad policy framework under the Treaty on European Union (Title V) that coordinates EU foreign policy, including responses to crises with humanitarian dimensions. It encompasses diplomatic efforts, sanctions, and support for stability, which can indirectly relate to humanitarian aid (e.g., addressing state failure or conflict causing refugee flows).

The CSDP, a subset of CFSP, focuses on security and defence, including civilian and military missions. Many CSDP missions have humanitarian aspects, such as stabilising post-conflict zones (e.g., EUFOR Althea in Bosnia) or supporting disaster response (e.g., EUCAP Sahel Niger), though humanitarian aid delivery is primarily managed by the European Commission’s Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO).

The role of space in European security and defence policy was gradually recognised, with a pivotal shift occurring after the September 11, 2001, terrorist attacks and the integration of the Western European Union (WEU) into the European Union in 2001. The urgent need for enhanced security and rapid information sharing prompted the European Council to prioritise the CFSP, strengthening the European Security and Defence Policy (ESDP, later CSDP).

In 2003, the General Affairs and External Relations Council (GAERC) formally acknowledged the critical role of Space-Based Assets in enhancing EU crisis management capabilities, enabling both civilian and military Crisis Management Operations under the ESDP. This decision was followed by the European Council’s adoption of the European Security Strategy (ESS) later that year, marking a milestone in establishing a comprehensive security framework. Subsequently, in 2004, the first "ESDP and Space" policy was established, further solidifying the integration of space capabilities into EU security efforts [15].

To leverage SBAs effectively, the EU Satellite Centre established in 1992 under the WEU and transferred to the EU in 2002 as an agency under the CFSP, delivers GEOspatial INTelligence (GEOINT) services. GEOINT exploits and analyses imagery and geospatial data to describe physical features and geographically referenced activities, using satellite and aerial imagery to produce critical products and services. This intelligence supports decision-making and actions by international organisations, EU agencies, and Member States, addressing key CFSP/CSDP priorities such as humanitarian aid, urban/rural planning, crime, and security ISR, critical infrastructure, military capabilities, and weapons of mass destruction.

2.2.1 EU Internal Security Strategies

The European Security Strategy of 2003 called for an early intervention and prevention of threats through diplomacy, partnership, and building capacity. The Space for Security (SPASEC) document, which was published in 2005, after the "ESDP and Space" policy was established, revealed how satellite technologies improve awareness and readiness of the operational environment. Also, SPASEC recognised that internal security needs from space align with external security needs, reflecting the EU's growing acknowledgment of space as a unified enabler across security domains. This convergence highlights the critical role of Space-Based Assets—such as satellite earth observation, communications, and navigation in addressing both internal threats (e.g., border security, public safety) and external challenges (e.g., military operations, regional instability).

The most important document, in this respect, is the Internal Security Strategy 2010, entitled "Towards a European Security Model" [16]. This included coordinating the MS and EU agencies to combat transnational crime, terrorism, and natural disasters. One aspect of this strategy has been the attempt to weld together existing bodies into a coherent security edifice − Europol and Frontex. Moreover, it highlighted the importance of optimal utilization of available technology for sharing of intelligence or enhancing operation such as SBAs [17].

On this basis, the 2014 Internal Security Strategy dealt with new and growing threats, including cyber-crime and hybrid warfare, which cannot be tackled through traditional methods. This strategy raised the notion of internal security, aiming at the ways organizations can address new threats. It demanded improving observation measures, especially satellite observation and real-time data release, to improve border security and anti-terrorism levels. In addition, the 2014 strategy introduced an increasingly important component of international cooperation since many dangers, including cyber threats and criminal organizations, are global [18].

The Internal Security Strategy of 2020, based on "A Europe that Protects", enlarges upon these earlier strategies and incorporates the concept of digital innovation and AI in the security sector. Although its aims and tasks are similar to those set by its predecessors – counter-terrorism, improving the management of external borders, and combating organized crime – the focus is shifted towards cyber defence and safeguarding critical infrastructure. Further, the strategy recognises using satellite systems, such as those developed under the EU Copernicus programme for high resolution images and situation awareness, necessary for border control and disaster management [19]. These strategies collectively show that the EU fully understands the need to transform its security strategy to meet new security threats.

2.2.2 Crime & Security

The CFSP/CSDP policies establish frameworks under which geospatial intelligence (GEOINT) is provided to European Union decision-makers by relevant operational agencies, such as the SatCen. This GEOINT supports a wide range of general crime and international security issues, including border security, counter-terrorism, maritime piracy, illicit cultivation, and cross-border territorial disputes.

The EU, to guarantee long term developments and operational capabilities of the MS and interactions with neighbouring countries has created the Instrument for Stability, aimed at supporting crisis response, conflict prevention, and peacebuilding. The Instrument for Stability was intended to finance the measures for protection or restoration of the operational environment that the MS and partner countries of the European Union cooperate.

Interparty conflicts often occur in areas that involve EU interest or where the EU is required to mediate a conflict. Satellite imagery is a non-intrusive technique for monitoring treaties and averting possible risky on-ground conditions. As such, SatCen supports the EU's Instrument for Stability by providing accurate GEOINT of disputed territories to the organization.

In the context of border control, the CFSP/CSDP policies prioritise addressing the drivers of uncontrolled migration, such as wars, instability, and poverty, which affect the borders of countries experiencing political or economic turmoil."

Large scale movements of refugees from conflict ridden areas can alter the political balance among countries in their vicinity and possibly create new conflicts in areas that the EU has strategic stakes. Furthermore, most refugees prefer to live in the EU countries especially those in the Mediterranean. To ensure safety of the EU countries, there is need to closely track cross-border displacements to reduce incidences of terrorisms, drug, and weapons trafficking among other risks. Since many of the areas where such events occur are remote, remote sensing is an essential technique, used to assist EU engaged Agencies. The daily high-resolution satellite imagery provides an independent view of the situation on the ground that can help in risk assessment.

Another area of concern of the CFSP/CSDP framework is global terrorism. After the 9/11 tragedy in the USA, the emergence of the ISIS and terrorist attacks on the territory of the EU, the Union has assumed more responsibilities of countering global terrorism. The EU Counter-Terrorism Strategy launched in 2005 to fight terrorism internationally, with respect for human rights and the promotion of conditions in which people can live in liberty, security, and justice. This is an international commitment that assists EU citizens in third countries; it also protects and sustains EU military and civilian assets in operation.

As outlined by the four main activities of the EU Counter-Terrorism Strategy (Prevent, Protect, Pursue, and Respond), the EU through the SatCen services provides potential patterns of terrorist activities in the form of geospatial analyses that involve identification of terrorist training camps and weapons smuggling.

Further, satellite imagery combined with other spatial data construct spatial vulnerability models to estimate the terrorism threats.

Another area of the CFSP/CSDP framework is piracy and coastal security. Piracy is a constant threat to world shipping and not only brings losses in terms of money, but also, and this is more important, lives are lost. The EU offers GEOINT derived from imagery to the EU agencies to prevent, deter and control piracy. To track movement of offshore vessels and to detect support structures on the mainland including pirate hide out zones, remote sensing is used.

The EU policy on drugs seeks to contain the difficulties of illegal cropping. Often, drug barons and paramilitary organizations compel farmers to grow cannabis, opium, or coca plant. For verification of illicit farming, multispectral and hyperspectral satellite images will differentiate between different crops. By applying the image processing techniques, it is possible to assess characteristics of crops such as moisture, chlorophyll or leaf area index, which in turn give information about the type of crop under consideration.

2.2.3 Disaster Response

With respect to humanitarian aid, specific policies within the framework of the CFSP/CSDP, such as civilian and military missions, focus on stabilising regions impacted by man-made or natural disasters, state failures, and conflicts affecting refugee populations, thereby enabling secure environments for addressing dangerous situations and supporting aid delivery. Disasters frequently arise either from human-induced or a natural threat. The magnitude of a disaster is determined by the extent of the impact a hazard has on both society and the environment, and the degree to which it surpasses the affected community or society's capacity to manage using its available resources.

Within the framework of the CFSP and CSDP, mapping products derived from satellite or GIS data are utilised to identify priority zones, vulnerable regions (such as potential landslide sites), and safer areas before, during, and after crisis events. These products, supplied by the EU SatCen, support assessments of flood coverage, earthquake damage, and landslide extents, thereby contributing to effective disaster management strategies in security and defence contexts.

A refugee camp serves as a temporary settlement designed to accommodate refugees. These camps, catering to both refugees and internally displaced persons, are typically established taking into consideration security and close monitoring by humanitarian agencies for efficient delivery of aid. Refugee camps can be a necessary establishment in humanitarian crises stemming from natural disasters, armed conflicts, and epidemics, which compel thousands to flee their homes, seeking refuge in such camps. Within the framework of the CFSP and CSDP, high-resolution satellite imagery is utilised to provide detailed information, such as the number and origin of refugees, and the layout of humanitarian or security facilities in refugee camps. This analysis, supported by agencies like the EU SatCen, also includes detecting potential paramilitary activities and assessing the likelihood of attacks on refugee camps, contributing to security and crisis management objectives."

Weak or failing states are one of the greatest long-term security threats facing the world today. State failures arise where there is a manifest breakdown of authority resulting from endogenous or exogenous stresses that the affected authorities, individuals, and society can ill afford to manage. They serve as fertile grounds for instability and terrorism, giving rise to immense humanitarian crises and large-scale refugee movements. Additionally, they create a convenient environment for various criminal activities, including drugs and human trafficking.

A recent and notable example of such state failures is witnessed in the 'Arab Spring' uprisings, which originated in Tunisia in late 2010 and subsequently spread in 2011 to countries such as Egypt, Libya, Syria, Yemen, and Bahrain. The consequences of the Arab Spring were prominent in the EU territory with a massive movement of vulnerable population and the penetration of criminals in the EU. Satellite imagery has played a crucial role in conducting battle damage assessments and providing GEOINT regarding the presence of military and paramilitary forces, delineating areas of influence, and monitoring gatherings of individuals.

2.2.4 Urban Planning & Critical Infrastructures

The CFSP and CSDP establish frameworks that enable the monitoring of urban and rural development, prioritising the support of procedures and actions to effectively address sudden and unforeseen crises.The main objective is to minimize the potential impact of an emergency by preventing loss of life and injuries, minimizing damage to infrastructure, facilities, inventory, and equipment, and facilitating restoration of normal operations. In that quest, GEOINT plays a crucial role in identifying vulnerable areas, assessing the potential scope of a disaster, and evaluating measures to mitigate or neutralize any hindrances to standard emergency protocols.

In addition, GEOINT contributes to evacuation planning. According to the CFSP/CSDP framework, a Comprehensive Evacuation Plan must encompass all phases of emergency management and consider various types of disasters along with their respective impacts. Whenever feasible, it's essential to gather regional data, to ensure more accurate results, while preventing ambiguity. Geospatial data and its analysis play a pivotal role in both planning and executing emergency management operations.

Within the CFSP and CSDP frameworks, the rapid mapping services of the EU Satellite Centre (SatCen) are employed to swiftly gather digital spatial data for security and crisis management purposes. Leveraging high-resolution satellite imagery, SatCen produces detailed geospatial intelligence—such as assessments of conflict zones or crisis-affected areas—within hours to days, depending on available data and collaboration with relevant agencies. The primary aim is to deliver timely information to support CFSP/CSDP objectives, with potential for expanded analysis as additional imagery becomes available.

Urban and rural planning takes into consideration critical infrastructures. Critical infrastructure refers to systems and assets, whether tangible or digital, whose destruction would significantly impair the security, health, or safety of a nation or group of nations. Examples of critical infrastructure include dams, water treatment facilities, oil fields, pipelines, pumping stations, airports, highways, and government buildings.

All facilities encounter certain risks stemming from a variety of threats, whether they arise from accidents, natural occurrences, or deliberate actions. Assessments of threats and vulnerabilities entail intricate analyses of influential factors, encompassing both spatial and non-spatial considerations. Typically, the outcome is a thematic map depicting the assessed facilities categorized along a vulnerability spectrum, ranging from minimal to severe.

Within the framework of the CFSP and CSDP, the visualisation of areas or assets vulnerable to natural or human-induced disasters is supported to enhance crisis preparedness and response. Identifying human settlements and critical infrastructure at risk empowers crisis management officials and first responders to anticipate potential damages, constituting a crucial preliminary step in assessing the vulnerability of critical infrastructures. In that quest several Agencies, have engaged in studies focusing on vulnerability assessments leveraging spatial data, including satellite imagery, digital terrain models and vector data, among others.

2.2.5 Military Capabilities

Within the frameworks of the CFSP and CSDP, GEOINT is utilised, primarily through the EU SatCen, to identify and assess military infrastructure, airstrips, naval installations, and elements linked to paramilitary operations. This supports the EU's efforts under CFSP and CSDP to enhance conflict prevention and crisis management capacities, bolstering military and security capabilities. The technologies engaged in this activity involve precise analyses spanning ground, air, and naval aspects of military forces. Furthermore, radar imagery is employed to monitor nighttime activities. GEOINT is also used for the analysis of physical damage as well as functional damage of military infrastructures and equipment.

Russia's invasion of Ukraine, beginning on 24 February 2022, underscored the critical role of satellites in modern security and defence, providing real-time intelligence, surveillance, and communication support that shaped the EU's response to the conflict. This evolving security environment prompted the EU's Strategic Compass for Security and Defence, endorsed in March 2022, which highlighted gaps in Europe's strategic autonomy and accelerated efforts to integrate space into its security framework. Building on this, the EU Space Strategy for Security and Defence (EUSSSD), launched in 2023, consolidated these efforts by promoting the dual-use potential of space programmes like Copernicus and

Galileo to serve both civilian and military needs, enhancing resilience and justifying investment.

Integrating space and defence requires overcoming political resistance among Member States and coordinating civilian efforts (e.g., ESA, Copernicus, Galileo) with military initiatives under the CSDP. The EU's €13 billion investment (2021-2027) in the European Defence Fund supports the development of SBA-related technologies for dual-use applications, reinforcing military and civilian capabilities. A cooperative approach within the CSDP is thus vital to shaping a long-term European defence vision, with space as a core pillar [20].

2.2.6 Conclusions on EU policies & strategies

Despite ongoing regulatory efforts, there remains a need for stronger integration between the space and defence sectors within the European Union to tackle emerging security challenges, such as those highlighted by the Ukraine conflict. Kolovos (2023) advocates a combined approach, blending top-down and bottom-up strategies to boost operational efficiency, coordination, and technological innovation. He argues that the EU Space Strategy for Security and Defence (EUSSSD), launched in 2023, streamlines efforts, enhances real-time data sharing, and strengthens strategic capabilities through international collaboration and advanced technologies to address threats like cross-border instability and hybrid attacks. The synergy of EUSSSD with CSDP measures provides a complementary advantage, leveraging space assets to improve mission effectiveness, resilience, and security, positioning the EU as a leading space actor.

2.3 The EU Space Programme

2.3.1 Introduction

The growing reliance on technological innovation and the globalization of security threats, such as transnational crime and climate-induced instability, demand a systematic approach to integrating satellite systems into the European Union's ISR capabilities. Satellites enhance the EU's ability to address challenges like border protection, climate change impacts, organised crime, and irregular migration. Real-time data processing and high-resolution satellite imagery, provided by programmes like Copernicus and supported by the SatCen as an agency, significantly improve operational efficiency and accuracy in modern security operations.

2.3.2 The Earth Observation Subprogramme

Satellite reconnaissance as a concept has shifted the dynamics of ISR operations, especially in the security and defence sectors. Closely related to these changes are improvements in spatial resolution, revisit rates, data handling and analysis that have recast the term “reconnaissance.” Such capabilities are important for contemporary ISR architectures, making the decision-making process more accurate and intervention more effective. Hence, ISR operations have evolved from mere surveillance to support predictive analysis and planning.

In areas characterized by a high level of instability or frequent criminal incidents across the border, high revisit times offer valuable and timely information that allows authorities to react to new threats. Satellites provide timely information that helps track the borders that are still vulnerable to irregular migration and smuggling, which are threats to the security of the European Union [21].

Supporting Europe’s civil, private, and governmental sectors, the European Union Agency for the Space Programme (EUSPA) boasts of programs, such as Copernicus, EGNOS (European Geostationary Navigation Overlay Service), Galileo, GovSatCom, IRIS², and SSA (Space Situational Awareness) that endeavor to be an integrated family of systems designed to support the EU internal market [22].

The **Copernicus Programme** is the European Union's flagship Earth observation initiative, designed to provide accurate and timely data for environmental management, climate change mitigation, and civil security enhancement. Managed by the European Commission in partnership with entities such as the ESA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), Copernicus offers open and free access to its data and services.

Copernicus incorporates ground-based, airborne, and seaborne sensors to calibrate and validate satellite data, ensuring accuracy and reliability. The programme delivers services across six thematic areas: land, marine, atmosphere, climate change, emergency management, and security.

Copernicus is defined by the Sentinel missions. Sentinel-1 provides Synthetic Aperture Radar (SAR) Imaging, is equipped with C-band SAR and delivers all-weather, day-and-night radar imaging for land and ocean services. With two satellites (Sentinel-1A and 1B), it achieves a 6-day global revisit time, with max spatial resolution at 5m. Sentinel-2 features a Multi-Spectral Instrument (MSI) with 13 spectral bands, providing optical imagery for land monitoring, with max spatial resolution at 10m. The two satellites constellation offers a 5-day revisit cycle at the equator [23].

Sentinel-3: Utilizes instruments like the Sea and Land Surface Temperature Radiometer (SLSTR) and the Ocean and Land Color Instrument (OLCI) to monitor sea and land surface temperatures, ocean color, and more. With two satellites, OLCI provides global coverage every 2 days with a max spatial resolution at 300m and SLSTR offers daily coverage at the equator, with a max spatial resolution at

500m. Sentinel-4 and Sentinel-5 are designed for high spatial resolution to monitor air quality trace gases and aerosols over Europe. Sentinel-4 provides hourly revisit times, focusing on Europe and Northern Africa. Sentinel-5P provides daily coverage with a max spatial resolution at 5km. Sentinel-6: Also known as Jason Continuity of Service, it measures sea-surface topography, contributing to ocean forecasting and climate monitoring. The key characteristics of the Copernicus satellites are presented in Table 1.

Table 1: Copernicus Programme Satellite Characteristics

Satellite	Primary Purpose	Spatial Resolution	Revisit Time	Orbit	Key Instruments	Launch Year
Sentinel-1	Radar imaging for land and ocean monitoring	5m x 5m (SAR)	6 days (with two satellites)	Sun-synchronous, ~693 km altitude	C-band SAR	2014 (1A), 2016 (1B)
Sentinel-2	High-resolution optical imagery for land monitoring	10m, 20m, 60m (Multispectral)	5 days (global coverage)	Sun-synchronous, ~786 km altitude	Multispectral Instrument (MSI)	2015 (2A), 2017 (2B)
Sentinel-3	Ocean and land monitoring	300m (OLCI), 500m-1km (SLSTR)	OLCI: 2 days, SLSTR: 1 day	Sun-synchronous, ~814 km altitude	OLCI, SLSTR, Radar Altimeter	2016 (3A), 2018 (3B)
Sentinel-4	Atmospheric composition monitoring	High-resolution air quality monitoring	Hourly (Europe)	Geostationary, Europe focus	UV, Visible, Near-IR Spectrometer	Planned
Sentinel-5P	Atmospheric monitoring precursor	5km - 15km (trace gas monitoring)	Daily (global)	Sun-synchronous, ~824 km altitude	TROPOMI (trace gas detection)	2017
Sentinel-6	Sea level measurement and ocean monitoring	Few cm accuracy in sea level measurements	10-day repeat cycle	Non-sun-synchronous, 1,336 km altitude	Poseidon-4 Radar Altimeter, AMR-C, GNSS-POD, DORIS, LRA	2020 (Sentinel-6A), 2025 (Sentinel-6B)

Beyond environmental monitoring, Copernicus provides accurate, timely, and accessible security-related data through EO, with real-time mapping and early warning systems to mitigate the impacts of natural disasters such as floods, wildfires, and earthquakes. Copernicus enhances security by improving border surveillance, crisis management, and disaster response. For example, the Copernicus Emergency Management Service (CEMS) provides real-time mapping and early warning systems to mitigate the impacts of natural disasters such as floods, wildfires, and earthquakes [24].

Taking into consideration Copernicus capabilities, EO could contribute to the monitoring needs of the following policies:

- Prevention and responses to crises related to natural and technological risks in Europe
- Humanitarian aid and international co-operation
- Conflict prevention including monitoring of compliance with treaties
- Surveillance of borders
- CFSP and CSDP to support the missions outlined in Article 17.2 of the Treaty of the European Union (humanitarian and rescue tasks, peace keeping tasks and tasks of combat forces in crisis management including peacemaking).

2.3.3 The European global navigation satellite Subprogramme

The Galileo positioning system is another flagship programme of the EU. The Galileo Programme is the EU's global navigation satellite system (GNSS), developed as an independent alternative to the United States' Global Positioning System (GPS) and Russia's GLONASS. Initiated in the early 2000s, Galileo aims to provide precise positioning, navigation, and timing services worldwide, enhancing Europe's technological sovereignty and reducing reliance on non-EU satellite infrastructure [25]. Unlike GPS, which is primarily controlled by the U.S. military, Galileo is a civilian-operated system designed to offer high accuracy and resilience, making it particularly beneficial for sectors such as aviation, maritime transport, and emergency response services [26].

The system consists of a constellation of 30 satellites in Medium Earth Orbit (MEO), strategically positioned to ensure global coverage and high-precision positioning [27]. Galileo offers multiple service levels, including the Open Service (OS) for public use, the Public Regulated Service (PRS) for government-authorized applications, and the Search and Rescue (SAR) service, which contributes to international efforts in disaster response [26]. Since its initial services became operational in 2016, Galileo has significantly improved positioning accuracy, reaching meter-level precision for civilian users and sub-meter precision for high-end applications [28]. The system's resilience and redundancy also make it critical for securing infrastructure and enhancing cybersecurity in satellite-based communications.

Beyond its technical advancements, Galileo plays a crucial role in the European Union's strategic autonomy and economic growth. It fosters innovation across multiple industries, including autonomous vehicles, agriculture, and telecommunications, with an estimated economic benefit of €90 billion by 2040 [29]. Furthermore, as satellite navigation becomes increasingly important for security and defence, Galileo's PRS ensures encrypted, interference-resistant signals for military and government use within the EU [30]. As the system continues to evolve with next-generation upgrades, it will strengthen Europe's leadership in space technology and reinforce its role in the global satellite navigation market.

The European Geostationary Navigation Overlay Service (EGNOS) is a satellite-based augmentation system (SBAS) developed by the European Union to improve the accuracy, reliability, and integrity of existing Global Navigation Satellite Systems (GNSS), particularly GPS and Galileo. Operational since 2009, EGNOS enhances positioning precision by correcting GNSS signal errors caused by atmospheric disturbances and satellite orbit deviations [31]. Designed primarily for aviation, maritime, and land-based navigation, EGNOS provides Safety-of-Life (SoL) services, ensuring high reliability for critical applications such as aircraft landing procedures and emergency services [32].

EGNOS consists of three geostationary satellites and a network of ground-based reference stations spread across Europe. These ground stations collect GNSS data, analyze signal deviations, and transmit real-time corrections to the EGNOS satellites, which then broadcast the improved signals back to users [33]. The system achieves horizontal positioning accuracy improvements from several meters to less than one meter, making it a key enabler for precision-based aviation approaches and maritime navigation [28]. In addition to standard positioning improvements, EGNOS offers integrity monitoring, ensuring that GNSS users are alerted within seconds if an error affects signal reliability.

Beyond its technical capabilities, EGNOS plays a vital role in enhancing European transport efficiency, safety, and economic competitiveness. It significantly benefits the aviation sector by enabling GNSS-based Instrument Landing System (ILS) alternatives, reducing dependency on ground-based navigation aids. Additionally, EGNOS facilitates precision farming, surveying, and autonomous vehicle navigation, contributing to the EU’s digital transformation strategy [34]. As part of its evolution, the EGNOS V3 upgrade aims to extend its coverage and improve performance, further solidifying its role as a critical element of Europe’s satellite navigation infrastructure.

Equally important is satellite reconnaissance through elaborated data processing. There is a need to process a huge amount of data from high-resolution satellite imagery within the shortest time possible. Modern ISR systems incorporate AI and machine learning algorithms to analyze this information. These tools enable the analyst to search for patterns, outliers, or trends much faster and accurately with much less time needed to convert raw satellite imagery into usable intelligence. Incorporating these advanced data analytical tools into the ISR frameworks has made satellite reconnaissance the bedrock of security operations to counter complex and emerging threats. This means that the spatial resolution, the revisit frequency, and the data processing technologies demonstrate how satellite systems are revolutionizing the reconnaissance field.

