5th AEROCOM Meeting (October 17-19, 2006 @ Virginia Beach)

Analysis of aerosol effects on climate system with an aerosol climate model

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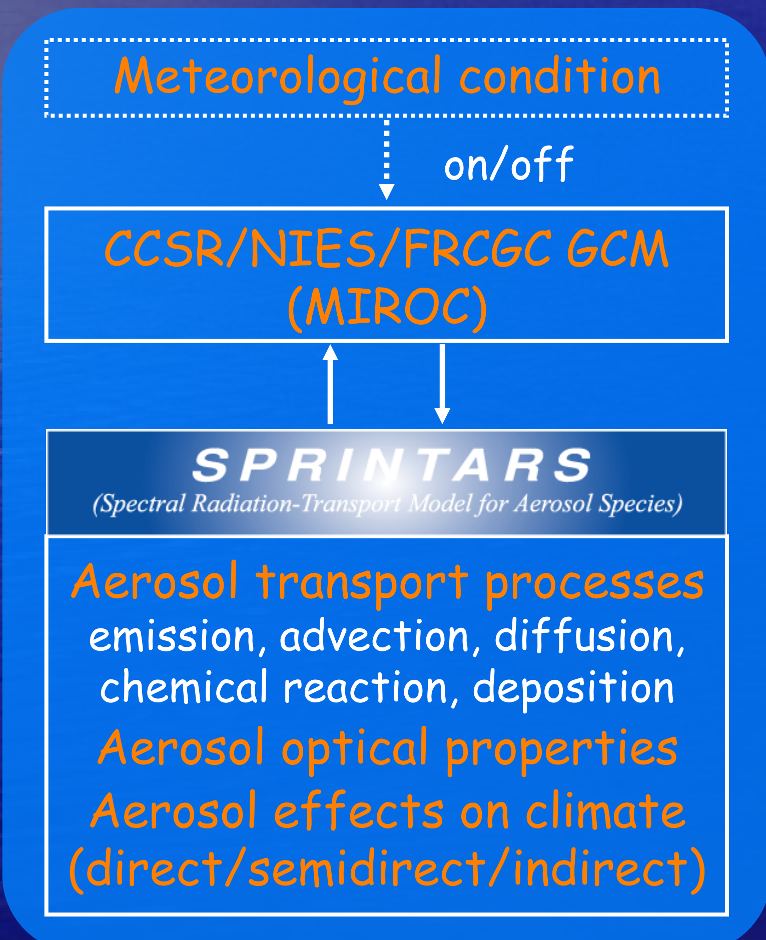
- Analysis of changes in cloud and precipitation by anthropogenic aerosols with a global aerosol climate model, SPRINTARS.
- Estimation of time evolution for various radiative forcings in the 20th century both at the tropopause and surface.

Model description of SPRINTARS (1)

References: Takemura et al.
- JGR, 110, 2004JD005029, 2005
- J. Climate, 15, 333–352, 2002
- JGR, 105, 17853–17873, 2000



§ Coupled to MIROC (CCSR/NIES/FRCGC GCM)

§ Tracers: black carbon (BC), organic carbon (OC), sulfate, soil dust, sea salt, SO_2, DMS

§ Emission
- BC, OC: biomass burning, fossil fuel, biofuel, agricultural activity, terpene
- SO_2: fossil fuel, biomass burning, volcano
- DMS: phytoplankton, land vegetation
- Soil dust: online calculation with wind speed, vegetation, soil moisture, snow amount
- Sea salt: online calculation with wind speed

§ Advection
- Flux-Form Semi-Lagrangian method
- Arakawa-Schubert cumulus convection

§ Diffusion

§ Chemical reaction (sulfur)
- Gas phase:
  $DMS + OH \rightarrow SO_2$, $SO_2 + OH \rightarrow SO_4^{2-}$
- Liquid phase:
  $S(IV) + O_3 \rightarrow SO_4^{2-}$, $S(IV) + H_2O_2 \rightarrow SO_4^{2-}$
- OH, O_3, H_2O_2: CHASER (Sudo et al. 2002)

