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Sharing Ships' Weather Data via AIS

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ABSTRACT: In the aftermath of the sinking of the US-flagged containership El Faro in October 2015, one of the U.S. National Transportation Safety Board's (NTSB) recommendations was for the National Oceanic and Atmospheric Administration (NOAA) to explore increasing the collection of weather data from ships in order to improve the weather forecast products that they distribute. Currently NOAA runs the Voluntary Observing Ship (VOS) program, where ships voluntarily submit weather observations to NOAA. However, only a small fraction of the thousands of vessels sailing worldwide participate in this program, and VOS weather observations are submitted infrequently, typically four times per day via a mainly manual process. One method being explored to automate and increase the frequency of data submittal is by using the existing Automatic identification System (AIS) equipment installed aboard vessels.
Most commercial ships (in particular those subject to the International Maritime Organization's (IMO) Safety of Life and Sea (SOLAS) convention) have a Class A AIS transceiver installed to comply with mandatory carriage requirements. Many vessels not required to carry AIS equipment voluntarily install AIS transceivers (either Class A or B). All of these AIS transceivers (except for the Class B "CS") can be used to transmit an AIS message 8 (broadcast binary message) by sending the transceiver an appropriately formatted NMEA sentence (BBM). Weather data can be embedded in an AIS application-specific message (ASM) carried by the AIS message 8 and automatically transmitted by the ship. This transmission can be received by terrestrial AIS stations (when in range) or by satellite AIS receivers. The AIS weather data can then be converted into the appropriate format and forwarded to the weather forecasting offices for use in models and weather predictions. This data may also be of use to other researchers monitoring climate change or other environmental factors. By leveraging this existing base of AIS transmitters, the volume of weather data being sent to weather forecast offices and others could be greatly increased.
The U.S. Army Corps of Engineers (USACE) and U.S. Maritime Administration (MARAD) have been exploring the feasibility of this concept. Following a simple bench test performed by Alion Science in September 2018, an initial proof-of-concept was tested aboard the MARAD vessel Cape Wrath while moored in Baltimore in October 2018. After this successful demonstration, a prototype was installed on the Massachusetts Maritime Academy training ship TS Kennedy during her training cruise Jan-Feb 2019. During this cruise, the AIS equipment aboard the ship transmitted weather data at 3-minute intervals. Several different ASM formats were tested, including two developed specifically for this test to improve satellite reception. This report will discuss the concept, the demonstrations, and the results to date including the efficacy of the various ASM formats.

1 INTRODUCTION

On the morning of 1 October 2015, the U.S.-flagged containership *El Faro* foundered and sank approximately 40 nautical miles northeast of Acklins and Crooked Island, Bahamas, while sailing close to the eye of hurricane Joaquin. The U.S. National Transportation Safety Board (NTSB) and U.S. Coast Guard (USCG) investigated the sinking; the NTSB's final report on the sinking [1] stated: "collection and near real-time dissemination of meteorological and oceanographic data is vital to… produce the best possible weather forecasts and advisories to keep mariners safe" and included the following recommendation addressed to the National Oceanic and Atmospheric Administration (NOAA):

Coordinate with the National Weather Service, vessel operators, automatic identification system (AIS) service providers, and required onboard technology vendors to perform a "proof-of-concept" project to establish whether AIS, or another suitable alternative, can practically deliver, in a single message, (1) meteorological and oceanographic data obtained directly from automated instrumentation and manual observation on board vessels at sea, (2) vessel position and time of observation, and (3) other important metadata, by satellite and land-based receivers, to global meteorological authorities via the Global Telecommunication System with acceptable time delay.

Currently NOAA runs the U.S. Voluntary Observing Ship (VOS) program [2, 3] as the U.S. component of the World Meteorological Organization (WMO) VOS [4]. Under this program ships voluntarily submit weather observations to NOAA. However, this data is submitted infrequently, typically four times per day and is primarily a manual process. Many ships participating in the VOS program use the TurboWin software [5, 6] to enter weather observations which are then sent to NOAA (or other meteorological offices) via email. This software allows for all observation data to be entered; however, it still requires the mariner to manually collect and enter it. One method being explored to automate and increase the frequency of data submittal is by using weather sensors, connected to an application that receives sensor data and converts it onto AIS messages, which are then transmitted using the ship's installed AIS transceiver.

