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Aerosol intervention technologies to cool the climate: costs, benefits, side effects, and governance (COOL)

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AIMS

- **Focus on black carbon emission reductions and aerosol-related geoengineering techniques as ”fast” options for cooling the climate**

- **The goal is to understand the risks, cost effectiveness, and regional distribution of costs, benefits, positive and negative side effects, legal aspects, and governance options of geoengineering.**

- **Clean technologies reducing black carbon emissions globally function as a benchmark alternative.**

- ***WP1: BC- emissions, transport, forcing***
- ***WP2: Climate modelling***
- ***WP3: Legal aspects***
- ***WP4: Analyses of framing***
- ***WP5: Synthesis – scenarios and future paths***

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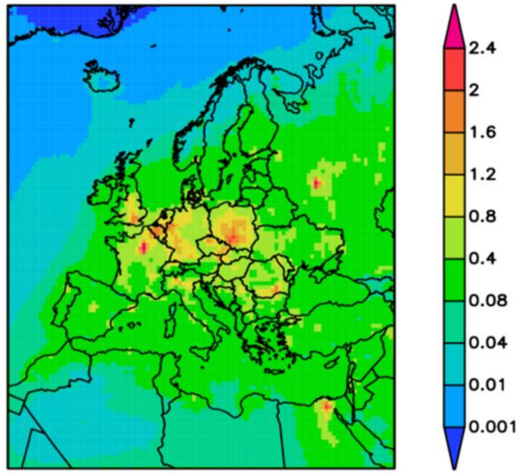
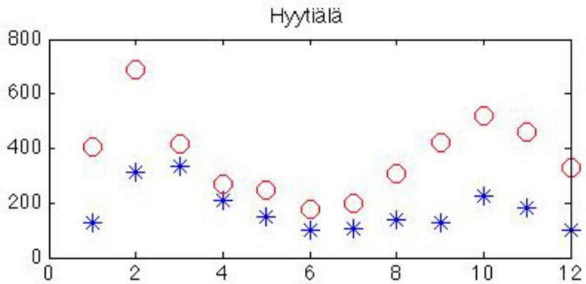
Finnish BC emissions

Simulations with regiaonal aerosol-climate model REMO-HAM

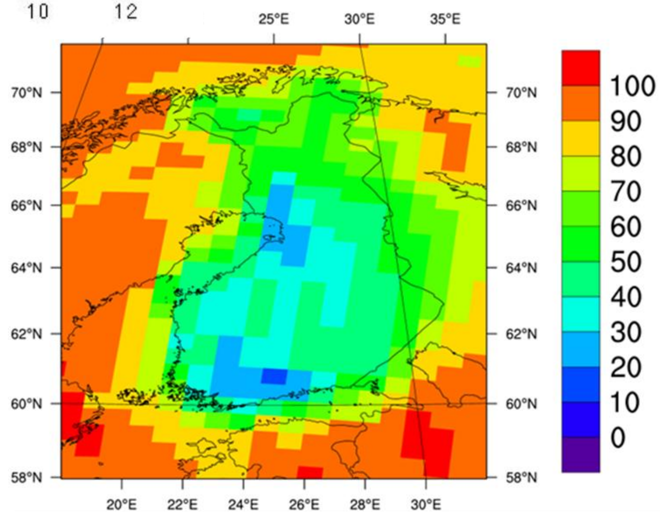
BC concentrations in Europe, 2005



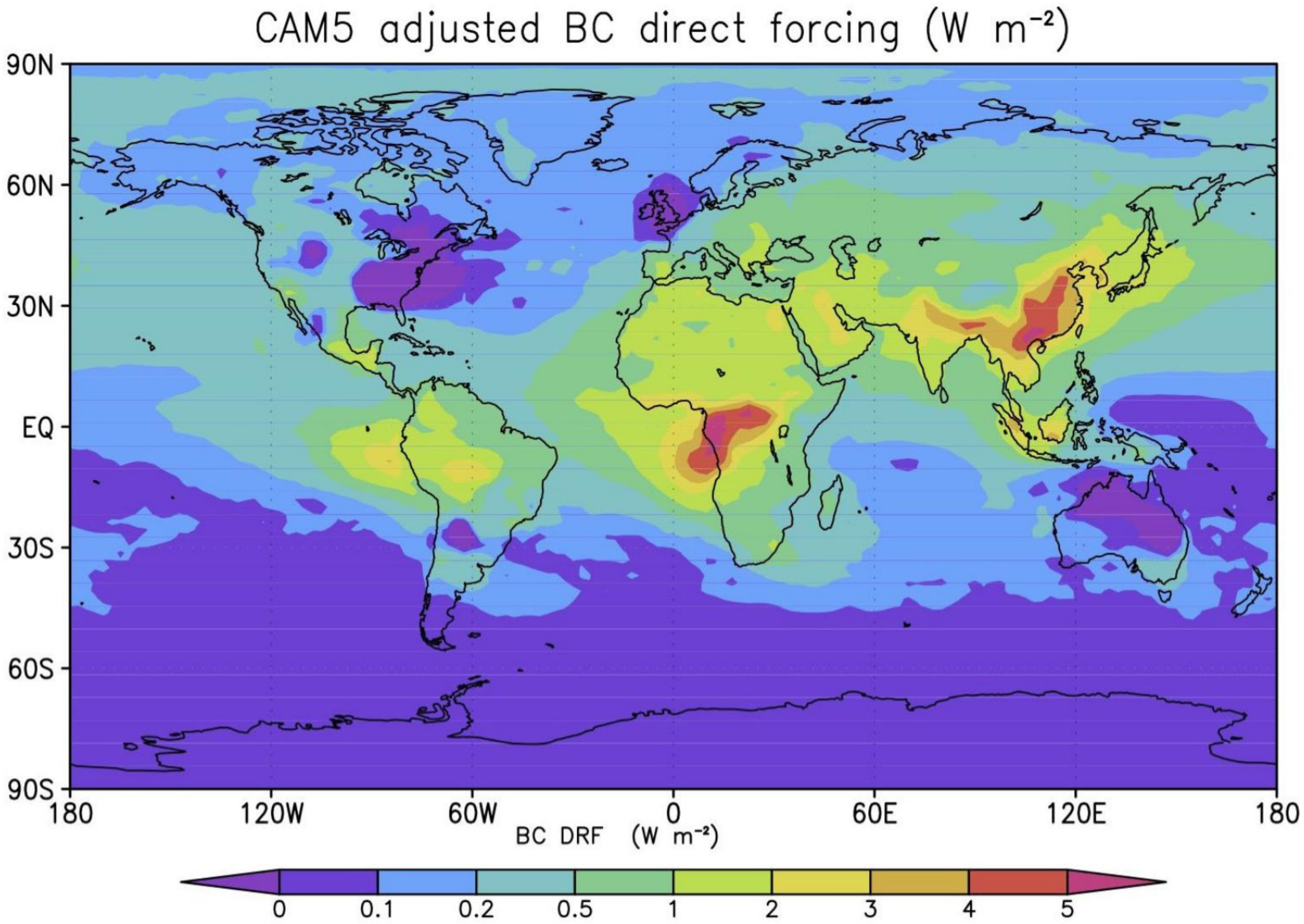
Monthly BC concentrations, measured vs. simulated



