DEVELOPMENT OF AN ACTIVITY-BASED MARINE EMISSION INVENTORY USING AIS DATA

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1. INTRODUCTION

Environment and Climate Change Canada (ECCC) is in the process of updating its marine emission inventory. At the same time, it is engaged in a multi-year study of emissions and air quality effects of marine-source fugitive Volatile Organic Compounds (VOCs) in Canada. The current Canadian marine emissions inventory include combustion emissions and fugitive VOC emissions from some crude petroleum loading, but is missing all fugitives (from loading and transit) from barges and fugitive associated with tanker transport of refined petroleum products.

Here we show how historical vessel position and speed data can be used to develop an activity-based inventory over the southern coast of British Columbia that includes both combustion and fugitive emissions. This work is part of a pilot project that is to be expanded nationally.

2. METHODS

2.1 AIS Data

All vessels above 300GT and all passenger vessels are required to use the Automatic Identification System (AIS) tracking system to assist in safe marine movement and allow the monitoring of vessel positions.
To accomplish these tasks, every few minutes, the AIS system transmits the vessel's identity, type, speed, course, draught and navigational status.

Over the January-December 2015 period, ECCC archived over 11 million AIS reports (at 10-minute intervals) from vessels movements within part of the Georgia Basin (between 47 and 51^{o}N and 121 to 123^{o}W), a geographical region within southern British Columbia and coastal Washington State.

In addition to the AIS data, for every vessel observed, we used its IMO number to gather its vessel characteristic (principally length, breadth, design draught, service speed, main engine power, auxiliary engine power and boiler fuel consumption rate) from the IHS Seaweb database[1].

2.2 Combustion Emissions

We used the AIS speed data, along with the vessel characteristics to compute its combustion emissions. From each transmission (or 'ping'), combustion emissions were estimated from the vessel's main, auxiliary engines and its boilers. All combustion emissions calculations involved pollutant- and engine-specific emission factors, taken from ECCC's 2010 Marine Emissions Inventory Tool (MEIT; SNC Lavalin, 2012),

2.2.1 Main Engine

For the main engine, emissions were calculated based on engine load and main engine size:

$$E_{MAIN} = EF_{MAIN} \times ME_{LF} \times ME_{LLF} \times MCR \times \Delta T \text{ [g]} \quad (1)$$

where EF_{MAIN} is the main engine emission factor (in g/kWhr), ME_{LF} is an estimate of the main engine load, ME_{LLF} is an additional factor to account for emission rates under low loads, MCR is the vessel's maximum continuous rating (in kW) and ΔT is the time between pings (in hours).

The load on the main engine was estimated using the AIS-based vessel speed:

$$ME_{LF} = Speed_{AIS}/Speed_{SERVICE} \quad (2)$$

where is $Speed_{AIS}$ is the AIS-based vessel speed and $Speed_{SERVICE}$ is the vessel service speed.

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[1] Sea-Web data (www.seaweb.com) is an online database of vessel characters and movements.

2.2.2 Auxiliary Engine

Emissions from the vessel auxiliary engines did not involve the AIS speed, but relied instead on estimates of the auxiliary engine load:

$$E_{AUX} = EF_{AUX} \text{ x } AE_{LF} \text{ x AuxPower x } \Delta T \text{ [g]} \qquad (3)$$

where EF_{AUX} is the auxiliary engine emission factor (in g/kWhr), AE_{LF} is a measure of the load on the auxiliary engine, *AuxPowe*r is the vessel's auxiliary power (in kW) and ΔT is the time between pings (in hours).

The auxiliary engine load was estimated based on the vessel status (e.g. `underway', 'anchor', 'berthing', etc.) as reported by AIS.

2.2.3 Boilers

Emissions from vessel boilers, where applicable, were calculated as:

$$E_{BOIL} = EF_{BOIL} \text{ x BFC x } \Delta T \text{ [g]} \qquad (4)$$

where EF_{BOIL} is boiler emission factor (in g/kg fuel) and *BFC* is the boiler fuel consumption (in kg/hour) and ΔT is the time between pings (in hours).

