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PMAR: Piracy, Maritime Awareness & Risks

Trial Implementation under MASE

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Abstract

During one year, from September 2014 to September 2015, the PMAR-MASE project has produced the real-time traffic picture of the reporting ships (that use the AIS or LRIT automatic position reporting system) over the entire Western Indian Ocean, and delivered it via a web viewer to two authorities in Africa with a regional maritime security responsibility: the Anti-Piracy Unit of the Indian Ocean Commission in the Seychelles, and the Regional Maritime Rescue Coordination Centre of the Kenya Maritime Authority in Mombasa. In addition, monthly ship density maps have been produced, and a number of satellite images have been analysed to assess the presence of non-reporting ships. The purpose of the project was familiarisation of maritime authorities in the Eastern-Southern Africa / Indian Ocean region with region-wide maritime monitoring, providing hands-on experience, and developing an understanding of what kind of information level is attainable and how to use the information. This report discusses the activities done under the project, the data that were used, the system design, the processing that was done, the visits to the region, the user feedback, and the performance of the system. The PMAR approach is based on the fusion of AIS and LRIT data from several sources, with satellite AIS being the most valuable data type, supplemented by a limited number of satellite SAR images. It is concluded that this approach provides a very powerful tool for region-wide maritime awareness, to which the authorities can avail themselves via commercial services.

Front cover: Screen view of the Maritime Situational Picture (MSP) as provided under PMAR-MASE. Each symbol is a ship, colour coded by type. Most ships are cargo (green) or tanker (red).

Executive Summary

To contribute to enhancing the maritime security in the Eastern and Southern Africa and Indian Ocean (ESA-IO) region, the European Commission's Joint Research Centre (JRC) has been running the project 'PMAR (Piracy, Maritime Awareness and Risks) Trial Implementation under MASE'. The project was funded under the Programme to Promote Regional Maritime Security (MASE) and carried out under a contract with the Indian Ocean Commission (IOC), supervised by the EU Delegation in Mauritius.

The PMAR-MASE project aimed at running a pre-operational trial providing regional maritime awareness during one year to two operational centres of maritime authorities in the ESA-IO region, namely the RMRCC/ISC Mombasa (in its capacity as Information Sharing Centre under the Djibouti Code of Conduct) and the IOC-Anti-Piracy Unit (APU) in the Seychelles. This was intended to build up capabilities with these authorities, for maritime security-related operations, activities and decision making; and to build up experience with using region-wide maritime surveillance.

The objectives of the PMAR-MASE project have been achieved in that:

- maritime awareness in the form of a real-time Maritime Situational Picture (MSP), showing the reporting ships in the entire Western Indian Ocean, has been continuously delivered to the two operational centres in Mombasa and the Seychelles for one year, from 15 September 2014 until 15 September 2015;
- monthly ship traffic density maps, real-time wind and wave conditions, and piracy incidents were provided as functional overlays of the MSP in order to better interpret the real-time situation;
- training was provided to the local operators in Mombasa and the Seychelles, initially to work with the PMAR system and build up experience with it, and later to provide the necessary feedback on how the system could be improved to better fit local needs.

For the latter point, three visits to the region have been carried out, that were also used to brief other stakeholders in the region including policy makers on maritime awareness.

It was decided in the project definition to involve only two centres in the PMAR-MASE trial, to save costs and to avoid burdening too many operational centres with a prototype product. However, during the trial much interest in the PMAR system was shown by other operational users. Indeed, for future operational use, it is one of the advantages of the region-wide MSP that it is one product that can be shared across many users, thereby making it cost-effective.

The MSP shows the locations of all the reporting ships in the Area of Interest (off East Africa), and is constructed by collecting automatic ship reporting data from a series of sources, fusing those together, extracting ship tracks, and predicting ship positions at the current time, in a continuous process. The ship reporting data are from AIS (Automatic Identification System) and LRIT (Long Range Identification and Tracking), systems that are globally mandated for carriage by IMO (International Maritime Organisation). Those data are collected by networked coastal receivers, receivers on satellites, and Flag State administrations, partly government owned and partly commercial, and have been brought together in the PMAR system. Each individual data source only collects a fraction of the ship position reports, so the more data sources are combined, the more complete will be the maritime awareness. The trial has quantified the completeness and accuracy of the resulting MSP as a function of the number of data sources tapped, knowledge that can be used in choosing operational systems / services. Of the order of five AIS satellites provide a reasonably complete picture, with LRIT adding accuracy to the positions (of those ships whose LRIT is received).

The MSP, that tracks all the reporting ships across the Area of Interest, does not show the non-reporting ships that do not carry AIS or LRIT. To assess the presence of that component of the ship traffic, a number of satellite radar images have been acquired and analysed. This indicates that around 35 % of the ships are non-reporting, although this number varies much from place to place,

and still excludes the very small ships (< 20 m) that are also not seen in the satellite radar images.

The PMAR concept comprises the real-time, region-wide MSP showing the positions of the reporting ships, that can be queried for their attributes and past track, based on fusing a set of sources of ship reporting data; with map backgrounds, and overlays for supporting information such as wind, waves, piracy incidents and ship traffic patterns; supplemented by occasional and targeted sampling by satellite radar of the non-reporting ships. The trial and the user feedback have shown that the PMAR concept is a valuable and efficient way to obtain region-wide maritime awareness, the user feedback in particular pointing to the need of further automatic analysis of the MSP and generation of alerts.

Considering the present situation, where several places in the ESA-IO region are planning to start up maritime Regional Information Fusion Centres (RIFCs), and given the experience gained from the PMAR-MASE trial, it is recommended that potential RIFCs turn to commercial providers for the delivery of region-wide maritime awareness along the lines of the PMAR architecture. Commercial provision of the MSP – as trialled under PMAR – as a service is probably the option that optimises the availability of the MSP to the end users with the lowest risk of discontinuity, compared to acquiring raw data and software and running the processing in the centre(s). Considering the regional coverage of the maritime awareness, one service can be shared by multiple centres / many countries in order to lower the costs. The PMAR experience can be used by the centre(s) to specify their requirements to the service providers, so that the users are better ensured that the service will really cover their needs.

Contents

1 Introduction

The project 'PMAR (Piracy, Maritime Awareness and Risks) Trial Implementation under MASE' (PMAR-MASE project) has been carried out by the European Commission's Joint Research Centre (JRC) under service contract No FED/2014/346-721 with the Indian Ocean Commission (IOC). Pursuant to section 7.1 bullet 3 of Annex II (Terms of Reference), this final report presents the main results of the project run over the past 15 months from 18 July 2014 until 18 October 2015.

The report covers how the project objectives and deliverables have been met, and discusses the activities that have been carried out to that end. It contains a description of the technical elements of the PMAR maritime awareness system that was used, and the main aspects of its performance.

Further technical details about the performance and results of the PMAR system during the PMAR-MASE project, including monthly ship density maps of the region, can be found in the separate report "Maritime Awareness Systems Performance in the Western Indian Ocean 2014-2015" (JRC Technical Report, 2015, JRC97935) that constitutes Annex 2 to this report (see List of Annexes at the end).

1.1 Background

The PMAR-MASE project followed on from two precursors, PMAR – Horn of Africa and PMAR – Gulf of Guinea, in which the JRC developed tools for maritime awareness and data sharing for counter-piracy for the mentioned regions. In particular, the PMAR – Horn of Africa (PMAR-HoA) project ended with a workshop in November 2012 in Mombasa, Kenya, concluding the need for a trial implementation of the maritime awareness tool, to be carried out to the benefit of the whole region.

The present PMAR project was part of the larger Programme to Promote Regional Maritime Security (MASE), funded by the EU's 10th EDF and being implemented by four Regional Economic Communities: the Intergovernmental Authority for Development (IGAD), the Indian Ocean Commission (IOC), the Eastern African Community (EAC), and the Common Market for Eastern and Southern Africa (COMESA). Under Result 4.2.1 of the MASE programme on improved maritime domain awareness (MDA), the objective is to evaluate and procure an adequate maritime domain awareness system, compatible with existing systems in particular the PMAR system. Result 4 is managed by the IOC.

1.2 Project objectives

The PMAR-MASE project aimed at capacity building for maritime security and counter-piracy in the Eastern and Southern Africa and Indian Ocean (ESA-IO) region. It focused on the component implemented by the IOC, and specifically on familiarisation with Maritime Situational Awareness.

The Area Of Interest was defined as the Western Indian Ocean off the coast of East Africa, from the Gulf of Aden down to south of Madagascar.

The JRC has run a pre-operational trial providing regional maritime awareness during one year, to two operational centres of maritime authorities in the ESA-IO region. These were the Regional Maritime Rescue Coordination Centre (RMRCC) of the Kenya Maritime Authority (KMA) in Mombasa, Kenya[1]; and the Anti-Piracy Unit (APU) of the IOC in the Seychelles. This was intended to build up capabilities with these authorities, and to build up experience with region-wide maritime awareness systems. The knowledge and tools developed in the PMAR-HoA project have been used.

More specifically and pursuant to section 2.3 of Annex II (Terms of Reference) to the Contract, the JRC has implemented the following Deliverables (D) in full:

[1] This is also one of the Information Sharing Centres (ISC) under the Djibouti Code of Conduct (DCoC)

D1.1 Real-time daily maritime awareness, in the form of a Maritime Situational Picture (MSP), showing the reporting ships, delivered to the RMRCC/ISC Mombasa and APU in the Seychelles.

D1.2 Regular (monthly) vessel traffic statistics, which functioned as reference benchmarks to enable better interpretation of the real-time situation.

D1.3 The integration of piracy incident statistics with the ship traffic situation, to enable risk assessment.

D2.1 Installation of the tools, and a first training for the use of local operators during a visit to the region.

D2.2 Further training to local operators, also taking stock of feedback, and control / maintenance of the tools, during a second visit to the region.

1.3 Specific work

In order to implement the Deliverables, the JRC provided services to the IOC, including:

- Procurement of the necessary data;
- Adaptation of the software tools to serve the two centres, and installation of software;
- Running the system for one year;
- Training of operators and decision makers;
- Preparation of software for transfer to the region.

The services provided are described in the following chapter.

2 Services provided

This chapter contains an overview of the activities, following the structure of the project's Terms of Reference document. More details on the technical aspects are given in Chapter 5.

In line with the contract to implement the Deliverables, the following services have been provided:

2.1 Data procurement

The JRC has tried to use as many maritime surveillance data of regional relevance as possible in order to provide the best possible region-wide maritime situational awareness. As described in Annex III to the contract, the sources used were ship reporting data from AIS and LRIT, non-cooperative observations of ships from satellite SAR, and piracy incidents reports:

Satellite AIS

Satellite-AIS data have been received from:

- the international, government-overseen MSSIS network which globally exchanges coastal AIS, following the permission granted to the JRC;
- Norway's AISSat-1 and -2 and NORAIS systems, under an agreement between the JRC and the Norwegian Coastal Administration (NCA); and
- the commercial providers exactEarth, Orbcomm/LuxSpace and SpaceQuest, after the JRC accepted their offers following a tender.

LRIT

LRIT data have been collected from the approximately 40 Flag States – including the 28 EU Member States – that participate in the EU LRIT Cooperative Data Centre. These data have been provided through the European Maritime Safety Agency (EMSA) following the kind permission given by the Flag States to the JRC.

Satellite SAR

Satellite SAR image data have been commercially acquired from Radarsat-2: Twenty-one (21) "ScanSAR Narrow B" images, with wider swath but lower resolution (at 1.4 k€ each) and eight (8) "WideFine" image, with narrower swath but higher resolution (at 2.8 k€ each).

Piracy incident reports

Access to piracy incident data through the International Maritime Bureau (IMB) website has been obtained. The request to IMO for (automatic) access to its piracy incident database was without success.

2.2 Software preparation and installation

In the run up to the project, the software had been prepared for the collection, ingestion, integration and transformation into the operationally usable results mentioned under Deliverables D1. The software had been made ready for use, on the basis of the following architecture and as foreseen in Annex III to the contract:

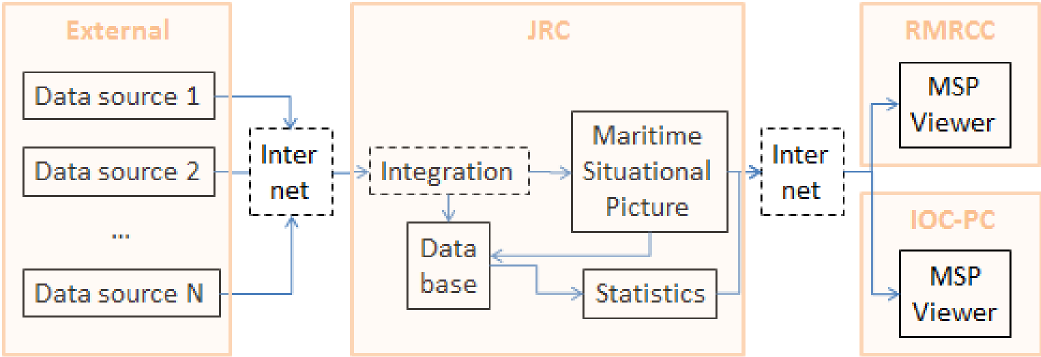

Figure 1. High level design of the PMAR-MASE system.

As indicated in the figure, the data processing has been done at JRC. The Maritime Situational Picture (MSP) has been transferred from the JRC to the two operations centres in Mombasa and the Seychelles via a secured web interface (https://bluehub.jrc.ec.europa.eu/). Access was allowed to only one fixed IP number per centre, and was login and password protected.

