Climate impact of shipping

A global perspective on the aerosol indirect effect

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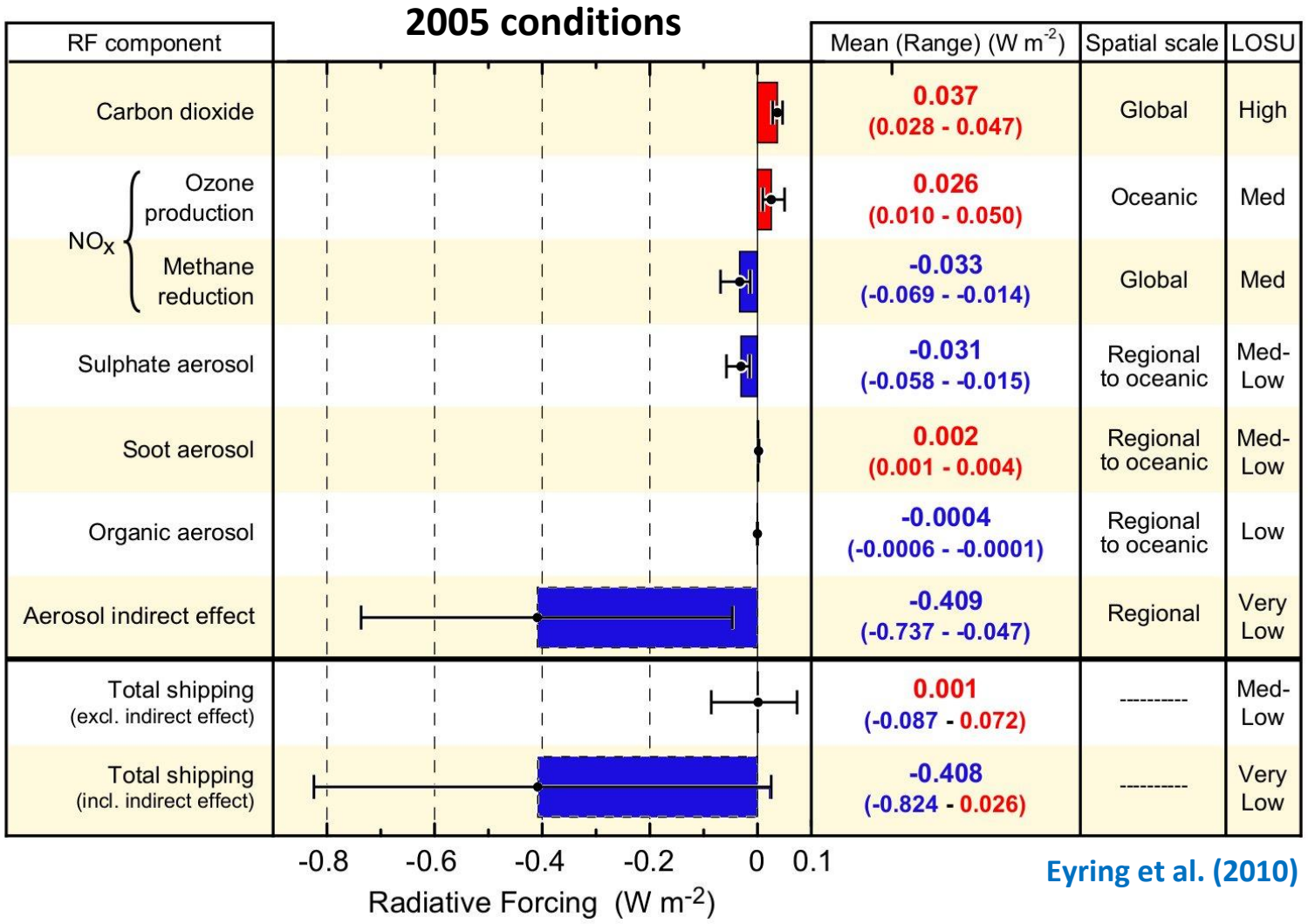
CSHIPP webinar on Clean Shipping International Policies
27 November 2020

