Air pollution with ultrafine particles from shipping in Barcelona

Ferry passing

Clean air (no ferry)

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Background

These measurements are part of the EU LIFE project: LIFE4MEDECA with the purpose to designate a Mediterranean Sea Emission Control Area (ECA) to reduce health and climate damaging emissions of air pollution from shipping. The purpose of air quality screening measurements in port cities is to visualise ship pollution for populations in the Mediterranean and thereby create awareness about air pollution from shipping and engage the public in discussions on a Mediterranean Sea ECA.

According to the European Environmental Agency air pollution causes about 31,500 deaths in Spain every year i.e. in 2020 and 2021 air pollution caused almost same mortality as COVID-19. Air pollution with SOx, NOx and particles from shipping in the Mediterranean Sea is an important pollution source contributing significantly to morbidity, mortality and to acid rain thereby damaging cultural heritage, crops and nature in the Mediterranean. Furthermore, CO_2 and black carbon from ships contribute significantly to climate change. An ECA for SOx and NOx in the Mediterranean Sea will minimize regional air pollution from ships. This will benefit all Mediterranean societies and protect populations in the Mediterranean from ship pollution to same extent as the Northern European ECA, where a sulphur ECA was implemented back in 2007 followed by a NOx ECA in 2021.

This air quality screening in Barcelona was mainly focused on cruise ships and ferries. Cruise ships are large floating hotels with high energy demands thereby emitting as much NOx and particles per second at berth as thousands of cars. Ferries significantly influence local air quality because of frequent arrivals/departures and overnight stays idle running at berth inside the heart of Barcelona. Most ships at berth in EU burn bunker oil containing 100 times more sulphur than road diesel. Onshore wind can thereby expose whole city communities to heavy air pollution with exhaust.

Freshly emitted exhaust particles from ships mainly consist of ultrafine particles ($PM_{0.1}$) with a diameter below 0.1 micrometre (100 nanometres). Due to their size, these particles can enter the finest parts of the lungs and continue into the bloodstream. Ultrafine particles have a high content of soot and polycyclic aromatic hydrocarbons (PAH's) classified as level 1 carcinogens by the World Health Organization. Particle pollution increases the risk of cancer, blood clots, brain haemorrhages, cardiovascular diseases, bronchitis, asthma, etc. Ultrafine particles emitted from ships at open sea will aggregate to toxic fine particles ($PM_{2.5}$) before reaching land and should be monitored together with SO_2 and NOx. However, in port cities air quality monitoring should as well include ultrafine particles freshly emitted from ships in the port thereby polluting local city areas.

Air pollution from ships in ports can be eliminated by switching to shore power and electric ferries. Larger cruise companies are retrofitting cruise ships to meet expected requirements for shore power in cities concerned about public health. However, this requires investment in shore power systems in ports allowing cruise ships to connect. This investment will (in contrast to traditional infrastructure projects) be paid back by connection fees and electricity sales to ships (resulting in an insignificant price increase for passengers). Pollution from international shipping in the Mediterranean Sea, that uses even more polluting fuels than ships at berth, can be reduced by establishing an ECA through international collaboration and public involvement. The EU Commission therefore initiated project *LIFE4MEDECA* bringing together nations around the Mediterranean Sea - and compiling experience from the Northern European ECA - to designate a Mediterranean Sea ECA.

Purpose

One of the purposes of project *LIFE4MEDECA* is to perform screening measurements of air pollution from ships in Mediterranean ports to create awareness about air pollution from shipping and engage the public in implementing a full Mediterranean Sea ECA to reduce SO_2, NOx and particle pollution and thereby significantly improve public health and the environment in the Mediterranean.

