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Space as an Enabler in the Maritime Sector

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A B S T R A C T

Space can be used as a tool for business decision and policy makers. The maritime sector is rapidly evolving as far as business and industrial activities are concerned. Space can assist in transforming this sector through satellite navigation and positioning, telecommunications and integrated applications as well as earth observation. Additionally, space can be used as a tool in developing, implementing maritime affairs. This paper focuses on the role of space in maritime policy. Space technologies have been serving the maritime community for over fourty years. Satellite technology is becoming increasingly important for a wide range of maritime activities through enhanced navigation accuracy, marine environmental monitoring and maritime surveillance. For this reason, agreements between the European Space Agency (ESA) and the European Maritime Safety Agency (EMSA), have been signed in 2007 and 2010, strengthening the framework for cooperation between the two agencies for the use of space-based systems in support of maritime activities. The first part of the paper summarizes European maritime related policy areas where space assets can contribute to achieve their objectives. The second part of the paper addresses how ESA's initiatives and programs could contribute and support the maritime sector in Europe. The main purpose of this paper is to come up with conclusions on whether and how the use of space assets, technology and applications, can contribute in achieving the maritime policy objectives for the benefit of Europe.

1. Introduction: the European Maritime Sector

The maritime sector is of crucial importance to modern societies. It plays a critical role as an essential element in terms of social and economic development, and as a potential source creating employment and job opportunities, with several million people currently working in activities and companies directly and indirectly related to oceans and seas worldwide [1]. Maritime has been traditionally connected with the fishing and shipping industry. Shipping has long been the major form of transportation, as well as an essential communication link connecting coastal cities, countries and continents. Next to rail transportation, water transportation is economically and environmentally the most efficient way to travel or transport merchandise; and, nowadays, around 90% of world trade is carried by the international shipping industry [2].

Europe, having 329 key seaports along its coastline and controlling around one third of the world's merchant fleet, constitutes one of the leading maritime centres in the world. It is also home to a thriving maritime services sector and marine equipment industry [3]. Ports are vital gateways, linking European transport corridors to the rest of the world. As 75% of European external trade transits through EU ports, the shipping sector plays a major role in connecting the European market with its trade partners. With a dynamic short-sea shipping sector, the European maritime sector also contributes to the development of a competitive and resource efficient transport system in the EU. Today, shipping accounts for around a third of intra-EU exchanges, and annually 400 million passengers embark and disembark at EU ports [4].

Maritime industries include both shipbuilding and recreational craft. These two sectors benefit from EU support for trade, the environment, and the application of standards on building provisions and administrative procedures [5]. The European shipowners control 40% of the world's merchant fleet and in particular: 60% of worlds container ships, 52% of world's Multi-Purpose vessels, 43% of world's oil tankers and 37% of worlds offshore vessels. The direct, indirect and induced value of the European shipping industry in 2015 was estimated in 140 billion euros (in particular, direct value was 54B, indirect value was 57B and induced value was 29B), while the European shipping industry directly and indirectly employs 2.1 million people [6].

2. MEuropean Policies related to Maritime Affairs and Fisheries

The European Union works to foster a thriving ocean economy while preserving its seas and oceans for future generations. The common fisheries policy (CFP) and the integrated maritime policy aim to secure a safe and stable supply of seafood, sustainable fisheries, healthy seas and prosperous coastal communities. The work includes a

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strong international dimension to ensure sustainably managed oceans around the globe [7]. European Commission's Directorate General for Maritime Affairs and Fisheries (DG MARE) is responsible to develop and carry out the EU relevant policies. In particular, it works to a) ensure that the ocean resources are used sustainably and that coastal communities and the fishing sector have a prosperous future, b) promote maritime policies and stimulate a sustainable blue economy and c) promote ocean governance at international level [8]. This section summarizes and provides an overview of the EU policies related to Maritime Affairs and Fisheries.

2.1. Common Fisheries Policy (CFP)

The Common Fisheries Policy CFP, originated in the Articles 38-43 of the Treaty on the Functioning of the European Union (TFEU) [9], is a set of rules for managing European fishing fleets and for conserving fish stocks. Designed to manage a common resource, it gives all European fishing fleets equal access to EU waters and fishing grounds and allows fishermen to compete fairly [10].

The original objectives of the CFP were to preserve fish stocks, protect the marine environment, ensure the economic viability of European fleets and provide consumers with quality food. The 2002 reform added to these objectives *the sustainable use of living aquatic resources, in a balanced manner and from an environmental, economic and social point of view*, specifying that sustainability must be based on sound scientific advice and on the precautionary principle [11].

According to the CFP, *"despite the importance of maximising catches, there must be limits. The current policy stipulates that between 2015 and 2020 catch limits should be set that are sustainable and maintain fish stocks in the long term. To this day, the impact of fishing on the fragile marine environment is not fully understood."* For this reason, the CFP adopts a cautious approach which recognises the impact of human activity on all components of the ecosystem. It seeks to make fishing fleets more selective in what they catch, and to phase out the practice of discarding unwanted fish. CFP has 4 main policy areas and in particular: a) fisheries management, b) international policy, c) market and trade policy and d) funding of the policy (European Maritime and Fisheries Fund) [12].

2.2. European Maritime and Fisheries Fund (EMFF)

The EMFF is the fund for the EU's maritime and fisheries policies for 2014-2020 [13]. For the next long-term EU budget 2021-2027, the Commission is proposing €6.14 billion under a simpler, more flexible fund for European fisheries and the maritime economy. The new European Maritime and Fisheries Fund will continue to support the European fisheries sector towards more sustainable fishing practices, with a particular focus on supporting small-scale fishermen. It will also help unleash the growth potential of a sustainable blue economy towards a more prosperous future for coastal communities. For the first time, it will contribute to strengthening international ocean governance for safer, cleaner, more secure, and sustainably managed seas and oceans. Finally, the Commission is reinforcing the environmental impact of the Fund with a focus on protecting marine ecosystems and an expected contribution of 30% of its budget to climate change mitigation and adaptation, in line with the commitments agreed under the Paris Agreement [14].

