Investigating Shipping Behaviour in Emission Control Areas
A Visual Approach to Data Analysis

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Abstract This paper explores a method of analysing large volumes of geographic data by combining visual and numerical components. For great parts of the work, we use an instance of *CartoDB*, a tool that enables the handling and analysis of such data with only little programming knowledge, and tailor it to our needs.

Our method has applications in researching the behaviour of the maritime transport sector, e.g. in response to policy changes. In this instance, we examine the MARPOL regulations for emission control areas that came into effect in North America in August 2012. We identify the number of ships that is affected by the regulations and whether there occur any significant operational changes using speed as a measure.

For traceability and transparency, we walk through the individual steps required to produce those results, which adds much needed weight when used in policy debates.

Keywords: AIS data, geo-spatial visualisation, emission control area, container shipping, vessel speed.

1 Introduction

As part of the MARPOL Conventions (on the prevention of pollution from ships), the International Maritime Organization (IMO) set out special areas where the emission by most vessels cannot exceed a certain threshold. These areas came into effect at different times, with the latest addition being the US Caribbean Sea ECA (emission control area) on 1 January 2014.

Much speculation by the shipping industry takes place around the financial and operational impacts of such regulatory changes. Some amount of theoretical research has been undertaken to shed light on the consequences, but only very little empirical evidence is available. In this paper, we want to investigate the behaviour of vessels in and near the North American ECA, covering a time span that includes its coming into effect on 1 December 2012.

We also want to ensure that our results and their production are easily understood and reproducible. For this we have chosen a collection of tools that is freely available and for the great part requires only little programming knowledge. We first walk through the individual steps of data analysis and then discuss the results gained from analysing a large dataset of individual vessel positions.

The paper is structured as follows. In Section 2, we give some background on air-pollution regulation, their (perceived) impacts on the shipping industry and two evidence-based studies on the topic. In the following section, we present the data used in our study, the choice of tools and why we chose them, and the individual analysis steps we perform. We then present the results in Section 4, and discuss a comparison to other studies. We conclude in Section 5 with an outlook on questions that remain open.

2 Background

2.1 Air-pollution regulation

The emissions of greenhouse gases and air pollutants from shipping constitute a significant proportion of global emissions, amounting to 2.2% of CO_2 (carbon dioxide), 13% of NO_x (nitrogen oxides) and 12% of SO_x (sulphur oxides) emissions solely by international shipping [19, p. 13]. In order to curtail these emissions, the IMO introduced "Regulations for the prevention of air pollution from ships" (MARPOL Annex VI). These regulations specify what ships are allowed to produce how much emissions in what sea area and what certificates a vessel needs to carry. Apart from some exceptions, these regulations apply to all ships equal and above 400 gross tonnage. More stringent emission limits are applicable in ECAs to "prevent, reduce and control air pollution from NO_x or SO_x and particulate matter [. . .] and their attendant adverse impacts on human health and the environment."[10, p. 254].

To date, four ECAs came into effect a year after coming into force, regulating for SO_x and particulate matter (PM) as listed in Table 1. The North American and US Caribbean Sea areas seek to regulate NO_x separately to other sea areas for a range of ships constructed on or after 1 Jan 2016.

Special area (ECA)	Emissions	Adopted	In effect from
Baltic Sea	SO_x	26 Sep 1997	19 May 2006
North Sea	SO_x	22 Jul 2005	22 Nov 2007
North American	SO_x, PM	26 Mar 2010	1 Aug 2012
United States Caribbean Sea	SO_x, PM	26 Jul 2011	1 Jan 2014

Table 1. Special Areas under MARPOL Annex VI [15].

Currently, the only mandatory limit for regulating emissions is the sulphur content of fuel oil, with different stringency within or outside ECAs, see Table 2.

Operating area	Sulphur limits and validity dates		
Outside ECA	4.50% m/m before 1 Jan 2012	3.50% m/m from 1 Jan 2012	0.50% m/m from 1 Jan 2020*
Inside ECA	1.50% m/m before 1 Jan 2010	1.00% m/m from 1 Jan 2010	0.10% m/m from 1 Jan 2015
California Waters	1.5% (0.5%) m/m from 28 Jun 2009	1.0% (0.5%) m/m from 1 Aug 2012	0.1% (0.1%) m/m from 1 Jan 2014

Table 2. Max. sulphur content in fuel oil (mass percentage, *= subject to revision) [10], California specifies MGO and MDO (=value in brackets) limits separately [4].

