Preparatory Action for Assessment of the Capacity of Spaceborne Automatic Identification System Receivers to Support EU Maritime Policy:

The PASTA MARE Project
Executive Summary

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1. Background

The PASTA MARE project aims at assessing the capacity of space borne AIS (Automatic Identification System) for supporting the European Commission's maritime policy.

PASTA MARE is a study contract issued by the European Commission and awarded to a consortium led by LuxSpace Sarl and ComDev Europe.

Space borne AIS is a new emerging technology with the potential to provide a cost effective solution for monitoring vessel traffic, the individual positions of ships, activities and cargoes around the world. Such vessel monitoring information is of particular interest of ship owners and port authorities but is also expected to be extremely useful for supporting maritime policy.

There are several activities ongoing, both from space research institutes and from space industry to further develop and operate space borne AIS satellites. Several AIS satellites are already in orbit, primarily to prove the feasibility and the potential of Satellite AIS systems. Due to their demonstration character, they have specific constraints related to their performance. However, the few results published so far clearly show the potential and usefulness of space based AIS systems, which needs to be exploited further.

2. Introduction

The deployment of space borne AIS satellite constellation has its own challenges due to the fact that AIS is primarily intended for sea-level reception.

One major concern is related to the self-organization principle of the terrestrial AIS communication system. All exchanged messages transmitted from ships within the VFH range of 30-40 nm are synchronized, meaning that there are no AIS reports sent at the same time at the same frequency. This guarantees the functioning of the system without any message loss. An AIS receiver mounted on a satellite however sees within his footprint (>3000 km diameter) several of these self organizing cells. Due to the fact that there is no synchronization between the cells, it's likely that the satellite receives AIS messages from various vessels send at the same time with the same frequency. This causes a message collision and leads to message loss.

Another issue is the saturation of the satellite sensor due to the high amount of messages, particularly in high density traffic areas such as the Mediterranean or the Baltic Sea.

Message collision and receiver saturation are know to be the main factors impacting the performance, measured as the Probability of Detection (PoD) of picking up an AIS position report transmitted by an AIS carrying vessel.

An in depth assessment of the real performance of the space based AIS systems in operation is not yet available, but required by the users to identify its potential benefit and the systems initiations.

2.1 PASTA MARE Objectives

The PASTA MARE project tries to fill the knowledge gap, aiming at assessing the performance of space based AIS through an in depth analysis of the system's particularities, capacities and limitations.

The results of the assessment will be the basis for DG MARE and other European Stakeholders to take an informed decision about the promotion of the utilization of space borne AIS data and the integration for supporting EU´s maritime policies. Moreover, the increased understanding of space based AIS gained through the PASTA MARE project shall contribute to the development of a future European space based AIS system currently planned by the European Space Agency (ESA) and the European Maritime Safety Agency (EMSA):

2.2 PAST MARE Tasks

The PASTA MARE project was conducted in three phases throughout the 2 year study period. The main tasks of the study were to:

1. Develop a digital global map of maritime traffic density in order to identify regions where the performance of a space borne AIS system may reach its limits.
2. Identification of potential radio-frequency interference which may have an impact on the AIS signal reception and the overall performance of space based AIS.
3. Assessment of the performance of space borne sensors already in orbit or to be launched during the time span of this project to detect vessels. The main parameter to be determined is the confidence that a vessel can be detected in a given geographical position.
4. Sampling of AIS raw frequency data which can be used to calibrate and validate sensors for future space missions.
5. Draw conclusions, draft lessons learned and recommendations for possible next steps towards a space-borne AIS service, supporting EU Maritime Policy.

3. Summary of the results of the PASTA MARE study

In the following chapters, the results of the PASTA MARE activities are briefly presented, including the conclusions, lessons learned.

3.1 Ship Density maps

Global ship density maps serve two main purposes:

- improved understanding of global vessel traffic
- indispensable input dataset for satellite AIS mission planning and simulation

Ship density maps are one way of to analyze ship movements and contribute to a better understanding of the global maritime traffic. They may help to answer questions like

- where are the main shipping lanes,
- how frequently there are used,
- which ship types are following which route,
- who transports what where etc.

