Marine Ship Automatic Identification System (AIS) for Enhanced Coastal Security Capabilities: An Oil Spill Tracking Application

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***Abstract*-National and international trade via shipping is already significant, and expected to continue increasing rapidly over the next decade. Both more ships and larger ships will contribute to this trade, including ships from countries with less rigorous shipping maintenance and inspection standards than the United States, and less strict pollution monitoring regulations. Changes in ship traffic management protocols have been implemented in recent years in the U.S. to minimize damage to coastlines, particularly near sensitive or protected marine environments. For example, to reduce risk to coastal resources off central California, shipping lanes for larger vessels were moved further offshore to allow for additional response time in case of accidents before such vessels might drift into coastal areas. Similarly, ships are now routed via specific approach channels when entering Boston Harbor to reduce impacts within adjacent National Marine Sanctuary resources. Several recent high profile cases have occurred where 'mystery' oil spills were found near shipping channels, but no vessel could be readily identified as their source. These incidents lead to extensive and expensive efforts to attempt to identify the ships responsible. As time passes in responding to these incidents, the likelihood of confirming the identity of the ships diminishes. Unfortunately, reports of vessels engaging in illegal oily waste discharge to reduce fees for offloading the waste in port are ongoing. We here discuss use of improved capabilities of near-continuous real-time position location monitoring of shipping traffic using marine Automatic Identification Systems (AIS) for ships that would facilitate identification of ships responsible for illegal oily waste discharge. The next phase of the National AIS, N-AIS Increment 2, can supply additional spatial coverage not currently included in the N-AIS Increment 1, which can provide an enhanced capability for monitoring shipping and improving management of coastal ship traffic and response to pollution incidents. These methods will not only improve response time, but reduce cost of response as well.**

I. Introduction

A. Shipping Trends

Shipping accounts for roughly 90% of international trade transport, amounting to approximately 5% of total world trade (UN Conference on Trade and Development [UNCTAD], see: [1]). The cost and also carbon footprint of shipping as a means of transport is far lower than land transport methods, and shipping continues to empower less developed countries with a cost-effective means of improving their economies. While increased fuel prices may limit the increase in shipping seen in recent years, in general shipping is expected to continue increasing in the near future. Independent of the efficiency or ethics of shipping of goods and raw materials for commerce, approximately 60% of world oil and fuel supplies are delivered by shipping, and the maritime delivery of fuels is expected to continue to increase into the future as liquid natural gas carriers become more common and new maritime oil producing reserves are tapped.

To obtain a perspective on shipping and its potential contribution to marine oil pollution, it is instructive to provide a snapshot of how many and what types of shipping vessels are in operation. The numbers of world ships on the seas as of January 2005 were: 46,222 total ships, of which general cargo ships comprised 18,150, tankers 11,356, bulk carriers 6,139, passenger ships 5,679, container ships 3,165, and other ships 1,733 vessels [1]. For clarification, bulk carriers are considered distinguished from general cargo ships in that their cargo is loaded into holds en masse, typically being either solids such as grain, concrete, ore, etc., or non-petroleum liquids. Bulk carriers are further subdivided into three types: "Panamax" those designed to be at or near the maximum size to go through the Panama Canal (roughly 50,000-80,000 dead weight tons); "Capesize," those too big to go through the Panama Canal and forced to go around Cape Horn; and, "handy-sized" those smaller than Panamax-sized vessels. The contribution of bulk carriers to maritime accidents exceeds those of most other types of ships in both frequency and severity due to the nature of the cargo: raw materials for commerce that are typically very heavy and contained in relatively few holds with large cargo hatches [1]. The dominance of bulk cargo ships in maritime trade is currently being challenged by an increase in the number of container ships, which has been steadily increasing, and is expected to continue to do so, along with an increased contribution of container ships to maritime accidents.

To gain a perspective on the rate of increase in shipping in the future, shipping totals, cited as "tonne-miles" of cargo carried rather than by reference to the number of vessels or transits involved, can be examined. In 2006 global shipping was accounted as 30,686 billon tonne-miles, and was projected to grow in 2008 to 33,000 billion tonne-miles, more than a 3% per year increase. Most analysts expect shipping

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trends to increase at similar per year rates for at least the next several years independent of possible price increases in fuel.

From the global perspective, we can look more specifically at areas where shipping is particularly expected to increase, and how these increases relate to environmentally sensitive and economically important regions of the ocean. The MARPOL (Marine Pollution) Convention is a combination of two treaties put forward in 1973 and 1978, largely in response to several catastrophic oil spills. This Convention, sometimes referred to as MARPOL 73/78, governs international shipping regulations with regard to marine pollution, and has been updated with two mandatory Annexes, and four voluntary Annexes. Annex I is mandatory and deals specifically with oil pollution. A new version of Annex I came into force at the beginning of 2007, including specifications requiring all oil tankers be double hulled by 2010, as well as detailing specifics for oil and bilge water handling equipment, oil hold washing protocols, and a 15 part per million discharge limit of oil content in bilge water.