2.3.4 Galileo Search and Rescue (SAR) and Emergency Warning Satellite Service (EWSS)

The European Union bases its space-based emergency communications infrastructure on two essential elements which include the Galileo Search and Rescue (SAR) service and the Emergency Warning Satellite Service (EWSS). The SAR system operates as part of the international Cospas-Sarsat network to provide fast and precise detection of distress beacons worldwide. The Return Link Service (RLS) stands out as its main characteristic because it gives users peace of mind through verification that their emergency alerts reach the responsible authorities. During the last quarter of 2023 the SAR system delivered outstanding results by detecting 100% of first beacon transmissions correctly and achieving localization accuracy above 99% which exceeded all performance requirements [35]. A worldwide network of Galileo satellites with SAR transponders together with MEOLUTs provides reliable system availability which enables smooth international search and rescue coordination. The EWSS implements proactive emergency communication features that expand upon the reactive capabilities of SAR. The system operates autonomously from terrestrial networks to distribute location-specific alerts within one minute during disasters and cyberattacks that might compromise traditional communication systems. The EWSS platform enables customizable multilingual alerts which help increase public trust in crisis situations. The Common Alert Message Format (CAMF) standard developed jointly with the Japanese Cabinet Office enables EWSS to support international system interoperability for coordinated emergency responses across borders [36].

2.3.5 The Satellite Communications Subprogramme

The use of SBAs has enhanced communication by means of satellite internet, satellite phones, and inter-satellite connections. Satellite internet systems including those from Starlink offer fast and low latency connection to areas that were previously not connected to the internet or had limited access with speeds exceeding 100 Mbps. Satellite cell phones rely on direct satellite communication to ensure that there is communication, where there is no terrestrial network, and this has been very useful during emergencies. These advancements help to overcome the challenge of the scarcity of terrestrial facilities and ensure stable communication for military, search and rescue operations, and other activities in remote areas.

Affordable satellite communication (SATCOM) is crucial in areas without ground-based infrastructure, such as remote regions and oceanic expanses, or where existing infrastructure is vulnerable to disruptions and unreliable during emergencies. It enhances the resilience of communication networks by serving as a backup in case of physical or cyber-attacks on terrestrial systems and in the aftermath of natural or man-made disasters.

Secure SATCOMs are vital for the EU's crisis management, border surveillance, and protection of critical infrastructure. The European Union Agency for the Space Programme (EUSPA) forecasts a fourteenfold increase in demand for secure SATCOM services between 2025 and 2040, reaching approximately 190 Gbps by 2040. This surge is driven by the need for robust communication channels in crisis scenarios and the safeguarding of essential infrastructures [37].

In response to growing security concerns and the strategic necessity for autonomous communication systems, the EU has initiated projects to secure uninterrupted SATCOM. The 2021-2027 EU Space Program encompasses both Governmental Satellite Communications (GovSatCom) and Infrastructure for Resilience, Interconnectivity, and Security by Satellite (IRIS²) as innovative, technologically advanced, and knowledge-intensive initiatives, with IRIS² serving as Europe's response to the U.S. Starlink mega-constellation program.

The GovSatCom initiative aims to provide secure, reliable, and cost-efficient satellite communication services to governmental and institutional users across the EU. It ensures strategic autonomy by reducing dependency on non-EU satellite networks. The initiative leverages pooling and sharing of national and commercial satellite assets, ensuring service availability even in crisis situations. It integrates GovSatCom Hubs to optimize access to satellite communication resources, particularly for defence, border security, and disaster response. Initially, the EU plans to procure satellite capacities from MS and commercial providers, ensuring a gradual transition towards independent satellite assets. The rollout follows a phased approach, starting with existing infrastructure and moving towards dedicated EU-owned systems. The initiative faces challenges related to security accreditation, governance, and ensuring interoperability between national and EU-level systems. Funding and coordination among stakeholders also pose significant hurdles. Overall, GovSatCom sets the foundation for more advanced initiatives such as IRIS², providing a steppingstone towards a fully integrated European space security framework.

Launched in 2022, IRIS² aims to deploy a constellation of up to 290 satellites across low and medium Earth orbits by 2030. This initiative seeks to provide secure, high-speed communication services to governmental entities and bridge connectivity gaps in underserved European regions. It is designed to support critical government services, crisis management, and defence operations. IRIS² will be deployed in phases, with a goal of achieving full operational capacity by 2030. The main challenges include ensuring interoperability with existing satellite systems, securing funding through public-private partnerships, and addressing regulatory hurdles within the EU framework. The IRIS² initiative will complement GovSatCom, aiming to create an integrated and secure communication framework across Europe [38].

In February 2025, Eutelsat, in collaboration with Airbus and MediaTek, successfully conducted the world's first trial of a 5G Non-Terrestrial Network (NTN) connection using OneWeb's LEO satellites. This milestone is part of the European Commission's €10.6 billion IRIS² program, aimed at enhancing internet access, especially in remote regions [39].

Several initiatives relevant to EU connectivity, such as the Advanced Research in Telecommunications Systems (ARTES) programme managed by the European Space Agency (ESA), enable industry stakeholders to explore innovative concepts and develop advanced satellite communications products and services across ground, space, and network segments. Supported by access to world-leading experts, mission opportunities, and technology and business development resources, ARTES—partly funded through EU investments—drives advancements in satellite connectivity, aligning with EU communication priorities

2.3.6 Integration of Systems

Satellite systems are applied within a single ISR architecture that would address the EU's complex and dynamic security threats. This integration requires the simultaneous operation of GPS, SARs, EOs, and SATCOMs with an aim of enhancing position awareness as well as increasing operational accuracy. Satellite Communications play a crucial role in this integrated system by providing reliable and secure communication channels. They enable real-time data transmission between various ISR components and command centers, ensuring that information is shared promptly and accurately. These are some of the basic components because they respond to the minimum positioning and navigation requirements for the right positioning of assets and the leadership of organizational security. SAR technology is most useful in probing objects that are mostly shaded or when daytime visibility is poor and can be used at night only.

Greater cooperation with other European EO satellites, including the Copernicus programme, helps the EU provide timely threat detection and response in different scenarios, which provides an all-encompassing outlook into security processes [40]. Such integration helps in ensuring that intelligence outputs are provided in real time and with minimal interferences from the environment, hence improving the ISR frameworks. For instance, studies show that integrating satellite systems such as GPS, SAR, EO, and SATCOMs with enhanced algorithms enhances the accuracy and timeliness of data, especially under adverse environmental conditions [22], [21].

A prominent example of system integration is the European Border Surveillance system (EUROSUR). Established in 2013, EUROSUR aims to prevent cross-border crime, prevent irregular migration, and contribute to protecting migrants' lives. EUROSUR is structured around two main pillars. The first pillar is related to Situational Awareness, i.e., gathering, analyzing, and sharing real-time data to give a clear and updated picture of events at and beyond EU borders. This is essential for making timely decisions in response to potential threats. The second pillar is interconnected with Reaction Capability, i.e., responding swiftly and effectively to incidents, such as search and rescue operations or security alerts, enhancing the EU's collective ability to manage crises at its borders.

The EU has to integrate these satellite systems into a proper ISR structure to successfully address complex security threats. Moreover, this integrated approach enhances the stability of the EU's security architecture since intelligence gathered from one system is inputted in the other to form a complete operational picture enhancing the efficiency of ISR operations [41]. Such integration can only be successful if there are well-developed standards for interoperability and data sharing between these systems, along with robust analytical tools capable of processing the large volumes of data they generate. In addition, the cooperation and co-ordination and harmonization with the other EU MS are essential to function the integrated ISR systems. Therefore, the EU should concentrate on the augmentation of technological cooperation of GPS, SAR, EO and SATCOMs in the worldwide ISR structure, which in turn would contribute to the enhancement of the EU's capability in dealing with security risks and safeguarding its borders.

2.4 Technical Characteristics of SBAs & Internal Security

SBAs can be used for ISR purposes. Satellites equipped with high-resolution cameras and sensors can monitor vast areas, providing real-time data on activities on the ground, in the air, and at sea. This capability is crucial for detecting illegal activities, such as smuggling, human trafficking, and unauthorized border crossings [42]. Furthermore, satellites facilitate secure communication channels for defence and security agencies. SBAs secure reliable communication as always especially in regions where terrestrial networks may not have been set-up or where they may be jammed [43]. Among these SBAs, two are critical to security: Galileo for navigation and Copernicus for earth observation. In addition, a new space-based system is proposed to perform secure communications under the name of Infrastructure for Resilience, Interconnectivity and Security by Satellite ($IRIS^2$). $IRIS^2$ satellite constellation is standing by to guarantee independence of the EU in defending its communication networks that are only partially autonomous of non-European orbiting satellites currently. Its primary objective is to ensure link availability and link integrity for a multitude of European systems including aviation and road traffic control; seaborne rescue; military and frontier control.

The UCS Satellite Database shows that currently, there are 7,560 operational satellites in orbit, of which 5,184 are operated by the United States (Union of Concerned Scientists, 2023). The most prominent SBA initiative in the EU is the Copernicus programme, which alone has 7 Sentinel satellites in orbit. Based on the Copernicus programme, the spatial coverage provided by EO satellites has expanded. The Sentinel-1 satellite provides global coverage every 12 days, ensuring that emergency response services have access to up-to-date information for any location on Earth. The integration of EO data into emergency response services has demonstrated a substantial economic benefit. It is estimated that the use of EO satellites in Europe saves approximately €500 million annually. by improving the efficiency and effectiveness of emergency management operations [44].

Spectral resolution is the extent to which a remote sensing instrument can distinguish between nearby spectral bands, providing accurate data on specific object characteristics. There is a series of scientific requirements that should be met to acquire useful information from SBAs. For example, in marine context, the radiometry of optical remote sensing instruments becomes critical for the range of parameters that can be observed and estimated. Furthermore, Signal-to-Noise Ratio (SNR) greater than 200, can help in the retrieval of parameters for color applications in VIS-NIR wavelengths. This SNR requirement is set because the returned light signal that is received by the system is relatively weak [45]. Additionally, spectral resolution of 5 nm is necessary to distinguish plantation types. Finally, the set of spectral bands with no more than 5 nm band-pass would be necessary for more detailed spectral characteristics of interest in, for example, maritime or land scenes [46]. These technical capabilities define values that are useful when defining system requirements for an Ocean Color or a Land Color remote sensing instrument and can present a difficult trade-off between spatial and spectral resolution as well as Spectral Range [47].

Critical components for the ISR users are the spatial resolution and revisit times of the satellites. For instance, Figure 1 Figure 3illustrates past, current, and future predicted satellite data from a range of different SBA types, including Visible/Infrared imagers. Although EO SBAs have achieved a spatial revolution of well below 1m (currently 0,30m), it appears that the revisit times is a significant obstacle in cases of ongoing incidents.

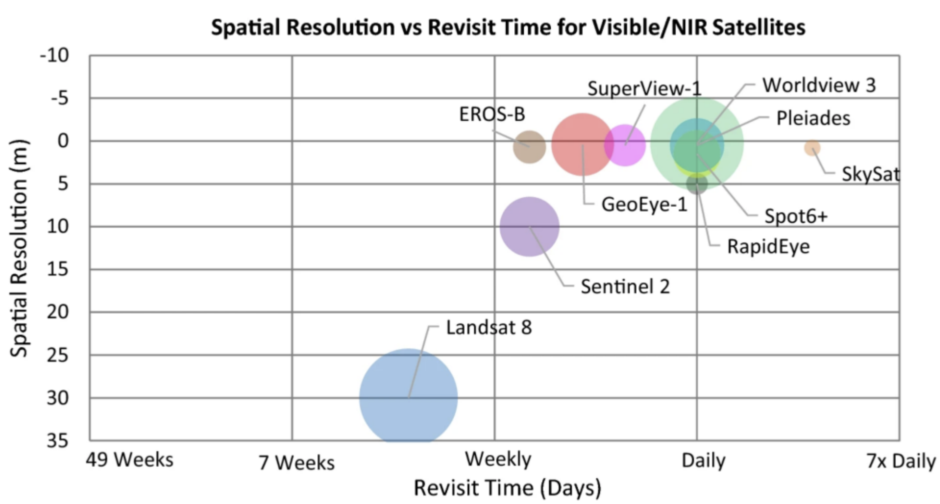

Figure 1: Spatial resolution against revisit time for visible and near-infrared imaging satellites [48].

Spatial resolution is the ability to distinguish between two objects in an image or the extent to which greater detail can be obtained [49]. Spatial resolution depends on the distance between the source and the receiver [50]. Several commercial satellites supply very high-resolution images of about 30 cm. The best commercial visual resolution available is provided by DigitalGlobe's Worldview satellites, currently at 30 cm [51]. The Maxar's WorldView-4 satellites provide imagery of 31 cm in panchromatic resolution and 1.24 m in multispectral resolution from an orbit of 617 km [52]. Likewise, Airbus's Pléiades Neo constellation offers native 30 cm resolution satellite imagery, enabling accurate tracking applications [53]. The capabilities of these SBAs are presented in Table 2.

Most advanced satellite characteristics				
Company/Satellites	**Spatial Resolution (Panchromatic / Multispectral)**	**Bandwidth**	**Revisit Time**	**Orbit Altitude**
DigitalGlobe's WorldView-2	0.46 m / 1.84 m	800 Mbps X-band	Up to 1.1 days	770 km
Maxar's WorldView-4	0.31 m / 1.24 m	800 Mbps X-band	<1.0 day at 1 m GSD	617 km
Airbus's Pléiades Neo Constellation	0.3 m / 1.2 m	1.8 Gbps via laser	Twice daily, anywhere	620 km

Table 2: Most advanced technical characteristics of operating satellites

On the other hand, most of the EO satellites have decreased spatial resolution, with the range of several hundred meters to kilometers. For instance, the Advanced Very High-Resolution Radiometer (AVHRR) sensor attached to NOAA satellites incorporates spatial resolutions of 1 km to 16 km for the spectral bands [54]. These low orbit satellites are generally employed for large scale applications such as meteorology, oceanography and observations of vegetation cover. The time required to obtain such data is still a critical issue in satellite imagery applications. Optical satellites such as WorldView-3 and Pléiades Neo can be quickly retargeted, increasing the revisit times depending on the need, which can minimize the time between imaging and information acquisition.

Nevertheless, there are other factors that include satellite tasking priorities, data processing time, as well as data transmission which may affect revisit times in their totality. Image acquisition includes the time required to capture the target, transit to a ground station, and download the raw data as well as the time to process the raw data into products [55]. The challenge in this case is in the satellite orbit parameters, namely, the time to reach the target may depend on the orbit. For example, sun-synchronous orbits, applied for EO, crosses some point in Earth at the same local time daily [56]. To secure optimum lighting conditions, the imagery is typically taken between 10:30 and midday. This planning results in a determinate delay with the time to get to the target and the time on top of that to get to the ground station. An example of the spatial resolution and the latency of each satellite system is presented in the Figure 2. Fixed time delays are unsuitable for those customers who need to cover a site at different time intervals.

System	Latency	GSD
DigitalGlobe Worldview (DigitalGlobe 2020)	2–5 days	30 cm–3.7 m
Planet SkySat	2hrs	0.7 m
Elecnor Deimos-2 (ESA Copernicus 2020)	90mins	0.75–3 m
ESA Sentinels + EDRS	NRT- Hours (18 min avg.)	10/20/60 m (Sentinel 2)
Earth-i Carbonite	NRT	1 m

Figure 2: Latencies for current visual imaging satellites [48].

Another issue is the time taken in the transfer of data, concerning the satellite to the ground distance. For example, the communication delay to orbit is usually more than that of the ground communications; it takes about 600ms to Geostationary Orbit, and 40ms to Low Earth Observation (LEO) [57], while high quality cable internet takes between 15 and 40ms, at least when sending data regionally over hundreds of km or less [58]. This restriction is even amplified further by the fact that EO data results are usually massive in size and thus would require equally massive transmission times. Lastly, with the commercialization of SBAs, other factors that may influence transmission time may include any existing rapport between the client and the supplier since the supplier may have a bias towards some clients. As such, the extent of delay from the above-discussed factors is still small compared to delay arising from orbit constraints. Thus, this part is not pursued any further at this point.

Another issue with satellite Earth Observation is the revisit time. Revisit time means the ability of a satellite to capture an image of the same area at a specific time interval [59]. Sentinel-1 and Sentinel-2 have revisit times of 5-6 days, which might be sufficient for monitoring some dynamic process, but for more dynamic scenes, additional coverage, or other sources of data, such as Unmanned Aerial Systems (UAS) imagery, such as drones, are needed. These parameters build up the functional operation of SBAs and enhance awareness and decision making on several scenarios.

Another issue with satellites is the assurance of the coverage of an incident as it unfolds. To monitor an unfolding incident, dynamic scenes are important. Dynamic scenes mean areas or events that are in constant flux which can include moving objects, physical environment, or even the content such as fire, water bodies, or traffic in cities. The revisit time for a dynamic scene is the amount of time that it takes for a satellite to take subsequent images of the same scene to track these changes adequately.

A new development towards this direction is satellite constellations [60]. Constellations offer the flexibility of global coverage. The revisit time and latency can be enhanced because at least one of the satellites in the constellation is likely to have a vantage point of the target area. Video from space is also a fairly recent concept that is directly linked with satellite constellations and UAS.

With respect to satellite constellations, there are two major service providers that produce dynamic scenes and videos, in operation: Planet's SkySat series [61] and Earth-i's Carbonite/Vivid-i series of satellites [62]. Currently, the video services offer high value data and live video of incidents as they happen. SkySat is a group of fifteen satellites that can provide 90 s clips of 1080p footage with 30 frames per second and 0.8-1 m GSD [63]. Carbonite is operated by two satellites, delivering pictures at 50 fps and 1 m spatial resolution for approximately 60 s with no less than two revisits per day. Carbonite is expected to further increase the revisit time with more satellites in the pipeline to launch.

More service providers that own satellite constellations for EO are Maxar Technologies that launched two new WorldView Legion satellites in May 2024 and was expected to launch four more by the end of December 2024. Also, Pixxel introduced their Fireflies, the first series of Pixxel's commercial satellites, a constellation of six next-generation hyperspectral satellites to be launched early next year [64]. Each satellite has a revisit time of approximately five days, with a possibility for revisit times once per day revisited in one day. A summary of existing constellations for EO is presented in Table 3.

Company	**Constellation**	**Resolution**	**Revisit Frequency**	**Key Features**	**Purpose**	**Dynamic Scene Capture**
Planet Labs	PlanetScope (Dove)	3–5 m	Daily global coverage	Multispectral imaging	Frequent, moderate-resolution imagery for environmental monitoring, agriculture, and disaster response.	No
Planet Labs	SkySat	50 cm	Up to 10 times daily	High-resolution video	High-resolution imaging for urban monitoring, intelligence, and change detection. Also captures high-	Yes (short video clips, up to 90s)

					resolution video.	
Planet Labs	Pelican	30 cm	Increased revisit rates	Enhanced imagery	Next-generation imaging system with 30cm resolution, designed for rapid revisits.	No
Earth-i	Carbonite/Vivid-i	1 m	Multiple times daily	Full-color video, high-resolution imagery	Provides high-resolution, full-color video and imagery for dynamic activity monitoring, such as vehicle and ship tracking.	Yes (Full-color video)
Maxar Technologies	WorldView Series	31 cm	Varies	Panchromatic and multispectral imaging	Captures high-resolution imagery for mapping, defence, and environmental applications.	No
Maxar Technologies	WorldView-3	31 cm	Varies	SWIR & atmospheric sensing	Includes SWIR and multispectral imaging for enhanced surface analysis.	No
Airbus Intelligence	Pléiades	50 cm	26-day revisit cycle	Panchromatic & multispectral	High-resolution satellite imaging (50cm), used for urban planning	No

					and mapping.	
Airbus Intelligence	Pléiades Neo	30 cm	High frequency	High-reactivity imaging	Advanced version with improved resolution (30cm) and revisit frequency.	No
ICEYE	ICEYE SAR	SAR Imaging	Frequent revisits	SAR for all-weather, day/night imaging	SAR imaging, allowing for cloud-penetrating, all-weather imaging.	No
Satellogic	Satellogic EO	70 cm	Frequent revisits	Low-latency imagery	High-resolution (70cm) imagery for agriculture, forestry, and climate monitoring.	No
Pixxel	Pixxel Hyperspectral	5 m Hyperspectral	Regular revisits	250+ spectral bands	Captures hyperspectral data across 250+ bands for precision agriculture and mineral detection.	No
Satrec Initiative	SpaceEye-X	Sub-0.5 m	N/A	High-detail EO	Sub-meter resolution Earth observation with military and commercial applications.	No
Satrec Initiative	SpaceEye-1	Better than 1 m	N/A	Enhanced EO	Enhanced optical imaging for defence and urban monitoring.	No

China Siwei	GaoJing-1 / SuperView-1	50 cm	12 km swath width	Detailed mapping & surveillance	High-resolution imagery (50cm) for government and commercial use.	No

Table 3: Satellite constellations for EO.

In many satellite programs, there is a tendency to improve data collection by integrating satellite assets with other forms of autonomous systems for example, UAS, Autonomous Surface Vehicles (ASVs), Autonomous Underwater Vehicles, among others [65]. Besides the globally accessible satellite facilities, additional equipment and vehicles offer a wide range of multiple platforms with different spectral, temporal and spatial resolution, surveying in the same area. This compilation of infrastructures and instruments forms the so-called observational pyramid, as illustrated in Figure 3.

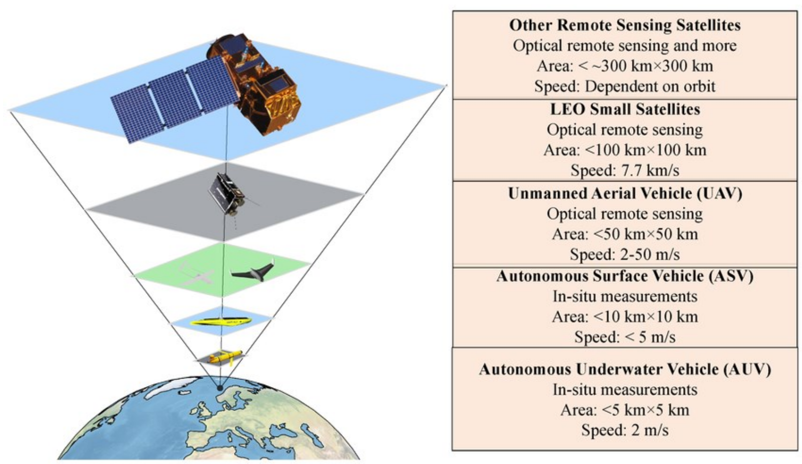

Figure 3: The observational pyramid presents a variety of autonomous data-collection agents developed at NTNU AMOS, combined with third-party satellite infrastructure. The right-hand side of the figure provides representative values for speeds, area coverage and data collection methods. [65].

The observational pyramid provides a combination of sources and data retrieved from different vehicles with a broad range of capabilities. It should be noted that while LEO satellites collect data from large areas, each image has smaller dimensions. For example, a LEO Maxar satellite can capture high-resolution images of areas up to 25 x 25 kilometers. As Planet Labs satellites have different constellations with varying coverage capabilities, the Dove satellites for Instance typically capture scenes sized around 24 x 7 kilometers. As for revisit times, GEOs always observe a certain area, and LEOs have a brief revisit time in contrast. The revisit time of LEOs depends on the position of the satellite and latitude of the area of interest and target. Features of interest can be detected from data collected by satellites. However, these features can be examined further by other autonomous agents. Unmanned Aerial Systems (UAS) have the capability to inspect features of interest in real-time and at a higher resolution with optical instruments or spot measurements [66].

The pyramid provides the necessary information for decision making for the prevention, monitoring or management of critical areas with respect to crime, natural resources and humanitarian support. It also provides a warning system with low revisit times and low latency, which are particularly useful when monitoring an ongoing incident.

Important advancements have been observed in Synthetic Aperture Radar (SAR) technologies. SAR operates as typical radars with the advantages of night-time imaging and capability to operate despite the presence of clouds. Furthermore, current SARs laboratory tests conducted using infrared synthetic aperture lidars generate imagery of fine spatial resolution of less than one meter and sub-millimeter modeling accuracy [67]. A similar resolution can be achieved with the help of instruments like TerraSAR-X [68]. It significantly surpasses the capabilities of current spaceborne SARs, which typically provide a resolution of only 25 meters using instruments like the Global Ecosystem Dynamics Investigation (GEDI) instrument aboard the International Space Station (ISS) [69].

During the last decade several other technologies attempted to fill the gap in SBAs' real time monitoring. The proposed solutions involved Very Low Earth Orbit (VLEO) satellites or UAS that would be permanently monitoring during an incident and would land only for charging. Tests conducted during the last decade indicate that at low altitudes, the atmosphere produces significant drug on the spacecraft [70]. In that case, the aircraft uses chemical or electric propulsion for drag compensations. Finally, a crucial aspect in low altitudes is the presence of atmospheric disturbances. It was observed that atomic oxygen, found in the upper atmosphere, caused extended erosion at the spacecrafts' outer surfaces. Hence, a protection film or a specific material coating would be required for the protection of the infrastructure [71].

