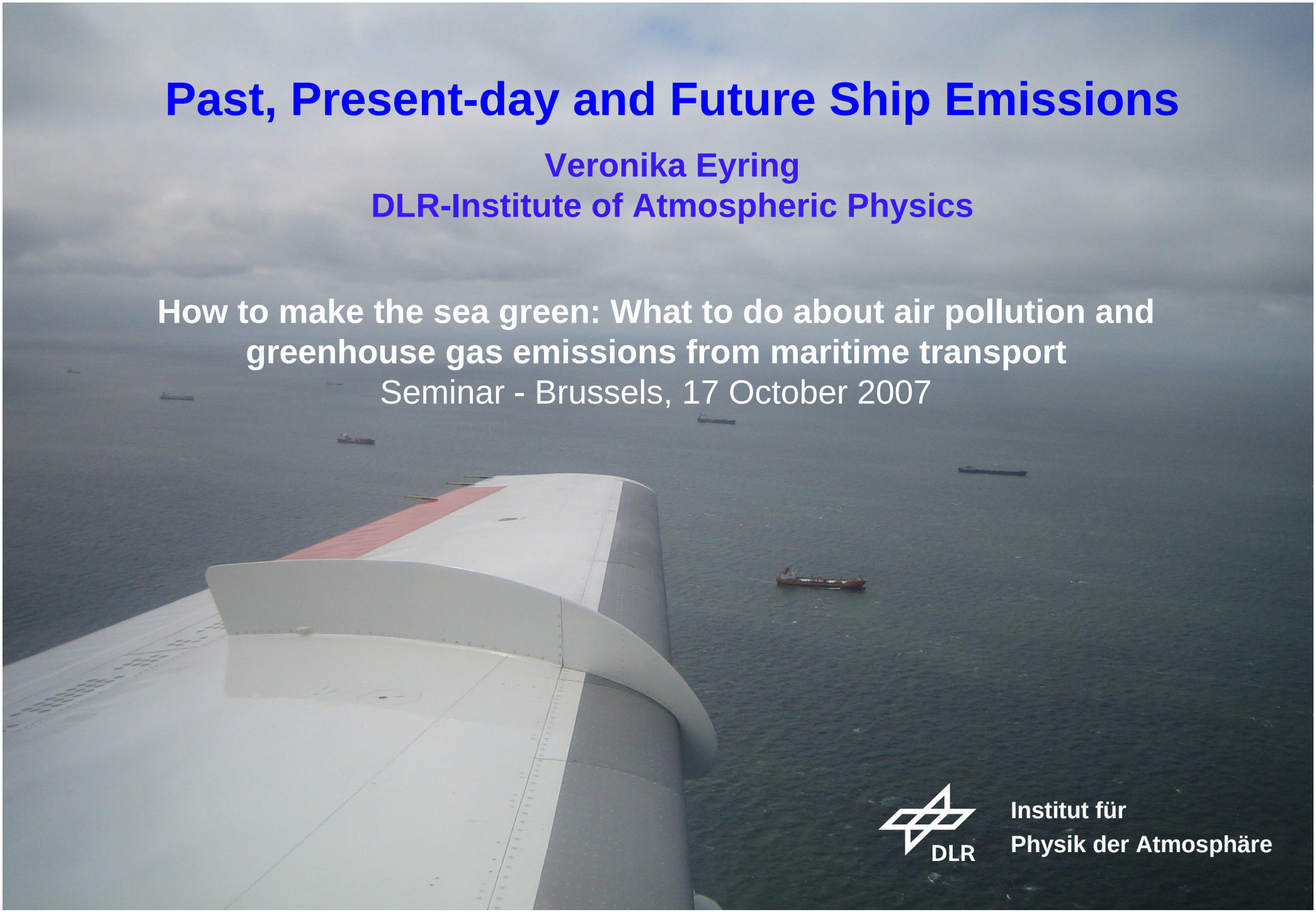


Past, Present-day and Future Ship Emissions

Veronika Eyring
DLR-Institute of Atmospheric Physics

How to make the sea green: What to do about air pollution and greenhouse gas emissions from maritime transport

Seminar - Brussels, 17 October 2007

DLR
Institut für
Physik der Atmosphäre

Emissions from international shipping

Overview

1 **Impact Chain of Ship Emissions**

2 Estimates of Past and Present-day Emissions

3 Estimates of Future Emissions

4 Validation Measurements

5 Impact Studies

6 Summary and Outlook

Impact Chain of Ship Emissions

Engine Emissions
CO_2, NO_x, CO, HC, SO_x, Particles & Soot

↓

Plume Dilution & Transformation
Chemical and microphysical processes in plumes

↓

Regional Impact on Air Quality

↓

Regional & Global Impact on Chemistry

↓

Radiative Forcing

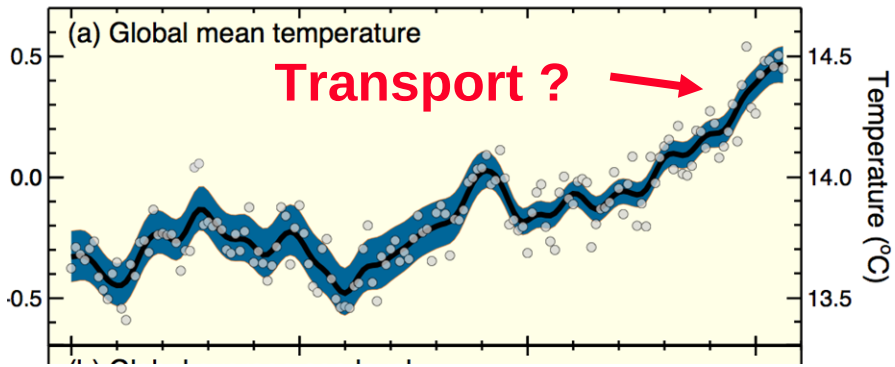
↓

Impact on Climate

DLR
Institut für
Physik der Atmosphäre

Environmental Impact of Ship Emissions

- **Chemical Composition of the Atmosphere (Air Quality)**
  - the emissions of ozone and aerosol precursors (NOx, CO, VOCs, SO_2 etc)
  - reduced air quality through formation of ground-level ozone and particulate matter
- **Climate change**
  - the emission of greenhouse gases, including long-lived species like CO_2
  - the emissions of indirect greenhouse gases, i.e., precursors of ozone
  - the emission of particles and their precursors (BC and SO_2);
  - by modifying natural clouds or forming additional clouds (e.g., ship tracks).
- **Acidification of the Oceans**
- **Biodiversity**
- **Noise etc.**



IPCC AR4

Emissions from international shipping

Overview

1 Impact Chain of Ship Emissions

2 Estimates of Past and Present-day Emissions

3 Estimates of Future Emissions

4 Validation Measurements

5 Impact Studies

6 Summary and Outlook

Principal approaches for producing spatially resolved ship inventories

1. **Bottom-up approaches** emissions are directly estimated within a spatial context

2. **Top-down approaches** emissions are calculated without respect to location
   - quantifying the fuel consumption by power production first
   - and then multiplying the consumption by emission factors.