Space based AIS data represent a unique data source for producing such a detailed insight in the global maritime traffic pattern, exemplifying the added value of global vessel tracking data delivered by S-AIS for many other applications.

Ship density maps are also an indispensable precondition for any satellite based AIS mission design. Only the detailed knowledge about the distribution of class A vessel carrying an AIS transponder allows for the estimation of the number of vessels in the Field of View (FoV) of the satellite. Based on this key figure the corresponding number of messages arriving at the satellite can be derived, necessary for estimating potential receiver saturation, number of message collisions and other important parameters needed for a sound payload and satellite mission design.

The approach developed in PASTA MARE is based on a combination of satellite and terrestrial AIS data. Satellite AIS data from Orbcomm and Pathfinder 2 delivering data from high sea areas and terrestrial AIS from the North Sea and the Baltic Sea, where current capacities of space based satellite reach their limits.

In Figure 1 the global ship density map of all class A vessels is displayed. The map clearly depict the high vessel density areas around the world Moreover, the global maritime traffic network becomes visible i.e. the main traffic lanes connecting the economic centres in Asia, Africa, Europe and the Americas crossing the Atlantic, Pacific and Indian Oceans. On the other hand also the low density areas are highlighted, for example the South Pacific and notable the area off the Somali Coast, a region where vessels are rarely encountered due to the recent piracy attacks.

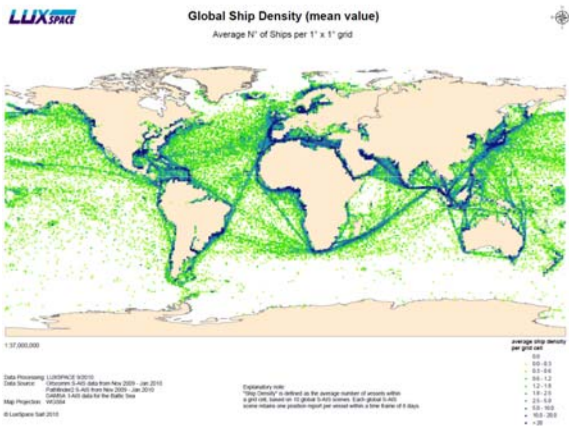

Figure 1: Global ship density map based on S-AIS data

The advantage of S-AIS data is that fact that for a huge share of the global vessel fleet precise track records is available. Other global vessel tracking data commonly used for compiling density maps, such as AMVER (Atlantic Merchant Vessel Emergency Reporting) or the WMO VOS (World Meteorological Organization Voluntary Observing Ships) do not provide these details.

AIS data provide additional details about each detected vessel, allowing the computation of specific density maps, i.e. differentiated according to ship type or navigation status.

To exploit the added value of AIS and to gain a deeper insight into the global vessel traffic pattern, ship density maps for specified vessel types have been generated, distinguishing between tankers, cargo vessels, passenger ships and fishing vessels.

The distribution of fishing vessels is presented as one example (Figure 2). The map shows a particular regional concentrations, which is linked to the main catch areas around the world, such as the central Pacific, North Atlantic (Iceland, Norway) Celtic Sea, along the East and West coast of South America (Peru, Chile, Argentina).

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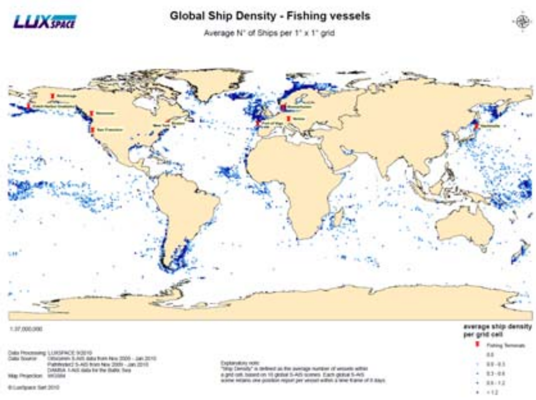

Figure 2: Global Fishing vessel density map

Moreover, particular density maps are produced in order to distinguish between the navigation status of the vessels (moored, under way), which is of utmost importance for satellite AIS mission planning due to the distinctive message update interval:

