NMIO Technical Bulletin

National Maritime Intelligence-Integration Office

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Director NMIO View:

Rear Admiral Elizabeth L. Train, USN

As the Director of the National Maritime Intelligence-Integration Office (NMIO), I am pleased to present Volume 9 of NMIO's Technical Bulletin. This volume is primarily focused on commercial space-based surveillance of the maritime domain. The articles provide insight into the maturation of commercial, space-based Automatic Identification System (AIS) monitoring, the new insights yielded through advanced analytics, and their contributions to meet the challenges that lie ahead to achieve effective understanding of the global maritime commons.

I would like to personally thank the authors who have invested their valuable time to contribute to this edition of our Technical Bulletin. As we work together to promote global maritime security, I encourage others to become more involved in this community publication by submitting articles to help us broaden the topics and regions covered in this product.

I am equally grateful to our readers. Your insights, commitment, and feedback continue to positively affect the safety of the international maritime domain. It is my hope that through increased awareness and collaboration, our mutual efforts will strengthen the maritime security overall. NMIO remains focused on identifying concerns and issues that resonate among government, academia, industry, and foreign partners to identify the most efficient and cost effective solutions to our mutual maritime challenges.

The Technical Bulletin is one of our key vehicles to promote enhanced maritime domain awareness and information sharing. We appreciate and invite your continued input, interaction, and contributions to this and other efforts that promote global maritime security. We hope you enjoy this publication, and I look forward to working with you to advance maritime security and build shared domain awareness.

NMIO Technical Bulletin **Volume 9, March 2015**

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Correspondence welcome: We welcome contributions from all Global Maritime Community of Interest stakeholders, both domestic and international. In submitting your article, please highlight who you are, what you are doing, why you are doing it, and the potential impacts of your work. Please limit your article to approximately one to two pages including graphics. Articles may be edited for space or clarity.

Cover Image: European Space Agency (ESA) Sentinel-1, the first in the family of Copernicus satellites. Its mission includes monitoring the extent of Arctic sea-ice, routine sea-ice mapping, surveillance of the marine environment, oil-spill monitoring and ship detection for maritime security, monitoring land-surface for motion risks, mapping for forest, water and soil management and mapping to support humanitarian aid and crisis situations. Copyright ESA/ATG medialab.

Table of Contents

INTRODUCTION

John Mittleman, PhD, Naval Research Laboratory (NRL)

The "Use of Space for Maritime Domain Awareness (MDA)" would have never been much of a topic of conversation until 2008, the year when both SpaceQuest and ORBCOMM put AIS (Automatic Identification System) receivers on satellites, and splashed computer screens around the world with the first near real-time reporting of ships everywhere, in every ocean and near every coast. There were those who were thrilled with the intuitively obvious presentation of major shipping lanes, and there were those who asked about the ships well outside those shipping lanes; begging the question, "what are they doing there?" AIS's ability to be received in space made the most remote places visible; the high seas and the polar seas were no longer unmonitored, at least as far as monitoring those ships that voluntarily chose to broadcast the AIS signal. That signal, being carried in the VHF part of the radio frequency (RF) spectrum, was previously received only by nearby ships and terrestrial stations. The implications for safety, security, protection of the environment, and the health of the maritime transport system were appreciated almost immediately and at several levels (policy, technical, and operational). AIS is mentioned numerous times in the 2005 National Plan to Achieve Maritime Domain Awareness[1], a document supporting the National Strategy for Maritime Security, ensuring its place in national MDA architecture.

This revolution in MDA, coupled with a dramatic change in our perception[2] of maritime threats, led ADM H.G. Ulrich, then Commander, Naval Forces Europe (NAVEUR) to form Task Force Sea Sentry in 2003 with the memorable declaration: "I want to know about every piece of iron in the Med!" This eventually led to the AIS-based Maritime Safety and Security Information System (MSSIS) that boosted NAVEUR's awareness from about 200 military ships operating in the Mediterranean to over 10,000 ships of all types. His next demand on the watchfloor was even more difficult, and equally enduring. Faced with a Common Operational Picture (COP) showing thousands of vessels, his challenge was: "Which one am I interested in?"

The fact that AIS carriage requirements associated with the Safety of Life at Sea (SOLAS) convention only apply to certain classes of vessels (typically cited as "all ships of 300 tonnage and upward engaged on international voyages"[3]) leaves the question of MDA for non-AIS ships unanswered. To put this in context, we typically see on the order of 60,000 AIS-broadcasting vessels at any given time, and know that something like 150,000 distinct vessels may broadcast AIS. But in the U.S. alone there are approximately 12 million vessels registered because they're big enough to carry toilet facilities, and of these there are over 600,000 that are over 26 feet in length, capable of significant voyages, either trans-

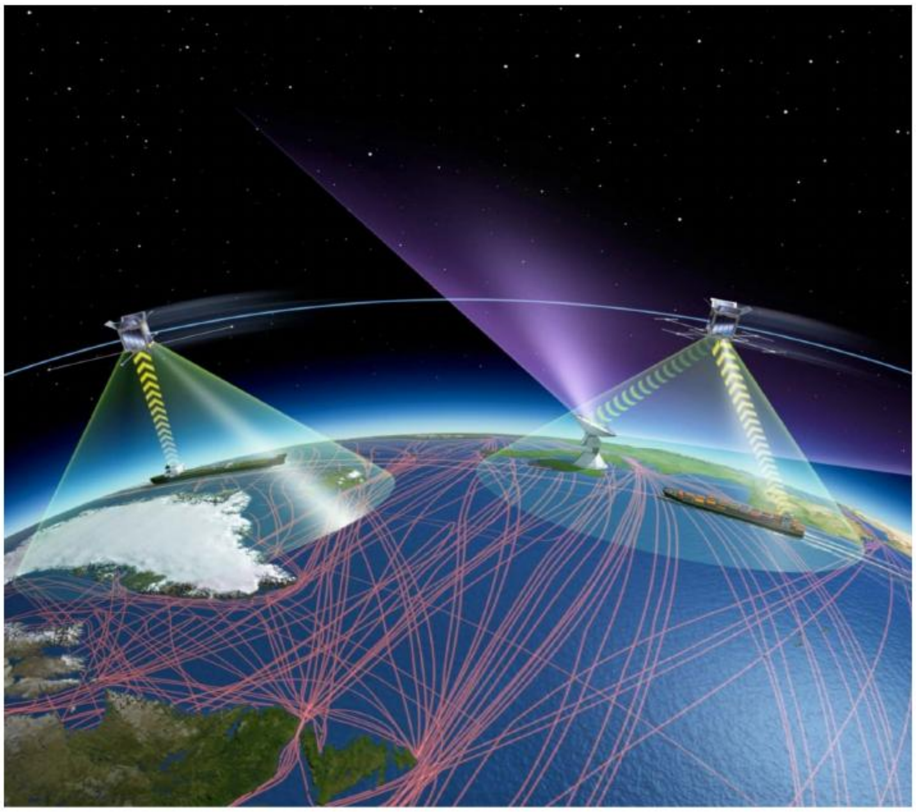

Image: Satellite-Automatic Identification System (S-AIS) artist impression, copyright ESA.

