An Updated Review of Satellite Technologies and Opportunities for Scottish Fisheries

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Executive Summary

The Space industry has continued developing rapidly over the past year. The predicted sector worth by 2030 is now £490 billion, a significant increase from the £400 billion 2021 estimate. Numerous new satellite missions have been launched, or are to be launched in the near future, many of which carry technology capable of applications within the fishing industry.

Remote sensing is undeniably one of the most relevant scientific technologies today. Countless research is being carried out on the engineering of sensors, potential applications, and data processing techniques. For example, new sensors capable of monitoring CO_2 emissions from small sources like fishing boats are being produced for launch on The European Space Agency's CO2M satellites, and artificial intelligence is now being employed to fuse data from multiple satellite technologies for enhanced marine surveillance.

New regulatory developments such as the Global Dialogue on Seafood Traceability (GDST) and the importance of sustainability to consumers are putting pressure on the fishing industry for increased transparency with the supply chain. Satellite technology can help Scottish fisheries adapt to these new norms, by increasing verifiability, efficiency and transparency across the supply chain, as well as providing the means to estimate CO_2 emissions and monitor/prevent illegal, unregulated and unreported (IUU) fishing. For example, using satellite communications technology, fishers can relay data about catch, location and weather conditions instantly to the next step in the supply chain. Satellite imaging can be used to verify catch and/or shipment locations and monitor IUU fishing in near real-time.

Introduction

This report is an update to the comprehensive review of available space technology and remote sensing methods for the Scottish fishery industry (FIS037), undertaken by Space Intelligence in 2021. Here, we take a look at the most recent research in the sector, including (1) new satellite missions, (2) new and improved remote sensing methods for marine surveillance, (3) how machine learning is taking the sector forward in terms of accuracy and efficiency, and (4) how space technology could aid in the digitisation of the fishing industry, including supply chain traceability and the reduction of carbon emissions and fuel use.

Recent Satellite Technology Advancements

New and Planned Spaceborne Missions

Land-based systems for maritime surveillance and other fisheries applications typically cannot provide detailed, frequent and widespread coverage of the maritime space. As such, the utilisation and development of spaceborne technologies are paramount in taking the fishing industry forward. A comprehensive list of new and planned spaceborne missions relevant to the fishing industry is included in Table 1, with further discussion of different sensor and satellite types below.

Table 1: Recent and future spaceborne missions relevant to the fishing industry

Mission	Organisation / Country	Launch year	Spatial resolution	Temporal resolution	Description / Fisheries Applications
Space-Based Automatic Identification System (SAT-AIS) Missions					
KOMPSAT-6	KORI/South Korea	2020	SAR: up to 0.5m	11 days	AIS receiver for vessel monitoring. Also provides SAR imagery of up to 0.5m and 1m resolutions in high res mode.
^{3}Cat-4	UPC/Spain	2020	N/A	N/A	AIS receiver for vessel monitoring. The satellite also has a GNSS-R and a radiometer on board.
Synthetic Aperture Radar (SAR) Missions					
NISAR	NASA/USA and ISRO/India	2023	≥3m	12 days	Provides SAR imagery at high resolutions for vessel monitoring and illegal, unreported and unregulated (IUU) vessel applications.
Biomass	ESA/Europe	2022	200m	TBC	First P-band SAR in space, with imagery focused on mapping forests and the carbon cycle. However, can be applied to marine applications such as monitoring IUU fishing.