   Two approaches to calculate **total fuel consumption**:

   - From **world-wide sales of bunker** by summing up per country.

   - **Model fleet activity and estimate fuel consumption resulting from this activity** (summing up per ship/segment).

Activity-based top-down approach (Reference year 2001)

Step 1: Fleet statistics

based on international shipping statistics from Lloyd's (90,000 ships divided into 132 sub-groups)

For all sub-groups

- **Accumulated installed engine power**
- **Average engine running hours**
- **Engine load factor** based on duty cycle profile
- **Power-based specific fuel oil consumption**

Step 2: Total fuel consumption 280 Mt in 2001

Power-based emission factors for each pollutant (NO_x, SO_x, CO_2, HC, PM)

Step 3: Global emissions

Step 4: Vessel traffic densities to distribute emissions over the globe

DLR Institut für Physik der Atmosphäre

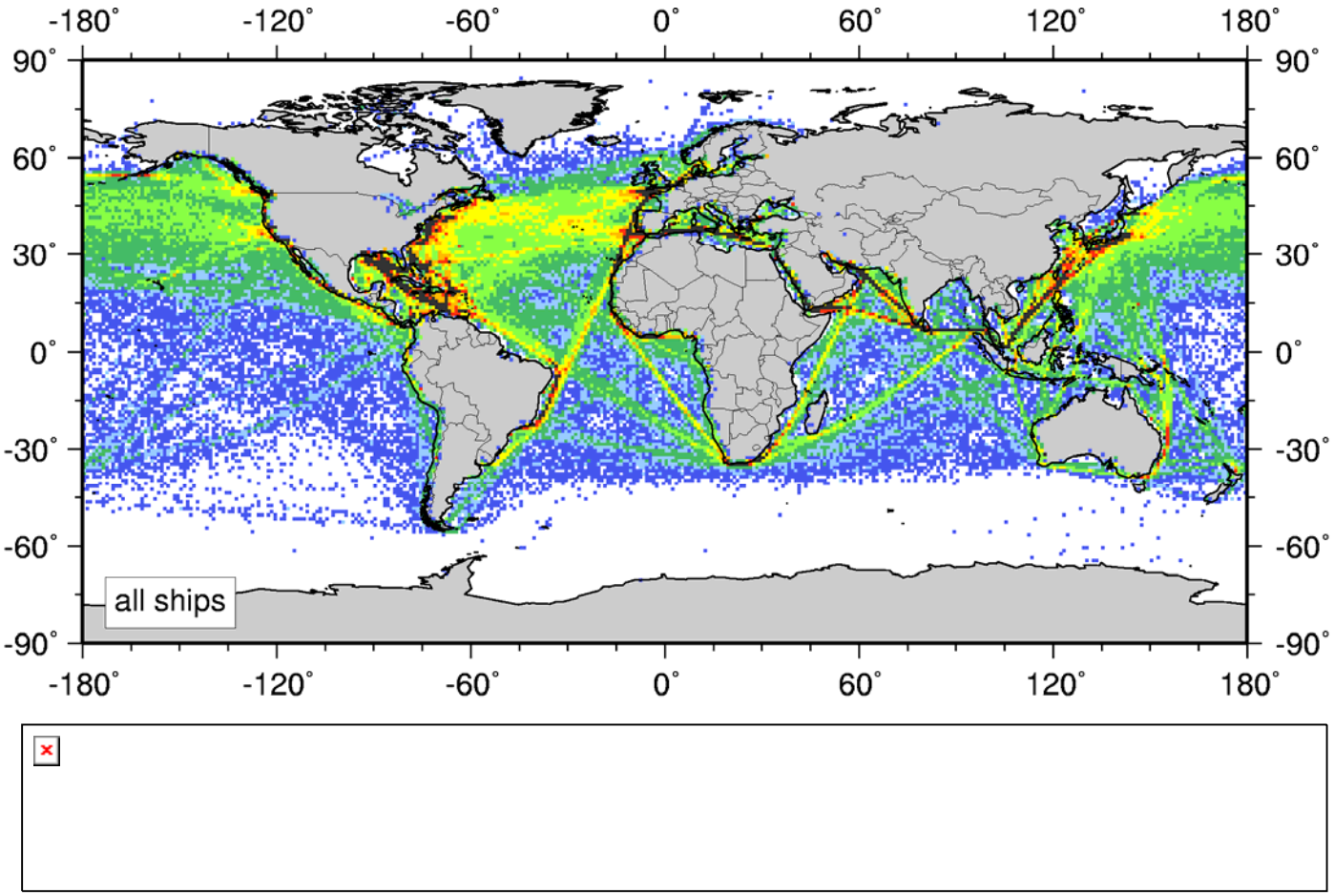
Eyring, V., Horst Köhler et al., Part 1, *JGR*, 2005

MAN

NOx-Emissions in 2001

Global Vessel Traffic Densities based on AMVER data (Endresen et al., 2003)

