Teasing out the detail: how our understanding of marine AIS data can better inform industries, developments, and planning

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Highlights:

- Creation and maintenance of a vessel database was key to fast processing
- Density mapping provided an excellent overview of vessel activity
- Vessel tracks defined up-to-date vessel routes
- Large temporal variations in vessel activity were noted for 2013
- Interpolations provided spatial information on vessel dimensions and speed

Abstract

Automatic Identification System (AIS) is becoming increasingly popular with marine vessels providing accessible, up-to-date information on vessel activity in the marine environment. Although AIS has been utilised in several different fields to address specific questions, no published work has outlined the potential of AIS as a tool for a wide range of industries and users of the marine environment such as spatial planning, developments, and local marine industries (e.g., fisheries). This work demonstrates a procedure for processing, analysing, and visualisation of AIS data with example outputs and their potential uses. Over 730 000 data points of AIS information for 2013 from around Shetland were processed, analysed, and mapped. Tools used included density mapping, vessel tracks, interpolations of vessel dimensions, and ship type analysis. The dataset was broken down by sector into meaningful and usable data packets which could also be analysed over time. Density mapping, derived from both point and vessel track data, proved highly informative but were unable to address all aspects of the data. Vessel tracks showed variation in vessel routes, especially around island groups. Additional uses of AIS data were addressed and included risk mapping for invasive non-native species, fisheries, and general statistics. Temporal variation of vessel activity was also discussed.

Keywords:
Automatic Identification System (AIS)
Vessel Movement
Marine Spatial Planning
Marine Renewables
Fisheries
Vessel Tracking

1 Introduction

The Safety of Life at Sea (SOLAS) Convention was published in 2002 by the International Maritime Organisation (IMO) which required all marine vessels over 300 gross tonnage on an international voyage, all cargo vessels greater than 500 gross tonnage, and all passenger
vessels irrespective of size to be fitted with an Automatic Identification System (AIS) as standard by 2004 [1]. AIS is a shipboard transponder which automatically transmits vessel information, through VHF, as a ship to ship or ship to shore signal. Information is transmitted on a regular basis and includes information on the vessel identity (mmsi number), position, speed, course, vessel type, dimensions, and other information as outlined by Ou and Zhu [2].

An increasing number of marine users have recognized the benefits of having an AIS system fitted aboard their vessels which has resulted in a large quantity of available vessel data ranging from large oil tankers to pleasure craft and sailing ships. The European Commission has additionally stated that all fishing vessels greater than 15 m in length must be equipped with an AIS transmitter system by 31st May 2014 [3].

The majority of studies conducted using AIS information have focussed on specific areas such as: ship surveillance, tracking, and security [2, 4-11]; prevention of maritime disasters including collision risks [6, 12-26]; shipping noise levels [27-34]; or vessel emissions [35-41]. Only one known study [see 42] has looked at AIS as a tool for marine planning in order to better visualise spatial and temporal variation in shipping activity but the authors did not use all the available vessel types, did not take into account any temporal variation in shipping activity, and concentrated their results on interpolated vessel tracks.

The aim of this work is to highlight the potential of AIS as a tool for marine spatial planners, marine developers, Marine Protected Areas (MPA) developments, fisheries, and other marine industries on how to best represent, process, and analyse relevant information from the AIS system in order to better represent shipping activity. A methodology to processing the AIS data is outlined, prior to analysis in ArcGIS, highlighting common problems with the data and ways of quality controlling the information. The various analysis options available through ArcGIS are outlined, with graphical examples, and discussed. Analysis included vessel tracks and creating shipping routes (Sections 2.2 and 2.5), creating density plots using both vessel track data and point data (Section 2.3), the benefits of interpolation for added information (Section 2.4), breaking down the information into more manageable units such as marine industries (Section 2.5), and the temporal variation in the data (Section 2.6).

2 Materials and Methods
AIS data was obtained from a single land-based receiver aerial on Shetland (located at 60°08'41.32"N 001°12'23.906"W), with the data saved in a database managed by the NAFC Marine Centre. Data has been collected, saved, processed, and analysed since December 2012 and has been incorporated into the Shetland Islands’ Marine Spatial Plan [see 43].