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[1] http://www.whitehouse.gov/sites/default/files/docs/national_maritime_domain_awareness_plan.pdf

[2] Our prior focus on the military ships of other countries was challenged by the successful attack on USS Cole by a small boat in the port of Aden, Yemen, on October 12, 2000. This attack made it abundantly clear that any vessel, no matter how small, could deliver a disabling blow. Other threats, such as trafficking and environmental abuse, are inherently vectored by non-military vessels.

[3] http://www.imo.org/OurWork/Safety/Navigation/Pages/AIS.aspx

oceanic or long-range coastal[4]. Those vessels, and even smaller ones, can vector significant threats to maritime safety, security, the environment, and the free flow of trade, which suggests that we need to tap into a wider range of sensors and phenomena to gain awareness of more than the AIS-broadcasting population of vessels. For this reason, the 2010 National Space Policy tasked the U.S. Federal interagency to look at civil and commercial space systems to enhance global MDA.

Three common classes of space systems add to the AIS picture:

- communications satellites (which carry a wide variety of reporting from ships at sea, including Long Range Identification and Tracking (LRIT) and Vessel Monitoring System (VMS) broadcasts, as well as periodic weather reports from ships at sea);
- electro-optical (E/O) imaging satellites (each of which has a fixed resolution and field of view, from low-resolution, wide area imaging (typically used for meteorology) to high resolution, narrow field-of-view imaging (often good enough to detect, classify, and even identify vessels)); and,
- synthetic aperture radar (SAR) imaging satellites (capable of changing resolution and field-of-view while on orbit, with a range of products from low-resolution, wide-area surveillance imagery to high-resolution vessel characterization imagery).

But while imagery can detect and locate vessels, neither E/O nor SAR imagery have the convenience of self-identification built into AIS and other broadcast messages from ships at sea. Those vessels that are not detected through RF broadcasts are termed “dark vessels.” By fusing imagery with broadcast information, we narrow the set of vessels we know to exist to a smaller set of vessels that we know to exist, but can’t identify. These systems provide some measure of enhanced global maritime domain awareness, but leave much undetected; i.e. we still don’t know about “every piece of iron in the Med.” Every new sensor type can contribute to expanded awareness. Beyond the visible spectrum, infrared imagers in space can help with vessels that turn on lights at night, regardless of size (a resolution issue) and regardless of construction material (a radar cross-section issue). NOAA, for example, reports on a prototype system using the Visible Infrared Imaging Radiometer Suite (VIIRS) to detect fishing vessels which use lights as fish attractors at night.

Even if we were to have sensors able to detect every ship at sea, the Admiral’s second challenge: “Which one am I interested in?”, goes beyond detection and geolocation. It sets the bar much higher, requiring entirely new data sets to be associated with each vessel to make sense of their activities, to assess the risk they might pose, and to evaluate the threat they might present. It certainly helps that AIS and other broadcasts identify ships by name, because this creates an easy link to business-related and historical data sets associated with the vessel. But even for unidentified vessels, fine-grained observation of the ships’ behaviors can help identify what type of activity it is or was engaged in (e.g. transit, fishing, rendezvous, etc.), which can lead to a deeper understanding of whether it should be on the Admiral’s short list of questions: Is it legal or illegal? Is it threatening or benign?

This edition of the NMIO Technical Bulletin delves into both important areas of awareness: existence and analysis. George Best sets the stage with an overview of broadcast systems and numerous applications for that level of awareness. Chan Smith presents a lucid overview of the factors contributing to satellite-based AIS systems’ technical performance. Dino Lorenzini presents an engaging story that argues for collaboration across many technical, policy and operational sectors to arrive at an effective response to the problem of Illegal, Unreported, and Unregulated (IUU) fishing. Harm Greidanus closes the issue with an article that focuses on measures of performance, to describe how AIS and other ship detection technologies provide a Maritime Situational Picture that supports strategic and policy deliberations, as well as operations. These articles are a snapshot in time, somewhere near the maturation of current capabilities to sense the existence of vessels and associate related data sets to each vessel, but well short of the point at which we routinely apply our understanding of maritime activity to automatically perform a risk assessment and threat evaluation for every ship detected. Take in this snapshot, and stand by for more, as this foundation is used to support the higher functions of sense-making.

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[4] National Marine Manufacturers Association data contained in communication between NMMA and EPA, November 9, 2010.

[5] http://www.ngdc.noaa.gov/eog/voors/download_indo_boat.html

PROGRESS OF SATELLITE AUTOMATIC IDENTIFICATION SYSTEM

George Best, ORBCOMM

A day in early 2008, when images were first displayed of shipping from around the world using Satellite AIS (S-AIS) inputs, was a remarkable moment. Many had anticipated that it could be done, and various tests were conducted using aircraft and computer models, but no one was quite sure how effective this new capability would be. Within a short time of each other, both exactEarth (COM DEV at the time) and ORBCOMM launched satellites to show the world that not only was it possible to capture and display such data, but that the results could provide a useful service to the maritime world.

Ecstasy describes the reaction of the people involved. Here for the first time was a global presentation of all ships of over 300GT, each equipped with a Class A AIS transponder. Shipping could now be seen in all parts of the globe, and the information collected was the same as that retrieved with coastal AIS.

Now was the time to ask the maritime world if they really wanted this new AIS service. The reaction was for the most part very positive, with a few people concerned about privacy issues and the legality of information captured from ships.

Market studies were conducted to discover how much an organization would pay for the service and what areas of interest would these organizations have. Those areas of interest included: Maritime Domain Awareness, Surveillance and Security, Search and Rescue, environmental monitoring, and historical data, et cetera. These studies, which included personal visits and phone surveys, highlighted the wide requirement differences of each organization.

Among the more revealing discoveries in this market survey was the value that maritime departments placed on the availability of the data. The data had a high value for military maritime departments, and the search and rescue potential was extremely valuable for some nations. For others, the ability to anticipate or monitor environmental threats, and to see compliance to certain shipping lanes because of the potential for an environmental catastrophe, was extremely important. Still others worried about illegal fishing, illegal oil transport, drug smuggling, and human trafficking, and so considered the S-AIS of great value.

