NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division
Washington, DC 20594

May 19, 2011

# Tugboat True Heading Study

**Specialist's Study Report**
**By Christopher Babcock**

## 1. EVENT

| | |
|---|---|
| Location: | Philadelphia, Pennsylvania |
| Date: | July 7, 2010, 14:37 Eastern Daylight Time (EDT) |
| NTSB Number: | DCA10MM025 |

## 2. SUMMARY

The Safety Board obtained AIS data transmitted from the *Caribbean Sea* around the time of the accident. Examination of the data revealed an anomaly in true heading and course over ground (COG) data. Specifically the true heading data transmitted by the AIS system was consistently offset approximately 10-12 degrees to the right of its COG. Accurate true heading information was necessary to evaluate the visibility from the lower and upper wheelhouse on the *Caribbean Sea*. The purpose of this study was to investigate potential sources and corrections of this anomaly.

This study was conducted in two parts. The first part examined satellite compass readings and compared them to heading data contained in AIS position reports.[1] The second part used images from the *Caribbean Sea's* radar display to determine if it was possible to quantify the bias between the AIS heading data and actual true heading.

## 3. DETAILS OF INVESTIGATION

Ship's heading relative to its COG can be influenced by, among other things, the effects of wind, current, turns, and presence of tow. The *Caribbean Sea* utilized a Furuno SC-50 satellite compass to determine true heading and report that information to the AIS equipment for broadcast. A satellite compass is comprised of multiple GPS antennae and differs from a magnetic compass in that it senses the difference in arrival time of GPS satellite signals to each antenna to determine heading instead of variations in the earth's magnetic field. The three antennae that comprise the SC-50 system are used to reduce the influence of pitch, roll, and yaw, and five GPS satellites are used to process 3-D data. If the GPS signal is blocked by a bridge or other obstructions, internal 3-axis solid-state angular rate gyros maintain the current heading.

AIS data from the *Caribbean Sea* earlier in the accident day was examined. During the period from 1148 to 1150 the tug was transiting without a load from the River Associates dock at the Philadelphia Navy Yard to pick up a barge. During this passage

[1] AIS data was received at shoreside antennae and archived by the Coast Guard

when the tug was not turning, the tug's COG and heading should be coincident, other than the minimal effect of current. The data show that the AIS heading was consistently 10-12 degrees to the right of the AIS COG data (Table 1).

**Table 1.** Comparison of COG and heading during no-load operation on day of accident.

| Time (EDT) | COG (º) | Heading (º) |
|---|---|---|
| 1148:45 | 280.5 | 293 |
| 1148:56 | 280.9 | 294 |
| 1149:07 | 281.7 | 295 |
| 1149:16 | 282.1 | 295 |
| 1149:28 | 282.5 | 295 |
| 1149:36 | 281.9 | 294 |

## *3.1. Satellite Compass/AIS Data Consistency Check*

The first part of the study compares satellite compass readings with true heading data from AIS position reports at or near the time of the satellite compass observation. Photographic and video evidence from the on-scene portion of the investigation were reviewed for images containing the on-board satellite compass display and valid time references to compare against recorded AIS data.

Figures 1 & 2 were obtained from the Coast Guard who boarded the *Caribbean Sea* shortly after the accident on 7 July 2010.[2] Figure 1 shows the satellite compass reading 13.8º. The GPS display, which contains time, is also visible, however the glare on the screen obscures the time reference on the unit, however Figure 2 contains a legible time reference on the GPS display (1648:53 EDT). Examination of the Exif data from Figures 1 & 2 indicate that the image in Figure 2 was taken 9 seconds prior to the image in Figure 1, thus the satellite compass reading in Figure 1 occurred at 1649:02 EDT.[3] The closest AIS position report was transmitted at 1649:04 EDT with a true heading of 13º, within approximately 1 degree from the satellite compass displayed heading in Figure 1.

[2] All images in this study can be found in full resolution in the public docket for this accident.
[3] Exif, or Exchange Image File Format, data is information embedded into the image file such as date, time, resolution, focal length, etc.