During the first visit to the region from 21 September to 1 October 2014, the PMAR access was successfully installed at the two operational centres in Mombasa and the Seychelles.

2.3 Running the PMAR system

The full data stream for running the PMAR system started on 15 September 2014. As the data had been requested for one year, either from government owners or commercially acquired, the system has been running until 15 September 2015.

Following the installation of the PMAR system access during the first visit to the region from 21 September to 1 October 2014, real-time daily maritime awareness in the form of a Maritime Situational Picture (MSP), showing the reporting ships, has been continuously delivered to the two operational centres in Mombasa and the Seychelles, in full compliance with Deliverable 1.1 of the Contract (D1.1).

Monthly ship traffic density maps have been generated automatically and could be accessed by the local operators as functional overlays on the Maritime Situational Picture (D1.2). In addition, real-time wind and wave conditions could be viewed. Similarly, piracy incident maps have been generated, based on data that has been updated hourly with the International Maritime Bureau (IMB) (D1.3). All these functional overlays should have helped operators to better interpret the real-time situation. Furthermore, ship density maps and ship counts per EEZ and per Flag could have been extracted on request to the JRC.

As from 15 September 2015, the PMAR system was no longer fed by the input data and users were informed accordingly by email on 16 September 2015. However, the system has remained on-line and accessible for the time being, but with less complete ship positions. Only coastal AIS data from the MSSIS system remained available as input stream, as that remained freely accessible, and some of the satellite AIS providers did not immediately close the data stream.

2.4 Training

In addition to installing the PMAR system access during the first visit to the region from 21 September to 1 October 2014, initial training has been given to the local operators in the two operational centres in Mombasa and the Seychelles. This training enabled them to work with the system, to start using and building up experience with it, and to provide the necessary feedback on how the system should be improved to better fit local needs. First feedbacks that were already given in the initial training have been addressed to the extent that the system and the contract's Terms of Reference allowed. In conclusion: Capability to local operators in the two centres has been provided in accordance with D2.1.

During the second visit to the region from 31 August to 9 September 2015, some limited further training has been given to the local operator in the two centres, also taking stock of their feedback and use of the PMAR system, in accordance with D2.2.

2.4.1 PMAR Viewer User Manual

Following feedback that was given by operators in and after the initial training, a user manual ("PMAR Viewer User Manual, Nov 2014", JRC Technical Report, 2014, JRC92486) had been compiled in November 2014 and sent to the local operators in Mombasa and the Seychelles. The user manual explained the enrolment procedure, the logging in and out process for normal access to the PMAR system, and the possibilities for use.

The manual was updated in February 2015 ("PMAR Viewer User Manual, Feb 2015", JRC Technical Report, 2015, JRC94785 – Annex 3 to this report, see List of Annexes) to include the description of a number of features that were newly implemented following further feedback. This second issue was also sent to the local operators concerned and made available under a button on the PMAR Viewer interface itself, as well as through the dedicated public PMAR website of the JRC.

2.5 Preparation of software for transfer to the region

For the PMAR-MASE project, the solution of a 'light web client' was chosen, in which most of the heavy processing was done at JRC ("server side"), and the processing on the side of the user was done for the most part by his web browser ("client side") which is a standard commercial product (e.g. Mozilla Firefox, Google Chrome). This choice was made for two reasons. First, the incoming data (AIS and LRIT messages) present a large data volume. About 20 million AIS messages per month were coming in to the PMAR-MASE system (see section 5.3 for further details on the numbers). This requires a good internet connectivity. The resulting MSP, after processing, is much smaller, and much easier to transfer over narrower internet bandwidth to the user. Secondly, the processing system is implemented on the JRC's infrastructure, that is designed for experimentation and trials. This facilitates the solution of any problems with the system or the software. And indeed, unexpected issues with the software have occurred during the trial, that could be fixed quickly but would have been much more difficult to fix had the heavy processing software been running at the user's location. This approach is in accordance with the system design of the picture above in Figure 1, which was taken from Section 5 "Outline technical design of the implementation of the PMAR system for the project" of Annex III "Organisation and Methodology" to the Contract.

There, it is also written "*This project, however, limits itself to «use of the system's output by maritime surveillance operators», and does not include extensive IT capacity building*", and "*During the project, some preparations will already be made for [an architecture that has processing at the centres in Africa]. How far these preparations will get will depend on the technical readiness both of the system itself, and of the IT staff in the operational centres*". Some work has been done on assessing the possibility to run processing software in the region and on preparing for that. A part of the PMAR software has been installed on a stand-alone laptop. This has been successful, but it has not covered the entire system.

2.6 User feedback

- During first visit to the region
- Written feedback from Mombasa through the EUNAVFOR liaison in Kenya.
- During second visit to the region

The user feedback from the first two occasions was used to make changes in the PMAR Viewer, as documented in the updated version of the manual (Feb 2015). The feedback from the last occasion, plus previous items that could not be implemented, are elaborated in Annex 1 to this report.

2.7 Extension of PMAR system to other users

The possibility to extend the use of the PMAR system within the time and budget of the PMAR-MASE project to other users has been explored. This was done following the interest expressed by several (regional and national) authorities, in the margins of the MASE National Focal Points meeting on 31 March and 1 April 2015 as well as the confirmation of no objections by the IOC, the EU Delegation in Mauritius and DG DEVCO. The possible extension included the Regional Information Fusion Centre (RIFC) to be established in Madagascar.

However, as the distribution of the data was licensed only to the two operational centres in Mombasa and the Seychelles, any further distribution was at the mercy of the data providers. As no suitable form of (non-monetary) compensation was found, it did not become feasible to implement the extension within the scope and timeframe of the current project.

3 Visits to the ESA-IO region

Three visits to the ESA-IO region were carried out, of which two in order to comply with Deliverables 2.1 and 2.2. and one upon invitation of the Contracting Authority (the IOC) to participate in the MASE National Focal Points meeting.

3.1 First visit from 21 September to 1 October 2014

The purpose of the first visit to the region from 21 September to 1 October 2014 was to introduce the PMAR system to stakeholders in the region, install it in the two operational centres, give first training, and obtain first feedbacks. The schedule was as follows:

- Mauritius, 22-24 September 2014: visit to the Indian Ocean Commission (IOC, the Contracting Authority) and the EU Delegation in Mauritius.
- Seychelles, 25-26 September 2014: visit to the Indian Ocean Commission – Anti-Piracy Unit (IOC-APU) and other relevant authorities.
- Mombasa, Kenya, 29-30 September 2014: visit to the Kenya Maritime Authority (KMA), the Regional Maritime Rescue Coordination Centre (RMRCC) and contacts with other relevant authorities.

The PMAR system access was successfully installed at the IOC's Anti-Piracy Unit (APU) in the Seychelles and at the Regional Maritime Rescue Coordination Centre (RMRCC) of the Kenya Maritime Authority (KMA) in Mombasa. Initial training was given to the staff in those two centres, and first feedbacks could already be obtained. This allowed the two centres to work with the PMAR system and to build up experience, while providing feedback to JRC on how the system should be improved to better fit the local needs.

Meetings took place with a number of stakeholders from the region – besides the ones mentioned above – in order to inform them of the PMAR-MASE project, to make them aware of the current technical possibilities for region-wide maritime surveillance such as pursued under the project, and to obtain further information about local requirements. These stakeholders included the Seychelles Ministry of Foreign Affairs and the Seychelles Coast Guard. Furthermore, the IOC-APU staff consisted of representatives from the five IOC countries (Madagascar, Comoros, Seychelles, Mauritius, France-Réunion), so these countries were thereby directly involved. The Kenya Navy had been informed through the intermediation of EUNAVFOR Atalanta.

Further meetings were held with representatives of other donor programs, mostly EU: apart from EUNAVFOR Atalanta already mentioned, these included EUCAP Nestor, the Danish Defence, CMR-MARSIC, REFLECS3 and UNODC. These meetings helped the coordination between the various initiatives, and some future collaboration, e.g. related to training, which could have been envisioned. MARSIC already supported the success of this mission by liaising with the KMA.

As a first reaction, the two centres where the PMAR system was installed confirmed the usefulness of the kind of information it provides. The potential value of PMAR for the future Regional Information Fusion Centre (RIFC) that the MASE countries were planning to set up had been referred to many times. Several other stakeholders also expressed a desire to have access to the PMAR system. Although that was not possible due to restrictions in data usage permissions and in the contract, it was stated that an extension of the number of users, e.g. after 4-6 months of initial experience, should be taken into consideration.

A detailed mission report of this visit, dated 8 October 2014, has been distributed.

3.2 MASE National Focal Points meeting from 31 March to 1 April 2015

Upon invitation of the Indian Ocean Commission, the JRC participated in the meeting of the National Focal Points of the MASE programme on 31 March and 1 April 2015 in Mauritius, and presented an update of the PMAR-MASE project results.

The meeting was attended by representatives from many countries on the eastern African seaboard, including the Somali Federal Government and the five IOC island nations, plus several regional organisations and the African Union. Unfortunately Kenya and Tanzania were absent. The meeting focussed on Result 4 of the MASE programme, in particular discussing the detailed provisions of a regional agreement for operational coordination of maritime governance ('accord régional de coordination opérationnelle pour l'action de l'état en mer').

The JRC explained that maritime awareness systems like PMAR can be used in future regional centres, of which there were at the meeting two foreseen in the region: a Regional Information Fusion Centre (RIFC) in Madagascar; and a Regional Operations Centre in the Seychelles. After having stated that PMAR-MASE served the maritime situational picture to two users in the region, several other authorities (regional as well as national) expressed interest to also get access. The IOC and EU Delegation Mauritius had no objections to such an extension, and it was agreed that this possibility would be pursued within the time and budget of the PMAR-MASE project.

A detailed mission report of this visit, dated 9 April 2015, has been distributed.

3.3 Second visit from 31 August to 9 September 2015

The purpose of the second visit to the region from 31 August to 9 September 2015 was to further train the users in the two operational centres in Mombasa and the Seychelles, to receive feedback on the PMAR for the final reporting, and to present the PMAR technology to the Regional Information Fusion Centre (RIFC) in Antananarivo, Madagascar. The schedule was as follows:

- Antananarivo, Madagascar, 31 August – 1 September 2015: briefing to the Members of the inter-ministerial committee for the RIFC, and visit to the EU Delegation in Madagascar.
- Seychelles, 3-4 September 2015: visit to the Indian Ocean Commission – Anti-Piracy Unit (IOC-APU), and meetings with several Seychelles authorities (Ministry of Foreign Affairs, Coast Guard, Fisheries Authority, Police Headquarters).
- Nairobi, Kenya, 6-7 September 2015: visit to EU Delegation in Kenya incl. EUNAVFOR, EUCAP Nestor and UNODC. Visits to the Ministries of Transport and of Internal Security were requested but did not take place.
- Mombasa, Kenya, 8-9 September 2015: visit to the Kenya Maritime Authority (KMA) and the Regional Maritime Rescue Coordination Centre (RMRCC).

The presentation to the inter-ministerial committee in Antananarivo who are setting up the Regional Information Fusion Centre in Madagascar was useful, because so far they had not been directly involved in PMAR-MASE. But also the briefs to stakeholders in the Seychelles and Kenya were useful, because even though the PMAR-MASE system had been running in those countries, many stakeholders had not had exposure to PMAR capabilities.

Concrete and detailed feedback on how the PMAR system met the user requirements was received from the operators at IOC's Anti-Piracy Unit (Seychelles) and at RMRCC Mombasa, who had been using the PMAR system in the last 11 months; and also from the Seychelles Coast Guard although they had not had direct access to the PMAR system. This feedback is listed and discussed in Annex 1.

A detailed mission report of this visit, dated 6 Oct 2015, has been distributed.

4 Outreach activities

In addition to the three visits to the ESA-IO region, the following outreach activities have been undertaken:

4.1 Contact Group on Piracy off the Coast of Somalia (CGPCS)

In preparation of the 17th Plenary of UN Contact Group on Piracy off the Coast of Somalia (CGPCS) on 28 October 2014 in Dubai, UAE, a presentation was delivered at the CGPCS Working Group 3 on Maritime Counter-piracy and Mitigation Operations. The presentation focused on the counter-piracy JRC assessment of needs in the region as well as the PMAR system. Many participants approached the JRC representative afterwards to collaborate closer or to express their interest in the PMAR system. It also allowed the JRC to discuss with stakeholders political and practical issues related to the project. In order to prepare for the Dubai Working Group meeting, the JRC participated in a meeting of the MSA Technical Sub Group on 25 September 2014 in London, United Kingdom.

Furthermore, a contribution was made to the report of the CGPCS Technical Sub Group on Maritime Situational Awareness (MSA) that was presented to the 18th Plenary of the CGPCS on 7-8 July 2015 in New York. The report included recommendations on how to maintain the current MSA framework in the Western Indian Ocean region, while capacity is being developed by countries in the region. In preparation of the report, the JRC co-chaired a meeting of the MSA Technical Sub Group on 29-30 January 2015 in Brussels, Belgium.