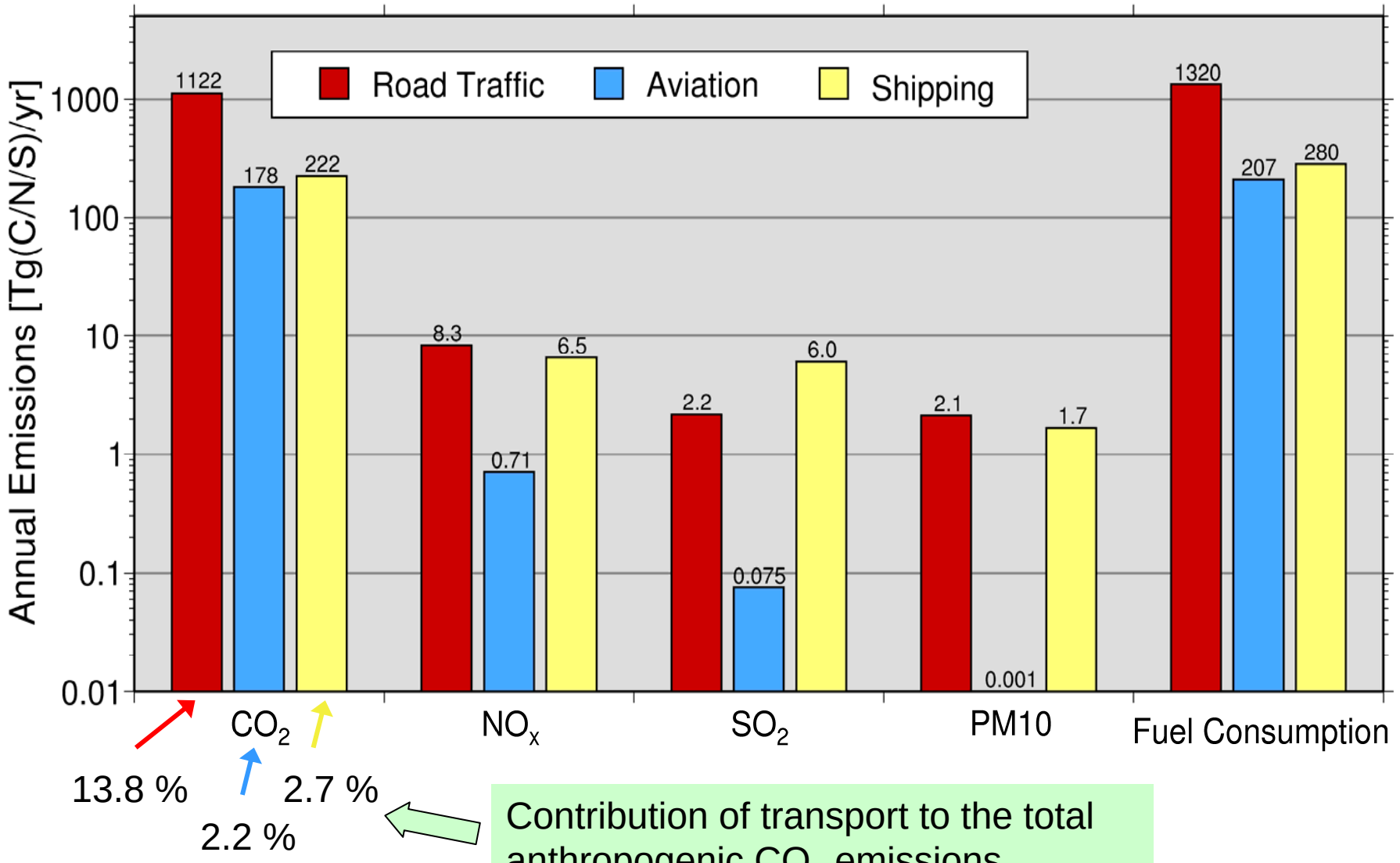
Global: 21.4 Tg (NO_2)



Institut für
Physik der Atmosphäre

Eyring et al., Part 1, *JGR*, 2005

Transport-related emissions for the year 2000



Contribution of transport to the total anthropogenic CO_2 emissions

DLR Institut für Physik der Atmosphäre

Eyring et al., Part 1, *JGR*, 2005

Emissions from international shipping

Overview

1 Impact Chain of Ship Emissions

2 Estimates of Past and Present-day Emissions

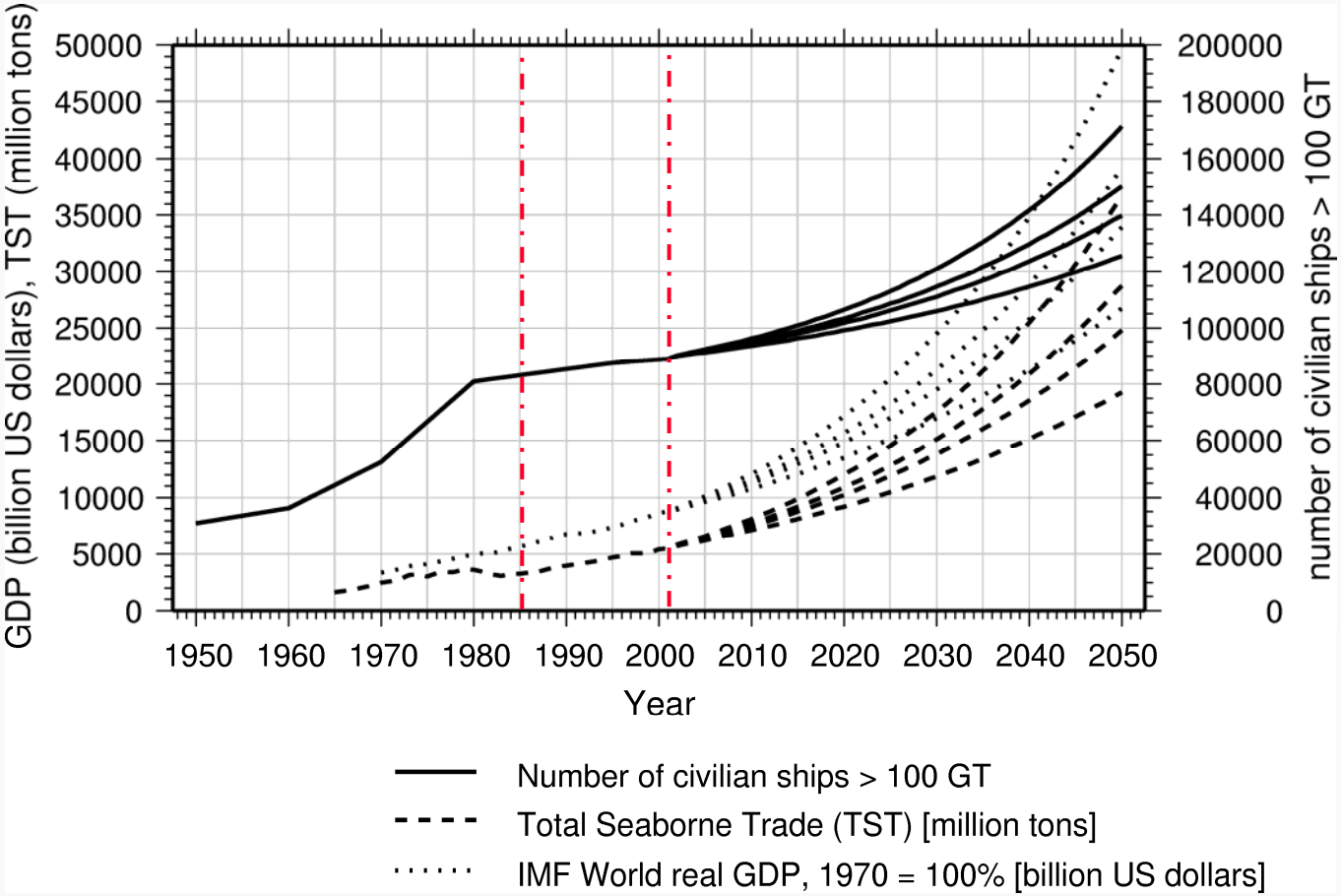
3 Estimates of Future Emissions

4 Validation Measurements

5 Impact Studies

6 Summary and Outlook

Ship Traffic Demand Scenarios until 2050



- **Ship Traffic Demand Scenario 1:** GDP growth 2.3%, following **IPCC SRES storyline A2** (**TST:** 2.6%)
- **Ship Traffic Demand Scenario 2:** GDP growth 2.8%, following **IPCC SRES storyline B2** (**TST:** 3.1%)
- **Ship Traffic Demand Scenario 3:** GDP growth 3.1%, following **IPCC SRES storyline B1** (**TST:** 3.4%)
- **Ship Traffic Demand Scenario 4:** GDP growth 3.6%, following **IPCC SRES storyline A1** (**TST:** 4.0%)

