Ship contribution to air pollution in Denmark – an assessment utilising AIS data

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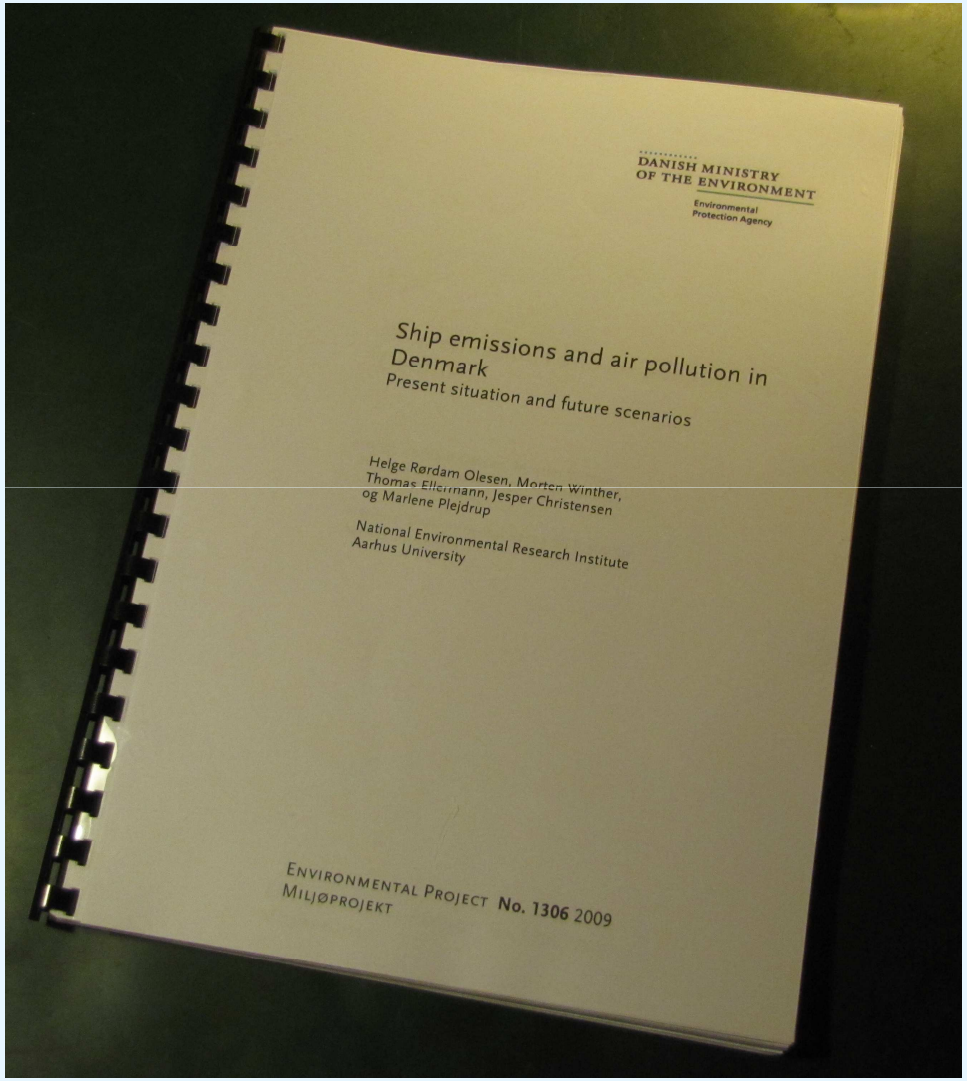
(Acts adopted under the EC Treaty/Euratom Treaty whose publication is obligatory)

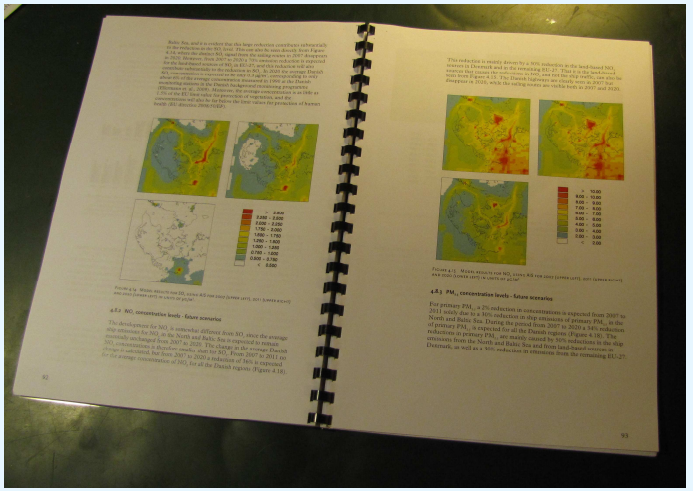
DIRECTIVES

DIRECTIVE 2008/50/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
of 21 May 2008
on ambient air quality and cleaner air for Europe

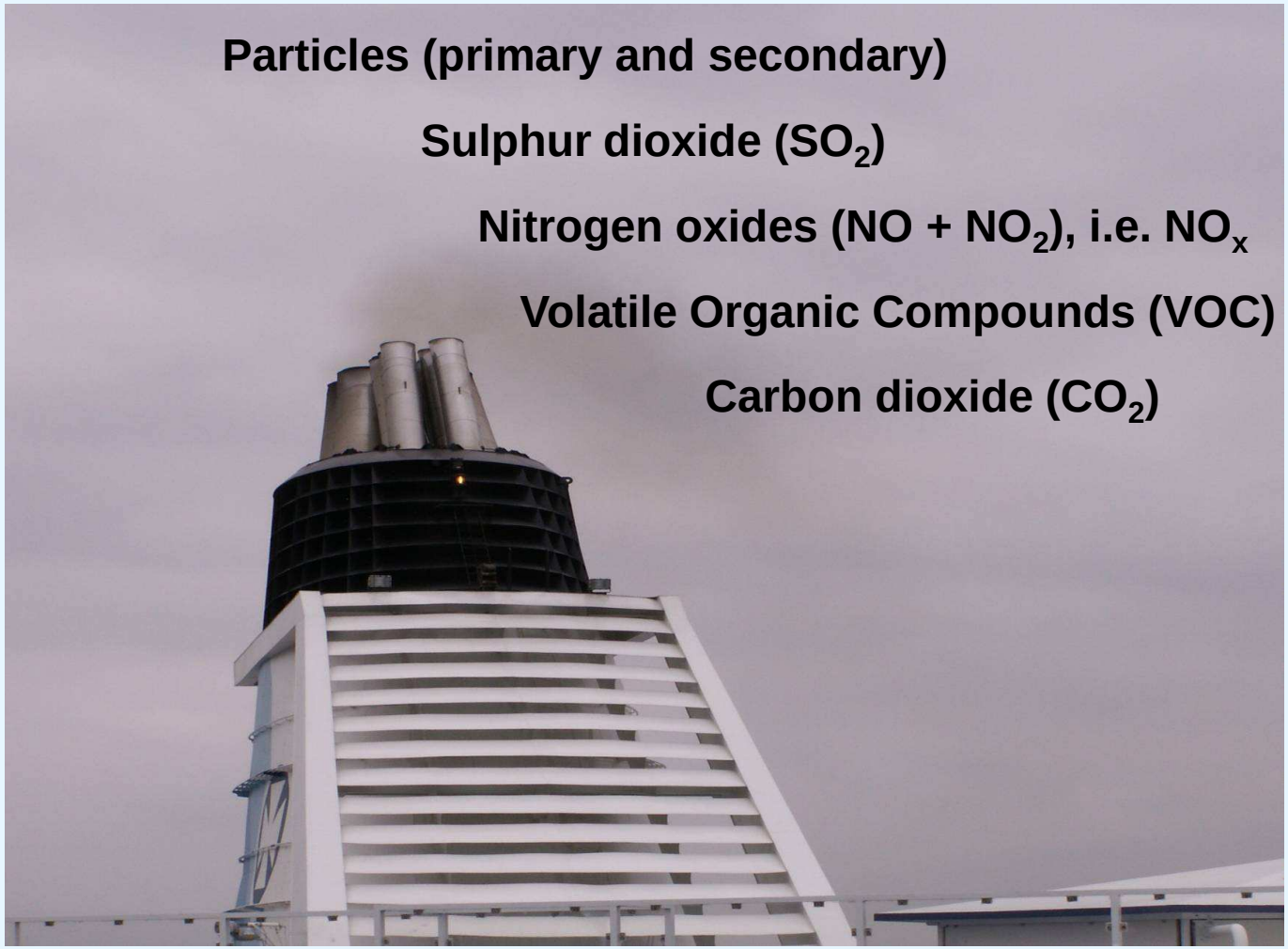


Report available on the Web

To find it:
Google for *ship emissions Denmark*



Air pollution from ships



The largest health-related air pollution problem:

Particles

Particles

A distinction is made between

- 'Primary particles'
- 'Secondary particles'

Particle pollution

- When measuring particle pollution in the air, only a relatively small fraction of the particles have been 'born' as particles. These are *'primary particles'.*
- Another large fraction have been created from gases.
- Pollution emitted as gases – in particular NO_x and SO_2 – can be transformed to particles during transport through chemical and physical processes.
- The reactions require time (several hours or days).
- These particles are referred to as *'secondary particles'.*

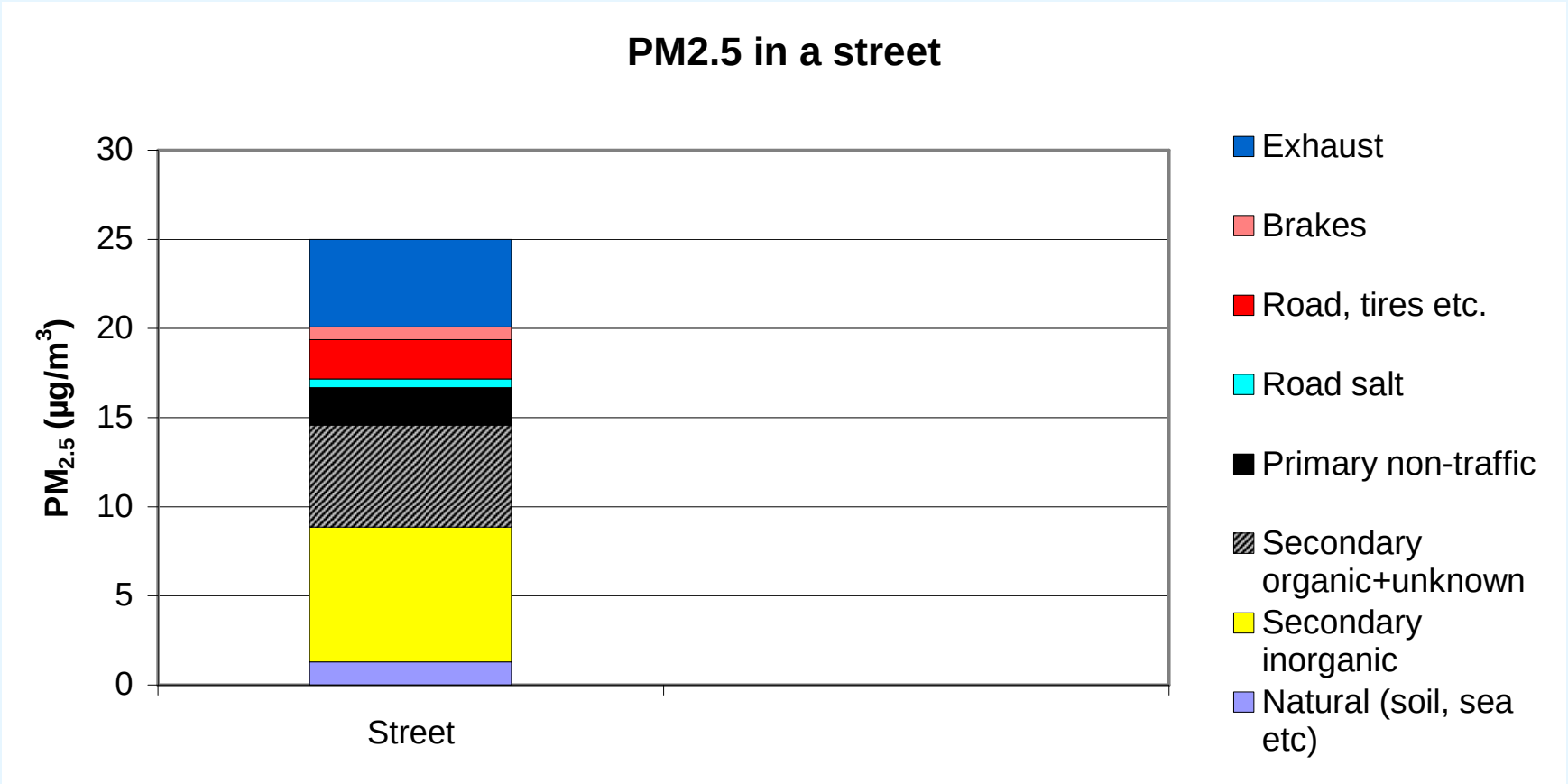
Fine particles: $PM_{2.5}$

- **$PM_{2.5}$ are particles with a diameter less than 2,5 μm.**
- **An EU limit value for the concentration of $PM_{2.5}$ applies. The yearly average value should not exceed 25 μg/m^3.**
- **Note: The value is a *target value* from 2010, but a *binding value* from 2015.**

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

What are the sources to $PM_{2.5}$ in general?



