Monitoring shipping emissions via AIS data? Certainly

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Abstract

While it is widely accepted that the shipping sector needs to work towards controlling its greenhouse gas emissions the quantity of these emissions is not exactly known. Various methods for estimating CO2 emissions from shipping in particular exist but they are associated with large uncertainties; estimates from different methods often disagree; and many methods can only produce estimates for a fixed point in time, typically in the past. Deriving shipping emissions from Automatic Identification System (AIS) data allows for nearly continuous monitoring, with very little time lag, based on actual ship movements, implying that the method is sensitive to measures aimed at reducing fuel burn, such as slow steaming. The key issue therefore is the feasibility and accuracy of the method. Comparing estimates from AIS data with the fuel burn as recorded in the noon reports of a sample fleet of 13 container and multi-purpose cargo ships, representing three different size and type categories, preliminary results demonstrate the feasibility of the method. The 13-member sample is used to calibrate the fuel consumption formula. Uncertainty is appraised in relation to the methods currently in use. Results indicate that the uncertainty of an aggregate estimate derived from a global data set will be smaller than that of the most authoritative estimates to date.

Keywords: Monitoring shipping emissions; AIS data.

1. Introduction

It is widely accepted that carbon emissions from international shipping should be controlled and reduced. However, the transition towards low-carbon technology and more fuel-efficient operations poses a challenge to the sector, and there are no straightforward solutions. Therefore, constructing a regulatory framework and a business environment that incentivise carbon reductions is seen as important (UNEP, 2012). One crucial element in building such a benign framework is accurate, and openly accessible, information on energy efficiency and carbon emissions in the shipping sector. However, current methods providing estimates of greenhouse gas emissions from shipping are associated with large uncertainty and fail to fulfill basic criteria for the usefulness of an emissions reporting method. As discussed in (Traut et al., 2012) and subsequently in (Fischbacher et al., 2012), estimating carbon emissions on the level of the individual ship, based on a re-construction of the ships' movements from the Automatic Identification System (AIS) records gathered by both space- and shore based receivers, provides a better fit with respect to greenhouse gas accounting criteria. For example, emissions could be monitored over time, and with very little time lag.

Jalkanen et al. (2009, 2012) have used AIS data to estimate emissions in the Baltic Sea. Deployment of AIS-receivers in Earth orbit opens up the possibility of tracking individual ships travelling across the globe (Meland et al., 2004 and Eriksen et al., 2006). However, besides the challenge of calculating a ship's fuel consumption from its movements, the key question is whether, globally, AIS data can provide sufficient coverage. Even while satellite and terrestrial AIS receivers naturally complement each other (Eriksen et al., 2010 and Traut et al., 2012), a ship might be outside the field of view of both shore- and space-based receivers. If a vessel is in the field of view of a satellite-borne receiver, disentanglement of the many AIS messages arriving at the receiver is difficult, in particular over regions of dense ship traffic, where coverage drops accordingly (Eriksen et al., 2010). Shifting focus from receiver to sender, a vessel may not transmit AIS messages during operations. While all large ocean-going vessels are mandated by the International Maritime Organization's International

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Convention for the Safety of Life at Sea (SOLAS) to use AIS, transmission may be interrupted or switched off for security reasons or because of damage to the equipment.
To explore the question of coverage and, more generally, the feasibility of deriving accurate estimates of shipping emissions around the globe, this paper compares AIS-based fuel consumption estimates with main engine fuel consumption as recorded in the noon reports of a sample fleet of 13 cargo vessels, throughout the year 2012.
The data sets – space- and shore-based AIS, noon reports, and a world cargo fleet database – are presented in section 2.1. The AIS records are ordered and processed to reflect the respective vessel's movements as accurately as possible, as detailed in section 2.2. Ship movements are mapped to main engine fuel consumption and carbon emissions by way of a simple formula, based on two vessel parameters: installed main engine power and service speed, as defined in section 2.3. Results are presented in section 3. Uncertainties are discussed in section 4. Section 5 concludes.