Global impact of shipping on the climate

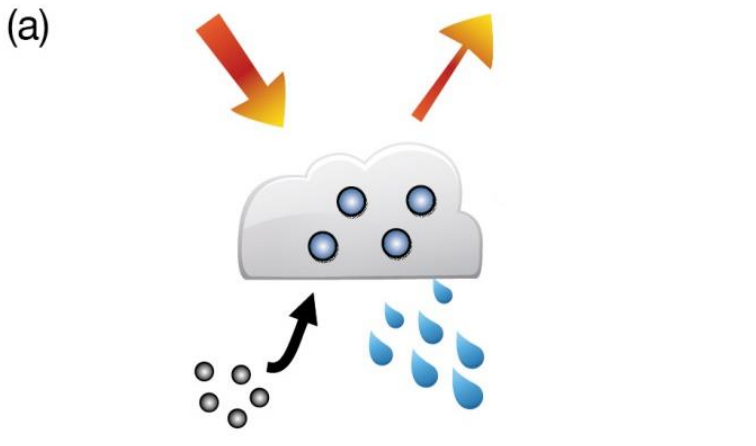


Eyring et al. (2010)

- The impact of different components on climate is usually quantified by means of the **radiative forcing** (RF).
- RF indicates a perturbation to the **radiative balance** of the Earth.
- A positive (negative) RF corresponds to a **warming (cooling)** of the system.
- There is an approximately **linear relationship** between global mean RF and change in global mean surface **temperature**.
- The global shipping RF is strongly dominated by the effect of aerosol on clouds (**aerosol indirect effect**)

Aerosol indirect effect

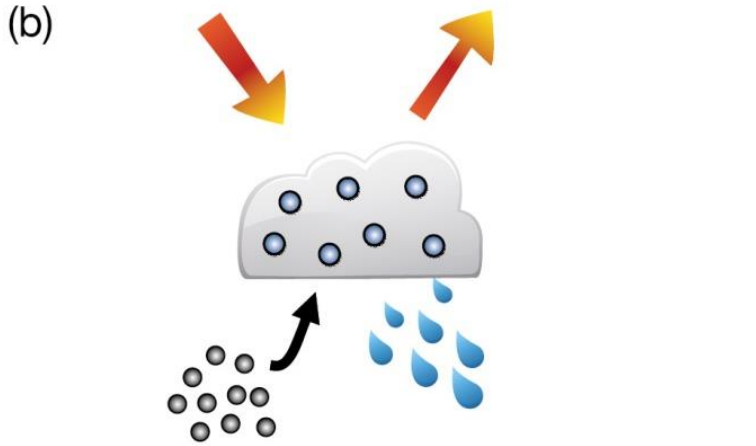
Unperturbed (clean) conditions



Aerosols serve as cloud condensation nuclei upon which liquid droplets can form.