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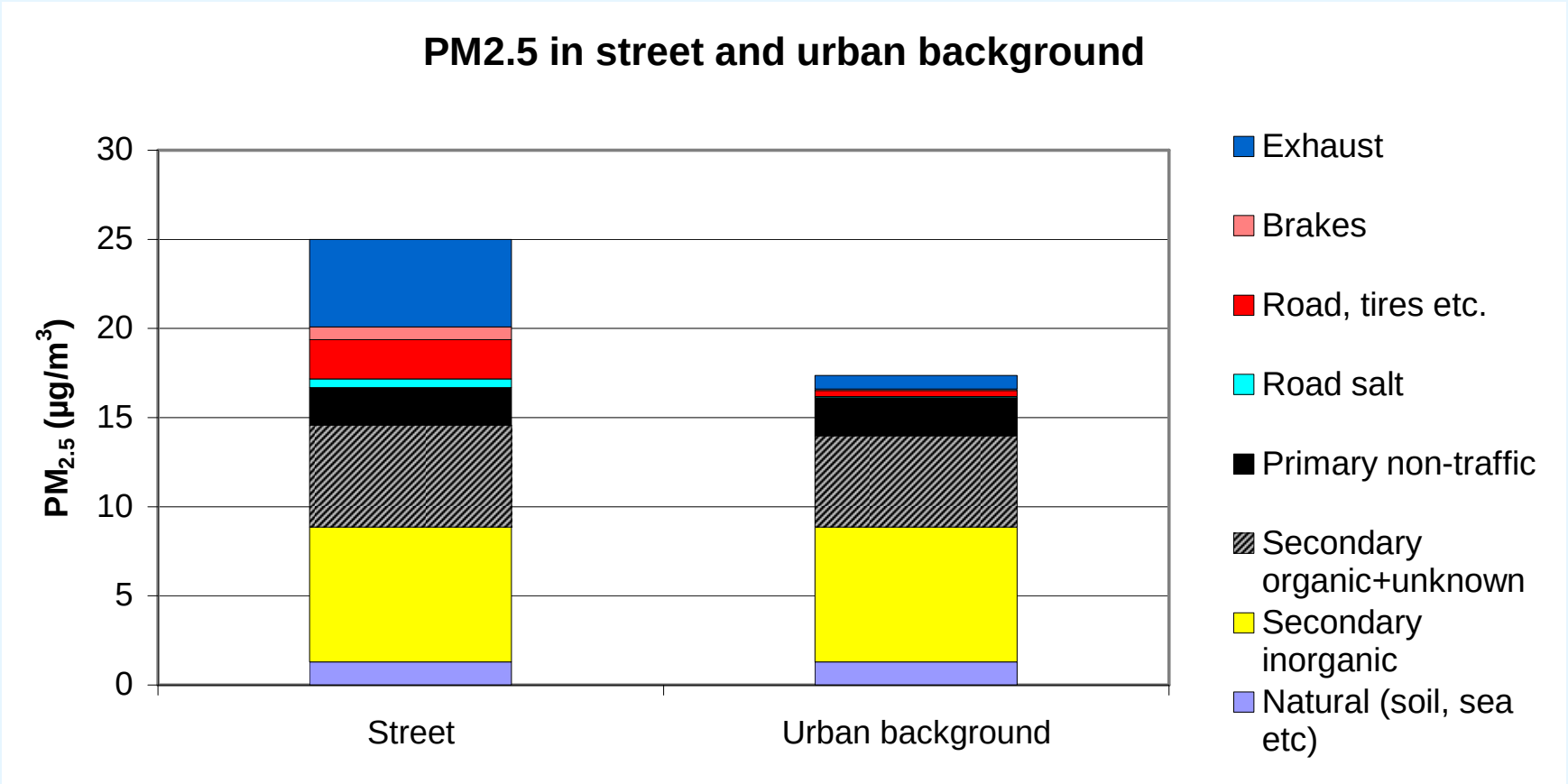
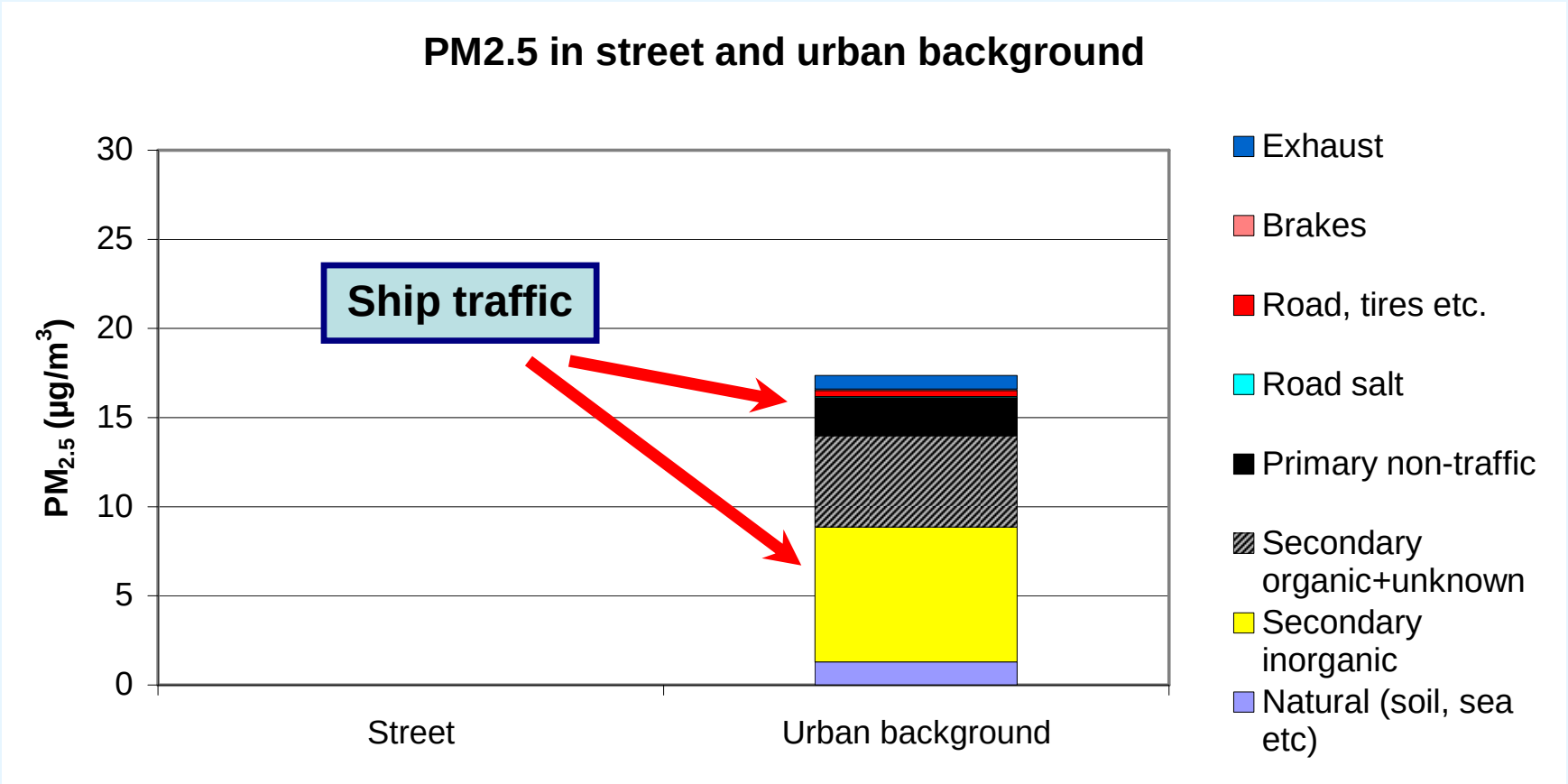


What are the sources to $PM_{2.5}$ in general?



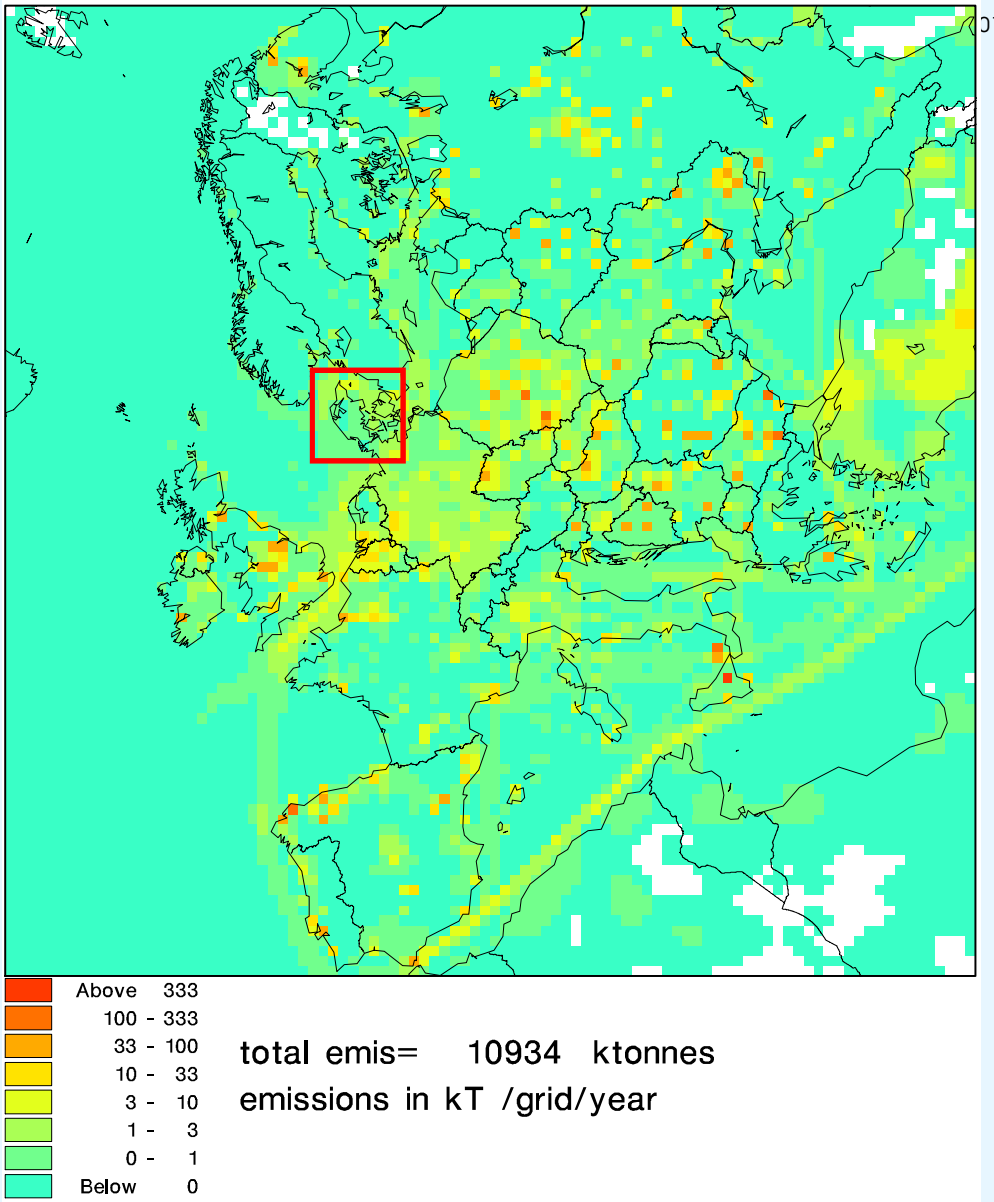
Steps to estimate ship contribution

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

Emissions of SO_2

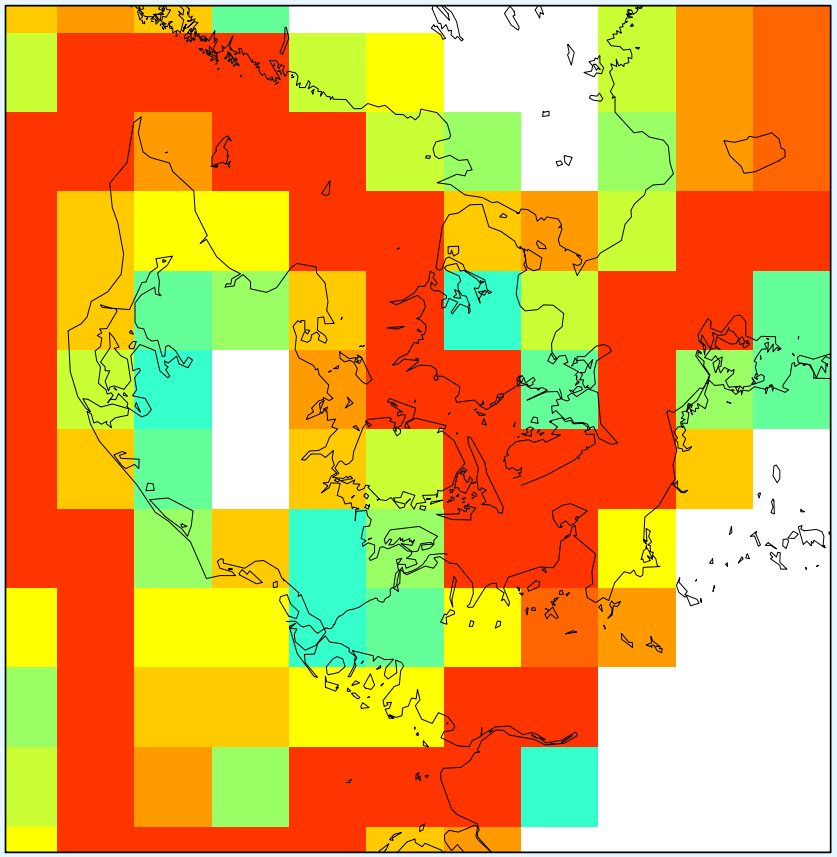
(year 2000)

Source:
EMEP, i.e.
'Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe'



The ”old” (EMEP) emission inventory

50 km x 50 km grid cells



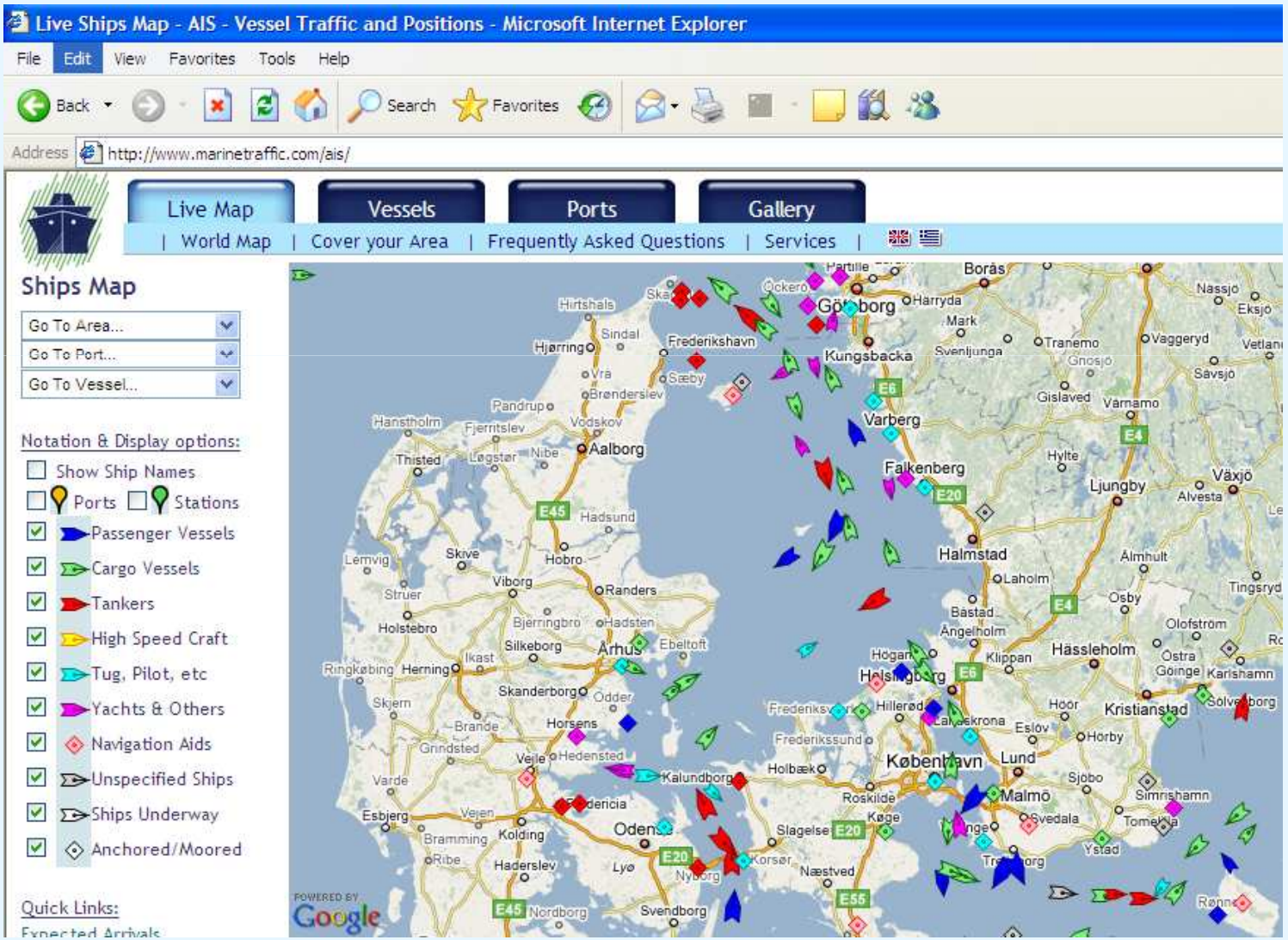
The ”old” (EMEP) emission inventory

- **50 km x 50 km grid cells.**
- **Information on sailing routes based on certain assumptions – thus not accurate.**
- **Assumed that ship engines operate at 80% load – in reality load is variable.**