AIS was originally designed primarily as a situational awareness tool, aiding in ship-to-ship collision avoidance, provision of vessel traffic services from shore authorities, and allowing coastal states to monitor their waters [7]. However, in addition to allowing the monitoring of ship locations, AIS may also be used for the transmission of other information between AIS stations onboard and ashore. This has been used extensively in the U.S. for the transmission of navigation safety information from shore to ship including weather, water levels, lock queues, navigation restrictions, etc. [8-10]. It could also be used to transmit weather information from ship to shore.

2 AIS WEATHER TRANSMISSIONS CONCEPT

There are three main components needed on the ship to generate and send an AIS weather message:

1 A source of weather data presented in a recognized industry standard.
2 An AIS transceiver.
3 A processor to take the sensor's weather data and format it for transmission.

To receive and use the messages on shore there are two main components:

1 An AIS receiver network.
2 A process to convert the received AIS messages into the desired format for input into the NOAA database.

This complete system is shown in Figure 1.

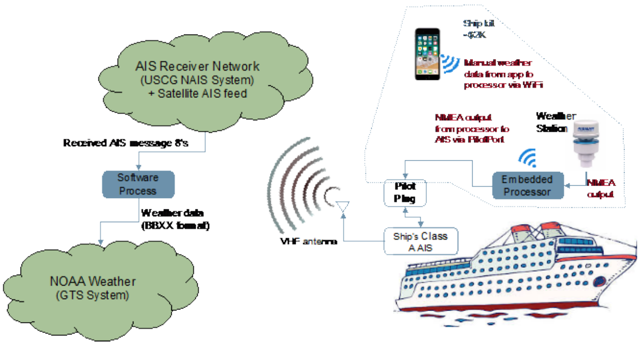

Figure 1. System Diagram.

The best source of real-time weather data is from a digital weather station because it generates the data automatically at up to a 1 Hz interval. There are numerous commercial options on the market that measure barometric pressure, wind (speed and direction), air temperature, dew point, and humidity and output the data in National Marine Electronics Association (NMEA) 0183 sentences [11]. Equipment used during our tests were the Airmar 220WX weather station and the Mintaka Duo weather station. The Airmar weather station contains a GPS and a variety of sensors to provide position, roll, pitch, true wind speed and direction, pressure, air temperature, and relative humidity data as NMEA 0183 messages via a RS-422 serial connection. The Mintaka weather station provides pressure data from dual sensors as TurboWin sentences via a USB connection. The weather station data can be directly read by a computer process and converted into an AIS message. Data from the weather station can be accumulated (averaged) and sent automatically without mariner intervention, allowing for more frequent weather updates.

Since some ships in the VOS program use TurboWin to enter marine weather observations, this can also be used as a source of data to be included in AIS transmissions. All of the data entered in TurboWin is encoded into ship's synoptic code (FM 13-X) [12, 13] and written to a text file for later transmission. This text file can be read by a computer process and converted into an AIS message. The data generated by TurboWin is more complete (includes sea state, wave heights, visibility, etc.); however, it is manually entered and typically only entered every 6 hours.

To maximize the use of the available data, both options can be used simultaneously. The manual TurboWin data can be combined with the automatic weather station data and coded into the message for transmission. The resulting message will thus be a full data set made up of a combination of data from TurboWin (which may be older) and up-to-date weather station data. Some of the ASMs allow for different time stamps for the different data fields so that this difference in age of the data can be communicated to the shore user.

Most commercial ships (in particular those subject to the International Maritime Organization's (IMO) Safety of Life and Sea (SOLAS) convention) have a Class A AIS transceiver [13] installed to comply with mandatory carriage requirements. Many vessels not required to carry AIS equipment voluntarily install AIS transceivers (either Class A or B). All of these AIS transceivers (except for the Class B "CS") can be used to transmit an AIS message 8 (broadcast binary message) by sending the transceiver an appropriately formatted NMEA sentence (BBM) [11].

