Integrated assessment of aerosol effects on atmospheric temperature and precipitation with global climate models

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Contents

- Precipitation Driver and Response Model Intercomparison Project (PDRMIP).
- Japanese research project investigating an optimum reduction path of SLCPs as integrating all of climate change, health impacts, and agricultural damages.
- SPRINTARS in a global cloud resolving model.
- SPRINTARS aerosol 7-day forecasting system to contribute researches and public.

Model description of 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
aerosol–radiation interaction
aerosol–cloud interaction

Resolution
T319/T213/T106/T85/T42; L56c/L40h/L20c

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

● Transport Processes

- Emission
  - BC, OM: biomass burning, fossil fuel, biofuel, agricultural activities, oceanic OM, terpene/isoprene 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
- Chemistry
  - sulfur oxidation (gas/liquid phases).
  - simplified SOA chemical scheme.
  - nitrate thermal equilibrium model (optional).
- 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

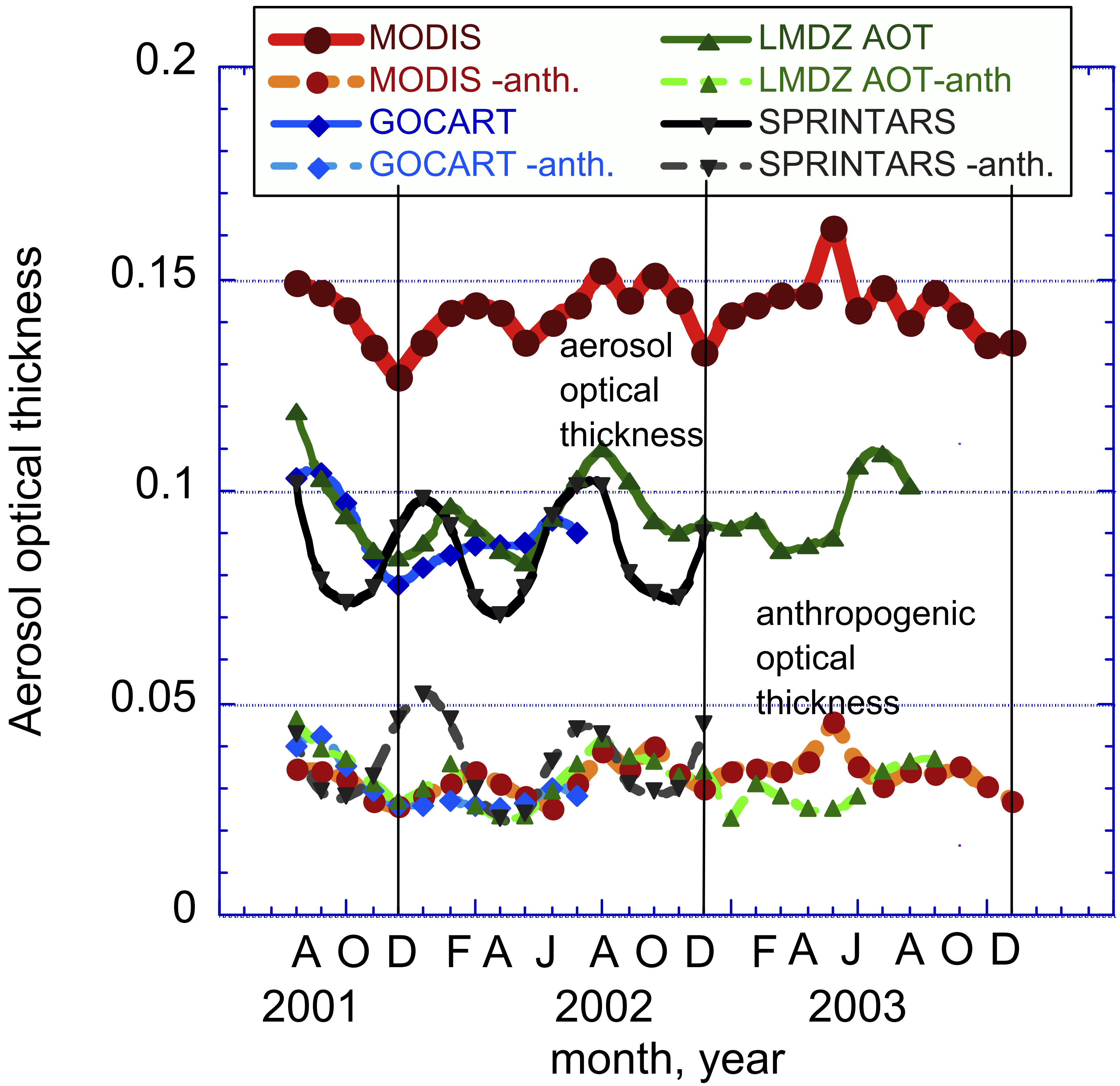
Aerosol–radiation interaction (direct effect)

- 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.

Aerosol–cloud interaction (indirect effect)