Particulate matter is implicitly regulated through SO_x limits (at least for particulate sulphates) but not explicitly monitored. All ships are required to carry an International Air Pollution Prevention (IAPP) certificate and employ a method of choice (fuel switching, sulphur scrubbing, etc.) for reducing emissions to the appropriate level before entering an ECA.

Whilst ECAs are regulated by the IMO, some port authorities devise their own strategies for curtailing emissions in their administrative area. For example, most vessels calling at a port in California (USA) need to use low-sulphur marine distillate fuels up to 24 nautical miles (nm) of the California baseline [4], see Table 2, and the Port of Long Beach gives further monetary incentives to reduce speeds to 12 knots or less on the last 40 nm when approaching their port [17].

2.2 Impact of air-pollution regulation

Since the adoption of emission control areas, researchers have tried to assess the impact this has on the shipping industry as well as the environment. Their work ranges from options to fulfil the regulations, over changes in vessel operations and transport patterns, to health benefits and related savings.

In 2014, *Transportation Research Part D* published an entire special issue about "Emission control areas and their impact on maritime transport" [5]. In [12], the costs and benefits of installing 'scrubbers'[1] versus using marine gas oil (MGO) in order to achieve the required SO_x reduction are discussed. For a low price difference between heavy fuel oil (HFO) and MGO or a vessel with a short remaining lifespan, a scrubber installation is unviable.

Depending on the method chosen in order to comply with the regulations, ship operators face a higher operating cost in ECAs. The price difference between MGO and HFO in particular, drives ship operators to optimise their fuel usage with respect to the sea area a vessel sails in. One option is to adjust speed, as it is highly correlated to fuel usage. Doudnikoff and Lacoste [6] investigate the effect of the (at the time future) reduction of SO_x limits from 1.00% to 0.10% in 2015. They find that for container ships, depending on the price difference and route taken, savings of up to 4.8% on bunker-fuel costs can be made (in

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[1] Scrubbers are devices that remove the sulphur content from the exhaust gas.

comparison to 'speed as usual') whilst adhering to schedules. Related to that, however, is an increase of up to 5.3% in CO_2 emissions due to higher speeds outside ECAs.

Further concerns about rising CO_2 emissions caused by ECAs stem from the apprehension that increased prices may cause a modal shift for goods transported on short sea routes. Panagakos et al. [16] research this shift for a hypothetically established Mediterranean Sea ECA and find that transport costs increase by 1.9%, which can lead to a shift of up to 17.1% of the total sea traffic towards land on a route from Greece to Germany. In this particular case, the modal shift would lead to a decrease of CO_2 equivalent emissions as the land route causes less pollution. These results, however, are very specific to the route analysed and can differ substantially for other routes. The European Maritime Safety Agency reviewed multiple studies of that kind and came to the conclusion that "many short sea shipping routes will remain competitive" even for a comparably high fuel price[2] [9]. Fears of modal shift also existed in Finland, however in practice, no shift has been observed over the first five months due to the regulation change in Jan 2015 [7].

Ng et al. [13] examine ship-borne emissions in the Pearl River Delta, which pose serious threats to public health, and the US Environmental Protection Agency argues that the North American ECA will save between 5500 and 14,000 premature deaths in 2020 alone [14]. Savings related to health benefits are projected to range between 47 and 110 billion US dollars[3].

2.3 Lack of evidence-based studies

Many studies on the effect of MARPOL Annex VI to date concentrate on the North Sea and Baltic Sea ECAs, especially on the change of sulphur limits from 1.00% to 0.10% in 2015. In addition, most studies examine impacts of ECAs from a theoretical point of view, projecting what is most likely to happen [5]. Only very few studies have been conducted that utilise evidence of what occurred during times when either an ECA came into effect or sulphur limits in an existing ECA became more stringent.

One data-driven study has been conducted by Adland et al. [1] who investigate the impact ECAs and market conditions have on vessel speed. They analyse the speed profile of 8000 ECA-boundary crossings in the North Sea over a five-year period and find that the introduction of the ECA, which fell into that period, had little or no effect on the operation of a vessel.

A second study [3] examines whether the shipping industry complies with the sulphur regulations in the North Sea and Baltic Sea ECAs. They evaluate data from laboratory tests of fuel samples, bunker-fuel delivery notes and oil record books, and conduct various interviews with port authorities and . Although the data available is too fragmented to assess compliancy across both ECAs, they

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[2] In this case, the price for MGO is considered to be around 1000 USD.
[3] US dollars as of 2006 assuming a 3% discount rate.

showed that in the areas of testing, compliance levels rise from 91% in 2001 to 97% in 2010, with local variations.

