Vessel Tracking Using the Automatic Identification System (AIS) During Emergency Response: Lessons from the Deepwater Horizon Incident

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Abstract. What does the marine Automatic Identification System (AIS) vessel tracking mean for mariners at sea and operations staff on shore during emergency response operations? Real-time AIS and e-Navigation related technologies enable closer coordination between all involved parties. Recorded historical AIS data give insight into what occurred before, during, and after an incident. Historical AIS analysis facilitates planning for future situations by creating a baseline model of operational procedures, as they currently exist. Mariner and responder safety can be an issue from sudden and drastic alteration of ship traffic patterns caused by emergencies. By planning ahead, the community can mitigate these risks and improve the efficiency of the response at the same time. AIS has limitations for both real-time tracking and historical analysis that must be understood by all involved. However, when used appropriately, AIS is an effective emergency response tool.

The Deepwater Horizon (DWH) oil spill was the first major oil spill where the US Coast Guards AIS ship tracking data was released to the public in real-time, and many response vessels were equipped with AIS transceivers. The Environmental Response Management Application (ERMA) provided the official Common Operational Picture (COP) to responders. The system archived more than 100 GB of AIS vessel positions reports from the Gulf of Mexico during the incident. This paper presents the history of the AIS tools behind ERMA, the initial investigations into how oil spill response operations progressed, and some initial lessons learned to improve future response efforts.

Keywords: AIS, COP, DWH, ERMA, Oil Spill, SONS, Vessel Tracking

Introduction

Our ability to track vessels for the last 70 years has been primarily dependent on VHF voice radio communication and RADAR. The wide deployment of the Global Positioning System (GPS) and other Global Navigation Satellite Systems (GNSS) together with digital packet radio has allowed ships to be able to communicate in new ways. The addition of Wide Area Augmentation System (WAAS) for the continental United States and parts of Alaska along with the disabling of Selective Availability (SA) in 2000 has made positioning devices cheap, effective, and common. However, studies have shown that up to 50% of the reports received from vessels giving position and ship information have errors (Calder and Schwehr, 2009; Harati-Mokhtaria et al., 2007). We must work to improve these systems from end-to-end so that the technology works for the responders, making their jobs easier, not harder. The experiences in this paper demonstrate the hard work of large distributed teams to get critical information to the people who need it. However, no matter how well we do as a response community, we can do better. We can work to identify risks, quantify them, and be ready rapidly deal with the results of an incident.

We must us use each incident as an opportunity to learn and improve our response tactics. While the long time period of the active oil spill/wild well of the Deepwater Horizon incident was horrible, it gave responders an unprecedented chance to move forward on developing and testing systems that are only rarely put through their full paces. Drills are important, but they are frequently not of the same intensity of an actual response. The costs to peoples' lives, the environment, and our economy must at least pay us back with knowledge gained for future responses. BP's estimates their cost from the oil spill at $16B (BP, 2011) - an amount that does not represent the total cost to all involved.

The background presented here highlights the need for increased funding, research and training for our hard working response teams.

What is AIS?

The marine Automatic Identification System (AIS) is a ship-to-ship and ship-to-shore messaging system sent without human intervention over marine VHF radio. The primary goal for AIS during the initial design during the 1990's was to assist with safety of navigation, and specifically, to improve situational awareness of mariners for collision avoidance. AIS is specified by an International Telecommunications Union Recommendation (ITU, 2010), IEC Standards, and documents by IMO, IALA, and a number of other organizations. While the IEC documents are not freely available, Raymond (2010a), as a part of the GPSD project, created the "AIVDM/AIVDO protocol decoding" document - written as an open summary of AIS without the author looking at the closed standards.

The transmission of AIS messages occurs on two VHF channels, VHF-FM channel 87B (161.975 MHz) and 88B (162.025 MHz), giving the system roughly line-of-sight capability (ranges typically 30-80km for ship-to-ship). The messaging architecture is built around 256-*bit* (32 byte) packets called "slots". Each channel is organized into 1 minute long "frames" composed of 2250 slots.

AIS transceivers work together in a self-organized time division multiple access (SOTDMA) scheme to pick which slots to use (Lans, 1996). Small areas effectively build up their own cells. Antennas at higher altitudes, such as on planes, are able to cover wider areas, but often receive messages from multiple cells and messages from neighboring cells may collide with each other. While satellites are proven platforms for receiving AIS messages, transmitting from spacecraft is certain to reach many different cells, each with its own organization of slots, causing interference with many ship messages.

An individual AIS message is allowed to be 1 to 5 slots long, but messages using 4 and 5 slots are discourage because of VHF noise issues that greatly reduce the probability of correctly receiving longer messages. The first slot of message contains 88 header bits, meaning that the first slot only contains 168 bits (21 bytes) of usable data. The result is that AIS messages are only 21 to 85 bytes in size. This is smaller than the space available in Twitter messages or short message service (SMS) mobile phone text messages. Within a cell, the overall 2-channel throughput has a theoretical capacity of 19.2 kbps that is reduced to 11.2-12.6 kbps by the slot overhead. There have been discussions as to what VHF Data Link (VDL) loads are reasonable for SOTDMA (Germany and Sweden, 2007). Assuming that a 50% load is sustainable without degrading the safety of life aspects of AIS, the maximum total throughput is only **5.6-6.3 kbps** of message data.

There are two classes of transceivers for ships. (Note: These are technically *not* transponders). Class A systems transmit with 12.5 W power and at a higher priority than Class B systems, which are limited to 2 W power. Class B systems also transmit position reports less often. A Minimum Keyboard Display (MKD) is mandated for Class A hardware and ship operators may choose to integrate the AIS information into their Electronic Charting System (ECS). Class B units typically have no built in display and must have an ECS to be able to view AIS information. Many small vessels carry receive only AIS units, trading safety for a very small monetary savings compared to purchasing a Class B transceiver. Arroyo (2009) summarizes the carriage requirements for AIS devices in the United States.