Historical correlation between TST and real GDP (1985 und 2001)

Historical correlation between TST and Number of Ships (1985 und 2001)

DLR **Institut für Physik der Atmosphäre**

Eyring et al., Part 2, *JGR*, 2005

Technology Scenarios in 2020 and 2050

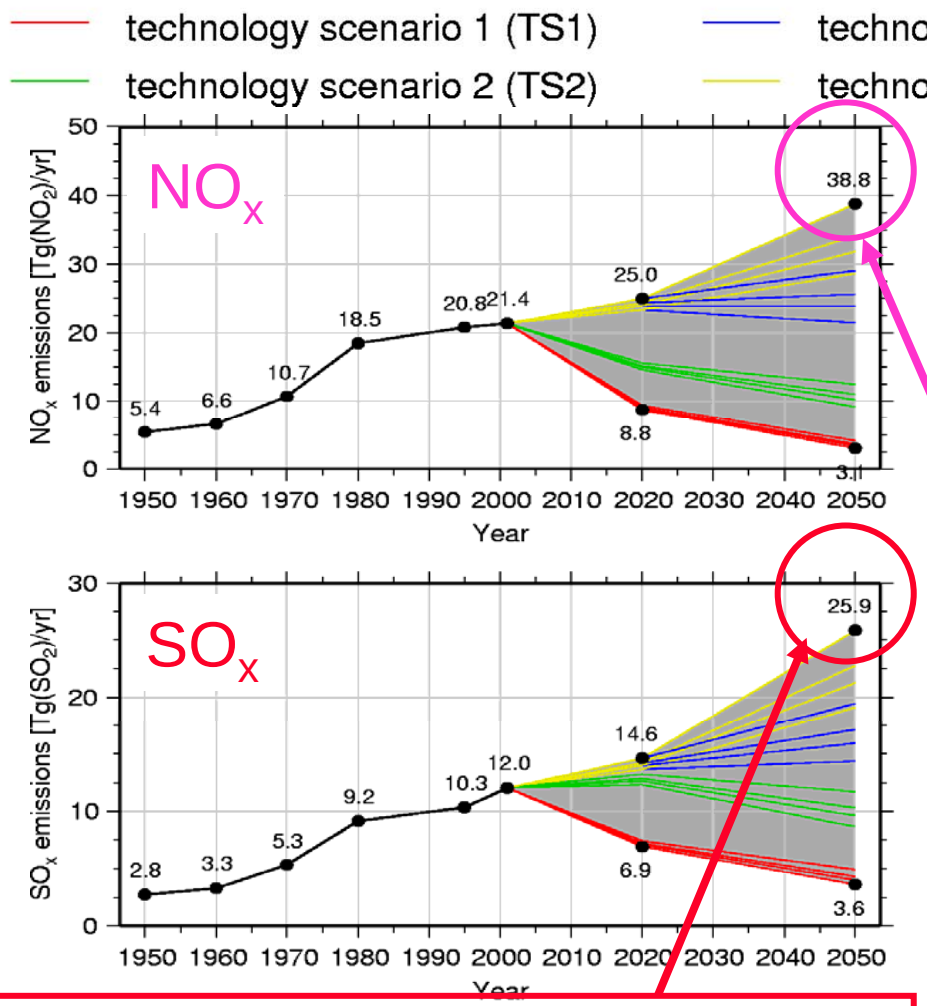
Eyring et al., Part 2, *JGR*, 2005

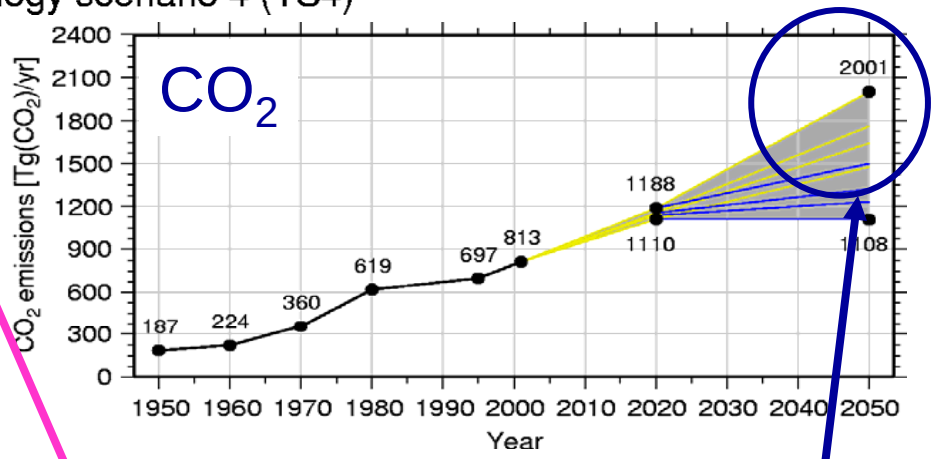
	Today's fleet average (2001)	Technology scenario TS1: clean scenario	Technology scenario TS2: medium scenario	Technology scenario TS3: IMO compliant scenario	Technology scenario TS4: business-as-usual, but meeting IMO emission limits
		Low sulfur content Aggressive NO_x reduction	Relatively low sulfur content Moderate NO_x reduction	Still high sulfur content NO_x reduction according to IMO regulations, but no further reductions	Still high sulfur content NO_x reduction according to IMO regulations, but no further reductions
			Fleet average fuel sulfur content in 2020 / 2050		
Fuel sulfur content	2.4	1 / 0.5	1.8 / 1.2	2 / 2	2 / 2
Emission indices	in kg/t fuel		**Technology reduction factors in 2020 / 2050**		
EI_{SOx}	43	0.42 / 0.21	0.75 / 0.50	0.83 / 0.83	0.83 / 0.83
EI_{NOx}	76.4	0.30 / 0.10	0.50 / 0.30	0.80 / 0.70	0.80 / 0.70
EI_{CO2}	2905	1 .0 / 0. 95	1.0 / 0.95	1.0 / 0.95	1.0 / 0.95
EI_{CO}	4.67	0.90 / 0.80	0.95 / 0.90	1.0 / 1.0	1.0 / 1.0
EI_{HC}	7.0	0.80 / 0.60	0.90 / 0.80	0.95 / 0.90	0.95 / 0.90
EI_{PM}	6.0	0.80 / 0.60	0.90 / 0.80	0.95 / 0.90	0.95 / 0.90

