THE DANISH ECOLOGICAL COUNCIL

Air pollution with ultrafine particles from cruise ships in Reykjavik, Iceland

Upwind cruise ships

Downwind cruise ships

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Background

Cruise tourism in Reykjavik and other Icelandic ports is increasing fast. In 2019 an expected 185 cruise ships and 190.000 cruise tourists will visit Reykjavik. Or in other words, in 2019 the number of cruise tourists is expected to reach the same level as the entire population of Reykjavik. This is an expected increase of 17% more cruise ships and 24% more passengers than the previous year.

Cruise ships are gigantic floating hotels hosting up to 10 times as many tourists as the largest hotel in Iceland. In port, cruise ships provide electricity, room heating and hot water to all facilities on board. Energy is produced by burning high amounts of extremely polluting fuel containing about 100 times more sulphur than road diesel. Air pollution is emitted without any efficient air pollution control. An average cruise ship in port emits as much health damaging air pollution (particles and NOx) per second as several thousand cars. An onshore wind will drive this pollution directly to the city centre. While at sea, cruise ships burn even more polluting fuel (HFO: heavy fuel oil) causing significant environmental and climate damage as well as destruction of nature if spilled or illegally discharged.

Exhaust particles from cruise ships mainly consist of ultrafine particles ($PM_{0.1}$) with a diameter below 0.1 micrometre (100 nanometres). These particles have a high content of soot and polycyclic aromatic hydrocarbons (PAH's) classified as level 1 carcinogens by the World Health Organization. Particles increase the risk of blood clots, brain haemorrhages, cardiovascular diseases, bronchitis, asthma, etc. Furthermore, soot particles (black carbon) contribute significantly to global warming.

Air pollution from cruise ships in ports can be eliminated by switching to shore power (*cold ironing*) produced from the clean Icelandic energy. Larger cruise companies are now retrofitting cruise ships to meet expected requirements for shore power in cities concerned about global warming and public health. However, this requires investment in shore power systems in ports allowing cruise ships to connect. This investment will (in contrast to many traditional infrastructure projects) be paid back by electricity sales resulting in an insignificant (less than 1 %) price increase for the cruise passengers, if the price is put back onto the passengers.

This work is funded by *Seas At Risk* and *Climate Works Foundation* and conducted as a part of the work carried out for the *Clean Arctic Alliance*: www.hfofreearctic.org.

Purpose

The purpose of this project was to perform screening measurements of air pollution from cruise ships in Reykjavik port and to recommend solutions.