In this paper, we want to investigate shipping behaviour in the North American ECA, over the period of time it came into effect in 2012, entailing a reduction of sulphur content in fuel from 3.30% to 1.00%.

3 Data-based investigation of shipping behaviour

For the analysis of shipping behaviour, we choose operating speed as our most important metric. We calculate how vessel speeds differ inside and outside the North American ECA, before and after 1 August 2012.

Operating speed is tightly connected to fuel usage of a vessel, typically $fuel\text{-}usage \propto speed^3$ [19], therefore it can act as a proxy for fuel. Concluding from several studies mentioned before, a vessel operator will aim to optimise fuel usage with respect to ECAs, as the lower sulphur requirement drives up operating costs in these areas. Hence, a differential in speed is to be expected should the new regulation have a noticeable effect on shipping behaviour.

In this instance we concentrate on container ships, as they operate at one of the highest speeds and thus consume a high amount of fuel, see [6].

3.1 Data sources

There are three different types of data we are going to use for this work. Firstly, dynamic vessel data harvested from the automatic identification system for collision avoidance and security; second, static vessel information from a fleet register; and third, geographic data to determine ECAs and other relevant sea areas.

Dynamic The Automatic Identification System (AIS), see [11] and [2], is a radio-frequency based communications system that broadcasts key details about vessels above 300 gross tonnage[4] (GT). These details are sent every few seconds, depending on a vessel's speed and manoeuvre, and include their identification, current position, heading and speed. The system was primarily designed to avoid ship collision when visibility is poor and to inform coastal regions of approaching vessels. The IMO mandated AIS transponders on board of vessels from 2004 and shore-based receivers collect positioning data (AIS messages), typically within a radius of 50 nautical miles. From 2008, these messages were increasingly harvested by satellites for government and commercial purposes. Satellite coverage now spans the entire globe, with the exception of heavily congested areas, due to message collision.

The data we are using here was provided by exactEarth[5] and contains satellite and shore-based observations throughout 2012 with good overall coverage.

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[4] 300 GT is the lower limit for vessels on international voyages, 500 GT otherwise.
[5] See http://www.exactearth.com/.

Static In order to determine vessel characteristics from identifiers such as the unique IMO number, we use a World Fleet Register provided by Clarkson's Research[6]. This register contains technical details of the global cargo fleet, such as IMO number, vessel type, design speed, design draught, beam, length overall, deadweight tonnage, capacity, TEU (twenty-foot equivalent unit, i.e. a standard twenty-foot long container), installed main engine power, fuel type of main engine, year built, and many more.

Geographic To specify the geographic constraints for our data analysis, we need to unify the constraints given by four data sources. Firstly, the North American emission control areas as set out in MARPOL, which are represented as coordinate pairs in degree format [10]. Second, the regulation for California waters which outlines the area 24 nautical miles of the California baseline minus some area described by a few coordinate pairs [4]. Third, a dataset containing US maritime limits and boundaries for the 24 nm line[7]. Fourth, a shapefile of the world continents, providing global land boundaries [8].

Together, these four sources can be used to produce the geography for the North American ECAs and California waters. We then added additional buffer zones of 200 nautical miles around each ECA, see Figure 1. These buffer zones will constitute our 'control group', which makes analysis independent of other speed trends.
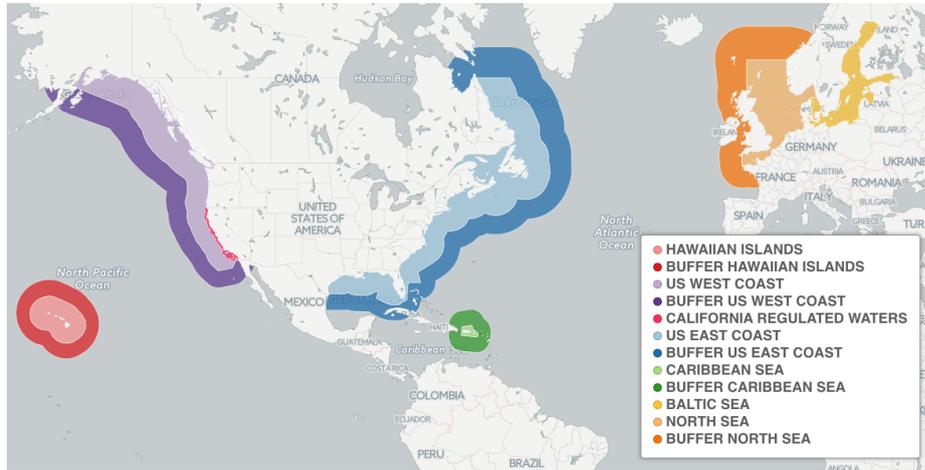
Figure 1. Emission Control Area (with buffer zones) and California Regulated Waters.

