



Pollution from ships in Copenhagen Port and the effect on city air quality

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Overview

- › Setting the scene
 - Air pollutants from ships
 - Pollution from ships in the seas around Denmark
- › Pollution from ships in the port of Copenhagen
 - Detailed study on docking cruise ships from 2004
 - Further studies on docking ships
- › Summary

Air pollutants from ships

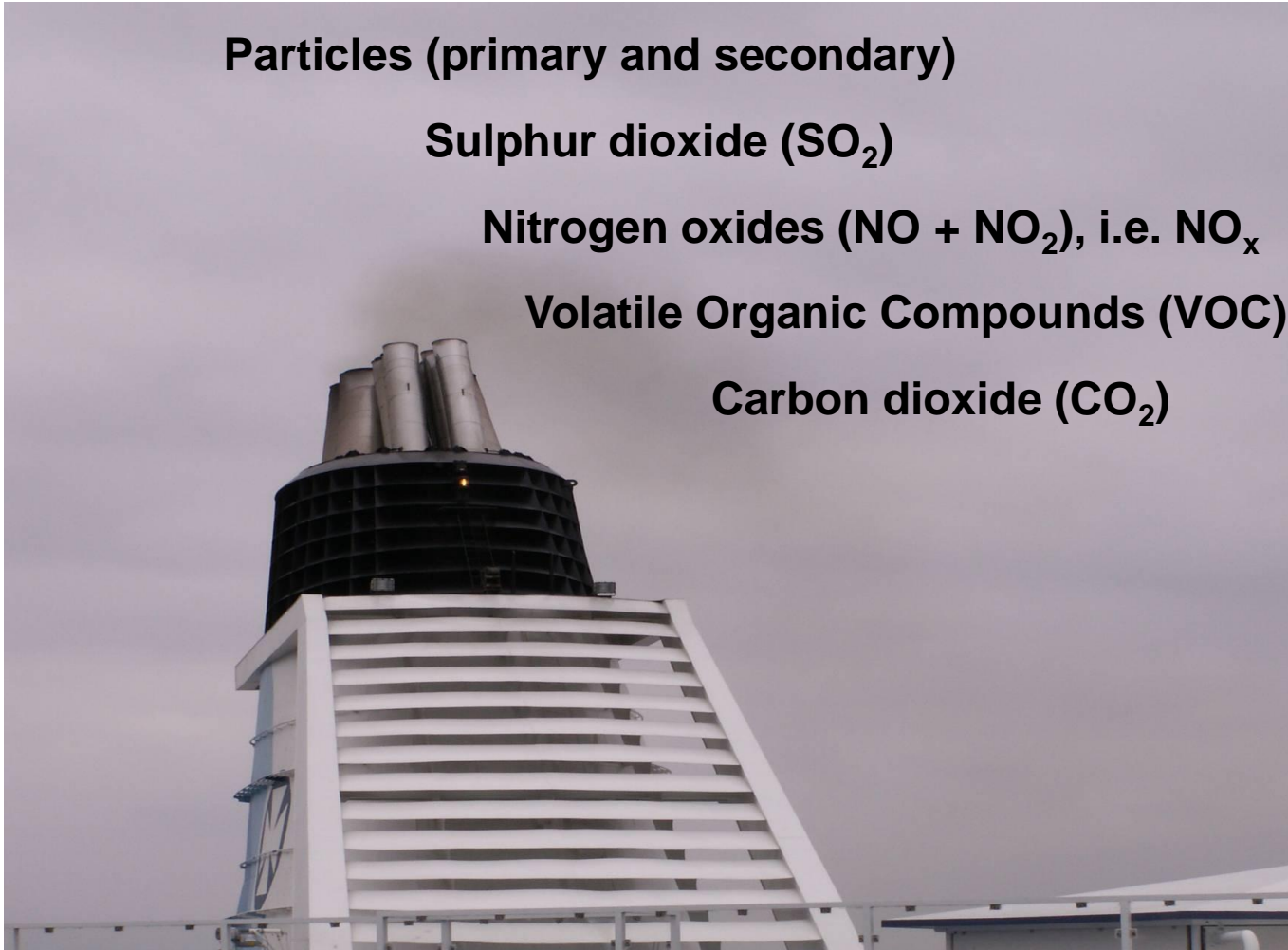
Particles (primary and secondary)

Sulphur dioxide (SO_2)

Nitrogen oxides ($\text{NO} + \text{NO}_2$), i.e. NO_x

Volatile Organic Compounds (VOC)

Carbon dioxide (CO_2)





The largest health-related air pollution problem:

Particles



Where do particles in the air outside Christiansborg come from?



Particles

A distinction is made between

- › 'Primary particles'
- › 'Secondary particles'



Important point about particles

- › When measuring particle pollution in the air, only a relatively small fraction of the particles have been 'born' as particles. These are *'primary particles'*.
- › Gases – in particular NO_x and SO_2 – can be transformed to particles through chemical and physical reactions in the atmosphere. They form *'secondary particles'*. These reactions require time (several hours or days).
- › **Therefore, a high proportion of the particles we find in the air have their origin far away.**



The role of ships

- › Ships are important contributors to both primary and secondary particles.



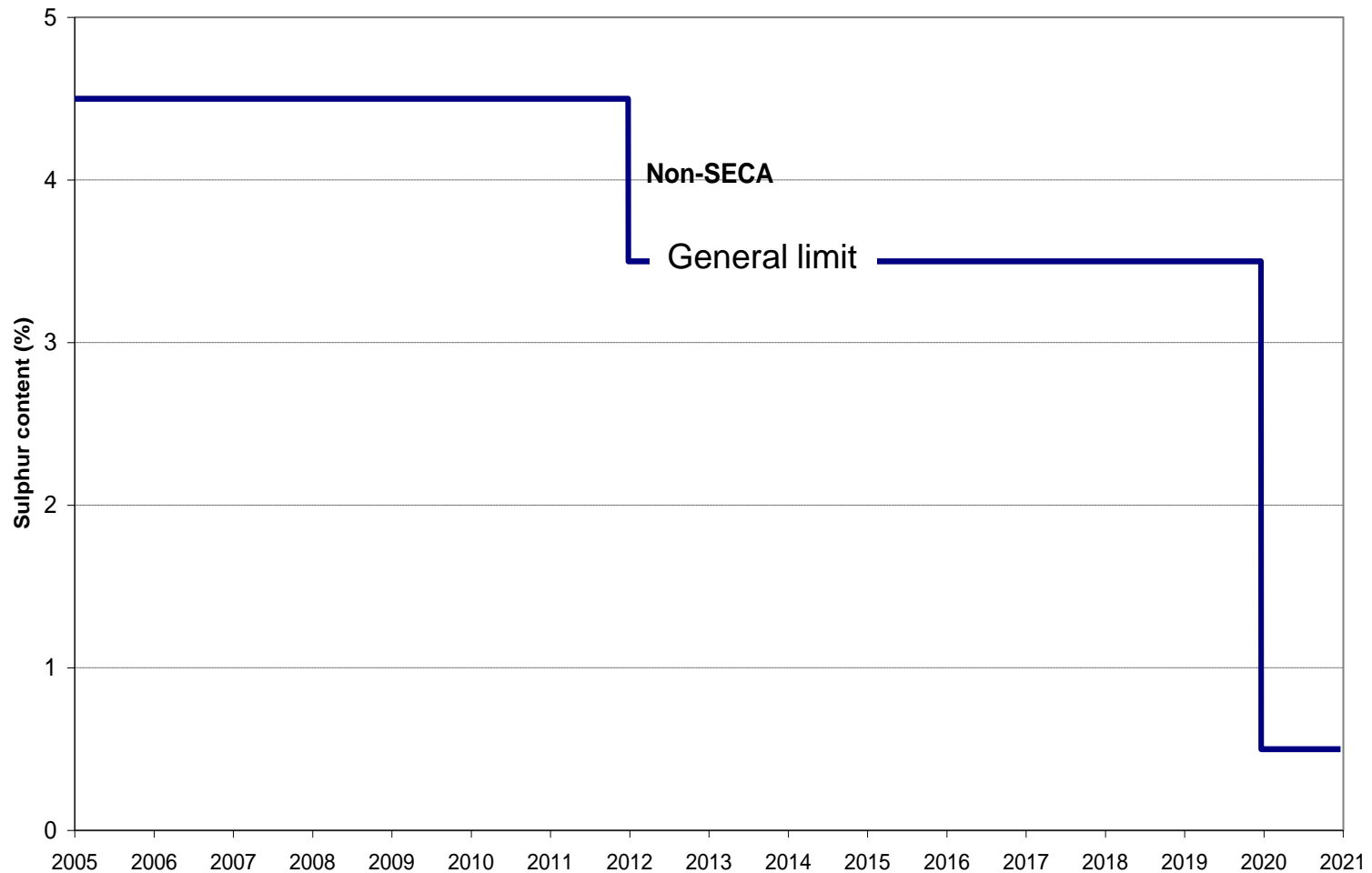


Ships and sulphur pollution

- › Fuel for ships contains sulphur.
- › Sulphur in fuel leads to formation of primary particles and SO_2 (a gas). Later, SO_2 leads to formation of secondary particles.
- › The International Maritime Organisation (IMO) has agreed on a set of rules for sulphur content.

