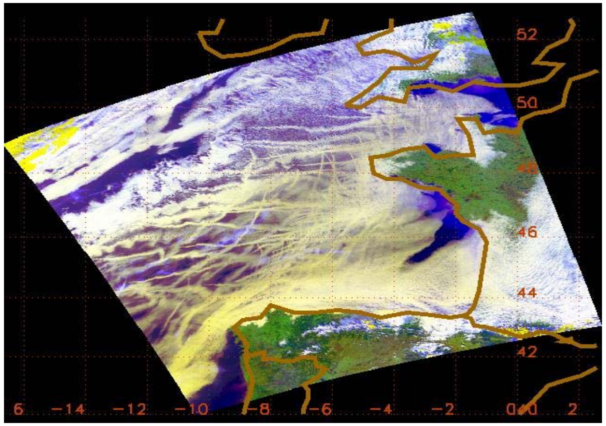
Emissions from shipping, air pollution and climate

Jana Moldanová

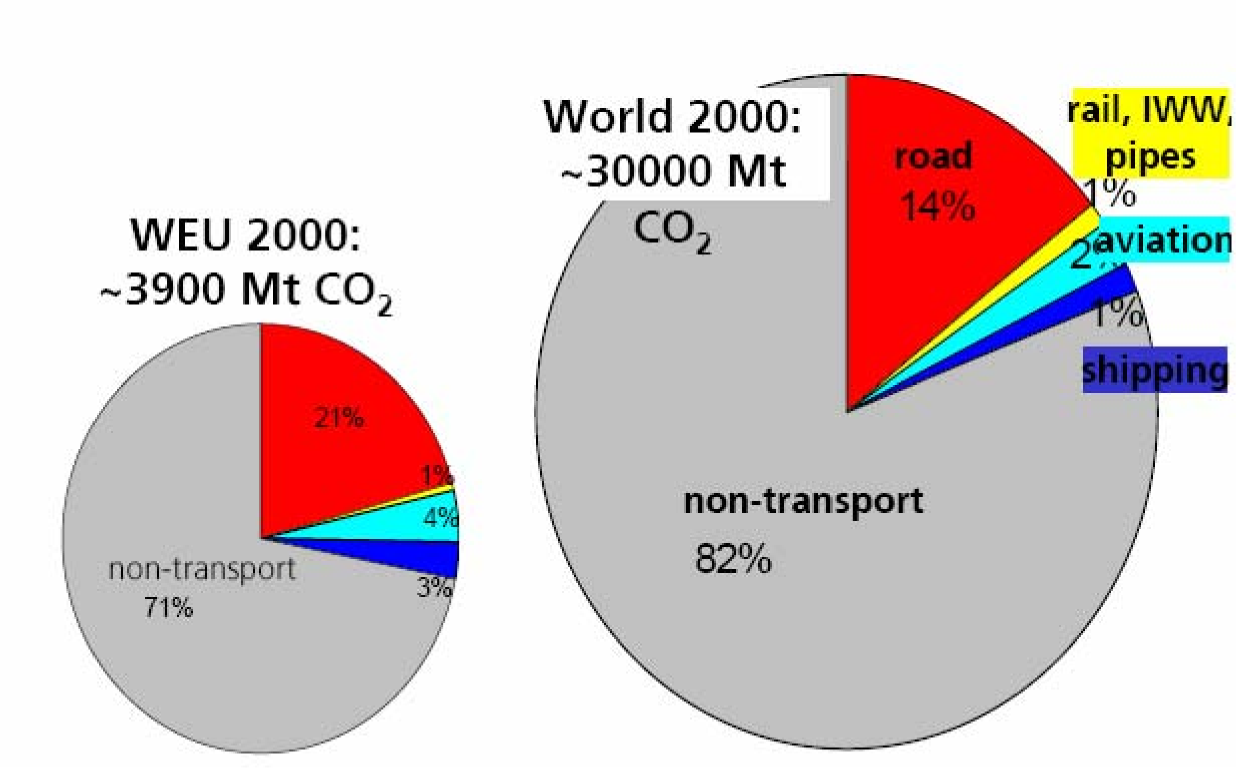
Swedish Environmental Research Institute

- Emissions from shipping and their effects on global, regional and local perspective
- Characterisation of ship emissions, plume processes



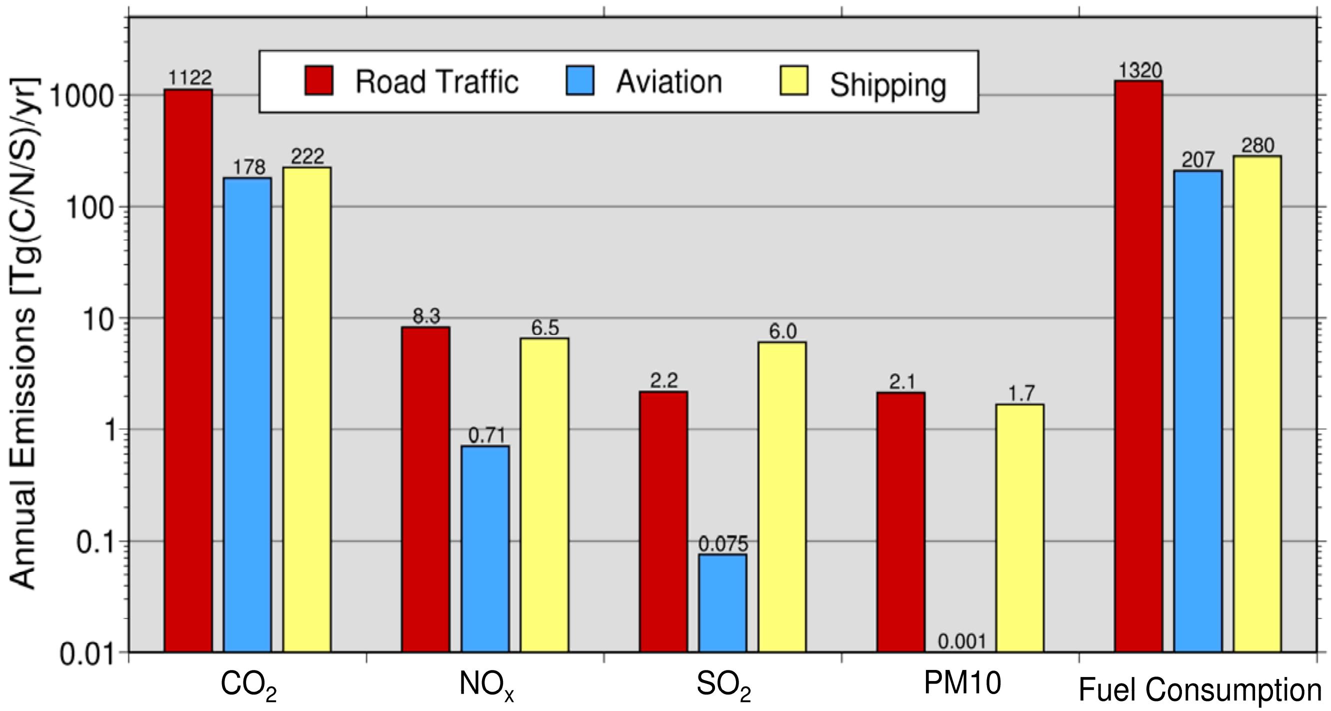
Ship tracks over the Gulf of Biscay (colour composition from AVHRR on 27 January 2003).

Share of CO_2-emissions from shipping and other transport sectors



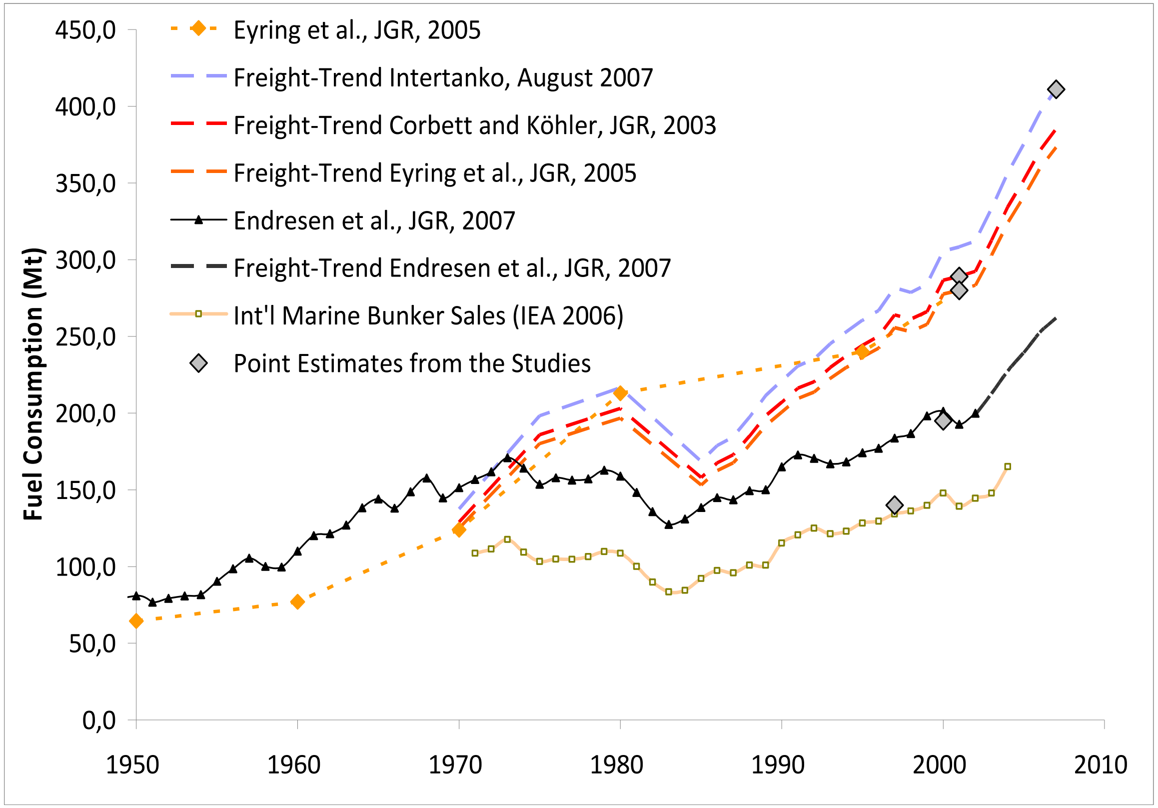
- Shipping moves **80-90% of world trade** by volume

