Using message brokering and data mediation on earth science data to enhance global maritime situational awareness

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Abstract. Maritime Situational Awareness is the understanding of anything associated with the maritime domain that could impact the security, safety, economy, or environment. The European Commission’s Joint Research Centre (JRC) has developed an in-house data collection, data analysis and data visualization facility, known as the Blue Hub. The Blue Hub operates as a research and development platform for integrated maritime surveillance and maritime situational awareness. It has global coverage and has been applied, for example, to support counter-piracy around Africa, to investigate fishing activity and to monitor the growing ship traffic in the Arctic. In order to improve maritime awareness and support risk assessment, the JRC has started to integrate data from the marine and atmospheric science community. In particular, the JRC is interested in using forecasts from operational ocean models and weather models. For the Blue Hub, a new type of data server, called ERDDAP, that performs message brokering and data mediation has become an essential tool for the accessing of ocean forecast data as quickly as possible in easy to use formats.

NOAA (National Oceanic and Atmospheric Administration of the USA) is making global oceanography and weather data available through the Environmental Research Division’s Data Access Program (ERDDAP) data broker. ERDDAP provides RESTful machine to machine communication, data brokering and data mediation by converting data to a number of standard and developer friendly formats, including some Open Geospatial Consortium formats. In this paper, we demonstrate how data brokering and mediation is making complex scientific data accessible. We show how such data is being integrated into the Blue Hub system to enhance maritime situational awareness.

1. Introduction

Automatic Identification System (AIS) is a tracking system used for identifying and locating vessels. The global deployment of AIS on maritime vessels with a gross tonnage (GT) of greater than 300 has created a data resource that can be used to develop software systems for the visualization of global ship positions.

The Maritime Affairs Unit of the European Commission’s Joint Research Centre (JRC) investigated the possibility of using AIS technology to provide a maritime domain awareness around the Horn of Africa and the Western Indian Ocean [1,12]. This action was a response to the piracy threat to maritime traffic in those areas, and the realization that the authorities in the region had no access to region-wide maritime awareness systems. A number of different data sources that could be used to identify and track maritime traffic were evaluated, and it was found that the combination of Maritime Safety & Security Information System (MSSIS), long-range identification and tracking (LRIT), satellite AIS, and Synthetic-aperture radar (SAR) had the potential to provide maritime domain awareness for the area of interest.

Based on their findings, the JRC developed an AIS data collation, processing and visualization facility called the Blue Hub. The Blue Hub collects AIS from a number of providers, including satellite and coastal networks. The AIS data is processed, stored in a Geo Database, and displayed in a web based Geographic Information System (GIS), thus providing a near real time picture of global shipping movements. The technology used in the Blue Hub facility consists of Open Source Web
Geographical Information System (Web GIS) software and corresponding Open Source data serving infrastructure:

- **Web GIS** – OpenLayers, an Open Source JavaScript library for displaying map data in web browsers (http://openlayers.org/)
- **Map Server** - GeoServer an Open Source technology for displaying maps from spatial data servers (http://geoserver.org/)
- **PostGIS** – An Open Source Geo Database extender for the PostgreSQL database http://postgis.net/
- **PostgreSQL** - Data Base Server (http://www.postgresql.org/)
- **Natural Earth** – Public Domain Map Dataset (http://www.naturalearthdata.com/)

An analysis of the timings of piracy attacks around the Horn of Africa and the Western Indian Ocean found that there exists a strong association between piracy attacks and weather and sea conditions (i.e. wave height and wind speed) [2]. A separate analysis of weather and ocean conditions during piracy attacks found that the transition of the summer monsoon limits piracy activity [3].

This establishment of the strong relationship between weather conditions and piracy activity led to the realization that the Blue Hub would need to include weather and sea conditions in order to improve maritime domain awareness for the area of interest. In this paper we show how forecasts of weather conditions and sea state where integrated into the Blue Hub by means of a technology that turns NOAA’s distributed data network of ocean and atmospheric data into a single point resource on the Internet.

To further illustrate the flexibility of this data brokering approach a version of the Blue Hub for the Arctic is described. Global Warming has had a major impact on the sea ice season in the Arctic. The extent of the summer ice edge has reduced enough to make growth in maritime traffic to transiting from the Pacific to the Atlantic a realistic possibility. In order to get an appreciation of current maritime activity in the Arctic, the scope of the Blue Hub was extended by adding Arctic data, in particular sea ice coverage.