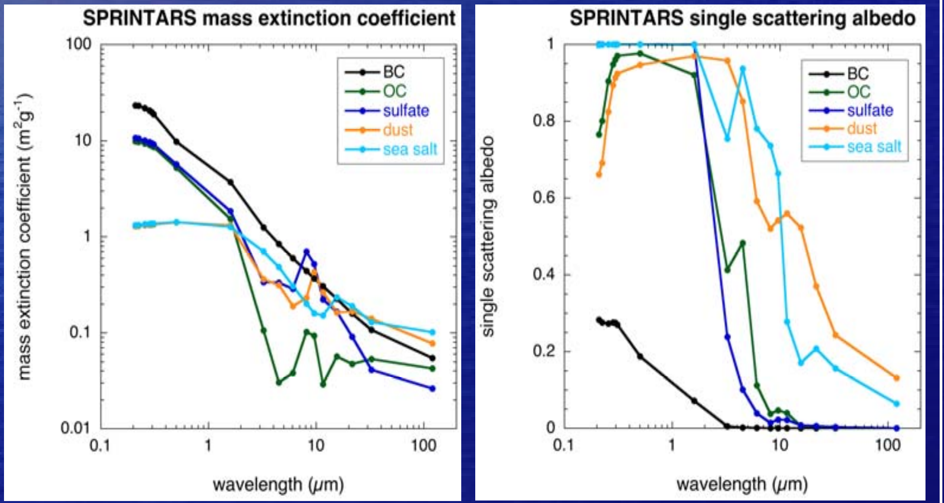
§ Deposition
- Wet deposition
- Dry deposition
- Gravitational settling

Model description of SPRINTARS (2)

Aerosol direct effect

Coupled to radiation process in GCM

- Refractive indices depending on wavelength, size distributions, and hygroscopic growth for each aerosol.
- Aerosol semi-direct effect if SPRINTARS is fully online with GCM.



Dependences of mass extinction coefficient (left) and single scattering albedo (right) on wavelength for dry particles of each aerosol in SPRINTARS.

Aerosol indirect effect

§ Cloud droplet number concentration N_c

Parameterization depending on

- Aerosol particle number concentration
- Aerosol size distribution
- Updraft velocity
- Curvature effect
- Solute effect

based on Abdul-Razzak et al. (2000).