2.3. Integrated Maritime Policy (IMP)

The EU Integrated Maritime Policy (IMP) is a holistic approach to all sea-related EU policies. Based on the idea that the Union can draw higher returns from seas and oceans with less impact on the environment by coordinating its policies, the IMP encompasses fields as diverse as fisheries and aquaculture, shipping and seaports, marine environment, marine research, offshore energy, shipbuilding and sea-related industries, maritime surveillance, maritime and coastal tourism, employment, development of coastal regions, and external relations in maritime affairs [15]. It seeks to provide a more coherent approach to maritime issues, with increased coordination between different policy areas. It focuses on: a) Issues that do not fall under a single sector-based policy e.g. "blue growth" (economic growth based on different maritime sectors); b) Issues that require the coordination of different sectors and actors e.g. marine knowledge [16]. Specifically it covers these cross-cutting policies: a) Blue growth; b) Marine data and knowledge; c) Maritime spatial planning; d) integrated maritime surveillance; e) Sea basin strategies [17].

2.4. Blue Growth

Blue Growth is the long term strategy to support sustainable growth in the marine and maritime sectors as a whole. Seas and oceans are drivers for the European economy and have great potential for innovation and growth. It is the maritime contribution to achieving the goals of the Europe 2020 strategy for smart, sustainable and inclusive growth. The 'blue' economy represents roughly 5.4 million jobs and generates a gross added value of almost €500 billion a year. However, further growth is possible in a number of areas which are highlighted within the strategy [18].

The strategy consists of three components:

- Develop sectors that have a high potential for sustainable jobs and growth, such as: a) aquaculture b) coastal tourism, c) marine biotechnology, d) ocean energy, e) seabed mining;
- Essential components to provide knowledge, legal certainty and security in the blue economy;
- Sea basin strategies to ensure tailor-made measures and to foster cooperation between countries [19].

2.5. Sea basin regional strategies

The EU recognising the importance of each sea region, has adopted dedicated strategies for Adriatic and Ionian Seas, Atlantic, Arctic Ocean, Baltic sea, Black sea, North Sea, Mediterranean Sea, exploiting the strengths and addressing the weaknesses of each large sea region such us the Arctic's climate change or the Atlantic's renewable energy potential, to problems of sea and ocean pollution, to maritime safety [20].

2.6. EU Coastal and Marine Policy

The EU Coastal and Marine Policy provides the legal impetus for the EU to protect and clean up its coasts, seas and oceans as part of an integrated strategy which will be the enabler of their sustainable use [21].

EU legislation to protect the marine environment has been progressively implemented in many relevant areas: for instance, the regulation of fisheries through the Common Fisheries Policy (CFP) or the control of input of nutrients and chemicals into the water through the Water Framework Directive (WFD). But these pieces of legislation, although crucial complementary tools to the protection of marine waters, contribute to the protection of the sea only from specific pressures resulting in a fragmented and sectoral approach. That is why the European Union has adopted two instruments, the 2002 EU Recommendation on Integrated Coastal Zone Management and the 2008 Marine Strategy Framework Directive, which offer a comprehensive and integrated approach to the protection of all European coasts and marine waters. The Marine Directive is the environmental pillar of the cross-cutting Integrated Maritime Policy (IMP) [22].

2.7. EU Maritime Security Strategy (EUMSS)

The European Union Maritime Security Strategy (EUMSS) for the

Table 1
The contribution of space programmes to maritime policy main objectives [36].

Space as an asset for maritime and fisheries policy			
Policy Areas - Main Objectives	• Ensuring exploitation of living aquatic resources covering internal and external aspects; • Sustainable environmental conditions; • Sustainable social conditions; • Measures for Community fishing licences, special permits; • Detailed rules for a balance between resources and exploitation; • Common standards for marketing, conformity check, guide price and withdrawal price; • Monitoring and support to Arctic operations; • Integrated Vessel Surveillance; • Maritime safety and security; • Free movement of services and the correct application of competition rules		
Contribution by space programmes	Navigation • monitoring independent access to maritime space; • navigation, monitoring and tracking of vessels; enhanced vessel's situational awareness; • collection, integration exchange and analysis of marine information through PNT technology; • Ensuring safety and security at sea and protection of marine environment through PNT technology; • Autonomous vessel navigation through artificial intelligence/machine learning sensor fusion; • wide-bandwidth two-way communications to all mariners; • monitoring overfishing and overcapacity; • monitoring fishing applications;	Earth Observation • monitoring the broader maritime environment (including sea levels, track pollutants, ice conditions, iceberg movements etc); • monitoring the health of the eco-systems; • monitoring climate change impact on the sea; • providing high precision sea surface temperature data and future ice conditions to support regular monitoring of marine habitats; • monitoring changes in fish stock; • monitoring fuel-intensive fishing practices contributing to • greenhouse gas emissions; • monitoring fishing applications; • countering illegal fishing as well as control marine resources including fisheries and aquaculture	Telecommunications • Satellite Automatic Identification System (AIS) for ship tracking and increased traffic management efficiency; • Strengthening transport safety and security (Continuous exchange of information and tracking control, including for deep sea navigation) • Contributing to a Trans-European transport network (TEN-T) through Maritime traffic control; • Assuring environmentally sustainable transport by satellite communication applications; • Communication services for on-board navigation applications and remote areas; • Communications services and safeguarding for the Arctic; • Diffusing maritime disputes (by i.a. security alert communications) • Emergency communications; • Scrutinising and managing climate change through collecting real-time environmental data; • Transmit data on weather events
Examples	• tracking fishing vessels. Track location of vessels to avoid overfishing. • Analysis of the navigation measurements, with respect to reference frames, allows following the shoals movements yields time series of daily site positions, containing both secular and seasonal variations. • tracking fishing locations. GNSS helps fishermen to return to the spots where fish are located.	• Operational surveillance of European waters by radar satellites to detect illegal discharges of oil into the marine environment [34]. • Routine monitoring of water quality parameters including chlorophyll concentration, transparency, suspended sediment and dissolved matter. Satellite based ocean colour measurements provide measurements of eutrophication such as chlorophyll concentration, transparency and detection of algal blooms [35].	• remote controlled shipping • important increase of tracking large cargo vessels and passenger ships (to prevent collisions and pollution) through AIS equipment • aid in the movement of dangerous goods • manage the national coast and waters for safety, emergency and transport planning • Combating piracy by i.a. security alert communication • Reducing the needs for in-situ presence of workers in remote mining exploitation sites.

global maritime domain, adopted by the European Council in June 2014, is a joint EU plan to improve the way in which the EU pre-empts and responds to these challenges. The EU strategic maritime interests include [23]:

- overall security and peace;
- rule of law and freedom of navigation;
- external border control;
- maritime infrastructures: ports and harbours, coastal protection, commercial facilities, underwater pipes and cables, offshore platforms and scientific equipment;
- common natural resources and environmental health;
- climate change preparedness.

