Modelling of pleasure boat activities and emissions at the Baltic Sea

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Motivation

- Emissions and activities for the registered marine traffic are fairly well known
  
  At the Baltic Sea some 8200 IMO-registered vessels are responsible for more than 95% of registered shipping emissions

- In the Baltic Sea there are hundreds of thousands of private pleasure boats
  
  Concentrated near populated areas
  
  Activities and emissions from this fleet are largely unknown

=> For the first time, pleasure boat activities and emissions are modelled across the Baltic Sea
  
  Temporal & spatial distribution included
  
  Gain perspective: results compared against the registered fleet modelling results
Outline

• Setting up the model
  • Fleet characteristics study
  • Utilization of AIS-data – temporal distribution of activities
  • Marina locations & boat counts – scanning the coastline (literally)

• Preliminary results
  • Exhaust emissions, anti-fouling paint leech
  • Comparison against STEAM model results for 2014 (commercial fleet at the Baltic)

AIS: Automatic Identification System, a messaging system used by the marine vessels for position, identification & status updates
Modelling approach

FMI-BEAM (FMI’s Pleasure Boat Emission and Activity siMulator)

Survey & study material → Fleet characteristics

AIS-data → STEAM (with pleasure boat data filters) → Temporal distribution → Emission factors

Marina locations & boat counts → Land-use mask & local distribution modelling → Geographical distribution → Pleasure boat activities

Pleasure boat emissions (PM2.5, NOx, CO, NMVOC, CuO, ZnO)
### Boat categories

The ones presented in Swedish pleasure boat survey study (*Båtlivsundersökningen 2010, 2015*)

<table>
<thead>
<tr>
<th>OSB</th>
<th>MB</th>
<th>LMB</th>
<th>LMSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Small Boat, with (or without) an engine smaller than 7kW</td>
<td>Motor Boat, with no possibilities for over-night stays</td>
<td>Large Motor Boat, with over-night stay capabilities</td>
<td>Large Motor Sail Boat</td>
</tr>
</tbody>
</table>

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Fleet characteristics

- Detailed characteristics exist for the Swedish fleet
  - Based on Swedish survey study (Båtlivsundersökningen, 2010 & 2015) and other research material

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<tr>
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</thead>
<tbody>
<tr>
<td>OSB</td>
<td>0.106</td>
<td>0</td>
<td>7</td>
<td>57</td>
<td>0.284</td>
<td>0.563</td>
<td>0.153</td>
<td>0.435</td>
<td>0.565</td>
</tr>
<tr>
<td>MB</td>
<td>0.531</td>
<td>0.2</td>
<td>11</td>
<td>228</td>
<td>0.207</td>
<td>0.411</td>
<td>0.383</td>
<td>0.435</td>
<td>0.565</td>
</tr>
<tr>
<td>LMB</td>
<td>0.216</td>
<td>0.48</td>
<td>16</td>
<td>323</td>
<td>0.104</td>
<td>0.207</td>
<td>0.689</td>
<td>0.435</td>
<td>0.565</td>
</tr>
<tr>
<td>LMSB</td>
<td>0.147</td>
<td>0.91</td>
<td>26</td>
<td>695</td>
<td>0.155</td>
<td>0.309</td>
<td>0.536</td>
<td>0.435</td>
<td>0.565</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ENGINE</th>
<th>SFC (g/kW)</th>
<th>PM (g/kg)</th>
<th>NOx (g/kg)</th>
<th>NMVOC (g/kg)</th>
<th>CO (g/kg)</th>
<th>Installed kW</th>
<th>EngineLoad_avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-stroke</td>
<td>791</td>
<td>12.6</td>
<td>2.5</td>
<td>322.0</td>
<td>539.8</td>
<td>50</td>
<td>0.5</td>
</tr>
<tr>
<td>2-stroke(2003)</td>
<td>791</td>
<td>12.6</td>
<td>2.5</td>
<td>57.5</td>
<td>232.6</td>
<td>50</td>
<td>0.5</td>
</tr>
<tr>
<td>4-stroke</td>
<td>426</td>
<td>0.2</td>
<td>16.4</td>
<td>50.7</td>
<td>431.9</td>
<td>50</td>
<td>0.5</td>
</tr>
<tr>
<td>DSL</td>
<td>281</td>
<td>5.0</td>
<td>64.1</td>
<td>7.7</td>
<td>19.8</td>
<td>40</td>
<td>0.5</td>
</tr>
<tr>
<td>DSL(2003)</td>
<td>281</td>
<td>3.6</td>
<td>34.9</td>
<td>6.3</td>
<td>18.6</td>
<td>40</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- Aim is to customize these tables for each Riparian state separately
  - For now we have used this Swedish PB characteristics
Anti-fouling paint leach

• Water pollutants: Cu(I)O, ZnO

• Passive leaching rates as a function of water surface exposure [sm²]

• Different leaching rates set for different parts of the Baltic Sea

• Work in progress:
  • Higher leaching rates for Spring?
  • Off-season ramp-up/ramp-down?