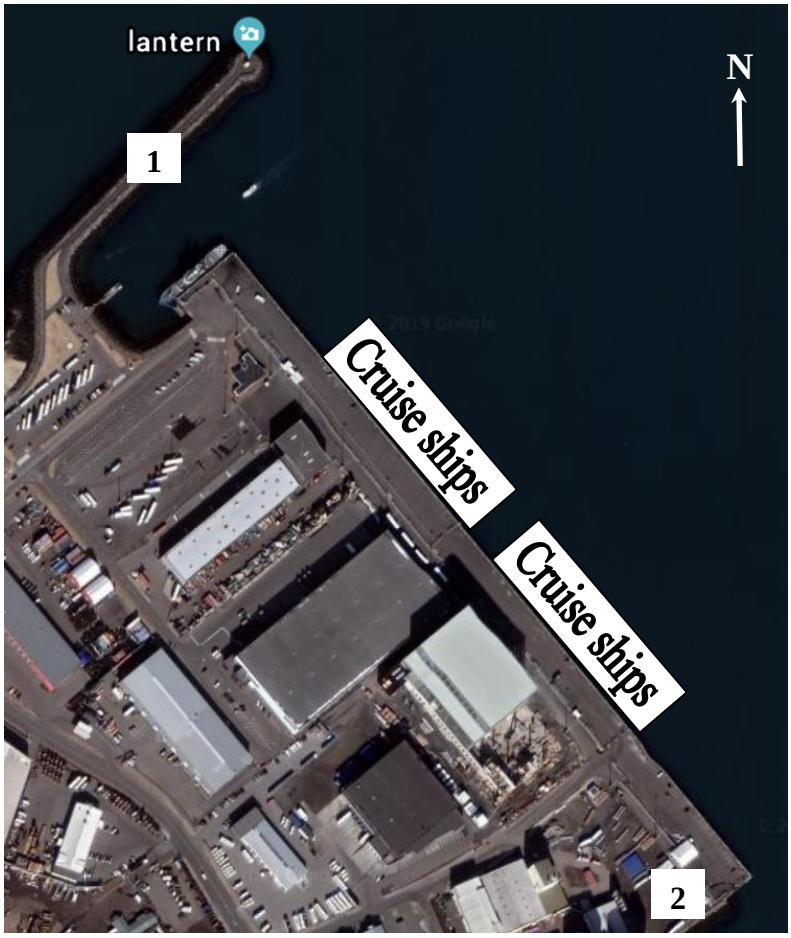
Measurements

Ultrafine exhaust particles from cruise ships were measured in the Port of Reykjavik in August 2019. Local wind speed/direction, temperature and humidity were measured on a daily basis.

Ultrafine particles were measured with a P-Trak's (Model 8525 Ultrafine Particle Counter) from TSI calibrated and cross-calibrated prior to measurements and control calibrated after the measurements. Calibration showed that the equipment worked well throughout the measurements. One measurement each second was used. However, average values are used in tables and graphs (minute averages).
Local wind speed/direction, humidity and temperature were measured with a WindMate 350.

Figure 1 shows measurement locations in Reykjavik cruise terminal. Sea background measurements were performed upwind of cruise ships and pollution measurements downwind of cruise ships. Figure 2 shows how the air pollution plume spread during different wind conditions.

Figure 1: Measuring locations in Reykjavik (Google Earth, 2019)