2.1 Processing, problems encountered, and quality control
Monthly information was exported from the database as a text file and imported into an Excel spreadsheet for processing, quality control, and initial analysis, prior to the final analysis in ArcGIS (see Sections 2.2 to 2.6). AIS data (pings) were received every three minutes while steaming and every ten minutes when stationary. The database export included 22 fields of information per ping which can be classed as either static (information programmed into the AIS system when commissioned on the vessel), dynamic (outputs based on the vessel’s sensors), or voyage related (manually entered for each trip), as described by Ou and Zhu [2] (see Table 1). Of these 22 fields, five (mmsi, latitude, longitude, speed, and the timestamp) were considered essential for using AIS information to inform marine sectors on vessel activity.
with the mmsi number providing additional information on each vessel. These five fields were also found to be consistently accurate. Due to the variation in the reliability of fields relating to the vessel category and dimensions, it was necessary to create a ‘vessel database’ based on the mmsi number of each vessel. The vessel database was a way of quality controlling the vessel information and was deemed necessary in order to capture all vessel types accurately. All new vessels to the area were recorded into the vessel database and all fields checked for accuracy. Missing information was entered where possible and all vessels recorded with a vessel type code in the 90s were re-coded. Additional codes were added in order to encapsulate the offshore oil industry (excluding tankers) and research/survey vessels. The information from the vessel database was then linked with the initial AIS export. The timestamp was split into two columns of date and time with an additional two columns of month and year added. Speed was divided by ten to give a speed over ground in knots. All columns were checked for obvious outliers and, if possible, were corrected (e.g. a vessel’s speed may be recorded as 50 knots, when it should read close to 0 knots, but the position might have the vessel listed as being in port or the previous timestamps may indicate the vessel is stopped or moving slowly). If it was not possible to correct an obvious outlier, the outlier was removed. The only vessel types to be removed were those classed as VTS (Vessel Traffic Services – static, land-based, receiving stations). The information was saved and a point shapefile was created in ArcGIS.

**TABLE 1 ABOUT HERE**

2.2 Vessel tracks and shipping routes
Using the Tracking Analyst extension in ArcGIS the date and time fields of the point shapefile were combined using the “Concatenate Date And Time Fields” function. It was then possible to create vessel tracks for each mmsi recorded in the area for that month. Ship routing information was extracted from the data by displaying particular ship type codes (e.g. ferry routes). A polyline was edited to create ship-specific routes and the limits of each route, based on ship type vessel tracks, which could then be incorporated into a marine spatial plan.

2.3 Creating density maps
In order to be able to compare monthly datasets, an initial grid was created using the Create Fishnet function in ArcGIS at two resolutions of 1 km² and 0.25 km². A join was created between the grid and the point shapefile for each resolution, creating a gridded polygon shapefile for that month. In order to reduce disk space and increase processing speed, all count values equalling zero were edited out of the polygon shapefiles. The resultant grid provided an excellent overview of the complete data set, however, it did not account for time spent steaming through a grid cell but not producing a ping and it overestimated density when vessels were at anchor. To address this it was necessary to create a second set of grids, at the same resolution, based on a join with the vessel track data (Section 2.2).

2.4 Interpolations
The point data was then interpolated, using the Natural Neighbour function in the Spatial Analyst extension, at a resolution of 500 m. Due to a higher concentration of data points within the 12 nm limit around Shetland, additional interpolations were carried out at a 50 m resolution for all pings within this limit. Interpolations were carried out on vessels’ speed, length, draught, and tonnage.
2.5 Ship type analysis
Ship type codes exported by the AIS system serve a functional purpose informing other users of what type of vessel it is but also what the vessel may be doing or what cargo the vessel may be carrying. Although this information is invaluable, it was appropriate to break down the original codes into more manageable groups (simplified categories) relating to the industry, rather than the activity (Table 2). This then enabled analysis at a group level based on industry type rather than function. Processing followed the same steps outlined in Sections 2.2 to 2.4 for each simplified category.