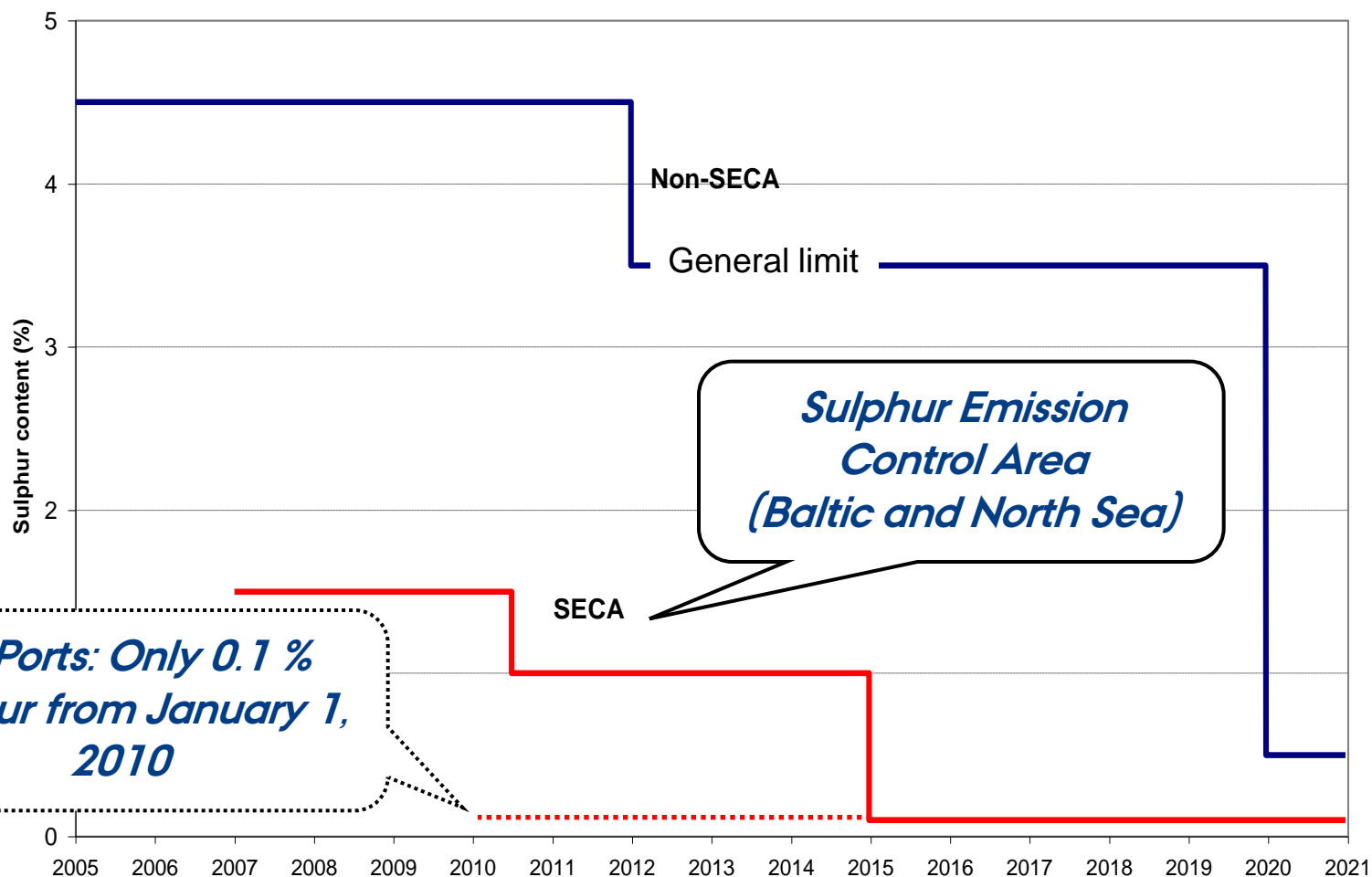


Limits to sulphur content in heavy fuel





Limits to sulphur content in heavy fuel





Nitrogen oxides

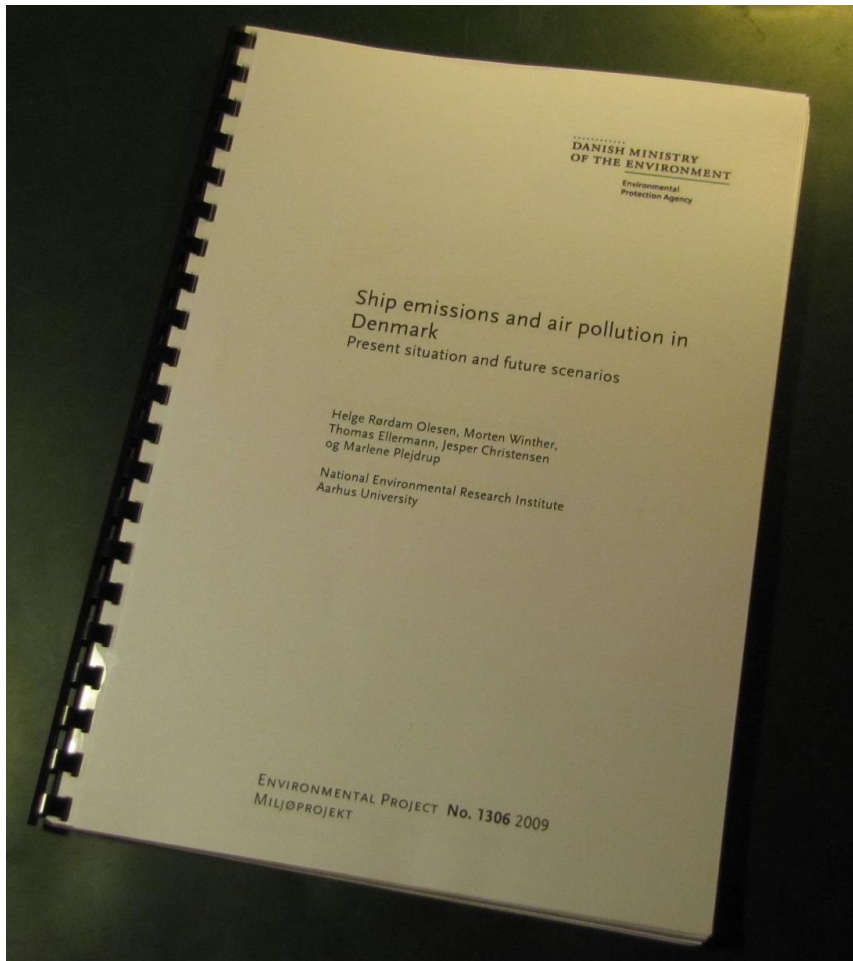
- › NO_x is the sum of NO and NO_2 . It is generated in combustion processes. The major part is emitted as NO .
- › **NO_2 is harmful to health.** NO is not.
- › NO can be transformed to NO_2 in chemical reactions. Some reactions are fast, others require many hours. Fast transformation requires the presence of ozone.
- › **Thus, the NO_2 concentration level is of concern**
- › **Further, NO and NO_2 both contribute to formation of particles.**



Limits to NO_x emissions

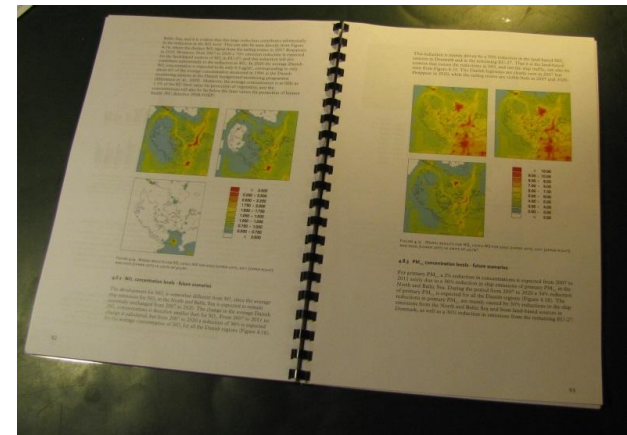
- › IMO has agreed to a set of regulations applying everywhere.
- › Further, it was expected that a *Nitrogen Emission Control Area* (NECA) would be implemented in the Baltic Sea from 2016.
- › The implementation of NECA has been postponed.
- › This would mean that for new ships from 2016 onwards, NO_x emissions would be reduced by 80% compared to ships built before 2011.
- › In some subsequent calculations we have assumed a NECA area to be implemented.

