SIMULATION OF SHIP EMISSIONS AT A HIGH SPATIAL AND TEMPORAL RESOLUTION

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1. Introduction

Shipping is a major source of air pollution and greenhouse gas emissions. Overseas studies have consistently found that ships have significant effects on local air quality in and around port areas (e.g. EEA 2013). Ships (ocean going vessels) use large diesel engines that run on heavy bunker fuels, generally without emission controls.

As a case-study, AIS (Automatic Identification System) data are used for ship emission modelling in and around an Australian port. A comparison with movement ship activity data is included. Both data sets were provided by Maritime Safety Queensland.

2. Method

A new empirical shipping (exhaust) emission model was developed by DSITI that uses available input data on local shipping movements.

The model first estimates fuel consumption by marine fuel type (3 classes) and ship type (15 classes), and subsequently uses fuel-based emission factors (g/kg fuel) to estimate emissions (NO_x, SO_2, PM_{10}, V, Ni, PAHs, CO_2, etc.).

As an example, the following set of algorithms are used to simulate fuel use for a bulk carrier for the main engine(s), auxiliary engine(s) and boiler(s):

$$F_{main.eng.,p} = 0.31\, S^{0.52}\, \Delta d\, p \left(\frac{\nu}{\nu_{ss}}\right)^3 \quad (1)$$

$$F_{boiler} = 0.03\, \varphi_1\, S\, \Delta t \,/\, (\tau\, \eta) \quad (2)$$

$$F_{aux.eng1.,p} = 0.31\, S^{0.52}\, \Delta d\, p \quad (3)$$

$$F_{aux.eng.2,p} = (\varphi_2\, 0.44\, S^{0.58} \Delta t - F_{boiler})\, p \quad (4)$$

Model variables are ship size (S, gross tonnage), distance (Δd, km), fuel mix proportion (p, -), ship speed (ν, km/h), service speed (ν_{ss}, km/h), time resolution (Δt, h), thermal efficiency (η,-) and lower heating value (τ, MJ/kg). For auxiliary engines, Eq. 3 applies to transit conditions, whereas Eq. 4 applies in manoeuvring conditions, defined as $(\nu/\nu_{ss})^3 \leq 0.20$ and stationary conditions (ν = 0). φ_1 and φ_2 are speed-dependent manoeuvring correction factors. Fuel mix proportion tables are used to quantify the distribution of relevant fuel-engine combinations for all ship classes.

The necessary ship activity data are obtained from processed and verified AIS data. AIS tracks each ship's identity, type, position, course, (spot) speed and other safety-related information at regular time intervals. However, before AIS data can be used in emissions modelling, it needs to be processed and verified. Code was therefore developed to check, correct and impute AIS data using the following steps:

- extract AIS data for each individual ship
- re-order data using date-time stamps
- add latitude/longitude (UTM)
- add distance travelled
- add (travel) speed and acceleration
- outlier detection and removal
- impute missing location and speed data

Outliers are associated with locational errors and are flagged as data points with an absolute acceleration larger than 0.15 m/s^2 and a vessel speed larger than 1.15 times the service speed.

Data gaps are addressed as follows. First a complete time-series is created for each ship using 1-minute time steps to identify where ship data are missing. For data gaps of less than or equal to 2 hours duration, UTM coordinates are linearly interpolated in space (i.e. time-steps of equal distance) using the last and first available UTM coordinates at either end of the gap.

For data gaps larger than 2 hours and ships > 300 GT, a similar spatial interpolation is applied, on the condition that the vessel remains in the same 1x1 km grid cell and that the last and first recorded speeds at either end of the gap are less than 2.5 km/h. The inclusion of these large data gaps ensures that berth/anchorage times are captured in the emissions estimation. It is noted that tugs, yachts and dredgers are excluded from this interpolation.

A T4253H speed filter is applied to remove noise and unrealistic variations in speed. Ship speeds less than 0.5 km/h are set to zero.

Figure 1 shows locational information from the processed AIS data for Abbot Point for a complete year (2015). The ship routes and anchorage areas are clearly visible.

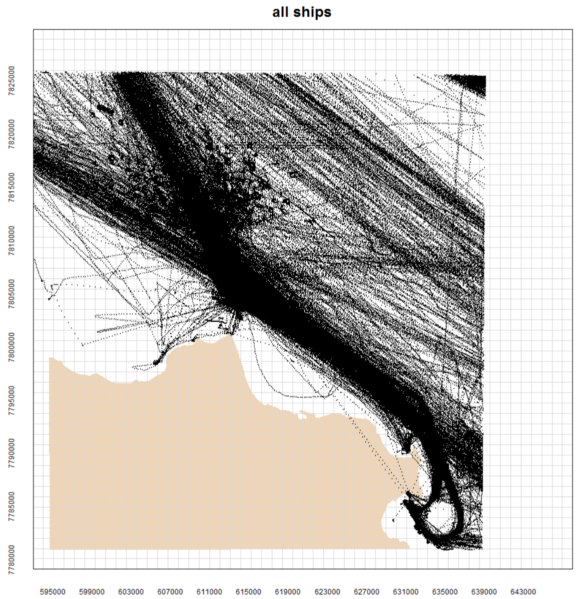

Figure 1. High resolution minute-by-minute ship activity data using modified AIS data for 2015 (Abbot Point).