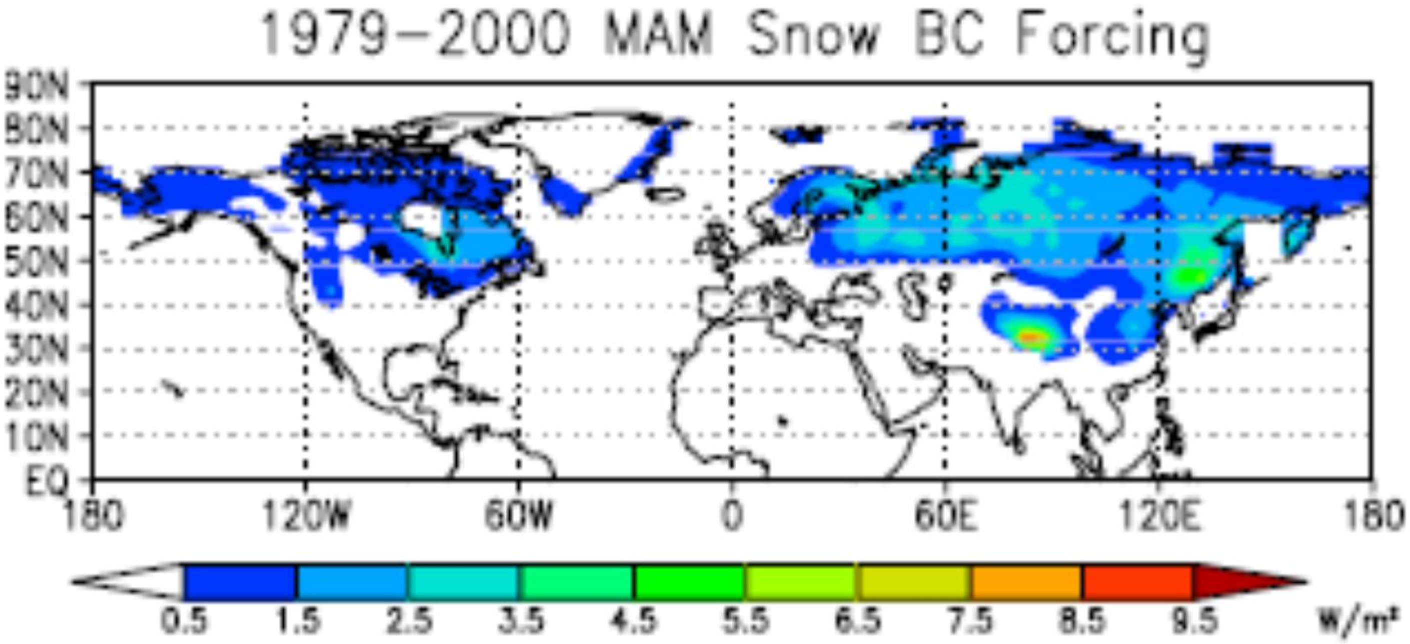
Estimated fraction of long-Range transported BC in Finland



Direct BC forcing, Bond et al. (2013)



Forcing from BC on snow, Flanner et al. (2009)



Preliminary results

- Results are based on the forcing maps scaled with the BC concentrations and deposition fluxes caused by Finnish BC emissions

Wm^{-2}

- Finnish emissions cause approximately 0.05% of the global direct BC forcing

- Finnish emissions cause approximately 1% of the global forcing by BC on snow

- The numbers have large uncertainty

Global emission scenarios

Two baseline scenarios 2020 and 2030:

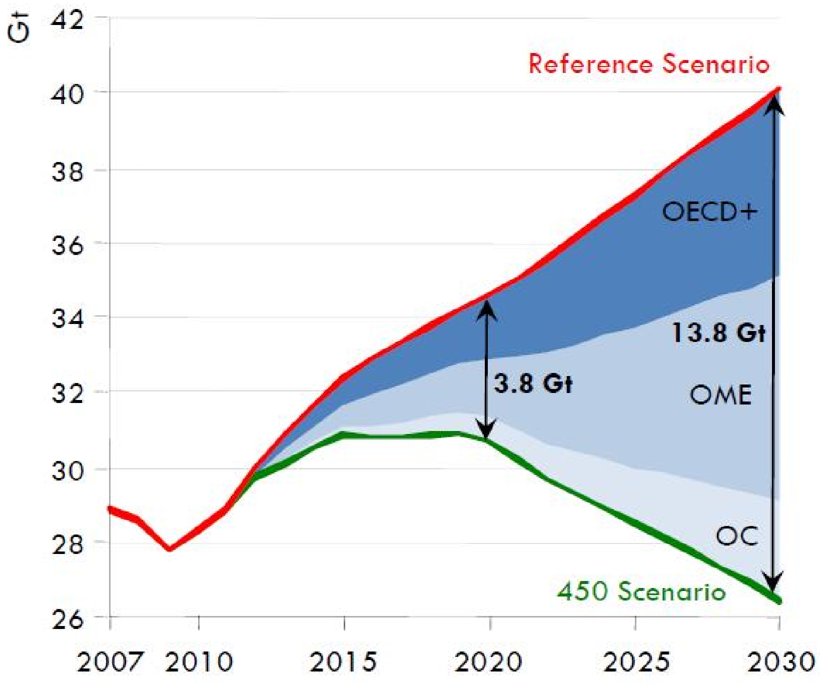
1. IEA World Energy Outlook 2009 reference scenario (CLEC)
2. baseline that follows the IEA World Energy Outlook 2009 450 scenario, limits the greenhouse gas concentration to 450 ppm CO2-eq by the end of the century (CLECC)

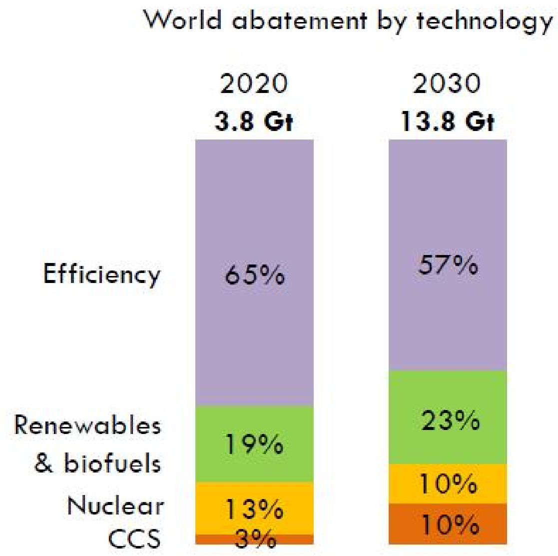
Both 1. and 2. scenarios include the existing air pollution legislation and policies.