Pollution from ships in seas around Denmark



Report from 2009

Google: *ship emissions Denmark*

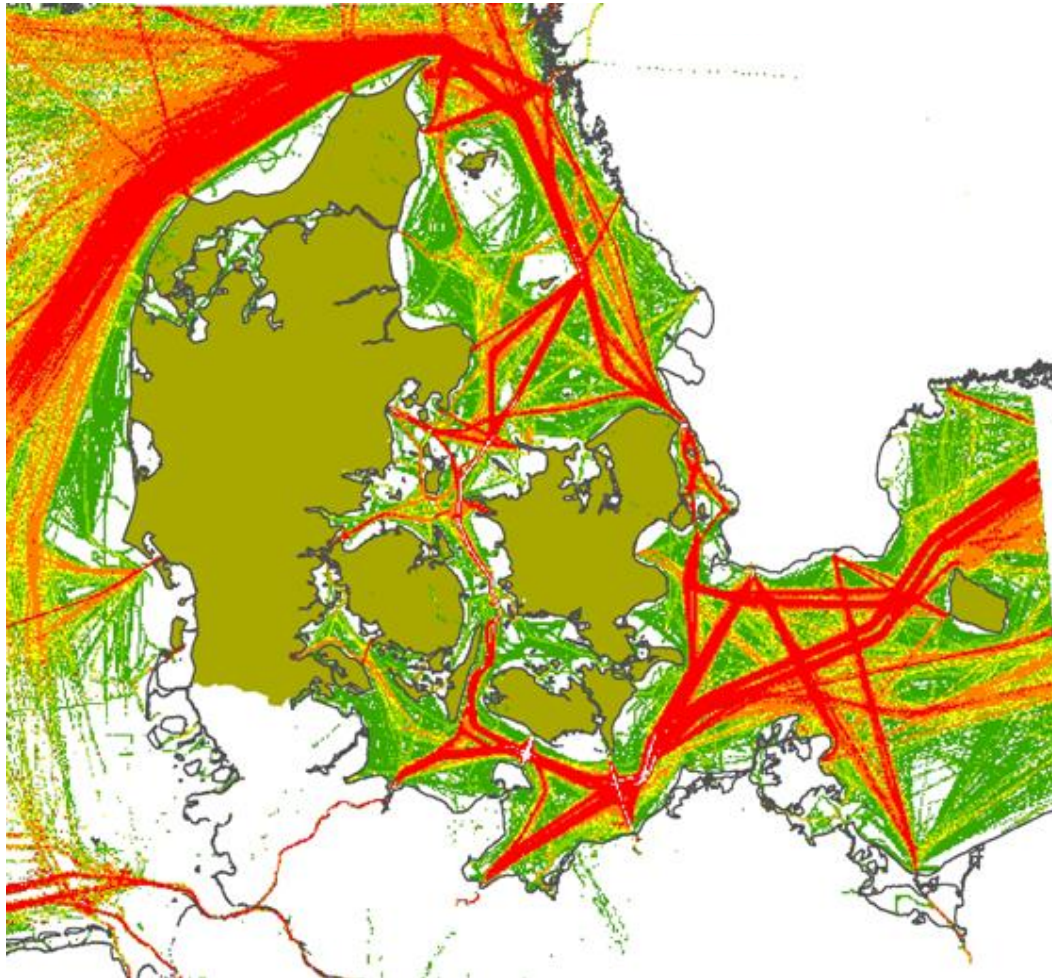




Steps to estimate ship contribution to concentrations

1. Compile an emission inventory
2. Make calculations of concentrations with an atmospheric dispersion model, accounting for transport and conversion of pollutants.
3. How much can be attributed to ships?
Estimated by comparing model runs with full emission from ships and model runs with reduced emission from ships.

Emission inventory for SO₂ from ships based on AIS data. 2007 situation.

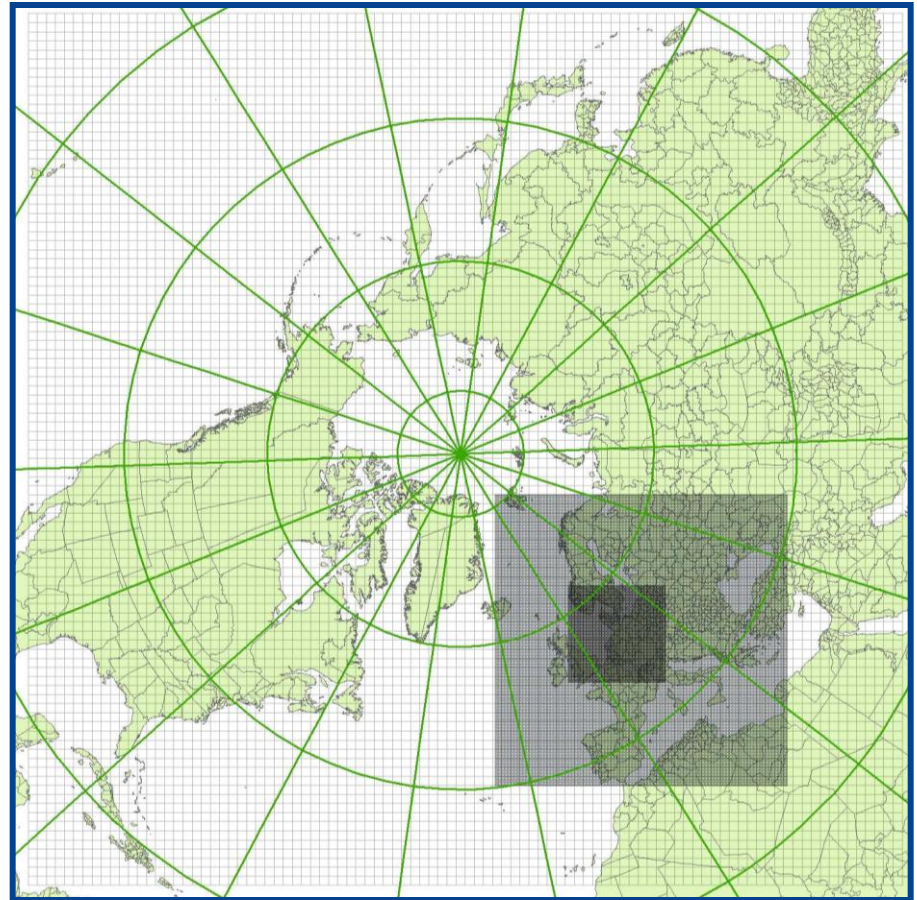


Ton SO₂ per
year per km²



Atmospheric model: The Danish Eulerian Hemispheric Model (DEHM)

- › 3D chemical transport model
- › Long range transport of air pollution on the Northern hemisphere
- › Grids of calculation points.
Horizontal resolution:
 - 150 km x 150 km
 - 50 km x 50 km
 - 17 km x 17 km
 - 6 km x 6 km





Study from 2009: Main assumptions for scenarios

- › The ship traffic in 2011 is assumed equal to traffic in 2007 – due to the financial crisis
- › The traffic of goods carrying vessels is assumed to increase by 3.5 % annually until 2020.
- › A NECA area is implemented in 2016
- › For 2020: Land-based sources based on a scenario set up by the International Institute for Applied System Analysis in Vienna ('Central case'). Involves a reduction in NO_x emission which has not taken place.



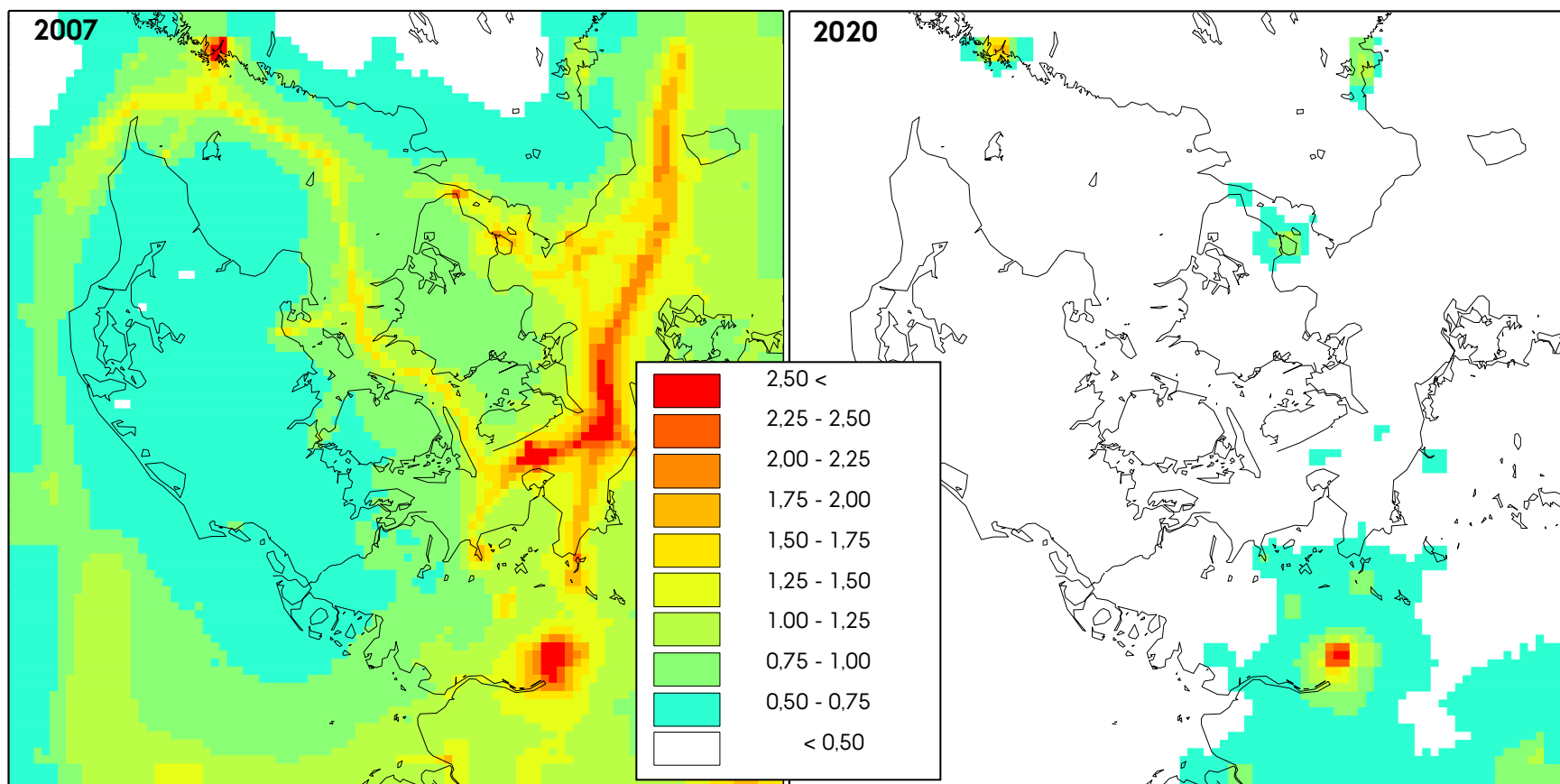
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DEPARTMENT OF ENVIRONMENTAL SCIENCE

Results in terms of concentrations

SO₂: Model calculations for 2007 og 2020

All sources, both landbased and ships.

