

Workshop on electronic technologies for fisheries

Part I: Transmitted positional data systems



Fisheries



RESEARCH FOR PECH COMMITTEE

Workshop on electronic technologies for fisheries

Part I: Transmitted positional data systems

Abstract

This study is the first research paper in a series of three, prepared for a PECH Committee Workshop. It reviews the state of the art of transmitted positional data systems, high resolution and synthetic aperture radar (SAR) for satellite image data used in fisheries control and fisheries research. It identifies the strengths and weaknesses of such systems and provides policy recommendations for a more effective fisheries control system based on currently applied electronic technologies (ET).

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CONTENTS

LIST OF ABBREVIATIONS	5
LIST OF FIGURES	7
LIST OF TABLES	7
EXECUTIVE SUMMARY	9
1. STATE OF PLAY OF TRANSMITTED POSITIONAL DATA SYSTEMS	12
1.1. Global Navigation Satellite Systems	13
1.2. NAVSTAR Global Positioning System	15
1.2.1. GALILEO	17
1.2.2. Other GNSS systems	18
1.3. Marine monitoring solutions based on GNSS data	18
1.3.1. Vessel monitoring system	18
1.3.2. Automatic identification system	18
1.4. Marine monitoring solutions based on satellite remote sensing (SRS)	20
1.4.1. Very high resolution remote sensing	20
1.4.2. Synthetic aperture radar	21
2. CURRENT APPLICATIONS USING TRANSMITTED POSITIONAL DATA SYSTEMS	23
2.1. Applications using a vessel monitoring system	23
2.1.1. The EU vessel monitoring system for fisheries control.	23
2.1.2. The US vessel monitoring system for fisheries controls	25
2.1.3. Use of VMS data in fisheries science in the EU	26
2.1.4. Use of VMS data in fisheries science in the United States of America	29
2.2. Applications using an automatic identification system	29
2.3. Applications using satellite remote sensing	31
2.3.1. European Maritime Safety Agency - Copernicus Maritime Surveillance	31
2.4. Applications combining different data sources	34
2.4.1. EMSA Copernicus Maritime Surveillance – Vessel Correlation Service	34
2.5. Private companies offering applications using satellite remote sensing (SRS)	35
3. BENEFITS AND RISKS OF TRANSMITTED POSITIONAL DATA SYSTEMS	37
3.1. Vessel monitoring system	38
3.1.1. Strengths of VMS	38
3.1.2. Weaknesses of VMS	38
3.2. Automatic identification system	39
3.2.1. Strengths of AIS	39

3.2.2. Weaknesses of AIS	40
3.3. Satellite remote sensing	41
3.3.1. Strengths of SRS	41
3.3.2. Weaknesses of SRS	41
3.4. Applications combining different data sources	42
3.4.1. Strengths of applications combining different data sources.	42
3.4.2. Weaknesses of applications combining different data sources.	42
3.5. Conclusions	43
4. POLICY RECOMMENDATIONS	44
4.1. Positional data devices	45
4.2. Emission time	45
4.3. Personal data protection	45
4.4. Satellite remote sensing and positional data	45
REFERENCES	46

LIST OF ABBREVIATIONS

3D	Three Dimensional
ADS	Activity Detection Service
AIS	Automatic Identification System
BDS	BeiDou Navigation Satellite System
CFP	Common Fisheries Policy
CMS	Copernicus Maritime Surveillance
MSFD	Marine Strategy Framework Directive
ECDIS	Electronic Chart Display and Information System
EEZ	Exclusive Economic Zone
EFCA	European Fisheries Control Agency
EMSA	European Maritime Safety Agency
ESA	European Space Agency
ET	Electronic Technologies
EO	Earth Observation
EU	European Union
EVS	Enriched Vessel Service
FDS	Feature Detection Service
FMC	Fisheries Monitoring Center
GFW	GFW Global Fishing Watch
GLONASS	Global'naya Navigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IMO	International Maritime Organisation

JDP	Joint Deployment Plans
LRIT	Long Range Identification and Tracking
MCS	Monitoring Control and Surveillance
MMSI	Marine Mobile Service Identification
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSP	Marine Spatial Planning
NOAA	National Ocean and Atmospheric Agency
OLE	Office of Law Enforcement
S-AIS	Satellite Automatic Identification System
SAR	Synthetic Aperture Radar
SWOT	Strengths, Weaknesses, Opportunities and Threats
TPDS	Transmitted Positional Data System
US	United States
USA	United States of America
VCS	Vessel Correlation Service
VDS	Vessel Detection Service
VHF	Very High Frequency
VHR	Very High Resolution
VHRRS	Very High Resolution Remote Sensing
VMS	Vessel Monitoring System
VTs	Vessel Traffic Service

LIST OF FIGURES

Figure 1: GNSS constellation systems	14
Figure 2: GNSS development timeline	14
Figure 3: Infographics explaining how GPS works	16
Figure 4: Key elements of a Galileo Full Operational Capability satellite	17
Figure 5: AIS conceptual operation view	19
Figure 6: Ikonos data showing the very high resolution of current images from remote sensing	20
Figure 7: Synthetic aperture principle	21
Figure 8: Classical ship wake pattern in SAR imagery	22
Figure 9: Data flow of the EU VMS system	24
Figure 10: Estimated fishing activity of UK vessels by trawl gear types	27
Figure 11: Workflow of AIS data from emission to the Global Fishing Watch website	29
Figure 12: Fishing effort of all fishing vessels present in European waters, January 2021	30
Figure 13: Support of fisheries control through Copernicus Maritime Surveillance Service	31
Figure 14: Example of vessel detection and detail of correlated vessel.	32
Figure 15: Example of Feature Detection System showing fish cages	33
Figure 16: Example of activity detection, in this case vessel search and rescue	34
Figure 17: Example of vessel in a SRS image correlated to AIS data	35
Figure 18: Squid fishing off the coast of Argentina	36

LIST OF TABLES

Table 1: Estimation methods for spatial distribution of fishing activities through VMS data	28
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EXECUTIVE SUMMARY

KEY FINDINGS

- The use of the current **vessel monitoring system (VMS)** for fisheries control and scientific advice for fisheries management is being replaced on some occasions by the **automatic information system (AIS)** due to data access problems and excessive time laps between transmissions.
- Although **AIS provides more information** due to its higher frequency of emissions, it does not have the same reception coverage and the same legal coverage. The application of AIS is required for **maritime safety** reasons and not for fishing control.
- Newly developed **electronic technologies (ETs)** for merging positional data with satellite images provide excellent data for both fisheries **monitoring & control** and fisheries **research**. However, these data are not always available due to the low number of daily images taken of a specific area or to the high price of such data fusion services.

Background

This study examines the existing ETs based on the collection of **positional data** as well as the respective **transmission systems**, which are both applicable for purposes of **fisheries control** and **research**. It also reviews **space-based** ETs providing very **high resolution images**, and assesses the potential of data fusion techniques, through merging positional data and satellite image data.

Finally, strengths, weaknesses, opportunities and threats (**SWOT**) of the different ETs were scrutinised with a view to achieve an improved **monitoring of fishing activities** in the fields of fisheries control and research.

Transmitted positioning systems currently available

Currently, **four global positional data systems exist**, which are owned by the United States, the European Union, Russia and China. They all use the same **receivers** as those installed in any common cellular phone, and indicate the **position of a vessel**. The data can be easily ascertained with very high accuracy.

A second type of spaceborne sensors used for fisheries control are the **very high resolution sensors**. This technology is based on the inspection of the **visual spectrum** or on **synthetic aperture radars** using microwave. Both systems can achieve **high-resolution images** of fishing vessels and are currently used for fisheries **control** and **research**.

In the European Union, the compilation of satellite images for **fisheries control** is done by the **Copernicus** Maritime Surveillance Service. It is also used by the European Fisheries Control Agency (**EFCA**) in collaboration with the European Maritime Security Agency (**EMSA**).

Applications for transmitted positioning systems

Positional data are used primarily to **study fishing effort and effects** of fishing on marine habitats, but also to support marine spatial planning activities. Regarding **fisheries control**, it is imperative to

know the **vessel's position** to understand **if, where** and **what** it is fishing and **whether** it is fishing in the areas for which it is **licensed**.

Two of these applications currently exist and are used in fisheries **control and research**: the **vessel monitoring system** (VMS), which was introduced in 1997 for fisheries position control, and the **automatic identification system** (AIS), which was introduced in 2002 for maritime navigation security. As a result, still today **VMS** is predominantly used for **control** purposes, while **AIS** is more frequently used by **fisheries researchers** due to its higher emission frequency and accessibility.

This report also presents **newly developed satellite imaging systems** and their use in connection with positional data. These systems are currently being used for fisheries control aiming to detect inter alia catch **transshipment** or the **position of boats** that have **turned off** their **VMS and/or AIS**.

Analysis of the different options

VMS and AIS are both **mature technologies** whose **accuracy has improved** over time from the first only prevailing global positional data system to the current multisystem scenario.

VMS has a more **robust transmission technology** using satellite communications, which make it very difficult to lose data. Nevertheless, long time-laps between the emissions of data create caveats for control and fisheries research.

AIS is more precise, as it has a **higher transmission frequency** due to its purpose of preventing collisions at sea. However, it transmitting to land receivers proves often to be difficult. In fisheries AIS data are used for ex-post analysis due to being a secondary use of generated data.

Very **high resolution satellite images** provide very valuable information, which is even more useful when combined with **positional data**. However, its main weakness are the longer time-laps between images taken of the same ocean sector.

All the data sources present concerns and problems regarding current data privacy and personal privacy rules, which need to be addressed.

Policy recommendations

Many of the newly developed satellite-driven electronic technologies based on positional data are being used with great success. However, they cannot fully substitute traditional VMS yet, since the spatio-temporal coverage of the fishing grounds is not sufficient and still depends on meteorological conditions.

Based on the present analysis the following policy recommendations can be given:

- **Extent the obligation to use tracking devices** in commercial fishing vessels to the maximum possible consensus.
- **Increase the accuracy of VMS positional data** so it can be of a similar magnitude as the actual data provided by current GNSS systems (20 metres). The enforced precision indication of 500 metres was intended for the GPS capabilities of the late 20th century and not for current GNSS systems like Galileo which enable accuracies of 20 metres at 99% confidence with free receivers such as those used in mobile phones.
- **Reduce the VMS emission time** of both data types to ten minutes (instant transmission) and one minute (stored data or delayed transmission), respectively. As our review of scientific literature suggests, this could be achieved and would be ideal, both for fisheries research and control. Nowadays cheaper means of transmission, as well as technologies capable of storing

and transmitting huge volumes of data exist. In this way sufficient spatio-temporal resolution to apply automated algorithms for detecting fishing activities could be achieved.

- Take the necessary actions to **grant access to the generated data** to control bodies and scientific advisors for fisheries management while preserving the personal privacy of fishers.
- **Follow-up on** the work started recently, by **combining VMS, AIS and VHR/SAR images** as complementary to the VMS data.

1. STATE OF PLAY OF TRANSMITTED POSITIONAL DATA SYSTEMS

KEY FINDINGS

- Two kinds of **orbiting systems** are mainly suitable for fisheries research, fisheries management and enforcement of legal measures protecting marine ecosystems:
 - a) systems enabling calculation of a **vessel's positional data** coupled to different kinds of onshore/satellite receivers; and
 - b) the use of **satellite remote sensing** with very high resolution (VHR) images of the visual spectrum or synthetic aperture radars (SARs) that detect vessels from space.
- **Positional** systems are based on **mature technologies**, with a proven history of successful data delivery, and have been used for decades in **fisheries control**.
- **Satellite** remote sensing and the use of visual or radar images is **more recent**; its results in **fisheries control** are promising, **complementing** the use of positional data.

