PAUL SCHERRER INSTITUT

PSI


**Sebnem Aksoyoglu**, Paul Scherrer Institute, Switzerland

# Contribution of ships to air pollution in the Mediterranean area

Int. Mediterranean Shipping Conference, 28 March 2017, Rome

*email: sebnem.aksoyoglu@psi.ch*

Paul Scherrer Institut

# 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)*

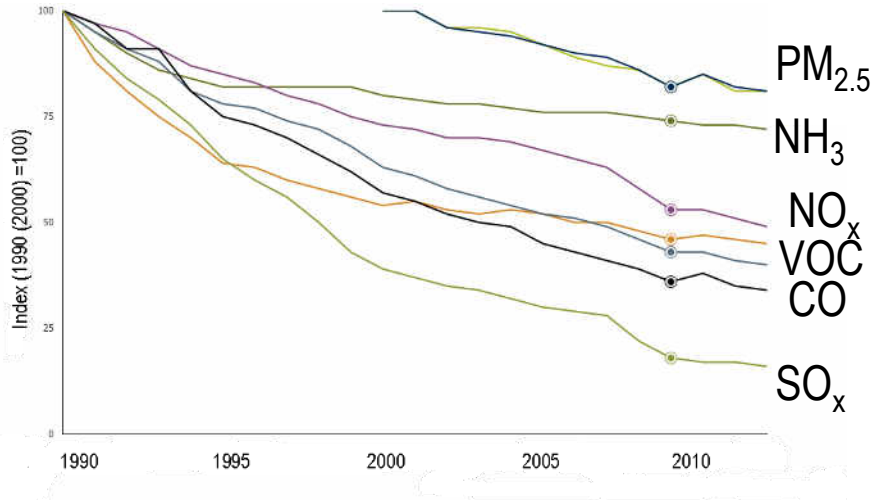
- shipping emissions not included in GP, subject to regulations of IMO *(International Maritime Organization)*, EU directives

  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



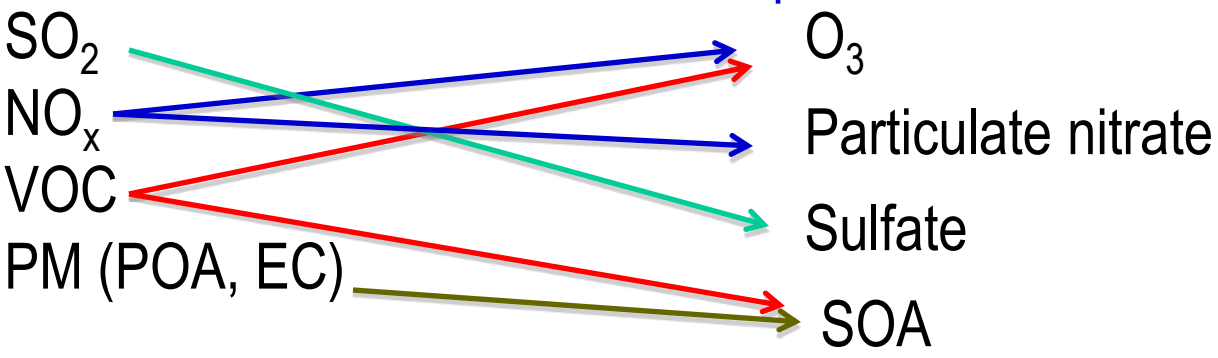

*(adapted from www.eea.europe.eu)*

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

Paul Scherrer Institut

# 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

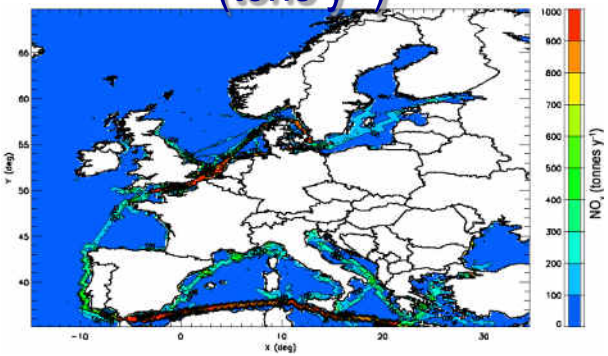
# Modeling Method

- **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)*

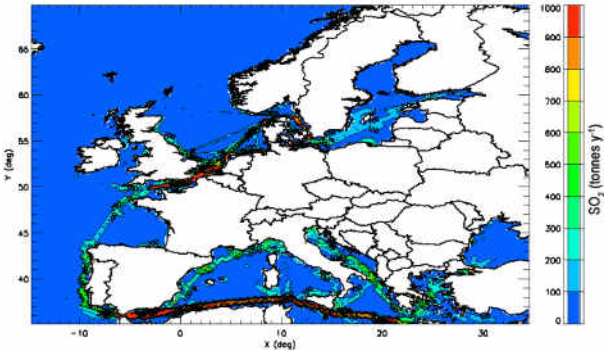
(*Aksoyoglu et al., Atmos. Chem. Phys., 2016*)