Fleet average emission factor for 2001 from first part of the study

Ship Emission Scenarios until 2050

4 Demand Scenarios (GDP growth based on IPCC SRES Scenarios) & 4 Technology Scenarios





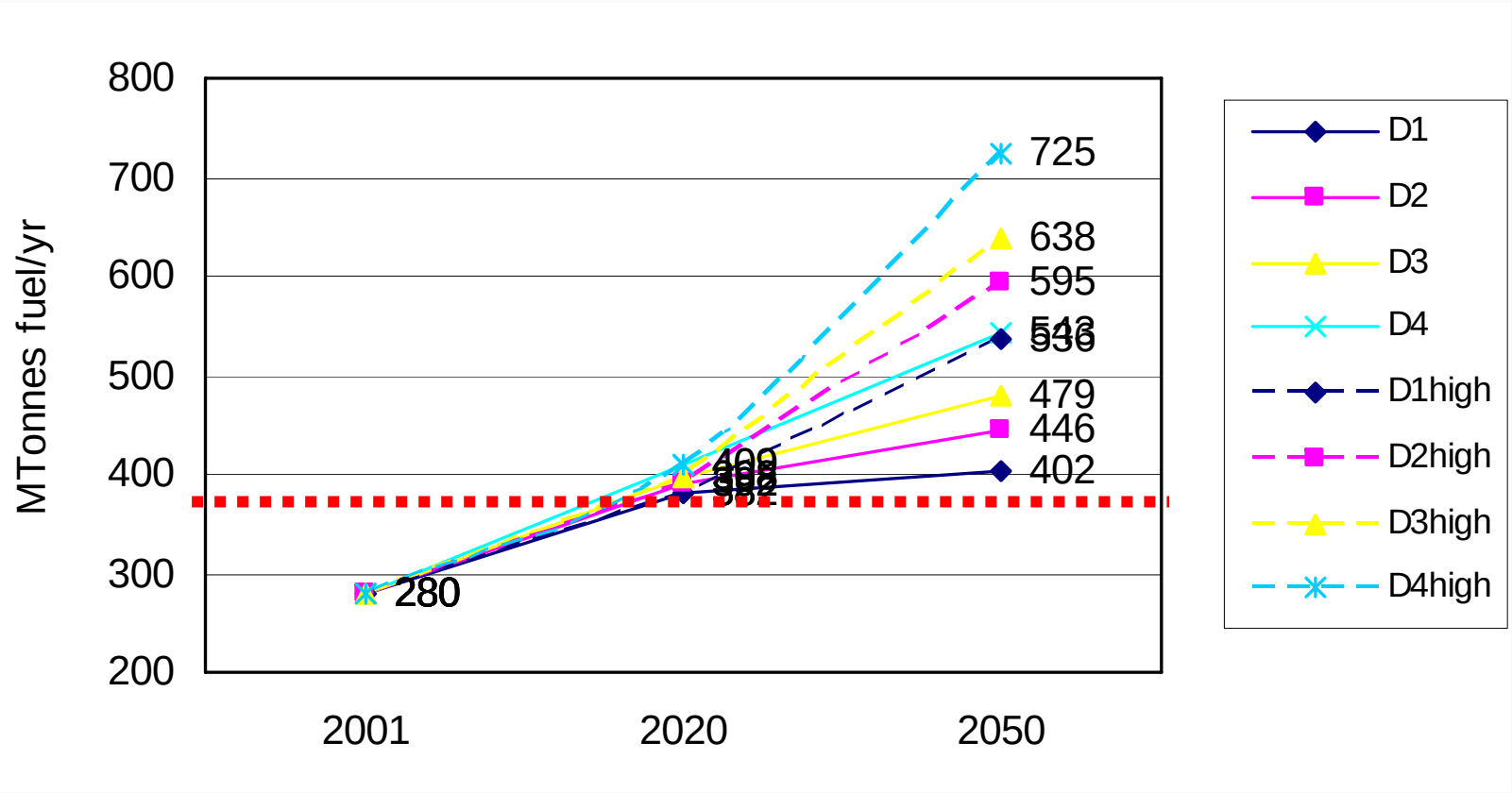
Predicted Growth in CO_2 in all scenarios

If no aggressive emission reduction strategies are introduced NO_x emissions could exceed present-day global road transport emissions in 2050.

If the fleet average sulfur content of the fuel remains at today's high level (2.4%-2.7%), SO_2 emissions from ships could double present-day values by 2050

Eyring et al., Part 2, *JGR*, 2005

Estimated Future Fuel Consumption - Recent Growth Rates



Fuel Consumption in Mt / yr	Endresen et al., JGR, 2003	Corbett and Köhler, JGR, 2003	Eyring et al., JGR, 2005	Intertanko, August 2007	5.2% annual growth rate in TST from 2001 to 2006 (Fearnleys, 2007) ←
2000	195				
2001		289	280		
2007	262	385	373	411	

Emissions from international shipping

Overview

1 Impact Chain of Ship Emissions

2 Estimates of Past and Present-day Emissions

3 Estimates of Future Emissions

4 Validation Measurements

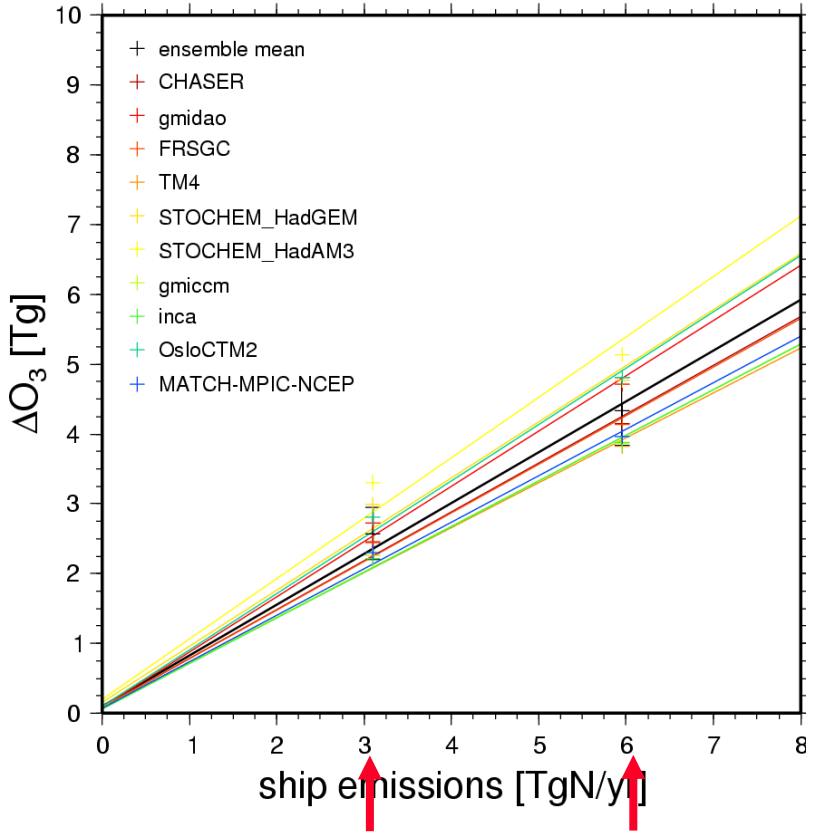
5 Impact Studies

6 Summary and Outlook

Change in Tropospheric Ozone Columns due to Shipping

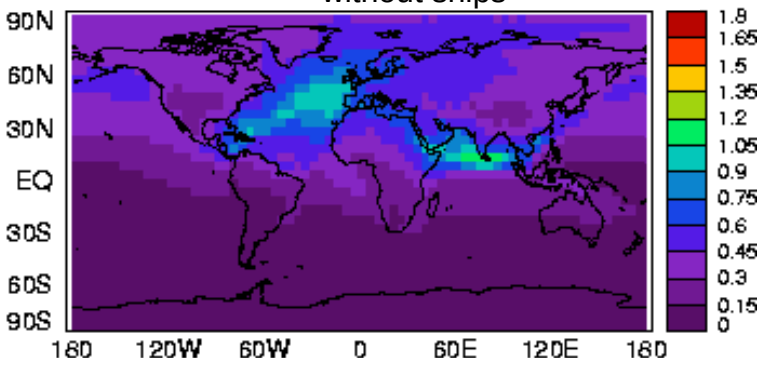
Constant Growth Scenario:
2.2% Annual Increase Rate