Scenario with additional emission mitigation:

3. Assumes full implementation of a set of air pollution mitigation technologies by 2030. The technologies were selected based on their net-radiative forcing of multiple pollutants (SLCFs)

World abatement of energy-related CO_2 emissions in the 450 Scenario

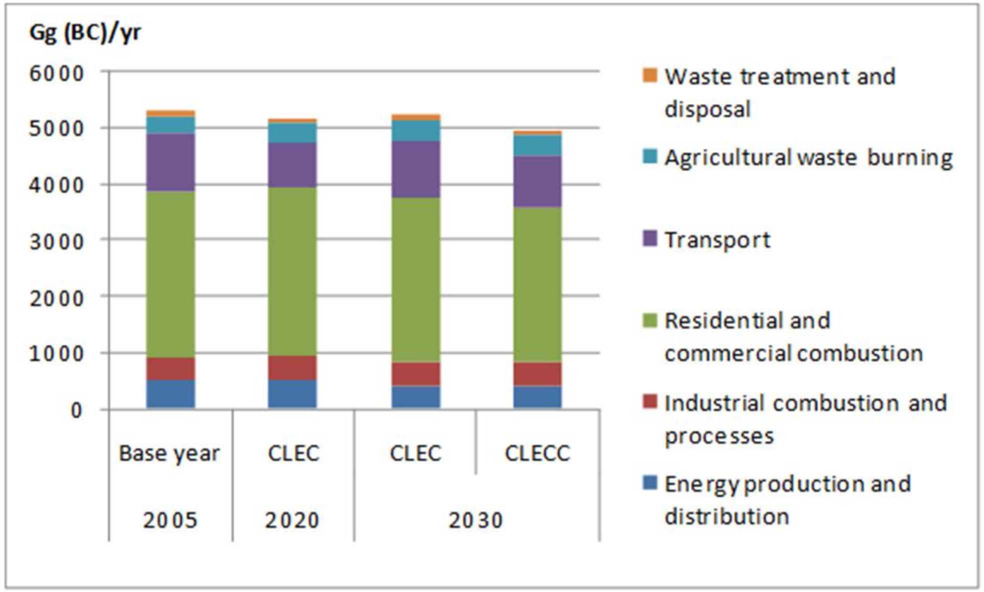


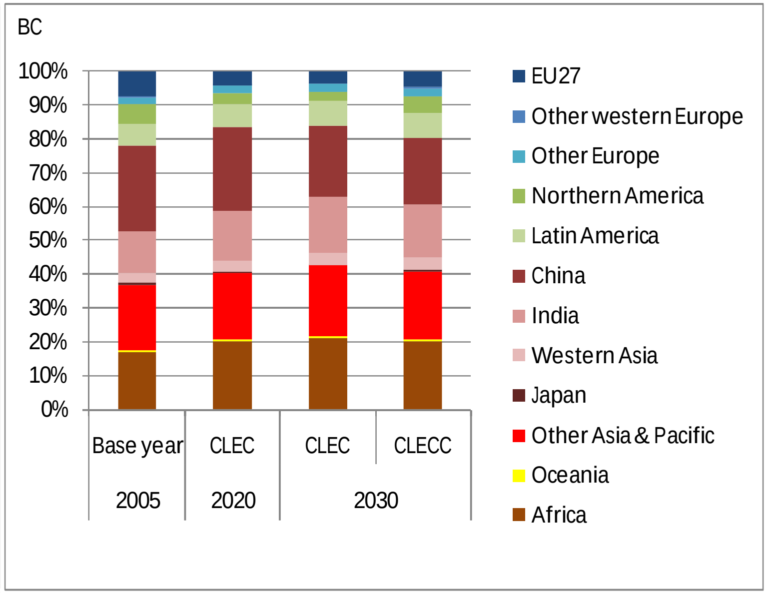


An additional $10.5 trillion of investment is needed in total in the 450 Scenario, with measures to boost energy efficiency accounting for most of the abatement through to 2030

Anthropogenic black carbon emissions 2005, 2020 and 2030 – comparison of baseline scenarios

