Basin-Wide Maritime Awareness From Multi-Source Ship Reporting Data

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ABSTRACT: A system was set up to ingest automatic ship position reports (terrestrial and satellite AIS, LRIT) and fuse these into a Maritime Situational Picture, tracking the ships within an ocean basin-wide area of interest in real time. Trial runs were made over several months, collecting reporting data from a number of different sources, over the Gulf of Aden and the Western Indian Ocean. Also satellite radar surveillance was carried out in order to sample the presence of non-reporting ships. The trial showed that satellite AIS is a powerful tool for basin-wide ship traffic monitoring; that multiple AIS satellites are needed for sufficient completeness and update rate; and that coastal AIS and LRIT still provide essential complements to the satellite AIS data. The radar survey showed that about half of the radar-detected ships are not seen in the reporting data. The ultimate purpose of this work is to support the countries around the Horn of Africa in the fight against piracy and to help build their capacity to deliver maritime security and safety.

1 INTRODUCTION

The aim of this paper is to address the feasibility of obtaining maritime awareness, i.e. continuous knowledge of the whereabouts of ships, over sea basin-wide areas, by collecting and integrating data from various ship reporting systems; and to assess the quality of the resulting maritime picture.

Ship reporting systems include LRIT (Long Range Identification and Tracking; IMO 2008, Popa 2011), AIS (Automatic Identification System; ITU 2010) and VMS (Vessel Monitoring System, for fishing vessels; FAO 1998), plus non-automatic reporting through radio call-in. These have been set up for different purposes and work in different ways, but in all of them, the ships send out short messages reporting their identity and position, and sometimes additional information. Thanks to the use of satellites as communication platforms, these messages may now be received from ships anywhere on the globe, allowing an unprecedented view of ship traffic.

For many applications, there is a requirement to have an up-to-date awareness of where, within a certain area of interest, all the ships are, who they are, and where they are going: i.e. to know the "Maritime Situational Picture". Such a requirement stems in particular from authorities who are responsible for maritime safety and security. A particular case is counter-piracy. The wide-area Maritime Situational Picture (MSP) is needed in piracy-affected seas for the authorities to assess emerging risks, as merchant or fishing ships approach locations where piracy activity has been reported, and to issue warnings directly to ships at risk. It is also needed to support the deployment of inspection or interception assets. Furthermore, from the historic collection of MSPs as they evolve over time, ship traffic patterns can be compiled, that allow the assessment of geographical

risk distribution and that can function as a reference enabling the recognition of abnormal behaviour that might indicate a problem.

With these applications in mind, the PMAR (Piracy, Maritime Awareness and Risks) study was performed to assess how maritime authorities around the Horn of Africa can acquire the level of maritime awareness needed to carry out counter-piracy responsibilities. Piracy off the Horn of Africa is a regional problem (Duda & Wardin 2012). In order to facilitate a regional approach, and to permit data sharing between different countries and government sectors, the data and systems used should be unclassified. For use within Africa, the technologies should match available infrastructural limits; and they should be cost-effective. As such, the PMAR project was aimed at Regional Maritime Capacity Building, and was part of an internationally coordinated effort from the European Union to combat piracy and increase maritime security off Africa (see also Perkovic et al. 2012).

This paper discusses how a continuous, real-time MSP may be maintained by maritime authorities in Africa, derived from integrating the data from a number of ship reporting systems. The MSP serves in the first place for counter-piracy purposes, but also for maritime security, safety and resource protection purposes. The paper will discuss the performance of the MSP in terms of (a) the number of different ships that are detected; (b) how often ship positions are updated, determining how well the ships can be tracked over time; (c) the marginal benefit of additional data sources (e.g. how many ships are detected using one reporting data source, two reporting data sources, etc.); (d) particular problems with the data and their impacts; and (e) the completeness of the MSP, by sampling non-reporting ships with satellite radar.