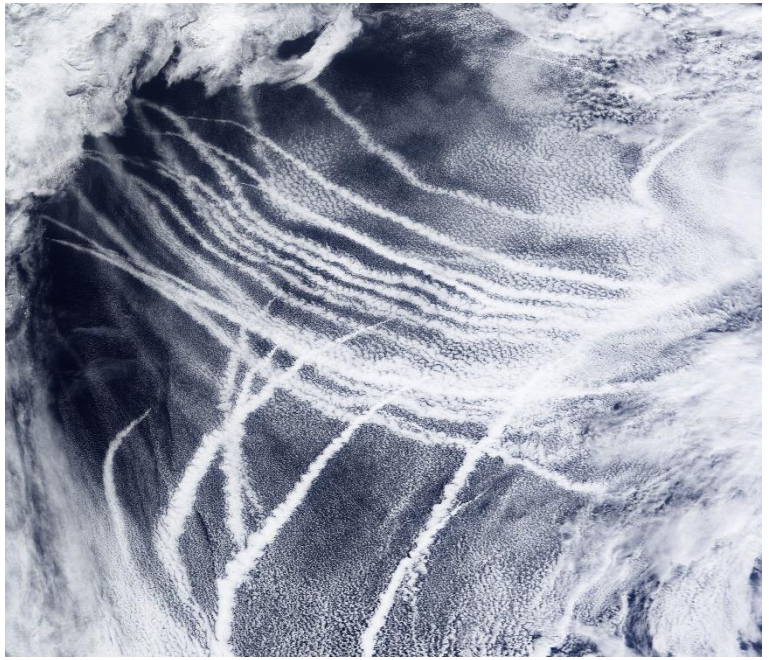
Source: IPCC

Perturbed (polluted) conditions



More aerosols result in a larger concentration of smaller droplets, leading to a brighter cloud. However there are many other possible aerosol–cloud–precipitation processes which may amplify or dampen this effect.

Ship tracks over the Pacific



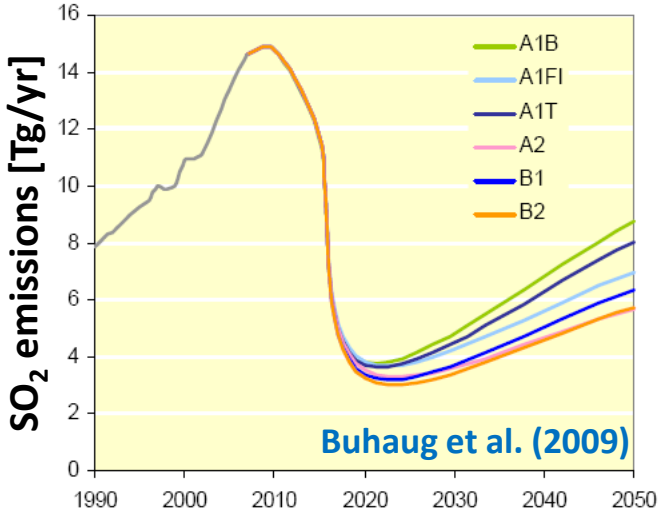
Source: NASA (MODIS-Terra)

Sulfur-rich shipping fuels lead to the emissions of large amount of **SO_2**, which can eventually oxidize and condense to form **aerosol sulfate particles**. These are known to be very efficient **cloud condensation nuclei**. This implies that **shipping** emissions have a very **large potential** of impacting the **climate** via this effect.

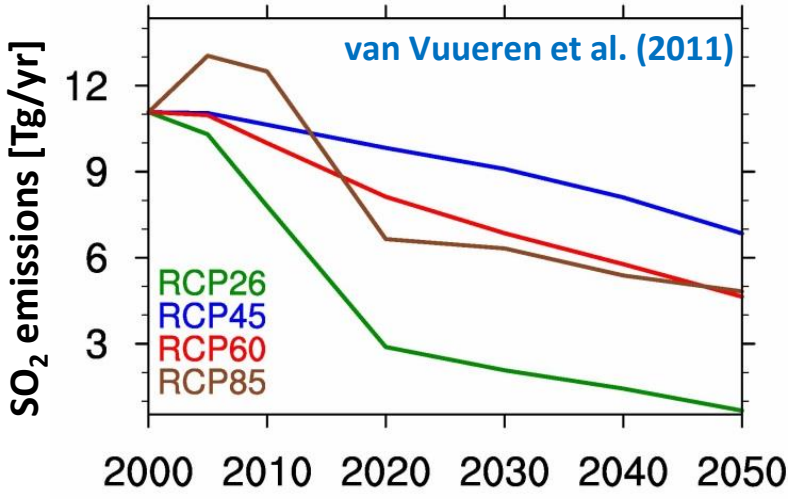
Impact of the IMO fuel sulfur content regulations

- Global fuel **sulfur cap** initially reduced from the current **4.5%** (by mass) **to 3.5% in 2012**, and then progressively to **0.5% in 2020.**
- Sulfur limits in emission control areas (**SECAs**): reduction from **1.5% to 1% in 2010**, and further down to **0.1% in 2015**.
- A number of global **emission inventories** and scenario **projections** have been developed over the years.
- These datasets represent an essential **input** for global climate **model studies** on shipping impact.

