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PSI

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Contribution of ships to air pollution in the Mediterranean area

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Air Pollution






primary pollutants

NO_x (NO_2 + NO)

SO_2

VOC

CO

PM

NH_3

(*EC, POA*)

chemical transformation

transport

secondary pollutants

O_3

HNO_3

H_2O_2

PM

(*NO_3, SO_4, NH_4, SOA*)

concentration in air

deposition

(*dry, wet*)

Impacts

human health, vegetation, ecosystems

POA: Primary Organic Aerosols, **EC**: Elemental Carbon, **VOC**: Volatile Organic Compounds, **SOA**: Secondary Organic Aerosols

Background

- significant decrease in land-based emissions over the past decades *(except for NH_3)*

  further decrease expected according to GP *(Gothenburg Protocol, signed in 1999, revised in 2012)*

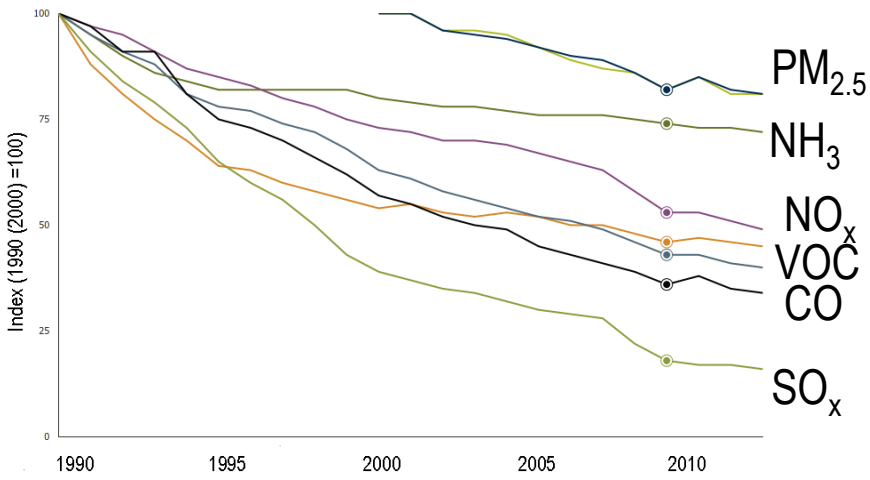
- shipping emissions not included in GP, subject to regulations of IMO *(International Maritime Organization)*, EU directives

  revised Annex VI to MARPOL *(since 2010)* restriction of sulfur content of the marine fuel in SECAs *(Sulfur Emission Control Areas: the English Channel, North Sea and Baltic Sea)*

- continuous increase in NOx emissions from ships

- continuous increase in all emissions in sea areas other than SECAs (especially Mediterranean) during the last two decades

Change in EU emissions since 1990



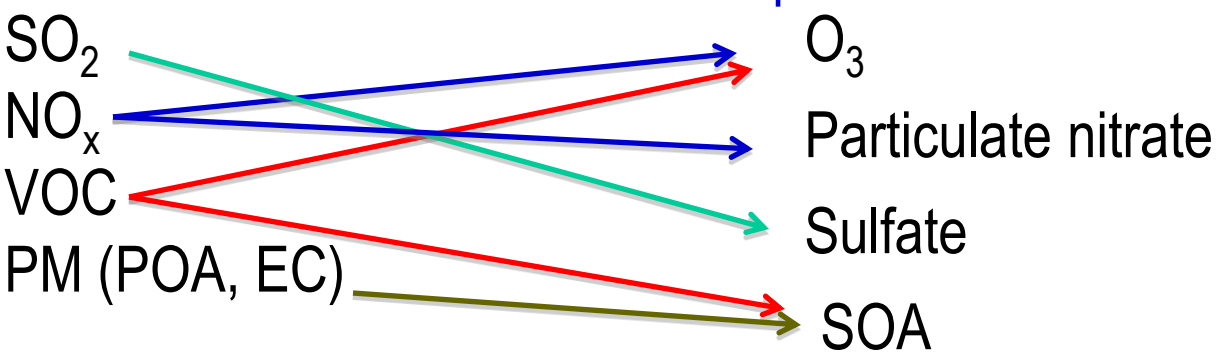
(adapted from www.eea.europe.eu)

while land-based emissions have decreased substantially over the past decades, emissions from shipping have increased

How ship emissions affect air quality?