Change in ozone burden in Tg



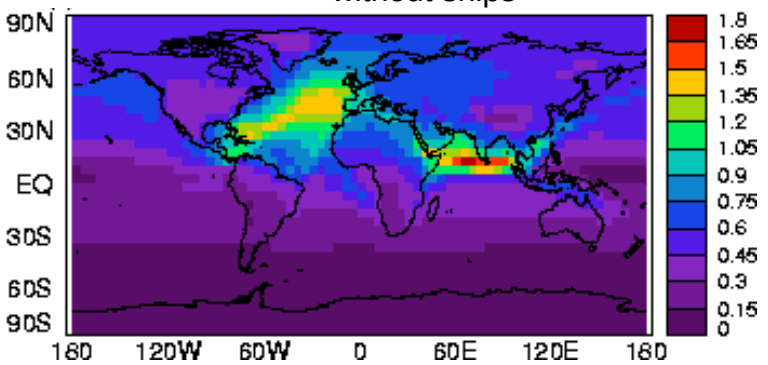
3.1 Tg(N) **6.0 Tg(N)**

2000-2000$_{\text{without ships}}$ in DU



Global mean increase of tropospheric ozone burden between 2000 and 2030 due to ship emissions (IPCC A2 Scenario + 'Constant Growth Scenario' for ships) is **3%**

2030-2030$_{\text{without ships}}$ in DU



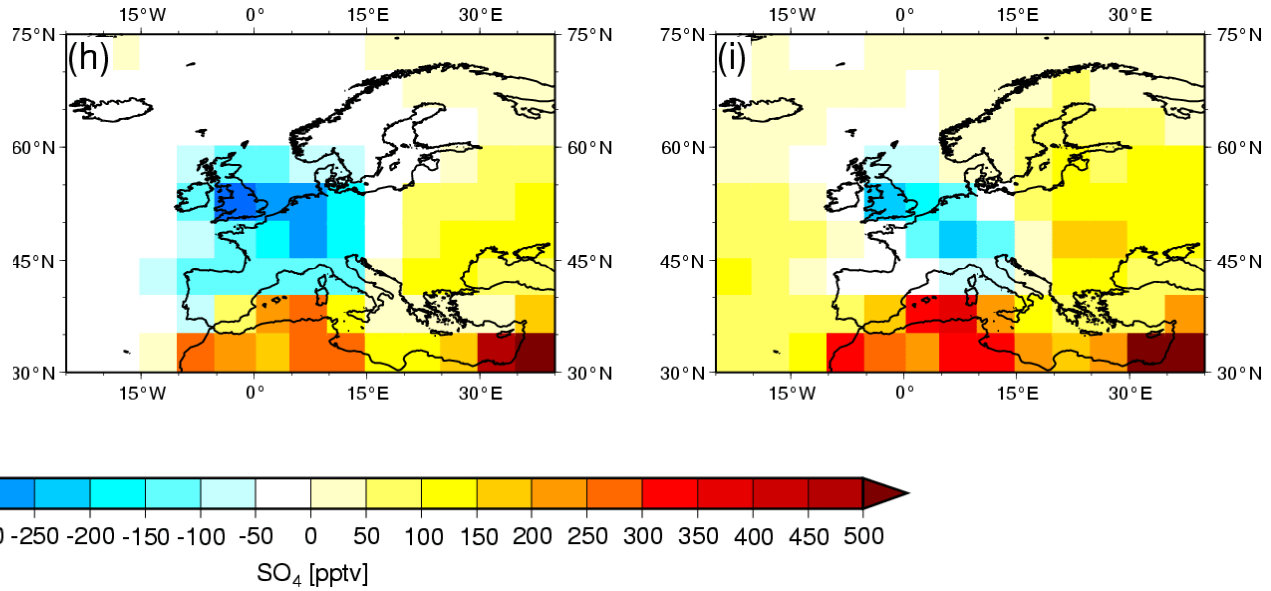
DLR
Institut für Physik der Atmosphäre

Eyring et al., ACP, 2007

Change in Sulphate between 2000 and 2030 over Europe

$2000\text{-}2030_{Schiffe,2000}$ $2000\text{-}2030_{Schiffe,2030}$

SO_4 [pptv]



SO_4: increasing emissions from shipping would significantly counteract the benefits derived from reducing land based SO_2 emissions from all other anthropogenic sources under the A2 scenario .