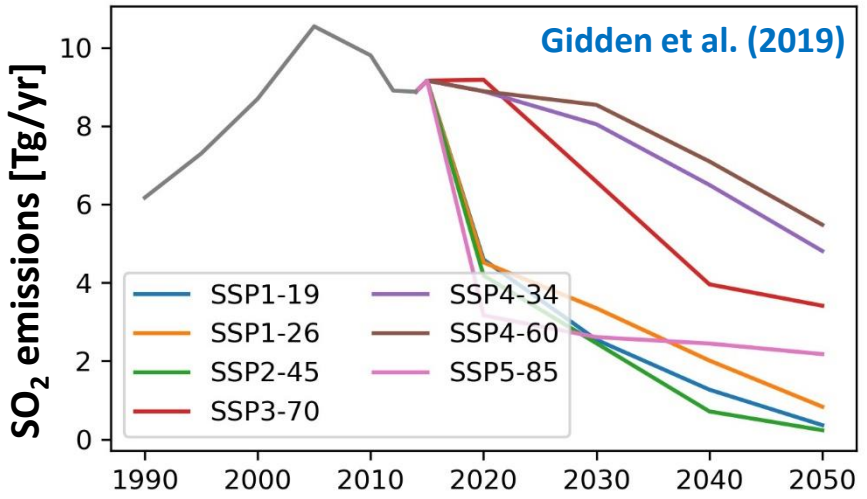
SRES scenarios (2009)



RCPs scenarios (2011)

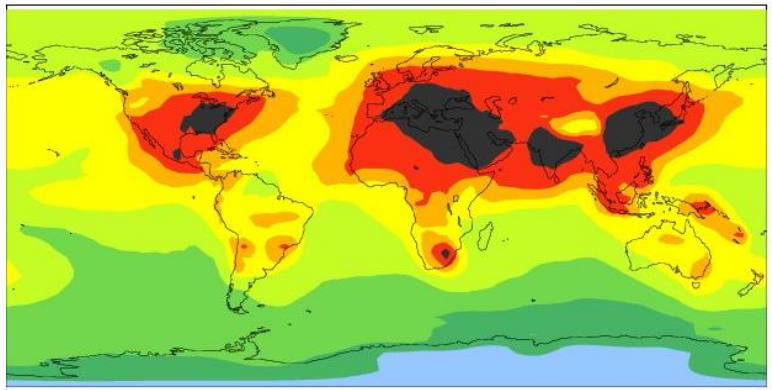


SSPs scenarios (2018)