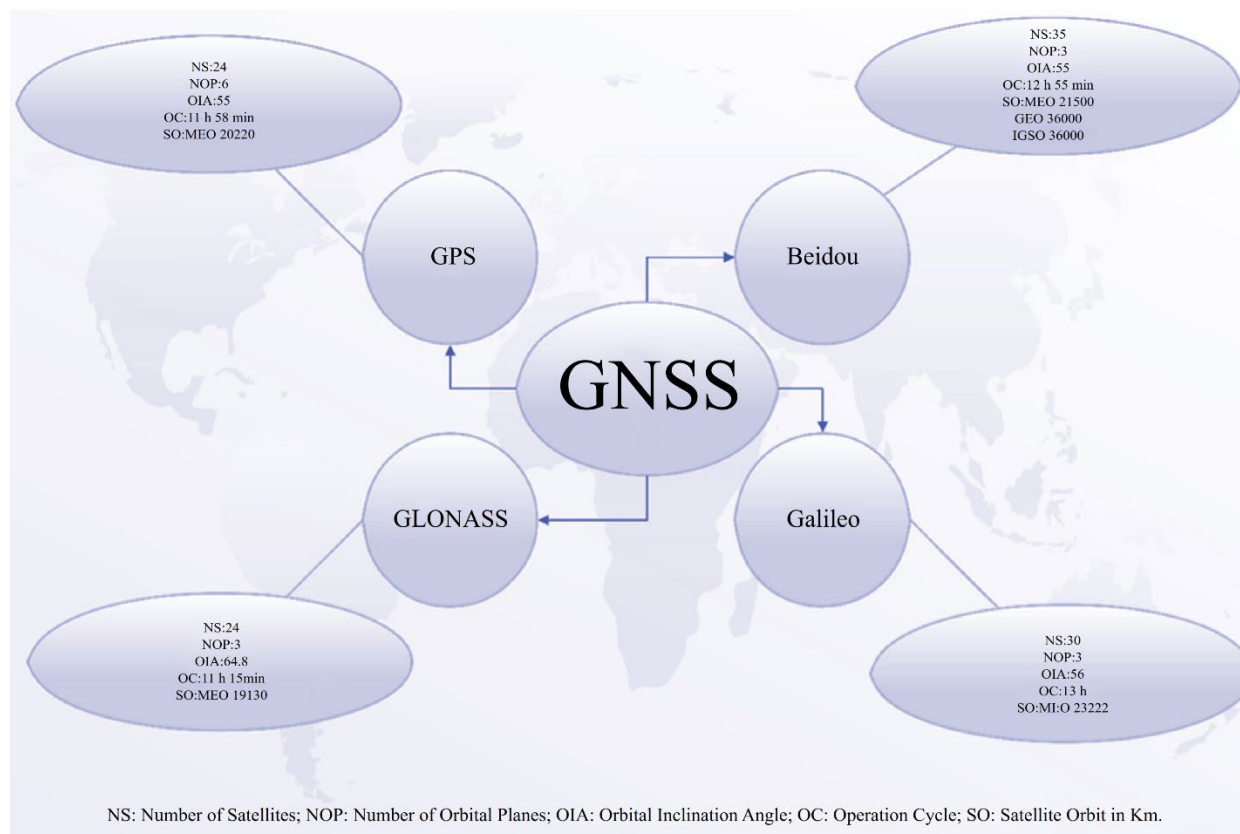
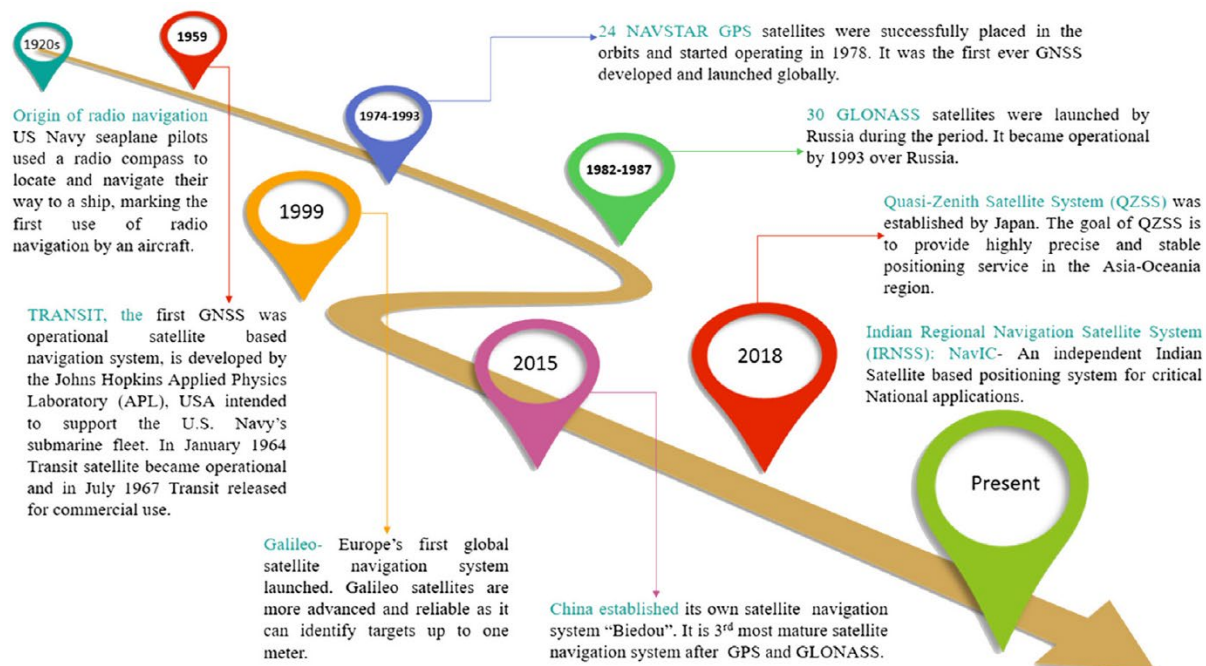
1.1. Global Navigation Satellite Systems

A global navigation satellite system (GNSS) involves a constellation of satellites orbiting Earth, which are continuously transmitting signals that enable users to determine their three-dimensional (3D) position with global coverage (Sanz Subirana et al. 2013; Kumar et al. 2021a).

Examples of GNSS include Europe's Galileo, the United States of America's NAVSTAR Global Positioning System (GPS), Russia's Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS) and China's BeiDou Navigation Satellite System (Figure 1) (GSA 2021; Kumar et al. 2021a).

A diagram of the historical development of global navigation from (Kumar et al. 2021b) is shown in Figure 2.

The positioning principle is based on solving an elemental geometric problem, involving the distances (ranges) of a user to a set of at least four GNSS satellites with known coordinates (Kumar et al. 2021b). These ranges and satellite coordinates are determined by a receiver using the signals and navigation data transmitted by the constellation of satellites; the resulting coordinates can be computed to an accuracy ranging from several metres to centimetre level when using more advanced techniques (Sanz Subirana et al. 2013).

Figure 1: GNSS constellation systemsSource: (Kumar *et al.* 2021a)**Figure 2: GNSS development timeline**Source: Kumar *et al.* 2021b

1.2. NAVSTAR Global Positioning System

GPS is an American space-based navigation system which enables calculation of a three-dimensional position to about a metre of accuracy (e.g. latitude, longitude and altitude). It further provides nanosecond-precise time anywhere on Earth where there is a direct line of sight to at least three GPS satellites. It operates independently of any telephonic or internet reception, providing critical positioning capabilities to military, civil, and commercial users around the world.

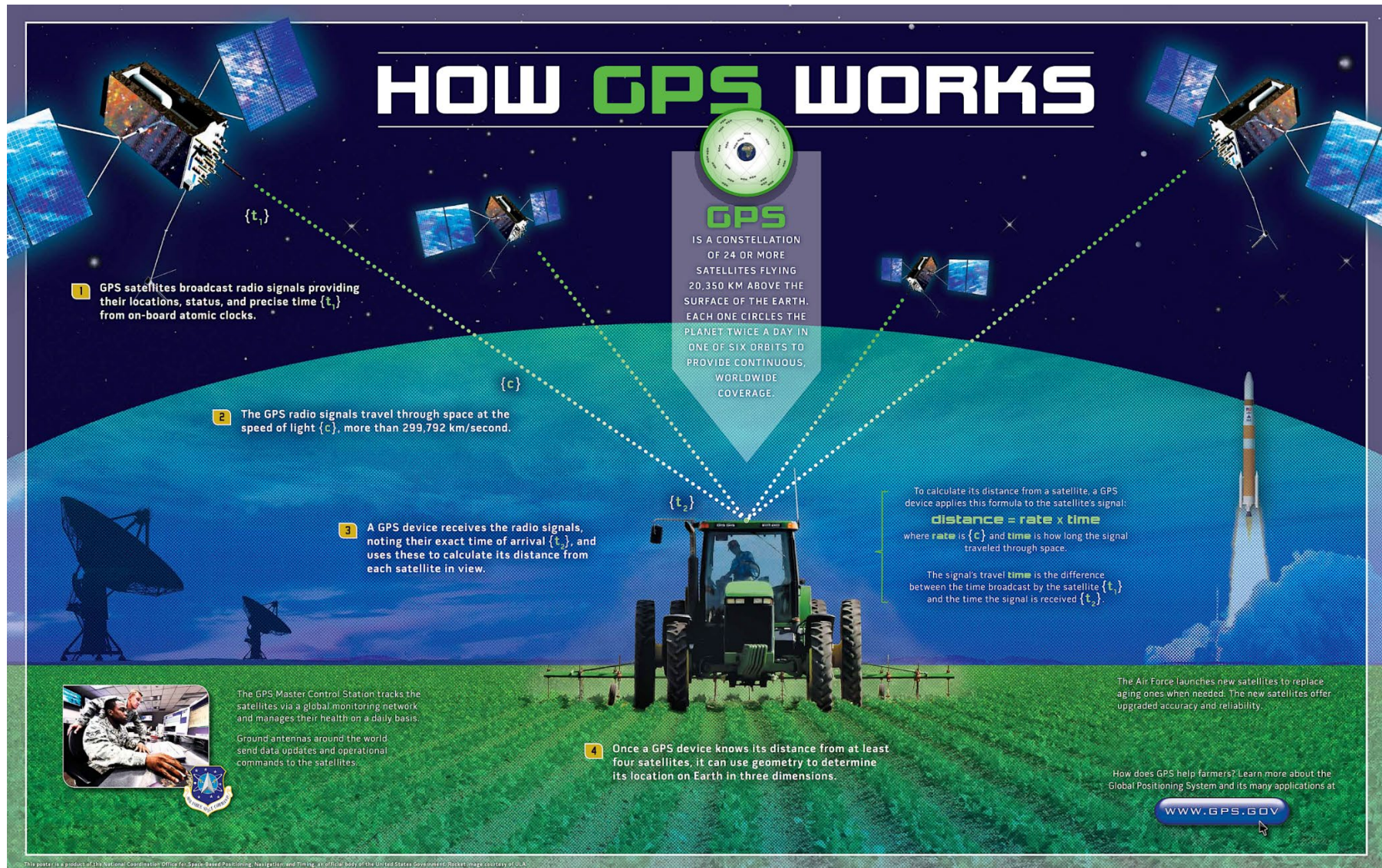
As with any other GNSS, GPS consists of three different parts (Sanz Subirana et al. 2013), see Figure 3:

- **Space Segment:** a constellation of at least 24 satellites owned by the US government distributed in six orbital planes in a medium Earth orbit at about 20,200 kilometres, circling the Earth every 12 hours;
- **Control Segment:** land stations monitoring and maintaining the satellites;
- **User Segment:** the receivers that process the navigation signals from the satellites and calculate position and time.

In the early 1970s, the United States Department of Defence sought to implement a robust, secure satellite navigation system. Adopting previous ideas from United States Navy scientists, the Department of Defence decided to use satellites for their proposed navigation system. The first GPS satellite was launched in 1978 and the GPS system became fully effective in 1993 (Mai 2017b).

Today, GPS is a multiuse, space-based navigation system owned by the US government and operated by the United States Air Force to meet national defence, homeland security, civil, commercial and scientific needs (Mai 2017a).

Figure 3: Infographics explaining how GPS works



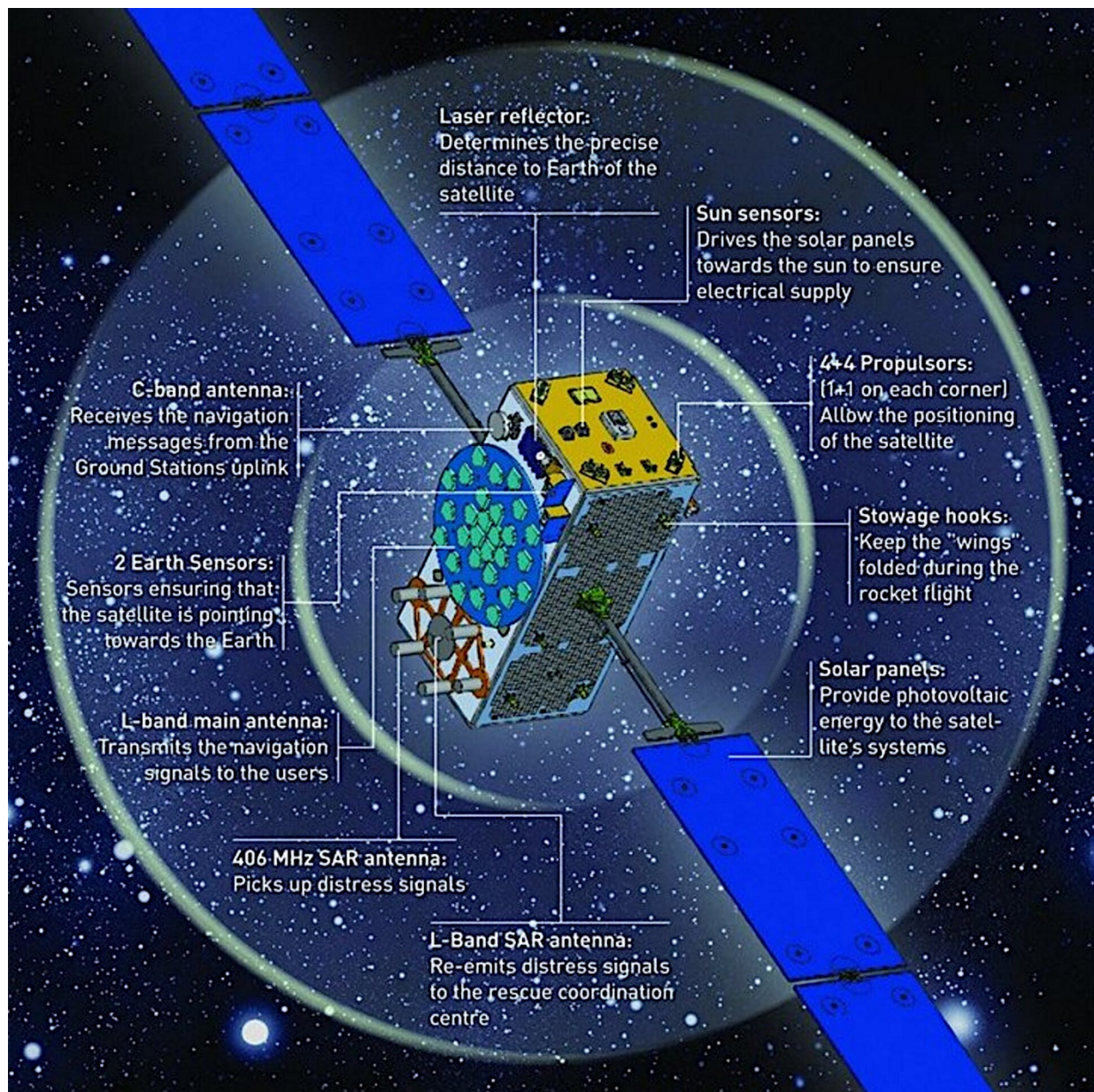
Source: <https://www.gps.gov>

1.2.1. GALILEO

The European Union is the main sponsor and the owner of Galileo, according to current regulations. Whereas the program was financed jointly with the ESA in its early stages, full deployment has been financed with European Union budget funds. As the executive arm of the European Union, the European Commission is the program manager (Javier Pérez Bartolomé et al. 2015).