2.8. European Maritime Transport Strategy

European regulations on maritime transport focus on the application of the principle of free movement of services and the correct application of competition rules, while ensuring a high level of safety, good working conditions and environmental standards. The European Commission published in January 2009, a communication on strategic goals and recommendations for the EU's maritime transport policy until 2018 (COM(2009) 0008)[24]. The identified challenges include [25]:

- *EU maritime shipping in globalised markets and in the face of increased competition;*
- *Human resources, seamanship and maritime know-how: possible strategic measures that could be taken included, in particular, increasing the attractiveness of maritime professions, improving the training of seafarers, promoting lifelong professional prospects in maritime sectors and improving the image of shipping;*
- *The long-term objective of 'zero-waste, zero-emission' for maritime transport, improvement in maritime safety and prevention of terrorism and piracy;*
- *Exploitation of the full potential of short sea shipping, for example by creating a European maritime transport area without barriers and fully implementing the projects to establish the motorways of the sea or to link ports to their hinterland.*

According to a Staff Working Document on the implementation of the EU Maritime Transport Strategy 2009-2018[26], published by the EC in September 2009, focus is given on the five following areas: (i)

Maritime Safety and Security; (ii) Digitalisation and Administrative Simplification; (iii) Environmental Sustainability and Decarbonisation; (iv) Raising the Profile and Qualifications of Seafarers and Maritime Professions and (v) EU Shipping: A stronger global player [27].

3. Space as a tool to support the objectives of maritime policy

Space technologies have been serving the maritime community for more than fourty years. Concrete examples could include among others: meteorological forecasts based on satellite observations and satellite telecommunications, enhanced navigation accuracy, leading to improved maritime safety as well as efficient marine environmental monitoring and maritime surveillance [28].

The European flagship programmes – Galileo and Copernicus – and space based information and applications through them can contribute in implementing the maritime policy objectives, described above, and respond to the specificities of the maritime sector. Their role can be also extended in carrying out conformity control checks on products and provide the necessary information to apply sanctions for any infringements. Additionally, navigation, earth observation and their respective space technologies can lead to restructuring, modernising and developing the fishery sector, to developing aquaculture, encouraging experimental fishing and tailor the European fishing capabilities to realistic possibilities. Other examples of the use of space based information can assist in providing desirable results in surveillance systems, inspection and surveillance activities, fleet control and application of penalties. Furthermore, systems like Copernicus and Galileo can provide the necessary tools at the European level for coordination of activities that are currently mostly operated at national level. Sustainable and responsible fisheries in fisheries policy could also be promoted at the international level through space assets facilitating and reflecting environmental and socioeconomic factors [29]. The Copernicus Marine Environment Monitoring Service (CMEMS) provides regular and systematic reference information on the physical and biogeochemical state, variability and dynamics of the ocean and marine ecosystems for the global ocean and the European regional seas. The observations and forecasts produced by the service support all marine applications, including: a) Marine safety; b) Marine resources; c) Coastal and marine environment; d) Weather, seasonal forecasting and climate [30].

Table 1 summarizes the main maritime policy interests and demonstrate how space assets can contribute to those policy objectives, whilst providing concrete examples.

A number of public and private key-actors in both maritime and space sector have been making use of space tools in support of maritime objectives. Some indicative examples include, among others, the International Maritime Organization (IMO), the European Maritime Safety Agency (EMSA) as well as Eutelsat.

Soon after the launch of the world's first telecommunications satellite, Telstar, in 1962, IMO recognised the potential for satellite communications to assist in distress situations at sea and initiated a study of the operational requirements for a satellite communications system devoted to maritime purposes. The Convention on the International Maritime Satellite Organization, was adopted by IMO in 1976 and entered into force in 1979, to establish and oversee satellite communications for shipping. Under the treaty, the International Mobile Satellite Organization (IMSO) has been established as the intergovernmental body that oversees the provision of certain satellite-based maritime distress communication services, specifically those used in the Global Maritime Distress and Safety System (GMDSS). The Convention defined the purposes of the International Maritime Satellite Organization as being to improve maritime communications, thereby assisting in improving distress and safety of life at sea communications, the efficiency and management of ships, maritime public correspondence services, and radiodetermination capabilities [31].

EMSA's CleanSeaNet is a European oil spill and vessel detection service based on Earth Observation Satellites. It offers assistance to participating States for the following activities: a) Identifying and tracing oil pollution on the sea surface; b) Monitoring accidental pollution during emergencies; c) Contributing to the identification of polluters. In particular, the CleanSeaNet service is based on the regular ordering of Synthetic Aperture Radar (SAR) satellite images, providing night and day worldwide coverage of maritime areas independent of fog and cloud cover. Data from these satellites is processed into images and analysed for oil spill, vessel detection and meteorological variables. The information retrieved includes among others: spill location, spill area and length, confidence level of the detection and supporting information on the potential source of the spill (i.e. detection of vessels and oil and gas installations). Optical satellite images can also be acquired upon request, depending on the situation and user's needs [32].

Eutelsat provides mobility services to the maritime sector delivering global solutions and coverage to a diverse range of markets that includes commercial shipping, sea-based oil and gas operations, governmental ships and luxury vessels. The VSAT technology provides corporate class networking services, interconnectivity and real-time data applications for businesses, leisure and crew welfare needs. Globally, via its resources and through partnerships with other satellite operators, it provides fleets and individual vessels the connectivity and infrastructure they need, wherever is needed [33].