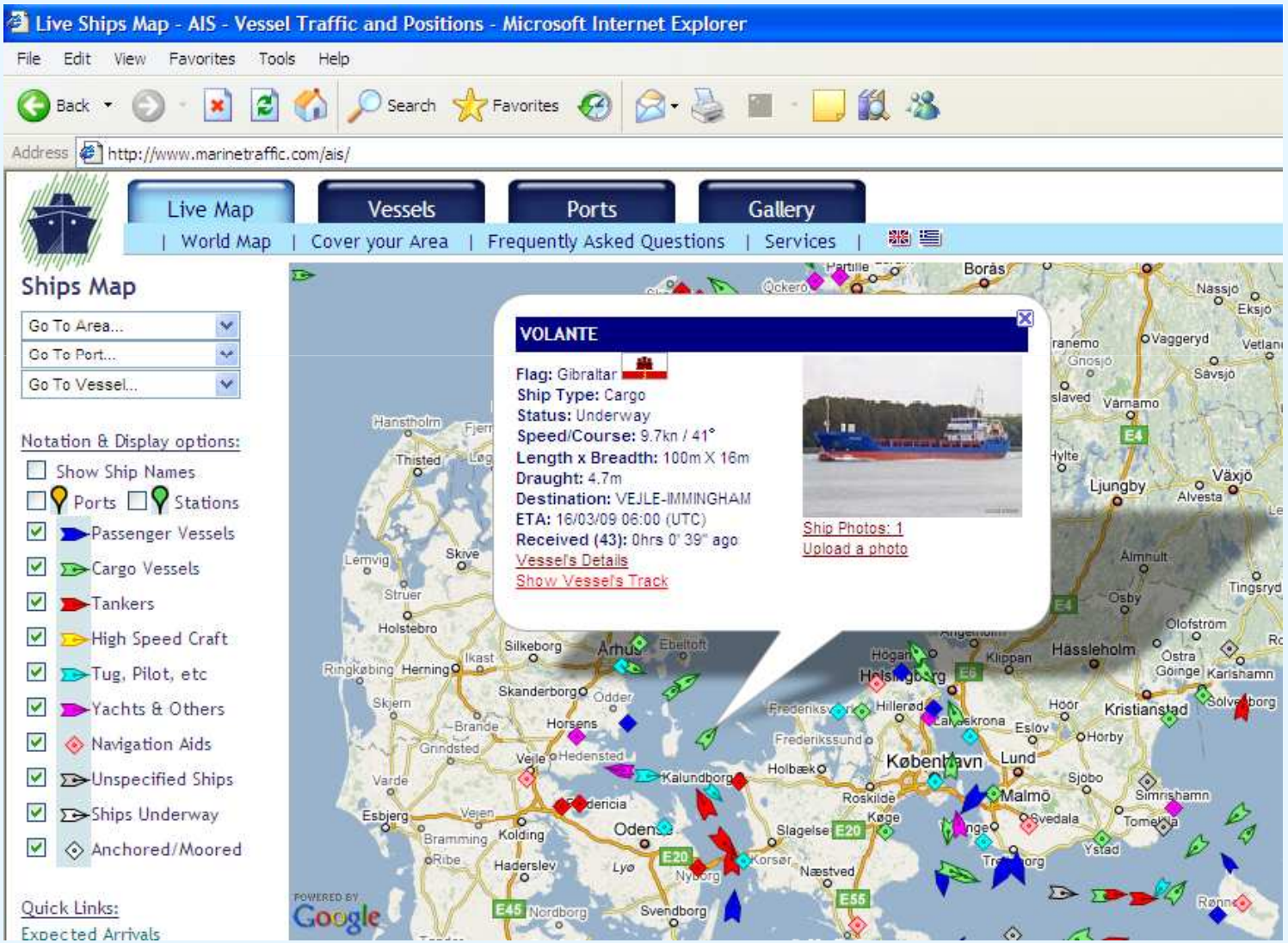
A new possibility

- **Automatic Identification System (AIS)**

AIS system: www.marinetraffic.com/ais



AIS system: www.marinetraffic.com/ais

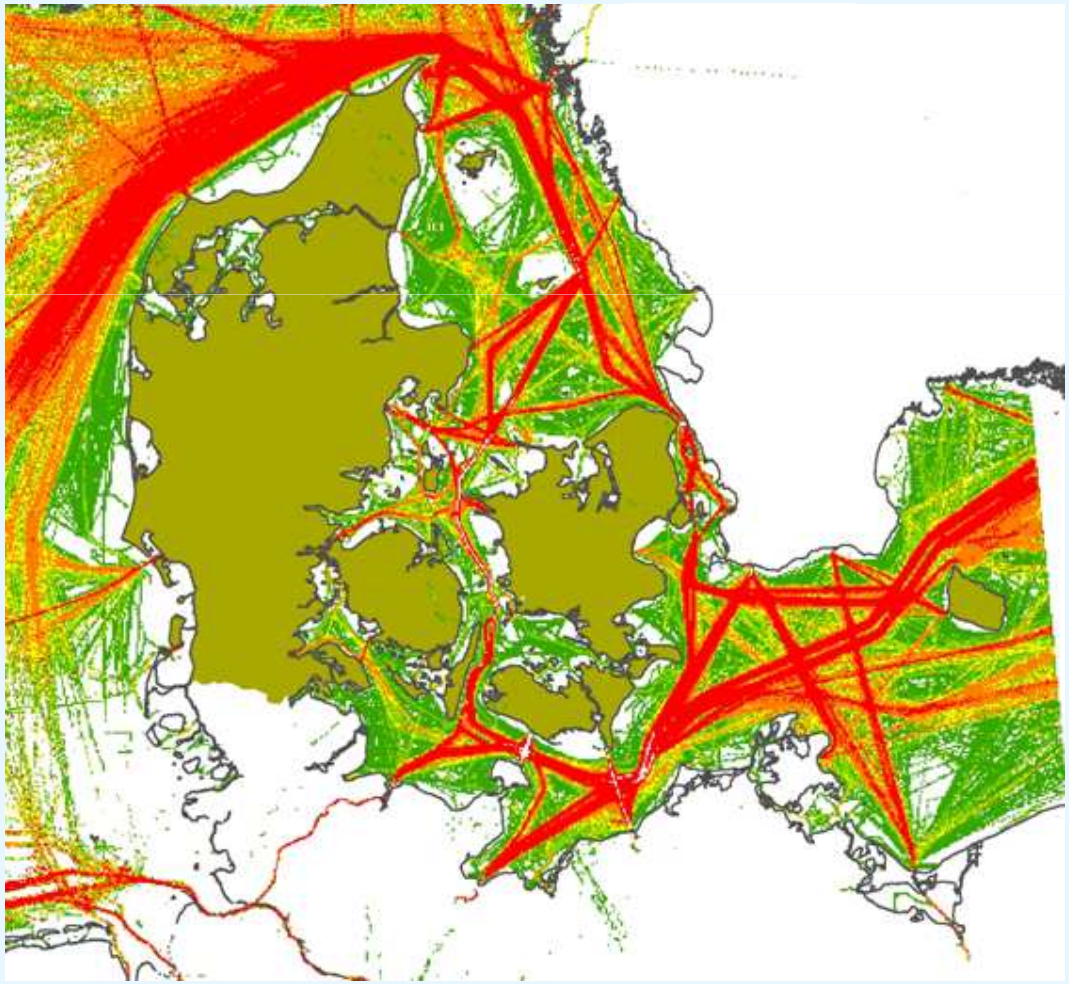


AIS (Automated Identification System) data:

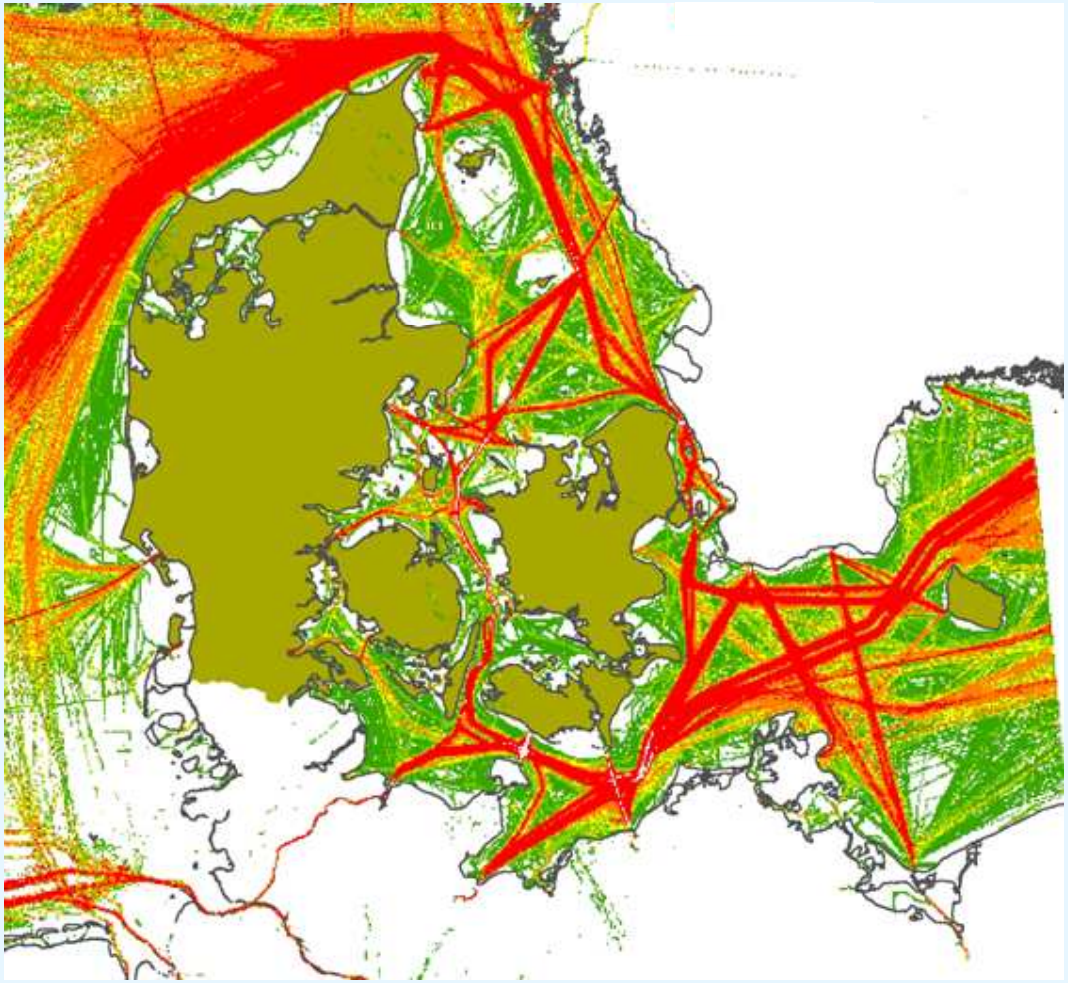
New emission inventory based on AIS

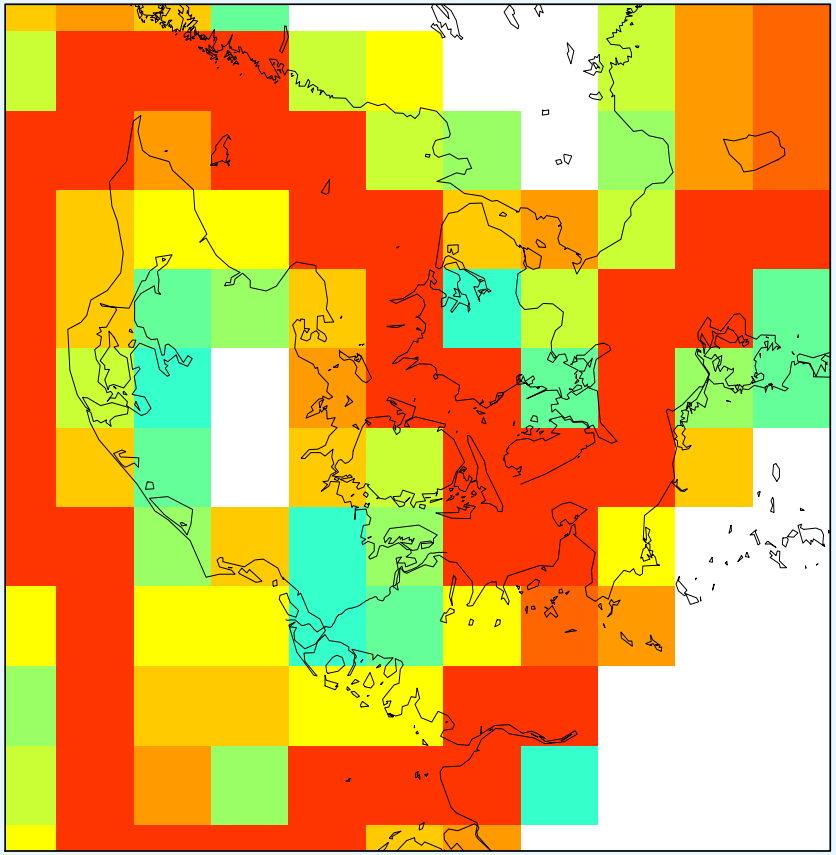
- **AIS data provided by Danish Maritime Safety Administration**
  - **Data records which contain: Vessel IMO codes; AIS signal time; vessel coordinates.**
    The year 2007 is represented by a sample of 24 days.
- **Vessel data provided by Lloyds**
  - **Main engine size and stroke, ship category.**
- **The data were processed at our institute**
  - **Deriving vessel speed, engine load, fuel consumption and emission of pollutants.**