DLR Institut für Physik der Atmosphäre

Eyring et al., ACP, 2007

Emissions from international shipping

Overview

1 Impact Chain of Ship Emissions

2 Estimates of Past and Present-day Emissions

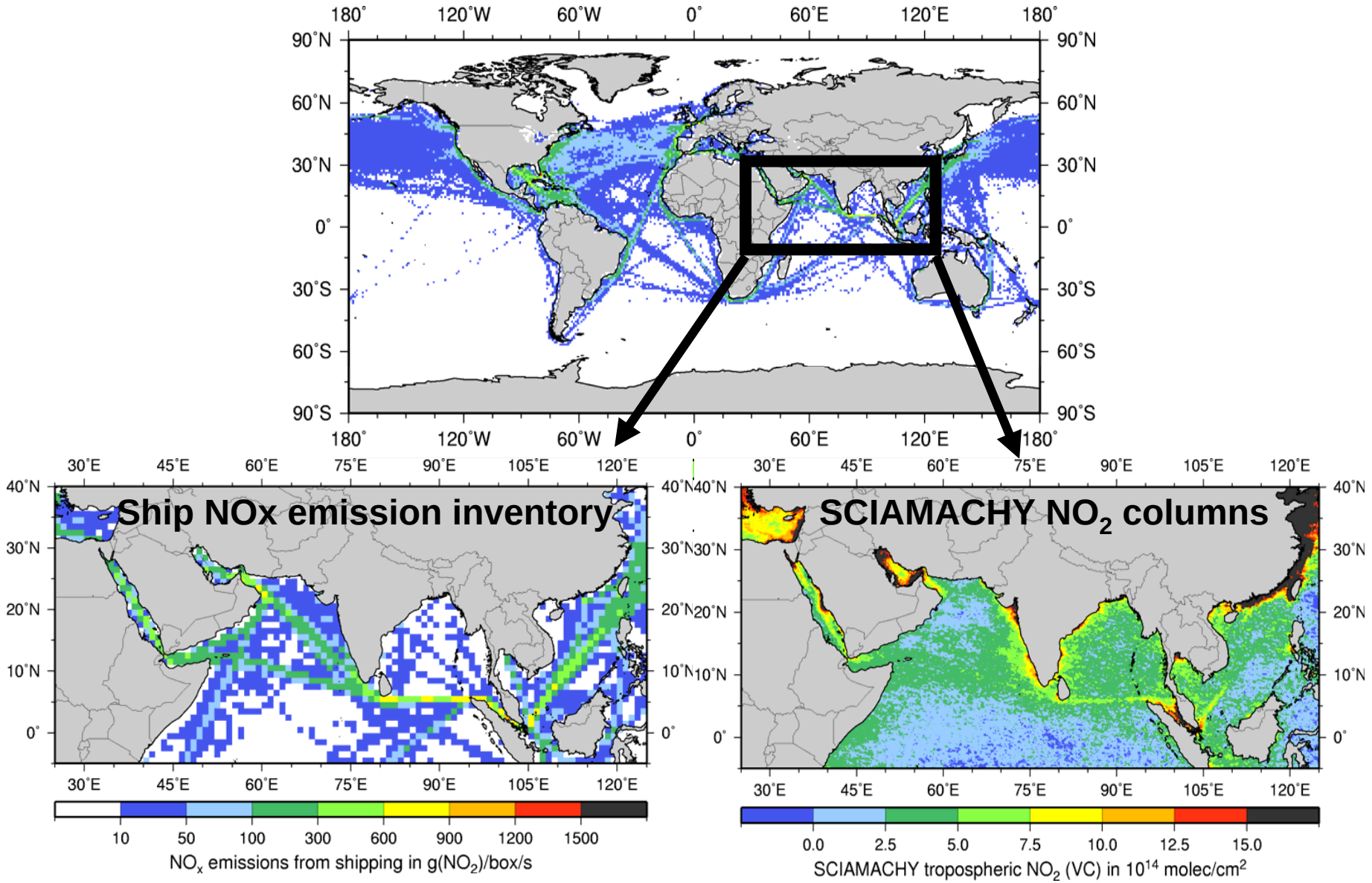
3 Estimates of Future Emissions

4 Validation Measurements

5 Impact Studies

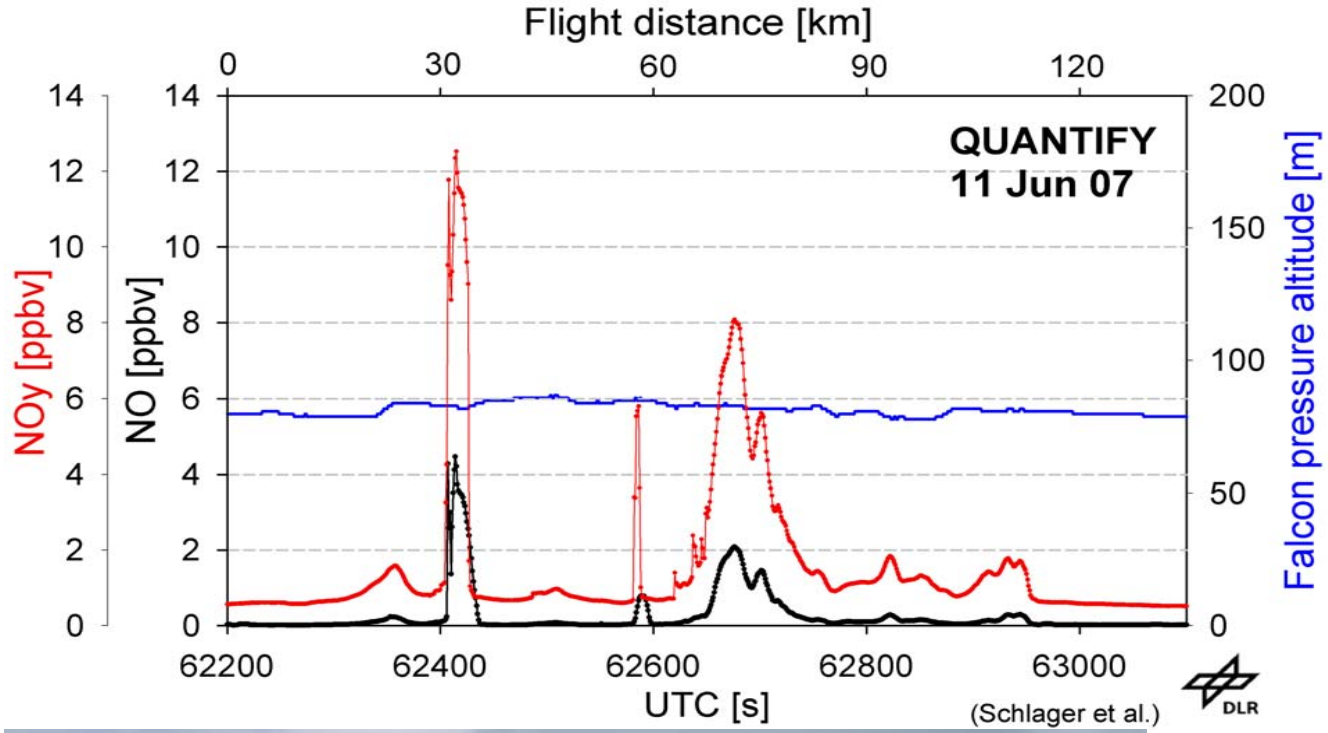
6 Summary and Outlook

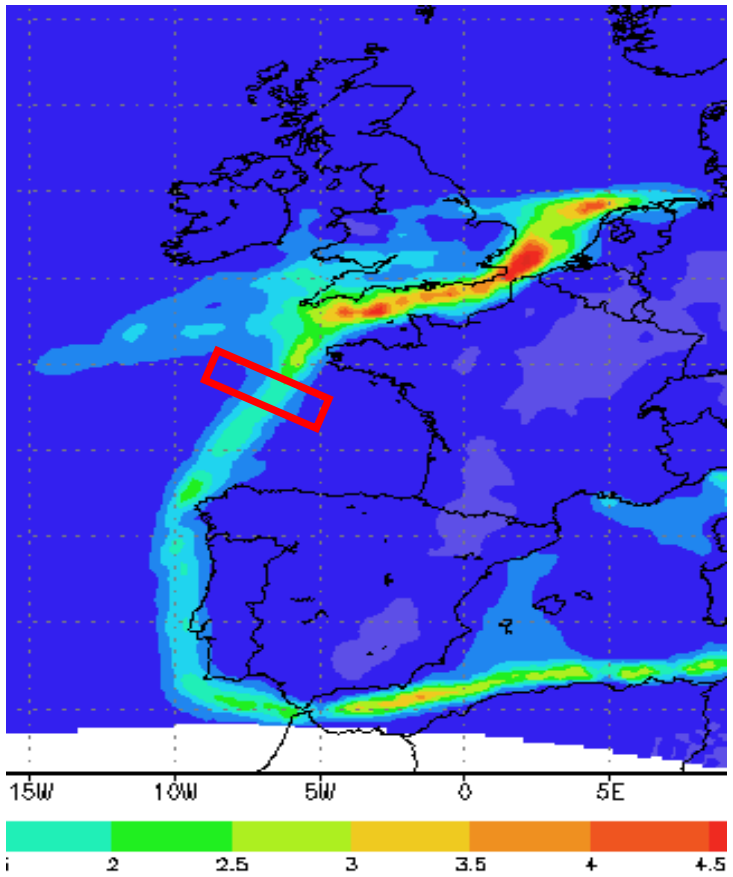
(A) Validation with Satellite Measurements