4. ESA's Initiatives and Programmes supporting the Maritime Sector

ESA as the Space Agency for Europe has been recognising the crucial role of space in supporting the maritime sector and serving the maritime community with many satellite capabilities. ESA supports the objectives of the European maritime/fisheries policy, not only through its role to implement the European Flagship Programmes –Galileo and Copernicus- but also through a number of other initiatives and programs, especially in the areas of Earth Observation, Navigation and Telecommunications and Integrated Applications. These initiatives contribute substantially to better understanding, monitoring and navigating the ocean [37]. Table 2 provides examples of ESA's maritime related projects and activities in all the three areas.

4.1. Earth Observation

ESA's EO services and technology contribute in various ways in a number of challenges of the maritime sector by creating recognised maritime picture over all marine areas of interest to Europe and by detecting, among others, illegal, unreported and unregulated (IUU) fishing, drug trafficking, piracy and movement of restricted materials such as weapons.

Maritime surveillance is one of the priority areas supported by Copernicus Security Services with the objective of ensuring the safe use of the sea and securing Europe's maritime borders. The corresponding challenges mainly relate to safety of navigation, marine pollution, law enforcement, and overall security. This component has been assigned to the European Maritime Safety Agency, EMSA. This service also builds on ESA's GMES Service Element (GSE) projects such as the MARitime Security Service, MARISS [38]. This project makes the integration of different satellite detection and tracking systems a fully operational maritime surveillance tool implemented as one of the Copernicus Security Services and operated by EMSA. EMSA's CleanSeaNet, a European oil spill and vessel detection service, had been also developed under the ESA GSE programme element and then transferred to EMSA.

Additionally, ESA's "Water Resources Management" project [39] under ESA's "Earth Observation for Sustainable Development" [40] seeks to demonstrate the benefits and utility of EO services in response to stakeholder requirements for water resources monitoring and management at local to basin scales. ESA's EO maritime related activities include also the "ESA LEX EO" (EO Based Information Services for the Law Enforcement Sector) that will address environmental crime,

Table 2
Examples of ESA's maritime related activities and projects [68].

Activities	Description and Main Focus and application to Maritime Sector
Automated Identification System (AIS) Detection from Space	The Automated Identification System (AIS) is a ship-based transponder system designed to transmit information such as vessel identity, position, heading, nature of cargo and so on to other ships and the shore.
Ballast water treatment installation	IPStar is carrying out a feasibility study on the technical and economical parameters to apply advanced grey water treatment technology developed by MELiSSA for the treatment of ballast water on board ships.
Coastal TEP	Through the provision of access to large volumes of EO and in-situ data, computing resources, algorithm development space and the fundamental processing software required to extract temporal and spatial information from Big Data, C-TEP shall provide a dedicated service for the observation and monitoring of our coastal environment and society.
Cospas-Sarsat antennas	The Cospas-Sarsat worldwide Search and Rescue satellite system has been in operation, rescuing more than 26 000 distress victims. The scope in this project was to develop a body-worn antenna, suitable to be integrated into a life vest platform together with a commercial Cospas-Sarsat distress transmitter.
Cymons	CyMonS provides water management organisations with data of several water quality parameters at a large spatial and temporal scale. This data is used to initialise models for providing short term forecasts.
ESA Navigation - Mapping and Positioning services	Galileo is Europe's own Global Navigation Satellite System (GNSS), providing a highly accurate, global positioning service, interoperable with the US GPS and Russian Glonass systems.
Grey Water recycling system - CONCORDIA	A recycling system for 'grey water' – water previously used for washing or food preparation – has been operating for the last decade at the French–Italian Concordia base in Antarctica. The multistep recycling process is based on a ceramic honeycomb peppered with holes 700 times finer than a strand of human hair followed by a pair of membranes that yield clean water.
I-PORT	This demonstration project constructed a pre-operational system for end users, which optimised the handling of intermodal freight transport through European ports.
I4S - Innovative Satcom Security System for Ships	Supported by ESA TELECOM, the i4s project has resulted in a maritime dedicated service based on an application hosted on the existing Novacom platform and called the "generic application".
ICWM - Integrated Coastal Water Monitoring for MED (Mediterranean Sea)	ICWM for MED solution provides water quality monitoring and surveillance of coastal areas by integrating information from: Earth Observation, Navigation and Communication satellite assets; in situ measurements; crowdsourcing information. It intends to address the current limitations from both Earth Observation based and traditional at sea measurements methods in order to support the duties of environmental agencies and coastguard authorities.
Intelligent sensor and satellite network - ISSN	The objective of the ISSN study, was the investigation of the technical feasibility and commercial viability of a flexible and reliable intelligent sensor network where satellites are among the nodes in the network. The services provided data from local sensor networks, satellite communication and Earth observation data to support environmental surveillance and safety offshore in particular related to oil spill, and search and rescue in remote areas.
M3I	M3i has three key steps for converting source data – much of it conforming to the 'big data' characteristics of large volumes and a wide variety of sources and formats – into actionable intelligence about a Landscape of Interest (LoI): The first step involves building; the second step encompasses enrichment; the third and final step comprises the analysis
MarIA - Marine Integrated Applications	This project has developed a cloud-based system to support more efficient management of sustainability standards in commercial fishing and processing operations.
NG RMP	The Next Generation Recognised Maritime Picture (NG-RMP) project aimed to provide a system to the Irish Naval Services (INS) that generates an advanced Recognised Maritime Picture (RMP) using emerging Satellite Automatic Identification System (S-AIS) technology.
PLASMA	Platform for Advanced SAT-AIS Maritime Applications. This project covers the specification, design, implementation and pre-operational demonstration of a 'Platform for Advanced SAT-AIS Maritime Applications' (PLASMA) at the UK's Satellite Applications Catapult facility in Harwell.
Profumo	Profumo proposes novel weather-based services for the Mediterranean navigation with the aim of granting fuel saving, pollution reduction and improving safety for passengers, crew, goods and ships' instruments.
Remote Sensing for Marine Litter	Marine Litter (ML) is a global issue, affecting all the major bodies of water on the planet, from the surface to the sea-bottom.
SASS@Sea	Satellite Based System and Services for Broadband Applications at Sea. The objective of the project is the development and validation of a system for the provisioning of an integrated maritime communications service.
SAT-AIS-Blue Belt	Embedded into the SAT-AIS context, this IAP Demonstration Project aims to support the EMSA Blue Belt project. Providing space-based AIS data, it seeks to complement the terrestrial AIS data and provide an added-value source of information for Customs Authorities interested in maritime situational awarenees for vessels and geographical focus areas.
SatCom4Mar	The aim of the SatCom4Mar project is to provide better communications systems for the maritime sector. The maritime user applications requiring access to communication systems can be divided into 6 main areas: 1) safety & security, 2) vessel operations, 3) regulations/policy, 4) tracking & monitoring, 5) crew welfare, and 6) shared situational awareness.
SHARC	The objective of SHARC (which stands for Satellite High-performance ARGOS-3/-4 Receive/transmit Communication), was to develop a new low-cost generation tag equipped with Argos-3/4 features dedicated to track migrating marine animals. Improvements for several key features include smaller weight and size, increased lifetime, enlarged data storage, bidirectional communication with satellite leading to increased volume of the satellite data transfer.
Ship's Sulphur Trails Emissions Aerial Measurements	An integrated solution to measure SOx emissions of exhaust plumes of ships and to follow the vessels during their journey in Sulphur Emission Control Areas.
STEAM - Ship's Sulphur Trails Emissions Aerial Measurements	The objective of this study is to investigate the technical feasibility, financial/non-financial viability and sustainability of a future service aiming at measuring the amounts of sulphur oxides components ejected by vessels travelling inside the Emission Control Areas (ECAs) as defined by the International Maritime Organization (IMO).
SUSSAT	This project aimed to provide a holistic assessment of the contribution of the Satcom industry to global sustainable development, considering economical, societal and environmental aspects.
Transparent Sea - Sustainable Management of Fishery Resources	The overall objective of the TransparentSea project is to contribute to the sustainable management of fishery resources world-wide by supporting fishery certification issuers, such as the Marine Stewardship Council (MSC) or