2. Data Sources and Availability

In order to derive some benefit from the analysis of the relationship between piracy events and weather conditions it was decided to add weather and ocean forecast data to the Blue Hub Web GIS. The key parameters required are wind speed, wind direction and significant wave height. From these parameters, geo-data layers could be developed and made available via the Blue Hub Web GIS.

The required parameters for the new layers would need to be extracted from the forecasts made by numerical models of weather and ocean conditions. A number of countries and international institutions produce regular global weather and ocean forecasts, however it was decided to use the forecast data published daily by the USA agency NOAA the following reasons:

- **Open Data.** The forecasts from the NOAA numerical models are covered under an Open Data license. See the United States Open Data Initiative (http://www.data.gov/open-gov/).
- **The forecasts are published with comprehensive supporting meta-data**
- **Reliability & Support.** These are operational forecast models with long term support commitments from NOAA
- **Accessibility.** The forecasts are available via NOAA’s new message broker and data mediator technology called ERDDAP [4]. This technology publishes a Web Application Programming Interface that makes access to the forecast data convenient, thus reducing development time

2.1. The ERDDAP Data Server

**ERDDAP** is an Open Source Cloud based technology developed in the Java language and hosted on Apache Tomcat web server. It was developed by the Environmental Research Division of NOAA with the specific purpose of making it easy for software developers to access scientific data, particularly gridded data such as that outputted by oceanographic and atmospheric numerical models as NetCDF
(Network Common Data Form) files. The technology is a product of NOAA’s United Access Framework (UAF) program to make environmental datasets easy to find and use. The UAF contributes to the NOAA’s vision of Global Earth Observation – Integrated Data Environment (GEO-IDE) [5]. ERRDAP is recommended within NOAA’s Data Access Directive, which includes it in its list of recommended data servers for use by groups within NOAA [6].

ERDDAP follows the Representational State Transfer (REST) software architecture, which is the software architectural style of the World Wide Web. ERDDAP communicates over Hypertext Transfer Protocol (HTTP) using the same HTTP verbs as web browsers. It published its Application Programming Interface (API) as Restful Web Services, which means that interaction with ERDDAP is via Uniform Resource Identifier (URI), i.e. web addresses. These services enable access to the collection of remote data sources listed in an ERDDAP catalog. ERDDAPs properties can be summarized as follows:

- It works as a message broker: it receives data requests (via html) to a resource listed in its catalog, and converts the requests into the language used by remote data servers.
- It can query datasets at remote servers and returns the requested subset of the dataset.
- It is a data mediator: it converts sophisticated science data formats to formats more familiar to web/software developers. For example JSON (JavaScript Object Notation), htmlTable or CSV (Comma Separated Values).
- ERDDAP can be used to create a catalogue of data being published at different remote data centers. This catalogue includes the metadata that was published with the original data and a catalogue search functionality.

Marine and Earth science data from various ERDDAP catalogues that were considered useful for maritime situational awareness research were collected into one ERDDAP catalogue and deployed on a publically accessible JRC web server (Figure 1).

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Figure 1: A screenshot of the Blue Hub Marine Domain Awareness ERDDAP catalogue.

This catalogue of data for research in maritime domain awareness can be reached at:
The data in the catalogue comes from a number of different national ocean data repositories.

2.2. Getting the Data and Producing the Layers

Listed here are the numerical models that were used to produce the wind conditions, sea state and sea ice parameters for the creation of new layers in the Blue Hub Web GIS:

- NOAA/NCEP Global Forecast System (GFS) Atmospheric Model. The GFS numerical weather prediction model makes an 8-day, 3-hourly forecast for the globe at approximately 50-km or 0.5-deg resolution.
- Wave Watch III (WW3) Global Wave Model. Through a collaborative effort with NOAA and National Weather Service Honolulu, the University of Hawaii has implemented a global-scale Wave Watch III (WW3) 5-day hourly forecast at approximately 50-km or 0.5-deg resolution.
- Real Time Ocean Forecast System (RTOFS). An operational ocean forecast model run by NOAA. This model includes sea ice predictions.

Once the Blue Hub ERDDAP catalogue was deployed it was a straightforward task to develop a workflow to display the daily global sea conditions, global wind vectors and Arctic sea ice conditions. This data is updated via batch scripts that process the data and add it to the appropriate layer table in the PostgreSQL database of the Blue Hub. Each of the scripts are similar. The call to Blue Hub ERDDAP to get data from the numerical models is made using WGET and an HTML string. The following example is for sea ice, the wind and wave strings are similar to it:

```
bluehub.jrc.ec.europa.eu/erddap/griddap/noaa_pfeg_6418_1448_e8d1.csv?ssh[($DATE_NOW)][1.0][($S_BOUND):($N_BOUND)][($W_BOUND):($E_BOUND)],ice_coverage[($DATE_NOW)][1.0][($S_BOUND):($N_BOUND)][($W_BOUND):($E_BOUND)],ice_thickness[($DATE_NOW)][1.0][($S_BOUND):($N_BOUND)][($W_BOUND):($E_BOUND)]
```

In this case `noaa_pfeg_6418_1448_e8d1.csv` (above) is the name of the data resource and `.csv` is file type we want returned. Everything after `noaa_pfeg_6418_1448_e8d1.csv` are query parameters.