4.2 Other outreach activities

The PMAR-MASE project has also been presented and/or discussed at:

- C-SIGMA 2014 conference on 'International collaboration for maritime awareness from space', 8-10 December 2014, Tokyo.
- MariSAR 2015 conference on 'Methods and applications of satellite SAR in the maritime domain', 14-16 January 2015, Cape Town (attended virtually by video link).
- Visit of two CRIMSON project experts to JRC Ispra, Italy, 23 January 2015, to exchange views on the PMAR system in consideration of the influence that this technology could have for future implementations of the EU Critical Maritime Routes programme.
- NATO Science & Technology Organisation (STO) workshop 'Maritime Situational Awareness enabled by Space-Based Systems', 24-26 February 2015, La Spezia, Italy.
- Global Maritime Forum (GMF) workshop organised by the National Maritime Intelligence Integration Office (NMIO), 1-4 June 2014, United States – including meetings with SPAWAR and Google.
- Europe Direct Network at JRC Ispra, Italy, 13 July 2015.

Finally, the project was the basis for a story in the context of the European Year of Development 2015, launched by DG DEVCO, under the title 'Technology for a more secure Indian Ocean'.

5 Technical discussion of the methodology and its performance

This chapter describes the technical approach to build up the region-wide maritime awareness. This approach was implemented in the PMAR system, that was run for a one year trial. The output of the PMAR system is the Maritime Situational Picture (MSP), i.e. the overview picture of the instantaneous ship traffic: a map that can be zoomed and panned, with real-time ship positions that can be queried, and selectable overlays.

The first section of this chapter, information content, describes the nature of the data and information in the system. The second section describes the functionality of the implemented system and in particular of the viewer that is used by the users to see the data. The third section discusses the completeness of the ship traffic picture that is obtained and the performance of the system and its parts. That section also includes the discussion of the use of satellite images to assess the completeness of the MSP.

A separate report as Annex 2 ("Maritime Awareness Systems Performance in the Western Indian Ocean 2014-2015", JRC Technical Report, 2015, JRC97935 – see List of Annexes) contains more details about the performance of the system, the derived monthly ship density maps, and the results of the satellite image surveillance to estimate the presence of the non-reporting ship traffic.

5.1 Information content

The discussion is split into the three data categories of ship data (ship positions, names, etc.), map data (coastlines, bathymetry, etc.), and auxiliary data (anything else, such as historic piracy incident data). All data is geographically linked, meaning it has a geographic position and can be put on a map.

5.1.1 Ship data

The ship data are categorised into the input data, that are externally obtained go into the system; the MSP data, which are the Maritime Situational Pictures, the ship positions at regular time intervals, derived from the input data; and the ship density data, which are maps of historic ship spatial densities per time interval (e.g. aggregated per month).

5.1.1.1 Input data

The input data consist of ship position reports from the AIS and LRIT systems. Both systems are used by the medium and larger ships to regularly report their position. Both are globally mandated by the UN's International Maritime Organisation (IMO) for carriage on ships of 300 gross tonnes (GT) and up. The precise carriage requirements are more detailed. Smaller ships can voluntarily carry AIS.

5.1.1.1.1 AIS

The Automatic Identification System is a transponder-based automatic ship reporting system in which the ship broadcasts its reports (short messages) on VHF, for reception in line-of-sight. The messages can be received by other nearby ships or by nearby coastal stations. Nowadays, they are also received by dedicated satellites, which provide global coverage. There are several types of AIS messages. Position messages contain the current geographic position of the ship, plus its speed, course and heading, plus additional information such as navigation status. Static messages contain the ship's name, IMO number, call sign, ship type, ship size, plus additional information such as destination. In all messages, the ship is identified through its MMSI number. Position messages are broadcasted by the ship with a frequency that is higher as the ship moves faster, between once every 3 seconds and once every few minutes. Static messages are broadcasted at a lower frequency, as their content does not often change.

Whereas AIS is mandatory for the ships of 300 GT and up, smaller ships may voluntarily carry the so-called Class B AIS, which is a slightly stripped-down version of the mandatory AIS that is referred to as Class A.

AIS received by coastal stations provides a persistent, uninterrupted surveillance, but only with a spatial coverage out to the horizon, which is usually about 30 nautical miles. (Although the range can be extended under particular meteorological conditions that influence the VHF propagation.) AIS receivers on satellite on the other hand can receive messages from wide swaths of ocean at the same time, and have near-global coverage as they scan the sea surface while orbiting around the Earth. However, their observation is not persistent; a certain area remains in view for about 15 minutes as the satellite passes over, and after that, the area may be revisited at the earliest 90 minutes later which is the typical orbit period. After one to three passes with 90 minute interval, there is a wait for half a day as the Earth rotates out from under the satellite orbit before coming back into satellite view at the other side 180 degrees away. Therefore, ship positions received by satellite AIS are updated at quite irregular intervals. Using more than one satellite, however, greatly improves the updating.

The AIS messages do not contain the time of broadcast. It is the receiver that has to affix the reception time.

As the AIS messages are emitted by the ships, transmitted over VHF, and received by the receivers, errors may be introduced. With thousands of ships transmitting at sub-minute intervals, the number of messages becomes very large, so even a low error rate leads to a significant number of erroneous messages. The situation is much exacerbated with satellite receivers. AIS was never designed for space-based reception, so often the signals are too weak or too many simultaneous to be successfully received. The error rate in satellite-AIS messages is higher than for coastal AIS, and the detection rate is much lower, and many messages may be missed.

5.1.1.1.2 LRIT

The Long Range Identification and Tracking system is an automatic ship reporting system which sends the ship's reports (short messages) by satellite communication directly to its Flag State authorities. Unlike the AIS messages that are broadcasted for each and everyone to receive, the LRIT messages only go to the Flag State authority. The LRIT report contains less information than the AIS reports: it has the ship's IMO number, name and Flag for identification, its geographic position, and the time of the message. The normal frequency of the LRIT reporting is 6 hourly, although it can be adjusted by remote command.

At the 6-hour interval, the number of LRIT reports from a ship is much lower than the number of AIS reports. However, the regular interval ensures that no very long (> 6 hour) gaps occur, which is possible with satellite AIS. The error rate in LRIT messages is smaller than for AIS, although sometimes drop outs do occur.

5.1.1.2 MSP data

As the AIS and LRIT position reports come in and are ingested in the system, the track of each ship can be built up. The ship's track is its geographic position as a function of time. In AIS, a ship is identified by its MMSI number, and in LRIT by its IMO number. To combine these two data sources, a look-up table is needed that links MMSI number to IMO number.

Collating the AIS and LRIT positions from a certain ship, the most recently ingested position will already be some time before the present (have a certain age). In order to obtain the present position of the ship, the track up to the most recent position is extrapolated to the present time. For coastal AIS, the reports are available with a very short delay, so this extrapolation is very short. For satellite AIS however, the messages that the satellite has received must be stored on board and downloaded to a ground station later, as the satellite overpasses a ground station some time later in its orbit; at the ground station they must be processed, and only then can they be sent to the user. Satellite AIS messages may therefore be hours old, and the extrapolation to the present is an important procedure. The extrapolated position is thereby of course only an estimate, that becomes less accurate as the most recently ingested position becomes older.

The set of present position (estimates) for each ship in the area of interest thus obtained is called the MSP. The MSP must be calculated (updated) at a regular frequency. The update frequency to use is suggested from typical ship speeds and desired positional accuracy. For a region-wide picture with many ships, it is not useful to use a high update frequency; of the order of 10 minutes is enough. For a small-area MSP near the coast, on the other hand, a higher update rate would be needed; minute or sub-minute.

The present position estimate of a ship is extrapolated based on its last reported position and last reported or measured speed. Lacking any further knowledge, it is assumed that the ship continue to move in a straight line at constant speed. Additional knowledge may be available e.g. in the form of known ship routes that can be followed or a coastline that must be avoided. These can be used for non-linear, improved extrapolation. But in any case, as the prediction time increases, the reliability of the extrapolated position decreases. Therefore, if a ship is not seen for a certain amount of time, its extrapolation is discontinued, and the ship is removed from the MSP. This amount of time can be longer on the open ocean, where ships tend to go straight, and shorter near the coast or near a port. It should also refer to the typical maximum time gaps in the reporting, which is 6 hours for LRIT or 12 hours if one report is missed, and also of the order of 12 hours for AIS with one satellite. For a region-wide MSP, the maximum time that a ship remains in the MSP after it has been seen last could therefore be e.g. 13 hours.

There are three main difficulties in tracking the ships. First, errors in the messages (mainly AIS) as mentioned above cause outliers. These have to be recognised and removed to prevent spurious ships appearing in the MSP or ships are wrong locations. Secondly, some ships use the same MMSI number, in spite that it should be a uniquely assigned number. The tracks of such ships should be disentangled. One tool for this is to use the knowledge that ships cannot move faster than several tens of knots. So two reported ship positions with the same MMSI that would need an unrealistically high speed to be linked are assigned to two different tracks, of two ships with the same MMSI number. In this way, two, three or even more tracks can be separated for ships that illegally use the same MMSI number. This does not work however for ships that are close to each other; in such a case no two ships will be recognised, and only a single track will appear on the MSP. The third main type of difficulty is a consequence of the lack of a message time in the AIS message. It was mentioned that instead, the receiver has to affix the time of reception. It does so with its own clock. Some receivers unfortunately have an unstable or offset clock, hindering a proper tracking. This can lead to jumps in the track or to spurious splitting of one MMSI number over two tracks.

Given a certain area of interest (AOI) for which input data are received and the MSP is calculated, the number of ship seen decreases if a ship leaves the AOI, if it switches of its transponder e.g. after having docked in port, or if the ship’s signals are not picked up by any satellite e.g. because its transponder is obscured from overhead view. Similarly, the number of ships increases with the opposite events.

5.1.1.3 Density data and ship counts

While the MSP shows the instantaneous distribution of ship positions, it is also of interest to know the typical or usual distribution of ship positions. For that, a ship density map can be used, in which shipping presence during a certain time period is counted per spatial grid cell. Such a density map can be constructed by gridding the MSPs and adding them. A density map can also be constructed by gridding and adding the original position messages. But when made in such a way, it is biased by irregularities in the frequency of the original messages: there will be more position counts during the overpass of a satellites, and none during the times no satellite was in view. For coastal stations the effect is even worse, as the density map will mostly reflect the spatial coverage of the coastal receiving stations. A density map constructed from the MSPs after the tracking does not have these defects. However, also that is not perfect because it incorporates predicted positions which may not be realistic for long prediction times.

The density map is quantified as the number of ships per unit of surface (e.g., per square degree) present at any time on average during the period of reference. When constructing density maps, it is found that the dynamic range in density can be very high. Some areas on open sea may have a very low number (there is almost never a ship), while areas near ports may get very high number (high and constant ship presence). For a useful visualisation, the density map is best shown with a logarithmic scale.

The ship density map shows the shipping patterns. When constructing a time series of density maps, e.g. for every month in the year, it is seen that some shipping patterns remain constant in time (e.g. the main transport routes), while some show large variations (e.g., fishing activity).

Density maps may be constructed to contain all ships, but alternatively only certain ships may be included in the density map. A selection can be made on ship type (e.g., only showing cargo ships, or only tankers); or on Flag (e.g., only showing Panama-flagged ships); or on speed (e.g., only showing all slow-moving ships, that would include and highlight fishing activity).

In addition to a density map that details the spatial distribution, also ship counts within a certain geographical area and time period can be made. The area can be a square box or a polygon, such as an EEZ. In that case, it can be specified how many different ships per Flag were present in the selected area during the selected time period; and how many days or hours they spent in the area.

5.1.2 Map data

The ship positions of the MSP are displayed on a geographical grid, and constitute points in longitude, latitude. In order to understand the picture, the context of a map is needed. Therefore, the ship positions of the MSP are displayed on a map. The map can be raster and also vector.

5.1.2.1 Raster data

A raster map is a usually non-transparent graphical map background. It can e.g. show a blue sea and a white land surface, on which the MSP points are displayed. It can also show bathymetry or hydrographic features.

5.1.2.2 Vector data

Vector map data can show lines or polygons such as coastlines or EEZ boundaries. It can also show points. This type of data can be overlaid over a raster map background as it is surface-transparent.

5.1.3 Auxiliary data

For further interpretation of the MSP, in addition to map data, many other types of information may be used. For the presence of maritime security and counter piracy, one may consider:

- A map of the wind field (force and direction). This can be used for piracy risk assessment, as strong wind discourages pirate attacks.
- A map of the wave field (significant wave height). This is related to the local current wind and the non-local wind history. As with wind, high waves hamper piracy attacks. Besides wave height, other relevant wave parameters are frequency, direction and steepness.
- Historic piracy incidents. The locations of past piracy attacks and sightings give a broad indication of where future ones may be expected.

Other auxiliary data may include sea surface temperature, surface current (very relevant for search and rescue), or locations of fronts or upwelling (may attract fish and thereby fishing).

5.2 Implementation and functionality

This section describes aspects that are specific to the present implementation, in the PMAR-MASE trial, of the maritime awareness approach outlined in the previous section.

5.2.1 Area of Interest

In consultation with the users, the Area of Interest (AOI) was defined as the maritime part within the box Longitude= 31 – 68 East; Latitude= 30 South – 19 North.