(*continued on next page*)

Table 2 (*continued*)

Activities	Description and Main Focus and application to Maritime Sector
	the International Sustainable Seafood Foundation (ISSF), in enforcing the value and credibility of certified seafood products by creating more transparency of fishery activities at sea using space-based technologies.
Blue SIROS	The project investigates the technical feasibility and commercial viability of an operational system for marine route optimisation, which integrates modelling/forecasts of ocean currents based on near-real time satellite altimetry data services.
OAPM	Being developed by CGG's NPA Satellite Mapping business unit, with support from ESA, OAPM aims to provide regular, cost effective, satellite-derived information over offshore assets to establish a baseline, and a programme of routine pollution monitoring
LUMEN	LUMEN provides a fully integrated end-to-end solution for real time monitoring and critical situation management with medium sized RPAS that can operate beyond line of sight.The service is demonstrated with two specific use cases representative for the target market: flood extend mapping and maritime coastal monitoring.
JERICHO VDE	Feasibility study, performed by a Polish team, providing a comprehensive overview of the VDES technology future maritime applications potential.
Pi-Link	Collection and transmission of ocean water column data opens up new data-based revenue streams across a range of industrial sectors and stakeholders.
SENSE	The preservation of safety and information distribution in the maritime transport market is currently enabled by systems, which already show signs of overload, such as AIS.
Cerberus	BlackShore's crowdsourcing platform Cerberus reinforces developing country economies by employing satellite imagery to support sustainable food production while preserving the environment.
SeaSearch	Based on mobile phone detectors and data correlation from other sources such as satellite, maritime and radar systems, SeaSearch focuses on the detection of small vessels at sea and generates Maritime Situation Awareness Pictures.
i-FishSAT	Intelligent Integrated Information System for Sustainable Fisheries Management via Satellite (iFishSAT) has developed a range of solutions that exploit space assets (Communication, Earth observation and GNSS satellites) to streamline the fresh seafood value chain by allowing fishermen to sell produce to customers whilst still at sea thus, providing direct linkage to a broader customer base and without geographical limitations as well as reducing waste through discard of produce that is desirable in the local market.
International Satellite Derived Shallow Water Bathymetry Service	A web-based service to provide immediate, off-the-shelf, online access to shallow water depth data derived from very high resolution satellite imagery.
POINTSAT	POINTSAT enables professional remote collaboration services of support, instruction and training in challenging conditions for the maritime, offshore, and energy industry sectors.
Blue Discovery	BlueDiscovery is an innovative and powerful technology platform designed to provide an efficient and low-cost Access Control and Visitor Information System to Marine Protected Areas (MPAs)and Tourist Ports, and at the same time to provide to them the capability to efficiently offer a rich set of added-value services to visitors.
MAPP-DEMO	Following a pirates' attack, onboard communication equipments are destroyed: the vessel's track is lost, the research area grows as time passes, making it harder to deploy rescue assets efficiently.The challenge is to answer to the question: “Where is my ship?”The ‘Keep in sight’ service combines a hidden tracker installed onboard and EO acquisitions to provide this critical information.
IceCast	IceCast project aims to develop and demonstrate a service based on IoT based capabilities combined with space assets, to help navigation planning in ice covered water areas.
Big data for migration study	“Big Data” refers to new computational capabilities, that warehouse huge set of data, technologies and analytics in order to extract added value from “bulky information” in a reasonable amount of time. The increasing possibilities offered by satellite technologies integrates with collateral data can support the ample range of activities of in assisting the whole complex of migration phenomena.
SYMPA	Sympa can be defined as an “All-around solution for the sustainable monitoring and control of Marine protected Areas”, Vitrociset Belgium, le Centre Spatial de Liège, and LaMMA are in fact developing a system for the supervision of the touristic and commercial traffic going through Marine Protected Area. Sympa service offer is completed by adding a “Water quality” monitoring which integrates EO data into innovative biogeochemical and hydrodynamic models as support of a sustainable and competitive tourism.
ASTROCAST	ASTROCAST is a network of nanosatellites providing cost effective global Machine to Machine (M2M) services in the context of the Internet of Things (IoT) to global businesses.
SIMONA	The aim of SIMONA project is to provide an information platform that based on the integration of satellite and terrestrial data can both complement and enhance existing Maritime situation awareness services operated by Italian Coast Guard and Navy over a wide area of the Mediterranean Sea and at the same time provide space-based services bringing functional advantages to private stakeholders like Merchant ships Insurance Companies and leisure boat users.
MARVELOWS	The project objective is to identify and specify new services using VDES (VHF Data Exchange System), so leveraging robust ship-to-ship, ship-to-shore and shore-to-ship communications that this technology makes available.
SatApps	The objective of the study is to perform an in depth requirements analysis on 2 focus pilot user groups: railway transportation and container/waste management.
SUMO	SUMO is a service to assist in the planning and monitoring of marine operations for offshore wind farms. The service integrates diverse information to allow the monitoring and forecasting of metoceanic conditions and track the locations of vessels and personnel involved.
Uam®	e2E intends to offer more affordable data communication services into niche markets currently underserved from existing infrastructure or where traditional satellite delivery is too expensive.
MULDIARCOS	The MULDIARCOS project will implement and demonstrate a cohesive end-to-end delivery chain of satellite and metocean data. The focus is on maritime operations in harsh Arctic regions.
WONDER	The project aims at developing an automated, cloud-based digital service for environmental monitoring which could be utilized globally.
DeSIRE II	DeSIRE II, Second Element of the ESA EDA RPAS Demonstration Roadmap, aims at developing and demonstrating a service based on a Remotely Piloted Aircraft (RPA) flying in Beyond Radio Line of Sight (BRLOS) using a dual satcom link supporting Command and Control (C2) and Air Traffic Control (ATC) functions. DeSIRE II will demonstrate that services, such as environment and maritime surveillance applications, can be rendered with RPAS flying beyond radio line of sight through the use of safe and secure satellite-based command and control data links.