- All class A – vessels under way: AIS message update every 2-10 seconds
- All class A vessels moored, at anchor: AIS message update every 3 minutes (see Figure 3)
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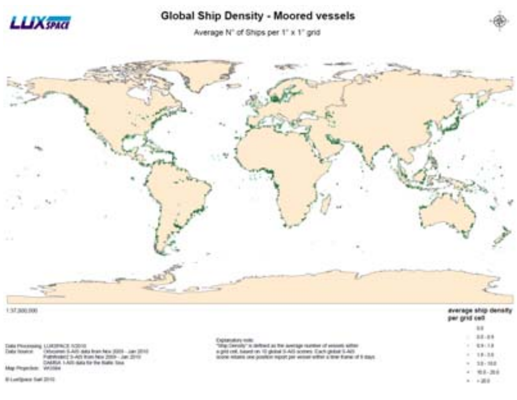

Figure 3: Global Distribution of moored ships

Apart from the information return of each density map, they exemplify also the value of historical space based AIS data, which goes far beyond the value of real time monitoring data. The historical AIS data archive represents a unique data source of global ship movements, providing not only precise track records but also detailed information about the ship itself (type, length, flag state etc). This illustrates the usefulness and the potential of the S-AIS data for many stakeholders. More detailed maps could be produced focusing for example on particular flag states, ship fleets, regions, or considering seasonal effects, changes over time. In collaboration with experts from the various maritime domains (business intelligence, fishery control, environment) additional data exploitation studies should be conducted, identifying the added value of globally available S-AIS data for other purposes, applications and users.

3.2 AIS frequency Interference

There are terrestrial sources that can create strong interference with a space borne AIS and thus impacting the overall performance of the system. Therefore a systematic analysis of the existence of interferences sources is essential, providing the foundation for:

- Delimitation of areas where space borne AIS services might be impacted, i.e. in the worst case might not be available, and/or
- Need to improved receiver/antenna design as well as for a mission planning aiming at coping/mitigating the effect of the interference.

Within PASTA MARE, the International Telecommunication Union (ITU) reports were consulted to investigate the legal AIS spectrum allocation. The Radio Regulation (RR), which defines the regulatory status of AIS VHF frequencies, states that

- the use of the VHF frequencies for AIS satellite reception is on a secondary basis with regard to Mobile and Fixed services, i.e. satellite shall not claim protection from emissions of Mobile and Fixed stations.
- In the mobile service, apart from ships, the only specific applications mentioned in the RR that could use the same frequencies are aircraft stations involved in search and rescue operations/safety related communications in the Americas and Asia-Pacific
- Concerning the Fixed service, no specific application is mentioned in the RR. However, those applications have to protect VHF transmissions from ships.

The analysis of the International Frequency Information Circular (BR IFIC), notifying national allocations revealed that there is not any relevant information for the frequencies of interest. This is not surprising, since there is no obligation for national authorities to register all of their terrestrial stations and frequency assignments. Only if neighboring countries are impacted, coordination and notification to ITU is requested.

However, that such legal usage of the AIS frequency for terrestrial services is common, could be shown during the flight campaign over Spain and Italy as well as from other airborne campaigns over Denmark and Germany. Local taxi companies use the AIS frequencies for communication between the taxi driver and the central unit.

Another important interference source was identified during a LuxSpace PATHFINDER2 AIS frequency sampling exercise over Northern Europe.

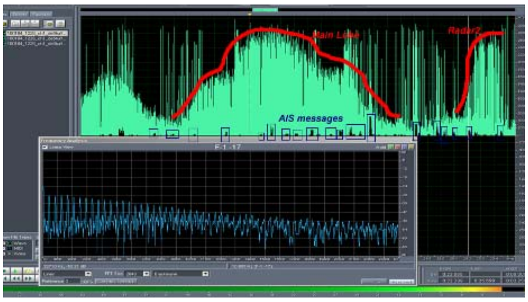

Figure 4: Screen shot of radar analysis, with spectral view of Pulse Repetition Frequency

Figure 4 shows interference produced by Russian Antiballistic missiles radars. The main lobe of the radar is shown in red (duration), along with the AIS messages marked in blue. It can be seen that the amplitude is quite challenging with respect to the one of the AIS messages

From the sampling of PATHFINDER2 and the sampling of the PASTAMARE flight campaign, it could be exemplified that an AIS satellite over Europe can have each AIS channel jammed several minutes. This obviously lowers considerably the performance of space based AIS over Europe.