3.2 Tools

We are using two tools for the visual part of the data analysis, QGIS and CartoDB. This combination constitutes a user-friendly solution for data ingestion, data manipulation and data analysis.

QGIS is a freely available Open Source desktop application for manipulation and visualisation of geo-spatial data. It integrates well with PostGIS databases (GIS for PostgreSQL), providing a large catalogue of GIS functionality complemented with several optional extensions. CartoDB is an Open Source web mapping framework that provides geo-temporal data storage on a cloud database as well as an API for data manipulation and different styling options to display these data on a web browser.

In our case, QGIS proved very useful for transforming the MARPOL, California Waters and coastline data into a shapefile compatible with CartoDB ingestion tools with points in decimal format, filtering out land areas. In the early stages of the technical assessment of our work, QGIS provided us with an initial quick view of the content of the existing AIS dataset. However, QGIS lacks a good temporal extension that handles large datasets[8] and an SQL extension for direct manipulation of the data, so we only used it as an auxiliary tool.

Several other tools were considered to improve the data-analysis work. Amongst them are Mapbox, OpenLayers, ESRI and CartoDB. Out of all these, CartoDB proved to be the most adequate. We considered several key factors:

- Data storage: The AIS data is a very large dataset (approximately 1 billion rows for a cleaned version of 2012 data) with data security constraints imposed by the data owners. Therefore, the data must be hosted locally with restricted access, and the data queries need to be efficient for large amounts of information.
- Utilities for data ingestion and sharing: The AIS data is constantly being refined and filtered by our research group. The chosen tool should ideally allow easy ingestion of data in CSV or SQL format, as well as export tools for data backup or data sharing with colleagues.
- Data visualisation capability: To make the tool easily adoptable to all researchers in our group, we require an intuitive graphical user interface with data filtering controls, different choices for AIS visualisation such as density and cluster maps and ideally the possibility to plot temporal data navigable with a time slider.
- Integration with other visualisation tools: Ideally, the chosen tool could be extended beyond data mapping and allow other types of data plotting options such as histograms or scatterplots for speed profiling, etc.
- Reliability and robustness: We require the software to be deterministic, i.e. it always returns the same answer to the same question, and to return correct results. Furthermore, the software should be stable enough to allow for an efficient usage.

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[8] Although some efforts are being made in TimeManager, a plugin for QGIS (https://plugins.qgis.org/plugins/timemanager/), this is insufficient for large datasets.

The last key factor was difficult to measure since the tools we tried were very varied. Test coverage, reported defects in their user community, user support or number of patch releases can assist on evaluating this parameter. We discarded some tools, like MapBox Studio Classic, which were not reliable for querying a local PostGIS database, partly because at the time of testing this particular tool it was in its first releases.

Several libraries for web mapping, e.g. OpenLayers, would have required a substantial amount of development work to adapt to our key requirements, hence were discarded.

CartoDB, however, provides an out-of-the-box solution that complies with our key requirements without much need of custom development or user training.

The freely available online CartoDB alternative was discarded in favour of manually installing a full CartoDB stack locally at our university[9]. This way, we could adapt the default CartoDB configuration to store larger amounts of data, allow longer data import times and give access to the data only to the project's researchers, whilst having a ready-to-use web mapping interface with an SQL query editor and several options for data visualisation and styling.