Multispectral Sensor (MSP) Missions					
ALOS-3	JAXA/Japan	2021	3.2m (MSP) 0.8m (PAN)	60 days	Global coverage and surveys of coastal fishing conditions.
Hyperspectral sensor (HSP) Missions					
³Cat-5/B	ESA/Europe	2020	VNIR: 75m IWIR: 490m	TBC	HSP in visible, near and thermal infrared, with in-built AI for cloud detection. Very high spectral resolution with VNIR: 16nm. Range of marine applications (e.g., sea ice information and imaging [1]).
EnMap	DLR/Germany	2020	30m	4 to 27 days	Very high spectral resolution HSP with VNIR: 6.5nm and SWIR: 10nm. Information about aquatic ecosystems; may provide unique data promoting sustainability within fisheries.
Global Navigation Satellite System Reflectometry (GNSS-R) Missions					
PRETTY	RUAG GmbH/Austria	2022	TBC	Varied; up to 9 times per week [2].	Slant geometry GNSS-R alongside radiation measurements; applications for weather forecast and climate research.
GEROS-ISS	GFZ/Germany	2022	10 - 100km	Varied; up to 4 days	Onboard International Space Station. The mission focuses on coastal regions, surface ocean currents, surface winds and wave heights [3].
G-TERN	GFZ/Germany and IEEC/Spain	2025	30km (at poles)	Varied; GNSS-R does not follow a repeatable pattern	Focus on polar areas; first satellite to use the full available GNSS bandwidth, capable of 12 simultaneous observations [4]. Measures key ocean/ice parameters.
Other Relevant Missions					
CO2M	ESA/Europe	2026	4km	11 days	Two satellites are planned for launch as a constellation in 2026. Sensors will measure anthropogenic CO2, CH4 and NO2 emissions using near-infrared and short-wave infrared spectrometers. Very high spectral resolutions of NIR: 0.1nm, SWIR-1: 0.3nm and SWIR-2: 0.35nm [5].

Up-to-date information about all past, present and new spaceborne missions is available on the ESA Earth Observation Portal: https://directory.eoportal.org/.

Space-based Automatic Identification Systems (SAT-AIS)

Automatic identification systems (AIS) were developed to avoid collisions, allowing vessels to transmit their position, identity, course and speed. However, an alternative form of this technology, space-based AIS (SAT-AIS), is growing in popularity. SAT-AIS improves the terrestrial coverage limitations associated with land-based AIS, allowing for the availability of AIS services at any point across the globe.

SAT-AIS provides accurate vessel information, with fast update rates of up to 2 seconds, alongside being cheap and compact with low power requirements. A study in the Indian Ocean found that 90% of the ships present in the study area were detected using only one SAT-AIS provider, with the number of ships detected increasing to 98% when adding another provider [6]. Combining SAT-AIS with land-based AIS systems further increased the number of ships detected. A study in Europe by The Norwegian Defence Research Establishment (FFI) found that by using SAT-AIS, the ship detection probability is close to 100% for 1,000 ships in the coverage area [7].

Due to the nature of satellite orbits, there cannot always be continuous monitoring of any one point on the planet. To decrease the time interval between sensors observing the same region, more satellites (or constellations of satellites) will be required. However, revisit times are much more frequent at higher latitudes [5], suggesting that Scotland may be in a prime position to utilise the technology.

Even with the future of AIS/SAT-AIS technology looking bright, it cannot be solely relied on for marine surveillance. AIS/SAT-AIS systems rely on vessels co-operating and having functional AIS equipment on board. Furthermore, AIS/SAT-AIS is still susceptible to hacking and spoofing, implying that other remote sensing techniques are still required to monitor non-reporting vessels.

Synthetic Aperture Radar (SAR)

Synthetic aperture radar (SAR) is a high-resolution imaging system that uses active microwave remote sensing technology to image the Earth's surface. Ship detection is a relatively new application for this type of remote sensing. Since SAR works in all weather conditions and all day, it is an effective method to investigate vessels that may be unresponsive to AIS methods.

Numerous studies have been carried out over the past few years, to improve both SAR detection accuracy and detection speed, while running at a low cost. Methods range from using convolutional neural networks such as U-nets, boasting results of 68.1% average precision and 67.6% average recall on SAR ship detection datasets [8], to 'balance learning' methods, displaying results with accuracies 0.5-5% higher than other competitive SAR ship detection methods [9]. The use of SAR data alongside other datasets is further discussed later in this report, within the section on machine learning advances.

