

Satellites and their Role in EU Maritime Security, Safety and Marine Environmental Protection

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Dr Angela Carpenter
Visiting Researcher
University of Leeds

Abstract

Satellite technologies offer many benefits to Europe's maritime regions and its marine environment. They have enabled the EU and its agencies to monitor large numbers of ships sailing in its waters under the Long-Range Identification and Tracking System (LRIT), and have enhanced security by tracking ships and allowing member states to evaluate the security risks posed by a ship and take action to reduce that risk. Satellites are used to track and monitor ships under SafeSeaNet (SSN), enhancing safety and efficiency of maritime traffic, reducing accidents or potentially dangerous incidents, and for search and rescue activities. SSN is also linked to a system, the Hybrid European Targeting and Inspection System (THETIS) which enables states to determine which ships entering ports need to be inspected against international standards and conventions (structural, safety equipment, crew training and safety for example). Finally, SSN can be used to track ships to ensure they do not intentionally pollute the marine environment, and to assist in a prompt response to maritime accidents which result in major pollution incidents. Satellites covering the EU's North Sea region have, for example, proved particularly useful in extending coverage of surveillance to identify illegal pollution taking place under cover of darkness, under a system known as CleanSeaNet (CSN), and also in conjunction with a regional body, the Bonn Agreement Secretariat.

**This working paper brings together a number of strands of research on the use of satellites to support maritime safety and security, for marine environmental protection, and also how satellite images can be used to identify sources of oil pollution at sea. It draws from a range of work which has already been published, together with works in progress. If you would like to discuss the content of this working paper, please email: a.carpenter@leeds.ac.uk and/or angela.carpenter@ntlworld.com*

6,743 words without abstract or references but including footnotes

1. Introduction

The maritime shipping industry is of major importance to the European Union (EU), with its merchant fleet making up over a third (37 per cent) of the world fleet.¹ The European Commission (2011a) note that around 90% of EU foreign trade is transported by sea with an estimated 1,720 million tonnes of cargo were transported by sea while 400 million passengers travelled through Europe's passenger ports in 2007 (page 7). Monitoring marine habitats to ensure adequate water quality, maintain biodiversity, and maintain or increase productivity is also economically significant to EU prosperity with fisheries, tourism and other activities within 50 kilometres of EU coastlines generating around €3.5 trillion (35%) of total EU GDP (see European Commission Directorate General for Maritime Affairs and Fisheries (DG-MAF), 2009, p 3).

The marine environment faces many threats, with human activities affecting almost all marine ecosystems (see Halpern et al., 2007, p. 1302). Those threats include: the introduction of organic and non-organic pollutants into the marine environment from a range of sources (from the atmosphere, land and sea); problems posed by illegal fishing, including over-fishing; the potential impacts of climate change including sea-level rise, sea-temperature rise, ocean acidification; harmful algal blooms, which can be toxic at sea or be hazardous if dead algae washes up on land; eutrophication, where the input of nutrients can reduce levels of oxygen in sea-water to a point where they can no longer support marine life; and also the impacts of commercial activities such as shipping, offshore drilling, offshore mining, and the dumping of waste at sea (see Halpern et al., 2007, Table 1, pp 1304-1305).

In addition to ships posing a potential threat to the marine environment as a source of pollution through at-sea dumping, they can also pose a threat to the economic and physical security of the EU through, for example, the smuggling of drugs, cigarettes, alcohol, weapons or illegal migrants, together with the threat of ships being used for terrorist activities or as targets for such activities (see Carpenter, 2013). Ships also face the possibility of accidents occurring, ranging from injuries to crew or passengers requiring medical assistance not available on board to the sinking of a ship with consequent loss of life if a rescue cannot be undertaken. In the case of a ship being damaged, for example if an oil tanker is holed or sunk, or if other types of ships carrying containers or large volumes of engine fuel on board sink, this is a further way for pollutants from a ship to enter the marine environment.

Section 2 of this paper provides an overview of how European space policy (ESP), the application of space research and the use of satellite technology has been beneficial to the EU, to the EU's Integrated Maritime Policy (IMP), and in support of EU agencies such as the European Maritime Safety Agency (EMSA), and to the wider marine environment for many years in the areas of marine environmental protection, maritime safety and security. Section 3 then examines specific systems in place through which satellite imagery and ship monitoring systems are used in practice, under the aegis of EMSA. Oil slick data has been collected in the Baltic Sea and the North Sea since the late 1980s under the aegis of regional agreements, those

¹ Total controlled fleet by world region, 2009 (dwt million): World = 1,144.4 of which EU-27 = 417.9. Source: European Commission (2011b). *EU transport in figures: Statistical Pocketbook 2011* p.90

agreements being the Helsinki Convention² and the Bonn Agreement³ respectively. Section 3 of this paper examines how satellite surveillance data is being used in conjunction with Bonn Agreement aerial surveillance in the North Sea to identify incidences of oil pollution in that region.

2. Integrating space and maritime policies – what is happening in Europe

The EU set out preliminary requirements for an ESP in 2005,⁴ emphasizing the vital role space can play in EU policies such as transport, environment and security, and integration of space and terrestrial components in areas such as monitoring and communication (see European Commission, 2005a, p 5). More recently, the Director General of European Space Agency (ESA) set out a Resolution on ESP providing a common political framework for space activities in Europe which recognised the need for stronger cooperation between ESA and the EU to promote a unified approach to space, and highlighted the significant contribution ESP can make to an independent, secure and prosperous Europe (see ESA 2007a, p 9).

This is very much in line with the proposition by Contzen and Ghazi (1994) who identify that a basic strategy of the EU has been to achieve full integration between its environmental policies and all other relevant EU policy areas, through shared activities and through “improvement in the range and accessibility of environmental data” (p 101). Topics for shared action and collaborative projects between EU institutions include the use of Earth observation imagery in the area of marine science and technologies included research around coastal zones (exploration and exploitation of resources), monitoring ocean currents and water circulation, ocean biology studies, and polar research (*ibid*, p 102).

One method identified by Contzen and Ghazi (1994) as a way of achieving better knowledge and understanding of Earth system interactions was through remote sensing activities and analysis of time series multi-satellite data obtained from joint projects and cooperative activities between the European Commission and ESA (p 102).⁵ The European Commission (2010) identified how observation of the sea and oceans can provide knowledge vital for sustainable growth in the maritime economy, and assist in areas such as better spatial planning and improved maritime surveillance, while the application of such knowledge can assist in ensuring the health of marine ecosystems and protecting coastal communities (p 3).

² *Convention on the Protection of the Marine Environment of the Baltic Sea Area, 1974*. Details of the activities of the Helsinki Commission and a map showing the geographical coverage of the HELCOM maritime area is available online at: http://www.helcom.fi/helcom/en_GB/aboutus/

³ *Agreement for cooperation in dealing with pollution of the North Sea by oil and other harmful substances, 1983*. The 2002 version of the Bonn Agreement is available at: <http://www.bonnagreement.org/eng/html/welcome.html> while details of geographical coverage and included as an Appendix within that URL. A map showing geographical coverage of (including zones of responsibility for contracting parties) is available at that URL.