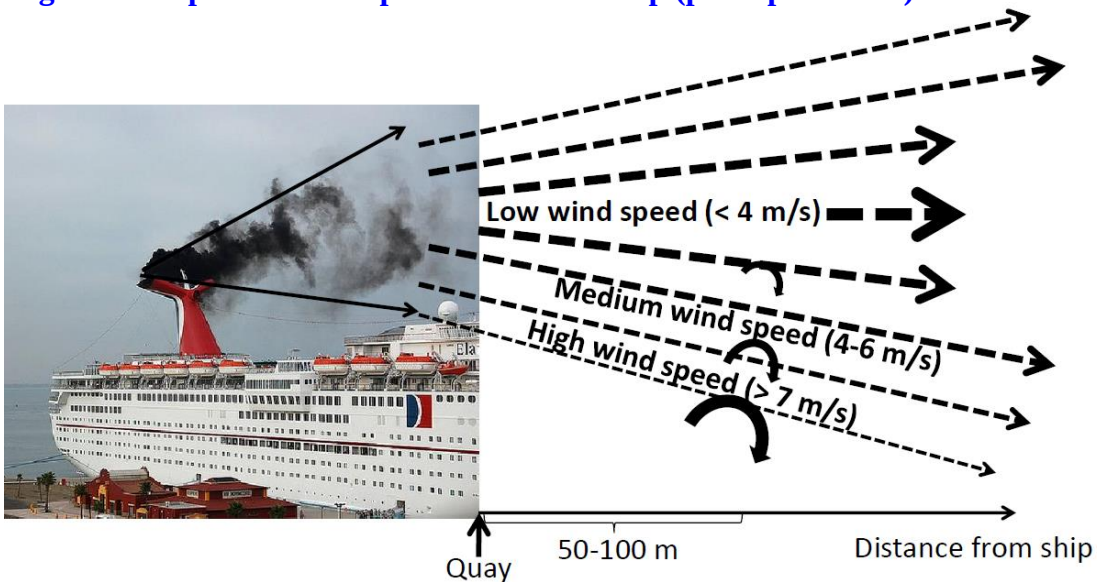
Measurements

Ultrafine exhaust particles from cruise ships and ferries were measured in week 14 and 15 in 2022 in Barcelona port. Data treatment and reporting was first done in May-June. Ultrafine particles were measured with P-Trak's (TSI: Model 8525 Ultrafine Particle Counter) cross-calibrated prior to measurements and control calibrated after the measurements. Calibration showed that the equipment worked well throughout measurements. The measurement frequency was once per second. Local wind speed/direction, humidity and temperature were taken from local weather forecasts.

The pollution plume

Air pollution from large ships is emitted from smoke stacks many meters above ground level. The exhaust is very warm and moves upwards until it is cooled down to the temperature of the surrounding air. In calm weather, the pollution will spread in all directions by dispersion. At windy conditions, the pollution plume moves in the direction of the wind and expands perpendicular to the wind direction. Expansion happens quickly at high wind speeds (> 7 m/s, due to high turbulence) and the diluted periphery of the pollution plume reaches ground level a few hundred meters from the ship. Expansion happens slowly at low wind speeds (wind speed < 4 m/s) and the concentrated pollution plume thereby reaches the ground level several kilometres from the ship. Ships are therefore able to pollute central city areas quite a distance from their location (Figure 1).

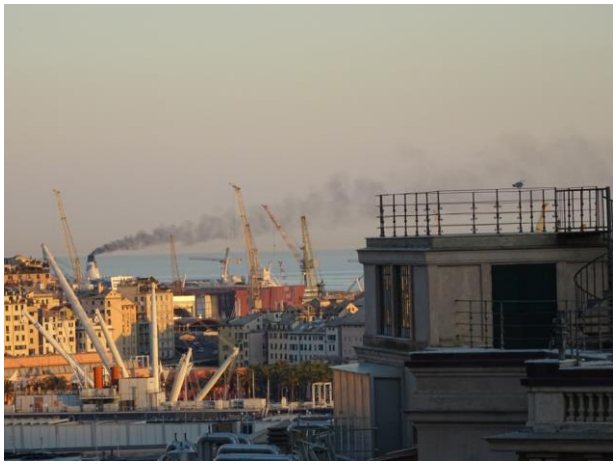
Figure 1: Dispersion of air pollution from a ship (principle sketch).



As it is very difficult to localise the pollution plume several kilometres inside cities where many other pollution sources, like traffic, also contributes to air pollution, the best measuring conditions are high wind speeds towards a convenient measuring position (typically on land or on a bridge/jetty). This allows measurements close to ships where the diluted periphery of the plume can be localised and is unaffected by other pollution sources. If possible, measurements must be performed both upwind the ship (sea background being unaffected by ultrafine particles from local ships) and downwind the ship (air being polluted by ultrafine particles from local ship emissions). Measurements with no ships can replace upwind measurements. Measurements during offshore wind typically require a boat.