The "glue" between the weather data and the AIS is a computer process. This can be an application running on the same computer as TurboWin, or if TurboWin is not used, it can be a separate "black box" processor. The computer process takes the weather data (both automatic and manually-entered) and creates the AIS application-specific message (ASM) [14-16] and embeds it in the NMEA BBM sentence for transmission. This can be done as often as desired (e.g., intervals of minutes rather than hours). The process can also average the real-time data from the weather station over whatever interval desired (10 minutes is what is defined in the VOS Handbook [12]). This process can also monitor the data transmission and push the message to the AIS transponder again if it fails to transmit the first time (the Class A will attempt to transmit a broadcast binary message using Random Access Time Division Multiple Access (RATDMA) within 4 seconds of receiving the BBM sentence, but transmission is not guaranteed). The complete ship-side data flow is shown in Figure 2.

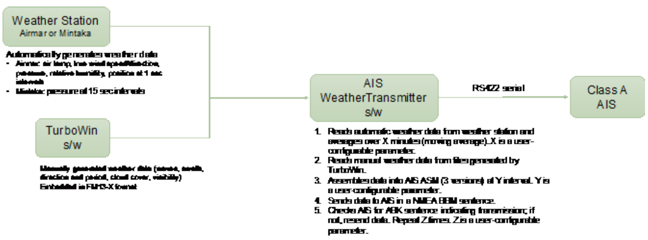

Figure 2. Ship-side data flow for AIS weather transmission.

On the shore side, these AIS messages will be received by terrestrial shore receiver networks when within range, as well as by satellite AIS networks (worldwide). For our tests, reception was via the USCG's Nationwide AIS (NAIS) network for coastal coverage and 2 commercial satellite AIS providers for offshore coverage. The key component on the shore side is the software processor that takes in the AIS data feed (in NMEA 0183 format) from the receiver network, isolates the AIS message 8s, parses the sentences to retrieve the data, and then reformats it into the desired format (BBXX [12] or BUFR [17] messages) for sending to NOAA over the GTS (see Figure 3). For the proof-of-concept, there is no error-checking of the weather data; however, this could be added to the software on the shore-side to discard data that is out of normal parameters.

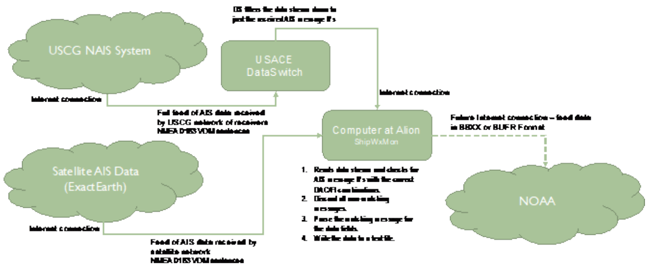

Figure 3. Shore-side data flow for weather messages via AIS.

3 PROOF-OF-CONCEPT TESTING

The concept described above has been tested on two ships to date, the *MV Cape Wrath* and the *TS Kennedy.*


Figure 4. MV CAPE WRATH. Equipment was installed on bridge (see arrow).

3.1 *MV CAPE WRATH*

The first test was conducted on the *MV Cape Wrath* (see Figure 4) in October 2018. The *MV Cape Wrath* was moored in Baltimore harbor for the duration of the test. For this installation an Airmar 220WX was used as the weather station; it was installed on the flying bridge with the cable running through a stuffing tube in the pilot house window (see Figure 5). The WeatherTransmitter and TurboWin software were running on a laptop computer. The laptop was placed on a ledge adjacent to the AIS pilot port; a cable from the pilot port was run to the laptop. A power strip plugged into the one available outlet was used to power the laptop and weather station (see Figure 6).

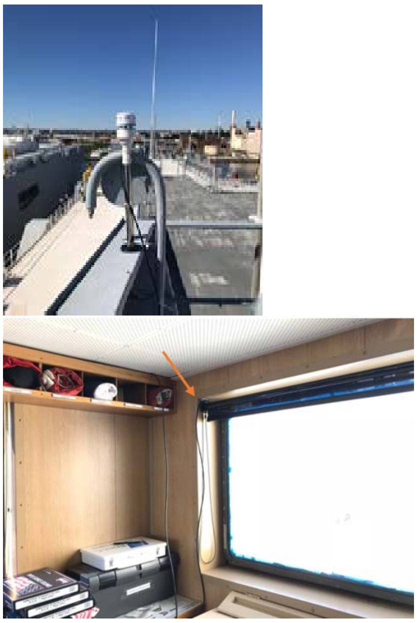

Figure 5. Airmar weather station mounted to rail (left) and cable coming through stuffing tube to bridge (right).