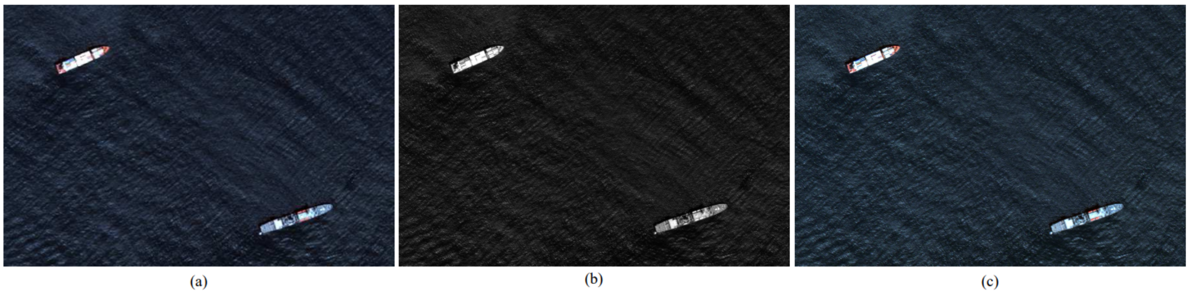
Drawbacks surrounding SAR imaging include the difficulty of analysing images and its sensitivity to speckle noise, which impacts both the processing of the images by computer programs as well as human SAR experts.

Multispectral (MSP) and Hyperspectral (HSP) Sensors

Multispectral (MSP) and hyperspectral (HSP) optical sensors cover the whole optical region between microwave and X-ray radiation. MSP instruments, such as the sensor on the new ALOS-3 mission, can capture optical images at high resolutions in the tens of centimetres, e.g. 0.8m on ALOS-3.

MSP sensors typically use RGB or panchromatic (PAN) images. PAN images have higher resolutions and are therefore the preferred option for smaller targets. RGB is generally used for target classification because of the specific spectral information. Pansharpening (PAN+RGB) has become popular in recent years for the detection of vessels and works by fusing the multispectral and panchromatic image, rendering a result with both the spectral resolution of an RGB image and the spatial resolution of the PAN image [10]. Figure 1 shows an example of this in practice from a high-resolution MSP instrument on the WorldView-2 satellite where (a) is the RGB image with a 2m resolution, (b) is the PAN image with a 0.5m resolution and (c) is the (PAN+RGB) image showing two detected vessels [11].

Figure 1: MSP sensing image from WorldView2 satellite, with (a) the RGB image, (b) the PAN image, and (c) the pansharpened (RGB+PAN) image [11].



HSP sensing is one of the newest forms of remote sensing technology today. HSP sensors can measure target radiance up to hundreds of bands over the visible and infrared spectrums, and to very high spectral resolutions of less than 1nm. HSP instruments can thus measure radiation from far distances and continuously record spectral signatures, allowing for advanced marine application such as chlorophyll mapping, atmospheric analysis, water quality control and marine debris mapping.

The main drawback of MSP and HSP instruments is their sensitivity to poor weather conditions such as clouds, as well as not being able to operate without the presence of sunlight. MSP methods are also limited by long revisit times and HSP methods suffer from high computational costs due to their high spectral resolution.

Global Navigation Satellite System Reflectometry (GNSS-R)

Global navigation satellite system reflectometry (GNSS-R) is passive sensing that takes advantage of an ensemble of active sources, using GNSS signals reflected from Earth's surface to infer information about surface conditions. GNSS-R can be used for marine applications such as ship detection and monitoring of variables such as sea surface height, ocean wind speeds and polar ice.

GNSS-R sensing allows for all-weather, any-time measurements. They are also compact, low-power and cheap instruments. Due to their low economic cost, there are more than 100 active GNSS satellites available, allowing for almost seamless global coverage. The main drawback with GNSS-R sensing is the low spatial resolution when compared to previous techniques.