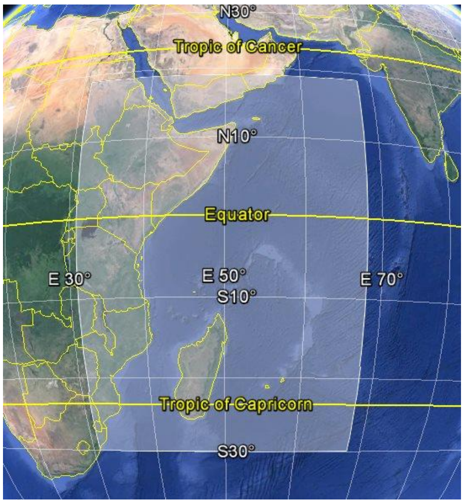

Figure 2. The Area of Interest of PMAR-MASE. (Google Earth map background.)

5.2.2 Time period

One year, 15 Sep 2014 – 15 Sep 2015.

5.2.3 Input data

5.2.3.1 AIS

The following AIS data sources were used:

Provider	commercial	# satellites	coastal
Norwegian Coastal Administration	no	2-3	
exactEarth (Canada)	yes	4-6	x
Orbcomm (U.S.)/ LuxSpace (Luxemburg)	yes	8	x
SpaceQuest (U.S.)	yes	3	
MSSIS (U.S. / international)	no		x

For satellite AIS, this represents all the existing systems other than a few experimental ones that only collect a limited amount of data.

The number of satellites varied during the year, as new satellites were launched and old ones discontinued.

The satellite AIS data from the Norwegian Coastal Administration (NCA) were obtained under permission of the NCA for use in this project at no cost.

The coastal AIS data of the MSSIS system were obtained from the Volpe Center of the U.S. Department of Transportation and the U.S. Navy at no cost.

The AIS data of the three commercial providers were procured under a commercial contracts at a cost.

The AIS message types that were received and used for the MSP are:

- Position reports Class A: Message types 1, 2, 3.
- Static reports Class A: Message type 5.
- Position reports Class B: Message type 18.
- Hybrid reports Class B: Message type 19.
- Static reports Class B: Message type 24.

The content of these message types is defined in "Technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band", Recommendation ITU-R M.1371-4 (04/2010), International Telecommunications Union.

5.2.3.2 LRIT

LRIT data were obtained from all Flag States that use the EU LRIT Data Centre that is operated by EMSA. These data were made available by permission of the individual Maritime Administrations of the Flag States for this project, and technically supplied by EMSA, all at no cost.

This means that the project did not use LRIT from all other Flags besides the EU ones. It is estimated that thereby maybe 25 % of all LRIT ships in the region were covered. This is to be contrasted with AIS, for which the data were obtained from the ships of all Flags.

EMSA took care of the assignment of MMSI numbers to IMO numbers in the LRIT messages.

5.2.3.3 Piracy incidents

Piracy incidents were provided by the International Chamber of Commerce's International Maritime Bureau (IMB) at no cost. Each incident has a set of attributes including geographic location, time, category (attempt, attack, hijack), and a narrative.

5.2.3.4 Wind and wave data

Wind and wave data were obtained from the U.S. National Oceanographic and Atmospheric Administration (NOAA). The wind data is the prediction of the wind field made by the NOAA/NCEP Global Forecast System (GFS) Atmospheric Model for the coming 6 hours, published every 3 hours. It is published on the web as a global data set, from which the PMAR-MASE AOI is extracted using the ERDDAP protocol. When the new prediction is available, the PMAR-MASE AOI is extracted and inserted into the PMAR system.

The wave data is from the Wave Watch III (WW3) Global Wave Model, implemented through a collaborative effort by the University of Hawaii with NOAA/NCEP and NWS Honolulu. It is similarly published on the web by NOAA and the AOI extracted with ERDDAP, once a day.

5.2.4 Data ingestion and storage

All AIS and LRIT input data were delivered to JRC via internet from their respective providers. Some via TCP/IP protocol and some via FTP.

The AIS data were delivered in NMEA format, which is a compressed/encoded format. The messages were decoded and stored in a PostGres data base.

The LRIT messages were stored in the same data base.

5.2.5 Processing

Apart from the continuous data ingestion discussed above that includes the decoding of the NMEA-formatted AIS messages and the storage in the data base, all positions are checked with a land mask to verify that they are not on land. This could happen because also some ships on rivers transmit AIS, but more importantly due to errors in the transmission. PMAR-MASE is not concerned with inland waters, and the errors will give rise to outliers or even spurious positions.

For each message that is presented for inclusion in the data base it is checked whether it is not already present, to prevent duplicate messages in the data base.

In the PMAR-MASE implementation, the MSP is calculated every 15 minutes. So every 15 minutes, a process is started that updates the track for each ship (based on MMSI number), and extrapolates the track to make the current predicted position at the MSP reference time. The MSP reference time is slightly in the future of the start of this process, the ensure that the 15 minutes that the MSP is displayed are centred around the reference time. Obviously, a requirement is that the time needed to compute the MSP is less than 15 min.

If the positions of a certain MMSI number are found to not belong to a single track (because they are too far separated), it is concluded that two (or more) ships use the same MMSI number, and the track is split as explained above.

The static data is associated with the position data, again based in the first instance on MMSI number. This association is needed because the static data is in AIS messages 5 and 24 (containing information like name, call sign, ship type, etc.), whereas the position data is in AIS messages 1, 2, 3 and 18. AIS message 19 (Class B) and LRIT contain both position and static data. In the case of a split track (multiple ships using the same MMSI number), it is not straightforward to assign the static data to the track. An association method based on frequency of occurrence is used.

When the MSP is completed, it is displayed on the viewer. The viewer is a web application, implemented with GeoServer. All data (MSP ship positions, background map, overlays of wind, waves, etc., as enumerated in the previous section) are computed at JRC, and served via the internet to the users, who only use their web browser to display the data. The web browser is also used for the interactive user input that includes panning, zooming, or clicking in a list to activate a choice of background map or vector overlays. Also, the symbol of a ship can be clicked in order to display its information (name, MMSI and IMO number, call sign, time of last received report, and further information from the AIS reports). The past track of a ship can be shown by clicking again, as well as the information about the ship on the public web site MarineTraffic.com that often includes a photo of the ship. Finally, a ship can be searched by entering its MMSI number, IMO number or call sign. All these functionalities and how to use them is described in-depth in the PMAR Viewer User Manual.

5.3 Performance and completeness

A thorough analysis of the performance of the PMAR system, in terms of completeness and accuracy of the MSP, is presented in Annex 2. This section highlights some aspects.

As mentioned before, the various data sources provide vastly different amounts of data. This is illustrated in Figure 3, which shows the spatial distribution and the amount of position reports received during one day from (a) Satellite AIS Class A, (b) Satellite AIS Class B, (c) Terrestrial AIS Class A, and (d) LRIT ("EU Flags" only as always).

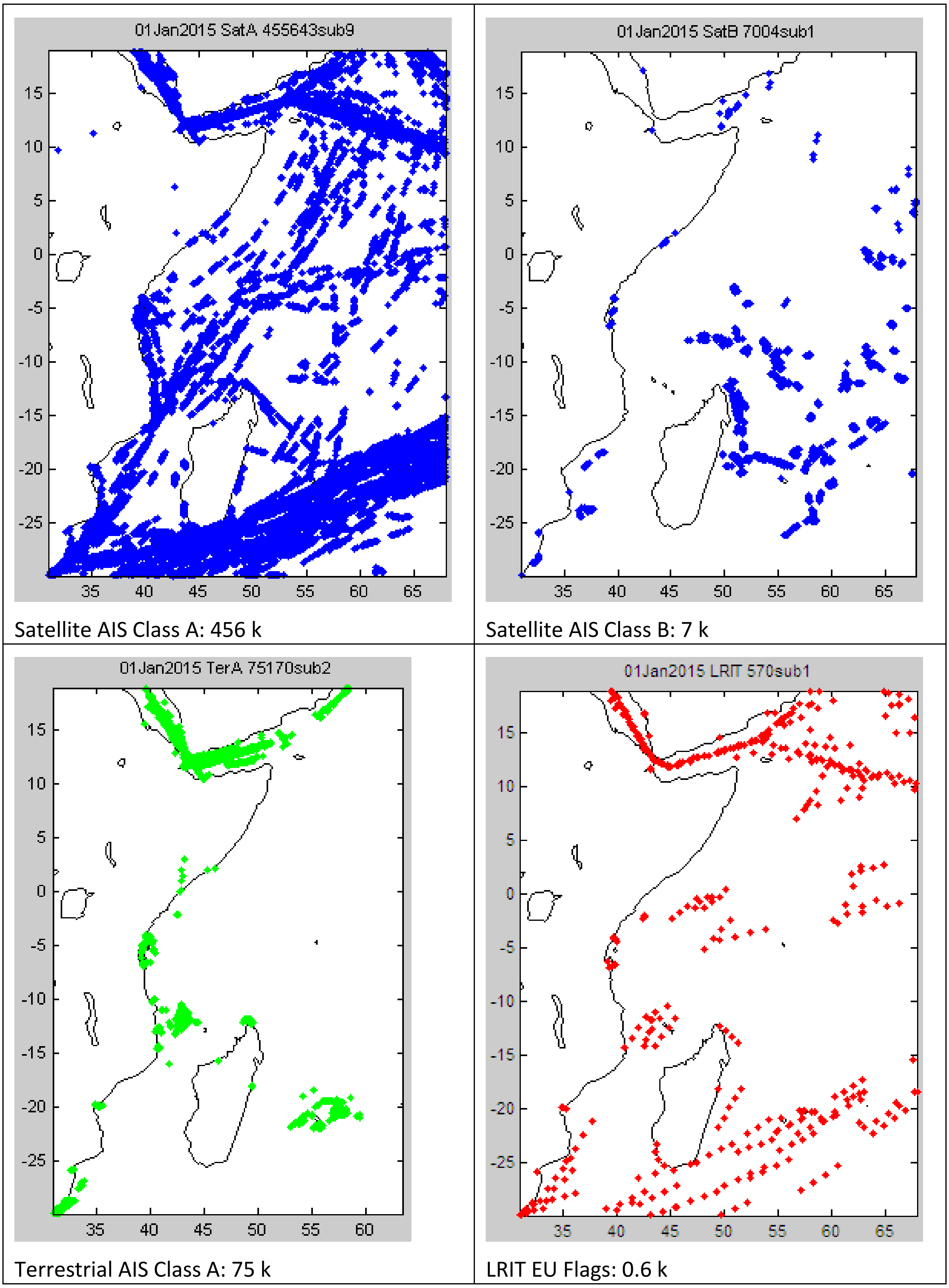

Figure 3. Spatial distribution and the amount of position reports received during one day (1 January 2015) from (top left) Satellite AIS Class A, (top right) Satellite AIS Class B, (bottom left) Terrestrial AIS Class A, and (bottom right) LRIT (EU Flags only).

Figure 4 shows the number of different MMSI numbers (number of different ships) seen per day for each day during one month, split into the same four categories with also Terrestrial AIS Class B added as a fifth.

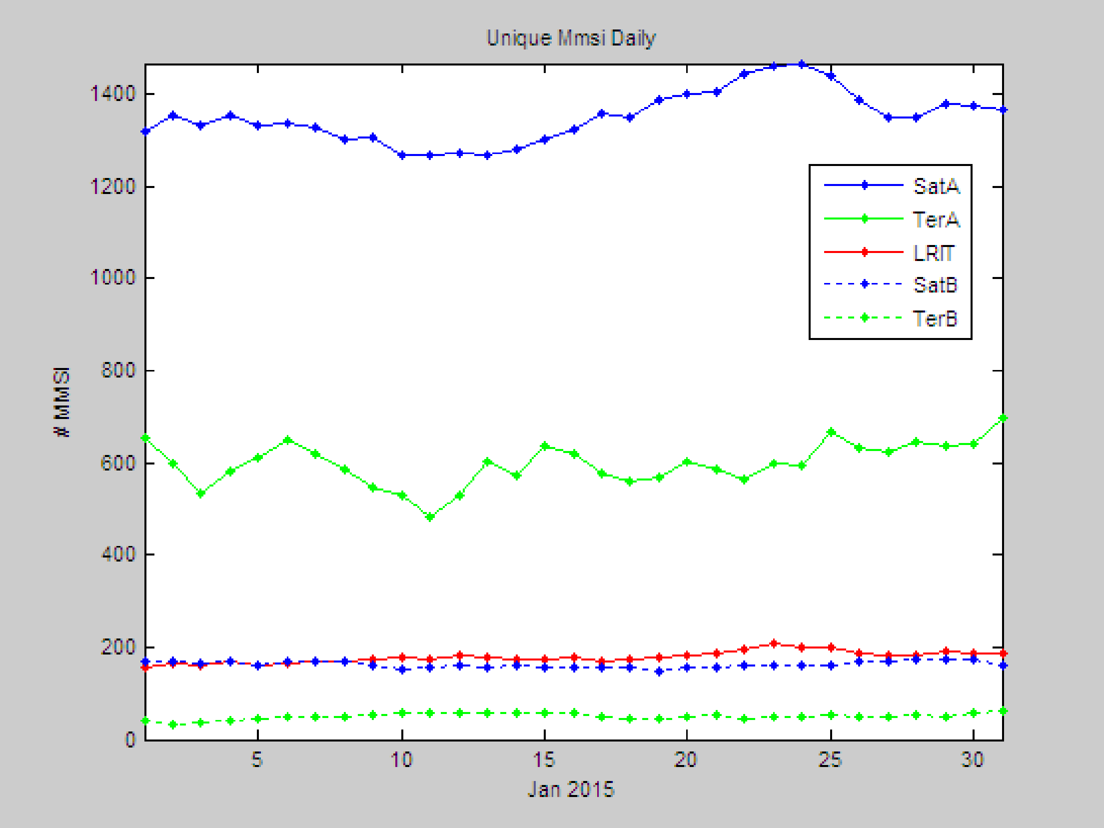

Figure 4. The number of different ships seen per day for each day during one month (January 2015), split into Satellite AIS Class A, Satellite AIS Class B, Terrestrial AIS Class A, Terrestrial AIS Class B, and LRIT.