Figure 6. Left: Laptop (orange arrow) on ledge to the right of the pilot port (green arrow). Right: close-up of pilot port.

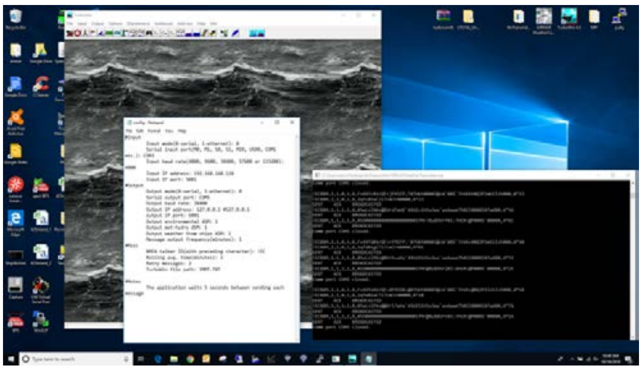

Figure 7. Screen shot of Laptop. TurboWin is in the back (wave picture) and AIS Weather Transmitter is the black window to the right. The configuration file for AIS Ship Weather is open as well (white window). You can see the messages being successfully transmitted in the AIS Weather Transmitter window.

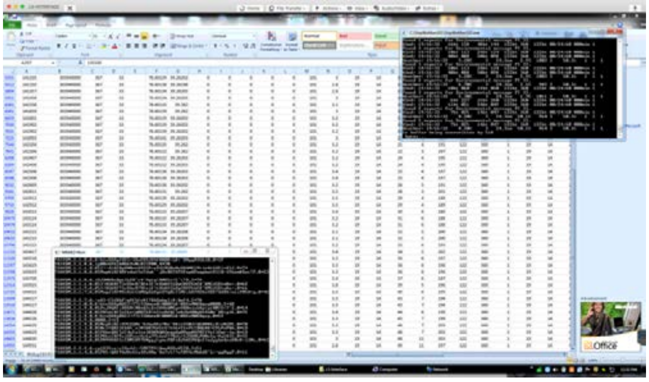

Figure 8. Shore side software (Ship Weather Monitor) is running in upper right window. The CSV file of logged data is shown in the background with reports from the CAPE WRATH (MMSI 303940000) showing.

The system successfully created and transmitted AIS messages using data automatically generated by the weather station and manually entered using TurboWin. Figure 7 shows the software running on the laptop. The messages were received by the USCG NAIS network and routed to the Ship Weather Monitor process running on a computer at Alion Science in New London. The received messages were parsed and put into a text file (see Figure 8).

Some lessons learned from this initial prototype:

– The system worked as planned.
– The installation of the weather station and laptop was very simple and not time-consuming.
– We found that the ship's pilot port was not correctly wired. This is a common problem according to ship's pilots. We thought we had this solved with a pilot port cable that was auto-sensing; however, it turns out that it only accounts for transmit and receive being swapped, not the individual transmit or receive pairs being reversed. Since most pilots are not transmitting with the AIS, most ships have never tested this part of the connection so any installation needs to be prepared for the possibility that the wires are reversed. It might be worth creating an inline wire-swapping box to enable quick correction of these types of errors in the future.

3.2 *KENNEDY*

The second and longer test was on the Massachusetts Maritime Academy training ship *Kennedy* (see Figure 9) during their winter cruise from 12 January through 26 February 2019. This was the first real-world test of the ability to collect, process and transmit weather observations from the ship via the ship's installed AIS transceiver of a ship sailing offshore. The goals of the test were to:

– demonstrate transmission of both automated and manually entered weather data from ship;
– demonstrate the ability to receive the data from terrestrial and satellite receivers; and
– demonstrate the ability to decode and save the data in various formats.

Figure 9. Training Ship Kennedy.

A laptop with the Weather Transmitter and TurboWin software was installed on the bridge and connected to the AIS via a pilot port installed near the chart table (see Figure 10). The laptop was connected to the ship's Mintaka Duo weather station via USB. Weather data was collected automatically from the weather station as well from the data file created by the TurboWin application. During the cruise the bridge crew and cadets entered the data hourly. This weather information was compiled every three minutes into several different AIS messages and sent to the ship's AIS Class A transceiver via the pilot port for transmission every three minutes. The software creating the messages created a log file of every attempt to transmit messages, a copy of the messages, and whether the transmission from the ship's transceiver was successful. See Figure 11 for a picture of the software running on the laptop.