- contribute to concentrations

as primary pollutants



as precursors for secondary pollutants

- contribute to deposition

Nitrogen

Sulfur

POA: Primary Organic Aerosols, **EC**: Elemental Carbon, **VOC**: Volatile Organic Compounds, **SOA**: Secondary Organic Aerosols

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Air Quality Modeling Sytem at PSI

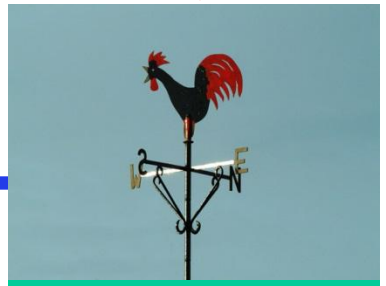
MOZART
global air quality model

Initial and Boundary Concentrations

meteorological model **WRF** (NCAR, USA)

Emissions

regional air quality model **CAMx** (RAMBOLL ENVIRON)



Meteorology

anthropogenic: **TNO**
biogenic: **PSI model**

concentrations, dry and wet deposition

CAMx: **C**omprehensive **A**ir quality **M**odel with e**x**tensions
WRF: **W**eather **R**esearch and **F**orecasting Model

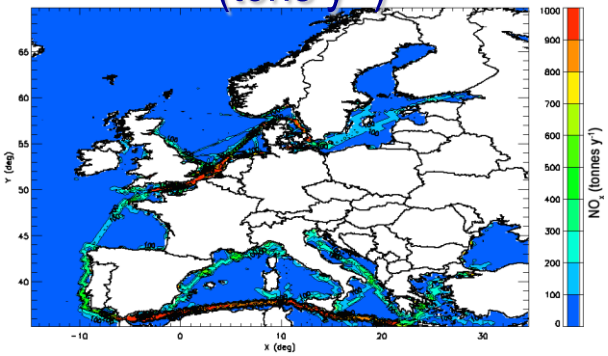
Modeling Method

- **modeling period**: 2006 with and without ship emissions
- **CAMx (v5.40)** 14 σ-layers
- **WRF** 31 σ-layers up to 100hPa, initialized by ECMWF data
- **horizontal resolution** *(0.250° x 0.125°)*
- **chemical mechanisms**: gas-phase CB05, aerosol phase SOAP *(fine/coarse modes) ISORROPIA*
- **dry deposition scheme**: Zhang (2003)
- **anthropogenic emissions**: TNO/MACC (*0.125° x 0.0625°)*
- **biogenic emissions**: PSI model *(isoprene, monoterpenes, sesquiterpenes)*

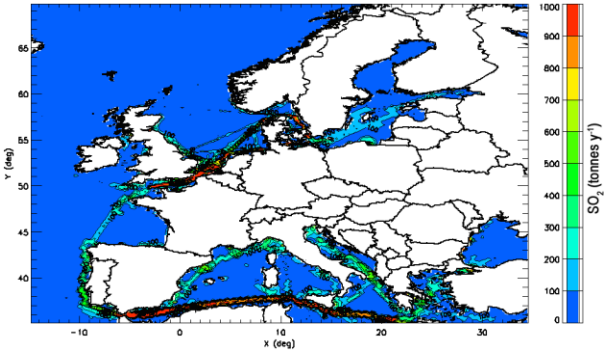
(*Aksoyoglu et al., Atmos. Chem. Phys., 2016*)

ship emissions in 2006 (tons y^{-1})

