Aerosol indirect effects in tropical shipping corridors: global modeling corroborates results from observations

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Motivation

Aerosol indirect effects (AIEs) are the largest source of uncertainty in estimates of anthropogenic climate forcing (Forster et al., 2007)

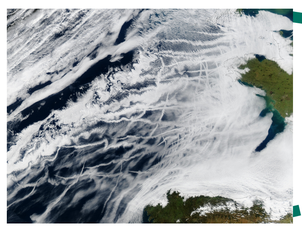
⇒ further basic research is needed

Why ships ?

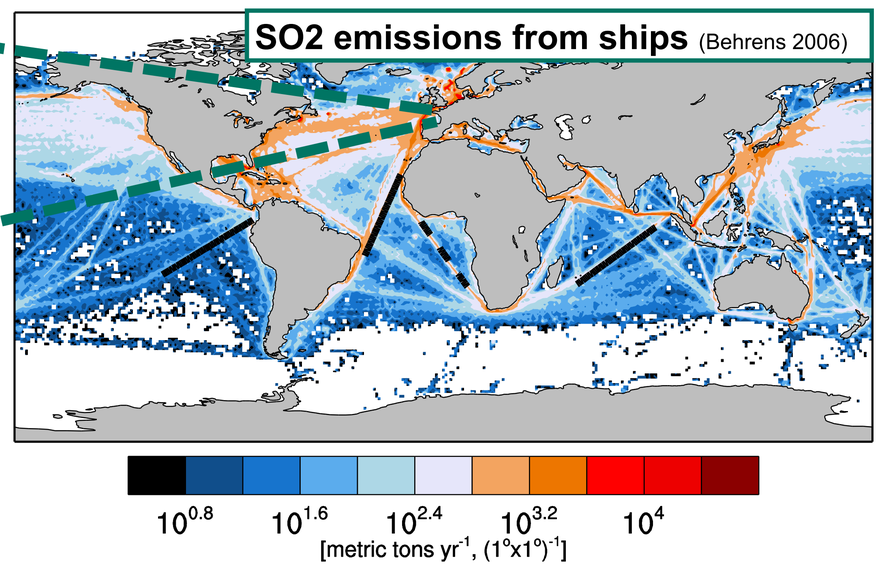
- Emissions from ships modify the composition of the often pristine marine boundary layer (MBL)
  - ⇒ Straight forward attribution of AIEs ("ship tracks") to the emissions
  - ⇒ Future implications through an increase in ship traffic (IMO (2008)

Local vs. large-scale effects of shipping emissions

- large-scale AIEs from shipping emissions **unconstrained from observations**
- global modeling suggests AIEs from shipping of up to -0.6 Wm^{-2} (Lauer et al., 2007)
  - ➢ **Combining observations and modeling yields opportunities for reducing uncertainties !**



AIEs from shipping emissions **on local scales**



Methodology

Global model

- ECHAM-HAM (Roeckner et al., 2003; Zhang et al., 2012)

Emissions (aerosols and precursor gases)

- EU-IP QUANTIFY for ships (Behrens, 2006)
- AeroCom otherwise (Dentener et al., 2006)

Setup

- T63 (1.8°×1.8°), 31 levels
- analysis period 2000 – 2004 (after spinup)
- prescribed SST
- nudged dynamics (ERA-Interim)

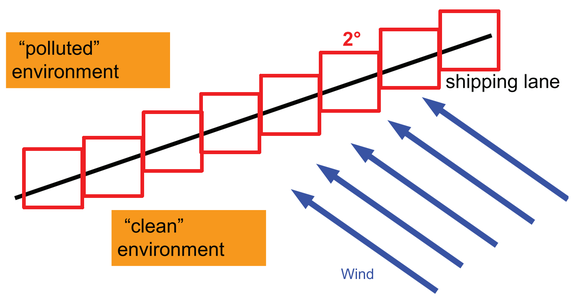
Experiments (among others)