MARPOL Annex II, also mandatory, similarly was revised and became effective in January 2007, and deals with ‘noxious liquid substance’ pollution, that is anything not meeting the definition of oil per se, such as hydraulic lube oil, other solvents or liquid chemicals. Annex II now classes all such liquid materials in three internationally accepted classes based on risk to the marine environment: Category X, the most hazardous, Category Y, of intermediate risk, and Category Z, non-oil liquid pollutants presenting a minor hazard to the marine environment, for example vegetable oils. The four other voluntary MARPOL Annexes deal with hazardous materials such as explosives (Annex III); sewage (Annex IV); garbage (Annex V); and air pollution (Annex IV), some of which may also be monitored using AIS methods. Discussions here focus on AIS use in relation to oil pollution.

With the advent of the new MARPOL Annex I and II regulations, we may consider where and how these regulations are likely to affect marine pollution in relation to increased shipping and areas of environmental sensitivity. It was necessary to review above what MARPOL is because the MARPOL regulations from the beginning in 1973 include specification of “Special Areas” considered particularly vulnerable to oil pollution specifically, in which oil discharge of any kind was to be completely prohibited. Even in 1973, long before MARPOL was internationally accepted, these areas included the Mediterranean, Black, Baltic and Red Seas, and some other areas, since supplemented to include waters around Antarctica, Northeastern Europe, and the Gulf of Oman, in which locations ships are required to retain all oily wastes aboard until docking, and must have oily water separating equipment and oil discharge monitoring equipment for all bilge discharges to verify compliance with the 15ppm oil content of discharged bilge water. The quite slow rate of ratification of these mandatory MARPOL Annexes by even the major nations involved in shipping, only now fully in effect after many years of discussion, and reluctance of all shipping nations to ratify and abide by these and the voluntary MARPOL Annexes mentioned above, suggest continued oil and oily waste disposal at sea pose an ongoing threat to the marine environment. This is of particular concern when viewed in terms of areas where global shipping may well increase in proximity to marine protected areas.

One source of increase in shipping specifically associated with potential oil pollution is in development of new natural gas and oil reserves. The advent of liquid natural gas (LNG) carriers has been quite rapid, and the establishment of ports and shipping systems to handle such carriers is still very much in development. More than thirty LNG port locations have been proposed for the United States, but to date there is little agreement on which sites will ultimately be developed. There is a great deal of maritime activity simply involved in the construction of facilities to handle LNG carriers, quite independent of the potential pollution risk from these vessels themselves. Areas such as the Stockman oil and natural gas fields east of Novaya Zemlya cannot be serviced by land-based facilities, and so not only the exploration and infrastructure for extracting oil and gas from such fields involves ships, but even the usual processing must be done from ships. The development of the Stockman fields is underway and will involve hundreds of ships operating in sometimes ice-infested waters in the high arctic away from more open coastal waters into areas where shipping has historically been much more limited [2], [3].

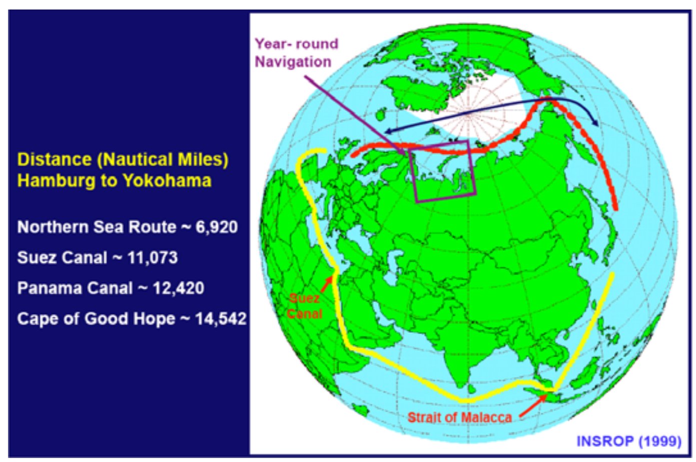

Figure 1. Existing shipping routes between Asia and Europe, comparing of arctic and non-arctic ocean routes [4].

The trend for additional international shipping in an ice-diminished arctic has been the focus of considerable recent discussion. In fact a trans-arctic route between Northern Europe and China cuts nearly 5,000 miles off the usual shipping routes via the Suez Canal, and regardless of ice conditions, the savings in fuel cost and time are making the route more attractive (Figure 1). New icebreaking cargo ships have already been constructed and transited the so-called Northern Sea Route along the Russian north coast. In the future these ships are expected to venture into the international waters of the so-called Trans-Arctic route directly across the Arctic Ocean near the North Pole, where neither escort now pilotage fees are required, and shipping distances and times are shortest leading to significant savings [4]. An IMO Arctic Marine Shipping Assessment (AMSA) is currently underway to assess the likely levels of ship traffic in the Arctic Ocean as additional icebreaking cargo vessels, already under construction, come into service, and other areas bordering the Arctic Ocean are developed.