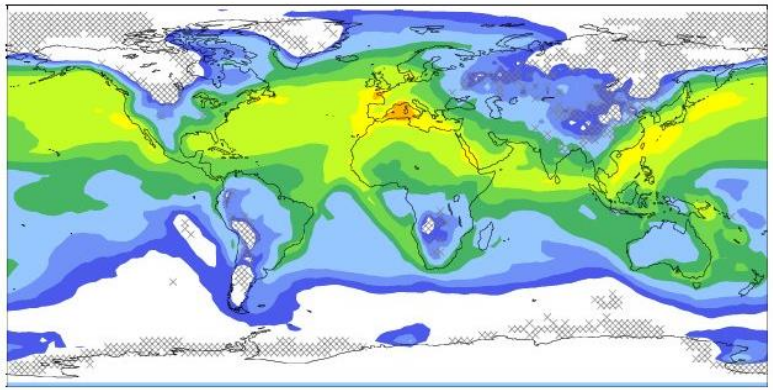


Projections with the EMAC-MADE global aerosol model

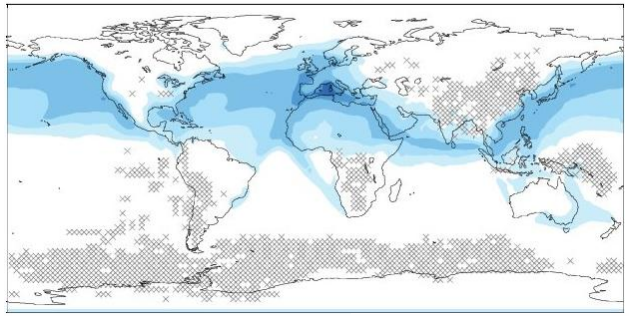
Surface-level aerosol sulfate (2000)



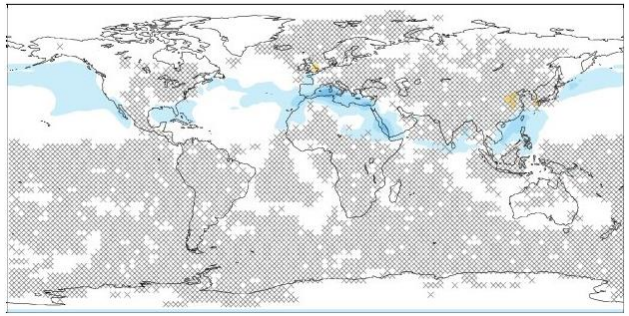
Ship-induced aerosol sulfate (2000)



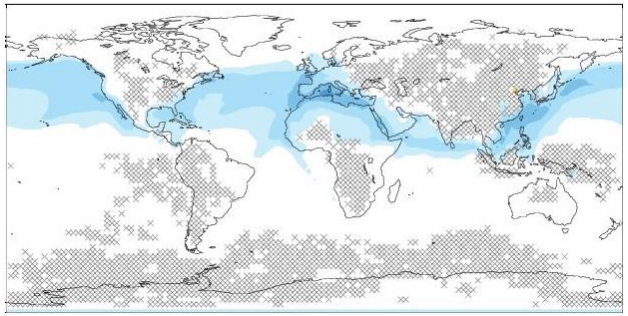
2030 w.r.t. 2000 (RCP2.6)



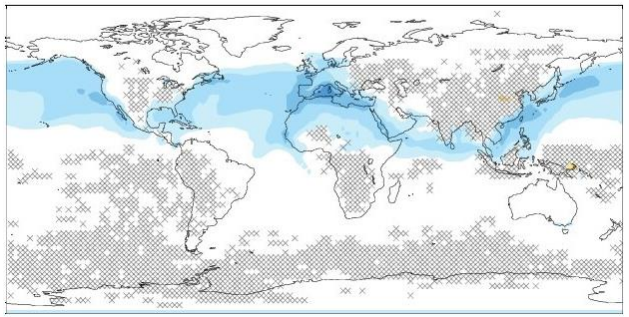
2030 w.r.t. 2000 (RCP4.5)

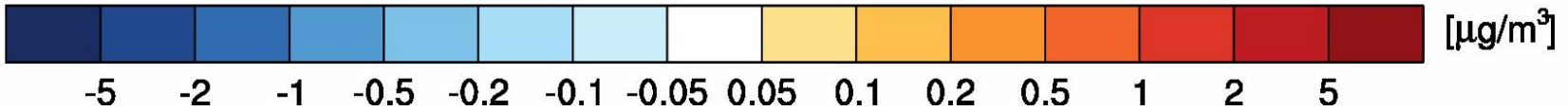


2030 w.r.t. 2000 (RCP6.0)



2030 w.r.t. 2000 (RCP8.5)