- Emissions from seagoing ships contribute significantly to the total emissions from the transportation sector
- Key compounds emitted are carbon dioxide (CO_2), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOC), sulphur dioxide (SO_2), black carbon (BC) and particulate organic matter (POM)

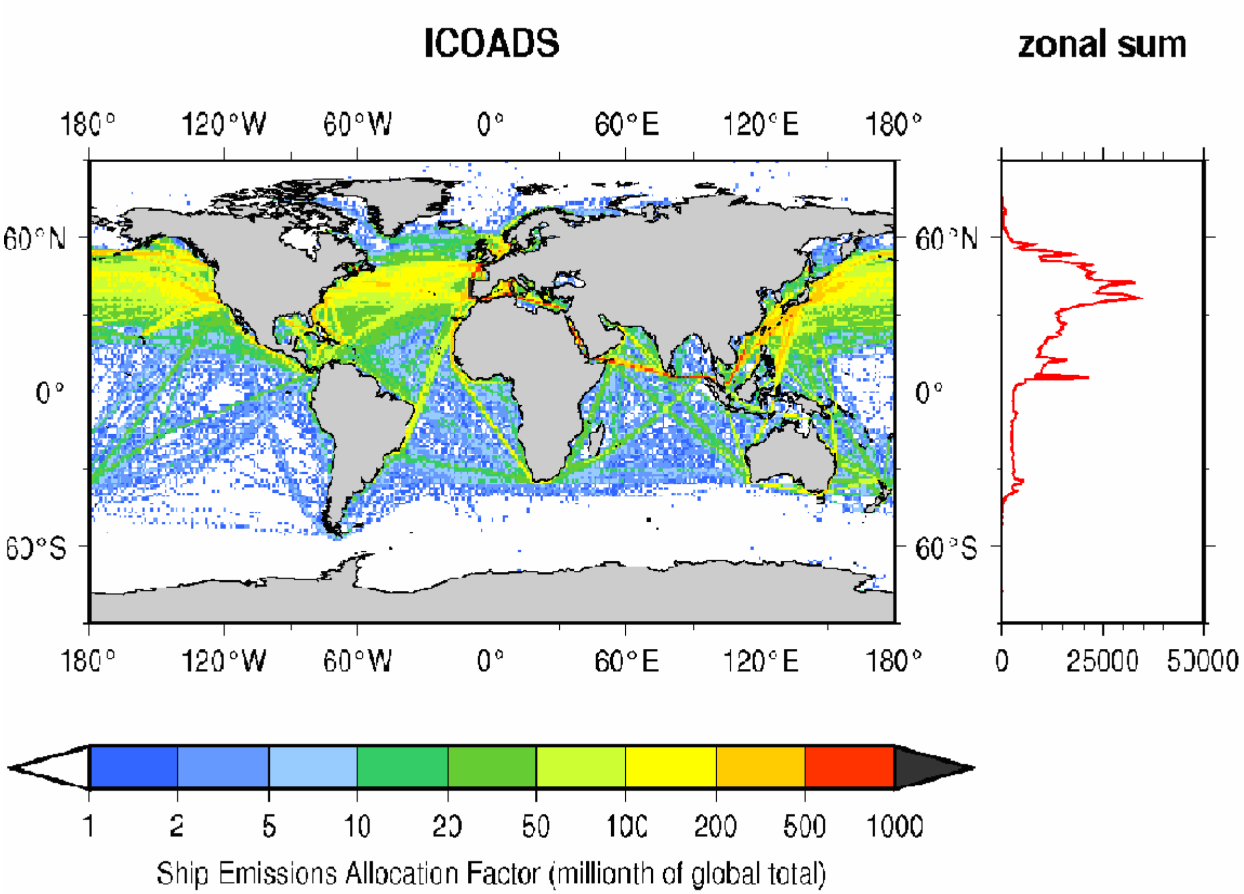


Transport-related annual emissions of CO2 in Tg (C), NOx in Tg (N), SO2 in Tg (S) and PM10 in Tg (PM) and the fuel consumption in Mt estimated for the year 2000 (from *Eyring et al.*, 2005a)

- Around 15% of all global anthropogenic NO_x emissions and 4-9% of SO_2 emissions attributable to ships.
- Uncertainties - ocean-going ships consumed between 200 and 290 million metric tons (Mt) fuel and emitted around 600 to 900 Tg CO_2 in 2000

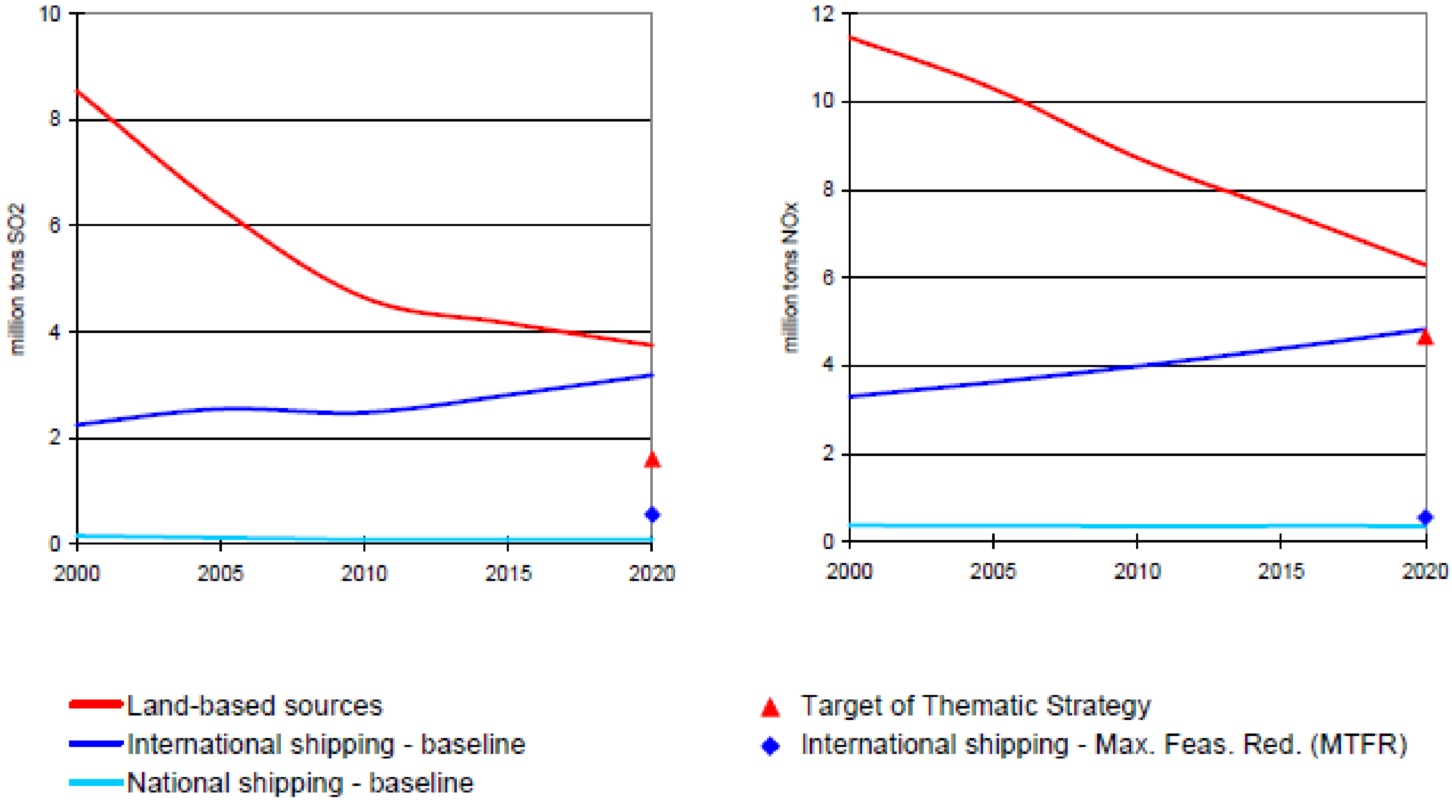


- The global emission totals are distributed over the globe using using data on ship movement frequencies, usually 1° longitude x 1° degree latitude



(*Eyring et al., 2009*)

