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SATELLITE SYSTEMS AS AN ADVANCEMENT OF SMART BORDERS IN EUROPEAN UNION BORDER MANAGEMENT

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Abstract
The current situation of a multiplicity of crises at the EU's external borders directly affects the surveillance of the Union's borders and its internal security. This requires the use of new and increasingly advanced technologies, which are framed by the idea of Smart Borders. Progressive crises require that 'traditional' methods of protecting the EU's borders are constantly supplemented and upgraded with new technologies to ensure the security of the Schengen/Union area. One of the most important in this field is the use of satellite systems for better border management. EU agencies, the Copernicus programme and other components of the European Union Space Programme serve to strengthen border management through geospatial intelligence and imagery of the situation at borders and in pre-border areas. Of particular relevance in this respect is the EUROSUR Fusion Services referred to as a 'system of systems', which integrates information from satellites, radar, drones, and other sources to enable more effective threat prevention at the EU's external borders. The aim of the article is to analyse and evaluate the utility of satellite systems in EU integrated border management (EU IBM) and to develop the Smart Borders concept with the latest satellite technologies to ensure EU security now and in the face of future challenges. Ultimately, it is pointed out that space technologies are becoming an enhancement, adding a new dimension to EU security. This leads to the creation of Future Smart Borders encompassing the support of EU IBM through evolving satellite systems.

Keywords
Smart Borders, Copernicus, satellite systems, EUROSUR, EU IBM

Introduction

The European Union is currently dealing with a number of crises that pose problems for the security of the 'area without borders'. The control of the external borders of the European Union is becoming increasingly challenging and requires solutions to be found that will significantly increase the effectiveness of the responses to current and future

threats. The multiplication of crises requires that the 'traditional' methods of EU border surveillance are continuously complemented and upgraded with new technologies to ensure Schengen/Union security. One of the most important developments in this area is the use of satellite systems for border management, and thus the idea of Smart Borders requires the extension of advanced technologies supporting border management not only from the ground and air, but also from space.

Satellite systems are a key component of the new Integrated Border Management (EU IBM), providing the capability to monitor land, sea and air borders in real time. EU agencies such as Frontex make use of Copernicus and other components of the European Union's space programme to provide geospatial data and imagery for situational awareness in border security. Of particular relevance is EUROSUR, which is described as a 'system of systems'. It integrates information from satellites, radar, drones, and other sources to enable more effective threat prevention at the EU's external borders. However, there is still a research gap in describing this development. For the purpose of this article, the broad definition of Smart Borders has been adopted to cover all systems, including satellite systems, in external border management.

The aim of this article is to analyse and evaluate the utility of satellite systems in integrated EU border management and to develop the idea of Smart Borders with the advantage of the latest satellite technologies so that the security of the EU can be ensured now and in the face of future challenges. This paper uses an analytical approach based on the main research methods, mainly doctrinal and socio-legal, including analysis of EU documents, legislative acts, and literature. This was complemented by an overview of the strategies of the Union agencies and new tools developing EU satellite systems, as well as an analysis of satellite data acquisition in border management. Consequently, research questions were posed on the importance of satellite systems in the context of the Smart Borders concept, and how their use contributes to the effectiveness of the integrated border management of the European Union. The main hypothesis of the article is that the integration of satellite systems into Smart Borders significantly improves the effectiveness of EU IBM and this process is the answer to the future challenges. Moreover the use of new satellite tools like HAPS or Copernicus Digital Twins will lead to improved threat prevention and effectiveness of EU border management.

The Smart Borders concept towards satellite systems

The Smart Borders idea is described as the future of integrated EU border management (EU IBM), which provides a response to contemporary challenges. The EU has a number of surveillance technologies programmed to patrol its maritime, land, and air borders. Most importantly, large-scale IT systems are centralised to form Europe's "smart borders", the most advanced border system in the world, which governs the Schengen area (Andreou, 2023, p. 8). It is certain that EU IBM's focus extends beyond legal solutions and has since shifted 'to an almost exclusive focus on systems of collection, exchange, and analysis of information, that is, to its "smart border" components' (Jeandesboz, 2016, p. 301). As a result, Smart Borders is becoming a key component of integrated border management, and in response to current and future challenges, it requires support in acquiring threat information not only from land, sea, and air, but also from space. This corresponds to Rumford's classic concept, which recognised the changing spatiality of politics in the de-

velopment of supranational governance of the EU. It means that border processes had achieved 'spatiality beyond territoriality' and that the full meaning of borders could not be exhausted by 'lines on a map' (Rumford, 2006, p. 156, 160). As nowadays this is a very dynamic field, it is difficult to define it unambiguously and continuously. However, there is no doubt that it is no longer sufficient to have individual advanced technologies, but that they need to be integrated into complex systems of which satellite technologies are becoming an essential component.

Consequently, in order to develop the idea of Smart Borders in border management, it will be reasonable to use the concept of systems encompassing increasingly high-technology surveillance instruments at maritime, land, and air borders as well as all satellite observation technologies and programmes. This should be understood in a broader sense than just acquiring information from the ground or from satellites. Integrated border management, especially in crisis situations, becomes possible with the rapid and efficient exchange of information received from all available sources that are able to interact in the area of imaging/imaging intelligence (imagery intelligence) from land (e.g., radar stations), sea (e.g., sonar), air (e.g., unmanned vessels), and space (e.g., satellites). As a result, this complex system allows increasingly intelligent detection of threats at borders with the support of the EU's main satellite programmes: Galileo, the European satellite navigation system, and Copernicus, the European earth observation system.