Figures: MACEB project

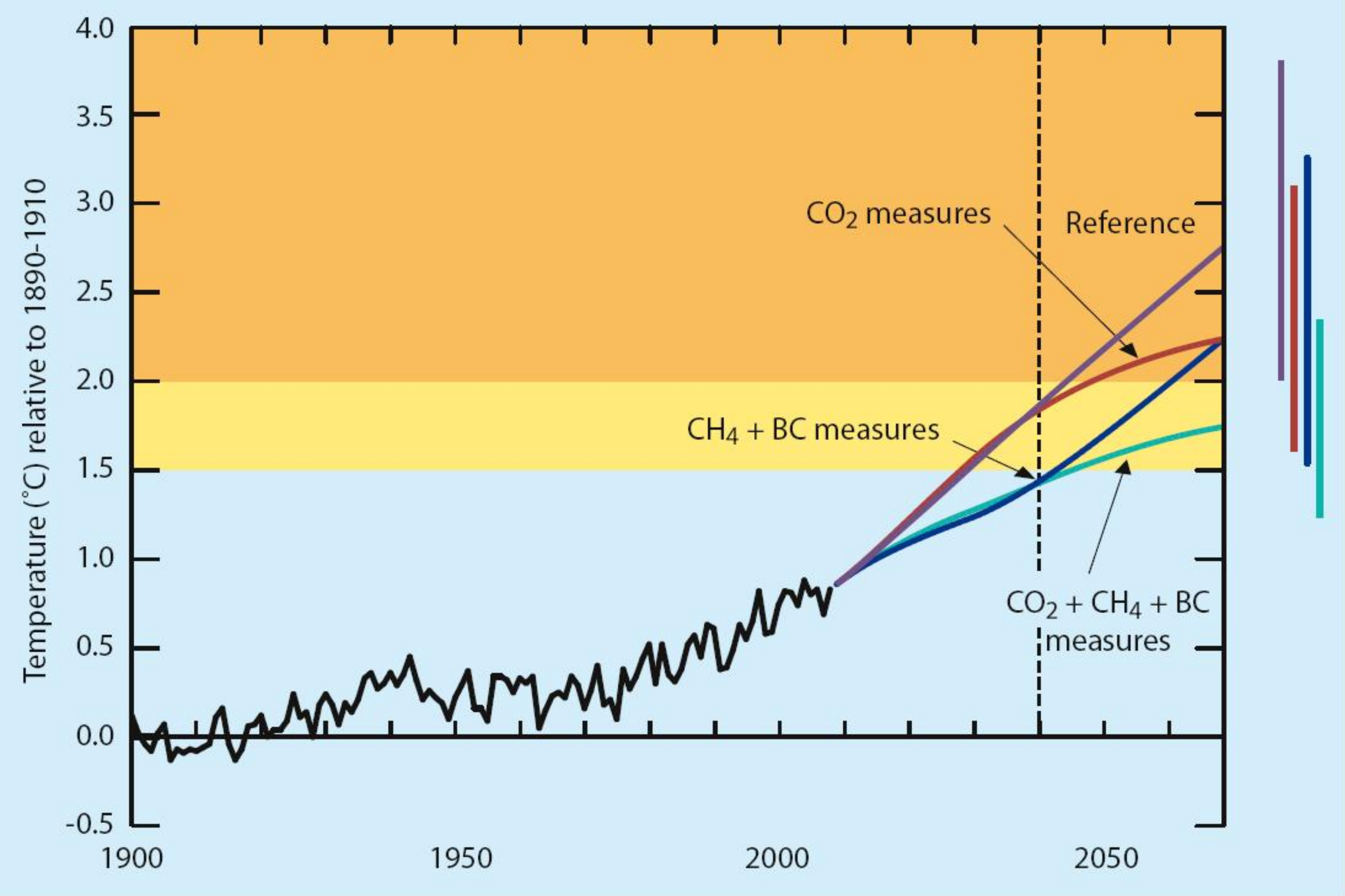




- Although the GHG emissions in CLECC are significantly lower than in CLEC (previous slide), effect on black carbon emissions is minor
- It is possible to design mitigation efforts of SLCFs so that there is no major influence on GHG emissions

Global temperature effect of different mitigation pathways

Source: UNEP/WMO 2011: Integrated Assessment of Black Carbon and Troposperic Ozone



Scenarios:

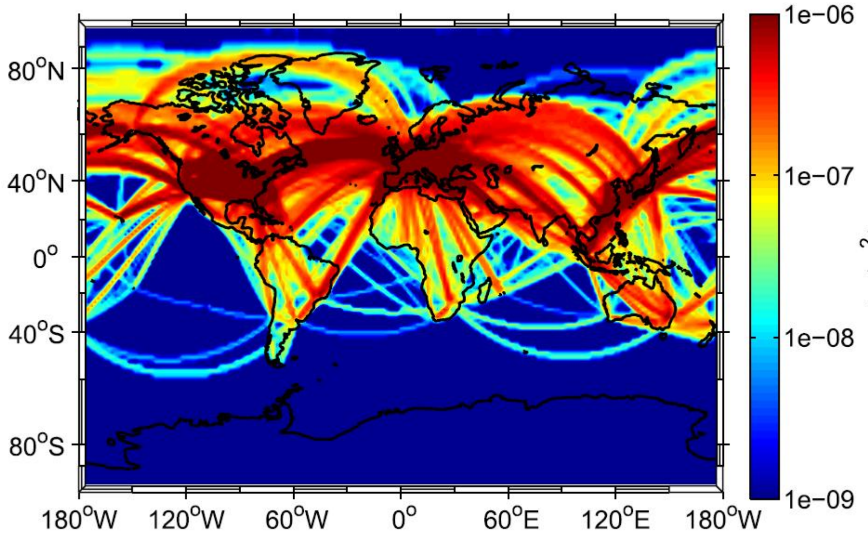
1) Reference: IEA WEO2009 reference

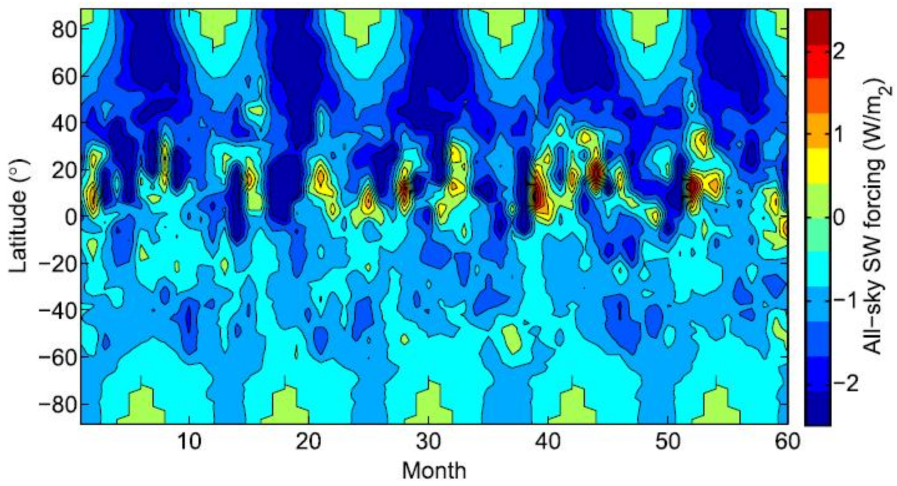
2) CO_2 measures: IEA WEO2009 450 scenario