The Trans-Arctic route is not the only arctic area subject to increased shipping and risk of oil spills. Offshore oil leasing of sites for oil and gas development in the Beaufort and Chukchi Seas are planned by the U.S. Minerals Management Service over the next several years. Potential exploration, not to mention exploitation, of any resources in these areas is expected to involve several hundred ships a year [5], in areas where ice, however diminished in summer, is still a risk a good portion of the year. Since the period of development of oil operations near Prudhoe Bay several decades ago, the Chukchi and Beaufort Seas have not been subject to a great deal of shipping activity, so this would constitute a significant increase in the risk of oil pollution in the area. There is also the potential for oil pipelines in the Canadian arctic that would increase shipping just east of the Alaskan Beaufort seacoast [6]. Beyond the potential for oil development related shipping increases along the Alaskan arctic coasts, there is a definite increase likely in shipping as a result of new mining operations in Canada, both for diamonds, uranium and other minerals [7], [8], [9]. Access to existing diamond mines by overland roads has been increasingly in question due to melting of permafrost and reduced winter ice thickness on frozen waterways used as highways during the winter [10], [11]. Additionally there are plans already underway for the construction of new diamond and other mines in the western Canadian arctic that will have to be supplied by ports, with ship traffic for the raw materials produced going around Alaska, through the Bering Straits to Asia [12], [13].

The threat of oil spills or illegal dumping in the Beaufort and Chukchi Seas in the Alaskan arctic represents an increased risk beyond the shipping activity at the time of the installation of the Prudhoe Bay oil project where the product was ultimately taken over land. The new ship traffic will not only have to pass through the Bering Straits routinely to reach Pacific ports and Asian markets, it must also transit through the Bering Sea, home to a large and economically significant U.S. commercial fishing industry. Climate changes are already affecting the Bering Sea fishery, and the outlook of these fisheries for the future is currently unclear [14]. Moreover, the Bering Sea is the location of reserves for endangered marine mammals, including the Stellar Sea Lion, whose population has been in rapid decline for reasons that remain unclear [15]. Additional oil pollution would be a potentially significant additional stress to both marine mammals and the valuable fishery as well.

In addition to increased ship traffic through the Bering Straits from the Chukchi Sea, there is some indication that shipping routes from the North Pacific may be directed increasingly to the north in order to better take advantage of Great Circle routes that save on time and mileage. Figure 2 shows how changes in shipping routes may increase shipping traffic through Unimak Pass in the Aleutian Island Chain to reach Asian ports more quickly from the U.S. west coast. Many U.S. west coast ports are expanding to accommodate increased ship trade. Ports like Anchorage, which handles 80% of maritime shipping for Alaska, have expansion projects underway that will triple their capacity [16].

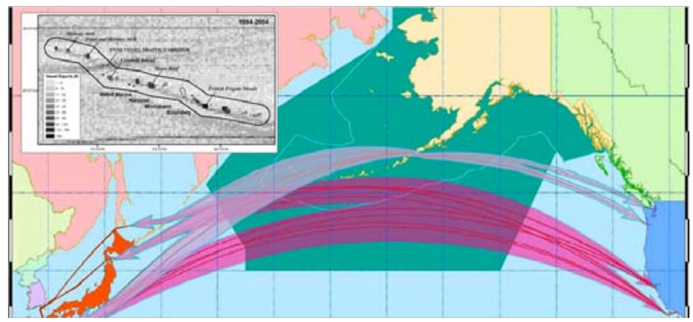

Figure 2. Shipping routes in the North Pacific via Great Circle Routes may in future move closer to the Aleutian Islands and increase traffic through the Aleutians at Unimak Pass (from [17]). Inset: Under conditions of inclement weather, vessel traffic moves south, some vessels transiting through the Northwestern Hawaiian Islands Marine National Monument (from [18]).

Shipping increases between U.S. west coast ports and Asia may take the routes shown in Figure 2 when weather conditions permit, but in the case of winter storms, this traffic moves further south. Ship traffic through the Northwestern Hawaiian Islands (NWHI) National Monument has already been shown to be increased seasonally and during bad weather to the north, with ship transits sometimes migrating so far south as to pass most typically between Pearl and Hermes Atoll and Lisianski Island [18]. Such ship traffic poses a number of risks for the delicate NWHI marine ecosystem, which include the severely endangered Hawaiian Monk Seal, endangered endemic bird species, as well as large seabird populations, and of course coral reefs. Nor is the threat of increased shipping and possible oil pollution limited to remote islands reserves in the mid-Pacific. As shown in Figure 3, the Gulf of the Farallones National Marine Sanctuary lies just beyond San Francisco Bay, a site of very extensive shipping activity (c.f. [19]). As elsewhere, shipping to San Francisco is sharply increasing: by volume, bulk cargo shipping in the first half of 2006 to San Francisco ports increased 28% over the same period in 2005 [20].