Smart Borders solutions are increasingly being used to improve borders and migration management thanks to new technologies, not only in the EU. Unmanned aerial vehicles are often used to monitor migrants in both the US and the EU. Big data analytics are used to monitor migrants approaching the border. Although methods of border security and management vary, many are increasingly being used to prevent migratory movements. Real-time data is collected from migrants by various Smart Borders and virtual wall solutions, such as satellites, drones, and sensors (Korkmaz, 2020). For a long time, the US has promoted the idea of a virtual wall: an ocean-to-ocean network of drones, sensors, and other technologies that could detect illegal border crossings. Proponents argue that such a system would be particularly useful in remote and unmonitored areas between ports of entry. This idea has received support from both major US political parties, largely because of the belief that it would be more effective, less expensive, and less disruptive than physical barriers (Tyler, 2022). Smart Borders, also recognised as technological borders (Val Garijo, 2020, p. 138), is what the European Union refers to describe the deployment of new solutions to regulate increased cross-border migration flows while applying safety standards. Increasingly, the EU's borders are being watched and monitored by drones, satellite imagery, and infrared cameras. The EU has significantly expanded the mandate of the relevant EU border management agencies, in particular the European Border and Coast Guard Agency (EBCGA/Frontex), encouraged by the rapid development of digital technologies and driven by security considerations as a result of the migration crises (Gandhi, 2024, p. 2). Moreover, using new technologies as a response to current challenges and threats is based on a preventive approach that promotes the use of the latest technology with various applications to border management, such as biometrics, databases, satellites, sensors, and drones (Val Garijo, 2020, p. 137). It is now impossible to imagine planning, preparing, and conducting border security emergency response without the use of imagery intelligence and geospatial reconnaissance (Jiang & Yao, 2010, pp. 3–5). Imagery intelligence enables the acquisition and processing of data using imaging technologies and de-

vices, and such devices can be located on land, sea, air, and space. Geospatial intelligence involves 'the use and analysis of imagery and geospatial information to describe, assess, and visualise physical and geographical features that speak to activities on the ground' (Liedel & Serafin, 2011, pp. 29–30). The first element of the geospatial intelligence cycle is the acquisition of data using optical sensors and radar systems installed on surveillance satellites placed in orbits around the Earth (Gruszczak, 2014, pp. 96–97). The majority are commercial satellites; there are currently more than four thousand active satellites, according to Orbiting Now.

Smart Borders in the strict and broad sense

For the purposes of this article, it is worth considering the strict and broad definition of Smart Borders. Smart Borders in the strict sense include the so-called Smart Borders Package. The Smart Borders Package is a set of new large-scale systems developed by the European Commission, consisting of the Entry/Exit System (EES), the European Travel Information and Authorisation System (ETIAS) and amendments to the Schengen Border Code, aimed at improving the management of the EU's external borders by facilitating border crossing for pre-vetted frequent travellers from third countries, while at the same time combating irregular migration and improving internal security by enhancing the identification of persons at the EU/Schengen external borders and detecting overstayers on EU territory. The Smart Borders Package is a great example of the essential role of digital technologies in the EU IBM strategy, as a nexus between migration and security, or as a comprehensive toolbox for collecting, processing, and sharing information between national authorities and other stakeholders. The Smart Borders Package has been officially heralded as the 'border of the future'.

In the broad sense, Smart Borders is an extension of the large-scale systems with the reformed Schengen Border Code and the evolving Frontex Agency and EUROSUR system, enriching the exchange of information with the use of satellite systems. The idea of Smart Borders is supported by a combination of satellite, radar, and imaging technologies, which all help EU border authorities to monitor levels and changes in migration patterns. Broadly understood, the concept of Smart Borders is based not only on the exchange of data on border crossers, but also on the exchange of images of the situation both at the external borders and in pre-border areas. This will make it possible to ensure the security of the 'area without borders' before threats occur at the borders and to take preventive measures by exchanging data from EUROSUR, Copernicus, and other satellite observation tools. Satellite systems are a further development of Smart Borders in the European Union's integrated border management or even the future EU IBM.

Copernicus and its supporting services – the main EU satellite systems for border management

The European Union has increasingly integrated space-based systems into its security and defence frameworks, particularly in response to migration crises. It brings to the surface the increasing relevance of space for security in Europe. Traditionally, 'space and security' has been defined in military terms. The concept of 'security from space' includes the contribution of space systems to achieving security on Earth in a broader sense, especially

in the context of border control and migration. Several key determinants influence space security, including: space support to terrestrial operations, the space environment, Space Situational Awareness (SSA), early warning systems, policies and legislation and civil-military synergies. The EU's space policy has undergone a paradigm shift, integrating defence and security requirements into its strategic objectives (Schrogl et al., 2025, p. 8).

