Comprehensive Observations of Non-CO_2 LLGHGs and SLCFs: Implications for Common Metrics

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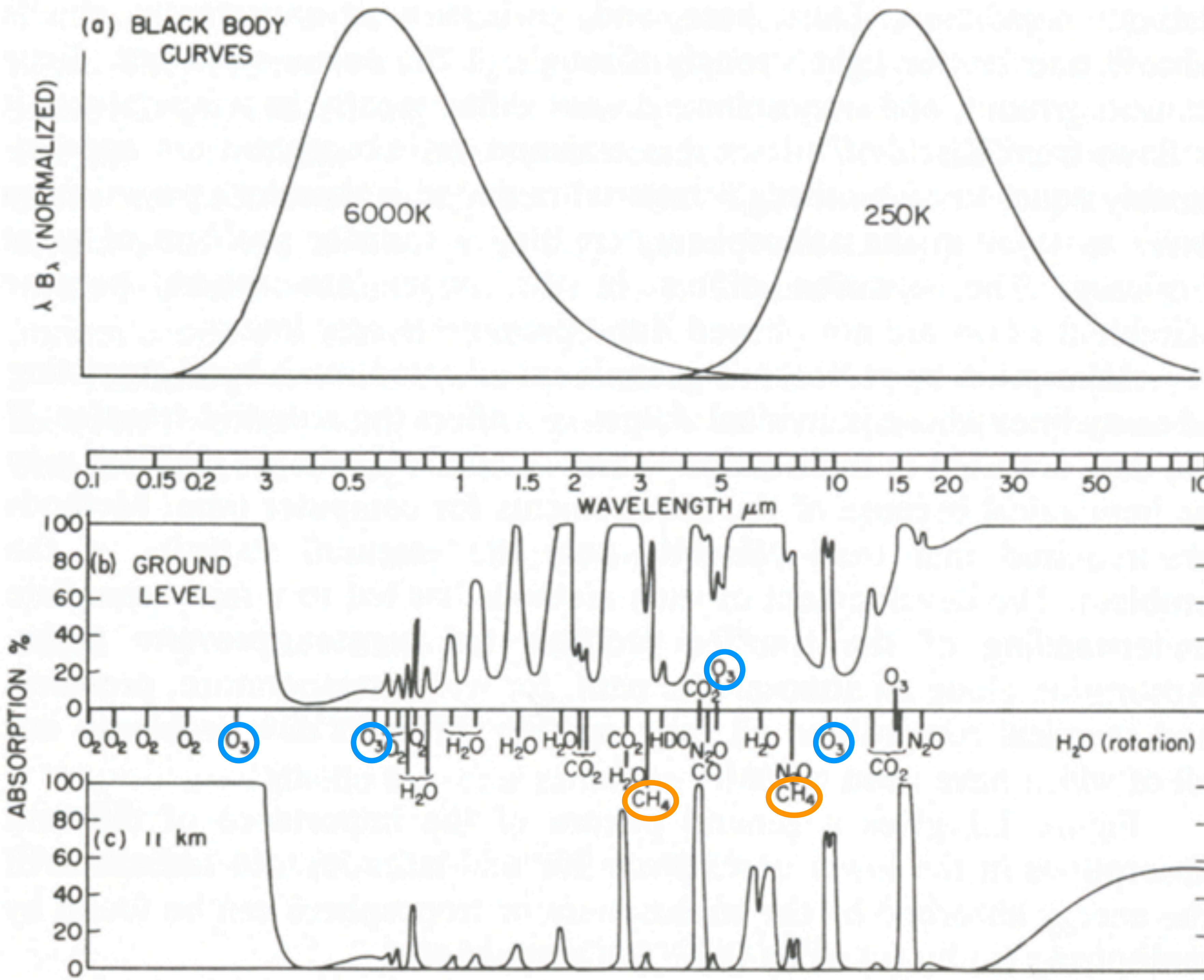
Contents