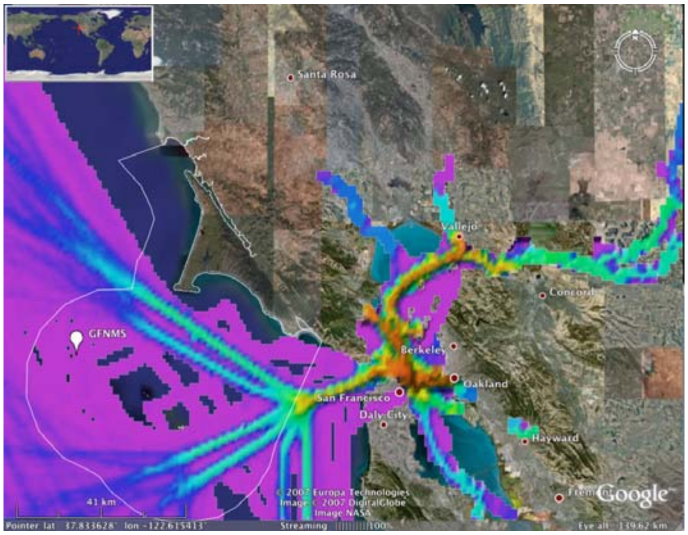

Figure 3. Ship traffic entering San Francisco Bay, also showing boundaries of the Gulf of the Farallones National Marine Sanctuary (GFNMS). Red through yellow colors show the regions with the largest numbers of ship transits. Blue and Magenta regions are areas with fewer transits. Data was gridded to 0.5 nautical mile cells. Ship tracks over land are an artifact of positional reporting en route in to port and then only once at the dock.

B. Oil Spill Trends

In relation to use of AIS technology to minimize maritime oil pollution, current maritime oil spills fall primarily into three basic categories: oil spills due to maritime accidents; oil spilled in port, harbor or waterway incidents; and, oil or oily wastes illegally dumped at sea, including illegal discharge of oily bilge or ballast waters. Oil spills due to accidents are considered to be something that cannot be eliminated: shipping accidents will continue to occur. The International Maritime Organization (IMO) has been working for years to reduce the rate of maritime accidents, and the number of accidents as a percentage of shipping has steadily declined from a maximum in the late 1970's of more than 0.6% to a level now roughly 0.1% [1]. The improvement in shipping practices, particularly of oil tankers is reflected in the reduction in numbers of oil spills over 700 tons: 24 in 1974, but only 4 in 2004 [1]. Oil spills due to high seas maritime accidents occur for a variety of reasons, including bad weather, mechanical failures, and human error. These accidents are considered to have the greatest potential effect in terms of both loss of human life and catastrophic oil spills, which is why they remain a focus of concern for the IMO and national governmental agencies charged with response.

AIS systems have a potential capability to reduce the occurrence of catastrophic shipping accidents simply by providing updated positional information that can perhaps minimize the effects of human error. Likewise, AIS systems can shorten the response time by agencies charged with responding to accidents by providing them near-real time situational information. When a ship goes aground, real-time availability of its positional information to response agencies can almost immediately alert them that response actions should be initiated. This is important, as studies have shown that response time to oil spills can be critical. Burning of oil spilled into the sea is considered to have the least effect on the marine environment, but if the oil is diluted more than about 50% with seawater, this option is no longer available [21]. Dilution of oil spilled into the sea to levels at which burning is no longer possible can be typically considered to occur within a period of roughly eight hours or less, so any ability of AIS to hasten response time to catastrophic maritime oil spills in particular is critically important.

The second major category of oil spill may be considered incidents within ports, harbors and waterways. There are many causes of these types of spills, including failures of equipment during fuel transfer operations, numerous incidences of grounding or sinking of both large and small vessels as a result of any number of causes, and not infrequently vessel collisions with other ships or allisions docks. Captains of the Port are usually rapidly aware of such problems as a part of their normal monitoring of shipping traffic, but here again AIS systems could reduce the time to awareness and response to such oil spills or potential oil spills in the case of sunken vessels.

The final category of oil spilled into the marine environment is oil illegally dumped or discharged. The amount of oil entering the marine environment in this manner does not have the catastrophic effects of an oil tanker breaking up on a coast in bad weather, and was thus not initially the highest priority to address by the IMO and other organizations concerned with marine pollution. However illegal high seas oil discharges have increasingly become a cause for concern, as this is a type of marine pollution that can and should be significantly reduced. Internationally, this has become a more common subject of prosecution [22]. The focus of this paper is to consider how application of AIS technology can assist in reducing this type of marine oil pollution.