There are two original flagship EU space programmes: Copernicus (formerly the Global Monitoring for Environment and Security, GMES) and Galileo. Nowadays, Copernicus is an Earth observation programme and Galileo is a global navigation satellite system. Galileo provides precise global positioning services similar to GPS, even more precise than GPS, to improve navigation, transport, and emergency response. The Galileo SAR/Return Link Service (RLS) offers fast location positioning and includes a new feature that informs the user that their distress alert has been received and located. The Galileo Open Service, which is part of telematics solutions, for example, supports drone navigation for rapid mapping, tracks device location history to uncover smuggling routes, and gathers crowdsourced location data to complement Earth observation data. The EU Space Programme, comprising Copernicus, Galileo, GOVSATCOM, and EGNOS, and their synergies, addresses the sustainable challenges facing an 8 billion people world today.

Copernicus, as the EU's Earth Observation Programme, provides high-resolution imagery and data on environmental and security-related issues. The shift towards security-oriented applications is further evidenced by the incorporation of combined civil-military user requirements in Space Situational Awareness (SSA) frameworks and the adoption of the Governmental Satellite Communications (GOVSATCOM) programme by the Political and Security Committee (PSC) in 2017. The European Commission is addressing the strengthening of the security dimension of the Galileo and Copernicus programmes in the interests of the EU security. Today, security services are put in place through the European Border and Coast Guard Agency (Frontex) for border surveillance and through the European Maritime Safety Agency (EMSA) for maritime surveillance. From the technology perspective, the European Commission is foreseeing the development of very high-resolution imagery via satellites. The European Commission is working with the European Space Agency (ESA) and the European Union Satellite Centre (SatCen) on operational services in response to security and defence challenges with drones and satellites (Papadimitriou et al., 2019, pp. 183–191).

Satellites play an important role in tracking migration flows and provide data to feed early warning systems that can alert in advance of the onset of a trigger event. Concerning the smuggling of migrants, Global Navigation Satellite System (GNSS) data can be used for tracking location and device history to uncover smuggling routes. The European Global Navigation Satellite System (EGNSS) comprises the Global Satellite Navigation System established under the Galileo programme and the European Geostationary Overlay Service (EGNOS). Moreover, it is possible to use optical and radar satellite technology to locate vessels suspected to be engaged in people smuggling that often put the lives of migrants in danger. Satellite data from Copernicus and Galileo plays a crucial role in addressing migration challenges. EGNSS and Copernicus support national, international, and private organisations in delivering humanitarian responses on land and at sea. Additionally, Copernicus data aids in intelligence gathering to assess the effectiveness of humanitarian efforts, particularly in migration crises triggered, for example, by natural disasters. The Copernicus Sentinel satellites, possibly combined with very high-resolution

data, provide radar and optical data that can identify and monitor migration routes and enable informal settlements mapping as well as border mapping and management. In the face of migration phenomena and humanitarian crises, Copernicus satellites and in situ data allow the assessing of the expected impact of those phenomena and support preparedness-related activities, for example, by pre-positioning emergency equipment and solutions or by implementing preparatory measures (United Nations, 2023, pp. 65–66).

Copernicus role in EU border surveillance

Under the umbrella of the Copernicus Security Services (CSS), there is the Copernicus Border Surveillance Service (CBSS), as the border surveillance component which supports border management authorities in their efforts to assess risk and detect irregular migration and cross-border crime. The CSS is a dedicated service to deliver information that helps the European Union improve crisis prevention, preparedness, and response, and to face security-related challenges in the areas of maritime surveillance, border surveillance, and support to European Union external action. The European Commission has entrusted EMSA, Frontex, and EU SatCen with the operation of the different components of the CSS. The Copernicus Maritime Surveillance (CMS) component supports coast guards in detecting, identifying, and monitoring suspicious vessels linked to trafficking and smuggling. GOVSATCOM provides an enhancement to Copernicus and EGNSS by facilitating refugee camp management, asylum operations, and border surveillance. Additionally, GOVSATCOM ensures secure communication among relevant operational actors involved in the operation or processes. GOVSATCOM is used as a common communication channel for, among other things, land border surveillance (e.g., trafficking vehicles), pre-frontier intelligence (e.g., illegal routes), and sea border surveillance (e.g., trafficking boats) (United Nations, 2023, pp. 65–66).

A key role in developing EU satellite systems is played by the aforementioned SatCen, which engages in collaborative efforts with other EU agencies to use satellite data for more efficient border management. In collaboration with the European Defence Agency (EDA), the Geospatial Information to Support Decision Making in Operations (GISMO) project was launched in 2014 to integrate geo-information data and create a holistic operational picture in support of the EU security policy. Thanks to GISMO, a GeoHub application demonstrator was used during the migration crisis in the EUNAVFOR Med Sophia operation to combat human smuggling, support border guards, and stabilise the Mediterranean. GeoHub provides real-time access to situational data through an intuitive interface, secure transmission, and advanced data processing. Recognition and surveillance of illegal migration and smuggling routes is crucial. The activities of SatCen show how the integration of satellite data and aerial Earth observation enhances the ability to detect and warn of threats and sources of risk. Similarly, the evolution of the geo-information component of Frontex activities underlines the dynamic growth in demand for geospatial intelligence products in the context of external border protection and migration crisis management in Europe (Gruszczak, 2019, pp. 301–302).