Until recently there were very few countries and companies that had the resource capacity (e.g. technology and cost limitations) to access space. CubeSats, unlike larger SBAs, are small satellites with low weight that significantly decrease production and launch costs. CubeSats' low costs resulted in the appearance of new providers and the reduction in waiting times for the implementation of new projects in space. On the other hand, the low cost of CubeSats means increased sensitive in electronics and generally a design to last only a short period of time, such as a few weeks, months or years before ceasing operations. Especially the CubeSats in low Earth orbit, they are designed to fall back into the atmosphere. However, CubeSats are designed to operate in constellations, thus the constellation of satellites provides alternatives and redundancy to the services they are expected to deliver.

Given the growing amount of data and the increasing demand for geospatial analysis there are several challenges that need to be addressed relevant to data storage, real time and speed of transmission and data integrity [72]. For instance, the data volume of some of the most well-known EO satellite systems operated by public institutions can reach 70GB/day (e.g. Landsat 7 and 8) [73]. CubeSats carry a more limited array of instruments and capacities. Ongoing research has shown that CubeSats can develop the capacity to collect data that is as good as the data from a billion-dollar government satellite [74]. Other studies work on improving the transmission rate of data with the use of lasers [75].

2.5 Technical Capabilities Comparison between satellites & drones

In emergency response, in cases of fire or floods among other disasters, satellites and drones have become vital, and each of them brings in different benefits and functionality. In this paragraph, these technologies will be compared and contrasted based on coverage and resolution, response time, data type and applications, limitations, and regulatory and ethical considerations regarding their synergy in improving fire disaster management [76], [77], [78].

2.5.1 Coverage and Resolution

Satellites have large areas of coverage in space thus making them ideal for observing large fires and their progression in large areas. For instance, Sentinel-2 has a swath width of 290km for imagery acquisition, which supports extensive analysis of fire behaviour and the effects of the fire on the environment. However, satellite imagery can be of different resolution. Sentinel-2 has an improved spatial resolution of 10m, 20m and 60m for its different spectral bands [79].

Drones, on the other hand, provide localized coverage with very high-resolution imagery with data at centimetre accuracy. This capability is useful for detailed inspection of specific areas, for example, for evaluation of the impact or for detection of high-risk areas [80]. Unmanned aerial vehicles can be dispatched to any part of a fire or flood affected region to offer timely information. Satellite and drone technologies complement each other to provide a wide-area view and close-up examination of extensive environmental threats to better control and prevent them.

2.5.2 Response Time

Satellites, such as Sentinel-2, have a revisit time of about five days, which hinders the ability to monitor events in real-time, especially those that are dynamic like wildfires [81]. Also, information gathered by satellites usually has to be processed and analyzed, which results in a delay before useful information is obtained. However, drones can be used on the spot and can be altered based on the actions of a fire, thus providing constant real time information. This capability is essential for identifying the right approach to extinguishing fires and the most appropriate resource distribution during active fire incidents [82].

2.5.3 Data Types and Applications

Satellites obtain different forms of data, for example, optical, thermal and infrared images that are used for fire detection, monitoring, burned area mapping, fire intensity and post-fire vegetation regeneration assessment [83]. The capacity to acquire big quantities of data is important for vast environmental surveys and extended research. Optical and thermal sensors mounted on drones are able to capture images and video at high resolution and record parameters such as temperature and relative humidity. Some of the uses include situation awareness and damage estimation, search and rescue, and delivery of goods and services in the impacted areas. Drones also provide real-time video feed, allowing the incident commanders to make the right decisions [82].

2.5.4 Operational Constraints

Satellite operation is governed by orbital mechanics, where revisit time may not always meet the needs of the emergency response. Optical imagery acquisition may be hampered by unfavorable weather conditions, for example, cloud cover, and data processing may also cause further delays. In addition, the expenses involved in the creation and deployment of satellites are rather high. Challenges of operations include restricted flight time because of battery power which ranges from 20 minutes to a few hours. External conditions such as wind and rain can also impact drones in a very big way. Nevertheless, drones are cheaper than satellites and can be used by trained personnel to deliver timely and specific data [82].

2.5.5 Regulatory and Ethical Issues

Satellites can be operated only under international laws and the data collected are used internationally for the assessment of the environment and ethical issues are negligible due to the altitude of the operation and the large-scale data collected. Drones on the other hand are tightly restricted regarding the airspace utilization, flight permits, and safety measures, which differ from one country to another. Privacy is even more of an issue with drones, as these devices can take high-definition photos and videos from relatively close distance. These challenges call for the formulation of guidelines to govern the application of drone technology, especially in crowded regions [82].

2.6 Internal Security Threats Monitoring Using SBAs

There has been increasing concern amongst scholars and policy makers on the role of satellites in improving internal security of nations and regions. The uses of

SBAs and remote sensing have been implemented across various fields, relative to the natural and physical environment like natural disasters [84], [85], agriculture [86], land use [87]. As for the humanitarian organizations, they have also used satellite technologies for positioning with GPS, tracking of vehicles, remote sensing, telecommunication, and natural disaster forecasting [88], [89]. According to Nagendra et al. 2020, the real-time operation has been guided by the remote sensing with offering imagery and mapping, Butenuth et al. 2011, Holguín-Veras et al. 2012 immigrants' movement using Fureder et al. 2015 and the number of affected people where according to Bjorgo [90] Today image analysis This new capability improves the accuracy of real time info delivery [24].

2.6.1 Crime & Security ISR

Organized crime is identified as a major threat to the EU's internal security strategies and policies. The Internal Security Strategy for 2010-2014 emphasizes the necessity of enhancing cooperation among law enforcement agencies across the EU to effectively combat organized crime [91]. Satellite navigation systems are vital for military operations, emergency response, and other security-related activities. The Global Navigation Satellite System (GNSS) has the potential to provide accurate positioning and timing information, which is crucial for crime prevention and security ISR. GNSS technologies are extensively deployed in transportation for positioning applications, enhancing the ability to monitor and respond to security threats. The latest internal security strategy, the EU Security Union Strategy 2020-2025, reiterates the importance of combating organized crime while leveraging advanced technologies, including satellite systems. It highlights, "Preparedness and resilience are key for quick recovery," underscoring the necessity of robust systems to ensure rapid and effective responses to emerging security threats [92].

2.6.1.1 Navigation & Positioning

Satellite Navigation systems, including the US Navstar GPS, Russian Glonass, BeiDou and EU Galileo, are becoming ubiquitous across many applications. GPS was initially developed to provide an all-weather, all-altitude navigation system for military platforms and long-range strategic weapons. Early adopters included US strategic bombers, warships, and submarines, with the first weapons being the AGM-86 and RGM-109 series cruise missiles.

As satellite technologies advance, there are ongoing comparative measurements among GNSS systems. The GPS system, augmented with the features of EGNOS and Galileo, emerges as the most reliable and accurate. Both EGNOS and Galileo undergo continuous development by European entities such as the Galileo Competence Centre [93]. Given their exceptional accuracy and coverage, specific application examples are provided below. Each example distinctly indicates the operating system in use.

The Public Regulated Service (PRS) is a highly secure, encrypted satellite navigation service offered by the Galileo global navigation satellite system (GNSS). It is specifically designed for government-authorized users, including law enforcement, emergency responders, and operators of critical infrastructure. PRS provides robust, encrypted positioning, navigation, and timing (PNT) services, ensuring operational continuity even in hostile environments. This resilience is achieved through the use of wideband signals that are resistant to interference and jamming. Access to PRS is restricted to authorized users, primarily public authorities such as police, border control agencies, and civil protection services. PRS is engineered to remain operational even in crisis situations when other services may be interrupted [27].

An increasing number of GNSS services are tied to transportation and vehicle traceability. For instance, in air transportation, EGNOS can pinpoint unidentified aircraft using its geostationary satellites and the SBAS system. The positioning accuracy of EGNOS is approximately ± 3 m [26]. Primary satellite measurements combined with statistical analysis are employed to harness these measurements. Recent studies suggest even greater accuracy with EGNOS [94]. For instance, a study employing numerical averaging models determined the position of aircraft with an average deviation of 0.2m. This methodology proved to be more precise than the GPS's Single Point Positioning by 29% in latitude, 46% in longitude, and 72% in elliptical height [95].

A new technology that has penetrated rapidly in the SBAs market is Unmanned Aerial Systems (UAS, including Drones). Originally designed for military applications, UAS have seen widespread civilian adoption, leading to the establishment of pertinent regulations. UAS, when used militarily, can monitor adversarial forces, or even deliver precision-guided munitions. Civilians initially utilized UAS for leisure, but their commercial applications have since expanded. Engineers deploy UAS for spatial mapping and surveys, while the media employs them for event coverage. Recently, UAS-based product delivery services have emerged.

The H2020 GAUSS project, which stands for "Galileo-EGNOS as an Asset for UTM Safety and Security," focuses on UAS positioning as a solution for the U-Space framework. This framework pertains to the EU directive for the safe management and monitoring of UAS flights. Specifically, the GAUSS project is developing frequency and cluster management protocols for UAS to guard against hijacking and ensure traceability and identification of each airborne unit. The resulting system will cater to all potential uses sanctioned by the European Aviation Safety Agency (EASA) [96]. New research is exploring not only the precision of the Galileo system but also the potential of integrating signals from GPS, Galileo, and aircraft, such as UAS, to bypass ground-based signal processing centres [97].

In maritime transport, approximately 1.9 million vessels utilize GNSS systems. Of these, 90% (both commercial and recreational) can integrate the EGNOS SBAS system. The positioning accuracy is comparable (<5m) between GNSS systems with or without EGNOS enhancements. However, the primary advantage of SBAs lies in its superior connectivity and coverage reliability. It employs globally recognized, interoperable protocols and can harness terrestrial data [98].

In particular, the Galileo system is perpetually refining its services for maritime routes. Research initiatives like GAMBAS (Galileo Advanced features for the Maritime domain: Breakthrough Applications for Safety and security) aim to bolster maritime security by identifying unlawful vessels and overseeing both natural and anthropogenic emergencies. Efforts to enhance measurement accuracy are ongoing, with objectives such as improving the detection and response capabilities of SAR (Search And Rescue) and SSAS (Ship Security Alert System), enhancing the performance and reliability of maritime space identification and detection, optimizing the response of the RCC (Rescue Coordination Center) during maritime emergencies, and reducing service operational costs [99].

SBAs can be instrumental in the protection of vessels from criminal activities. All vessels, regardless of size, extensively utilize electronic services, making them susceptible to theft, hacking, disconnection, and cyber-attacks. Safeguarding valuable and critical vessels necessitates innovative external solutions. One such solution, based on Galileo, is ARGOS (Anti-theft Robust Galileo-based Operational System). Supported by the EU Space Program Agency (EUSPA), ARGOS leverages Galileo's services and the latest diversifiers to shield yachts and vessels from criminal actions. The system provides the vessel's precise location and employs Galileo's Open Service Navigation Message Authentication (OSNMA) to verify the authenticity of the navigation message. ARGOS is user-installed via an onboard device and sends alerts during alarm activations. A control center oversees the process, using advanced algorithms to track and manage the vessel's position. The gathered data, along with alarms and notifications, is relayed to the user through a user-friendly mobile app or web portal.

With the positioning data from Galileo, ARGOS can expand in a variety of applications such as the guarding of vessels against theft, tampering, disconnection, and power interruptions, the offering of real-time tracking for anchored or docked vessels, the precise monitoring of a vessel's location, ensuring it remains within a predefined area and the protection of navigation systems from cyber-attacks, spoofing, and other manipulations.

A recent study that focused on drug trafficking indicated that the use of open-source data significantly reduced monitoring costs. The satellite data covered an area of 1,200 square kilometers, providing extensive monitoring capabilities for the region. Over a period of six months, 150 suspicious vessel movements were identified, correlating with known drug trafficking routes in the Colombian Pacific region. The use of Sentinel-1 SAR (Synthetic Aperture Radar) data with a spatial resolution of 10 meters enabled detailed monitoring of vessel activities in coastal and open sea areas.

A machine learning algorithm was developed, improving the detection accuracy by 15% compared to manual analysis. The processing time for detecting vessels was reduced to 24 hours, allowing for near real-time monitoring and response. The study facilitated data sharing and collaboration among five different law enforcement and intelligence agencies, improving coordinated efforts to combat drug trafficking. The technology proved effective under various environmental conditions, including detecting vessels in cloudy and nighttime conditions. The satellite data successfully correlated 85% of the detected vessels with known drug trafficking events, enhancing the reliability of the data. Compared to traditional ISR methods, the cost was reduced by approximately 80% [100].

Beyond the maritime sector, the EGNOS is particularly useful in all types of transportation, including ground transportation and passenger vehicles. Mobility applications are evolving by incorporating vehicle-sharing services. Another instance is fleet tracking or "pay-as-you-go" vehicle insurance policies based on the GPS system, enhanced by EGNOS's accuracy capabilities, which has proven reliable in both rural and urban settings [101].

GNSS can be employed to track ground vehicles transporting hazardous materials. On average, European territories transport 60 billion tons of dangerous goods per kilometer annually, either by road or rail. Monitoring these movements is crucial not only for the businesses involved but also for the safety and integrity of the infrastructure they utilize. As early as 2011, the SCUTUM project (SeCUring the EU GNSS adopTion in the dangeroUs Material transport) utilized EGNOS to precisely locate hazardous goods in terrestrial transport. Presently, this program oversees 1,200 trucks on European roads, spanning countries like Italy, France, Austria, Slovakia, Hungary, Romania, and the Czech Republic. Subsequent programs to SCUTUM, such as CORE, offer similar monitoring services by amalgamating different transport modes and assessing the benefits of combined usage with the Galileo system. These satellite services, which address the challenges posed by individual national legislations, can be adopted for cross-border transport with the appropriate standardization and member state agreements of the EU [102].

2.6.1.2 Communications

The communications sector has undergone enhancements which are directly proportional to the application of SBAs. For example, Quantum Key Distribution (QKD) has recently attracted much attention. The performance assessment of QKD is conducted in Ntanos et al. (2021) based on a system of ten satellites in LEO in sun-synchronous orbits for one year of communication with three OGSs in Greece. When accounting for atmospheric turbulence and the background solar irradiance, the analysis establishes that it is possible to attain positive normalized Secure Key Rates (SKRs) of up to 3.9×10^{-4} (bps/pulse). This implies that satellite-to-ground QKD can be possible under different scenarios with realistic assumption in an existing environment.

Satellite-based communication has recently gone through a lot of improvements and has improved data transmission. For example, the European Data Relay System (EDRS) uses laser communication to provide data transmission rates of up to 7.2 Gbps to support near-real-time exchange of data between satellites and ground stations [103]. Also, the incorporation of Low Earth Orbit (LEO) satellite constellations has enhanced the latency in satellite internet services. Research shows that LEO constellations like Starlink can provide round-trip latency of as low as 45 ms which is similar to broadband services on the ground [104].

Finaly, the IoT market requires extremely accurate new applications. The aim is to reliably navigate for automation and sensor purposes in smart homes and self-driving cars. These services have to be protected by GNSS, including high levels of security, as the Galileo’s encryption and protection system against data leaks and pre-emptive measures against cyber threats that might be catastrophic for society. Recent studies propose other techniques for IoT devices positioning by means of satellite technology. For example, while old approaches employ GNSS in their design, new ones employ Doppler shifts, as well as angle-of-arrival from LEO satellites. This approach is especially beneficial for IoT applications where issues of power usage and cost are main considerations [105].

2.6.1.3 Irregular Migration

Irregular migration poses a significant challenge to the EU's internal security strategies and policies. The EU attributes the root causes of migration to instability and insecurity in countries of origin, such as Syria and Libya. Conflicts, terrorism, and economic decline in these regions are seen as primary drivers [12], [106]. The EU's policy discourse often correlates migration with human security issues, focusing on war, regional conflict, terrorism, and economic underdevelopment as trigger factors [12], [107]. The politics of immigration control and the criminalization of undocumented immigrants are driven by social-legal systems that allow their marginalization and exploitation [108]. Effective integration policies are essential to prevent social disruption and marginalization of immigrants. However, punitive governance and restrictive measures have often been preferred, leading to cycles of radicalization and criminalization [109].

Immigration is correlated to human trafficking networks that have caused significant loss of life, particularly on routes from North Africa and Asia to Southern and Eastern Europe respectively. According to the United Nations Office on Drugs and Crime (UNODC), between 2008 and 2019, the number of identified trafficking victims worldwide quadrupled from around 30,000 to nearly 120,000, reflecting both an increase in trafficking activities and improved detection efforts (UNOCD, 2023). Among these victims, a considerable number of them are connected to the migration movements from war-torn countries as the Syrian civil war [18], [109].

The UNHCR shows that the Syrian civil war has led to over 6.6 million internally displaced persons and more than 5.6 million refugees in other countries. Additionally, the IOM reported that more than 23000 migrants have died or disappeared, while trying to cross the Mediterranean to Europe in the period between 2014 and 2019. Most of these deaths were recorded from the Central Mediterranean route, from North Africa to Southern Europe. Even after settling in the host country, migrants often face illegal work, exploitation, involvement in prostitution, and human organ trafficking networks [110]. Consequently, migrants might face legal marginalization and exploitation [111].

The rise of international terrorism has significantly influenced the development of migration-security policies. Terrorist attacks in the EU have led to the inclusion of immigration issues in anti-terrorism agendas. In turn, the rise of immigration has brought about the rise of right-wing populism in the European continent. This is partly because extreme right wing and Eurosceptic parties capitalize on the effect of economic crises to garner support. The findings show that Muslims are discriminated more in western democracies than any other religious minorities and this has been observed since 2001 [112].

The EU policies regarding irregular migration have aimed at enhancing the protection of the EU's external borders, fighting against human trafficking and organizing the migration flows. After applying satellite technology during the 2015-2016 refugee crisis, Greece enhanced cooperation with EU agencies that led to better organization of migration processes. Before the application of satellite ISR, Greece was struggling with control of the unauthorized migration, particularly during the height of the refugee crisis. Satellite technology offered a wide range of ISR solutions, including over the land and sea borders; it made it possible to identify suspicious activities in real-time [113].

Satellite coverage allows surveillance along and across the borders, including the most remote and those located on water bodies are covered. Especially, the Copernicus program has been useful in identifying illicit, unreported, and unregulated transboundary activities. The Sentinel-1 and Sentinel-2 satellites are watching particular areas, and they detect suspicious movements of vessels and migration flows. In particular, Sentinel-1 radar imagery has improved the ISR of the Aegean Sea, and the rates of detection of illicit migration and smuggling have risen by 70%. In general, satellite ISR has increased detection rates by 85% compared with conventional approaches and has made interventions faster. Greece also recorded a 55% cut on operational costs and this is the economic implication of the use of SBAs in irregular migration and border security [114].

Furthermore, the EU has committed more than €1 billion to spending on AI and satellite technologies for the improvement of borders' security. In operation Sophia in the Mediterranean, AI and satellite technology were used to detect and track human smuggling boats. The "Central Mediterranean operation" deployed AI algorithms and big data from satellites, to detect suspicious behaviors and achieved 15% more intercepts. For instance, it was possible to identify over 1,000 unauthorized entries only in 2020, based on SBAs and AI algorithms. Furthermore, during Operation Triton, AI systems deployed to rescue over 5,000 migrants in distress. Moreover, in the Adriatic Sea, the AI system allowed for more targeted patrols, reducing fuel consumption by 18%, while maintaining security protocols intact [115]. The successful interceptions, especially across the Mediterranean region, were a result of a better allocation of resources in Easter Europe, based on improved prediction of migration patterns.

Furthermore, the use of alternative means of observations can assist in the detection of illegal activities. Cross-referencing satellite images with ground data enhances the accuracy of identifying illegal border crossings. For instance, the use of satellite and ground data in the Baltic Sea region led to a reduction of illegal fishing activities, by identifying illegal crossings. For instance, enhanced surveillance and imagery anomaly detection in the Baltic Sea identified and intercepted 200 unauthorized vessels and prevented 500 illegal crossings in 2019 [115]. In addition, drones coupled with AI can increase the coverage area for border ISR. The “Aegean Sea operation” where AI-driven drones increased the coverage area by 30% and helped track and intercept smuggling vessels. Overall, a 40% reduction in undetected border crossings due to AI and satellite integration has been estimated [116].

2.6.1.4 Cybersecurity

Another key threat to the EU's internal security is cybersecurity. The EU Security Union Strategy for the period from 2020 to 2025 emphasizes the need to enhance the EU's cybersecurity capabilities, to protect against cyber-attacks and safeguard critical infrastructure. While satellites themselves can be targets of cyber-attacks, they also play a role in enhancing cybersecurity by providing secure communication channels and detecting cyber threats from space.

Over the past decades, GNSS has improved aeronautical navigation. However, in recent years flight crews have reported a growing number of radio frequency interference events, rendering this technology temporarily unavailable in large areas. Radio frequency interference events have been identified in three different regions: the Baltic States and Poland, Eastern Europe bordering the Black Sea, and the Eastern Mediterranean, impacting civil aviation in Europe significantly. Research has revealed incidents from isolated events to regular disruptions affecting thousands of flights daily. This highlights the widespread impact of GNSS disruptions on air traffic in Europe. Aircraft types affected by jamming and the formation of alternative flight plans are crucial for air traffic control to provide necessary assistance in case of GNSS disruptions [117].

Satellite jamming is an important component of cyber security as it can be a tool of censorship. The initial jamming incidents began in 2003, traced to rogue frequencies from Havana, Cuba. A recent example is prominent in Iran. The Iranian government is engaged in systematic efforts to control information flow through satellite jamming. Despite over 98% of Iranians watching television weekly and more than 32% tuning into satellite TV, the government justifies jamming activities as necessary to prevent immorality and insecurity, especially targeting channels like BBC. Legally, these actions violate international regulations, raising significant human rights concerns. The Iranian government has demonstrated technological adaptability in maintaining their jamming efforts, using advanced methods to continue their control over information dissemination. Ultimately, satellite jamming is a deliberate strategy by Iranian authorities to suppress dissent and maintain power, highlighting the ongoing struggle for information freedom in the country [118].

The uninterrupted use of GPS is particularly important in transportation. GPS can assist early detection mechanisms for identifying cyber-attacks on vehicular networks. Algorithms identifying cyber threats have been evaluated in real-world urban environments. One of the critical threats addressed by the system is GPS spoofing. A testing in Munich, Germany involved the deployment of 50 connected vehicles, where advanced algorithms identified and mitigated 98% of the detected threats. The mitigation strategies employed reduced the impact of such attacks by 90%, ensuring reliable navigation and timing information. The system demonstrated excellent scalability, handling up to 1,000 vehicles simultaneously without degradation in performance. This scalability is crucial for large-scale urban deployments. The system seamlessly integrated with existing vehicular communication protocols, ensuring that no additional infrastructure changes were needed for deployment. Privacy-preserving algorithms were incorporated to protect user data. The application of the system provided a 20 percent decrease in traffic accidents resulting from communication breakdown and cyber threats. Such enhancement was measured by conducting multiple field trials during a six-month period. They enhance road safety and organizational performance; these systems have proven to be a feasible solution for protecting key vehicular communication networks against new types of cyber threats [119].

2.6.1.5 Detecting Earthquakes, Tsunamis & Nuclear Tests

GNSS sensors, such as those utilized in GPS and GLONASS, are capable of detecting seismic activities and atmospheric disturbances. These sensors measure variations in the Earth's ionosphere and troposphere, induced by seismic events or tsunamis [120]. Real-time identification of these disturbances aids in tsunami detection and improves early warning systems. In this case, GNSS satellites transmit signals that pass through the ionosphere before reaching ground-based receivers. A measure of electron density in the ionosphere is extracted from these signals. Sudden variations in electron density indicate atmospheric disturbances, which can be linked to seismic or tsunami events. Seismic events (e.g., earthquakes) create atmospheric gravity waves, which propagate into the ionosphere. Tsunamis cause large-scale water displacement, generating disturbances that propagate upwards and can be detected in the ionosphere [121].

Nuclear tests are linked with particular sensoring activity, that causes the aforementioned variations in the atmosphere. The GNSS sensors are normally incorporated in an international monitoring system that identifies characteristics of nuclear explosions including seismological, acoustic, and radiochemical characteristics. This capability is used for the implementation of international treaties as well as for the control of unauthorized nuclear tests. This SBA capability is pivotal in ISR of clandestine nuclear tests and policies compliance [122].

Although chemical detection from satellites is currently limited to climate changing gases, the addition of meteorological information helps in the determination of the environmental conditions that affect the spread of nuclear agents. Furthermore, another measure of the surface properties is useful in identifying possible nuclear tests. The existing satellite data for meteorological, surface property, and chemical detection are highly beneficial to Authorities that address or reduce possible threats. The lack of biological and radiological detection and data resolution are significant throwbacks, but they cannot underestimate the valuable sources of information provided by SBAs.

2.6.2 Environmental Monitoring & Disaster Response

Satellites are equally able to pick up signals of environmental changes that are security threats such as rising sea levels or a loss of forests. Moreover, SBAs can aid authorities in monitoring adherence to environmental conventions and the location of violations such as fishing or logging. Additionally, in the aftermath of natural disasters or conflict, satellite information is invaluable for searches and rescues and assisting in disaster response. Overall, it is evident that SBAs have the technical capacity to conduct mappings of the impacted areas, evaluate the damage as well as directing the response teams. This section analyses a variety of case studies with respect to environmental monitoring and disaster response.