2.3 Fugitive Loading Emissions

Fugitive emissions from the loading of petroleum products was calculated based on estimates of volumes loaded at the various terminals in the Georgia Basin. For tankers[1], we estimated the amount of petroleum product being carried and loaded using the observed draught and vessel characteristics using methodologies based on what was developed to assess the CO_2 efficiency of the existing maritime shipping fleet by (Smith et al., 2015).

The type of product being carried (e.g. crude oil, gasoline) was estimated based on the marine terminal being visited. Results from a survey of vapour control technologies used at marine terminals within the Georgia Basin were used to calculate loading (or unloading depending on the terminal) emissions:

$$E_{LOAD} = EF_{PROD} \text{ * Load x (1-eff)} \qquad (5)$$

where EF_{PROD} is the emission factor associated with the loading of a specific petroleum product (g/L), *Load* is the estimated volume of product loaded/unloaded (in L) and *eff* is the terminal-specific vapour control efficiency.

(3)

2.4 Fugitive Transit Emissions

2.4.1 Tankers

Fugitive emissions were calculated using the estimated loaded volume:

$$E_{fVOC} = EF_{fVOC} \text{ * Load * } \Delta T \qquad (6)$$

where EF_{fVOC} is fugitive transit emission factor (in g/L of product/hour), *Load* the amount of petroleum product being carried (in L) and ΔT is the time between pings (in hours).

2.4.2 Tugs

Estimating fugitive transit emissions from barges were more difficult to calculate because AIS provides a tug's name but not what it is pulling/pushing. Furthermore, we could not use reported tug draught to estimate product volumes within the barges. As a result, we assigned fugitives from barge movement uniformly over tug movement footprint and estimated the volume of petroleum being barged based on local fuel use, and published data.

2.5 Temporal and spatial emission allocation

2.5.1 Spatial Allocation

We treated combustion emissions from tanker, cargo and passenger vessels as point sources. We assigned combustion emissions from these vessels, and from each of its AIS pings, to 1kmx1km cells over our domain. We then treated each 1 km cell as a single point source, with a stack height of 30 m, stack diameter of 1.5 m, exit velocity of 22.8 m/s and exit temperature of 500 K (Figure 1).

[1] For barges, for which recorded AIS draught is not available, we estimated cargo based on typical or average barge size carried by a particular tug or tug company

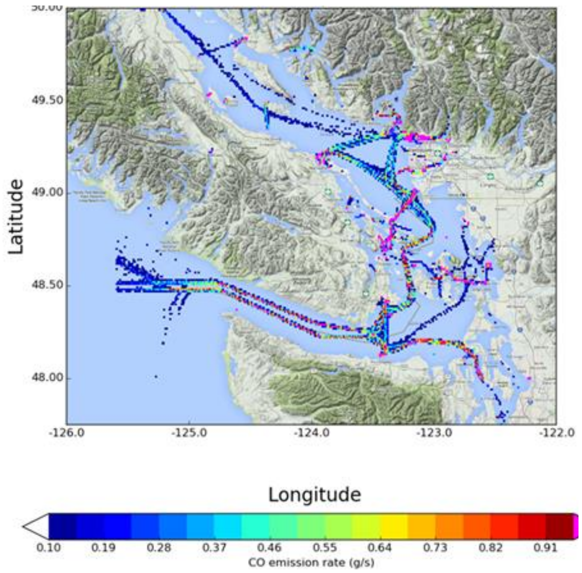

Fig. 1. Hourly CO emissions, modeled as individual point sources, from ocean going vessels as calculated from the AIS-based emission inventory.

Because of their smaller size, and less restricted movements, we treated combustion emissions from tug and fishing boats as area sources, gridding them to a 4km x 4km domain (Figure 2).

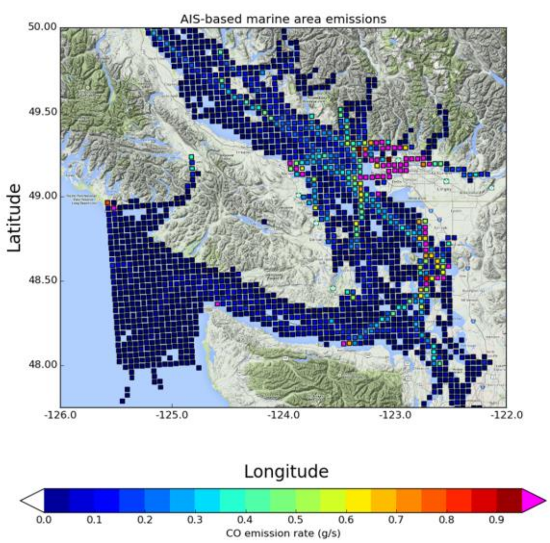

Fig. 2. Hourly CO emissions, modeled as an area source, from tug and fishing vessels, as calculated from the AIS-based emission inventory.