However, a number of unanticipated revelations also came to light during the studies. One of the most significant was the question of the accuracy of the data received. AIS data is transmitted at VHF frequencies, and the receivers of such transmissions are similar to radio receivers that accept whatever is transmitted. The quality of the data is determined by whatever has been entered into the AIS transponder, and if such data is inaccurate or nonexistent, then the information received will be inaccurate or nonexistent. Many of the survey participants revealed that the accuracy of the data was between 85 and 90%. It meant that between 10 to 15% of all information received was inaccurate or nonexistent.

A second great concern to the onshore users of AIS was the difference in the refresh and latency rates between coastal and satellite AIS. Coastal AIS operates in the same manner as the AIS communication between two vessels, which can be considered to be in real time. Satellite AIS has latency and refresh rate delays thus causing a discrepancy between shipping images from coastal AIS when compared to the shipping images from satellite AIS.

Once the euphoric joy of seeing global shipping for the first time wore off, users of the satellite service started to appreciate the challenges that they still faced to ensure its use was of benefit to their organizations and that they could use it with accuracy.

At the same time as the first satellite AIS signals were received, International Maritime Organization (IMO) mandated Long-Range Identification and Tracking (LRIT) were being implemented worldwide. LRIT is also based on a satellite service but uses a collection of worldwide databases shared by the members of the IMO that stores the collected data for distribution to various parties as required. Its normal collection rate of data is every six hours, though manually initiated polling can reduce this. There were those in the maritime community that considered satellite AIS to be a threat to LRIT, but it soon became apparent that satellite AIS complemented LRIT, and, as both services evolved, their use became equally imperative to those collecting shipping data.

It was obvious to the commercial suppliers, exactEarth and ORBCOMM, that there was a need for additional satellites and ground stations to improve the latency and refresh rates of the data being provided to users. The launch of additional satellites became imperative for both companies.

By the end of 2014, each company had a small constellation and were also operating a number of ground stations. As the satellite AIS service improved, so did the development of applications for satellite AIS.

Maritime Government Agencies

With the initial advent of AIS and LRIT, what became very apparent to maritime government agencies was that increasing the volume of inputs improved the quality of information about the world's shipping. For shipping control, navigational assistance, security, and other surveillance requirements, a combination of satellite radar surveillance, satellite optical monitoring, satellite infrared monitoring, LRIT and the satellite AIS combined with coastal radar, coastal AIS, and VTS capabilities provided an incredible and accurate source for the identification and control of shipping. This combination could be used for controlling fishing vessels, identifying human trafficking vessels, monitoring drug maritime supply lines, etc. Each individual service could not provide the necessary data to allow for such surveillance, but the integration of all services provided a very accurate picture of all shipping activities in the areas where they were monitored.

Environmental Monitoring

Again, a combination of optical satellites, radar satellites, and satellite AIS provided an accurate picture of shipping that was releasing hazardous waste in the oceans. This capability identified shipping within polluted areas that enabled follow-up testing and eventually fines for ship owners.

Commodity and Brokerage Services

For the commercial world, the ability to follow LNG, oil, and other fossil fuel vessels was of great importance to companies who set commodity pricing. The ability to know when ships were arriving in harbors assisted commodity and brokerage services to determine the availability of such commodities.

Search and Rescue

The availability of nearby vessels to provide assistance to a vessel in distress is of great importance. Quickly identifying nearby vessels and directing them to the vessel in distress can mean the difference between life and death for the crew and passengers if the disabled or floundering ship. Satellite AIS assisted in the rescue of a number of personnel who may have otherwise faced certain death because information on the location of nearby vessels was not readily available via other means.

Fisheries

The need to monitor illegal fishing has become more important with increased competition for maritime protein sources and the resulting extension of national economic zones. Fishing stocks require careful nurturing to ensure that they are replenished; such nurturing requires diligent observation of fishing vessel activities. Using a display polygon, government maritime observers can set alarms to identify fishing vessels that have strayed into restricted areas. The introduction of satellite AIS has aided the ability of governments to monitor fishing vessels and determine which are fishing illegally.

Limitations

Satellite AIS is a passive receiver of information sent from shipborne AIS transponders. If the information is inaccurate, then the information received by a satellite receiver is also inaccurate. While commercial satellite AIS operators can determine anomalies, such as erratic movements, changes of direction, the meeting of ships, and the cessation of AIS transmissions, they cannot determine a ship's location if the transponder is turned off and remains off. However, by using satellite radar combined with satellite optical imaging, such ships can be positioned and investigated.

In a bid to ensure that satellite AIS transmissions are accurate, the Australian Maritime Safety Agency (AMSA) has introduced a training program for technicians who install AIS transponders. This is to ensure that they understand the use of the transponders and that they are set up correctly. AMSA conducted a study that discovered that many transponders had never been correctly installed and the transmitted information was incorrect.

Today

With the launch of additional satellites equipped with AIS receivers, latency and refresh rates are now less than 60 minutes for most places around the world. The ability to determine a ship's name, position, course, and speed, plus other relevant information from an AIS transponder, is making the use of satellite AIS an essential requirement of any Global Maritime monitoring system. When combined with other satellite services, the ability to quickly identify and verify a ship, that only 15 years ago would be virtually invisible to the world, is a mandatory requirement for global shipping. Satellite AIS is here to stay and its use has become an important tool in the management and safety of ships at sea, and to promote legitimate global commerce.

SATELLITE AIS (S-AIS) CAPABILITIES NOW AND IN THE FUTURE

Chandler Smith, exactEarth-USA

Introduction

In the early 2000s, the International Maritime Organization required ships of greater than 300 gross tons to broadcast Automatic Identification System (AIS) messages with their identities, positions, speeds, headings, and other information. Initial attempts to detect AIS messages from space, or S-AIS, were hampered because multiple broadcasts at the same time and at the same radiofrequency (RF) created co-channel interference. The latest S-AIS systems must deal with co-channel interference, improve geographic coverage, and reduce delay from the time of broadcast until the delivery to the end user. This article addresses the current state-of-the-art of S-AIS from exactEarth Ltd.'s perspective.

exactEarth's S-AIS Constellation in 2015 and the Near Future

exactEarth's S-AIS system began operation mid-2010. Over the past five years, governments around the world have received exactEarth S-AIS data services, including Argentina, Australia, Brazil, Canada, Denmark, France, Germany, India, Japan, Peru, Singapore, South Africa, Spain, and the United Kingdom, among others. The U.S. Government began demonstration contracts in 2011, moving increasingly in the direction of operational use. U.S. Government agencies that have sponsored contracts for exactEarth S-AIS include the Office of the Undersecretary of Defense for Intelligence, the U.S. Navy, the U.S. Coast Guard, the Customs and Border Protection Agency, the Department of Energy, the National Oceanographic and Atmospheric Administration, the Environmental Protection Agency, and others. exactEarth maintains an uninterrupted archive dating back to 2010.