Emissions from shipping on seas surrounding Europe



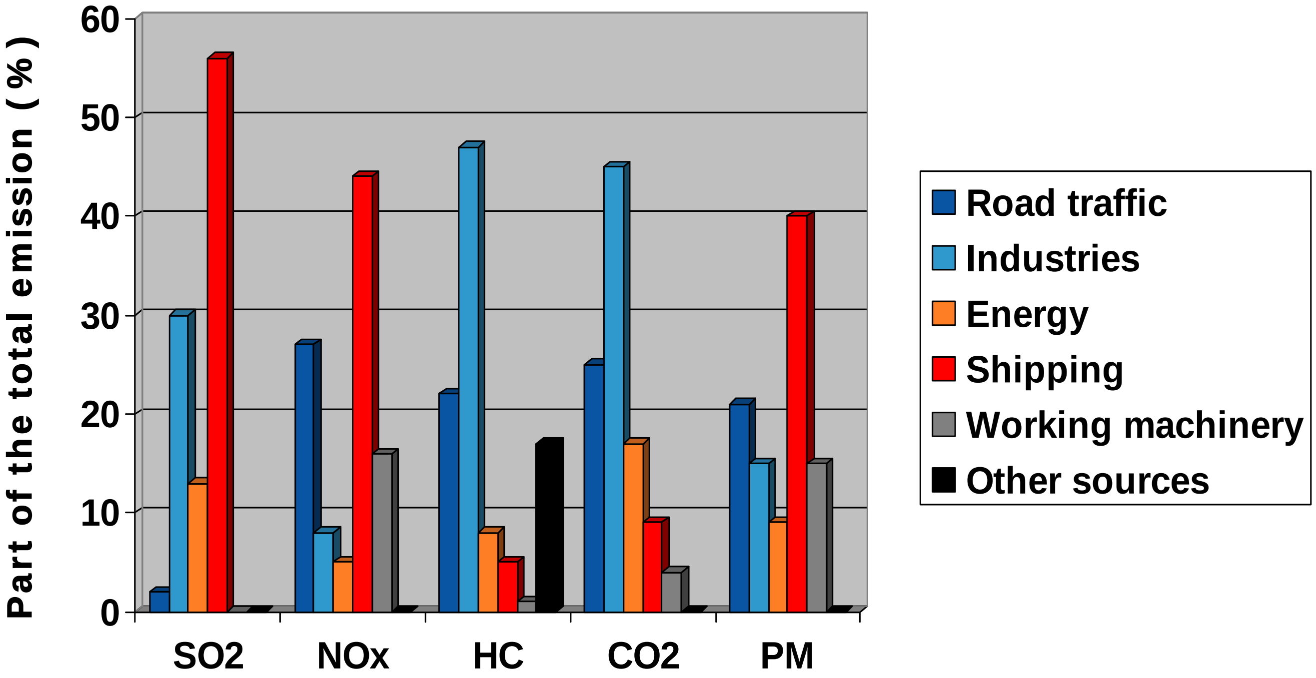
Emissions of SO_2 (left panel) and NOx (right panel) from shipping (baseline scenario) compared with the emissions from land-based sources in the EU25, million tons (From Cofala et al., 2007).

International Maritime Organisation (IMO) regulation of ship emissions

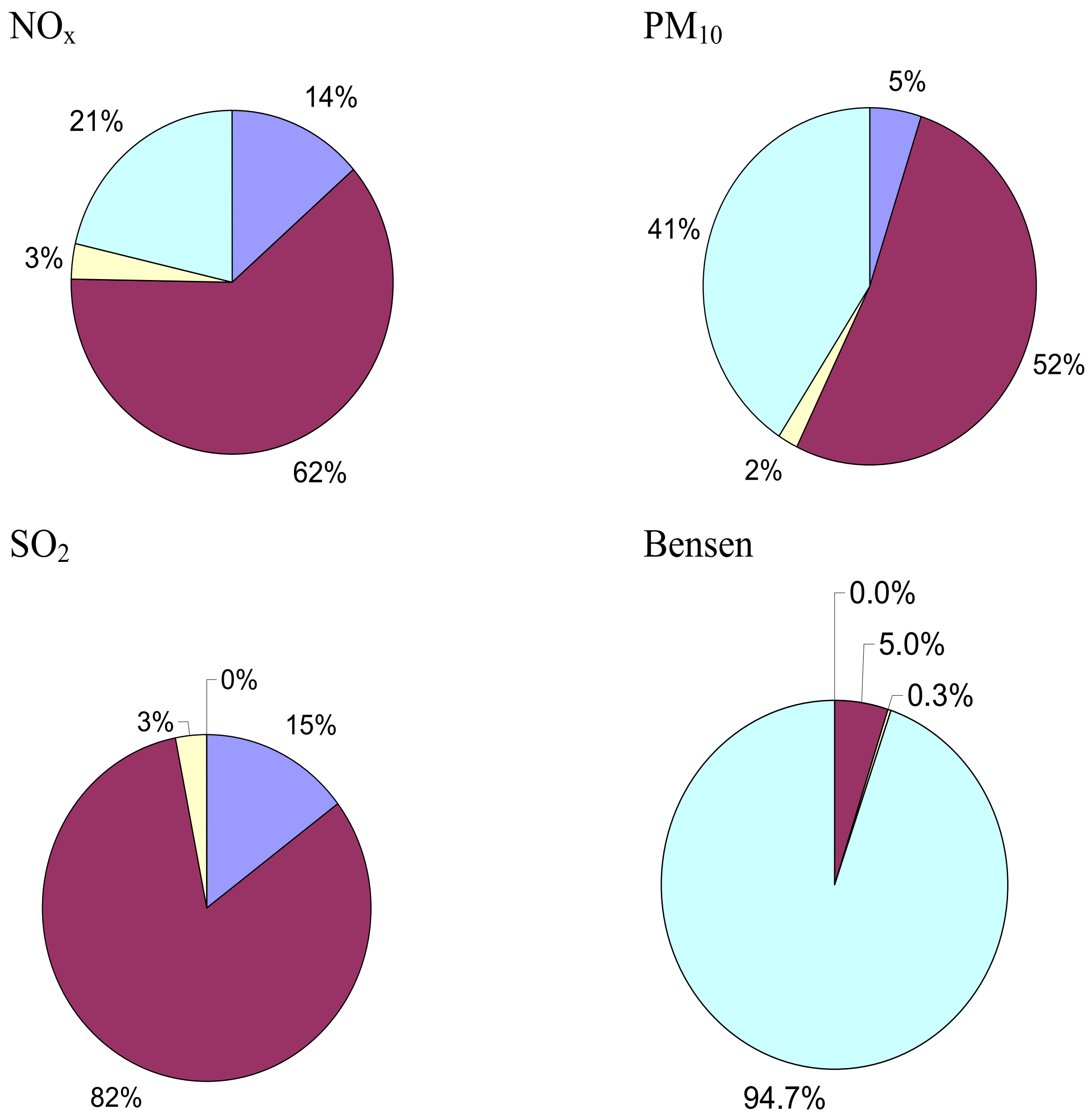
- 2008 - Marine Environmental Protection Committee (MEPC) of International Maritime Organisation (IMO)
  – Sulphur content in fuel globally under 0.5% from 2020 (the average today is around 2.7%)
  – In special Emission Control Areas (ECA) sulphur content will be reduced from today's 1.5% to 0.1% in 2015
  – ECAs: Baltic Sea entered into force in May 2006, North Sea and English Channel in August – November 2007 further are developing around the world
  – reduction of NOx emissions from new-installed engins from 2016

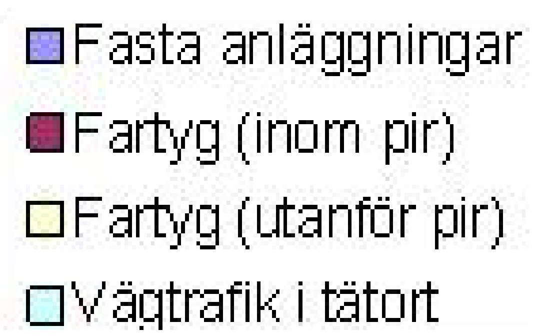
Local-scale emissions

Emissions to air in Göteborg – large contribution to SO_2, NO_X and PM from shipping