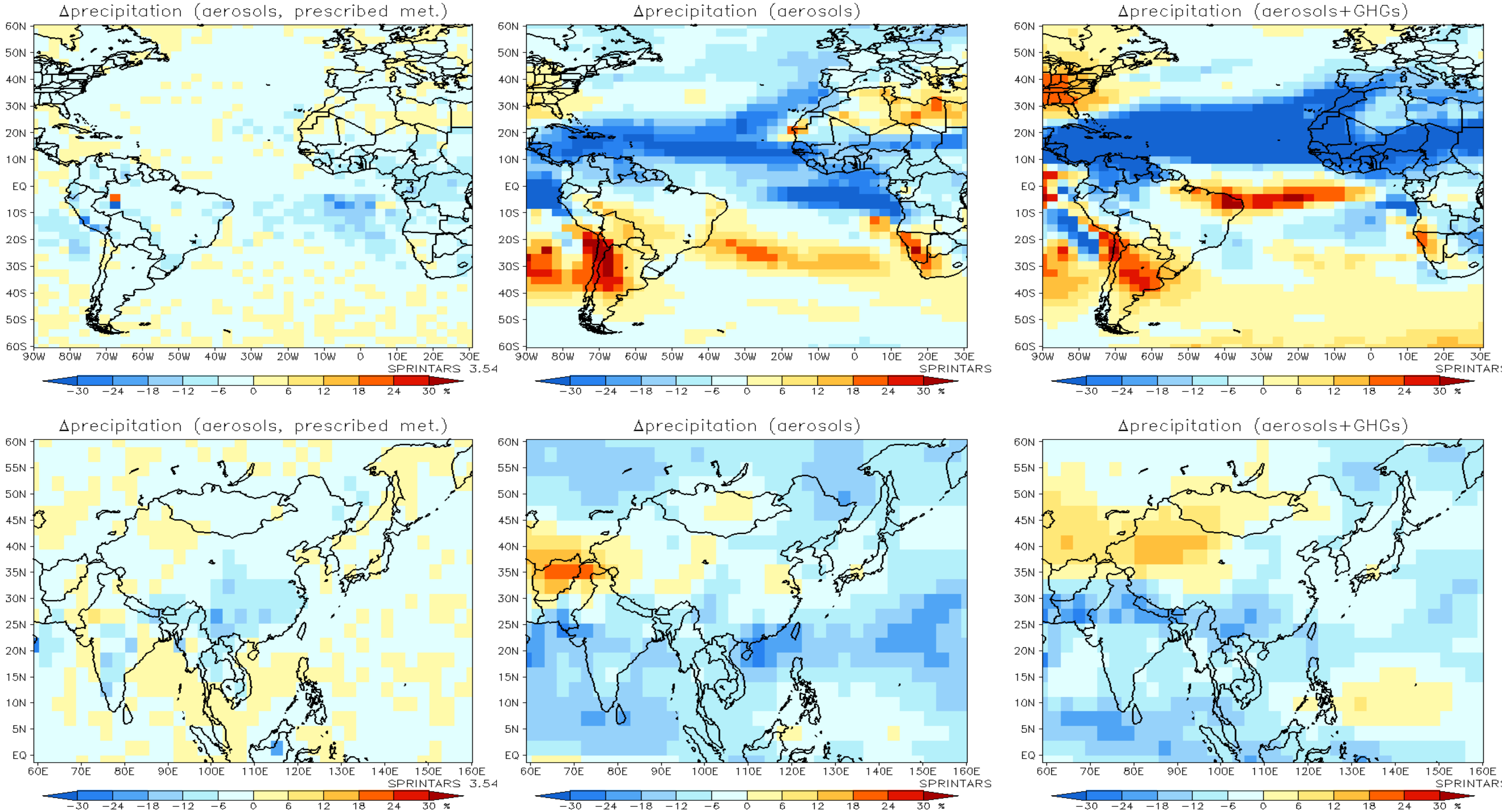
- coupled with radiation and cloud/precipitation processes in GCM.
- prognostic number concentrations of cloud droplet N_l and ice crystal N_i.
- cloud droplet and ice crystal effective radii depending on N_l, N_i
  ➡ **1st indirect effect.**
- precipitation rates depending on N_l, N_i
  ➡ **2nd indirect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

Intercomparison between satellites and models



Global average aerosol optical thickness over cloud free ocean measured by MODIS (red), and simulated by GOCART (blue), LMDZ (green) and SPRINTARS (black) models (Kaufman et al., GRL, 2005).

Aerosol effects on precipitation



Annual mean changes in the simulated precipitation from pre-industrial to present days due to aerosols with prescribed meteorological field (left), and due to aerosols (middle) and aerosols +LLGHGs (right) with a mixed-layer ocean model in equilibrium experiments.

(Takemura, Kaufman et al. GRL, 2007).