Galileo is a complete GNSS. Since becoming operational in 2016, it has aimed to provide an independent high-precision positioning system so that the European Union and other nations do not have to depend on systems owned and controlled by other countries (Javier Pérez Bartolomé et al. 2015), which can degrade or shut off their systems at any time.

Figure 4: Key elements of a Galileo Full Operational Capability satellite



Source: https://www.esa.int/Applications/Navigation/Galileo/Satellite_anatomy

Full operational capability of Galileo was predicted for late 2019. However, this goal was only reached at the end of 2020 (Nurmi. J et al. 2015). The next generation of satellites (Figure 4) is set to become

operational after 2025, replacing older equipment that may begin developing technical problems due to ageing (Lohan 2015).

The Galileo system's accuracy is greater than its US counterpart GPS. Galileo is accurate to less than one metre when using broadcast ephemeris (GPS: three metres) and 1.6 centimetres when using real-time corrections for satellite orbits and clocks (Lohan 2015).

1.2.2. Other GNSS systems

Russia's **GLONASS** or Global Navigation Satellite System is another space-based satellite navigation system (Kumar et al. 2021a). It provides an alternative to GPS and GALILEO and was the second navigational system in operation, with global coverage becoming fully operational in November 2011 (Nurmi J. et al. 2015).

The **BeiDou Navigation Satellite System (BDS)** is the Chinese GNSS. The Compass or Beidou-2 GNSS is being developed by China and has a regional and a global component (Nurmi. J et al. 2015). BDS currently provides global coverage for timing and navigation, offering an alternative to the other systems (China 2016).

1.3. Marine monitoring solutions based on GNSS data

1.3.1. Vessel monitoring system

Advances in **satellite tracking technologies** have moved very quickly over the past 25 years, though tracking of fishing vessels did not attract much attention until the mid-1980s, when satellite technology became commercially viable for tracking purposes (FAO 1998). About 1991, several fisheries agencies began investigations and trials that ended with the implementation of different **vessel monitoring systems (VMSs)**.

VMS is a general term for systems that are used on board commercial fishing vessels to allow control agencies to track and monitor fishing activities. VMS is nowadays a key part of the **monitoring, control and surveillance (MCS)** systems of almost all the countries involved in world fisheries (FAO 1998).

The exact function of VMS varies among countries, but all have several **common characteristics**.

- it provides **position information** to the control agency in near to real time;
- it can also provide **speed and heading** or they can be computed by the control agencies;
- the vessel operator can indicate the **start and end of fishing operations** and transmit other codes (i.e. entering a port or fishing zone) (FAO 1998).

The term VMS is only used for systems controlling the activity of fishing vessels and should not be confused with **vessel traffic services (VTS)** such as the **automatic identification system (AIS)**, which are marine traffic monitoring devices focused on safety in ports and busy waterways.

1.3.2. Automatic identification system

The International Maritime Organisation's International Convention for the Safety of Life at Sea requires that the **automatic identification system (AIS)** be fitted on board international voyaging ships with 300 or more gross tonnage and on all passenger ships regardless of size (IMO 1980). For various reasons, ships can legally turn off their AIS transceivers, mainly when navigating in risky zones with a persistent pirate presence.

AIS is one of the first **open-standard data-broadcast communication systems** on board ships. It operates in the VHF maritime band and has been adopted within the global maritime environment as a vessel traffic service (Chaturvedi 2019). AIS data exchange supplements human use of **marine radar**, which is still the primary method of preventing vessel collisions.

An approved AIS must transmit **different message types**, including ship data, required by the International Maritime Organisation (IMO) performance standards, as follows (IMO 1980):

- Static and voyage related data (name and call sign, MMSI (maritime mobile service identification), size, type, draught and route plan, etc.);
- Dynamic information (ship position, time of data transmission, course over ground, speed over ground, heading, rate of turn, pitching and yawing, etc.).

AIS transceivers can be tracked by other AIS transceivers on board a different vessel or marine platform or by **AIS base stations** located along coastlines or through a growing number of satellites that are fitted with special **AIS receivers** that can decode a large number of signatures (Perez et al. 2009), see Figure 5.

Studies and experiments are in progress for the reception of **AIS signals from space** by small low-Earth orbit constellations (Chaturvedi 2019) this will improve the AIS reception when a vessel is far from coastline AIS base stations; when satellites are used to detect AIS signatures, the term **Satellite-AIS (S-AIS)** is used.

Figure 5: AIS conceptual operation view



Source: Perez et al. 2009

1.4. Marine monitoring solutions based on satellite remote sensing (SRS)

Among all the **spaceborne sensors** deployed so far, two are especially appropriate for **vessel detection** and **tracking**. Their main characteristics and capabilities are explained below.

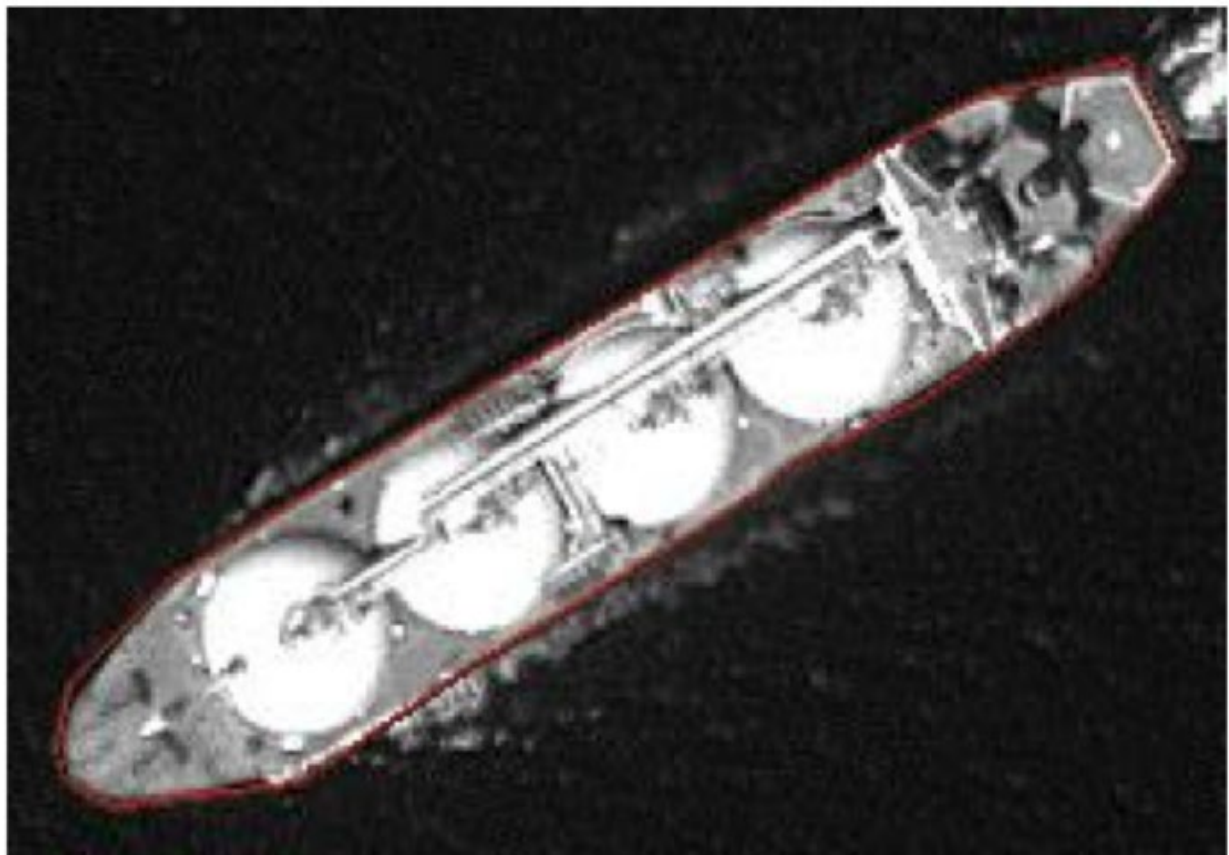
1.4.1. Very high resolution remote sensing

A **very high resolution** (VHR) remote sensing satellite is an orbiting satellite mounting optical sensors that provide multispectral and panchromatic images at resolutions from 50 metres (1 pixel = 60 metres) to less than 1 metre.

Ikonos was the first commercial high-resolution satellite sensor (1999) to break the one metre mark (see Figure 6). Since then, many other very high resolution (VHR) satellites have been launched (Eugenio & Marcello 2018). Another important milestone was the launch in 2009 of **WorldView-2**, the first commercial non-military VHR satellite to provide eight spectral channels in the visible to near-infrared range.

Images from these **commercial satellites** can be used to detect and track vessels, mainly in **inland waters**, since there are **still few VHR-capable satellites watching the open sea**. Most of the companies that own VHR satellites have divisions or subsidiary companies which provide paid access to raw images or products derived from analysis of VHR images.

Figure 6: Ikonos data showing the very high resolution of current images from remote sensing



Source: SpacelImaging, Europe

1.4.2. Synthetic aperture radar

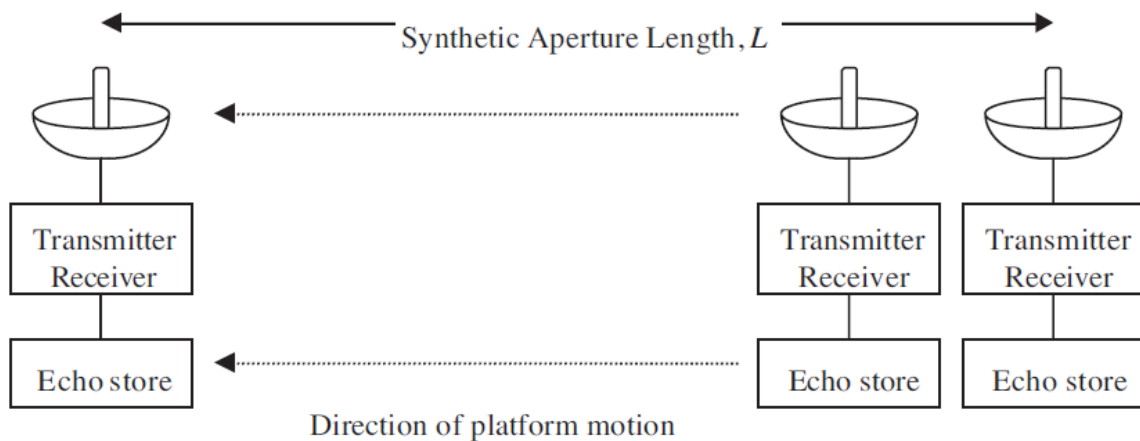
Radar has long been used for military and non-military purposes in a **wide variety of applications** such as imaging, guidance, remote sensing and global positioning (Chan & Koo 2008).

Side looking airborne radar, a predecessor of **synthetic aperture radar** (SAR), was developed in the 1950s. In 1952 a Doppler beam-sharpening system was developed by Wiley of the Goodyear Corporation, opening the way to development of the first airborne SAR (Chan & Koo 2008).

In SAR, the forward motion of the actual antenna is used to 'synthesise' a very long antenna enabling the **creation of two dimensional images** (pictures) or **three-dimensional estimations of the shape of real objects**. Since SAR usually uses operating **frequencies in the microwave range**, it can penetrate clouds, haze, rain, fog and other precipitation with almost no attenuation. As an active sensor which illuminates the inspected object, SAR **operates day or night** without differences.