**Figure 1.** Satellite compass reading.

**Figure 2.** Time reference.

Figures 3 & 4 are image captures taken as a video camera pans over the instrument panel in the lower wheelhouse and show a similar time/heading comparison. The video was from an exemplar voyage on the *Caribbean Sea* on 15 July 2010. The time reference cannot be compared to recorded AIS data, as the AIS dataset from 15 July is from a different source than the Coast Guard and the timestamp of the AIS data is known to have several minutes uncertainty due to the restraints of the recording system; however, position, speed, and course data displayed on the GPS unit can be compared to position data from the AIS dataset to determine the correct position report to compare to the observed heading from the satellite compass (Figure 4).


**Figure 3.** GPS display.

**Figure 4.** Satellite compass display.

Table 2 contains the AIS data that is the best match for the position, course, and speed in the GPS display in Figure 3. Satellite compass heading displayed on board the ship is within approximately 1 degree of the heading reported by the AIS transceiver.

**Table 2.** Comparison of AIS data with ship's navigational equipment.

| | Time (EDT) | Latitude (° North) | Longitude (° West) | COG (°) | SOG (kt) | Heading (°) |
|---|---|---|---|---|---|---|
| GPS display | 1012:04 | 39.8955 | 75.2085 | 119[a] | 6.3 | 121.7 |
| AIS position report | 1018:27 | 39.8956 | 75.2087 | 118.4 | 6.3 | 121 |

[a] COG is reported to nearest degree on Furuno GPS display

[b] Heading is reported to nearest degree on AIS position reports

Figures 5 & 6 show another similar comparison. Speed, course, and heading from Figures 5 & 6 were compared with AIS position reports at the same position shown on the GPS receiver in Figure 5.

**Figure 5.** GPS display.

**Figure 6.** Satellite compass display.

Table 3 contains the AIS data that is the best match for the GPS display data in Figure 5. Satellite compass heading displayed on board the ship is within approximately 1 degree of the heading reported by the AIS transceiver.

**Table 3.** Comparison of AIS data with ship's navigational equipment.

| | Time (EDT) | Latitude (º North) | Longitude (º West) | COG (º) | SOG (kt) | Heading (º) |
|---|---|---|---|---|---|---|
| GPS display | N/A[a] | 39.9381 | 75.1381 | 35[x][a] | 5.4 | 6.[x][a] |
| AIS position report | 1128:02 | 39.9376 | 75.1379 | 348.5 | 5.5 | 5 |

[a] Time, least significant digits of course over ground and heading on the GPS display were illegible.

In summary, Part 1 of the study determined that for the three points in the postaccident photographs and videos the satellite compass displayed on board was consistent with the true heading broadcast by the *Caribbean Sea's* AIS equipment.

## *3.2.* Caribbean Sea *true heading determination using radar*

Part 2 of this study attempted to determine the *Caribbean Sea's* true heading using its onboard radar display and compare that true heading to the heading reported by the onboard AIS equipment which, as established in Part 1 of this study, was consistent with the heading displayed on the satellite compass

Figure 7 shows an image captured by the Coast Guard upon boarding the *Caribbean Sea* shortly after the accident. The GPS display indicates the photo was taken at 1649:45 EDT.


**Figure 7.** Radar display and GPS display.

The image in Figure 7 was cropped to show the radar display only. Using the own ship position from the GPS display, the cropped radar display was overlaid into Google Earth, matching the radar returns with shoreside features (Figure 8). The radar operated in heads up mode with the line shown on the radar display indicating the ship's heading. The Google Earth measurement tool was used to determine the true heading of the ship by measuring the true heading of the radar heading reference line. The measurement tool indicated the ship's heading in this case was 1.9º. AIS data provided by the Coast Guard indicates that, for the closest position report at 1649:46 EDT, the true heading was 13º. Satellite compass displayed heading was biased approximately 11º to the right of the derived heading using the radar heading reference.

