Difference in sensitivities to climate change between black carbon and sulfate aerosols

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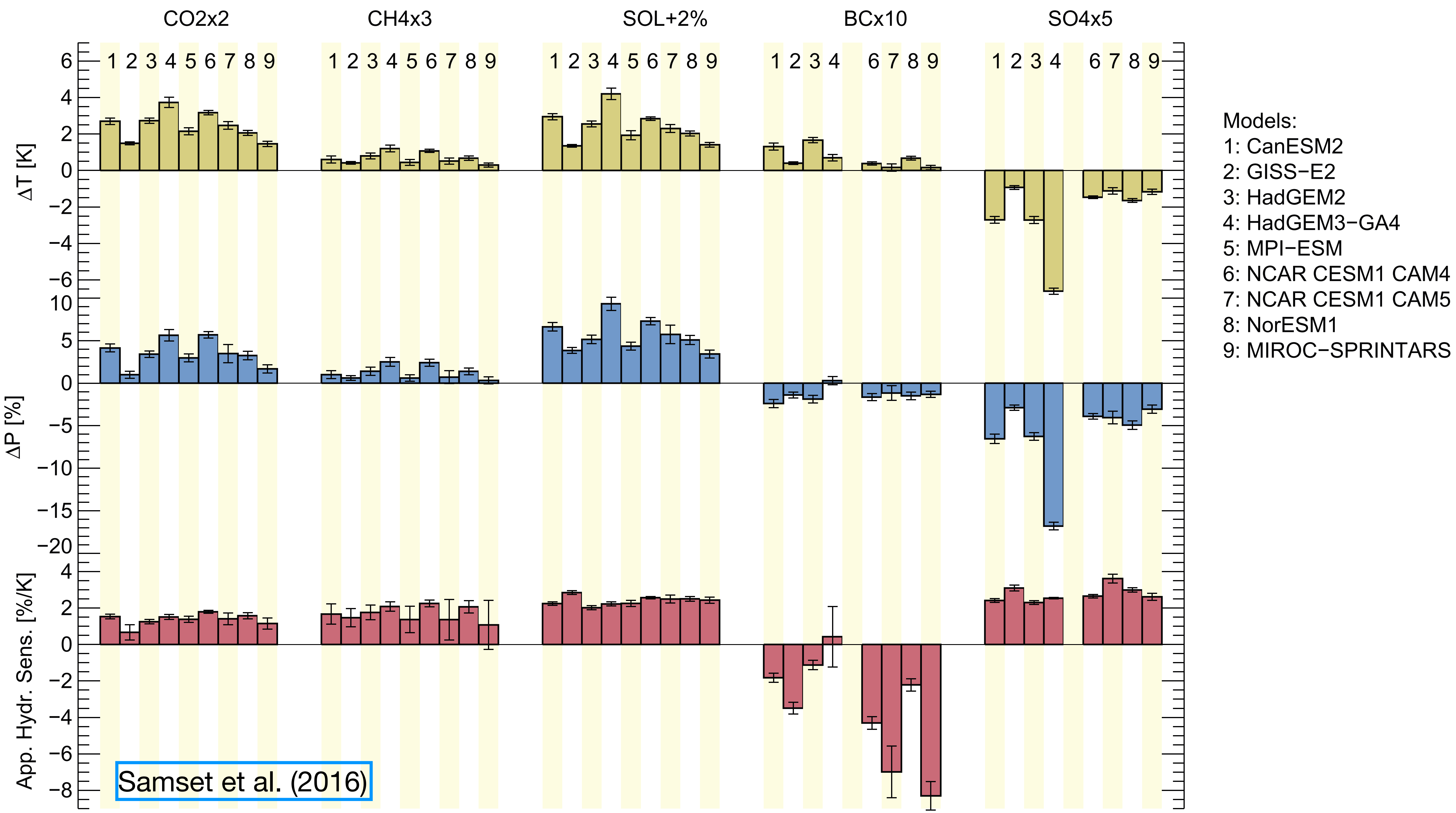
Sensitivity analysis of changes in the temperature and energy budget by fast adjustment and slow response due to changing SO_2/BC emissions from MIROC-SPRINTARS both with the prescribed SST and coupled-ocean experiments.

Change in temperature and precipitation in PDRMIP



The increase in surface air temperatures with 10-times BC emissions is weaker than would be expected from the magnitude of its positive instantaneous radiative forcing due to the dominant negative rapid adjustment (Samset et al. 2016; Stjern et al. 2017).