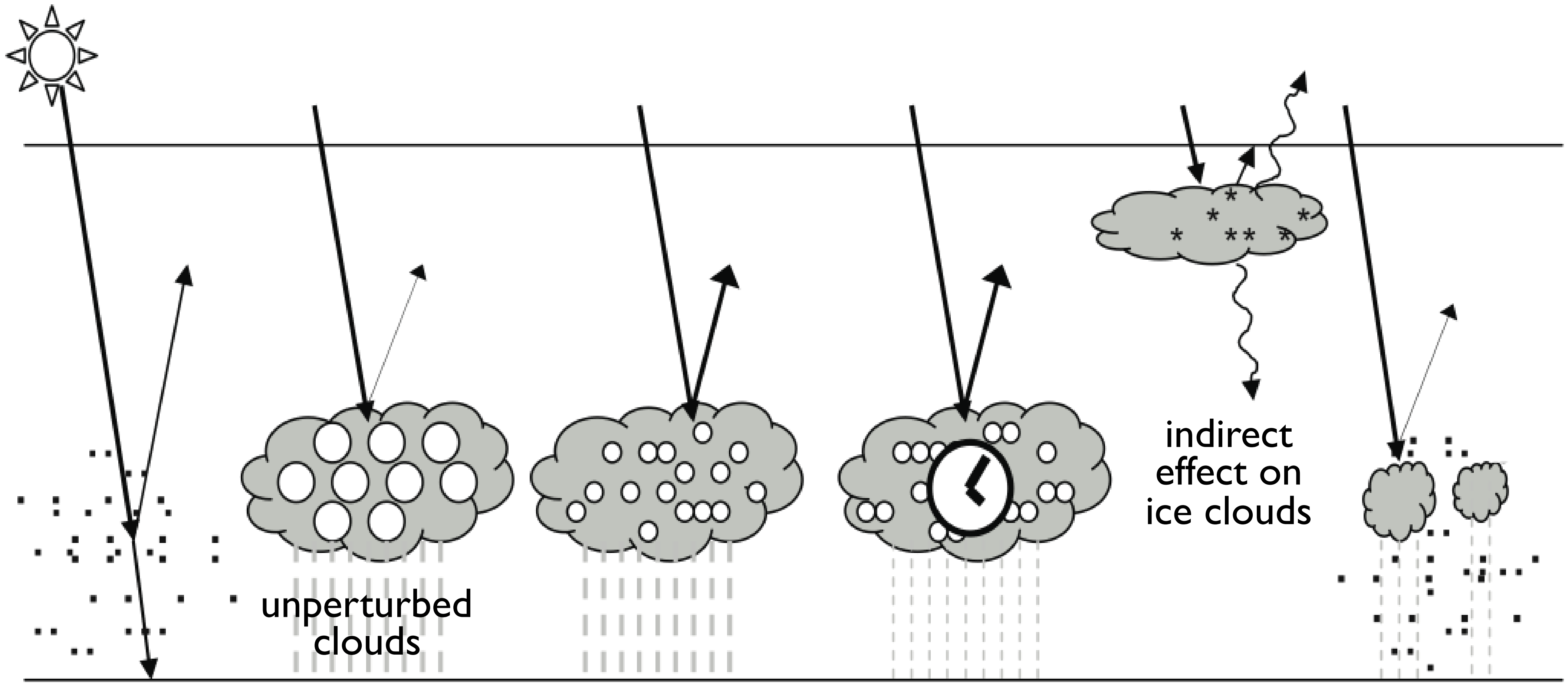
- Radiative forcing of each short-lived climate forcers (SLCFs; gases and aerosols) simulated by climate models.
- Implications for metrics of SLFCs which are reliable and easily understood by policymakers and the public.

Spectral absorption by gases



Atmospheric absorption: (a) blackbody curve for 6000K and 250K, (b) atmospheric absorption spectrum at ground level, and (c) same as (b) but at the tropopause (Goody, 1961).

Aerosol effects on climate system



direct effect
scattering & absorption of radiation

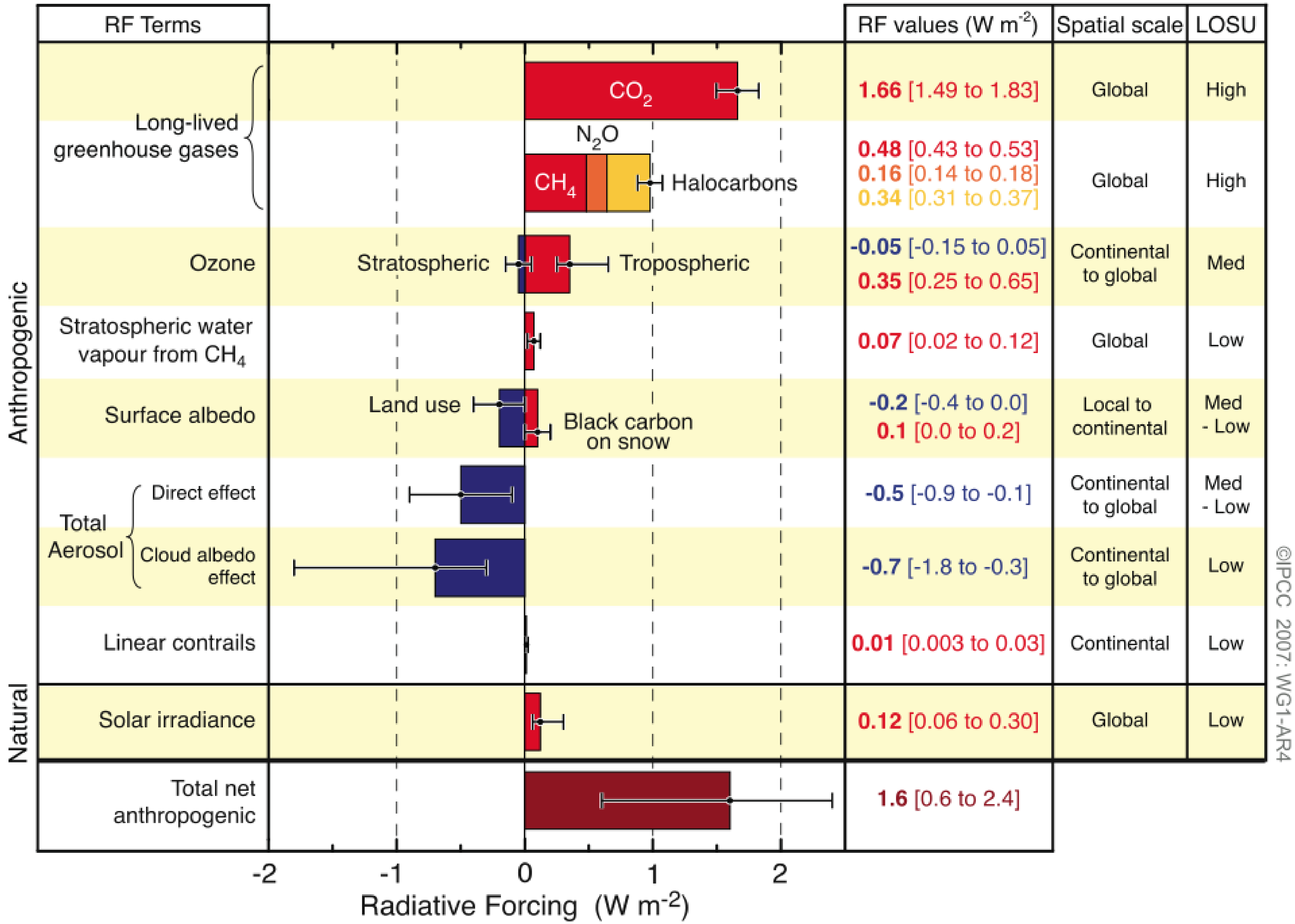
1st indirect effect
increased CCN
➡increased cloud droplets
➡increased cloud albedo

2nd indirect effect
increased CCN
➡increased cloud droplets
➡increased cloud lifetime & decreased precipitation

semi-direct effect
atmospheric heating by radiative-absorbing aerosols
➡decreased/ increased clouds

Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols. The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The vertical grey dashes represent rainfall (based on IPCC AR4, 2007).