The objective of the Copernicus system, as implemented by ESA and SatCen, is to build, launch and use for Earth observation satellites working exclusively for the EU through the Sentinel series of satellites equipped with instrumentation to continuously observe the surface of land and sea, mainly for the detection of environmental hazards and human

safety and crisis response. Sentinel uses AI for observational purposes and the latest Sentinel-6 will provide altimetry data for 90% of the world's ocean surface. Sentinel-6 is a joint mission between the space agencies of Europe and the US (ESA and NASA). Launched in 2020, the Sentinel-6A instrument is expected to operate for 5.5 years, later to be replaced by its twin satellite Sentinel-6B, which should hit orbit in the second half of 2025. Ocean level measurements help to obtain more detailed data on the coastal zone, so important for the protection of maritime borders (Królikowski, 2020).

In addition, SatCen uses the entire spectrum of geo-information analysis methods, aiming to best align intelligence products with the needs of EU external border management coordinated by Frontex. Since the height of the migration crisis, it is that Agency that has received the most SatCen products among EU actors, and this is due to the increasing demand from Frontex for satellite and aerial imagery of the external borders of EU Member States and border areas of increased migration flows, mainly in the Mediterranean and the Balkans., With appropriate software and real-time data transmission, SatCen and Frontex working together as part of the Copernicus programme, are able to create situational pictures as interactive, multi-layered maps, and to track objects in order to detect various forms of goods and human smuggling. This is done using all forms of imagery reconnaissance and geospatial intelligence available within Copernicus with the support of EU agencies (Gruszczak, 2019, pp. 304–307).

The increasing use of satellite systems in border protection is confirmed not only by qualitative analysis, but also by quantitative data from Frontex, which reports that there is a growing demand for satellite data. The Agency currently provides 17 different Copernicus imaging products, and we are seeing an increase in demand for these products year on year. This is, of course, related to the geopolitical situation and what is currently happening at the borders. "In the first six months of 2024 alone, there were nearly 500 requests for Copernicus products from member states concerning the situation at the borders," says Marta Krywanis, senior research officer at the European Border and Coast Guard Agency. She also emphasises that: "Satellite data is very useful as baseline data, but we should think about what else it can be integrated with to make the picture of the situation at the borders even more accurate, delivered even faster, so that the response at the borders is quicker. I am talking here about the use of, among other things, unmanned aerial vehicles and ground sensors. It is only this integration of different technologies that gives us the information we need during operations to protect the European Union's external borders" (Leśniewski, 2024).

EUROSUR – Smart Borders – Smart Space Data

The European Border Surveillance System (EUROSUR) is part of the implementation of the Smart Borders concept. The establishment and development of EUROSUR follows the Schengen reforms (extension of the mandate of Frontex). It has been operational since December 2013 and has since become a key asset for Frontex to manage Europe's external borders. The EUROSUR is a framework for information exchange and cooperation between Member States and Frontex to improve situational awareness and increase reaction capability at the external borders by creating situational pictures (EUROSUR, 2016). The EUROSUR system provides for the use of satellite imagery to monitor third country maritime areas, pre-frontier areas, as well as to track vessels on the high seas. It allows for the

exchange of border-related data in real time with the aim of improving the overall control of the EU's external borders. Data from EUROSUR provides situational awareness at national and EU level and could include surveillance of small vessels close to sea borders, intelligence reports on migration routes, and information on other incidents at the EU's external borders. EUROSUR is the most important EU system in border management using satellite imagery.

Developed independently of other EU Smart Borders initiatives, EUROSUR extends surveillance from borders to migrant departure and transit points, similar to systems like ETIAS and EES, though it focuses on unauthorised migration rather than legal travellers. Unlike EES or ETIAS, EUROSUR does not primarily collect personal data but uses satellite and other surveillance tools for general area monitoring. However, as satellites do not enable specific and targeted surveillance but create a general image of an area, it can be assumed that the common application of surveillance tools constitutes general surveillance of the area around the EU external borders (Ghandi, 2024). The system uses coastal radar, satellite tracking, drones, and autonomous targeting to detect vessels approaching the EU. While initially aimed at border control, EUROSUR may be expanded into broader applications, including maritime security, law enforcement and defence, marking it as the EU's most ambitious surveillance system in terms of geography, technology, and interoperability (Bigo et al., 2012, pp. 37–38).

The European Border Surveillance System aims to improve situational awareness and increase the capacity to respond to incidents occurring at land and sea borders. Furthermore, the overarching goal is to protect the safety and lives of incoming migrants. The main tasks of EUROSUR are to monitor, track, identify, and intercept persons entering the EU illegally and to take preventive measures against this phenomenon. Each Member State, via its National Coordination Centre (NCC), maintains and then communicates to its superior authorities, a national situational picture based on the input from its monitoring. The Frontex Agency obtains information from all states and, on this basis, creates a European situational picture, which incorporates information on the situation at the European borders and in border areas. The functioning of EUROSUR enables Member States to quickly share information in order to arrange for the necessary cooperation and to jointly respond to current events. Satellite imagery is among the main tools used to monitor and identify threats at land and sea borders. As part of its EUROSUR activities, Frontex finances the operation of information systems to facilitate information sharing and cooperation with other bodies, including the European Union Satellite Centre, in order to make optimum use of EU-wide resources and information systems. As part of the Frontex services, programmes related to border security harness both radar and optical data feed from the Sentinel satellites to enable persistent area analysis and monitoring, and collect information during the day and night and through all weather conditions, and the data so obtained is often utilised to create and update reference maps used to determine, for example, potential routes of illegal crossing of the EU land borders. Satellite imagery is used in border monitoring and is the first step in verifying events occurring in threatened areas. When a potential threat is detected, the information derived from satellite data feeds is validated against aerial data (Jaskuła- et al., 2020, pp. 371–372). All of the above system links claim to be SMART SPACE DATA, which develops the concept of Smart Borders.

