Estimating the Relative Impact of Shipping, Traffic and Domestic Solid Fuel Combustion upon Air Quality in Cork City, Ireland- A Case Study

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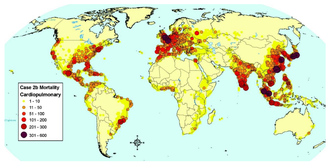
Background

Shipping-related particulate matter (PM), NO_x and sulfate emissions have been estimated to contribute approximately 60,000 deaths annually on a global scale, with impacts focused on coastal regions, predominantly in Europe and Asia.[1]



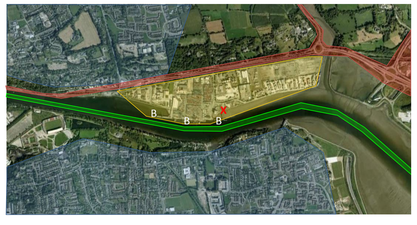
Annual cardiopulmonary deaths attributed to PM from global shipping. Reproduced from[1]

Current policy is aimed at reducing the sulfur content of marine residual fuel oil used in ocean-going vessels to <0.5% m/m by 2020.[2] Measurement-based source apportionment studies are necessary to assess the current impact of shipping emissions and monitor the effectiveness of these abatement strategies in coastal environments.

Cork City

Cork City is the second largest city in Ireland with a population of approximately 200,000 inhabitants. Located in a harbour, the city is subject to local emissions of PM from sources including shipping, vehicular traffic and the domestic combustion of solid fuels. The prevailing winds are southwesterly, from the Atlantic Ocean, and thus background PM levels are quite low. Poor air quality events are controlled almost entirely by local emissions, and therefore Cork is ideally suited to effective source apportionment.

Methodology



Sampling site (x), shipping berths (B), port area (yellow), major roads (red), domestic combustion areas (blue)

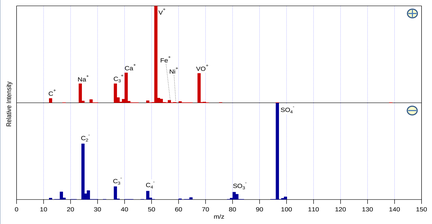
The sampling site was located in the Port of Cork, and is characterised by significant shipping activity. Sampling was carried out for 3 weeks in August 2008, and involved a suite of instrumentation, with an emphasis on PM composition. Particle size, number, mass and composition were measured in real time.

Routine measurements of PM involve filter sampling and off-line analysis, resulting in poor temporal resolution. Instruments that can measure PM composition in real time can capture the variability of sources that are dominant at different times of the day. The Aerosol Time-Of-Flight Mass Spectrometer (ATOFMS, TSI 3800) was deployed to measure the size and chemical composition of single particles in real time. The different types of particles detected were then assigned to their respective sources based on their temporality and composition.

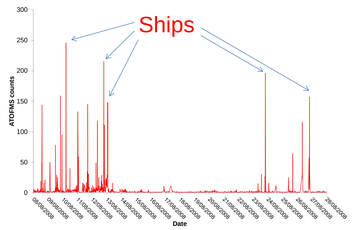
The ATOFMS instrument on site

Shipping Results

Analysis of the ATOFMS data revealed a particle type that contained **vanadium, nickel** and **sulfate**, all species associated with marine residual fuel oil.[3] The temporal behaviour was very different to all of the other particles observed during the campaign.



ATOFMS mass spectrum of ship exhaust particles

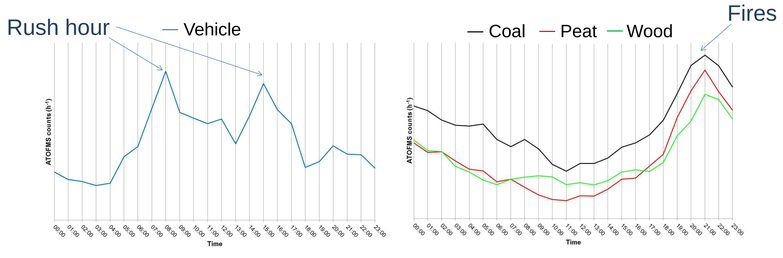


Temporal trend of ship exhaust particles

Particles arising from combustion of marine residual fuel oil were detected over 30 times during the three week period. Short events, lasting less than 15 minutes, were observed, corresponding to ships docking at the nearby berths. Every event was confirmed with data from the Port of Cork shipping logs. During these events, particle numbers reach very high concentrations (>150,000 cm^{-3}), approximately 20 times higher than background levels.