The pollution will spread in all directions by dispersion when there is no wind and mainly pollute the port area.
(Photo from Genoa 2016)

Low wind speeds will give a dense pollution plume that can reach ground level several kilometres from the ship.
(Photo from Genoa 2016)



Results

Humidity and temperature were within the validity range of the measurement equipment at all times. Results of the measurements are summarized in table 1.

Table 1: Particle pollution in Barcelona port (spring 2022)

		Date	Particle pollution (particles per cm^3)		Wind (direction : speed)
			Average	Max.	
Sea background	**No local ship pollution**	April 9th	1,200	1,550	SE : 7 m/s
Ship pollution	**500-600 m from cruise ships idling**	April 8th	---	240,000	SW : 5-6 m/s
	500-600 m from cruise ships idling	April 10th	45.650	161,500	S : 3-4 m/s
	500-600 m from a cruise ship sailing	April 10th	72.800	273,000	S : 3-4 m/s
	150 m from ferry sailing by	April 11th	84.600	386,000	E : 4-5 m/s
	175 m from ferry sailing by	April 14th	135,000	403,000	NE : 4-5 m/s
	75 m from ferry idling	April 14th	64,400	401,000	NE : 4-5 m/s
	200 m from ferry idling	April 14th	36,850	78,400	NE : 3-4 m/s
Road traffic	**0 m from street (Ciutat Vella)**	April 14th	11,100	18,000	NE : 3-4 m/s

From Table 1 is seen that air unaffected by local ship pollution in Barcelona (sea background) in average contains around 1,200 particles per cm^3. In comparison, polluted air hundreds of meters downwind ferries and cruise ships was measured to contain 36,850-135,000 particles per cm^3 in average and have maximum peak values around 400,000 particles per cm^3. This clearly illustrates the intense air pollution from ships in Barcelona. Ships are able to pollute whole city areas downwind. In comparison, the average concentration of particles alongside streets in Barcelona was around 11,100 particles par cm^3 - and all new road vehicles have very efficient particulate filters; but there are still no filter requirements or shore power for ships sailing and idle running in the heart of Barcelona.

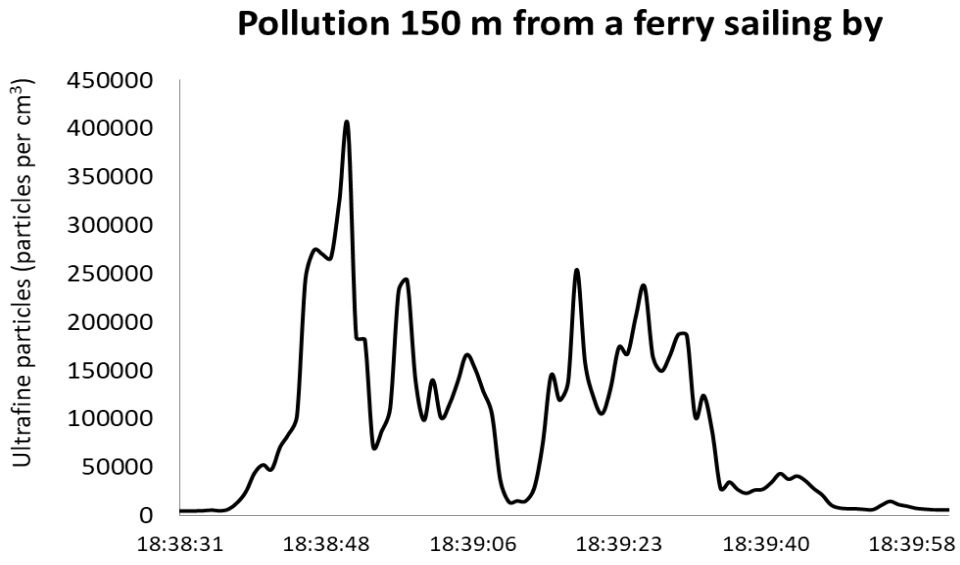
The World Health Organization has discussed a limit value of maximally 10,000 particles per cm^3. However, a limit value for ultrafine exhaust particles has not yet been decided. The recommendation is to inhale as little ultrafine exhaust particles as possible since there seems to be no safe limit for this kind of air pollution (like tobacco smoking - the only safe thing is not to smoke at all).