2. Methods

2.1 Data sets

The point of reference for the fuel consumption estimate is provided by the noon reports, from the year 2012, of 13 cargo vessels engaged in international trade, in which – on a typically daily basis, hence the name – ships record their current state of operation, course, destination, and, among various other parameters, their fuel consumption. The sample fleet comprises of two groups of container vessels – vessels 1-3, and 4-7 – of the same build, respectively, and one group of six multi-purpose carriers all of the same build – vessels 8-13. The cumulative main engine fuel consumption at a given point in 2012 is given by summing up the three (heavy fuel oil, marine diesel oil, and marine gas oil) fuel consumption fields over all reports from the beginning of that year. In one case, vessel 5, a gap exists in the series of noon reports so that it has been excluded from any steps aimed at calibrating the method, to avoid distortion of the results.
A set of space-based and a set of shore-based AIS data complement each other. The satellite data are all recorded AIS messages coming from one of the 13 test vessels for 2012. The Maritime Mobile Service Identity (MMSI) number serves as vessel identifier. An initial data analysis showed that vessel 1 changed its MMSI number in mid-2012 so only messages from the second half of 2012 are included in the AIS data sets and it was excluded from aggregate results and any calibration steps. The shore-based data are all AIS messages recorded from vessel 1-12 over the course of 2012. Messages in this data set were pre-processed, for example, to include the vessels' IMO numbers. Also, in a comparative analysis of both AIS data sets no faulty messages were found in the space AIS data, but a number of apparently mis-identified AIS messages were found in the terrestrial data. In the process chain deriving fuel consumption estimates a filter was included to go over all data, discarding erroneous messages (cf. the section 2.2).
Vessel parameters installed main engine power, service speed, and deadweight tonnage, input to the main engine fuel consumption formula (equation 1, section 2.3), are taken from the Clarksons Register of the world cargo fleet.

2.2 Workflow

The fuel consumption records from the noon records, as test cases for validation, are operated on in spreadsheets. But the emissions estimation method is set up to work in an automated manner because it would be unfeasible to analyse a whole fleet otherwise, running through a series of main steps:

(1) processing of raw AIS messages
(2) ordering of messages, by IMO number and time stamp
(3) quality filtering
(4) pathfinding
(5) fuel consumption calculation

In the first step, all AIS data are converted into a common file format, including fields for the IMO number, MMSI number, time stamp, latitude, longitude, speed over ground, course over ground, and draught. In the second step, all messages are filed according to IMO number, and data sets pertaining to a given IMO number are ordered by time stamp. In the third step, messages that are identified as faulty are discarded. In the fourth step, an implemented A*-algorithm finds the shortest route between all pairs of consecutive messages for which $\Delta t > 8h$ and the distance between the positions $\Delta s > 60km$. The graph is defined by a land-sea mask with a resolution of 0.1°; every node has 32 neighbours. Finally, the main programme reads in a fleet database – which in this case contains the sample fleet of 13 – and for every vessel looks up the file containing the pertinent AIS messages, calculating the fuel consumption between every pair of consecutive AIS messages, and the cumulative fuel consumption over the time interval under analysis – the whole year 2012 in this study.

2.3 Fuel consumption formula

A vessel's main engine fuel consumption fc during the time interval between consecutive AIS messages is estimated according to the formula:

$$fc = 0.8 \cdot p_{ME} \cdot SFOC \cdot \left(\frac{v_{transient}}{v_{service}}\right)^3 \cdot \Delta t \qquad (1)$$

where 0.8 represents a generic engine load factor, p_{ME} is the vessel's installed main engine power, the engine's specific fuel consumption is assumed to be $SFOC$ = 200 g/kWh, $v_{service}$ is the ship's service speed, $v_{transient}$ is the current travel speed, and Δt is the time interval between the two messages. There are two straightforward choices for the value of $v_{transient}$. First, the values given in the AIS messages; second, the geographical distance between the locations given in the AIS messages divided by the time interval. Discriminating between different ranges of Δt, a combination between the two choices is used, including various plausibility checks for resulting values.

3. Results

Qualitatively, the fuel consumption of the test vessels as recorded in their respective noon reports and as estimated from the AIS recordings agree well. I.e. the curves of the two values plotted over time are similar in shape. Besides relatively small differences in shape, in most cases the main difference appears as a constant factor. Figure 1 shows the ratio of the cumulative fuel consumption over the year 2012 as estimated from the AIS data and as recorded in the noon reports.
Vessels excluded from further analysis, because they were not included in some of the data sets (note that they were not included for ulterior reasons rather than because of any inherent problems associated with the AIS-method) are plotted as triangles, all other vessels are plotted as squares. The AIS-method tends to under-estimate fuel consumption, with values ranging from 70% (vessel 7) to 108% (vessel 2).