There are now seven exactEarth satellites in polar orbit, providing continuous global coverage. By special agreement, International Space Station S-AIS is available via exactEarth. In May 2015, Spain will launch a radar satellite with exactEarth receivers collecting AIS data to support correlation with radar imagery from any radar satellite in similar orbits. In mid-2015, an exactEarth satellite orbiting the equator will be the only commercial AIS satellite in such an orbit, providing further coverage improvements. Finally, after 2015, two additional exactEarth AIS enabled satellites will launch, providing additional system level resiliency and assured supply for Canada and the European Space Agency.

exactEarth S-AIS Performance Metrics

exactEarth's S-AIS performance metrics as of mid-2015 are shown below:

- Marine Mobile Service Identifiers (MMSIs) detected per day: ~63,400
- Messages Detected per day: ~7,600,000
- Messages per MMSI day: ~120
- The average revisit rate ranges from 42 minutes at 60 degrees latitude to 66 minutes at the equator.
- Maximum coverage gaps average from 96 minutes at 60 degrees latitude to 120 minutes at the equator.

These metrics are for S-AIS only and exclude terrestrial AIS (T-AIS) data. Each of these metrics is discussed in more detail below.

Detection of Maritime Mobile Service Identities (MMSIs). The number of MMSIs detected per day is a common metric; however, it does not reflect how frequently a vessel is detected during the day. For example, detecting a vessel once during 24 hours counts the same as 12 times, but 1 observation is of limited value for tracking that vessel compared to 12 observations. Maximizing the number of messages received per vessel is essential to understanding vessel movement. To do this means maximizing the detection messages, and thus MMSIs, on every individual satellite pass, i.e., single pass detection.

Detection of Messages. exactEarth accomplishes message detection both by decoding messages on orbit and then, after downlink, processing the RF signals further, which improves message detection in high co-channel interference regions. By maximizing the message detection during a single pass of a

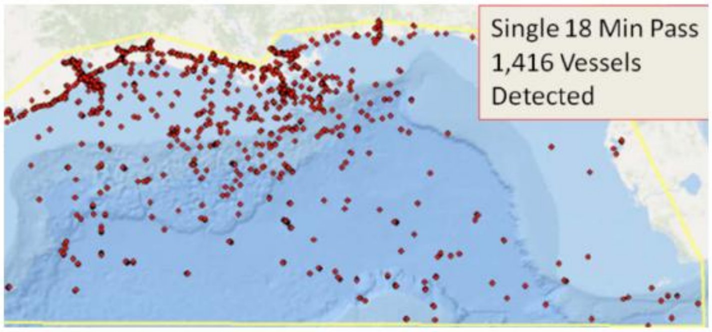


Figure 1. Single pass detection in the Gulf of Mexico.

satellite, there is no need to wait for multiple passes of lower detection satellites to occur to reach the same level of detection. For example, the ability of a single satellite pass to detect vessels in the northern half of the Gulf of Mexico is shown in Figure 1. The Gulf of Mexico was selected because it is one of the most congested vessel traffic regions in the world, with a high level of co-channel interference. The performance in Figure 1 is for a single satellite during a single pass, not multiple passes of a single satellite or multiple satellites passing in succession. No T-AIS data are included. As new high detection S-AIS assets are implemented, such performance metrics can be updated.

exactEarth's signal processing algorithms also improve detection of non-positional messages with valuable information such as vessel destination, estimated time of arrival, communication state messages that indicate the presence of other vessels, and application specific messages that include encoded information broadcast by the ship that could be valuable to the analyst.

Number of Messages per MMSI per day. By producing 100 messages per day per vessel as of early 2015, and nearly 120 messages per day by mid-2015, exactEarth S-AIS contributes to the fidelity of vessel tracks and supports detection of other kinds of messages that have valuable information.

IMO: 9004413
MMSI: 352281000
Call Sign: HPWI
Size: 109.0m x 20.0m
Latest Position at: 2015-02-01 18:25:07
Latitude: -16.221482
Longitude: 64.694190
Course: 51.9°
Speed: 14.8kn
Heading: 55.0°
Rate of Turn: -10.0° /min
Status: Under Way Using Engine
HOLSTEIN EXPRESS

Figure 2. Typical one day ship track.

A typical track is shown in Figure 2. As S-AIS detection and revisit rates improve, the density of points in tracks will increase, thus supporting improved track fidelity. The number of messages per day per vessel can be characterized as a frequency distribution, where some vessels may only be detected a few times or less, while others may be detected often. Smaller increments such as hourly can also be measured.

Revisit Rate. Revisit rate is critical to be able to observe vessels as continuously as possible. The exactEarth S-AIS constellation is designed to provide coverage approximately every hour at all latitudes. This means that strategically important regions such as the Arctic are covered as well as areas with maritime security issues such as the Gulf of Guinea, the Western Pacific, the mid-East, and the Gulf of Mexico/Caribbean.

Average Daily Maximum Coverage Gaps. While there may be multiple observations per day, typically they are not evenly distributed which results in variable gaps between periods of coverage. Minimal coverage gaps improve fidelity of vessel tracks used to tip and cue other sensors, to understand patterns of behavior, and to identify anomalous movements. exactEarth's S-AIS constellation is designed to keep the maximum coverage gaps to two hours or less at all latitudes on average.

Terrestrial AIS Data. Ships in port broadcast every few minutes as opposed to multiple times per minute while at sea. This means that when a satellite goes overhead, it is less likely to detect vessels in port than on the open sea. Thus, many end users opt to include terrestrial data to supplement satellite data. Figure 3 shows where T-AIS data (red) supplements S-AIS data (blue). With terrestrial receivers included, the number of vessels detected per day increases from 63,400 to approximately 130,000. In addition to S-AIS data, exactEarth offers end users the option of T-AIS data from 2,600 terrestrial receivers in the VesselTracker network. When comparing the performance of S-AIS systems, it is important to separate S-AIS and T-AIS data.