C. Case Studies

It is instructive to take a look at a few recent incidences of oil spilled in U.S. waters, which demonstrate how an AIS-based detection and response system could facilitate the reduction of illegal discharge of oil or oily wastes. Several examples are provided here. The first example is one in which the ship owners and master directed the crew of the Greek vessel M/V KATERINA to discharge very large quantities of oily waste and oily bilge water and sludge at sea using specially installed pipes, which they were careful to have removed and hidden before entering port where they might be detected in the course of possible United States Coast Guard (USCG) vessel inspections. These procedures might have worked were it not for the fact that when inspected by the Coast Guard, four of the crew when questioned blew the whistle on their employer's illegal practice. This led to the crew being awarded $250,000 in bounty payments under the Act to Prevent Pollution from Ships law, and the imprisonment of the Captain, First and Second Engineers for eight months [23]. However, in the case of many ships in operation even when inspected by the Coast Guard, language barriers and crew intimidation may prevent such whistle-blowing, and the case serves to emphasize the direct instructions from the ship owner for this practice as being routine in too many instances. Characteristically in this case, as in many others, the discharge of the illegal oily wastes was undertaken outside the three mile limit of near-coastal waters, but within the 200 nautical mile U.S. Territorial Sea, in proximity sufficient to impact National Marine Sanctuaries and important fishing areas.

Two other recent oil spill cases involve oily waste discharge in the Bering Sea and around the Northwestern Hawaiian Islands. Ships from international fleets routinely fish along the U.S.-Russian Maritime Boundary Line (MBL) in the Bering Sea, composed typically of ships from these two countries, but at times including vessels of other nationalities. Winds and currents can easily move oil released at sea from the Russian side of the MBL into U.S. waters. In the summer of 2007 six vessels were seen to be near oily waste clearly dumped at sea, but fog and poor visibility precluded the positive identification of the ships by surveillance aircraft, and such illegal discharge could not be further investigated. Similarly around the Northwestern Hawaiian Islands in the spring of 2007 tar balls from oily waste illegally dumped at sea began to wash up along the coasts of these islands. There was no way for the source vessels for this oily waste to be determined.

Another case study in maritime oil pollution took place off the central California coast in November 2001 when considerable numbers of oiled seabirds began showing up on beaches. A search was made for ships transiting the area that could have released the oil involved. No obvious candidates appeared likely. After much time, effort, and damage to wildlife the source of the oil was determined to be due to a storm around this time that is presumed to have affected the hull of the vessel JACOB LUCKENBACH that had sunk near the Gulf of the Farallones National Marine Sanctuary in 1953. Subsequently operations were completed to remove more than 30,000 barrels of oil from the sunken vessel. This example serves as a reminder that not all maritime oil pollution is from current ship traffic, and indeed there are many sunken ships worldwide gradually rusting away with oil still in their hulls that may yet be released. Clearly the availability of an AIS system would have greatly reduced the time and manpower it took to finally locate the source of this pollution.

Finally, not all oil found at sea is from shipping: natural seeps and events also occur. One of the authors of this paper detected oil in the middle of the Sargasso Sea in an area little transited by any ships, which turned out to be the result of a submarine earthquake off the Lesser Antilles. The estimated volume of oil released into the sea during this event was more than all the ship-related oil spills worldwide that year [24]. AIS can assist in distinguishing natural event or sunken vessel oil releases from probable current ship-related incidents.

II. Methods for Using AIS for Spill Tracking

A. *AIS Development*

The maritime VHF Automatic Identification System (AIS) was created in the 1990's primarily to provide an aid in safety of navigation [25]. AIS is intended to operate independently of the vessel crew and additionally provide monitoring and tracking information to shore based stations [26]. These messages are sent using several variations of Time Division Multiple Access (TMDA) to interleave traffic from multiple vessels and base stations using two channels 161.975 MHz (Channel A) and 162.025 MHz (Channel B). By using these VHF frequencies, transmissions are primarily limited to line of sight communication with typical receive distances of roughly 30 nautical miles.

Complete deployment of AIS to Safety Of Life At Sea (SOLAS) class vessels was required by December 2004 [26]. Vessels equipped with AIS units automatically broadcast two primary message types. The most important message is a position report that includes the ship's "User ID" (the MMSI or Maritime Mobile Service Identity) for identification, the position from the ship's GPS, speed over ground, course over ground, rate of turn, and several additional parameters. The position updates range from every two seconds to every three minutes depending on vessel speed. The second key message is a ship and cargo data report. This message contains the name, call sign, type of ship and cargo, estimated time of arrival (ETA), size of ship, draft, and destination. Much of the information in the ship data message is entered by hand and as such care must be taken when relying on information that may be incorrectly entered or not updated.