§ Cloud droplet effective radius r_{eff}

$$r_{eff} = k\left(\frac{3}{4\pi\rho_w}\frac{\rho l}{N_c}\right)^{\frac{1}{3}}$$

→ 1st indirect effect

ρl: Cloud water content
ρ_w: Water density

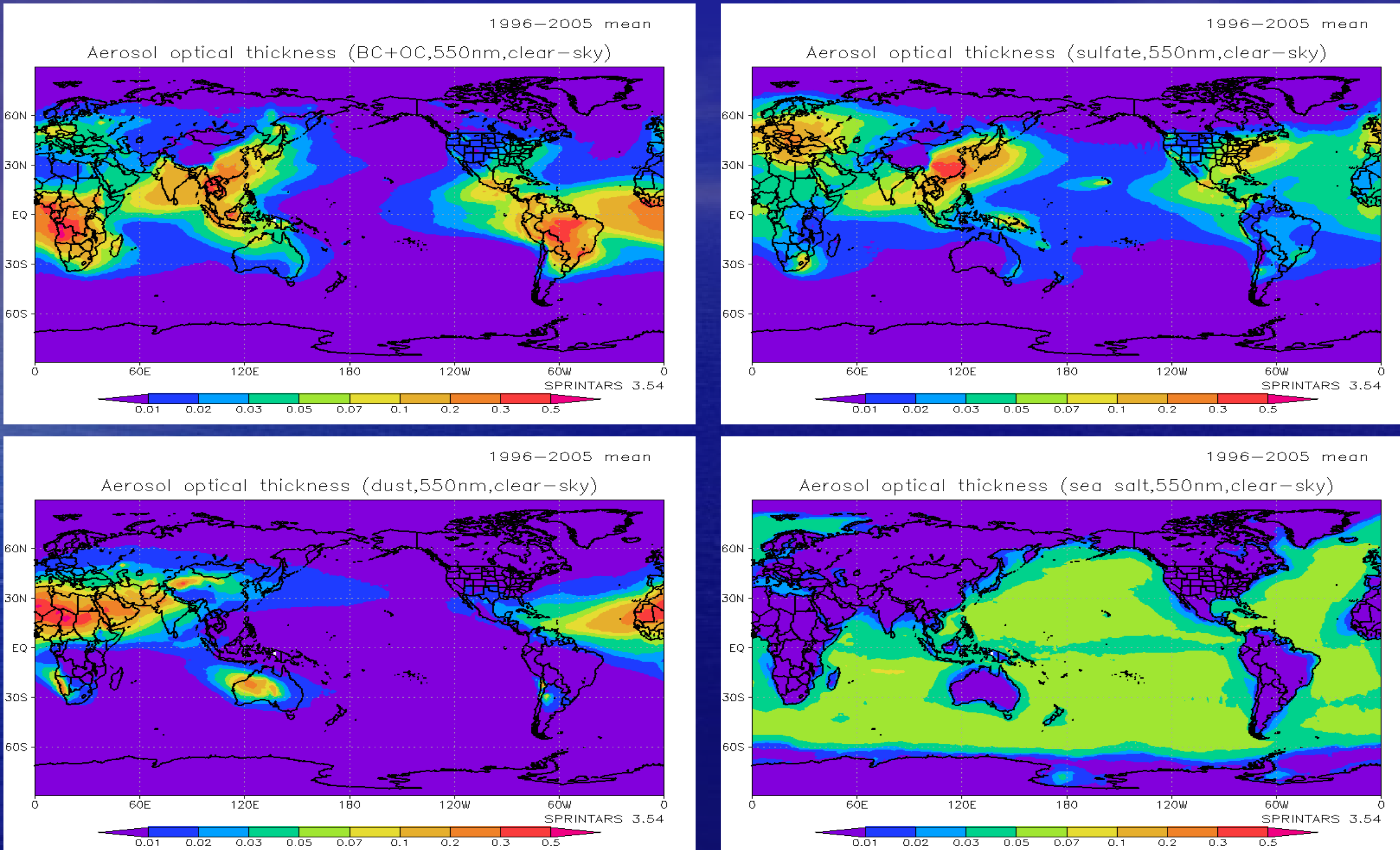
§ Precipitation rate P

$$P = -\frac{dl}{dt} = \frac{\alpha \rho l^2}{\beta + \gamma \frac{N_c}{\rho l}}$$

→ 2nd indirect effect

α, β, γ: Constants

Global aerosol optical thickness



Annual mean aerosol optical thickness for BC+OC (top left), sulfate (top right), soil dust (bottom left), and sea salt (bottom right) under clear-sky.

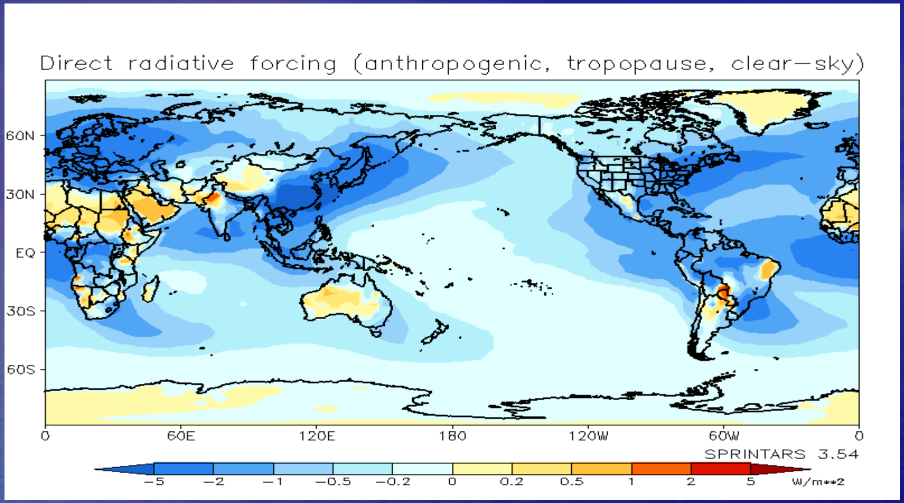
Experiments for analyses of aerosol effects on climate

- Resolution: T42 (approx. 2.8°x2.8°) / L20.
- Emission data for anthropogenic aerosols of pre-industrial (1850) and present days (2000) (CCSR/NIES).
- Meteorological field
  - Prescribed wind, temperature, specific humidity, SST, and sea ice
    Integration for 6 years → Analysis for last 5 years.
  - Coupled with a mixed-layer ocean model (equilibrium experiments)
    Integration for 50 years → Analysis for last 30 years.
    3 ensemble members