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

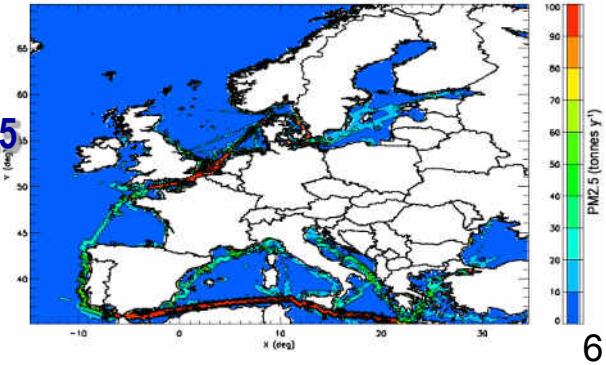
$NO_x$




$SO_2$



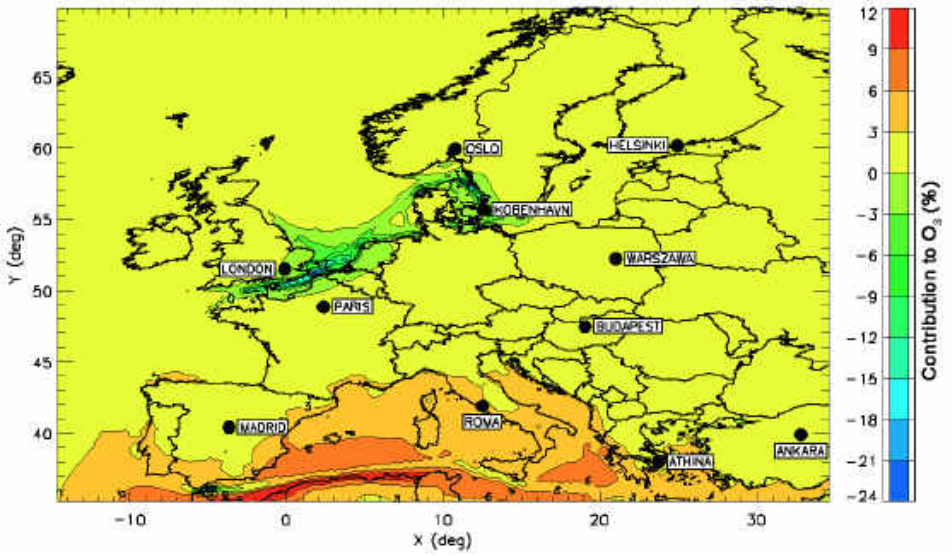

$PM_{2.5}$



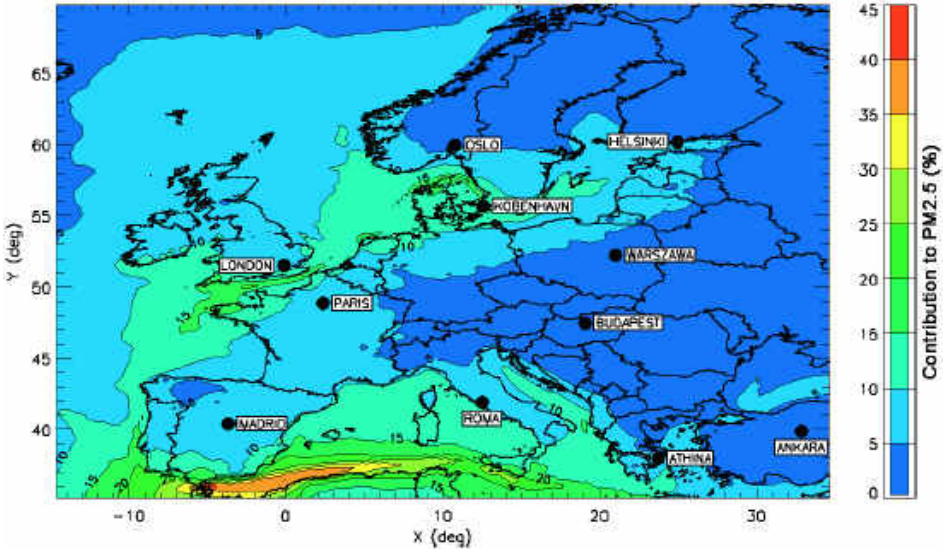
Paul Scherrer Institut

# Annual contribution of ship emissions

## to ozone (%)




## to $PM_{2.5}$ (%)




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

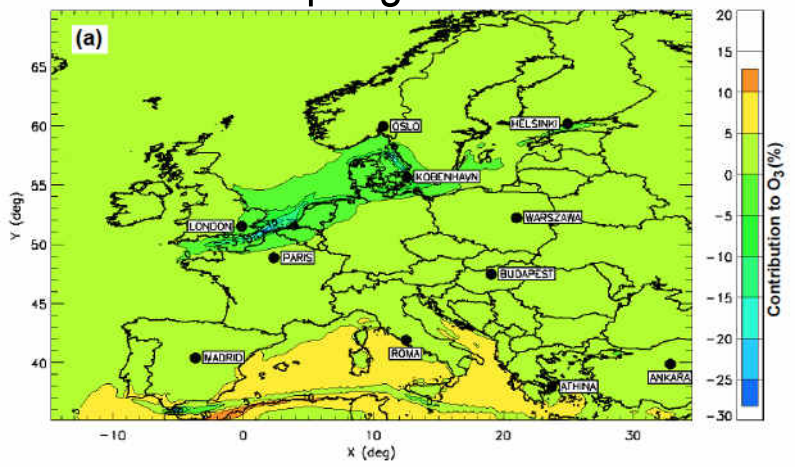
decrease in $O_3$ along the English Channel and North Sea (10-20%)