3) CH_4 + BC measures: UNEP/WMO mitigation portfolios

4) CO_2 + CH_4 + BC measures: 2) and 3) combined

Stratospheric injection: commercial air traffic



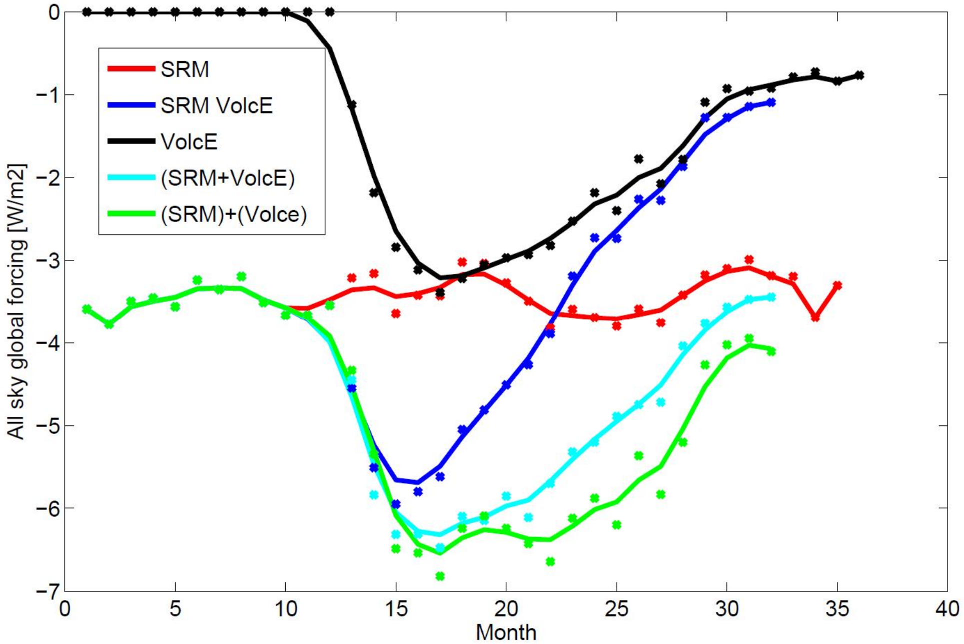


Significant increase in fuel sulphur content required if one wishes to achieve geoengineering as a by-product of stratospheric aviation.

Strong spatial and seasonal variation in RFP due to injections in the mid-latitudes.

Laakso (2012), ERL, 034021

Stratospheric injection + volcanic eruption?



Maximum forcing from simultaneous SRM and volcanic eruption is 25% smaller than their summed individual forcings

Volcanic eruption increases forcing only for 1 year ← strong sedimentation

Geoengineering via organic stratospheric aerosols (UHEL+ UEF)

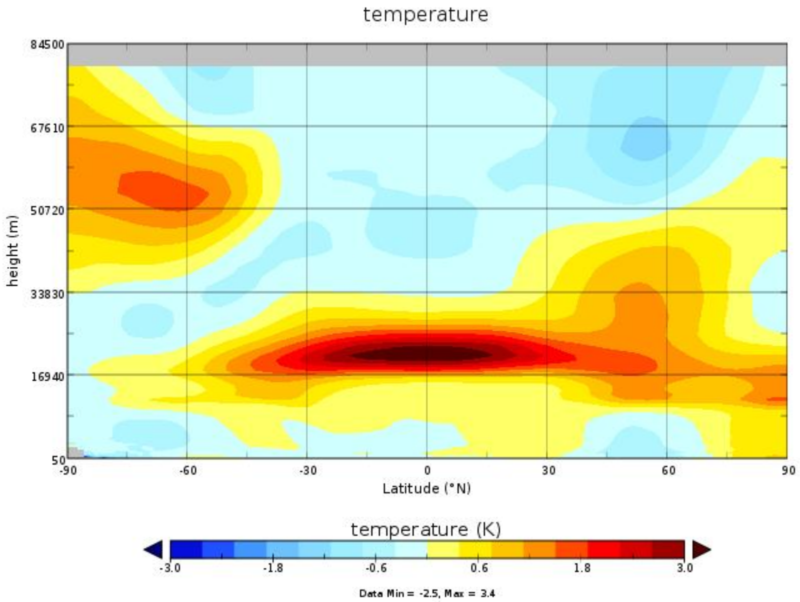
- Volcanic eruptions show that stratospheric sulfate aerosols cool the climate => artificial sulfate suggested for climate cooling
- However, sulfate aerosols cause enhanced ozone depletion mainly through heterogeneous chemical reaction

$$N_2O_5 + H_2O \text{ (surface)} \rightarrow 2HNO_3$$

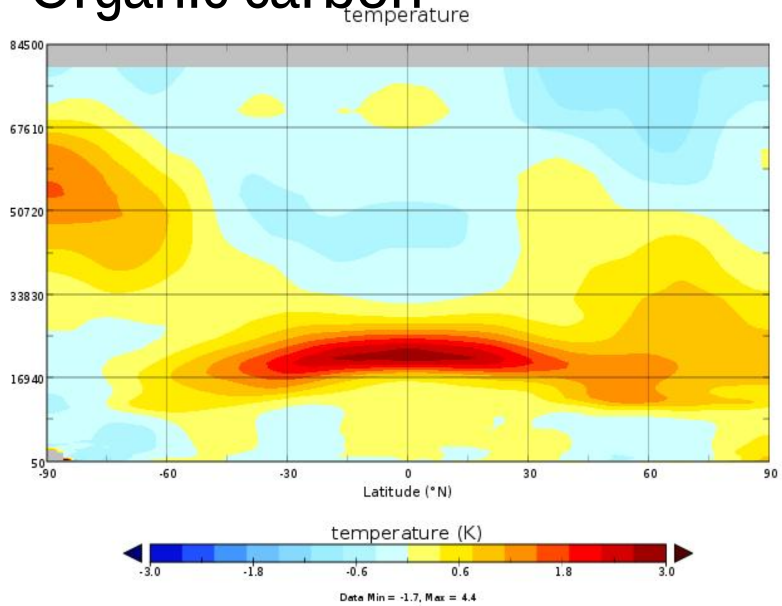
- This reaction is a hundred times slower on the surface of organic carbon aerosols => they can be a safer alternative to sulfate

Geoengineering via organic stratospheric aerosols (UHEL+UEF)