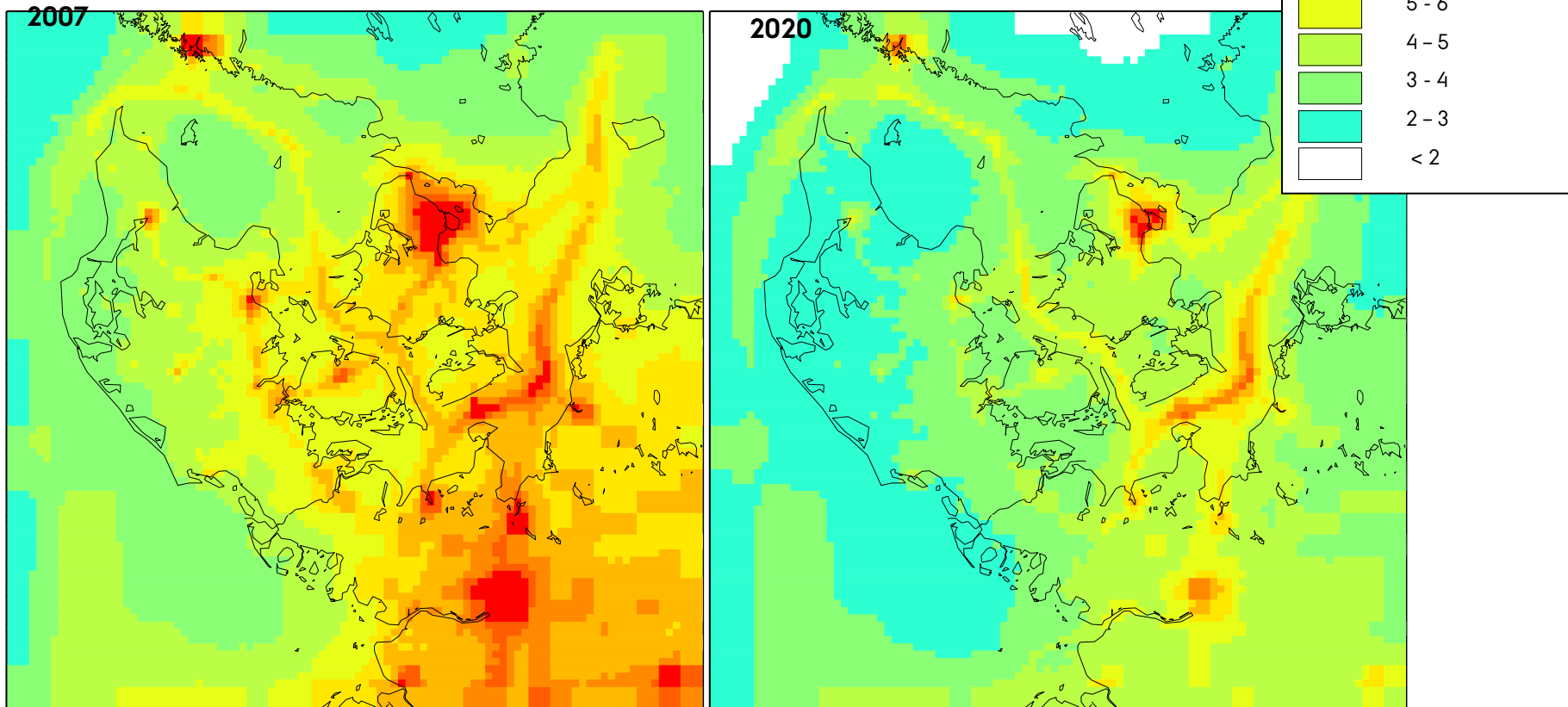
Concentration of SO₂ in $\mu\text{g}/\text{m}^3$





NO₂: Model calculations for 2007 og 2020

Koncentration af NO₂ in µg/m³





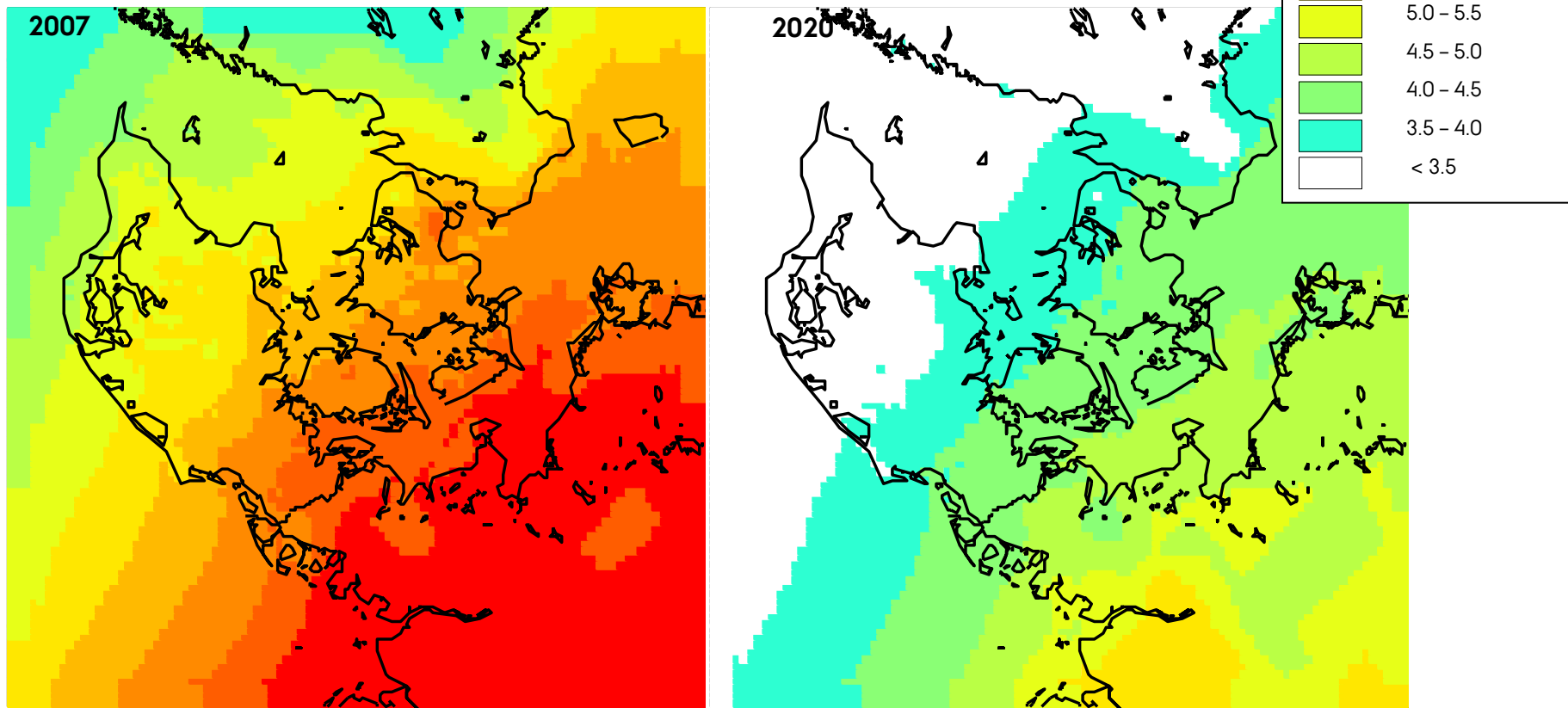
Particle pollution – limitation in calculations

- › With the DEHM model we can describe
 - primary particles
 - secondary inorganic particles
 - but not secondary *organic* particles
- › We use the designation **mPM_{2.5}** (modelled PM_{2.5}) for the particles.