3.3 Data-analysis steps

In this work, we want to research whether the introduction of the North American ECA has any effect on shipping behaviour, and we choose the speed of container ships as a proxy. The goal is to compare differences in vessel speeds in two different geographical areas (ECA and a buffer zone) and two time frames (1 January–31 July and 1 August–31 December 2012) as shown in Figure 2.
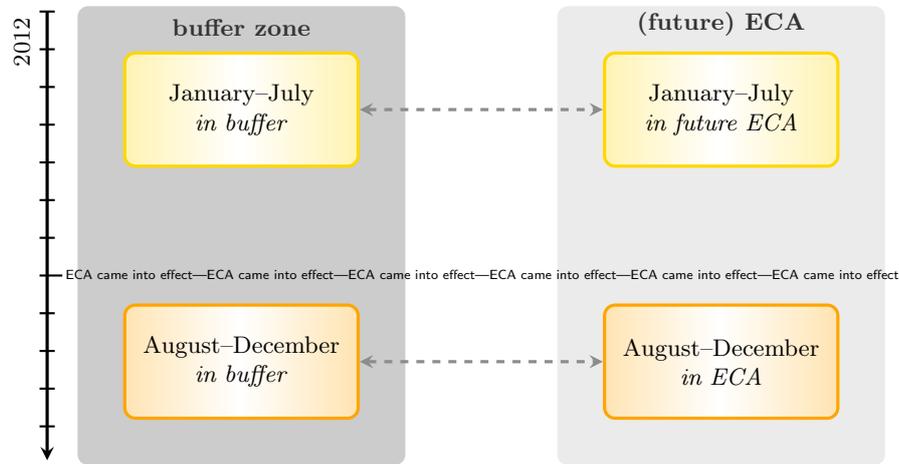
Figure 2. Geographical areas and time frames for calculating individual vessel speeds.

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[9] We followed instructions at http://cartodb.readthedocs.org/en/latest/install.html.

For the data analysis we follow these steps:

1. We extract AIS data for all vessels that we can identify as container ships using the world fleet register and aggregate the data per vessel and hour over the course of 2012.
2. We upload this data, the fleet register and the shapefile to CartoDB and select all vessels with messages occurring in all four time–area combinations.
3. We tag and export[10] only the messages that lie within one of the ECAs or buffer zones—but not in the California Waters as there is a second set of regulations valid different to the regulations in ECAs, see Table 2. Each message now comes in the format

$$(\texttt{IMO, time\_stamp, speed, sailing\_area}).$$

4. Following [18, p. 214], we discard all messages where the speed is lower than half the design speed, which is used there as a threshold for the minimal sailing speed.
5. For each individual vessel i, we calculate the average[11] sailing speed within each of the four time–area combinations. For time stamp t between January and July and sailing area a being the buffer, we have

$$average\left(vessel_i, \left[Jan, Jul\right], buffer\right) = \frac{\sum_{t\in[Jan, Jul], a=buffer} speed_{(i,t)}}{\sum_{t\in[Jan, Jul], a=buffer} 1}.$$

6. For each individual vessel, we calculate the difference in average speeds when present in the buffer zone as opposed to the (future) ECA:

$$diff\left(vessel_i, \left[Jan, Jul\right]\right) = average\left(vessel_i, \left[Jan, Jul\right], eca\right) -$$
$$-average\left(vessel_i, \left[Jan, Jul\right], buffer\right),$$

similarly for $diff\left(vessel_i, \left[Aug, Dec\right]\right)$.

7. We then compute the relative difference between the Jan–Jul difference and the Aug–Dec difference to find out whether vessels slow down (or accelerate) more crossing areas in the Jan–Jul or the Aug–Dec period, still for each individual vessel i

$$rel\_diff\left(vessel_i\right) = diff\left(vessel_i, \left[Aug, Dec\right]\right) - diff\left(vessel_i, \left[Jan, Jul\right]\right).$$

8. In the last step, we aggregate these individual vessel values by size bin. There are seven size bins which categorise the vessels according to the maximum number of containers, i.e. twenty-foot equivalent units (TEU), they can carry. Table 3 shows the size of these bins in TEU ranges.

4 Results and discussion of the speed analysis

In this section, we present and discuss the results that were obtained from analysing AIS data according to the eight steps described in Section 3.3.

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[10] The remaining data analysis is purely numerical, hence we switch to python.
[11] In this work, average is synonymous to the arithmetic mean.

size bin	TEU range	vessels in bin	messages in bin
1	10–999	42	15,207
2	1000–1999	68	35,860
3	2000–2999	102	50,630
4	3000–4999	344	138,513
5	5000–7999	238	89,776
6	8000–11,999	100	31,487
7	12,000–14,500	1	239
total	—	895	361,712

Table 3. TEU ranges of container size bins, including vessel/message counts per bin from the dataset used in this work.

4.1 Results

In Step 1, we extract data from 4785 container ships and aggregate it into hourly readings for each vessel. This results in 14,810,154 messages, as we do not observe the vessels every single hour but only about every three hours (35.2% of hours).