2 METHOD

First, an IT architecture was designed and implemented (Fig. 7) which: (a) Continuously ingests incoming data streams from several ship reporting systems. (b) Tracks each ship based on its MMSI number (the main identifier in the AIS messages). Sometimes (in LRIT), the ship is identified by its IMO number; in that case, a ship register is used to convert this to an MMSI number. (c) Predicts the position of each ship to a certain reference time, based on the ship's last reported position and speed which may be some hours old. If no speed is reported in the message, then it is computed from the two most recent positions. The reference time is the same for all ships, at or just ahead of the current time, and in this way, a real-time MSP is created; this step is updated at fixed intervals, e.g. every 15 minutes. (d) Displays the resulting MSP on a screen, whereby the ship positions are clickable to display information about the ship and its past track. (e) Can sum all MSPs computed over a certain time period to obtain ship traffic density maps. The IT system furthermore: (f) Ingests positions of ships that have been detected in satellite images ("VDS" for Vessel Detection System; Greidanus & Kourti 2006). In contrast to the

continuous stream of positions from the ship reporting systems, the VDS positions are only available when a satellite image is taken over the area, and the VDS ships are unidentified. (g) Correlates the VDS positions with the positions of the known ships (from the reporting systems), so that a distinction can be made between VDS ships that were already known, and non-reporting VDS ships. Finally, the IT system can (h) Ingest piracy incident data (location, time, incident description) and can plot these on a map together with the MSP or historic ship density maps for risk assessment purposes.

With this system, two test campaigns were executed; the first to help design the system, and the second to tune it and measure the performance. Data were mainly collected from AIS, LRIT and satellite-borne Synthetic Aperture Radar (SAR). AIS is globally mandated on SOLAS vessels (mainly ships of 300 GT and more) and its messages are broadcasted on VHF with high update rate (at intervals of seconds to minutes). The AIS messages, which contain a lot of information, can be received by coastal receivers or by dedicated satellites passing overhead. For their use in ship tracking see e.g. B.J. Tetreault 2005 and Carthel et al. 2007. LRIT is also globally mandated on SOLAS vessels, but the messages are sent by satcom directly to the ship's Flag State usually at 6-hourly intervals and contain much less data than the AIS message. As a SAR satellite passes overhead, it can make a snap-shot radar image of the sea surface of an extent of up to several hundred kilometres on the side, enabling the detection (but not identification) of the larger ships (> 20 m). It is also possible to make more detailed SAR images that can detect boats as small as a meter in favourable conditions, but such images only have a very limited extent (5-10 km on the side) and are therefore not suitable for surveying extended areas.
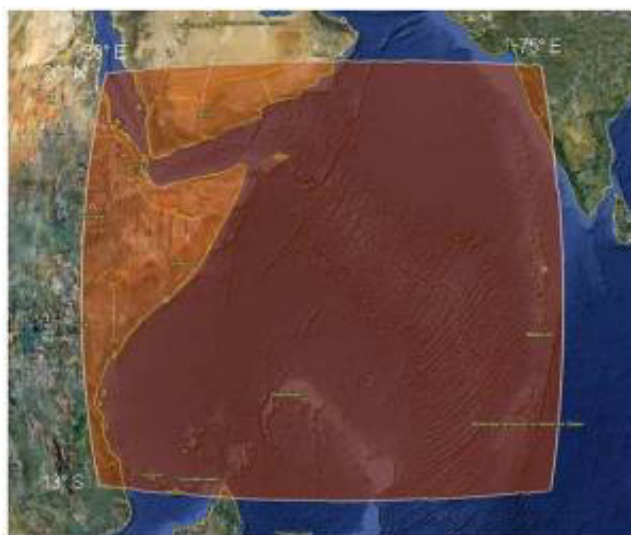

Figure 1. Trial area (viewed on Google Earth).

The data were obtained from many providers, both commercial and institutional. Table 1 gives an overview of the data sources that were used in the second test campaign, on which the results reported here are based. (Some results of the first test campaign were reported in Posada et al. 2011.) References to the AIS data sources are: Wychorski (2010), Eriksen et al. (2010), Eiden (2010), Flessate &

Loretta (2010), Lorenzini (2010) and Martin & Allen (2010). The AIS and LRIT data were continuously collected within the box shown in Figure 1 during the period 1 Aug 2011 – 31 Jan 2012 (however not each data source was available during that entire period). The SAR images were collected during a limited number of days in the period Oct – Dec 2011, mostly concentrated in the Gulf of Aden and off Mombasa, Dar As Salaam and the Seychelles. Auxiliary data that were used included publicly available ship registers and digital map data. Further data that were collected included VMS reports, and optical images from the ALOS-PRISM, SPOT, IKONOS and DEIMOS satellites, but those were only used to a limited extent and are not discussed here.