PDRMIP experiments

Precipitation Driver and Response Model Intercomparison Project

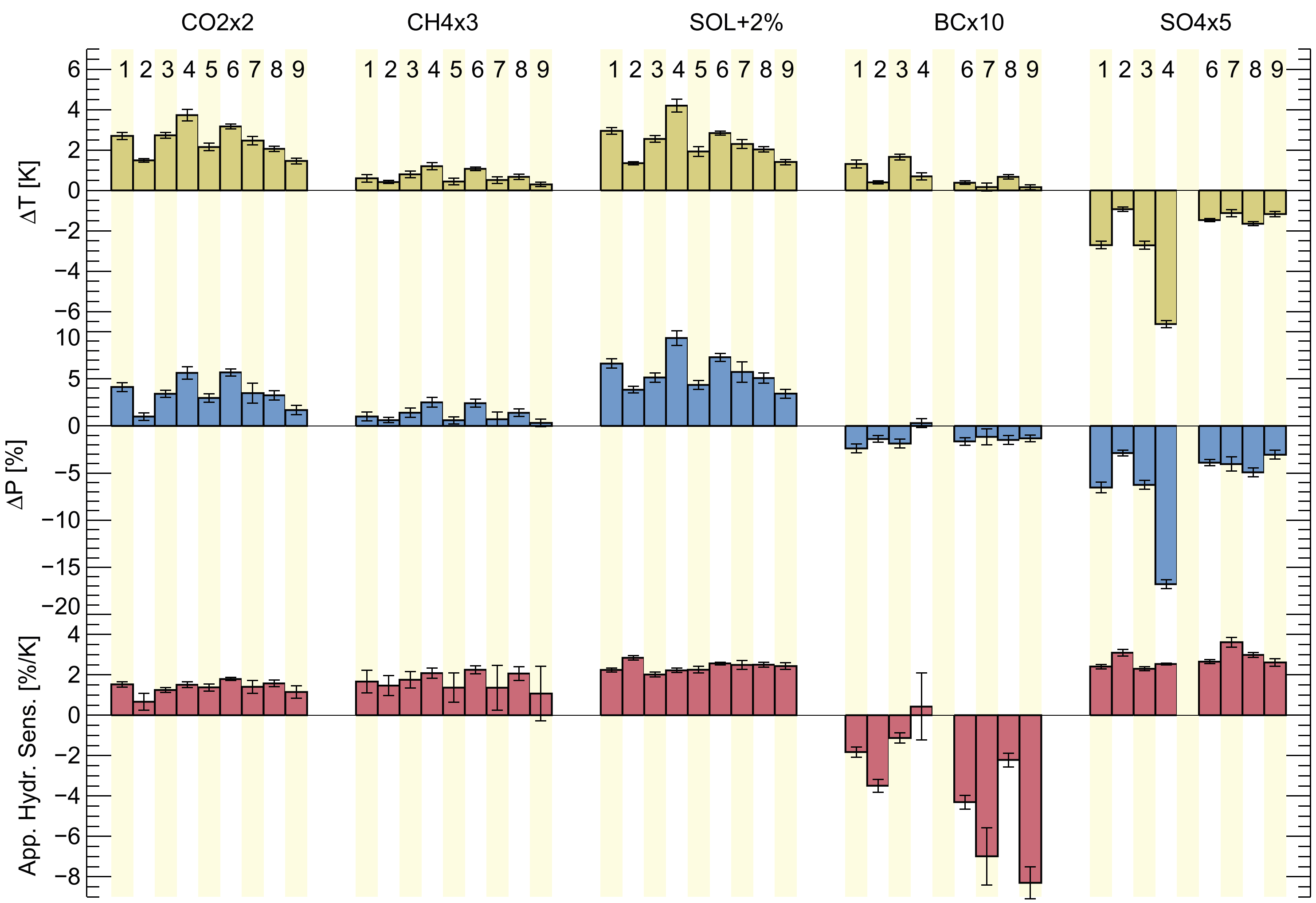
http://cicero.uio.no/en/pdrmip/

PDRMIP compares the precipitation response to various climate drivers across models. Planned analyses include a better understanding of the drivers' importance for inter-model differences in precipitation changes, energy budget analysis and extremes related to precipitation.

Core experiments	fixed SST: 15yr	slab/full ocean: 100yr
Base	Specified present day CO_2, CH_4, solar constant, aerosol concentration	
CO_2x2	CO_2 concentration from PDC to 2xPDC	* PDC: present-day
CH_4x3	CH_4 concentration from PDC to 3xPDC	
Solar	Solar constant increased by 2%	
Sul	Sulphate concentration from PDC to 5xPDC	
BC	BC concentration from PDC to 10xPDC	

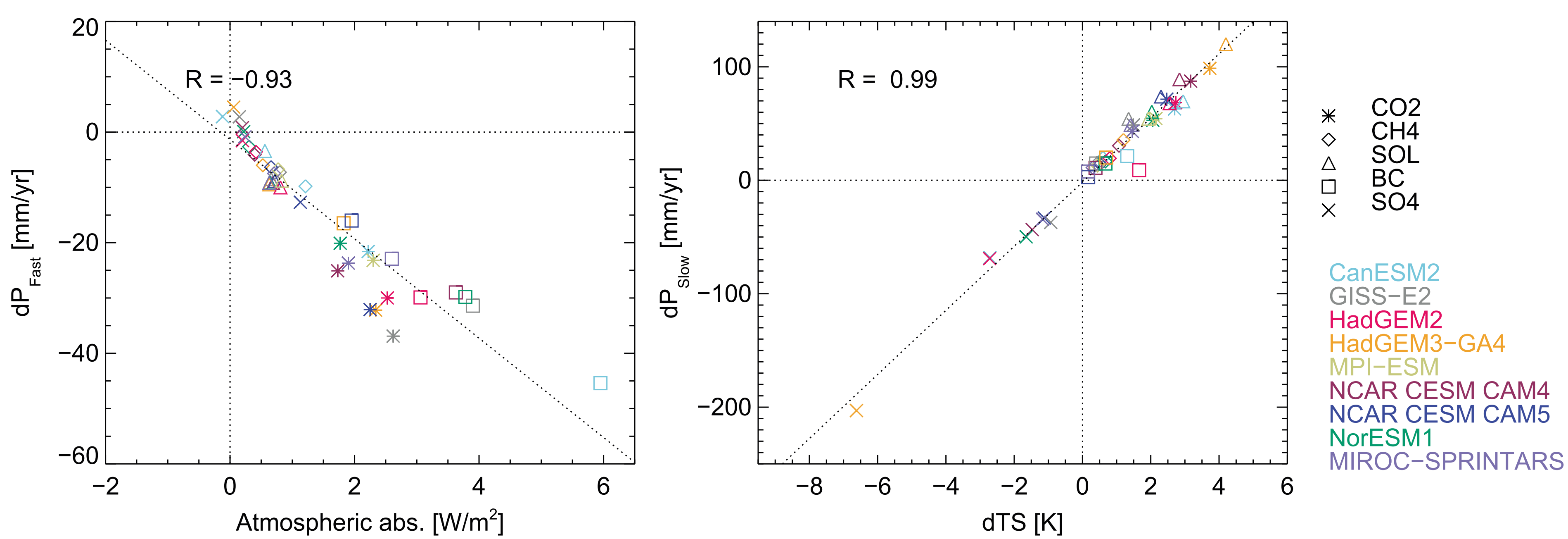
Additional experiments	fixed SST: 15yr	slab/full ocean: 100yr
Sulred	Sulfate concentration from PDC to PIC	* PIC: pre-industrial
Suleur	Sul multiplied by 10, Europe only	
Sulasia	Sul multiplied by 10, Asia only	
BCasia	As BC, but Asia only	
Sulasired	As Sulred, but Asia only	
O_3asia	Add O_3, Asia only, comparable forcing to Sulasia	