2.6.3 Land Degradation

Soil depletion or land degradation is a global concern because it demands actions on the protection of biodiversity and ecosystems that in turn sustain human operations and food production. Different parts of the GEOSS system can help in the tracking of land degradation at different scales (national, regional, global). EO methods generate the possibility of creating platforms of data analytics that can help countries evaluate land degradation. Scholars have demonstrated that a standard area of 10m x 10m of coverage with the capability to acquire data at various frequencies of revisit (e.g. Sentinel-2 at 5 days, Landsat at 16 days) is sufficient to develop decision support systems for combating soil degradation [123].

Especially in the southern European countries' agriculture has been one of the large employers with the continual requirement of human resources. Mediterranean crops exhibit large seasonal fluctuations and at least over the last decade has relied heavily on migrant labor. Southern European agriculture is reported to be diverse and in equal development within the different countries. Mediterranean agriculture products are export quality because they are famous all over the world. Current production systems in the area range from very intensive vegetable production to extensive cereal production systems. Also, the process of modernization of agriculture has led to changes in production patterns. For example, family labor is declining relative to non-family wage labor, and arable crops and stockbreeding are replacing extensive cultivations [124]. These trends have aggravated cases of exploitation of the immigrants in return for cheap manpower. Such cheap labour is usually provided by migrant workers who constitute 90% of the agricultural workforce in Greece [125].

As highlighted in the current research studies it seems that over 40 million people globally are in one way or another in a situation of modern slavery and other forms of labor exploitation. Humanitarian operations try to address labor abuse in global society. Compulsory or unlawful migration leads to labor exploitation as a rule. In addressing these challenges, SBAs can be employed to systematically review and evaluate the probabilities of labor exploitation in a specific region. Satellite remote sensing in conjunction with the multi-criteria analysis decision-making model may be useful instruments of identification and assessment of the relevant territories.

The use of SBAs was recently employed in the strawberry fields in the south of Greece and the study selected six informal settlements to assess the risks of labor exploitation. The objective was the development of an evidence-based approach to targeting interventions against labor exploitation. The study also shows how the use of remote sensing technologies helps in finding informal settlements. Housing without a formal structure could reveal possible cases of labor abuse across a vast area of 140 square kilometers. Conducting a study to identify the illegal settlements by the operators on the field ground would entail taking a tour round the whole area of interest in search of the violations. The ground search could be dangerous and would be expensive and inefficient because many of the settlements cannot be seen by road network. The monitoring process used imagery data that was updated each time to find new settlements that were constructed each season. The process revealed 6 out of 50 settlements with high levels of illicit labour in extreme working conditions [126].

2.6.3.1 Wildfires

All wildfires are required in some ways and have been essential for many ecosystems for years. Pyrodiversity, the variation in fire regimes, is needed to sustain the species and biome distribution. This balance, however, is not a permanent fix and depends on the degree, size and time of the year when the wildfire is. A well-timed and well controlled fire can help in removing the accumulated dry plant material and also help in enriching the soil and in the germination of new plants.

In addition to loss of lives and property, wildfires affect the climate as well as the quality of air in the surrounding environment. According to the European Space Agency, around four million square kilometers of land is burnt globally annually [27]. According to the National Interagency Fire Center, there were fifty large-scale wildfires in the United States in the first half of 2022 only and around 192,016 acres were burned, which is far beyond the ten-year average [127]. Due to climate change and the increase in areas affected by drought, the period which is known to be the fire season in the Northern Hemisphere from July to September has now extended. For instance, CalFire has recorded a rise of 75 days each year in the fire season in the Sierras in California. Further, the records show that 75 percent of the most lethal wildfires in California have happened in the 21st century [128]. These trends show that wildfires are gradually emerging as one of the most critical climate challenges of this century which needs multi-hazardous attention and action. The carbon dioxide emitted by wildfires is a greenhouse gas which enhances the greenhouse effect of the earth’s atmosphere by increasing the level of heat in the atmosphere. This contributes to climate change and hence leads to frequent occurrence and severity of future wildfires.

Wildfires are significant sources of greenhouse gases, particularly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Wildfire frequency and intensity have significantly risen, which is a major threat to the environment. New records show that temperatures are rising, dry spells are becoming longer, and erratic have favored the occurrence of wildfires. Where in the last few years recording some of the worse fires in history. For instance, the California Air Resources Board realized that in the year 2020, wildfires let out around 112 million metric tons of CO_2, the highest in the last one decade [129].

For comparison with the global wildfire emissions, the Copernicus Atmosphere Monitoring Service stated that 1.76 billion tons of CO_2 were emitted by global wildfire in 2021 [130]. Such emissions are equal to a number of large industrial sources during the year, thus pointing to the severe effect of wildfires on carbon output. For perspective, each of these figures could be the emissions from a large industrial source. According to the Hellenic Energy Annual Sustainability Report (2023), three oil refineries with a combined processing capacity of 300,000 barrels per day (Kbpd) emit around 4 million metric tons of CO_2 annually. Thus, the emissions from the 2020 California wildfires are equivalent to the annual emissions from about 28 such refineries. Global wildfire emissions in 2021 exceed the emissions from hundreds of such industrial sources, underscoring the substantial impact of wildfires.

Wildfires also have a tremendous effect on human lives. Wildfires like Oregon's Bootleg Fire may cause health consequences to people in cities far from the fire scene, where smoke from the fire has traveled three thousand miles and more. Wildfires that lead to the release of more particulate matter and hazardous gases are undoubtedly associated with diseases such as asthma, bronchitis and reduced lung volume. Newer studies also point to the likely link between exposure to particulate matter and high incidences of cardiovascular illnesses and neurophysiological disorders like autism and memory impairment in children. Disadvantaged, low-income communities, people of color, and elderly individuals are particularly vulnerable, facing an increased risk from wildfires and disproportionately suffering from the aftermath, including smoke-related health issues, homelessness, displacement, and psychological stress. On average, wildfire smoke is responsible for 339,000 deaths annually, with Southeast Asia and Africa bearing the heaviest burden of this crisis [131].

The 2023 wildfire in the Evros region, which recently ravaged northeastern Greece, has highlighted the critical need for advanced tools to monitor and manage such ecological disasters. As of August 28th, more than 80,000 hectares were destroyed in the Evros region, marking the largest wildfire in Greece in over two decades. The fires claimed at least 20 lives, underscoring their devastating impact [132].

In response to these significant challenges, EO using SBAs like the European Space Agency's Sentinel-2 satellite constellation have proven to be invaluable.

With frequent revisits and an open data policy, Sentinel-2 facilitates swift, detailed monitoring of active fires. The recent availability of 10-meter resolution datasets through super-resolution processing greatly enhances its utility for emergency mapping and damage assessment, making it a pivotal resource in wildfire management efforts. The evolution of the wildfire in the Evros region was illustrated by Sentinel-2 as shown in Figure 4.

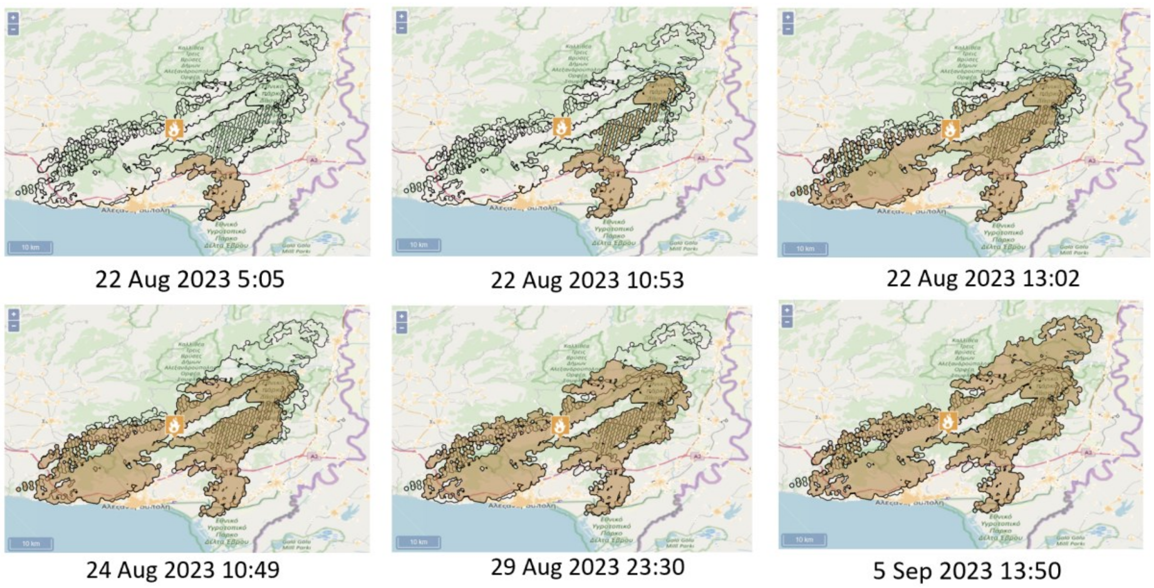

Figure 4: Wildfire evolution in the Evros region, with imaging retrieved from Sentinel-2 [133]

Tracking forest fires and monitoring post-fire ecological impacts present complex remote sensing challenges. The result from the Sentinel-2 imaging is an optimum example for the direct illustration of the aftermath of a wildfire. MODIS (Moderate Resolution Imaging Spectroradiometer) data is operationally used in systems like the European Forest Fire Information System (EFFIS) for near-real-time wildfire monitoring. MODIS is processed in EFFIS into two full mosaics daily, so that the system can be updated at least twice a day. This frequent update offers information on fire impacts in Europe immediately, which proved the efficiency of the system in monitoring the fires. Higher spatial resolution imagery from other sensors such as Advanced Wide Field Sensor (AWiFS) were used to validate fire perimeter mapping. A trial with higher spatial resolution imagery from sensors such as Advanced Wide Field Sensor (AWiFS) was carried out for mapping of fire perimeters. Burnt area mapping is possible with high precision using satellites such as Landsat, QUICKBIRD, and SPOT, that afford high resolution imagery. The incorporation of these high-resolution images has enhanced the assessment of fire damage and planning of restoration. burnt area mapping using Landsat Thematic Mapper and other high-resolution sensors has been testified to be accurate in several studies.

Further, SAR data has been used to identify the extent of burnt area by comparing the moisture content of the burnt area with the unburnt area. Research conducted on SAR in boreal forests of the Mediterranean area revealed that burnt areas had relatively higher moisture content and therefore SAR imagery presented dark areas. This technique has been useful in fire scar mapping, and with polarimetric SAR images, better visual of fire scar images can be obtained. The International Space Charter enhances the possibility of quickly receiving data from various satellites based on crisis management. These satellites are RADARSAT, ERS, ENVISAT and LANDSAT, through which fast response to significant fire incidences is enhanced. This partnership makes certain that the necessary and wide-ranging remote sensing data is available for efficient fire management and disaster response [134].

As for drones, it seems that by expanding the number of drones, it can greatly expand the coverage of the area surrounding the wildfire. In particular, the success rate of cordoning off the fire from 70% to 95% could be achieved, by expanding the drone constellation size from 10 to 50. It is found that one of the features, such as speed and direction of fire spread, can be essential characteristics for drone functionality. For a fire spreading at 2 meters per second, the constellation of 30 drones provided an effective perimeter 85% of the time according to the simulation. While simulation of a fire rate of 3 meters per second was effective at 90%, when the fire rate increased to 5 meters per second the effectiveness reduced to 60% showing the difficulty posed by rapidly spreading fires.

The swarm was able to keep a constant perimeter of the area, with a success rate of 90% for an area of 1 square kilometer. When the area of observation became 5 square kilometers the success rate reduced to 70% meaning that more drones were required or better coordination algorithms for bigger areas. The time taken for the information to get transmitted from the drones to the ground control was kept below one second to make the data current. This real-time data was very important in the coordination of the firefighting as well as in modifying operations in accordance to the changing fire conditions. It could be shown in empirical models that for a fixed rate of fire spread and area, the requisite numbers of drones could be calculated with 95% confidence level. This model assists in planning and allocating sufficient resources to execute the intended mission effectively and with a high likelihood of success [135].

2.6.3.2 Floods

Remote sensing has found that the number of people living in the flood prone zones has increased by 34.1% over the period 2000 to 2015, or 58 to 86 million people. New urban developments in flood-dangerous areas have been growing faster than in less risky areas, driven by economic and social factors that push vulnerable populations into these regions [136]. Without significant mitigation efforts, the annual cost of flooding could increase by 13% to 23% above recent historic levels due to climate change. Meeting global emission reduction targets could limit this increase to around 4% [137].

Accurate flood mapping and data collection are crucial but challenging. Limitations in current satellite technologies, such as difficulties in capturing urban floods and the impact of cloud cover during heavy rain. Advancements in satellite technology, such as cloud-penetrating synthetic aperture radar (SAR) systems, are anticipated to enhance the accuracy of flood monitoring data and improve strategic planning capabilities. Satellites can be used in early warning systems for instance to identify risks such as floods. They can help to gather essential information enabling an organization to address such threats. The European Flood Awareness System (EFAS) offers flood predictions for what could happen in the next 10 days. The ensemble forecast method implemented by EFAS demonstrates enhanced performance with an NSE value enhancement of 0.49 and a decrease in RMSE by 31.7% compared to conventional approaches to forecasting [138].

Modern satellite sensors include high spatial resolution such as Sentinel-1 and Sentinel-2 with an image resolution of 10 meters. The high-resolution data provide an excellent platform for delineating the extent of the floods especially in the urban areas where accuracy is vital in response to the calamity. Satellite data should be acquired as soon as possible to enable a quick response. Sentinel-1 with a revisit time of 6 days can give near real-time data on flood occurrences. The flood area is often depicted by these sources hence making it easy to identify any differences in the coverage of the flood and map them. Several examples estimated that the satellite derived flood maps were 85-90% accurate from the ground actual data. This is as the results from the multiple satellites for instance optical and radar imagery make the flood maps more reliable and have wider coverage. This multiple-sensor strategy minimizes such issues as cloud contamination of the optical imagery and contributes to enhanced flood monitoring. For instance, the integration of both radar data from Sentinel-1 and the optical data from Sentinel-2 improved the accuracy of the flood detection by 15-20% more than the use of each kind of data source as proposed by Schumann et al., (2018).

The percentage of occurrence of flood in a specific location is another aspect; the effectiveness of the automated flood mapping algorithms which is used during the processing of the satellite imaging is also unique. For instance, the comparison of three algorithms including Edge Otsu, Bmax Otsu and Fuzzy Otsu show that while two algorithms, namely Edge Otsuand B max Otsuachieved 87% / 85 % success; respectively – Fuzzy Otsualgorithm only achieved only 78 % success on average in respect to the standard reference maps. In general, the extent of floods was overestimated by digitally enhanced data methods by about 15% and underestimated by SAR data by about 10%, when compared to the reference map generated by the Copernicus Emergency Management Service [139].

Disaster response, particularly in the case of floods, can be significantly expedited with the use of drones. For example, during a bridge assessment following an extreme flood, drones completed the initial site survey in just 4 hours, compared to the traditional method, which may take several days. The drones operated twice a week and produced more than a thousand images per flight. These images were post processed to generate new 3D models so that engineers can monitor the repair process with a high level of accuracy and make prudent decisions regarding the next construction phase. These models were rendered at a density of 2 cm per pixel which enabled assessment of damage such as cracks and displacements, which cannot usually be observed from the ground. The inspection team saved 15 potentially risky site visits and thus reduced the chances of getting injured or coming across more dangerous elements, such as unstable structures and still flowing floodwaters. The overall cost of employing UAS for the whole process was expected to be 40 % cheaper than conventional inspection techniques in terms of manpower, equipment, and time. The low cost makes UAS feasible for use in larger-scale operations for disaster response. Last, this rapid deployment gave the opportunity to get data for decision-making in the rapid first hours of the disaster response [140].

Several publications have analyzed the use of SBAs in environmental monitoring and disaster response. This literature review presented the aforementioned examples to indicate the range of technological capabilities of SBAs in this research field. Further research could focus on the technological advancements in the use of SBAs in environmental issues. However, this research area is beyond the scope of this thesis.

2.6.4 Urban Planning & Critical Infrastructures

The use of SBAs and advanced computing not only enhances operational efficiency and environmental sustainability but also improves the quality of life for urban residents. Case studies of New York and Barcelona illustrate the application of satellite communications in combination with computing to enhance urban sustainability and livability. In New York, the deployment of advanced sensor networks and IoT devices facilitated real-time monitoring of various urban parameters, including traffic flow and air quality. This extensive data collection allowed for dynamic traffic management, reducing congestion by 15% and improving air quality indices by 10%. Applying machine learning approaches helped to schedule infrastructure maintenance, and it was possible to save approximately 20% on emergency repairs. In Barcelona, the emphasis was made on the way that big data and urban computing frameworks can help to optimize urban planning and management. Applying GIS approach along with the big data analysis of the situation allowed the city to redesign the routes and timetables of the public transport which contributed to a 12% increase of the people using public transport. Moreover, smart lighting systems installed while regulating the pedestrian and vehicular traffic reduce energy consumption by one third. These methods demonstrated that urban management has enhanced its efficiency and sustainability, which validates the potential of urban computing in driving change in the urban system [141].

Some examples are presented related to the utilization of SBAs, as well as the four presented machine learning approaches in the domain of urban planning and management. One such application is the ability to incorporate machine learning models to model the growth of cities in Brazil. These models employed satellite and socio-economic data to properly predict areas with future expansion potential.

They used supervised learning algorithms for classification and regression analysis on data history to predict future urbanization.

The primary finding of this study was that the proposed machine learning approach achieved an average of 20% higher prediction accuracy than conventional forecasting techniques, demonstrating the efficiency of machine learning in dealing with intricate spatial data. The second example was devoted to the evaluation of land use shifts in European urban areas. By employing the methods of clustering and principal component analysis, which are employed in unsupervised learning, the researchers will be able to analyze the patterns of change of the patterns of land use. It is from this analysis that major findings concerning the effects of policy shifts on urban growth were established. Based on these case studies, the conclusion made highlighted that the effectiveness of adopting machine learning with GIS was particularly noted for its dynamic and detailed spatial analysis, with greater accuracy and timeliness of the prediction, to support policymaker decision-making [142].

Some of the publications have discussed the application of SBAs in critical infrastructures, urban evolution, and risks. The literature of this research area was presented with the above examples to show the spectrum of the technological competence of SBAs in this research field. This study could be expanded in the future to explore the technological innovation in implementation of SBAs in urban projects. However, this research area is beyond the sphere of this thesis.

2.6.5 Military Capabilities

During the 1990s, Europe had almost no involvement in satellite navigation. The only global satellite navigation systems operating worldwide were those of the USA and Russia, with the US navigation system [143].

GPS was initially developed to provide an all-weather, all-altitude navigation system for military platforms and long-range strategic weapons. Early adopters included US strategic bombers, warships, and submarines, with the first weapons being the AGM-86 and RGM-109 series cruise missiles. The size, weight, and power consumption of GPS receivers significantly declined in the early 1990s, making them suitable for installation in guided bomb tail-kits.

This advancement overcame the limitations of television and laser homing guidance systems, which required clear line of sight to the target, in particular, the US Air Force's Inertially Aided Munitions program aimed to produce all-weather smart bombs. These bombs introduced platform referenced differential GPS, significantly improving accuracy by compensating for GPS errors seen by both the bomb and the launch aircraft. One group of the first GPS aided inertially guided bombs, JDAM, was used extensively during the 1999 bombing of Serbia, and their success led to accelerated production and integration across various combat aircraft. The USAF distributed computer-generated precise strike planning, which in combination with the mass production of low-cost GPS inertial packages, facilitated the retrofit of these systems across a wide range of munitions. Since then, GPS technology has also been incorporated into large caliber guided artillery shells and advanced missiles.

The widespread adoption of GPS guidance led to the development of GPS jammers, particularly by Russian industry. This prompted US efforts to enhance the jam resistance of receivers and develop advanced phased array technology antennas. Both Russian and Chinese militaries have developed their own GPS guided munitions, equivalent to US systems. This includes Russia's KAB-500S bomb and Kh-25MSE missile, and China's FT series of bombs and LT-3 laser guided bomb. These advancements demonstrate the global proliferation and dominance of satellite-aided inertial guidance in modern weaponry [144].

GPS is an open signal provider, but it is not assured since the system is run by the US military. The US government, however, continues to maintain the prerogative of closing the services at any one time if there is some kind of risk of insecurity. On the other hand, Galileo provides guaranteed service, which is important for safety-oriented applications. From Legat and Hoffmann-Wellenhof (2003). France, Italy, and Spain try to increase their commercial and strategic independence pointing on Galileo as more of an unhampered service rather than a mere commercial project. Moreover, the civil authorities and armed forces have imposed their influence on the military application of this system. Thus, in May 2007 the EU concluded to officially sanction the use of Galileo in the armed forces through the European Space Policy [145]. The use of Galileo is viewed not only as a key instrument in the modernization process of the Common Foreign and Security Policy (CFSP) and the European Security and Defence Policy (ESDP) but also as in the ongoing integration of the European Union’s defence industry [143], [146].

Navigation signals work with smart weapons, aircraft, ships, individual portable units for soldiers and unmanned surveillance systems. The sophistication of the Galileo system offers several possible advantages to Europe’s security. Their accuracy and increased accessibility to the urban areas greatly augment the capabilities of security forces and facilitate other important applications, making full use of the potential that has been declared by the Galileo in ISR, secure communications and information processing [147].

The adoption of SBAs in the Ukraine war shows how valuable and helpful they are. Satellite pictures obtained from the commercial satellites and featured in most international newspapers brought out the probability of a Russian invasion. Russia has been keeping numerous military bases near its border with Ukraine and inside Crimea since 2014, however, satellite images showed that the size and scale of Russian military formations in early 2022 were different from the photos taken earlier. These images made it possible for the U.S. intelligence services to forecast the Russian invasion of Ukraine. MAXAR Technologies of the United States revealed through very high-resolution satellite images in early February 2022 that Russia has increased troop build-up near the Ukraine border and in several places in Belarus. For example, satellite images identified a huge Russian convoy of 40-60 km length moving towards Kiev but was immobilized by the mud.

SBA has been most helpful during the early stages of war escalation. For example, while Ukrainian forces were using GIS, the system was being supplied with real-time information from commercial satellites for immediate targeting and firing. This integration brought the target engagement process from twenty minutes down to one minute. The geolocation data derived from satellite images play a critical role in the Ukrainian Armed Forces' battle management system enhancing the accuracy of attacks and the military capability. It has been said that this system has helped to identify and neutralize Russian generals on the frontline.

The Starlink constellation was also extensively used by the Ukrainian Command and Control. Consequently, when the system went out of operation in October 2022, Ukrainian forces experienced a significant loss of communication on the eastern frontline. Real-time monitoring was further enhanced by Planet Labs' satellites, which can image the same area up to four times a day, providing timely and actionable intelligence. The growing use of microsatellites indicates that in the near future, permanent aerial coverage will always be possible.

Following the extensive use of Starlink in Ukraine, there are proposals to extend its capabilities to GPS signaling. Starlink could offer stronger and faster signals due to the lower orbit of the satellites, enhancing resilience against attacks. Additionally, Starlink satellites have potential military applications, such as tracking hypersonic missiles, which has raised concerns among nations like China about the strategic implications of these constellations [20].

The significance of space technology became increasingly evident to the public during the Ukrainian conflict. Satellite images were frequently displayed on television, keeping people informed about the situation on the ground. This exposure also heightened public awareness of issues related to satellite communications, such as the vulnerability of terrestrial systems and interference with GPS signals.

The use of satellite imagery in providing pre-conflict information has revolutionized the response time for those involved, enabling them to quickly assess situations, develop a shared understanding of threats, and coordinate strategies effectively. This technological advancement has also transformed international public awareness, allowing people to track the progression of a crisis into a war with concrete, daily evidence [20].

The application of SBAs in military operations gives rise to a question concerning the credibility of information. Dependable satellite communications could be affected by various phenomena which resulted in degradation of the communication quality and hence reduced operational capability. For instance, an important aspect of military and emergency response operations is the tropospheric ducting in the Very High Frequency (VHF) and the lower Ultra High-Frequency (UHF). The new approach that uses AI algorithms to enhance interference detection has been found to reduce the number of false alarms by 20%, and increase the accuracy in detecting interference by 15%, when compared to conventional techniques.

The detection latency can be also decreased from 10ms to 7ms, which allows to react quicker. Adaptive algorithms are able to perform well under varying interference patterns and guarantee an ability to correctly detect an RFID tag under different interference conditions. With these improvements, operational costs are reduced, due to the decreased need for manual interference management. Overall, these advancements enhance both the efficiency and cost-effectiveness of critical communication operations [148].

2.7 Security threats for SBAs

As of February 28, 2025, there are approximately 30.279 objects being tracked in Earth's orbit, including both active satellites and space debris [149]. As of April 2024, there are over 9,000 active satellites orbiting Earth [150]. A McKinsey & Company analysis anticipates that, in a base-case scenario, there could be about 27,000 active satellites by the end of 2030, nearly a fourfold increase from the current count [151].