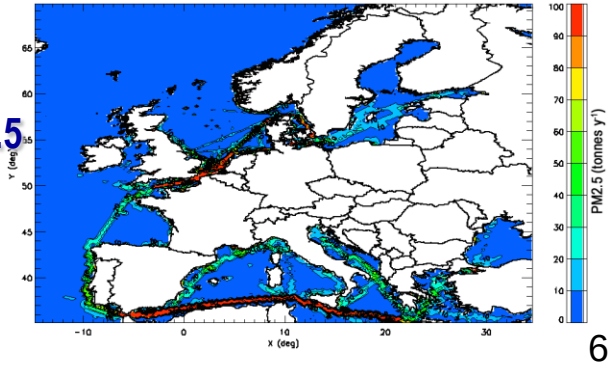
NO_x



SO_2



$PM_{2.5}$



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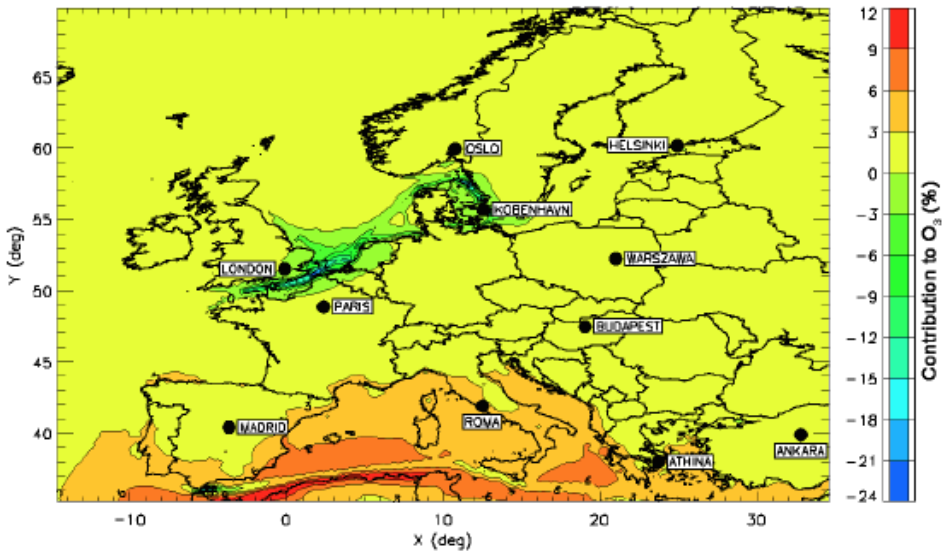
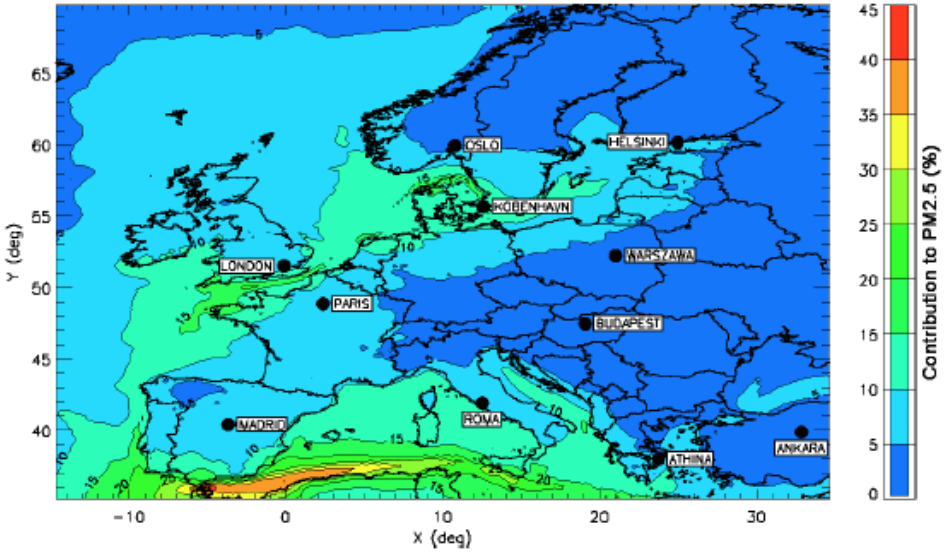
Annual contribution of ship emissions

to ozone (%)



to $PM_{2.5}$ (%)



increase in O_3 in the Mediterranean (5-10%)

decrease in O_3 along the English Channel and North Sea (10-20%)

increase in $PM_{2.5}$ along the shipping routes and coastal areas, largest increase in the Mediterannean (up to 45%)

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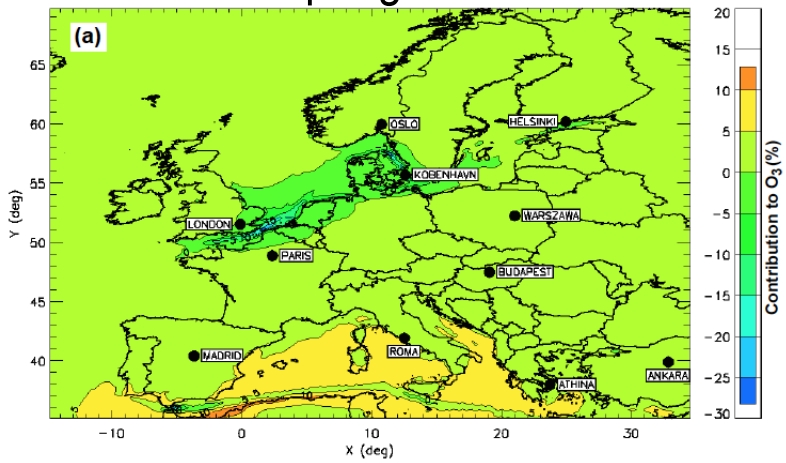
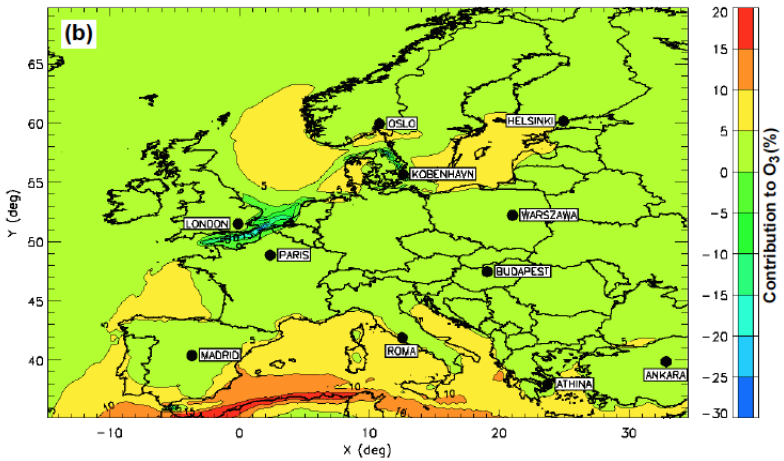
Effect of ships on ozone (seasonal variability) (%)