Frontex and Copernicus cooperation – EUROSUR Fusion Services

The EUROSUR system is seamlessly integrated with the EUROSUR Fusion Services (EFS), a set of services introduced in 2017 and provided centrally by Frontex in cooperation with EMSA and SatCen and including the provision of Copernicus security services. Based on satellite imagery supplemented by information from other sources directly integrated into EFS, Frontex creates the European situational picture and the common pre-frontier intelligence picture, focusing on areas beyond the Schengen area and the EU borders. These two specific pictures contain information on current events at the EU borders and operational activities and analysis, and are shared with Member States, thus allowing continuous monitoring of the EU borders. These services include automated vessel tracking and detection capabilities, software capabilities for predicting vessel positions or accurate weather and oceanographic forecasts. The provision of EUROSUR Fusion Services by EUROSUR will allow Member States to further improve their situational awareness, facilitate their access to state-of-the-art technologies and help reduce duplication of effort and costs (Diaz, 2021).

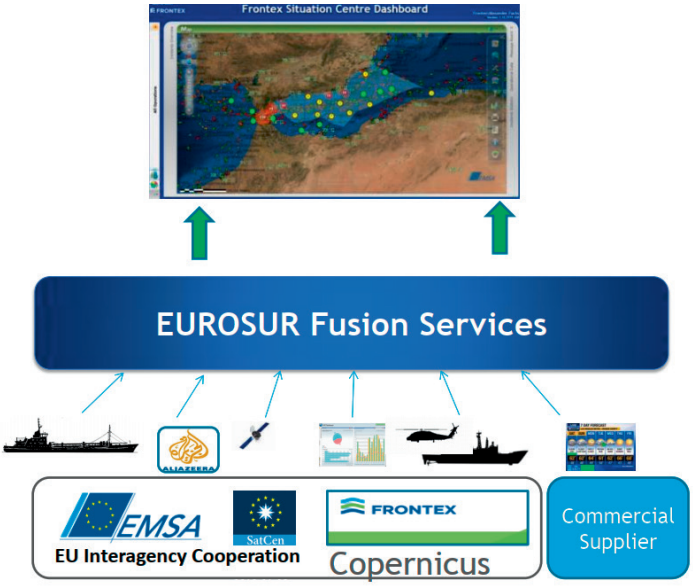
The EUROSUR Fusion Services, known as a 'system of systems' is a system where Frontex shares with Member States information collected by satellites and other surveillance tools, such as those used by EMSA and SatCen. The cost of space-based surveillance services and other platforms provided by the EUROSUR Fusion Services could not be met by any Member State on its own. These services will allow each Member State to access advanced technologies, avoid duplication and reduce costs.

The EUROSUR Fusion Services (EFS) support EUROSUR in fulfilling its core tasks of ensuring situational awareness and response capability at the external borders of the EU Member States by providing surveillance and tracking data to establish a European situational picture and a common pre-frontier intelligence picture. EFS also include a number of multi-domain functional services provided to the EU by Member States and non-EU Schengen States. Products are made available to recipients by fusing data and information provided by Frontex and relevant EU agencies, such as SatCen or EMSA, and commercial partners. Certain examples of practical applications of these services illustrate the increasing importance of accurate situational awareness in the Mediterranean for EU operational activities, especially since the outbreak of the migration crisis (Gruszczak, 2022, pp. 138–139). The EUROSUR Fusion Services structure is presented on figure 1.

EUROSUR Fusion Services provide the Member States and Frontex with value-added information services related to EU IBM. EUROSUR Fusion Services are likely to be fully deployed in 2020–2027. Copernicus data allows the Agency to enhance its product portfolio, systems, and technologies based on Earth observation, enriched with other data sources, and adapt them to the end users' needs. The transformation of the Copernicus Border Surveillance Service (CBSS) fits with the general vision of Frontex becoming even more data, product, and customer centric, together with a joint approach. Thus, Frontex provides new CBSS products, such as reports and maps, and cartographic, digital, and interactive products. The Copernicus Security Services continuously deploys ready-to-use technologies (data, services, algorithms, processing capacities and capabilities, etc.), which immediately enhance current product portfolios. Consequently, Frontex is actively participating in, and contributing to, the development of strategic research priorities in Copernicus, providing information such as end users' feedback on their needs, lessons

learnt during operations, and research on the latest technology that can improve integrated border management (Frontex. Copernicus, 2025).