Emissioner i Ystad kommun

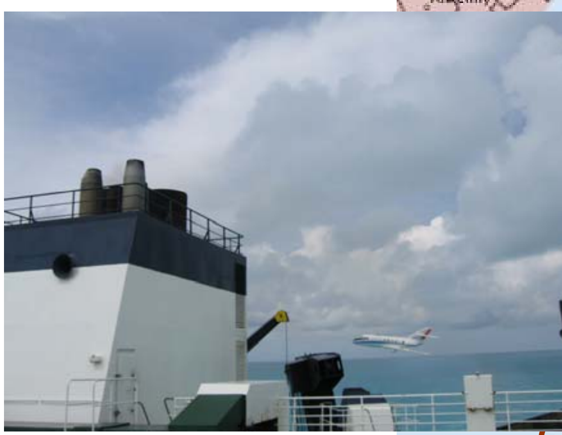




QUANTIFY

PM characterisation

Measurements onboard of Atlantic Conveyor 13-15/6 between Liverpool and Antwerp



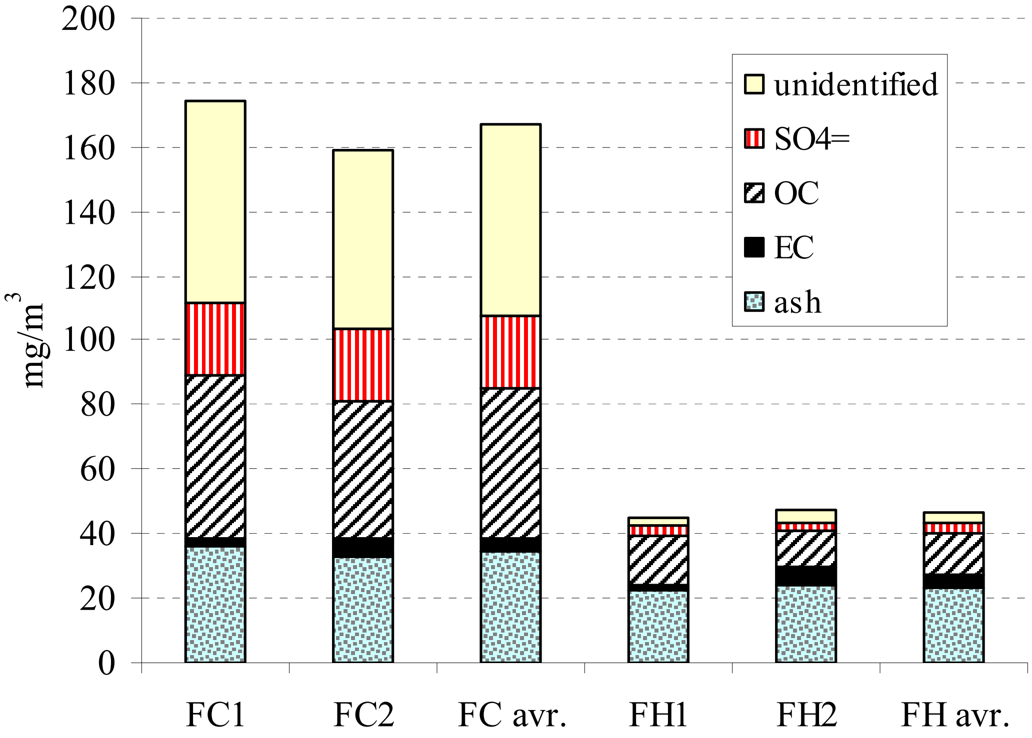
IVL Swedish Environmental Research Institute

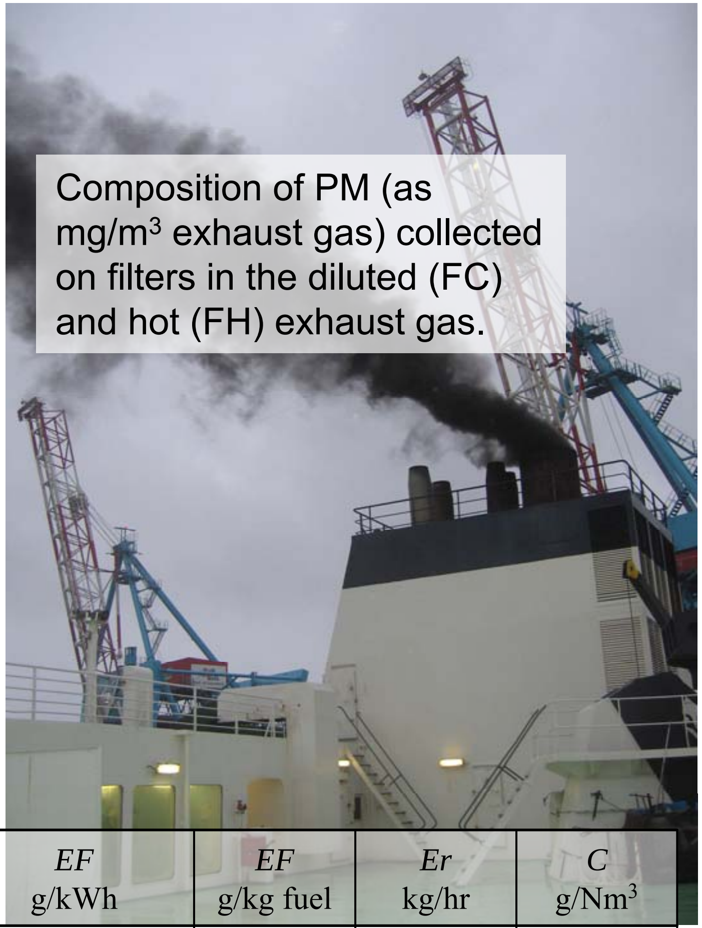
Emission factors *EF*, emission rates *Er* and concentrations *C* in exhaust from the main diesel engine operating under conditions as listed in Table 2 (84% power load) and using the HFO with composition given in Table 3. Concentrations are given at normalized conditions (273.14 K, 1013.25 hPa).

Exhaust component	*EF* g/kWh	***EF* g/kg fuel**	*Er* kg/hr	*C* g/Nm^3
NO_x	14.22	**73.4**	241.7	2.20
CO_2	667	**3 441**	11 339	103.1
CO	0.42	**2.17**	7.1	0.065
HC	0.07	**0.36**	1.2	0.011
O_2	1270	**6 553**	21 590	196.3
SO_2	7.62	**39.32**	129.5	1.18
SO_3	0.11	**0.57**	1.9	0.017
Benzene	0.012	**0.06**	0.21	0.002
PM	0.29	**1.49**	4.86	0.044
PM*	1.03	**5.31**	17.43	0.158
OC*	0.30	**1.58**	5.15	0.047
EC†	0.02	**0.13**	0.42	0.004
Ash†	0.19	**0.98**	3.19	0.029
Sulphate*	0.15	**0.76**	2.47	0.022

*after cooling in the dilution system
†average hot exhaust and diluted exhaust

Emissions from shipping – particulate matter

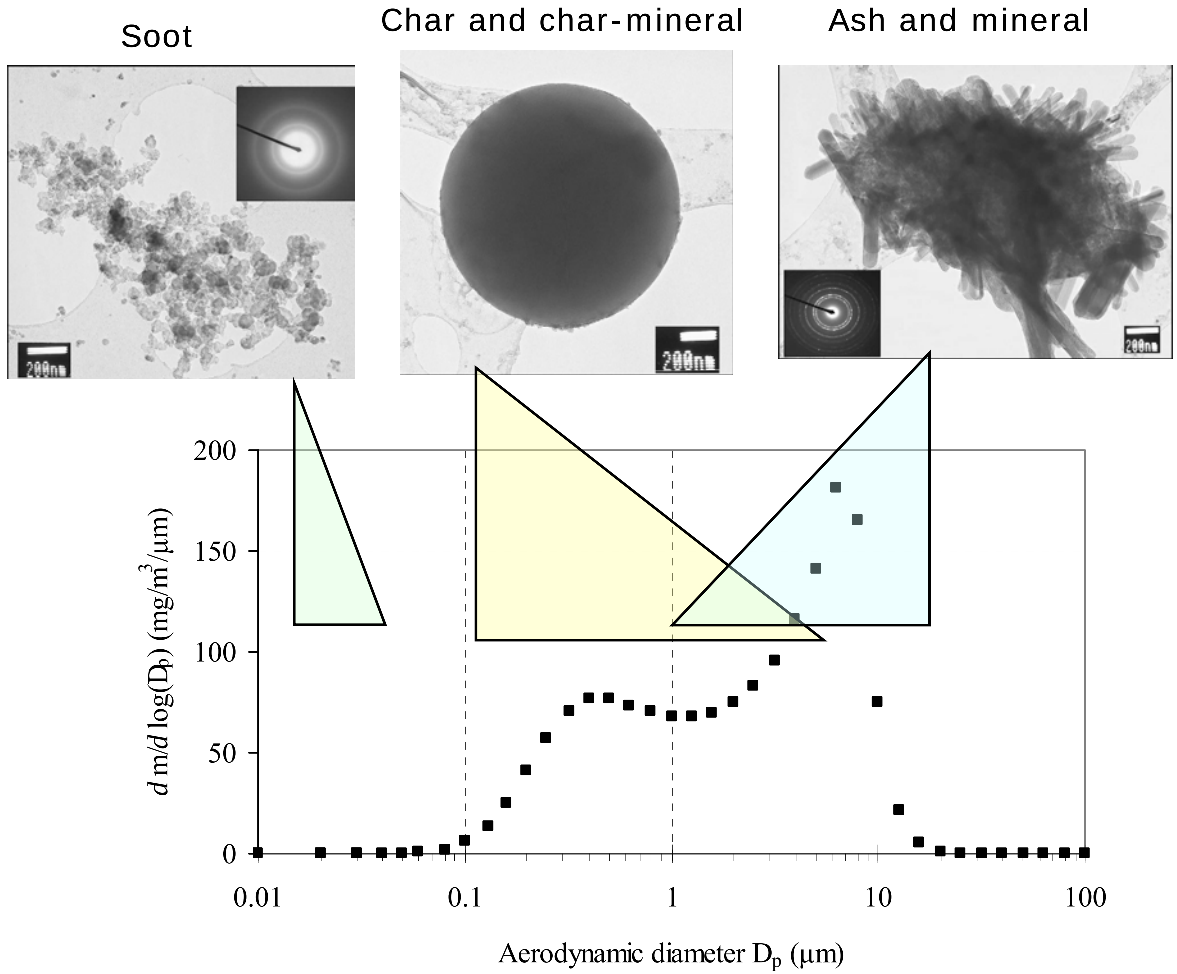




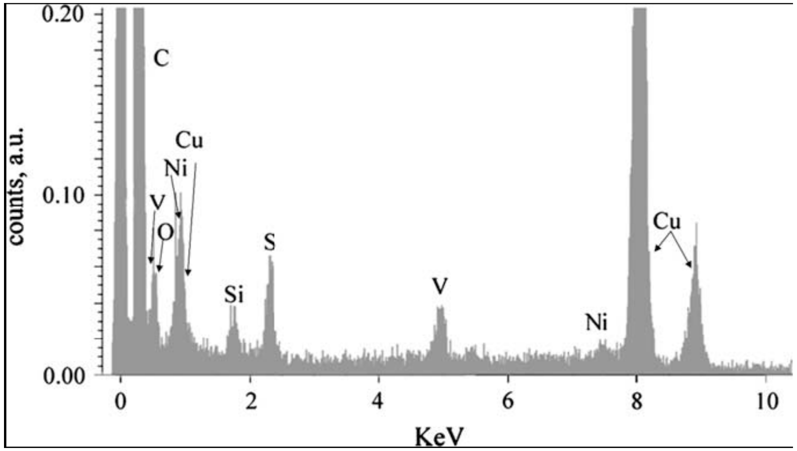
Composition of PM (as mg/m³ exhaust gas) collected on filters in the diluted (FC) and hot (FH) exhaust gas.