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

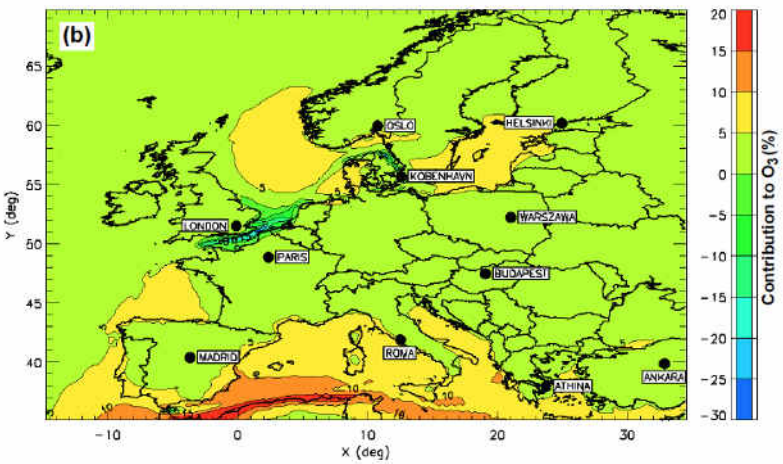
Paul Scherrer Institut

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

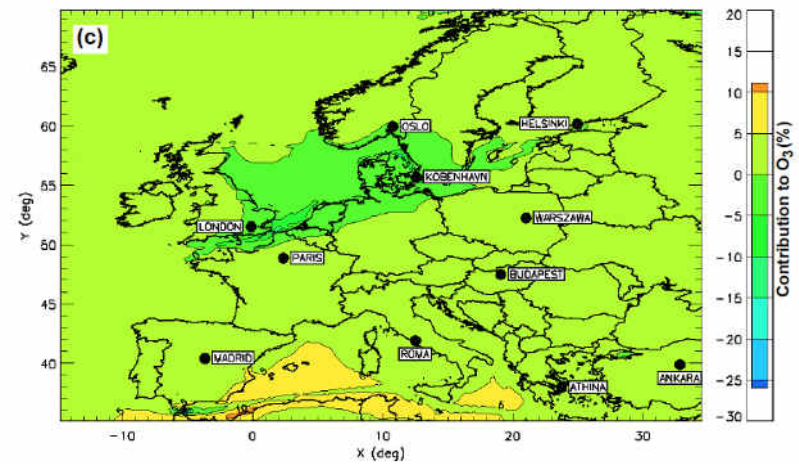
spring



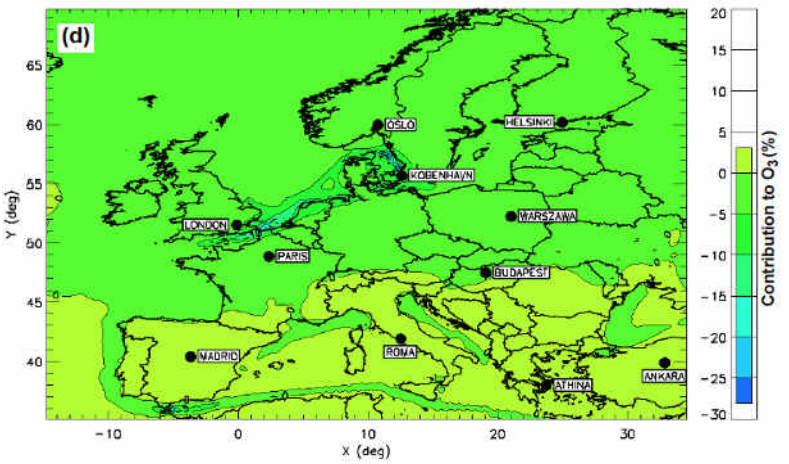

summer




fall




winter

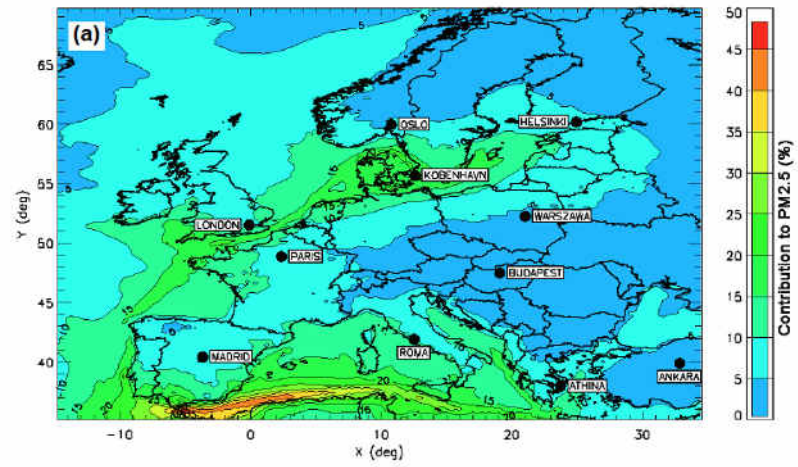



ship emissions cause an increase in $O_3$ in seasons with active photochemistry, (spring to fall in the Mediterranean), largest in summer (10-20%)