Radiative forcing of various climate forcing agents



Global average radiative forcing (RF) estimates and ranges in 2005 relative to pre-industrial era (1750), together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU) (IPCC AR4, 2007).

AeroCom and ACCMIP

Global Aerosol Model Intercomparison — AeroCom (http://aerocom.met.no/)

- Initiated in 2002.
- ~20 models participated in coordinated model experiments.
- 10 workshops (~1 workshop/year)

Phase I experiments (2003 – 2004)

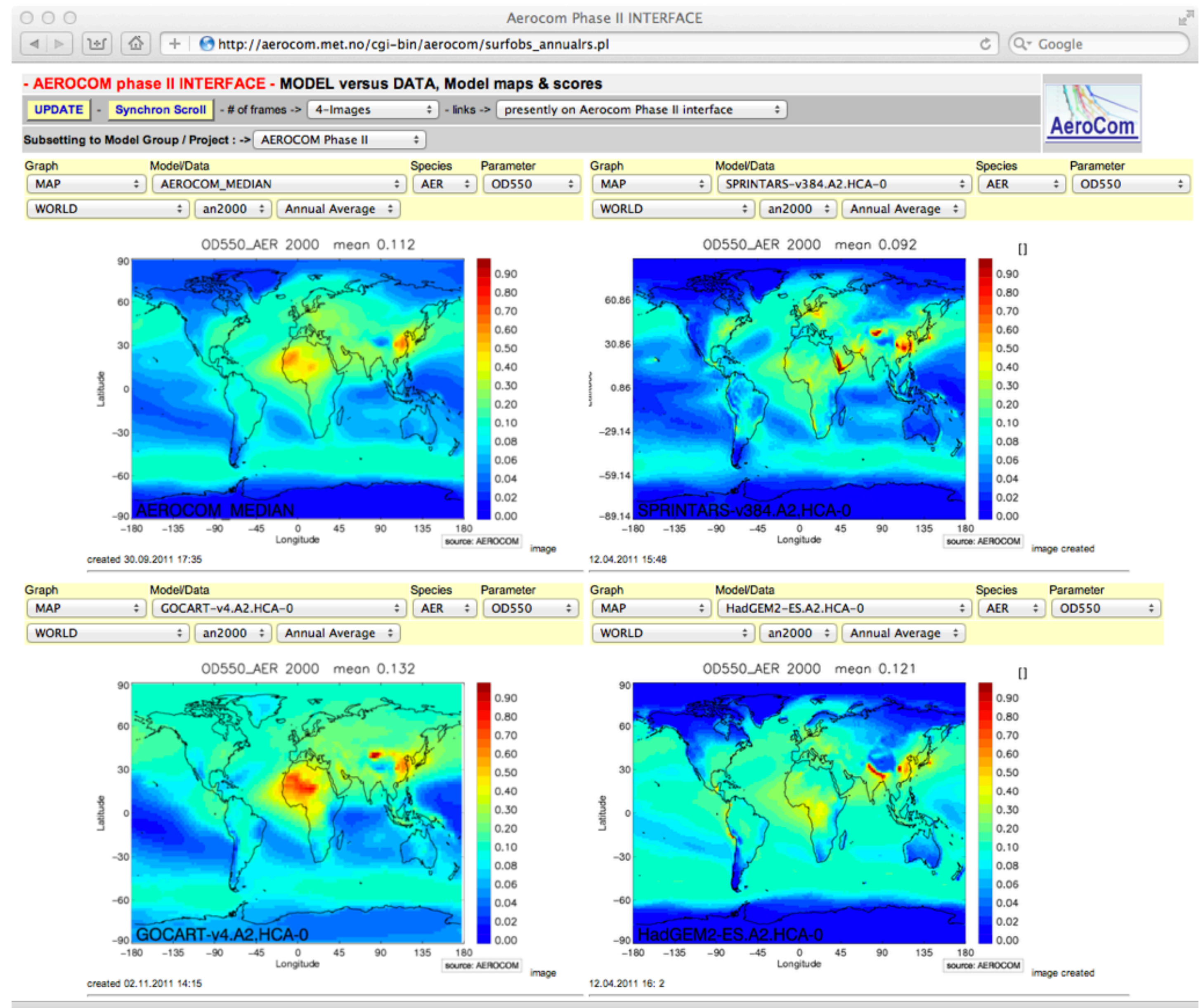
- Experiment A: models as they are.
- Experiment B and PRE: models with prescribed AeroCom emissions for present (B) and preindustrial (PRE).

➡ IPCC AR4

Phase II experiments (2008 – 2011)

- Control: simulations in 2006 – 2008, preindustrial, etc.
- Hindcast: simulations from 1980 to 2008.
- For analyzing indirect forcing.
- etc...