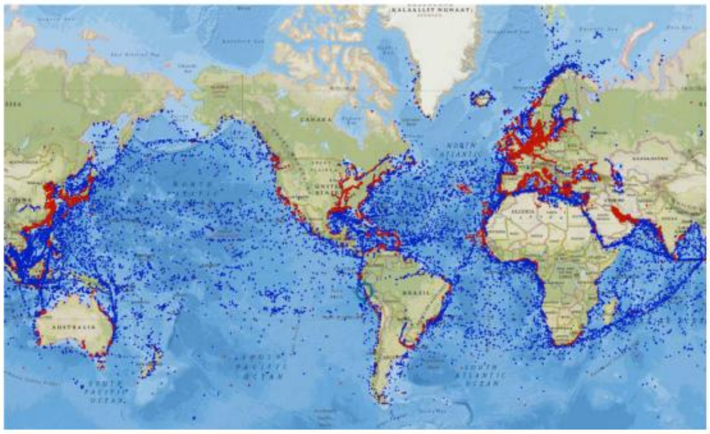


Figure 3. Terrestrial AIS (T-AIS) shown in red.

exactEarth S-AIS Ground Segment in 2015 and the Near Future

Once a satellite receives the AIS broadcasts, it downlinks the data to the next available ground station. The data then must be processed and disseminated. The performance of the downlink and data processing infrastructure impacts the timeliness and reliability of customer access to the data.

Ground Stations. Figure 4 depicts the exactEarth Ground Station Network, with current stations shaded

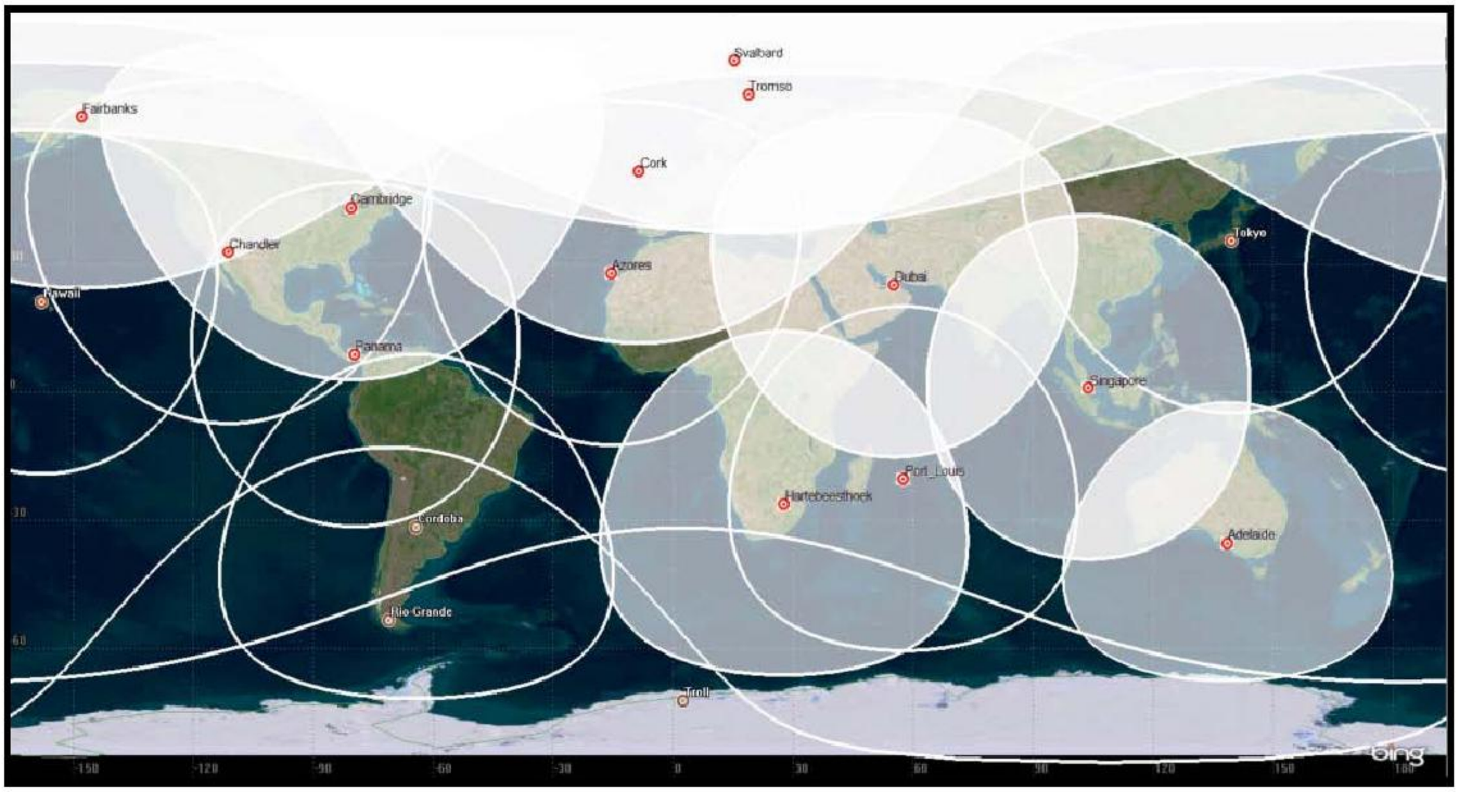


Figure 4. exactEarth's ground stations.

in and future stations shown in outline. In February 2015, there were 15 exactEarth ground stations in 11 locations, most in the northern hemisphere, indicated by shaded-in coverage areas. The two newest downlinks are at Troll, Antarctica, and Mauritius, providing improved latency and near-real-time downlinks for the Mediterranean, East Africa, and the Middle East. Future coverage areas are shown in outline, totaling 23 ground stations in 18 locations.

Data Processing Centers. All data is processed at a secure Bell Data Center in Toronto, Canada with fully dual-redundant processing and storage. Additional processing centers are being implemented at physically distinct locations in Canada and Europe to provide emergency back-up and assured supply for sponsors.

Latency. As ground stations and data processing centers are built out, the median delay between message broadcast and dissemination to end users will drop from 39 minutes to 15 minutes or less.

Summary

The exactEarth S-AIS system offers state-of-the art vessel tracking capability that is evolving steadily to meet government maritime domain awareness needs. Performance metrics for the S-AIS system are established and will be measured as system enhancements are implemented. In addition to live S-AIS data, exactEarth can supply terrestrial data and archive data dating back to 2010.

ENHANCING MARITIME SITUATIONAL AWARENESS THROUGH INFORMATION INTEROPERABILITY

Dino Lorenzini, PhD, SpaceQuest

Recently, four unlikely partners effectively teamed and formed a partnership to solve a long-standing global maritime problem. The four companies could not be more different; the problem could not be more difficult; and the results could not be more stunning. Who are they? What brought them together? And more importantly, how did they achieve such success? These questions deserve some explanation as we unfold this amazing maritime domain awareness case study.