2.6 Temporal variation
As vessel activity is not homogenous over time, it was necessary to analyse the datasets at regular intervals appropriate to the required outputs. This work combined both point and track data at quarterly, six monthly, and yearly intervals. Due to time constraints, only grid densities were processed for the quarterly and six monthly datasets with more in-depth analysis carried out for yearly datasets following Sections 2.2 to 2.5.

3 Results
For the purpose of this work, and to demonstrate the achievable outputs, data were combined for the whole of 2013. All AIS data were processed monthly taking an average of one day to complete per month. After combing the processed monthly data, 731 614 vessel pings were recorded for 2013, 84% of these were recorded within the 12 nm limit (Fig. 1). AIS data pings outside the 12 nm limit had a geographic range extending from Faroe in the northwest, the west coast of Norway (around 300 km from the receiver) in the east, and out to a maximum of 830 km to the south in the southern North Sea. The point data in Fig. 1 shows the main overall distribution of the AIS coverage with distinct shadow areas. Shadows were due to areas of high land elevation blocking the signal to the receiver aerial used for obtaining the data. Shadows included the north and northwest of Shetland, an area to the east of Shetland, and in the southwest.

Vessel tracks were found to be denser to the east of Shetland and were wide-spread (Fig. 2). Although the shadows, due to land elevation, were not as distinct in the vessel track data, caution should be taken in the interpretation of the information within these areas and the point data should always be used as the primary guide, especially for areas with a large shadow effect. Smaller shadows, such as the area to the east of Shetland would have negligible effect on the vessel track information but the shadow to the north and northwest of Shetland was found to still be prominent in the vessel track data (Fig. 2).

Vessel densities for 2013 were displayed in two formats based on the point data (Fig. 3) and the vessel tracks (Fig. 4). The point data provided a real picture of vessel density with shipping routes clearly displayed as a lighter shade. The highest density values corresponded with ports and harbours which were heavily influenced by vessels tied to the pier but still sending an AIS signal. The high density to the southeast of Shetland corresponded with the southern
approach to the main port, Lerwick harbour in the east of Shetland, with a very high density to the south of Lerwick corresponding with a known anchorage. The large dense area to the northwest of Shetland, outside the 12 nm limit, corresponded with the Clair oil field and the smaller dense area further out from that to the northwest corresponded with the Laggan oil field. Fishing grounds were clearly visible closer to shore, on the 12 nm limit north of Foula, depicted as a circle of high density. The ferry route between Foula in the west and the Shetland mainland was also clearly visible. The density grid, based on vessel tracks (Fig. 4), showed many of the features seen in Fig. 3. This output gave a more complete picture of vessel activity displaying a large amount of information. However, it lacked some of the definition seen in the point data density map, such as anchorage points and, where information is shown within known shadow areas, the data should be treated with a degree of caution. Areas of potential interaction between different shipping routes, as seen to the west and northwest of Foula, are easily identifiable as a shade of very light grey (Fig. 4).

FIGURE 3 ABOUT HERE

FIGURE 4 ABOUT HERE

Length interpolations of the point data show the larger vessels (denoted as black in Fig. 5) remaining, for the most part, outside the 12 nm limit. There is a clear dark patch to the southern entrance of Lerwick harbour on the east coast of Shetland corresponding with a known anchorage. A darker zone was also present in the north at the northern entrance to Yell Sound, leading to the Sullom Voe oil terminal. Interpolations were also affected by the shadows due to land elevation, noted previously. Detail in the interpolations decreased with distance from the AIS receiver aerial as pings became less frequent.

FIGURE 5 ABOUT HERE

Breaking down the vessel track from Fig. 2 into ship type categories provides a more in-depth analysis of industry specific ship activity (Fig. 6). In this example, oil industry vessels, not including oil/chemical tankers, around Shetland were extracted highlighting the two main ports in Shetland, Lerwick in the east and Scalloway in the west, which help service the industry. The information highlighted the traffic routes from offshore oil fields, such as the Clair oil field to the northwest of Shetland, and the Scottish mainland. This north-south route highlighted the need, when creating shipping route information, to include the limits of the shipping routes, in addition to the main route used, and so define the full extent of the route. It was evident from the information that vessels in Lerwick harbour were found to service offshore oil fields to the east and west of Shetland but Scalloway primarily serviced the west of Shetland.