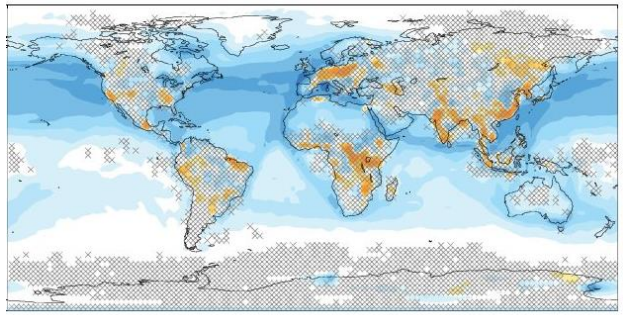


Righi et al. (2013)
Righi et al. (2015)

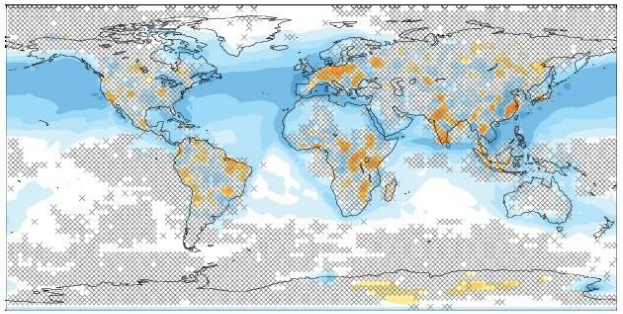
Impact of the IMO regulations on the aerosol indirect effect

Ship-induced particle number concentration (surface-level)

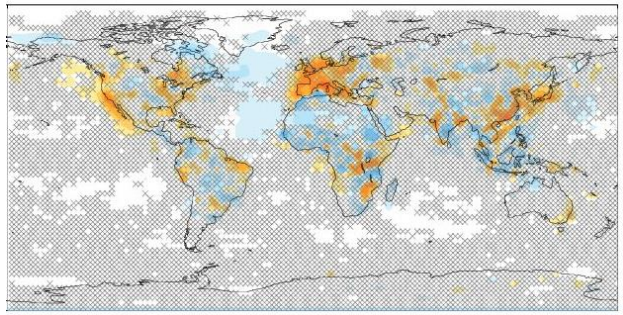
2030 w.r.t. 2000 (RCP2.6)



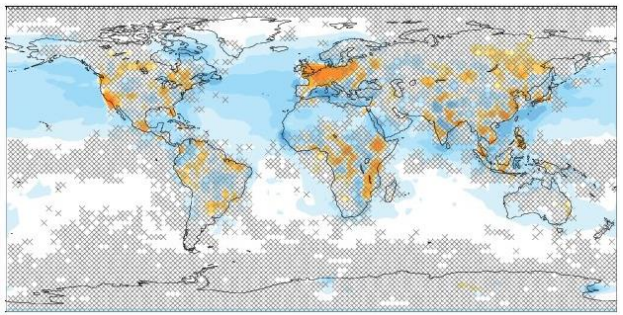
2030 w.r.t. 2000 (RCP6.0)

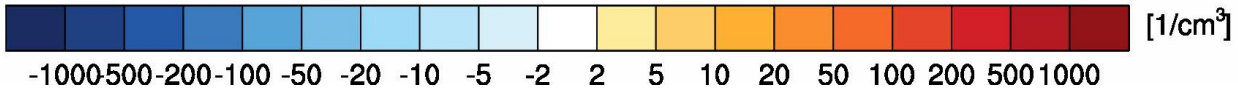


2030 w.r.t. 2000 (RCP4.5)