The partners include four very different companies, all in some way interested in technology and in solving very hard global problems. First is SpaceQuest, an agile satellite manufacturing company headquartered in Fairfax, VA. SpaceQuest has built, tested, and launched their own low earth satellites for the last 20 years, including 8 AIS satellites that collect vessel location information continually from the open ocean. Second is a technical non-profit company called SkyTruth. Headquartered in West Virginia, SkyTruth made a name for themselves by using environmental data to prove the exact size of the September 2009 British Petroleum Oil spill from the Deepwater Horizon oil well in the Gulf of Mexico when no one else could. Third is an advanced big data analytics company called Analyze Corporation. With five fulltime employees, Analyze wields petabytes of data with the alacrity of a ballerina. Finally, there is the global behemoth, Google. This mega-billion dollar-a-year company has revolutionized the visualization of land-based navigation and insight with Google maps. They are now doing the same for the world's oceans.

It is actually the world's oceans that brought these four unlikely partners together. For their own reasons, they each are interested in solving one of the most difficult problems imaginable: global Illegal, Unregulated, and Unreported (IUU) fishing. This is a significant economic and environmental challenge for countries around the world. It is estimated that up to 40% of the fishing catch in certain parts of the world is unlawful or unregulated, resulting in approximately $10B to $20B in economic losses to legitimate fisheries and, more significantly, dangerously depleting international food stocks.

Maybe even more amazing than the fact that these companies willingly took on this challenge and are on a path to make a very significant contribution toward solving this menacing problem is that they can actually work together. The secret is that they have very effectively implemented a collaborative model of partnering.

This team defines collaboration as "the willingness to share information for a common objective to achieve a mutual benefit." With that in mind, each of the four companies is free to pursue their own equities while always committed to sharing to solve the problem at hand. Although it sounds simplistic, this approach has the ability to transcend historically parochial stovepipe teaming. Specifically, the collaborative process can be defined for this type of technology cooperation as beginning with data sharing, then analysis, then collaboration, and finally yielding insight.

Data sharing for this team comes from SpaceQuest. It willingly contributes its spaced-based AIS data (over 18,000,000 data records a day on more than 100,000 ships on the ocean) to get the analysis done. Analyze, a company of data scientists specializing in high-end behavioral and predicative data models, took the satellite data and developed a novel, reliable method for characterizing fishing behaviors among ships on the high seas based on geospatial position information reported through the AIS. Analyze shares the results with the rest of the partners. The team is not limited by storage and processing power. Google contributes through access to its cloud and hosting platforms, including WebGL visualization. This all goes into Google's ocean platform. Finally, the ability to collect, process, and display results in real time is necessary, but not sufficient. Insight and domain knowledge is required. SkyTruth uses its vast experience to provide understanding to the IUU problem and the meaning behind the behaviors being displayed in the data.

If this sounds too good to be true, look at some of the results of their work:

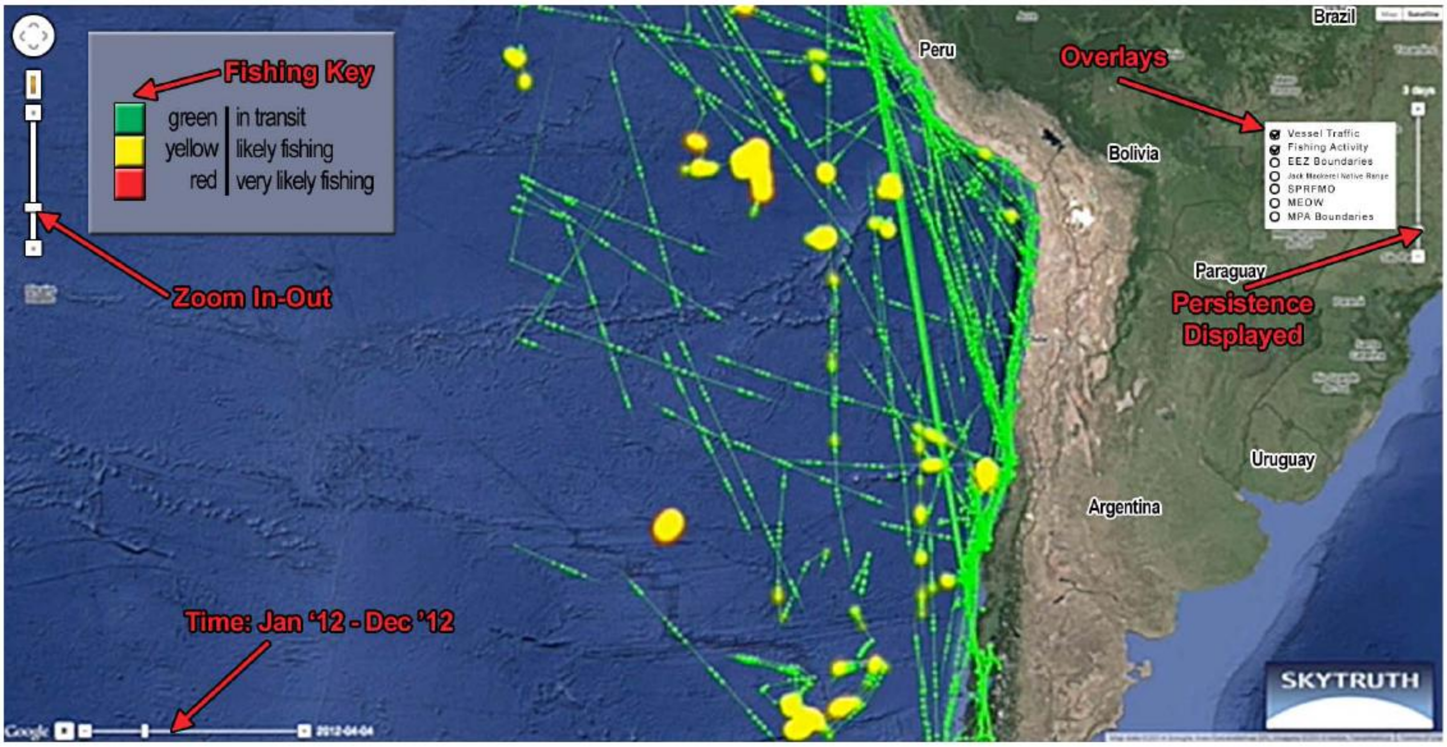


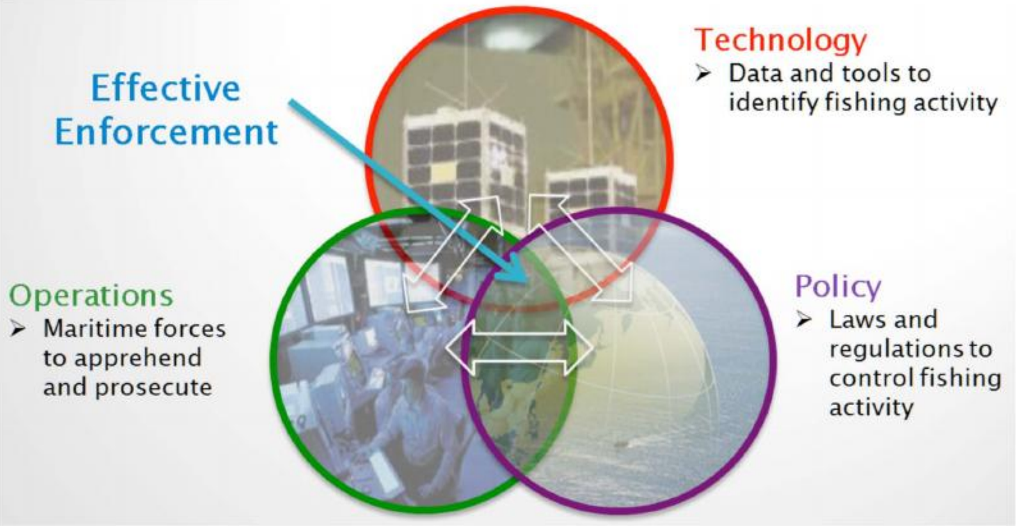
Figure 1. Illustration of SkyTruth Analysis

This is just the tip of the iceberg. The team knows there is a larger context of sharing and collaboration that needs to happen to make a final blow to IUU fishing with effective interdiction. The collaboration described is how things work on the technical side. There are still another two areas to integrate: policy and operations.

If this broader cooperation can be achieved, the value of the collaboration as a "whole" becomes greater than the "sum of the parts", expanding the overall solution space; leveraging individual skills and resources; gaining economies of scale; and building trust, understanding, and synergy. The key to making this work is "all must be willing to give, to get".

The technical method developed by these four partners, when integrated into a broader system of vessel monitoring, behavior detection and enforcement, has the potential to significantly improve interdiction of illegal fishing on the high seas. Even without the integrated system, the method offers scientists new ways to measure fishing capture yields, monitor the change of fishing behavior over time, and inform cause and effects of fishing on fish populations and their ecosystems.

By observing long-term vessel movement patterns of all the ships on the ocean, and employing a feature reduction and behavior classification-based machine learning approach, the method which Analyze implemented through a proprietary python



software program termed Mercury makes reliable determinations as to whether a ship is fishing as distinct from other maritime activities such as cargo transiting, passenger service, tug and rescue activity, or maritime law enforcement. Their approach relies on the semi-voluntary reporting of position information via the AIS, which is received via low earth orbit satellite and processed by Analyze. It does not depend, however, on a vessel's self-reporting of status or IMO classification as a fishing vessel. Only geometric patterns of motion are used to make a behavior determination.

SpaceQuest collects the data from AIS, which is a VHF-frequency automated aid to navigation required for vessels over 300 gross tons and used by many smaller vessels. Originally conceptualized for collision avoidance, AIS is used for a number of applications related to monitoring of ship movements. The system was originally designed to be operated via shore and vessel-based receivers, and an extensive network of coastal sensors has been developed for this purpose. The ease of reception of VHF frequencies by low earth orbit satellites, however, has led to the introduction of space-based AIS sensing. Space-based sensors have several advantages over land-based AIS receivers, most significantly the ability to detect AIS messages beyond 30 miles from shore-based sensors.

A spokesman for the Analyze Corporation commented, “We are excited about applying our expertise to help combat illegal fishing. This team project gave us the opportunity to bring a fresh perspective, be innovative, and ultimately let our algorithms speak for themselves. We appreciate working on these types of difficult problems because it's difficult for first movers to overshadow our data science techniques and technologies with less sophisticated models, and we couldn't have done it without the other three partners.”

SkyTruth is now working with Google to host AIS data and Analyze's algorithm in its cloud and make Big Query available to support an open system on the web that will enable global visibility into fishing on the open ocean.

The team continues to collaborate together and has plans for advancing what other vessel behaviors can be identified through motion analytics using the satellite AIS data. Insights will be pushed to operational elements for interdiction. Policy-makers are being engaged to improve AIS policies to increase the overall effectiveness of the technology. Watch for real time results displayed on Google Earth.

MARITIME AWARENESS AT REGIONAL AND GLOBAL SCALES

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Automatic ship reporting systems (mainly AIS and LRIT) can today provide rather complete coverage of all the larger (>300 GT) vessels. Coastal receivers linked in networks (e.g., Maritime Safety and Security Information System [MSSIS], SafeSeaNet) and a growing number of space-based receivers provide a truly global reach.

At JRC (the European Commission's Joint Research Centre), the so-called "Blue Hub" data fusion facility has been set up to serve as a maritime awareness R&D platform. One of its functionalities is to continuously ingest data from ship reporting systems (via Internet), store them in a (PostgreSQL) database, compile ship tracks based on Maritime Mobile Service Identity (MMSI) number, predict ship positions to the current time (to compensate for delays in downlinking satellite data), and display the resulting real-time Maritime Situational Picture (MSP) on a web browser. Historic data, including the collection of stored MSPs (at 15 minute intervals), are used to derive statistical distributions of ship density, as a function of season, ship type and/or ship behaviour (e.g., fishing). Also main ship routes are extracted, providing patterns of normality that allow for the flagging of anomalous behaviour.

The system has been trialed to produce MSPs during 6-month periods over ocean-basin wide areas in the Western Indian Ocean (2011-2012) and in the Gulf of Guinea / West Africa (2012-2013), ingesting and fusing data from up to eight AIS satellites (run by exactEarth, SpaceQuest, Orbcomm, LuxSpace, and the Norwegian government), the MSSIS network, and LRIT from ships of flags that use the EU-LRIT data centre (via European Maritime Safety Agency [EMSA]). Long-term ship tracking on a fully global scale is also done, on a subset of these data sources, with up to 50,000 ships tracked simultaneously.

Such maritime awareness is, in the Horn of Africa and the Gulf of Guinea regions, intended to support the capacity building of maritime authorities in Africa for counter-piracy and maritime security; activities that have been carried out under the "Piracy, Maritime Awareness and Risks" (PMAR) projects, in coordination with other counter-piracy activities of the international community.