In the last several years, a number of AIS receive networks have been created to collect AIS message traffic for large regions of the world. In 2002 the Maritime Transportation Security Act (MTSA) was passed by the U.S. Congress instructing the U.S. Coast Guard "to collect, integrate and analyze information concerning vessels operating on or bound for waters subject to the jurisdiction of the United States," for which AIS was considered a key component. The goals of the MTSA program are specifically to improve maritime security, marine and navigational safety, search and rescue operational capabilities, and environmental protection. The MTSA also called for two-way maritime data communications using AIS, which has the capability of allowing vessels at sea with AIS that are operating in proximity to create a virtual network, forwarding information from each other along to shore stations, and carrying information from the shore to ships at sea beyond normal AIS range.

The U.S. National-AIS (N-AIS) is being developed as a system that is to be deployed in three Increments. The Increment 1 research version of the N-AIS is currently operational. The goal of the N-AIS system is to create a so-called Common Maritime Operational Picture (COP). The N-AIS information will be transmitted to a National Vessel

Movement Center and a Maritime Intelligence Fusion Center (MFIC) that coordinates input for a Maritime Global Awareness Network (MAGNet) for use by the U.S., allowing information to be shared with other countries in the interests of maritime safety and security. If illegal actions by ships are documented or suspected, the MAGNet data would be used as input for the Marine Information Safety and Law Enforcement System (MISLE) used by the Coast Guard and other maritime safety and security agencies for law enforcement actions.

The current N-AIS system consists of receivers on shore-based towers with a few offshore buoys and oil platforms to extend coverage. Coverage is initially intended around ports and harbors within the 12 nautical mile Territorial Sea of the U.S.. The SAFE Port Act (H.R. 4954), passed in by Congress in 2007, includes provisions to improve and extend AIS coastal coverage and permit long-range vessel tracking. N-AIS Increment 1 does not have complete coverage of U.S. Territorial Waters, but Increment 2 will provide more complete coverage of coastal waters with a goal of extending AIS range to 50 nautical miles offshore. N-AIS Increment 2 will also provide the USCG the ability to transmit messages to individual vessels or all vessels in a region of interest. Increment 2 is currently in the bidding process and will begin development in 2008.

N-AIS Increment 3 adds NOAA buoys and satellite receivers to cover areas farther from coastlines with a goal of extending coverage throughout the 200 nautical mile U.S. Exclusive Economic Zone. The goal of buoy and satellite inclusion into AIS systems is to extend ship tracking capabilities to 2000 nautical miles offshore into international waters of the high seas. Satellites are expected to work well in regions of low densities of ship traffic in the open ocean and the polar seas. The U.S. Department of Defense launched TACSAT-2 in December 2006, which permitted the first demonstration of satellite AIS capabilities with twice daily data downloads. Other AIS satellites are being planned by ORBCOMM and the Norwegian firm Kongsberg. The Norwegian AIS effort is a joint undertaking with the Canadians, and this satellite, planned for launch in 2009, is intended to permit AIS data download capabilities much more frequently than the twice a day initial success shown with TACSAT-2, to permit improved ship tracking capabilities on the high seas.

While underway at sea, vessels typically broadcast AIS position messages every 2 or 6 seconds depending on the vessel speed (Tables I and II; Tables 1a,b in [25]). Under the presently envisaged plan, the N-AIS stations will forward a subset of received messages from AIS based on vessel distance offshore (Table III). There are both “threshold” (i.e. required) and “objective” (i.e. planned or intended) data transmission frequencies. Five zones are relevant in terms of frequency of AIS data transmissions.

TABLE I

AIS CLASS A BROADCAST INTERVALS

Ship’s velocity/status	Reporting Interval
Anchored	3 min
Anchored moving >3knots	10s
0-14 knots	10s
0-14 knots and changing course	3 1/3s
14-23 knots	6 s
>14 knots changing course or >23 knots	2s

TABLE II

AIS CLASS B BROADCAST INTERVALS

Ship’s velocity/status	Reporting Interval
< 2 knots	3 min
2-14 knots	30s
14-23 knots	15s
>23 knots	5s

TABLE III

N-AIS COVERAGE REQUIREMENTS

Coverage Area	Threshold (1 message per/every)	Objective (1 message per/every)
Ports	1 minute	15 seconds
< 24 nm	5 minutes	1 minute
24-50 nm	2 hours	5 minutes
50-300 nm	2 hours	1 hour
300-2000 nm	4 hours	1 hour