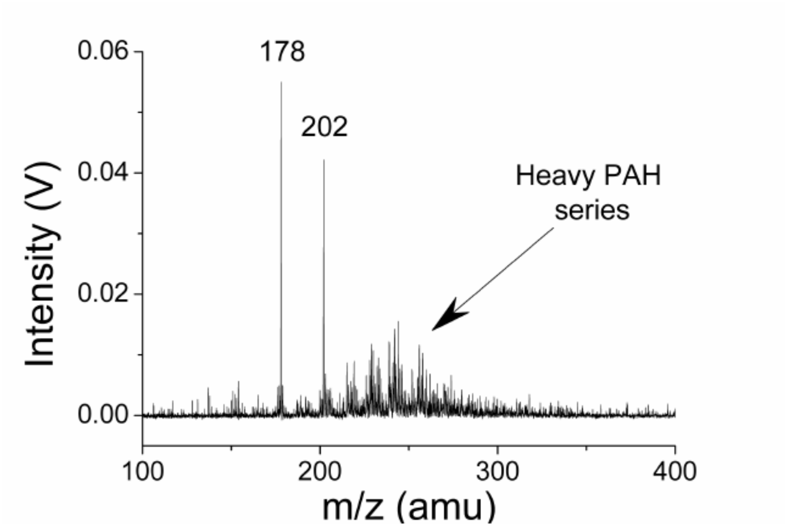
Exhaust component	*EF* g/kWh	*EF* g/kg fuel	*Er* kg/hr	*C* g/Nm^3
PM hot exh.	0.29	1.49	4.86	0.044
PM cooled exh.	1.03	5.31	17.43	0.158

Emissions from shipping – particulate matter



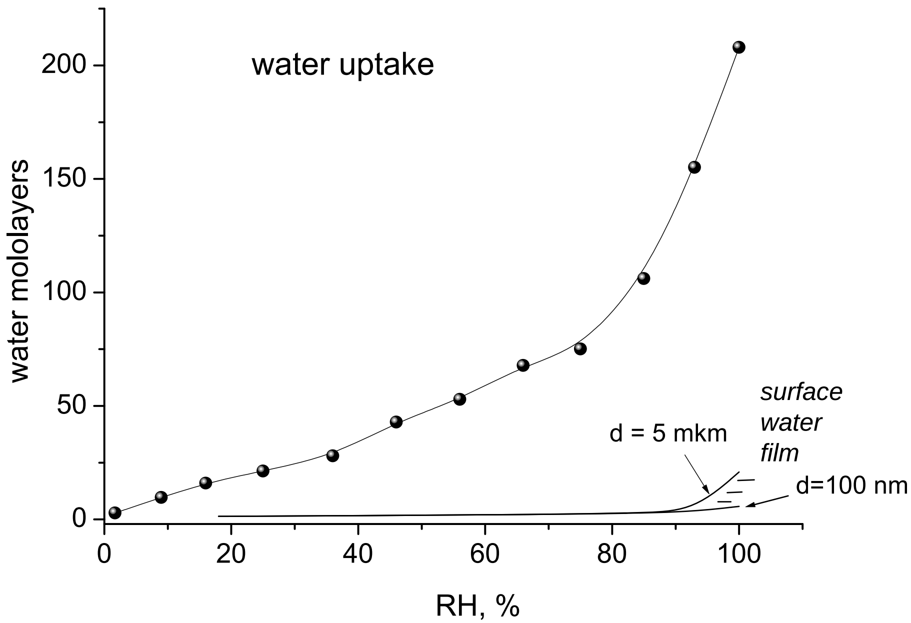
Emissions from shipping – particulate matter





- The ship-emitted PM with surfaces covered with transition metals and organics has a potential to cause reverse health effects.
- Mudway et al. (2004): higher oxidative stress on epithelial lining fluid in lungs caused by particles from residual oil using diesel engine exhaust
- Impact of PAHs on human health Armstrong et al. (2004)

Emissions from shipping – particle-water interaction

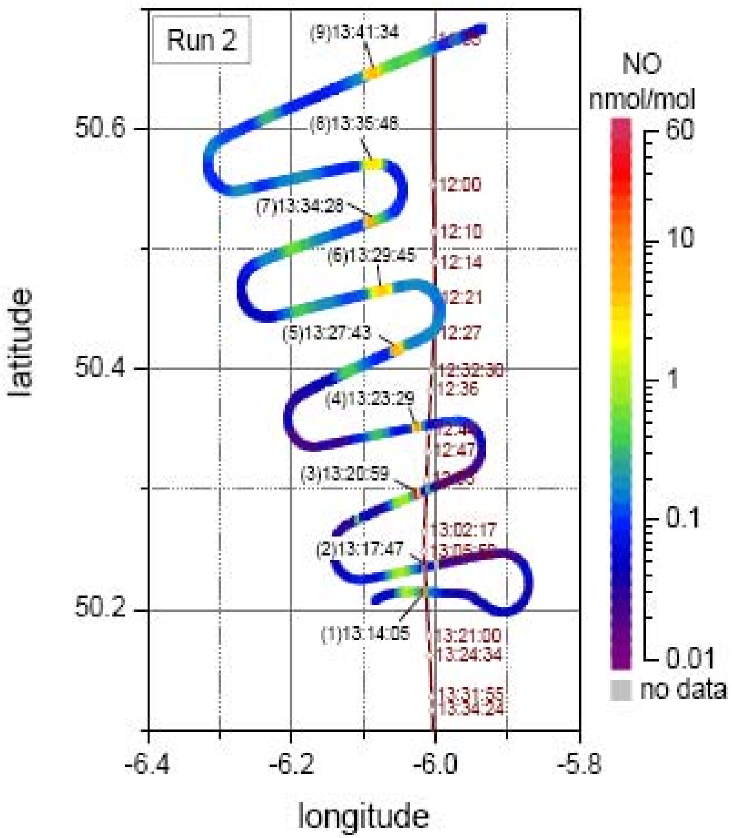


Popovicheva et al., 2009

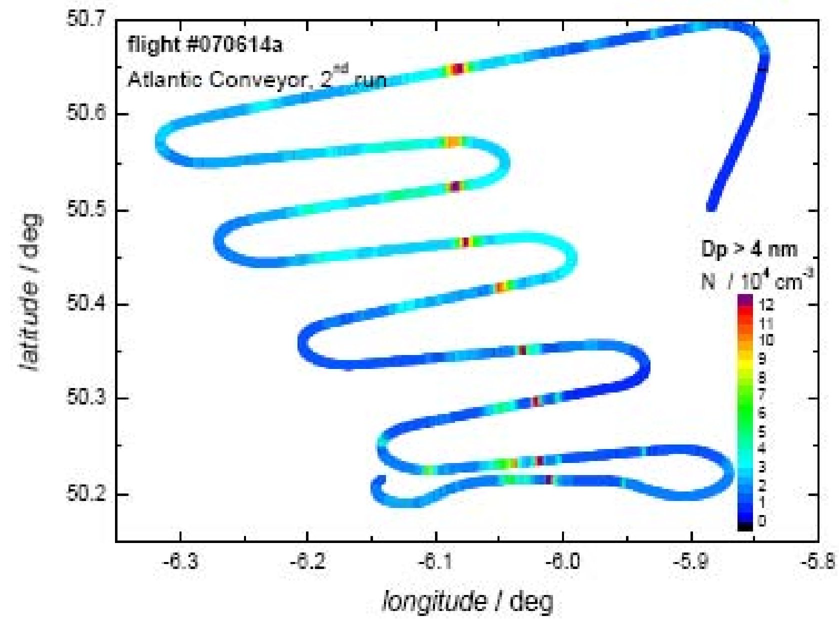
- Interaction with cloudwater with consequent effects on radiative forcing and climate