Sensitivity experiments to changing aerosol emissions

Multi-model PDRMIP experiments (shown aerosol-related only)	
Sul	5 times sulphate concentration (or related emissions) from the present
BC	10 times black carbon (BC) concentration (or emission) from the present

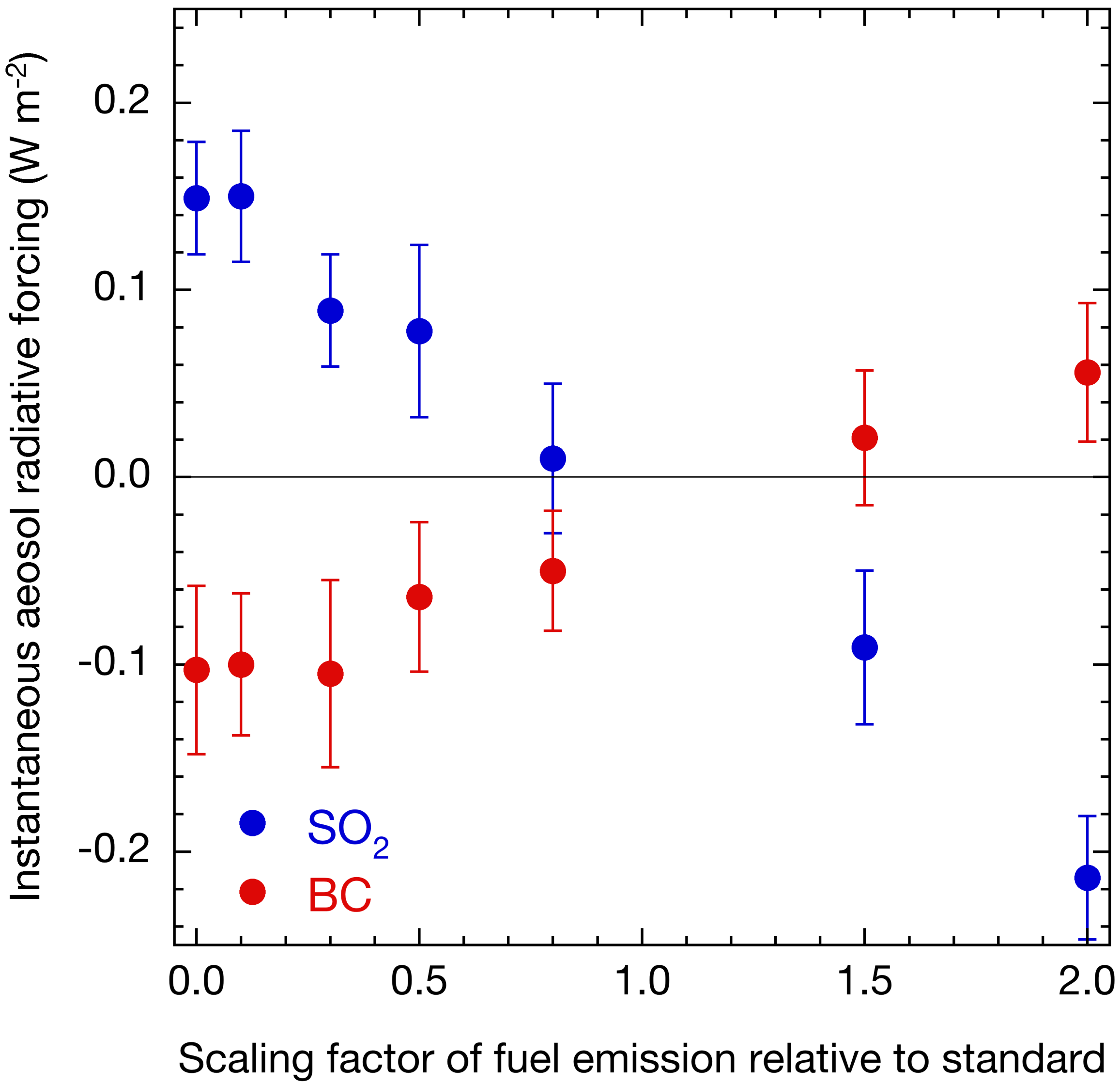
➡ **single-model approach excluding contamination with differences in physical representations that vary across models.**