Although the number of reports and ships seen in satellite AIS is much larger than that in terrestrial AIS and even more so in LRIT, still there are ships that are only seen in terrestrial AIS or LRIT and not in satellite AIS. This can happen when a ship has an AIS transponder that is too weak to be successfully received by satellite, or mounted such that it is hidden from overhead view. Figure 5 shows the number of Class A ships seen by terrestrial AIS and LRIT that are not seen by satellite AIS, on a daily basis during one month; it is on average 65 ships (black drawn line). It similarly shows the number of Class B ships missed by satellite AIS (on average 10, black dotted line), and the ships that are seen by LRIT but not by satellite AIS (on average 13, red line).

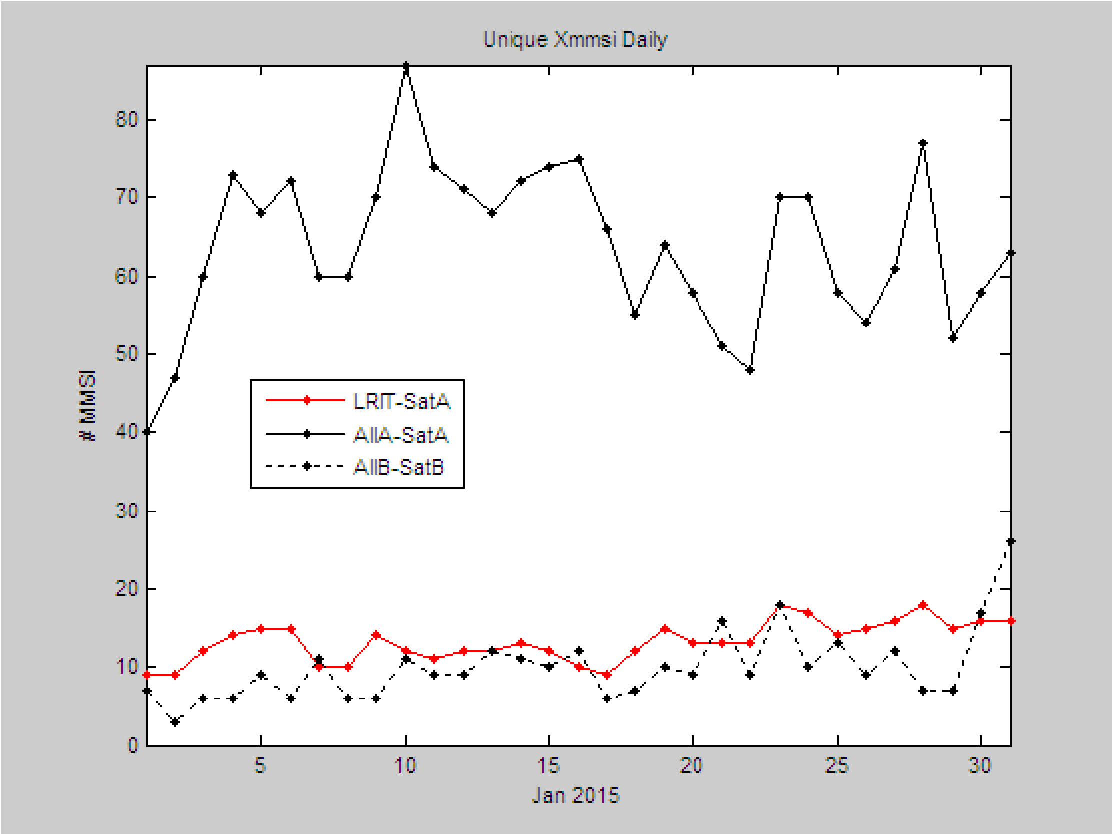

Figure 5. The number of reporting ships not seen by satellite AIS, on a daily basis during one month (January 2015). Black drawn line (highest): Class A ships seen by terrestrial AIS and LRIT. Black dotted line (lowest): Class B ships seen by terrestrial AIS and LRIT. Red line: ships (Class A) seen by LRIT.

Figure 6 shows the impact of the input data sampling on density maps that are derived directly from the incoming position reports without any further processing. In that case, the resulting density maps are influenced by the spatial and temporal sampling of the input data. This indicates why it is important to use input data sources with homogeneous coverage, and to compute the ship tracks before making a ship density map. This has been done for the monthly ship density maps that are included in Annex 2.

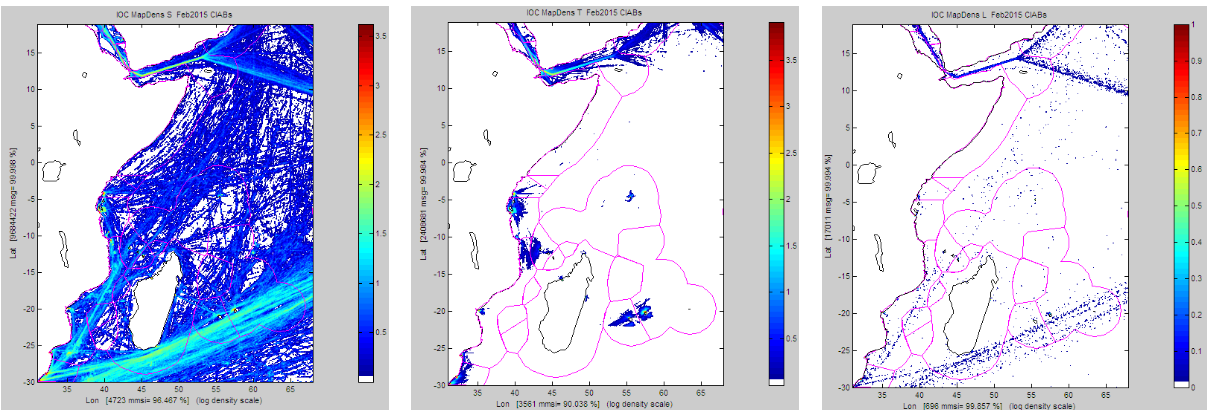

Figure 6. Monthly density maps constructed from raw input data, without tracking or re-sampling to a regular time grid. Left, using only satellite AIS. Middle, using only terrestrial AIS. Right, using only LRIT.

5.3.1 *Performance per provider*

This section quantifies the number of ship position reports and the number of different ships seen in those reports, separately for each of the providers. Some of the providers include AIS from both satellites and coastal receivers, some from only one of those, and the LRIT is treated separately.

The figures shown here represent the contributions of the various providers during the PMAR-MASE project. They should not immediately be taken to chose a future provider. In choosing a service provider, it is more important to look at the expected future performance. One main factor in this is the number of satellites that the provide will be operating. The impact of the number of satellites is analysed in Annex 2.

5.3.1.1 *Number of messages per provider*

The providers are identified as (all are AIS except "L"):

- A: MSSIS – Coastal only
- B: Orbcomm / LuxSpace – Satellite and coastal
- C: exactEarth – Satellite and coastal
- D: Norwegian Coastal Administration – Satellite only
- E: SpaceQuest – Satellite only
- L: EU LRIT Data Centre Flag States / EMSA – LRIT only

The number of messages for a provider depends on how many satellites he operates and how many coastal stations are in his network. This varies in time, as old satellites go defunct and new ones are launched, an as coastal stations go on and off line. More messages may mean more information, but not necessarily. A high number of messages can result from many messages that follow each other shortly, collected within one satellite overpass. All these messages are nearly identical, as the ships do not move so much during one satellite overpass. Then there may be a large time gap until the next overpass, and the next burst of messages. It is better when the sampling is more evenly distributed, and then the number of messages need not be so high for a good tracking. This is the case for LRIT, which has a regular 6-hour reporting, so only 4 messages per day are received, but they are equally spaced with the gap never larger than 6 hours (unless a message is missed).

Figure 7 shows the number of position reports received during June 2015 for each provider. Note that the grouping per provider mixes satellite and terrestrial AIS: MSSIS has only terrestrial AIS, NCA and SpaceQuest have only satellite AIS, and Orbcomm/LuxSpace and exactEarth have both.

Figure 8 shows how the number of position reports varies per day.

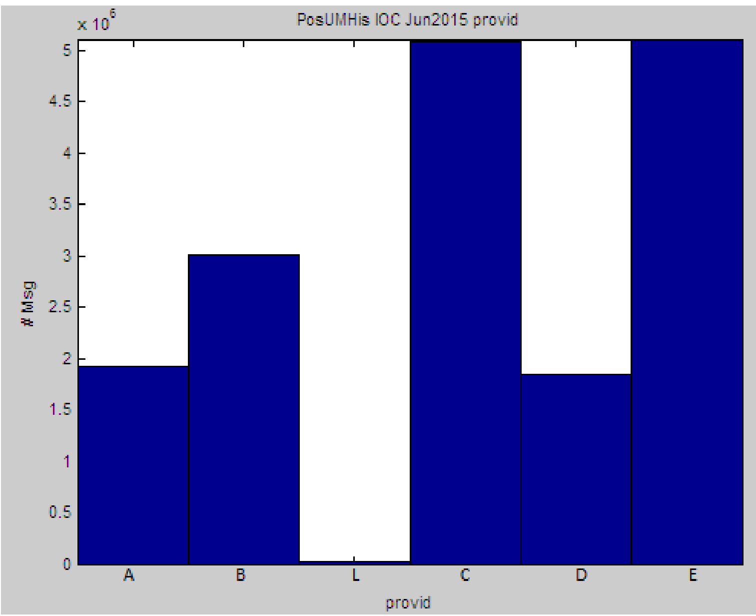

Figure 7. The number of position messages received for each provider. The numbers are for the whole month of June 2015 and the vertical scale is in units of one million messages. See the main text for the provider IDs.

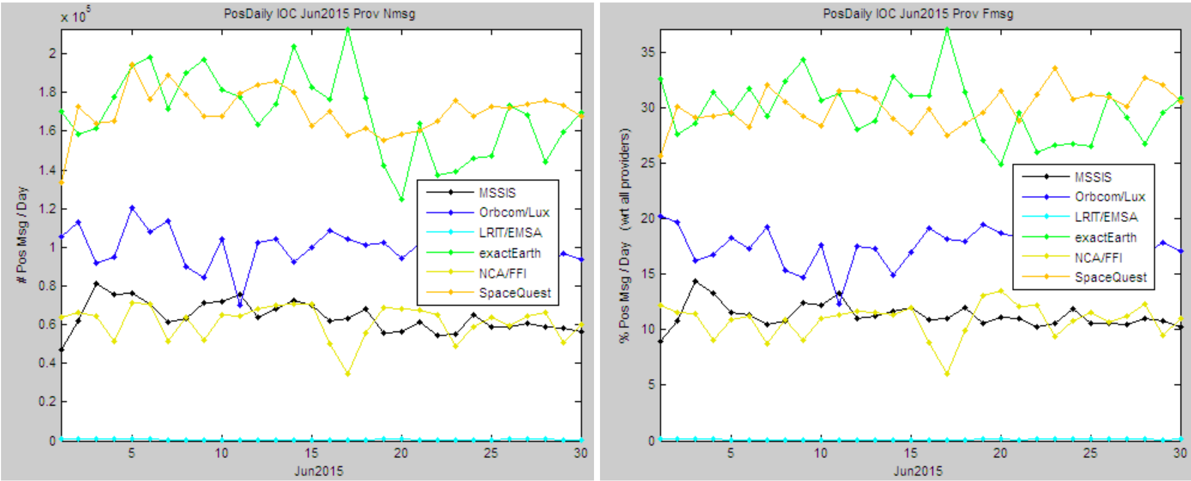

Figure 8. Daily position messages during June 2015 received from each provider. Left, the number of messages; the scale is in units of 100,000. Right, the percentage. Each day, the percentages add up to 100. The two graphs have quite similar shape. These numbers do not immediately correspond to quality.

5.3.1.2 Number of MMSI numbers seen per provider

Ships are identified in their position reports by a nominally unique MMSI number. The number of different MMSI numbers that is seen, is close to the number of reporting ships in the AOI. Why only close and not equal is discussed in Annex 2. Figure 9 shows the daily number of MMSI numbers seen by each provider, and for all combined, in absolute number and as percentages.