ACL exhaust plume sampling run 2

NO mixing ratio



Particle (>4nm) concentration



QUANTIFY

DLR Institut für Physik der Atmosphäre

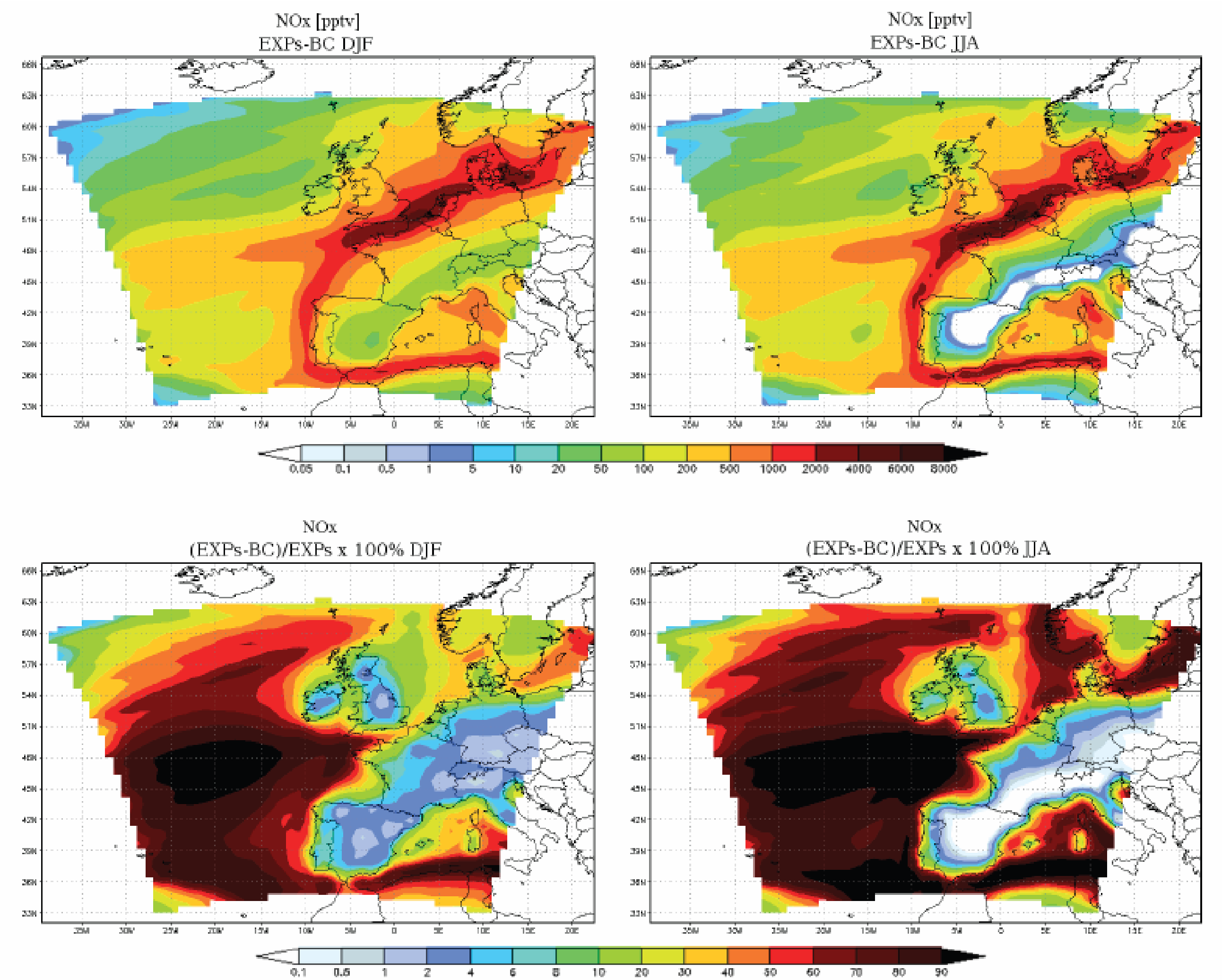
Effects of shipping on air pollution and radiative forcing (RF)

- Emissions of NO_x and other ozone precursors lead to tropospheric ozone (O_3) formation and perturb the hydroxyl radical (OH) concentrations, and hence the lifetime of methane (CH_4).
- The important aerosol component is sulphate ($SO_4^{=}$), which is formed by the oxidation of SO_2
- For CO_2, O_3 and black carbon (BC) the RF is positive, while for sulphate particles and decreased methane concentrations the RF is negative (*IPCC*, 2007)
- The particles can also have an indirect effect on climate through their ability to alter the properties of clouds

Effects of shipping on health and ecosystems

- Health effects:
  - Particles (PM)
  - Ozone (O_3)
- Acidification: Sulphur (SO_2) oxides of nitrogen (NO_X)
- Eutrophication: NO_X
- Corrosion: SO_2, NO_X, O_3

NOx at the surface due to ship emissions

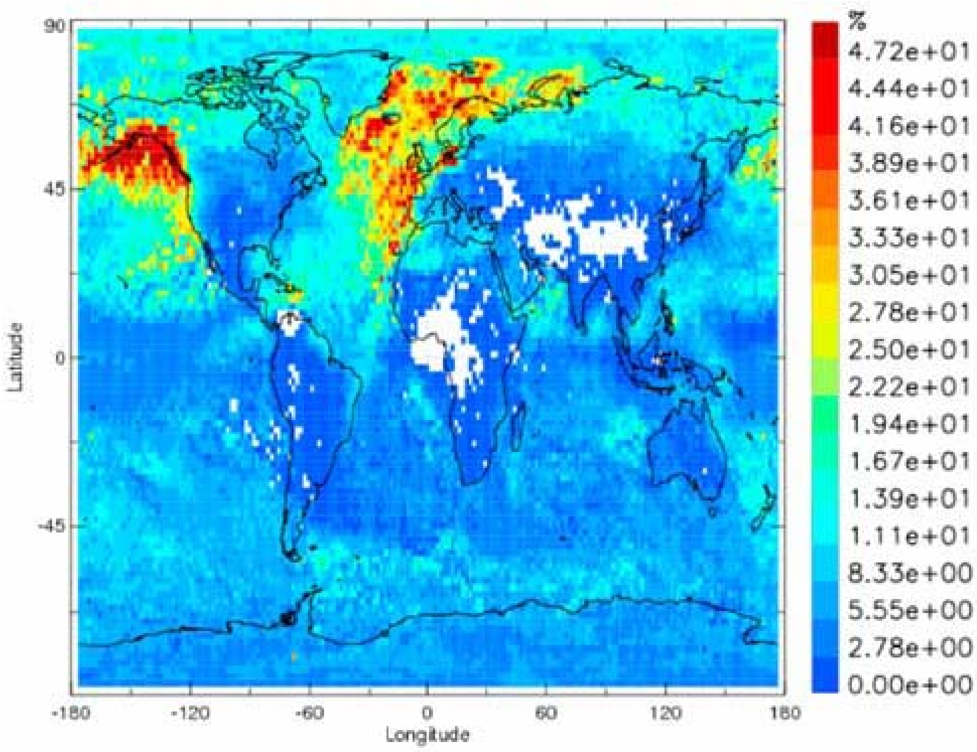


- For Europe the modelled contribution of shipping to NO_2 concentrations vary from 0.1-0.5 ppb (5%-15%) over the coasts of north-western Europe (*Dalsøen et al., 2007*).

Top row: average absolute NOx change on surface in pptv introducing ship emissions for winter (left) and summer season (right)
Bottom: the relative contribution of ship NOx to the total NOx as 100*(EXPs-BC)/EXPs is plotted.

Nitrate deposition due to emissions from shipping

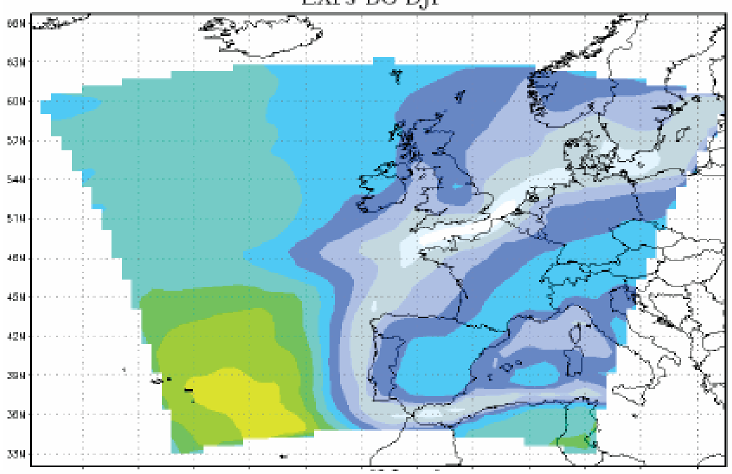
- Contribution to nitrate deposition up to 50%

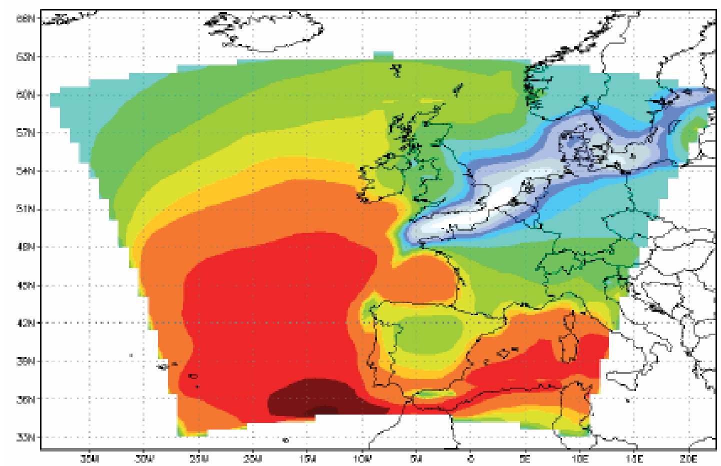


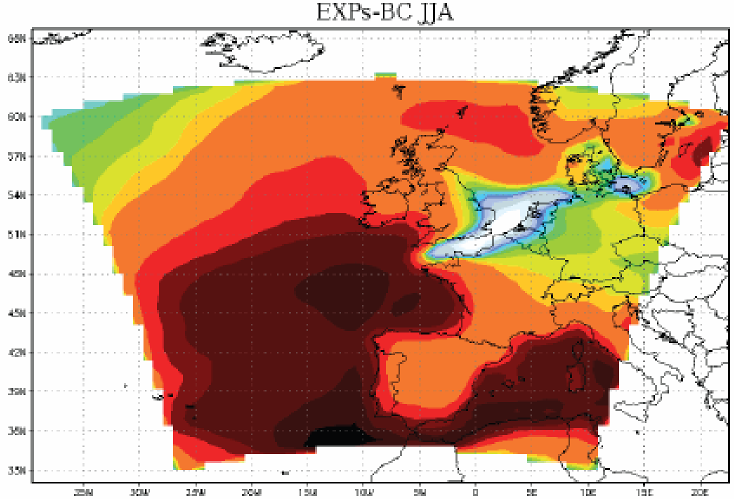
Nitrate wet deposition, contribution by 2000-year shipping (Dalsøren et al., 2007)

Ozone at the surface due to ship emissions

- Europe: contribution to summertime mean surface ozone concentrations 2-4 ppb (5%-15%) over the coasts of north-western Europe (*Derwent et al.*, 2005; *Collins et al.*, 2007).
- Prematural deaths due to ozone exposure in Europe 20 000, 5% reduction if the most ambitious reduction scenario for shipping applied for 2020 (Cofala et al., 2007).