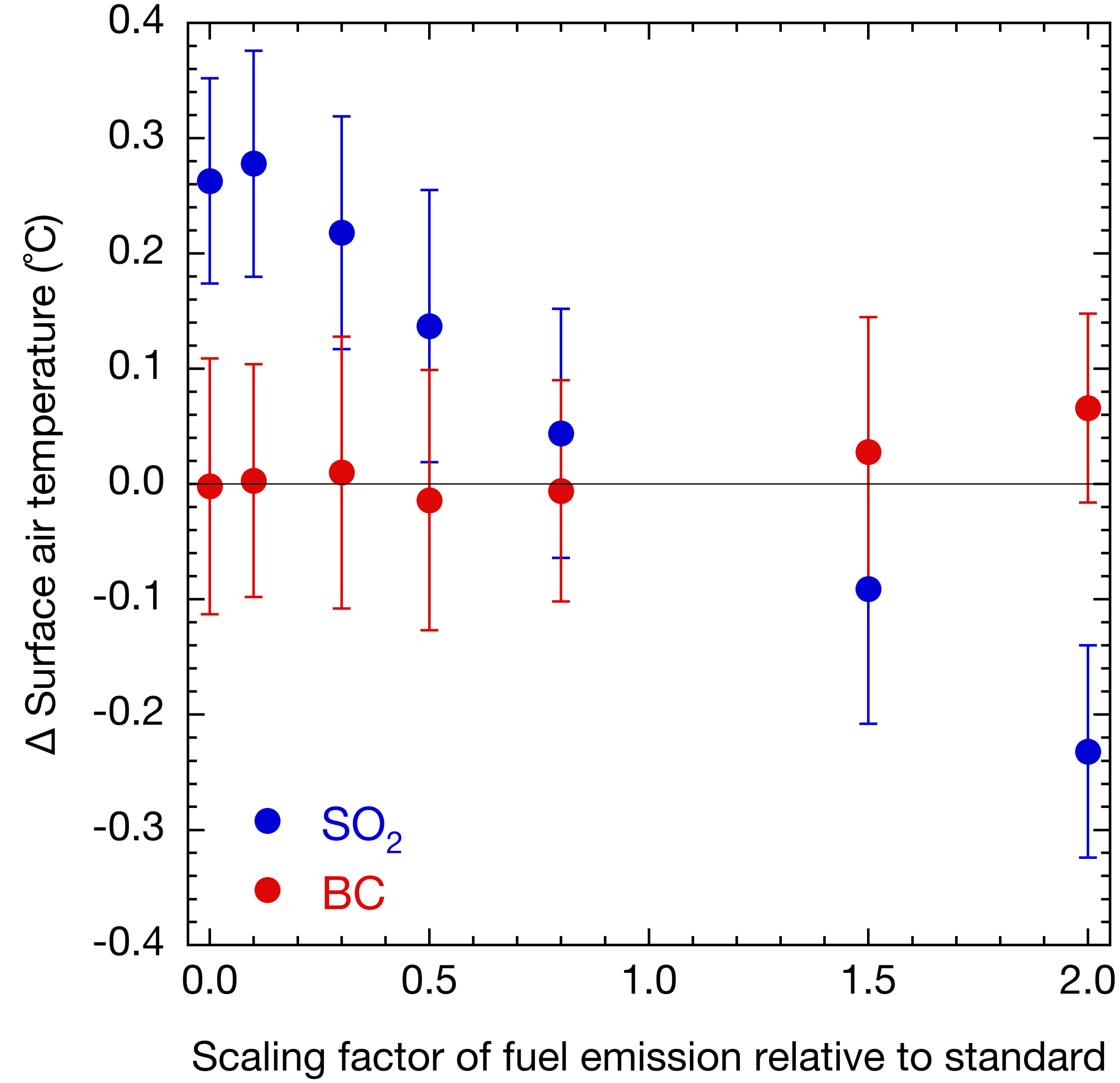
Single-model experiments by MIROC-SPRINTARS	
Sulx, BCx****	0, 0.1, 0.3, 0.5, 0.8, 1.5, 2, 5, 10 times SO_2 or BC emissions from the present

Experiment setup

- Model version: MIROC5.9-SPRINTARS (almost same ver. used in CMIP6 (MIROC6)).
- Resolution: T85 (256x128), L40.
- Integration time
  15 years for fixed SST (analyzing last 10 years) ➡ **rapid adjustment**
  100 years for coupled-ocean (analyzing last 50 years)
  ➡ **rapid adjustment + slow response**
- Emission inventories: HTAP2 for anthropogenic sources
  GFED3.1 for biomass burning
- Oxidizer for sulfur: simulated by MIROC-CHASER under the CMIP5 setup