There are a number additional types of equipment that complement the AIS transceivers on vessels. First, there are specially designed high end receive only units meant for monitoring AIS from towers, aircraft, unmanned aerial vehicles (UAVs), autonomous surface vehicles (ASVs), and satellites (S-AIS). These use specially designed antennas, electronics, and filtering systems to receive the largest number of AIS messages possible. Decoding data in a slot with a collision is sometimes possible with fancier processing algorithms. Additionally, some AIS receivers can direction find AIS transmissions thereby assisting locating vessels that have AIS units with non-functioning GNSS position systems (a common short term problem).

Onshore units called base stations provide monitoring and have the ability to control some parts of how AIS works for Class A and Class B transceivers. AIS aid-to-navigation (ATON) devices are generally designed to be deployed on equipment in the field and transmit the status and location of the equipment. Both these basestations and ATON units are used to transmit special Application Specific Messages (ASM) that add extra functionality to the AIS system. There are currently 262,144 possible ASM messages types that could be defined. While the number of ASMs in current use is not publicly documented, there are probably several hundred types in use and 19 are currently defined internationally by IMO (2010).

A subset of mariners, companies and governments have expressed privacy concerns with AIS. AIS is a public broadcast system that is usable by any mariner, individual, company, or government. Once an AIS message has been transmitted, there are *no* provisions for privacy, data use agreements, or use restrictions of received data. Government vessels have the right to transmit their position and identification messages as encrypted, "blue force," messages. During non-law enforcement or military actions, the current encrypted messages hamper the use of the public AIS frequencies by degrading the ability of the SOTDMA algorithms to figure out when to transmit and the position reports are not available to infrastructure that does not have the decryption keys (McNeil, 2006; Davis, 2008). Some of the issues of public release of AIS data were discussed in public responses to the USCG 2009 request for comments on release of AIS data collected by the USCG and its contractors (USCG, 2010; Schwehr, 2010a; Raymond, 2010b).

Environmental Response Management Application

In April 2006, as a part of the Center for Coastal and Ocean Mapping / Joint Hydrographic Center's (CCOM/JHC) Chart of the Future Project, I was able to connect to the USCG Research and Development Center's (RDC) AIS listening network that, at the time, consisted of approximately 64 AIS receive sites. The original CCOM/JHC project goal was to model how ships behave for use in navigation and charting research. I created a Python software package called noaadata (Schwehr, 2010b) as a research tool to decode AIS messages. CCOM/JHC installed an inexpensive SR-162 AIS receiver in the Portsmouth, NH harbor to gain experience with AIS hardware and track local ships, as there were, at the time, no USCG receivers close enough to track ships in the harbor.

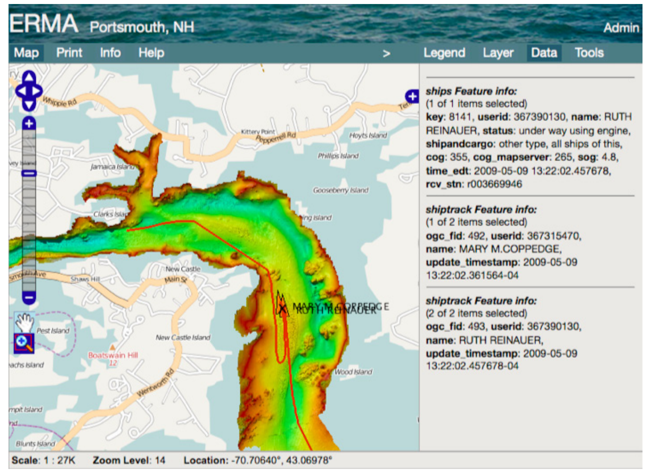

Figure 1. Portsmouth Response web interface showing a tug and cargo ship seen via AIS over high resolution multi-beam bathymetry.

The initial project quickly grew, as it was clear that real-time ship positions and historical analyses are important for a wide range of situations within the marine environment ranging from such diverse topics as ocean noise (Hatch et al., 2008) to grounding risk (Calder and Schwehr, 2009). One primary opportunity is streamlining the management of response to environmental disasters such as oil spills. When one response manager was asked how he tracked all of the vessels working a response, his reply was that he calls them on the VHF radio every 30 minutes for a position report. AIS is a way to track ships automatically - freeing mariners and responders on the water to better focus on the cleanup efforts. It was clear from discussions with response managers that, in 2006, AIS was poorly understood in the community as the use of AIS was initially was not seen as beneficial.

During late 2006 and early 2007, Rob Braswell, Michele Jacobi of NOAA's Office of Response and Restoration (OR&R), Tom Milliman, myself, and the Coastal Response Research Center (CRRC) put together an initial web mapping software application known as Portsmouth Response (Figure 1). The system combined static geospatial data on incident planning, environmental restoration, and nautical information with real-time tide data from NOAA Center for Operational Oceanographic Products and Services (CO-OPS) / Physical Oceanographic Real-Time

System (PORTS), weather and sea surface data from NOAA nowCoast, and AIS ship tracking. The Portsmouth Response website was password-protected and provided basic services such as uploading and downloading data sets and saving polygons digitized on the web map by users.

The Portsmouth Response application was presented to a diverse audience at the Portsmouth Harbor Response Initiative (CRRC, 2007), including commercial responders and local, state, and federal government response managers for the New England area. It was clear from participant reaction to the web application that there was a need for an open web mapping system usable by all of the response team to supplement the GIS professionals armed with ArcGIS. However, the Portsmouth, NH harbor is small and the system needed to be upgraded to handle larger areas with more concurrent users, and improved to add new features required by responders. At this point, the entire system was running on a Mac Mini sitting on an office desk at UNH. Requirements were gathered from all the participants and the project was renamed to the Environmental Response Management Application (ERMA).