The space economy is expanding rapidly, with commercial satellite initiatives changing the dynamics in space capabilities. The rate of space activity has been rising steadily. In 2021 there were 182 satellite launches. As of February 27, 2025, Starlink alone has launched 8,029 satellites, with 7,083 currently in orbit and 7,050 operational.

This trend underscores the need for robust space traffic management and collision avoidance measures. Interference with these assets could have broad economic repercussions, affecting everything from telecommunications to global positioning systems. Adversaries are employing a range of strategies to exploit vulnerabilities in space systems. This includes direct attacks on satellites, jamming of communication signals, and cyber-attacks targeting satellite control systems.

The total amount of tracked orbital debris has reached 32,300 pieces. This growing debris field poses substantial risks to both current and future space operations. Space-based assets are integral to military operations, providing essential services like GPS, communications, and reconnaissance. Disruption of these services by counterspace activities could significantly impair military effectiveness. Countries are bolstering their military space capabilities. For instance, the establishment of the U.S. Space Force reflects a strategic emphasis on protecting space assets and ensuring space dominance.

Nations such as China, Russia, Iran, and North Korea are actively developing and testing counterspace weapons. These weapons range from kinetic kill vehicles to electronic jammers and cyber capabilities. The war in Ukraine showcased the tactical use of counterspace capabilities, with Russia employing various space-based assets to support its military operations and disrupt Ukrainian communications and ISR [152].

The performance of space infrastructures is threatened by the increased number of information sources and the higher real time requirements. As space becomes more crowded it also becomes more competitive, with more prominent hostile behaviors. For instance, there is an increasing number of space systems which are privately-owned and managed by commercial operators, that could create conflicts to EU space-based infrastructures.

In 2019, a Russian satellite moved so close to an American national security satellite that military officials feared the two would collide, causing an international incident. Instead, the Russian satellite maneuvered away, deployed a small target, and destroyed the target in what appeared to be a weapons test. Following this incident, the American military officials, especially the newly created Space Force, considered that Russia could threaten US national security assets in space [153]. Thus, protecting space interests should be a top national security priority.

Currently, one of the greatest threats to American satellites comes from cyberweapons developed by the Chinese PLA. China first began incorporating cyberattacks into its military exercises in 2005. By 2008, Chinese hackers had the ability to gain access to a civilian imaging satellite not once but twice. China organizes its military capabilities in space through the PLA Strategic Support Force, which is also responsible for information warfare and cyberweapons. Russia has shifted its focus toward cyberweapons since 2010, but it has not reached the level of sophistication of the Chinese strategy.

On the other hand, the shared-ownership or community-owned systems, such as Copernicus Sentinel missions or EUMETSAT satellites, could create delays in the development of new capabilities, as many stakeholders are required to act and agree according to plans. The development of dual-use capacities raises crucial ethical considerations. There is extensive literature on the use of space for security and military purposes, the so called “double use of space”. The differentiation has legal implications as the later approach could treat geolocations as battlefields that legitimate actions of war can take place [154].

Another threatening issue for SBAs is the increasing presence of space debris. More space debris from destroyed satellites or anti-satellite (ASAT) weapons tests could make Earth’s orbit too dangerous for future exploration. China’s 2007 test of an ASAT weapon, for example, sent space debris hurtling toward the ISS, endangering the astronauts aboard. According to the Union of Concerned Scientists, the destruction of one large satellite alone could more than double the amount of space debris currently in low Earth orbit (LEO). The most common ASAT weapons are so-called “kinetic energy weapons,” which use an inert projectile launched at high speeds to pulverize a satellite like a rock thrown at an apple. Especially when used against high altitude satellites, kinetic energy weapons can generate tremendous amounts of debris that will remain in orbit around the Earth for decades [155].

SBA owners are concerned about the security of their assets. Recently Russia was accused by the USA for the launch of a LEO satellite, which could be utilized as a counter space weapon. For instance, lasers could be employed to blind or dazzle satellite optical sensors. Additionally, the blockage of satellite communications is a significant concern. In the past, France has accused Russia of attempting to intercept signals from the Athena-Fidus satellite, an asset which it shares with Italy. This year, U.S.A. officials disclosed that Russia was developing a nuclear anti-satellite weapon. A nuclear space weapon is of great concern for the space policy experts, who promote the ban of the development of weapons of mass destruction in orbit. Official attempts towards this direction front the United Nations, have not led so far to an agreement [156].

As space becomes an increasingly complex strategic domain, major space powers are concerned about the safety of their assets and the counterspace capabilities of competitors. For instance, the prominent initiatives of China and India and their positioning as space powers has a significant impact on overall space security activities and policies. A first ASAT test was conducted by China in 2007 and resulted in the destruction of a difunctional weather satellite. India followed with its own ASAT test in 2019, named "Mission Shakti," successfully targeting a live satellite in low Earth orbit. Both tests reflect the strategic importance of space for China and India, emphasizing the militarization of space and its impact on global security dynamics [157].

From the study of Stroikos it is concluded that the comprehension of national space technology development is highly dependent on structural factors, domestic factors, and state identity factors. Structural Imperatives are the political and strategic enmities that make ASAT tests happen because countries want to prove their power and security in space. Domestic Influence means that politics inside a country and patriotism are important for the progress of the economy. Technological demonstration is thus beneficial for China in two ways: it reflects the goal of modernization and supports the agendas of the CCP. For India, it fits into the concept of ‘technological indigenisation’ and enhances the nation’s image. Thus, the foundation of both programs is in the desire of the nations to claim their status as members of the space club and as major space powers. These tests are a part of other activities that are aimed at gaining international status and power. Both tests have provoked considerable international concern with space debris. China’s test in 2007 created a large amount of large size debris that will remain in orbit for many years and India test may have produced less debris though it was conducted at a lower altitude, it still contributes to the space debris. Such factors have sparked debates on the need to set higher standards and laws that would ban the use of space. Therefore, the ASAT tests could result in a turn into a space arms race which will not augur well with international cooperation in space and space governance.

2.8 Ethical considerations

The improvement in satellite technology, including better image resolution and the ability to process data in real time has greatly improved ISR. Such advancements are not without legal and ethical implications, especially on the extent and intensity of ISR operations. Therefore, a number of works stress the need for effective legal provisions to govern satellite observation stressing the importance of privacy rights, as well as security concerns. For instance, legislative activities like the Electronic Communications Privacy Act and the USA PATRIOT Act try to address these issues but fail to do so given the dynamism of technological evolution. However, ISR practices should be made clear and answerable to avoid some form of misuse of authority. These two reasons, coupled with the likelihood of technology being abused, mean there is need for more stringent laws and supervision to ensure that the subjects being observed give informed consent.

There are many examples of successful application of satellite data in law enforcement and national security; however, there are also many examples of ethical issues connected to it. For instance, measures in increasing ISR along the border of the United States and Mexico reduced the flow of illegals by 30%. In the same way, satellite imagery showed an increased deforestation in the Amazon by 15% in five years, which triggered governmental action and new policies to diminish the illicit logging operations. Satellite data in urban areas showed that the traffic flow efficiency has been increased by twenty percent in the cities where the data-generated traffic control systems were installed, thus making the cities less congested and polluted [158].

Satellite technology also has a profound impact on human rights advocacy. Human rights organizations, such as Amnesty International and Human Rights Watch, use satellite imagery alongside open-source data to document and report human rights abuses. These methods have successfully verified mass graves in Burundi, the destruction of towns in Nigeria, and military abuses in Venezuela [159], [160].

On the other hand, it is crucial to understand the distinction between "control privacy" (control over personal information) and "access privacy" (nonaccess to personal information). Modern ISR tends to reduce privacy control, while leaving access privacy mostly intact [161]. Mass ISR creates an environment of suspicion, leading individuals to alter their behavior, speech, and communication due to fear of being monitored. This inhibition impacts the legitimate exercise of rights, such as freedom of expression. ISR affects individuals' autonomy and dignity, making people feel constantly monitored and less free to experiment or express themselves, which is crucial for societal evolution and democratic discourse.

Furthermore, mass ISR obstructs the separation of powers by allowing the executive branch to conduct operations without stringent oversight, undermining democratic principles and treating all individuals as suspects. The accumulation of big amounts of data erodes privacy by decreasing the levels of data ownership even where the data is not retrieved. Despite the fact that artificially intelligent systems might be employed for harmless ends in the future, nobody can predict what the application will be in the future. The facial recognition algorithm trained to recognize criminals can be reprogrammed to identify those in the dissident category, whereby alteration turns the relationship balance around power in favor of the state. All in all, for this very reason; mass ISR is not only a violation of the right to privacy; it is also the key to the violation of other human rights such as the right of assembly, the right of movement, and no discrimination right. That is why, there is a necessity to provide the concept of all-embracing perspective for ethical intercourse concerning satellite ISR on an international basis. Similarly, it is the general ideas of making global standards, of global authorities exerting better control as well as increasing awareness among the people also depends on the consensus among the countries. As for the aforementioned complicated subjects, societies can gain better positioning regarding satellite monitoring and can prevent further advancement from becoming a threat to human rights.

2.9 Conclusions

The literature reveals that SBAs, GNSS, and RPAS are essential in improving the EU's security systems. These systems greatly enhance the maritime security, border protection and combating of organized crime, through high resolution imagery, real time data feeds and accurate positioning. The EU, through the Copernicus program and cooperation with agencies including Frontex, European Maritime Safety Agency (EMSA) and Satellite Center, has shown that cooperation and innovation are crucial for dealing with wide and intricate security threats. Nonetheless, the literature also points to the need to increase the compatibility of these technologies, process data in a timely manner, and develop policies to enable the full benefits of these technologies. Thus, the EU, which is still experiencing new challenges, needs to enhance these technological opportunities together with the development of partnerships for security and stability.

3 The Role of Frontex and EU Cooperation

3.1 Introduction to Frontex's Role

Frontex – the European Border and Coast Guard Agency, has appeared as a new actor and is now an essential factor in border governance in the EU. Since its creation in 2004, the agency has been enlarged to face the migration crisis in 2015, which showed that the EU cannot control and protect its external borders [162].

Frontex's mandate has expanded significantly since its establishment in 2004, now encompassing 21 distinct tasks as per the European Border and Coast Guard Regulation. These activities include coordinating joint operations, conducting risk analyses, facilitating intelligence sharing, and organizing joint return operations for irregular migrants. The agency collaborates with EU member states, third countries, and other agencies like Europol to implement integrated border management strategies. Notably, Frontex plays a crucial role in operations such as migrant identification and registration in hotspots like the Moria camp in Lesbos, Greece, where its personnel are involved in screening, document verification, and fingerprinting of migrants upon arrival [163].

Frontex's is characterized by a rapid organizational growth, with its budget increasing from €6.2 million in 2005 to €845 million in 2023, and staff numbers rising from 45 in 2005 to over 2,200 in 2023. This expansion reflects the agency's enhanced responsibilities and the EU's prioritization of border management. Frontex operates as an autonomous EU agency with its own legal personality, governed by a management board comprising representatives from Schengen member states and the European Commission. The agency has also established a standing corps of 10,000 border guards, including personnel directly employed by Frontex and those seconded from member states, to strengthen its operational capacity.

Frontex operates across the EU and is based on an **impact level map**, highlighting different border regions in Europe and their levels of impact concerning migration, border security, or other related challenges, as illustrated in Figure 5.

The read areas are characterized of high impact. These are areas with significant challenges, most notably along Greece's maritime and land borders, parts of the Central Mediterranean, and some locations along the Western Mediterranean (Spain). The orange areas, of medium impact, are found in parts of the Greek islands, Italy, and Spain, indicating moderate but still considerable challenges. The green areas, of low impact, are most of Europe's land borders and northern maritime borders. They grey areas, along the Balkan route and Greece's land borders, are under assessment and further evaluation with respect to their impact.

From the map it is prominent that the Aegean Sea and Greek-Turkish land border have the highest risk levels, likely due to irregular migration flows. The Central Mediterranean route (Libya to Italy/Malta) remains a medium to high-risk area. The Western Mediterranean (Spain's southern coast and Canary Islands) shows varying levels of risk. Finally, Northern and Eastern European borders (e.g., with Russia, Norway, and the Baltic states) have low impact levels. This map visually represents border security and migration challenges across Europe. The high-risk zones (in Greece, the Central Mediterranean, and Spain) align with historical migration routes. The low-risk areas suggest well-managed or less active migration and security concerns.

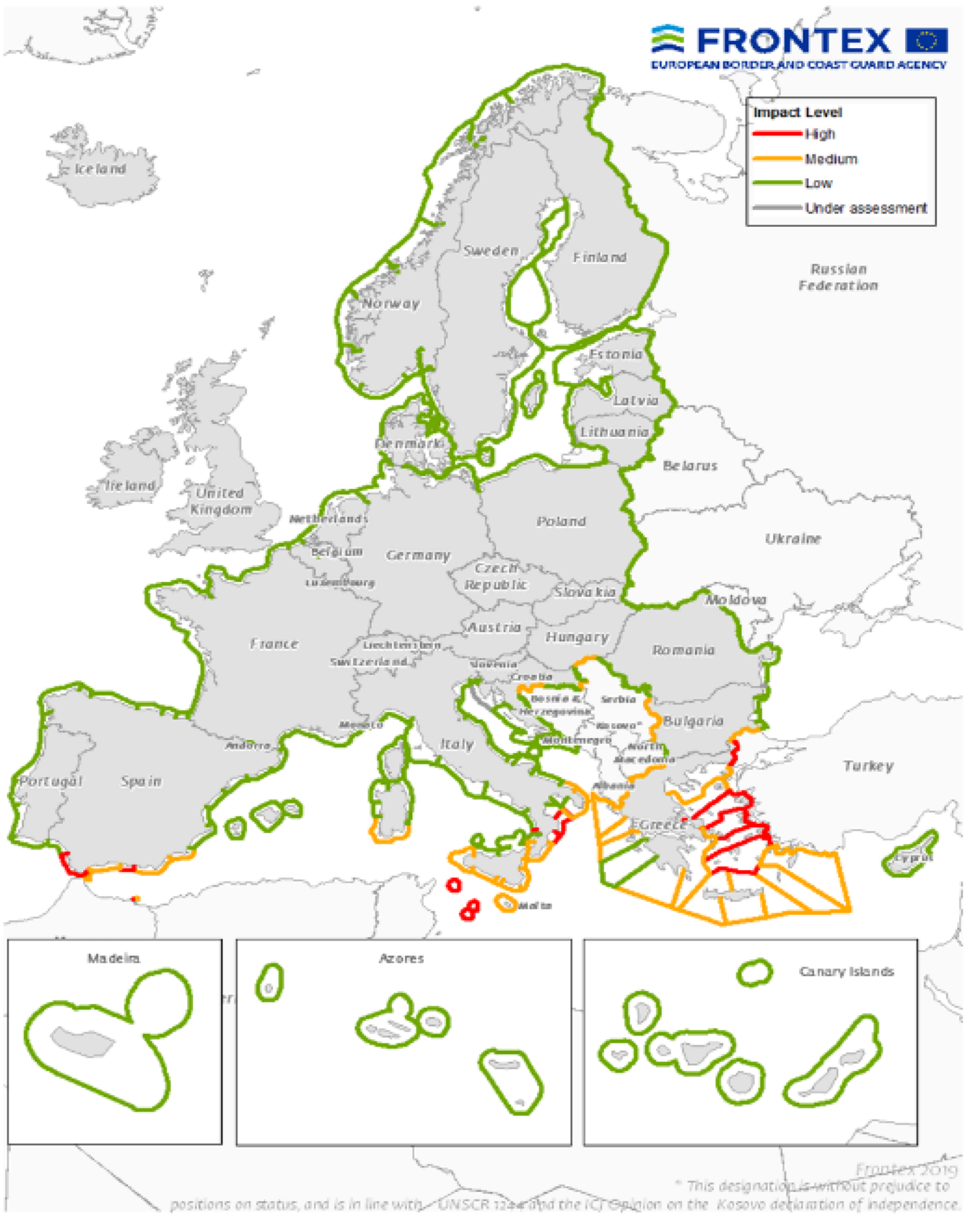

Figure 5: Impact level map of migration - Frontex [164]

Furthermore, it has now become an authority to organize joint operations and to employ Rapid Border Intervention Teams and to coordinate threats at the external borders of EU such as irregular migration, organized crime, and human trafficking. These activities are supported by Frontex's capacity to effectively use recently developed tools, such as satellite images and geospatial data to enhance its capacity to monitor and control the EU external frontier. This agency has been defined in accordance with its cooperation agreements with other EU bodies and offices such as European Maritime Safety Agency and SatCen.

EMSA plays a key role in providing technological and operational assistance to enhance maritime safety and security. Some of such partnerships have helped in increasing Frontex's effectiveness, in the sense that has integrated hi-tech into control and monitorial work. For instance, SatCen has offered Frontex with the high-resolution satellite images and, in the meantime, EMSA offered Frontex with the maritime security for dealing with various threats within the land, sea, and air domain.

An illustration of the interconnectivity and information sharing between agencies is shown in Figure 6. In particular, if a Frontex operator identifies a threat at land, a request is sent to SatCen for closer ISR, while if a threat is identified at sea, ESMA receives a request for closer monitoring. For the most efficient ISR of the threat satellite images are requested initially via ESA and Copernicus. If Copernicus ISR is not adequate for a particular threat, further imaging can be requested from civil or commercial satellites. Such partnerships tackle challenges on how the EU can fashion a coherent strategy in managing the borders while threats are changing and are becoming more transnational [114].

The agency's joint operations, such as Operation Hera, have been instrumental in intercepting irregular migrants and reducing unauthorized border crossings. For instance, during the initial phase of Operation Hera in 2006, Frontex coordinated maritime patrols along the coasts of West African countries, leading to the interception of over 20,000 migrants attempting to reach the Canary Islands. These efforts have contributed to a decline in migration flows along targeted routes. However, there are concerns regarding the agency's involvement in activities that may impinge on human rights, such as the interception and return of migrants without adequate assessment of their asylum claims, underscoring the complex balance between effective border management and the protection of fundamental rights [165].

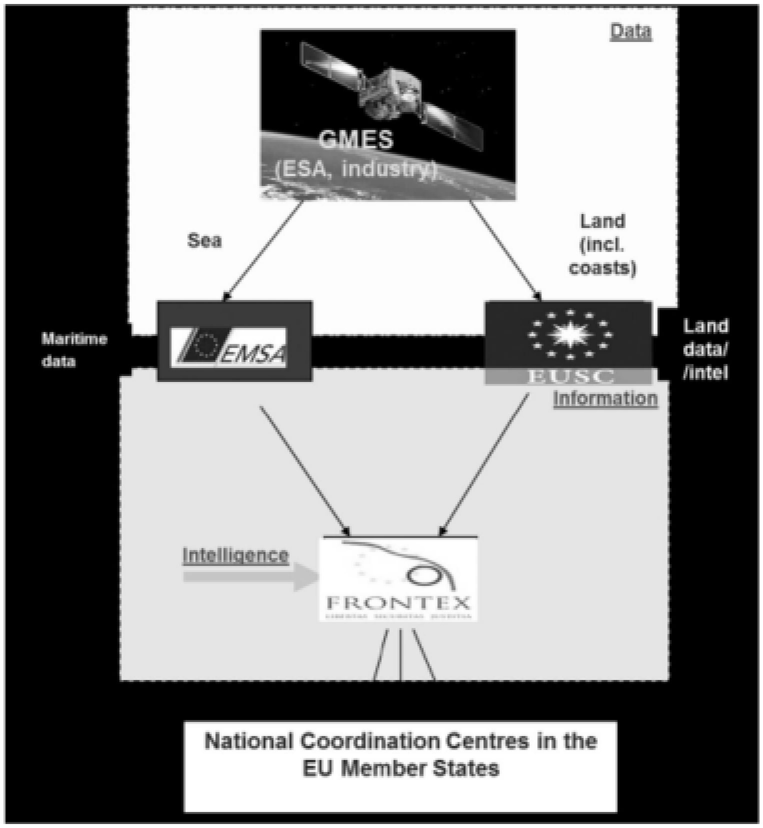

Figure 6: Schematic illustration of the implementation of the EU-FRONTEX Agreement [114].

Nevertheless, Frontex has been instrumental in enhancing the common external border and cooperation between member states of the European Union. It works as a central body that connects the national authorities with the well-equipped and well-equipped agency. Kolovos (2016) explains how Frontex is enriched by cooperation with ESA through the Copernicus program. This program offers satellite imagery for border control purposes, as well as consolidating data from different sources within the nation to meet the common challenges of the EU. The integration of common components and consistent data gathering systems, guarantees the unity of approach to external threats management.

Moreover, the establishment of operational arrangements, such as the GMES (now Copernicus) Border Surveillance Working Group also shows that Frontex is involved in the process of determining the operational needs and mobilizing the collective assets to strengthen the borders. The EU's Copernicus program works in cooperation with Frontex and other EU, resulting in the creation of services that meet the needs of end-users. For instance, the incorporation of satellite data into the EUROSUR system, or the SAGRES and LOBOS projects, which respond to different ISR needs by offering specific information on the sea and the borders on the ground.

3.2 Maritime ISR and Cooperation with EMSA

Frontex has collaborated with the EMSA, boosting the security of the maritime domain in the EU. The EU controls a very large area of the coastline, which is very advantageous for legal conduct of business, transportation of goods, but at the same time it is a weak link and used by refugees and smugglers. EMSA also helps Frontex to provide access to the monitoring solutions such as AIS and EO data.

These tools facilitate the tracking of movements of vessels and hence it becomes possible to assess security threats in real time for the EU zone. For instance, AIS (Automatic Identification System) data provides real-time information on the location and movement of ships by transmitting signals from vessels, whereas satellite imagery captures broader spatial data, including ship movements, even for vessels not equipped with AIS. CleanSeaNet service offered by EMSA complements this cooperation as far as it identifies oil slicks and other environmental threats that may coincide with illicit sea activities [166].

Remotely Piloted Aircraft Systems (RPAS) also increase the EU's maritime ISR capacity because RPAS provide high-resolution images and real-time video streams. These unmanned systems allow Frontex to observe extensive areas of the seas, which are almost impossible to monitor by other technologies of ISR. Frontex practical experience, together with EMSA advanced technologies, has been rather helpful in dealing with maritime security threats. It is particularly important in the Mediterranean area, where movements of migration and smuggling operate at the absence of coverage in sea ISR. Implementing these technologies into Frontex's operational context demonstrates how synergy and cooperation can collectively counter more complex threats at sea [167].

3.2.1 Satellite-Based ISR for Land and Port Targets

Organization has enhanced the cooperation with the SatCen, and this has boosted the capacity of this institution in analysing and managing the security threats in the land borders and ports. SatCen provides resolutions of satellite images and geographical information that are essential in determining illegitimate actions and in preventing losses. These operations are supported by Copernicus program which is the foundation of EU EO activities and provides data from the Sentinel series of satellites. For instance, Sentinel 1 & 2 have high resolution and thus, the following can be detected: Movement, smuggling routes, and changes in border among others. Such observations are especially informative in areas of the greatest migration activity and transnational crime, including the eastern and southern borders of the EU.

Concerning ports, ISR using satellite technology can be used by Frontex to monitor movement of freight containers and establish security threats such as smuggling of prohibited goods and human trafficking [168]. Incorporating satellite imagery into operational procedures guarantees that the port authorities can detect odd activities in real time. This capability has been most useful in counteracting threats in the EU's sea-borne supply routes, which criminals often target. Thus, SatCen's technological experience allowed Frontex to show the effectiveness of space-based systems in enhancing the protection of borders and the EU's critical infrastructure.

3.2.2 Implementation of EU-Frontex Agreements

The EU-Frontex Delegation Agreement, signed in November 2015, implements the Border Surveillance component of the Copernicus Security Service. Under this agreement, Frontex is allocated €47 million until 2020 to provide services derived from fused sensor data, including ship reporting systems and satellite imagery. These services are designed in collaboration with end users and focus on land and maritime surveillance, utilizing satellite imagery to analyze ports, coasts, beaches, and border crossing points. However, the public has limited access to the full details of this agreement, as certain technical specifications are withheld to prevent compromising the effectiveness of law enforcement activities supported by the Copernicus Security Service [114].

The implementation of the cooperation agreements with EMSA, SatCen, and the European Commission to operationalize Frontex's role is reflected in the utilization of EUROSUR. EUROSUR provides a multi-layered structure for border management, incorporating land, maritime, and air surveillance. Each EU Member State operates a National Coordination Centre (NCC), which functions as the central point for coordinating and exchanging information between national authorities responsible for border surveillance. These NCCs ensure that situational awareness at the national level is maintained and shared with other NCCs and Frontex. The national situational picture compiled by each NCC includes real-time data on external border activities, deployed assets, and background intelligence.

Frontex consolidates this information into the European Situational Picture (ESP), offering a comprehensive overview of security conditions at European borders and in pre-frontier areas. This centralized approach allows Member States and Schengen-associated countries to rapidly exchange critical intelligence, foster intergovernmental cooperation, and respond collectively to emerging border security challenges. Furthermore, neighboring states within the EU share real-time data on external border sections, improving regional coordination and crisis response. Frontex is integral to the functioning of EUROSUR, with its responsibilities spanning coordination, risk analysis, crisis response, and technological innovation. The agency ensures that EUROSUR operates efficiently and effectively to safeguard EU borders.