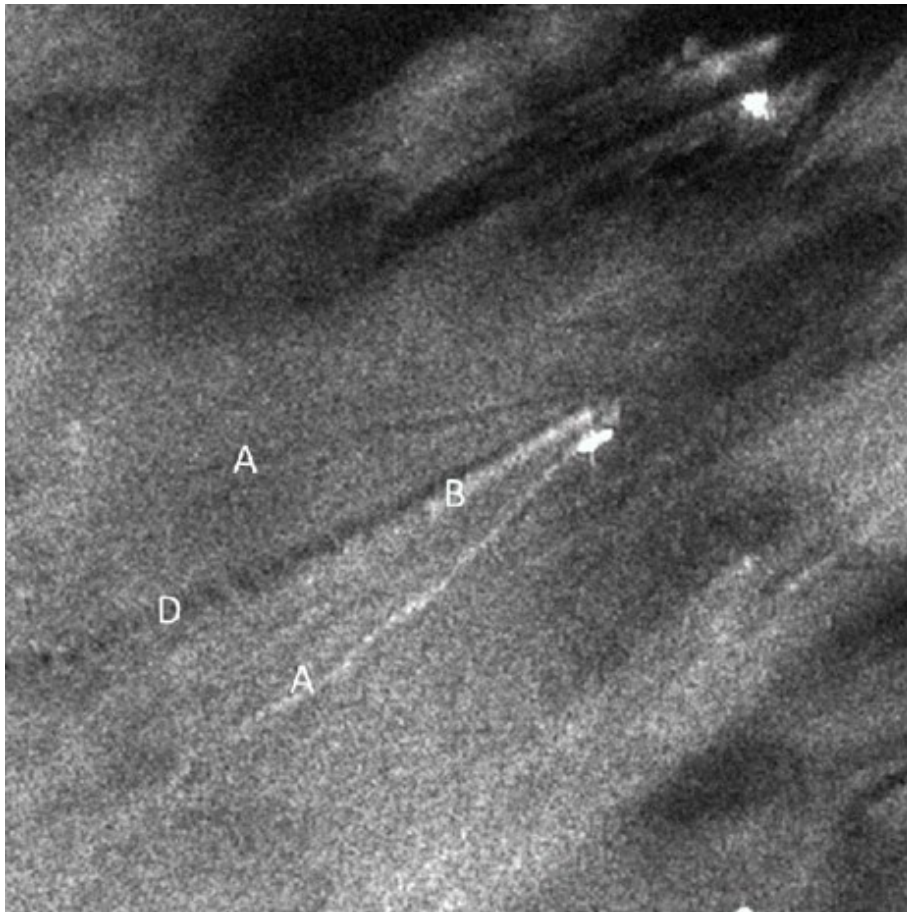
As in conventional photo cameras, the larger the aperture, the higher the image's resolution. In the case of spaceborne SAR, the antenna is synthetic and created by the real antenna's movement along the satellite orbit (see Figure 7). This principle added to the aperture given by the distance to the object enables the production of high-resolution images from spaceborne SARs that can be used to detect vessels from space (see Figure 8).

Figure 7: Synthetic aperture principle



Source: (Chan & Koo 2008)

Figure 8: Classical ship wake pattern in SAR imagery



Source: <https://sentinels.copernicus.eu/>

The EU Copernicus programme has had the Sentinel-1 satellites in service since 2014. These satellites use an SAR with wide area coverage and improved revisit times and can potentially detect smaller ships than older satellite missions.

The mission's ability to observe in all weather during the day or at night makes it ideal for precise cueing and location of ship activities at sea, allowing for more efficient and cost-effective use than other security assets such as patrol aircraft and ships (ESA 2012a).

Sentinel-1 data relevant to ship detection is transmitted by the satellite in real-time for reception by local collaborative ground stations supporting European and national services which will be described in section 2.3.

2. CURRENT APPLICATIONS USING TRANSMITTED POSITIONAL DATA SYSTEMS

KEY FINDINGS

- The **use of each of the data sources** identified has been analysed from literature and sources publicly available on the internet.
- **VMS has mainly been** used by **EFCA** and the Member States' **fishing authorities**. But it has been increasingly used in the **academic world** since the change in some user/usage rules enabling easier access to such data.
- Among all the **transmitted positional data systems** (TPDS) identified, **AIS is the most widely used** due to the short time between transmissions, public availability of data and increased detection on the high seas with the deployment of more satellite AIS receivers. All these characteristics make AIS, a system not designed for fisheries control, the main spatial data source used by fishery researchers and non-governmental organisations to develop spatial research of fisheries (effort distribution, marine spatial planning, etc.).
- Finally, the use of satellite VHR and SAR systems has mainly been for enforcement and control and as such only accessible to the national or European Fisheries Control bodies through the **European Maritime Safety Agency** (EMSA) or to private clients with the financial ability to pay very specialised companies that offer solutions very similar to those of the EMSA.

To depict the applications currently used to enforce fisheries legislation or fisheries research, a representative group of case studies will be presented for each of the transmitted positional data systems shown in Chapter 1 and for both satellite imaging sources.

2.1. Applications using a vessel monitoring system

2.1.1. The EU vessel monitoring system for fisheries control.

The VMS is a satellite-based monitoring system which provides data at regular intervals to fisheries authorities concerning the position of European fishing vessels (EFCA 2021).

VMS is nowadays a standard tool for fisheries monitoring and control worldwide. The EU had led the way, becoming the first part of the world to introduce compulsory VMS tracking for all larger boats in its fleet (FAO 1998).

EU legislation requires that all coastal EU countries should set up systems that are compatible with each other, so that countries can share data and the Commission can monitor compliance with rules. EU funding is available for Member States to acquire state-of-the-art equipment and train their people to use it (EFCA 2021).

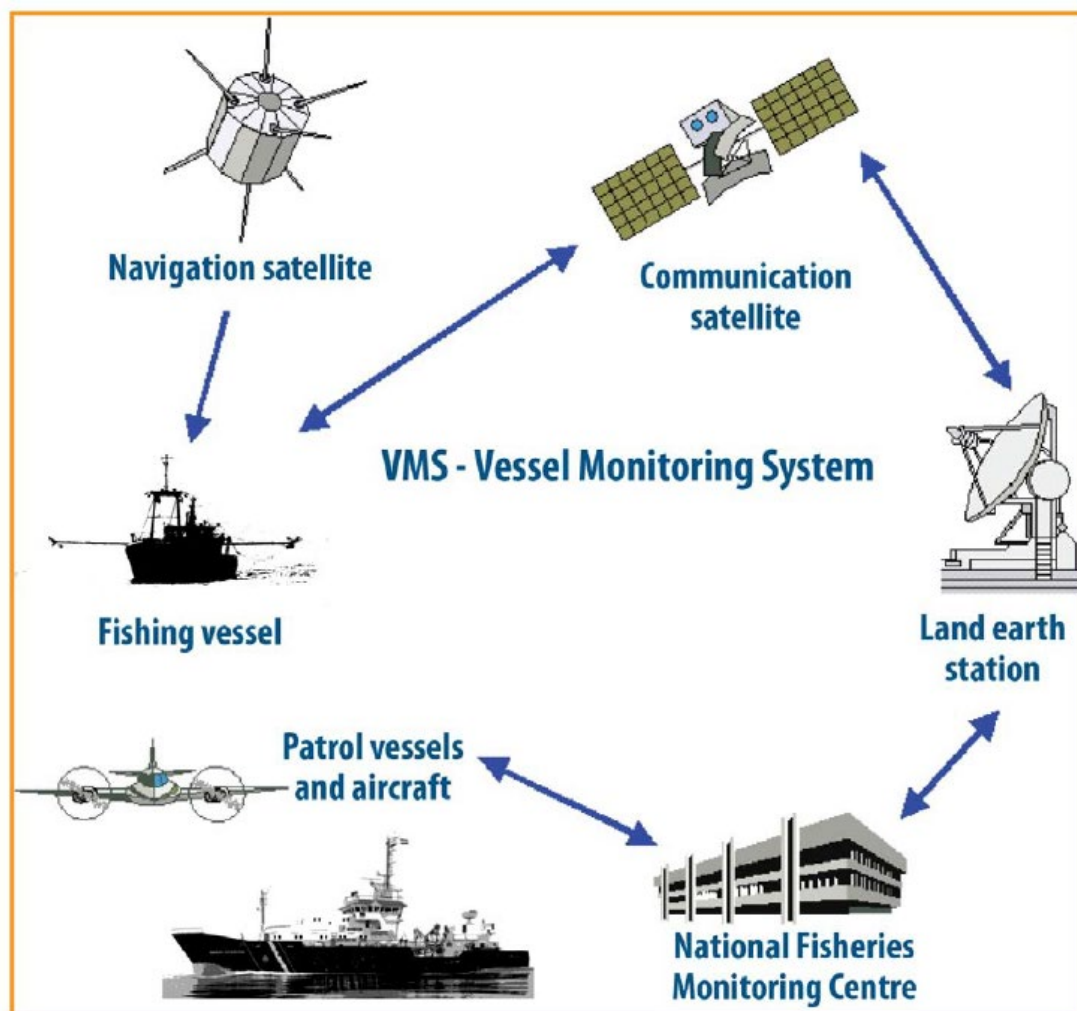
The European Fisheries Control Agency (EFCA) was created by the European Union to promote the highest common standards for control, inspection and surveillance under the Common Fisheries Policy

(CFP) and to ensure Europe-wide that European obligations are complied with by everyone and that everyone in the fishing sector is treated equally, wherever they might be operating.

The EFCA's work comprises joint deployment plans (JDPs) established for fisheries deemed a priority by the European Commission and the concerned Member States. EFCA control activities are planned for each year based on the results of regional risk assessments.

When a Member State or the EFCA performs a sea-based inspection, the VMS data are used by patrol vessels and aircraft to find the inspected fishing vessel at sea. In the event of land-based inspections (see Figure 9), VMS advises beforehand that a fishing vessel is approaching its harbour to land catches so that land-based inspectors can be ready to inspect them. Finally, VMS is used by the different national fishing authorities as a tool to monitor that a vessel is not fishing in prohibited or closed zones such as marine protected areas (MPA) or territorial waters of a different EU Member State.

Figure 9: Data flow of the EU VMS system



Source: ECA 2017

Even though legal provisions regarding the use of satellite-based VMS for fisheries control have been updated at several occasions by the European legislator since 1997¹, the main technical provisions for the characteristics for satellite-tracking devices remained merely unchanged:

Art. 19, Commission Implementing Regulation (EU) 404/2011²):

"The satellite-tracking device installed on board Union fishing vessels shall ensure the automatic transmission to the FMC [Fisheries Monitoring Centre] of the flag Member State, at regular intervals, of data relating to:

- (a) the fishing vessel identification;*
- (b) the most recent geographical position of the fishing vessel, with a position error which shall be less than 500 metres, with a confidence interval of 99 %; [...]."*

As a consequence, Union's legal requirements for the use of VMS were neither adapted to the level of data precision of newly developed GNSS systems with a standard position error of less than 50 metres, nor to the improved and more cost-efficient satellite communication systems allowing a much higher position transmission frequency (Lambert et al. 2012).

2.1.2. The US vessel monitoring system for fisheries controls

The VMS in the US is used to support law enforcement initiatives and to prevent violations of laws and regulations. VMS also helps enforcement personnel focus their patrol time on areas with the highest potential for significant violations (NOAA 2021b).

The VMS programme currently monitors more than 4 000 vessels, the largest national fleet forced to have an active VMS during its fishing operations. The system operates 24 hours a day, 7 days a week with near-perfect accuracy, which is why the programme is of interest to other users, including the US Coast Guard and fishery researchers. VMS data are, by law, subject to strict confidentiality requirements (NOAA 2021b), making it very difficult to use this data for academic work (Westfall et al. 2020).

The US VMS hardware architecture is very similar to the one used in the EU. But it differs mainly in the time between position reports, typically once an hour, and the ability to automatically decrease time intervals when the vessel is approaching environmentally sensitive areas such as MPAs. Alerts can be sent to the VMS technicians and other personnel when a particular vessel location might require additional inquiry or contact with the vessel operator (NOAA 2021b).

Other uses for the vessel monitoring system in the US are:

- Managing sensitive and protected areas such as marine sanctuaries;
- Monitoring the activity and arrival of vessels in port to plan for inspections;
- Supporting the catch share programs;
- Tracking, monitoring, and predicting fishing effort, activity and location;
- Managing observer programs;
- Verifying/validating data from other sources;

¹ See: [Commission Regulation \(EC\) No 1489/97 of 29 July 1997](#) laying down detailed rules for the application of Council Regulation (EEC) No 2847/93 as regards satellite-based vessel monitoring systems

² See : [COMMISSION IMPLEMENTING REGULATION \(EU\) No 404/2011 of 8 April 2011](#) laying down detailed rules for the implementation of Council Regulation (EC) No 1224/2009 establishing a Community control system for ensuring compliance with the rules of the Common Fisheries Policy

- Identifying fishing vessels.

Similar to the EFCA, in the United States the National Oceanic and Atmospheric Administration (NOAA) created the Office of Law Enforcement (OLE). The OLE is dedicated to enforcing laws that conserve and protect US marine resources and their natural habitat by ensuring compliance with domestic law and supporting international treaty requirements designed to preserve global fish resources (NOAA 2021c).

The OLE publishes on its website all relevant inspections and law infringements on a weekly basis (NOAA 2021a). This makes it difficult to compare the performance of the EFCA and the OLE in pursuing fishery infringements.

2.1.3. Use of VMS data in fisheries science in the EU

In Europe, vessel monitoring systems were introduced for fishery control and enforcement purposes but are increasingly used to support the assessment of fishing activity and marine spatial planning (Murawski et al. 2005).