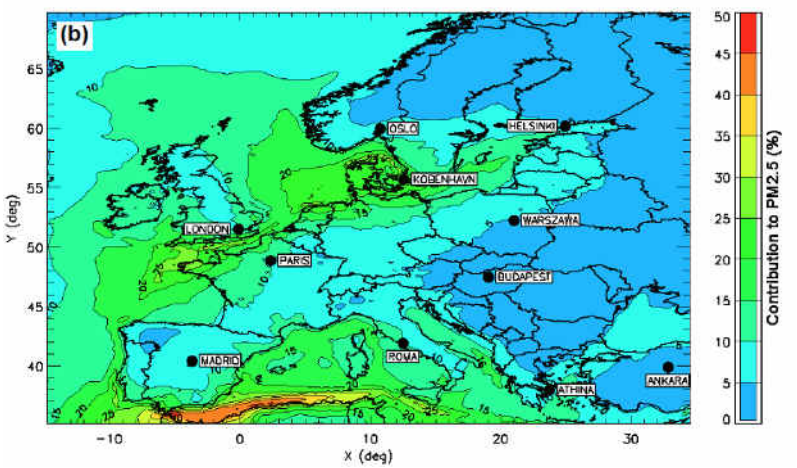
Paul Scherrer Institut

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

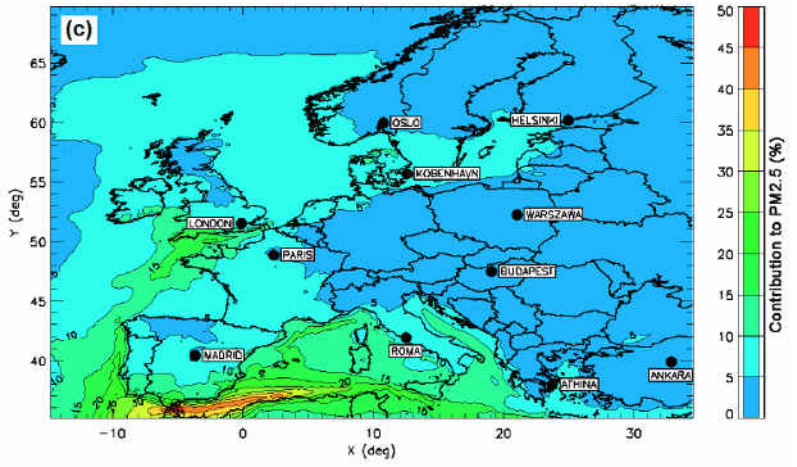
spring



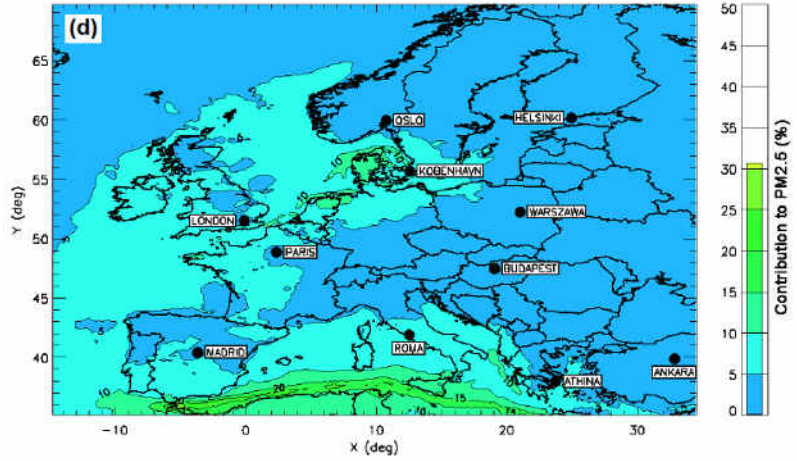

summer




fall




winter



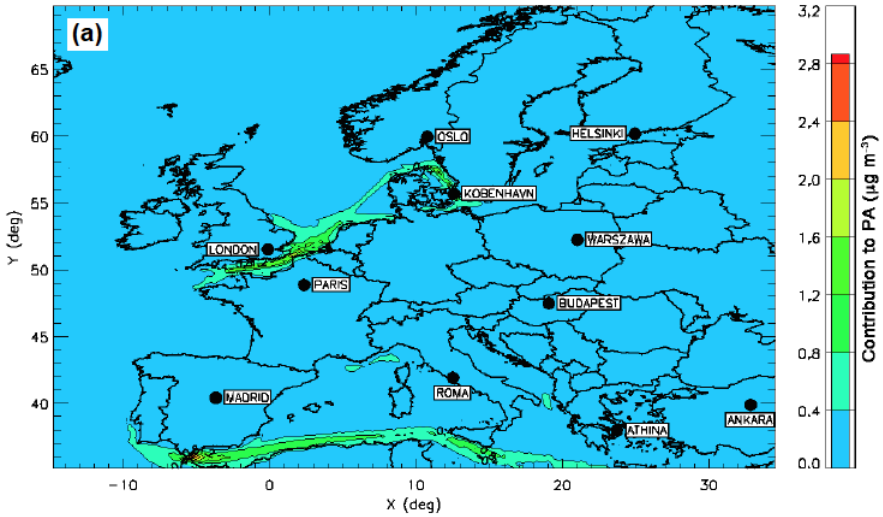

effects of ship emissions are larger in summer

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

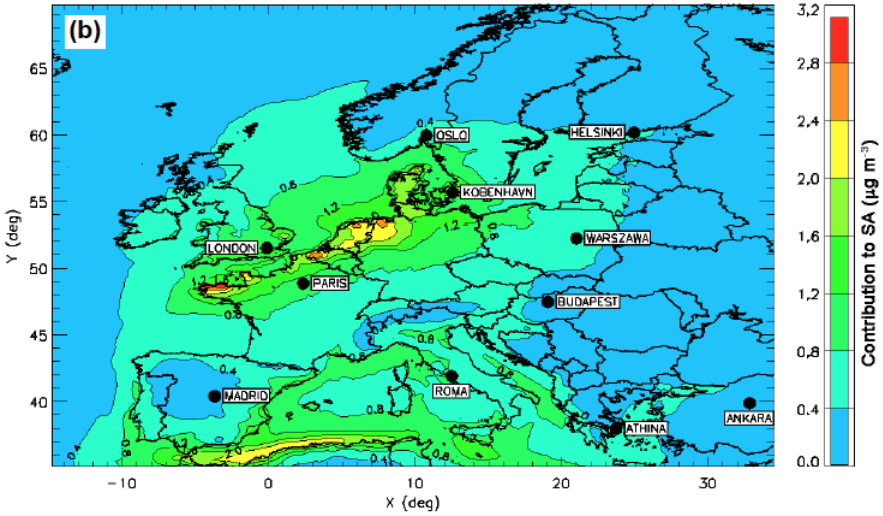
40-50% increase in the western Mediterannean