Utilizing EUROSUR capabilities, Frontex acts as an intermediary between national border management authorities, enabling the seamless exchange of real-time intelligence. The agency manages both the ESP and the Common Pre-frontier Intelligence Picture (CPIP), crucial tools that aggregate and disseminate intelligence across the EU. Frontex conducts comprehensive risk assessments to identify and address potential border security threats before they escalate. These assessments target issues such as illegal immigration, human trafficking, and transnational crimes, allowing EUROSUR to adopt a preventive approach in its operations. During emergencies, such as sudden surges in migration, Frontex mobilizes resources to assist national authorities. This includes deploying additional personnel, coordinating with national forces, and providing essential assets for border control and maritime rescues.

Frontex enhances EUROSUR’s capabilities by incorporating state-of-the-art technologies, including satellite surveillance, RPAS, and artificial intelligence-based threat detection. The integration of data from EMSA and SatCen has significantly improved border monitoring and early threat detection. The EUROSUR Fusion Services, coordinated by Frontex, aggregate intelligence from satellites, drones, and other surveillance technologies. These services provide Member States with advanced security capabilities without the need for duplicative investments, reducing costs and optimizing resource allocation. Given that no single Member State could afford the independent deployment of space-based surveillance platforms, EUROSUR ensures access to such technologies in a cost-effective manner.

Nevertheless, the experience of EUROSUR implementation has shown that it faces challenges, such as interoperation and data sharing. Member States use many different technological systems, and these do not seem to be compatible, which slows down the exchange of information and the platform's efficiency. These issues are best solved by creating best practices for the field and using big data analytical methods that can analyse large sets of information. Overcoming these challenges will enable Frontex to improve its operational efficiency and guarantee that EUROSUR remains the key component of the EU’s border protection strategy [25].

The European Commission, under the 2019 Frontex Regulation, is mandated to develop a European Integrated Border Management (EIBM) strategy. This EIBM strategy has been published. The latest version covers the period from 2023 to 2027 [169]. A key priority of EIBM is the capacity and preparedness to conduct search and rescue operations, overcoming interoperability barriers, at external sea borders. This commitment aims to protect and save lives, integrating humanitarian efforts into border surveillance activities.

Implementing modern technologies is key to overcoming interoperability barriers. Integrated systems, such as the European Travel Information and Authorization System (ETIAS), enhance the efficiency and security of border controls. These tools facilitate pre-screening of travelers, contributing to better risk assessment and management. Moreover, the establishment of systems like the Schengen Information System (SIS) and EUROSUR enhances information sharing and situational awareness. These platforms support coordinated responses to security threats and irregular migration. In addition, developing a common culture among border guards, characterized by high professionalism, ethical values, and integrity, is essential. Training programs should ensure that all personnel are equipped to perform their duties while respecting fundamental rights. Furthermore, EIBM emphasizes the importance of collaborating with neighboring non-EU countries [170].

This initiative of the EU MS, placing FRONTEX at the forefront of activities, aims to address root causes of irregular migration, enhance border security, and manage migration flows more effectively. Overall, EIBM seeks to find an equilibrium between maintaining high levels of internal security and facilitating legitimate movement of people and goods across EU borders. This balance is crucial for the economic and social well-being of the Union.

3.3 Conclusions on the Role of Frontex

The rationale for Frontex in the management of the EU borders has evolved over the years because of the agency's efficiency in the exploitation of the new technology as well as establishment of strategic partnership. The cooperation with EMSA and SatCen has demonstrated that satellite ISR systems can dramatically change the concept of border security. These partnerships, using the EUROSUR platform, have provided Frontex with the tools and information as to respond efficiently to the complex security challenges. Nevertheless, Frontex has still to tackle challenges such as interoperability between Agencies, threats development and climate change. In this manner, Frontex can continue to provide and develop its effectiveness in fulfilling the EU's border protection requirements through acquisition of new technologies and strengthening of cooperation. The skill to apply new ideas and to meet new and unique challenges will determine the security and stability of the EU borders in the future. In addition, Frontex attempts to enhance secure communications. Frontex has shown interest in participating in the ENTRUSTED project. The project focuses on end-user requirements for secure satellite communication services [171].

4 Methodology and Key Findings

The previous section utilized a literature review to identify opportunities and potential threats in the use of SBAs for internal security. While the use of SBAs for security purposes is widely recognized, it is important to note that the data retrieved from these technologies often become available after critical incidents have occurred, serving as a post-event analysis. To assess whether the uptake of field operators can be increased and whether the use of SBAs can be used in real time, interviews were undertaken with EU security Agencies operators and humanitarian aid organisations. The EU security operators represent the perspective of authoritarian control and risk assessment, while the humanitarian aid organisations represent the view of vulnerable populations on the move. This section describes the methodology used, the interview structure and key findings from the interviews.

There was an effort to make the interviews as conversational and analytical as possible to allow interviewees to understand the concept and be accurate [172]. The interviews were semi-structured, using open-ended questions, to address key themes that would make interviewees more talkative [173]. This way, the research was not limited by traditional questionnaires, where the selection of questions could lead to biased results [174]. The interviews were conducted in person or via phone, making the process faster and cheaper [175]. Furthermore, background information on the operational interests of each Agency or Organisation was gathered in advance, allowing for a flexible discussion that adapted each time to the interviewee's expertise and interests [176].

The methodology followed logical steps to understand the operational procedures on the field, define the valuable timely information that an operative should have in order to make a decision, select a reliable sample of interviewees in order to address a variety of perspectives, form an interview that allows a sufficient analysis of the topic, collect and analyse the data and ensure validation of the results via extensive research in relevant publications [177]. With respect to ethics, at the beginning of each interview, there was a clarification, that all data will be treated as confidential [178], which was aligned with the desire of the interviewees for confidentiality.

Security issues are extremely sensitive and information from professionals that deal with security crisis is extremely limited. Therefore, the aim was to tackle one main issue of internal security that is well described through extensive literature and could be addressed to relevant professionals that were willing to provide feedback anonymously. The topic that was chosen based on the availability of interviewees was illegal immigration and cross-border crime.

4.1 Sampling

The first stage involved understanding the operational procedure and the timely data requirements from the perspective of professionals. At the beginning two Security Agency Operators, from now on the Operators, were contacted to explain in depth the process of monitoring illegal immigration and cross-border crime. The first Operator serves as a Frontex Officer and analysed refugee issues. The second Operator serves as a Police executive at the Hellenic Police and analysed issues related to the monitoring of internal threats and cross-border crime. After the completion of the Operators' interviews, a good understanding of the Authorities' practices and security procedures had been established. To investigate the humanitarian aspect of migration, more than twenty humanitarian aid providers, from now on the Providers, were interviewed. To assess and compare the similarities and deviations between cross-border incidents and wildfires, the interviews were extended to Firefighters.

The initial plan was to find and contact as many as possible organizations relevant to immigration, cross-border crime and disaster management, but this was not possible in the end. Although the maximum sample couldn't be achieved, there is still confidence in the results of the interviews, based on the fact that the same challenges were identified by all the professionals and to similar extents.

One concern was that a survey including only professionals on immigration could be biased, requiring the inclusion of other security threats. As it is impossible to investigate and interview professionals from all Agencies and Organizations that deal with possible threats, adequate and representative sampling of professionals dealing with other threats is essential to ensure reliable conclusions [179].

This dissertation went beyond the immigration issues and attempted to connect and compare the utilisation of SBAs with cases of natural disasters and with wildfires. As there are confidentiality issues that do not allow direct information sharing with Agencies, the research focused instead on publicly available information on the executed plans related to specific natural disasters. This methodological approach allows the identification of common operational ground as well as the strengths and the weaknesses of the uptake of SBAs for immigration and for natural disasters.

4.2 Interview Structure

The two Operators were interviewed about the way operations are structured and how operatives receive and use data to make real time decisions on the field. Finally, they were asked on the use of SBAs during operations and whether they could suggest improvements for the further penetration of these technologies in security Agencies. After the Operators, analysed common practices and potential weaknesses the interviewer attempted to explain the benefits from the use of SBAs, beyond the information provided by satellites. The interviewer explained the advanced capabilities provided using UAS, equipped with adequate tools to provide real time data. The Operators were asked to assess and compare the benefits from the use of satellite and UAS capabilities, in incidents' prevention and response and whether satellites or UAS could improve decision-making and action plan formation.

The Providers were probed about the uncertainties and the dangers they face, new operational patterns that they believe should be incorporated to improve handling of vulnerable groups and the most crucial information that they could use on the field. Finally, they were asked about the usability of SBAs in their operations and potential benefits in search and rescue activities. The interviewer addresses the benefits of UAS to the Providers and asked them to assess operational improvements due to the use or real-time data.

The Firefighters were asked to explain operational procedures and uncertainties they face in the field. Hey, were then asked to explain the current use of SBAs in their operations. The interviewer then discussed alternative technologies of SBAs and the benefits they could have in real-time data. The Firefighters were then asked to assess and suggest a combination of technologies that could be valuable in their operations.

Finally, the interviewer presented to the interviewees a table of SBAs choices that they would consider as useful in their operations. During the interview, the interviewees were introduced to the SBA choices and were asked to argue in favour or against each SBA, based on the requirements of their operations. The table introduced to the interviewees is shown in Table 4. The table was formed in a way to present one choice per SBA technology, making the interviewee understand the range of EO that each technology provides and the scale of the required investment.

SBA Earth Observation Characteristics and Cost of Investment				
SBA	Spatial Coverage (km)	Spatial Resolution	Latency	Cost of SBA
GEO Satellites	300 x 300	50 m – 1 km	Minutes to hours	$100 Million
Sun-synchronous & LEO Satellites	25 x 25 (min)	0.5 m	90 min	$ 500 k
UAS	50 x 50 (max)	0.1 cm	1 sec	$ 25 k (max)

Table 4: SBA earth observation characteristics and costs [180], [62], [181], [182], [32], [183], [184].

The table illustrates an indicative performance of each technology. The main aim was to discuss the level of detail, and the frequency of the information received from each technology in comparison with their cost. One concern was the rightful representation of each technology in the aforementioned table. Based on the discussions during the interview, the table proved to be sufficient for adequate answers in comparison to EO requirements for operations. Additional information and examples were provided by the interviewer upon request during the interviews.

The accuracy of the spatial resolution, latency, and coverage values was validated using established literature and technical sources. For instance, the resolution and coverage estimates for GEO satellites are based on system capabilities described by EUMETSAT (2020) and eoPortal (2021), while latency considerations reflect analyses by Wu et al. (2021). Cost assessments align with OECD’s (2020) estimates of space infrastructure investments. Specifications for Sun-synchronous and LEO satellites were referenced from ESA (2023) and Maxar Technologies (2021), and UAS capabilities were benchmarked using operational insights from NOAA (2022).

4.3 Interview Responses

The section provides an overview of the main points that interviewees stressed as being problematic about field operations and real-time data availability from SBAs. The results are divided into three categories according to the interviewees. The first category involves the Operators, and the second category refers to Providers. The third category involves Firefighters in an attempt to correlate and compare the SBA requirements and usability in security and disaster operations. The discussion was mostly targeted on questions that arise after the identification of a threat, during the monitoring or the escalation of an event and before a prevention or an action plan is formed. The initial plan was to have separate areas of discussion with the Operators, the Providers, and the Firefighters. However, it was discovered that their responses sometimes overlapped, as they all had wide knowledge of operational procedures, even for stages in which they were not involved.

4.3.1 Security Agency Operators

Operators initially explained the operational procedures related to their involvement. When a potential threat is identified, the team of officers responsible for the formation of an action plan, makes a decision of specific procedures that will take place. Decisions are usually based on weather forecasting, the sources available by the authorities on the field, the sources used by the moving population and the scale of the movement. The weather forecasting is available once or twice per day by the local meteorological service. The available sources are confirmed by the operators on the field. The sources used by the moving population are usually confirmed by secret services and operators on the field.

A crucial component is the spatial distribution of resources. Operators are ordered to secure a broad area of interest, often without indication of potential spots that require special attention. In a situation where a cross-border movement is identified, the Operators should be prepared and act with a plan, knowing in advance the number of people in movement to secure efficient number of operators and whether the people in movement are equipped with objects that could become threats, such as weapons or drugs. Unfortunately, this information is usually unavailable, and Operators are asked to act without adequate knowledge of the potential threat.

The lack of a holistic prevention or response plan makes Operators question the credibility of the operations, as the initial event assessment is based on information retrieved the previous days. They also identify that not all the measures have the same effectiveness as the evaluation of the plans, at the aftermath of an incident, is not properly recorded. Hence there is lack of comparison between incidents and the effectiveness of prevention and response plans. Operators expressed the opinion that better decision-making tools with the ranking of options, based on effectiveness and on the results of previous operations and even with the use of existing sources of data, would significantly increase their confidence on the field.

Furthermore, the lack of technical approach is prominent. The lack of operational evaluations and training on different scenarios based on previous evidence, create a gap of technical knowledge. Properly monitored response practices and evidence of performance from previous event could create a new model of operational approached at all levels of decision making.

They also argue that future migration flows are not taken into considerations, thus prevention plans could be sometimes outdated. Operators are concerned with high immigration flows that reach the borders when the authorities are unprepared and therefore are outnumbered in absolute terms. In that case operators could claim unexpected inability to cope with an event and ask for additional help, which will reach the area of interest hours after the request.

Operators claim that the data from SBAs are available at the aftermath of an incident and therefore they are unable to use them while an event escalates. Thus, SBAs that are currently included in operations are limited to satellite imaging with low resolution that are retrieved days after an incident. Hence, SBAs are not available during the formation and execution of operations and therefore do not contribute to real-time decision-making. They usually have a list of fixed operational procedures and best practices, authorised by superior officers in each Agency.

To mitigate the effect of performance failures, additional sources of information could be important. The use of SBAs, not restricted to satellite imaging, but extended to UAS, could provide valuable information, which could lead to prevention actions, hours before an incident occurs. With the introduction of real-time data and with alternative scenarios of incident escalation, the risk assessments would be more reliable and the field operations more targeted and efficient. UAS could assist in the identification of peoples' movement, number of people, equipment used by the moving population and threats that are under the umbrella of cross-border crime. Having knowledge of information regarding the aforementioned characteristics, Operators on the field can form realistic plans with precision and can be more confident for the efficiency of operations.

Although the use of SBAs is undoubtedly an upgrade in operational efficiency, Operators are worried that infrastructures, such as UAS, shall be properly maintained to be available for use at any time. They also express the need for special training for UAS to become valuable assets for the Authorities. When the interviewer asked about the contribution of the private sector in that quest, the Operators expressed a concern about the execution of private contracts. Based on their experience, private contractors deliver the agreed product but then there is inefficient maintenance or prioritization of other customers, against contractual obligations. This issue is based on administrative weaknesses of the Authorities to properly overview private contracts' obligations at all stages of executions. Thus, UAS could be offered as a private sector service, under strict contractual agreements for 24/7 coverage and maintenance and under sufficient supervision for the execution of the contracts.

Operators also claim that the technological advancements come with vulnerability to hostile behaviours, i.e. UAS could be downed or could be malfunctioning. Hence, they should be always ready to use traditional equipment and sources of information to act upon a threatening incident. In that case, the investment should extend to a constellation of UAS with alternative sources that could fill the gap in case one of the vehicles is out of operations.

As technology advancements are commercialised in an unforeseen rate, it is expected that cross-border criminals will be able to use cutting-edge technologies to hide their activities from Authorities. Thus, there is a concern that UAS might be used by traffickers. This is a particularly dangerous scenario where criminals are one step ahead of Authorities. In this situation, traditional use of information won't be adequate to deal with cross-border activity and countermeasures using the same if not more advanced technologies is mandatory for the security of the borders but more importantly for the safety of human lives.

4.3.2 Humanitarian Aid Providers

Providers have no influence on migration monitoring, as they usually operate without access to SBAs. They operate at the aftermath of an event and only to provide support to migrants that are in danger. They are legally allowed to act when migrants arrive at the borders or at the facilities that offer temporary accommodation to third-country nationals. The expected number of people is usually known by the official authorities, which is then communicated to the Providers. The sources required to deal with an incident are first aid supplies, which are typically stored in areas with increased flows of immigrants. Apart from first aid support, Providers can inform larger organizations such as the UNHCR for vulnerable individuals that require special accommodation and treatment. Based on the workload Providers face, they can apply for relevant funding, with financial streams coming from the EU and international organizations. The financial aid is directed to first aid resources and personnel that will operate on the field.

Providers' role is limited to first response aid, and they are extremely careful to avoid any association with traffickers. It has been proven in the past that traffickers or even terrorists mingle with migrants and cross countries without being confronted for their crimes. Providers are very concerned that while an incident escalates and they attempt to save migrants that are in danger, they are unable to identify criminals, who deliberately hide in this chaotic and in some cases life threatening situation.

The most crucial information for Providers is the number of people that require assistance at each incidence. An estimation of the number of people that require help is usually given by the Authorities to Providers. The actual number of people helped in each incident usually is larger than the initial estimation. This gap in information usually has ripple effects to the available first aid resources and personnel present in the field. Thus, Providers continuously request for better monitoring of the flows and additional resources, after the first response is complete. The optimum monitoring of the flows is a responsibility and a legal obligation of the Authorities. The further involvement of humanitarian aid, if there is no immediate life-threatening situation, is illegal and could be considered as support to illegal migration.

The legal limit between humanitarian aid and fostering criminal activities is very specific, especially at sea. Providers can act only in a situation of a sinking boat. In the open sea a GPS would be sufficient to track down a ship and follow it as a precaution. However, when it comes to illegal migration, traffickers use incredibly old and poorly maintained ships with absent GPS receivers. Hence, these are called “ghost boats” as they are untraceable. According to the Providers, this is the worst-case scenario at sea, where Providers are called to act over a sinking boat or even a shipwreck, with the most vulnerable passengers, such as women and children, having less chances to survive.

With respect to SBAs, Providers have no access to satellite imaging, unless Authorities decide to share relevant information. Despite the lack of technology in their operations, Providers acknowledge that the use of commercially available drones, equipped with cameras, IR sensors, night vision and AI software could be a crucial infrastructure for the identification of ghost boats. Although these sensors come at an increased cost, commercially available drones equipped with cameras could be used for real-time frequent scanning of areas, especially across the Mediterranean Sea where ghost boats tend to be used from Africa with a direction towards Europe.

4.3.3 Firefighters

Effective wildfire management is a crucial function for disaster management. The involved Authorities are typically organized into four key divisions: preparedness, emergency and logistics, rehabilitation and reconstruction, and data and information. An integral component of their operations is the Information Management System (IMS), which supports disaster management activities by collecting and centralizing disaster-related information swiftly and accurately.

Fire Agencies consider all fires as potentially serious. Fires under extreme conditions start and spread quickly. The fire burning intensity can dramatically increase when fire fronts meet. The response time of fire fighters is the most crucial aspect of stopping a fire. The best opportunity to stop a fire is immediately after ignition. If the fire is not handled at the very early stages of development, then a direct attack is no longer an option. A direct attack in a fully developed fire front is dangerous for the Firefighters and the impact to the development of the fire front insignificant. When a fire is developed in a wild forest, the only opportunity to control the fire front is during a weather change. Heavy rain or a wind change towards the already burnt area creates optimum conditions for the control of the fire front.

Fire Agencies are in close collaboration with weather forecasting services and therefore they are aware of increased fire risk, a day in advance. A day of increased risk is a day with increased temperature, low humidity, and increased wind. A predictive rule of thumb, known as the 30-30-30 rule, indicates extreme fire risk when the temperature exceeds 30°C, humidity falls below 30%, and wind speed surpasses 30 km/h. The most critical territories are forests with dense plantation. Fire Agencies are also equipped with maps that highlight danger zones, evacuation plans and routes. Fire Agencies can use ground and airborne forces to stop a fire.

Weather forecasts reach Fire Agencies twice per day. If the weather conditions change in the meantime, it is only the ground forces that will realise the change. The ground forces spread across an area of several km and in a formation to be able to evacuate at all times. For the movement of resources on the field, Firefighters require directions from the headquarters, to change formation and positions. One critical issue is the use of communication channels. So far, the two most prominent agencies on the field, civil protection and Firefighters communicate via Tetra Networks. Tetra is useful for immediate communications but should be combined with advances IMS that are frequently updated utilising information form a combination of technologies.

The process of changing an action plan and approving an updated plan requires at least an hour. If the weather forecast, with a potential change of weather conditions reaches the Agency twice per day, then the Agency has the opportunity for altering the distribution of resources after these two times of weather forecasting updates. Firefighters believe that real-time data and an hourly update on weather conditions could be beneficial for the optimum distribution of ground and airborne resources. In that respect, UAS with sensors for weather forecasting, which could target a specific incident and could fly and provide data on an hourly basis, could be beneficial. UAS can also investigate the area in front or behind the fire forefront, to provide useful information for the rescue of humans and animals.

UAS are increasingly used in wildfire management due to their ability to be remotely operated and travel by flight. They provide real-time, accurate data from areas that are otherwise inaccessible, dangerous, or time-consuming for emergency responders to reach. The mobility of UAS allows for rapid and continuous visual monitoring throughout a fire's progression, with a spatial range of up to 9km. Drones collect data in various forms, including GPS locations, images, and video feeds, and can be remotely controlled by humans or automated systems. While individual drones may struggle with dynamic and complex tasks compared to those operated by dedicated pilots, their autonomy enables quick command and organization within a fleet, regardless of its size. Advanced data processing algorithms have the ability to analyze the video feed from UAS, and swiftly detect active wildfires, assessing their intensity, and determining the rate of spread. However, UAS, which are typically equipped with various cameras, such as video, infrared, and imaging, are limited by low-capacity power sources due to structural constraints that prevent the use of heavy, energy-dense batteries. Thus, a constellation of UAS could provide continuous monitoring of an incident, allowing individual drones to land and charge, while the rest of the constellation monitors the incident.

A holistic approach is required for the accurate and timely detection of wildfires. The most useful technology that can identify the initiation of a fire is the use of sensors, spread across a forest area. Sensor nodes, which typically consist of low-power sensors for humidity, temperature, and gases, are crucial for monitoring areas for fire and generating alerts. A wireless sensor network (WSN) is created when such sensor nodes are integrated and can transfer data wirelessly. Every node in the WSN is managed by a microcontroller, which is typically solar operated and backed up by rechargeable batteries to enhance its durability. In the event of a fire, environmental variables like temperature fluctuate greatly from their daily fluctuations in a very short time. For instance, temperature has a gradual increase that does not follow the normal variation patterns. Sophisticated methods have been developed to differentiate between wildfire and non-wildfire situations using, for instance, regression of temperature, humidity, and carbon monoxide data collected by sensors.

Sensoring can be combined with stationary fixed cameras placed in higher latitudes in forests. Fixed camera networks are essential in the identification of wildfires and are composed of complex and multifaceted interconnected cameras that surveil large regions for the first indications of fires. These are useful in offering live streams and are placed in both the developed and the rural regions as fire preventing and predicting gadgets. Equipped with infrared and thermal filters, these cameras enhance their ability to detect fires by identifying heat signatures even in challenging conditions. Satellite access enables cameras to communicate, allowing live broadcast of feeds to a network that notifies directly specified users. Despite their effectiveness, camera networks face common weaknesses in smoke detection and image-based detection, particularly due to the deterioration of image quality at night and the presence of haze. Largely autonomous, these camera networks are positioned farther away from potential fire sites compared to sensor networks. Meanwhile, UAS, equipped with specific features, can provide a broader ISR scope, while minimizing the risk to the ground equipment.

Finaly, satellite technologies, with revisit times of a day, can be particularly useful in the aftermath of a wildfire. Satellite imaging with a spatial resolution of 1m can give insights into the severity of a wildfire by accurately calculating the burned areas. Nowadays, the level of satellite accuracy is unprecedented. The example of the wildfire in Evros in 2023 and the calculation of the damaged territory, would be impossible with ground sources.

5 Analysis from Interview Results

This paragraph presents the results of the interviews conducted with border security Operators, with Humanitarian Aid Providers and with Firefighters, regarding their operational procedures, decision-making processes, and the integration of SBAs in their duties. The insights reveal critical challenges and potential improvements in handling natural disasters and cross-border threats, with respect to resource distribution, and the utilization of SBAs that provide real-time data.

5.1.1 Security Agency Operators

The Operators acknowledged that they face operational challenges that could be improved with the use of SBA that can provide real-time data.

Operators explained how they are involved in the formulation of action plans when threats are identified and how decision making depends on such factors as weather, field sources and scale of movement. Weather information, which is given by local meteorological services at least once or twice a day is greatly helpful in planning and operation. Also, the field information collected by the Operators on the field confirms that accurate information is used in decision making. In addition, data on population movement, confirmed by secret services and operators, helps to assess the scale and direction of migration, which is critical for countering new threats appearing in response to migration at the present stage.