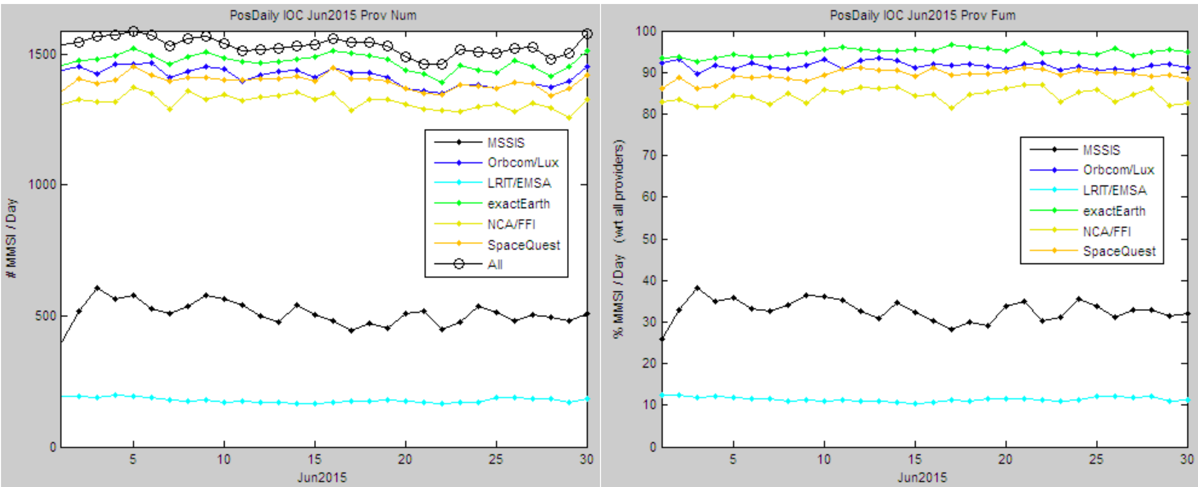

Figure 9. Number of different MMSI numbers seen during the month of June 2015 for each provider. Left, the absolute number, with the number for all data sources combined drawn with circles (top line). Right, as a percentage, where 100 % represents the amount of MMSI numbers seen by all data sources combined. These numbers depend on how many satellites are in operation and they change per month.

The table below lists the average percentage of the daily MMSI numbers seen by each provider over the month of June, as an example. These are the mean values of the lines of Figure 9 right. It can be seem that the percentage for LRIT is lowest, because it is only a subset of all ships (the “EU Flagged” ones). Then follows MSSIS with 33 % of the MMSI numbers seen. This is due to its limited coastal coverage – in fact, geographically the coverage is much less than 33 %, ref. Figure 3 and Figure 6, so the performance is relatively very good. Then follow the various providers that include satellites, with scores between 86 % and 96 %. Of those, the one with the lowest score is NCA/FFI, which does not include a coastal network and deploys the lowest number of satellites. Then follows SpaceQuest with 91 %, which also does not include a coastal network. The two providers with the highest score, Orbcomm/LuxSpace with 93 % and exactEarth with 96 %, both include a large set of satellites and data from a coastal network. In other months, these numbers are different.

Id	Provider	% MMSI seen
A	MSSIS	33.2
B	Orbcomm/LuxSpace	92.5
C	exactEarth	96.0
D	NCA/FFI	86.1
E	SpaceQuest	91.0
L	LRIT/EMSA	11.6

Table: Average daily percentage of number of different MMSI numbers seen for June 2015. All data sources together represent 100 %. The percentages change from month to month.

5.3.2 Satellite images to assess completeness

The ships included in the MSP are only the reporting ships, as explained in the foregoing. Non-reporting ships do not appear in the picture. In order to assess how many non-reporting ships there are in addition to the reporting ones, satellite images are used. There are satellites in low-Earth orbit that carry imagers; these imagers include cameras that can make images in the visual (optical) part of the spectrum, and so-called Synthetic Aperture Radars (SAR) that can make images in radar wavelengths. The latter are used for this exercise, because they are not hindered by clouds like the optical ones. In the radar images taken from satellite, ships show up as bright dots, and can thereby be detected. The detected ships can then be compared with the positions of the ships that are in the MSP at the time of the satellite image, and it can be established how many of the SAR-detected ships correspond to reporting ones, and how many ships are seen additionally in the SAR image to the reporting ones. Also locations of the non-reporting ships (their spatial distribution) can be established.

There however are a number of limitations to detecting ships with satellite images. First, because the imaging satellites are in Earth orbit, like the AIS receiving satellites, they do not remain in place but instead pass over quickly. The satellite images are therefore only snapshots taken at the time of satellite overpass. Overpasses can be days apart. Therefore, the satellite images cannot determine the motions of the detected ships, nor can they monitor the evolution of the MSP. Secondly, the spatial extent of the satellite images is quite limited, at best some 400 km but more typically 150 km, or even less. Third, only ships down to a certain size can be detected by the satellite images. Targets that are very small are not seen. The minimum detectable ship size is related to the image size – the smaller the image, the smaller the smallest detectable ship. For wide images (300-400 km) we may expect to detect ships down to maybe 35 meter. For 150 km wide images, this can go down to 15 m. It is even possible to make satellite SAR images that show details down to 1-2 m, but then the image size becomes very small (5-10 km) and such images are not useful for a region-wide application. Fourth, the ships have to be detected against the background of the sea surface, which contains clutter (noise) due to waves, fronts, and other meteorological and oceanographic features. With higher wind and waves, but also close to the coast, there is more background clutter, and the ship detection is less successful. Fifth and final, the satellite images are costly.

On account of all these reasons, it is not possible to obtain a complete coverage over the area of interest, neither in time nor in space. The best that can be done is to select a limited number of satellite images, yielding a small sample in order to make an estimate of the non-reporting ship presence.

For the PMAR-MASE project, satellite SAR (radar) images of the Radarsat-2 satellite were chosen, because this instrument has proven in the past to perform well for ship detection. From the various modes (ranging from wide area at low resolution, down to small area at high resolution), two modes were chosen: the ScanSAR Narrow B mode with 300 km image size at 50 m resolution, and the Wide Fine with 150 km image size at 8 m resolution.

The schedule of acquisition has been as follows:

Date	ScanSAR # images	WideFine # images	Somalia	Kenya-Madagascar
15 Aug	5			x
22 Aug		4		x
23 Aug	2		x	
26 Aug	2		x	
30 Aug	4		x	
5 Sep	6			x
6 Sep	2		x	
9 Sep		4	x	
Total	21	8		

On each day, a few consecutive images have been acquired in a row.

In the following two figures, the locations and times of the images are shown; first the ScanSAR images and then the WideFine images.

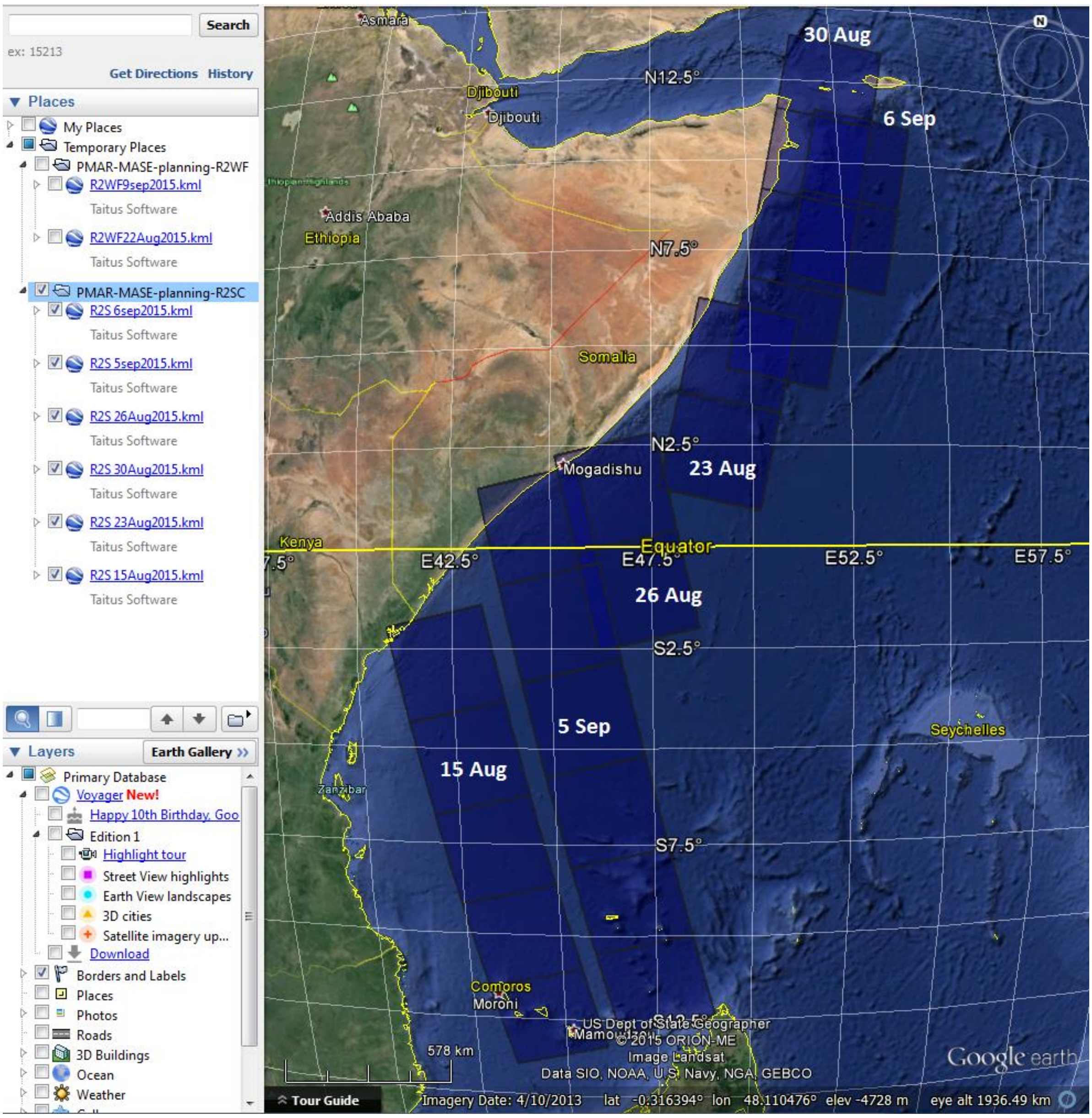

Figure 10. The 21 Radarsat-2 SanSAR images with their acquisition dates. (Google Earth map background.)

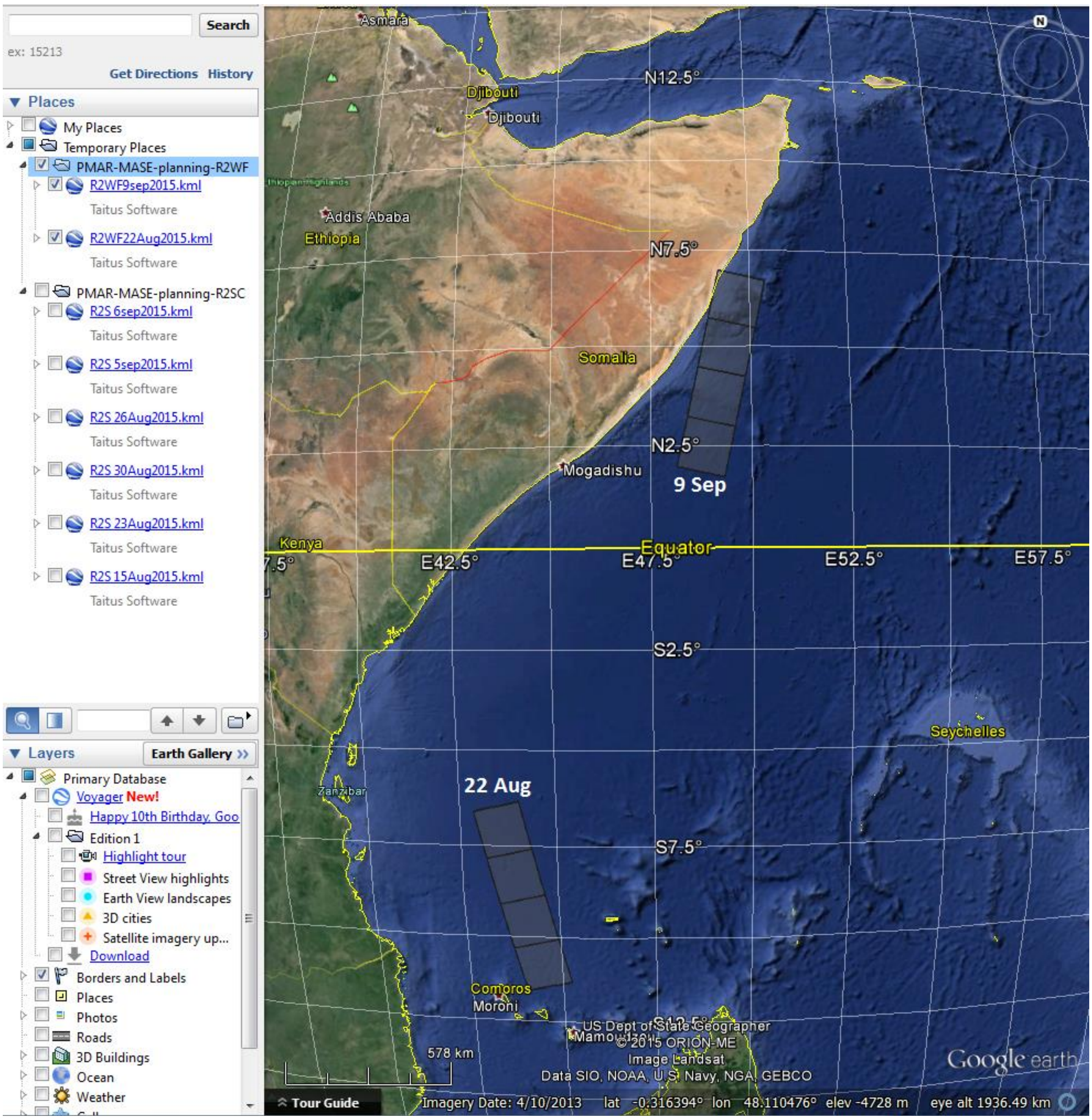

Figure 11. The 8 Radarsat-2 WideFine images with their acquisition dates. (Google Earth map background.)