Result of the new inventory for SO_2

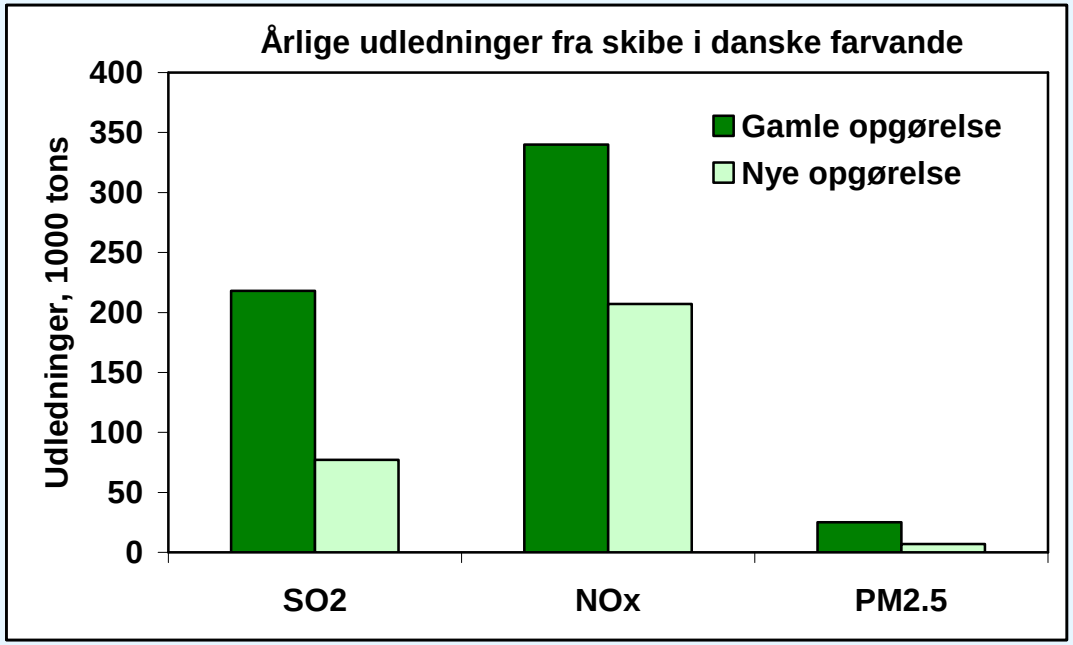


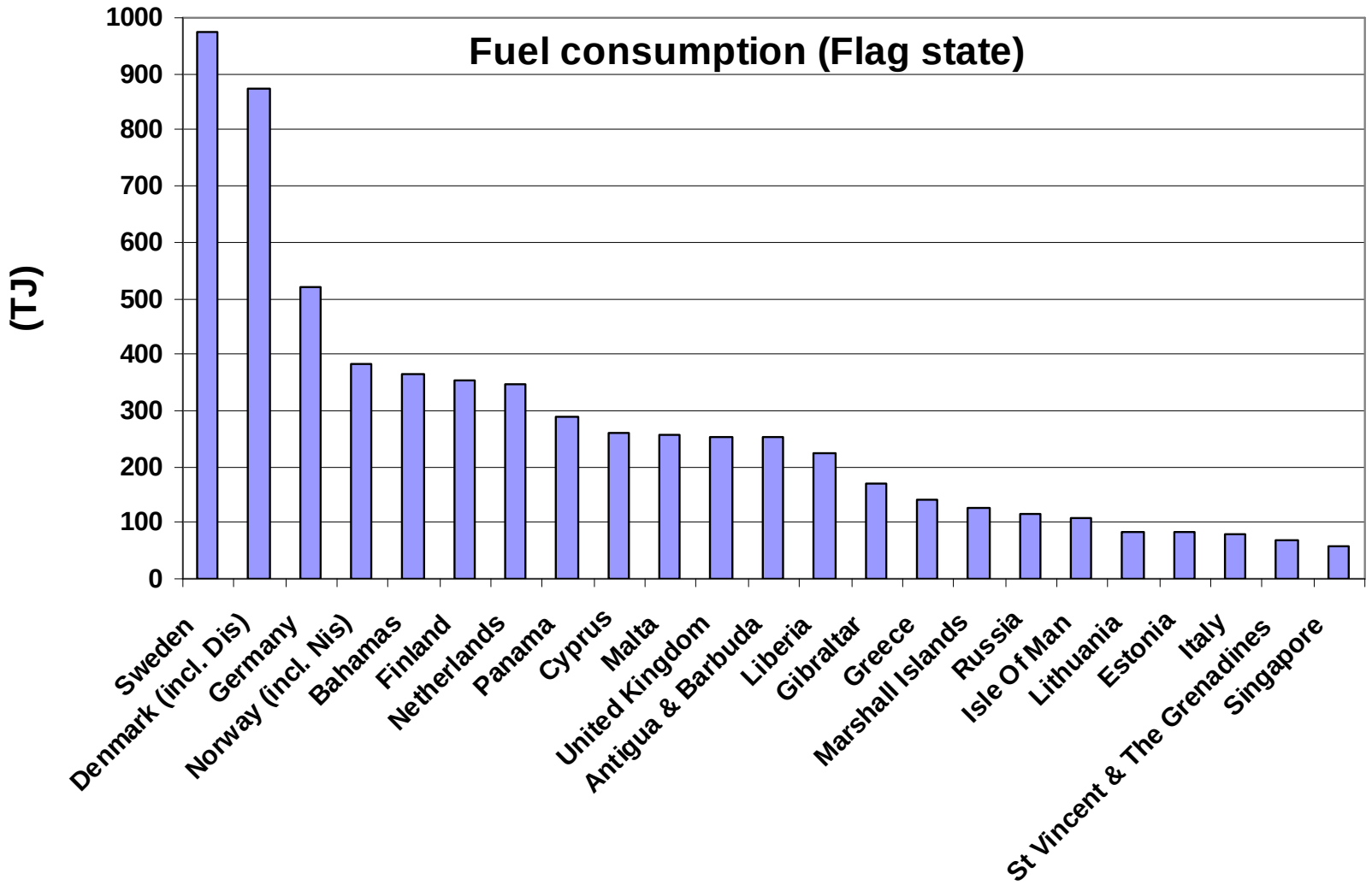
New and old inventories for SO_2





Emissions according to old and new inventories

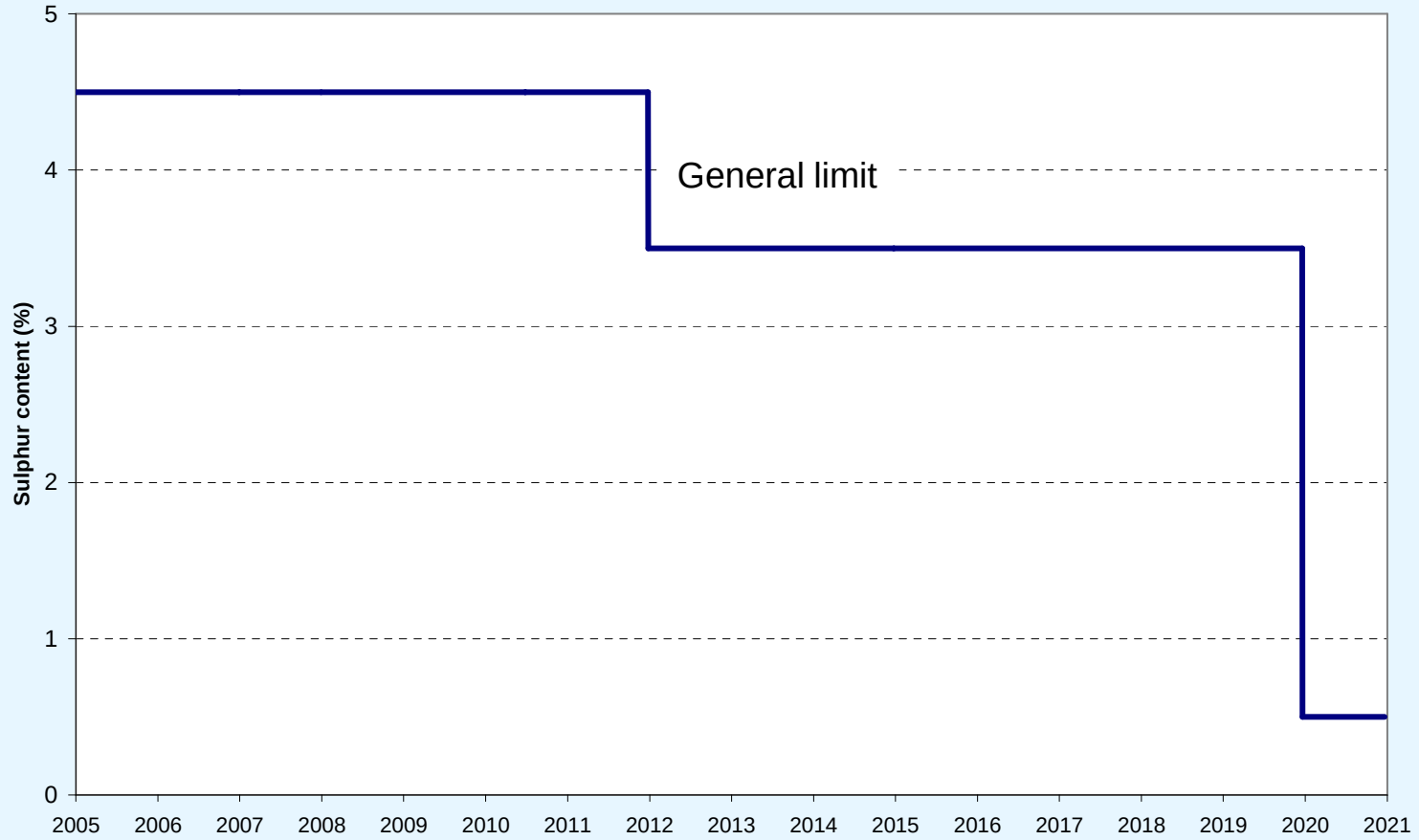



Fuel consumption (Flag state)
(TJ)
1000
900
800
700
600
500
400
300
200
100
0
Sweden
Denmark (incl. Dis)
Germany
Norway (incl. Nis)
Bahamas
Finland
Netherlands
Panama
Cyprus
Malta
United Kingdom
Antigua & Barbuda
Liberia
Gibraltar
Greece
Marshall Islands
Russia
Isle Of Man
Lithuania
Estonia
Italy
St Vincent & The Grenadines
Singapore

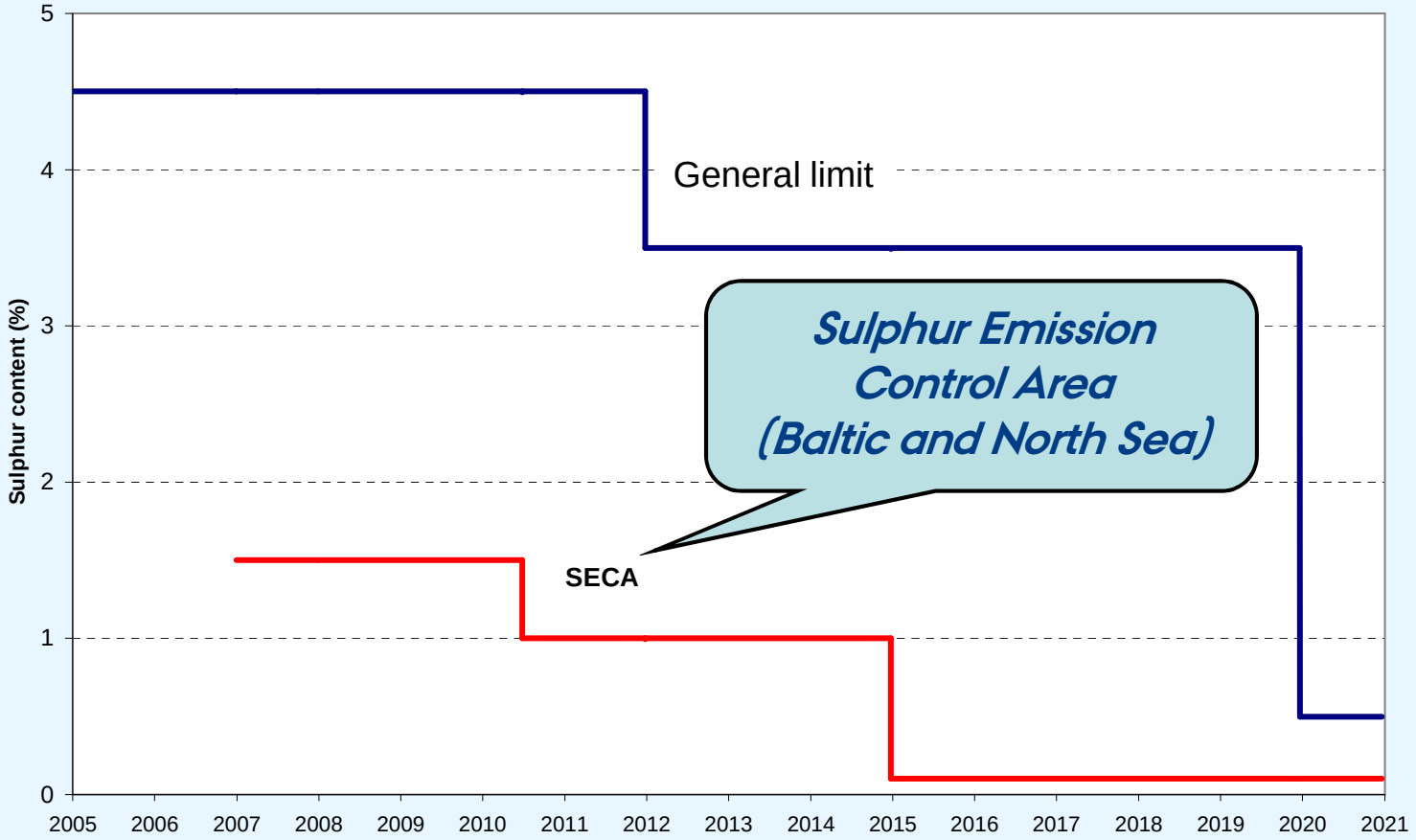
Prognosis for ship traffic

- **Based on an estimate from the Danish Ship-owners' Association**
- **The ship traffic in 2011 is assumed equal to traffic in 2007 – due to the financial crisis**
- **The traffic of goods carrying vessels is expected to increase by 3.5 % annually until 2020.**