Richter et al., GRL, 2004

Shipping corridor survey flight
- Validating Emission Inventories -





Schlager et al., 2007

Emissions from international shipping

Overview

1 Impact Chain of Ship Emissions

2 Estimates of Past and Present-day Emissions

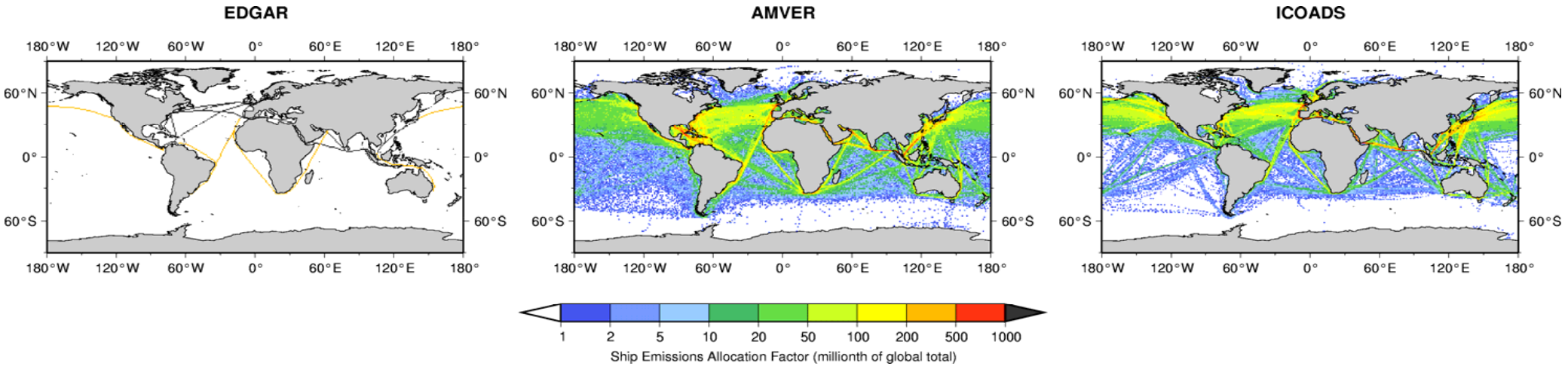
3 Estimates of Future Emissions

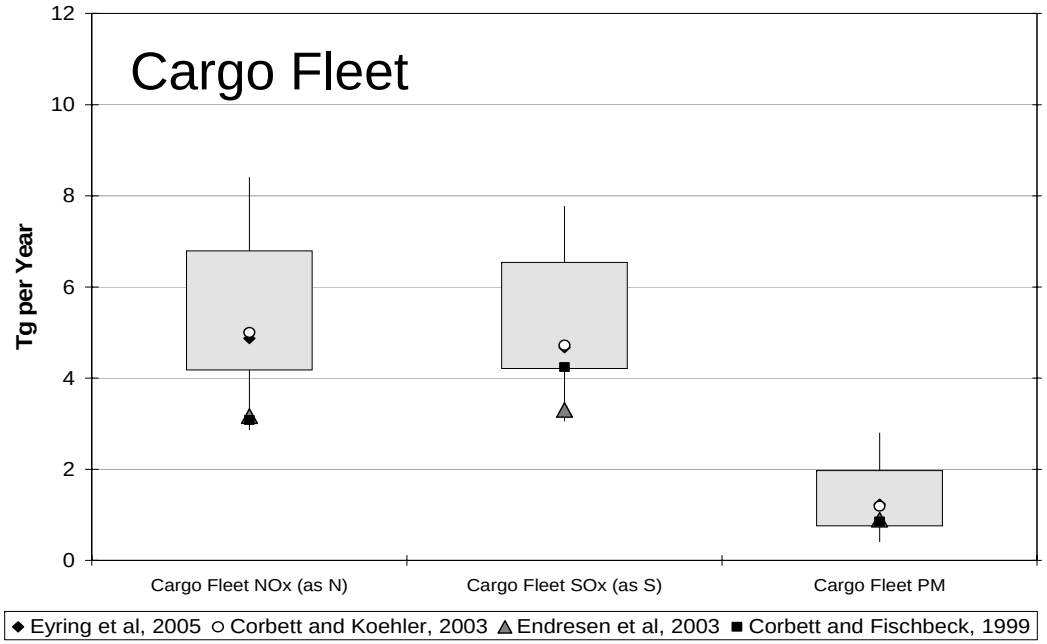
4 Validation Measurements

5 Impact Studies

6 Summary and Outlook

Uncertainties in Ship Emissions





DLR
Institut für
Physik der Atmosphäre

Key Statements on Emissions (1)

- **Over the past decades**, the world merchant fleet, fuel consumption and emissions from international shipping have steadily increased.
- **Present-day: Considering the different estimates reported**
  - shipping moves more than **90% of freight** within a bounded range of **600-900 Tg CO_2/year** and contributed between **2-2.7% to all anthropogenic CO_2 emissions in 2000**.
  - **This corresponds to a fuel consumption** between **200 and 290 Mt**.
  - **Other comparisons suggest** that shipping accounts for around **15% of all global anthropogenic nitrogen oxides (NO_x) emissions** and for around **4-9% of sulphur dioxide (SO_2) emissions**.
- **Future: Emission scenario calculations up to the year 2050** show that a significant increase has to be expected in the future if ship emissions remain unabated,

Key Statements on Emissions (2)

There is agreement that better input data on ship activity and **improved means of allocating activity geospatially** will reduce current differences among inventories

- true despite ongoing scientific debate regarding whether bunker sale statistics are representative when estimating fuel based emissions, and whether input data on engine operational profiles for different ship types and size categories are representative
- **Tier 3 method to estimate fuel consumption needs development:** For emission reporting under Tier 3, improved / newly developed bottom-up estimates and updates on a yearly basis are needed **(Input data expensive!)**