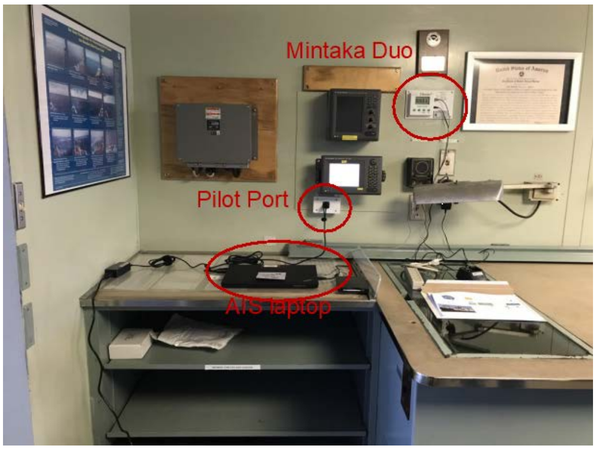

Figure 10. Equipment installation on the TS KENNEDY.

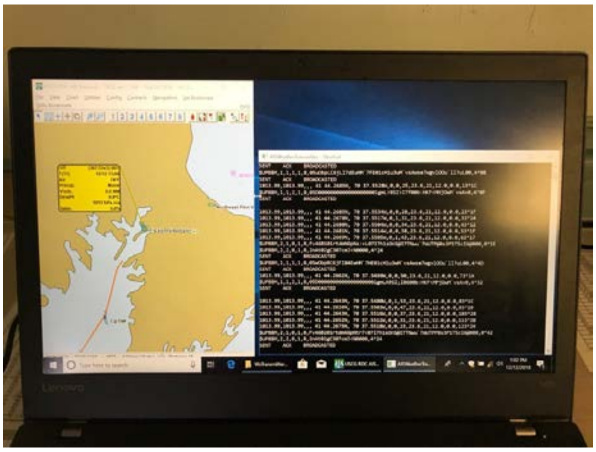

Figure 11. Weather Transmitter and Electronic Charting software running on the laptop on the KENNEDY.

Messages were received via the USCG NAIS network of terrestrial transceivers when *Kennedy* was within range. The USCG provides the U.S. Army Corps of Engineers (USACE) with a live feed of their data; this was filtered to only collect messages transmitted by *TS Kennedy* and sent to Alion Science, the USACE contractor for this effort, where they were logged and parsed to extract the weather observation data, which was also logged. ExactEarth, a provider of satellite-based AIS information provided a live feed of the data they received from *TS Kennedy*. Another satellite AIS provider, Spire Global, agreed to provide a data file at the conclusion of the test of data their system received from *TS Kennedy*.

4 DATA RESULTS

4.1 *ASMs*

Initially three different ASMs were transmitted (see Table 1) to assess the differences between them. These three ASMs are all part of existing standards. Mid-way through the cruise, two additional (shorter) ASMs were developed to try to improve satellite reception. A software update was pushed to the ship and starting on 29 January these additional two ASMs were transmitted along with the initial three.

Table 1. ASMs Used During KENNEDY test.

DAC	FI	Title	Marker Color	Notes
1	21	Weather observation report from ship	Blue circle	Circ 289 ASM, 2 slots (360 bits)
1	31	Meteorological And Hydrographic data	Cyan diamond	Circ 289 ASM, 2 slots (360 bits)
367	33	Environmental Message	Black +	ASM developed by USCG RDC and used by the USACE, multiple (typically 3) slots (470 bits)
367	23	Satellite Ship Weather	Red +	Test ASM – single slot weather data (168 bits)
367	24	Satellite Ship Weather Small	Magenta +	Test ASM – less than single slot weather data (128 bits)

4.2 *Transmit*

Figure 12 shows the locations of all transmissions from the KENNEDY. The ship regularly transmitted AIS messages 1 and 3 (position reports) and message 5 (static information) per the ITU Standard [18]. The message 1s are plotted as yellow •s (but not visible at this scale). These could have been as often as every 2 seconds. The ship additionally transmitted AIS message 27s (Long-range AIS broadcast message). These were transmitted at 3 minute intervals during the entire cruise, and are plotted as black •'s.[1] The ASMs (see Table 1) were also transmitted at 3-minute intervals. These are indicated in Figure 12 with the colors indicated in Table 1. There was a large gap in the southbound transit where the software was not working (due to a Windows 10 glitch that was resolved mid-way through the cruise) and thus there are no ASMs transmitted. In Figure 13, which is zoomed in on the ship's track north of Cuba, the different reports are more visible (except for the red and magenta + which are under the black +).