Additional AIS frequency samplings a global level are required to identify other legal, but also illegal interference sources, created by countries or entities interested in hiding specific areas or voluntary “jammers”, who are interested to blank out the view of the space based AIS receivers over certain areas.

3.3 Assessment of current space based AIS satellites

The main activity within PASTA MARE was the assessment of the performance of current satellite AIS systems, bearing in mind that these are demonstrators.

The results obtained form Orbcomm, Pathfinder2, NTS1 and AprizeSat clearly demonstrate the feasibility to capture AIS signals from space and clearly indicate that space based AIS is able to deliver a quality of service in terms of coverage and Probability of Detection of class A ships.

Assessment approach/methodology:

Regarding the methodology applied for assessing the capabilities of space based AIS, three basic approaches were developed.

The first approach is the most straight forward performance measurements, counting

- the number of messages received in a defined time interval,
- the average number of messages per vessel during one orbital pass and
- the total number of ships detected during a defined time interval

These indicators specify in particular the receiver’s capabilities to decode AIS messages and allow the comparison of the performance of different AIS receiver designs.

The second approach tries to cross correlate the S-AIS data with reference data to assess the Probability of Detection (PoD). For those coastal areas where terrestrial AIS is available, this approach delivers robust performance indicators. An example in given in Figure 5.

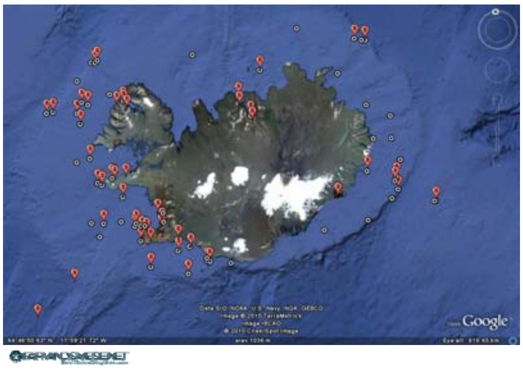

Figure 5: t-AIS (white) and Pathfinder 2 (red) vessel locations captured 19th January 2010 over Iceland

The third approach tackles the assessment of S-AIS outside the reach of terrestrial AIS stations. Long Range Identification and Tracking (LRIT) data could serve as a reference dataset, but due to confidentiality reasons could not be made available to the project. The lack of independed validation data was compensated applying a statistical approach, estimating the “real” number of ships using the observation of several AIS satellites at the same time in the same region (multiple sensor approach). This method allows the compilation of a reference number of ships which was used to deduct the share of vessels identified by each individual S-AIS system.

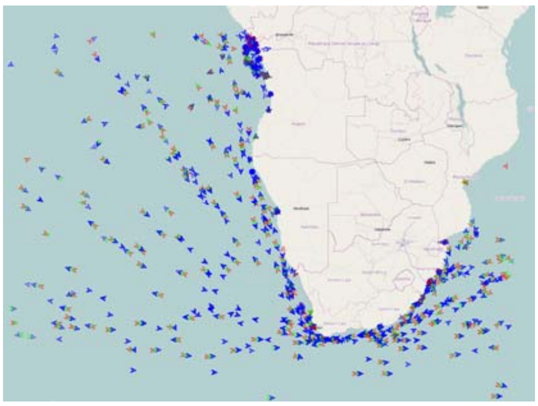

Figure 6: Orbcomm FM37 (green), FM39 (red) and Pathfinder 2 (blue) AIS data captured 2nd of January 2010 over South Africa

The cross correlation of S-AIS with reference data capture the overall performance of the entire S-AIS system, composed e.g. of the antenna, on board processing capabilities, storage and download capacity as well as the ground station network. Only the proper functionality of all components together determine the performance of a space based AIS systems and is thus a suitable measurement of the end to end system performance.

Orbcomm – Pathfinder – NTS1 – AprizeSat comparison

Regarding the performance of existing space based AIS systems, it can be shown that, although demonstration missions with certain constraints, all satellites systems provide a good quality of service.