The tracking is designed to be run in real-time. Because satellite AIS data only become available with a delay of the order of hours (due to the time needed for downlinking and processing), prediction of the ships' current positions to the "now" is essential. Furthermore, all ingested data are stored in a database, and the tracking can be re-run off-line as well. When doing so, it is possible to choose a sub-set of all available data sources. In this way, one can explore the impact of different combinations of data sources on the completeness and quality of the resulting MSP. This is important to know, because each data source has an associated cost, and one wants to use the lowest-cost combination of data sources that still provide the necessary level of quality.

Table 1. Main data sources used in the second trial. The period 15 Nov – 15 Dec 2011 (31 days) is used as a reference period for the results in this paper.

Data type	Provider	C/I*	# Platforms in 15 Nov – 15 Dec
Terrestrial AIS	MSSIS	I	Set of coastal receivers plus a few receives on mobile platforms
Satellite AIS	FFI	I	2 satellites: NORAIS, AISSat-1
	LuxSpace / Orbcomm	C	2 satellites
	exactEarth	C	2 satellites
LRIT	EU Flag States / EMSA	I	17 Flags
Satellite SAR	TerraSAR-X	C	2 satellites
	Radarsat-2	C	1 satellite
	CosmoSkyMed	C	4 satellites
	Envisat-ASAR	I	1 satellite

*: Commercial / Institutional

3 RESULTS

Results will be given here for the one-month reference period 15 Nov – 15 Dec 2011 (31 days), when the system was performing well and many data streams were on line at the same time. During this period, on average 49,000 messages (AIS, LRIT) per day were received (from the area of Fig. 1).

Figure 8 shows an example of an MSP. Such a picture is typically refreshed every 15 minutes.

As can be seen from Table 1, there were 7 different AIS platforms available, the terrestrial MSSIS (counted here as one platform) and 6 satellites (from 3 providers). Figure 2 plots, as an example, all AIS position reports received during one day, from one single satellite (top), and from all 7 platforms together (bottom). It is immediately apparent that in order to do meaningful tracking of ships over the open ocean, more than one AIS satellite is needed.

In Table 2, it can be seen that with MSSIS only, on average 110 different ships are seen at any given time, whereas with one satellite AIS platform, on average 607 are seen. This is because the coverage of the satellite is much wider than that of MSSIS which is mostly coastal and with a limited number of coastal stations in this area. When combining the data of all systems (MSSIS, LRIT and 6 AIS satellites, bottom line), 1011 different ships are seen at any given time on average. This is still a bit more than the 931 (one line before last) from combining MSSIS, LRIT and only 4 out of the 6 AIS platforms. So not only does the quality of the tracks increase as more AIS platforms are used, as illustrated in Figure 2, but also the number of ships that can be tracked.

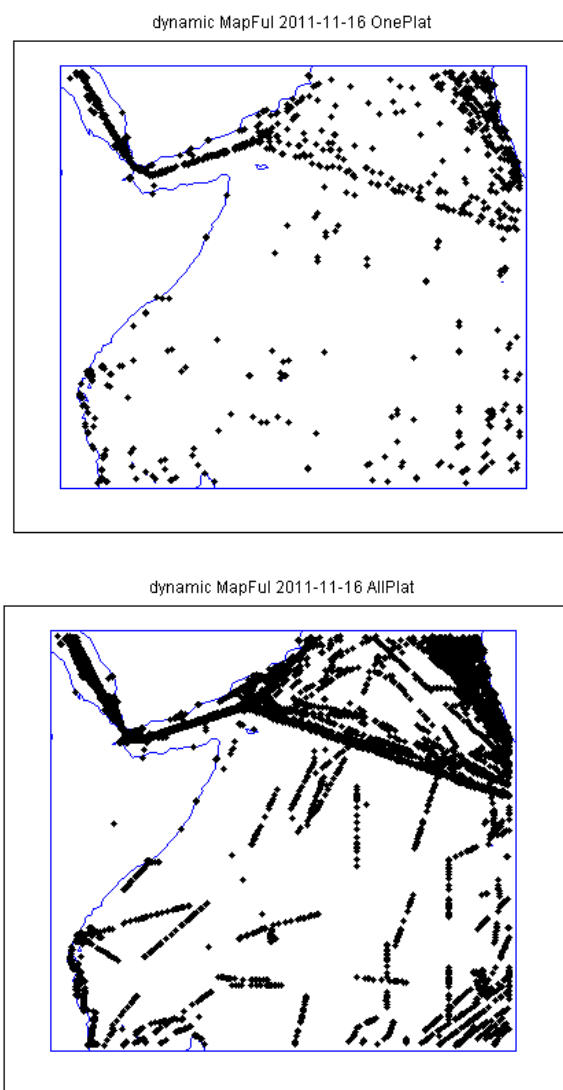dynamic MapFul 2011-11-16 OnePlat

dynamic MapFul 2011-11-16 AllPlat

Figure 2. All AIS position reports received during one day; top: from one single satellite; bottom: from 7 different platforms together (6 satellites and MSSIS).