Radiative forcing and temperature change with sulfate/BC

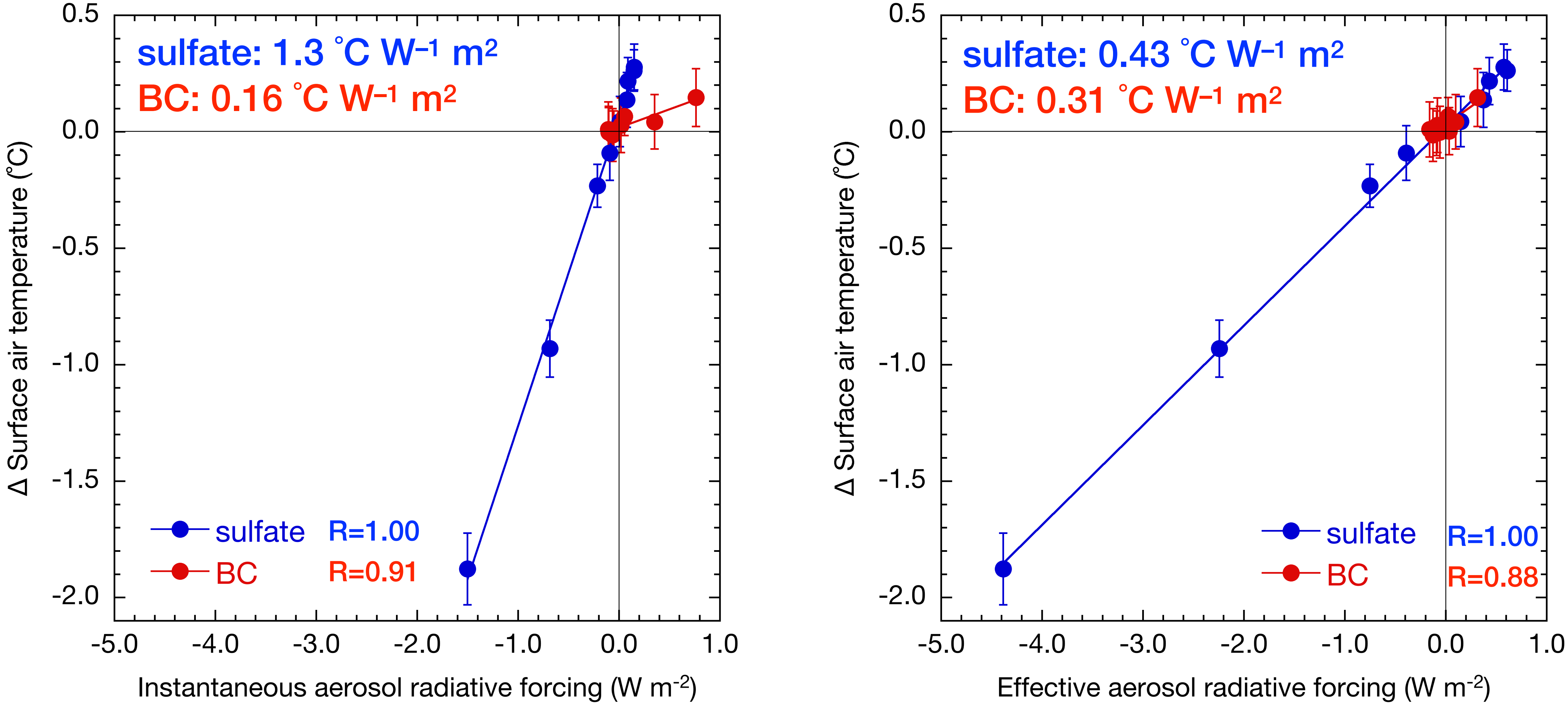




Global mean (left) instantaneous aerosol radiative forcing and (right) change in the mean surface air temperature with emission perturbations of SO_2 and BC simulated by MIROC-SPRINTARS (Takemura and Suzuki, 2019, doi:10.1038/s41598-019-41181-6).

- Changes in the instantaneous radiative forcing are linear with emission perturbation both for sulfate and BC.
- While the sensitivity of surface air temperature is linear to the SO_2 emission (sulfate concentration), it is not clear for the change in BC emissions.