During 2008 and 2009, the ERMA team worked to improve the infrastructure behind ERMA. As a part of this process, the team created a Caribbean instance of ERMA for Puerto Rico. To extend AIS coverage to other parts of the country, I connected ERMA to the USCG Nationwide-AIS (NAIS) data. AIS data was post-processed to aid in understanding several incidents in the waters around Puerto Rico.

The ERMA software was moved into the controlled environment of the UNH Research Computing Center (RCC) and managed by the RCC team. During this time, noaadata, the AIS decoding software used in ERMA, had a difficult time keeping up with the volume of AIS traffic, even on a more powerful server. Noaadata was designed for research and was never optimized for speed. One small drill with ERMA was held in the Portsmouth Harbor, but with only one AIS equipped response vessel, it was difficult to evaluate the use AIS in ERMA.

Spill of National Significance Drill 2010

In March 2010, oil spill responders from around the country met in Portland, Maine for a Spill of National Significance (SONS 2010) drill. This was an opportunity to observe USCG, NOAA, and other responders using ERMA and traditional response tools for a simulated oil spill off of Maine, New Hampshire and Massachusetts (Figure 2). I attended the drill as an observer and was surprised by the extent of the difficulties encountered by participants in the drill. NOAA and other groups involved in response drills typically have a review meeting a short time after the drill, called a "hot wash," to gather lessons learned and directions for future improvements. The USCG refers to this as an After Action Report (AAR; Lloyd, 2010). In preparation for a hot wash after the drill, I submitted a list of observations about the command center operations based solely on one day. It is challenging to extrapolate one day of a drill to what might occur during an actual incident. However, there are a number of key points that can be addressed.

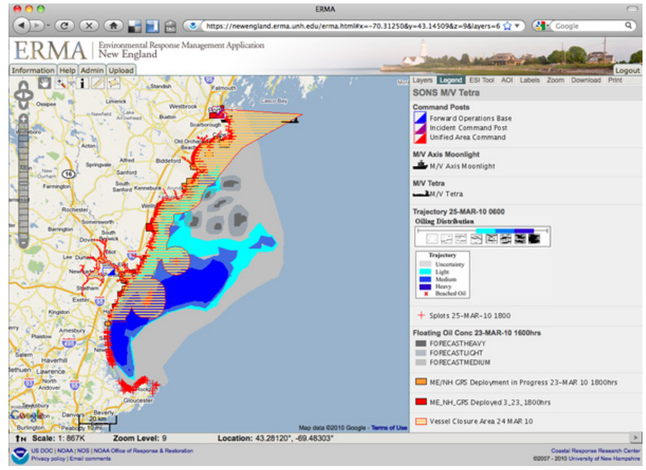

Figure 2. ERMA New England displaying simulated oiling area and response management zones during SONS 2010.

The most striking observation was how frequently location names caused difficulties. Local names were unfamiliar to staff from out of the area and problems were compounded by spelling errors and misheard names. Names used by those in the field were frequently not available in public mapping systems such as Google Maps, Map Quest, Open Street Map, USGS Geographic Name Information Service (GNIS), etc. This miss-communication created a confusing environment where staff in the command center were unsure where responders were located when reporting their observations by voice communication. To add to these name issues, almost no numeric coordinates were transferred over phone and radio, which also have accuracy issues. Names work best when all parties involved are familiar with the names, and the names are not ambiguous (e.g. "rocky point").

During the drill, traditional response software tools, such as WebEOC, were not available to all participants and there was no way to enter information via mobile devices. Tools such as Open Data Kit (ODK) or Disaster Cam have the potential to greatly increase the situational awareness, but were not available to any of the teams participating in the drill.

I was surprised that there was no simulation of AIS vessels movements for response systems. Even if there had been a simulated AIS feed, there was only one vessel that the command center knew was participating in the drill. When asked, the staff did not know if the vessel was equipped with AIS or what particular information would be needed to identify the vessel using AIS. To compound this problem, there was no plan to add AIS transceivers to small Vessels Of Opportunity (VOO) that were not currently equipped to broadcast their position. Military vessels often have their AIS positions encrypted, and the USCG had no plan to disable the blue force encryption on USCG vessels participating in the drill to allow responders to better coordinate with those USCG vessels. AIS systems and procedures were not exercised in a way that would train staff or highlight where vessel tracking needed to be improved.

I payed particular attention to navigation and charting during the response drill to search for opportunities for better uses of these tools by responders. Printed maps in the command center rarely included nautical charts with neither raster nautical chart (RNC) or vector electronic navigation chart (ENC) data. Additionally, most people in the command center were focused on hard copy printouts and pen-on-paper annotations. Those documents were not made available to the rest of the staff, are not archived, and cannot be tracked. Handwritten notes on maps have the potential to be confusing or illegible. There was no use of the Coast Pilot by staff working to familiarize themselves with the coastal areas. I believe that there is a large potential for assisting responders by including staff familiar with nautical charts and publications in the command center. Having more training for responders in use of navigation tools from the perspective of people interacting with mariners on the water will increase responders' ability react to quickly changing marine incidents. Future drills should consider including a small-scale hydrographic surveying, mapping and chart production project that delivers a small temporary ENC and a Bathymetric Attributed Grid (BAG) for an area near the simulated incident.

Taking these observations together, it appeared that, unintentionally, there would be substantial friction between teams as they work to coordinate efforts during an actual spill. Simulating an oil spill is difficult. The team running the drill worked hard to create a range of conditions that kept all of the groups engaged, but it is challenging to mimic the environment of an actual spill. The SONS 2010 drill was an excellent platform for discovering what works and what needs refining. There will always be room for improvements systems or tweaks to techniques that were not as effective as they could be. Drills provide opportunities to train staff on response procedures, both new and old trusted approaches. One of the items that needs more research is how to effectively simulate oil spills (and other emergencies) to give the teams the best opportunity to be prepared for disasters big and small.