# 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

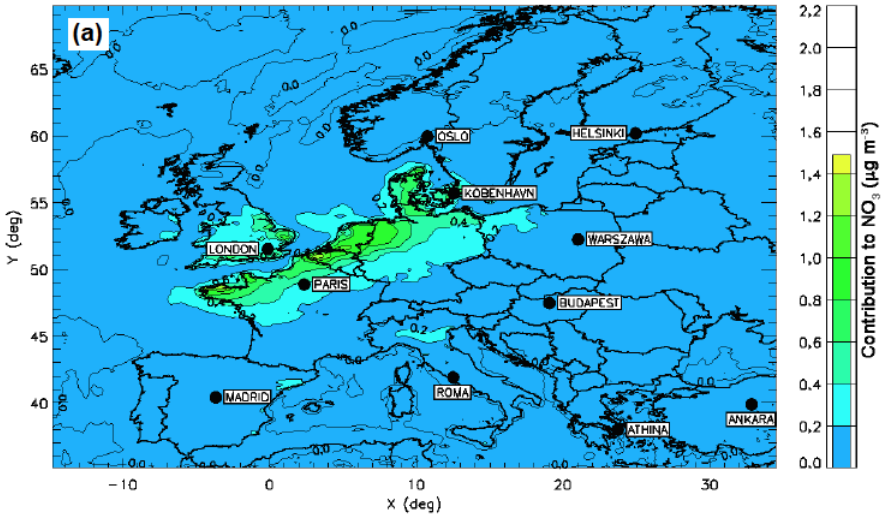


**POA**: Primary Organic Aerosols, **EC**: Elemental Carbon, **SIA**: Secondary Inorganic Aerosols, **SOA**: Secondary Organic Aerosols

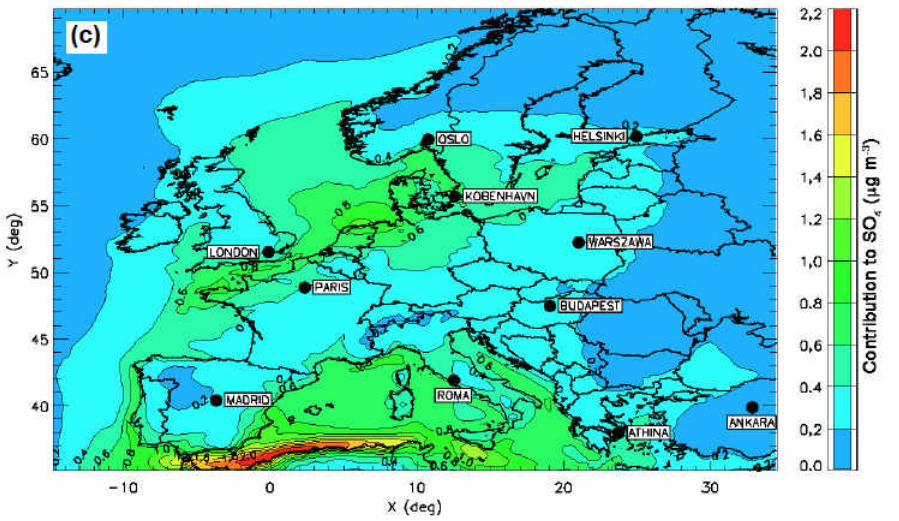
# Effects of Ship Emissions on Secondary Aerosols

(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)*

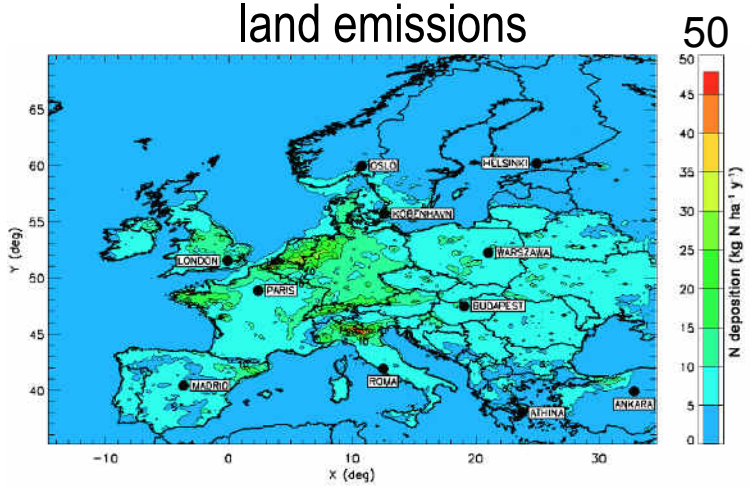
largest contribution to $SO_4$ *(50-60% in western Mediterranean)*