The growing time-series of VMS data are beginning to allow fishery scientists to take into account fine-scale spatial and temporal aspects of commercial fishery data, enabling the mapping of fishing effort (see Figure 10) (Murawski et al. 2005; Witt & Godley 2007; Bastardie et al. 2010; Lee et al. 2010; Gerritsen & Lordan 2011; Lambert et al. 2012; Enever et al. 2017; Birchenough et al. 2021).

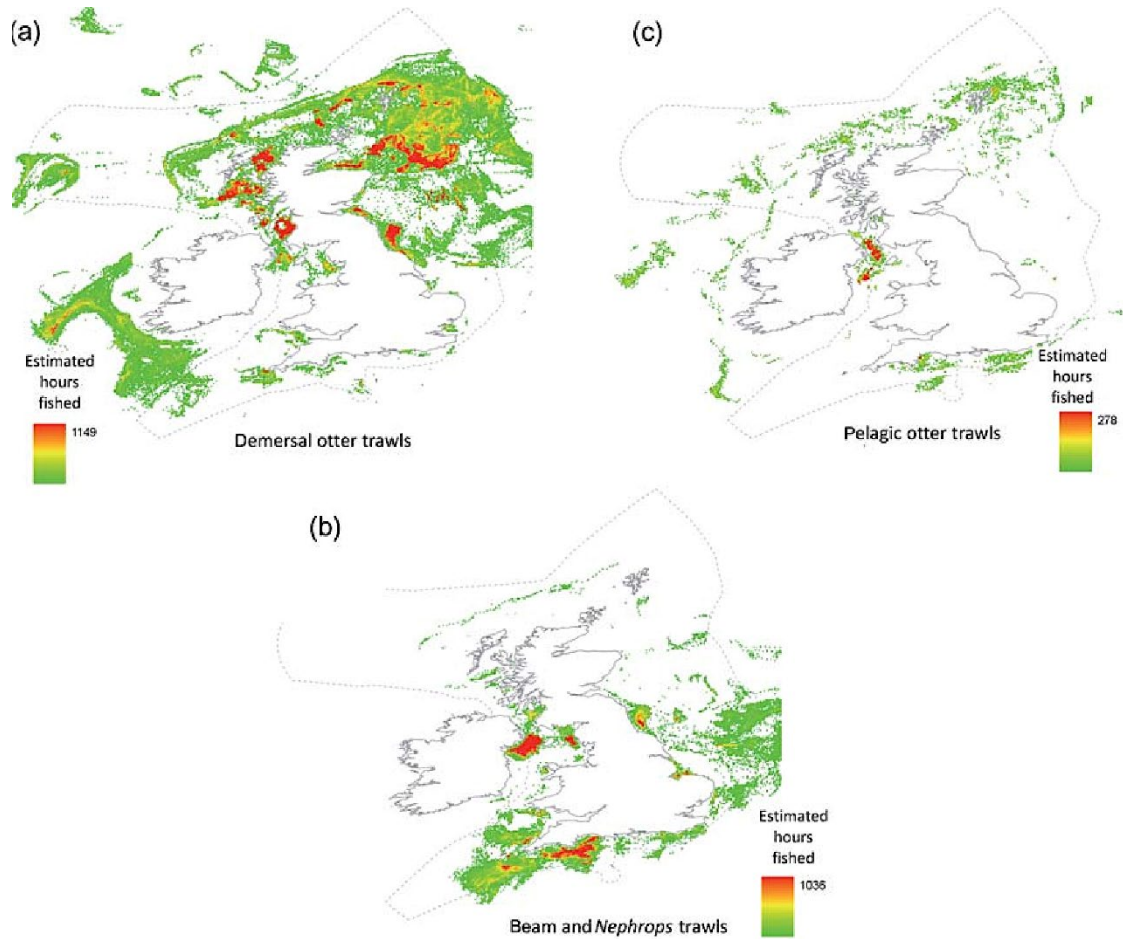
Based on all these studies, almost all the main fishing gear operating in Europe have a published method to identify fishing times (Table 1), enabling an estimate of fishing effort to be produced (Lee et al. 2010). This information and the methods are nevertheless not routinely used when producing scientific advice for fisheries management, because it is difficult for scientists to gain access to VMS on a regular basis due to confidentiality rules (Hinz et al. 2013).

Another major area of scientific study using VMS data are marine spatial planning (MSP), which tries to spatially arrange different uses of the seas (Murawski et al. 2005; Campbell et al. 2014; Tolvanen et al. 2019).

The third main area of study is to quantify the effects of fishing in the marine benthos by means of the number of fishing operations over the different habitats studied (Lambert et al. 2012; Gerritsen et al. 2013; Rijnsdorp et al. 2013; Eigaard et al. 2017).

Given the original purpose of introducing such systems, the use of VMS data for research and impact assessment has some limitations. These include incomplete coverage of vessel activities, overly long durations between position records and a lack of information about whether a vessel is fishing or not when the position is reported (Lee et al. 2010).

Due to such problems, different authors have proposed various approaches to interpolate fishing tracks from insufficient VMS data (Hintzen et al. 2010; Russo et al. 2011), methods to solve the mismatch between VMS temporal resolution and fishing activity time scales (Katara & Silva 2017) or even to compare VMS and AIS data to test the best interpolation for fishing tracks (Shepperson et al. 2018)

Figure 10: Estimated fishing activity of UK vessels by trawl gear types

Source: Lee et al., 2010

In order to make it easier for more scientists to use the European VMS, two open software packages have been developed and are available to the scientific community for VMS data analysis (Russo et al. 2011; Hintzen et al. 2012), including many of the previously cited extrapolation methods.

Table 1: Estimation methods for spatial distribution of fishing activities through VMS data

Table 1. Review of published methods to estimate the spatial distribution of fishing from VMS.

Source reference	Gear	VMS interval (min)	Method of identifying fishing activity	Method of converting from points to surface showing effort	Resolution of estimate	Region
Rijnsdorp <i>et al.</i> (1998)	Beam trawl	6	Mean speed ± 2 knots	Points per grid cell (positional data from loggers not VMS)	3×3 miles	Netherlands
Dinmore <i>et al.</i> (2003)	Beam trawl	120	Speed ≤ 8 knots	Trawling frequency calculated as (number of points \times estimated area disturbed per point)/area of cell	1×1 to 8×8 miles	UK
Deng <i>et al.</i> (2005)	Prawn trawl	1–120	Speed < 4 knots, not at anchor (same location for several hours), not in port or seasonal closure	Tracks overlaid to give intensity of trawling; spatial resolution of output grids not stated	–	Australia
Murawski <i>et al.</i> (2005)	Otter trawl	–	Speed < 3.5 knots	Points per grid cell	1 degree	USA
Salthaug and Johannessen (2006)	Bottom trawl	60	Not stated	Number of (VMS) hours spent in the specified area	Summary for specified polygon area	Norway
Eastwood <i>et al.</i> (2007)	Beam and otter trawl and dredge	120	Speeds, 1–6 knots for otter trawls and dredges, 2–8 knots for beam trawls	Following methods from Mills <i>et al.</i> (2007)	2×2 miles	UK
Harrington <i>et al.</i> (2007)	Scallop dredge	Not stated	Not stated	Points per grid cell and kernel density	250 m to 5 km	Tasmania
Mills <i>et al.</i> (2007)	Beam trawl	120	Speeds (2–8 knots) and turning angles	Tracks overlapped to give a footprint (no intensity), ellipses to represent uncertainty in paths between points	3×3 km	UK
Piet <i>et al.</i> (2007)	Beam trawl	6 and 120	Speed 3–6 knots for small vessels, 5–8 knots for large vessels	Points per grid cell (and swept-area estimates using average speed and gear width but not applied per grid cell)	1×2 min ($\sim 1 \times 1$ mile)	Netherlands
Walter <i>et al.</i> (2007)	Scallop dredge	60	Speed < 5.5 knots	Radial search, 1.9 miles from centre of grid cell	1×1 mile	USA
Witt and Godley (2007)	All gears, not differentiated	120	Speed (km h^{-1}) ≥ 3 and ≤ 10 (~ 1.5 – 5.5 knots); aided by trip reconstruction	Hours at points per grid cell	3×3 km	UK
Fock (2008)	Gillnet, pelagic trawl, otter trawl, beam trawl	60	Otter and beam trawls, mean speed per vessel calculated from all speeds < 8 knots, all points $<$ mean speed + 2 knots classed as fishing; gillnets same as above, but 5 knots	Hours at points per grid cell, plus some value added to neighbouring cells to represent uncertainty in paths between points	0.05×0.1 degrees ($\sim 3 \times 3$ miles)	Germany
Hintzen and Brunel (2008)	Beam trawl	6 and 120	Not stated	Cubic Hermite spline method used to interpolate between successive VMS points	Various	Netherlands
Stelzenmüller <i>et al.</i> (2008)	Beam and otter trawl, and dredge	120	Speed, values following Eastwood <i>et al.</i> (2007)	Tracks overlapped to estimate intensity of pressure	2×2 miles	UK
van der Hulst <i>et al.</i> (2008)	Beam trawl	120	Not stated	Following methods from Hintzen and Brunel (2008)	Various	Netherlands

Source: Lee *et al.*, 2010

2.1.4. Use of VMS data in fisheries science in the United States of America

VMS data from US fishing vessels have only rarely been used in research (Murawski et al. 2005; Palmer & Wigley 2009), despite the fact that the US has more vessels with VMS (> 4,000) than any other nation. Since the installation of VMS devices is compulsory in the USA, there are tens of millions of VMS records available for some fisheries. This data represents a major source of information for fisheries management but is nevertheless largely under-utilised as it is linked to strict confidentiality rules.

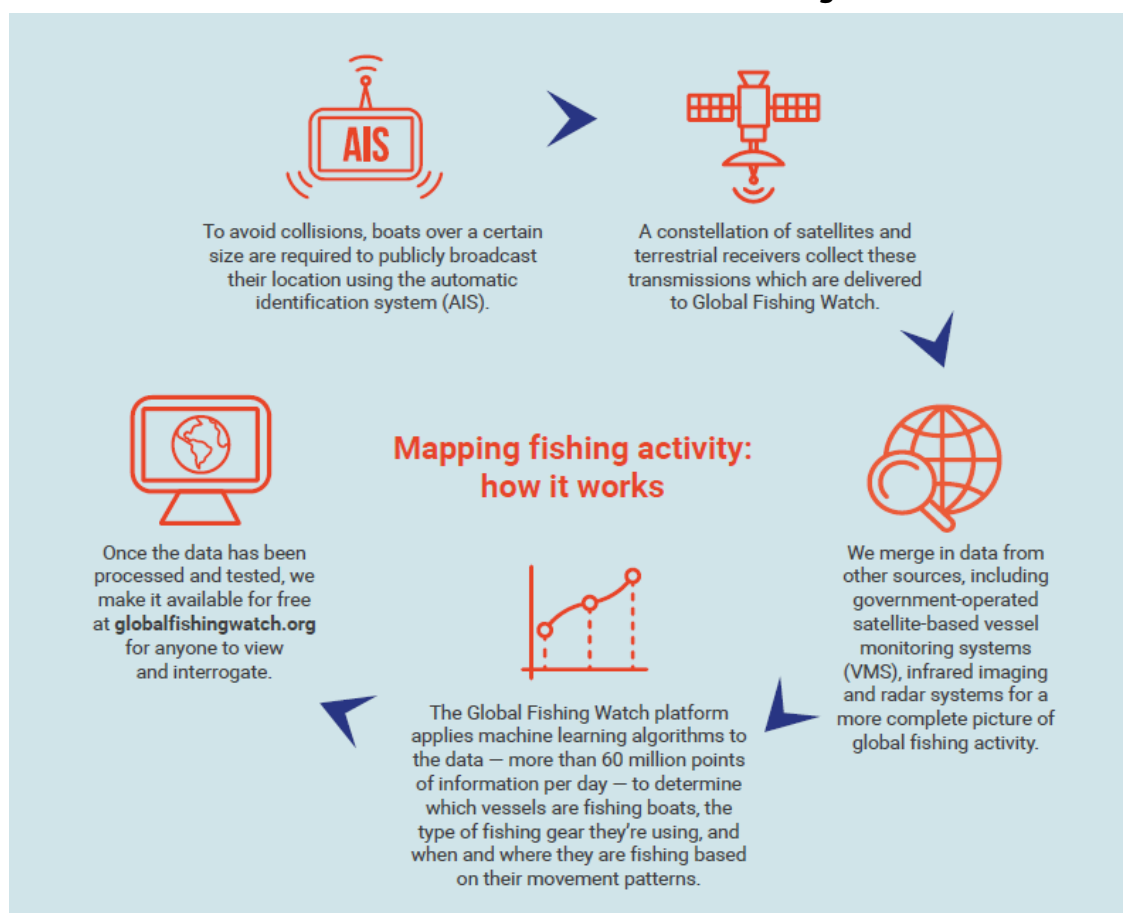
2.2. Applications using an automatic identification system

As stated in the Chapter 1, the need to negotiate access to VMS data with national control authorities has so far confined research applications to specific fisheries and local areas (Natale et al. 2015).

In addition to VMS, another system providing detailed vessel positioning data are the automatic identification system. The AIS was introduced in 2002 by the International Maritime Organisation (IMO) to improve maritime safety and avoid ship collisions (Bastardie et al. 2010).