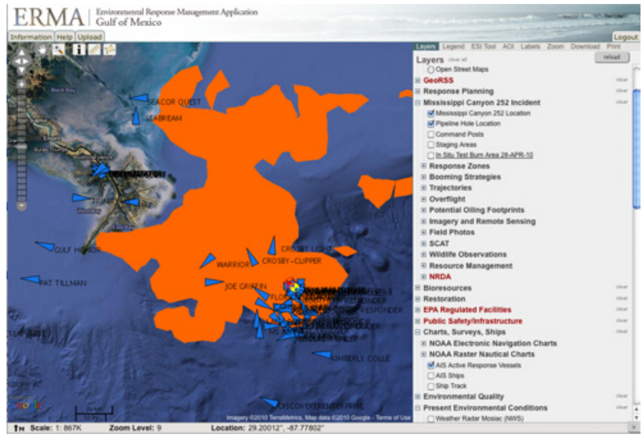

Figure 3. An early version of the GOMEX ERMA web application with the oiling area, response vessels, and the well site.

Unfortunately, the Deepwater Horizon incident occurred before the hot wash meeting was able to take place.

The Deepwater Horizon incident

On April 20, 2010, the Deepwater Horizon (DWH) semi-submersible oil rig suffered a catastrophic blowout and caught fire (gCaptain, 2010; Graham et al., 2011). At this time, the ERMA team was in the process of thinking about lessons learned from SONS 2010. However, by April 22, the team had hurriedly put together a new ERMA site for the Gulf of Mexico (GOM or GOMEX). At that point, the system contained limited background data. On April 24th, NOAA contacted me for help with getting AIS for the Gulf of Mexico into the GOMEX ERMA (Figure 3). The Joint Unified Com-

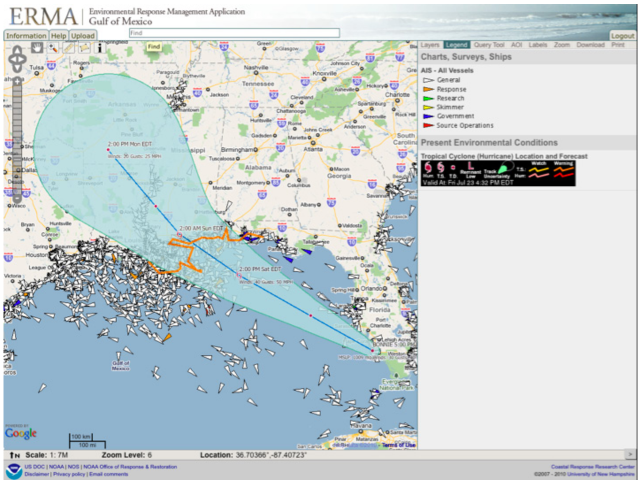

Figure 4. ERMA displaying all NAIS positions for ships reporting in the last 24 hours using libais. A storm track from nowCoast is overlaid to assist in planning how to deal with a hurricane coming into the response area.

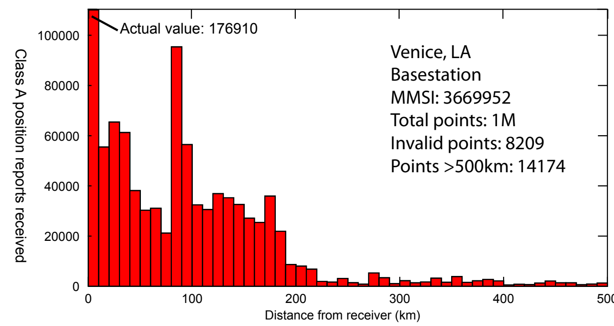

Figure 5. Number of Class A position reports received by distance from the receiver at Venice, LA. The fall off of the tail is a combination of fewer vessels far out into the Gulf of Mexico and being beyond the typical reasonable maximum reliable receive distance.

mand required that this work be accomplished out of public view, completely hidden by password protection.

Unfortunately, the noaadata AIS decoding software initially used by ERMA was not able to keep up with the volume of NAIS data from the USCG. The decoding software had to drop a random subset of messages to stay in a real-time mode, counting on redundancy from the rate of transmitted position reports to keep ship position updates usable. The AIS decoding system was on a list of ERMA software to be redesigned for improved efficiency. During the first couple of weeks of the DWH incident, the ERMA web site provided the most effective display of AIS available to most responders, even with the server overloaded.

To reduce the load on the server running noaadata and the spatial database, I worked with the USCG to switch the NAIS feed from a full network configuration with over 4GB of AIS data per day (60-70M NMEA lines), to cover just the Gulf of Mexico and remove duplicate messages received from neighboring receivers. This reduced the AIS data volume to 1GB/day. These changes kept the system more stable, improved the probability of ship positions being up-to-date, and gave some breathing room for a rewrite of the AIS processing software.

The middle an emergency response is not a good time to be doing major software engineering. However, the ERMA team had no choice but to improve the core ERMA system, add new data types, and support active response - all at the same time. I started creating a new AIS decoding library called libais, written for speed (Schwehr, 2011b). I redesigned the spatial database to only keep the longitude, latitude and time stamp from the most recent position report and a line for the recent track for each ship. The older noaadata software kept the entire AIS position report history, rapidly filling up the database and slowing queries. The new libais algorithm utilizes a queue containing a limited number of positions for each vessel to avoid querying the database for vessel position history. The first public release of the libais source code was on May 3rd and we switched the ERMA server from noaadata to libais on May 21. ERMA is now able to ingest, in real-time, the entire NAIS feed covering all available stations, not just the Gulf of Mexico, utilizing only a small fraction of the server's compute power (Figure 4).