Traffic and Solid Fuel Combustion

Two other sources were found to contribute significant numbers of particles during the campaign: (i) traffic and (ii) solid fuel combustion for home heating. The ambient concentrations of these particles reflect the daily activities of the inhabitants of Cork City.

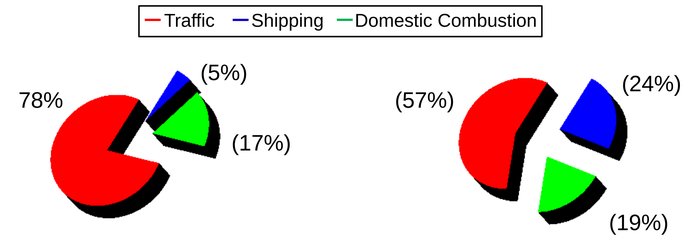


Dependence of traffic particles (left) and domestic fuel combustion particles (right) upon time of day

The dominance of these particle types depends upon the time of day. Traffic particles containing soot contribute significantly to particle number concentrations, peak during the morning and evening rush hours, and decrease at night. Domestic solid fuel combustion particle numbers peak in the evening hours, as open fires are lit in households surrounding the site. Concentrations then slowly decrease during the early morning hours. This temporal behaviour is very useful for separating the impact of these sources. Positive matrix facorization (PMF) was used to combine these temporal trends with other variables, including PM mass and number, to estimate the relative impact of each source on air quality.

Sources: Relative Impact

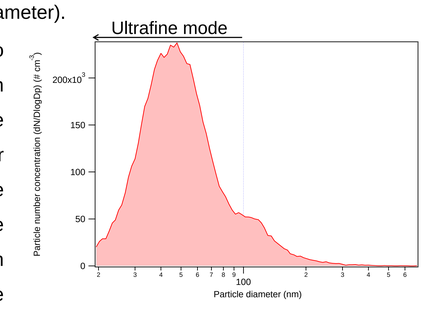
Analysis of the temporal trends of the various particle types allowed the estimation of the relative impact of each local source to PM concentrations in Cork City. The impact upon PM mass concentrations and number concentrations were evaluated.



Relative contributions of each local source to ambient PM mass (left) and number (right)

As expected for most urban environments, traffic is the largest contributor to particle mass concentrations and number concentrations in Cork City. Despite the fact that the campaign was performed in the summer months, domestic combustion of solid fuels is also a significant source. Domestic combustion has been demonstrated to be the dominant source in winter months, despite the introduction of a national ban on coal burning in urban environments in Ireland under the Clean Air Act (1995). Although shipping activity has a relatively low contribution to PM mass concentration, the contribution to PM number is higher by almost a factor of 5. The size distribution of ship particles demonstrates that most lie in the ultrafine mode (<100 nm diameter).

Ultrafine particles have been linked to adverse health effects and are of concern from an exposure perspective.[4] The size of shipping particles, coupled with their composition (vanadium and nickel have known toxicological effects), highlights the requirement for improved emission controls for shipping exhaust. All of the ship plumes detected during the campaign contained markers for residual fuel oil combustion. The methodology applied here can be used in Cork City and other coastal locations to evaluate the effect of new ship emission policy upon local air quality.[2]



Number-size distribution of ship exhaust particles

Acknowledgements

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1 *Corbett et al. Environ. Sci. Technol. 41, 8512-8518, 2007* ***2*** *MARPOL Annex VI*
3 *Viana et al., Environ. Sci. Technol., 43, 7472-7477, 2009.* ***4*** *M. Lippmann et al., Environ. Health Persp. 114, 1662-1669, 2006*