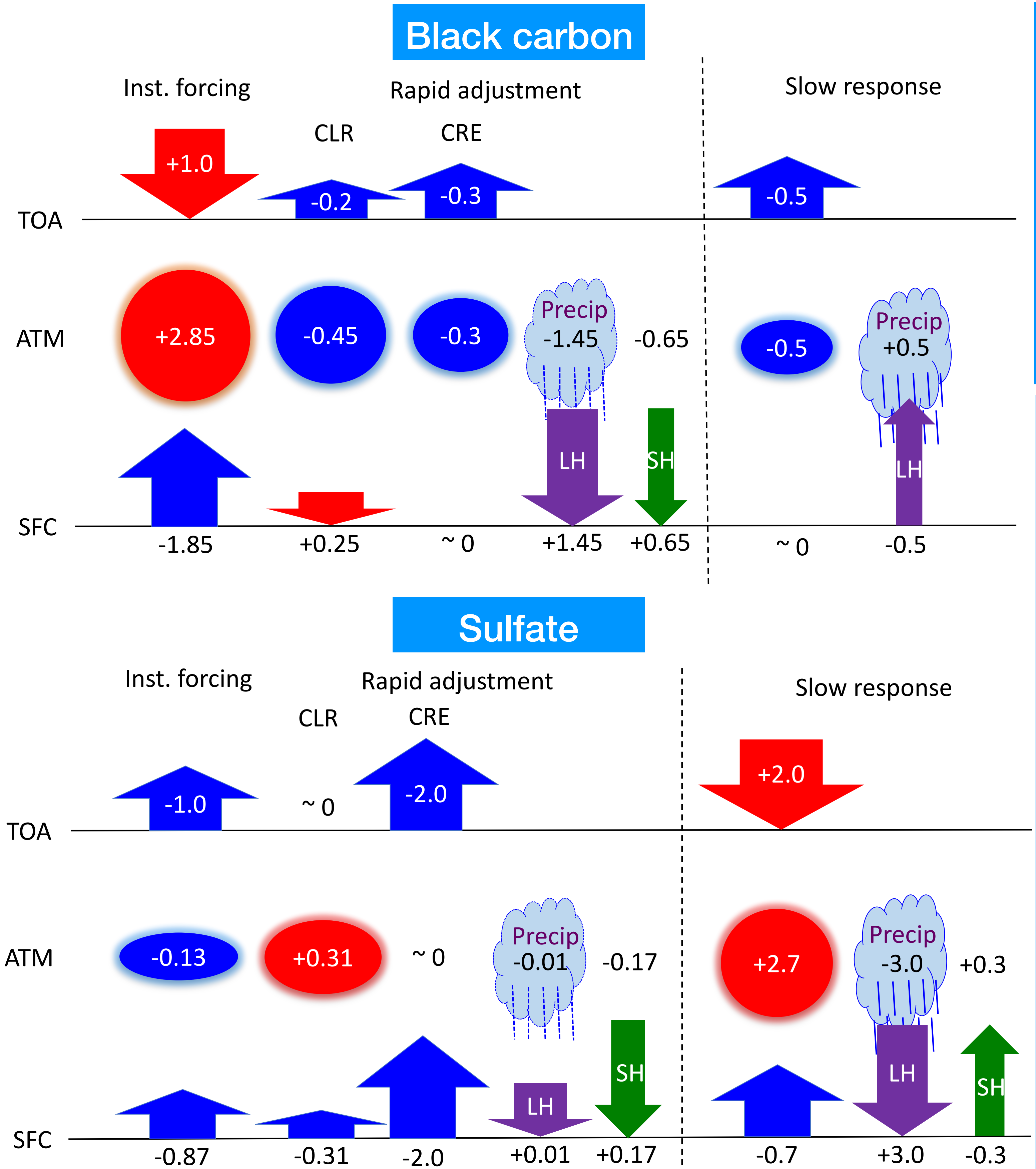
Climate sensitivity parameter of sulfate/BC



Relationship between aerosol (a) instantaneous or (b) effective radiative forcing and changes in surface air temperatures for SO_2 and BC simulated by MIROC-SPRINTARS (Takemura and Suzuki, 2019, doi:10.1038/s41598-019-41181-6).

- The relationship between radiative forcing at the TOA and surface temperature change is linear for both sulfate and BC.
- The surface temperature change due to BC is much smaller than sulfate with instantaneous radiative forcing.
- Climate sensitivity parameters based on the effective radiative forcing shows a smaller discrepancy between sulfate and BC.

Analysis of change in radiation budget by sulfate/BC



Changes in normalized radiation budget at the TOA, atmosphere, and surface due to (upper) BC and (bottom) sulfate simulated by MIROC-SPRINTARS (Suzuki and Takemura, JGR, 2019).