One of the main challenges in border security operations is the distribution of resources in space, since Operators are often forced to secure vast territories without reference points to critical hotspots. This is made worse by the need to prepare for movement across borders where Operators need to know the number of persons in movement and potential threats like weapons or narcotics that are often unknown. As a result, the credibility of operations becomes an issue since operational event assessments are derived from old information and this leads to doubt as to the efficiency and accuracy of the operational strategies.

Interviewees were clear that there was a need to enhance decision-making tools and techniques, and this raised a number of important issues. One of the issues is the absence of adequate documentation and comparison between accidents and response measures that could help assess the efficiency of the current approach. Furthermore, it is quite evident that to rank options based on the results of the previous operations new decision-making tools are required. Tools such as these would greatly improve Operators' confidence in their assessments, thus helping to provide better countermeasures to new threats and improve the general effectiveness of border security operations.

One of the main concerns expressed by Operators is the absence of technical thinking and appropriate training; as a result, Operators have numerous knowledge gaps in this aspect. They pointed out the fact that training on various scenarios based on past evidence was necessary for improving their operational capability. These improvements would help improve Operators' preparation in terms of technical competence for a range of scenarios.

Operators are extremely sensitive to the absence of readiness for high immigration rates, for which they can quickly exhaust all available resources. They pointed to particular concerns, including when border security forces are caught off-guard with large influxes of people. Frequently, high flows arriving at the borders could be without sufficient advance preparation, and, therefore, require more help at that level. However, to such immediate needs, the response is often slow, help comes many hours after the call, which aggravates the situation and the outcomes of the operations. This delay causes a major challenge for effective response and underlines the necessity of improving preparedness and increasing efficiency of the management of high immigration rates.

Interviews revealed that there was a suboptimal adoption of SBAs by the operators due to the following key constraints. Currently, SBAs rely on raw satellite imagery of low definition which is retrieved days after an event has happened and hence not suitable for real time decision making. This long time to obtain operational intelligence greatly limits Operators' capacity to act quickly and decisively in response to new risks. In response, operators suggested the use of UAS to supply data in real-time. The application of UAS could provide important information as to the mobility of people, machinery, and potential hazards, which would improve reaction rates and general effectiveness.

However, operators had concerns regarding the participation of the private sector in the use and management of UAS. One of the issues is ineffective management of maintenance and other priorities than contract customers that can affect the stability of UAS services. In response to this, operators called for proper contractual provisions that would guarantee availability, maintenance, and supervision around the clock. They would be of immense importance in ensuring that UAS are always available and in the best state for use in the security of the borders.

The operators also admitted to the technological risks of such modern equipment like UAS. The vulnerability of UAS to being shot down or develop mechanical problems requires traditional equipment and information back-up. This redundancy is important to ensure that there is always a backup of operational systems in case of technological breakdowns. To this end, operators advised for the acquisition of a swarm of UAS to counter this particular risk. This approach would make certain that there is continuity in the coverage regardless of the state of any one UAS hence the continued efficiency of the border security operation.

There is also a growing worry that criminals are now incorporating higher technologies to enable them avoid identification. Operators stressed that traffickers could use UAS to outcompete Authorities, which underlined the necessity of developing new countermeasures. These counter-measures must integrate the best technologies to be able to address the challenge posed by criminals. The safety of the physical borders and human lives call for the need to be technologically superior, which make the investment in counter measures paramount.

Consequently, the success of the border security operations is dependent on few key elements that include weather information, field information and credible information on the movement of people. However, some of the main issues are still present and they include issues to do with distribution of resources in space as well as issues to do with preparation towards cross-border movement. This poses a challenge to the Operators since this information is often stale and thus the credibility and reliability of the operators is in jeopardy. It is apparent that there is a definite demand for better decision-making resources and assessment techniques to augment the efficacy of contingency measures.

Further, there is no technical training, and a lack of systematic evaluation of past incidents also indicates the need for better training and more monitoring. The under-preparedness for high immigration flows compounds the operational issues besides highlighting the need for quicker and better resource mobilisation. The existing limitations of current SBAs and possible benefits of integrating UAS call for real-time data in enhancing the operational efficiency. However, issues that relate to the private sector and the susceptibility of UAS to certain kinds of technology risks require robust contractual provisions and provision of backup systems. Last but not the least; the increased use of sophisticated technologies by the criminals also necessitates the need for creation of better counter technologies to safeguard the lives of human beings and borders. These strategies need to be constantly reviewed and evolved to help deal with the cross-border risks appropriately.

5.1.2 Humanitarian Aid Providers

Migration crises are well handled by humanitarian aid Providers. However, they are poorly provided with SBAs which considerably restricts their operational impact. Providers are usually established after the migration incidents and are oriented on the help for migrants in the dangerous situation. Their legal authority allows intervention only at the time migrants reach borders or temporary accommodation settings. Although Authorities are supposed to provide the estimated number of migrants, Providers must rely on stored first aid products in high flow areas to handle incidents. They also act as intermediaries for large organizations including the UNHCR for special issues and the vulnerable groups. EU and international bodies' funding applications are dependent with the workload and field needs, hence the support in a way is primarily on response resources and personnel rather than on technology for preparedness.

Providers know that it is possible to contribute to trafficking or terrorism by mistake, as offenders blend with migrants. This is the case because the migration incidents are characterized by chaos and danger which make it difficult to identify criminals. This concern points out to the need to have a clear line of sight on the humanitarian operations without compromising into areas that may be used to support unlawful activities. There is always a challenge of having criminal elements within the migrants, including traffickers and Providers must act quickly to save lives yet they cannot be involved in any way with the trafficking rings.

Quantitative data about the population in need is very important for efficient humanitarian intervention. Authorities provide estimates that are usually lower than realities on the ground, and providers rely on such estimates. This gap stretches available resources and personnel and reveals an ongoing lack of systematic coverage of migrant flows. Providers perpetually campaign for increased scrutiny and more funding to manage these issues effectively. The legal regulation excludes a possibility of additional humanitarian assistance in a situation unless there is an imminent danger to human life; this emphasizes the importance of accurate and verified information from the Authorities.

The legal difference between humanitarian aid and actions that could facilitate unlawful immigration are the most blurred at sea. Providers are only allowed to act when the situation is evident, for example, to save the lives of migrants in a waterless boat. Another challenge is the use of "ghost boats" – un-trackable, old boats used by traffickers. These boats do not have GPS receivers, which in effect, can only be tracked almost close to impossibility until something goes wrong. Such situations are described by the providers as the worst in terms of risk and impact on women and children in particular. As the nature of disaster response involves working within legal frameworks for providing essential assistance, the concepts of immediacy and legal compliance are contextualised in this paper.

To address current challenges, Providers appreciate the need to adopt and implement new technologies to handle their operations. Satellite imaging is usually limited to Authorities, however, commercial off the shelf drones with cameras and infrared, night vision and AI software can greatly improve their capabilities. It is of this technology that would enable tracking and detection of the ghost boats instantly especially in the Mediterranean Sea region. While these technologies are rather expensive, the ability to increase the efficiency of ISR and response time makes this investment rather attractive. The existing shortcoming in the monitoring of immigrant flows might be filled with advanced technologies including Unmanned Aerial Vehicles thus the technological support required to respond to migration crises.

Therefore, Providers are restricted in different ways; they do not have access to the latest monitoring equipment, and the legal framework governing their work is clearly defined. The threats they experience such as helping criminals and the gap between estimated and actual numbers of migrants call for better cooperation and technological compatibility. There is a strong potential for using more advanced monitoring tools, for example, UAS, to significantly improve the timeliness and effectiveness of their assistance while remaining fully compliant with the law. Sustained pressure for improved ISR and resource commitment is still required to close the gap between urgent humanitarian requirements and the multifaceted nature of migration emergencies.

5.1.3 Firefighters

Fire agencies always approach all fires with a view that all may be serious particularly at times where fires can develop and grow quickly in extreme situations. This is because the intensity of a fire rises sharply when fronts combine;

hence, the response times of Firefighters are the most critical in halting fires. The greatest chance for managing a fire is in the initial moments of its ignition. If this time window is not exploited, a direct attack becomes too risky and counterproductive. In wild forest fires, control is only possible during the change in weather conditions such as rain or wind direction to the already burnt areas.

Fire Agencies liaise with weather forecasting services to determine the periods of high fire risks. High temperatures, low RH and high wind velocities are considered the critical conditions, summarized by the 30-30-30 index above 30°C, below 30% RH, greater than 30 km/h. Fire Agencies need maps that show the danger zones, evacuation plans, as well as the evacuation routes. People on the ground and aerial units are deployed to fight fires, and their operations are informed by weather reports provided twice daily, but real-time data is vital for practical application.

The cooperation between civil protection and firefighters is based on information exchange media such as Tetra. Although Tetra can be used for real time talking, it must be linked with other superior IMS for regular change, which requires a blend of technology. It may take at least an hour to update and approve the action plans, which means that it is difficult to respond to the changes in the condition rapidly. Information about the environment and its conditions in real-time and in one-hour intervals can enhance resource allocation and operational efficiency with the help of UAS with sensors.

They have been widely used over the recent past in managing wildfires since they are operated remotely and offer real-time data from areas that may be hard to access or even risky. UAS provide real time ISR with a coverage of up to 9km using GPS, images and videos. Although each of them has a comparatively small power capacity, a system of UAS can guarantee permanent coverage; one UAS lands to charge, while others continue to work. This capability improves the capability to track fire progress and conditions in a dynamic manner.

Wildfire detection is therefore complex and is enhanced by the use of sensor networks as one of the technologies needed for this task. These networks comprise of sensor nodes responsible for measuring physical factors such as temperature, humidity and concentrations of gases and raising alarms in the event of a spike, which is characteristic of fires. Sophisticated processing procedures are used to identify the specific conditions of wildfire or non-wildfire situations through sensing data analysis. Wireless sensor networks on solar and recharged batteries offer long-time functionality and early warning systems.

Sensor networks are supported by stationary camera networks that offer live stream features and initial fire detection. These are installed at vantage points and employ infrared and thermal filter to capture heat emitting objects. Although there are some limitations like smoke detection and image quality in night these networks provide important ISR and early warning if satellite access for live telecast and communication is also available.

Satellite technologies have a major role of evaluating the impact of wildfires. Satellite imaging at one-meter scale proves very effective in giving insights on the intensity of the wildfires and accurately measure the burned extent. The level of clarity incorporated in the satellite images today makes it possible to conduct a detailed assessment of damages that would not be possible through ground information alone.

To sum up, wildfire management involves the use of real-time data, technologies, and interdivisional cooperation to enhance the efficiency of the process. It is important to detect as soon as possible and act immediately; UAS, sensors, and other fixed cameras are essential tools for fire ISR. These technologies integrated with accurate weather forecast and efficient communication system improves the assessment, handling and aftermaths of wildfire occurrences. The results reveal the need for continuous investment in technology and training, as well as sound information management systems for enhancing the effectiveness of wildfire management and preventing the negative effects of these calamities.

5.1.4 Conclusions

This chapter discussed how SBAs, GNSS, and RPAS are vital in improving the EU's security posture. It explained how these technologies assist in maritime security, border protection, and combating of organized crime through provision of real time information, high resolution images and accurate location. The analysis also underlined the need for cooperation between EU agencies, such as Frontex, EMSA and SatCen, to overcome interoperability issues and to enhance the use of technologies. However, the chapter also highlighted the fact that these advancements have made a very strong security architecture of the EU but at the same time called for better legal frameworks and ethical issues to be taken into consideration while using these technologies. In total, it is necessary to continue using innovation together with increased cooperation as the main key to preserving security and stability in the context of new threats.

6 Discussion

Space-based assets have been useful tools for the prevention, monitoring and response to security threats. The EU and its member's states can use these tools for resilience against natural disasters, environmental preservation, and illegal actions taking place at the sea or across the borders and mainland. Technological advancements in ISR, via SBAs, are particularly useful, when dealing with an increased number of incidences or with events that their scale cannot be handled by ground capabilities. For instance, Sentinel-1 has the capability to pass through atmospheric disturbances, such as clouds and rain showers and can identify objects independent of daylight. The visual analysis and observation provide information, with sixty-five percent (65%) of the times representing realistic threats. The algorithms used for this approach are able to calculate the length of an object automatically but are limited to the resolution capacity in comparison with the size for objects.

The images provided by satellites are already used for the development of holistic monitoring systems, taking advantage of key elements from open data. The monitoring systems work supplementary for decision making and actions within legal frameworks that allow the authorities to guarantee regional, national and continental safety. Using these tools, decision makers utilise quality data, with relative low cost and easy access. The applicability of space technologies should be extended to developing countries as most of the threats are developed beyond national borders.

6.1 Summary of interview findings

The interviews highlighted several issues and concerns regarding operations related to migration, cross-border crimes and natural disasters. The following section is devoted to the discussion of the use of SBAs for the critical operational components that were mentioned in the interviews.

6.1.1 Security Agency Operators

Accurate Weather Forecasting:

SBAs can greatly improve the quality of weather forecasting as they include the data from satellites and the atmosphere. These satellites can track weather conditions in the real-time and provide accurate and timely data on temperature, humidity, wind speeds and much more. This information can be utilized to forecast fire perils and plan for other daunting climate situations to enhance the tactical and logistical planning of the operation of border security.

Reliable Field Sources and Verified Data on Population Movements:

With satellite imagery, large human movements within and across borders can be monitored by satellites fitted with enhanced imaging systems. With the help of the optical and infrared sensors with high resolution, SBAs can obtain the real-time information on migration indicating the reliability of the data received from the field sources. This capability guarantees that operators obtain credible and timely information thus increasing the credibility and reliability of operations.

Spatial Distribution of Resources:

In this case, one of the most important issues that border security faces is the problem of spatial distribution of resources. SBAs can offer complete coverage as well as improved ISR of a large area, to find out future hotspots and areas of urgency. A continuous monitoring ability of satellites also enhances identification of optimum tactical locations for deployment of ground and airborne forces to address urgent needs.

Preparation for Cross-Border Movements:

SBAs can enhance preparation for cross-border movements since they can provide constant monitoring and signals of possible events. A satellite can detect the movements of a group of people and follow their movements towards the border more effectively than an airplane, giving the authorities enough time to counteract the action. The early warning system is important to prevent or control large number of migrants and threats.

Outdated Information:

Lack of up-to-date data is one of the greatest challenges facing border security operations. SBAs give raw data and this cuts down the use of reported data that may be outdated. This constant stream of current information means that decision making can be timelier and therefore effective with regards to border security operations.

Decision-Making Tools and Evaluation Methods:

Satellite data when included in decision making tools can significantly improve on the tools. These tools can be more accurate and detailed because they can include real-time satellite imagery and data and should enable operators to better assess response plans. One of the most important applications of satellite data is that it can be analysed with help of complex algorithms that rank options according to their expected efficiency, which helps to make better decision.

Technical Training and Systematic Evaluation:

Hence, the application of SBAs requires technical training in order that the operators can understand the satellite data they are applying. This requirement can stimulate the emergence of improved training curricula related to satellite imagery and data analysis. Moreover, the process of systematic assessment of past events can be enhanced with the help of satellite data stored in the archives, which will make the assessment of previous events more precise.

Unpreparedness for High Immigration Flows:

The monitoring of movement by SBAs can help reduce the lack of preparedness for high numbers of immigrants by providing constant updates of movement patterns. Satellites track and report the presence of large groups of people approaching borders to allow the authorities to allocate the necessary resources and take appropriate action. It also helps border security forces not to be taken by surprise by sudden mass movements.

Limitations and Potential of UAS:

UAS provide real time data and information, but they suffer from power issues and range issues as well. SBAs can do this in a way that UAS cannot, which provides consistent, wide-area ISR that is not restricted by these factors. Satellites are stationary and can survey large areas at once without requiring charging or upkeep in-between their operations.

Private Sector Involvement and Technological Vulnerabilities:

Fears of having the private sector doing the UAS operations such as perpetually experiencing maintenance problems or favouring other clients can be alleviated by use of SBAs. Data from satellites offered by the national or international space agencies can be reliable and trustworthy. Furthermore, satellite systems offer more redundancy and reliability than UAS, which open them to problem areas like being shot down or having a technical issue.

Advanced Technologies Used by Criminals:

The combination of SBAs with other advanced countermeasures will enable authorities to keep pace with criminal use of the latest technologies. Unauthorised UAS and other unlawful activities can be spotted by satellites which give an important information to counter these threats. With the help of the most advanced satellite technologies, the measures that border security needs can be improved to protect borders and people’s lives.

In conclusion, it is argued that incorporating Satellite-Based Assets in the operations of border security can solve many of the issues raised as major challenges among the operators. From weather predictions to data credibility to resource distribution and response strategies SBAs hold the potential for upgrading and fortifying current border security initiatives. This kind of investment and constant improvement of these technologies are crucial to deal with cross border threats in a world that is becoming more hostile.

6.1.2 Humanitarian Aid Providers

Limited Access to Advanced Monitoring Technologies:

Providers work under the conditions of low access to the technologies of monitoring, which hinders them in receiving real-time data and managing emergencies. SBAs can include a complete solution that can have constant and live monitoring. Satellite-based technologies and accurate remote sensing are useful for providers to survey extensive geographical regions and the migratory movements of the population, the environment and risks. They enable better planning and response even in the remote or difficult to get to areas due to the access to updated information.

Strict Legal Boundaries:

Providers are very much constrained by the legal framework that sets down their responsibilities and governs their conduct. SBAs can assist in maintaining providers within these legal requirements because it is a way of collecting important data without violate the restrictions imposed by law. Satellites can be used to track borders and migration without physical contact, thus avoiding entanglement in legal issues that may arise with physical interference. This approach enables providers to capture any relevant information they require but with a view of legal requirements, the delivery of their services will not violate the law.

Risk of Aiding Criminals:

The providers also encounter the difficulty of assisting the wrong people, for instance, traffickers or terrorists who could blend with the migrants. To avert this risk SBAs should ensure that they give precise information on movement of migrants and detect any illegitimate activities. Use of special imaging techniques like infrared and thermal imaging helps in identification of some unusual patterns and movements that would probably be associated with the criminal elements. This data can be used to communicate with authorities so that humanitarian operations are not jeopardized, and adequate security is observed.

Discrepancy between Estimated and Actual Migrant Numbers:

This tends to be a continual problem when it comes to estimated and actual number of migrants that puts a lot of stress on resources and planning. SBAs can give the exact number of migrants within particular regions in real-time, which can help providers make better decisions. Satellites can then play an important role in narrowing the gap between estimates and actual migration flows so that resources can be properly allocated, and effective response measures put in place. This capability is useful in preventing cases by which humanitarian aid is scarce in the regions that require it the most.

Improved Data Sharing and Technological Integration:

SBAs improve the exchange of information and technology integration since they offer a reference point for information integration. Satellite data can be complemented by other methods of monitoring such as UAS and ground sensors to get the overall picture of what is going on. This integration enhances the ability to work together because everyone in the system gets the same real and up-to-date information. Improved data sharing leads to improved collaboration, improved resource distribution and utilization within the context of managing migration crises.

Investments in Advanced Monitoring Tools:

Authorities must therefore direct more resources towards the purchase of enhanced monitoring instruments like SBAs in a bid to enhance the performance of providers. For instance, devices like high resolution cameras, thermal sensors, and other gizmos which are fitted on satellites provide vital data on large parts of the environment, population mobility, and other hazards. These tools help the providers make better decisions and be more ready to address new emerging situations. One of the important benefits that providers receive in return for their investments in SBAs is the enhancement of their operational capacities to respond to the needs of affected populations.

Adherence to Legal Frameworks:

The SBAs ensure that there is compliance with the legal requirements since they are remotely placed and do not impose themselves on the entities being monitored. This reduces the legal vices that are likely to be encountered in a direct intervention to providers to make them adhere to the law. Satellites can acquire the necessary information without violating the legal requirements, so the providers can continue to perform their humanitarian work. This capability is especially valuable in areas that are either politically or legally tender or in dispute, where legal regulation is most demanding.

Continuous Advocacy for Better Monitoring and Resource Allocation:

What is more important is that there is always a need for advocacy to ensure that the monitoring and resource requirements in managing the dynamic aspects of migration crises are well addressed. SBAs offer exactly this data and evidence for this advocacy of enhanced and advanced monitoring technologies to enhance humanitarian operations. As providers demonstrate the potential of satellite data, they can promote the need for better investments in SBAs and other monitoring instruments to increase the effectiveness of humanitarian aid.

In conclusion, incorporating Satellite-Based Assets in the humanitarian aid operations presents a solution to many issues affecting providers. It will thus be important for SBAs to advance monitoring functions, data reporting and sharing, as well as compliance with legal frameworks to enhance the quality of humanitarian interventions. Substantial funding for and support of these technologies are required to meet the dynamic and diverse nature of migration emergencies and deliver humanitarian assistance as rapidly as possible.

6.1.3 Firefighters

Early Detection and Rapid Response:

One of the most significant factors in the effective fighting of wildfires is the early identification of the fire and the subsequent quick response. SBAs can be useful in this regard by supplying uninterrupted high-resolution image and thermal data which identify fires at the initiation stage. Satellites are capable of observing large and hard to access regions where ground-based sensors and UAS cannot reach as soon as fires are spotted and can be followed throughout their development. The combination of satellite data with new technologies like UAS, sensor networks and stationary cameras can provide a comprehensive ISR system that can trigger alarms as well as promptly mobilize firefighting resources.

Integration with UAS, Sensor Networks, and Stationary Cameras:

SBAs add value to the operation of UAS, sensor networks, and static cameras by providing context and plugging gaps in coverage. Whereas UAS can provide real time images and details of a specific area, sensor networks give localised environmental data, satellites can also monitor heat signatures over large areas. This integration ensures a multiple paradigm of wildfire detection and management because satellites can identify fire prone areas while UAS can give more detailed results and ground sensors can confirm the conditions on the ground. It also enhances the appropriate combination of the strengths of the different technologies used in combating wildfires thus improving the efficiency of its management.

Accurate Weather Forecasts:

Weather plays a very vital role in determining fire occurrence and therefore requires a detailed forecast for a particular area for proper planning of firefighting. SBAs further aid this by constantly feeding the atmosphere information which improves the weather models and forecasts. Satellites can capture data on the type of weather, temperature, humidity and wind at the same time, which if analysed can predict the behavior of a wildfire. It enables the authorities to predict shift in fire intensity and direction and, therefore, mobilize resources early enough.

Efficient Communication Systems:

SBAs can improve communication systems through offering a solid data infrastructure that can include different information sources. Satellite communications make it possible that information originating from remote locations, where other wire-line communication systems are either rudimentary or non-existent, is relayed to the coordinating centres. This capability makes it possible to provide relevant information to the ground crews as well as the command stations and hence enable timely and co-ordinate responses. Satcoms systems improve understanding of the surrounding environment as well as coordination during wildfire events.

Continuous Investment in Technology and Training:

Firefighters require constant enhancement, and satellite technology needs consistent investment for better wildfire management. New features like improved imaging resolution, quicker transfer rates and compatibility with other observing systems are however provided by the developments in satellite technology. To fully harness the potential of satellite technologies, training of personnel to use the acquired data for planning and coordination with ground operations must be provided. This way the teams engage in frequent updating and consequently are well equipped with the current tools to enhance accurate prediction of wildfires, monitoring, and response.

Robust Information Management Systems:

Since SBAs generate a large amount of information, effective information management systems are critical to the analysis of such information. These systems can also combine satellite imagery with data from other UAS, sensors on the ground, or fixed cameras to give a full picture of the situation regarding wildfires. Sophisticated methods and analysis of data can enable one to recognize trends, the capability of fire to spread and the extent of the loss. Appropriate information management means that the decision makers acquire the most relevant information to guide the management of wildfires, thus enhancing effective management of the disasters.

Predicting, Responding to, and Recovering from Wildfires:

SBAs are instrumental in all phases of wildfire management: prediction, response, and recovery. During the prediction phase satellites give early warning and risk assessment of heat because they are used to monitor the environmental conditions and heat signals. In response phase, information from satellite plays an important role in the direction of operations, resource management, and protection of people. During the recovery phase, post-fire satellite images can help in estimating the level of burned area severity, mapping of recovery initiatives and in tracking the recovery process. This over-arching capability aligns with a total- fire management perspective.

Mitigating the Impact of Wildfires:

SBAs reduce the effects of wildfires through early detection, efficient response, and adequate recovery in ways that are explained below. This means that early identification and response to fire outbreaks minimizes on the extent of catastrophe. Damage surveys and tracking of relief measures guarantee that all damaged areas are rebuilt to the best of standards. In conclusion, the incorporation of SBAs in the wildfire management systems result in more resilient societies and environment to wildfire disasters.

In conclusion, Satellite-Based Assets is found to be a valuable aid in improving wildfire management throughout all pre-fight, fight, and post-fire phases. Through coordination with UAS, sensor networks and other stationary cameras, SBAs offer ISR and data gathering solutions. Weather forecasting, communication and information management complement the effectiveness of these efforts. To maximize on the opportunities of SBAs there is need to constantly invest in technology and training to maintain effective strategies of combating the effects of these calamities.