Figure 1. The EUROSUR Fusion Services structure



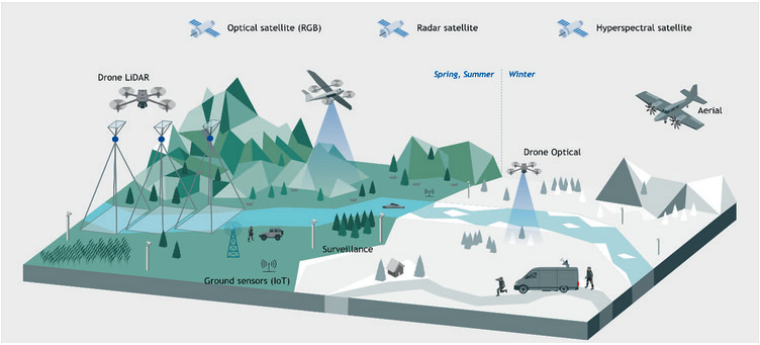
Source: Malinowski, P. (2018). *Copernicus and EU Border Management*. https://www.d-copernicus.de/fileadmin/Content/pdf/Forum_2018/003_Copernicus_and_EU_border_management_PPT_Berlin.pdf

Copernicus Digital Twins for smarter border management

The latest project that illustrates the idea of Smart Borders in its broad sense is Copernicus Digital Twins. Due to a combination of geopolitical pressures, political complexities, and operational difficulties, the control of the EU's external borders is facing several major challenges. In order to ensure that the CBSS is able to meet these and future challenges, Frontex is launching a new competition aimed at improving the service to better support the European Border and Coast Guard community, so that EUROSUR and Copernicus services can improve border security and explore how to leverage digital twin models to enhance border surveillance capabilities.

A digital twin model of the EU's external borders will provide a realistic and flexible platform for testing and simulations. By replicating real-world conditions, it will allow officials to simulate specific scenarios, such as environmental hazards damaging border infrastructure or criminals attempting to cross illegally, and plan effective responses. These simulations enable better allocation of resources and improve preparedness for real-life situations. Another key strength of digital twins is their ability to integrate diverse geospatial data, such as Digital Surface Models (DSM) and high-resolution hydrological information. Digital twins provide insights to improve border surveillance strategies and optimise the deployment of surveillance and monitoring equipment under different scenarios by combining these data into dynamic, multi-dimensional representations that simulate real-world conditions and assess border permeability. Below is an infographic showing how surveillance technologies, including drones, satellites, ground sensors, and aerial vehicles, monitor landscapes across the seasons.

Figure 2. A visual representation of a digital twin of a border region.



Source: Copernicus (2025, January 6). *Copernicus digital twins*. https://www.copernicus.eu/en/news/news/observer-driving-innovation-border-surveillance-copernicus-digital-twins

To develop the capabilities of CBSS and improve security monitoring, emergency threat management and operational planning, Frontex is launching a contest to develop digital twin solutions for EU external border areas. In this contest, participants are tasked with developing Copernicus-based digital twin solutions which provide virtual representations of EU external border areas. These models will support the European Border and Coast Guard community by enabling scenario simulations for operational exercises and technical equipment deployment planning. Participants are invited to propose innovative solutions which improve the capabilities of the current CBSS (Copernicus, 2025). It is connected with the theory of modulation of borders, which is currently digital modulation. Originally, there is a modulation in the way that a political-administrative system of the EU, through its programme renders the border controls of its member and its neighbouring states into calculable, comparable data and makes them subject to continuous adjustment (Walters, 2006, p. 201). Currently, since June 2025, Romania is hosting an important stage of the competition about Copernicus-based digital twin solutions, in order to simulate complex operational scenarios relevant to integrated border management. This digital modulation is designed to become an essential tool for tactical and strategic decisions in the protection of the EU borders. Frontex, with the support of the Romanian Border Police, has provided a representative area of the external border, on the basis of which the participating teams (from Romania, Poland and Spain) will test their ability to build accurate and functional digital models. Unmanned aerial systems (UAS), satellite data, and other sensors – all are integrated into the systems developed by the competitors (Digital Border, 2025). The winner in first place was the Institute of Geodesy and Cartography of Poland.

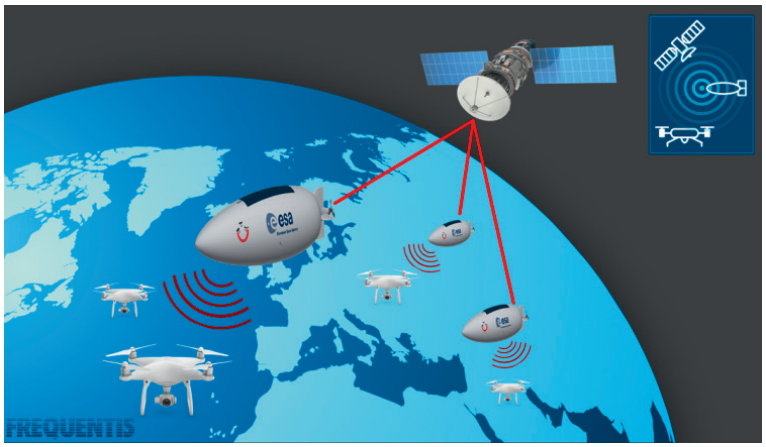
The missing link between satellites and drones – HAPS – Future Smart Borders