⁴ See European Commission (2005). “Communication from the Commission to the Council and the European Parliament of 23 May 2005 “European Space Policy - Preliminary Elements”. Available online at: <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0208:FIN:EN:PDF> (last accessed 18 December 2012)

⁵ Those joint projects included, in respect of the oceans, the *Ocean Colour European Archive Network* to study and analyze areas such as ocean primary productivity and the modelling of marine transport processes (Contzen and Ghazi, 1994, p 102).

2.1 *EU Integrated Maritime Policy*

ESA (2007b), in discussing the EU's 2007 IMP,⁶ noted that it had been actively involved in providing support to the maritime sector for over 25 years. ESA (2008) highlighted three areas where space technologies are being used in the context of IMP. These are: providing monitoring and support to Arctic operations; marine environmental protection; and integrated vessel surveillance, the latter including both safety and security activities. For example, ESA has undertaken water quality monitoring, sea ice monitoring, wind and wave forecasting and ship detection, providing continuous time series oceanographic measurements (see ESA, 2007b). As a specific example, ESA (2004a) identifies how Advanced Synthetic Aperture Radar (ASAR) imagery from ENVISAT is used in conjunction with other systems to identify ice coverage enabling ship operators to better plan their routes to avoid hazards such as icebergs or sea ice threats to commercial shipping in the Baltic Sea, which also has implications for safety and search and rescue activities in the event of an accident. In addition, route planning for merchant ships to take advantage of ocean currents or avoid severe weather can result in faster voyages and a reduction in the fuel consumption, potentially reducing greenhouse gas emissions from ships, ESA (2004b) indicating that radar equipment on ENVISAT spacecraft can, for example, measure sea surface roughness, wave height and wind speed for those purposes.

The European Commission (2007) identified that access to a wide range of natural and human-activity data – including satellite data – was vital in enabling it to make strategic decisions on maritime policy, a key component of the IMP (p 6). Co-operative activities between ESA, ESP and IMP can, therefore, be considered highly significant to marine environmental protection and maritime safety and security, the areas considered in this paper.

2.2 *ESA's work with international agencies*

In addition to the contribution that ESA makes to the EU and its agencies, and specifically EMSA in this paper, through space policy and satellite applications, ESA (2012) also notes that it works with the secretariats of various international conventions and treaties to provide satellite based services to support the operational requirements of those treaties, including the Bonn Agreement which is discussed later in this paper. The role played by ESA in maritime and wider Earth observation is clearly vital. Satellite data for Earth observation, together with tools such as remote sensing satellites, play a significant role in monitoring a state's compliance with its international obligations under environmental agreements and for conducting environmental research (see Peter, 2004, pp 189-190), providing the EU with a tool to meet its commitments to a range of international treaties such as the 1992 UN Framework Convention on Climate Change and its 1997 Kyoto Protocol (pp 192-193), and the 1973 International Convention for the Prevention of Pollution from Ships and its 1978 amendments (MARPOL). In respect of MARPOL, Peter (2004) identifies this as an example of a Multilateral Environmental Agreement which explicitly mentions using remote sensing, in this case to support oil pollution monitoring (p 190).

⁶ For more information on the EU Integrated Maritime Policy see: http://ec.europa.eu/maritimeaffairs/policy/index_en.htm (last accessed August 2013). In particular, see the Communication from the Commission to the European Parliament, etc. on An Integrated Maritime Policy for the European Union. COM (2007) 575 final, Brussels, 10 October 2007, available online at <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0575:FIN:EN:PDF>

3. The European Maritime Safety Agency and its Operational Tasks

There are a wide range of user communities for whom earth observation data, satellite images, maritime surveillance information (including satellite surveillance), and vessel monitoring are vital. There are also many different actors with an interest in, or responsible for, aspects of maritime safety and security and, in each of those areas, there are a range of (sometimes overlapping) problems and issues to be dealt with. The European Commission DG-MAF (2010) identified seven user groups for whom access to satellite surveillance data is relevant: general law enforcement, customs, marine environment, maritime safety and security, defence, fisheries control, and border control – in each member state (p 6).

In the case of maritime safety and the marine environment, EMSA is the EU agency with responsibility for ensuring uniform maritime safety and the prevention of pollution from ships operating in EU waters. EMSA was established in 2002 (see European Commission, 2002) and was tasked with providing objective, reliable and comparable information and data in those areas which would enable Member States to take steps to improve safety and pollution prevention by collecting, recording and evaluating data on maritime safety, maritime traffic, and both accidental and deliberate pollution. While the use of satellite imagery and Earth Observation to obtaining such data is not stated explicitly in that Regulation, it appears implicit that EMSA should obtain data from any source possible and thus the work of ESA will assist EMSA in fulfilling its operational tasks.

The tasks and services of EMSA which use satellite technologies are outlined in Table 1 (overleaf). In addition, EMSA also operates the Hybrid European Targeting and Inspection System (THETIS), developed in cooperation with Member States and the European Commission (see EMSA, 2010a). THETIS supports existing measures enabling ships to be inspected under Port State Control (PSC) procedures (see EMSA, 2010a). Paragraph 9 of Directive 2009/16/EC requires EMSA to work in conjunction with the Paris Memorandum on Port State Control (Paris MOU⁷) to develop and implement such a database (see European Commission, 2009, p 58) with information on vessel inspections collected by Member States being transferred into SSN. Fully operational since the end of 2010, THETIS receives around 12,000 ship notifications daily through its interface with SSN, resulting in more than 19,000 ship inspections in 2011 within the Paris MOU region (EMSA, 2012a, p 39). THETIS helps Member State agencies to identify ships requiring inspection by profiling against common selection criteria, those ships being selected for inspection to assess their compliance against a range of international conventions, EU Directives and Regulations (see Carpenter, 2011). Ships which fail inspections face a range of sanctions including detention in port or being banned from operating in EU waters.

⁷ The Paris MOU was established in January 1982 and covers Europe and North Atlantic Region. For an overview of Regional MOU Regimes, including signatories, see Carpenter (2011), Table 4, p 79.

Table 1 – EMSA Operational Tasks⁸ and Services

Task and Service	Key points
Vessel tracking globally – Long Range Identification and Tracking of Ships	<ul style="list-style-type: none"> • The EU LRIT is part of a global system administered by the International Maritime Organization (IMO) under Safety of Life at Sea Convention, 1974⁹ • Established under amendments of SOLAS in May 1986, Contracting Governments can obtain ship identity and location information to evaluate security risks and take measures to reduce risks. • Also supports search and rescue, safety, and marine environmental protection activities. • All passenger ships, high speed craft, mobile offshore drilling units and cargo ships over 300 gross tonnes are required to carry AIS transmitters which report a ship's position to satellites and coastal stations¹⁰. • EU LRIT Data Centre (operational since 2009) tracks and monitors all EU flagged vessels, irrespective of location, and links to International Data Exchanges for information on foreign flagged vessels sailing in EU waters
Vessel traffic monitoring in EU waters – SafeSeaNet (SSN)	<ul style="list-style-type: none"> • System established under Directive 2002/59/EC to enhance maritime safety, port and maritime security, marine environmental protection, and efficiency of maritime traffic and maritime transport • Centralised European platform for maritime data exchange, linking maritime authorities across the EU plus Norway and Iceland. • Used by port authorities, traffic monitoring services, coastguards, pollution prevention agencies and search and rescue services. • Allows early identification of high-risk vessels; earlier precautionary actions and risk mitigation; and improved emergency response in the event of pollution, through standardised access to data.
Satellite oil spill monitoring – CleanSeaNet (CSN)	<ul style="list-style-type: none"> • Uses radar satellite images to: identify oil pollution on the sea surface; monitor accidental pollution during emergencies; contribute to the identification of polluters. • If a possible oil spill is detected, the relevant member state is alerted and analysed images made available • Vessel detection – if the identity of the polluting vessel can be determined, that vessel can then be tracked using SSN

For all of these operational tasks, EMSA make use of Automatic Identification Systems (AIS) as a way of tracking ships and sea. In the case of EU LRIT, part of a global network of vessel tracking conducted by EMSA on behalf of the IMO, vessel tracking and identification can play a significant role in ensuring the security of the EU's borders and by countering criminal activities. ESA (2008), for example, noted that improved satellite technologies for vessel identification and location tracking means that EU coastal states can better control and manage access to their territorial waters and exclusive economic zones for fisheries, and also counter illegal activities such as people, drugs and weapons trafficking.