Display issues

A common ENC method for displaying vessels from AIS position reports is to update the position of a vessel after each position report and to keep the ship for a short time (e.g. 15 minutes) after the last position and to blink any vessel for which the system has not seen a recent update (e.g. 10 minutes). For ENC software, the number one requirement is safety of life in real-time and thus this display style makes good sense.

For ERMA, the primary goal is to keep track of all of the response vessels in the region. In the Gulf of Mexico, with ships operating far from all shore based NAIS receivers in the area ($>$ 200km), NAIS was only able to sporadically receive position reports (Figure 5). Ships

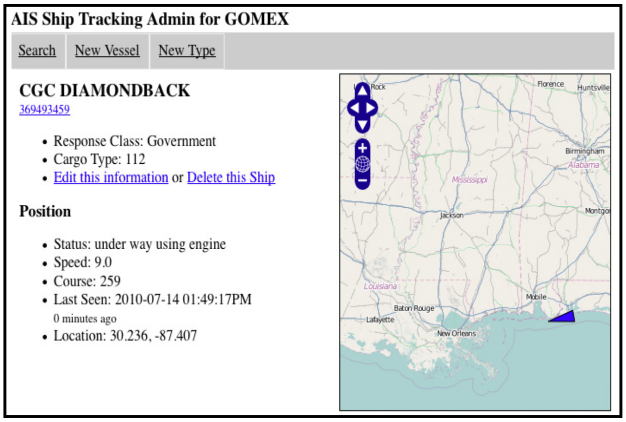

Figure 6. Web-based administration interface for managing the list of response vessels built using GeoDjango.

Incident Resources by Area

Incident: Mississippi Canyon 252 — Operational Period:

ID	Resource Type	Resource Description	Supplier	Quantity
Sector New Orleans				
19161	Tug	1800 HP Tug	MSRC	1 each
Staging - Biloxi				
17057	Tug	M/V Capt Jason (J&W Marine)	U.S. Environmental Services LLC - L	1 each
17045	Tug	M/V Capt Skitttles (J&W Marin	U.S. Environmental Services LLC - L	1 each
17021	Tug	M/V Jane B	U.S. Environmental Services LLC - L	1 each
17033	Tug	M/V Jane B (J&W Marine)	U.S. Environmental Services LLC - L	1 each
17088	Tug	M/V Jerry Bollinger (J&W Mari	U.S. Environmental Services LLC - L	1 each
17069	Tug	M/V Oyster	U.S. Environmental Services LLC - L	1 each
24255	Vessel	25 feet or under	MSRC	2 each
24470	Vessel	25 feet or under	MSRC	2 each
21129	Vessel	deployment vessel	ES&H Environmental Services	6 each

Figure 7. Example of vessel list that made identifying responders through AIS very difficult. Many names were ambiguous at best. Identify vessel by "1800 HP Tug owned by MSRC" and "deployment vessel" was not possible with the information at hand.

in distant operational areas went as long as 16 hours between reports captured by NAIS. Knowing which ships were generally out in these more distant areas was critical enough that it was considered acceptable to display older ("stale") position reports. Therefore, we switched ERMA to show position reports that were up to 24 hours old, as opposed to the standard 15 minutes (Figure 4). Some ENC software have the ability to control how long the display will show older position reports, but it is often clamped. For example one software package allows this threshold to be adjusted up to 1 hour, which makes it less useful for response managers.

Response Vessels

As a part of the libais tracking system, I modified the vessel name database table to record a custom vessel classification marker. This marker allows the team to flag vessels as a part of the response. The vessel classification allows users of ERMA to display just the response vessels and have them color coded. It is then possible to then overlay the response vessels over all other vessels in the area. There are currently 5 vessel classifications, with the ability to add as many as required on the fly. The current classifications are non-response, response, research, skimmer, and government.

Until the end of June, the software engineers on the ERMA team had to manually run Structured Query Language (SQL) database commands by hand on the server to change the status of vessels. The lead ERMA engineer, Aaron Racicot, brought in Chris Schmidt, author of the OpenLayers and FeatureServer software used by ERMA. Schmidt created a web-based interface for the vessel classification system using the Django web framework. Beginning in July, any of the ERMA team members could use the web interface to modify vessels. Additionally, using GeoDjango (Bronn, 2008), Schmidt added a tool to map the location of a particular vessel on a map (Figure 6). In the ERMA web site, responders currently have to visually search the map for the location of a vessel.

Finding information about which vessels were involved with the response proved extremely challenging during the first month of the incident. Existing incident management software provided PDF reports like those shown in Figure 7. Some of the vessel types were not clear and AIS requires identifying vessels by their unique Maritime Mobile Service Identity (MMSI) number. Names were only sometimes given and I gathered many names by watching TV news reports and noting vessels seen. Often names of response vessels were reported from the command center in such a way that it was very difficult to figure out which MMSI was the vessel in question. Resolving these instances required pulling all of the vessel tracks for ships with possible names and using ship behavior to determine if the ship was involved in the response. This process is extremely inefficient and consumed large amounts of time. Future responses need to record MMSI, size, IMO number, and a time stamped location to have a higher probability of tagging the correct ship. A mobile phone application that captains could use when they head out and return would make this process painless. Additionally, a number of vessels (commercial and government) entered the response with invalid MMSIs. It took time to find the person who could correct the vessel's AIS unit.