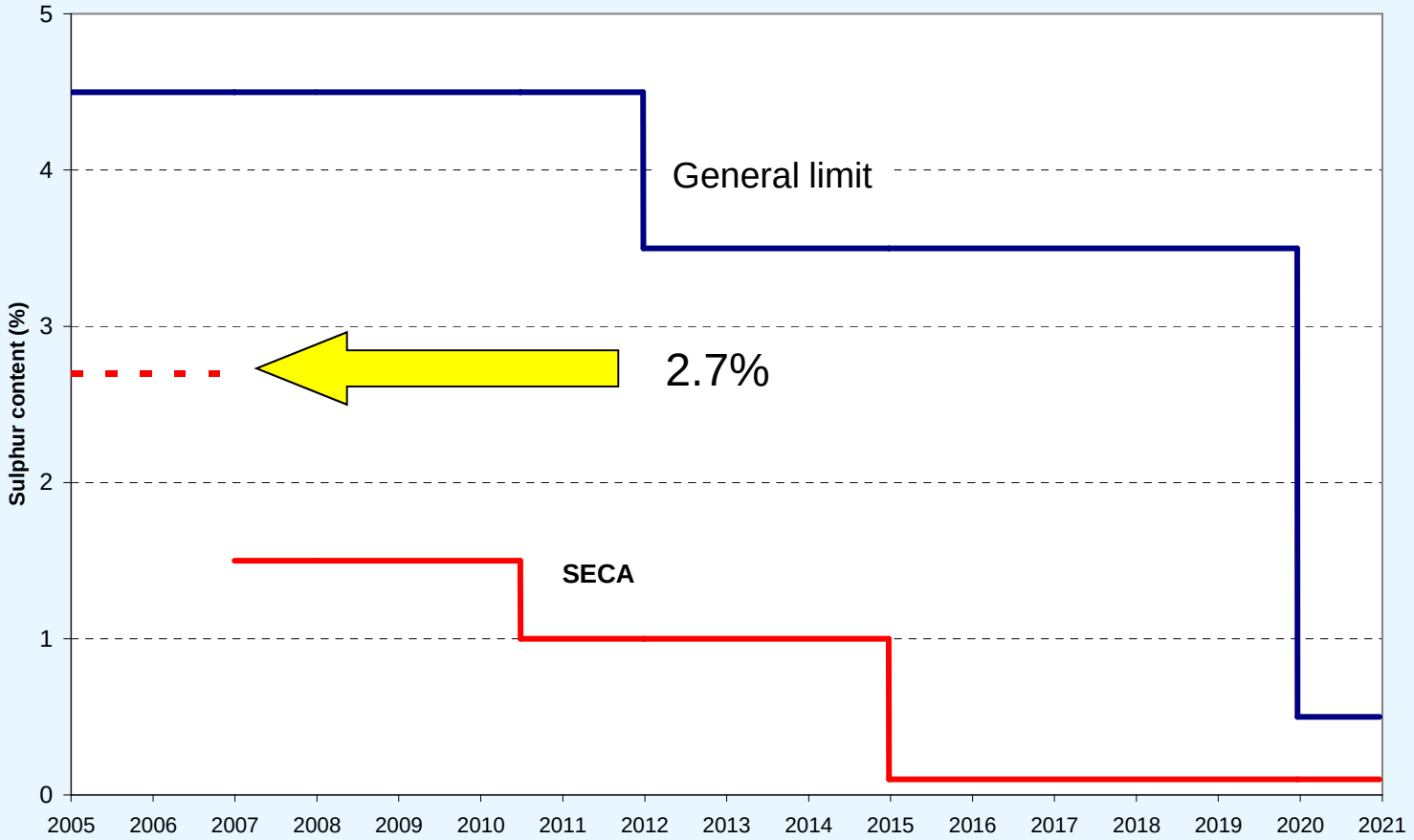
Limits to sulphur content in heavy fuel



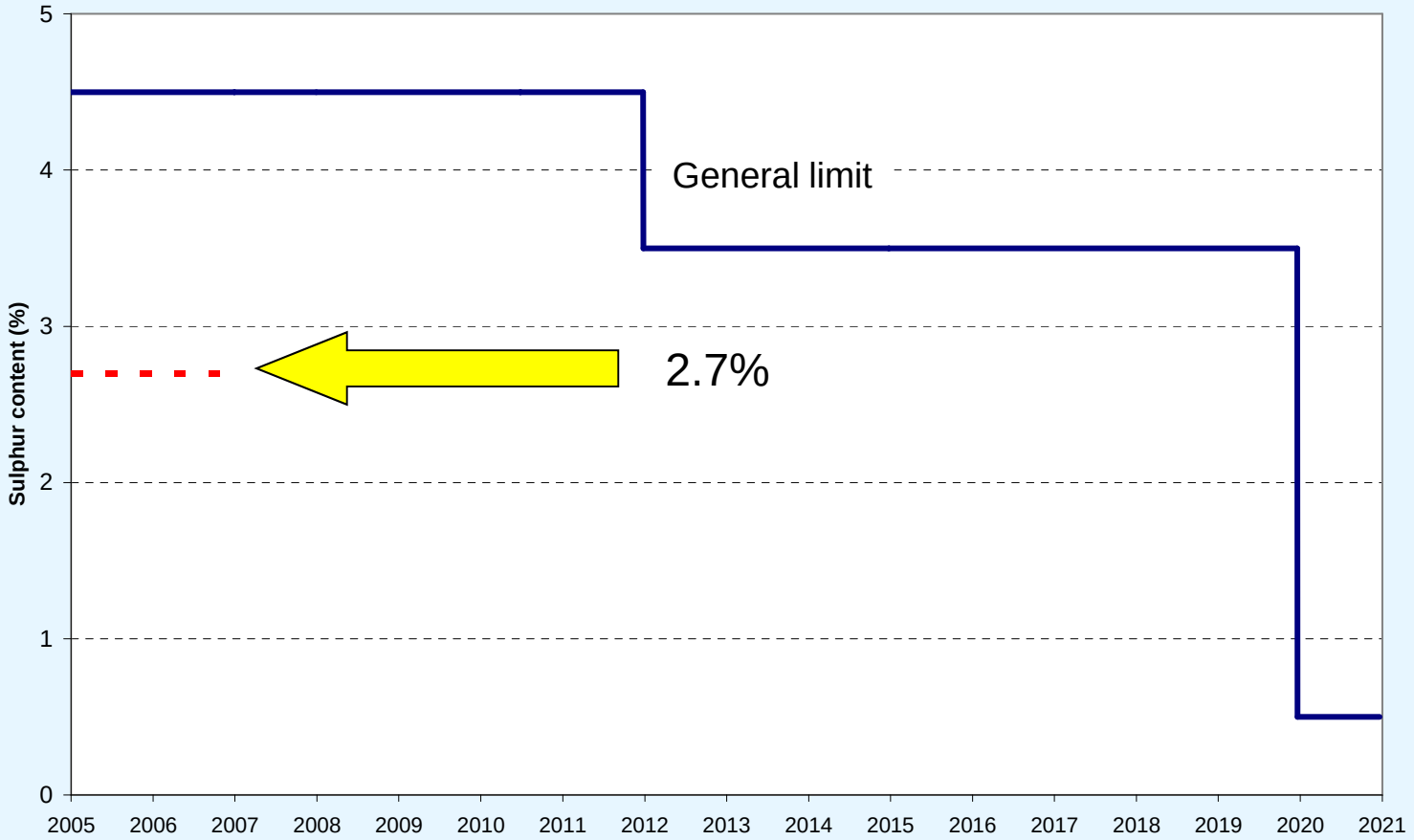
Limits to sulphur content in heavy fuel



Limits to sulphur content in heavy fuel

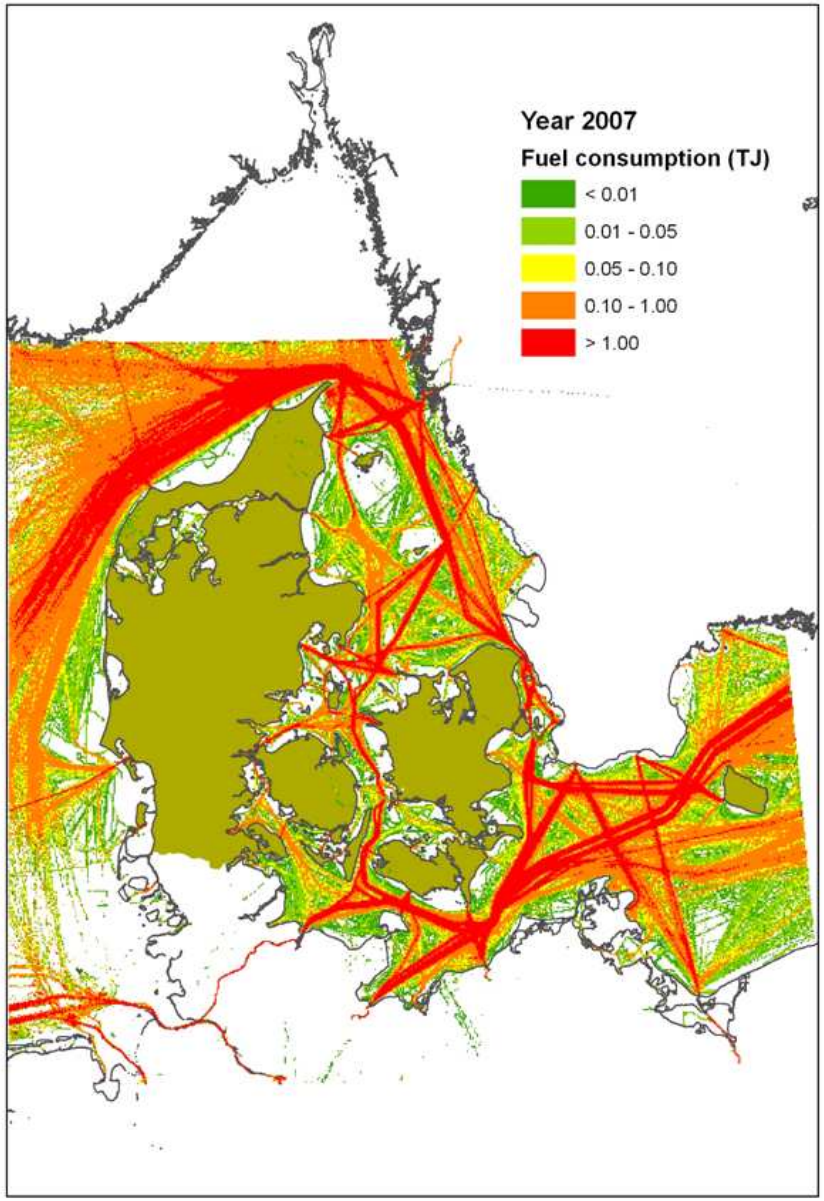


Limits to sulphur content in heavy fuel



Limits to NO_x emissions

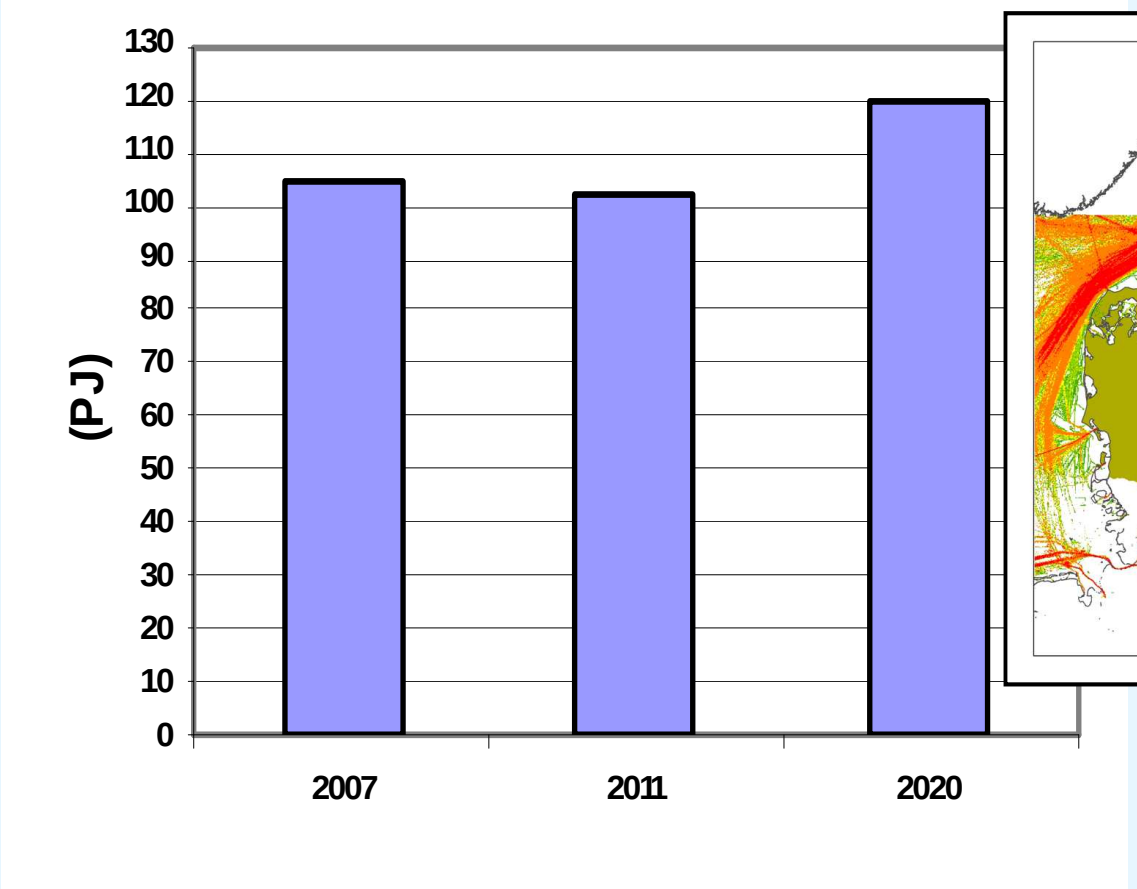
- **We have assumed MARPOL regulations to be effective.**
- **Further, assumed that a *Nitrogen Emission Control Area* (NECA) will be implemented in the Baltic Sea from 2016.**
- **For new ships from 2016 onwards, NO_x emissions are reduced by 80% compared to today.**



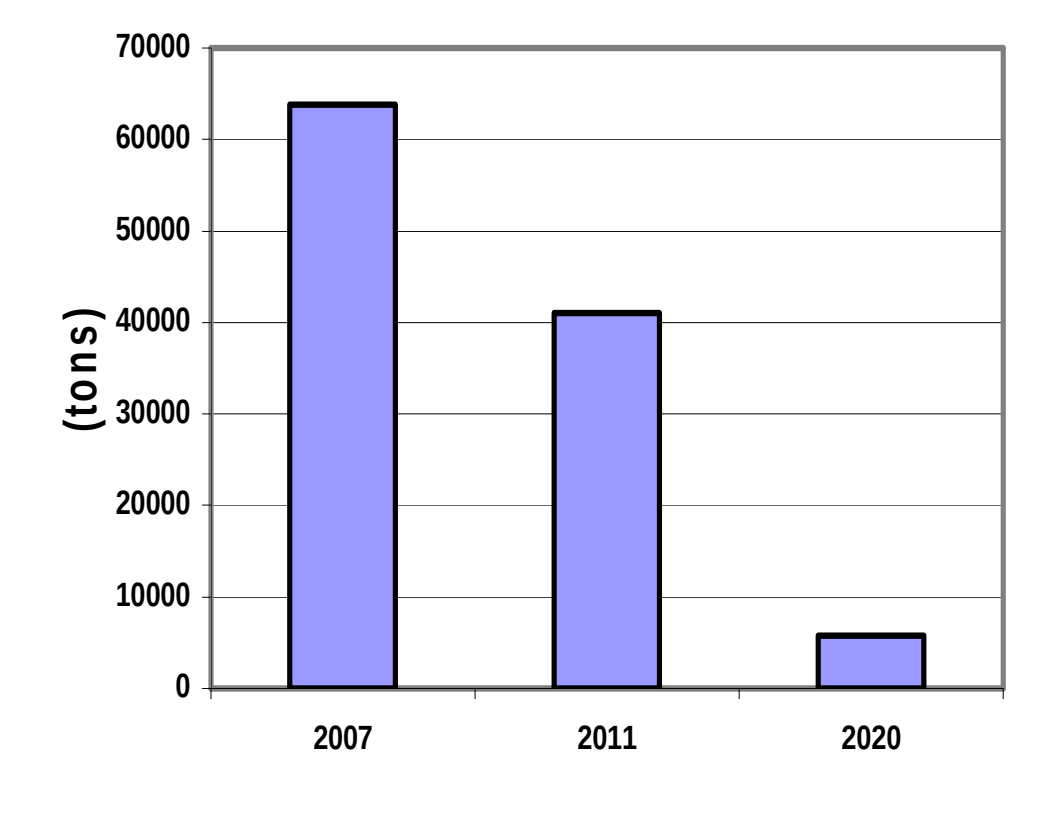
Area with detailed information

"The *AIS inventory area*"