3.1 Maritime Security

There are a number of maritime security challenges facing the EU according to the European Commission (2006), including: illegal immigration by sea; smuggling and drug trafficking; terrorism; and piracy and armed robbery at sea (pp 29-31). In the case of smuggling and drug trafficking, large amounts of cigarettes and tobacco are smuggled into the EU from China at an estimated cost to the EU economy of €10 billion

⁸ For details of all the operational tasks of EMSA see <http://www.emsa.europa.eu> and select Operational Tasks

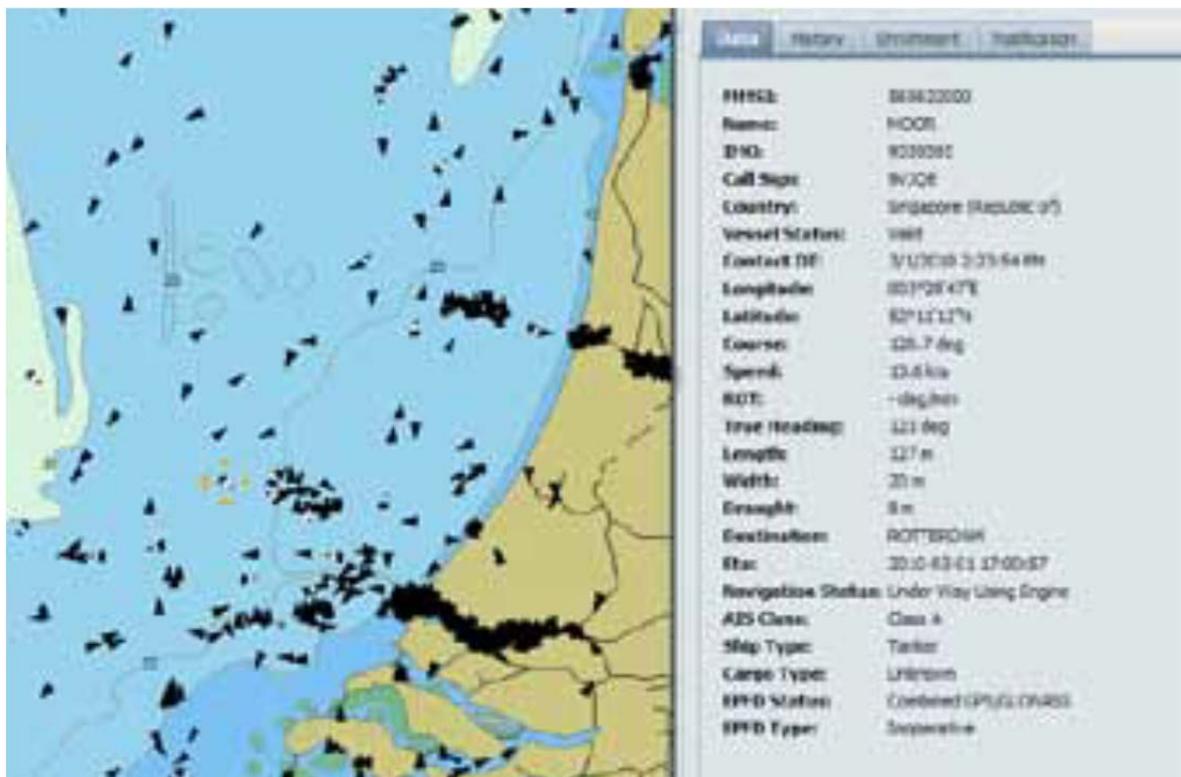
⁹ International Convention on the Safety of Life at Sea, 1974, as amended in May 2006. Further details of this Convention are available at: <http://www.imo.org/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-%28SOLAS%29%2c-1974.aspx>

¹⁰ This is a requirement of SOLAS, Chapter V - Carriage requirements for shipborne navigational systems and equipment. For further details see: <http://www.imo.org/OurWork/Safety/Navigation/Pages/AIS.aspx>

per year (see European Anti-Fraud Office, 2011) while drug smugglers are using containerised sea transport as a simple, convenient and cost effective mode of transport (see Griffiths and Jenks, 2012, p 37).

As noted previously, the main EU and national agencies with responsibility for maritime security include general law enforcement bodies, customs and excise, security services and defence agencies (in line with the user groups identified by the European Commission DG-MAF (2010, p 6). Using AIS, the EU LRIT and SSN Services can assist both civilian and military agencies as ship location data enables EMSA to monitor the position of up to 17,000 ships in and around EU waters daily (EMSA, 2012a, p 23). SSN can, for example, identify the current position of all ships or just one ship in and around EU waters by clicking on an individual icon (see Figure 1), to display specific vessel types (tankers, banned vessels, ships carrying hazardous goods), and show historical positions for ships (see EMSA, 2012b).

Figure 1 – Screenshot showing ships around the Dutch coastline at an unspecified date and time



Source: EMSA (2010b), page 3.

The use of AIS data by SSN therefore provides more accurate tracking of ships for safety purposes and that same data can be used for maritime security and marine environmental protection under a Combined Maritime Data (CMD) operational task of EMSA (see EMSA, 2012c). Additionally, by combining satellite imagery with AIS, it may be possible to exclude known vessels from images and identify those without AIS transmitters on board which might be involved in illegal activities. For example, in the case of fisheries control, AIS data could support monitoring of compliance with regulations or enforcement operations, and

aid in the identification of illegal fisheries and fish landings (see European Commission DG-MAF, 2010, Annex, p 23).

As an example of a potential security threat from a ship, it has been suggested that ships carrying liquefied natural gas (LNG), a highly flammable substance, have the potential to cause severe damage and loss of life if there is an explosion on board while they are in a port, whether because of an accident or the result of a terrorist attack on a ship and port (see Testa, 2004; McNicholas, 2008, p 248). Richardson (2004) identified a similar threat posed by ships transporting ammonium nitrate, an agricultural fertilizer, which can be used as an explosive (pp 45-48), and how radiological materials could be used by terrorists to make so called 'dirty bombs' (pp 51-52). Many ships carry materials that have the potential to be turned into bombs, should a ship be taken over by terrorists, and so using AIS tracking information through the EU LRIT and SSN systems could be used to track those vessels to ensure that they have followed the most appropriate route, arrived at their destination in good time, and have not made any unexplained stops at sea. If any of these eventualities occur, a ship could be prevented from entering a port or might be boarded for inspection while still at sea. Stankiewicz (2005) concludes that to eliminate danger from a terrorist threat, collective and cooperative action is necessary to fight organized criminality at sea (p 697) and this offer a clear example of where satellite data collected by the EU LRIT, SSN and CSN systems could provide a tool to support such rapid action.