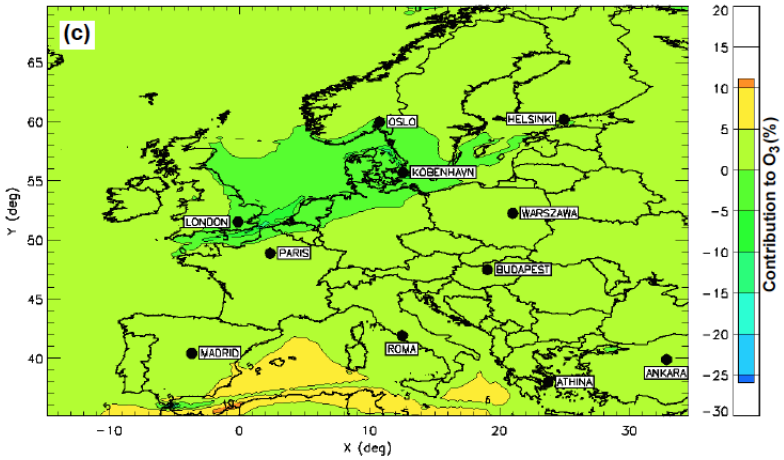
spring



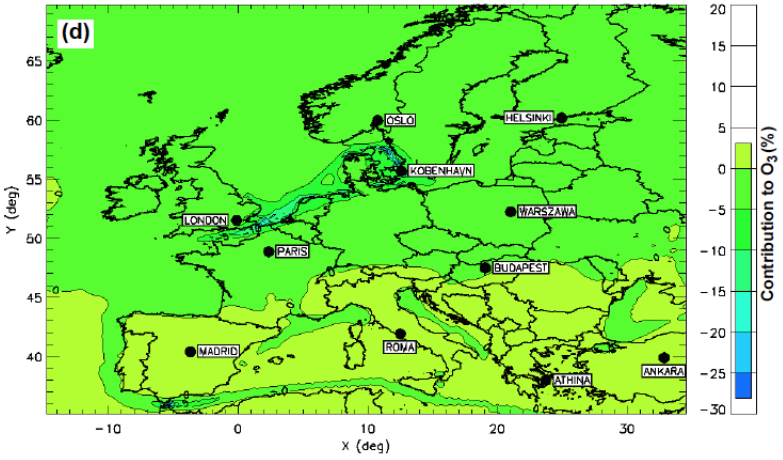
summer



fall



winter



ship emissions cause an increase in O_3 in seasons with active photochemistry, (spring to fall in the Mediterranean), largest in summer (10-20%)

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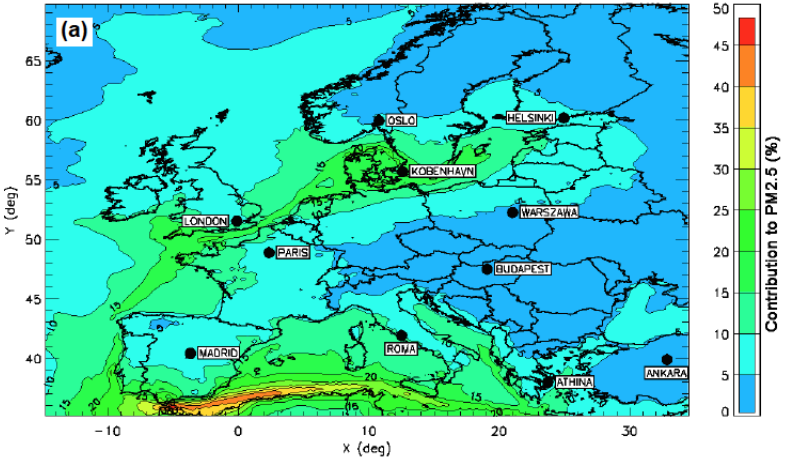
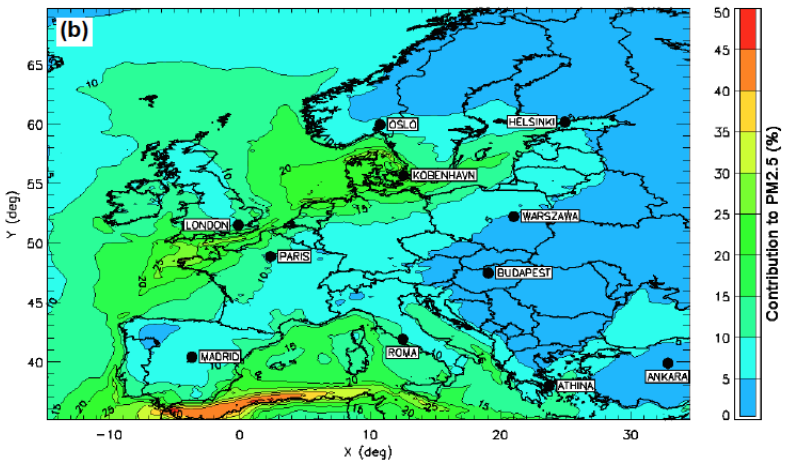
Effect of ships on PM2.5 (seasonal variability) (%)