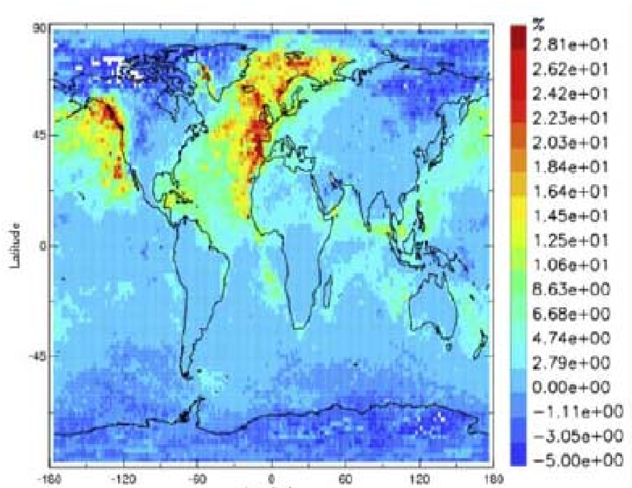




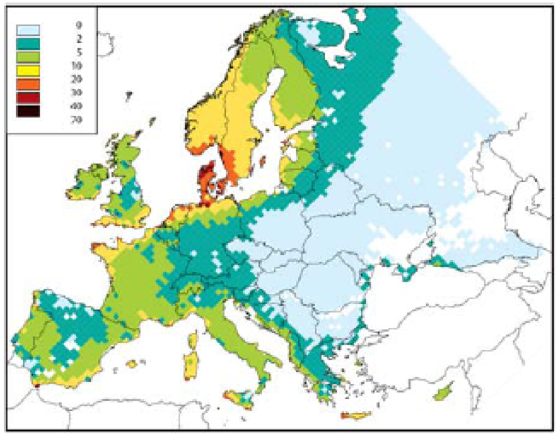


Average absolute O3 surface perturbation introducing ship emissions for winter (upper left) and summer (upper right) season and for whole year (Huszar et al., 2009)

Sulphate deposition due to emissions from shipping



Dalsøren et al. 2007



Percentage of sulphur deposition originating from international shipping in 2000

- In Europe maximum annual sulphate deposition from ship emissions ~ 50% of the total sulphur deposition (400 mg S m^2 $yr^{-1)}$ over the North Sea and Baltic Sea (Derwent et al., 2005))
- Along the western coasts of the UK and Scandinavia, the calculated percentage of total sulphur deposition from shipping 10-25% (Dore et al., 2006; Dalsøren et al., 2007; Collins et al. 2007).
- Mediterranean 54% of the mean sulphate aerosol concentration in summer.
- Sulphate deposition increases the acidity of soils, rivers and lakes. North Sea and Baltic Sea - decrease of sea alkalinity 0.5 meq/m^3/year (Doney 2007).

PM due to emissions from shipping

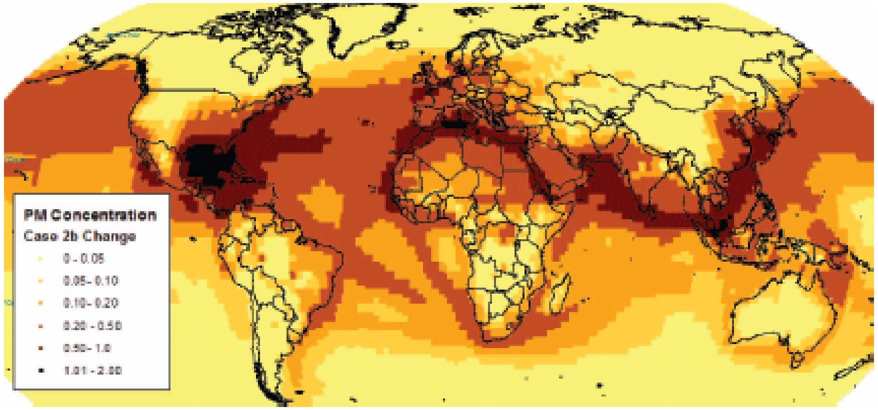


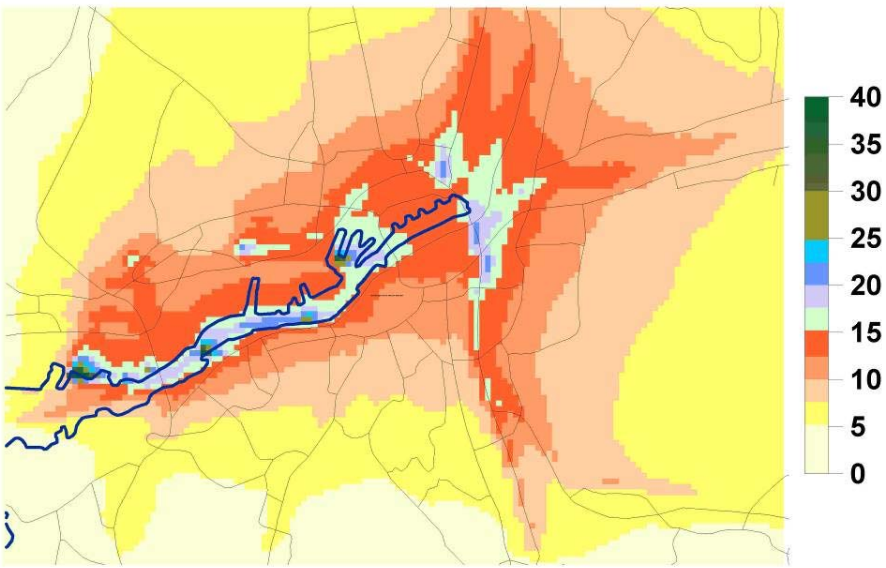
FIGURE 1. Annual average contribution of shipping to $PM_{2.5}$ concentrations for Case 2b (in $\mu g/m^3$)

Corbett et al. (2007)

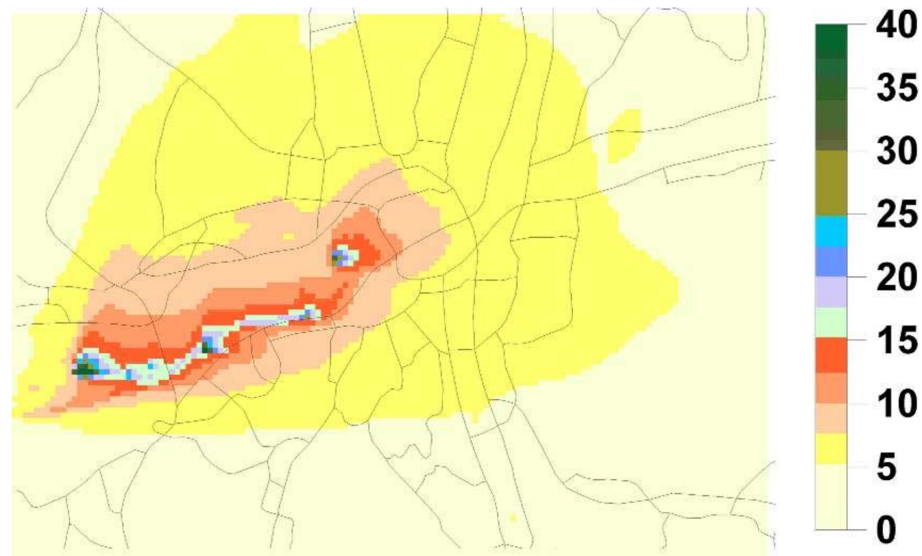
- Health effects: Premature mortalities – Corbett et al. (2007) 60 000 deaths globally (3-8% of PM-related deaths), Andersson et al., (2009) ~20 000 death in EU-27 (7%)
- Lost of life expectancy: Cofala et al. (2007) all anthropogenic PM - 8 months for EU-27, 9% reduction if the most ambitious reduction scenario for shipping applied for 2020.