Border security is also a significant issue for the EU, given that its coastline is estimated to be between 70,000 and 89,000 kilometres in length (see Germond, 2011, p 564; European Commission Research Information Centre, 2009). For example, illegal immigration by sea is a particular problem in the Mediterranean and the southern part of the Atlantic external sea border (see European Commission, 2006, p 29), the United Nations Office on Drugs and Crime (2011) reporting that more than 100,000 migrants cross the Mediterranean every year from West and North Africa, sailing from countries such as Egypt towards Greece or Turkey (p 21). Those migrants travel in small, overloaded boats and there have been many examples of those boats sinking with consequent loss of life (see Pugh, 2004, p 56).

3.2 *Maritime Safety*

The use of AIS for vessel traffic monitoring under SSN can help ensure the safety of ships sailing in EU waters. In the event of a shipping accident, irrespective of whether the ship sinks or not, there is the potential for injury or loss of life among crew or passengers (depending on vessel type) and for accidental pollution to occur. In the case of the *Costa Concordia* accident in January 2012, more than 30 people died despite the accident occurring just off the shore of Isola del Giglio¹¹. This accident was highly visible and rescue services were close at hand. However, when an accident occurs at sea it can be much more difficult to undertake rescue operations so a system which can identify the position of a vessel, provide information on the number of people on board, and also information about any hazards faced by rescue teams. EU LRIT, SSN and AIS data may also be used to target nearby vessels and request they move to a position to render assistance to a vessel in distress.

¹¹ Isola del Giglio is located in the Tyrrhenian Sea off the western coast of Italy and some 100 km north-west of Rome

Other maritime safety hazards include natural hazards such as floating ice-bergs in shipping lanes (discussed at Section 2.1) or man-made hazards such as the loss of containers overboard in bad weather or as a result of an accident. Recent developments in the design of cargo containers transported on board ships including the addition of GPS (global positioning system) tracking devices means that, if one or more containers are lost overboard, they can be tracked or monitored to ensure that they do not pose a hazard to shipping. There is also the potential for loss of life in the event of a collision involving ferries or passenger ships sailing in areas of heavy sea traffic colliding with other vessels (for example, the English Channel), although EMSA (undated) indicates that loss of life is minimal in the event of such collisions. Guedes Soares and Teixeira (2001) identify that up to 80% of shipping accidents between 1987 and 1997 were caused by human error (pp 301-302) and examples of accidents where human error has resulted in loss of life include the *Costa Concordia*, discussed previously, and the *MV Herald of Free Enterprise*, a roll-on roll-off ferry which partially sank in Zeebrugge harbour in March 1987 with the loss of 188 lives (see Marine Accident Investigation Branch, 1987).

EMSA (2012d) identified a range of shipping accident types which impact on maritime safety including capsizing, collision, fire or explosion. Search and rescue action in response to such accidents falls under the aegis of the International Convention on Maritime Search and Rescue (1979) and the Global Maritime Distress and Safety System Regulation adopted in 1988 (see International Maritime Organization, undated). That system uses Inmarsat¹² maritime satellites to track vessels, either from radio transponders on board life rafts, or using Emergency Position Indicating Radio Beacons (EPIRBs) which can transmit details of a vessel in distress anywhere in the world. Using positioning information in combination with SSN information on number of persons on board a ship and whether there are any specific hazards, search and rescue teams can act to ensure the safety of crew and passengers.

3.3 Marine Environmental Protection

There are many examples of Earth Observing Missions undertaken by ESA using satellites including ENVISAT, ERS (Earth Remote Sensing satellites), Meteosat¹³ European weather satellites and MetOp¹⁴ polar orbiting satellites. The ESA website¹⁵ identifies a range of areas where space technology is used in relation to the marine environment including satellite observation and satellite telecommunication links for vessel trafficking or as a navigational aid. In this latter example, radar equipment on board ESA's ENVISAT satellite is used to support the routing of ships operating in ice-affected areas such as the North Atlantic routes, Arctic oil fields, and the Baltic Sea, as noted previously. In the Arctic region, ESA (2008) indicates that meteorological satellites including the European Polar System provide information which contributes to

¹² Inmarsat PLC is a British satellite telecommunications company providing a range of services through a number of geostationary telecommunications satellites. For details of Inmarsat and its role as a company providing satellite services to the Global Maritime Distress and Safety System (GMDSS) see <http://www.inmarsat.com/services/types/safety>

¹³ For details of Meteosat Second Generation meteorological satellites for Europe see: [http://www.esa.int/Our_Activities/Observing_the_Earth/Meteosat_Second_Generation/MSG_overview2/\(print\)](http://www.esa.int/Our_Activities/Observing_the_Earth/Meteosat_Second_Generation/MSG_overview2/(print)) (last accessed 18 December 2012)

¹⁴ For details of the MetOp polar orbiting satellites see: http://www.esa.int/Our_Activities/Observing_the_Earth/MetOp_overview (last accessed 14 December 2012)

¹⁵ For details of ESA's Earth Observing Missions see: http://www.esa.int/Our_Activities/Observing_the_Earth (last accessed 18 December 2012) and select the missions from the list on the left side of the webpage.

short term forecasting of ice conditions, and collect data which allows the regular monitoring of marine habitats in the region.

Another area where satellite data can make a significant contribution is in assessing the health of the marine environment through monitoring of pollutants entering the marine environment. Those pollutants fall into 4 categories according to Clark (1993): physical, including sediments; chemical, including toxic and acidic waste and oily waste; biological, including– sewage and dissolved organic compounds (a major problem in enclosed seas such as the Baltic Sea; and thermal, where industrial discharges or the cooling requirements of power stations can raise the water temperature (pp 361-365). As an example of a problem caused by biological pollution and how satellites can help monitor that problem, ENVISAT images have been used to monitor algal blooms of the phytoplankton *cyanobacteria*, a blue-green algae which is visible at high concentrations (several hundred thousand to several million cells per millilitre of water), Paerl and Huisman (2008) noting that such bacteria can have a detrimental effect on aquatic plants and on invertebrate and fish habitats, a particular threat in the Baltic Sea (p 57). Examples of physical pollutants include plastic debris which Derraik (2002) identified as making up most of the marine litter worldwide, suggesting that between 60% and 80% of total marine debris is made of plastic (p 843). Marine debris includes fishing gear (nets, buoys and ropes) which can tangle with the propellers of small vessels, causing damage to them, and which also impact on marine mammals, surface-feeding and diving birds, and fish. However, such debris is hard to observe by remote sensing (satellite or airborne) due to their size and that they may be mostly submerged (see Mace, 2012, p 23).