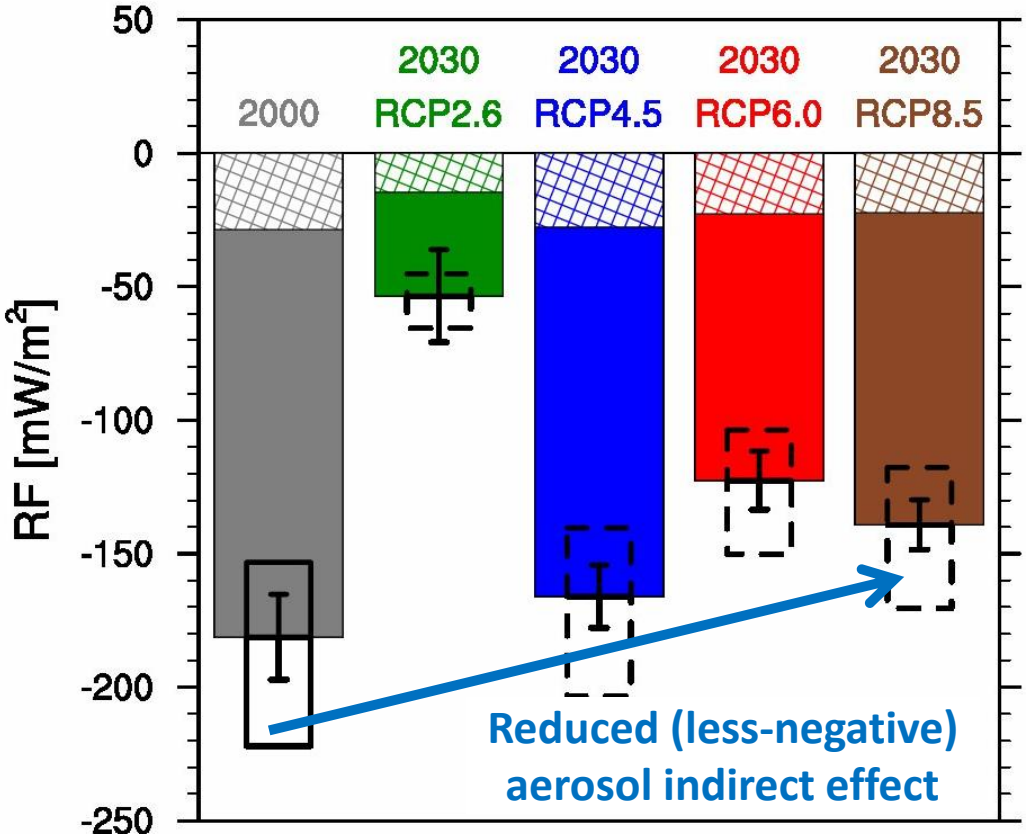


2030 w.r.t. 2000 (RCP8.5)