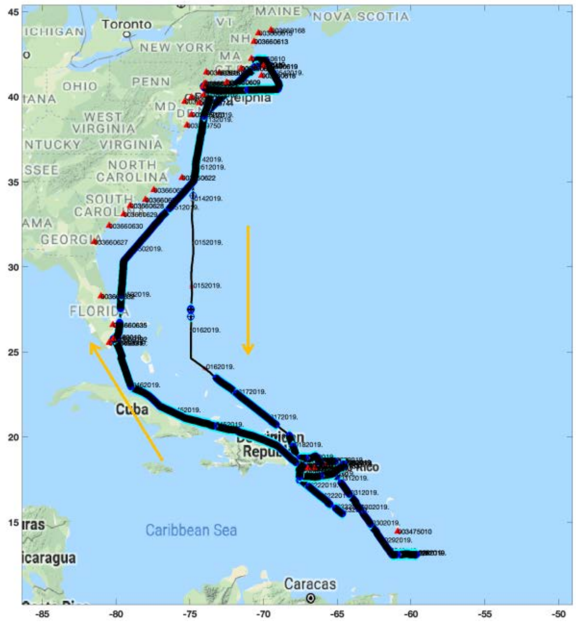

Figure 12. KENNEDY transit, southbound (on right) and back north (on left).

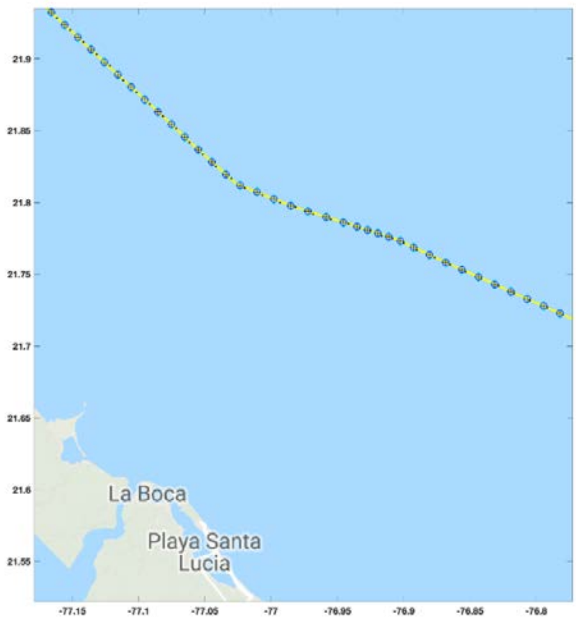

Figure 13. Close-up of part of the KENNEDY transit; north of Cuba.

[1] Typically message 27s would not be transmitted within range of a base station (the base stations received by the KENNEDY are marked on Figure 12 with red triangles); however, the AIS Class A must receive both message 4 and message 23 from the base station in order to turn off the message 27s and the USCG is only transmitting message 4s.

4.3 *Terrestrial Reception*[2]

When the ship was within range of a base station in the USCG NAIS network, the ASMs were all received at fairly high percentages (see Table 2). The lower percentage on day 53 is due to the ship not being in reception range of the terrestrial network the entire day. There also appears to be some correlation between number of slots and reception percentage; the shorter messages are received with a higher percentage than the longer. This is to be expected since the ASMs are sent in RATDMA mode.

Table 2. Terrestrial Reception Percentages (slots in parens).