Drones (also known as Unmanned Aerial Vehicles, UAVs, or Unmanned Aircraft Systems, UAS) are increasingly used in EU IBM and are considered high-performance tools in border surveillance, due to their enhanced capabilities in the areas of detection, observation, data collection, and information sharing. Drones and satellite systems are also instrumental in implementing current policies of contention of migration that rely on cooperation with third countries and, at times, on pull-back operations. They are becoming important

tools in the area of border surveillance, as they enhance performance in border-guarding operations and increase the operational capacity of the surveillance system (Val Garijo, 2020, pp. 136–138). Drones have revolutionised border patrols by offering unmatched coverage and flexibility. Equipped with high-resolution cameras, infrared sensors, and even radar systems, drones provide real-time aerial surveillance of difficult-to-access areas. These UAS operate at a fraction of the cost of manned patrols while covering more ground (Tashji, 2024).

A new technological advancement that is a type of hybrid between drones and satellite systems are High Altitude Pseudo Satellites (HAPS), known as high altitude UAVs or stratollites. High Altitude Pseudo Satellites are unmanned aircraft operating in the stratosphere at altitudes of approximately 20 km or above (*i.e.*, much higher than drones). They can operate continuously for up to 12 months. There are two large categories of HAPS, entailing lighter-than-air (LTA) applications or heavier-than-air (HTA) applications. They can fly high above conventional aircraft, such as airships, planes or balloons, and provide continuous day and night coverage of the area below. Their target applications include border management tools such as search and rescue, surveillance and communications, disaster relief, environmental monitoring, and agriculture. High Altitude Pseudo Satellites provide persistence and flexibility to complement satellites and drones. Moreover, HAPS are particularly useful for providing communications in remote areas without infrastructure, or on the high seas (Eulaerts& Joanny, 2022, p. 5). As HAPS vehicles get lighter, they get smaller. This means instruments must also get smaller, particularly remote-sensor miniaturisation. On the systems side, artificial intelligence may have a role to play with the amount of data a HAPS vehicle can collect. Using automation and AI to parse such data can uncover significant trends and determine decisions (Amprius, 2025).

Figure 3. Satellite-HAPS-drones



Source: European Space Agency. (2022). *RPAS-HAPS- Broadband Satellite Communications to Remotely Piloted Aircraft Systems (RPAS) Using High Altitude Pseudo-Satellites.* https://connectivity.esa.int/projects/rpashaps

The HAPS as a missing link between satellites and drones, Copernicus Digital Twins and other technologies described above are beginning to create an expanded and modernised vision of Smart Borders, which can be described as Future Smart Borders. That new concept encompassing the support of EU IBM through evolving satellite systems.

Future Smart Borders is a response to the challenges of migration and potential future challenges and threats at external borders, which are the goal of the EU IBM specified in Art.1 (see Regulation EU 2019/1896). For example, regular HAPS flights now monitor the Atlantic between Gambia and the Canary Islands. With the help of the pseudo-satellites, boats carrying migrants can be "recognised at an early stage". The deployment of the HAPS is intended to "respond proactively and effectively" via the €1.86 million "Agamenon" project funded by the European Regional Development Fund. HAPS platforms require special take-off and landing sites and the first European "Stratoport" was built on Fuerteventura (Monroy, 2025).

Future of HAPS in Frontex policy for better border management

High Altitude Pseudo Satellites are the development of a knowledge platform with information on the border checks procedures, and Frontex is conducting a Research Study on High Altitude Pseudo Satellites and Border Checks and Migration Management Equipment. Cooperation with the EU Satellite Centre also improved Frontex's ability to keep its risk analyses up to date, especially for pre-frontier areas, and might allow a very wide interpretation that would enable the Agency to extend its satellite surveillance and application of EUROSUR worldwide, without limitation (Commission, 2024). In the Frontex research study, HAPS was compared to the three competing technologies across a number of parameters, including operational prowess, financial costs, and the level of readiness of the technology. High Altitude Pseudo Satellites were highlighted as the best-in-class technology with regard to the range and coverage of its payload, since they can return to the ground and be easily adapted – and due to their level of sustainability, given the lack of space debris and the use of solar energy. As such, HAPS occupies the sweet spot between UAS and satellites, leveraging the capability of being operational for longer than the former, while being cheaper, more precise and more flexible than the latter, opening up potential use cases in navigation, Earth observation, and communication. Nevertheless, HAPS technology is still at an early stage and will require additional development and research going forward, for example, with regard to the existing challenges posed by power supply issues and the lack of regulatory framework, including in the EU. As it stands, the desk research and stakeholder insights indicate that HAPS ideally would be used in conjunction with other technologies, providing the highest level of operability and added value for Frontex. HAPS, in general, proved to have a significant potential for increased payload capacity. It offers more possibilities for the telecommunication and Global Navigation Satellite System (GNSS) vity in remote areas, allowing for more accurate positioning, navigation, and timing information, so HAPS can improve emergency communication. The deployment of this technology would definitely be able to contribute to EU IBM and there are more benefits than downsides. HAPS have their own power source (either solar-powered or hydrogen-powered), eliminating the need for a launch vehicle. This provides HAPS with the ability to manoeuvre in the stratosphere or remain stationary at one location. As HAPS operate closer to the surface of the Earth, they offer lower latency compared to satellites. HAPS can be brought back to the Earth once their operation cycle ends, lessening the congestion within the stratosphere, but since HAPS are placed closer to the surface of the Earth, their coverage area is less extensive than that of satellites. Hence, HAPS require a larger number of vehicles in the stratosphere to cover a similar