Although MMSI numbers are supposed to be unique, sometimes the same MMSI is used by different ships. This happens in particular with invalid MMSI numbers such as 0, 1, 123456789, etc. The tracking algorithm has to resolve such situations. (Some ship tracking and prediction issues were discussed in Falchetti et al. 2012.) Whereas the total number of distinct MMSIs during the month was found to be 5155 (Table 2), in fact a total of 5235 distinct tracks (actually distinct ships) could be recognised. The right column "# Ships" in Table 2 indeed refers to tracked ships, not to MMSI numbers.

Figure 3 depicts in a different way the cumulative value of adding more AIS data sources. It plots the number of different MMSIs seen per day as a function of using one AIS provider, 2, 3 and 4 (the four providers from Table 1). (Note that the final number of just under 1200 MMSIs in the top plot is higher than the final 1011 from Table 2, because during a whole day more ships are seen than at one instant.)

Table 2. The number of different MMSIs that are seen in the area during the entire month, and the number of different ships that are present at any one moment (on average); given for MSSIS only (top line), for a single AIS satellite (averaged over all 6 satellites, 2nd line), when combining MSSIS, LRIT and four satellites from two providers (averaged over the three possible combinations of two providers, 3rd line), and when taking all systems together (bottom line).

Systems	# MMSI in whole month	# Ships at one time (mean)
MSSIS	1851	110
Single Sat-AIS (mean)	4363	607
Four Sat-AIS + LRIT + MSSIS (mean)	5022	931
All	5155	1011

In order to be able to track the ships, and predict their positions at the time of the MSP, their positions must be updated frequently. Whereas coastal AIS is received continuously (as long as the ship is in range), satellite AIS is only refreshed when a satellite passes over. The orbit period of a satellite can be of the order of 100 minutes, so a single satellite can provide updated positions once again after that time, but then the earth rotation causes the area of interest to revolve out of the satellite's swath, so that the next update is then only after many hours. The use of more than one satellite is needed to obtain more frequent updates. In addition, the AIS transmitters fitted on the ships were not originally designed for satellite reception, and only a certain fraction of all emitted messages are actually received. This fraction depends on the individual ship, as well as on the density of the ship traffic. The result is that for some ships, many updates may be received, while for others only few. Figure 4 shows this effect. It plots a distribution of the number of ships as a function of how many times their position is updated. The horizontal scale, the number of messages received from the ship, is logarithmic. The peak on the extreme left are the ships from which only a single message is ever received (during the one-month period used here); there are 310 such

ships. Most ships are seen with between 50 – 500 messages (during the month). From some ships (extreme right), nearly 10,000 messages are received. Figure 6 shows message update intervals per ship, again compiled over the one-month period and on a logarithmic horizontal time scale. The top graph is using a single AIS satellite only. The left peak with update times shorter than 10 minutes, is from updates received within one single satellite overpass. An isolated peak is seen at around 100 minutes, corresponding to the refresh after one satellite orbit. Then follow updates after longer than some 9 hours when the earth has revolved the area again into the satellite swath. The bottom graph is made from combining all systems; the two gaps between 10 minutes and 9 hours are now filled, enabling much better tracking.
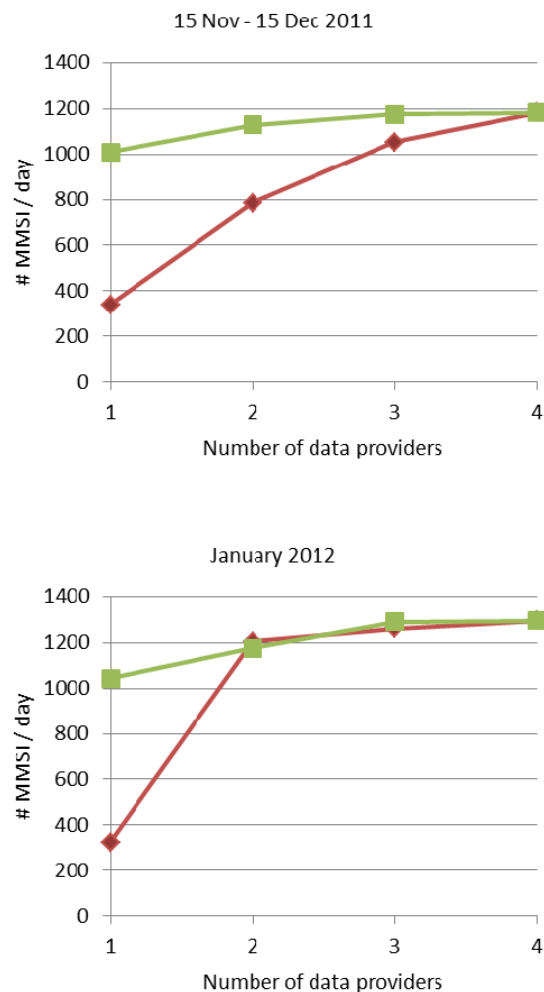