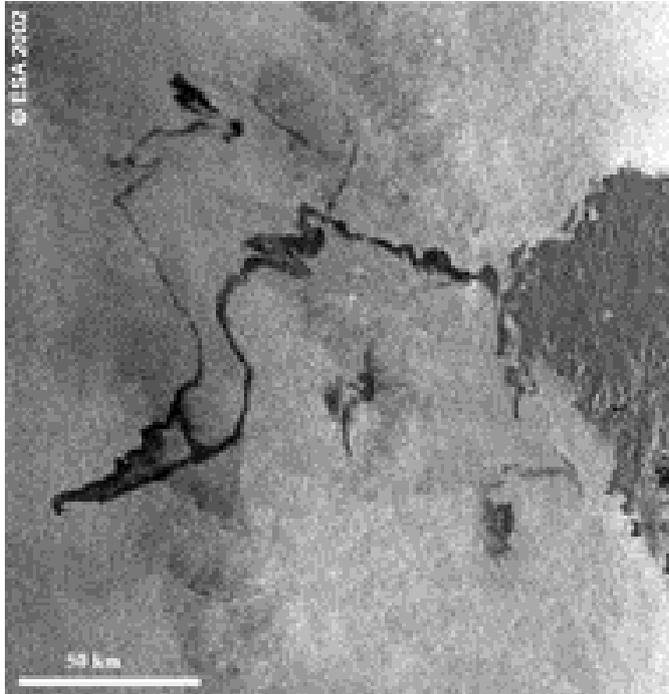
In contrast to the difficulty of identifying marine debris, Clark (1993) indicates that oil is much better suited for remote sensing investigation (p 362), and is one of the main areas in which satellite imagery has been used to protect the marine environment is through the observation of oil spills. An image of oil pollution was, in fact, one of the earliest images received from ENVISAT, newly launched in 2002. That image (see Figure 2 overleaf) shows the twin “tails” of an oil slick which resulted from the sinking of the *MV Prestige*, a single hulled tanker which sank approximately 100 miles off the coast of Galicia, Spain in November 2002. The resulting oil slicks washed up along 200 miles of Atlantic coastline between the Spanish border and L’Ile d’Yeu and the ENVISAT image of the slicks was used by organisations such as the World Wide Fund for Nature to illustrate the extent to which oil can spread and cause damage following an accidental spill¹⁶.

Under the SSN system, information is held on ships carrying hazardous materials or dangerous and polluting goods, or substances that can cause environmental damage or pose a hazard in the event of an accident. This information is invaluable if there is an accident where chemicals or hazardous materials are spilt, for example, enabling search and rescue agencies to identify potential hazards faced during rescue operations. In addition, it provides pollution monitoring and prevention agencies with information about high risk vessels (for example, single-hull oil tankers), enabling them to closely monitor such vessels sailing in

¹⁶ For more details on the Prestige Oil Spill, see World Wide Fund for Nature (WWF) website at: http://wwf.panda.org/wwf_news/press_releases/special_coverage/spain_oil_spill/latest_facts/ (last accessed 18 December 2012)

EU waters (see Carpenter, 2012, pp 248-267) and linking in with the CSN system for monitoring marine pollution incidents.

Figure 2 – ENVISAT image of the Prestige Oil slick, November 2002



Source: ESA Multimedia Gallery¹⁷

There are a range of space-borne and airborne remote sensing devices, with satellite sensors being used for preliminary oil spill assessment and airborne ones for more detailed analysis of an oil spill (see Jha et al., 2008, p 236) and also provide daily images of oil spills (see Karantzalos and Argialis, 2008, p 6282). Such remote-sensing devices can, according to Coppini et al. (2011), provide substantial support to routine surveillance for oil slicks in both the open-ocean and in coastal areas, as well as observing oil spills in remote and inaccessible areas (p 140), and identify that satellite images can provide robust operational information during an oil spill incident, enabling more accurate prediction of oil spill drift, including identification of where oil may come ashore, and that a system using optical sensors and Synthetic Aperture Radar (SAR) on board satellites can also aid in developing international action plans to clean up such spills and for hindcasting (back-tracking) an oil spill to its source (pp 152-153).

Back-tracking of vessels and linking them to the location of an oil spill is vital if there is to be any hope of bringing a polluter to justice and is an area where CSN could play a significant role. CSN enables EU Member States to obtain (additional) satellite images to identify potential polluters and follow up on incidents using aerial surveillance. This covers all EU waters and images of possible intentional spills and accidental spills are produced several times a day. For example, Konstanoy et al. (2008) indicates that

¹⁷ ENVISAT ASAR image of 17 November 2002 showing oil spill from the Prestige tanker, lying 100 km off the Spanish coast. ESA Multimedia Gallery ID number: ESANHD7708D. Available online at: <http://www.esa.int/esa-mm/mmg/mmg.pl?b=b&topic=Pollution&subtopic=Marine%20pollution&single=y&start=10>

there are around 10,000 oil spills in the Baltic Sea each year (p 71), and so the Helsinki Commission's (2010) suggestion that AIS be used to back-track from a detected oil spill and that matching a spill to a ship's track should increase the likelihood that a polluter will be identified and prosecuted (p 36).

This illustrates the importance of satellite observation in that region, and the benefit that region can gain from CSN. Section 4 illustrates how satellite imagery has been used in conjunction with the aerial surveillance activities of the Bonn Agreement to positively identify oil slicks.

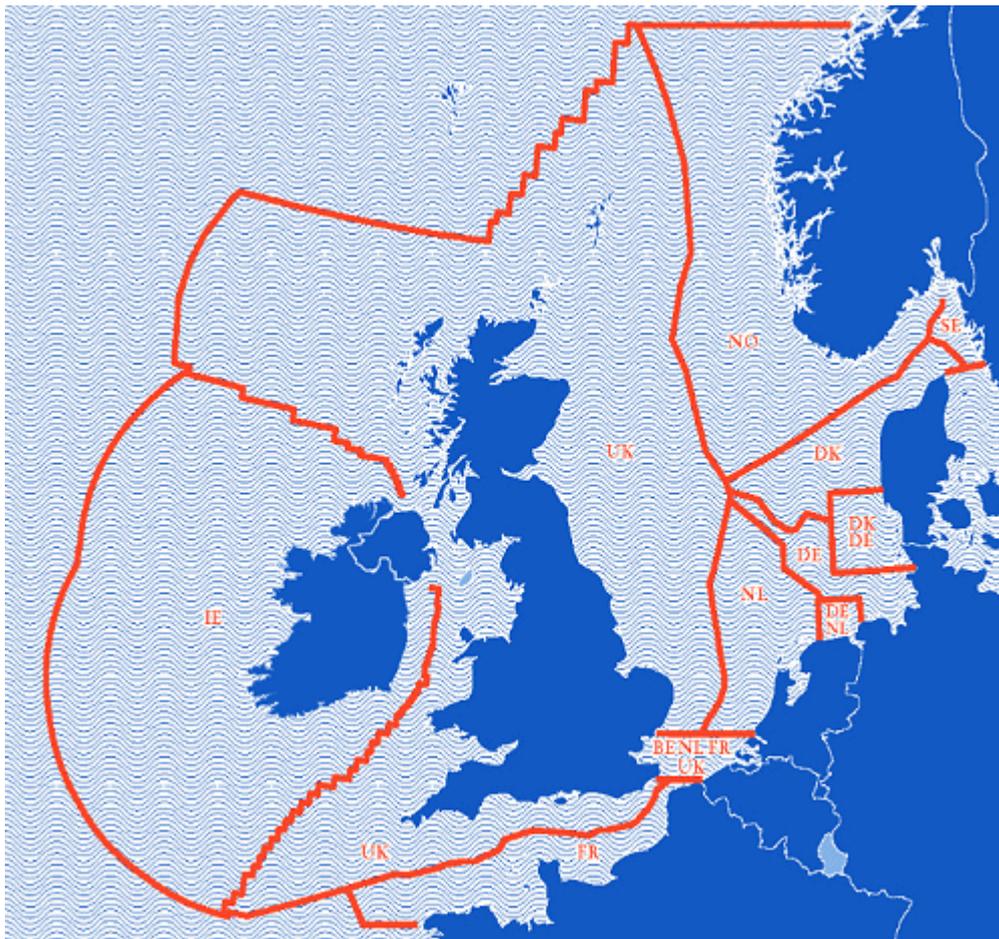
4. Bonn Agreement Aerial Surveillance and the use of satellite images