(*continued on next page*)

Table 2 (*continued*)

Activities	Description and Main Focus and application to Maritime Sector
Com4Offshore	The Com4Offshore services enable communication and information exchange between offshore and onshore supporting logistics processes and construction workflow with the aim to significantly reduce the time and costs of the costly offshore construction projects.
STAR-FISH Feasibility Study	STAR-FISH is a management system that will automatically monitor and record fishing activity and fish discarding, in order to verify compliance with discarding regulations.
ISSWIND Demo	ISSWIND provides value-adding services to wind power industry in the areas of planning and operations, with financial and organizational benefits, to a wide range of wind power stakeholders.
JACKSON (AMAZON CCN#1) Temp	This project is based on several ESA-backed projects, which resulted in the successful development of a set of telemedicine systems for civilian, military and commercial aviation applications.
RAPSODY	RAPSODY, a project led by TEKEVER, will demonstrate the use of remotely piloted aerial systems (RPAS) in a wide area maritime context, through the execution of search & rescue and pollution monitoring missions.
PROTECT	The PROTECT project aims to exploit existing systems and infrastructure in conjunction with applicable space based assets to provide cost-effective added-value technology centred services that provide improved situational awareness to both on-board and shore based stakeholders, based on real-time innovative integration of piracy and sensor information/data.
ARCTICSAT	The objective of this feasibility study is to assess and validate the requirements for space technologies in support of optimising situational awareness in the Arctic. The major focus is on two application areas – shipping (e-Navigation in the Arctic) and oil & gas (Arctic oil spills).
EO Crowd	Over 90% of our seas are unsurveyed. EO Crowd uses crowd sourcing, EO data and open data to fill this data gap.
SaMoLoSa FS	The Ovinto SaMoLoSa study addresses the use of satellite technology for the reduction of transport risk, security enhancement and optimisation of logistic operations by the tracking and monitoring of extremely dangerous goods in unpowered, mobile transport units such as rail tank cars and intermodal tank containers.
SEA SEARCH	SeaSearch provides detection and identification capabilities of small vessels, agnostic to vessels' size. Based on the mobile phone detectors and other sensors such as radars, AIS and SAR, SeaSearch builds Maritime Situational Awareness Pictures.
EUROPORT Demo Project	Ports are fundamental and main part of inter-modal global transport in the world. The growth in freight transport stresses the existing infrastructure to its limits. There are already considerable signs of congestion in the European transport system, e.g. on the roads and in harbors. Congestion will have a negative impact on the costs and time of transportation, which affects the prices and the quality of products.
METSAR	The METSAR project objective is to investigate the feasibility of developing and demonstrating a new concept to the Search and Rescue (SAR) community.
ISABELIA	The ISABELIA Feasibility Study specified and validated the sustainability of services and that would provide users at sea with near real time information on dangerous ice situations, indicators of collision risk and on risk of grounding, thereby improving the safety of vessels in the Baltic Sea.
CAESAR	The CAESAR feasibility study, finished in March 2014, focused on a service able to provide detailed and timely information on the weather and marine conditions to the maritime Search and Rescue (SAR) coordination centres, with the aim of reducing the risks and improving the efficiency of SAR operations.
SAMBA	The objective of SAMBA is to establish feasibility of space-based services for maritime emission monitoring.
I-Fish North Sea	I-fish North Sea aims to provide an integrated information and communications system that will utilise a combination of satellite communications and satellite navigation to enable unified timely and accurate collection, management, and use of marine fisheries data to provide value added services to fisheries stakeholders for improved sustainability of our fast depleting fisheries resources.
FISHSAT	FISHSAT is conceived as a system of systems employing space assets (Earth Observation, Satellite Navigation and Satellite Communication) to improve collaboration between markets, fisheries and enforcement authorities. The intended benefit of FISHSAT is to increase the efficiency of fishing activities, match better the market demand, improve catch traceability and strengthen enforcement.
SEMAFORS	SEMAFORS, the Ship Efficiency Monitoring, weAther Forecasting and Optimised Routing Service is a user focused project in support of the shipping industry.SEMAFORS will investigate, establish and demonstrate through sea trials a concept to improve ship fuel efficiency by providing the means to better planning, avoiding of adverse weather and by making better use of ocean currents.
EASY feasibility study	The objective of the EASY feasibility study has been to carry out an analysis of the technical feasibility and commercial viability of “one-stop-shop” services to the high value leisure yachting market mainly but not limited to the Mediterranean Sea, integrating various space assets (Satellite Communications, Satellite Navigation, Earth Observation).

counter-proliferation and terrorism/organized crime, all of which have a maritime surveillance component. ESA's EO activities include also a number of regional Initiatives for several European regions including Atlantic, Black Sea, Baltic Sea and Mediterranean.