FIGURE 6 ABOUT HERE

Temporal variation in vessel traffic activity around Shetland was found to vary between months (Fig. 7). Monthly vessel pings within the 12 nautical mile limit ranged from 16 999 in May to a high of 122 355 in December. Although a distinct variation in AIS pings were noted on both the east and west sides of Shetland, variation was more distinct to the west.

FIGURE 7 ABOUT HERE
4 Discussion

4.1 Data management and processing

Making sense of over 730,000 data points, each with 22 fields of information, is a complex task but one that is made easier by carrying out monthly processing. This work has highlighted the need for a coherent approach to processing and analysis of AIS data and provides a means of obtaining that. Development of a vessel database was key to managing the data and for quality control. Initially this was the most time-consuming factor but saved time in future processing. A previous study [see 42] removed all vessel types classed as “Other” (ship type code range in the 90s) and all fishing vessels (due to ‘replication’ of information with the Vessel Monitoring System, VMS). Experience from this work has shown a large portion of vessels classed as “Other” were either oil related, (e.g. anchor handling vessels or offshore supply ships) which did not fit into the standard categories listed in the AIS system, or fishing vessels. If vessels classed as “Other” were not re-categorised within the vessel database, a large portion of an entire industry service sector would have been lost. Although fishing vessels greater than 12 m in length are also represented by VMS, there may be difficulties accessing the VMS data, due to ownership of the data remaining with the vessel [3], and the VMS system only reports every two hours. AIS does not have ownership restrictions on the broadcast data [44] allowing more freely available information on fishing activity at a higher resolution (see Section 4.4).

4.2 Analysis and mapping

The data from this study showed distinct shadows due to land elevation interfering with the AIS signal. This would be easily overcome by installing a network of AIS receiver aerials at appropriate positions around Shetland in order to maximise coverage. Shadows would pose a problem in other geographic areas too and, depending on the spatial scale of the required coverage, a network of AIS receiver aerials would have to be installed at appropriate locations. At sea, it has been estimated that an AIS signal has the potential of travelling between 30 to 80 km between vessels [11, 44]. With an appropriate placed receiver aerial, it would be possible to exceed these distances, as demonstrated with this work.

The main analysis outputs were the density maps (Section 2.3, Figs. 3 and 4) and the vessel tracks (Sections 2.2 and 2.5, Figs. 2 and 6). Vessel track density maps (Fig. 4) provided greater detail with a more complete, denser picture enabling the user to identify specific features such as fishing grounds and vessel routes, but not anchorage points. They highlighted areas where routes intersected and interpolated over any shadows. The density output, based on vessel pings, was limited by the coverage of pings with the possibility of mistaking shadows for areas of low use (Fig. 3). However, vessel track density maps require a much higher quality control and processing time [as outlined by 42] and should always be referenced alongside the vessel ping density maps.

Vessel tracks, broken down by types of vessels, were found to be highly informative, especially in creating and modifying vessel routes. By displaying the data as tracks, rather than pings, routes were easily identifiable and so too were the route limits. In some instances within the Shetland Islands’ Marine Spatial Plan routing information, particularly around islands, was adjusted using AIS to better represent actual routes taken [43]. This information can be used to help guide future use of the marine environment, ensuring that shipping and navigational safety is adequately considered in development planning and marine spatial plans.
Interpolations of the ping data provided an additional level of querying and were primarily used with vessel dimension data and speed. As with vessel track data, these could be broken down by type of vessel and analysed at a sector specific level, rather than the entire dataset as detailed here (see Fig. 5). Within the 12 nm limit, interpolations were found to be more informative due to the increased density of pings.

4.3 Temporal scale
The temporal scale of the processed datasets will vary depending on the required outputs. Processing data on a monthly basis was found to be highly beneficial as it allowed greater flexibility for future outputs and provided a manageable quantity of data for analysis and processing. However, it would be expected that the influence of external factors (e.g. weather conditions or seasonality of surrounding industry types) will play a significant role in determining the degree of temporal variation in vessel activity. Shetland is a remote archipelago, heavily influenced by weather conditions which would directly affect local vessel activity; a problem which may not be as obvious in other geographic regions.