PDRMIP experiments



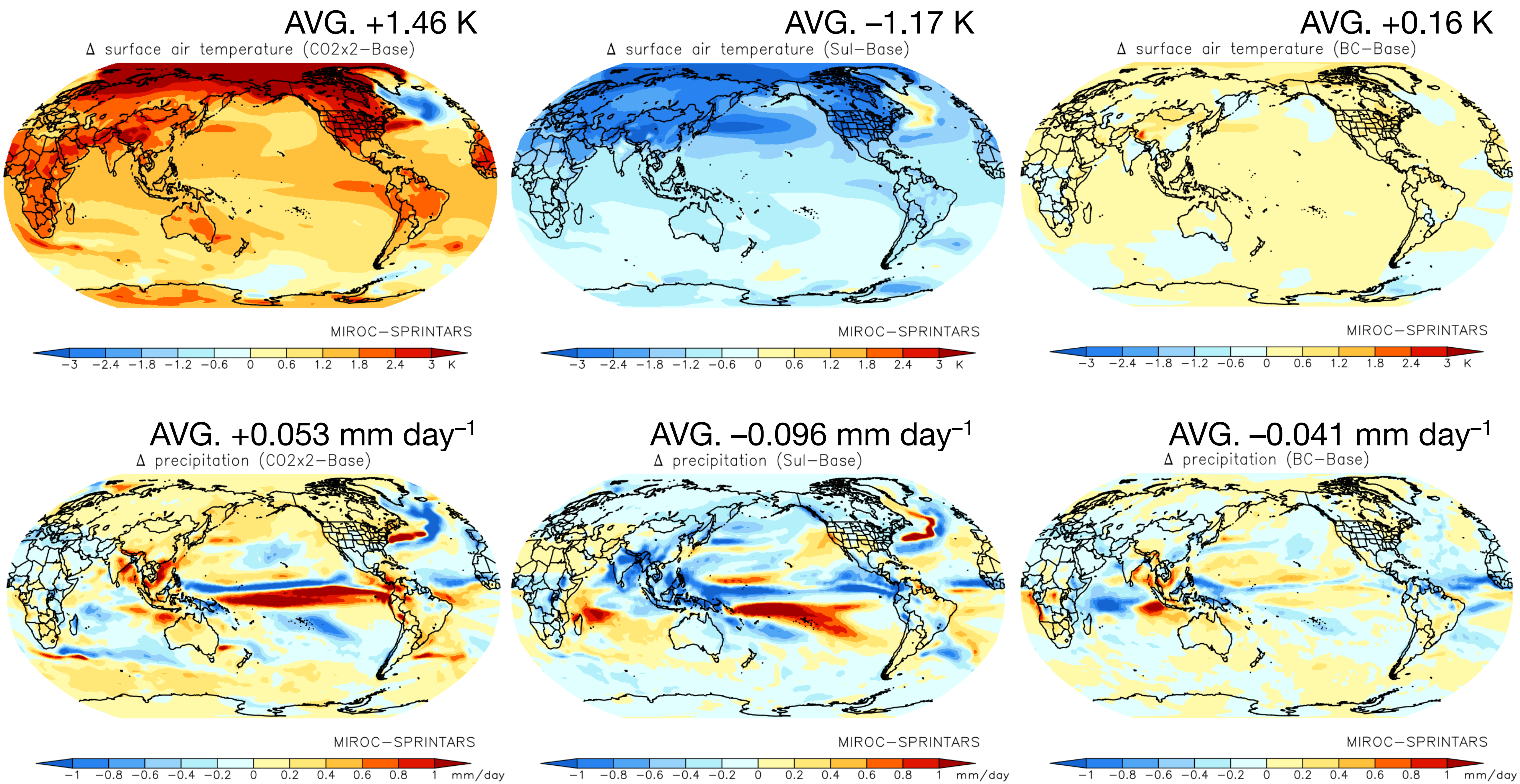
Global, annual mean (top) temperature and (middle) precipitation change for years 51–100 following a climate perturbation and (bottom) the resulting apparent hydrological sensitivity. The numbers indicate the participating models. Error bars indicate ±1 standard deviation of interannual variability. (Samset et al., 2016)

Models:
1: CanESM2
2: GISS−E2
3: HadGEM2
4: HadGEM3−GA4
5: MPI−ESM
6: NCAR CESM1 CAM4
7: NCAR CESM1 CAM5
8: NorESM1
9: MIROC−SPRINTARS



Regression of (left) fast precipitation change versus atmospheric absorption and (right) slow precipitation change versus surface temperature change. The shown regression lines and correlation (R) are for the combined data from all models and climate perturbations. (Samset et al., 2016)

Δ temperature & precipitation by MIROC in PDRMIP



Annual mean equilibrium changes in (top) surface air temperature and (bottom) precipitation in the experiments of CO_2x2, SO_2x5, and BCx10 with a coupled-ocean general circulation model MIROC-SPRINTARS.

Japanese SLCP project

S-12 Project (FY2014–2018)
“Active evaluation of SLCP impacts and seeking the optimal pathway”

- Theme 1 **Inventory**
- Theme 2 **Scenarios**
- Theme 3 **“Assessment of climate and environmental impacts by SLCPs with numerical models”**
- Theme 4, 5 **Integration Toolkit**

Objective of S-12-3

Quantitative assessment of effects of SLCPs on climate, hydrological cycle, health, and agriculture with climate-air quality coupled models.
➡ Contribution to scientific bases for suitable reductions of SLCPs/WMGHGs.