Figure 3. How the number of different MMSIs found per day, averaged over one month, increases as more AIS providers (MSSIS, LuxSpace/Orbcomm, exactEarth and FFI) are added. The two colours relate to two orders of adding the providers, red starting with MSSIS, green starting with one of the satellite providers. For two different periods of 1 month.

Figure 2 (bottom) shows one ship position on land; this is an error in the AIS message content. From analysing the number of reports on land (taking into account a buffer zone to correct for ships in ports), it is estimated that of the order of 1 in 10,000 AIS messages may contain an error. The error rate varies noticeably with platform, indicating that some errors

happen on receive. However, in some instances the same erroneous message is received by two different platforms, proving that errors can also occur on transmit. It is thought that some of the unique MMSIs that are seen only once (from the 310 mentioned in Fig. 4) are also the result of message errors.
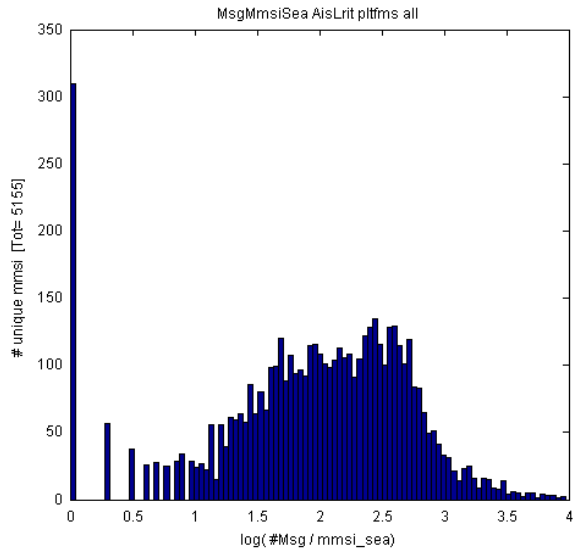

Figure 4. This distribution shows how many ships occur (vertical axis) for each number of messages per ship received during one month (horizontal axis, logarithmic scale).
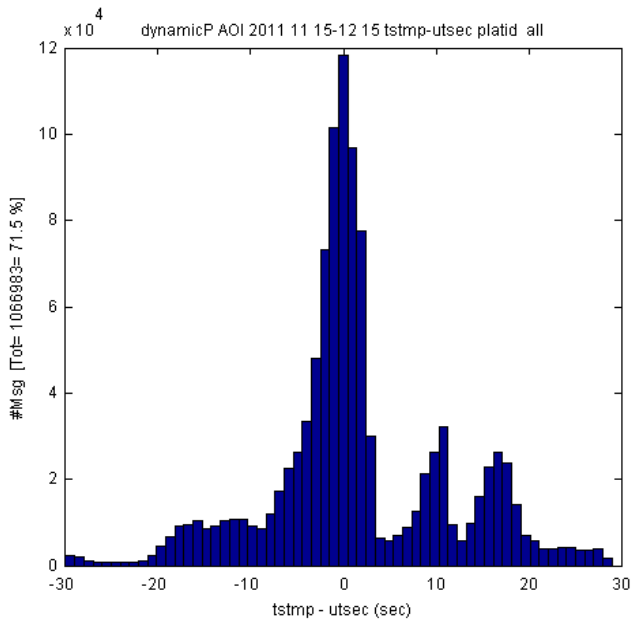

Figure 5. Histogram of the difference between the AIS message internal time stamp (seconds) and the seconds part of the externally affixed time stamp. All platforms are combined in this graph, from one month data, even though they individually show quite different behaviours.