4.4 Additional uses
In addition to the uses outlined by Ou and Zhu [2], and those outlined in this work, it would be possible to additionally apply AIS information to risk mapping of invasive non-native species, fishing activity, and general statistics.

Information on vessels’ last port, their destination, and type of vessel can be used to create risk maps, combined with information held within a marine spatial plan, for biosecurity planning for invasive non-native species [45]. Vessels’ last port and destination provides information on total connectivity of an area, not based just on where the vessels originated from but also where they were going, which can be used to examine the on-going spread of species.

Information on fishing activity can be obtained using AIS with all EU vessels over 15 m required to have a working AIS system fitted [3]. In Scotland, this covers all the pelagic vessels, 87.2% of demersal vessels (four vessels less than what is obtainable through the Vessel Monitoring System, VMS), and 8.2% of shellfish vessels (72 vessels less than what can be obtained through VMS) and in Shetland, AIS would cover 79% of all fishing vessels over 10 m in length [46]. Due to the high reporting frequency of AIS it is possible to obtain an excellent resolution on fishing ground areas, compared with VMS data, and transit routes (NAFC Marine Centre unpublished data). However, when using a land-based receiver aerial, the AIS coverage will be limited to areas closer to shore.

Providing general statistics on vessel activity is a useful way of informing local industries and guiding potential research on vessel activity. Ou and Zhu [2] broke down the statistical output into three groups: static information, voyage related data, and dynamic positioning. The latter two have been covered in this work but static information would include aspects such as numbers of vessel types visiting an area, industries which the vessel types would be related to, size of vessels visiting an area compared to size of vessels passing by an area.

4.5 Summary
This is the first known text which has examined marine AIS data as a single package aimed at multiple marine industries, outlining ways to analyse the data with examples of the expected outputs. Processing the monthly AIS data was relatively quick at one day processing per
The creation and incorporation of a vessel database enabled faster processing of raw data while providing a quality control element. Multiple outputs were available but were based mainly upon density mapping and vessel tracks. The outputs from this work would provide an excellent base for marine spatial plans, developments, and other marine industries with AIS providing high-quality, up-to-date information on marine vessel activity.

5 Acknowledgements

Thanks go to all NAFC Marine Centre staff involved with setting up the AIS system, especially the IT team. Thanks also go to the Shetland Marine Spatial Planning team who were incredibly helpful in advising on the required outputs.

6 References


**Fig. 1.** Distribution of AIS pings for all received vessels during 2013 around Shetland.

**Fig. 2.** Vessel tracks, based on 2013 AIS ping information, for all vessel types around Shetland.

**Fig. 3.** Gridded density map of AIS vessel pings around Shetland during 2013. Areas of higher vessel density are depicted by lighter colours.

**Fig. 4.** Gridded density map of AIS vessel tracks around Shetland during 2013. Areas of higher vessel density are depicted by lighter colours.

**Fig. 5.** Interpolation of vessel length for all vessel types around Shetland during 2013. Darker areas denote larger vessels.