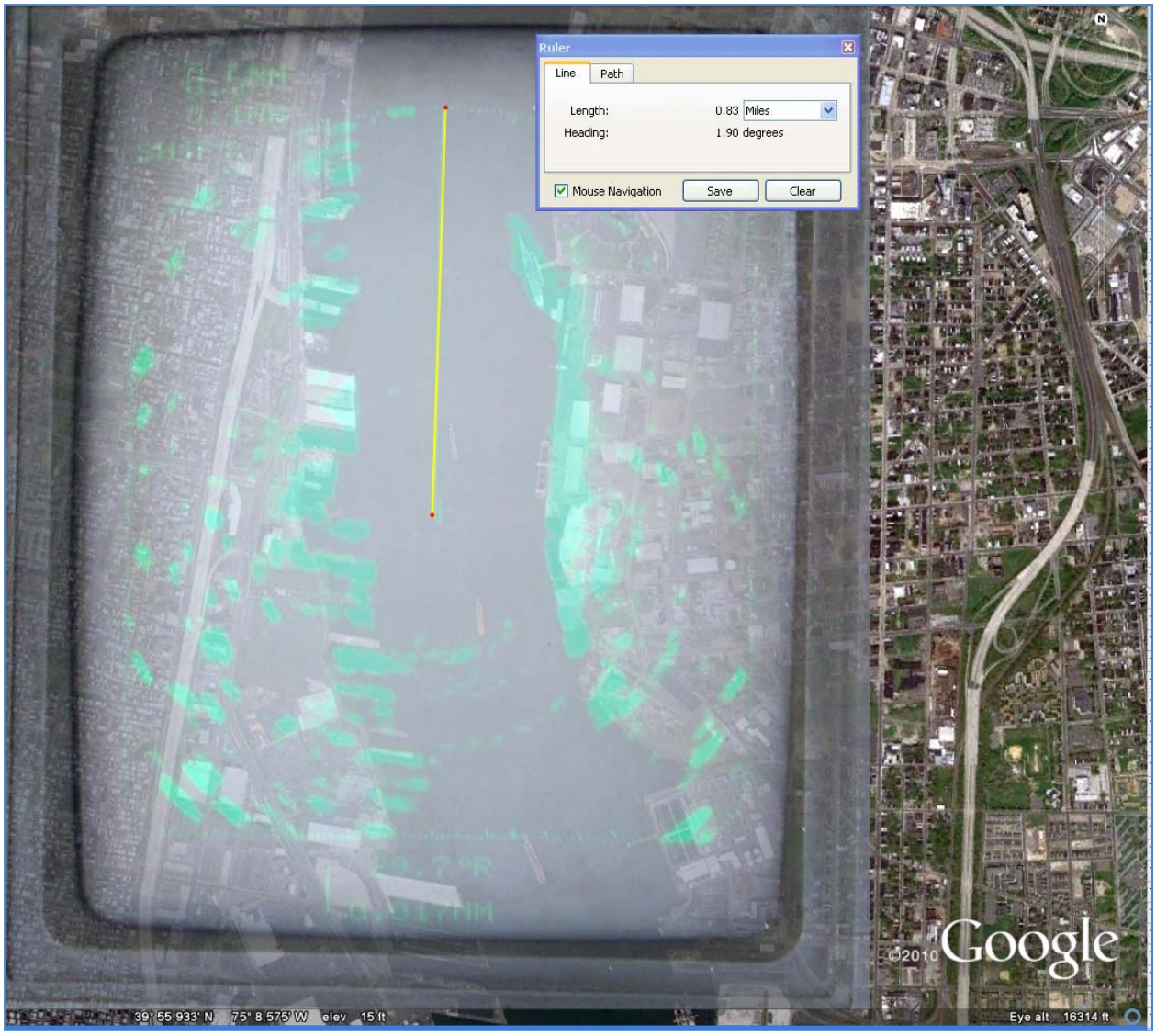


**Figure 8.** Radar overlay showing true heading.

The day following the accident the navigation and communication equipment was tested by a third party contractor at the River Associates facility at the Philadelphia Navy Yard. Figure 9 shows a photograph of the radar screen during this testing.


**Figure 9.** Radar image during equipment testing.

A cropped version of Figure 9 was overlaid on Google Earth using the bridges and shoreline and the radar heading reference line was again measured (Figure 10). The measurement tool indicated a true heading of 113.5º. Photos taken immediately prior to and following this test series show satellite compass readings of 123.8º and 123.5º true heading, respectively. Satellite compass displayed heading was biased approximately 10º to the right of the derived heading using the radar heading reference.