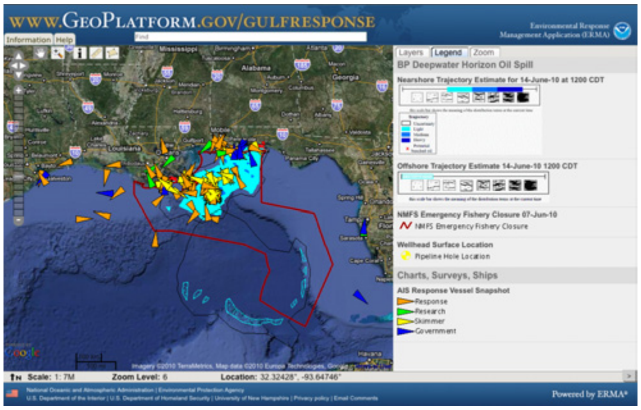

Figure 8. Response vessel positions from NAIS as released to the public through GeoPlatform.

NAIS Public Release

On May 31, I was informed that the NOAA Web Operations Center (WOC) was working to clone portions of ERMA for the public through a project called GeoPlatform (Figure 8). The original intent of ERMA, as viewed by Rob Braswell and myself, was that anyone, either inside or outside of NOAA, should be able to clone most of the ERMA system for an emergency response without requiring our help. It is very encouraging that GeoPlatform went live on June 10, 2010 using much of ERMA without anyone from the GeoPlatform group having to contact Rob Braswell or me.

However, the ERMA system is still not as simple as we would prefer. There was a lot of collaboration between the WOC team, NOAA ERMA contractors and the UNH RCC required to setup GeoPlatform. Additionally, many of the data layers in ERMA are unfortunately restricted to responders only, or cannot be released to the public due to NOAA rules forbidding release of data without proper metadata.

Early in the DWH response, there were multiple requests for NAIS data in ERMA to be released to the public in real-time. The communities both inside and outside of the USCG are split on whether or not the USCG should publicly release NAIS-collected data and, if NAIS is released, how much data should be made public and with what time delay, if any. The USCG has an interim release policy (USCG, 2010) that prohibits any public release of NAIS during the first 12 hours after receipt of a message. On June 11, after much discussion at the USCG, Admirals Thad Allen and James Watson, along with Roger Parsons, decided to mandate real-time public display of response vessel locations from

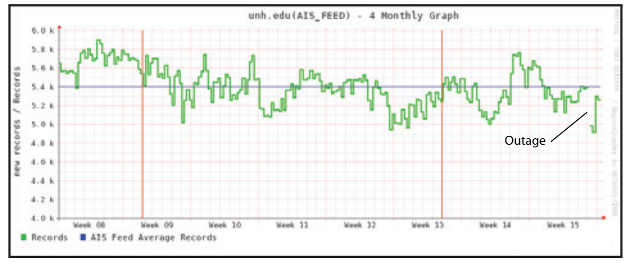

Figure 9. 56 days of Nagios tracking of the ERMA feed at UNH. Nagios examining the number of unique ship MMSI's received in a 10 minute sliding window, and emails a notice when it detects the count dropping below a threshold.

AIS position reports. The GeoPlatform project, which was already accessible by the general public, allowed for the display any vessel that is classified as involved in the DWH response. ERMA, with the full NAIS feed, was reserved for response personnel only. ERMA forwarded the response vessel positions to GeoPlatform every 2 two minutes. This open access to vessel locations greatly aided communication between responders and the public trying to understand events occurring in the Gulf of Mexico. Additionally, this allowed responders even better access to critical ship position information without having to worry about authenticating with the ERMA web application.

Reliability and fault recovery

As the complexity of the systems grew at CCOM/JHC, we reached the point where it was essential to have an automated system (e.g. Nagios, OpenNMS, or Antelope) provide continuous integrity monitoring of servers, software and data feeds. We began monitoring the ERMA NAIS processing server in early 2010 using Nagios. This only included checks of the basic machine health. During the DWH incident, the ERMA NAIS feed up time became a critical issue with many people depending on the ERMA vessel display. Jordan Chadwick and I set up a Simple Network Management Protocol (SNMP) check of the vessel database in Nagios. Our initial check watches the number of unique MMSI seen in the last 10 minutes (Figure 9). We can control the minimum number of ships ship before a warning is issued. This allows us to catch a general failure anywhere in the system before it substantially impacts users of ERMA. The web display is only updated every two minutes for ship motion and during the response

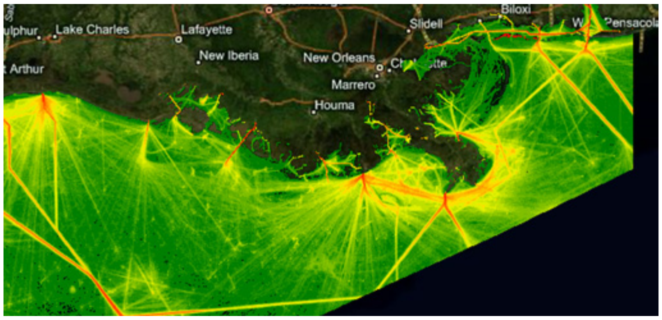

Figure 10. AIS position report density in the Gulf of Mexico. Data has been clipped to near shore, where the AIS coverage is excellent. Far offshore, the chances of receiving position reports falls quickly. Image courtesy of Kyle Ward.

ships were generally moving very slow.

Once the responders started to depend on ERMA for vessel positions, the USCG began working closely with me to ensure the best possible connectivity between UNH and the USCG. On June 8, the NAIS team designated ERMA as a "Critical Client" . The ERMA and NAIS OSC teams worked hard to maintain the ERMA NAIS feed on a 24/7 basis. There were some of these connection issues that are expected to be resolved as a part of the NAIS Increment 2 project, with new NAIS software that will run on the ERMA server, replacing the existing USCG software that was developed during the original USCG AIS research project.