Within the overall N-AIS architecture described above, there are many regional AIS receive projects underway or planned intended to extend links beyond simply government agencies. For example, the Alaska Secure Passive AIS (SPAIS) uses AIS receivers in Alaskan major port data centers operated by the USCG receive AIS information and distribute positional data to key stakeholders in a secure manner in order to facilitate early response in case of emergency situations. Similarly, the U.S. Department of Transportation (DOT) Marine Safety and Security Information System (MSSIS) program is being developed as an Internet-based, unclassified but password protected means of sharing data on vessel movements internationally, and has begun a demonstration project with European countries. The data is carried using Secure Socket Layer methods for security on the Internet, and allows ship positions to be displayed either on electronic raster charts commonly used on ships, or on Google Earth geospatial mapping applications. The software is being provided for free by the U.S. DOT. Other federal agencies are also participating in development of the N-AIS program: most notably the National Oceanic and Atmospheric Administration (NOAA) is deploying AIS systems on various buoys they maintain as part of the National Data Buoy system. These buoy deployments are important N-AIS components in helping extend the range of AIS offshore. The various programs underway as part of N-AIS can be tracked on a webpage, http://www.naisproject.net. AIS is currently required only on relatively large vessels, the specifics of which can be found at http://www.navcen.uscg.gov/enav/ais. For reasons of national security and safety, there are plans to extend the requirements for AIS systems to fishing and small passenger vessels in the future. A proposed rule in relation to AIS requirements for smaller vessels is intended release and comments some time in 2008. Additionally, when the USCG approves AIS Class B transponders for use, many small vessels may adopt these smaller units that broadcast less frequently than the SOLAS Class A transponders.

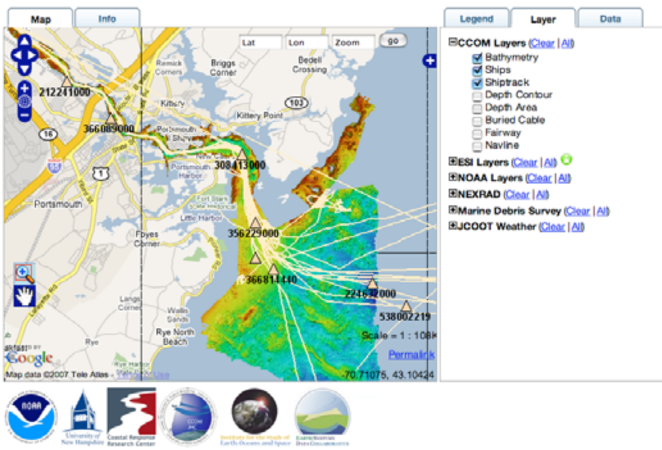

Figure 4. Portsmouth Harbor Response Initiative prototype web-based Geographic Information System (GIS) application using OpenLayers, MapServer, and PostGIS. The yellow lines are interpolated ship tracks and the yellow triangles are the last known position of a ship and the ship MMSI identifier. Image courtesy R. Braswell (UNH), M. Jacobi (NOAA), and K. Schwehr.

B. AIS Use for Oil Spills

The ability to receive AIS messages for a wide coverage area is leading to the use of AIS for a range of coastal and ocean management tasks. Environmental incident tracking and response using AIS is becoming a focus of interest for the USCG and NOAA. For example, the University of New Hampshire Coastal Response Research Center (CRRC) and the Center for Coastal and Ocean Mapping (CCOM) have developed a prototype of the Portsmouth Harbor Response Initiative (PHRI). The PHRI prototype demonstrates use of a web-based GIS platform for environmental incident response (e.g. an oil spill). The prototype integrates AIS data to provide ship position information to enhance Maritime Domain Awareness (MDA) for the shore based response management teams (see Figure 4). The small size of newer AIS units and the power of laptops creates the potential for Maritime Domain Awareness via AIS data analysis and display system in a suitcase-sized waterproof container that can be actively linked to an incident response command post within minutes of a field response team arriving on site. In the future maritime responders aboard response vessels, including the smaller Maritime Safety and Security Team (MSST) boats used for port and harbor security patrols, may be able to receive real-time tasking and updates from their command post via AIS messages termed binary messages. Binary messages are able to forward information via the VHF communication system directly into the Electronic Navigation System of a vessel without of the aid of the mariner. Communications with the response team can transmitted via AIS and automatically appear on the vessel's electronic display.

Concern over oil pollution in European seas has led to international programs attempting to detect illegal oil dumping at sea to permit law enforcement of ships violating MARPOL regulations. Efforts include a Norwegian program using AIS data to assess risks of oil spills associated with specific ships [27]. An international consortium is underway to use aircraft surveillance to monitor pollution. This program has the capability of incorporating AIS to link ships to illegal oil dumping for the purposes of legal action [28]. Initial studies using near real time satellite imagery have also begun in Europe to effectively utilize AIS for correlating oil spills documented by international monitoring programs with vessels of interest that need to be included in the subsequent investigations (e.g. [29]). These studies demonstrate how critical the time component of response. Oil slicks and vessels responsible for oil pollution can move quickly apart. However, it is critical to store these AIS data for litigation. For example, Lloyds of London is already using AIS logs from the AISLive service in court proceedings involving ship accidents. Analysis of AIS logs will certainly be extended to spill response and investigations throughout the world [30]. The key challenge to using AIS to identify ships responsible for oil pollution is extending AIS receiving capabilities to more remote regions [26].