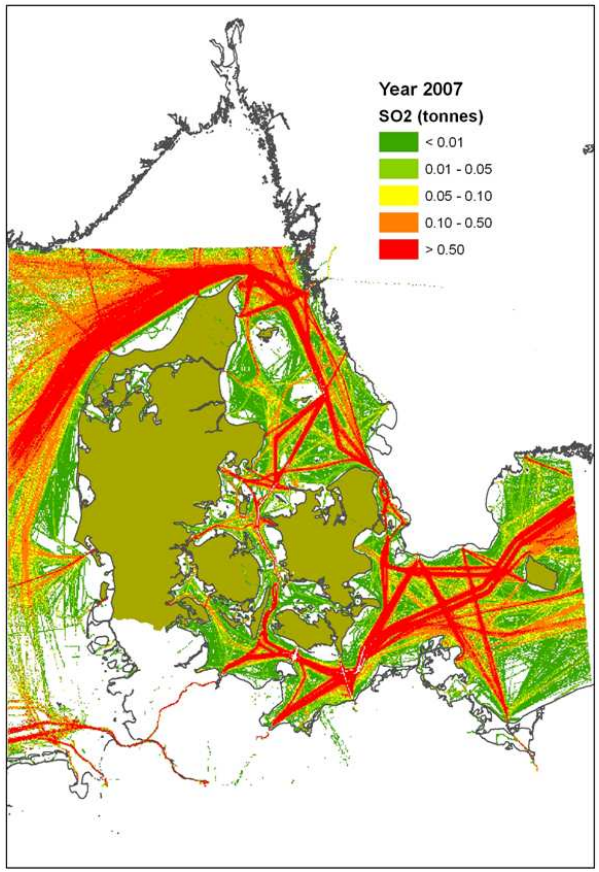
Energy consumption (in AIS inventory area)

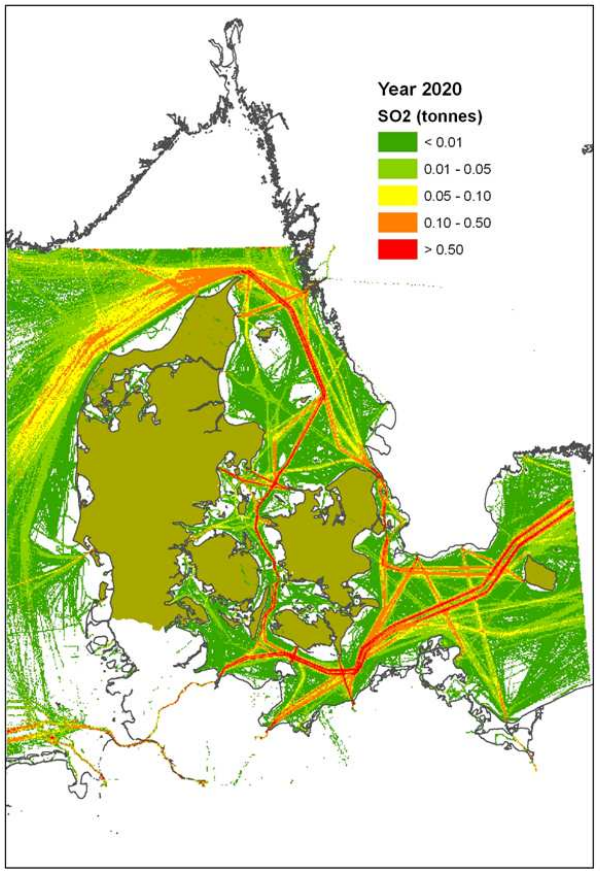


SO_2 emissions from ships in AIS inventory area

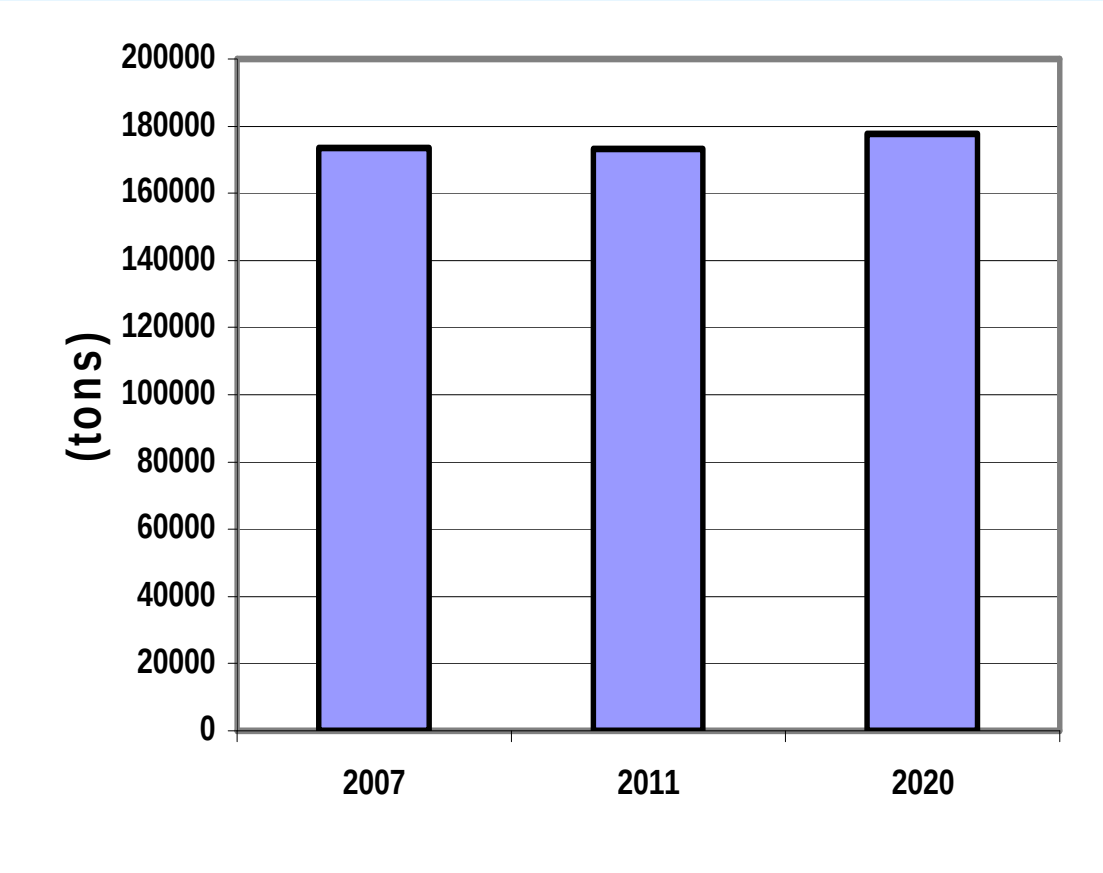


SO_2 ship emissions in 2007 and 2020

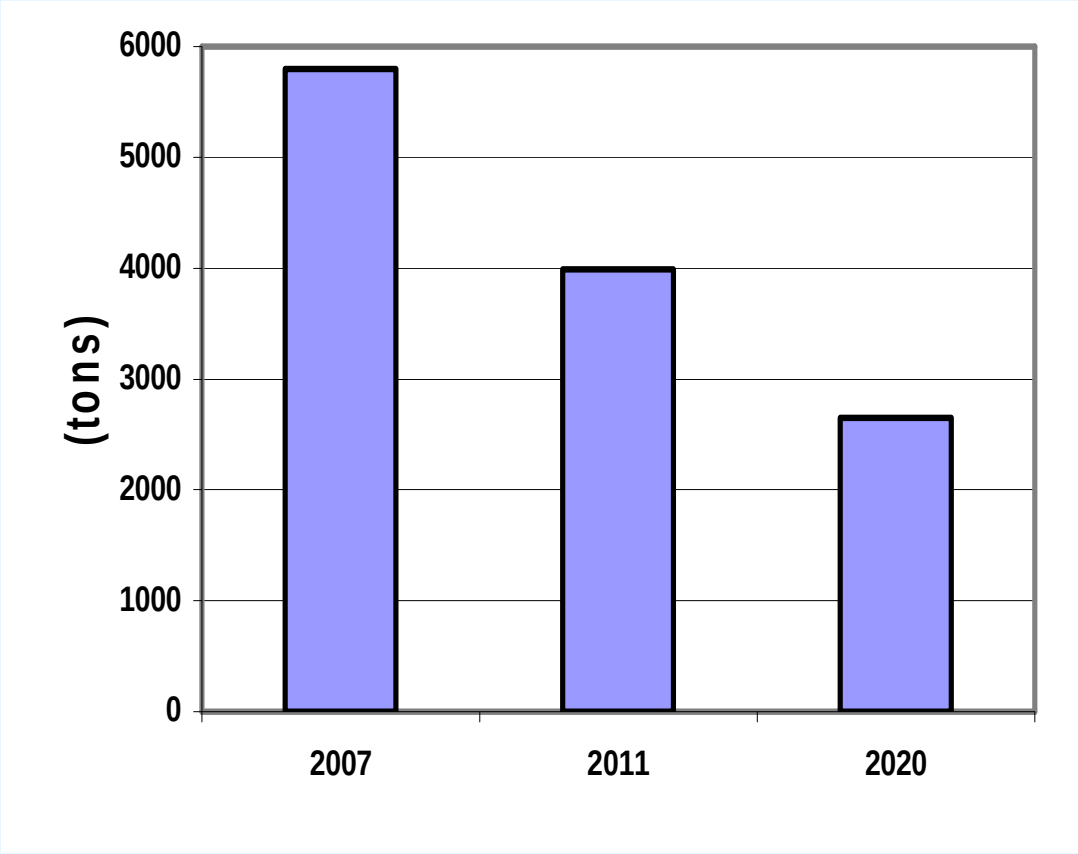




NO_x emissions from ships in AIS inventory area



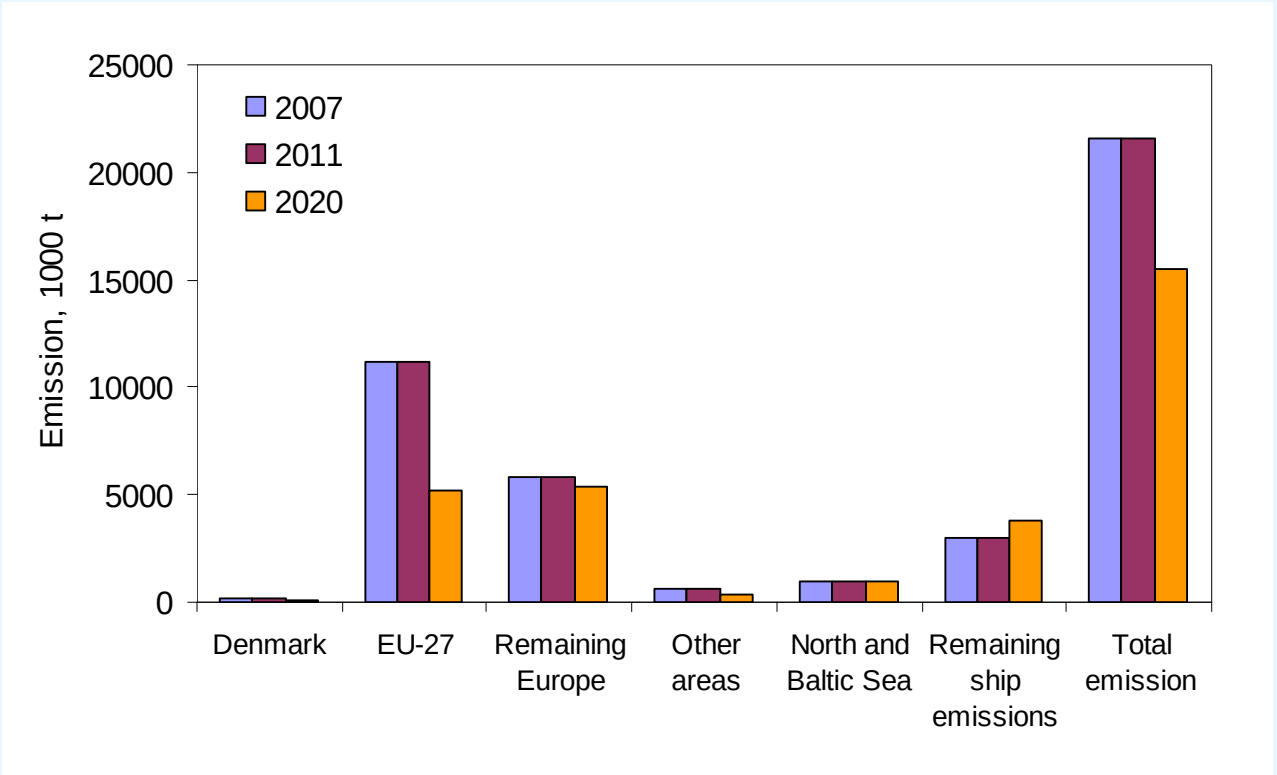
Emissions of primary $PM_{2.5}$ in AIS inventory area



Inventories of total emission (Ship + Land)

- **Two ship emission inventories are combined:**
  - **The detailed for the *AIS inventory area***
  - **a crude inventory for the waters outside of this area.**
- **Further, these inventories are combined with an inventory for land-based sources.**
- **Land-based European sources based on EMEP data from 2006.**
- **For 2020: Land-based sources based on a scenario set up by the International Institute for Applied System Analysis in Vienna ('Central case').**

NOx emissions, land and sea



Steps to estimate ship contribution

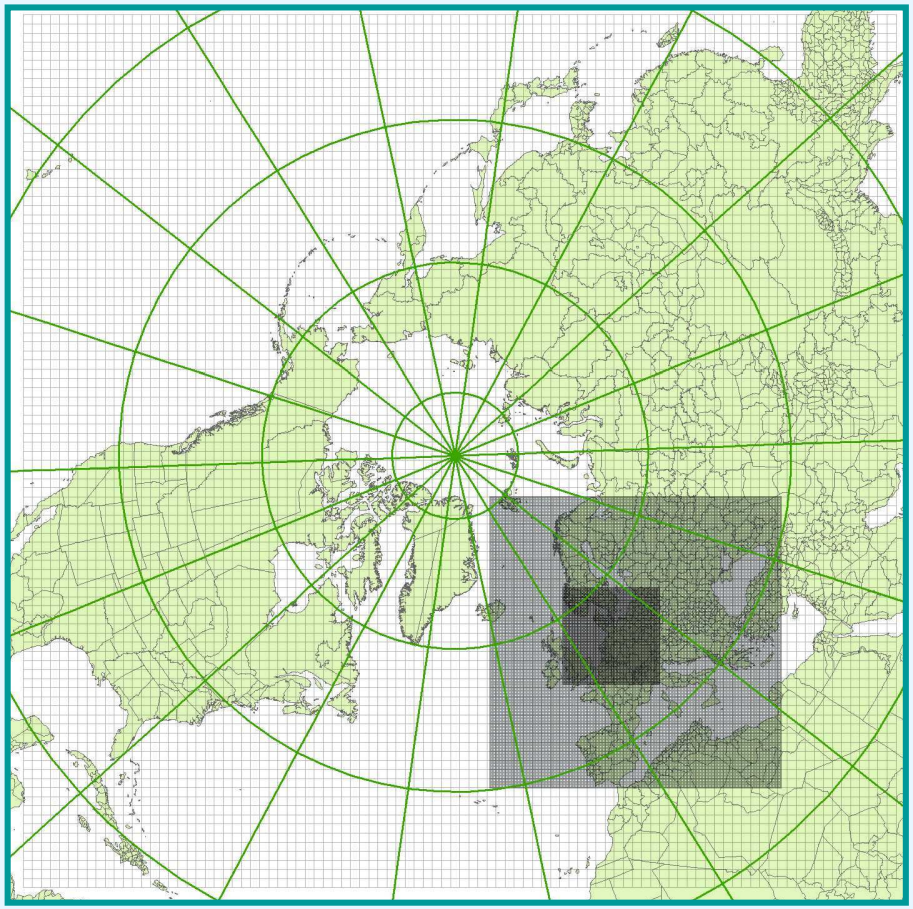
- **Compile an emission inventory**
- **Make calculations with an atmospheric dispersion model, accounting for conversion and transport of pollutants**
- **How much can be attributed to ships?**
  Estimated by comparing model runs with full ship emission and with reduced emission from ships.