These monitoring techniques are only the beginning of what responders using AIS need. Monitor MMSI counts does not fully capture the reception ability of the NAIS network and many issues will not be caught. We need tools that show coverage quality of the overall network, thereby reducing the number of surprises experience by responders during an emergency response. A part of this problem comes from the infrastructure of the NAIS system. Some NAIS stations are built on base stations, rather than more advanced receives, and do not have receive single strength metadata. The USCG publishes no metadata of station location or configuration changes, preventing end users from being able to easily evaluate the system performance. We have yet to look into technologies such as Event Stream Processing (ESP) / Complex Event Processing (CEP), which are specifically designed for data streams such as NAIS. Additionally the time stamping process as implemented in NAIS has been shown to have errors up to 8 minutes, thereby making many analysis techniques challenging or impossible to implement.

NAIS coverage near the coast of the continental United States is excellent (Ward and Gallagher, 2011; Figure 10). However, aside from a few receivers on oil platforms in the western Gulf of Mexico, the coverage rapidly degrades in the central Gulf. AIS requires redundant coverage to be reliable. There are several potential solutions to coverage issues far from fixed receivers. These solutions should be used in combination. First, having S-AIS contracts in place that allow the USCG to distribute satellite data in place and that include proper receive time stamps will allow for coverage in more remote regions. Second, NOAA, USCG and possibly other ships with satellite uplinks, should locally time stamp AIS messages and forward that data back to the NAIS system. Even with several minute delays to allow for batching and compressing data, this method would help to fill holes with only modest latency. Third, portable receive sites should be available for rapid deployment to the field with the understanding that these stations are temporary. Where there are existing commercial installations, the USCG needs to work with these companies to establish NAIS receive sites before incidents occur. Finally, data from other types of tracking systems should be blended with AIS in the ERMA interface.

Other tracking systems

During the DWH incident there were many other real-time tracking technologies that were discussed for inclusion in ERMA. Each of these technologies had different issues that led to either including or excluding the data from ERMA. Discussing several of these technologies and the resulting decisions will illustrate some of what must to go into evaluating integration of new systems into ERMA. The cost and complexity of adding AIS to smaller vehicles during the time frame available appeared prohibitive and some of these other technologies were already is use.

One of the first additions suggested to ERMA during the Deepwater Horizon was from the USCG, who suggested ERMA use a GeoRSS NAIS derived vessel position feed. GeoRSS would move the decoding work from noaadata or libais back to the USCG Operations Support Center (OSC) in West Virginia and offload processing from servers located at UNH. However, GeoRSS suffers from a very loose definition, with 6 different possible formats, and the format is designed with a focus towards human readers. The result is that the GeoRSS is missing many of the AIS data fields, increases the number of bytes for each ship report, and contains only

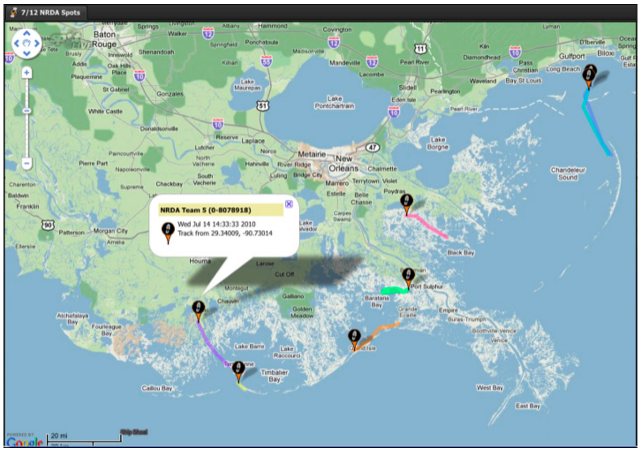

Figure 11. Find Me Spot web-map interface for monitoring the NOAA NRDA teams in the field.

a small subset of the ships in the area. GeoRSS, as currently implemented for AIS positions, requires writing a parser for loosely structured text. We decided to keep the GeoRSS as a backup to libais, but retain libais as the primary AIS parser. In the long run, GeoRSS or other similar techniques such as JavaScript Object Notation (JSON) are attractive solutions as they allow for extra information to be added to position report records before they are distributed to response systems. JSON is a much more compact ASCII transfer format commonly used in web services. With the addition of GeoJSON (Butler et al., 2008) and initial work on JSON for AIS (Hannikainen and Dimitris, 2008; Burrows, 2010; Raymond, 2010c; Schwehr, 2011a) show the potential, if the community can create a fully functional standard. JSON appears to be more flexible and have require less network bandwidth than the Maritime Domain Awareness project's XML messages Spalding et al. (2009), while still providing a human readable form.

The ERMA team added support for Find Me Spot personal satellite trackers (Figure 11). Find Me Spot devices are inexpensive hand-held trackers that transmit position reports to a geosynchronous satellite. These devices were used effectively by NOAA Natural Resource Damage Assessment (NRDA) response teams in coastal environments, who use boats that are not typically equipped with AIS transmitters. Merging the trackers into ERMA allow NRDA and other response managers to monitor their teams through a single interface, which helped to reduced the complexity of their tasks.

The USCG command staff requested ERMA track all of their personnel via their USCG work phones. All USCG personnel carry cell phones running tracking software from Good Technology. Given the added complexity that would be required to ensure personal privacy protection for each individual tracked, I strongly cautioned against such tracking using ERMA. Based on that concern, the USCG decided not to use ERMA to show the locations of people, but continue to use the interfaces provided by Good to the USCG. ERMA had been tracking only physical assets up to this point, rather than people. While Find Me Spot trackers can be used to track people, the devices are not necessarily attached to a particular person and are often fixed to the window of a vehicle or vessel.

Discussion

As a developer working as a part of the ERMA team and being physically located in New Hampshire, it was difficult to follow the decisions as they progressed in the command structure. However, the USCG released a Incident Specific Preparedness Review (ISPR) for DWH (Papp et al., 2011). This document gives insight into the decision to use ERMA as the COP system for the oil spill.