The Copernicus Marine Environment Monitoring Service delivers information on the physical and biogeochemical state and dynamics of the ocean to help protect and manage the marine environment and resources more effectively. The Copernicus Marine Service supports four main domains: a) Marine safety, b) Marine resources, c) Marine and coastal environment, d) Seasonal and weather forecasting. Based on the provision of satellite imagery and data from the Sentinel constellations and contributing missions, this service processes observation data into quality-controlled datasets at various thematic data assembly centres and runs numerical ocean models in near-real time. The data are assimilated to generate analyses and forecasts for different regions, namely, the Arctic Ocean, Baltic Sea, Atlantic European North West Shelf Ocean, Atlantic Iberian Biscay Irish Ocean, Mediterranean Sea, Black Sea, and for the global ocean [41].

ESA's Copernicus Services relevant to the marine environment include monitoring for marine safety and transport, oil-spill detection, water quality and the polar environment [42]. In particular, it provides satellite based services to efficiently detect illicit discharges, identify polluters and track evolution of oil spills. In particular, Satellite-based oil spill detection captures the dimension of oil spills, allows pollution

control authorities to initiate actions before the oil drifts on-shore, helps to detect illegal discharge and to organise recovery activities [43]. In addition, Copernicus satellites operationally monitor European coastal waters to provide regular geospatial up-to-date information on the state of the global ocean and European regional seas. This supports water quality monitoring and the management of water resources in coastal zones. The main advantage of satellite data is in supplying synoptic information about bathing water quality for a whole region at low cost and appropriate frequency, complementing in-situ measurements [44]. Copernicus satellites also protect the oceans by a) providing key information for correcting models that predict accumulation of marine litter. b) supporting research on marine litter by providing expeditions to the great ocean garbage patches with forecasts of sea currents and sea-surface heights. This optimises ship routing to locate plastic convergence areas [45]. Furthermore, Copernicus satellites assist polar expeditions by tracking and forecasting sea-ice spread and thickness, through rapid support for ice-trapped vessels, by providing precise up-to-date information to better planning and adapting polar expedition routes such us the location of ice edges and open water as well as the ice type and its concentration along the vessel's route [46]. Copernicus, using satellites data assists also in jellyfish prediction by providing information on the state and dynamics of the ocean including a range of physical and biological ocean parameters that favour jellyfish blooms [47]. It also delivers continuous, reliable and accurate information about the extent and effects of sea-level rise in Europe's low-lying coastal areas thereby supporting coastal management activities and adaptation measures [48]. By providing frequently updated global data for satellite-based services, Copernicus contributes to the protection of marine environment and sustainable fisheries policies [49]. It also supports the sustainable management of marine aquaculture sector to develop and unlock its remarkable growing potential [50]. Additionally, Copernicus and EO satellites play a significant role in the early detection and monitoring of harmful algal blooms in marine ecosystems, affecting aquaculture and human activities [51], while it also supports maritime navigation, marine safety and ship routing including icebreakers sent to rescue stranded ships, in the ice-infested waters of the Arctic and Baltic Seas [52].

4.2. Telecommunication and Integrated Applications

ESA has helped coastal authorities through AIS (Automatic Identification System) to track up to 70% more ships and pick up nearly three times more ship positions via satellite than was possible before. AIS transmits the course and speed as well as identification and position information to other vessels and shore stations. Originally developed to prevent collisions, it also tracks ships to help prevent pollution, aid in the movement of dangerous goods, and promote routine surveillance [53].

ESA's EDRS (European Data Relay System) allows maritime customers to track their ships in near-real time [54]. ESA's is also promoting SAT-AIS (Satellite Automatic Identification System) systems, technologies and services in partnership with the European Maritime Safety Agency. This is part of ESA's Advanced Research in Telecommunications Systems (ARTES) which permits identification and track seafaring vessels all over the world, covering the oceans and the Antarctic [55]. Following the signature of an Administrative Arrangement in 2011 between ESA and the European Defence Agency (EDA) the two agencies agreed to pursue their cooperation in the domain of Remotely Piloted Aircraft Systems (RPAS) with the signature of the DeSIRE II Project Arrangement. This project's objective is to demonstrate that services, such as environment and maritime surveillance applications, can be rendered with RPAS flying beyond radio line of sight through the use of safe and secure satellite-based command and control data links [56]. Additionally, a number of EMSA's capabilities (such as MARISS and CleanSeaNet, mentioned above) have been extended by various ARTES projects to use VMS, satellite AIS and coastal AIS data to track movements of vessels.

ESA and Rolls-Royce signed a Memorandum of Intent (MOI) with Rolls-Royce on 30 November 2017, as the two entities agreed to investigate how space technology can be used in support of autonomous, remote controlled shipping and promoting innovation in European digital logistics [57]. The collaboration with the Rolls-Royce Ship Intelligence division aims to develop and validate new ship-to-shore integrated land-based and satellite-based systems solutions, which ESA has been working on for some time under its Satellite for 5G (S45G) initiative. S45G aims at developing and demonstrating integrated satellite- and terrestrial-based 5G services, across multiple vertical markets and various use cases. The 5G next generation of communication services will rely on this harmonious integration of networks, driving a convergence of fixed and mobile services, including satcom services. ESA is supporting the technological and supply chain evolutions that are required to weave together terrestrial and space services, with a focus on the transport sector (maritime, aviation and land base), and on other vertical markets like public safety and media. This unified space-and-ground service is what will enable the operation of commercial autonomous shipping, as well as drive innovation in future commercial marine vessels, cargo logistics and smart ports. The two partners agreed to cooperate to test, validate and innovate on satcom connectivity technologies and applications between vessel and shore, as well as support the testing and modelling of the safety-critical software that would make self-operated ships viable [58].