When the data is downloaded it is then processed and stored in the PostgreSQL database from where it can be published as a Web Mapping Service (WMS) layer on GeoServer. The main layers created are:

- Wind Conditions. From GFS forecast, obtained every 4 hours. This layer displays global wind conditions in meters per second, and grouped as the Beaufort scale. The wind directions is conveyed via arrows pointing in the direction that the wind is flowing.
- Waves. This layer is displayed as sea state, as defined by the World Meteorological Organization (WMO). It is based on the significant wave height forecast from the Wave Watch III model and is obtained once a day [15].
- Sea Ice Coverage. This layer displays the daily sea ice coverage for the Arctic as predicted by the RTOFS. The data is displayed using the color code for total concentration as defined by the WMO [16].

Each layer also has at least one corresponding Styled Layer Descriptor (SLD) file. An SLD is XML document complying with an Open Geospatial Consortium (OGC) standard for describing the display of map layers. For example the definition for the Beaufort wind scale for the wind layer is contained within the corresponding SLD.
3. Results
By using the Beaufort scale for wind speed, the Blue Hub Web GIS combines visualization with analysis, using this scale highlight wind conditions in a way that is meaningful for the maritime community as this scale is used in shipping forecasts by many nations. For example, in figure 2 the active hurricanes in the Pacific Ocean are highlighted by default because the wind speeds are displayed on the Beaufort scale.

![Figure 2: The very rare event of three hurricanes in the Pacific, as seen in the Blue Hub.](image1)

Before the inclusion of the meteorological and oceanographic conditions, the Blue Hub Web GIS only displayed maritime traffic positions and topographic data (see left panel in figure 3). With the inclusion of meteorological and oceanographic data it is now possible to combine maritime traffic, topographical data, and sea state and wind conditions. For example in the right panel of figure 3 the maritime traffic data is combined with the sea state conditions.

![Figure 3: The panel on the left is shipping traffic. On the right is shipping traffic with sea state.](image2)

This ability to see sea state and wind conditions is particularly useful for assessing the risk of piracy around the Horn of Africa. The analysis of the piracy incidents and weather conditions around the Horn of Africa found that wave heights of at least 2.5 m and wind speeds greater than 9 m/s greatly reduces the risk of successful piracy [3].

One of the difficulties facing the research in maritime situational awareness is finding appropriate data to illustrate an operational situation. One example is the need for datasets that can be used to
illustrate the behavioural patterns of Arctic shipping and hence develop operational capability around situational awareness in the Arctic. For the Blue Hub this challenge has been met by using the outputs from various heterogeneous sources. For example in figure 4 the daily Sea Ice coverage prediction from the RTOFS model is combined with the long term analysis of Russian Arctic shipping routes from the Arctic Council [14].

![Sea Ice Coverage, updated daily, for the Arctic and Russian Shipping Routes (see arrow). Data for routes comes from Arctic marine shipping assessment (AMSA) [14].](image)

The wind and wave data is also available for the Arctic area. In the Blue Hub Web GIS, this data is accessible by simply switching on the layer in the layer control box, seen on the right hand side of the image in figure 4.

4. Discussion
In this paper we have shown two cases of how Open Data from the Earth Science community have improved Maritime Situational Awareness on two distinct regions of Earth. While the Blue Hub facility had developed a work flow for the gathering, processing and displaying of AIS and other ship position data in a Web GIS, it did not have any auxiliary data other than what was available as base maps from the Open Street map community. For the Blue Hub facility, auxiliary data is data not strictly pertaining to the Maritime and Security domain; in essence this had restricted the Web GIS to shipping tracking data and topographic data.

This restriction needed to be overcome in particular for the PMAR (Piracy, Maritime Awareness and Risks [7]) campaigns of the European Commission, where the Blue Hub facility was used to analyse the shipping activity of the Horn of Africa and was a live feed of shipping activity in that area. Research elsewhere had shown that activities of Somalian pirates were restricted by wind speed and sea state, therefore including this type of information within the Blue Hub Web GIS became a necessity.