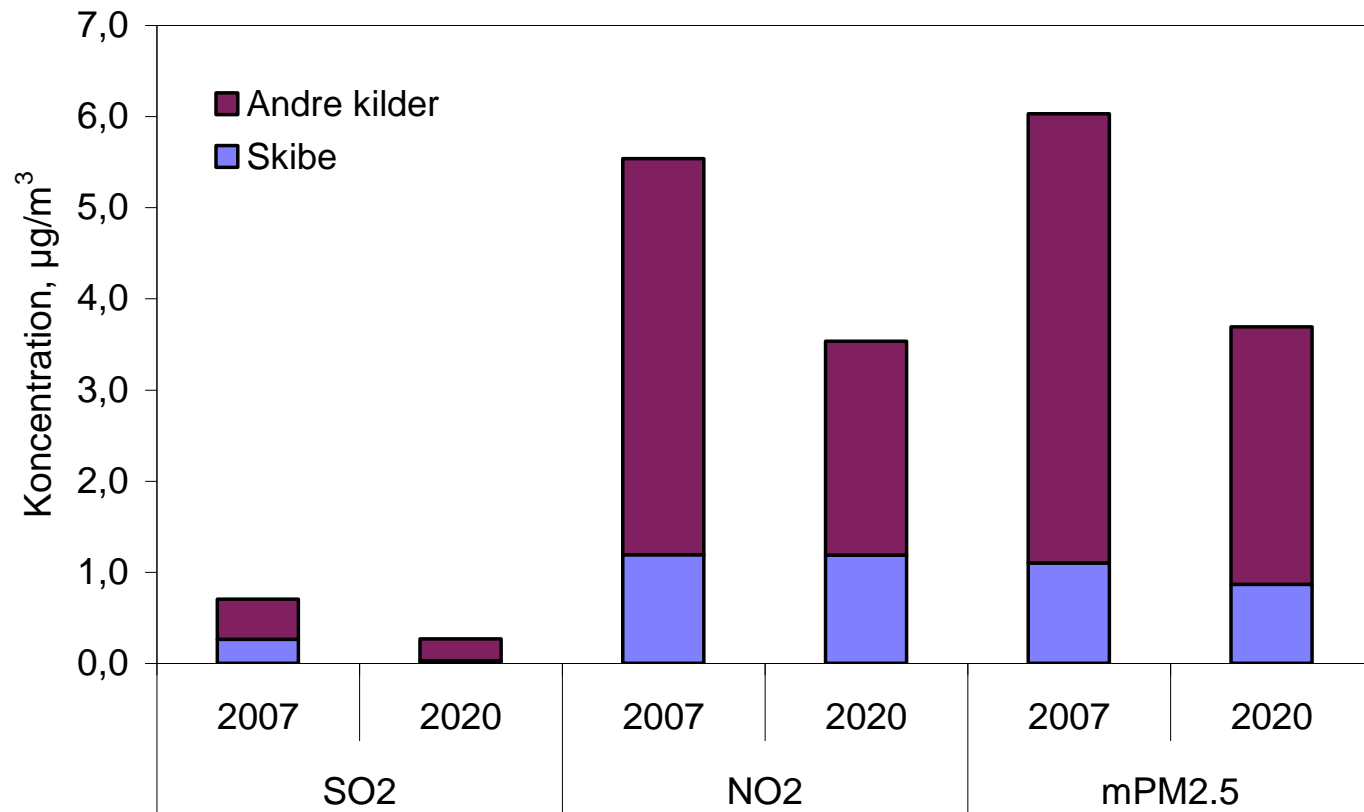
Model calculations for 2007 and 2020

Concentration of $mPM_{2.5}$, $\mu g/m^3$ ($mPM_{2.5}$: modelled $PM_{2.5}$)





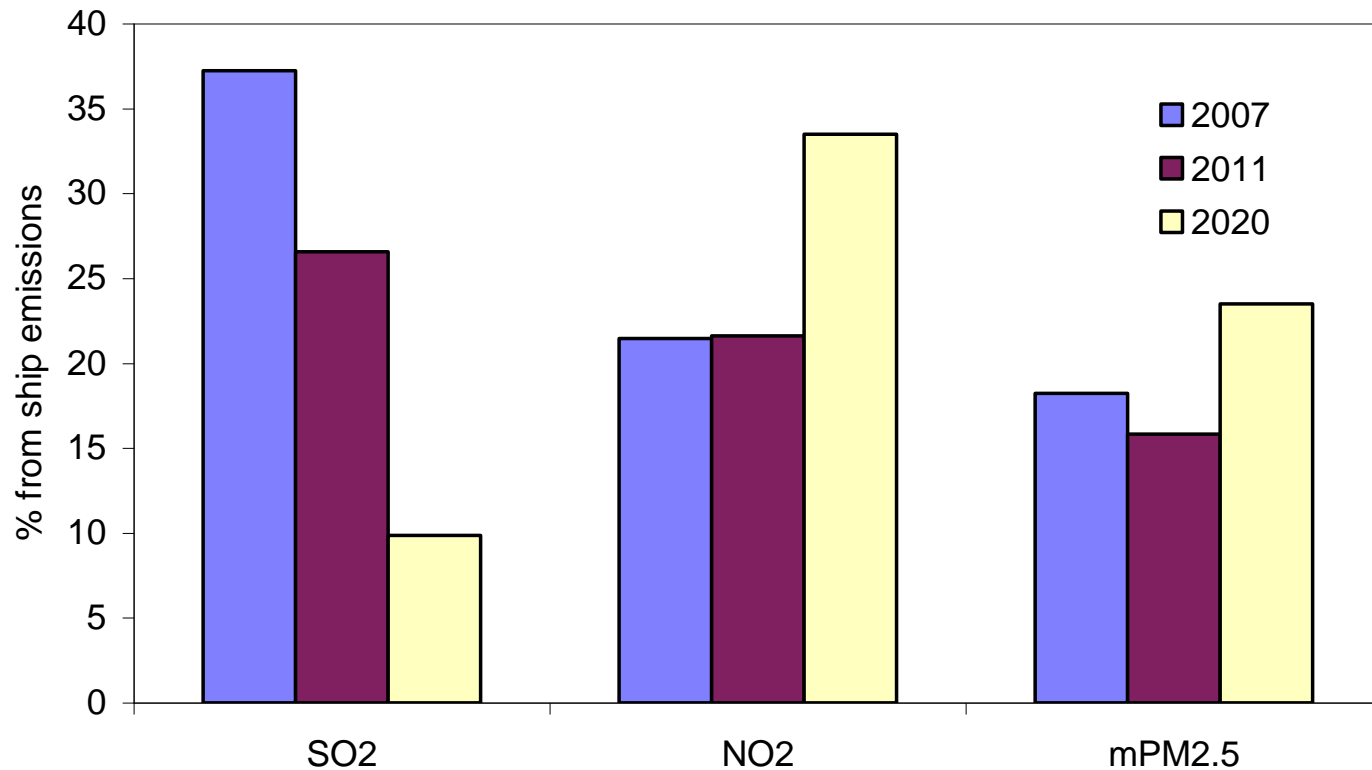
Trend in air quality in Denmark towards 2020 – average over land area



Average concentration over Danish land areas



Relative contribution (percent) from ships to concentration levels (average over Danish area)





Summary until now...

- › On Danish national scale emissions from ships give a significant contribution to air pollution levels for:
 - Sulphur dioxide
 - Nitrogen oxides
 - Fine particles
- › For instance, in the Danish rural districts ship traffic is responsible for around 20% of NO_2 concentrations in the air.
- ›



Pollution from ships in the port of Copenhagen





Available studies concerning ports (1)

- › **Pollution from docking cruise ships in Copenhagen.** 2004 emission data. Environmental Project 978, 2005 for the Danish EPA.
- › **Chapter in report from 2009.** 2008 emission data. No explicit concentration calculations, but emission data for both Copenhagen and Aarhus. Data are adjusted to reflect sulphur regulations for ports introduced 2010. Environmental Project 1306, 2009 for the Danish EPA



Available studies concerning ports (2)

- › Study conducted 2007 to investigate interaction between planned cruise ship terminals and future residential areas. Unpublished.
- › Study concerning planned high rise buildings (ca. 100 m tall) at Marmormolen and Langelinie.



Available studies – features and limitations

- › The studies have very detailed emission inventories, especially for cruise ships.
- › However some years old. No recent, detailed emission data have been compiled.
- › Emissions are based on the assumption that engines run in normal operation at a certain fraction of full load. We do not take account of any transient bursts of pollution during start of engines.