The filtering in Step 2 (only vessels that occur all four time–area combinations) leads to a set of 895 vessels for which we have 3,182,569 messages, meaning we observe them for 40.5% of the hours. CartoDB allows us to easily plot this data, and we extracted two 'sailing networks' by different size bins. The first one, see Figure 3 top, shows the routes being sailed by the 42 vessels that fall into size bin 1, i.e. vessels that carry between 10 and 999 TEU. These routes are predominantly in the Gulf of Mexico and Caribbean Sea where distances are short, only few vessels venture to islands further out in the oceans or Asia and Europe. The second network displays the route from the 100 vessels that fall into size bin 6, i.e. that carry between 8000 and 11,999 TEU. These vessels cover much longer distances, and typically go to major ports in Asia and Europe, see Figure 3 bottom.

After tagging and exporting only messages that fall inside the ECA or buffer zones (without California Waters), and subsequently discarding all messages with low sailing speeds (i.e. below half the design speed for that vessel), we remain with 361,712 messages, see Table 3.

We then calculate the individual average sailing speeds within the four time–area combinations (see Figure 2), and the absolute speed difference between the areas in the months January to July and August to December. In Figure 4, these values are aggregated by size bin into a Turkey boxplots[12]. Negative values mean that a vessel sails slower (on average) in the (future) ECA than in the buffer zone, positive values mean they sail faster. The figure shows that for most vessel sizes, over 75% of vessels slow down when entering a (future) ECA.

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[12] The horizontal line inside the box represents the median of speed differences of individual vessels within that group, the lower and upper edge of the box represent the first and third quartile, and the length of the whiskers represent the last values that fall into the 1.5 inter-quartile range which is added to the first/third quartiles. Outliers are shown as diamonds.
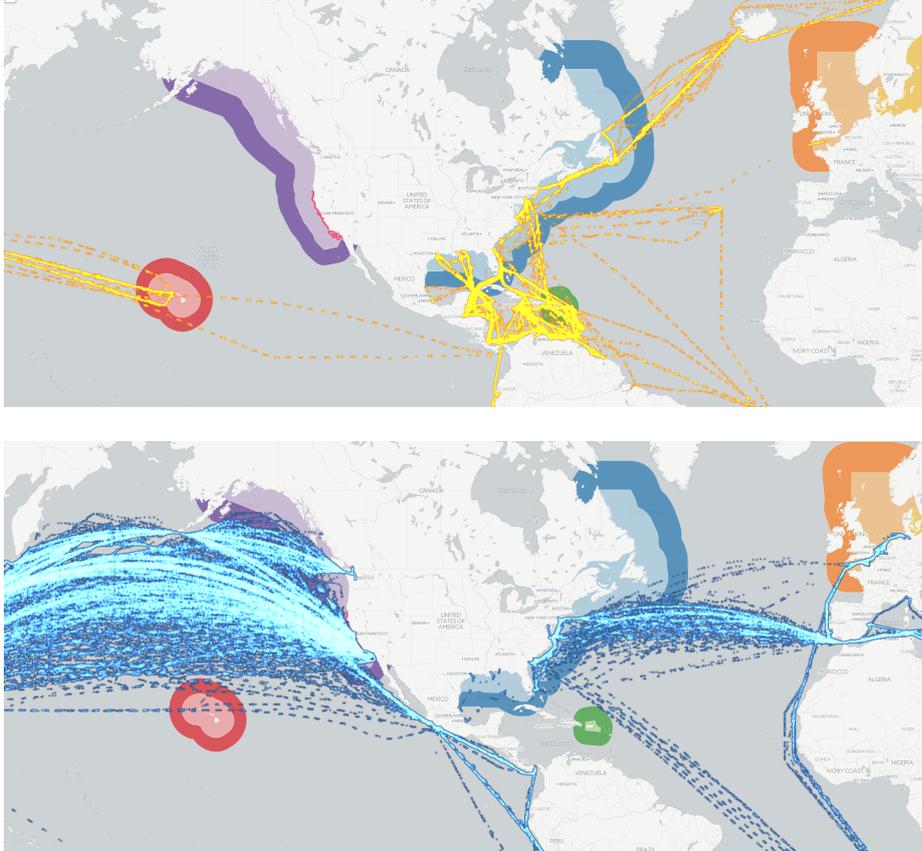
Figure 3. Route network by container vessels that enter the North American ECA of size bin 1 (top) and size bin 6 (bottom).

In order to estimate the effect that the introduction of the ECA had on sailing speeds, we calculate the relative difference of $diff\,(vessel_i, [Aug, Dec])$ and $diff\,(vessel_i, [Jan, Jul])$ for each single vessel i, and aggregate those values by size bin, see Figure 5. This figure shows that the medians of the relative speed difference in the seven bin sizes is very close to 0, i.e. about 50% of vessels are sailing slowing down more than they did before the introduction of the ECA and about 50% are slowing down less than they did before.