Steps to estimate ship contribution

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

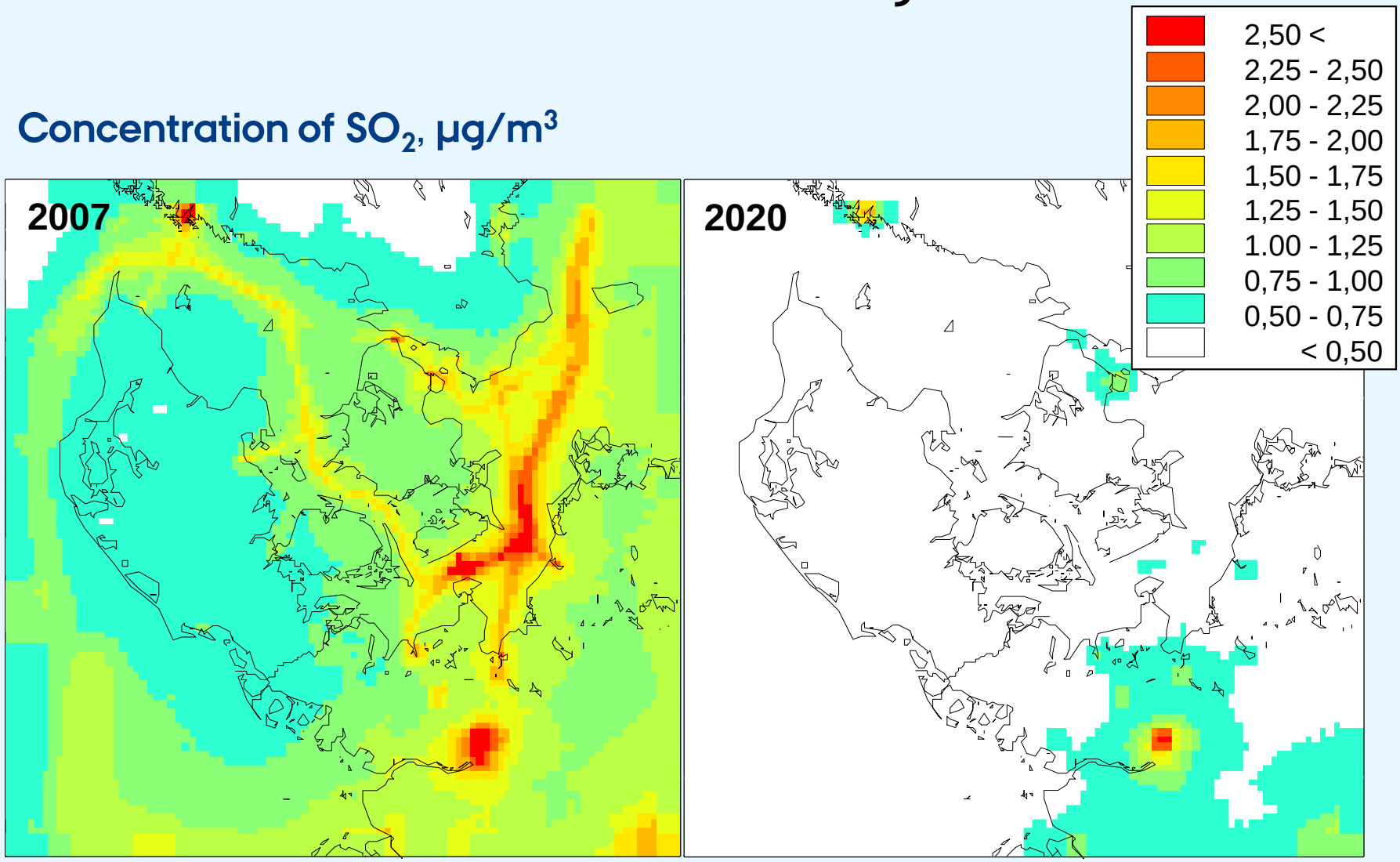
The Danish Eulerian Hemispheric Model (DEHM)

- 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

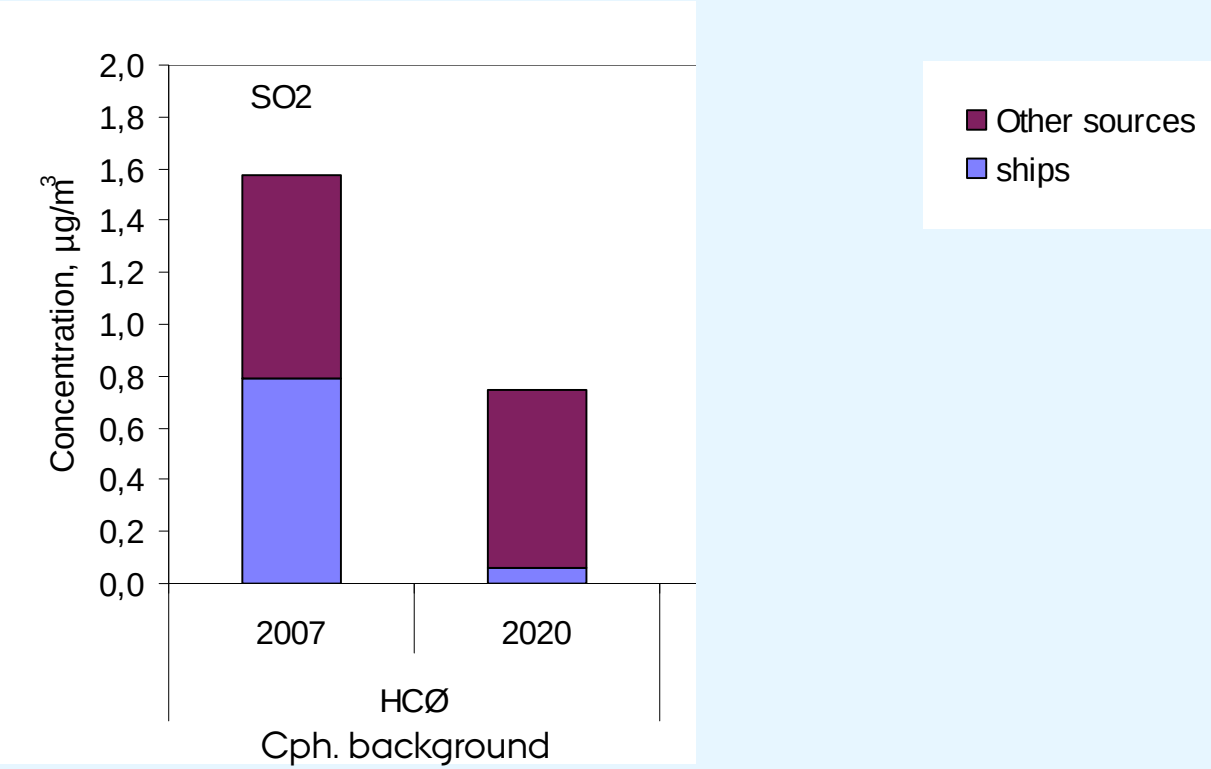


Model calculations for 2007 og 2020

Concentration of SO_2, µg/m^3



Concentration of SO_2: Levels in Copenhagen – urban background



Concentration of SO_2: Ship contribution – average over DK

- **In 2007: Ships are responsible for 37% of the SO_2 concentration load**
- **In 2020: Ships are responsible for 10%**

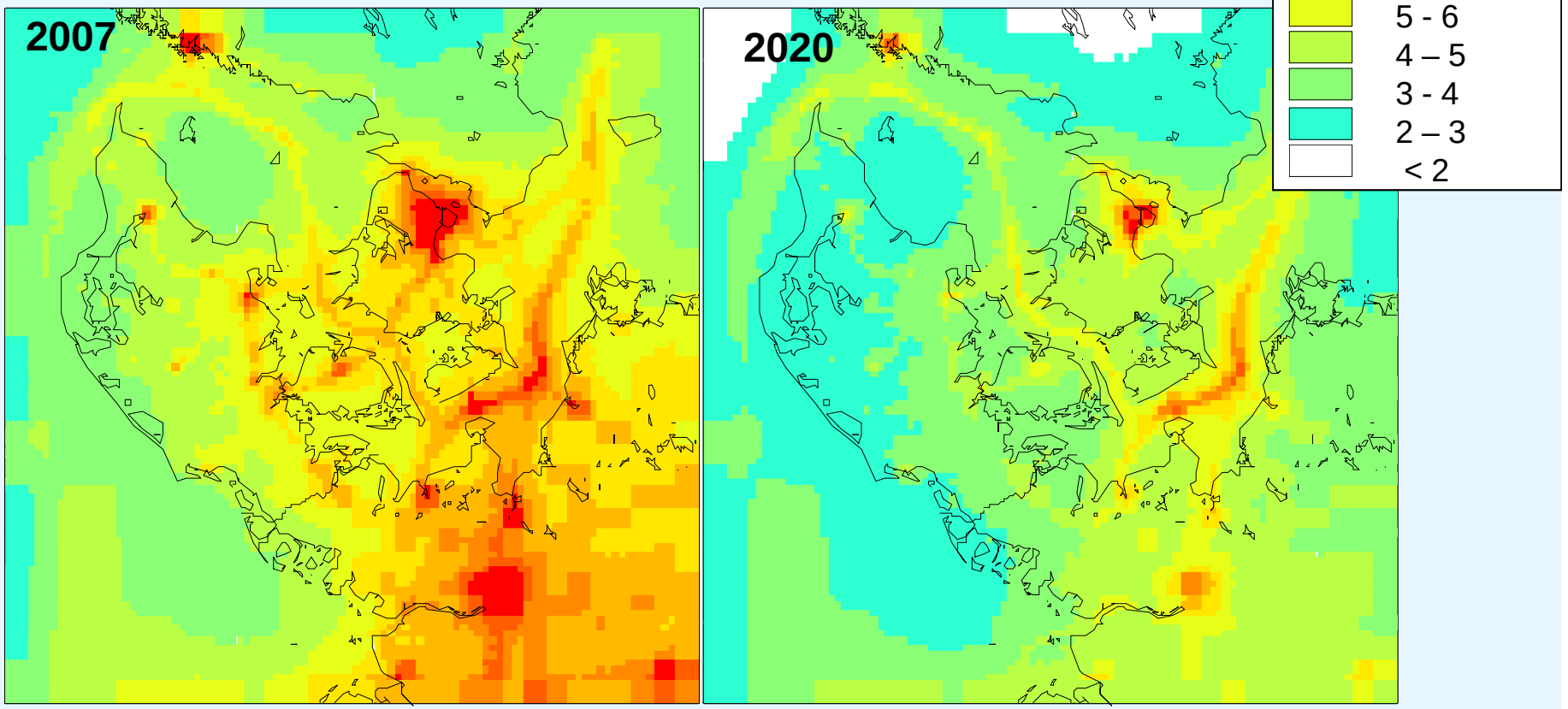
Nitrogen oxides

- **NO_x is the sum of NO and NO_2**
- **NO_2 is harmful to health**
- **NO can be transformed to NO_2 in chemical reactions. Some reactions are fast, others require many hours.**

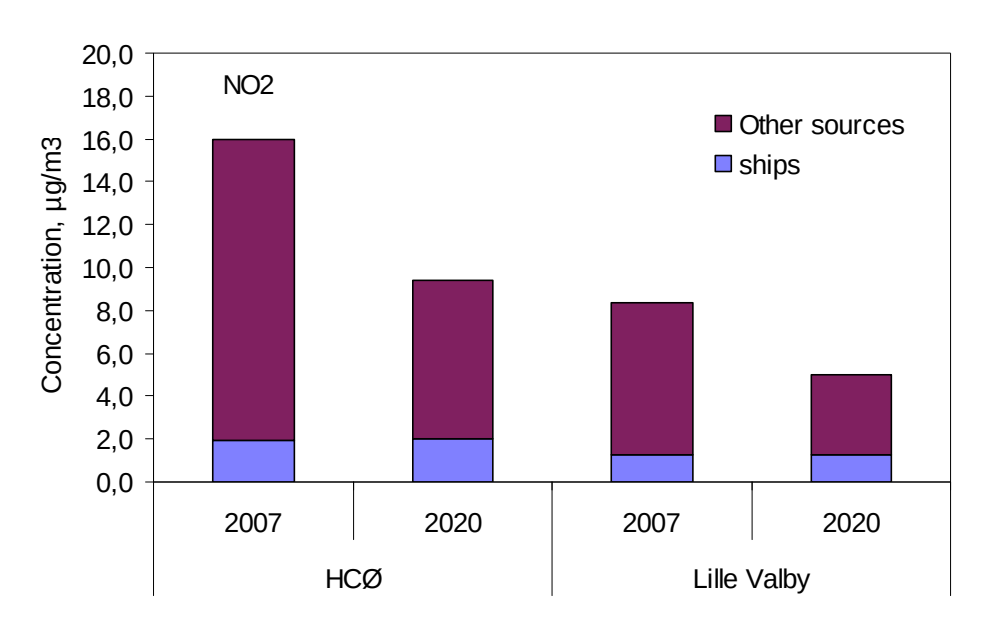
- **Thus, the NO_2 concentration level is of concern**
- **Further, NO and NO_2 contribute to formation of particles.**

Model calculations for 2007 og 2020

Concentration of NO_2, µg/m^3



Concentration of NO_2: Levels in Copenhagen and a rural area:

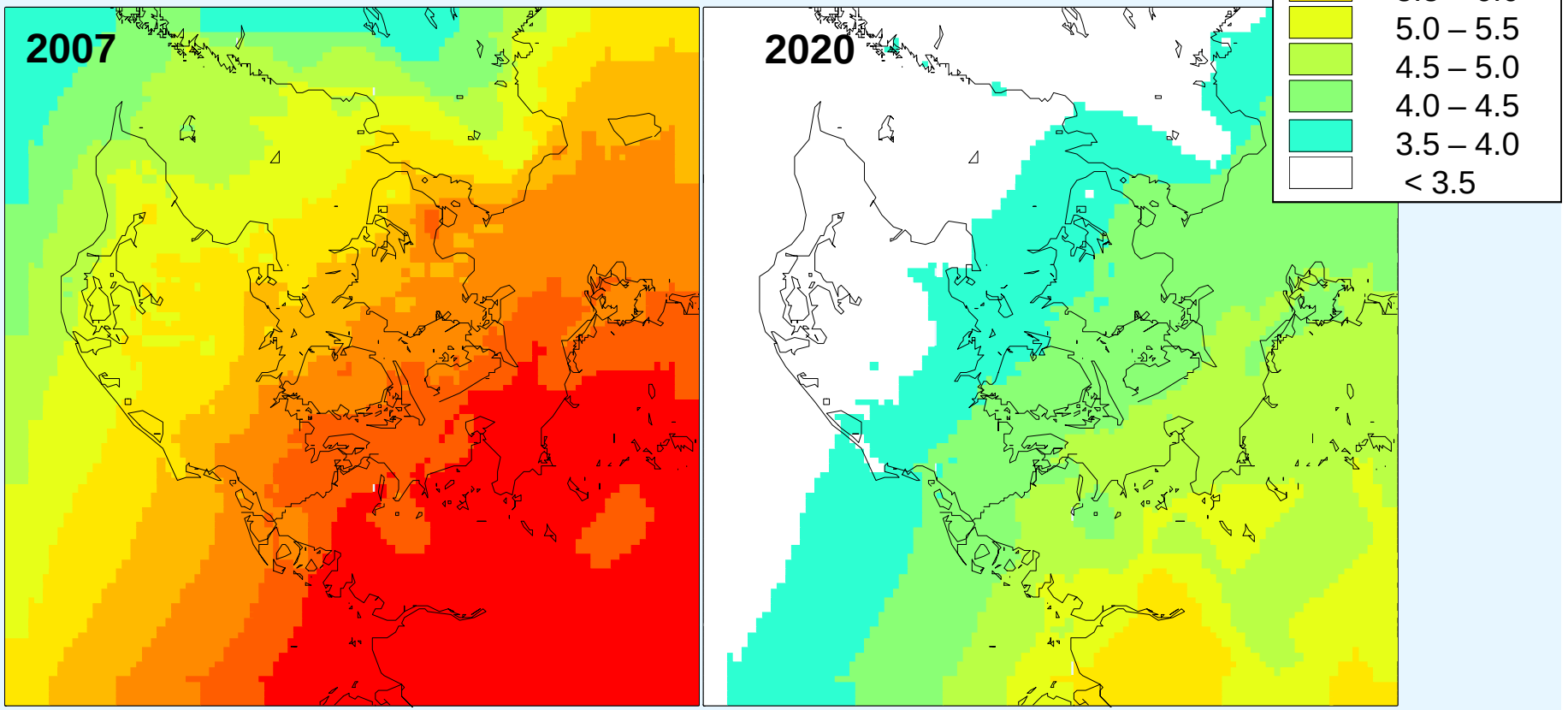


Particle pollution

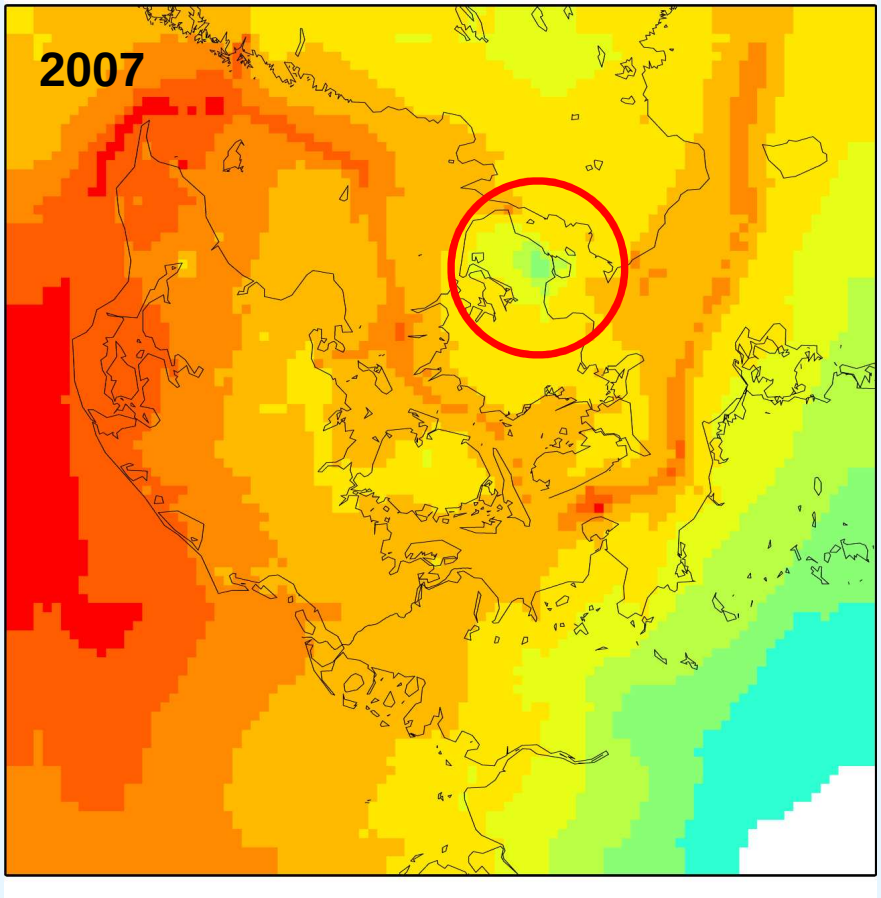
- When measuring particle pollution in the air, only a relatively small fraction of the particles have been 'borne' as particles. These are *'primary particles'.*
- Another large fraction have been created from gases. These are '*secondary particles'.*
- With the DEHM model we can describe
  - primary particles
  - secondary inorganic particles
  - - but not secondary *organic* particles
- The particles accounted for are referred to as modelled $PM_{2.5}$ ($mPM_{2.5}$)

Model calculations for 2007 og 2020

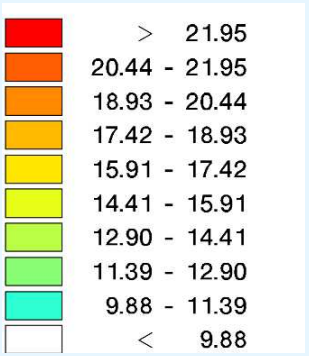
Concentration of $mPM_{2.5}$, µg/m³ ($mPM_{2.5}$: modelled $PM_{2.5}$)



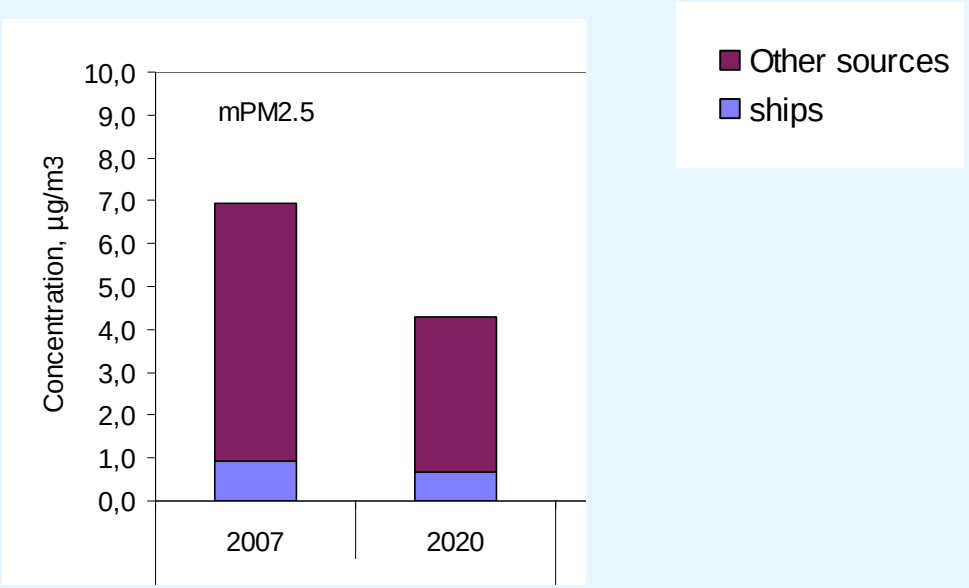
Ship contribution to modelled $PM_{2.5}$ (percent)



Unit: percent

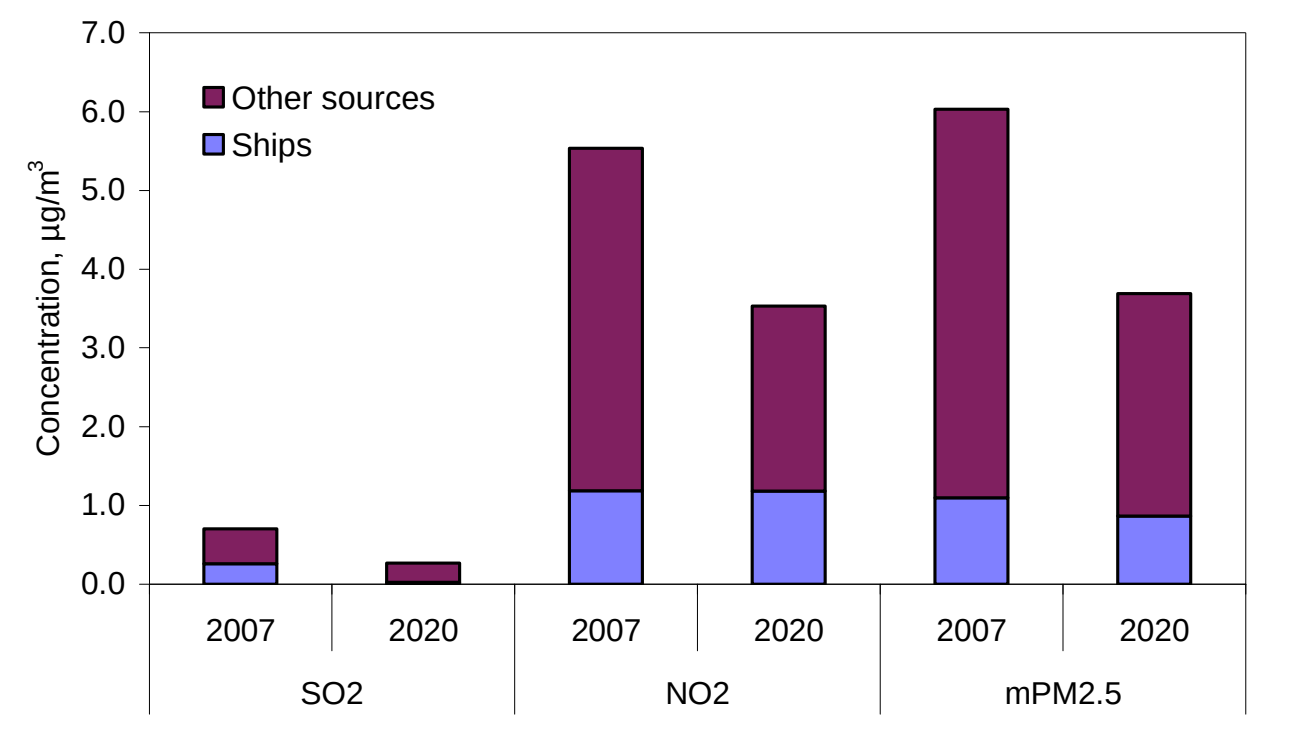


Concentration levels in Copenhagen: $mPM_{2.5}$ (modelled $PM_{2.5}$)

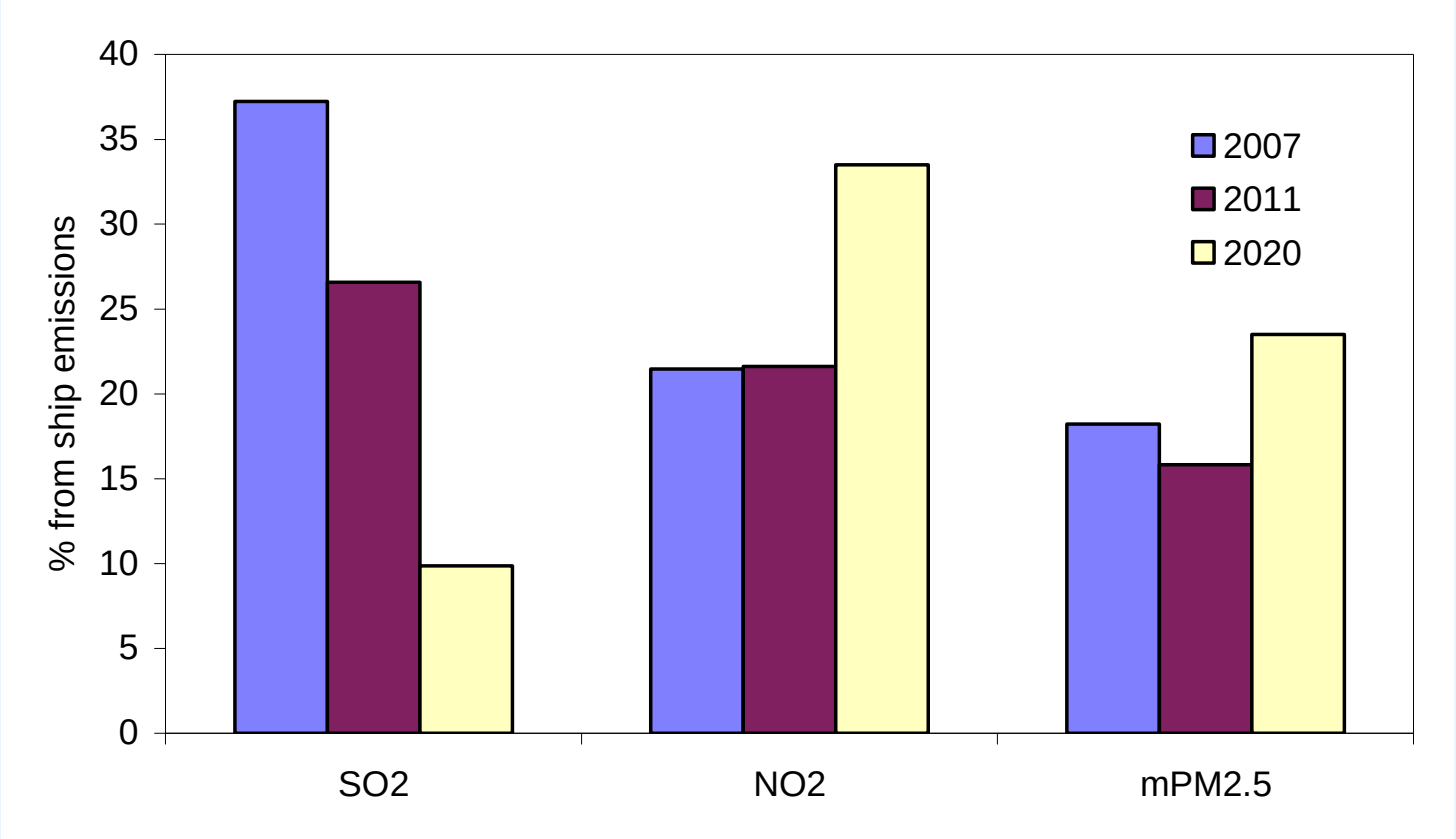


Copenhagen, background level

Concentration levels now and in 2020 – average over Danish land areas



Percent-wise contribution from ships to concentration levels (average over DK)



Conclusions (1 of 3)

- **A new, better emission inventory has been established. Use of AIS data is recommended for similar inventories in future.**
- **The 2020 scenario shows a major effect of IMO regulations concerning sulphur. The regulations lead to a large decrease in SO_2 concentrations.**

Conclusions (2 of 3)

- **Emission regulations for NO_x are not able to fully outbalance the expected increase in ship traffic in the period until 2020.**
- **As a consequence, the contribution from ships to NO_2 concentrations will remain almost unchanged in absolute terms.**
- **In relative terms the contribution from ships to NO_2 is expected to increase in the period.**

Conclusions (3 of 3)

- **For fine particles ($PM_{2.5}$), keep in mind that a large share of $PM_{2.5}$ is secondary particles. This means that $PM_{2.5}$ concentrations are not only affected by sulphur emission, but also by NO_x emission.**
- **In absolute terms, the contribution from ships to $PM_{2.5}$ concentrations will decrease slightly towards 2020.**
  In relative terms the contribution from ships is expected to increase in the period.