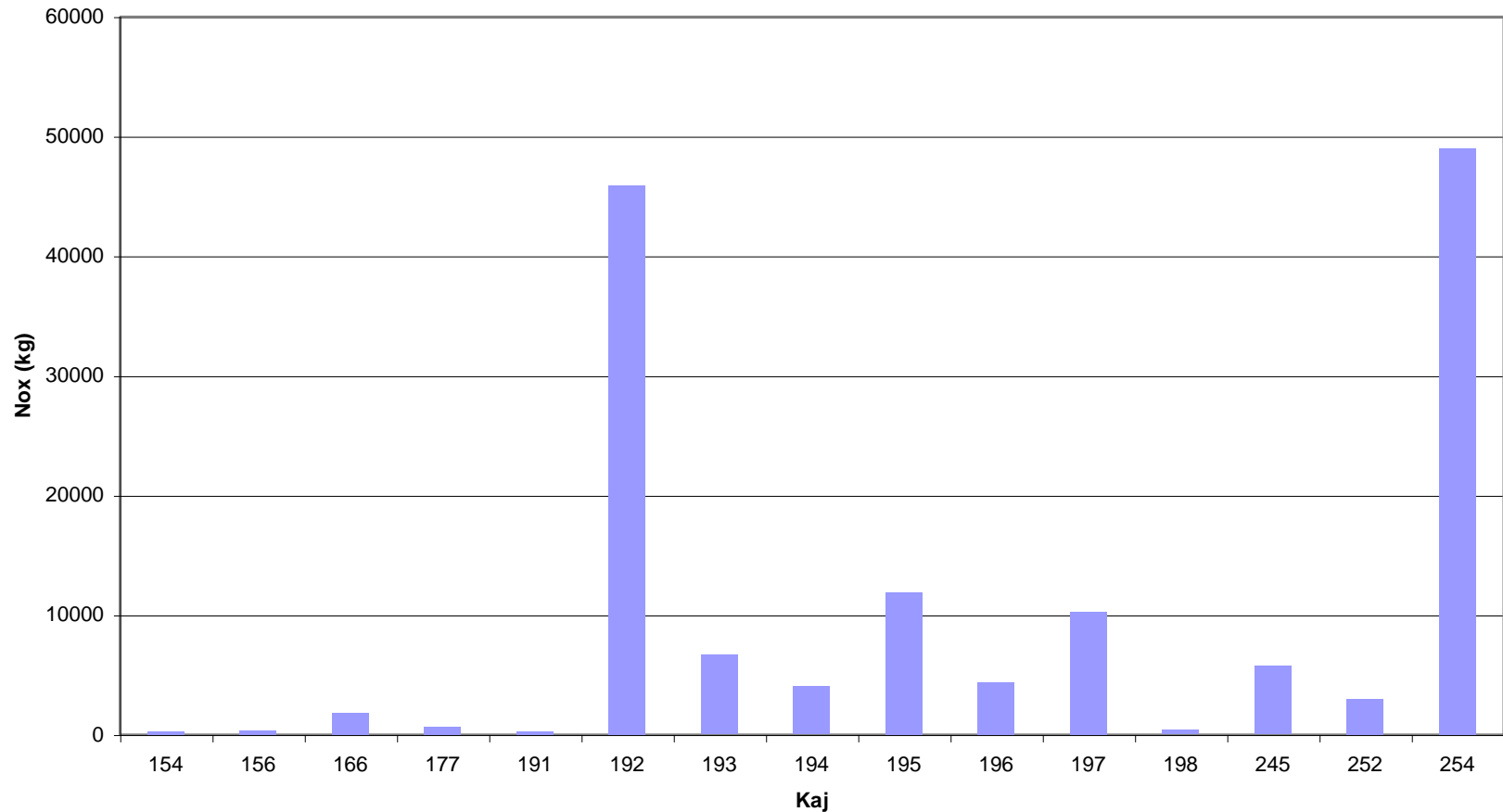
Results from the most detailed study: Pollution from cruise ships based on 2004 data.



Cruise ship quays in Copenhagen (2004)



NO_x emission at each quay (entire season)





NO₂ concentration as yearly average (2004 data)

- › NO₂ has a background level of approximately 23 µg/m³. **The level is increased by 0.8 µg/m³**, where the contribution is largest (600 meter East of Langelinie). The limit value is 40 µg/m³.
- › The small increase may appear surprising because ships are large NO_x emitters.
- › However, chemistry is involved. The amount of available ozone in the background air sets a kind of 'ceiling': It limits the amount of NO that can be converted to NO₂.
(This applies only as long as we consider local scale)



PM_{2.5} concentration as yearly average (2004 data)

- › **PM_{2.5} is increased locally close to cruise ships by 0.035 µg/m³ (background level ca. 15 µg/m³). The limit value is 25 µg/m³.**
- › Note:
 - The relative contribution is small, but any contribution of PM_{2.5} has a negative health effect.
 - No account is taken of special conditions during engine start



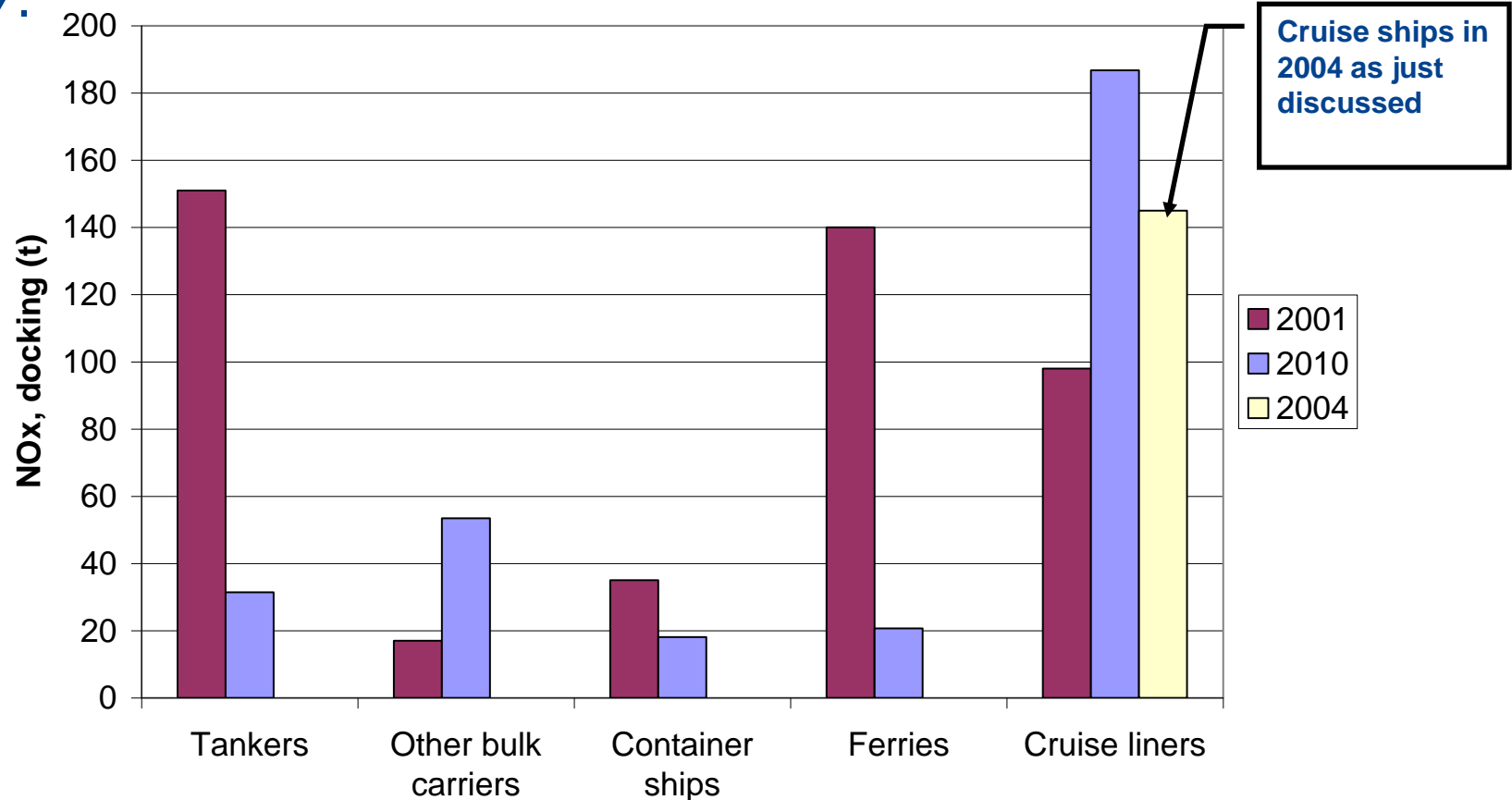
SO₂ concentration as yearly average (2004 data)

- › **SO₂ was increased locally close to cruise ships by 1.5 µg/m³. The background level was around 5 µg/m³ in 2004.**
- › **Note:**
 - Due to sulphur regulations in port, beginning in 2010, a 16 times reduction could be expected.



Various ship types and development over time

> **NO_x emissions (docking)** according to report from 2009.





NOx emissions from ships in Copenhagen Port compared to other sources.