A study released this year showed the potential of using GNSS-R for the detection of red tides, which due to the intensification of human activities on the ocean, pose an ever-increasing threat to the marine environment and ecology [12]. They developed a model capable of monitoring and predicting red tide densities using spaceborne GNSS-R observations, showing a correlation coefficient of 0.74 between model results and real data.

New AI and Machine Learning Advancements

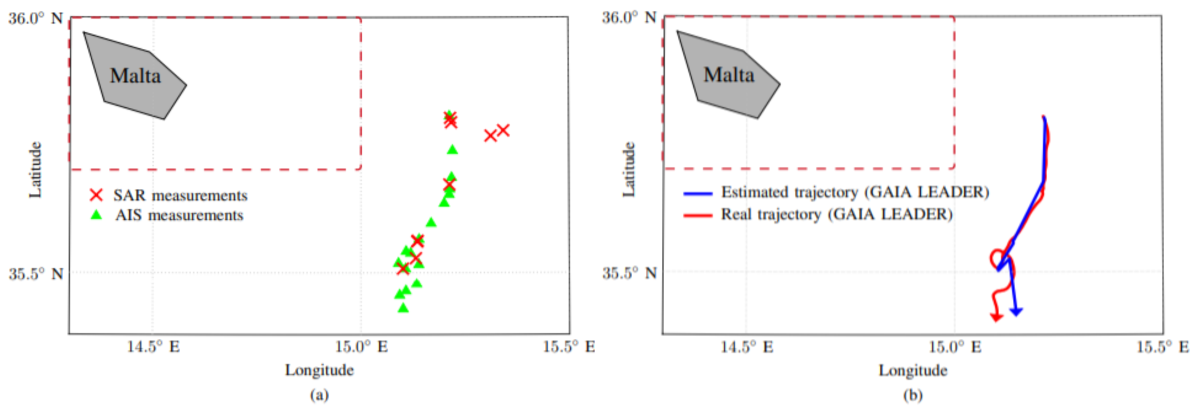
In many marine surveillance applications, recent efforts are being made to combine space-based sensors, using artificial intelligence (AI) to fuse the data. Multi-target tracking (MTT) algorithms and sum-product algorithms (SPA) are becoming popular AI techniques due to their numerous advantages:

- They can fuse information from multiple satellites.
- They have low computational complexity.
- They can determine information based on context - e.g., maritime routes or ship class information based on the coordinates of the satellite image.

One use-case scenario undertaken by the Institute of Electrical and Electronics Engineers (IEEE) exhibited the effectiveness of this technique off the coast of Malta. The study used an SPA-based MTT method, measurements from SAR (from the COSMOSkyMed constellation) and AIS messages to estimate ship trajectories [13].

Results from the study are shown below, with Figure 2(a) showing the SAR and AIS measurements used in the study, and Figure 2(b) showing the estimated and real trajectories, with estimated positions of targets (ships) determined after every SAR measurement and using any AIS messages retrieved in the time between each measurement. As well as estimating the number and trajectories of targets, the algorithm also assigns each a Maritime Mobile Service Identity (MMSI) identifier. In this case, there was only one target, whose MMSI (GAIA LEADER) was correctly identified, along with a good estimate of trajectory**.**

Figure 2: AI method to fuse AIS and SAR techniques for vessel detection and trajectory estimates: (a) the AIS and SAR measurements and (b) the estimated and true vessel trajectory [13].