6.2 Contribution to knowledge & theoretical frameworks

The increasing frequency and intensity of emergency incidents globally necessitate advanced technologies for effective management. It appears that while satellites can be extremely useful and accurate in the aftermath of an event, UAS such as drones are more efficient during the development of an event. Proof of this argument is the extensive literature analysed in Chapter 2 for drone use in floods and fires, in comparison with the use of satellites. A second proof of this argument is prominent from the results of the interviews that promote the use of immediately effective tools on the field rather than expensive technologies with longer revisit times. The aim of this discussion I to highlight the unique attributes of each SBA and promote further research on a potential technoeconomic comparison supported by a multicriteria analysis.

Both satellites and drones are indispensable tools in fire and flood response, each offering distinct advantages. Satellites provide broad, large-scale monitoring and long-term environmental assessments, while drones deliver high-resolution, real-time data crucial for immediate response and localized assessments. The integration of both technologies, which necessitates an appropriate and interoperable legal framework, can offer a comprehensive approach to managing fire disasters, leveraging the extensive coverage of satellites and the detailed, flexible capabilities of drones. This synergistic use can significantly enhance the effectiveness of fire disaster management, improving both immediate response and long-term recovery efforts.

6.3 Limitations of the thesis

While this thesis provides valuable insights, there are some limitations that present opportunities for future research. One limitation is the relatively small number of interviewed authorities and experts in the field. Although the collected information offers useful perspectives on the necessary tools for field operations, expanding the number of interviews could provide a more comprehensive understanding of the role of SBAs in security work. Including a more diverse range of participants, such as policymakers at the central level, field implementers, and technical experts, could yield additional insights, uncover more challenges, and generate a broader array of recommendations for enhancing SBAs within security frameworks. Future research could benefit from incorporating more interviews to validate and build upon the findings of this thesis.

Qualitative research methodology is used in this thesis to investigate the opportunities and limitations of SBAs in security ISR. Thus, while the method used in this research yields detailed qualitative information on the usage of these instruments, the use of a quantitative approach would serve as a useful supplement to these results. Opportunities for identifying measurable outcomes of the concepts espoused by this thesis are quantitative research studies using field tests and controlled experiments that involve the implementation of the SBAs in operational scenarios for measurable response time, coverage efficiency, and accuracy. These empirical data points would add to the understanding of SBAs' effectiveness in practice and would provide a very strong validation of qualitative findings, thus providing a bridge from the theoretical to the applied.

As more SBAs become integrated into security operations it is necessary to conduct further research into their use in mitigating new threats. The ever-evolving security threats ranging from natural disasters, such as those caused by the current climate change to the ever-emerging conflicts, ensures that the best ways through which SBAs can be optimized for the new uses are constantly under review. Furthermore, as technology progresses it is important to investigate how next generation of satellites and tools can be integrated into SBA framework and security ISR. At the same time, the fact of using SBAs in military and civilian applications raises the issue of these technologies being used for malicious intent. Studies on the risks that SBAs face and the protection of these resources from malicious parties are essential to guaranteeing that these resources are utilized positively, as intended.

This thesis explores the strengths and weaknesses of SBAs. An issue that shall be taken into consideration in future work is the economic feasibility of using SBAs in security ISR. An evaluation of the cost-benefit of procuring, using and maintaining SBAs is therefore a prerequisite to determining the value of the technology. This analysis should also compare these costs with the advantages of using the same such as increased efficiency, shortened response time and increased coverage. Such an economic evaluation, in turn, when used in conjunction with the results of the present thesis, would give a better view of the overall feasibility and viability of integrating SBAs into security operations. Future research could look at this aspect to help policymakers and other stakeholders make better investment decisions.

One more limitation is the following: Question 4 of the questionnaire (“What types of SBAs are or could be useful for security-related applications?”) was provided to respondents—Security Agency Operators, Humanitarian Aid Providers, and Firefighters—with the intent of allowing them to freely mention any aspect of SBAs, including Satellite Communications. Despite its open-ended formulation, the responses predominantly focused on Intelligence, Surveillance, and Reconnaissance capabilities, which aligns with the widespread use of these systems in their daily operations. This finding suggests that the respondents’ familiarity with ISR is greater, likely due to its established application in scenarios such as border monitoring or natural disaster management. Consequently, it was chosen to examine how SATCOM, as a complementary tool, can support and enhance the existing security practices of the EU, taking into account the significant efforts already undertaken.

The EU has demonstrated consistent commitment to leveraging SBAs to strengthen internal security, with programs like Copernicus providing advanced surveillance capabilities, while initiatives such as GovSatCom and IRIS² advance the development of reliable satellite communications. SATCOM offers considerable potential, particularly in situations where terrestrial infrastructure is inadequate, such as during crises or in remote areas. For instance, their ability to ensure continuous communication between field teams and central authorities is essential for effective coordination, as indicated by the firefighters’ views on the need for timely data transmission. The limited mention of SATCOM by respondents reflects that their full integration into operational processes is a domain still evolving gradually, which is consistent with the nature of technological progress and the coordination requirements at the European level.

This analysis underscores that SATCOM represents an area with significant prospects, which can be further harnessed within the framework of the EU’s existing efforts. Particularly for organizations like FRONTEX, tasked with border security, greater recognition and familiarity with SATCOM could enhance their operational effectiveness, ensuring reliable communication in remote or critical zones. Despite technical challenges, such as the need for improved bandwidth or protection against interference, initiatives like IRIS² demonstrate that the EU is methodically addressing these issues.

6.4 Recommendations for future research

As security threats continue to rise due to war, climate changes and other emergent factors, it is important for the EU to ensure that SBAs are incorporated into the security framework. This includes the use of the latest satellite technologies to monitor conflict areas, disaster prone areas and vulnerable infrastructures on a real time basis. policies should support funding for research and development of predictive models using satellite data for improving early warning systems for natural and manmade disasters and crises.

Development of new technical features of SBAs, such as increased spatial resolution, higher bandwidth and better compatibility with other technologies are crucial to enhance their use. The EU should encourage the creation of new generation SBAs for fulfilling certain security requirements such as the high data rate processing and multispectral imaging. Conducting such a process with technical specifications in the Member States would also enhance compatibility and integration into the other parts of the security system.

6.4.1 Technological Recommendations

Regarding monitoring internal security threats, including illegality and migration, a broader use of SBAs should be promoted, paying more attention to real-time observation and information exchange. Thermal and infrared imaging provided by satellite systems can identify abnormalities, including unauthorized activities, while data feeds can monitor migration movements with a high degree of precision. The enhancement of SBA applications in internal security would help authorities to act proactively to existing and potential threats, as well as distribute resources optimally.

Interview feedback reveals that there is a demand for technologies that enhance the use of SBAs in the Earth Observation domain. Some of the recommendations include use of satellite systems with automatic detection systems, integration of SBAs with UAS for local area ISR, and use of easy-to-use data platforms to enhance decision making. Efforts to train personnel in these new technologies as a way of enhancing their applicability should also be pursued to the greatest extent possible.

6.4.2 Policy Recommendations

While the cooperation between authorities and policy recommendations has been discussed, attention should be paid to the development of the coherent strategies that incorporate SBA capabilities as an integral part of nation-wide and EU-wide strategies. More elaborated forms of coordination, financing and data management structures would facilitate the utilization of the SBAs and promote multi-lateral security cooperation among the Member States

A strong unified EU's comprehensive strategy to leverage space capabilities for enhanced security and defence, in the new geopolitical framework of the EU

REARM, could ensure the protection and sustainable use of space assets in an increasingly contested domain. In that context, the development of a threat heat map across the EU and with annual revisions and updates could showcase rising security threats.

An annual classified threat landscape analysis at the EU level could be prepared, based on SBAs and collecting intelligence from Member States to ensure a common understanding of threats. To strengthen the resilience of EU space systems, the establishment of an EU Space Law would provide a consistent framework for security, safety, and sustainability. This initiative would require the sharing of best practices among commercial and public entities. Such a strategy would have as a prerequisite long-term EU autonomous access to space, particularly addressing security and defence needs.

Thus, a priority would be the enhancement of technological sovereignty by reducing strategic dependencies and ensuring the security of supply for space and defence sectors. This implies a strong plan to ensure a secure supply chain for space and defence, by supporting synergies between space and defence sectors and enhancing the skills within the EU defence and space industries.

The existing space threat response mechanism and knowledge acquired, currently used for protecting Galileo, could be expanded to cover all space systems and services in the EU. A unified strategy could have two main directions, one for space domain awareness services and another for a new governmental earth observation service as part of Copernicus. Hence, it would be possible to develop as a Union, space security dialogues with third countries like the United States and enhancing EU-NATO cooperation.

Budgets utilization could be possible from existing programs such as the European Defence Fund, Horizon Europe, and the EU space program. This approach could foster greater synergies between space and defence without changing the governance of these programs. Since the EU owns space assets, it must have access to necessary security information to protect them. A unified strategy shall explore modalities to support an EU response to space threats, ensuring that the EU can effectively protect its space assets. The EU is committed to preventing an arms race in outer space. A unified strategy advocates reducing space threats through norms, rules, and principles, promoting a responsible approach to space security.

The European Union’s strategic approach to implementing SBAs has greatly improved its security architecture, especially on border control, communication and control of ground activities. The results of this thesis reveal the peculiar advantages of using satellite technologies in security operations. The literature review indicated that the use of satellite imagery in border control has enhanced the identification and monitoring of unlawful incidences, showing that SBAs can effectively respond to sophisticated security threats. Furthermore, satellite communication for real-time exchange of data in military operations has brought down response time, due to improved situation awareness and improved cooperation among the Member States. Such enhancements underscore the change that is possible through SBAs of the efficiency and effectiveness of EU security measures.

SBAs have emerged as critical tools in enhancing the European Union's internal security. Their capacity to provide real-time monitoring and high-resolution data enables authorities to respond effectively to various threats, including natural disasters, organized crime, and cyberattacks. By integrating these technologies, the EU can significantly reduce the impact of emergencies while improving decision-making processes.

The EU has strategically embedded SBAs into its Common Security and Defence Policy and established institutions like the EU Satellite Centre. These initiatives underscore the growing recognition of SBAs' importance in addressing internal and external security threats. Geospatial intelligence derived from these technologies supports EU agencies and member states in their efforts to promote stability and operational efficiency. Collaborations with key organizations such as Frontex and the EMSA demonstrate the transformative potential of SBAs in border and maritime ISR. By integrating satellite data into platforms like EUROSUR, the EU has improved its ability to detect and respond to cross-border crimes such as human trafficking and smuggling, enhancing overall situational awareness.

Migration remains a pressing issue for the EU, and SBAs play a pivotal role in addressing the challenges it poses. Satellites provide critical insights into migration patterns, enabling authorities to monitor border crossings and detect irregular movements. By leveraging satellite data, the EU can better manage migration flows, support humanitarian efforts, and ensure the safety and security of those on the move. SBAs also aid in identifying and mitigating risks associated with unauthorized border crossings, such as human trafficking and exploitation, while facilitating coordinated responses across member states to address this complex and evolving challenge.

While SBAs offer advanced spatial resolution and rapid data collection, challenges such as revisit times, latency in data processing, and interoperability issues persist. Addressing these limitations is crucial for maximizing their efficiency, particularly in dynamic and time-sensitive situations such as wildfires or floods.

In disaster management, SBAs play an invaluable role by providing accurate assessments of affected areas, guiding rescue operations, and aiding in resource allocation. Satellites like Sentinel-2 have been instrumental in mapping the impacts of natural disasters, ensuring a more effective response during emergencies.

The synergy between SBAs and unmanned aerial vehicles (UAS) creates a powerful ISR system. While satellites offer extensive coverage, UAS provides localized, high-resolution data, ensuring real-time responsiveness to emergencies and enabling better decision-making in dynamic scenarios.

The use of SBAs also raises ethical and legal concerns, particularly around privacy and data protection. The EU must navigate these challenges by developing robust frameworks that align with its values of liberty and democracy. Ensuring compliance with these principles will support the responsible deployment of SBAs in security operations.

Interviews with professionals in security, humanitarian aid, and firefighting highlight the practical benefits of SBAs. These technologies have proven to be vital in improving field operations, although challenges such as resource limitations, lack of training, and coordination gaps remain. Addressing these issues will further enhance the effectiveness of SBAs.

Emerging technologies, including Very Low Earth Orbit (VLEO) satellites, synthetic aperture radar (SAR), and satellite constellations, are addressing some of the limitations of existing systems. These innovations promise enhanced coverage, improved data accuracy, and faster response times, making them indispensable for tackling evolving security threats.

However, there are some areas in need of more attention even if these innovations have been made. The cost aspect of SBA implementation has not received much attention in literature, despite being an important part of the success of these technologies in the long run. Also, increasing threats, for instance, the possibility of using SBAs for ill intent, require more studies and appropriate protective measures to prevent negative utilization. The general acceptance of SBAs as both commercially available and as having military applications confirms the importance of policies that weigh the advantages of using these technologies with the disadvantages of their employment.

The thesis also reveals the imperatives of sustained expenditure on technology and education. Satellite technologies are not a single purchase, but an ongoing technological development, where upgrading existing infrastructure and integrating new generation capabilities will require constant attention to maintain the EU's position in security operations. Furthermore, any training program for personnel needs to address the issue of preparing them to analyze and apply satellite data. In this manner, the EU should cultivate creativity and flexibility in its approaches to security so that continued changes in its environment will not necessarily render its security plans ineffective.

Also, the further development and increased utilization of SATCOM, to become a more recognizable tool in FRONTEX's activities, could contribute to optimizing responses to threats, complementing the already successful applications of ISR. This study seeks to highlight this complementary value, enhancing the understanding of how SBAs can continue to evolve in support of EU security.

To fully harness the potential of SBAs, the EU must focus on addressing interoperability challenges, fostering international collaborations, and investing in advanced data processing and communication technologies. By doing so, SBAs can continue to play a vital role in improving security, disaster management, and humanitarian aid across the EU, solidifying their position as essential assets in modern governance.

Overall, adoption of SBAs as a part of EU security architecture can be viewed as a positive development in attempt to meet the demands of postmodern security environment. SBAs have been shown to be of immense value in areas such as borders security, disaster management, communication, and resources management among others. The Member States of the EU will continue to invest in technology and training for the development of such technologies to foster security. In this way, the EU can develop an improved system by eliminating the present deficiencies and predicting potential future challenges that will help the EU create a better defensive mechanism to protect its citizens and become a prominent safety pioneer around the world.

7 Conclusions

The thesis examines the capabilities and challenges of Space-Based Assets in the context of civil response and suggests potential future enhancements to Intelligence, Surveillance, and Reconnaissance tools. The integration of SBAs into the European Union's security framework has proven to be a vital step in tackling contemporary security challenges. This thesis seeks to address two key research questions. First, it investigates whether existing SBAs can provide accurate and timely information to the specific authorities tasked with responding in the field. Second, it explores the extent to which interoperability and technological advancements are necessary to further integrate SBAs into civil response operations.

The literature review focused on EU policies relevant to security, where a unified framework of resources, the interoperability of technologies and protocols is attempted across the continent. On that front, there was a special acknowledgement on the role of Frontex and the collaborations with ESMA and SatCen. The governance of the EU's space policy presents complexities, particularly concerning the roles of various international organizations and member states. The ESA and national bodies significantly influence the shaping and execution of EU space initiatives. Additionally, the EU's competence in space-related matters, as delineated in treaties, varies between civil and defence sectors, leading to intricate decision-making processes.

With respect to border security, Frontex stands as the cornerstone of the EU's border security strategy, integrating advanced satellite services from ESMA and SatCen via EUROSUR, aiming to enhance surveillance and threat detection across external borders. By operating as a centralized agency, Frontex ensures that MS benefits from state-of-the-art security technologies, without bearing the prohibitive costs of individual investments, effectively reducing overall expenditure while maximizing efficiency. Furthermore, the agency plays a critical role in safeguarding the interoperability of diverse EU and national security systems, ensuring seamless data exchange and coordination between MS. Its ability to provide real-time intelligence and field-based feedback, through its deployed operators, enhances the responsiveness of border management, allowing authorities to address security threats proactively. Additionally, Frontex contributes to risk assessment, crisis response, and operational coordination, ensuring that the EU remains resilient against evolving migration challenges, transnational crime, and security threats. Moving forward, the continued enhancement of Frontex's technological capabilities and its commitment to international cooperation will be crucial in maintaining the integrity and security of Europe's borders.

Industrial competitiveness is another critical area. Analysts advocate for reforms in the ESA's "geographic return" principle, which allocates funding based on national contributions. This model, while promoting broad participation, may hinder efficiency and innovation. Proposed reforms include establishing an EU space fund to support critical technologies and harmonizing standards to create a unified market for space services, thereby enhancing the global competitiveness of the European space industry.

Furthermore, the literature reviewed specific cases and references related to the use of SBAs in security, such as border control, crime, disaster response and critical infrastructures. From the literature review in was prominent that the use of satellite technologies in ISR systems is continuously increasing, while technological advancements are unprecedented. However, even more important than the technological advancements that provide detailed information, is the timely acquisition of data, the interoperability and compatibility of systems across the continent.

To validate literature outcomes, interviews were conducted with professionals that operate in security posts, with a special focus on migration flows and wildfires. Different Authorities and key professionals that are involved in security operations identify the importance of ISR. However, depending on the nature of operations, it is not satellite technologies per se that could alter the outcome of a situational procedure. For instance, Security Agency Operators urge for real time ISR as they face significant operational challenges, particularly in securing broad areas without specific threat indicators. They rely on weather forecasts, field sources, and migration data for decision-making, but outdated information often undermines their credibility.

Operators emphasized the need for real-time data, improved decision-making tools, and better evaluation methods to enhance response strategies. A lack of technical training and preparation for high immigration flows further complicates operations. Combined with satellite information, the use of UAS could provide real-time insights. When it comes to the use of technological tools, there are concerns about private sector involvement and technological vulnerabilities that highlight the need for strict contractual agreements and redundant systems. Advanced countermeasures are also essential to address criminals using similar technologies.

Humanitarian Aid Providers also stressed the requirement for real time data. They operate under strict legal constraints, focusing on post-migration support with limited access to advanced monitoring technologies. They face challenges in accurately estimating migrant numbers, often straining resources. Providers must also navigate the risk of inadvertently aiding traffickers or terrorists hidden among migrants. At sea, the difficulty of tracking "ghost boats" complicates rescue efforts, particularly for vulnerable groups. Providers lack access of satellite data but recognize the potential of UAS and advanced technologies to improve real-time monitoring and response. However, the high costs related to the acquisition, operation and maintenance of SBAs remain a barrier. Enhanced data sharing and technological integration are critical to bridging the gap between immediate humanitarian needs and the complexities of migration crises.

Aligned with the aforementioned interviewees, Firefighters emphasize the importance of rapid response to wildfires, as early intervention is critical to containment. They rely on weather forecasts and real-time data to anticipate fire risks and coordinate efforts. UAS, sensor networks, and stationary cameras play vital roles in monitoring fires and providing early warnings, especially in inaccessible areas. Satellite imaging provides detailed post-fire assessments, which is important but unavailable when the fire front escalates. Effective wildfire management requires integrating these technologies with robust communication systems and accurate weather updates, highlighting the need for continuous investment in training and advanced tools to mitigate the impact of wildfires.

A notable finding from the interviews with Frontex practitioners and other stakeholders is the predominant focus on the ISR capabilities of SBAs, with minimal reference to Satellite Communications, despite their concerns about the timely delivery of data to end users. This omission suggests that, while existing SBAs provide accurate information, the lack of emphasis on SATCOMs may limit their full potential to enhance real-time data transmission. The integration of SATCOMs, as evidenced by initiatives such as GovSatCom and IRIS², could complement ISR efforts by ensuring reliable communication in remote areas or during crises where terrestrial networks fail. Consequently, future research and EU policies should promote awareness and training on SATCOMs to boost operational efficiency and bridge the gap between data collection and its prompt delivery to relevant authorities.

Following the interview results and aligned with the literature outcomes, this thesis proceeded with recommendations for future policy and research. The recommendations emphasize the need for continuous technological advancements, policy development, and strategic investments to enhance the efficiency and effectiveness of SBAs. By incorporating cutting-edge satellite technologies, improving spatial resolution, and fostering interoperability with other security systems, the EU can significantly improve real-time monitoring and threat detection capabilities. Additionally, the development of predictive models for early warning systems and the integration of SBAs with other emerging technologies such as UAS will further strengthen crisis response and resource allocation. To maximize the benefits of SBAs, investment in personnel training and enhanced data-sharing mechanisms among EU Member States must also be prioritized to ensure optimal utilization and coordination.

Beyond technological advancements, the establishment of a unified policy framework that integrates SBA capabilities into the broader EU security and defence strategy is paramount. Strengthening multilateral security cooperation, fostering partnerships with international organizations, and developing a common EU Space Law will provide a stable foundation for long-term sustainability and security. Additionally, ensuring a secure supply chain and reducing strategic dependencies will reinforce the EU's technological sovereignty. Expanding space threat response mechanisms to cover all EU space systems, as well as leveraging existing funding programs such as the European Defence Fund and Horizon Europe, will further enhance the resilience of space-based security measures. By addressing both technical and policy-related challenges, the EU can reinforce its position as a global leader in security innovation, ensuring a safer and more resilient future for its citizens.

Incorporating advanced technologies and ensuring timely access to detailed information are essential for enhancing security operations within the EU. For professionals in security roles, receiving critical intelligence before an incident escalates is key to effective preparedness and response. The seamless integration of SBAs with ground forces, coupled with continuous user feedback, offers a highly effective and practical approach to strengthening security measures. By strategically combining these technologies with field operations, the EU can significantly enhance real-time data sharing, situational awareness, and operational efficiency. This not only improves response times but also optimizes resource allocation, reducing redundancies and increasing cost-effectiveness.

Finally, incorporating user feedback ensures that SBAs remain adaptable and tailored to the evolving needs of security professionals, enhancing their effectiveness in dynamic and complex scenarios. As the EU continues to refine its security strategies, this integration will play a pivotal role in reinforcing its defence capabilities and maintaining stability across its borders. By embracing technological innovation and fostering collaboration between space-based assets and ground operations, the EU can solidify its position as a global leader in security and defence, ensuring long-term resilience in an increasingly uncertain geopolitical landscape.

Acronyms

AI	Artificial Intelligence
ASAT	Anti-SATellite
ASV	Autonomous Surface Vehicle
AUV	Autonomous Underwater Vehicles
CFSP	Common Foreign and Security Policy
CSDP	Common Security and Defence Policy
EO	Earth Observation
EGNOS	European Geostationary Navigation Overlay Service
ESDP	European Security and Defence Policy
EU	European Union
Fps	frames per second
GAUSS	Galileo-EGNOS as an Asset for UTM Safety and Security
GEOINT	GEOspatial INTelligence
GNSS	Global Navigation Satellite Systems
IOM	International Organization for Migration
IMS	Information Management System
IRIS	Infrastructure for Resilience, Interconnectivity, and Security
IoT	Internet of Things
ISR	Intelligence, Surveillance, and Reconnaissance
LEO	Low Earth Orbit
OGS	Optical Ground Station
QKD	Quantum Key Distribution
SatCen	EU Satellite Centre
SBA	Space-Based Asset
SKR	Secure Key Rates
SNR	Signal-to-Noise Ratio
WSN	Wireless Sensor Network
UAS	Unmanned Aerial Systems
UHF	Ultra High Frequency

UNHCR	United Nations High Commissioner for Refugees
UNODC	United Nations Office on Drugs and Crime
VHF	Very High Frequency

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Appendix: Questionnaire Template

Section 1: Satellite-Based Systems (SBAs)

1. How do you perceive the role of satellite-based systems in improving maritime surveillance and border control in the EU?
2. What specific challenges do you think exist in the real-time processing of data collected from SBAs?
3. How could satellite technologies like Sentinel-2 further enhance the EU's capacity to monitor large-scale security threats, such as wildfires or migration patterns?

Section 2: Operations

4. Based on your experience in the field, what types of SBAs are or could be useful for security-related applications?
5. In your opinion, how effective is the Galileo system in addressing potential threats and ensuring security?
6. What improvements would you suggest for integrating SBAs with other technologies to support your work in the field of operations?

Section 3: Remotely Piloted Aircraft Systems (RPAS)

7. How do you think RPAS, such as drones, contribute to enhancing maritime surveillance and real-time data collection?
8. What are the main operational challenges associated with RPAS, and how could they be mitigated?
9. In what ways could RPAS be further integrated into the EU's existing security framework to increase their effectiveness?

Section 4: EU Cooperation and Partnerships

10. How would you assess the role of agencies like EMSA and SatCen in supporting EU security initiatives through partnerships and technological collaboration?
11. What opportunities do you see for enhancing cooperation between EU Member States to address interoperability issues in security systems?
12. How can the EU's internal security strategies be adapted to leverage advanced technologies more effectively in the future?

Section 5: General Reflections

13. What do you believe are the key technological advancements needed to address emerging security threats within the EU?
14. How can regulatory frameworks be improved to better facilitate the integration and deployment of advanced security technologies?
15. What are your recommendations for future research or initiatives to strengthen the EU's security capabilities using advanced technologies?