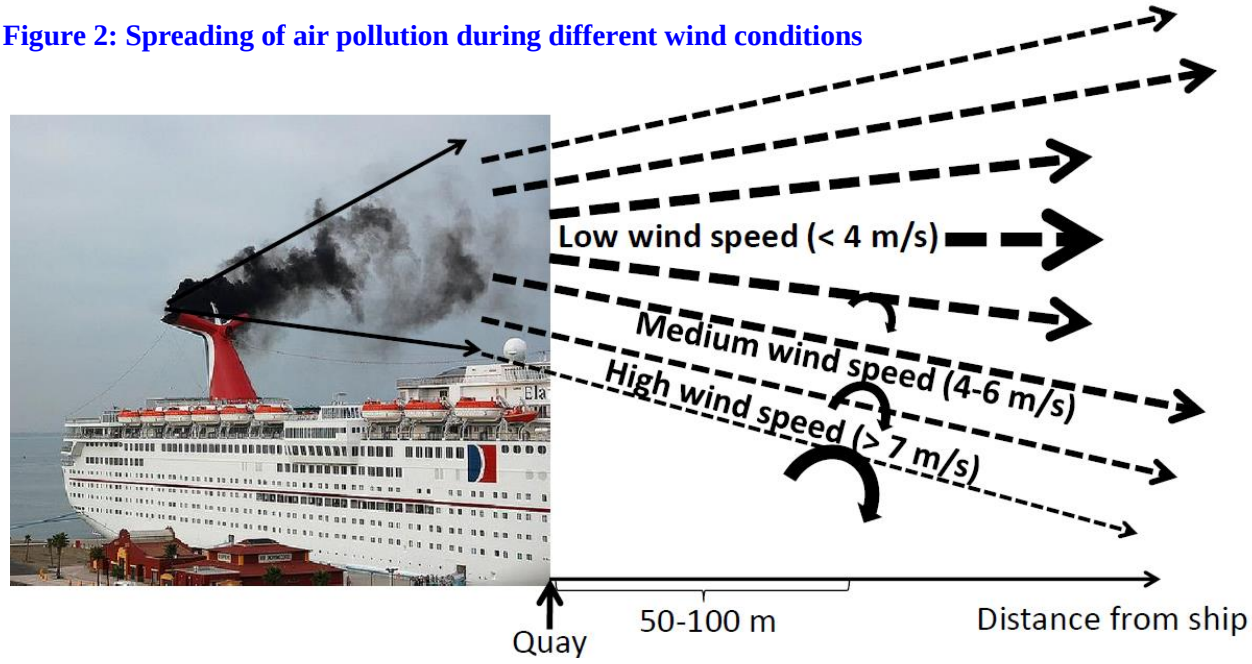
Measurement positions

Measurements of air pollution from cruise ships were performed during wind from north.

1: Upwind (sea background)
Measurements of the background pollution in air from the sea before the air passes (is polluted by) cruise ships at quay.

2: Downwind (cruise ship pollution)
Measurements of the (polluted) air after passing cruise ships at quay.

Figure 2: Spreading of air pollution during different wind conditions



From Figure 1 and 2 it is clear that optimal conditions for measuring air pollution from cruise ships in Reykjavik would be during rather strong (> 7 m/s) wind from north or east. Then the outer part of the pollution plume would reach the ground (measuring height) in the port area even though the pollution would be significantly diluted. Under less powerful onshore wind the pollution plume would be much more concentrated but only reaching the ground up to several kilometres away inside the city where it would be much more difficult to locate.

Results

Humidity and temperature were within the validity range of the measurement equipment at all times. Unfortunately several days with offshore winds (wind from north-west) or weak winds made it difficult to measure pollution from cruise ships in Reykjavik. However, there were some days with powerful winds from the north which made it possible to measure pollution from cruise ships over two days. Results are summarized in Table 1.

Table 1: Particle pollution in Reykjavik port

	Date	**Cruise ships in Reykjavik**	**Wind** (from: speed)	**Particle pollution** (average particles per cm^3)
Upwind	10/8	*Nieuw Statendam* and *The World*	N: 5-8 m/s	350
Downwind				106,700
Upwind	11/8	*Nieuw Statendam* and *Boudicca*	N: 7-9 m/s	450
Downwind				145,050

From Table 1 is seen that unpolluted clean air from the sea upwind the cruise ships contains 300-500 particles per cm^3. In comparison, polluted air downwind the cruise ships contain 100,000-150,000 particles per cm^3 during a rather strong wind where the pollution plume from the ships is much diluted. This clearly illustrates the intense air pollution from cruise ships. Even during strong winds and high dilution, cruise ships increase air pollution with toxic particles more than 300 times the sea background several hundred meters downwind of the cruise ships. In comparison, air pollution measured directly in the exhaust of a new diesel car with particulate filter (requirement since 2009) is about 1,200 particles per cm^3.

Movies from measurements: https://www.dropbox.com/sh/xnbwgecv9atl9n2/AACFMPNXx8vgTc92xwcsg1GAa?dl=0

The measured air pollution, several hundred meters downwind cruise ships during rather strong winds, is 3-5 times higher than the average pollution on the most polluted street in Denmark during rush hour on a calm day without any wind. However, at similar strong wind speeds (5-9 m/s), air pollution from the street would decrease significantly due to dilution and not be measurable 100 m downwind on the street. This again underlines the extremely high emissions from the cruise ships.

Hence, the pollution from cruise ships in Iceland causes same serious air pollution as documented in many other cruise cities. The pollution happens in the daytime, during the summer, when people are outside and have open windows thus increasing the exposure of the population.

Figure 3 and 4 shows the detailed measurements from August 10th and 11th of the clean Icelandic air upwind of the cruise ships and the polluted air measured downwind of the cruise ships. Fluctuating concentrations downwind the cruise ships were caused by turbulence and wind gusts.