smaller effect on SOA *(not shown)*

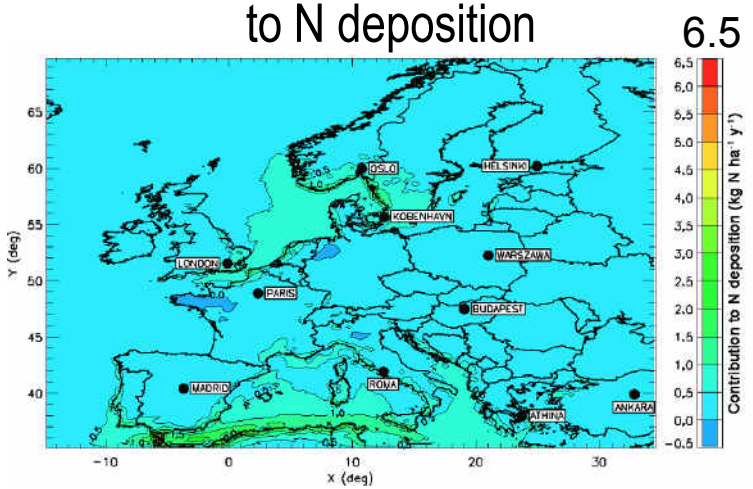
# Effects of Ship Emissions on Nitrogen Deposition

(annual)