> Because of the pressure to provide information in real-time, several versions of a COP were developed independently at each ICP. In addition, private sector responders (e.g., BP, O'Brien's Response Management, and so forth) had their own COPs to track their internal resources. For more than a month, there was no single COP available. As a result, various agency leads for the COP worked together to create one COP for the entire Deepwater Horizon incident. The COP platform selected was NOAA's ERMA, also known by its public Web site, Geoplatform.gov.

Interoperability and flexibility are key to successful work in complicated and changing incidents. Especially for a situation that occurred over such an extended time period, open standards are critical to success. This is explicitly discussed in the ISPR:

> The incompatibility of proprietary databases and software used by the private sector appeared to be a hindrance to developing a universal COP for the response organization. Integrating data from multiple, restricted sources slowed the development of a complete and an accurate COP.

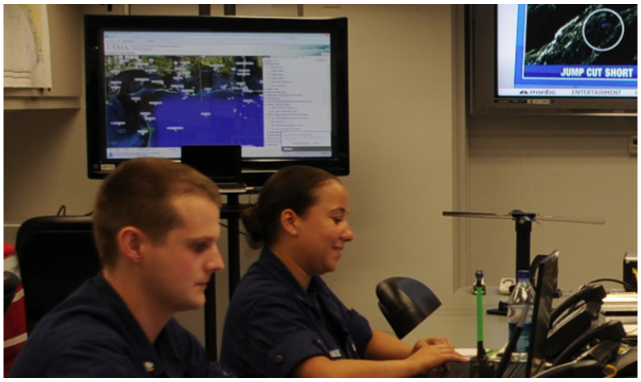

Figure 12. Photo of ERMA in use inside of a mobile command center in Alabama. Credit: USCG, Shinn (2010)

While the ISPR does not directly discuss vessel tracking and AIS, a report from the Deepwater Horizon Study Group by Epperson (2011), does mention AIS:

> An even more challenging dynamic of this response was the pressing Requests for Information (RFI) that inundated command posts, staging areas, and command and control vessels. Although this response made great strides to utilize a significant number of emerging technologies to provide situational awareness, it was never sufficient to feed the information "beast." The use of tools like the Homeland Security Information System's (HSIN) Jabber Chat, WebEOC, and Automatic Identification System (AIS) provided advancements in situational awareness, but those capabilities were rarely utilized in conjunction to develop a common operating picture that connected all levels of the organization.

Comments like these suggest that we as a response community have more work to do to integrate technologies into user friendly interfaces and provide training to responders, so that they can best utilize these newer tools of the trade.

Response plans, such as the BP's plan for the Gulf of Mexico (The Response Group, 2009) are generally considered protected material. This hampers the ability of outside review of the plan and means that responders might not have been able to review plans before problems happen.

I have attempted to request photographs and use case descriptions from responders in the field. However, with an incident of this magnitude, many of the sites using ERMA reported back to me that all photography was prohibited. This makes it difficult to understand how and when ERMA and other response tools were used. I was able to find one image with ERMA in the background on the incident Flickr web page (Figure 12). This is not enough information to understand the needs of the response staff. More information about an incident of this magnitude will facilitate better responses in the future.

Figure 13. Screen shot from JPL's IPRW demonstrating the interface for creating a multiple person TV press conference with both static images and movies.

There remains a nearly infinite list of improvements that could be developed for environmental disaster response. For example, ERMA and other response teams might consider collaboration with other open source disaster management platforms such as Ushahidi Platform and Vesuvius, in addition to the Google Crisis Response project, Disaster Cam, and ODK. There is also potential for collaboration with groups that might not be expected. For example, at NASA JPL the Solar System Visualization group has developed a web application called Image Product Review Website (IPRW) for handling the release process for images and movies during space missions (Figure 13). IPRW assists with people submitting material, tracking permissions to release images, writing captions, managing the process of running a live TV press conference, and releasing images and movies to public distribution channels. For spacecraft missions, they have used the system effectively with press releases happening every 24 hours and mission members located all over the globe creating and submitting content.

For future responses, we can be better prepared to handle situations with a lack of infrastructure. For example, in remote islands or Alaska, there might not be cell phone or internet coverage as there was when near shore in the Gulf of Mexico. The concept of "response in a box" is becoming easier to build. Combining a portable GSM cellular base station (e.g. OpenBTS), a satellite link, WiFi, and an AIS ATON transceiver with a portable generator and small antenna tower would allow responders in a remote a location to be up and running with standard gear with minimal setup time. Using a satellite link, they could be forwarding data collected via AIS and mobile phones back to normal operations facilities that require full internet connections.

Additionally, now that AIS ASM messages for area notices, environmental sensor reports, and ship data reports have been approved (IMO, 2010), it is possible to send information directly to ship board electronic charts in real-time. However, these techniques will require planning and testing to be usable under the intense pressure that occurs during incident response. AIS is a very small data link and has to be utilized carefully to not put response vessels and other ships in the area at increased risk. Alexander (2011) discusses some of the many issues that have to be address to make AIS notices an operational success.

Conclusion

While it was horrible that the spill went on for so long and ended up being the worst oil spill in U.S. history, this extended time period allowed responders to iterate on techniques to improve how oil spills are managed. We owe it to future responders to work hard to capture these experiences and lessons. This paper attempts to describe the context for how AIS was used during the DWH incident. However, only limited details are available to the author. AIS as a response tool is clearly in its infancy and is not a full-proof technology. We need to continue working on creating monitoring and analysis tools that bring out the most information from AIS and other tracking tools. It is important that in future incidents, these tools be available during the time of response and that responders already be familiar with how to most effectively utilize them.

We now have an large database of position reports for an emergency response that occurred in an area of the world with well established infrastructure. This paper only brushed the surface of the analysis that needs to be on the AIS data and the vessel traffic captured within the data stream.

Disclosure

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Copyright

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