➡ IPCC AR5

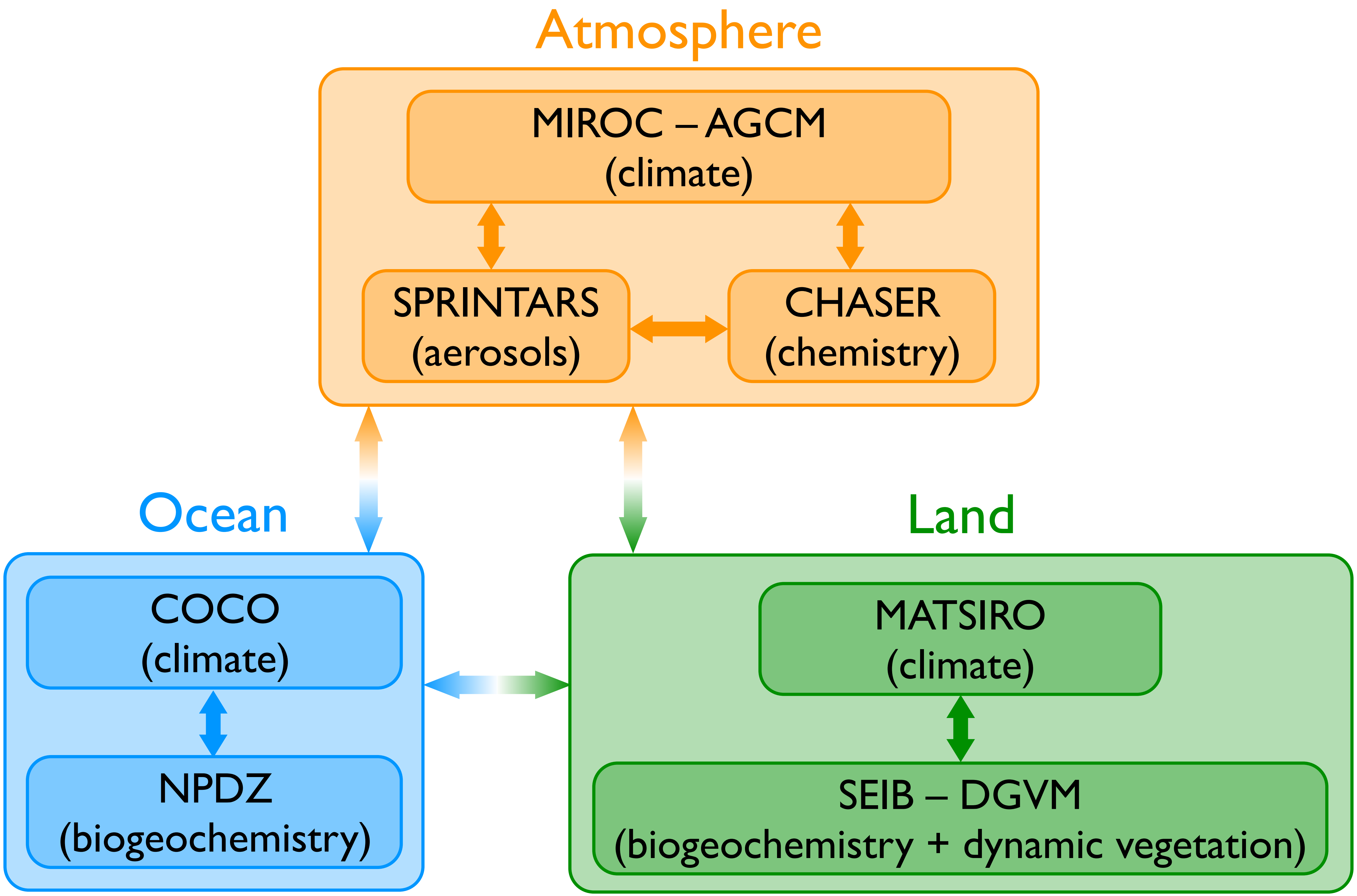


Atmospheric Chemistry and Climate Model Intercomparison — ACCMIP (http://www.giss.nasa.gov/projects/accmip/)

Organized by International Global Atmospheric Chemistry (IGAC) and Stratospheric Processes and Their Role in Climate (SPARC) under IGBP and WCRP.

➡ IPCC AR5

Japanese earth system model — MIROC-ESM



(Watanabe et al., GMD, 2011)

Global aerosol climate model SPRINTARS

Met. condition

on/off

MIROC
Atmospheric-Ocean GCM

SPRINTARS
(Spectral Radiation-Transport Model for Aerosol Species)

http://sprintars.net/

- Tracers
  black carbon, organic matter, sulfate, soil dust, sea salt, SO_2, DMS
- Aerosol transport processes
  emission, advection, diffusion, sulfur chemistry, deposition
- Aerosol optical properties
- Aerosol climate effects
  direct / semi-direct / indirect

Resolution: T213/T106/T85/T42
L56/L40/L20

References: Takemura et al. (JGR, 2000; JCLI, 2002; JGR, 2005; ACP, 2009)

Transport Processes

Emission
- BC, OM: biomass burning, fossil fuel, biofuel, agricultural activities, terpene origin.
- SO_2: fossil fuel, biomass burning, and volcanoes.
- DMS: oceanic phytoplankton, land vegetation.
- soil dust: depending on surface wind speed, vegetation, soil moisture, snow amount, LAI.
- sea salt: depending on surface wind speed.

Advection
- Flux-Form Semi-Lagrangian.
- Arakawa-Schubert cumulus convection.

Diffusion

Sulfur chemistry
- sulfur oxidation (gas/liquid phases).
- simplified SOA chemical scheme (option).
- nitrate thermal equilibrium model (option).

Deposition
- wet deposition (wash out, rain out).
- dry deposition.
- gravitational settling.

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Aerosol optical properties

- optical thickness.
- Ångström exponent.
- single scattering albedo.