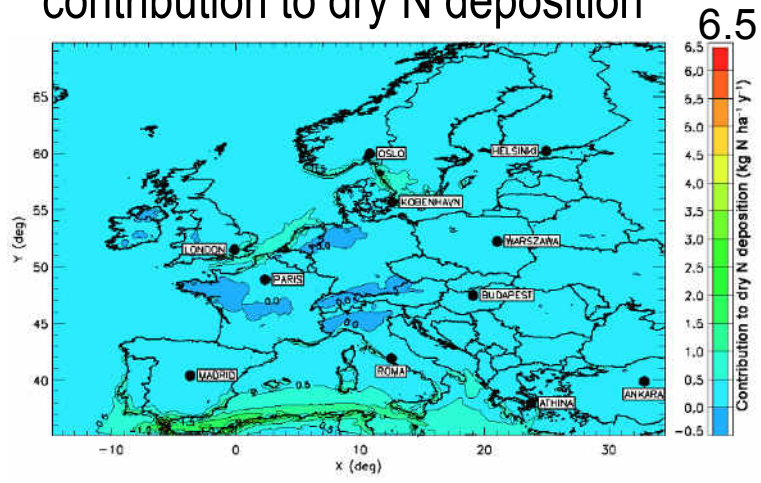
N deposition only due to land emissions



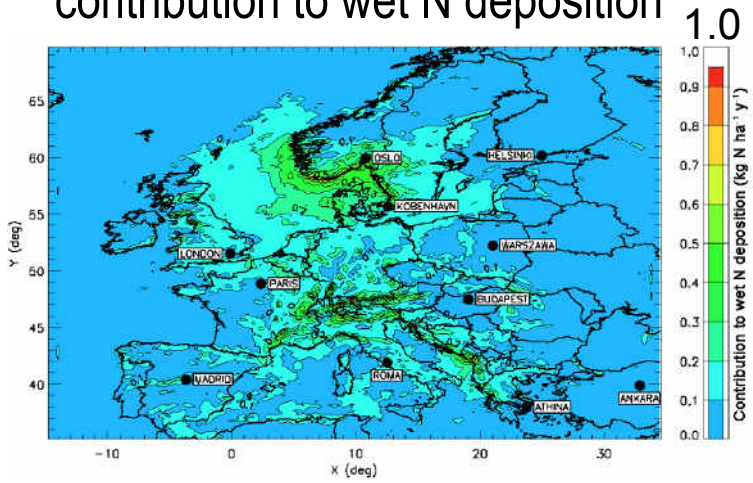

contribution of ship emissions to N deposition




contribution to dry N deposition




contribution to wet N deposition



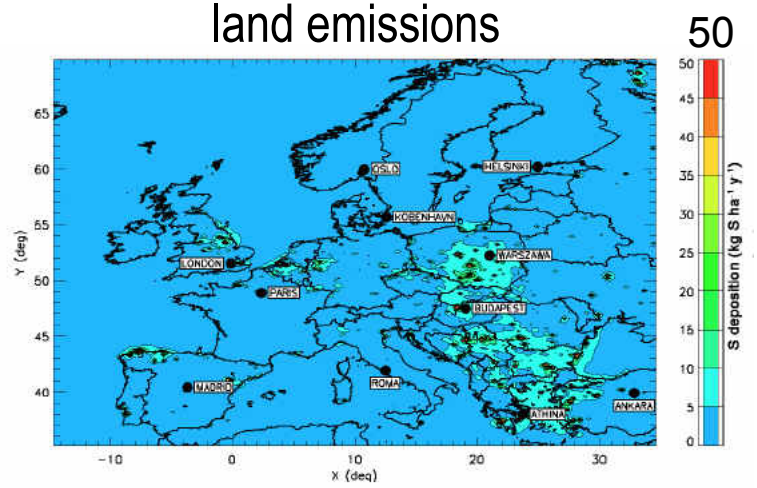

increase along the shipping routes (especially around the Mediterranean) mainly due to dry deposition of oxidized nitrogen (in the form of $HNO_3$)

Paul Scherrer Institut