Figure 3: Air pollution from cruise ships in Reykjavik on August 10th 2019

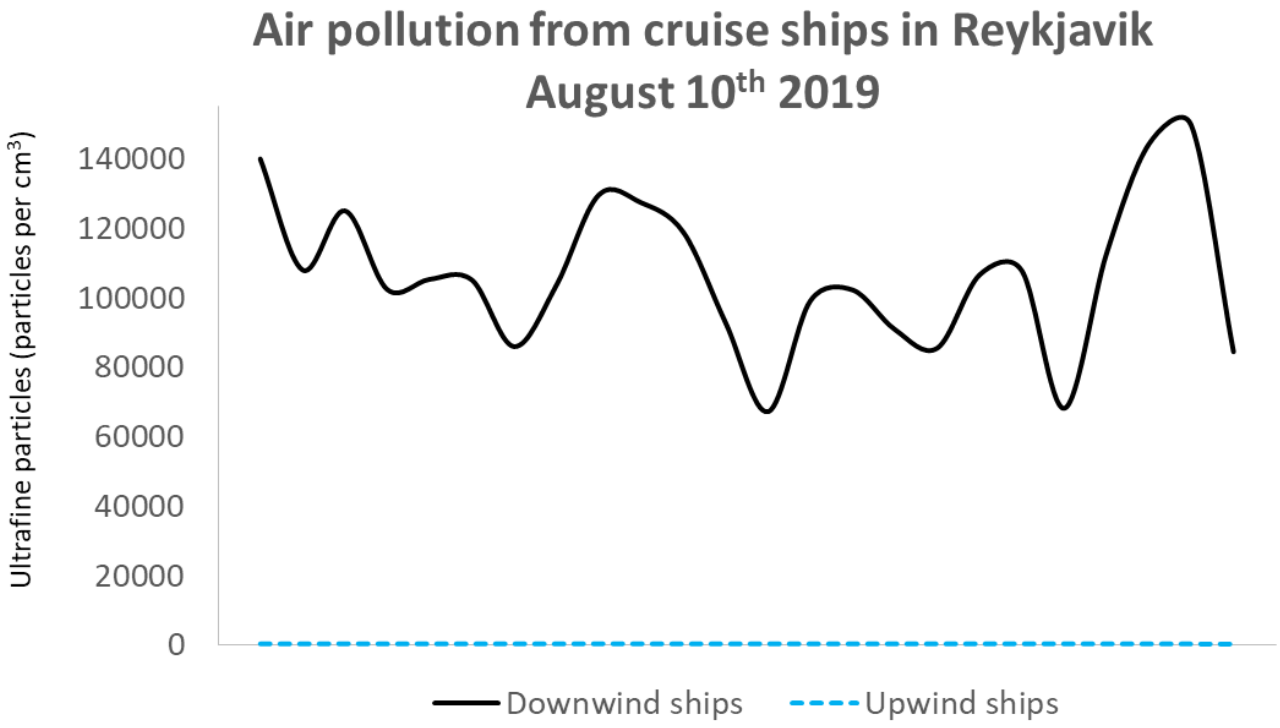
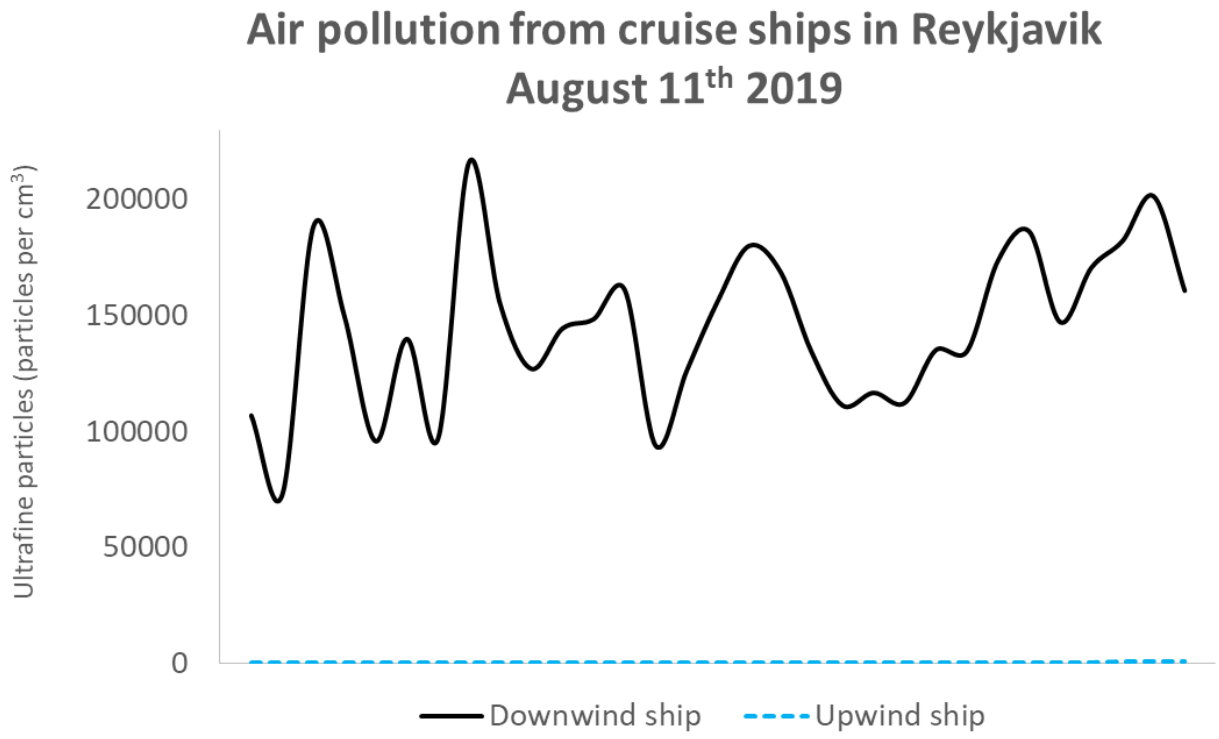