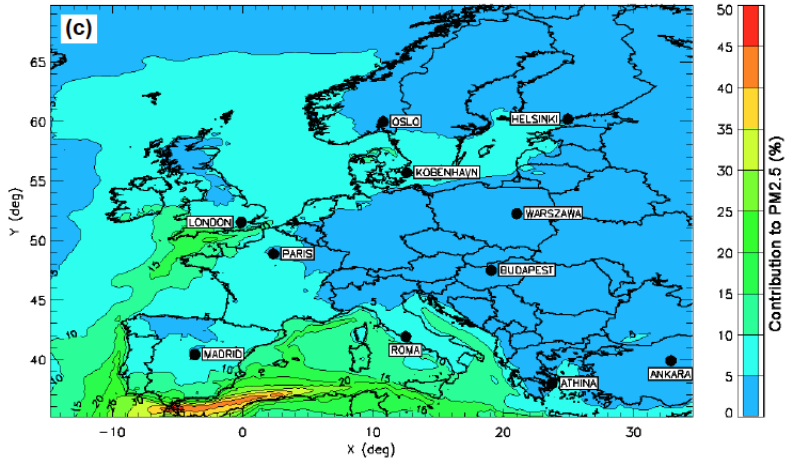
spring



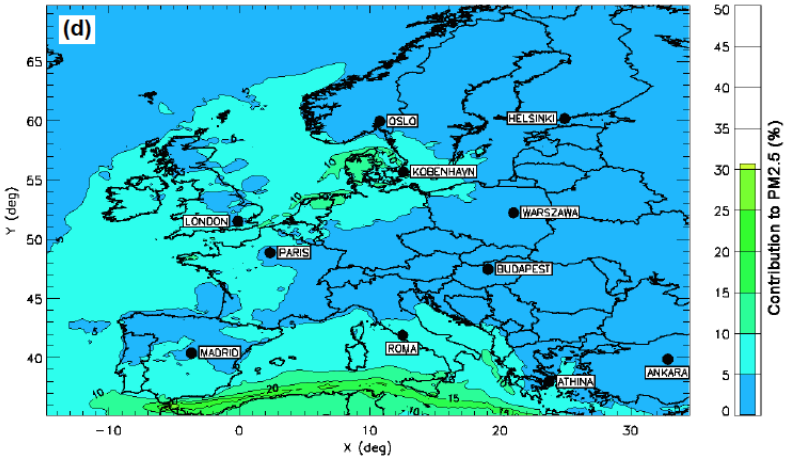
summer



fall



winter



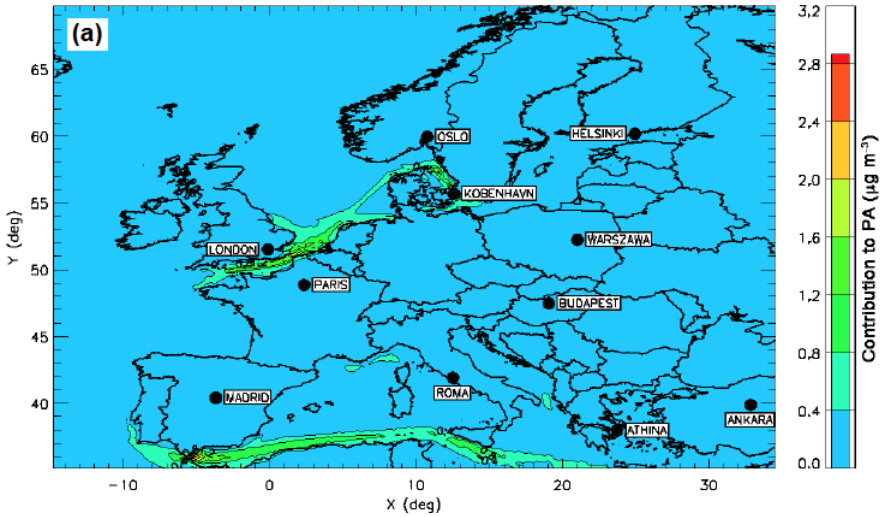
effects of ship emissions are larger in summer

20-25% increase around the English Channel, North Sea

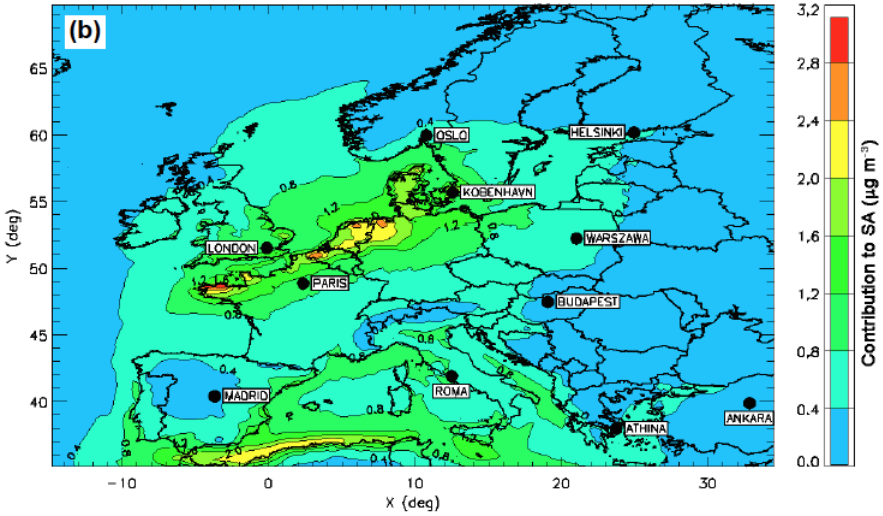
40-50% increase in the western Mediterannean