C. AIS Human Interface Issues

Other difficulties with the use of AIS for identifying sources of pollution from ships are problems with the AIS system itself. On board ships, AIS has potential for errors with the required Minimal Keyboard Display (MKD) that made initial SOLAS Class A transponders difficult to use, the so-called Human-Systems Interface problem [28], [29]. Anytime a user has to enter data into a system mistakes may occur, and the current MKD is challenging at best. The dimension, draft, destination, name, call sign, MMSI, and other parameters are entered into the system each time these change. In addition to human error, installation and operation can lead to AIS messages containing inaccurate information. For example, some earlier AIS units reset to factory defaults under certain power failure modes leading to ships broadcasting with MMSI values of 0, 1, or 1193046. Improvements to AIS training programs, advancing the state of AIS technology, integration of AIS into ship and shore communication systems, and feedback to mariners from N-AIS monitors will help to minimize data errors that now pose challenges in the reliability and easy of use of AIS data.

Figure 5. Simplified task-specific user interfaces can make using AIS much easier. a) The Thames River in England requires ferries to notify the local Vessel Traffic Service (VTS) with the number of passengers via AIS. b) With the right interface, an AIS application can be ported from fixed computer to a handheld. c) USCG Los Angles station personnel using a PDA while working on a smaller patrol boat. Integrating AIS into these mobile devices can aid in incident response. Images from [33] and USCG.

In addition to AIS displays based in desktop computers and vessel bridge systems (Figure 5a), there is an emerging class of potential AIS systems for field use - hand held computers (see Figure 5b,c). Hand held computers such as Blackberries, Treos, and other handhelds are beginning to see use on the smaller USCG patrol vessels (Figure 5c), and by shore based environmental responders. An example of such an AIS device is show in Figure 5b, where a ferry operator is entering in the passenger count into a hand held device. This device uses local wireless to communicate with the ship's computer, which then forwards the message to the local VTS via an AIS binary message. The screens on these portable devices have improved to the point that they are practical even in bright outdoor environments. Traditional graphical displays or the minimal LCD displays on AIS units, do not work well for hand help devices due to spatial constraints. If graphical application software is carefully crafted, these displays can be converted to the smaller form factor and be optimized for utility despite the lack of full keyboards on these portable systems. More work needs to be done on both the user interface (UI) and messaging technology to make these devices better achieve of their potential utility.

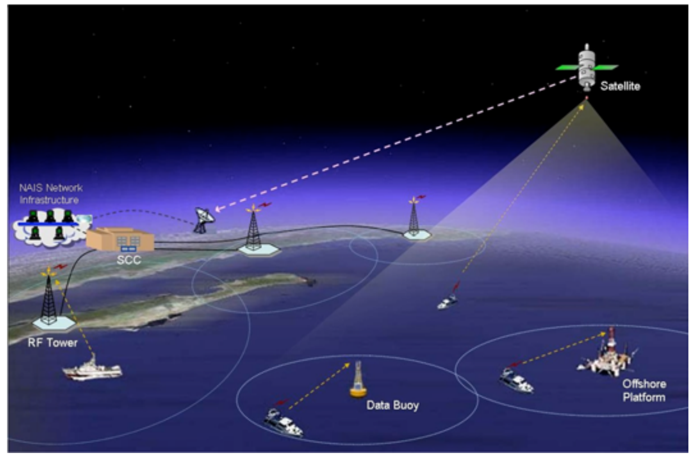

Figure 6. Schematic diagram of N-AIS Increment 3. Satellites and buoys acquire AIS position reports from regions out of view of shore based receive towers. The goal of Increment 3 is to be able to track AIS targets out to 2000 nm.

III. Summary

AIS will become an important component of the technology to aid in the process of responding to oil spills and the subsequent investigations to determine liability. AIS is currently proving its value in the areas of real-time collision avoidance, marine habitat management, and marine casualty investigation. Increased AIS coverage both alongshore and offshore through the Increment 2 and 3 phases of the U.S. Coast Guard's N-AIS system are shown in Figure 6. The goal is for these systems to extend coverage fully along U.S. coasts to a distance of 2000 nautical miles offshore, which should greatly reduce the ability of vessels to illegally dump oil at sea when satellite and aircraft detection methods are in place to verify the occurrence of such oil pollution. Some problems remain to be addressed with Increment 3 AIS deployment due to collisions caused by receiving messages from multiple TDMA cells. However the advent of a fully implemented AIS system will make the use of AIS position reports for oil spill cleanup and investigation commonplace in the future in the U.S., and these techniques will also be available to other coastal nations to the benefit of all of use and rely on the sea.

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