✳ CLR: clear-sky response
CRE: cloud radiative effect

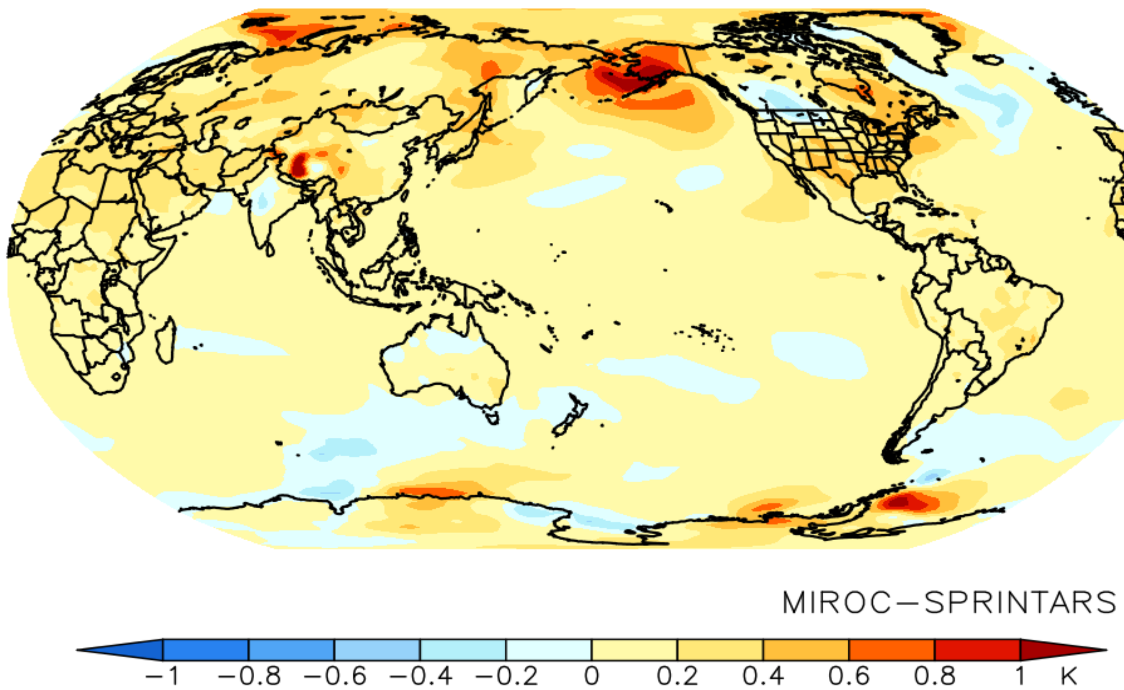
- Atmospheric heating with instantaneous radiative forcing of the aerosol-radiation interaction due to an increase in BC.
  ➡ Increase in outgoing longwave radiation due to an increase in water vapor.
  With more stable atmosphere
  - ▸ More scattering solar radiation due to an increase in low clouds.
  - ▸ Decrease in latent heat due to weakening precipitation and decrease in sensible heat.

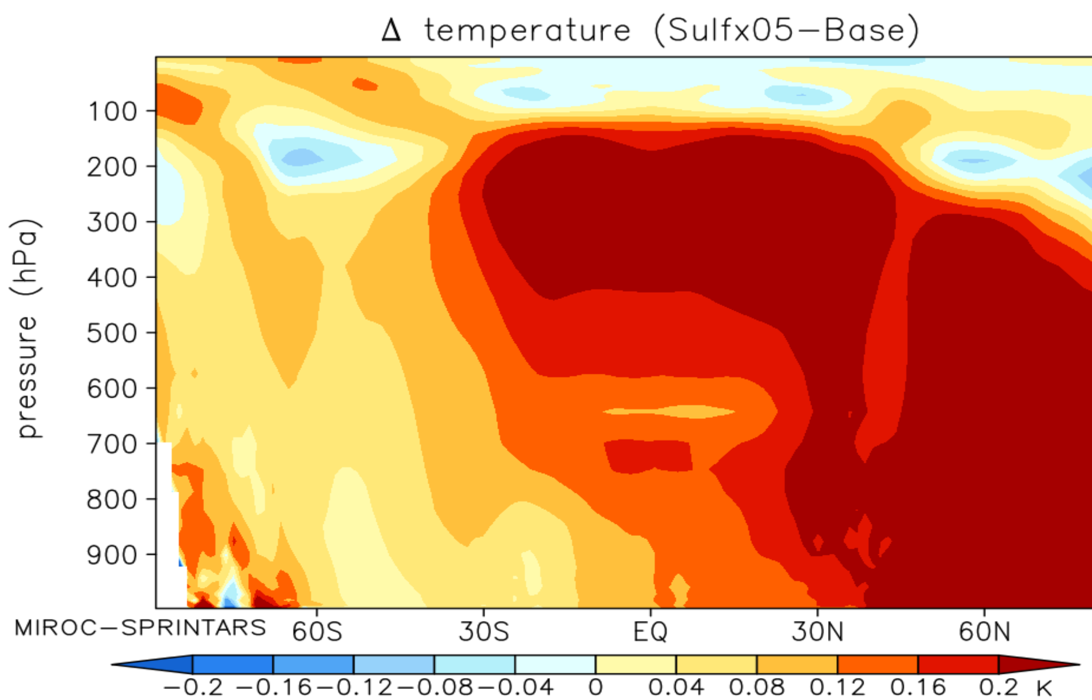
  ➡ Offset of atmospheric heating with rapid adjustment.
- Less atmospheric cooling with instantaneous radiative forcing due to an increase in sulfate.
- The forcing at the TOA and surface is strengthened by the aerosol-cloud interaction.
  ➡ Sustaining imbalance of radiation budget even in slow response.
  ➡ adjustment through ocean.
  ➡ temperature change.