- › 373 ton in 2010 from all ships (docking & manoeuvring)
- › **Of these: 200 ton from cruise ships** (docking & manoeuvring)
- › 7.760 t from all ships in Øresund
- › 568 ton from "Amagerværket" i 2008
- › 19.000 t from all road traffic in the greater Copenhagen area



Cruise ship calls in Copenhagen Port

- › 2004: 259 calls in Copenhagen port
- › 2008: 295 calls in Copenhagen Port
- › 2013: 347 calls in Copenhagen (10 in Malmø)



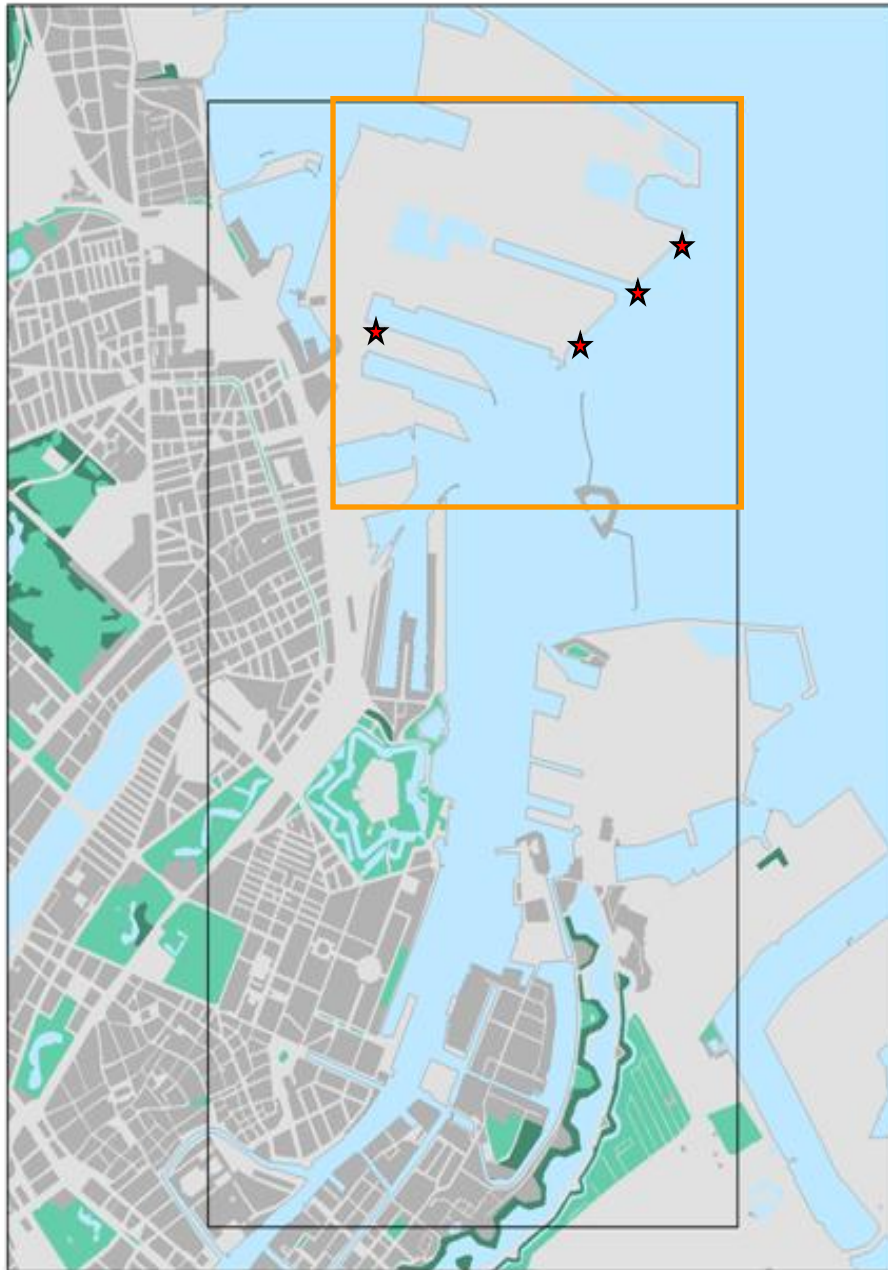
Study conducted 2007: 2010 and 2017 scenarios

Will there be a conflict between more cruise ships and planned new residential areas?



We now focus on an
area to the North,
2000 x 2000m

Various scenarios
are considered.



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area to the North,
2000 x 2000m

Various scenarios
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Limit value for NO₂

- › The hourly concentration of NO₂ is allowed to exceed 200 microgrammes/m³ *no more than 18 times a year.*
- › Therefore, the 19th largest value is of interest: Is it larger than 200?



Scenario with very high frequency of call of relatively large cruise ships

Calculations for NO_2

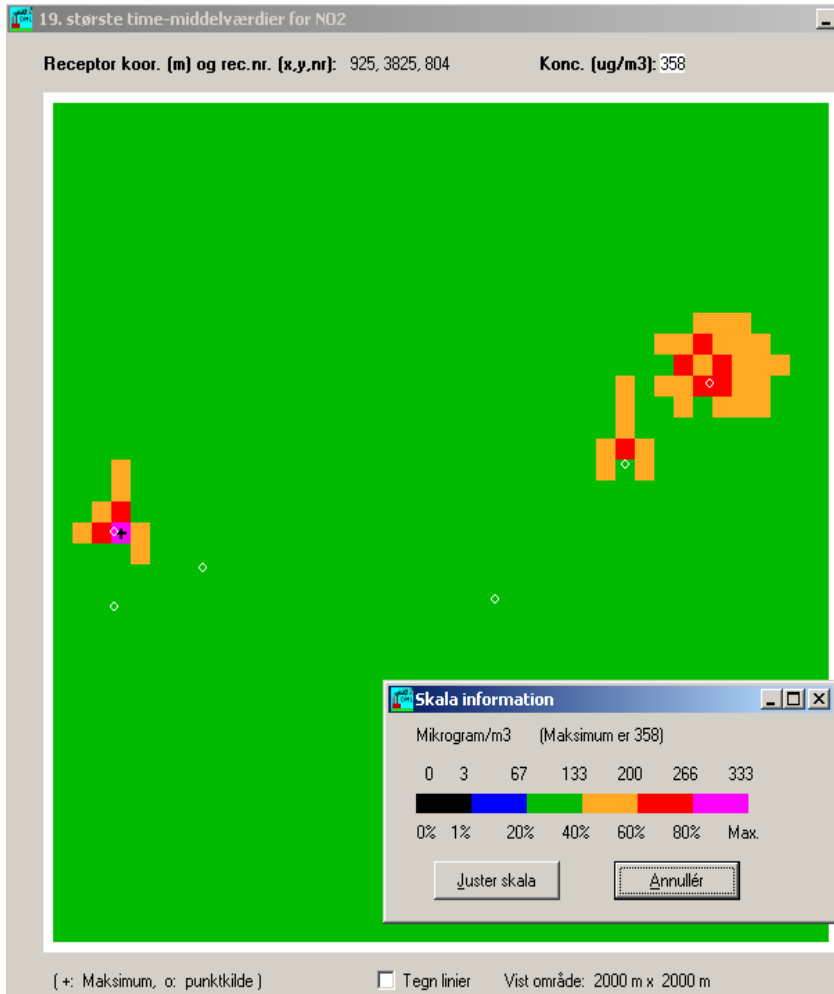
We consider the 19th highest hourly concentration at various heights

Scenario with very high frequency of call of relatively large ships

At a height of 1.5 m there are no problems in complying with the limit value.

At a height of 20 m also no problem

Receptors at 30 m level

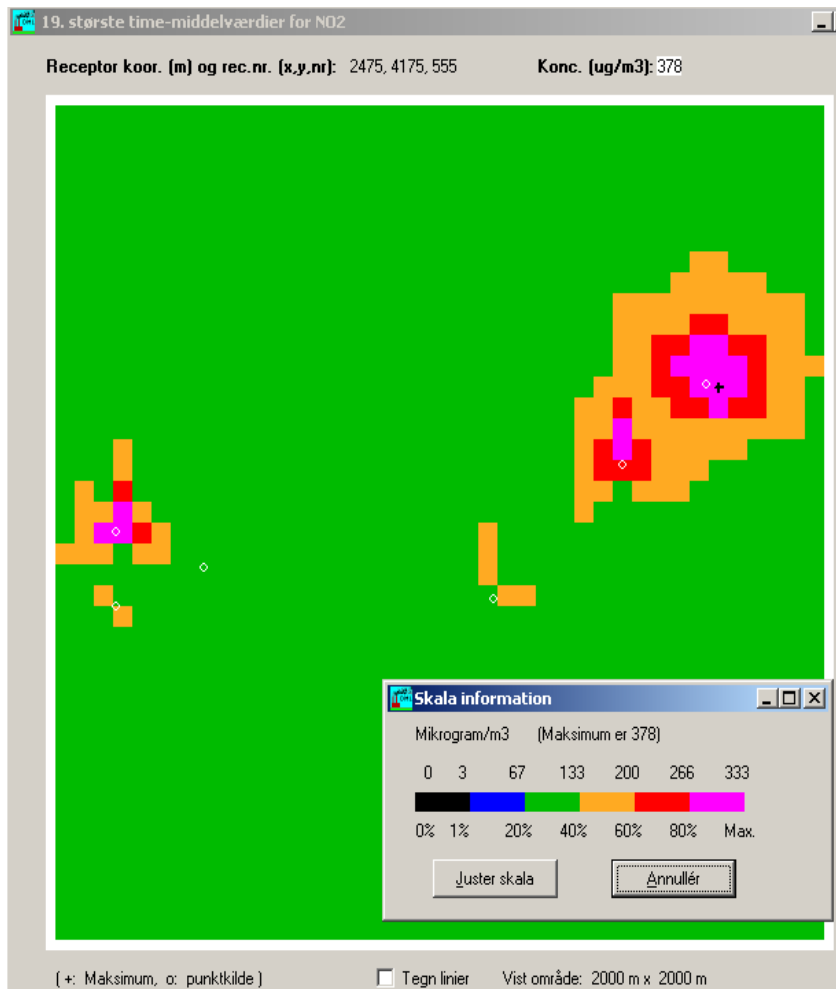


NO2 calculation.