In qualitative terms and for most of the specified indicators NTS1 performs best followed by Pathfinder2 and Orbcomm FM39 and Orbcomm FM 37.

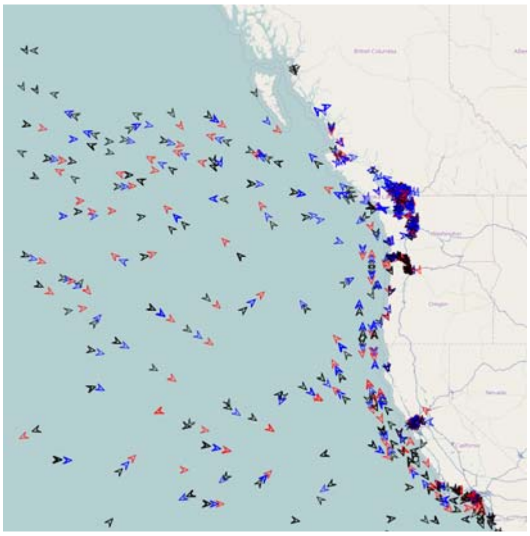

Figure 7: NTS1 (black) Pathfinder 2 (blue) and Orbcomm FM39 (red) AIS data over the Northern Pacific

The observed differences in the performance are closely linked to the different system concepts used for these AIS satellites. The Orbcomm AIS data collection system is a subset of the Orbcomm satellite messaging system, i.e. most of the space infrastructure used by the AIS data collection is shared with the Orbcomm messaging system (e.g. antenna, data downlink). However, Orbcomm is the only system providing a constant data stream of AIS messages, enabling the permanent observation of the vessel traffic around the world. Pathfinder 2 is an attached payload and with certain power restrictions and an unknown antenna pointing.

The NTS1 system concept differs considerably since it “just” records raw AIS frequency data for 90 seconds. While Orbcomm and Pathfinder process the AIS signals on-board the satellite, data processing of NTS1 data is done on ground, using the full computer power available in the ground segment, enabling also the use of latest decoding and demodulation schemes.

In this sense, a one to one comparison of the performance can be misleading.

The comparative analysis between on-board satellite processing using AprizeSat3 (AS3) and ground base processing of the raw AIS spectrum data down-linked via AprizeSat 4 (AS4) confirms the advantage of ground processing, since the algorithms in general enhances the AIS signal detection, thus the number of messages detected. However, AIS raw frequency sampling has its own challenges, since massive data are collected by the satellite receiver, which are to be stored and downloaded to ground, requiring a fast downlink and demanding a high power supply.

Figure 8: S-AIS performance test areas

Performance test areas are displayed in Figure 8. The test regions cover both high and low density areas, areas for which terrestrial data could be obtained.

The performance test results returned promising results over low and medium dense shipping areas (South African Coast, Atlantic, and Pacific Ocean). Over high density areas, such as the North Sea and the Baltic Sea the performance of current demonstration satellites is limited. The main reasons for this are high number of vessels causing message collisions and receiver saturation but also the existence of interference sources such as the Russian radar.

Unfortunately the data of ADS1, the first operational AIS satellite with advanced receiver and antenna technology, were not available during the project lifetime due to the shift of the launch date to Q1 in 2011. It would have been of particular interest and benefit to the project to investigate the impact of the advanced satellite design on the performance, especially over high density vessel areas.

Additional important factors impacting the performance of S-AIS

Apart from the above mentioned impacts of receiver saturation in high density areas, message collisions and interferences from terrestrial services, the investigations revealed that additional factors are to be having a strong impact on the system performance:

- Orbit geometry
- Navigation status
- Ship AIS antenna gain
- Topography

The capability of the satellite to identify a vessel strongly depends on the satellites orbit geometry. Depending on the satellites pass, an AIS satellite “sees” a certain region during its successive orbits from different viewing geometries. The Field of View (FoV) changes accordingly, hence the number of vessels varies in successive orbits. It may happen that a high density shipping area completely “fills” the FoV of the satellite, causing receiver saturation and returning only a small share of or even not any AIS message. During the successive orbit the high density area is only partially within the satellites FoV, still allowing the receiver to decode more AIS messages. This explains the high variability of the observed PoD in many regions in successive orbits.