4.3. Navigation

ESA Navigation activities provide fundamental tools for bringing innovation and progress in a number of marine activities such as fishing, oceanography and oil and gas exploitation. Satellite navigation benefits all maritime applications, including leisure boats, commercial vessels, and unregulated and Safety of Life at Sea (SOLAS) regulated ships. Each application can take advantage of the characteristics offered by EGNOS and Galileo: increased accuracy and integrity, certified services and high availability. EGNOS and Galileo can be used in every phase of marine navigation: ocean, coastal, port approach and port manoeuvres, under all weather conditions [59].

Additionally, ESÁ's PNT (positioning, navigation and timing) technology contributes to IMO's strategy for e-Navigation defined as *"the harmonized collection, integration, exchange, presentation and analysis of marine information on board and ashore by electronic means to enhance berth to berth navigation and related services for safety and security at sea and protection of the marine environment."*. [60] ESA's NAVISP programme [61], element 1 on Innovation in satellite navigation provides the following three opportunities: a) Multipath & Interference Error Mitigation Techniques for Future Maritime e-NAV Services [62], b) Multi-System Multi-Sensor Maritime PNT Test Equipment [63], and c) Artificial Intelligence/Machine Learning Sensor Fusion for Autonomous Vessel Navigation [64].

4.4. Technology

ESA is part of an ambitious effort to upgrade an existing VHF system to provide wide-bandwidth two-way communications to all mariners. The name of this successor system is the VHF Data Exchange System, or VDES for short. ESA is supporting Member State industrial partners who are contributing to working groups at the IMO and the International Association of Marine Aids to Navigation and Lighthouse Authorities to develop it and prove its feasibility. The system would enhance vessels' situational awareness, allowing mariners to downlink updated charts of ice and other hazards, to transmit information such as ships' manifests to shore, or to pass augmented navigation signals to the Arctic: the north polar region beyond the reach of Europe's EGNOS (European Geostationary Navigation Overlay Service) – whose satnav-sharpening signals are transmitted via geostationary satellites – around the curve of

Table 3
Space and the Maritime sector –Potential Areas of Interest.

	Needs of Public Sector	Development of Domestic Industry	Integration of space technologies and applications
Development of shipping equipment for commercial use		✓	✓
Monitoring fishing activities	✓	✓	✓
Maritime and Coastal surveillance	✓	✓	
Monitoring illegal activities/tracking possible targets - e.g. for smuggling	✓	✓	
Applications for tackling SAR cases efficiently	✓	✓	
Monitoring sea traffic/tackling of possible risks at navigation	✓	✓	✓
Smart logistics applications using satellite based services on maritime environment			
New space technologies and products in robotics and automation (to support Autonomous Ships, cooperation between manned and unmanned ships (Machine2Machine)			
Green energy technologies for maritime (lighter and robust materials, green propulsion technology, environmental friendly materials)			
Support to renewable energy at sea	✓		
Reliable, secure and high bandwidth SATCOM for maritime use			
Space based services for increased maritime safety and natural disasters prevention			
Understanding and monitoring of the ocean and atmosphere status and evolution, weather, climate			
Sustainable economic development of the islands			

Earth [65].

4.5. ESA - EMSA Agreements

An agreement was signed in March 2007 between the European Space Agency (ESA) and the European Maritime Safety Agency (EMSA), strengthening the framework for cooperation in the field of maritime monitoring and surveillance. Under this arrangement, EMSA would be supported by ESA on issues relating to the development of space technologies for maritime monitoring and surveillance. In the light of its role as a long term operational European user of satellite technology, EMSA would advise ESA on user requirements for new space systems and infrastructure [66].

In July 2010, ESA and the European Maritime Safety Agency signed a further Agreement to ensure that satellite data are available to enhance maritime safety and help combat pollution from shipping. The signing of this Agreement further strengthened collaboration between ESA and EMSA for the development and use of space-based technologies with respect to keeping European seas safe [67].

4.6. Space and Maritime Initiative

A “Space and Maritime” initiative [69] was established by the European Space Agency in 2018, under the leadership of Greece and upon request of the same country. ESA had already established before an initiative on Atlantic, led by Portugal. For the “Space and Maritime” initiative, a dedicated internal task force has been created which was tasked among other to identify areas of interest for Greece and the other interested ESA Member States as well as ESA's programmes that would be concerned. This initiative will be consistent and complementary to the already existing Arctic [70] and Atlantic Initiatives of ESA [71]. Additionally, this initiative has been announced by the Greek Prime Minister during a public speech in June 2018 [72] and by the Greek Minister of Digital Policy, Telecommunication and Media during his speech at the Hellenic Parliament's Committee on Research and Technology in the same month [73]. Some potential areas of interest of Space addressing the Maritime sector are summarized in Table 3.

5. Concluding remarks

Maritime is vital for many human activities and maritime activities continuously expand, bringing benefits for people across the world. Space assets can contribute to achieving maritime policy objectives mainly via navigation, earth observation and telecommunication assets and applications, with specific purposes identified in the paper. Additionally, the efficiency of traditional maritime activities can be increased through space technologies. Space tools and applications can contribute, among others, to the sustainability of the maritime environment and its natural resources as well as the efficiency in shipping and the security and safety in the maritime environment. As such, satellite technology is becoming increasingly important for a wide range of maritime activities. A number of ESA's initiatives and programs already serve the outlined maritime/fisheries policy objectives. These can be identified across ESA's programmatic activities in its various directorates, including mainly earth observation, telecommunications and integrated applications and navigation. This reaffirms the crucial role of space assets and applications in achieving maritime policy purposes. However, the efforts made for the role of space in support of maritime policy should be continued and strengthened to deal with short and long term technological challenges in the maritime sector.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actaastro.2019.06.017.

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