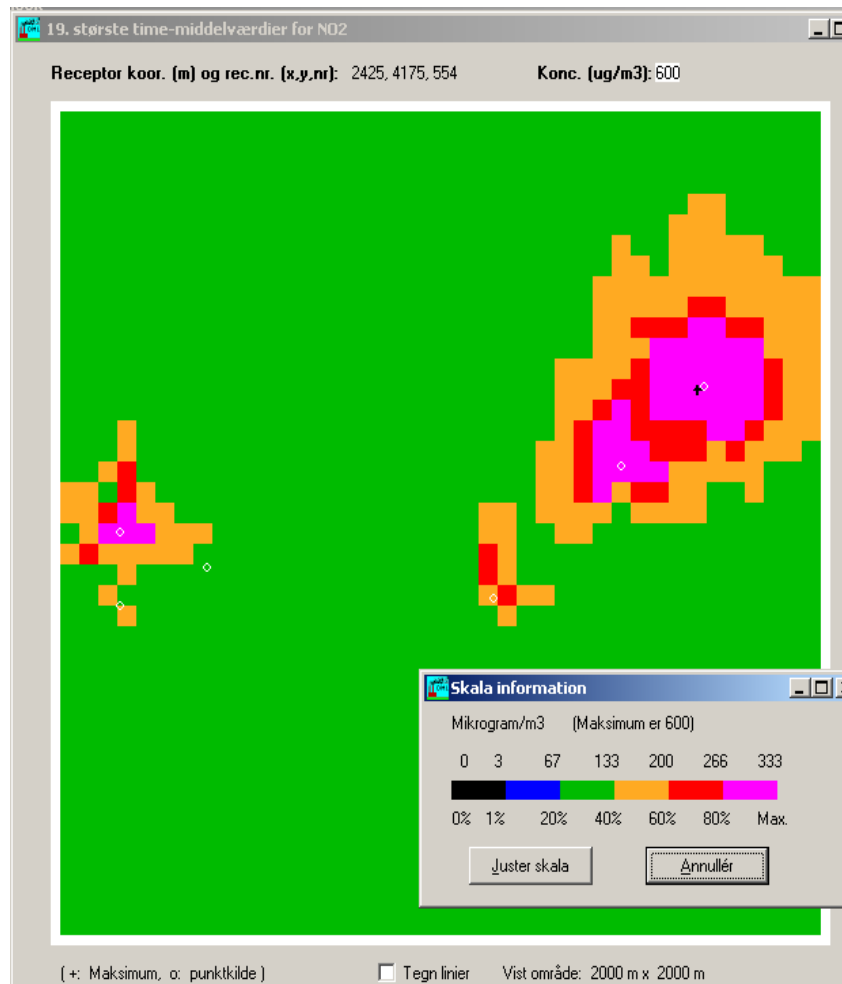
Each square is 50 x 50 m.

Very local problems at a height of 30 m.

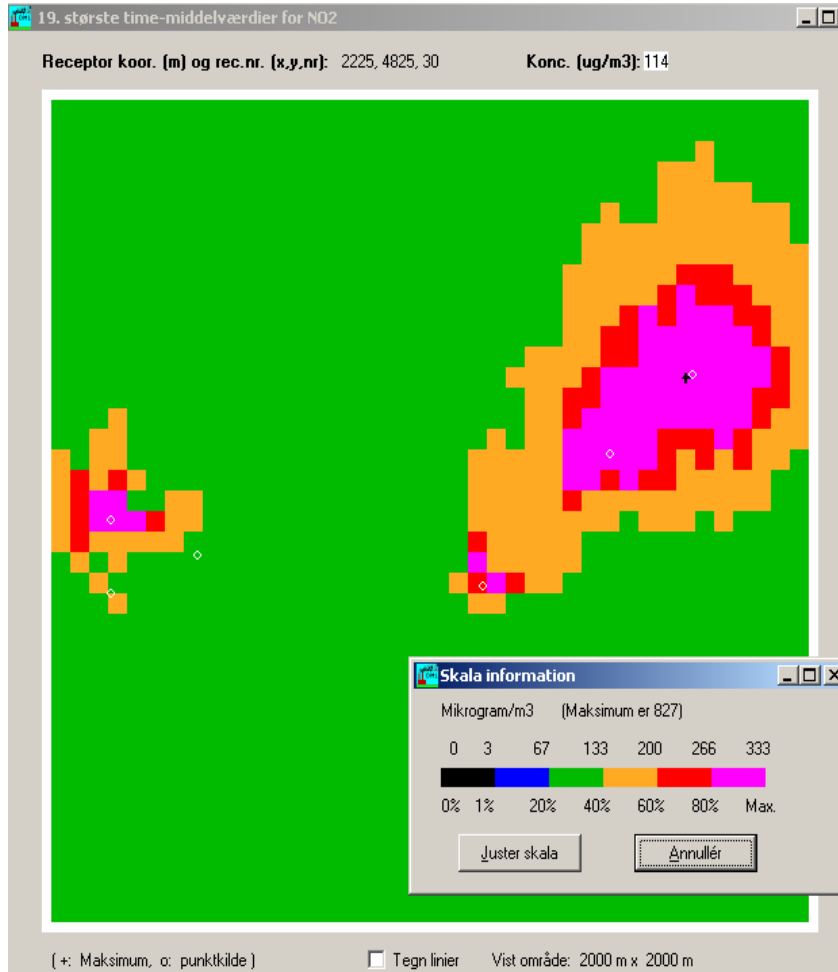
Receptors at 40 m level



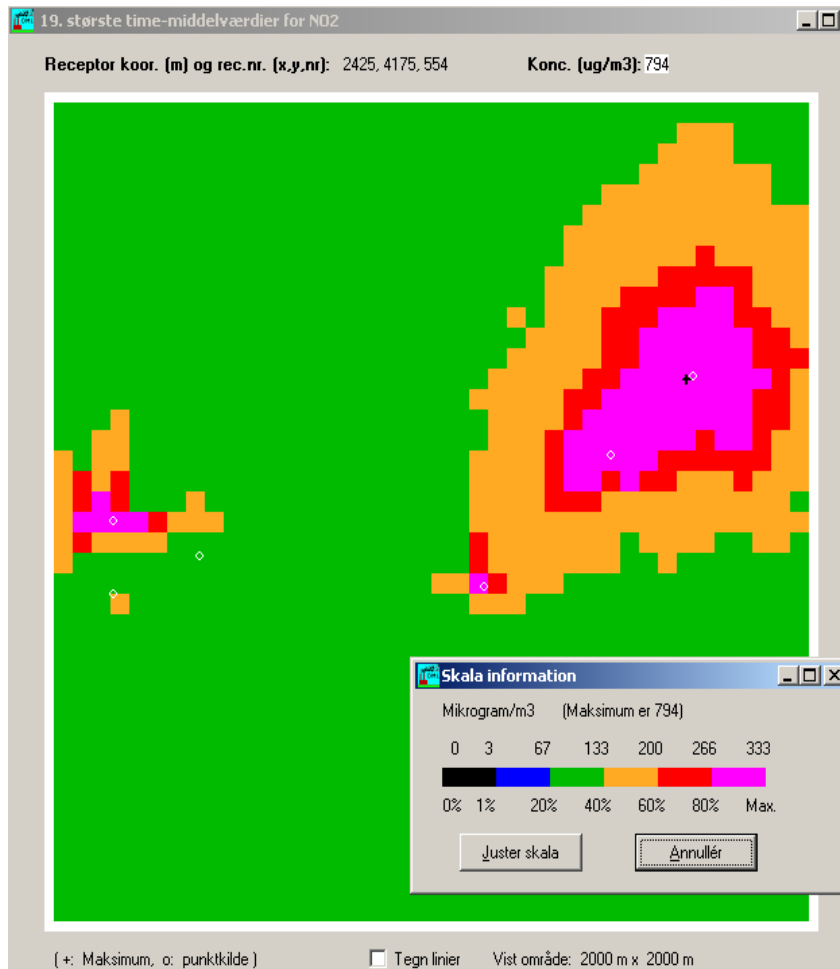
Receptors at 50 m level



Receptors at 60 m level



Receptors at 80 m level





Lesson to be learned

- › For high rise buildings close to quays with high activity level there is a potential for violations of NO_2 limit values, depending on the precise conditions regarding emissions, stack height and building geometry.



Summary (1)

- › On Danish national scale emissions from ships in seas around Denmark give a significant contribution to air pollution concentration levels for:
 - Sulphur dioxide
 - Nitrogen oxides
 - Fine particles
- › For instance, in the Danish rural districts ship traffic is responsible for around 20% of NO₂ concentrations in the air.



Summary (2)

- › There is a major effect of IMO regulations concerning sulphur. The regulations lead to a large decrease in SO_2 concentrations.
- › Ships are an important contributor to both primary and secondary particles.



Summary (3)

- › Docking cruise ships is a considerable source to NO_x emissions in Copenhagen. Cruise ships (2008 data) are responsible for 55% of the total emissions of NO_x from ships in Copenhagen Port.
- › Cruise ships do not cause any exceedances of limit values for NO_2 concentrations at ground level close to the ships.
- › For high rise buildings close to quays with high activity level there is a potential for violations of NO_2 limit values, depending on the precise conditions regarding emissions, stack height and building geometry.



Summary (4)

- › The detailed study for docking cruise ships showed a local increase of $PM_{2.5}$ by $0.035 \mu\text{g}/\text{m}^3$ (background level ca. $15 \mu\text{g}/\text{m}^3$).
- › The relative contribution is small, but any contribution to $PM_{2.5}$ concentrations has a negative health effect.

Thank you!