Effects of Ship Emissions on $PM_{2.5}$ Components (summer)

contribution to Primary Aerosols ($\mu g\ m^{-3}$)



contribution to Secondary Aerosols ($\mu g\ m^{-3}$)



increase in Primary Aerosols, PA (POA + EC), only along the shipping routes

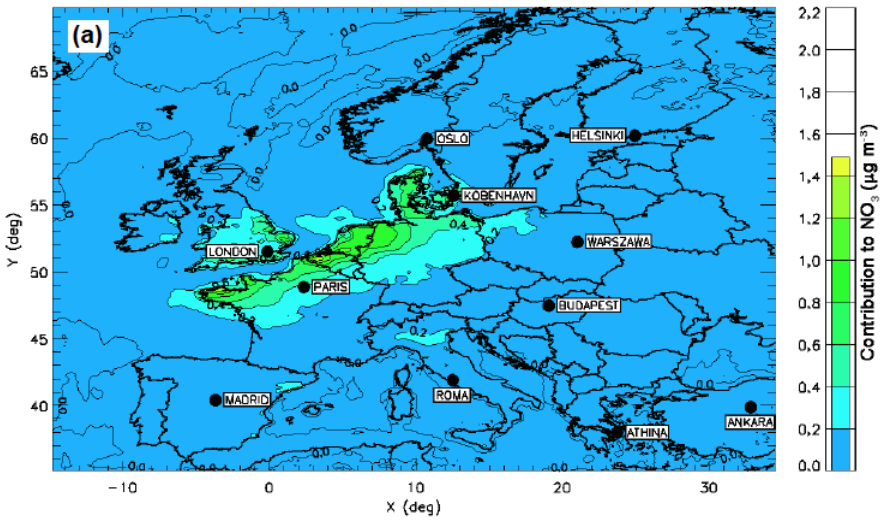
increase in Secondary Aerosols, SA (SIA + SOA), over larger areas including the continent

POA: Primary Organic Aerosols, **EC**: Elemental Carbon, **SIA**: Secondary Inorganic Aerosols, **SOA**: Secondary Organic Aerosols

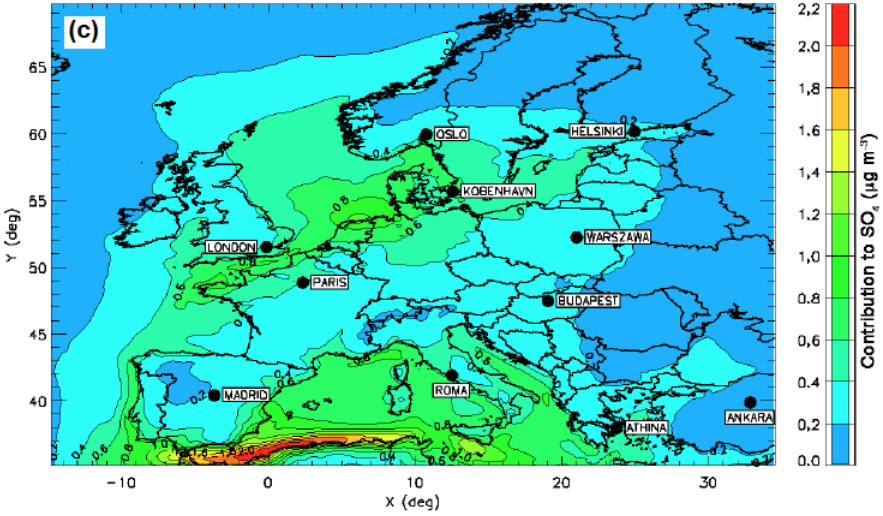
Effects of Ship Emissions on Secondary Aerosols

(Summer)

contribution to NO_3 ($\mu g\ m^{-3}$)



contribution to SO_4 ($\mu g\ m^{-3}$)



contribution to NO_3 along the English Channel and Benelux *area*

high NH_3 emissions from the land, high NO_x emissions from ships leading to formation of particulate nitrate (ammonium nitrate)