The satellite images were subjected to ship detection, and the resulting targets were compared to positions of ships that are present in the MSP, i.e. to the locations of the known reporting ships. Any ship detection that cannot be correlated with a known ship from the MSP is interpreted as a non-reporting ship. The result is shown in Figure 12. Four out of the 38 ships that were detected in the Radarsat-2 satellite images could not be correlated, indicating a fraction of 11 % for the non-reporting ship traffic, in that area and time. The analysis of the satellite images is described in much more detail in Annex 2. There, also further satellite images are taken into account, in other locations and at other times, which indicate a higher fraction of the non-reporting ship traffic, closer to 35 %.

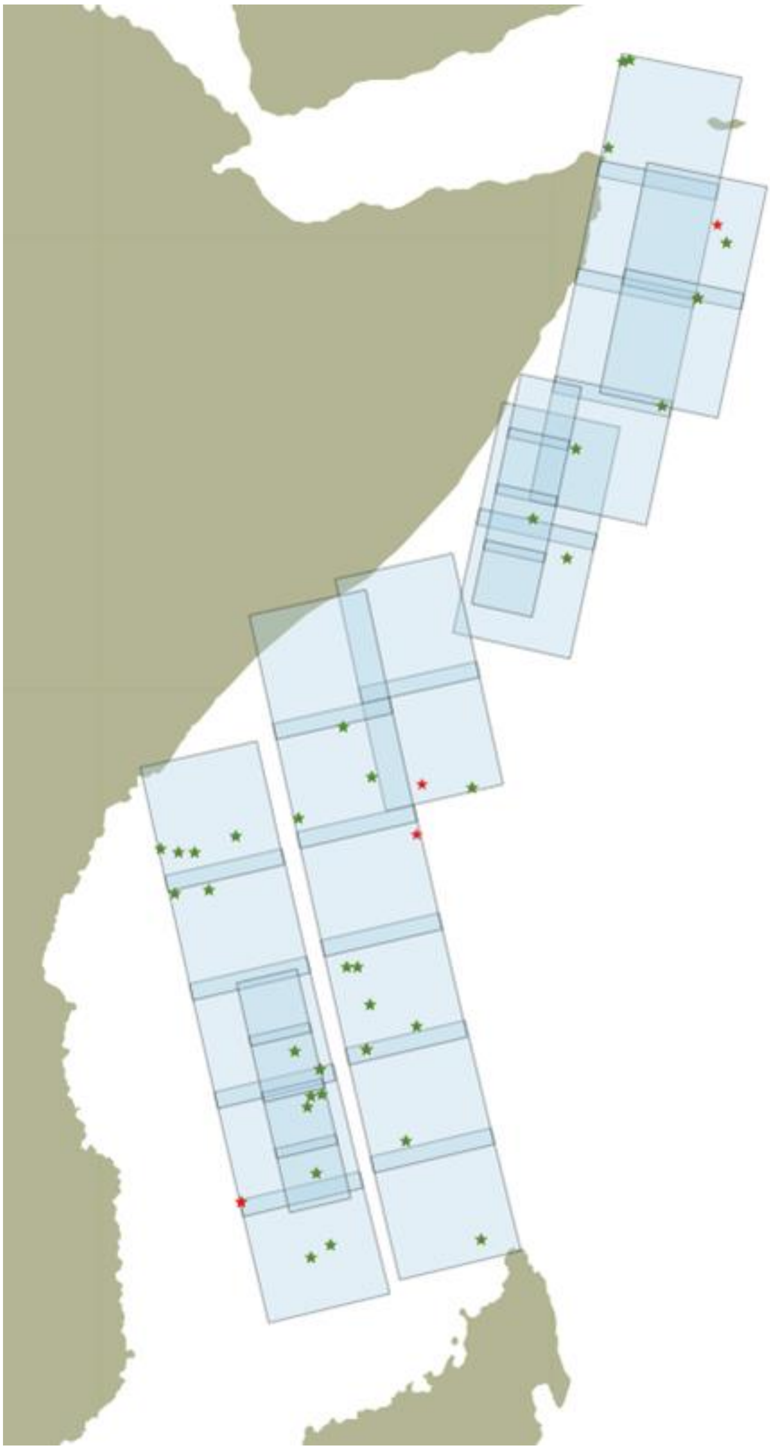

Figure 12. The outlines (blue) of the Radarsat-2 images, with detected targets (stars) that are green in case they could be matched to a known (reporting) ship from MSP, and red in case they could not be matched.

5.4 Cost

Most of the input data, the ship position reports of AIS and LRIT, are collected at a cost. This is a key component in the cost of an operational system, because they are recurring costs that have to be expended every year.

For both the coastal AIS networks and the AIS satellites, some are government-operated and some commercially. The MSSIS AIS network is an international collaboration of nationally-operated systems that makes the data available for free. Three of the AIS satellites that were used, NORAIS, AISSat-1 and AISSat-2, are operated by the Norwegian government, that has provided the data to this project without cost. In those cases, all the costs are borne by the national governments that run the systems. For the future, the MSSIS data will probably remain accessible without cost. For the government-run AIS satellites, it is not known whether their owner will also provide data free of cost for operational use.

The LRIT data used in this project (of the Flags that use the EU LRIT Data Centre) were also made available without cost. Normally, LRIT data carry a cost as agreed under IMO's LRIT framework. For reasons of combatting piracy, these costs have been suspended at several occasions in the recent past. Again, it is not known whether governments will make LRIT data available for operational use in PMAR-like systems in the future and if so, at what cost.

In any case, the bulk of the data used in this project came from the commercially operated satellite AIS systems. In the PMAR-MASE project, *all* available AIS satellites have been used, in order to find out how many are really needed (sufficient) for operational use. Annex 2 contains an in-depth analysis of the additional information content of using 2 AIS satellites instead of 1, 3 satellites instead of 2, 4 instead of 3, etc. It is found that with every extra AIS satellite, the completeness and accuracy of the information in the MSP increases; however, the increase becomes always smaller. After 7 satellites, the increases become very small. Three AIS satellites already provide quite a good completeness, registering 95 % of the ships that are seen by all available AIS satellites together. The next satellite added, from 3 to 4 satellites, adds approximately one percentage point to that. This means that one commercial provider of AIS satellite data could be enough, as the commercial providers tend to have at least 3 satellites each.

The price that is charged for (satellite) AIS data by commercial providers depends on negotiations. There is no common or posted price list available. The price will depend on the area covered, on the time duration, on the number of end users that can have access to the data, and on any special service requirements.

The use of satellite images to monitor for non-reporting ships is relatively more costly than the use of AIS, in the sense that a spatially and temporally complete coverage of the AOI is financially completely out of reach (it is also technically out of reach). For satellite images, however, fixed price lists are available with the various commercial providers. These providers include the European companies e-Geos (for the Cosmo-Skymed satellites) and Airbus Defence & Space (for the TerraSAR satellites), the Canadian company MDA (for the Radarsat-2 satellite) and the Japanese consortium Pasco (for the ALOS-PALSAR-2 satellite). These images may often also be acquired through local resellers. Most have prices published on the internet. For larger order, discounts may be available.

Under the EU's Copernicus program, images of the Sentinel satellites, including Sentinel-1, are available for free. This is a very attractive option. Derived, value-added products, such as ship detections, are however not freely included. Moreover, unlike the commercial satellites, Sentinel-1 cannot be programmed for acquisitions on request. Acquisitions follow the strategic Earth observation program of the EU and the European Space Agency, and requests should be brought in at that level.

6 Conclusions

The general objective of the MASE project is the improvement of the maritime security in the ESA-IO region. One element needed for that is maritime awareness, the ability to know about human activities at sea. At the start of the PMAR-MASE project, it had already been shown that the automatic ship reporting systems AIS and LRIT, globally mandated by IMO for usage on the medium and larger ships, can provide basic data for maritime awareness; and that the ship position reports from these systems can be fused into a real-time view of the ship traffic. This capacity had been developed and demonstrated by the JRC in the two previous PMAR projects, PMAR – Horn of Africa and PMAR – Gulf of Guinea. It had also been shown that it is feasible and beneficial to use AIS data from a multitude of sources – coastal receivers in various networks, and satellites from various companies; and how these sources contribute to a view of the ship traffic that is region-wide but contains details down to local scales. It had been confirmed that the ships that can be seen and tracked across the whole region are the medium and large ships (> 300 GT), the ones that carry the mandatory AIS and/or LRIT, plus some smaller ones that carry the voluntary "Class B" AIS. This means that the authorities can be aware of the positions and behaviours of e.g. tankers, cargo ships, passenger ships, many fishing ships, tugs and drilling rigs. For small ships (roughly < 40 m), however, the automatic reporting systems are not mandatory, so these are mostly missed, except for many yachts and some fleets of fishing ships that use voluntary AIS. It had been demonstrated that this small-ship traffic, on the other hand, can be seen by imaging satellites (down to 10-15 m size), but only occasionally and only over limited areas; no tracking of the small ships on region-wide scales is yet possible, just a sampling that is sparse in space and time. The PMAR approach had been designed with users in Africa in mind who may have limited infrastructures at their disposal in terms of IT capacity, therefore putting an emphasis on having most processing at the supplier side (JRC in the case) while keeping the data flows to the user as compact as possible. Furthermore, the processing of the raw AIS and LRIT data into a reliable, robust and accurate real-time picture of the ship traffic was still a matter of development and continued adaptation of the algorithms and software, making it difficult to put processing software at the user side.

The PMAR-MASE project has for the first time tried out the approach for region-wide maritime awareness with actual operational users in Africa for a sustained period of time. During this period, much has been learned. On the processing (JRC) side, problems with the data and the software have been found and corrected, and the software and system set-up have been further developed and improved. On the user side, a better understanding of the possibilities and limitations of the maritime awareness has been built up. The users have formulated concrete feedback and comments (listed in Annex 1 on User feedback in the column 'Issue'), which clarify the both usefulness and the shortcomings of the maritime awareness. Some of these comments could immediately be taken into account and have led to changes in the user interface and the information content. Some elements of feedback point to improvements that are consistent with the PMAR design concept. A few others go somewhat beyond, and two deserve mention here. The first is the requirement to have occasional access to the track of specific ships, but with a global reach instead of limited to the geographic Area of Interest that was used in the PMAR-MASE project. This will need special agreements with the data providers. The second is the requirement to be able to manually enter information into the system, which then also becomes visible to other users (other operators). This needs some redesign, because up to now the data flow was essentially one way, towards the users, not away from them. In any case, these requirements and all others (listed in Annex 1 in the column 'Remark') can now be specified when procuring an operational system.

As planned, the one-year trial of the supply of the maritime picture to the two operational users in Africa has ended on 15 September 2015. Most of the incoming ship position data came from commercial suppliers who operate AIS satellites and sell the data, and the PMAR-MASE project had the funding for only one year of data. Other data, such as the LRIT (from the Flags that use the EU LRIT Data Centre) and some of the AIS (namely those from the Norwegian satellites), are government-owned, and were provided to the PMAR-MASE project free of cost, however only for the same one-year period as the commercial data.

Concerning the software / system side, during the trial and according to plan, the JRC has been assessing the feasibility of transferring the (experimental) software to users in Africa. What has been provided to the users are the tools needed to use the PMAR web viewer. However, no further software has been transferred, for mainly two reasons. Firstly, the resources in the project did not allow to take the processing chain that is implemented at JRC, or parts of it, and implement it elsewhere. Secondly, the incoming raw data (2 Gigabytes per month) need a robust and high capacity internet connection that is available at JRC at no cost to the project. Outages or delays in the internet connection would lead to a loss of data and the MSP not being up-to-date. In the present project, this risk was minimised by keeping the processing at JRC, and providing the users with the processed end results, which put much less requirements on the internet connection at the users.

Like the previous two PMAR projects, the PMAR-MASE project has collected raw ship reporting data from as many sources as possible, in order to be able to define how much data sources are really needed for adequate completeness and accuracy. It is necessary to use data from more than one source, because each source is incomplete. (One data source can be: an AIS satellite; a coastal AIS network; LRIT from a set of Flags.) The LRIT data are only from the participating Flag States (in the case of PMAR-MASE, the Flags that use the EU LRIT Data Centre) and they only come at 6-hour intervals. The coastal AIS data have a continuous temporal coverage but a very limited spatial coverage. The biggest data source is satellite AIS, but it has a discontinuous / irregular sampling, and many of the reports that the ships emit are not successfully received by the satellites. Therefore, one single data source does not give adequate information, whereas on the other hand the information (completeness, accuracy) keeps increasing as more data sources are added. What exactly is an adequate level of information is a bit arbitrary and up to the user to define, also taking into account the costs that keep increasing as data sources are added. Unlike in the previous two PMAR projects, now each of the bigger commercial providers has so many satellites in operation, that probably one single of the bigger providers can give the required level of information. Limiting to a single provider of AIS data could make the procurement of data / services easier. However, although the number of satellites overall shows a growing trend, leading to continuous improvement in the information level, there is always the risk that one or more satellites that are operated by a provider fail prematurely, before they are replaced – this has happened already. Using several providers would lower that risk, but an alternative could be to demand from one supplier that he guarantees a number of satellites, forcing the supplier to obtain data from other operators himself in case of need.