Day	FI 21 (2)	FI 23 (1)	FI 24 (<1)	FI 31 (2)	FI 33 (3)
051 2019	89.96%	90.79%	92.90%	89.73%	89.33%
052 2019	85.36%	88.10%	87.87%	86.01%	83.89%
053 2019	65.62%	69.25%	70.08%	65.63%	65.00%
054 2019	97.90%	98.53%	98.11%	98.74%	96.44%
055 2019	97.28%	98.54%	96.65%	97.28%	96.23%
056 2019	94.76%	95.80%	96.01%	92.66%	92.45%
057 2019	95.36%	96.83%	98.31%	95.15%	92.81%

4.4 *Satellite Reception*

The percentage of messages received via satellite was much lower than originally expected. Although the authors have not seen any reception statistics from the satellite providers, the impression given is that most messages are received. This was definitely not our experience. Figure 14 shows all of the AIS messages received via satellite from the KENNEDY. The color-coding is the same as listed in Table 1, except that +'s are used for all of the ASMs. In the first part of the transit, it was noticed that the reception of the ASMs was very poor, so two additional ASMs were quickly developed: one that was a single slot (168 bits), and one that was less than a single slot (128 bits). These were added into the transmit software and were broadcast starting on day 29. The long southbound stretch with no transmissions is when the software was offline due to the Windows 10 issue discussed previously.

[2] While not part of this test, messages transmitted by the TS Kennedy could also be received aboard other vessels. It is assumed that most vessels do not have the capability to parse and display the received messages. However, on at least one occasion TS Kennedy was contacted by a nearby ship and asked about the weather data that appeared on the nearby ship's navigation display near the Kennedy. It is assumed that the manufacturer of the navigation equipment used aboard the nearby vessel incorporated the ability to display at least one of the ASMs (likely DAC 1, FI 21 or 31) on their systems. This may be a consideration for wider implementation of this capability, to address concerns such as "screen clutter" and "information overload."

Table 3. Sample Satellite AIS Reception Percentages.

Day	% Msg 1	% Msg 3	% Msg 27	% F21	% F23	% FI24	% FI31	% FI33
029 2019	0.40%	5.2%	64.4%	0.64%	2.38%	7.14%	1.07%	0.00%
030 2019	0.43%	5.7%	75.0%	0.47%	3.53%	6.13%	1.41%	0.00%
031 2019	0.32%	4.1%	62.8%	0.27%	1.89%	4.05%	1.62%	0.00%
032 2019	0.14%	1.7%	61.5%	0.21%	2.08%	2.51%	1.04%	0.00%
033 2019	0.00%	3.1%	63.1%	1.05%	2.73%	2.94%	0.21%	0.00%
034 2019	0.00%	3.1%	66.7%	0.42%	3.35%	4.61%	0.42%	0.00%
035 2019	0.07%	2.3%	65.8%	0.64%	1.91%	6.37%	0.21%	0.00%

Table 4. Additional Satellite AIS Reception Data.

Day	% Msg 1	% Msg 3	% Msg 27	% F21	% F23	% FI24	% FI31	% FI33
051 2019	0.09%	0.6%	68.5%	0.21%	0.41%	0.63%	0.00%	0.00%
052 2019	0.08%	7.0%	67.7%	0.21%	1.88%	9.60%	0.21%	0.00%
053 2019	0.06%	8.0%	71.9%	0.21%	2.92%	15.27%	0.21%	0.00%
054 2019	0.19%	3.8%	75.2%	0.42%	3.35%	2.93%	0.00%	0.42%
055 2019	0.01%	18.9%	77.3%	0.21%	3.98%	24.11%	0.21%	0.00%
056 2019	0.00%	24.6%	63.8%	0.00%	5.02%	21.97%	0.63%	0.00%
057 2019	0.08%	18.8%	70.2%	0.84%	6.93%	22.90%	0.84%	0.63%
058 2019	0.33%	20.7%	68.3%	0.42%	3.59%	22.78%	1.27%	0.21%