2.5.2 Temporal Allocation

When averaged over the entire year, we found that there was very little diurnal or hebdomadal variability in the emissions estimates, so we allocated hourly and daily emission uniformly in across each weak. However, we did find noticeable monthly variability in the emissions.

4. INVENTORY EVALUATION

To test the accuracy of our inventory, we used actual fuel consumption from a number of passenger vessels sailing within the Georgia Basin. For 12 different vessels, we compared monthly round trip specific fuel consumption based on observed fuel sales versus fuel consumption based on estimated CO_2 emissions.

For each vessel, we used the AIS data to calculate fuel use for each round trip during the month of May 2015. We also used the AIS data to estimate main engine load so as to report both the observed and predicted fuel use as specific fuel consumption (g fuel/kW-hr).

In Figure 3, we show the observed (red dots) and mean predicted (blue dots) specific fuel consumption for each of the 12 vessels. We also show the range of estimated fuel use (blue whiskers) on each of the round trip voyages taken during the month (minimum 7, maximum 114 and a mean of 55 round trips).

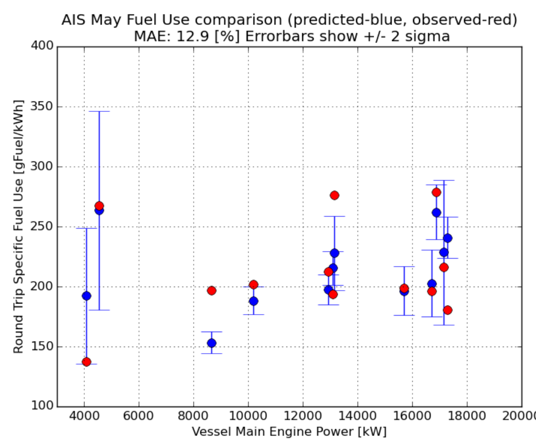

Fig. 3. "Observed (red) and predicted (blue) fuel consumption (in g fuel/kWhr) for a number of different passenger ferry routes within the Georgia Basin. The figure shows the range of estimated May round trip fuel use (whiskers) along with the estimated monthly mean (blue circles) and actual monthly mean (red circles) as a function of vessel main engine size (in kW). Fuel use has been scaled by the estimated power consumed over each round trip. No corrections to vessel power use have been made to account for the influence of tidal currents. Several of the vessels used in the analysis have identical values for main power, and so small

offsets to vessel main power have been added to improve plotting clarity,

3. DISCUSSION

AIS data has been used to development an activity-based and bottom-up emission inventory. This methodology also provides, in addition to emission totals, the spatial and temporal emission patterns.

Aulinger et al. (2016) have recently used AIS data to develop an activity-based marine emission inventory for the North Sea. Our work extends on their methods through the inclusion of fugitive emissions from both the loading and transport of petroleum products. In addition, the current work attempts to quantify the accuracy of the emission inventory through comparisons of predicted and actual fuel use from 12 different passenger ferries operating in the Georgia Basin.

The AIS-based vessel speed is relative to land, whereas main engine load is related to cube of vessel speed relative to water. Thus, for vessels traveling at low speeds during high tidal current periods, appreciable errors in emissions may arise. ECCC intends to correct for this by integrating tidal data into the analysis in order to account for current speed.

This is a pilot project, performed over a limited area, which ECCC plans to use as a test bed as it develops its next national marine emission inventory using Canadian Coast Guard data, which estimates marine emissions for all vessels in Canadian waters, including the Arctic. In addition, ECCC is using the present inventory to assess the potential environmental benefits of vapour control during the loading of petroleum products at marine terminals in Canada.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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