Ivanov and Zatyagalova (2008) identify a number of different types of slicks which can be seen in SAR images from satellites: natural slicks where what appears to be a slick is actually a film on the ocean surface caused by biological material produced by plankton and fish; 'look-alikes' which appear as dark patches on SAR images but are not actual oil slicks (examples including low wind areas, algal blooms, floating vegetation); and man-made oil spills - crude oil and refined products released into the sea from ships or from oil drilling platforms (p 6300). It is the last example which is considered in this section, where aerial surveillance and satellite images are used to identify oil spills at sea. Such information can, according to Ivanov and Zatyagalova (2008) be particularly useful in mapping marine areas exposed to oil pollution, in providing information to decision makers and experts from environmental agencies, and in enabling those actors to plan and respond to the threats posed by man-made spills (p 6310).

One such agency is the Secretariat of the Bonn Agreement. That Agreement was originally signed in 1969 and was, according to the Bonn Agreement Secretariat (2009, page 8)¹⁸, a direct response to the *Torrey Canyon* disaster of 1967 when the tanker, carrying nearly 120,000 tonnes of crude oil, ran aground on the Seven Stones reef close to the Isles of Scilly. The geographical area covered by the agreement is shown in Figure 3 overleaf, which includes all signatories to that agreement and some overlapping zones, for example between Denmark and Germany and Germany and the Netherlands.

¹⁸ As a result of the recognition that international action was necessary to deal with oil pollution, the original Bonn Agreement was signed by Belgium, Denmark, France, Germany, the Netherlands, Norway, Sweden and the UK as the original Contracting Parties. Subsequently, the Agreement was amended in 1983 to include other harmful substances in addition to oil and, at the same time, the European Community became a Contracting Party (CP), while Ireland became a CP in 2001

Figure 3 - Bonn Agreement geographical coverage and zones of responsibility for aerial surveillance



Source: Bonn Agreement Website - <http://www.bonnagreement.org/eng/html/contractingparties/welcome.html>

An examination of trends for the whole Bonn Agreement region for the period 1986 to 2004 has previously been produced by Carpenter (2007). At that time, no satellite observation data was available for the North Sea in the Bonn Agreement annual reports¹⁹. However, for all years since 2004 the Bonn Agreement annual reports²⁰ have included information on satellite observations, identifying slicks other than those identified by aerial surveillance activities. Figures 4 and 5, show the total number of spills identified in Danish and German North Sea zones since 2000, by aerial surveillance and from satellite imagery. Since 2003, the observation data has been further refined so that only those slicks confirmed as oil spills rather than just number of detections which may not be oil spills but rather things like sheen from biogenic origin, i.e. from algal blooms or slicks that are identified as not being oil upon closer investigation. Subsequently, additional verification has provided using EMSA CSN oil spill data since 2007.

¹⁹ For Bonn Agreement Aerial Surveillance reports go to: <http://www.bonnagreement.org/eng/html/welcome.html> and select publications

²⁰ For HELCOM Aerial Surveillance reports go to: http://www.helcom.fi/shipping/waste/en_GB/surveillance/

Figure 4 – Total number of spills observed in the Danish zone of responsibility

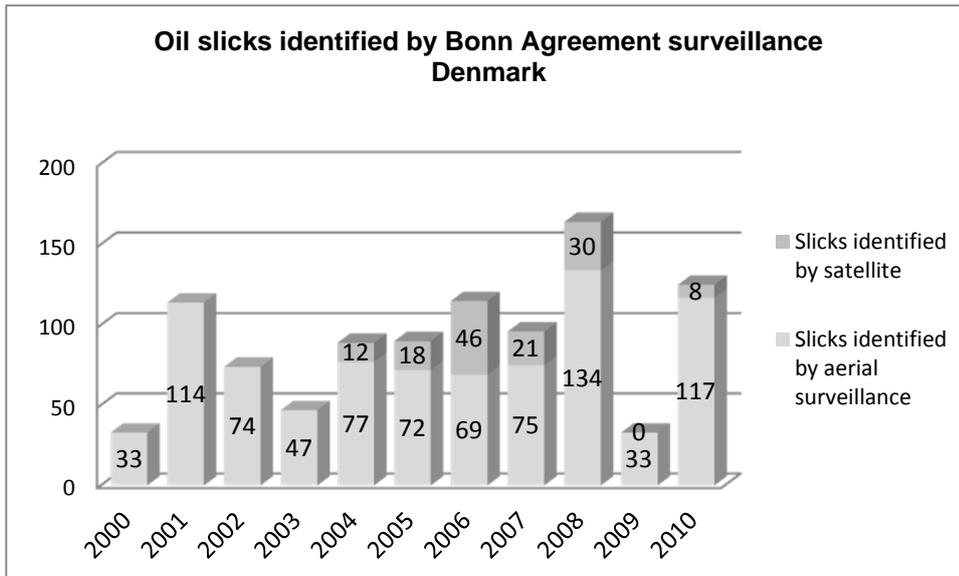
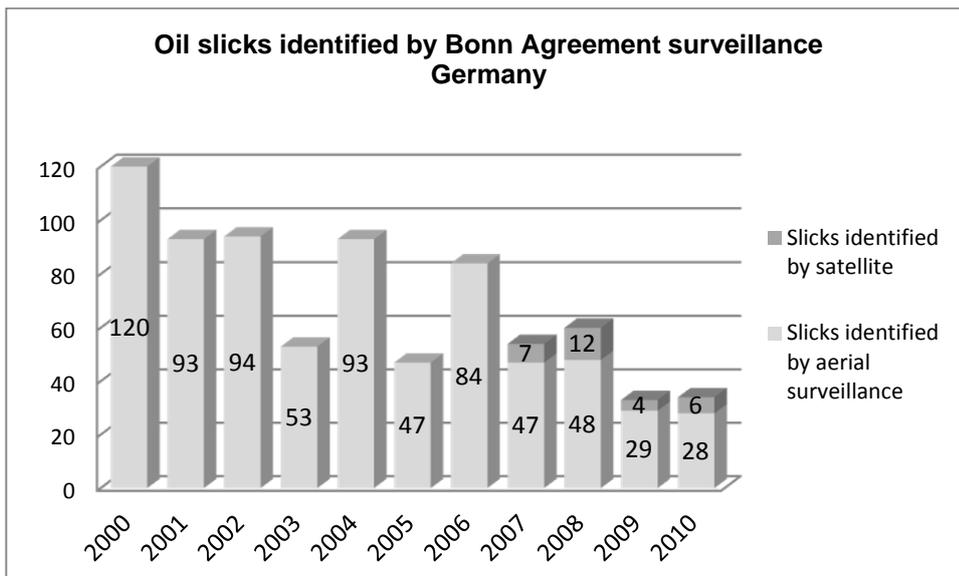


Figure 5 – Total number of spills observed in the German zone of responsibility



Original Source Data: Bonn Agreement Aerial Surveillance – Annual Reports 2001 to 2011

The use of satellite imagery and CSN data means that oil spill observation has become much more accurate in recent years. Figures 6 and 7, which have been adapted from CSN First Generation data for the period April 2007 to January 2011, show the number of satellite observations in the Danish and German zones of responsibility. Green dots are the number of satellite detections, yellow dots the number of observations where confirmatory action was taken, and red dots are confirmed oil spills.