Sulfate

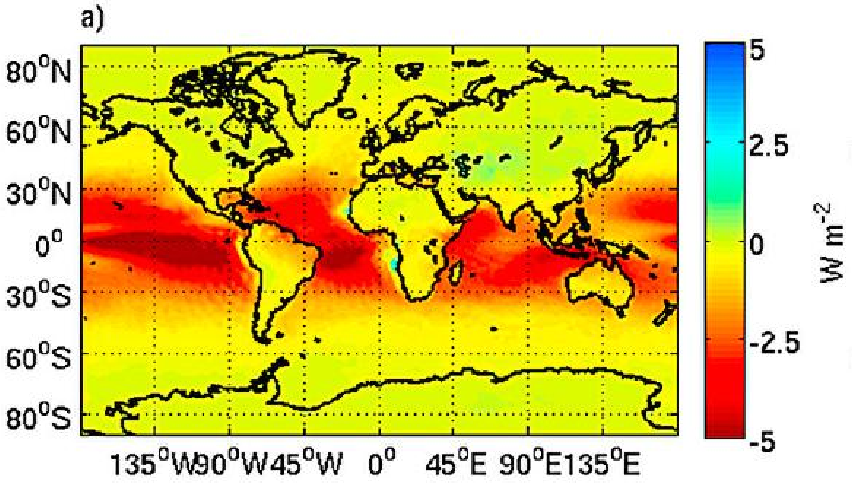


Organic carbon



- Initial runs show similar cooling with the same amount (3 Tg/yr) of sulfate or organic carbon aerosols
- Impacts on ozone chemistry will be studies in the future

Cloud brightening: direct effect and particle size



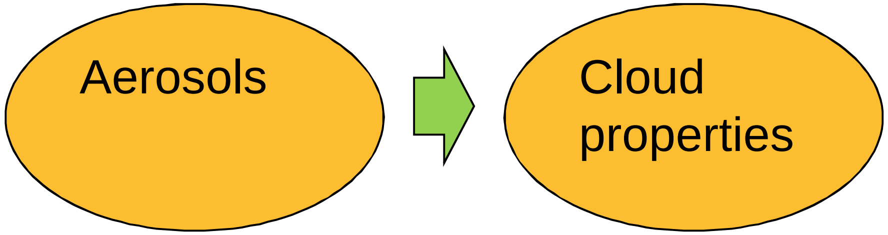
Direct radiative effects can be important in non-cloudy conditions

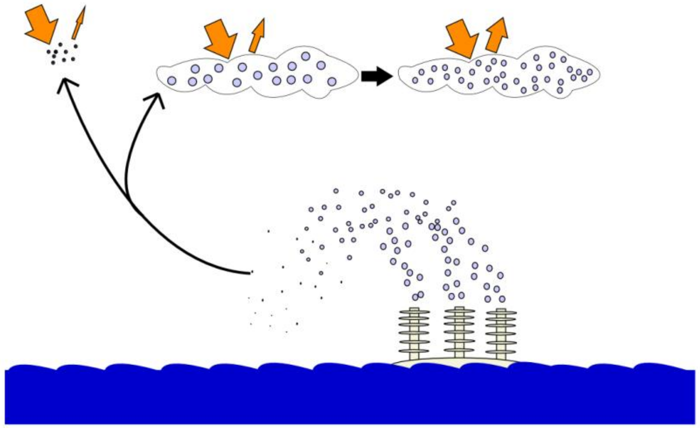
	Baseline (250 nm)	5 x Baseline (250 nm)	Baseline (100 nm)
RFP (W/m^2)	-0.8	-2.2	-2.1
Direct (W/m^2)	-0.1	-0.5	-0.1
Indirect (W/m^2)	-0.7	-1.7	-2.1

Optimizing injection size can reduce significantly the required amount of sprayed sea water

Partanen (2012), JGR, 117, D02203

Studies of marine stratocumulus whitening in the cloud resolving scale (COOL-UEF, Kuopio)





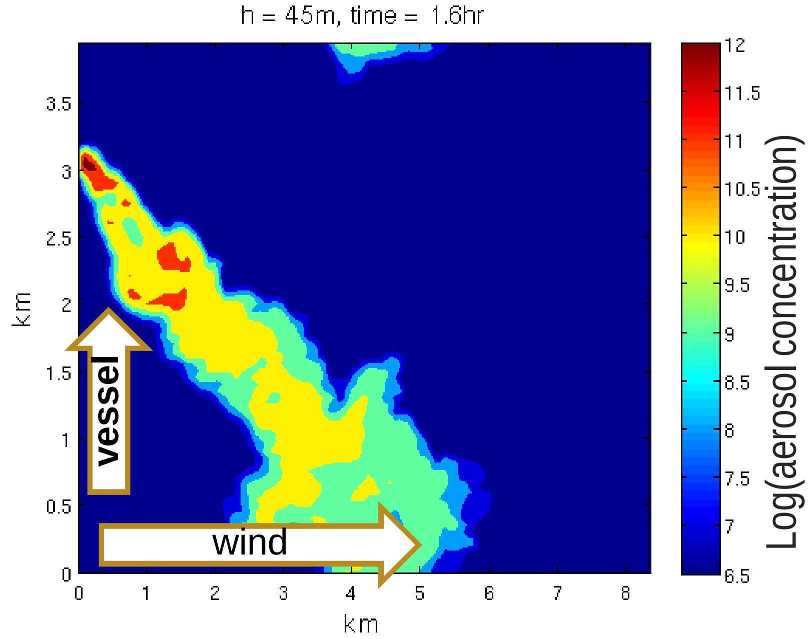
How big fraction of emitted particles is lost before they start affecting cloud properties?

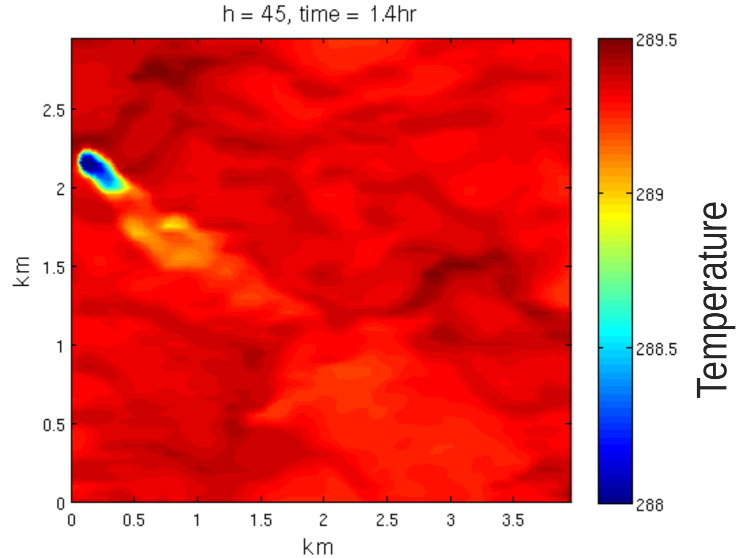
- **Dispersion**
- **Coagulation**
- **Deposition on surface**
- **Boundary layer dynamics (latent heat), aerosol cloud interactions**

How these particles are affecting cloud properties

- **What would be the optimal size of particles**
- **Nighttime vs. daytime emissions**