Temperature change with sulfate/BC

SO_2 emission x 0.5

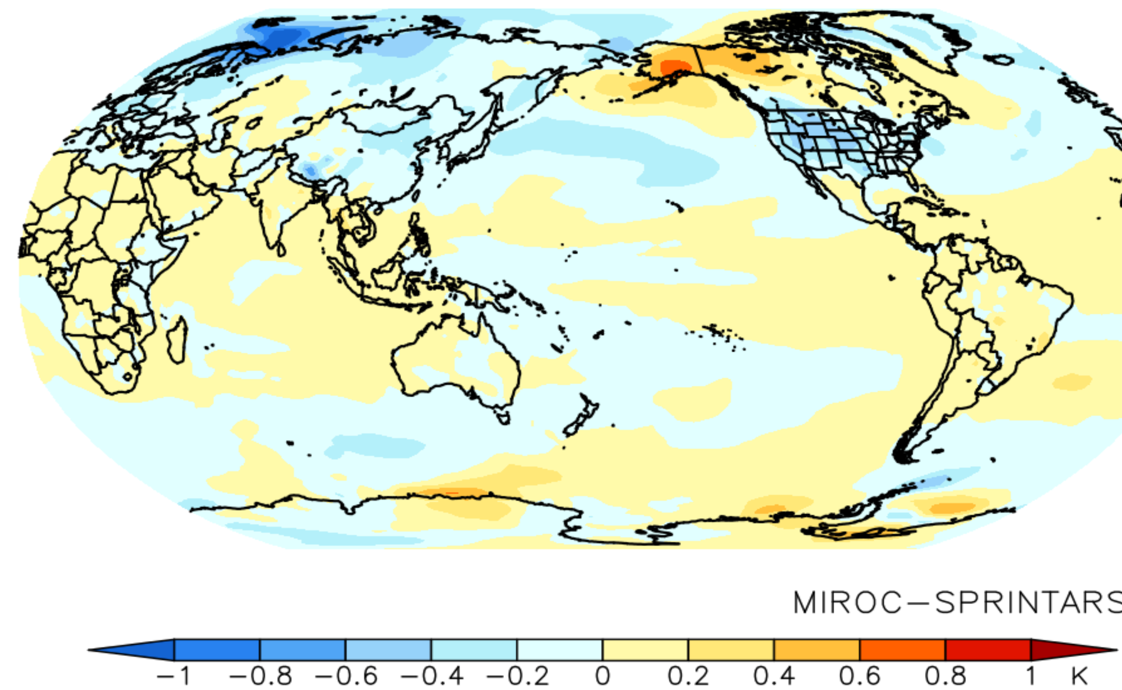
AVG. +0.14 K

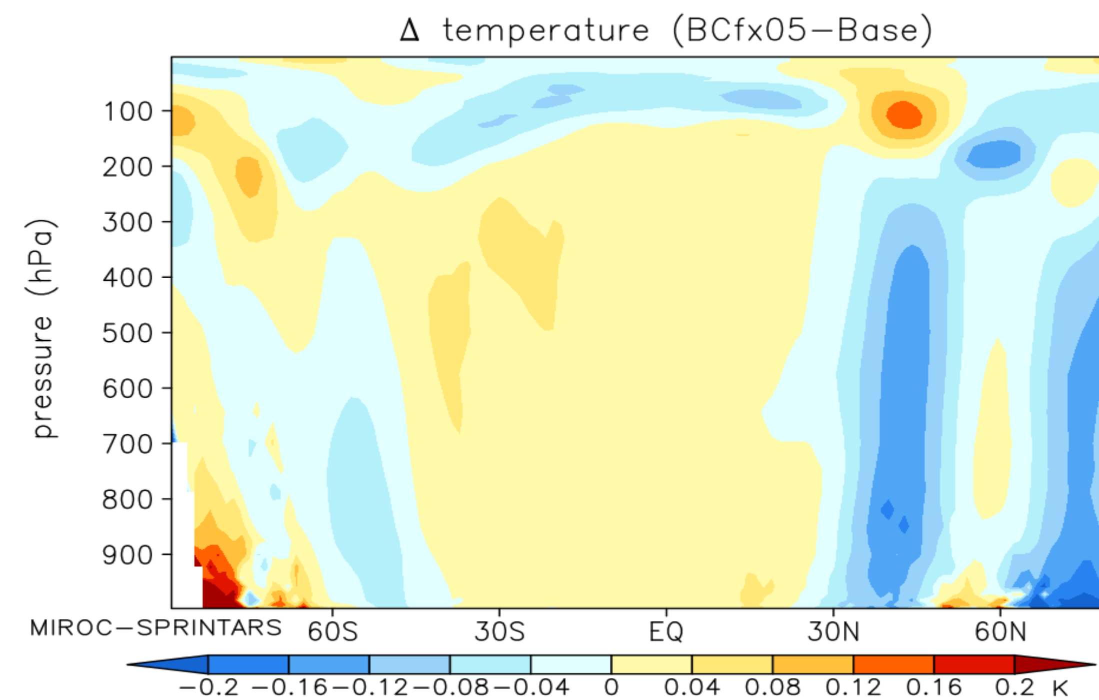




BC emission x 0.5

AVG. –0.01 K





New project: Hierarchical simulation of SLCFs

MIROC-SPRINTARS / MIROC-CHASER

Atmosphere-ocean GCM **MIROC**

Aerosols

SPRINTARS
(Spectral Radiation-Transport Model for Aerosol Species)

Chemistry

CHASER
Chemistry Climate Model

Horizontal res.: tens of km Integration time: 10～100yr

Simulation of both **atmosphere-only** and **coupled atmosphere-ocean** models with varying SLCFs-related emission **by regions, compositions, and origins.**

➡ Evaluating the impact of SLCFs dividing the contributions of fast adjustment and slow response.

Use as knowledge to improve quantitative representation of clouds.

Comparison and improvement of hydrological cycle by fast response due to SLCFs.

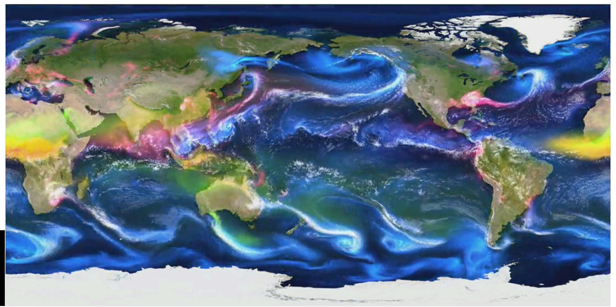
NICAM-Chem

Global cloud resolving model **NICAM**

SPRINTARS
(Spectral Radiation-Transport Model for Aerosol Species)

CHASER
Chemistry Climate Model

Horizontal res.: 3.5, 7, 14km Integration time: a few yr



sulfate
sea salt
dust
carbon
cloud

Detailed spatio-temporal SLCFs distributions and aerosol-cloud interaction based on explicit expression of cloud dynamics and physical processes.

SCALE-LES

Horizontal res.: tens to hundreds m

Direct treatment of cloud dynamics and physical processes.

large

Spatio-temporal scale

small

Summary

- Changes in the surface air temperature are basically linear to the radiative forcing with emission perturbations both for sulfate and BC.
- Reducing BC concentrations may not be effective for the decline in global mean temperature because of predominance of the fast adjustment with atmospheric heating, although the reduction is crucial for air quality.

Next step

- Aerosol climate effects other than temperature are estimated with hierarchical spatio-temporal models focusing on differences in regions, compositions, and origins.

Progress of the AeroCom III experiments with MIROC-SPRINTARS

- Control: completed. Resolution: T213L56
- HIST incl. ACRI, UTLS, VolcACI, etc.: in progress (to be completed: mid-Oct.)

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