The observed performance of all S-AIS satellites also shows a strong dependency regarding the navigation status of a vessel. Under way, a vessel transmits every 2 – 10 seconds an AIS message report, while moored or anchored only every 3 minutes. The probability of receiving a message from a moored vessel is thus significantly lower than that of receiving a message from a ship “under way”, considering a maximum visibility of a vessel of about 13 – 15 minutes.

Another important issue is the AIS equipment on board the vessel and particularly the vessel’s AIS antenna. The radiation pattern of the AIS antenna has a strong directionality in the horizontal plane (see Figure 9). An AIS message can be best received by the receiver at a low satellite elevation angle, meaning that the satellite can best capture AIS signals when it is close to the horizon. However, since installation of the AIS transmitter and the location of the antenna are not tightly regulated, it might be possible that parts of the superstructure of the ships (chimney, masts, etc.) distort the antenna radiation pattern. The angular relationship between the ship and the satellite makes the signal path highly unpredictable. For some ships, messages are received during almost all of the passes, whereas, for others, messages are received only at low elevation or only within a restricted azimuth angle.

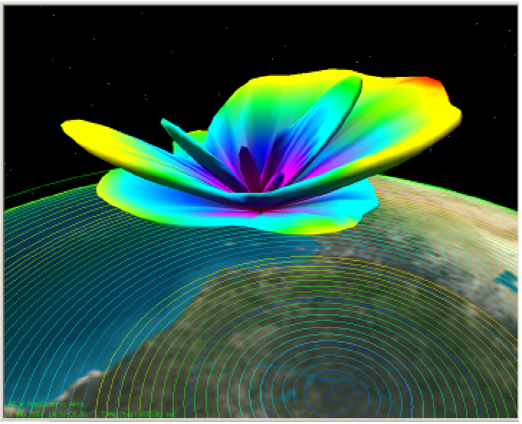

Figure 9: Simulated radiation pattern of an AIS antenna on board a ship

Examples from the Norwegian Coast show, that also the topography also impacts the reception of an AIS message. Particularly in rugged mountainous coastal areas, signal blockage due to obstacles is quite frequent. Combined with the horizontal directivity of the vessel AIS antenna and a transmission interval of 3 minutes it is likely that AIS messages cannot be received by a satellite.

The complex interaction of all this factors determines the general performance of S-AIS and also explains the particularities of capturing AIS signals in specific areas.

3.4 AIS frequency sampling during the flight campaign

The 12 hour raw data sampling during the flight trials along the European coastal areas generated huge amounts of raw data (approximately 2-3GB per flight) and it is certain that this data will be invaluable in the future to be used during mission, payload and satellite definition.

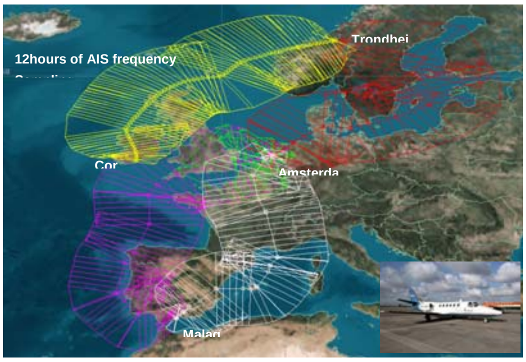

Figure 10: Flight route and coverage area of flight campaign

In particular several key conclusions can be drawn:

- When comparing the same geographical area and time, the airborne receiver consistently identified more ships than the terrestrial data. This has implications for the 'ground truthing' exercise as it is clear that terrestrial AIS data is not a complete 'truth'.
- Due to the availability of AIS data from a third party satellite (AprizeSat operated by SpaceQuest) an additional element of correlation between the airborne trial, S-AIS and ground AIS data was possible. This shows some of the problems with S-AIS data for these first generation systems in getting reliable data over high density areas.
- Comparison of COM DEV and Luxspace processing of the same raw data showed similar performances (COM DEV being marginally better).
- The excellent sensitivity of the receiver (the same design that will be used in the ADS1 satellite) was proven and it is unfortunate that the launch delays in the ADS1 mission prevented further comparison.