**Fig. 6.** Vessel tracks of oil related traffic, excluding oil/chemical tankers, around Shetland during 2013.

**Fig. 7.** Variation in vessel pings around Shetland for the months of February (n = 50 454 within 12 nm), April (n = 21 438 within 12 nm), October (n = 81 287 within 12 nm), and December (n = 122 355 within 12 nm). All maps are displayed at the same scale and show the 12 nm limit around Shetland.
<table>
<thead>
<tr>
<th>Data field</th>
<th>Information type</th>
<th>Reliability</th>
<th>Usefulness</th>
<th>Vessel database</th>
</tr>
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<td>mmsi</td>
<td>Static</td>
<td>Excellent</td>
<td>Essential</td>
<td>Yes</td>
</tr>
<tr>
<td>Latitude</td>
<td>Dynamic</td>
<td>Excellent</td>
<td>Essential</td>
<td>No</td>
</tr>
<tr>
<td>Longitude</td>
<td>Dynamic</td>
<td>Excellent</td>
<td>Essential</td>
<td>No</td>
</tr>
<tr>
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<td>Excellent</td>
<td>Essential</td>
<td>No</td>
</tr>
<tr>
<td>Course</td>
<td>Dynamic</td>
<td>Excellent</td>
<td>Essential</td>
<td>No</td>
</tr>
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<td>Time stamp</td>
<td>Dynamic</td>
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<td>Essential</td>
<td>No</td>
</tr>
<tr>
<td>Ship name</td>
<td>Static</td>
<td>Excellent</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Ship type</td>
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<td>Checked</td>
<td></td>
</tr>
<tr>
<td>imo</td>
<td>Static</td>
<td>Good</td>
<td>Possible</td>
<td></td>
</tr>
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<td>Possible</td>
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</tr>
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<td>Desirable</td>
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</tr>
<tr>
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<td>Desirable</td>
<td>No</td>
</tr>
<tr>
<td>Destination eta</td>
<td>Voyage related</td>
<td>Moderate to Poor</td>
<td>Desirable</td>
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<td>No</td>
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<tr>
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<td>Checked</td>
<td></td>
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<tr>
<td>Year built</td>
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<td>Good</td>
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<td></td>
</tr>
</tbody>
</table>

**Table 1.** A summary of the outputted fields from the AIS database highlighting the information type (based on [2]), and the reliability and usefulness of the information. The final column refers to the vessel database and what information is included, checked before entering, and information that could possibly be included.
<table>
<thead>
<tr>
<th>Ship code or range</th>
<th>Description</th>
<th>Simplified category</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 to 29</td>
<td>WIG</td>
<td>Aircraft</td>
</tr>
<tr>
<td>30</td>
<td>Fishing</td>
<td>Fishing</td>
</tr>
<tr>
<td>31 to 32</td>
<td>Towing</td>
<td>Other</td>
</tr>
<tr>
<td>33</td>
<td>Engaged in dredging or underwater operations</td>
<td>Oil related</td>
</tr>
<tr>
<td>34</td>
<td>Engaged in diving operations</td>
<td>Oil related</td>
</tr>
<tr>
<td>35</td>
<td>Engaged in military operations</td>
<td>Law and rescue</td>
</tr>
<tr>
<td>36</td>
<td>Sailing</td>
<td>Pleasure</td>
</tr>
<tr>
<td>37</td>
<td>Pleasure craft</td>
<td>Pleasure</td>
</tr>
<tr>
<td>40 to 49</td>
<td>High Speed Craft (HSC)</td>
<td>Other</td>
</tr>
<tr>
<td>50</td>
<td>Pilot vessel</td>
<td>Harbours</td>
</tr>
<tr>
<td>51</td>
<td>Search and rescue vessels</td>
<td>Law and rescue</td>
</tr>
<tr>
<td>52</td>
<td>Tugs</td>
<td>Harbours</td>
</tr>
<tr>
<td>53</td>
<td>Port tenders</td>
<td>Harbours</td>
</tr>
<tr>
<td>54</td>
<td>Vessels with anti-pollution facilities or equipment</td>
<td>Law and rescue</td>
</tr>
<tr>
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<td>Law enforcement vessels</td>
<td>Law and rescue</td>
</tr>
<tr>
<td>58</td>
<td>Medical transporters</td>
<td>Law and rescue</td>
</tr>
<tr>
<td>59</td>
<td>Ships of States not parties to an armed conflict</td>
<td>Other</td>
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<td>60 and 69</td>
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<td>Cargo ship</td>
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<tr>
<td>80 to 89</td>
<td>Tanker</td>
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<tr>
<td>90 to 99</td>
<td>Other ship type</td>
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<tr>
<td>130</td>
<td>Vessel Traffic Service (VTS)</td>
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</tr>
<tr>
<td>150 to 159*</td>
<td>Offshore vessels</td>
<td>Oil related</td>
</tr>
<tr>
<td>160*</td>
<td>Research/survey vessel</td>
<td>Research</td>
</tr>
</tbody>
</table>

* Codes 150 to 160 were additional codes manually assigned during processing in order to capture oil related traffic such as anchor handling vessels and offshore supply ships, as well as research and survey vessels.

**Table 2.** Simplified categories, their general description, and corresponding AIS codes.