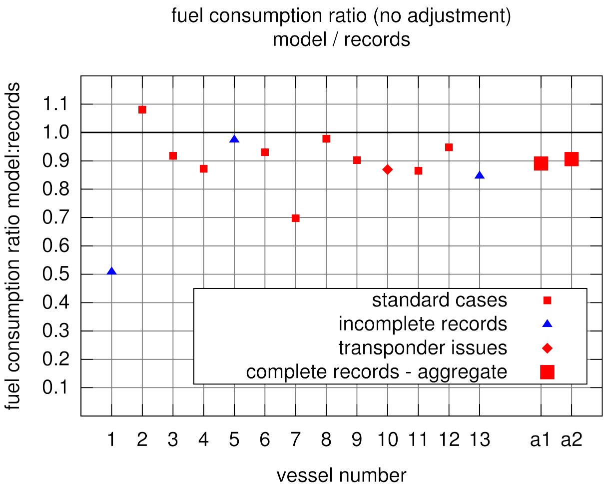

Figure 1. Main engine fuel consumption estimated from AIS records, normalised with main engine fuel consumption according to sample vessels' noon reports, for entire year 2012. Data sets for vessel 1, 5, 13 are incomplete and have been left out of the further analysis. Vessel 10 had transponder problems for a time interval of several months that were only discovered afterwards. But because there is no way of automatically recognising trouble with the transponder it is included in the subsequent analysis. Aggregate value a1 is the total main engine fuel consumption of vessels 2-4 and 6-12, normalised with the main engine fuel consumption according to noon reports while a2 is the average of normalized fuel consumptions of the same vessels.

On aggregate, the fuel consumption according to the estimates is 89% of the test fleet's fuel consumption as recorded in the noon reports while the average of the normalised fuel consumption estimates is 91% (with respect to average/aggregate values, the test fleet excluded incomplete cases, i.e. it comprises of vessels 2 to 4 and 6 to 12).
In the fuel consumption formula (1) the engine load factor and the SFOC are assumed to be constant. While both values are not mere fit values but represent engineering parameters, they could be used to calibrate the formula. In principle, they need not be constants but could assume either vessel-specific values or be functions of a more general parameter, such as a vessel's deadweight tonnage. Attempting to find best-fitting values is difficult with such a small number of data points. Still, it is instructive to choose an engine load factor that equates the aggregate fuel consumption estimate to the recorded fuel consumption. Relative fuel consumption estimates for the test fleet for that engine load factor of 0.891 are shown in figure 2. Values range from 78% (vessel 7) to 121% (vessel 2).

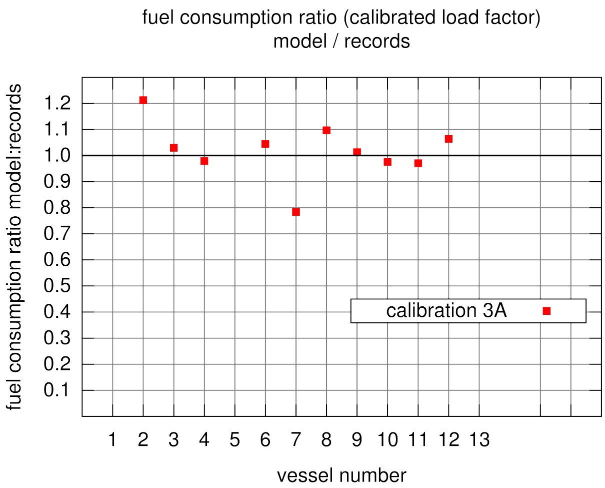

Figure 2. Normalised main engine fuel consumption, as in figure 1 but with the main engine load factor of 0.891, cf. equation (1), chosen to match the sample fleet's aggregate main engine fuel consumption with the noon records.

Defining the standard deviation σ as:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(r_i - a)^2} \qquad (2)$$

where r_i are the fuel consumption estimates relative to the recorded values, and a is their average, then $\sigma = 9\%$ for the original values as shown in figure 1.