3.5 Complementarities between S-AIS terrestrial AIS and LRIT

The comparison of space based AIS data with terrestrial AIS data showed that t-AIS data do not necessarily provide a 100% reference to which S-AIS can be compared. The examples from Iceland as well as those obtained during the flight campaign showed that the terrestrial AIS coverage in certain areas can be patchy, not necessarily covering the entire coastal areas. Thus satellite AIS data is perfectly complementary to terrestrial AIS:

- S-AIS provide valuable data for regions outside the reach of the terrestrial AIS stations network and at a global scale and fills the gaps of the terrestrial station network.
- T-AIS provide position reports over high density vessel areas, i.e. in regions where the S-AIS performance is limited.
- LRIT adds value to S-AIS as it can provide position updates every 15 minutes for specific ships (data poll) which is hardly possible with a space based AIS system.

The combination and integration of terrestrial AIS, space based AIS as well as LRIT can form part of the International Maritime Organisation (IMO) e-navigation strategy currently under development.

4. Final conclusions

Based on the findings the following overall conclusions can be drafted:

Tracking and tracing of vessels using satellite AIS is feasible. The current demonstration AIS satellite systems of Orbcomm, ComDev/ExactEarth and LuxSpace already deliver a quality of service for high sea areas.

The comparison of the available experimental space based AIS systems revealed, that the current AIS demonstration systems do not fulfil the 80-90% PoD requirements specified by European users. There are many areas, specifically on high sea, where the demonstration systems already come close, but for other areas, particularly high density coastal areas, current space based AIS systems reach their limits. The next generation satellites will definitely further improve system capacities and the data quality.

Apart from message collision, receiver saturation and interferences, additional parameters could be identified which impact the overall performance of S-AIS such as orbit geometry, navigation status of vessels, ship AIS antenna gain and output level as well as the topography in certain coast areas. This needs to be considered when defining user requirements, particularly in terms of expected Probability of Detection.

The implementation of a dedicated S-AIS frequency as discussed in the ITU working group 5b will definitely overcome the limitation of current S-AIS and will improve the Probability of Detection of class A ships significantly. However, even this will not solve all the above described dependencies.

Despite the limitation of existing experimental space based AIS systems, the potential has been clearly demonstrated. Currently space based AIS data is provided to various institutional users, such as EMSA, NATO, EU national coast guards as complementary data for compiling maritime awareness pictures.

The commercial market is in development with port operators, ship owners and trading companies realising the added value of space based AIS. In fact it is likely that commercial systems will be firmly established well in advance of institutional systems thus questioning the need for institutional investment in infrastructure rather than service.

Satellite AIS can be considered as one additional element, improving the compilation of an overall maritime awareness picture. Terrestrial and satellite AIS as well as LRIT are complementary providing a global vessel tracking information.

Earth Observation data coming from optical, SAR or even navigation radar (NAVRAD) detection sensors will be also required in the future to detect non cooperative vessels or those which are too small to carry an AIS transceiver.

Regarding future activities, the project identified the following issues to be promoted:

- During the course of the project, examples provided to different customers showed the overall utility of S-AIS for maritime monitoring. This application driven approach should be further developed by setting up more demonstration projects. In addition the implementation of application projects would also support the fine-tuning of the requirements for a future European space based AIS constellation.
- Today, EO data are provided to GMES and other applications through a specific mechanism and funding on EU level and it might be worthwhile to consider a similar approach for S-AIS data.
- Several projects will be implemented within ESA under ARTES 5, 20 and 21.These studies will provide valuable inputs to a technically sound basis for a future European AIS constellation and improving the knowledge in Europe in this field. In addition, it is proposed to further investigate the AIS signal behavior and specifically the parameters not linked to the satellite but to the vessel itself.
- Another issue is related to the commercialization of S-AIS data. Even though, the recording of AIS data is not forbidden there are still some major questions about the commercial distribution of S-AIS data on global scale. IMO and ITU are still discussing a possible approach. However, some countries have a strong interest in keeping S-AIS for institutional use only. The definition of a legal framework related to the data policy is definitely needed, but requires a global approach supported by all stakeholders.