area. Finally, HAPS solutions can be deployed in a turnkey fashion where they can quickly become operational to serve specific use cases. Additionally, HAPS can complement the existing ecosystem of terrestrial and satellite infrastructure and their proximity to Earth, along with their station-keeping capabilities, enables better spatial resolution and time resolution of the images (Frontex, 2023, p. 5–9). According to Frontex, the growing HAPS market in Europe may expand more than three-fold by 2029, as a telecommunication service nod. Moreover, HAPS is a convenient approach to circumvent the network outages in future 5G network services, especially considering the potential of an increase in the number of autonomous ground vehicles and consequent data traffic expansions (Bagarić et al., 2025, p. 594, 597).

Conclusions and recommendations

The constantly emerging challenges at borders require effective action and forecasting of future threats. In the European Union's response, prevention is becoming key and this has resulted in 'traditional' methods of protecting the EU's external borders becoming insufficient and the need to use new technologies to ensure the security of the Schengen/EU area is constantly emerging. One of the most important in this field is, without doubt, the use of satellite systems for border management, so detailed pre-border surveillance is becoming an increasing challenge for policymakers The analysis carried out clearly indicates that, in the face of growing challenges for EU IBM, satellite technologies play a key role in ensuring effective control and security. The integration of satellite systems into the Smart Borders concept reinforces this and responds to the increasing complexity of threats, including irregular migration, and the need for prevention and detection of cross-border crime. This is done using the current large-scale Schengen information systems, but above all the EUROSUR system operated by Frontex, which, in combination with Copernicus satellite data and other advanced Earth observation technologies, enables effective monitoring of the situation at borders and in pre-border areas.

Therefore, policy recommendations for the future can be formulated with a new direction of EU strategic thinking, which is shifting from reactive border management to anticipatory, integrated surveillance systems. Frontex's cooperation with EU satellite agencies, such as SatCen and ESA, highlights the growing synergy between space systems and integrated EU border management. Good cooperation between EU member states and the use of US expertise could lead to the introduction of Smart Border walls. These walls would consist of traditional systems and drones, as well as HAPS, which is a bridge between satellite and drone technology. More and more advanced EUROSUR, by using satellite systems, is part of the implementation of Smart Borders, including the exchange of new smart space data from an increasingly intelligent space.

The multifaceted analyses carried out in this article allow to positively verify the hypothesis that the integration of satellite systems into Smart Borders significantly improves the effectiveness of future EU IBM. The article answers the research question, indicating the growing importance of satellite systems in the development of Smart Borders, and to confirm that their use significantly contributes to the effectiveness of the integrated management of the European Union's borders. According to the latest data from Frontex, the number of irregular border crossings into the EU fell by 18% to 95,200 in the first seven months of 2025 (Frontex, 2025). Ensuring the security of EU borders requires

comprehensive support from land (radar stations), sea (sonar), but increasingly also air (unmanned aerial vehicles and satellites). Based on the issues analysed in this article, it can be confirmed for policymakers, that satellite systems not only support classical border protection methods, but also open new possibilities for risk analysis and prevention of future threats. The development of EUROSUR/Copernicus Fusion Services and the implementation of newly developed technologies such as HAPS or Copernicus Digital Twins point in the direction of Future Smart Borders. This transformation includes not only the improvement of the technical infrastructure, but also the integration of systems within the wider EU IBM.

It should be pointed out that the policy recommendation is that the concept of FUTURE Smart Borders should be developed, subject to continuous evolution and upscaling in response to new and future challenges. Through the extension of satellite systems, the 'system of systems' EUROSUR Fusion Services, HAPS, and Copernicus allows traditional risk analysis to be extended to satellite-based risk analysis. Thus, space technologies are definitely an enhancement of EU IBM, aligning its objectives and capabilities with the needs of the new EU security dimension. In the context of the projected increase in border traffic and dynamic changes in the security environment, the future of Smart Borders must include the development of modern satellite technologies. This requires further integration of EU border management systems with Copernicus Border Surveillance Services and further evolution of EUROSUR Fusion Services to create a future EU IBM of the next generation. Not only will it be crucial to implement innovative technology solutions, but also active political will and cooperation will be required to be much more effective against growing threats.

In summary, the Smart Borders concept is a dynamic process, and a challenge for policymakers constantly evolving in response to new and future challenges. Its development requires not only the implementation of new satellite technologies, but also their appropriate adaptation to the changing threat environment and focusing not only on the aspects of new technological solutions, but above all on their efficient management and financing at EU level. The future of Smart Borders lies in combining traditional border management tools with intelligent satellite systems, providing a new dimension to the security of the European Union's borders. To this end, Smart Borders tools should be continuously complemented by SMART SPACE DATA, and thus create a more efficient FUTURE EU IBM.

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