largest contribution to SO_4 *(50-60% in western Mediterranean)*

smaller effect on SOA *(not shown)*

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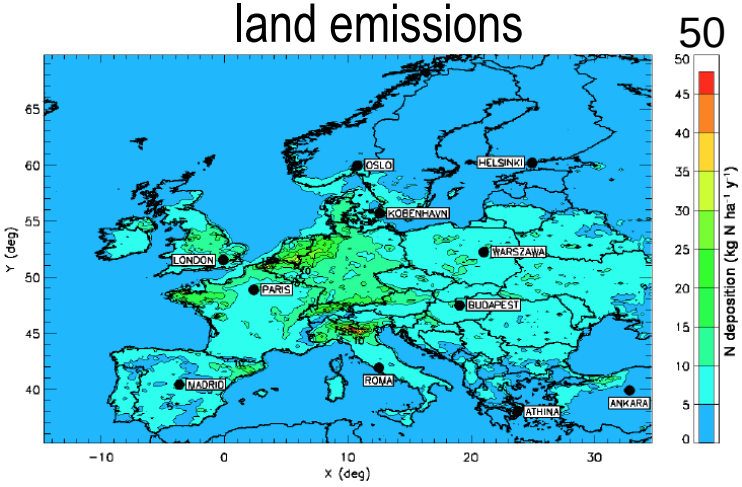
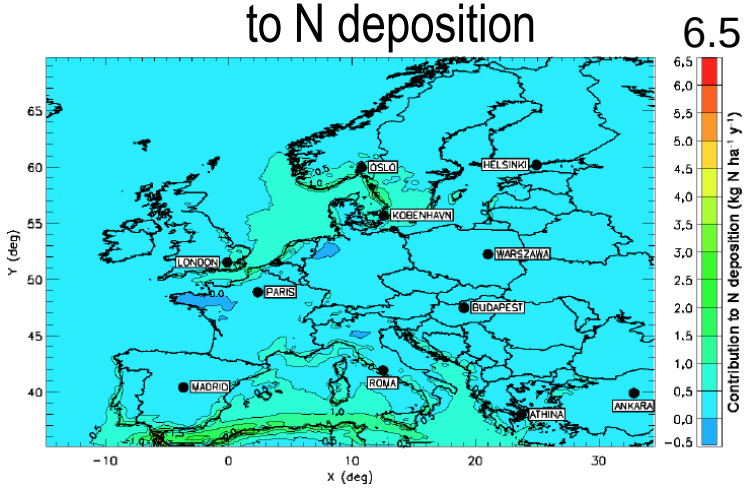
Effects of Ship Emissions on Nitrogen Deposition

(annual)

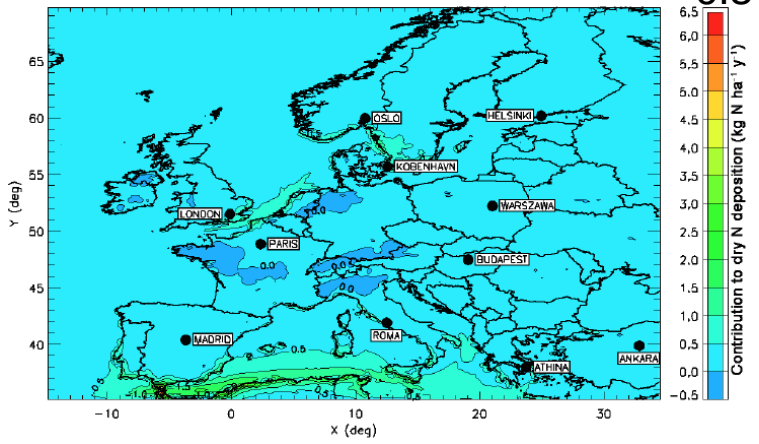
N deposition only due to land emissions



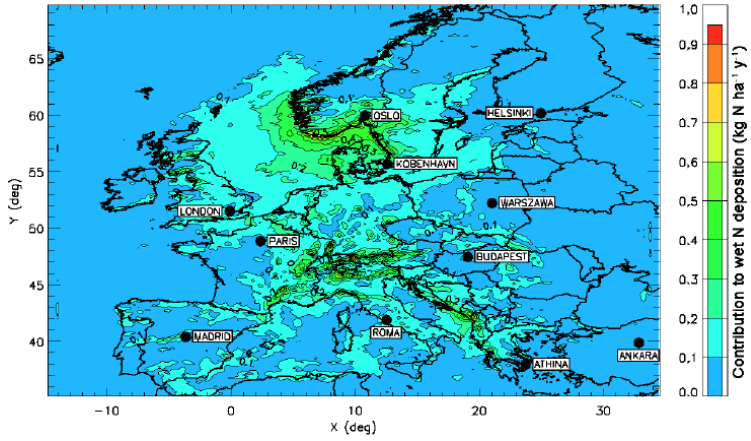
contribution of ship emissions to N deposition



contribution to dry N deposition



contribution to wet N deposition



increase along the shipping routes (especially around the Mediterranean) mainly due to dry deposition of oxidized nitrogen (in the form of HNO_3)