Contribution of shipping emissions on local scale – case of Göteborg

a)

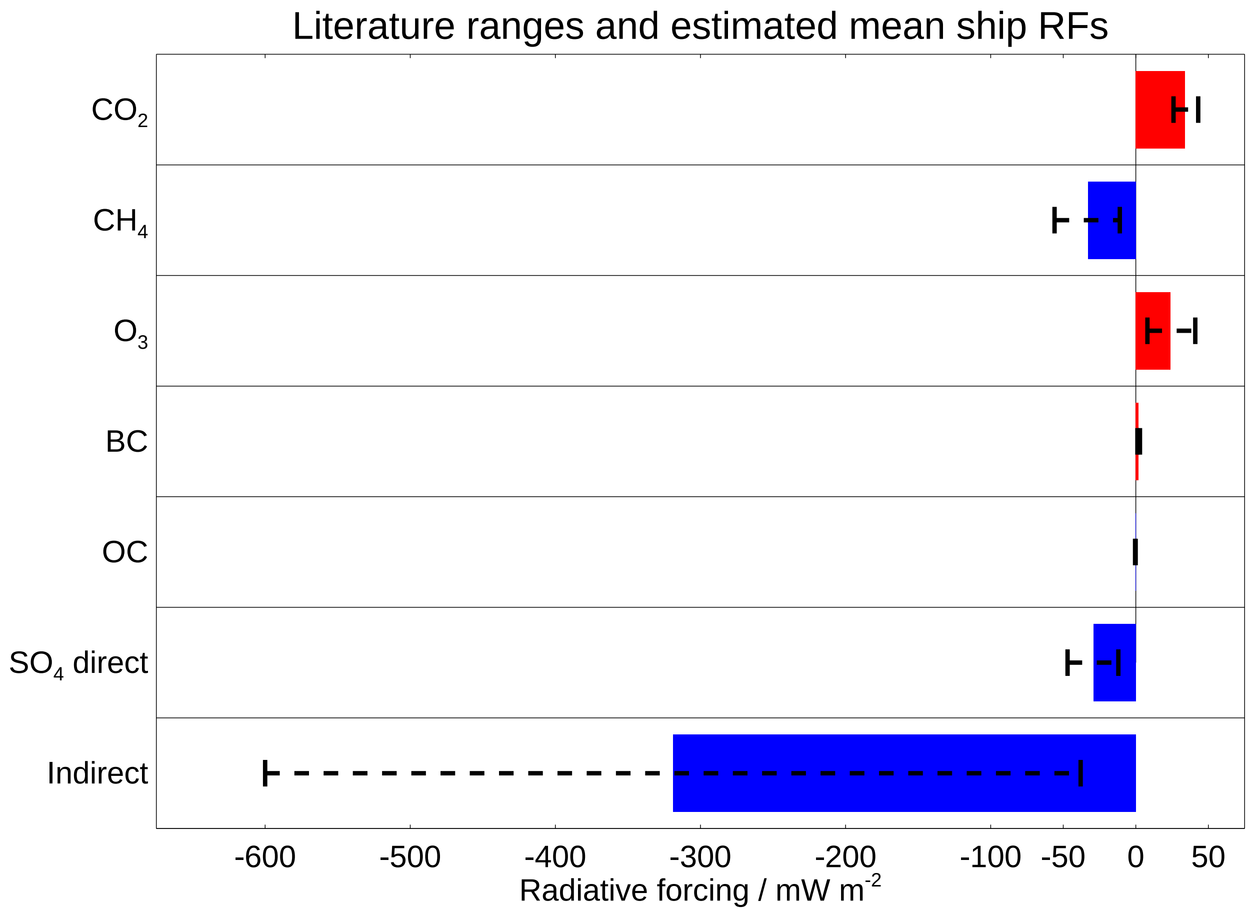


b)



a - Total NO_2 concentration calculated with TAPM. The blue line indicates the main part of the harbor. b- NO_2 concentration from ship emissions

Klimatpåverkan av sjöfarten



Literature range of annual mean radiative forcing due to emissions from international shipping in mWm−2. The boxes show the mean of the lower and upper estimate reported in the literature and the whiskers show the upper and lower values reported

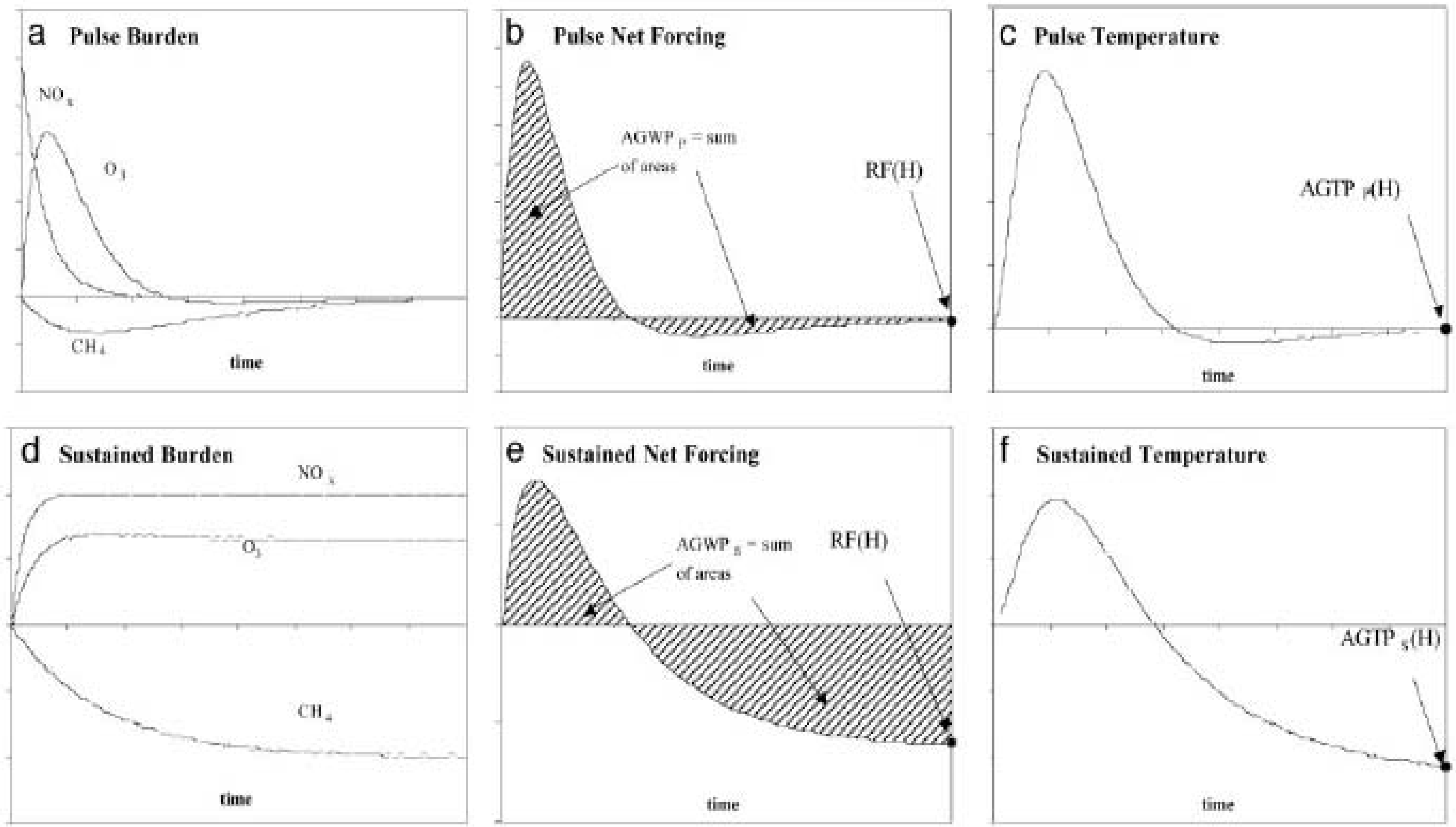


Fig. 1. Schematic illustrating possible metrics for NO_x emissions that lead to perturbations of both ozone and methane. Shown are the cases of a discrete pulse emission of NO_x (*a*–*c*) and a sustained emission change (*d*–*f*). (*a* and *d*) The evolution of the concentrations of NO_x, ozone, and methane. (*b* and *e*) The net (ozone plus methane) RF (the individual ozone and methane RFs follow the curves for the burden in *a* and *d*) and the parameters that can be used for climate metrics. The absolute GWP (AGWP) is the time-integrated RF over some time horizon (H). The degree of compensation between the ozone and methane RFs depends on the value of *H*. The RF at some time *H* could also be used in a metric. (*c* and *f*) The global-mean surface-temperature change in response to the RF from *b* and *e*. The absolute global temperature potential (AGTP) at some time *H* is another possible metric.

Shine et al., 2006

Conclusions

- Shipping moves 80-90% of world trade by volume, emitting 600-900 million metric tons (Tg) CO_2/year. This contributed between 2.0 and 2.7% to all anthropogenic CO_2 emissions in 2000.

- Globally, shipping accounted for around 10-15% of anthropogenic nitrogen oxides (NO_X) emissions and for around 4-9% of sulphur dioxide emissions in 2000.

- About 70% of the emissions from international shipping occur within 400 km of the coastlines. In coastal regions ship emissions can therefore have an impact on the air quality and may partly offset the recent decline of pollution from land-based sources due to national control in many developed countries. The emissions have impact on human health, ecosystem growth and biodiversity, soil and fresh water acidity and alkalinity of the coastal seawater.

- Ship emissions directly perturb the marine stratiform cloud field. Global model simulations confirm a significant increase of the cloud droplet number concentration of low maritime water clouds leading to a cloud optical thickness increase.

- All studies agree that the present-day net RF due to shipping is negative. Limited studies of the larger scale impact of ship emissions give a net RF from all direct forcings in the range –12 to –38 mW m^{-2} while the indirect effect is larger being in the range –190 to –600 mW m^{-2}. Main uncertainties in RF estimates stem from emissions inventories, aerosol-cloud microphysics, plume processes, and chemical processes.

QUANTIFY / Attica

Quantifying the Climate Impact of global and European Transport Systems

Mål: Att kvantifiera påverkan av globala och Europeiska transportsystem på klimat för nuvarande situation och för olika framtidsscenarier.

Koordinator: Robert Sausen, DLR-IPA
Deltagare: 41 från 17 Europeiska länder, + 6 associerade (USA, Kina och Indien)
Tidsram: Mars 2005 till Februari 2010
Finansiering: 8.0 M€
Totalkostnader 12.0 M€