The AIS message itself does not specify the time that it was broadcasted, but it does contain the seconds part of that time. It is up to the receiver to affix the full time stamp. A comparison was made between the time stamp (seconds only) inside the AIS message, and the seconds part of the externally affixed time stamp. Significant differences were found, varying systematically with AIS platform and, per platform, as a function of time. Figure 5 displays a histogram of the differences between the two time

stamps, lumping together all platforms; ideally, this should show a peak around 0. Also in the tracking it was found that ship positions jumped between messages received from different platforms. These jumps indicate time errors of up to several minutes. These time errors, due to inaccurate receiver clocks, turn out to be rather problematic when estimating speed, sometimes leading to serious prediction errors.
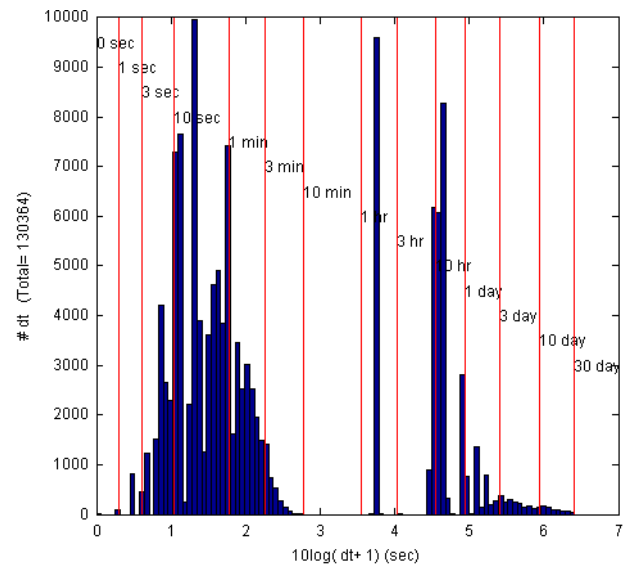

Figure 6. Histogram of time intervals between messages of the same ship, for all ships together during one month. The horizontal axis is the time interval (logarithmic scale). The vertical axis is the number of time intervals that occurred. Top: from one satellite AIS platform only. Bottom: from all platforms together.

Concerning LRIT, there are 577 ships of which LRIT data are received (again referring to the 1-month period 15 Nov – 15 Dec 2011), a number that can be contrasted with the total of 5155 of Table 2. Of course the number is much lower because only EU Flagged vessels are considered. However, from these 577 ships, 37 were seen exclusively with LRIT and not on AIS. One reason could be that they did not transmit on AIS, which was at that time the recommended best management practice when sailing through high-risk areas. Alternatively, their AIS transmissions could

have been too weak to be picked up by the AIS satellite receivers. In any case, this underlines the value of having LRIT in addition to AIS.

As for the non-reporting ships, Figure 9 shows as red dots the non-reporting ships that were found in a satellite SAR survey from 22 Nov to 4 Dec 2011 over the Gulf of Aden. The linear concentration running down the Gulf of Aden represents the transit corridor that was set up for better piracy protection. About 55 % of the total number of ships detected in the SAR images were non-reporting. This can be because these ships are not subject to AIS or LRIT carriage requirements (mainly because they would be smaller than 300 GT), or because they are not reporting even though they should, or because their AIS signals were not successfully received.
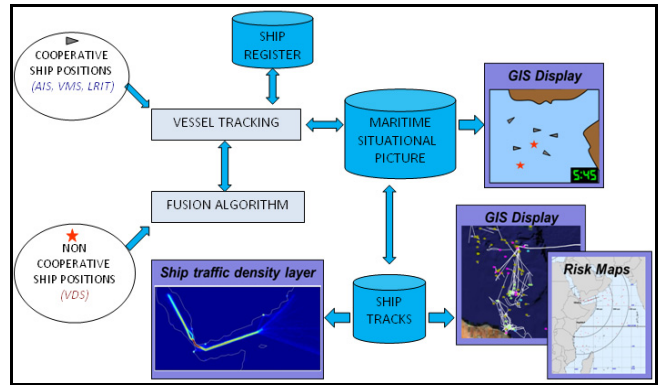