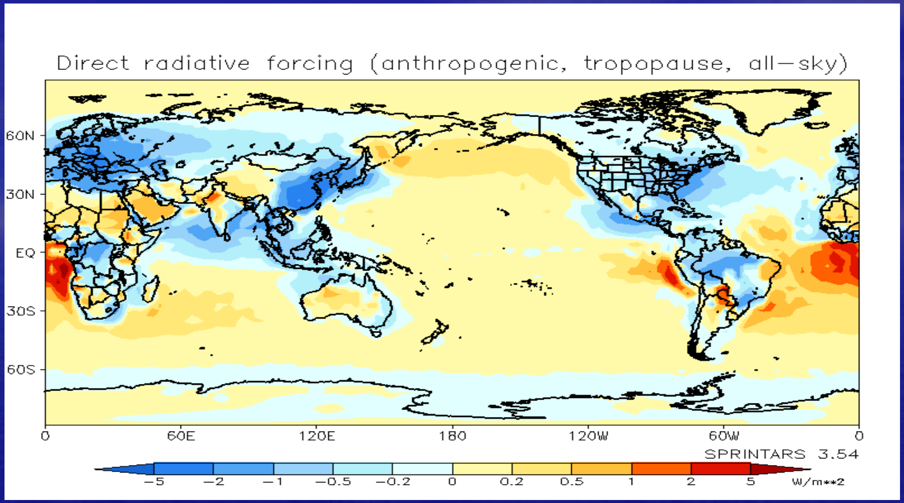
Experiment No.	E1f	E2f	E1	E2	E3
Aerosols	present	pre-industrial	present	pre-industrial	pre-industrial
GHGs	present	present	present	present	pre-industrial
Prescribed met.	O	O	X	X	X
Mixed-layer ocean	X	X	O	O	O