Aerosol climate effects

Direct effect

- coupled with radiation process in GCM.
- considering refractive index of each aerosol depending on wavelengths, size distributions, and hygroscopic growth.
- semi-direct effect if SPRINTARS is fully coupled with GCM.

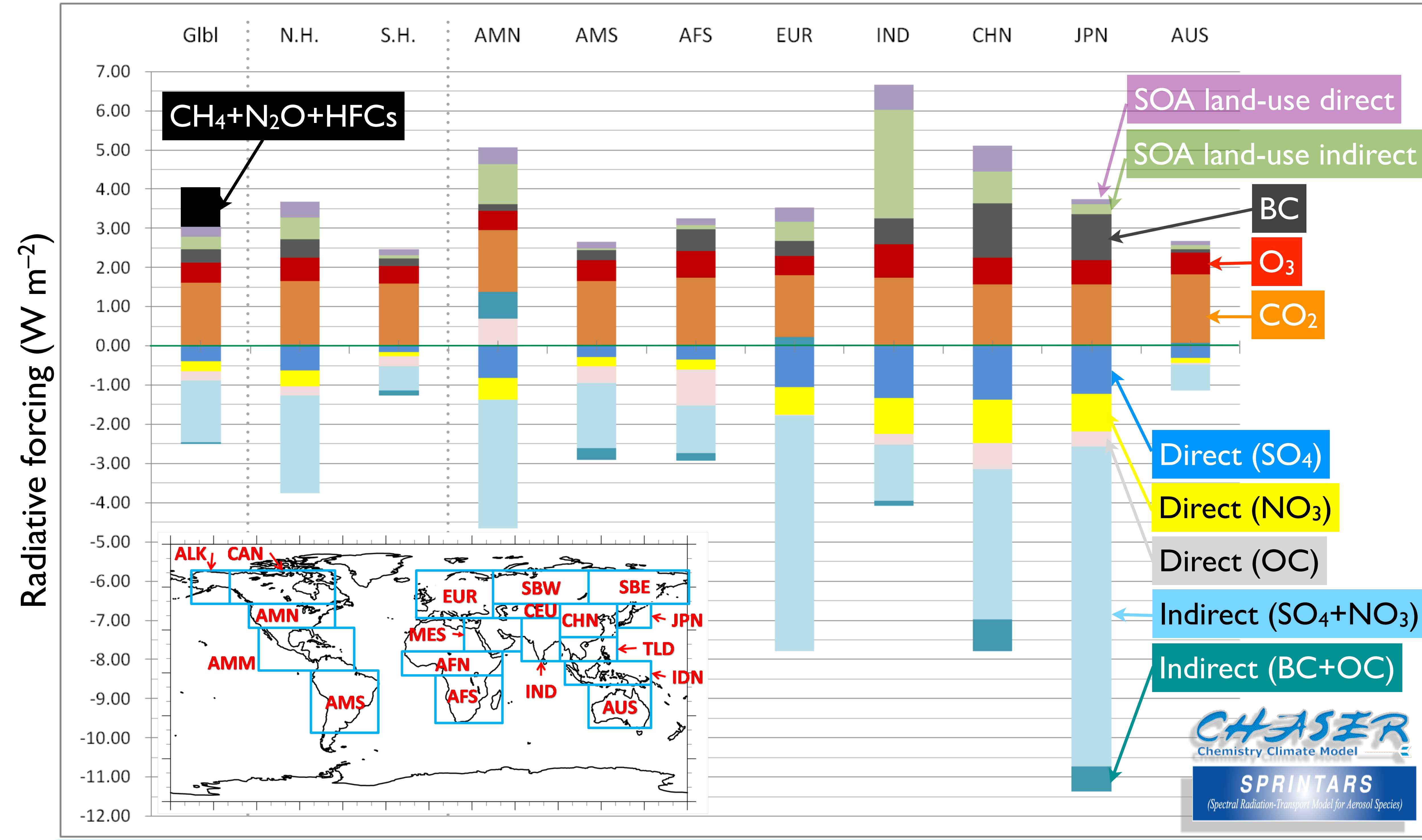
Indirect effect

- coupled with radiation and cloud/precipitation processes in GCM.
- prognostic cloud droplet and ice crystal number concentrations N_l, N_i.
- cloud droplet and ice crystal effective radii depending on N_l, N_i » 1st indirect effect.
- precipitation rates depending on N_l, N_i » 2nd indirect effect.

Global chemical transport model CHASER

Climate model	MIROC (CCSR/NIES/FRCGC GCM)
Transport processes	flux-form semi-Lagrangian, cumulus convection, and vertical diffusion
Chemical processes	chemical species: 56 chemical reactions (gas- and liquid-phase, heterogeneous): 142 • O_3 – HO_x – NO_x – CO – CH_4 • oxidation of non-methane hydrocarbons (NMHCs) • oxidation of SO_2 and DMS for sulfate aerosols
Photodissociation	on-line calculation with the ultraviolet radiation from the radiation process in GCM
Emissions	NO_x, CO, C_2H_6, C_2H_4, C_3H_8, acetone, isoprene, terpene, methanol, SO_2, DMS from industries, transportation, biomass burning, vegetation, soil, and ocean NO_x from lightnings
Dry deposition	depending on vegetation, temperature, solar radiation, snow cover, etc.
Wet deposition	rain out, wash out, and ice sedimentation, reemission with evaporation
References	Sudo et al. (JGR 2002), Watanabe et al. (GMD 2011)