Emission inventories and scenarios [Themes 1 & 2]

Suitable reduction path [Theme 4, 5]

Theme 3

Assessment of SLCPs effects on climate with climate-aerosol-chemistry models (SPRINTARS/CHASER)
[Sub-themes 1 & 2]

Assessment of changes in hydrological cycles by SLCPs with climate models
[Sub-themes 5 & 6]

Assessment of impacts on health and agriculture by SLCPs
[sub-themes 3 & 4]

Extended PDRMIP-type experiments in S-12

PDRMIP Core experiments (shown only aerosol-related)	fixed SST: 15yr	slab/full ocean: 100yr * PDC: present-day
Sul	Sulphate concentration (or related emissions) from PDC to 5 x PDC	
BC	BC concentration (or emission) from PDC to 10 x PDC	

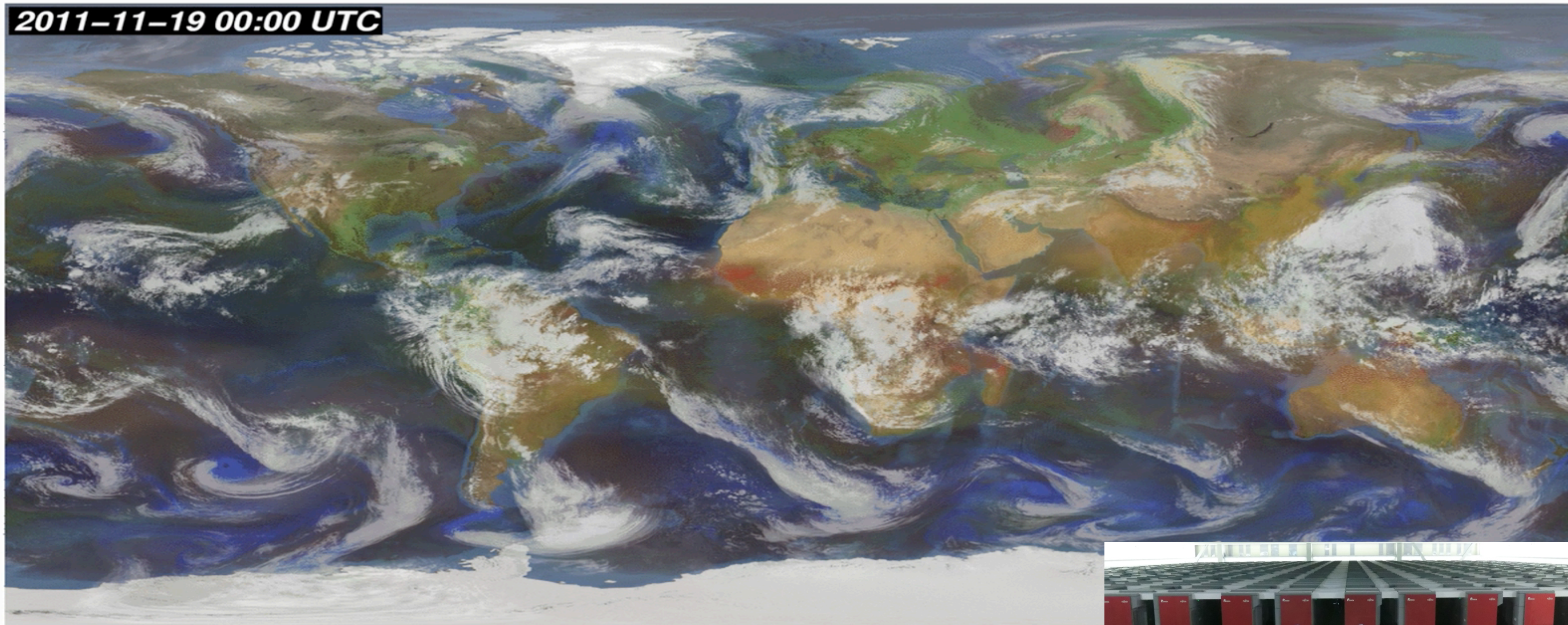
Extended experiments	fixed SST: 15yr	slab/full ocean: 100yr
Sulx, BCx****	SO_2 or BC emissions from PDC to 0, 0.1, 0.3, 0.5, 0.8, 1.5, 2, 5, 10 x PDC under 1 x CO_2 and 2 x CO_2	

Contribution to scientific bases for suitable reductions path on aerosols with minimum climate change

Global high-resolution aerosol simulation

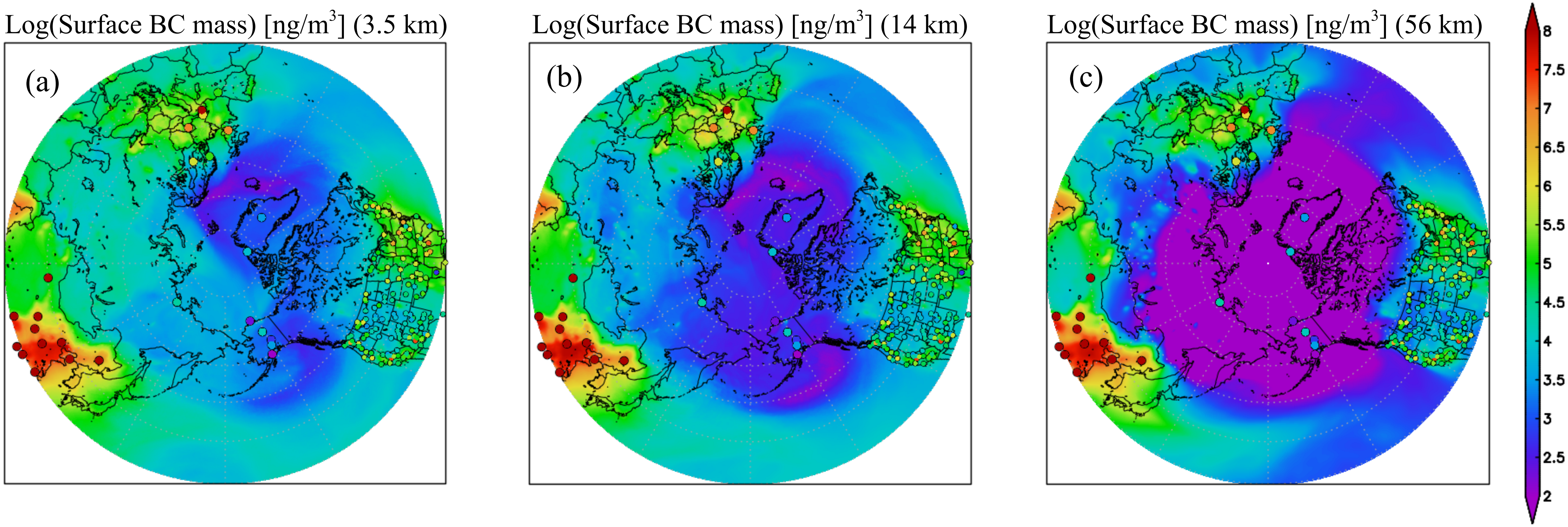
Aerosol transport and climate processes with a global cloud resolving model.