ns	Control simulation **without shipping emissions**
A	**AeroCom** emission parameterisation
Bsc	More soluble particles emitted, emissions scaled by 1.63
Bsc10	as **B**, but emissions scaled by 10

cf. Peters et al. (2012) for detail

Consistency check with observations

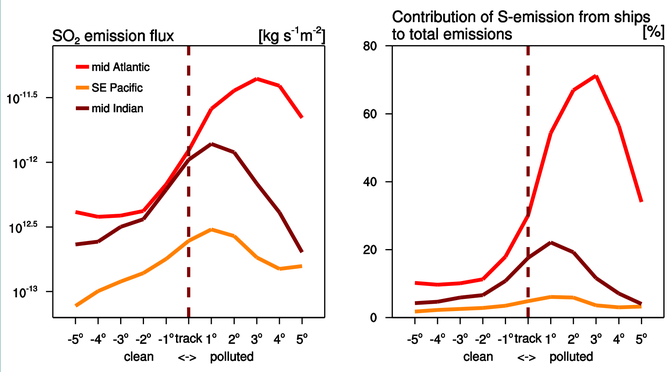
- systematic sampling for "clean" and "polluted" oceanic regions
  - ➢ **Eulerian-type sampling as in Peters et al. (2011)**, who **did not** find statistically significant AIEs on large-scale cloud fields over tropical oceans (using satellite data)



Eulerian sampling – conceptual illustration

Sampling of cloud- and aerosol properties along straight lines parallel to main shipping lane. Time-averages computed over red boxes, *i.e.* one model grid-box.

What to expect OR "How clean is the clean environment" ?



Across-corridor emission gradients in experiment **Bsc**.

Left: annual mean ship-emission fluxes

Right: Share of sulphur (S) emissions from ships in the **total** emissions

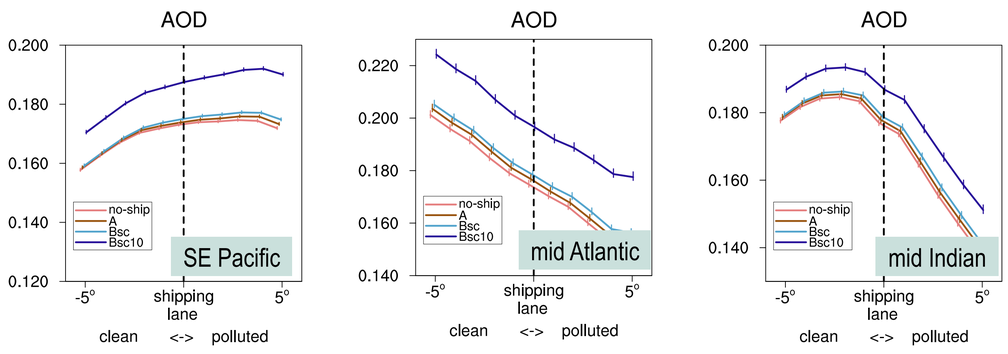
See top right figure (Motivation) for definition of shipping corridors.

Conclusions

- Shipping emissions **clearly modify** the environment of main shipping corridors
- Manifested as **"offset"** compared to control case
- Sampling for **continuous wind** (*O*(days)) yields no significant differences either
- **Consistent with observations** (Peters et al. (2011)), large-scale effect of shipping emissions not clearly discernible

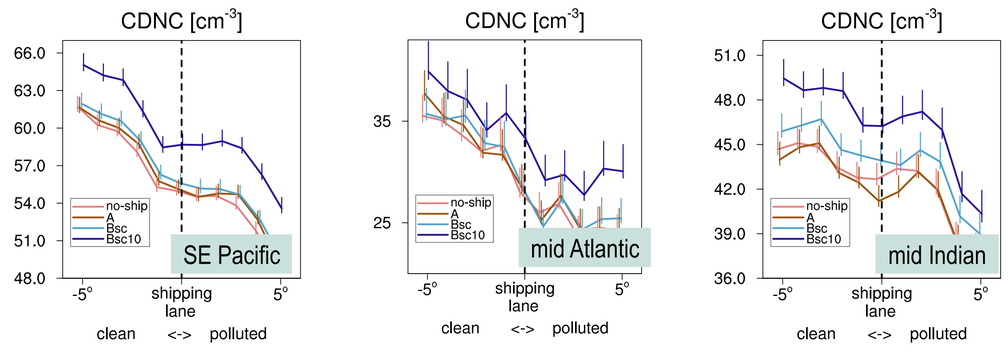
Results

1st order signal, i.e. altered aerosol population ?