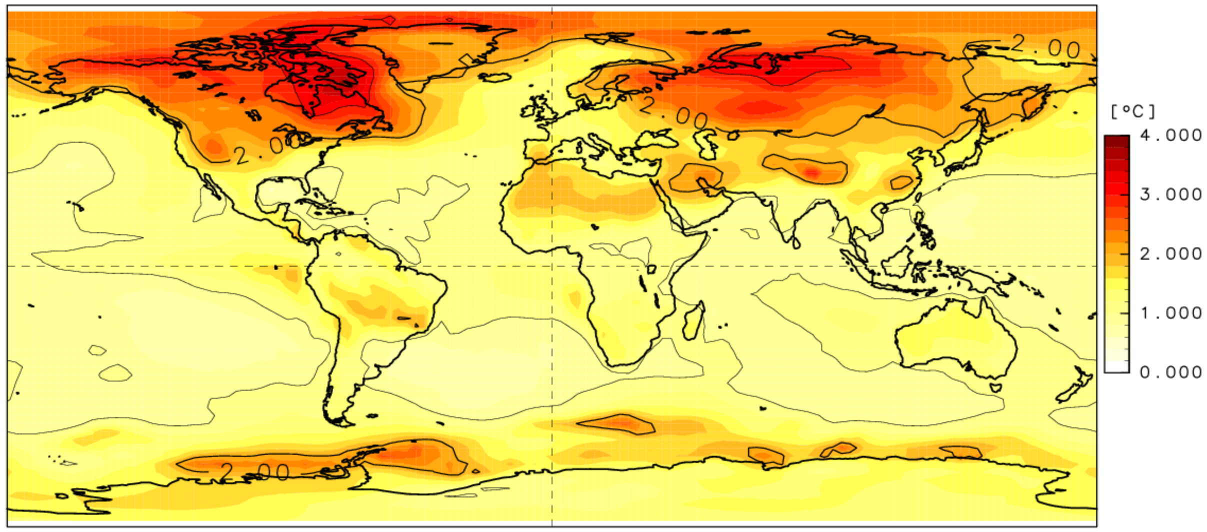
Radiative forcing of CO_2 and SLCFs



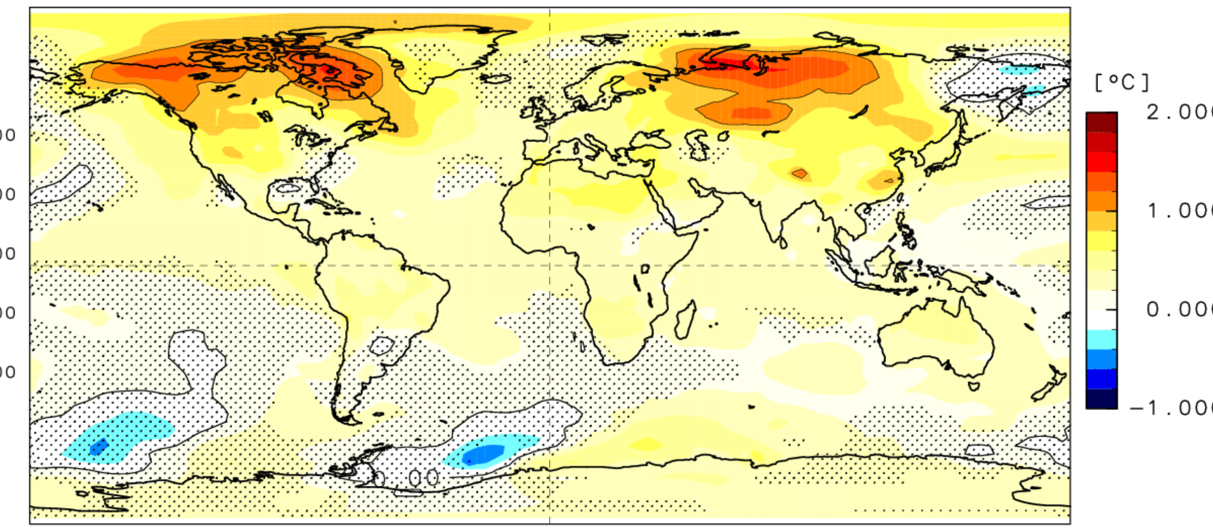
Annual global and regional mean radiative forcing (RF) for CO_2 and each SLCFs in the present relative to pre-industrial era estimated by MIROC-SPRINTARS-CHASER.