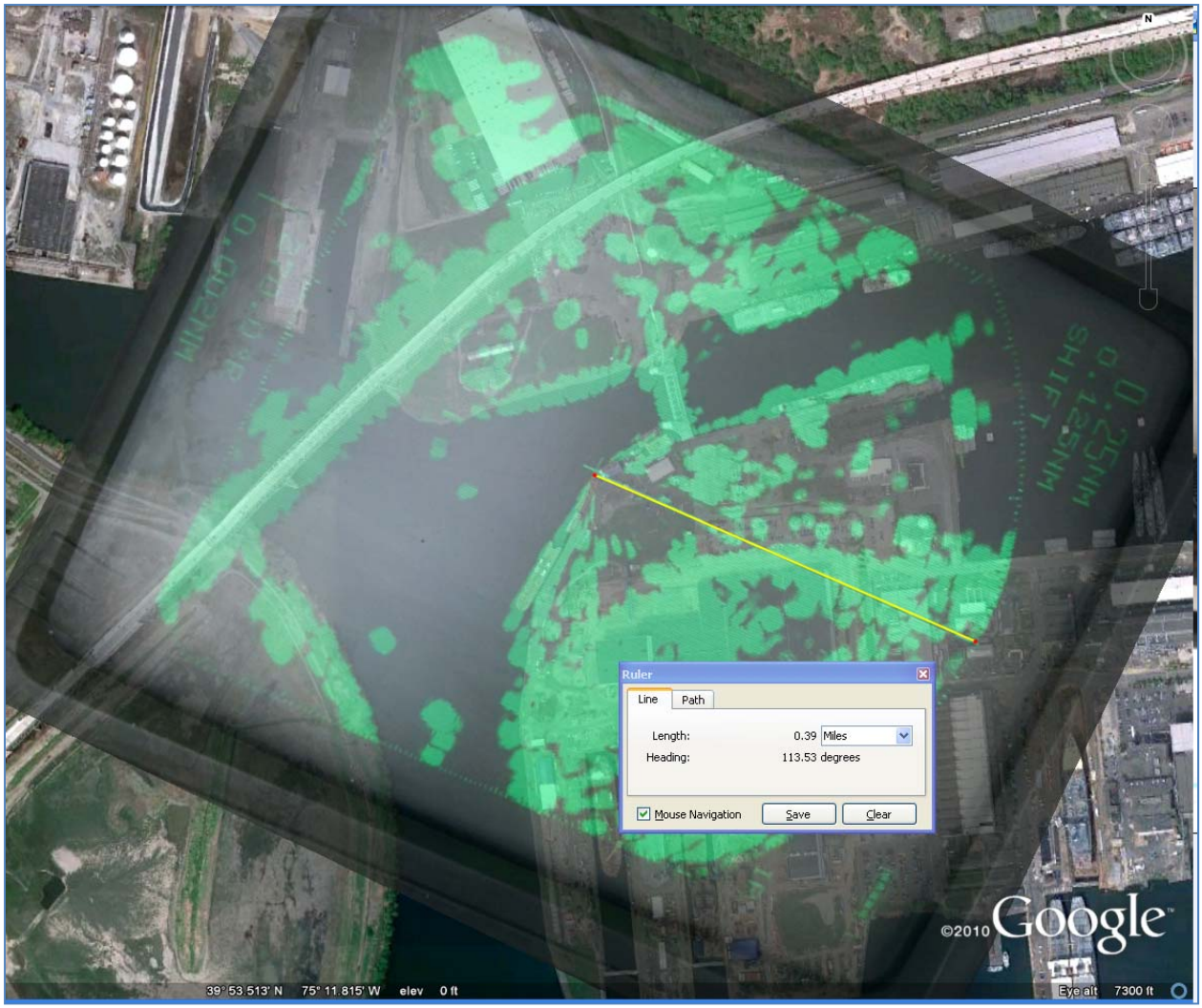


**Figure 10.** Transparent radar overlay showing true heading.

The *Caribbean Sea* made an exemplar voyage with investigators aboard on 15 July 2011, 8 days following the accident. High-definition video was taken of this voyage. Although AIS data from this transit was obtained and used in Part 1 of this study, due to limitations of the receiving equipment, the timestamp has an uncertainty of several minutes (the timestamp was not used in Part 1). Because the timestamp on the AIS true heading data was not precise, the video footage was examined for images of the radar display and satellite compass display in or near the same timeframe.