- obvious differences in column-integrated radiative properties
- mostly identical shape
  - ➢ "offset-like" perturbation
- relative differences to "no-ship" show change at shipping lane

2nd order signal, i.e. altered cloud properties ?

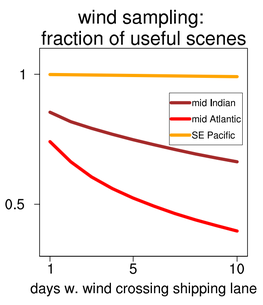


- only unrealistically high emissions show "real" effect
- across corridor gradients also mostly identical
  - ➢ impossible to detect signal for current emissions level **using single simulations**

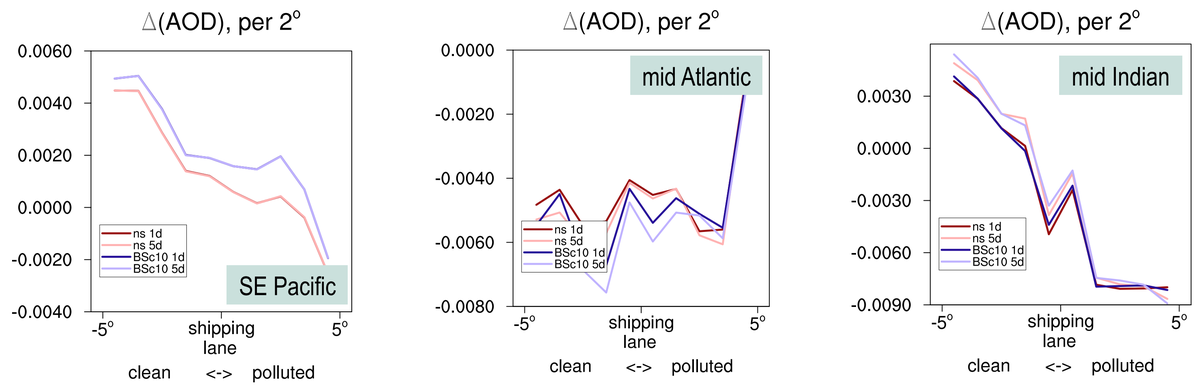
Extracting a signal (Δgradient ?) from single simulations ?

➢ constant wind direction sampling *O*(days)

- Assertion: evident change in gradient downwind of shipping lane with increasing duration of across-corridor winds



1st order signal, i.e. altered aerosol population ?



Subtle differences in across-corridor gradients, similar for both experiments up- as well as downwind of shipping lane, suggest higher importance of air-mass history than expected.

Effect of shipping emissions **at the level of individual shipping lanes** (in the tropics) fails to be detectable as "step-like function" even in strongly forced GCM experiments; modification of the large-scale environment is evident, though !

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References

Behrens, QUANTIFY deliverable D-1-1-2-2 (confidential), 2006; **Dentener et al.**, Atmos. Chem. Phys., 6, 4321-4344, 2006; **Forster et al.**: Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2007; **IMO**, MEPC.176(58) Amendments to the Annex of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (Revised MARPOL Annex VI), 2008;– 2391, 2010; **Peters et al.**, J. Geophys. Res., 116, D24205, 2011; **Peters et al.**, Atmos. Chem. Phys., 12, 5985–6007, 2012; **Roeckner et al.**, Max-Planck-Inst. für Meteorol., Hamburg, Germany, Tech. Rep., 349, 2003; Zhang et al., Atmos. Chem. Phys. Discuss., 12, 7545 – 7615, 201222

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