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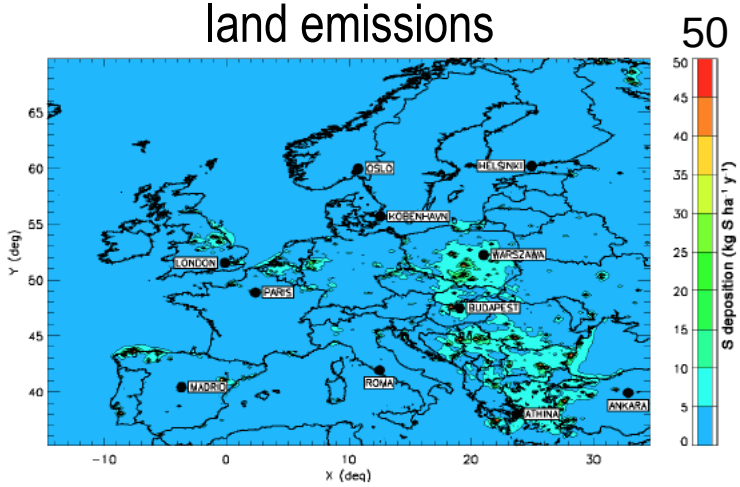
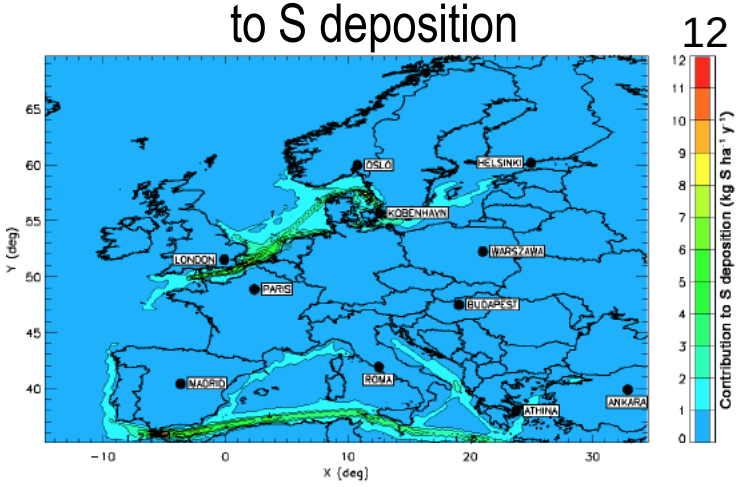
Effects of Ship Emissions on Sulfur Deposition

(annual)

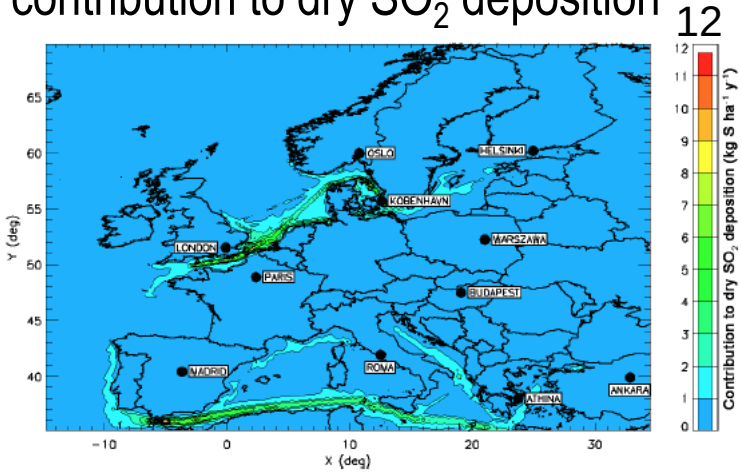
S deposition only due to land emissions



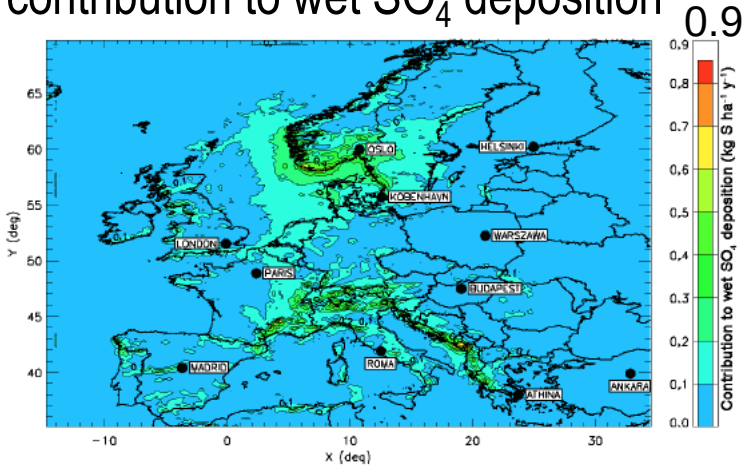
contribution of ship emissions to S deposition



contribution to dry SO_2 deposition



contribution to wet SO_4 deposition



increase along the shipping routes due to dry deposition (SO_2)

smaller increase in wet deposition (as SO_4) at high-precipitation areas

Summary

- ship emissions lead to a larger increase in ozone (10-20%) over a longer period (spring to fall) in the Mediterranean than in the other areas in Europe, due to higher photochemical activity
- ships contribute to $PM_{2.5}$ concentrations in all seasons with largest effect in the Mediterranean in summer (40-50%), mainly due to an increase in secondary sulfate particles
- ship emissions lead to an increased deposition of sulfur and nitrogen along the shipping routes and coastal areas

while land-based emissions and ship emissions in SECA will continue to decrease in future, ship emissions in the other areas especially in the Mediterranean will be more important for the future European air quality

Thank you

Acknowledgements

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NABU