4. Discussion

In assessing the accuracy of the presented method for estimating emissions from shipping, four issues are discussed here: choices made in deriving a ship's main engine fuel consumption from its AIS data records, e.g. the choice of parameters governing equation (1); sources of uncertainty, and their bearing on the overall accuracy of the method; assessing the accuracy of the model results gauged against the noon reports, and comparing the achieved accuracy with that of existing methods; outlining further steps towards calibrating, verifying, and applying the method.
The method presented here assumes that a vessel's main engine fuel consumption goes with the cube of its speed. It scales with the vessel's installed main engine power, the (inverse cube of) its service speed, and with a couple of constant factors. In principle, it would be possible to derive a vessel's power requirements more directly from its shape (or just its geometrical dimensions), as investigated by Jalkanen et al. (2012). Also, additional information on conditions affecting fuel consumption could be included: a ship's loading condition is reflected in its draught, which is included in AIS messages; wind, wave, and ocean current conditions could be included – with information gathered from additional data sources, such as weather models or satellite observations. This first issue is inter-connected with the second issue: uncertainty. Uncertainties can be grouped into two categories. In the

first category, uncertainties are due to a discrepancy between a vessel's actual fuel consumption and the underlying model used to estimate it. For example, the cubic speed dependency of the fuel consumption is only an approximation. As mentioned above, environmental conditions are not included in the fuel consumption estimate although they clearly affect the actual fuel consumption. While it may be possible to include environmental conditions in the methodology, there is no straightforward data source hinting at a vessel's hull and propeller condition. In the second category, uncertainties arise from incomplete or incorrect data input to the model, for instance, results depend critically on the installed main engine power, and service speed. Both are taken from a global ship database, which itself is not expected to be completely accurate. Most important in relation to the presented method is the question whether a vessel's movements are re-constructed from the AIS data source with sufficient accuracy.

In this study, uncertainty is assessed in a quantitative manner by comparing estimates with fuel consumption as recorded in the sample vessels' noon reports, under the assumption that the latter are accurate. Without any calibration of the applied formula, the aggregate main engine fuel consumption estimate lies at 89% of the recorded value. The standard deviation as defined in equation (2) is 9%, suggesting that the calibrated method provides a significant reduction in uncertainty, compared to other methods. The 2nd IMO GHG study (Buhaug et al., 2009) states an uncertainty range of 20%. The difference with respect to other estimates considered in the 2nd IMO GHG study, e.g. (Paxian et al., 2010) or an estimate based on IEA fuel sale statistics (IEA, 2012), is higher still. Unless significant systematical errors – due to the switch-off of AIS messaging – turn out to have a significant impact, whole-fleet estimates will, on aggregate, be far more exact than uncertainty on the individual ship level.

By comparing estimated cumulative fuel consumption over the course of a full year to the sample vessels' fuel consumption records, the above analysis shows that it is possible to monitor carbon dioxide emissions from ocean-going cargo vessels around the globe, with the potential to significantly reduce uncertainty, compared to methods currently in use. Beyond comparing full-year results, forthcoming work will compare fuel consumption records and AIS-based methods as a function of time, including a more detailed analysis of qualitative agreement between estimates and records. The method stands ready to be applied to more complete data sets – including a full global set – subject to data availability. Here, two points are worth noting. The AIS data used in this project were selected according to the available noon records, so the data providing global coverage exist. Satellite-AIS is a relatively new phenomenon (cf. section 2.1) and various public and commercial efforts are underway aiming at more and/or improved space-based receivers, so that improved coverage is to be expected in the future. Besides scaling up application, there is ample scope for further development, calibration, and verification of the methodology. In particular, this includes comparison of estimates with more detailed fuel consumption records, inclusion of other information like weather data or more refined ship characteristics, and comparison with other methods that use the same data but different fuel consumption models.

5. Conclusions

Monitoring greenhouse gas emissions from international shipping is a key element of climate change mitigation in the shipping sector. However, methods currently in use are found wanting with respect to several criteria. Estimating emissions based on individual ship movements, inferred from a combination of space and terrestrial AIS recordings, has some advantages but, to our knowledge, it has not yet been attempted globally. This paper analyses AIS data from a sample fleet of ocean-going cargo vessels, comprised of space- and shore-based data, covering the full year 2012. For each individual vessel, AIS data are processed, and based on vessel-specific parameters taken from a register of the global cargo fleet, main engine fuel consumption estimates are derived. Estimates are compared to each vessel's cumulative fuel consumption according to its noon reports. Without any calibration steps, on aggregate, the fuel consumption estimate of the sample fleet is 89% of the value indicated by the noon reports. The standard deviation of the normalised fuel consumption estimates is 9%. Barring the emergence of significant errors due to wide-spread switch-off of AIS messaging, fleet-wide aggregate estimates will significantly reduce the uncertainty of currently used methods. Over time, data coverage will improve as the number and power of space-based receivers grows. It is shown that on a global level, application of AIS-based emissions monitoring has the potential to provide an accurate and up-to-date picture of greenhouse gas emissions from shipping, informing any effort to reduce the sector's greenhouse gas wake.

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