➡ Expectation of reducing uncertainty of the aerosol-cloud interaction which is the most uncertain factor in evaluation of climate change.
Improvement also of simulated aerosol concentrations.



(Colors) aerosol and (white) cloud optical thicknesses simulated by **NICAM-SPRINTARS** with a global horizontal resolution of 3.5-km (yellow: sulfate, green: organic matter, red: soil dust, blue: sea salt) (Sato, et al., 2016).

Arctic aerosol transport with high resolution



Simulated near-surface concentration of black carbon by **NICAM-SPRINTARS** with a global horizontal resolution of (left) 3.5-km, (middle) 14-km, and (right) 56-km. Filled circles indicate observed data from IMPROVE, CAWNET, CABM, and EUSAAR (Sato, et al., 2016).

✳ IMPROVE: Interagency Monitoring of Protected Visual Environment
CAWNET: China Atmosphere Watch Network
CABM: Canadian Aerosol Baseline Measurement
EUSAAR: European Supersites for Atmospheric Aerosol Research

SPRINTARS aerosol 7-day forecasting system

* automatically operated once a day.

Kyushu University/RIAM NEC SX-ACE 60PE

▸ Download forecasted meteorological field and semi-realtime biomass burning data.

- daily sea surface temperature and 3-hourly horizontal wind speed and temperature of NCEP Global Forecast System (GFS).
- daily MODIS hotspot data from Fire Information for Resource Management System (FIRMS) of University of Maryland/NASA GSFC.

➡ conversion to BC, OC, and SO_2 emissions using climatological GFEDv2 data.

▸ Simulate global aerosol distributions and its radiative forcing by SPRINTARS.

* Horizontal resolution of operating version: T316 (0.375° x approx. 0.375).

- 8-day simulation from the day before the starting time of forecast.
- initial values from the simulation the day before.
- nudged by the GFS wind and temperature.

▸ Make figure and HTML files.

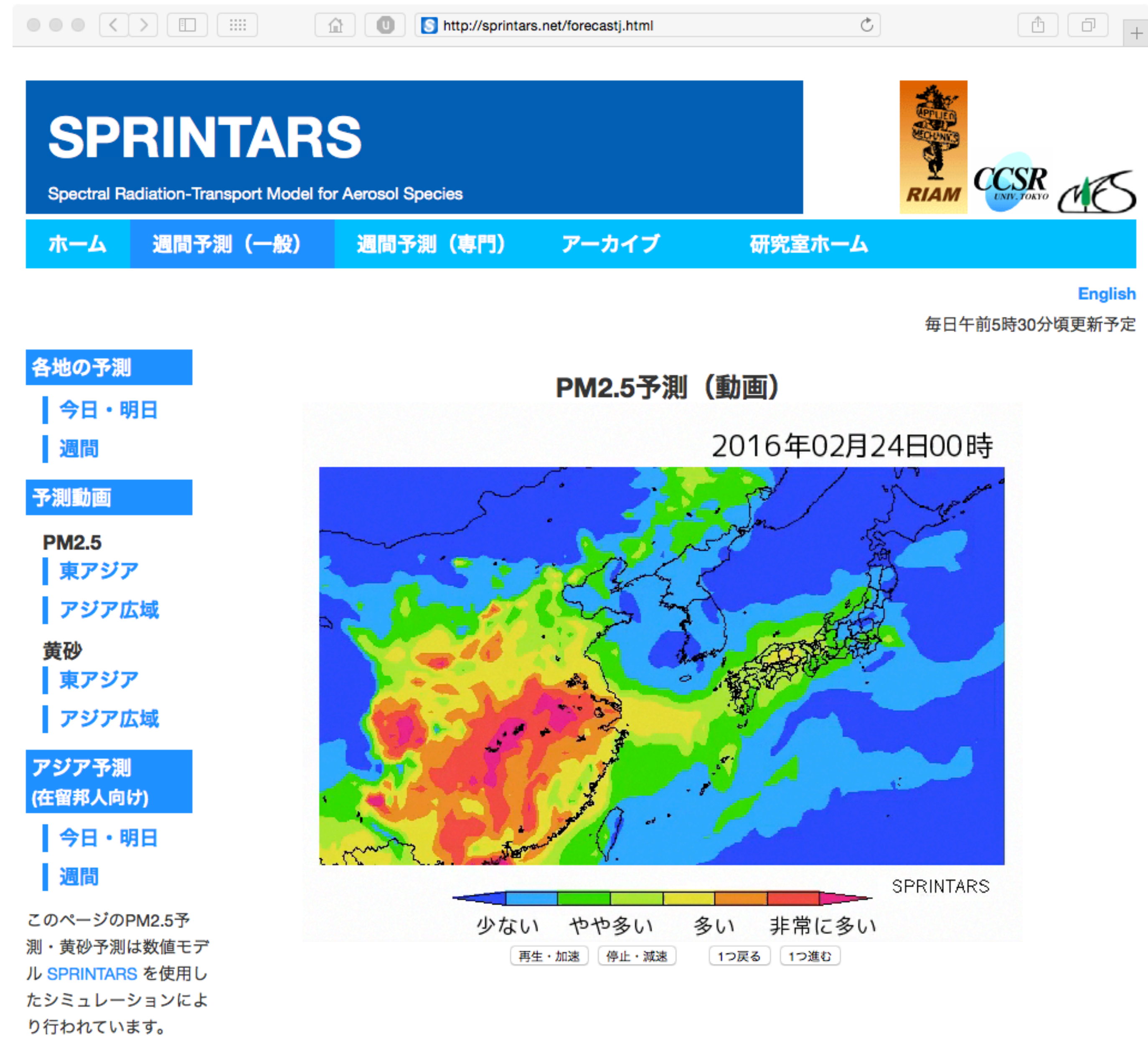
upload around 5:00JST (20:00UTC) every day.