The AIS has some advantages over VMS, as the time between transmissions is shorter, from two seconds to three minutes, and it is relatively easy to access AIS data from free repositories or from private companies, subject to a fee (Dupont et al. 2020).

Figure 11: Workflow of AIS data from emission to the Global Fishing Watch website



Source: <https://globalfishingwatch.org/>

But the AIS also shows disadvantages, such as difficulties in receiving the respective signals if the vessel is more than 50 miles from a land antenna or if this signal is not received by one of the AIS satellites (Harati-Mokhtari et al. 2007).

Different authors have tried to compare the estimates of fisheries effort calculated from AIS data and from VMS data (Natale et al. 2015; Stasolla et al. 2016; Shepperson et al. 2018) or to develop algorithms to detect transshipments (Miller et al. 2018) or even formulate methods to detect sailing anomalies for law enforcement (Pallotta et al. 2013).

The areas of research in fisheries using AIS are mainly the same as when using VMS, but with a larger number of studies due to the easier access to AIS data (Miller et al. 2018; Dupont et al. 2020)

The most extensive scientific work using AIS data to research fisheries is being carried out by “*Global Fishing Watch*” (GFW), an independent, international non-profit organisation originally set up through a collaboration between three partners: “*Oceana*”, an international organisation dedicated to protecting and restoring the ocean; “*SkyTruth*”, experts in using satellite technology to protect the environment; and “*Google*”, who provides the tools for processing big data. The main product of the GFW is a web page (<https://globalfishingwatch.org/map/>), providing all kinds of fishing activities based on AIS data received from satellites, and merged with data from some governments (mainly VMS data) as well as SARS data. The workflow of GFW is showed in Figure 11 and the main product of GFW are fishing effort maps like the one shown in Figure 12.

Figure 12: Fishing effort of all fishing vessels present in European waters, January 2021



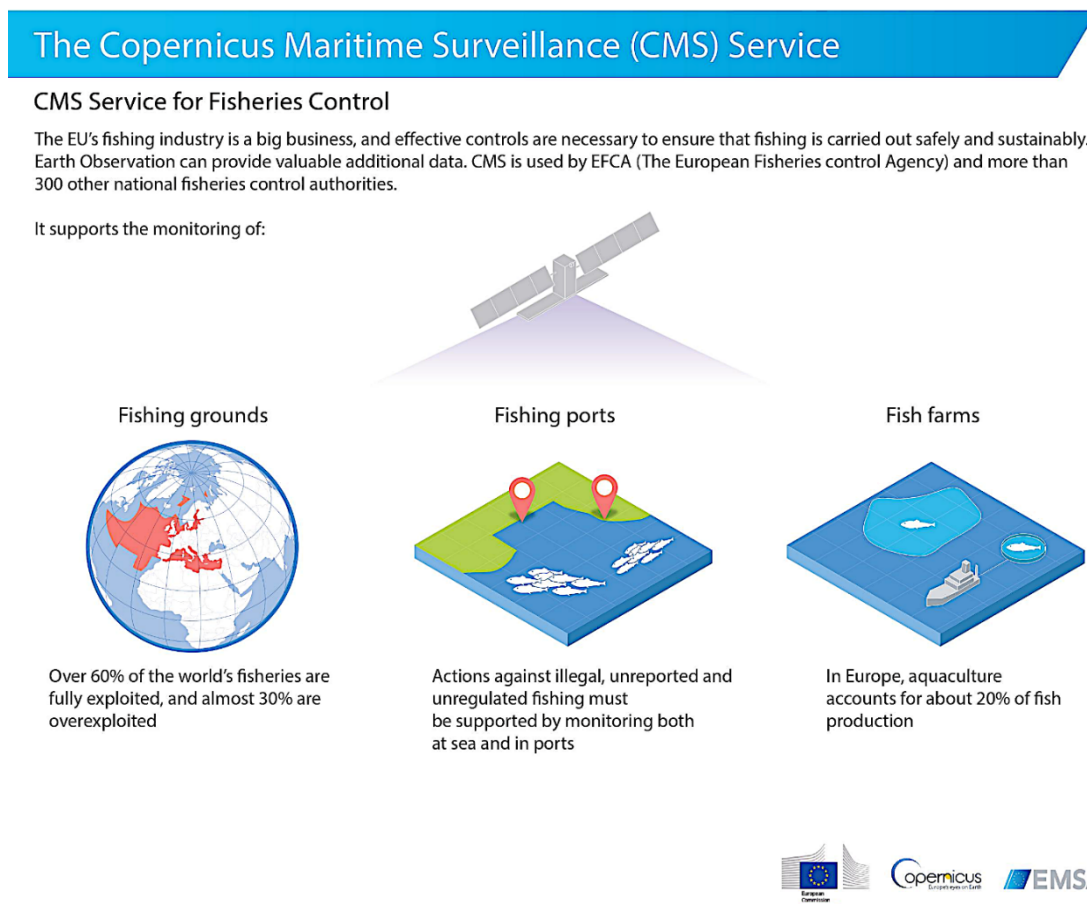
Source: <https://globalfishingwatch.org/map/>

2.3. Applications using satellite remote sensing

2.3.1. European Maritime Safety Agency - Copernicus Maritime Surveillance

The European Maritime Safety Agency (EMSA) is a regulatory agency that originated in the late 1990s along with a number of other major European maritime safety initiatives. The EMSA was established by Regulation (EC) no. 1406/2002 as a major source of support for the Commission and the Member States in the field of maritime safety and prevention of pollution from ships. Subsequent amendments have refined and enlarged its mandate.

Figure 13: Support of fisheries control through Copernicus Maritime Surveillance Service



Source: © EMSA 2018

The European Commission initiated studies on integration of remote sensing in fisheries control in the first years of the 21st century, starting with SAR images (Kourti et al. 2014) and adding VHR multispectral images when available (Kourti et al. 2005).

These studies were the starting point for the “*Copernicus Maritime Surveillance*” (CMS) Service (see Figure 13), which provides earth observation products (satellite images and value-adding products) to support better understanding and improved monitoring of activities at sea (EMSA 2020).

CMS has a wide range of operational functions such as maritime safety and security, fisheries control, customs, law enforcement, marine environment pollution monitoring, and others. Implemented by the EMSA, it is a security service of the EU's Copernicus Programme for maritime surveillance purposes (EMSA 2020).

The benefits from Earth observation data do not lie solely in the volume of data available, but rather in its intelligent use in a targeted manner. The value-added products offered by the CMS service aid users by extracting particularly valuable information from the basic image products, allowing authorities to undertake higher level analysis of objects, features or activities at sea more quickly and efficiently (EMSA 2020).

The value-added products can be provided either as a layer on top of the original satellite image product or as a separate layer of information, for example a vector layer. This enables users to select which individual product or combination of products is relevant to them.

For example, a user requesting high resolution optical data to support the search for an individual vessel may want a vessel detection layer to quickly identify the location of all vessels in the area, but also the original image product layer to see the details of the vessels to narrow down the search.

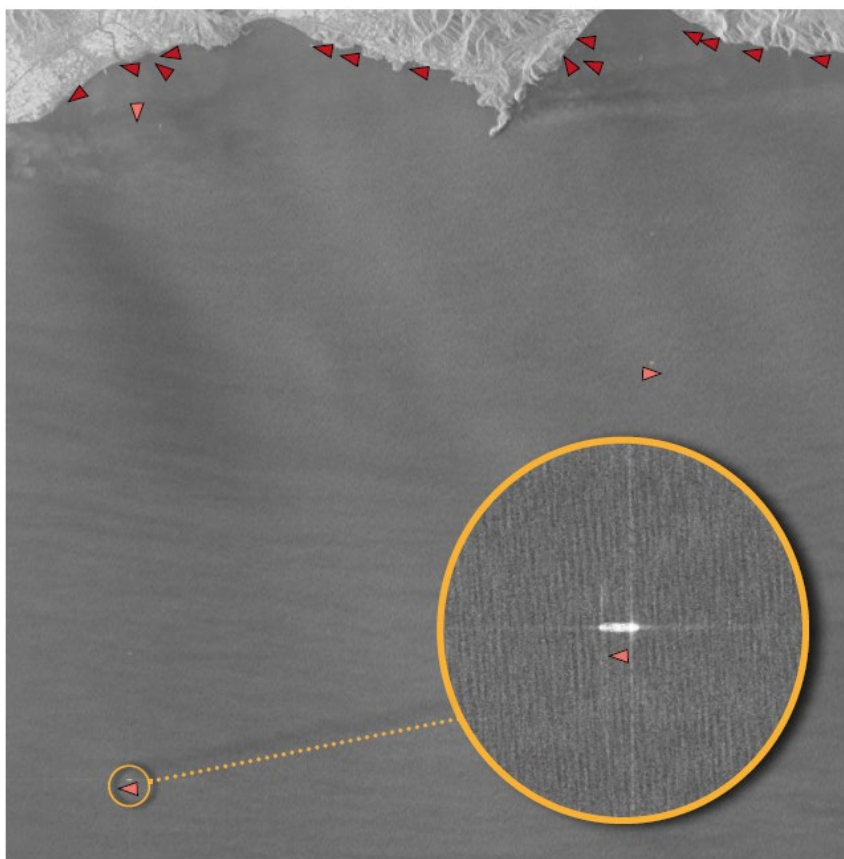
The value-added products currently being offered by EMSA to users include the following:

- “Vessel Detection Service” (VDS),
- “Feature Detection Service” (FDS), and
- “Activity Detection Service” (ADS).

a. EMSA Vessel Detection Service (VDS)

This service entails the delivery of value-added products, mainly using high and very high resolution images, focusing on vessel detection. The “*Vessel Detection Service*” (VDS) refers to the extraction of vessel positions based on echoes or detectable objects in the satellite image that may be vessels.

Figure 14: Example of vessel detection and detail of correlated vessel.



Source: © EMSA 2019

“Enriched Vessel Service” (EVS) merges vessel detection and classification. It entails further analysis of satellite images and contains elements which were not included in the VDS.

b. EMSA Feature Detection Service

This service entails the delivery of value-added products, mainly using high and very high-resolution images, focusing on feature detection. The “Feature Detection Service” (FDS) aims to detect features of interest at sea, along the shoreline and in harbour areas which are not covered by other EMSA EO products (oil spill detection, vessel detection or activity detection).

Figure 15: Example of Feature Detection System showing fish cages



Source: © EMSA 2019

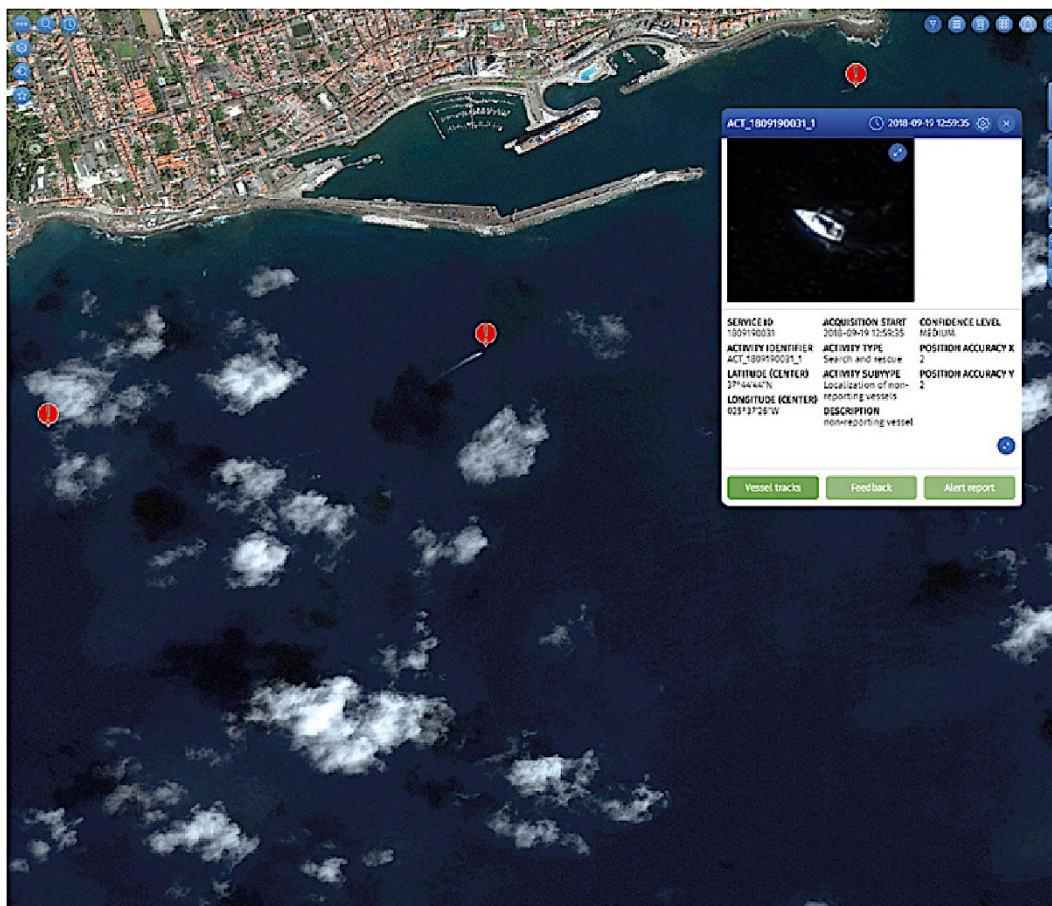
FDS includes the following attributes:

- Feature description – high-level description of the detected feature;
- Position – latitude/longitude coordinates;
- Time stamp – date/time of acquisition.

c. EMSA Activity Detection Service (ADS)

This service entails the delivery of value-added products, mainly using very high resolution images, focusing on activity detection. The purpose of the “*Activity Detection Service*” (ADS) is to report information about activities of interest detected in the satellite images, over a defined area at a given time. For example, when the user requests an ADS for at-sea-encounter only at-sea-encounters shall be included in the delivered product and no other activities such as oil pollution.