AI combined with satellite imagery and other datasets is also capable of promoting sustainability in marine environments through:

- Identification of oil spills - Oil-covered waters are characterised by certain surface tensions due to the oil film. However, seaweed-covered regions can also display similar characteristics. Using SAR sensing, AI allows for the differentiation between the surface roughnesses resulting in the distinction between waters with and without oil [14].
- Mapping of marine debris - Plastics and microplastics (less than 5mm) can be mapped using HSP sensors, by observing the spectral signatures of the debris. An algorithm trained by Plymouth Marine Laboratory used ESA satellites to map marine plastics in seas including Scotland, resulting in the differentiation between plastics and natural materials with 86% accuracy [15].
- Monitoring of marine life - AI, machine learning and neural networks are promoting the automation of biodiversity monitoring in the ocean, by providing a minimal disturbance method for monitoring marine life and identifying species. For example, using high-resolution imaging, whale fins and flukes, and whale shark markings can be detected [14].

Applications of Space Technology for Fisheries

Supply Chain Verification

Space technology can help address two main issues in fisheries supply chain verification: (1) the traceability of products and (2) the monitoring of illegal, unregulated and unreported (IUU) fishing.

Fisheries can use SAT-AIS to verify where and when a catch was made, allowing clients to know exactly where the product came from and if it was sourced responsibly. The catch information can then be sent to the next step of the supply chain (using satellite communications) before the vessel even reaches the shore, increasing the efficiency of the process. High-resolution SAR sensing or optical imaging could intermittently be used to verify catches and product transfers, and to prevent or dissuade spoofing or malpractice attempts (see caveat in Box 1 below).

Using a combination of SAR, MSP, HSP and GNSS-R remote sensing techniques, IUU fishing can be monitored at any time of day or night, when satellite data is available. This will allow relevant authorities to investigate any suspected illegal activity.

Box 1: Remote sensing for supply chain verification

For the successful application of remote sensing techniques for supply chain verification, a satellite needs to be passing over the area of interest at the exact time required for verification of an event (e.g., a catch or transshipment), or otherwise be tasked to monitor a specific area during a time when activity is planned or likely to occur. This can limit the monitoring capability and lead to gaps in coverage.

Satellites' temporal resolutions must therefore be carefully considered to mitigate the impact of these gaps, or alternatively, satellites can be tasked to monitor specific locations more frequently. For example, known hotspots for illegal fishing, and hotspots for certain species (e.g., during squid season) could be monitored more frequently by tasked, high-resolution satellite imagery to prevent illegal fishing and promote sustainability.

The Global Dialogue on Seafood Traceability (GDST)

The global dialogue on seafood traceability (GDST), first drafted in 2017, aims to improve the interoperability and verifiability of seafood traceability systems. A set of standards and guidelines were produced to ensure companies can be confident in the legal origin of products, and allow efficient, verifiable and affordable traceability.

This is a new, challenging development in the industry. However, space technology can help fisheries become GDST ready, monitoring many of the key data elements (KDEs) required for compliance. Table 2 highlights the KDEs which could be measured using space technology. Note that the same caveat regarding successful application of remote sensing data found in Box 1 on the previous page also applies to the monitoring of several of the KDEs listed in Table 2.

Table 2: GDST standards/key data elements (KDEs) with satellite technology solutions

KDE No.	KDE Name	KDE Definition	Space Technology Solution
W06	Unique Vessel Identification	Identifier associated with a vessel for the duration of its existence that cannot be re-used by another vessel	AIS / SAT-AIS systems would automate the sending and receiving of unique vessel identification.
W09	Date(s) of Capture	Date of seafood capture event(s) during vessels voyage	AIS / SAT-AIS and SAR or high-resolution imagery can be used to verify catch time/date.
W10	Gear Type	Equipment used to extract seafood from water for capture	Very high-resolution imagery (sub-meter) such as MSP or a combination of MSP and HSP could allow for verification of equipment.
W14	Catch Area	Location(s) where the capture of seafood occurred	AIS / SAT-AIS and SAR or high-resolution imagery can be used to verify catch locations.
W17	Transhipment Location	Geographic location where seafood is discharged from a fishing vessel to a transhipment vessel	AIS / SAT-AIS and SAR or high-resolution imagery can be used to verify discharge location.
W18	Dates of Transshipment	The date on which seafood was discharged from the fishing vessel to the transhipment vessel	AIS / SAT-AIS and SAR or high-resolution imagery can be used to verify discharge time/date.