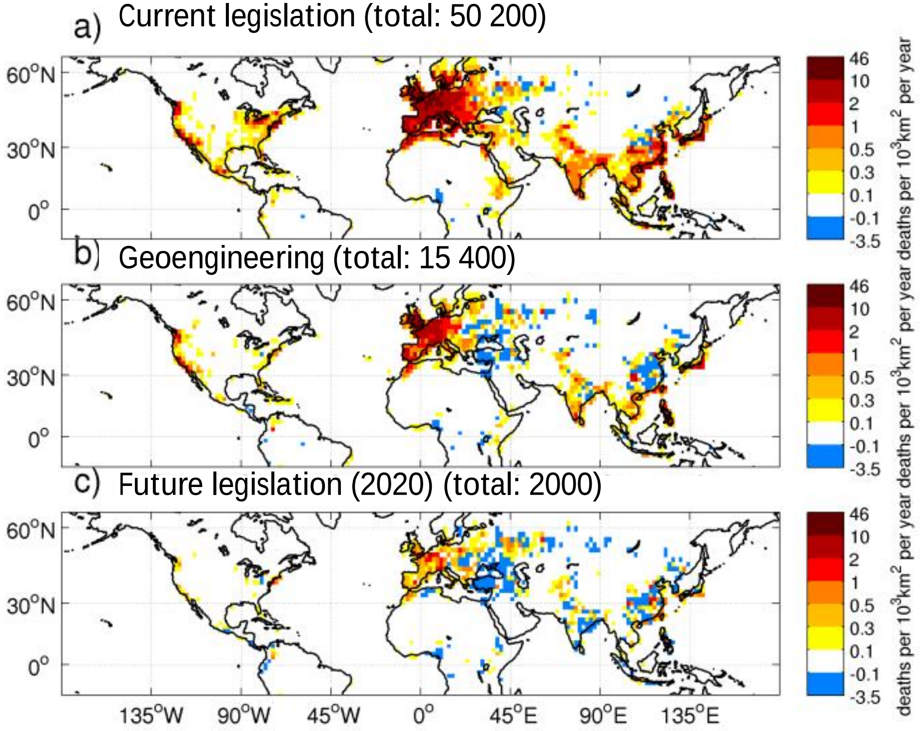
- **Work this so far**
  - Large eddy model UCLALES is further developed to include aerosol module SALSA with explicit treatment of aerosol (also water).
  - UCLALES-SALSA is now working, and the first simulations using CSC supercomputers are conducted to study aerosol dispersion.
- **First results**
  - The evaporation of water from seaspray will cool the air around emission and cause negative buoyancy.
  - This will enhance particle deposition on the surface and decrease the effectiveness of emissions.



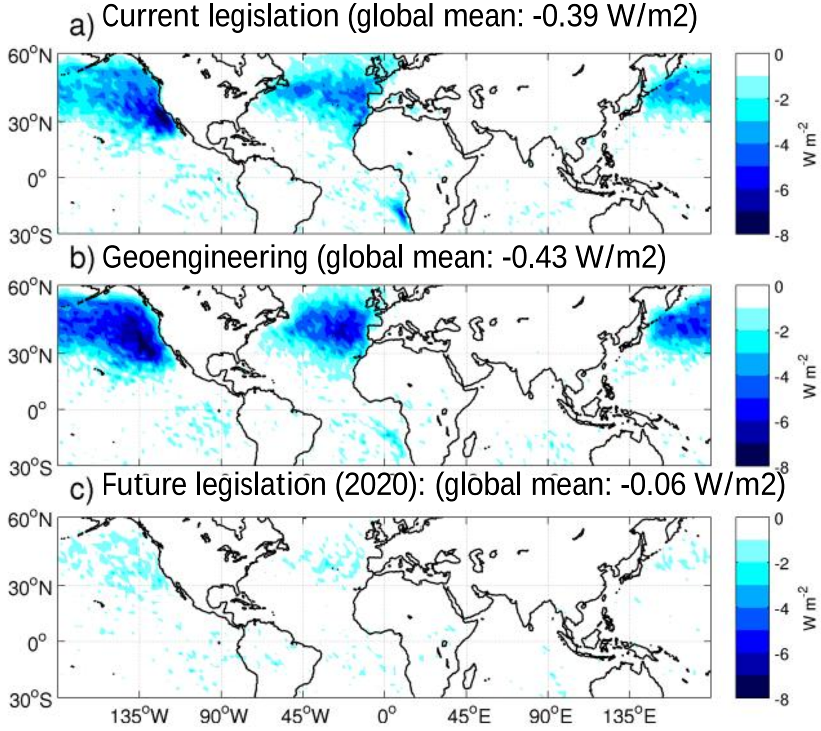


Climate and air quality trade-offs from shipping

Mortality due to shipping (PM)



Radiative forcing from shipping



Partanen (2013), submitted to ES&T

Plans for the remaining 20 mths of the project

Focus on climate effects of aerosol technologies (regional temperature and precipitation patterns)

→ international law implications based on predicted changes

”Optimization” of stratospheric injections to maintain current regional climates as closely as possible

Legal aspects of geoengineering – tentative conclusions (UEF Joensuu)

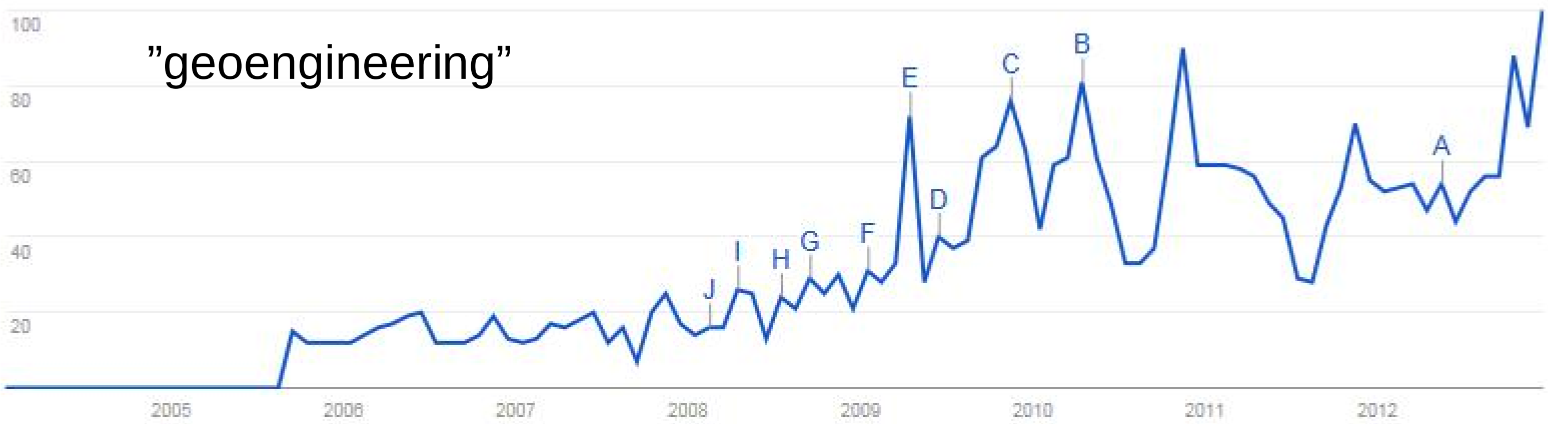
- **Climate change law has emerged as a distinct legal discipline**
- **A party suffering loss or damage as a consequence of climate change has a limited chance of claiming damages in court**
- **Existing international law rules apply to geoengineering**
- **No need for a new international treaty on geoengineering**
- **Use existing regimes in elaborating new regulations on geoengineering**
- **Enhance interaction between environmental regimes and aim for coherence and synergy**