Movies and pictures from measurements in Barcelona for free use:
https://www.dropbox.com/sh/vqvuro72r52111i/AAC4Wc5Rl_cRlvHVrWvthm7Sa?dl=0
Please acknowledge: EU LIFE4MedECA project when using the movies and pictures.

Cruise ships and ferries in Barcelona thereby cause the same serious air pollution as documented in many other port cities and expose the local population to carcinogenic and toxic air pollution.

Figure 2 shows air pollution (second by second) in Barcelona port when a ferry is sailing by.

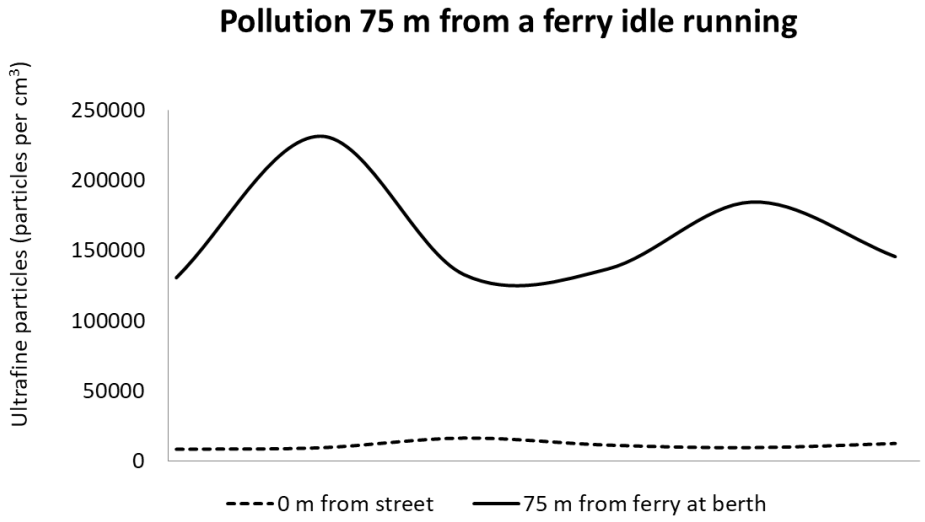
Figure 2: Measurements 150 m downwind from a ferry sailing by (second measurements).



The figure illustrates the influence of the wind on spreading the pollution plume from the ferry. The highest levels are measured under highest wind speeds (wind gusts) blowing a more concentrated part of the pollution plume from the ferry down to measuring height (as explained in Figure 1).

Figure 3 shows air pollution (minute averages without maximum peak values) in Barcelona port when a ferry is idle running at berth compared to road traffic (minute averages as well) in Barcelona.

Figure 3: Measurements 75 m downwind a ferry idling compared to a street (minute averages).



Ferries idle running in the heart of Barcelona will thereby cause significant local pollution of larger city areas on days with on-shore wind.

Conclusion

Emissions from large ships in Barcelona cause the same intense air pollution as observed in other port cities. The pollution plumes can pollute whole city areas several kilometres downwind large ships. This pollution increases the risk of morbidity and mortality in Barcelona. The solution is to build shore power systems for ferries, cruise ships and cargo ships like done in Northern Europe to avoid ship exhaust. Furthermore, fully electric ferries (batteries) should be promoted. At sea, pollution from ships will be significantly reduced by introducing a Mediterranean Sea Emission Control Area (ECA) like the successful ECAs in Northern Europe and USA.

Recommendations

It is recommended that Barcelona:

- Build shore power systems for ferries, cruise ships and cargo ships now.
- Start investing in fully electric ferries as in Northern Europe.
- Support designating a Mediterranean Sea Emission Control Area as agreed at COP22.
- Ban the use of heavy fuel oil and scrubber systems in territorial seas.
- Stop all investments in LNG since it is a very climate damaging fuel.

In addition to improving public health in Barcelona, these actions would improve public health in the whole Mediterranean region, reduce global warming, and reduce the risk of serious environmental damage in the Mediterranean Sea from discharge of scrubber water and heavy fuel oil.

Further reading

Cleaner shipping: https://rgo.dk/wp-content/uploads/GTD_Cleaner_shipping_2021_Final-2.pdf