Figure 16: Example of activity detection, in this case vessel search and rescue

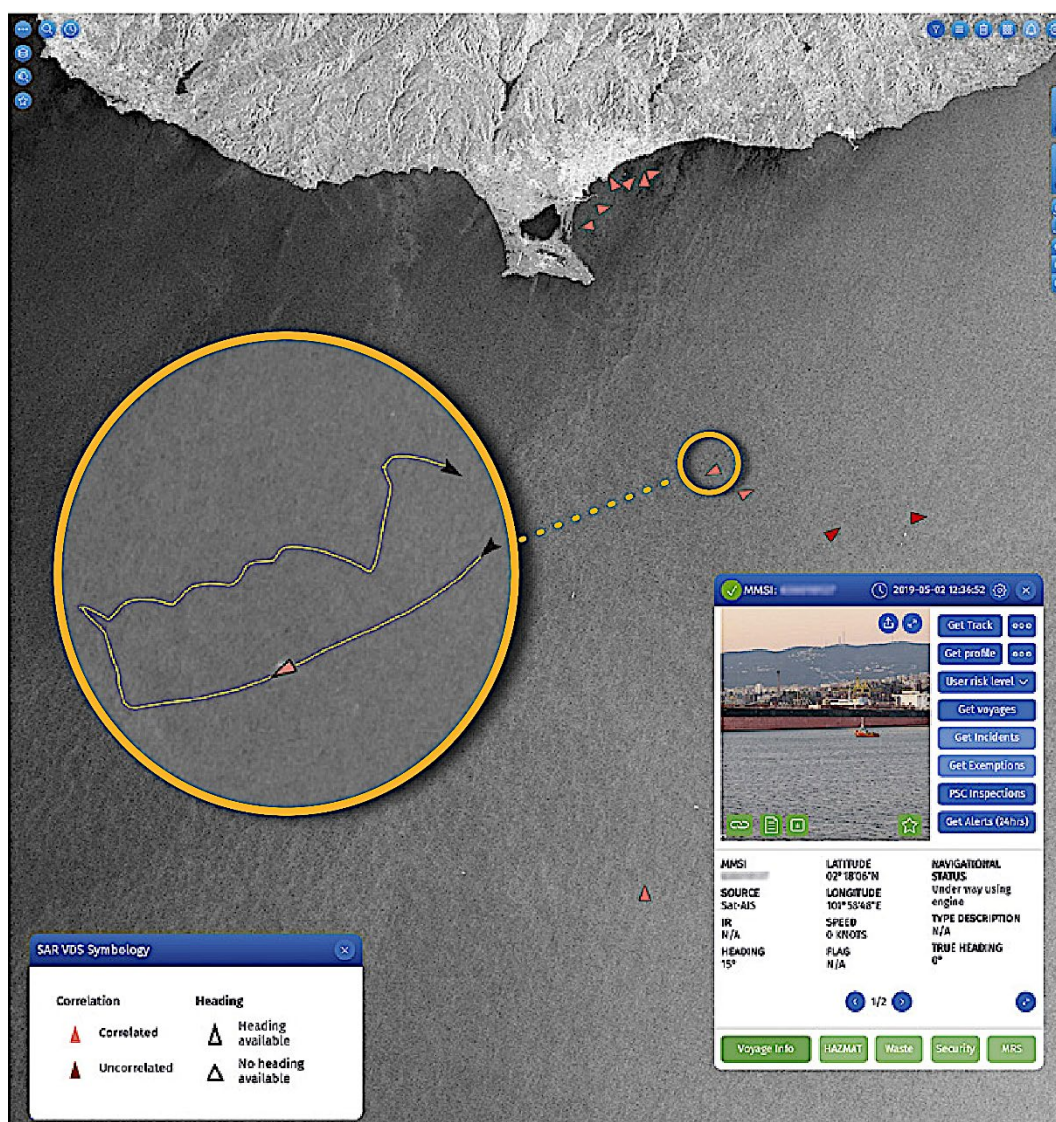


Source: ©EMSA 2019

2.4. Applications combining different data sources

2.4.1. EMSA Copernicus Maritime Surveillance – Vessel Correlation Service

Copernicus Earth observation images can be integrated with other data both from EMSA’s maritime information applications and from external data sources. This additional data may include information such as vessel location, identification and tracking data (for example, “*Automatic Identification System*” (AIS), “*Long Range Identification and Tracking*” (LRIT), and “*Vessel Monitoring System*” (VMS)), intelligence data provided by users and external meteorological data (EMSA 2020). Combining data makes the overall information provided to Member State users more operationally valuable. Vessel position and track information, for example, overlaid on satellite images with a vessel detection layer Figure 17, provide a very powerful tool for checking on vessel activity at sea – including verifying those vessels that are reporting and locating vessels that are not reporting their whereabouts (EMSA 2020). EMSA provides these fusion products to CMS service users according to their needs and to their data access rights.

Figure 17: Example of vessel in a SARS image correlated to AIS data

Source: © EMSA 2019

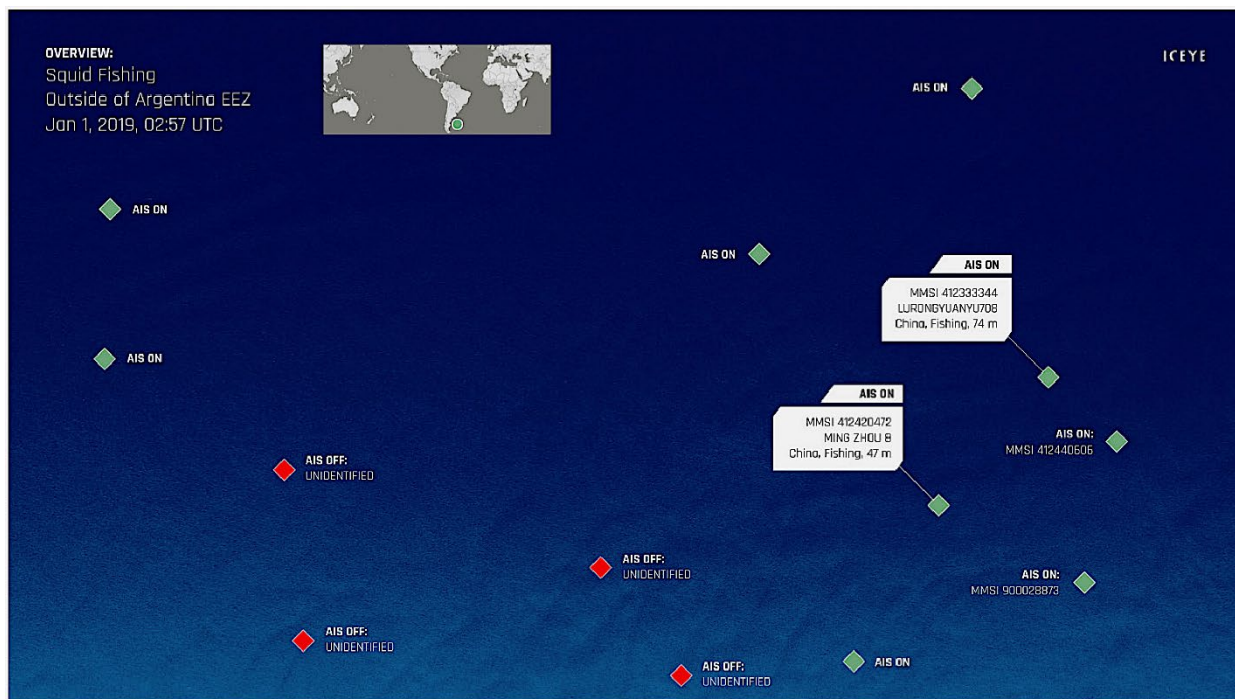
2.5. Private companies offering applications using satellite remote sensing (SRS)

A growing number of private companies, most of them subsidiaries of companies owning private satellites, are offering applications very similar to the services granted by EMSA to European and national control bodies. For instance, German European Space Imaging offers a Total Maritime Situational Awareness product that merges VHR, SARS and AIS data, whose capabilities range from vessel detection and oil spill monitoring to assistance for marine fish farms so they can avoid algae bloom contamination.

Another example of a company offering to the private sector products similar to the ones in the EMSA portfolio is the Finnish ICEYE, which detect vessels through SAR images and correlates them with AIS data to find vessels that have intentionally switched off their AIS transponders and gone 'dark'. An example is shown in Figure 18, where 'dark fishing' vessels are identified.

An AIS match was found with several Chinese fishing vessels. Additionally, there are several unidentified dark vessels which are presumed to be engaging in fishing.

Figure 18: Squid fishing off the coast of Argentina



Source: ICEYE Analytics

3. BENEFITS AND RISKS OF TRANSMITTED POSITIONAL DATA SYSTEMS

KEY FINDINGS

- To identify the benefits and risks of each of the electronic technologies analysed in Chapter 2, a **strengths, weaknesses, opportunities and threats (SWOT) analysis** of each of them was carried out. From the different SWOT analyses, it was concluded that none of the **current technologies are ideal** for the current objectives of control and scientific studies in fisheries and that **a technical update of the current VMS** could be the best solution.
- The **current VMS specifications have become obsolete**, considering the current technical capacities. The main problem is that legislation makes its use compulsory for fishing vessels, with the **technical requirements (precision and frequency) formulated in 2002** and not updated since then.
- The **AIS**, which has aged better and adapted to new technologies, **could satisfy scientific needs**, but it was **not designed for fisheries control** and its use conflicts with laws governing privacy protection and personal data use.
- High-resolution **satellite images** offer uses that are not covered by the two previous technologies when it comes to **providing evidence of unwanted behaviour**, but the **number of satellites is insufficient** in order to continuously monitor fisheries and there are doubts as to whether they comply with privacy requirements.
- The use of **combined**, transmitted **positional data** and **satellite images** provides **results that cannot otherwise be offered**, though also combines the legal weaknesses of both data sources.

In this chapter the benefits and risks of each of the technologies studied in Chapter 2 will be analysed for fisheries control and fisheries science. The analyses consisted of a SWOT analysis of technologies identified in Chapter 2 and the identification of technologies more suitable for fisheries control and scientific use of the compiled data.

The SWOT analysis was performed for strengths and weaknesses by studying the scientific literature that will be cited in the bullet points after each SWOT. As for opportunities and threats, a group of AZTI researchers, experts in the areas of data collection and stock evaluation in different fisheries (Atlantic Ocean, tropical tuna fisheries, small local fisheries), was invited to a meeting to discuss and identify these parameters; the results for that meeting were used for the OT part of each SWOT analysis.

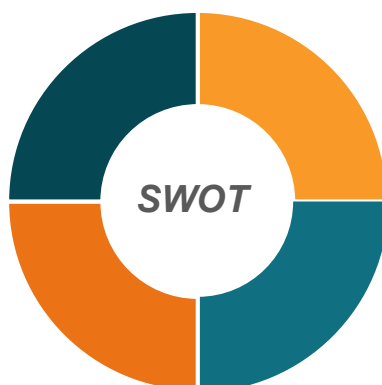
3.1. Vessel monitoring system

STRENGTHS

- Reliable and well tested.
- Rules of use well known by fishers.
- Infrastructure already in place in all Member States.
- Real time reception and use of data.

OPPORTUNITIES

- Upgradeable to current technological developments.
- Can be adapted to new and cheaper communication technologies.
- Potential to be routinely used in fisheries science.
- Machine learning and fishing events identification methods developed with AIS could be easily adapted if faster emission frequencies are implemented.



WEAKNESSES

- Legal rules not adapted to current technological development.
- Long time lag between transmissions.
- Low legal spatial accuracy.
- Confidentiality impedes use for uses not controlled.
- The GPS can be jammed.

THREATS

- If updated, fishers would be reluctant to abide by stricter control measures.
- Confidentiality issues from data protection laws could impair its use for fisheries science if this is not addressed in the new fisheries control framework.

3.1.1. Strengths of VMS

VMS technology can be defined as a reliable and well-tested technology (FAO 1998; Vermard et al. 2010; Gerritsen & Lordan 2011) which in the case of EU countries has been used since 1997 and operates in all Member States (EFCA 2021).

The facilities of the different National Fisheries Monitoring Centres and the European Fisheries Control Agency can receive and use the CMS data in real time to ask for sea-based or land-based inspections (EFCA 2019).

Finally, fishers are well-informed about the VMS rules (Borit & Olsen 2012) and fishers positively value that the monitoring be carried out by public institutions and no other agents (Garza-Gil et al. 2015).