4.2   Discussion

We do not see a noticeable effect due to the introduction of the North American ECA on vessel behaviour. Aggregating the relative difference (*rel_diff*) over all vessels irrespective of their size bin, the mean is -0.15 knots with a standard
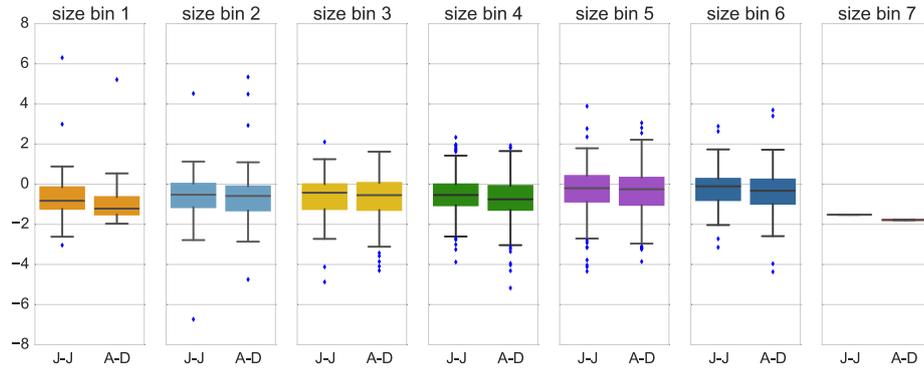
Figure 4. Speed difference of vessels sailing in ECA as opposed to buffer zones in time frames Jan–Jul or Aug–Dec.
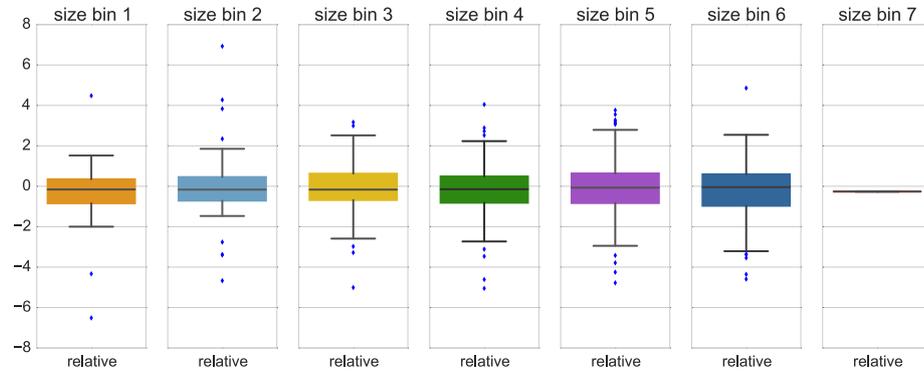
Figure 5. Relative difference between Jan–Jul and Aug–Dec of vessels sailing in ECA as opposed to buffer zones.

deviation of 1.27 knots. In view of the large standard deviation, we would not classify this as a significant result.

Doudnikoff and Lacoste [6] determine the speed differences for container using a cost-optimisation model. They focus on vessels sailing to the North Sea and Baltic Sea area in 2015, when the sulphur limits drop to 0.10% m/m. Their speed estimates for the category of vessels carrying 8500 TEU on a transatlantic route are as follows:

- 1.7 to 2.8 knots speed reduction in ECAs compared to outside based on a scenario with USD 300 per tonne difference in price between regular and ECA-compliant fuel,
- 3.0 to 5.4 knots speed reduction at USD 700 per tonne price difference.

The difference in fuel prices between ECA-compliant and non-compliant fuel in 2012 for the North American ECA, however, were only USD 93 per tonne [21].

The mean speed reduction for the comparable size bin 6 in our dataset is 0.39 knots with a standard deviation of 1.20 knots. This is about 40% below the reduction that would at least be expected when interpolating the values of the model from [6].