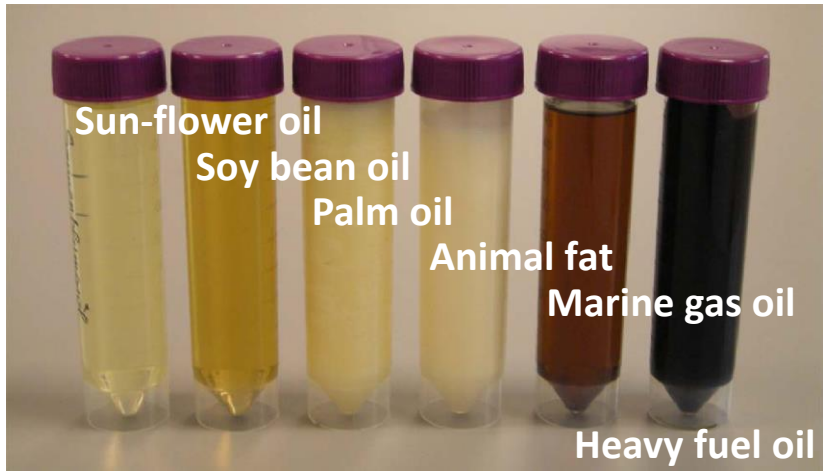


Shipping radiative forcing

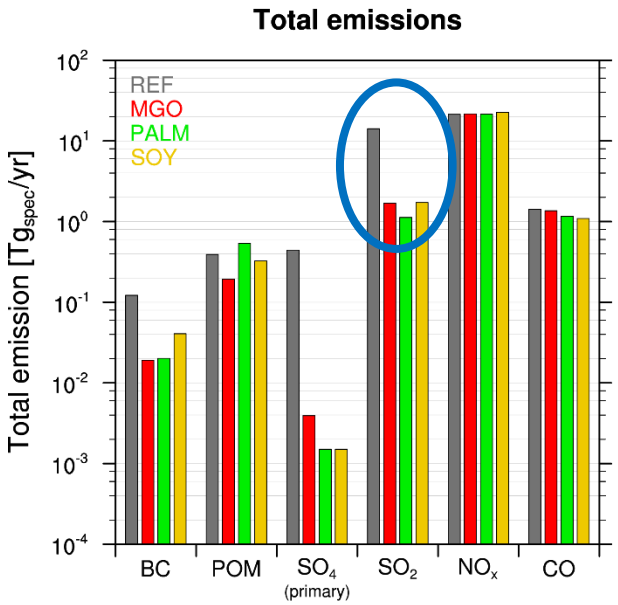


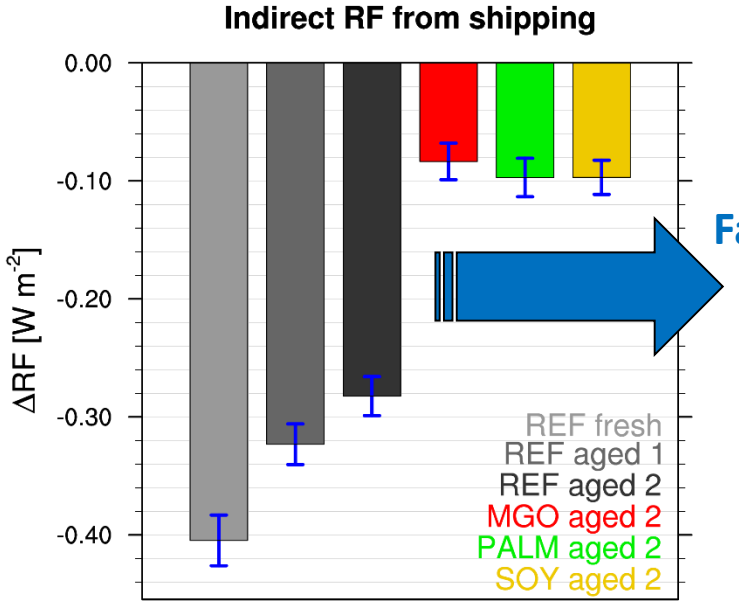
Righi et al. (2013)
Righi et al. (2015)

Use of biofuels to meet IMO regulations



- No technical modifications to the engine are needed
- The investigated set of biofuels demonstrated good combustion properties in the single-cylinder four-stroke test engine.
- The energy content of biofuels is about 10% lower than for conventional fossil fuels
- The optical inspection show no significant increase in engine degradation and corrosion for biofuel use.





Factor of 3 reduction in aerosol indirect effect if alternative fuels are used globally

Petzold et al. (2011)
Righi et al. (2011)

BIOclean
alternative fuels in shipping

DLR MAN

Summary and outlook

- Models show that the **aerosol** effect on clouds represent the **largest contribution** to shipping climate impact, much larger than the one of CO_2 or NO_x.
- IMO regulations on **fuel sulfur content** will lead to a reduction of the aerosol indirect effect from shipping (**reduced cooling**), but with benefits for **air quality**.
- Climate models are the only available tool to estimate **global impacts** of shipping and their **future projections**, nevertheless significant **uncertainties** exist:
  - ⇨ Emission **inventories** and future scenarios.
  - ⇨ Model representation of specific **processes**: cloud processes, particles transformation in plumes, unresolved processes below model resolution (100 km scale).
- Ongoing activities to further **improve** models and **update** the existing estimates with the new SSPs global inventories (DLR Project **TraK**).

Thank you!

Photo by Mattia Righi