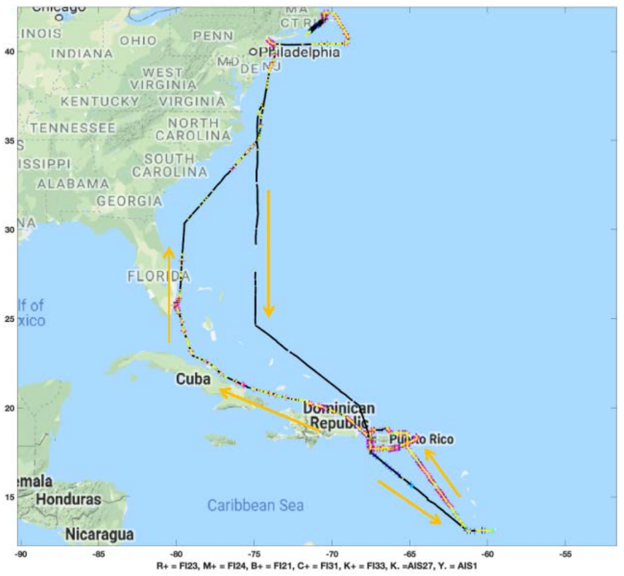

Figure 14. AIS reports received via satellite.

Table 3 is a sampling of satellite reception results for when the KENNEDY was in transit between Barbados and the British Virgin Islands (after the new ASMs were added). The reception percentage for all of the ASMs was very low. There is a very strong correlation with message length: the longest ASM (FI33) was not received at all, and the shortest (FI24) was received the most. The AIS message 1's were received less than 1% of the time. Interestingly the message 3's were received at a higher percentage (though still low). After consultation with the satellite provider, we determined that this was due to their filtering of the data to 1 message of each type (1,3,5) in every 10 minutes. Also of note is that the reception of AIS message 27 was the best by far; this is because these messages are only 96 bits long and more importantly, are transmitted on two different VHF channels (75 and 76) and thus avoid any conflict with AIS traffic on channels AIS1 and AIS2.

Data from the end of the transit is shown in Table 4. Of interest are the times that the vessel was in port. On day 53 the *Kennedy* was in New York and days 55-58 she was back at homeport (Bourne, MA). On these days the reception of most messages was significantly higher. After consultation with the satellite provider we determined that we had also been receiving some messages via terrestrial receivers, which skewed these results (except for the message 27s which are only received via satellite). We also discovered that due to overlapping satellite coverage, at times we received duplicate message 27s; these duplicates have been removed from the data before the percentages in Table 3 and Table 4 were calculated.

5 CONCLUSIONS

It is clear from the data reviewed thus far from this single voyage that reception of weather ASMs when in range of shore stations is very reliable, on the order of 90%. This was not a surprising result. Of more interest are the results for satellite reception. In particular, that smaller ASMs are received much more reliably via satellite. The downside of the smaller messages is less data. The largest message (ASM FI 33) carries the most met/hydro data and also has time stamps for each data element allowing for the most information transfer. This message however, does not work well with the satellite link. It should also be noted that although the percentage of messages received via satellite is low, it is still more messages per day than the number of synoptic reports that a vessel would typically send (i.e., 4).

6 RECOMMENDATIONS/FUTURE

Some avenues for further research are:

- Another test ASM will be developed to reduce the size to 96 bits (the same as the AIS message 27). To reach this size, the position will be dropped from the weather ASM, and we will assess the feasibility of linking the received weather ASM to the position from the AIS message 27s.

- Additional ship testing is planned, using a larger pool of vessels (perhaps 10). Testing satellite reception on trans-oceanic voyages may also increase satellite reception for multi-slot messages, due to fewer vessels being in the satellite footprint.
- Expanded tests aboard commercial vessels would be beneficial from several aspects:
- Evaluating this capability in various environments (coastal, deep sea, Great Lakes, transoceanic, etc.)
- Gathering information about the different weather collection capabilities and AIS equipment aboard commercial vessels
- Gathering feedback and concerns from vessel and shipping company personnel
- Gathering more data to test reception from other terrestrial and satellite sources
- For the additional ship testing, a small embedded processor will be used to assess the feasibility of small, low-cost, hands-off kits for wider installation.
- Beginning work on the back end requirements for decoding, routing, quality checking, and using the received observations in modelling, forecasting, and other systems.

ACKNOWLEDGEMENTS

This work has been a partnership between USACE, U.S. Maritime Administration (MARAD), and NOAA. The shipboard data collection was supported by the Chief Engineer on *MV Cape Wrath*, and by the Captain and crew of *TS Kennedy*, especially Arthur Levine and Steve Gardiner. Evaluation of the feasibility of satellite reception of the AIS weather messages would have been impossible without the in-kind contributions of satellite AIS data by ExactEarth and Spire Global.

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