The general trend for average vessel speeds is to go down over the course of 2012, but this fact should not influence our results which take into account the differences in speed rather than absolute values. Looking at this difference from a different perspective, for example by calculating the difference in speed within a given area for the two time periods, we are able to identify only one size bin whose median vessel is travelling faster in the buffer zone post ECA introduction than before, see Figure 6, however this bin's vessel population is only 1.
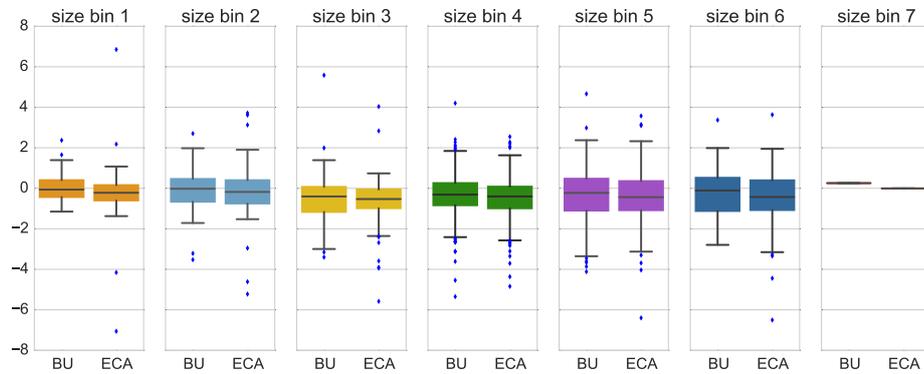
Figure 6. Speed difference of vessels sailing in ECA as opposed to buffer zones.

The calculations for the buffer regions were

$$diff\left(vessel_i, buffer\right) = average\left(vessel_i, \left[Aug, Dec\right], buffer\right) -$$
$$-average\left(vessel_i, \left[Jan, Jul\right], buffer\right),$$

similar for $diff\left(vessel_i, eca\right)$.

This type of behaviour would be expected from operators that want to regain 'lost' time from sailing slowly in the ECA, in line with the findings in [6], however we do not see this behaviour in our data more often than not. The only trend we can see is that vessels are sailing marginally slower within one and the same region in August–December than in in January–July.

Adland et al. [1] also observe no noticeable difference in speeds when investigating the introduction of the North Sea and ECA in November 2007, most likely because there are other speed determining factors than purely fuel price.

This leads to the conclusion, that speed optimisation been of little concern when sailing in the North American ECA, but due to the huge variation of the data, we cannot exclude that other factors are responsible for this behaviour.

5 Summary and further work

Despite the large volume of trade that is carried by sea, shipping does not often become the centre of attention. Most of the time, the general public is unaware of and disengaged with the shipping industry [20]. Even in trade and transport studies, shipping as a sector often goes completely unnoticed due to the level of aggregation. Concerns from within this sector are often expressed as anecdotes or claims, a fact that complicates the development of effective regulation, especially with regard to absolute emission reductions, which are feared to negatively impact competitiveness. We recognise a shortage of data and knowledge derived from such data, which is suitable to scrutinise those claims and substantiate policy-specific questions.

This paper constitutes a first step towards a rigorous analysis of impacts on the shipping industry caused by regulatory processes. We present a method of visually and numerically analysing vessel speeds using freely available tools (albeit licensed data). In Section 3.3, we outline step by step how we conduct our analysis, which ensures the transparency and reproducibility of our research.

The research question we set out to answer is whether there are any changes to the shipping behaviour in the North American ECA, since it came into effect on 1 August 2012.

For each vessel, we determine the average sailing speed in four time–area combinations, see Figure 2: (1) in a buffer zone of 200 nautical miles adjacent to the North American ECA over the course of 1 January to 31 July 2012, (2) in the same area between 1 August and 31 December 2012, (3) in the area that constitutes the future North American ECA from 1 January to 31 July 2012, and (4) in that same area—now the ECA is in effect—between 1 August and 31 December 2012. The vessel speeds within the same time frames are then subtracted from one another for each single vessel, (3)-(1) and (4)-(2), and the differences are aggregated by size bin, shown in Figure 4. In a subsequent calculation, we determine the relative difference of these values, again for every single vessel and aggregated by size bin, see Figure 5.

The results of our analysis show that, whilst 72.2% of vessels sail slower in the ECA as opposed to the buffer area (69.4% before the ECA came into effect), the introduction of the ECA did not cause a trend of sailing even slower in that area compared to the buffer zone. Hence, we cannot say that this particular air-pollution regulation caused significant behavioural changes, at least not in terms of sailing speed.

Even though there is 'nothing to report', this is still an important first step towards analysing shipping behaviour and providing evidence for policy-makers. In a next step, we would like to extend our analysis to other cargo vessels, such as bulk carriers, tankers and gas bulk.

We are not only interested in the sailing speed of vessels, but also in their fuel usage and associated greenhouse-gas emissions. Understanding the relationship between existing regulations, their implementation and their consequences is fundamental for ensuring the effectiveness of future regulations.

Acknowledgements

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