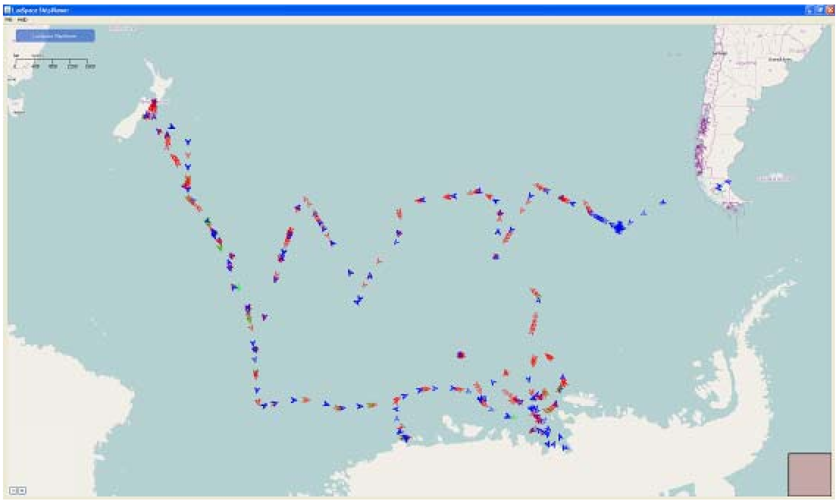

Figure 11: Track of the German research vessel Polarstern on their arctic mission 2009/10

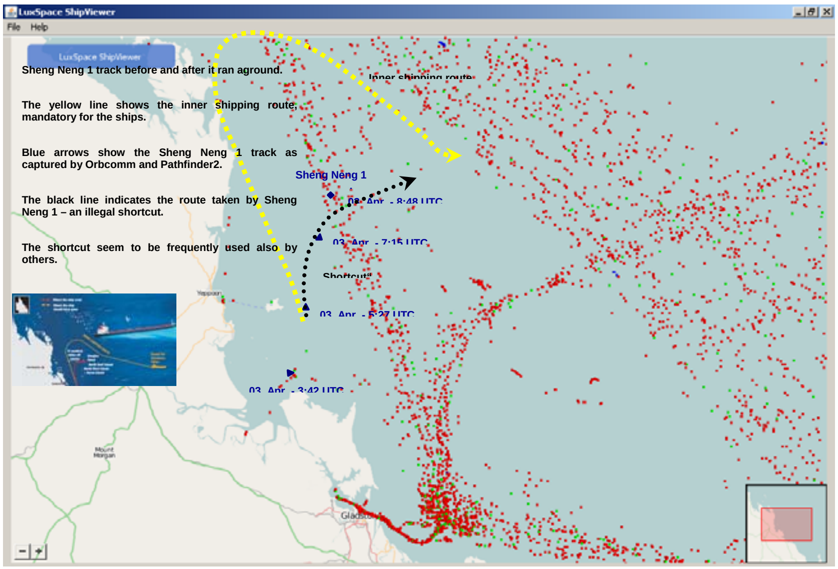

Figure 12: Track of Sheng Neng running aground on the Barrier Reef/Australia 3. April 2010

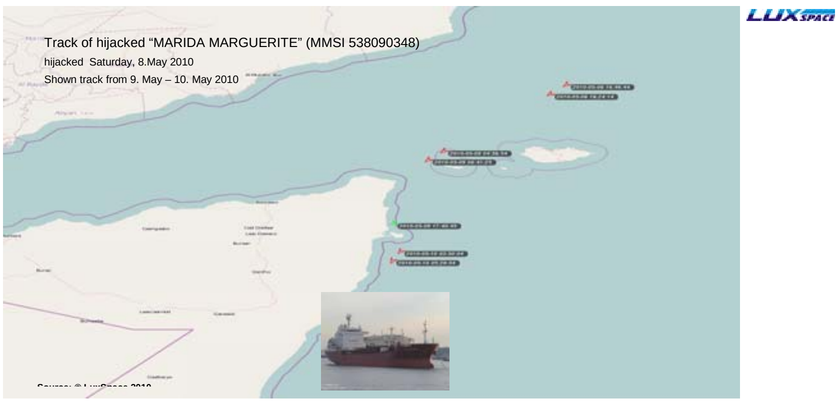

Figure 13: Track of hijacked “MARIDA MARGUERITE” (MMSI 538090348)

hijacked Saturday, 8.May 2010