Radiative forcing of anthropogenic aerosol direct effect

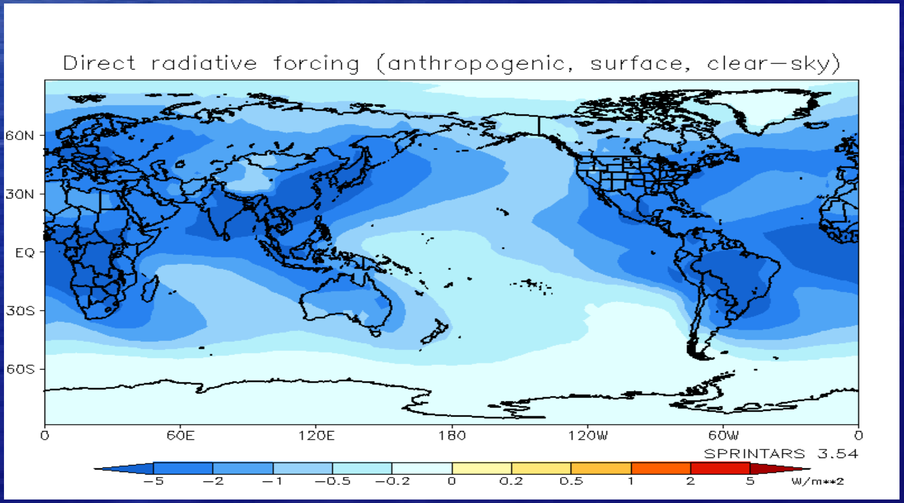
AVG. $-0.80\ W\ m^{-2}$



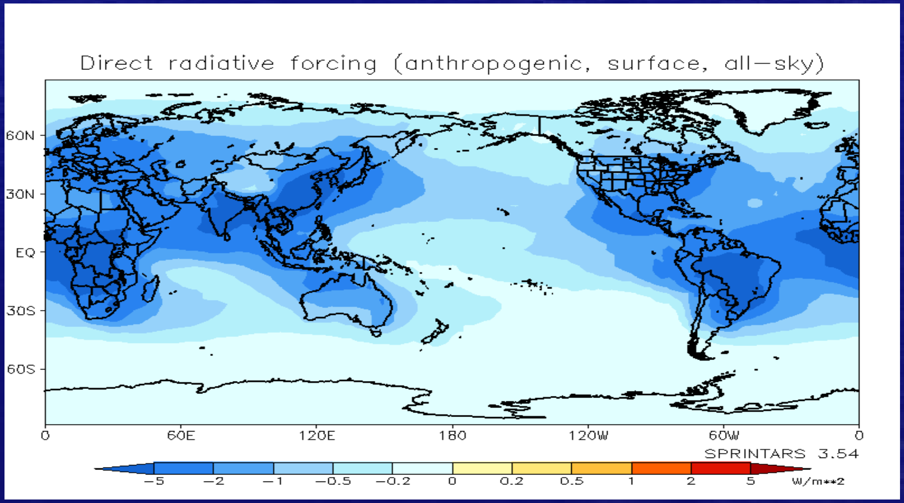
AVG. $-0.06\ W\ m^{-2}$



AVG. $-2.27\ W\ m^{-2}$



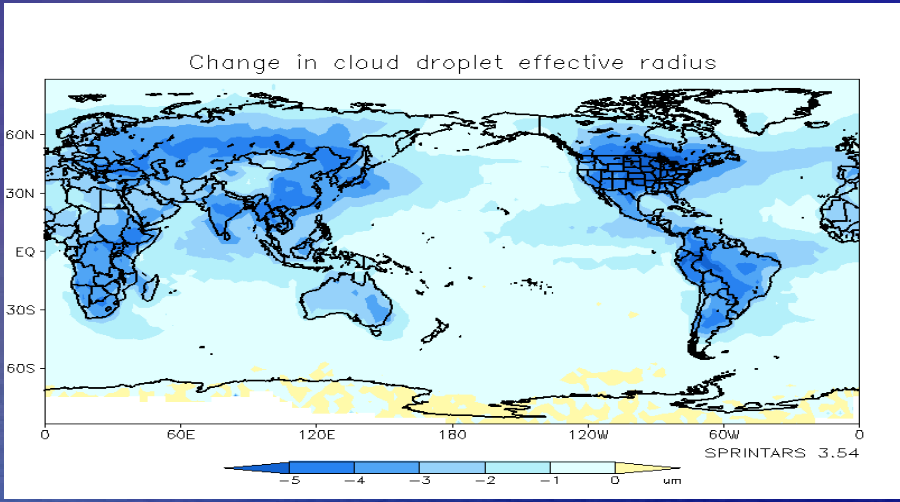
AVG. $-1.62\ W\ m^{-2}$



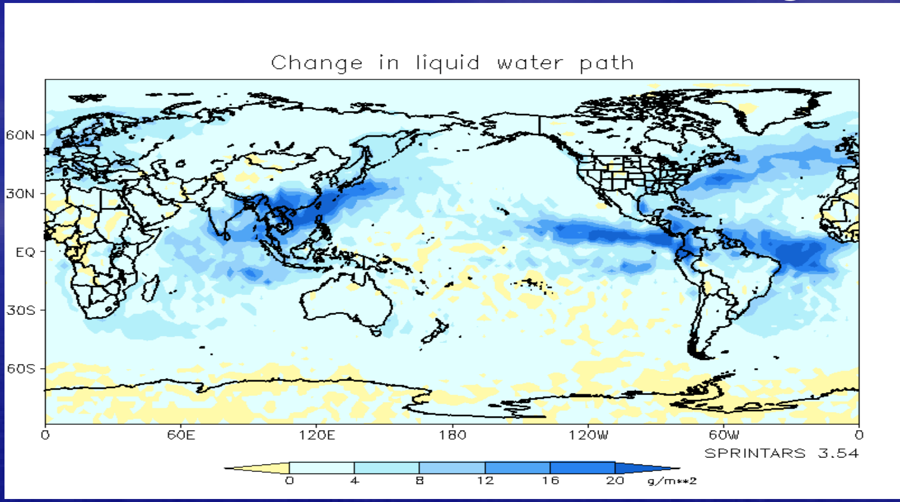
Annual mean direct radiative forcing of anthropogenic aerosols at the tropopause (top) and surface (bottom) under clear-sky (left) and all-sky (right) conditions.