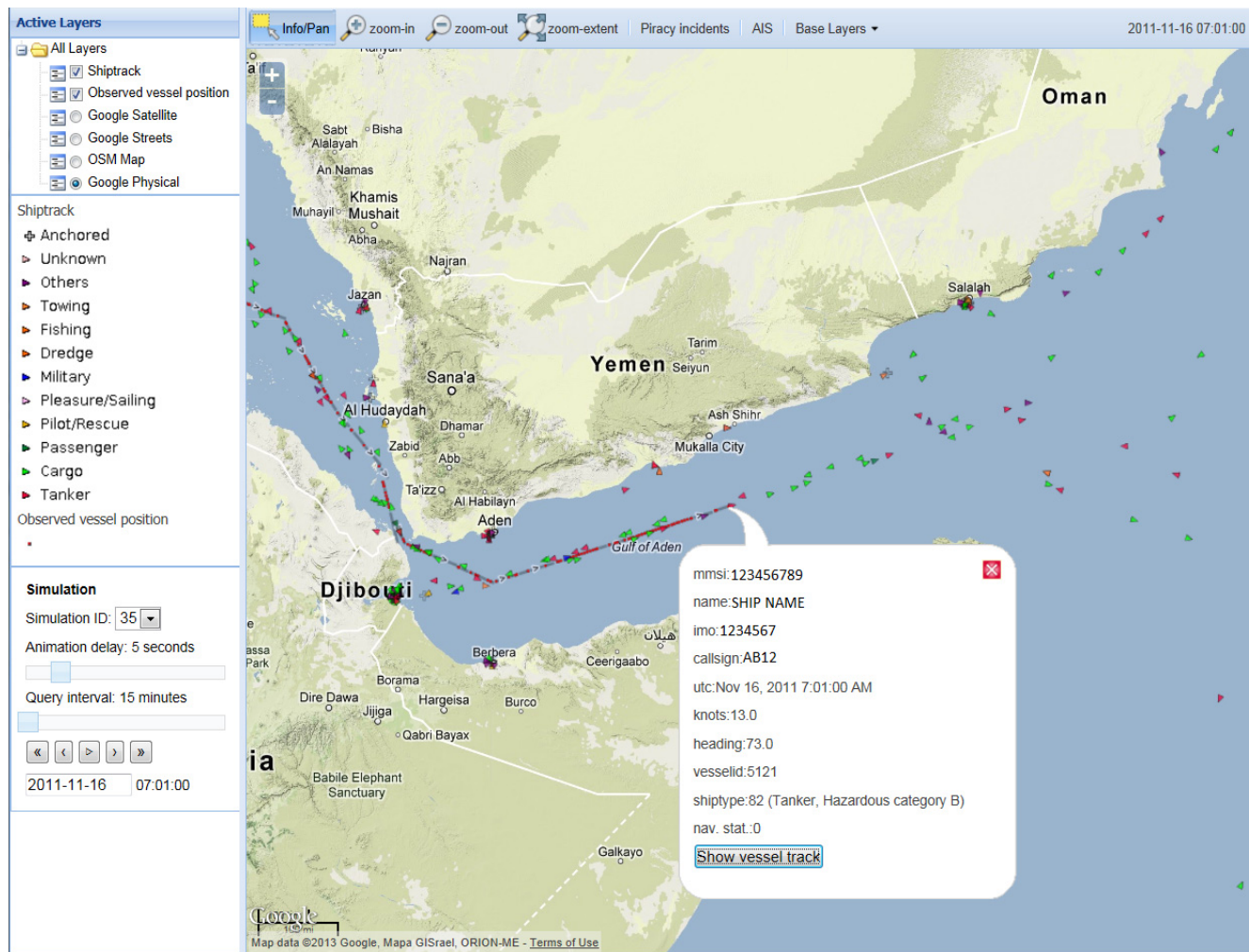Figure 7. Data fusion architecture as described in the text.