Topics for forthcoming articles

- **Regulating and managing geoengineering in international environmental law**
- **Promoting green buildings through structural incentives in the Finnish land use and planning system**
- **International Governance of Climate Change and Energy Issues**
- **The Governance of International Collaboration in the context of the Intergovernmental Panel on Climate Change: Lessons for International Cooperation in Science, Technology and Innovation**

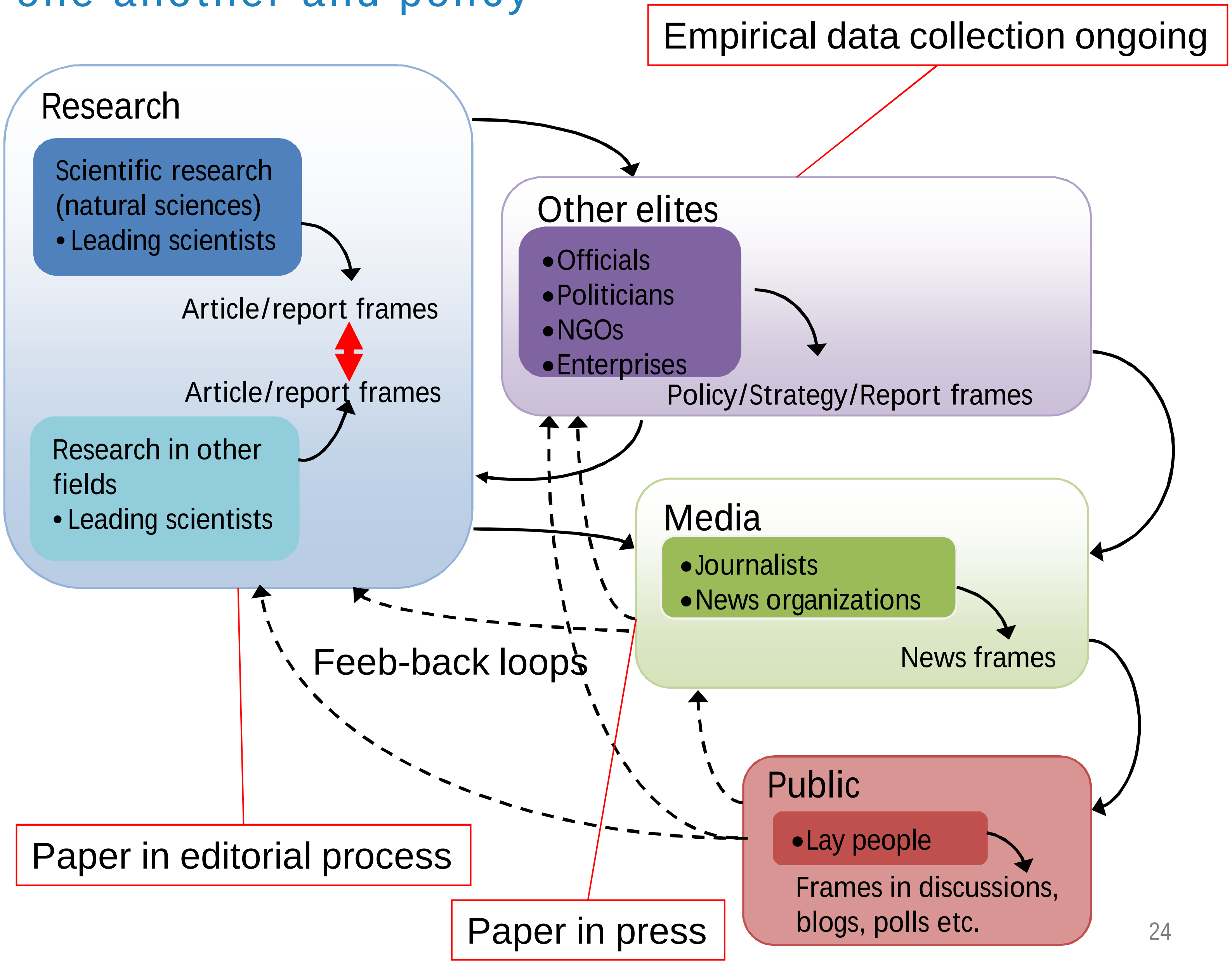
CLIMATE CHANGE PROGRAMME

COOL WP4 explores geoengineering as a social phenomenon [google trend indicates increasing although still budding interest]



SYKE

COOL WP4 studies how different actors influence one another and policy



SYKE

Findings so far and work ahead in WP4

- Metaphores play an important role in shaping the understanding of geongineering in the popular press/media.
- Researchers have framed geoengineering in different ways. The controversies surrounding geoengineering are reflected in the frames, making science-policy dialogues potentially very difficult.
- Ongoing work: how do the policy documents and policy makers view geoengineering?

What's next? *WP5 : Synthesis - scenarios and future paths*

- There will be no "final truth" about applying the aerosol technologies to climate problems, but political and public discussions are needed and emerging).
- The COOL-team will jointly reflect on <u>what is important to discuss </u>(from a scientific and a societal perspective), taking benefit of the multidisplinarity of the team: from physicists to legal scholars.

The key questions for the synthesis: how to govern geoengineering?

- is it possible?
- which are the knowledge needs?
- what processes can be designed?

SYKE