Surface warming: CO_2 vs. O_3 / BC / SO_4

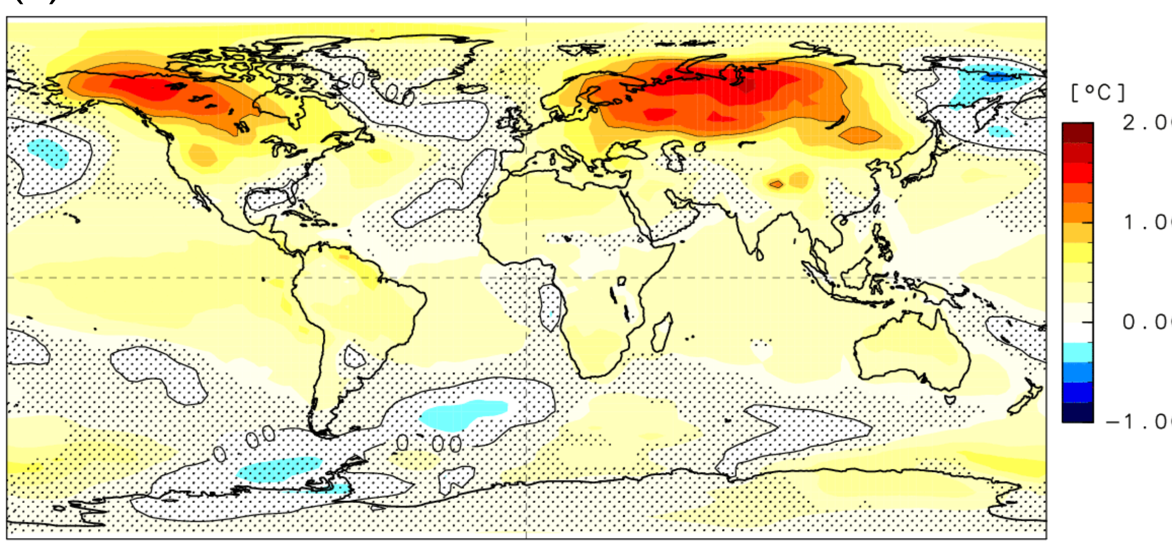
(a) CO_2 AVG. +1.31°C



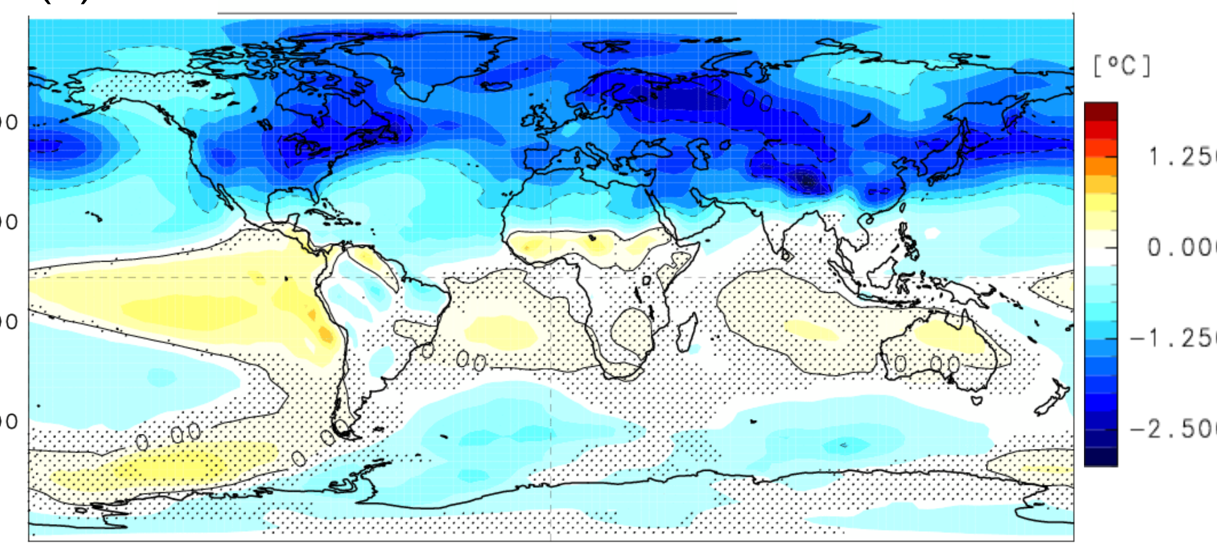
(b) O_3 AVG. +0.31°C



(c) BC AVG. +0.28°C

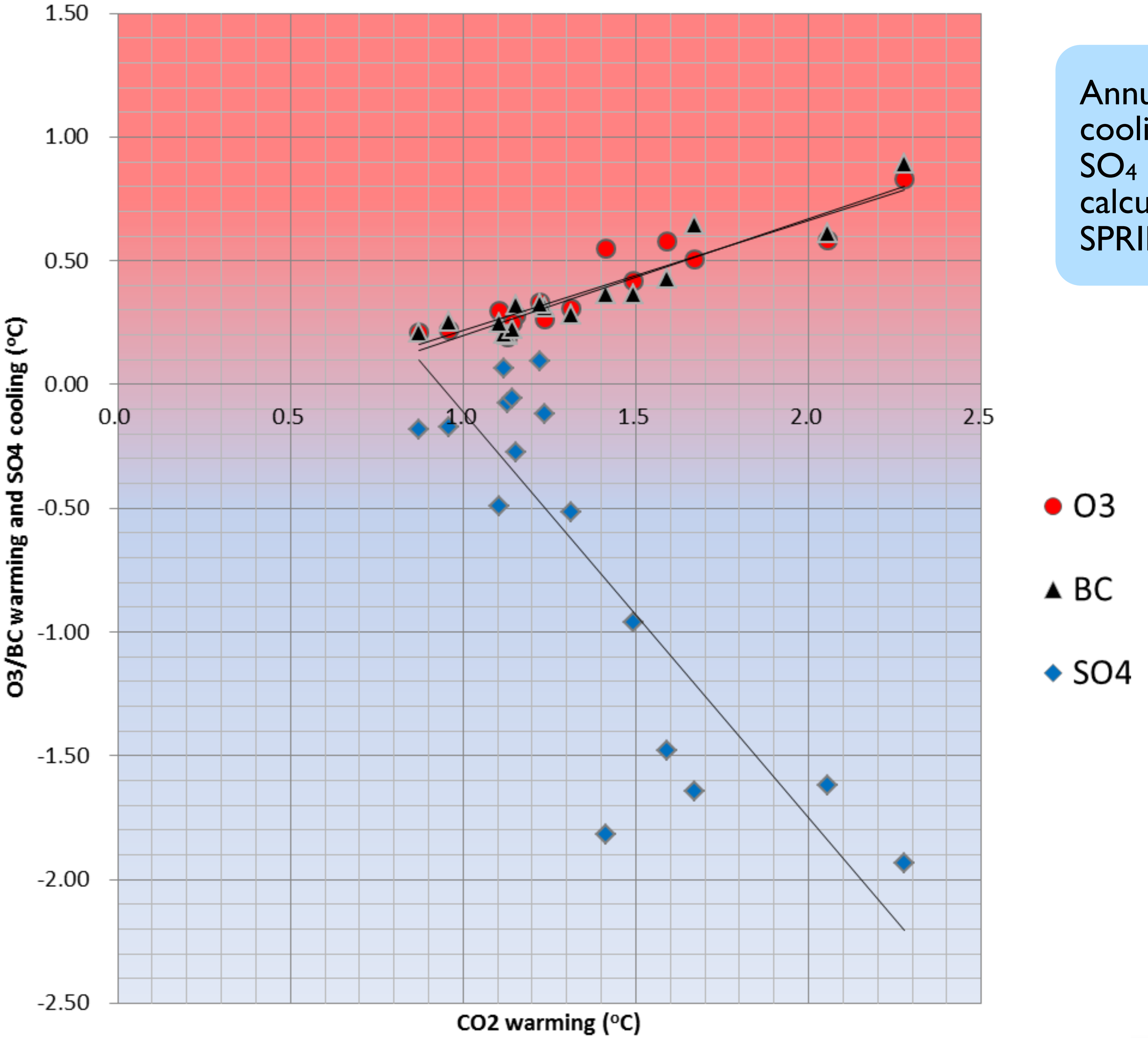


(d) SO_4 AVG. –0.52°C



Equilibrium responses of annual mean change in the surface air temperature from the present to pre-industrial era due to (a) CO_2, (b) O_3, (c) BC, and (d) SO_4 calculated by MIROC-SPRINTARS-CHASER with a slab ocean model.

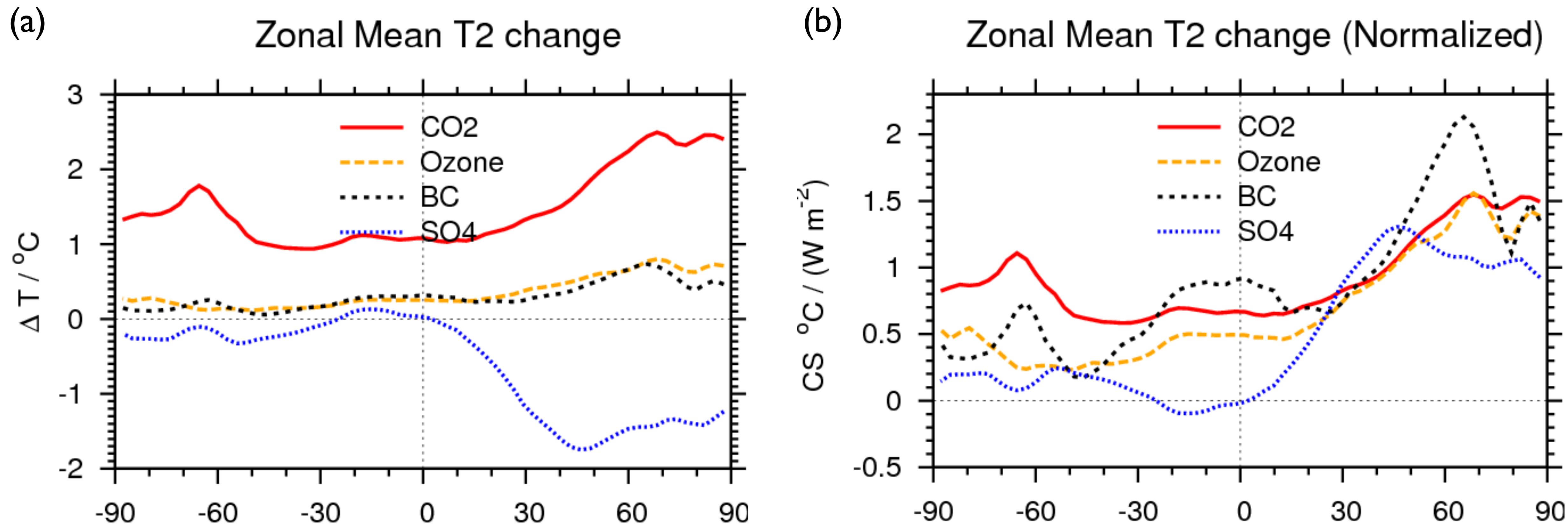
Surface warming: CO_2 vs. O_3 / BC / SO_4



Annual regional mean warming/cooling due to O_3, BC, and SO_4 against CO_2 warming calculated by MIROC-SPRINTARS-CHASER.

- Warming due to O_3 and BC has a linear relationship with warming due to CO_2.
- Relationship of cooling due to SO_4 against warming due to CO_2 is a little dispersed.
  ➡ Mainly because of the aerosol indirect effect.

Climate sensitivities of CO_2 and SLCFs



(a) Annual zonal mean change in the surface air temperature from the present to pre-industrial era due to CO_2, O_3, BC, and SO_4 calculated by MIROC-SPRINTARS-CHASER. (b) Same as (a) but the normalized one by a unit radiative forcing ($W\ m^{-2}$).

- Increases in O_3 and BC cause warming in comparable magnitude.
- Northern mid-high latitudes and tropics are more sensitive to BC than to O_3 and CO_2.
- SO_4 cooling is significant only in >20˚N, and its sensitivity is equivalent with O_3 and CO_2.

Global mean efficacy (warming efficiency compared to CO_2): O_3: 0.73, BC: 1.0, SO_4: 0.47

Implications for metrics of SLCFs

- Metrics of SLCFs (O_3, BC, SO_4, etc.) must be defined because their contributions to the temperature change of the atmosphere is large.
- Uncertainties in estimating the radiative forcing of SLCFs is gradually small due to a large number of researches with numerical modelings and observations.
  ➡ GWPs of SLCFs are getting reliable.
- GTP is a straightforward metric for policy on controlling under the specific temperature increase. However there are still large uncertainties in the climate sensitivities of SLCFs as well as CO_2.
  ➡ We need more researches to derive statistically reliable GTPs of SLCFs.

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