SPRINTARS web server (http://sprintars.net/)

SPRINTARS aerosol 7-day forecasting system

Takemura (Tenki, 2009 (in Japanese))

http://sprintars.net/ (in Japanese/English)



SPRINTARS PM2.5 forecast is cited and used by TVs, radios, newspapers, other websites, apps, and local governments → Direct contribution to public.

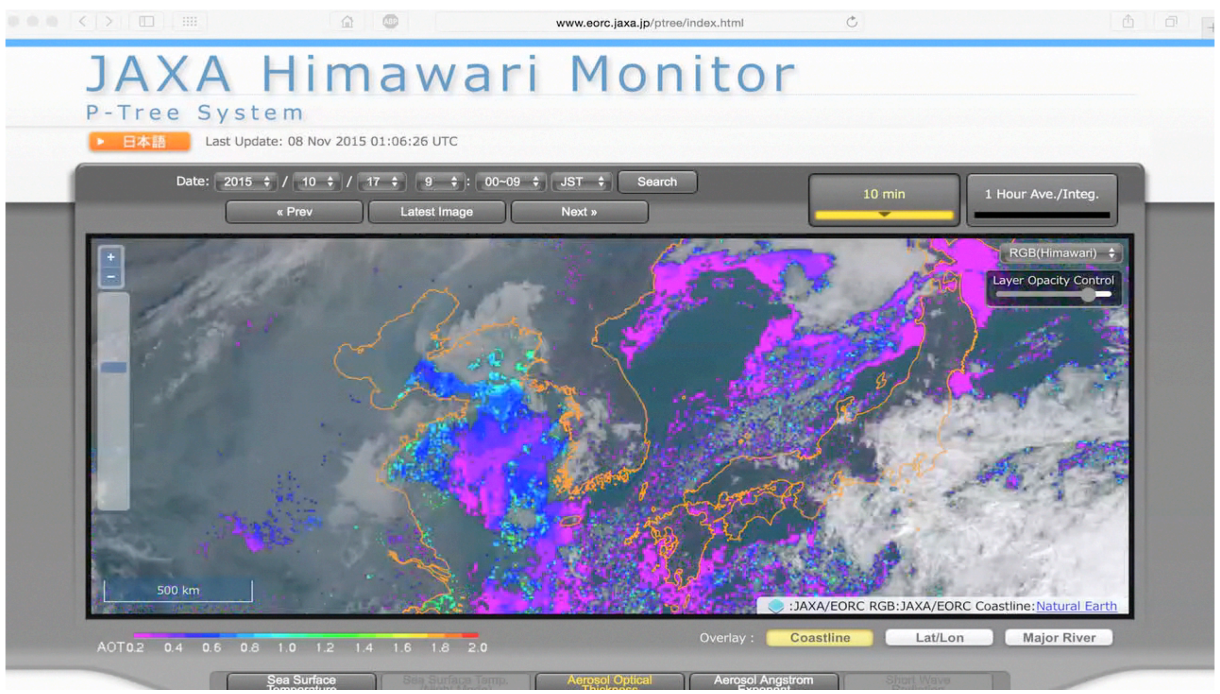
Collaboration on aerosol monitoring and forecast

Collaboration on development of aerosol monitoring system in Japan

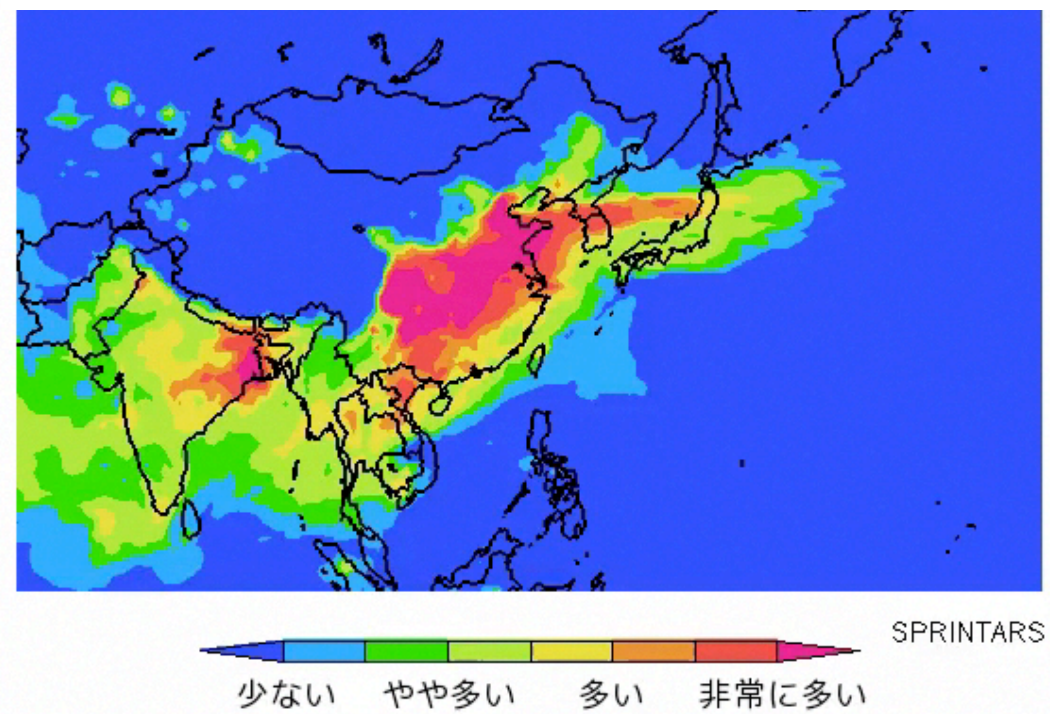
- JAXA/EORC, RIAM/Kyushu Univ., MRI/JMA, NIES