The PMAR-MASE trial has provided detailed experiences with the entire data processing chain, involving ingestion, decoding, storage, retrieval, tracking of ships, error removal, ship position prediction, visualisation and statistics calculations. Based on these, it is concluded that the 'best' approach for operational availability of maritime awareness along the lines of the PMAR approach, is to procure a service from a commercial provider. 'Best' in the sense of giving the highest priority to making information available to the maritime authority operational end users, and the lowest risk of discontinuity in the information flow. Future users in the region (such as the foreseen Regional Information Fusion Centres) will much increase their chance of successful operation, if they will procure the end product (real-time ship traffic screen) from a commercial provider, as opposed to procuring the raw data and processing those to the end product in house. The commercial supplier would provide the region-wide Maritime Situational Picture to the users, in the same way as was done in PMAR-MASE by JRC, but now on a fully operational basis, with 24/7 availability, maintenance, support, etc. In the formulation of the specifications for the procurement, the PMAR design can be used as a reference, extended by the points given by the users as feedback.

When such a service for region-wide maritime awareness is procured for use in a Regional Information Fusion Centre, it can be cost-effective, as the costs are being shared by the various countries who participate in the centre, while the results benefit all. This is a way of regional data sharing that involves 'new' data, meaning data that is not owned by any of the sharing parties until it arrives from the outside provider. It is therefore not beset by the barriers to regional data sharing that apply to 'existing' data that are already owned by one party who is therefore reluctant to give them away.

Acronyms

AIS	Automatic Identification System
APU	Anti-Piracy Unit (of the Indian Ocean Commission)
CGPCS	Contact Group on Piracy off the Coast of Somalia
COMESA	Common Market for Eastern and Southern Africa
CMR	Critical Maritime Routes (programme run by the EU)
CRIMSON	CMR Monitoring, Support and Evaluation Mechanism (a project run under the CMR programme run by the EU)
CSDP	Common Security and Defence Policy (of the EU)
D [1.1, etc.]	Deliverable, as specified in the contract
DG	Directorate-General
DLR	German Aerospace Center
DEVCO	Development and Cooperation – EuropeAid, a DG of the European Commission
EAC	Eastern African Community
EEAS	European External Action Service
EEZ	Exclusive Economic Zone
EMSA	European Maritime Safety Agency (of the EU)
ESA-IO	Eastern and Southern Africa and Indian Ocean
EU	European Union
EUNAVFOR	EU Naval Force (EU military mission)
EUCAP	EU civilian mission
GT	Gross Tonnes
HoA	Horn of Africa
IFC	Information Fusion Centre
IGAD	Intergovernmental Authority for Development
IMB	International Maritime Bureau of the International Chamber of Commerce
IMO	International Maritime Organization (of the UN)
IOC	Indian Ocean Commission
ISC	Information Sharing Centre
JRC	Joint Research Centre (a DG of the European Commission)
KMA	Kenya Maritime Authority
LRIT	Long Range Identification and Tracking
MARSIC	CMR Western Indian Ocean project (run by the EU)
MASE	Programme to Promote Regional Maritime Security
MSA	Maritime Situational Awareness
MSP	Maritime Situational Picture
MSSIS	the Maritime Safety and Security Information System
NATO	North Atlantic Treaty Organization
NCA	Norwegian Coastal Administration
NOAA	National Oceanographic and Atmospheric Administration of the U.S.
PMAR	Piracy, Maritime Awareness and Risks
R&D	Research and Development
REFLECS3	Regional Fusion & Law Enforcement Centre for Safety & Security at Sea
RIFC	Regional Information Fusion Centre
RMRCC	Regional Maritime Rescue Coordination Centre
SAR	Synthetic Aperture Radar
SPAWAR	Space and Naval Warfare Systems Command (of the U.S. Navy)
UAE	United Arabic Emirates
UN	United Nations
UNODC	United Nations Office on Drugs and Crime

List of Annexes

Annex 1: User feedback. In this document.

Annex 2: "Maritime Awareness Systems Performance in the Western Indian Ocean 2014-2015", JRC Technical Report, 2015, JRC97935, EUR 27612 EN, ISBN 978-92-79-54033-2, doi 10.2788/420868. This is a separate document delivered together with this report.

Annex 3: "PMAR Viewer User Manual, Issue Feb 2015", JRC Technical Report, 2015, JRC94785.
This document has already been delivered in February 2015. It can be found on:
http://publications.jrc.ec.europa.eu/repository/bitstream/JRC94785/lbna27117enn.pdf

Annex 4: Mission reports
1. First visit to the region: 21 September - 1 October 2014: Mauritius, Seychelles and Mombasa
2. Meeting MASE National Focal Points, 31 March - 2 April 2015, Mauritius
3. Second visit to the region: 31 August - 9 September 2015: Madagascar, Seychelles, Nairobi and Mombasa

These have been separately distributed.

Annex 5: PMAR-MASE project presentation 1 April 2015.
Already delivered. Can be found on:
https://ec.europa.eu/jrc/sites/default/files/reqno_jrc95479_as%20presented%20but%20ships%20anonymised.pdf

Annex 6: PMAR-MASE project presentation 1 September 2015.
Already delivered. Can be found on:
https://ec.europa.eu/jrc/sites/default/files/Status%20Update.pdf

Annex 7: PMAR-MASE monthly ship density maps (version 17 Sep 2015).
Already delivered. Can be found on:
https://ec.europa.eu/jrc/sites/default/files/Monthly%20Ship%20Density%20Maps.pdf

Annex 8: Joint Research Centre (JRC) Science Hub, link to: Piracy, Maritime Awareness and Risks (PMAR):
https://ec.europa.eu/jrc/en/research-topic/piracy-maritime-awareness-and-risks

Annex 9: European Year of Development 2015 story 'Technology for a more secure Indian Ocean':
https://europa.eu/eyd2015/en/european-union/stories/technology-more-secure-indian-ocean

Acknowledgments

LRIT data were obtained courtesy of the National Competent Authorities of the Flags that participate in the EU LRIT Data Centre, with the help of EMSA (European Maritime Safety Agency).

Satellite AIS data from NORAIS, AISSat-1 and AISSat-2 were obtained courtesy of the Norwegian Coastal Administration and the Norwegian Defence Research Establishment (FFI).

MSSIS data were obtained courtesy of the Volpe Center of the U.S. Department of Transportation, the U.S. Navy and SPAWAR.

Piracy incident data were obtained courtesy of the International Chamber of Commerce – International Maritime Bureau (IMB).

A coastline data base of OpenStreetMap, © OpenStreetMap contributors, was used.

Predictions by the Global Forecast System (GFS) Atmospheric Model and by the Wave Watch III (WW3) Global Wave Model of NOAA/NCEP were used for the wind and wave layers.

Map background layers World Ocean, World Imagery and World Topographical of Environmental Systems Research Institute (ESRI) were used.

Map backgrounds of Natural Earth were used (free vector and raster map data @ naturalearthdata.com).

The map background layer Nautical Charts of TRANSAS Web Map Services was used.

Map backgrounds of Google Earth were used.

Satellite AIS data were purchased from exactEarth, Orbcomm / LuxSpace, and SpaceQuest.

Satellite SAR were purchased from MDA through e-Geos.

Annex 1: User feedback

This is the compilation of the feedback by the users and stakeholders after (almost) one year of use, provided orally to JRC during the visit to the region in early September 2015. The feedback sources are:

APU: IOC Anti-Piracy Unit, Victoria, 4 Sep 2015;

KMA: Kenya Maritime Authority/RMRCC, Mombasa, 9 Sep 2015;

SCG: Seychelles Coast Guard, Victoria, 3 Sep 2015.

In fact the Seychelles Coast Guard were not a user of the PMAR-MASE system (only APU and KMA were), but nonetheless they have given inputs which are useful because of their operational experience.

The comments of these three parties have been included in the table here. To give some structure, they have been split into four categories:

- Information content: relating to the type of information that is provided by the system.
- Functionality: related to what is to be done with the information.
- Operations use: related to how the system should be used to support operations at sea.
- Performance: related to comments that were specifically on the performance of the PMAR system during the trial.

Sometimes the comments of two parties were nearly identical, and then they have been combined in the same line in the table. Sometimes they were close but not quite identical, and then two quite similar lines are retained in the table. Almost all feedback is pointing in similar direction; only in one instance did the comments diverge, on the issue of availability of the PMAR system during the trial.

The last column of the table gives a short reaction to the feedback.

Category	Issue	APU	KMA	SCG	Remark
Information content					
	The geographical extent of the PMAR-MASE AOI was ok (required is: N-S Bab-el-Mandeb to Cape, E-W East African coast up to but not including Maldives)	x			Ok

	Within the region-wide AOI, any location can become a local temporary area of concern to be inspected and monitored, following a particular event (e.g. sighting of a pirate mothership)	x	x		This was indeed possible because of the zooming/panning functions. Maybe it would be helpful to be able to define areas of concern (sub-AOIs) that can be brought into zoom by a button click
	The geographical scope is too narrow, in the sense that it is sometimes required to see where a ship that has entered the region comes from, or goes to, not ending at the AOI boundary but with global extent		x		Considering that the commercial satellite AIS data is charged per area, it is not worthwhile to procure data with global coverage, but instead it is better to make an agreement with the data provider for incidental requests of track data of individual ships
	It should also cover inland waters (there is great interest in Lake Victoria and the other lakes, often for safety / search & rescue and for fisheries)		x		We don't know to what extent the inland ships in the region are fitted with AIS transponders. If they are not, they won't be visible
	Would like access to the historic data (DB)		x		We will look into this
	A satellite image as map background, such as in Google Earth, can help with navigation in coastal areas			x	This was already possible, with the background map layer 'ESRI World Imagery'
	PMAR is not sufficient to satisfy the maritime security needs, more tools are needed	x			This is acknowledged
Functionality					
	There should be an alert functionality that automatically indicates situations of interest / concern	x			This was not present, but the need is understood, and it is a topic of current developments. However, also the user needs to specify what exactly should be an alert for him
	The capability to analyse the data is lacking		x		Some analyses were done at JRC, regarding ship traffic statistics, and the results are being provided. As for the previous point, indeed no analysis options were in the interface but the need is understood. But it needs to be specified with the users what kinds of analyses are needed
	Analysis is now left to the operators, but more automatic functionality (software) for that is needed	x			See above
	There is an interest in port-related ship activities, how many ships are coming in or leaving the port, what are waiting times		x		See above; this is one specific type of analysis

	A functionality should be present to project the closest approach of two ships, e.g. between a patrol ship and a target ship			x	This should be possible to implement
	It should be possible to show the IDs of all ships simultaneously, not just of one ship at the time		x		This should be possible to implement
	A search on ship name is needed, in addition to those on MMSI or IMO number		x		This is easy to implement; it was not done because of ambiguities in the spelling of ship names, but the need is anyway understood
	A functionality should be present to simulate / predict the trajectory of a floating object since its last reported position, based on wind, current and object type			x	This goes beyond what the PMAR system is designed for. Models exist for that, but they are complicated, and rely on good input data which are often not available (in particular, accurate currents are difficult to obtain). An extension of PMAR with that functionality is not recommended
	It should be possible to display all information on one screen			x	PMAR has gone some way in that direction, with its many displayable information layers. A requirement to keep well in mind
	A distance / routing tool should be present that also tells the time and fuel needed to go there			x	The distance tool is in PMAR. It could be extended to include time and fuel, if data on speed and consumption of the patrol ship are provided
Operations use					
	It should be possible to draw boxes / polygons on the map, e.g. areas that have been searched; and to put markers on the map; with annotations			x	This was not in PMAR, but it should be possible to make that
	It should be possible to export a screen			x	The only possibility was making a screen dump and saving that in a file, e.g. using Microsoft Paint or similar. See remarks in the next point
	The MDA picture / information needs to be shared with other operators in the same operations centre. If one operator draws or tags something on his screen, the others should see it too			x	This would need some adaptions in the system design, because currently the information flows from the processing server (which was at JRC during PMAR-MASE) to the user; while this requirement needs also an information flow the other way

	The MDA picture / information needs to be shared with other centres	x	x		Similar to above, the difference being within one centre or across centres. The technical solution would be similar
	A chat facility would be useful to communicate with other operators / others who are working on the same event	(x)		x	The need is understood. It would probably be easiest implemented outside of PMAR, independently. Exchanging specific PMAR views would fall under the previous point
	It should be possible to use the screen as a debriefing tool			x	This implies annotation possibilities (see first point in this section) and play-back functionality. This was not implemented but could be done
Performance					
	The system was down very often. It was far from 24/7 operational	x			It is interesting to compare this comment from APU with the next one from KMA. Maybe there was a difference in internet connection quality
	The system was down only twice and these problems were quickly solved. It worked during a conference with high level attendance		x		See above
	Not enough training was given	x			It was thought that the user manual, version Feb 2015, would be adequate. Furthermore, for some identified events JRC has not received any further information or invitation
	It was only a trial version. The limitation of the access to only a single terminal (screen) was a disadvantage.		x		This is acknowledged. For operational use, it should be considered how many terminals are needed
	It is an advantage that it is a “light” system (only a client, a web interface)		x		This confirms the approach to have most of the computations and processing done at the service provider
	Consider to improve the wind display to moving vectors such as now shown on windyty.com			x	Could be taken into account in the specification, but as far as the display is concerned, it may also be a matter of taste – to be confirmed by other users. On the other hand, the widyty.com website is very comprehensive, so it might even make the inclusion of the wind / wave layers in the PMAR viewer redundant

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