Figure 8. Display of Maritime Situational Picture, for 16 Nov 2011, 07:01 UTC. (Ship details anonymised.)
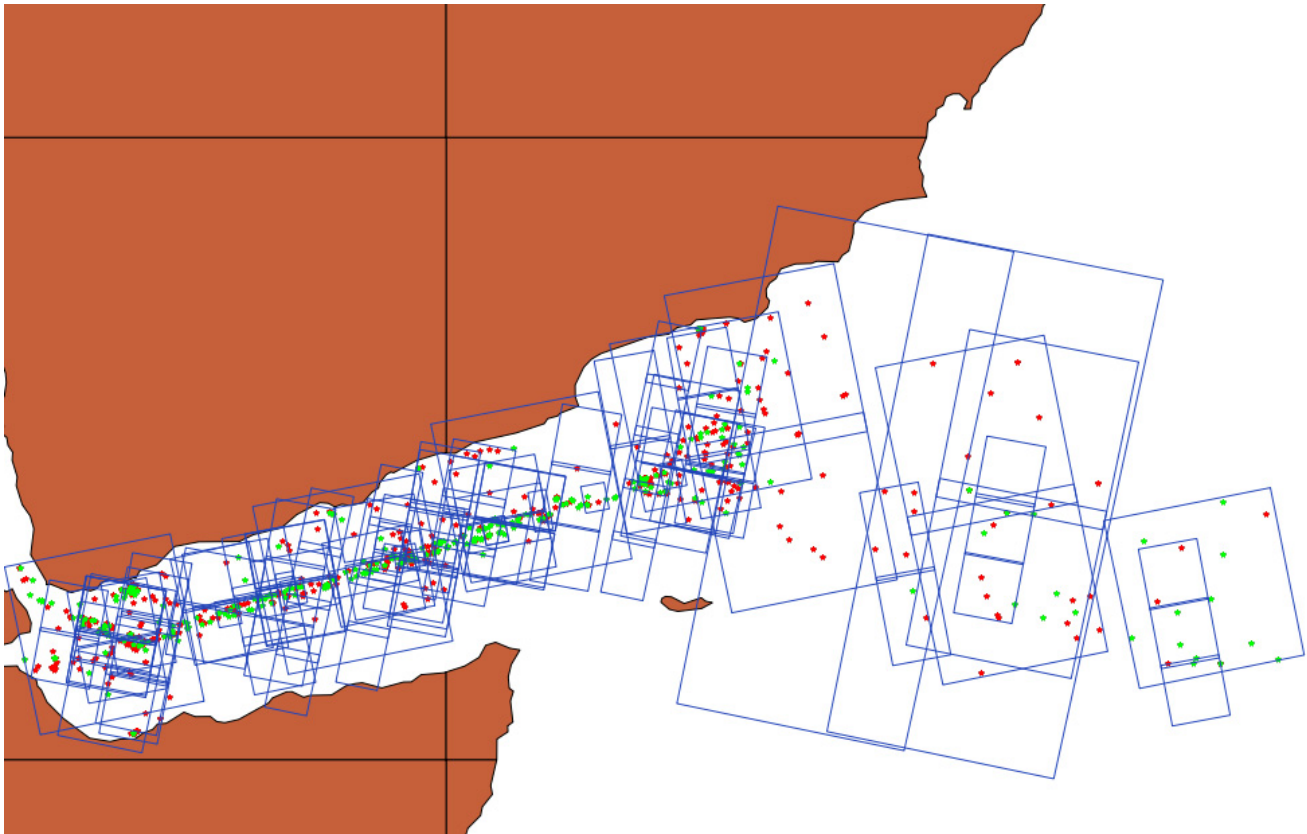
Figure 9. Satellite SAR images taken in the Gulf of Aden in the period 22 Nov to 4 Dec 2011. The blue boxes are the outlines of the images; the dots are ship detections. Green dots are ships that could be correlated with reporting ships. Red dots are non-reporting ships. The satellites used are mentioned in Table 1.

4 CONCLUSIONS

By using AIS data received from satellites, reporting ships can be tracked and a Maritime Situational Picture can be maintained across an entire ocean basin. A single AIS satellite does not provide sufficient completeness and update rate, so data from several are needed. As more satellites are added, the number of different ships that are found keeps increasing, but after about 5-6 satellites, the increase levels off. Time stamps on AIS messages, which must be externally affixed by the receiver, must be accurate to seconds ideally, to prevent significant errors in tracking and prediction using multi-platform data; this accuracy is not yet available. Although LRIT reports less frequently than AIS, some ships are only found in LRIT, so its addition is valuable. Addition of coastal AIS further improves the completeness of the picture, as well as the real-time tracking performance in coastal areas where reaction times should be faster than far away from the coast. Observations with satellite SAR show that about half of the SAR-detected ships do not report. Future work should further analyse the SAR detections to establish to what extent this is because they are too small to report.

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