Technically, the production of an MSP has some challenges related to errors in the data, update rate, and completeness. The availability of large amounts of data (e.g., 600,000 incoming AIS messages/day in March 2013 over the West Africa area) has allowed some analysis on these issues. The glaring occurrence of AIS positions on dry land already shows that errors do happen. Other indicators confirm this, such as improbable combinations of drift angle and speed, or messages with an invalid MMSI number that is only seen once. Comparison of error occurrences and error rates between different receivers shows that part of the errors is caused in reception, but part also in transmission. Individual receivers (satellites) display a range of sensitivities (number of messages, unique MMSI numbers received), but also a range in error rates. Individual ships display a wide range of detectability as evinced by their numbers of messages received per day.

Concerning completeness and the marginal value of additional receivers, we consider the area between -30 and 15 longitude and -10 and 30 latitude off West Africa which includes the Gulf of Guinea. The average of 2,090 unique MMSI numbers was seen per satellite per day in dynamic AIS messages during January 2013. This is an average over eight different single satellite receivers. When two satellites are used, i.e., doubling the number of receivers, the number of unique MMSIs detected on average increases to 2,327, i.e., by 11%. Adding a third satellite raises the number of MMSIs to 2,421, i.e., by 4%. Each additional satellite adds less, the 8th one adding only 0.5%, bringing the average total to 2,553. The added value of LRIT can likewise be quantified. On average, 381 different ships are seen daily in the area on LRIT (from "EU-Flagged" vessels only). Adding LRIT data to a single AIS satellite, 2,166 daily unique MMSIs are seen on average, an increase of 4% over single satellite AIS only. LRIT plus 8 AIS satellites gives 2,575 MMSIs, 1% more than 8 AIS satellites only. Even if this is only a small number, those 22 ships (daily on average) would never have been seen without LRIT. Finally, MSSIS adds 14% unique MMSIs to one AIS satellite and 4% to 8 AIS satellites. These numbers are of course much dependent on the coastal MSSIS coverage, which is not so high in that region.

For ship tracking, the update rate of the position messages is important, which for satellites is constrained by their orbital nature. We give some numbers from one week in March 2013 over the same area (Figure 1). Using AIS data from a single provider (two satellites), the average maximum daily

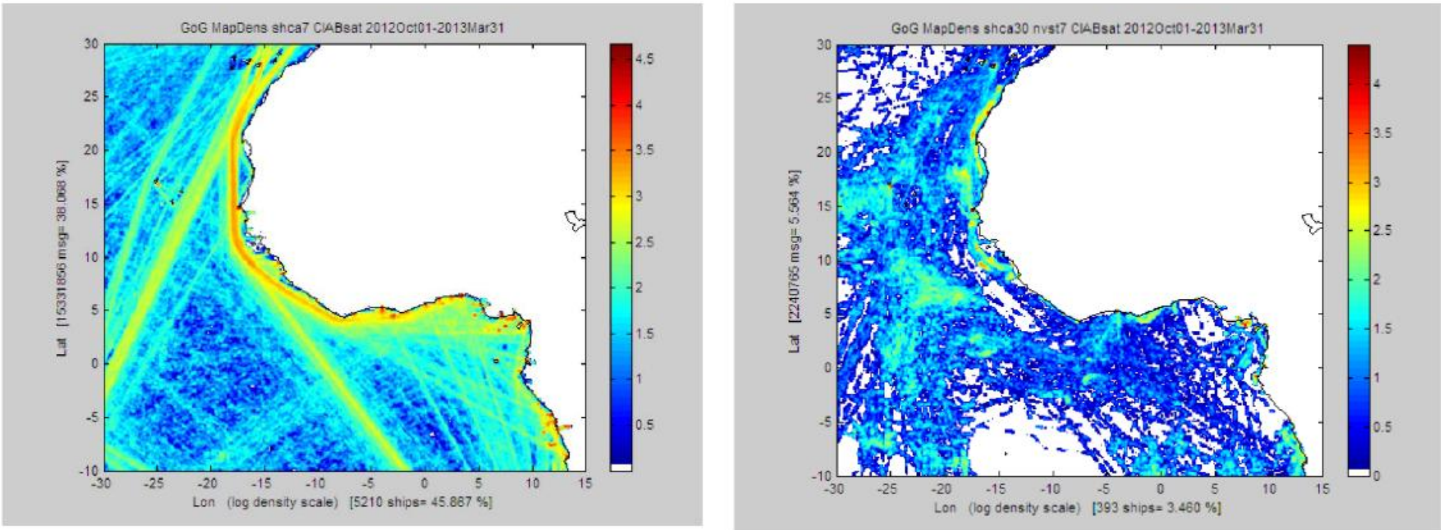

Figure 1. Ship distributions combined over 6 months (Oct 2012 - Mar 2013). Left, Cargo ships (AIS ship/cargo type = 70-79). Right, Fishing ships (AIS ship/cargo type = 30 or navstat =7).

time gap per ship is almost 11 hours. Using data from all three satellite providers (eight satellites), this gap is reduced to just over 6 hours. Adding MSSIS, it is reduced further to 4.4 hours. So even if many additional sensors have a low extra impact on the number of different ships seen, they do help in tracking them better. Combining satellites with polar and equatorial orbits prevents all satellites from passing over at the same time each day (as sun-synchronous orbits remain popular). The regular 6-hour interval for the LRIT messages is also helpful to fill up larger time gaps left open during the day as a result of AIS satellite orbits, being able to reduce the average maximum daily time gap per ship, as obtained from eight satellites, by another 0.5 hour.

The ship reporting data also includes ship type. Again referring to the same area of interest off West Africa, it is found that during the full 6 months of the trial period, on average 5% of the ships seen were fishing ships; 8% passenger ships; 20% tankers; and 34% cargo ships. Monthly spatial distributions show that the cargo ships and tankers keep following the same routes, but that the activity of the fishing ships, as well as of Class B AIS messages (8%) presumably mostly coming from yachts, changes much from month to month.

Finally, the continuously available MSP based on the ship reporting data can be complemented with samplings of non-cooperative ships as detected in satellite SAR images (Synthetic Aperture Radar from the Cosmo-SkyMed, TerraSAR-X and Radarsat-2 systems). Both off East Africa and in the Gulf of Guinea, this shows that only about 50% of the ships detected in satellite SAR images are reporting in AIS or LRIT.

Current work includes a 1-year surveillance campaign off East Africa, and special attention to using Sentinel-1, the new satellite SAR of the EU's Copernicus Earth Observation program.

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