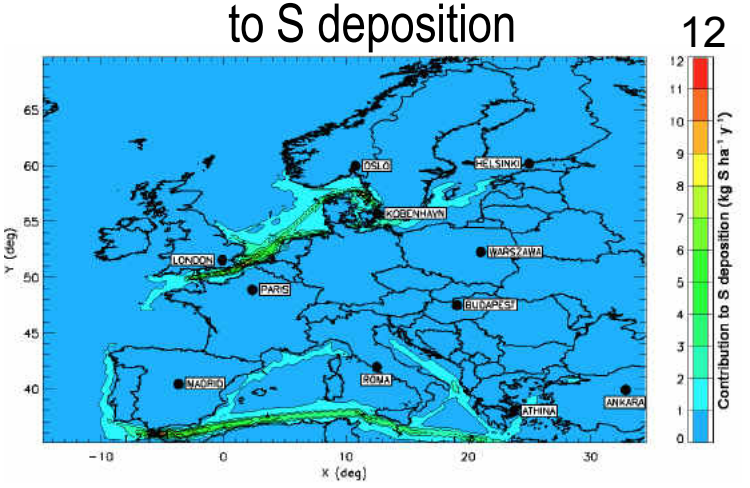
# Effects of Ship Emissions on Sulfur Deposition

(annual)

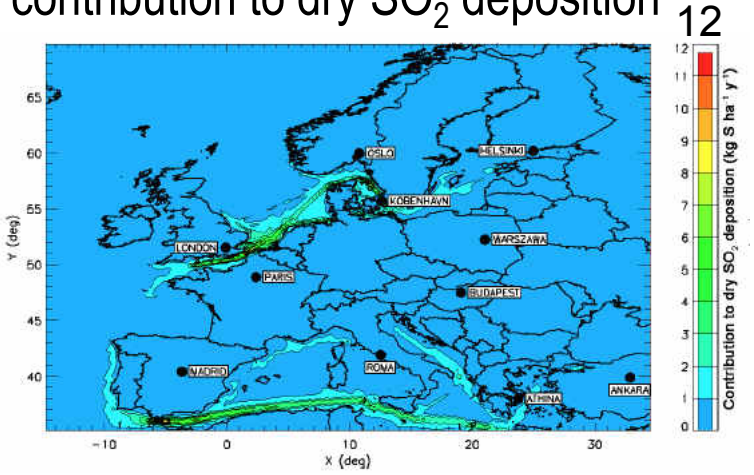
S deposition only due to land emissions



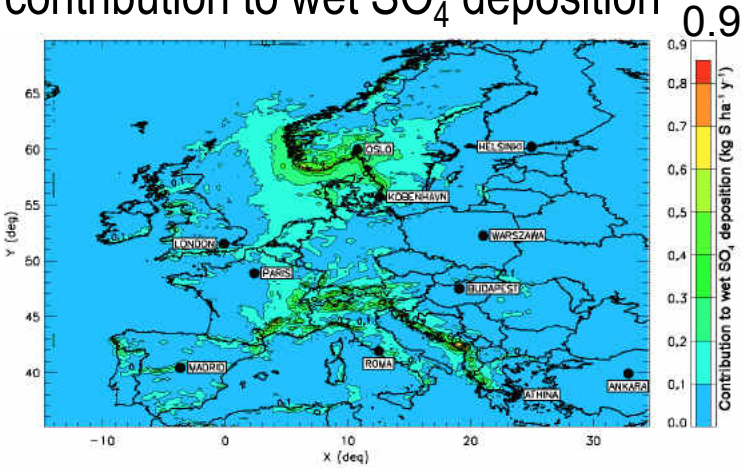

contribution of ship emissions to S deposition




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

TNO

ECMWF

Ramboll-Environ

AQMEII

The Competence Center Energy and Mobility (CCEM)

Swiss Federal Office of Environment (FOEN)

NABU