The conventional approach to obtaining weather and ocean forecast is fraught with a number of obstacles. For example some of the forecast data is only available under restrictive research licences. Even when the data is available it can prove cumbersome to access, requiring bulk downloads and local processing before it can be used.
The European Union Commission has identified this problem and steps are in process to improve the situation, primarily through the Copernicus Marine Service [8] and the European Marine Observation and Data Network [13], however their protocols for accessing data still have limitations.

In separate research also funded by the E.U. Commission (as part of Digital Agenda for Europe) the Framework 7 Programme project ENVIROFI [9] conducted research into the Future Internet and evaluated the new technology from NOAA called ERDDAP that specifically tackles the problem of making the Big Data from models of the oceans and the atmosphere easily available to the software development community. The technology was found to be suitable for the publication of the marine science data within the context of the Future Internet, i.e. for Cloud Based computing [10].

By using the ERDDAP Web API, the Blue Hub can regularly access the forecast models of NOAA, and import the requested data into the Blue Hub technology framework without having to invest in data storage infrastructure. ERDDAP also enabled the creation of a data catalogue of over 120 data sets that was deployed to serve both the needs of the Blue Hub facility and the maritime domain research community.

This non-traditional approach to utilising the output from ocean and weather forecast models proved its usefulness after the Maritime Affairs Unit decided to expand the scope of the Blue Hub to cover shipping in the Arctic. Not only was the data needed to generated sea ice layers, weather conditions and sea state already in the catalogue but it was exploited using the same software development pattern as was used for the Indian Ocean. This information combined with AIS ship tracking data for the Arctic provided useful insights into shipping behaviour.

How the wind, waves and sea ice data was displayed in the Blue Hub Web GIS proved to be as crucial as the data itself. By adopting standards familiar to the maritime community, users could derive more information from the system than by just having ship position data alone. In the case of the PMAR Web GIS, the display of wind via the Beaufort scale and wave height via the Sea State standard meant that users knew when piracy risk along the Somalia coast was least likely by looking at the wind field and sea state layers.

5. Conclusion
In a quest for maritime situational awareness, the collection and processing AIS data in order to view the movement of shipping in a GIS system is crucial. While analysis of this AIS data can give insights into the patterns of movement, it struggles to explain reasons for behaviour without auxiliary data. For example by using wind and wave forecast with AIS of the East of Africa made it possible:

- To see when wind and sea state of the East Coast of Africa had reached a level that made the handling of small boats difficult. The majority of attacks were from small boats launched from Somalia
- To derive other information like the location of fishing fleets
- To get better insight into safe sea conditions

For the Arctic the combination wind conditions, sea ice prediction and AIS gave insights into:

- How sea ice thickness was effecting the operations of shipping
- The operations of ice breakers and the routes of tourist vessels

In both of these scenarios it is important to classify and display the data in a manner that suits the target audience. Here it is the maritime community and the scientific data used should be translated accordingly using the appropriate World Meteorological standards for display wind speed, sea state and ice thickness.

In the past, using data from the marine and atmospheric science community has required using exotic file formats and the storage and processing of large files from numerical models. These technical challenges combined with restrictive licenses imposed on some forecast data have proven to
be an obstacle for data utilisation by research community and beyond. There are efforts by both E.U. Commission and the U.S.A. to make it easier for people to make use of scientific data. In the area of oceanographic and atmospheric data the U.S.A. is leading the way due to a combination of factors:

- A decision by the US Government to make most public produced data Open Data
- The NOAA Data Access Procedural Directive, published March 2015. The purpose of this Directive is to declare that all NOAA environmental data (with limited exceptions, upon approval of a waiver) shall be made discoverable and accessible via the Internet in a timely fashion
- The technology output (e.g. ERDDAP) of the Unified Access Framework (UAF). UAF is a NOAA-wide effort to make environmental datasets easy to find and use

The adoption by the Maritime Affairs Unit of the JRC of the ERDDAP technology has enabled it to use marine and atmospheric data very efficiently. It has made it easier for the unit to access data a from other organizations using ERDDAP, for example the Irish Marine Institute publish fisheries survey data and their daily forecast of sea conditions for the North East Atlantic on the ERDDAP [11].

Finally the potential of knowledge discovery by combining observations from different thematic areas is significant, as we have demonstrated here. The use of data brokers removes the barriers to data utilization by making data and geo-data published in different formats available via a common interface. This technology is step in the right direction for the concept of the Digital Earth by being a key element in a Spatial Data Infrastructure and by bridging the gap between the scientific and mainstream software development communities.

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