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Temporal distribution

- AIS not mandatory for pleasure boats, yet some may still use it
  - "Hidden" among unknown, non-IMO vessels.

- AIS data from Helcom in 2014-2016 and the STEAM model used

- Identification of pleasure boat-like vessels, criteria:
  - No activities during Winter
  - Low annual travel amounts
  - Low (temporal) utilization
  - Size & type limitations (if static AIS data exists)

Using the the identified vessels only, STEAM model run again to estimate hourly travel distances.

Resulting profiles for the three years combined and normalized => Several temporal patterns visible: **monthly, week days, diurnal.**
Spatial distribution (1/2)

• Approach: identify the number of boats in each marina and simulate their activities near-by
  - Satellite image analysis used
  - Available marina data used
  - 3000 locations spotted, with 250 000 PB:s

• Sweden: approx 2000 marina locations
  - 115 000 boats
  - This is only 50% from the expected count!

Interpretation: for every counted boat there is another one outside of the marina locations => Largest source of uncertainty!
Spatial distribution (2/2)

• For each marina a local distribution of activities is simulated
  • Survey data: only 10% of PB owners report to have trips longer than 50km
  • Marina-to-Marina activities are excluded at this stage
• Propability distribution based on distance from a) marina b) coastline

Marina locations (indicative example)
Pleasure boat emissions compared against STEAM vessels

BEAM / STEAM (Baltic July 2014)

- NOx: 1.4%
- Fuel consumption: 4.8%
- PM2.5: 10.7%
- AFP_Cu(I):O: 45.5%
- CO: 258.3%
- AFP_ZnO: 214.8%
- Travel: 359.2%
- NMVOC: 642.2%
### Results – Flagstates & types

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<tr>
<td>Sweden</td>
<td>6532</td>
<td>1980</td>
<td>518</td>
<td>194</td>
<td>14.7</td>
<td>17.7</td>
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<tr>
<td>Finland</td>
<td>2911</td>
<td>882</td>
<td>232</td>
<td>87</td>
<td>5.9</td>
<td>7.4</td>
<td>12</td>
</tr>
<tr>
<td>Denmark</td>
<td>3046</td>
<td>923</td>
<td>243</td>
<td>91</td>
<td>18.0</td>
<td>11.5</td>
<td>13</td>
</tr>
<tr>
<td>Germany</td>
<td>1107</td>
<td>335</td>
<td>88</td>
<td>33</td>
<td>6.6</td>
<td>4.4</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>471</td>
<td>143</td>
<td>37</td>
<td>14</td>
<td>1.1</td>
<td>1.4</td>
<td>2</td>
</tr>
</tbody>
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</tr>
</thead>
<tbody>
<tr>
<td>OSB</td>
<td>470</td>
<td>102</td>
<td>3</td>
<td>9</td>
<td>2.6</td>
<td>2.4</td>
<td>1</td>
</tr>
<tr>
<td>MB</td>
<td>9923</td>
<td>3374</td>
<td>277</td>
<td>271</td>
<td>20.8</td>
<td>19.0</td>
<td>30</td>
</tr>
<tr>
<td>LMB</td>
<td>3914</td>
<td>812</td>
<td>583</td>
<td>122</td>
<td>12.2</td>
<td>11.2</td>
<td>25</td>
</tr>
<tr>
<td>LMSB</td>
<td>230</td>
<td>79</td>
<td>258</td>
<td>26</td>
<td>13.4</td>
<td>12.3</td>
<td>6</td>
</tr>
</tbody>
</table>

Mostly from: older 2-stroke gasoline engines

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Annual fuel consumption

Simulated geographical distribution of pleasure boat fuel consumption based on survey data (national totals) and marina data (location, ship count)
Conclusions

• A model has been developed for the assessment of pleasure boat activities and emissions
  • High level of uncertainty at this initial stage

• Some pleasure boat emission species seem surprisingly relevant with respect to those of registered marine traffic
  • NMVOC, CO, anti fouling paints

• More research needed, especially:
  • Fleet characteristics for non-Swedish fleet
  • Boat count disparity
  • What would be the result if these PB emission datasets were used in ecological/atmospheric models?