The full list of GDST standards and key data elements (KDEs) is available here:
http://traceability-dialogue.org/wp-content/uploads/2022/03/GDST-1.1-Core-Normative-Standards.pdf

Monitoring and Reduction of Carbon Emissions/Fuel Use

Small sources of CO_2 emissions from small or medium vessels are difficult to measure directly from satellites, pushing the fishing industry to find other innovative methods of monitoring their vessels' emissions. SAT-AIS can be an effective way to estimate CO_2 emissions and fuel consumption indirectly, by using the frequent information stream about the ship's speed and location, alongside environmental data [16].

ESA is continuing production of their CO2M satellites, with the planned launch of two new satellites in 2026. Each will have a near-infrared and shortwave-infrared spectrometer on board, capable of measuring atmospheric carbon dioxide at high spatial resolution. They promise to reduce the uncertainty in carbon dioxide emission estimates from the combustion of fossil fuels at local, national and regional scales [17]. This provides insight into the future potential of monitoring carbon emissions for small sources such as fishing boats from space.

UK start-up Smart Green Shipping has developed technology using satellite data to aid the shipping industry in reducing its CO_2 emissions. Their 'FASTRIGS' system consists of numerous vertical aerofoils (automated sails) mounted on vessels, which respond to data retrieved through satellite observations and weather forecasts. This system promises to realise at least 20% of fuel and greenhouse gas emission savings, as well as being completely automated, requiring no additional crew to operate it. The technology is suitable to be fitted on already existing vessels with sufficient deck space such as bulkers and tankers. However, they also plan to build their own optimised 'FASTSHIPS' vessels for small and medium-sized ships. Their FASTSHIP model was tested by the University of Southampton with performance data analysed by the Met Office and UCL, concluding that their design would save 50% of fuel on the modelled routes.

Summary

This report provides an update to the review on satellite technology and opportunities for Scottish fisheries undertaken by Space Intelligence in 2021. This update aims to inform the reader about any new advancements in the world of satellite technology, with a focus on how new technology could aid in the digitisation of the Scottish fishing industry in terms of supply chain verification, as well as the reduction of carbon emissions and fuel use.

New and upcoming satellites have inspired innovative remote sensing possibilities and applications. SAT-AIS can be used for a multitude of new applications, ranging from indirectly estimating CO2 emissions and fuel consumption of vessels to being combined with other satellite technology such as SAR imaging to track vessel trajectories. New satellites such as the ALOS-3 satellite have spectral ranges of up to 0.52μm and spatial resolutions of up to 0.8m, making them capable of capturing 'pansharpened' images, from which fine details of marine activity can be observed from space. The planned CO2M mission from ESA promises to be capable of observing CO2 emissions from small sources, which has never been done before from space.

The use of AI and machine learning within marine applications is growing in popularity due to their numerous advantages. They can automate processes and handle large amounts of data with relatively low computational costs. For example, AI and machine learning have been used to fuse data from multiple satellite technologies, as well as for identifying oil spills and marine debris from space.

Becoming GDST-ready and enhancing supply chain verification are two important steps in the digitisation of the fishing industry. Through consideration of the GDST standards and KDEs, six KDEs were found to have possible space-based solutions. These mainly include using AIS / SAT-AIS services and other imaging techniques such as SAR to verify aspects such as location, time and gear. These verification techniques can also be applied to other supply chain verification efforts.

Satellite imaging such as SAR, MSP/HSP and GNSS-R can be employed to monitor IUU fishing in near real-time, an aspect of importance to many stakeholders on the supply chain. Continuously improving satellite communications also allows for efficient communication along the supply chain where data and imagery can be sent to relevant stakeholders and used to sell products before a vessel reaches the shore, or to enhance consumer or retailer confidence in product source and sustainability.

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