Figure 6 – CSN First Generation Data with overlay of Danish zone of responsibility

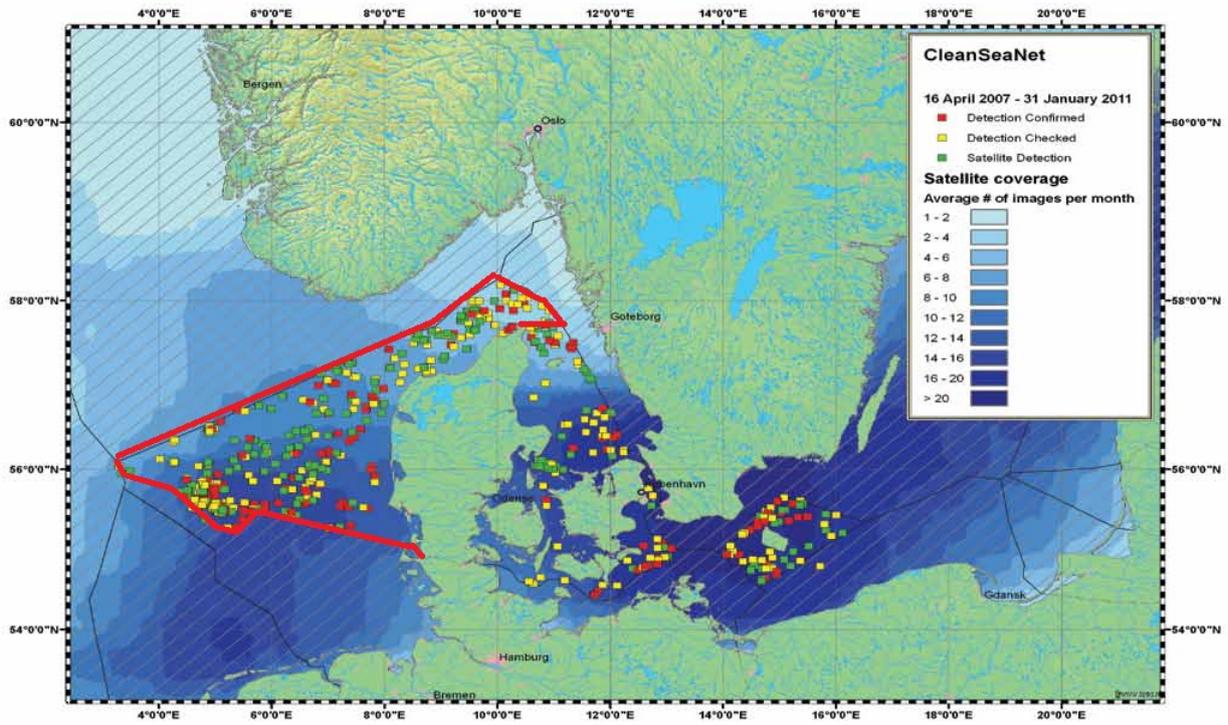
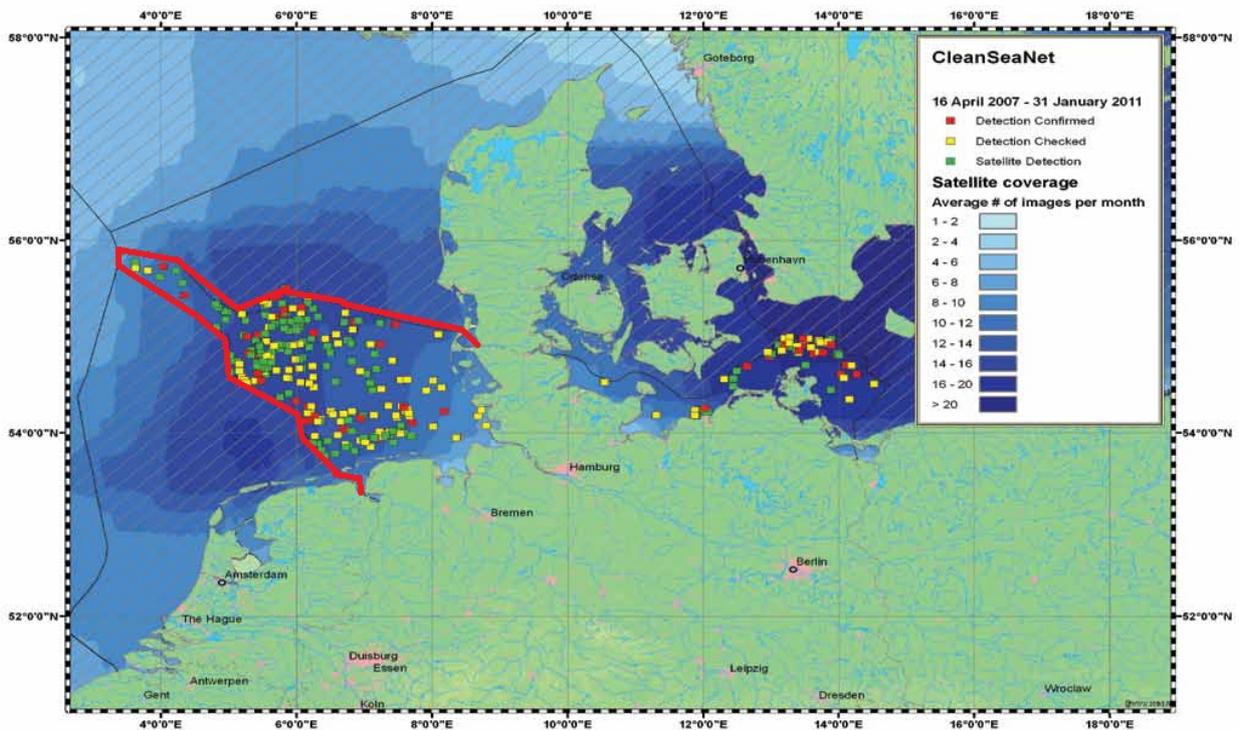


Figure 7 – CSN First Generation Data with overlay of German zone of responsibility