Figure 11 shows an image taken on the exemplar voyage. After overlaying the image in Google Earth, measurement of the true heading reference showed a true heading of 347.2º (Figure 12). Video footage caught an image of the satellite compass display right after the image in Figure 11 was captured and displayed 358º (Figure 13). The tenths of a degree digit was partially obscured, but it appears to show 358.1º. Satellite compass displayed heading was biased approximately 11º to the right of the derived heading using the radar heading reference.

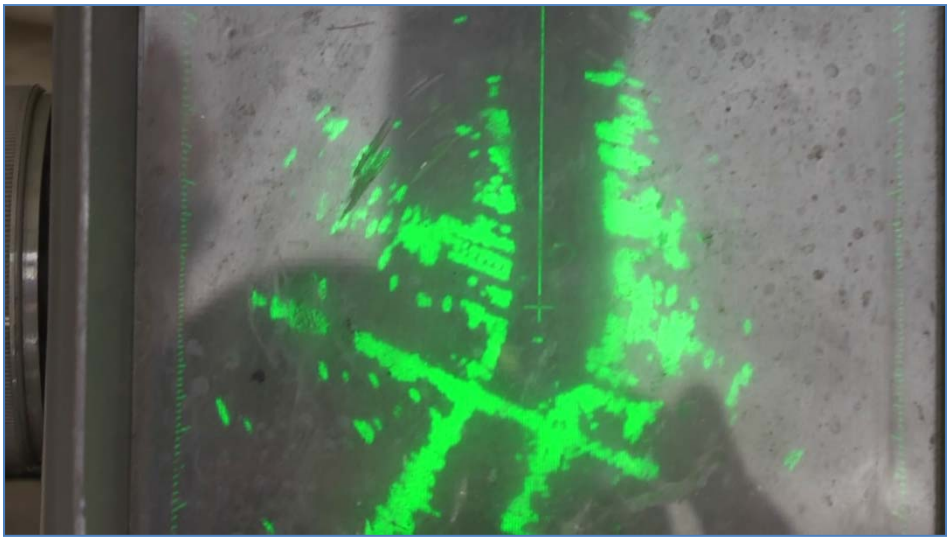

**Figure 11.** Image from exemplar voyage showing radar display.

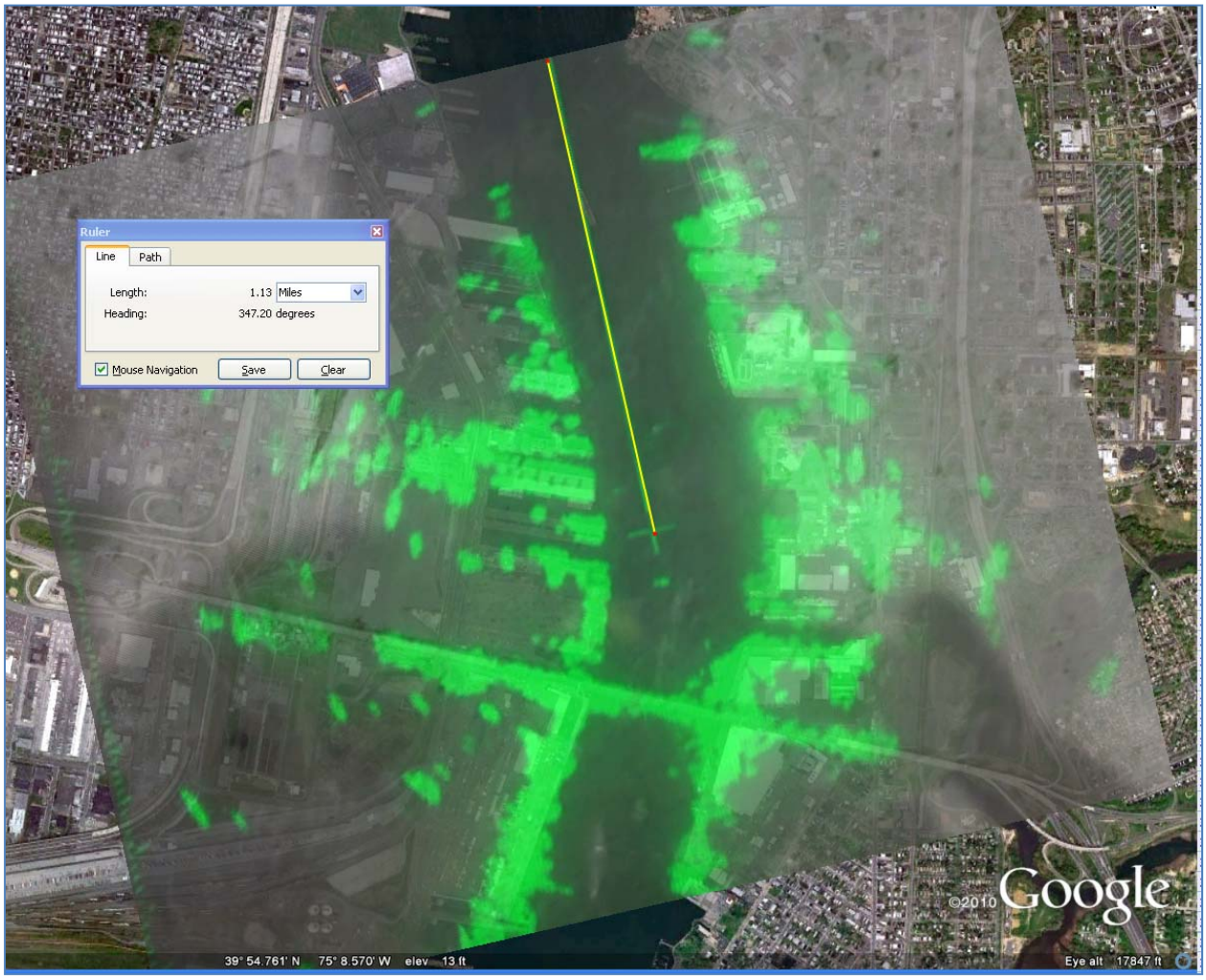


**Figure 12.** Transparent radar overlay showing true heading.


**Figure 13.** Satellite compass display.

Figure 14 shows another image from later in the exemplar voyage. After overlaying the image in Google Earth, measurement of the true heading reference shows a true heading of 4.0º (Figure 15).