3.1.2. Weaknesses of VMS

One of the main weakness of VMS is that the minimum technical requirements requested in current legislation are outdated and far from the current capabilities of GNSS with respect to spatial accuracy (Mendo et al. 2019; Kumar et al. 2021a) and time between transmissions (Katara & Silva 2017; Shepperson et al. 2018; Mendo et al. 2019).

Regarding scientific use, another major weakness is the confidentiality issues which currently hamper scientific access to this high-resolution effort data, thus endangering the provision of management advice based on the best available knowledge (Hinz et al. 2013).

The received global navigation satellite system (GNSS) signal has very low power due to travelling a very long distance and the nature of the signal's propagation medium. GNSS signals are thus easily susceptible to signal interference (Shehaj et al. 2017). Signal interference can cause severe degradation or interruption in GNSS position, navigation, and timing (PNT) services which could be very critical.

Nowadays small jammers can be purchased relatively easily (Elghamrawy et al. 2020). Since the main data source of a VMS is received from GNSS, it is clear that VMS could be easily jammed.

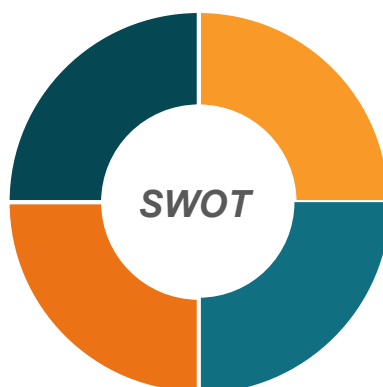
3.2. Automatic identification system

STRENGTHS

- Reliable and well tested.
- Rules of use well known by fishers.
- Infrastructure already in place all around the world.
- Short time lag between transmissions.
- Algorithms for analysis developed.

OPPORTUNITIES

- Historical data could be used for fisheries science.
- Many algorithms for large amounts of data have been developed and are available for use.



WEAKNESSES

- Legal rules enforcing its use not intended for fisheries.
- Confidentiality obstructs use for non-security purposes.
- Best reception infrastructure not owned by Member States.
- No authority enforcing use in fishing vessels when far from ports.

THREATS

- Data protection laws could invalidate use to enforce fishing rules.
- Larger databases owned by private companies.

3.2.1. Strengths of AIS

Since AIS began being used, its technology has a proven history of reliability (Harati-Mokhtari et al. 2007) in its primary use of avoiding collisions and in many other uses such as fishery research (Taconet et al. 2019), marine spatial planning (Le Tixerant et al. 2018; Dupont et al. 2020), detection of anomalies in law enforcement (Pallotta et al. 2013) or conservation policies (Robards et al. 2016).

As with VMS, fishers have a good knowledge of the rules governing AIS use (IMO 1980); they normally follow the AIS rules.

A spaceborne (Cervera et al. 2011) and land-based infrastructure has been created around AIS which receives and collects AIS data by public institutions (EMSA 2020), private companies such as ORBCOMM or even networks of open data access enthusiasts such as AISHub (www.aishub.net). This makes the number of AIS emissions in public or private databases increase every year.

Compared to VMS, one of the parameters that makes AIS stronger is the shorter time between emissions. This allows better coupling of fishing events timing with the positions received (Shepperson et al. 2018), or enables investigation of the high-resolution effects of trawlers in benthic habitats (Le Guyader et al. 2017; Morgan & Baco 2021), identifies transshipment behaviour in tropical tuna fisheries (Miller et al. 2018; Seto et al. 2020) or even tracks the global fisheries footprint, analysing AIS with neural networks to identify fishing events (Kroodsmas et al. 2018).

3.2.2. Weaknesses of AIS

Despite having many strong points, AIS also has a number of evident weaknesses, starting with the fact that setting up and enforcing AIS use is based on international maritime traffic security rules (IMO 1980), which do not allow any amendment or change of rules that could benefit the respective use in fisheries control or research.

A second weakness, in common with VMS, is that confidentiality laws might obstruct the use of AIS (Hinz et al. 2013; Dupont et al. 2020) for fisheries research.

It is to be noted that the best reception infrastructures are owned by private companies, particularly in the case of AIS data received from satellite constellations (Cervera et al. 2011; Fournier et al. 2018).

Finally, it is well known that AIS data has 'black holes', defined as areas where due to the lack of land-based antennas the AIS emissions are not received (Salmon et al. 2016) and stored. Even worse for the use of AIS in control or fisheries science is the 'AIS switch-off', which refers to the fact that many vessels turn off their AIS transponder in order to hide their whereabouts when travelling in waters with frequent piracy attacks or potential illegal activity, thus deceiving either the authorities or other pirate vessels (Emmens et al. 2021).

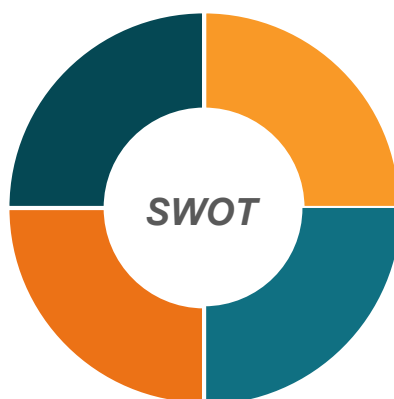
3.3. Satellite remote sensing

STRENGTHS

- Very High Resolution.
- Infrastructure is growing continuously.
- EU-funded satellites provide open data to scientists and companies.
- Algorithms for detection and classification are developed and open-sourced.

OPPORTUNITIES

- Deep learning algorithms will allow huge amounts of data to be processed.
- Computing power keeps getting cheaper.



WEAKNESSES

- Legal rules not adapted to this data, no final position from the European Data Protection Board.
- Long time between transmissions.
- Confidentiality problems increase the higher the resolution of the satellite images.

THREATS

- Fisheries control could be illegal using this data due to confidentiality issues.
- Private companies are offering products similar to those developed for fisheries control to anyone with the money.

3.3.1. Strengths of SRS

The first great strength of SRS is the very high resolution of current SAR and VHR sensors, enabling detection of a small-size fishing vessel (10-15 m) (Longepe et al. 2018; Chaturvedi 2019; Snapir et al. 2019) or even its visual identification from VHR images in the case of larger vessels (30-40 m).

A second strength is the growing space, land and big data infrastructure which are allowing broader access to Copernicus/Sentinel program products and images (ESA 2012a, b).

It is clear that the open data access policy for EU-funded satellite images and products is promoting the development of new ways of fishery control enforcement (Santamaria et al. 2017; Snapir et al. 2019) and fisheries research (ESA 2012b, a).

Thanks to the open data access policy, the scientific community is producing algorithms for detection and classification of vessels which are open-sourced for control and research of fisheries (Heiselberg 2016; Stasolla et al. 2016; Greidanus et al. 2017; Huang et al. 2018; Kanjir et al. 2018; Zhuang et al. 2020; Li et al. 2021).

3.3.2. Weaknesses of SRS

The weakness associated to the long time between transmissions derives from the fact that the Sentinel1 mission is based on a constellation of two identical satellites, Sentinel-1A and Sentinel-1B, launched separately. In SAR mode, Sentinel-1A can map global landmasses once every 12 days. Since there are two Sentinel 1s one or both will pass over the same place at the equator every six days. In the case of Europe, the time is reduced to every two days, due to European latitudes (ESA 2012a).

Many Earth observation experts and legal scholars agree that parallel to the more enhanced resolution of remote sensing images, the likelihood of privacy issues also grows (von der Dunk 2009; Aloisio 2017).

For example, observing a boat via remote sensing VHR imagery can identify the boat with a large likelihood that the captain will be on board even if the captain is never actually depicted on deck, at least not in a sufficient resolution to identify him by his looks. The mere fact of tracking the boat could be violating the captain's, and possibly also the crew's, right to privacy, as their position and movement is tracked (Aloisio 2017).

The above provides an idea of the main weakness of VHR images, which is the need to adopt legal rules that clarify the privacy issues regarding use of VHR and SAR images for fisheries control.

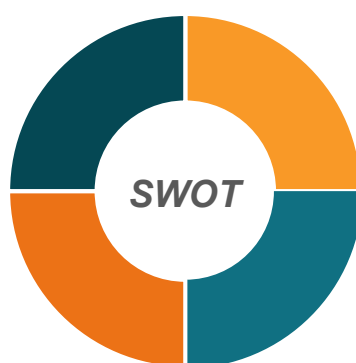
3.4. Applications combining different data sources

STRENGTHS

- Using two or more data sources enables gaps to be filled.
- They allow detection and documentation of illegal actions that cannot be demonstrated without combining data.
- Useful not only for fisheries control but for control in general.

OPPORTUNITIES

- With the increasing number of commercial satellites, the dark zones will be reduced.



WEAKENESS

- There is no specific legislation.
- Confidentiality issues.
- Not applicable to routine control.
- Satellite images of a given zone only available for short periods of time.
- Not accessible from EMSA by scientists.

THREATS

- Vulnerable to confidentiality issues when used for enforcement.
- Not only in public hands.

3.4.1. Strengths of applications combining different data sources.

Since AIS and VMS data are sources completely independent of the sources of VHR or SAR images, when combined the gaps encountered using only one data source are in many cases filled (Kourti et al. 2005; Kourti et al. 2014; Krumme et al. 2015; Longepe et al. 2018).

Combining different data sources enables detection and documentation of illegal actions that cannot be demonstrated without combining data (Longepe *et al.* 2018; Galdelli *et al.* 2021).

These new developments are not only useful for fishery control but for control in general (Galdelli *et al.* 2021).

3.4.2. Weaknesses of applications combining different data sources.

Evidently, all the weaknesses identified in VMS, AIS and SAR/VHR data are present or are even worse when combining such data sources, especially with respect to the confidentiality issues.

3.5. Conclusions

In summary it can be concluded that none of the described electronic technologies (VMS, AIS, SRS and combined solutions) currently used are ideal. However, there is no technological obstacle that would prevent taking the best elements of each of the existing ETs to develop a far better transmitted positional data system than the currently imposed VMS.

Available technology would allow to easily design a VMS that would collect data for position, speed and heading of fishing vessels with much greater precision (for example ± 25 m) and with a frequency similar to that of AIS (every 5-10 seconds).

Such data would be transmitted to control agencies with a frequency of no more than 15 minutes by using the present satellite communications. The recorded data would be downloaded and encrypted to control agency datacentres through current telephone networks (4G or 5G) when the fishing vessel is within coverage. Furthermore, this method would allow better data to be obtained in the event of legal disputes and for fisheries science, while not increasing the transmission costs for fishers.

As shown for the case of AIS, the higher frequency of data collection would make it possible to receive evidence not only on the fishing vessels' positions, but also if and how often they were engaged in fishing operations.

For fisheries science and management, such data could ideally be used for assessing total and spatial distribution of fishing effort or effects on habitats. But also, data for marine spatial planning and other relevant parameters for fisheries management, including data relating to the different objectives of the Marine Strategy Framework Directive (MSFD) could be easily collected.

Furthermore, processing of combined data would contain important information for fisheries control. A new VMS combined with VHR or SAR images would allow EFCA together with EMSA, to identify and document illegal fishing activities.

EMSA uses this possibility of combining different data sources already with AIS data. But the use of new and more accurate VMS data with shorter emission time would enable data collection independent from AIS, which was not designed for fisheries control.

4. POLICY RECOMMENDATIONS

KEY FINDINGS

- Extend the **obligation** to use **tracking devices** in commercial fishing vessels.
- Increase the **accuracy of VMS positional data** from 500 to 20 metres.
- Reduce the **VMS emission time** to ten minutes for instant transmission, and one minute to stored data on delayed transmission.
- Find the right balance to **grant access to the generated data** while preserving the **personal privacy** of fishers.
- Follow-up on the work started, by **combining VMS, AIS and VHR/SAR**.

4.1. Positional data devices

- **Extent the obligation to use tracking devices** in commercial fishing vessels to the maximum possible consensus.
- **Increase the accuracy of VMS positional data** so it can be of a similar magnitude as the actual data provided by current GNSS systems (20 metres). The enforced precision indication of 500 metres was intended for the GPS capabilities of the late twentieth century and not for current GNSS systems like Galileo which enable accuracies of 20 metres at 99% confidence with free receivers such as those used in mobile phones.

4.2. Emission time

- **Reduce the VMS emission time** of both data types to ten minutes (instant transmission) and one minute (stored data or delayed transmission), respectively. As our review of scientific literature suggests, this could be achieved and would be ideal, both for fisheries research and control. Nowadays cheaper means of transmission, as well as technologies capable of storing and transmitting huge volumes of data exist. In this way sufficient spatio-temporal resolution to apply automated algorithms for detecting fishing activities could be achieved.

4.3. Personal data protection

- Take the necessary actions to **grant access to the generated data** to control bodies and scientific advisors for fisheries management while preserving the personal privacy of fishers.

4.4. Satellite remote sensing and positional data

- **Follow-up on** the work started recently, by **combining VMS, AIS and VHR/SAR images** as complementary to the VMS data.

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This study is the first research paper in a series of three, prepared for a PECH Committee Workshop. It reviews the state of the art of transmitted positional data systems, high resolution and synthetic aperture radar (SAR) for satellite image data used in fisheries control and fisheries research. It identifies the strengths and weaknesses of such systems and provides policy recommendations for a more effective fisheries control system based on currently applied electronic technologies (ET).