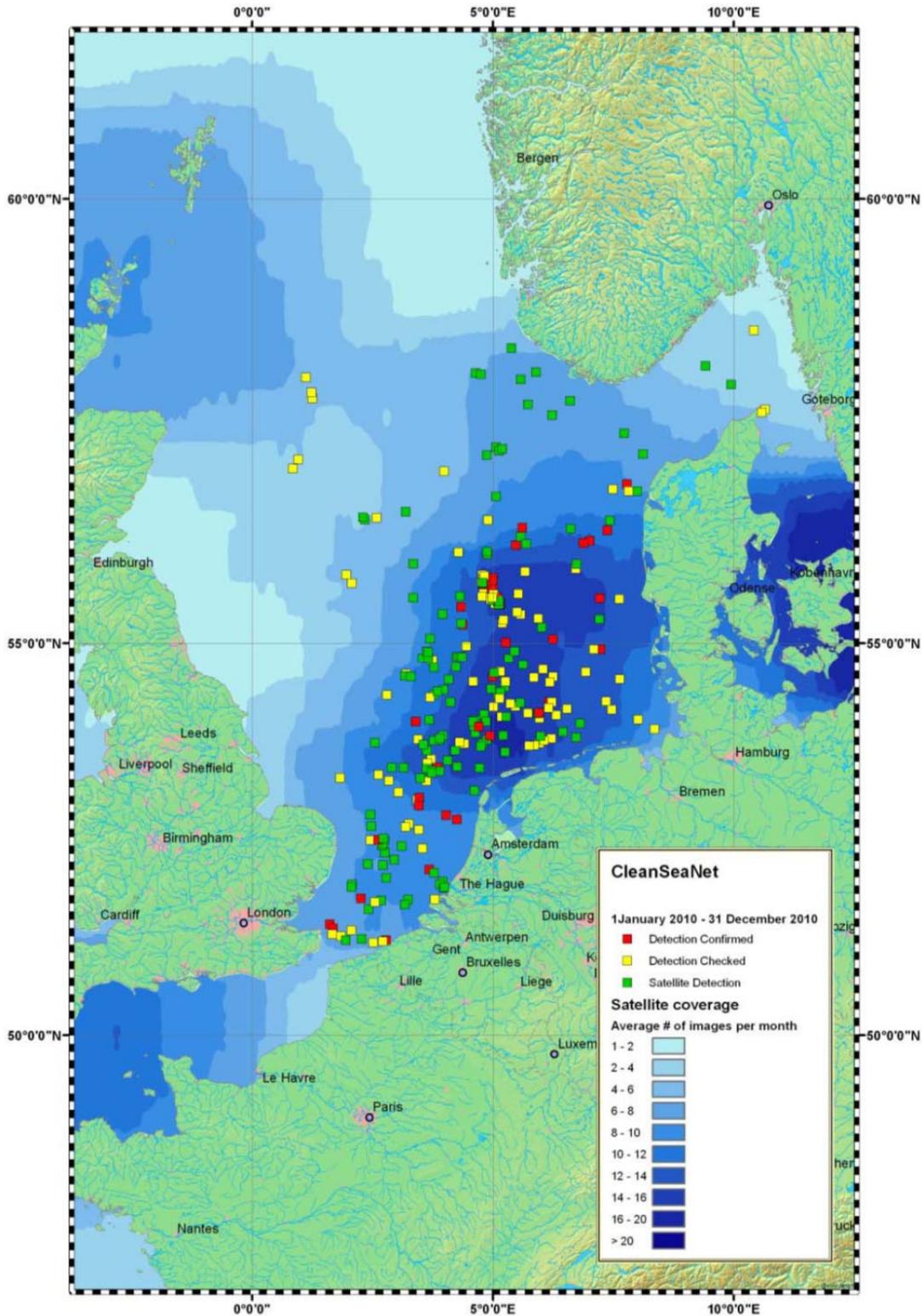


Source for Figures 6 and 7: *EMSA CleanSeaNet First Generation Report*. Pub: EMSA (2011), pages 20 and 28.

It should be noted that there is an area of overlap of the zones of responsibility for the two countries under the Bonn Agreement which has not been identified in figures 6 and 7 (see Figure 3 for a more detailed view of boundaries and areas of overlapping responsibility).

Based on the data under the EMSA CSN, Figure 8 illustrates all the observed and confirmed spills identified originally using satellite imagery for the entire North Sea region in 2010.

Figure 8 – Overview of possible oil slicks detected by CleanSeaNet in the North Sea



Source: Bonn Agreement (2011). Annual Report on Aerial Surveillance for 2010, page 35

Coppini et al. (2011) identify a limitation of the use of SAR, through its the long revisit time and the limited width of area covered by the sensors on board satellites such as ERS-2, RADARSAT-2 and ENVISAT (p 141), SAR offers the possibility of more frequently collected images and images which cover areas outside the usual flight zones patrolled by Bonn Agreement flights. However, the use of satellite imagery in conjunction with the CSN service has already made a positive impact through increased levels of observation of spills in Europe's maritime areas, providing EMSA and Member States with more complete, accurate and verified oil spill information. It also provides the additional benefit that observations can be made during the hours of darkness, or during periods of bad weather, thus increasing the potential to identify and prosecute the owners of vessels which intentionally discharge oil at sea.

5. Conclusions

There is a clear need for continued satellite observation of the marine environment in order to maintain and support the activities of EMSA, other EU agencies, CSN and the Bonn Agreement. There are also areas of overlap where data obtained from satellite observations, images or vessel monitoring can contribute in more than one area.

Satellite monitoring of vessel positions using AIS is vital to EMSA's EU LRIT and SSN operational tasks in the area of maritime security, by tracking vessels that pose a threat to the EU and its member states. At the same time, that data can also be used in respect of maritime safety, enabling search and rescue actors to locate a ship at sea if it is involved in an accident, to have available information on the number of persons involved in that accident, and by providing information on potential hazards that might affect rescue operations. In addition, it can also assist in anti-pollution measures necessary if oil or other substances are spilt as a result of such an accident, by providing information necessary to ensure appropriate clean-up operations take place. Also in the area of maritime safety, satellite observation of ocean currents, weather patterns and ice formation also play a role in assisting ship safety, by ensuring that they are not sailing into hazardous conditions, and by helping identify the most appropriate routes of travel (for example see ESA, undated).

In the area of marine environmental protection, satellite imagery used in conjunction with AIS and aerial surveillance provides a crucial tool in monitoring for ship-source pollution by helping identify incidents of both accidental and intentional pollution at sea. Having identified such pollution, it may be possible to identify the actual ship from which it comes and to prosecute the ship's owner or captain as a result. Without adequate monitoring systems, there remains an incentive to deliberately dump oil and other substances at sea, irrespective of whether there are regulations in place or voluntary agreements to stop them from doing so, as the likelihood of being identified as the source of pollution is low.

While tracking of ships carrying appropriate AIS equipment on board is relatively straightforward, the movement of small vessels involved in illegal activities such as drug smuggling, or the smuggling of individuals into the EU, is more problematic and is an area where satellites may be able to make a

contribution. Continued development of “high revisit time all-weather day-and-night” satellite surveillance, where satellite images can be obtained on a frequent basis and irrespective of weather conditions and time, would make a significant contribution in identifying and tracking such vessels, particularly along known routes of travel across the Mediterranean or for drugs being transported from South America for example. This would also benefit maritime safety in reducing loss of life from the sinking of small vessels, contribute to border security by monitoring migration routes, and contribute to the detection of criminal activities by tracking vessels used for drug smuggling and other illegal activities.

Satellite imagery and observation play a significant role in maritime security, maritime safety and marine environmental protection across EU maritime regions. It is apparent, therefore, that continued cooperation between ESA, EMSA and other EU agencies in policy areas relevant to the marine environment are vital to the continued security, safety and economic prosperity of the EU.

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