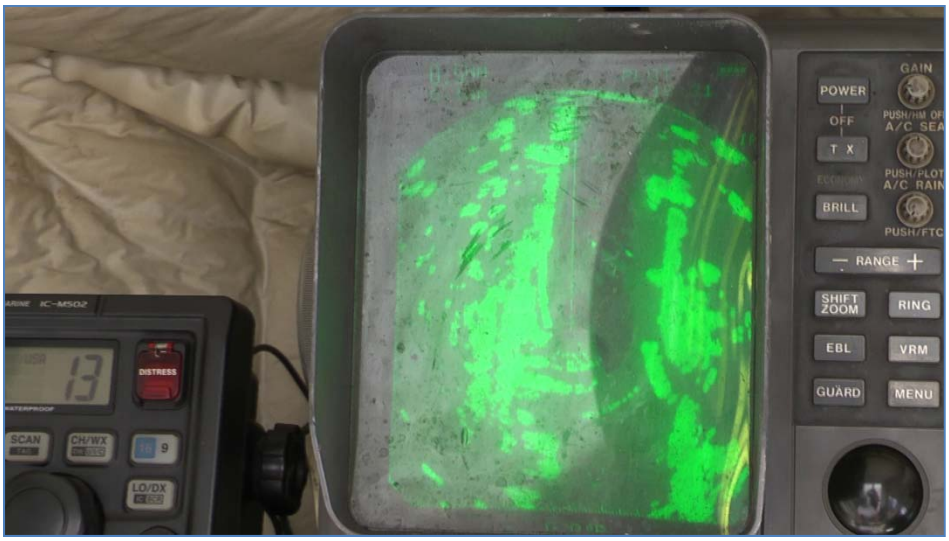


**Figure 14.** Image from exemplar voyage showing radar display.


**Figure 15.** Transparent radar overlay showing true heading.

Figure 16 shows what is visible of the satellite compass and GPS display at this time. As the AIS heading data and satellite compass displayed data were shown to be consistent in Part 1, the AIS heading data can be compared to the radar heading reference using the AIS position report nearest to the position shown on the GPS display. Table 4 shows this comparison. The AIS reported heading was biased approximately 11º to the right of the derived heading using the radar heading reference.

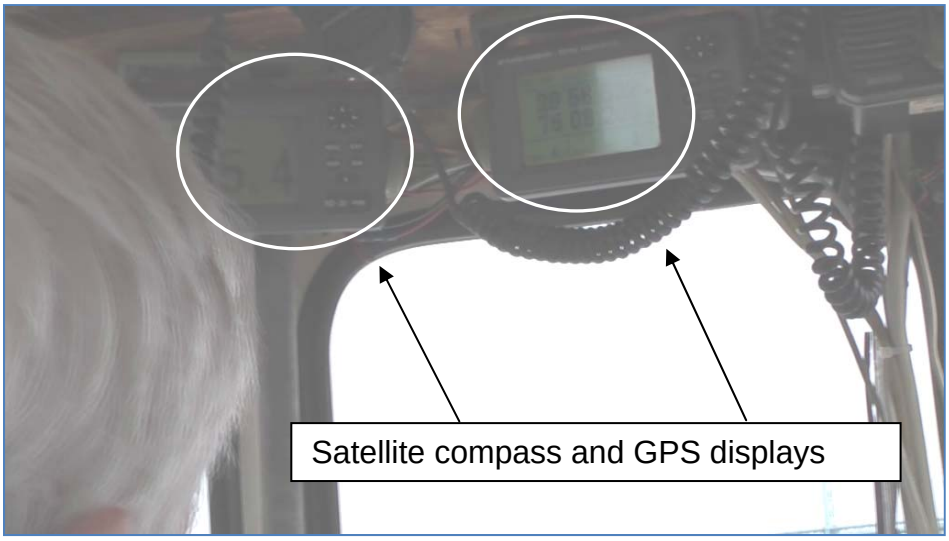


**Figure 16.** Satellite compass and GPS display.

**Table 4.** Comparison of AIS data with ship's navigational equipment.

| | Time (EDT) | Latitude (º North) | Longitude (º West) | COG (º) | SOG (kt) | Heading (º) |
|---|---|---|---|---|---|---|
| GPS display | N/A[a] | 39.9422 | 75.1381 | N/A[a] | 4.7 | [x]5.4[a] |
| AIS position report | 1131:23 | 39.9422 | 75.1383 | 2.3 | 4.7 | 15 |

[a] Time, course over ground, and the tens digit (if any) of heading on the GPS display were illegible.

## *3.3. Assumptions & Uncertainty*

This study relied on the assumptions that GPS data shown on the display was accurate to within the accuracy requirements of the equipment and that GPS position displayed was transmitted by the AIS equipment. The radar heading reference line was assumed to lie along the longitudinal axis of the tugboat.

Distortion of the radar image due to the incident angle between the camera point of view and the radar screen could induce some error, however this should be small as the camera point of view was nearly perpendicular to the radar screen in nearly all the images used. Placement of the image overlays in Google Earth was based on judgement of the best fit of the radar returns with shoreside features. There is uncertainty of less than a degree in the measured heading reference line in Google Earth. As AIS data is transmitted irregularly, it is possible for AIS reported heading to change by a small amount between the time of the AIS position report and the satellite compass display to which it was compared. This error should be limited as the rates of turn experienced on the exemplar voyage were small. Because rates of turns were small, the time difference, on the order of a few seconds, between the camera view of the radar display and associated satellite compass or GPS display should not affect the results of the study.

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