Figure 4: Air pollution from cruise ships in Reykjavik on August 11th 2019



Emissions from ships at sea will be even worse than in the Icelandic ports if ships at sea burn heavy fuel oil (HFO) which is much more polluting than the fuel used in ports. In Europe, air pollution from shipping causes around 50,000 premature deaths every year and millions of respiratory diseases. Furthermore, HFO spills and illegal discharges from ships cause serious environmental damage.

Shore power systems allowing cruise ships to connect and use the clean Icelandic electricity (and heat) would almost eliminate air pollution from cruise ships in port. A shore power system would cost around 7 million US dollars. However, it would (unlike many other infrastructure investments) be payed back within 10-15 years from electricity sales. A cruise passenger survey from Copenhagen port documents that the passengers are willing to pay for connecting their ship to clean shore power. In addition, still more cruise companies adapt their ships to receive shore power to avoid polluting the cities the passengers pay to visit.

Conclusion

Emissions from cruise ships in Reykjavik cause same intense health damaging pollution as observed in other cruise cities. The solution is to build shore power systems and require the ships to use clean Icelandic electricity (and heat) instead of using their own polluting engines. Investments in shore power systems will be paid back from electricity sales. If no action is taken, increasing cruise tourism will expose Icelandic people to increasing levels of toxic air pollution. Furthermore, an Icelandic HFO ban would limit air pollution from ships sailing around Iceland and from the damaging consequences of oil spills and illegal discharges of bunker oil.

Recommendations

It is recommended that Icelandic cruise ports in cooperation:

• Decide to build shore power systems at cruise berths.

• Charge higher port fees to cruise ships that do not connect to shore power.

• Coordinate similar actions with other North European cruise ports and port authorities.

• Ban HFO or increase port fees significantly for cruise ships carrying HFO in their fuel tanks.

In addition to improving public health in Iceland, these actions would reduce global warming from ships and the risk of serious environmental damage due to HFO spills and illegal discharges.