A comparison was made with ship movement data, which lists arrival and departure date/time and location for individual ships. The parameters considered in the comparison were ship ID, start of berth time, end of berth time and duration of berth.

A total of 312 berth sets from the movements datasets were analysed, which involved 275 unique ships with single or multiple visits to Abbot Point Terminal. The AIS dataset listed a total of 282 vessels for the same period; vessels not included in the movements' dataset were identified as small specialised vessels (e.g. tugs, pilot vessel). This suggests that the AIS dataset is more exhaustive than the movements' dataset.

Average berth duration of the AIS and movement data was 27 hours for both datasets. The average difference in berth duration was 0.2 hour. However, a large difference of 15 hours was found for one ship. Further investigation revealed that this was due to signal loss in the AIS data. As a consequence, the AIS data started in the middle of the berth period. Berth duration is generally comparable in both the AIS and the movement datasets.

The average difference in start time and end time was 0.2 and 0.1 hour, respectively. Start and end time in both the AIS and the movement datasets are generally consistent, except for the signal loss case discussed before.

It is noted that the definition of arrival time in the AIS dataset is not exactly the time at which the vessel actually starts the berth, but the time it stops moving in the berth area (1x1 km grid cell).

The comparison shows that movement and processed AIS datasets are generally consistent and that differences are small, with one exception where AIS data is missing due to interruption in signal transmission.

Figure 2 shows an example of the results of ship emission simulation in the study area. Total annual emissions are presented in 1x1 km grids. It is noted hourly emission files can be readily extracted for each grid cell, and used in air quality modelling.

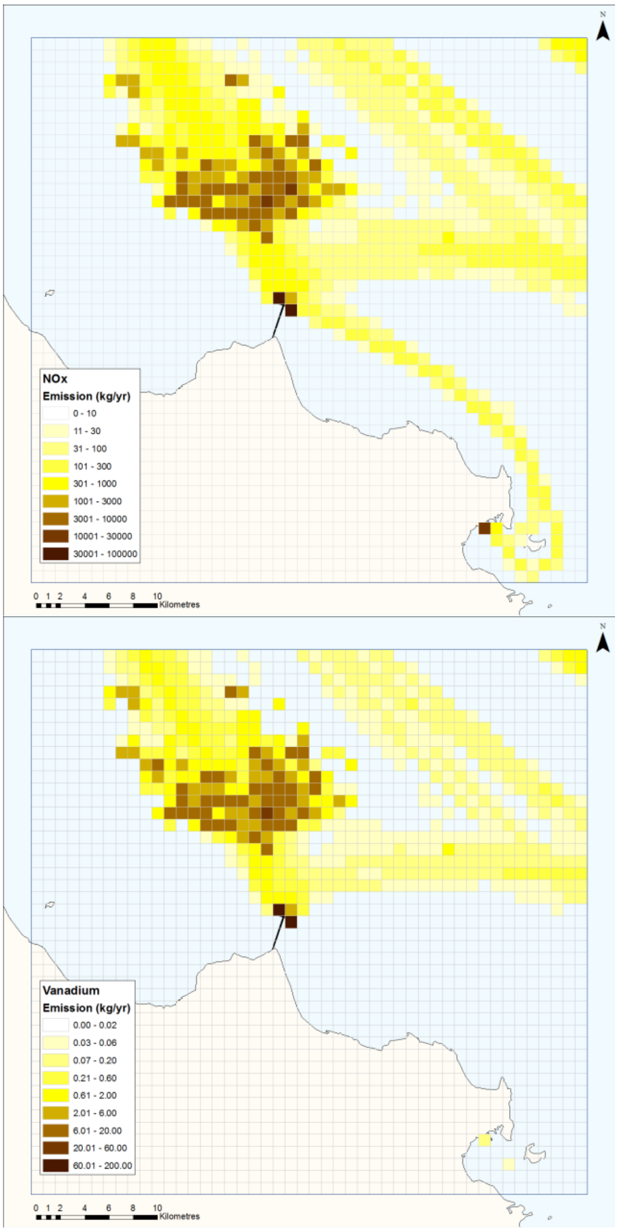

Figure 2. Gridded 1x1 km NO_x and V emission inventory for ships (Abbot Point).

References

European Environment Agency, The Impact of International Shipping on European Air Quality and Climate Forcing, Technical report No. 4/2013.