Aerosol retrievals from latest Japanese satellites

Himawari-8, GCOM-C, EarthCARE, GOSAT2



Aerosol forecasting system SPRINTARS, MASINGAR



Data assimilation

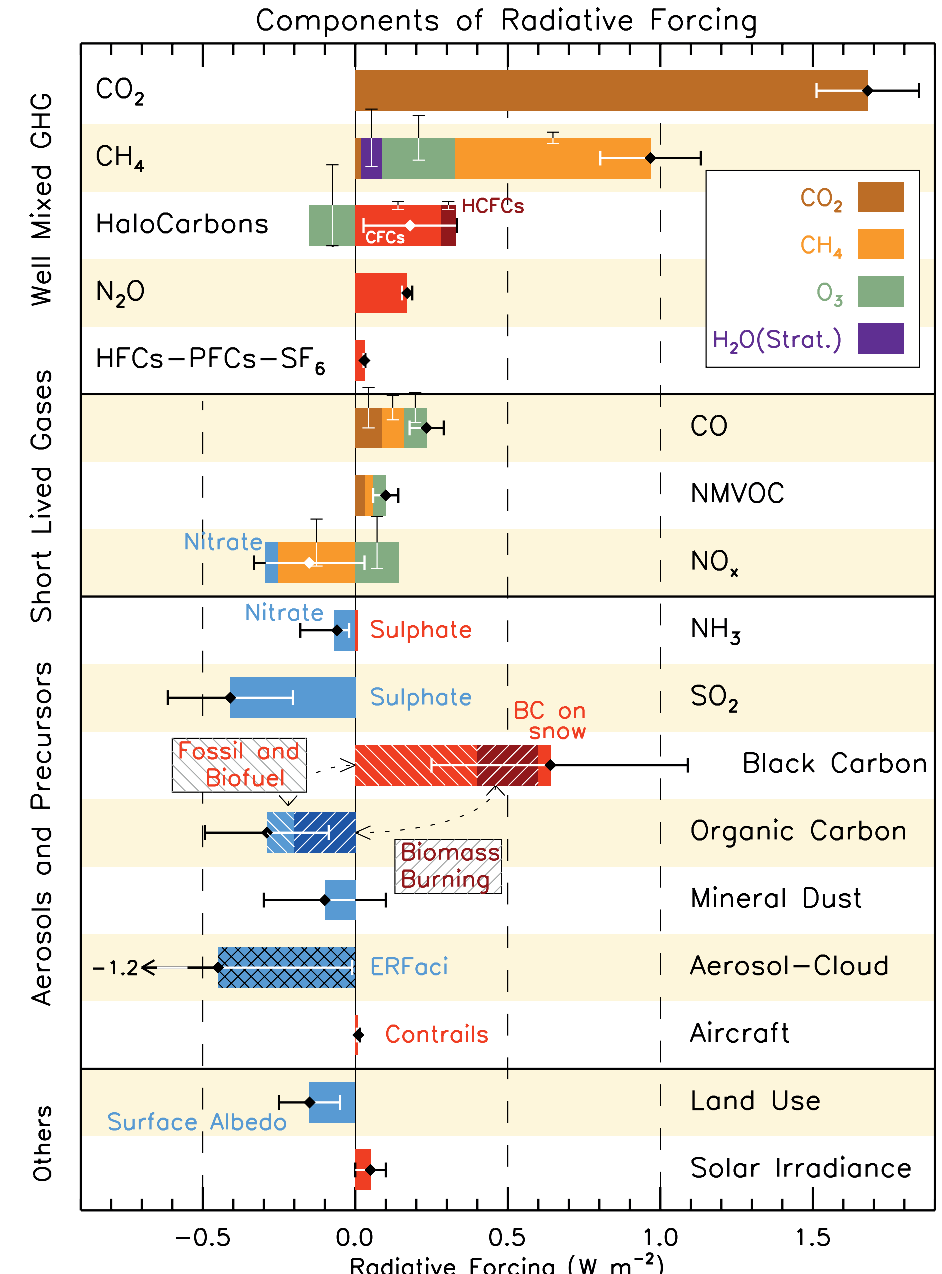
4D-Var, Ensemble Kalman Filter

Yumimoto and Takemura (2011, 2013, 2015); Schutgens et al. (2010a, 2010b)

High-quality distributions of aerosol concentrations

Summary

- There are a lot of past studies on concentrations and radiative forcing of atmospheric aerosols.
  - ➡ The present stage is moving to assessment of quantitative climate change due to aerosols.
- It is difficult to quantify aerosol effects on climate system with a single model.
  - ➡ Model intercomparisons are essential.
- It is also important to elucidate uncertain processes in aerosol-radiation and aerosol-cloud interactions, and modeled them.



IPCC AR5 (2013)

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