Anthropogenic aerosol indirect effect

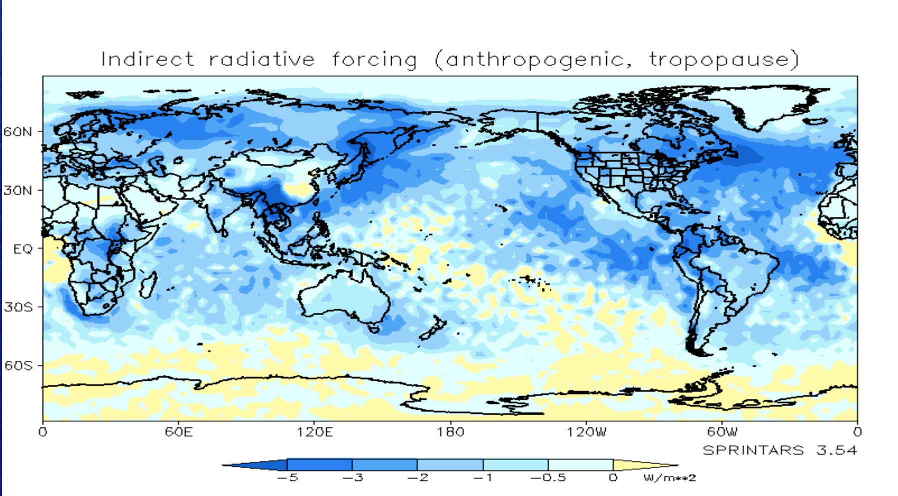
AVG. −1.57 μm



AVG. −3.90 g m^{-2}

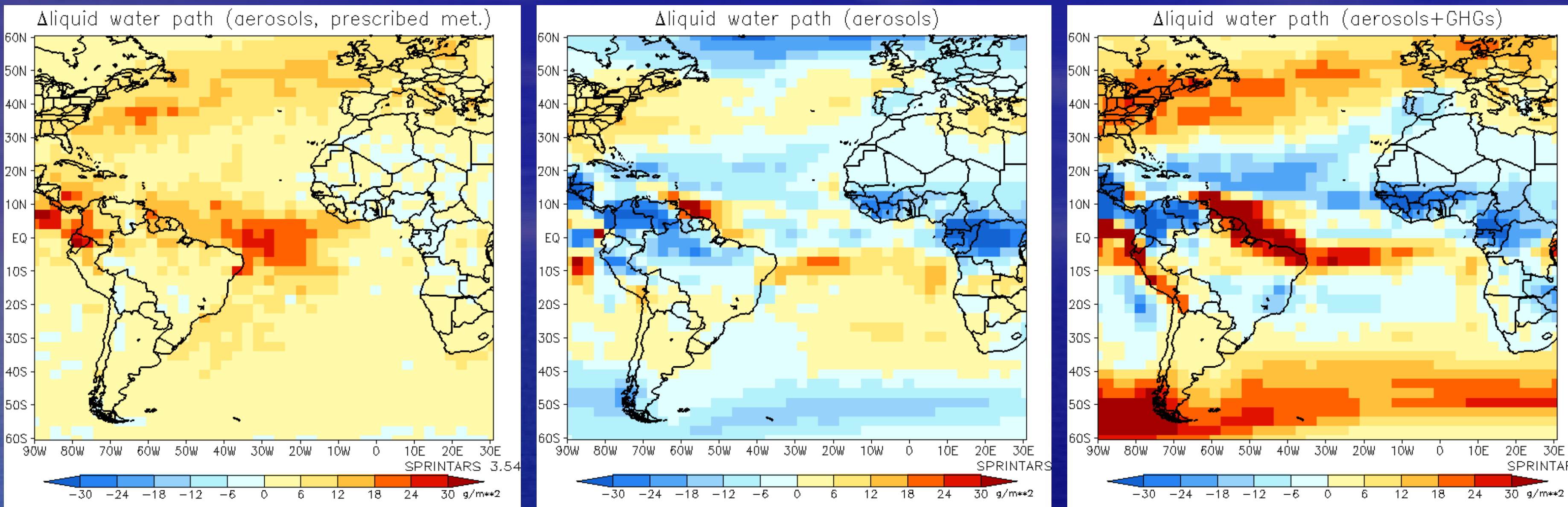


AVG. −1.27 W m^{-2}



Annual mean indirect effect for anthropogenic aerosols; changes in the cloud droplet effective radius (top left), liquid water path (top right), and radiative forcing (bottom).

Aerosol effects on clouds — Atlantic



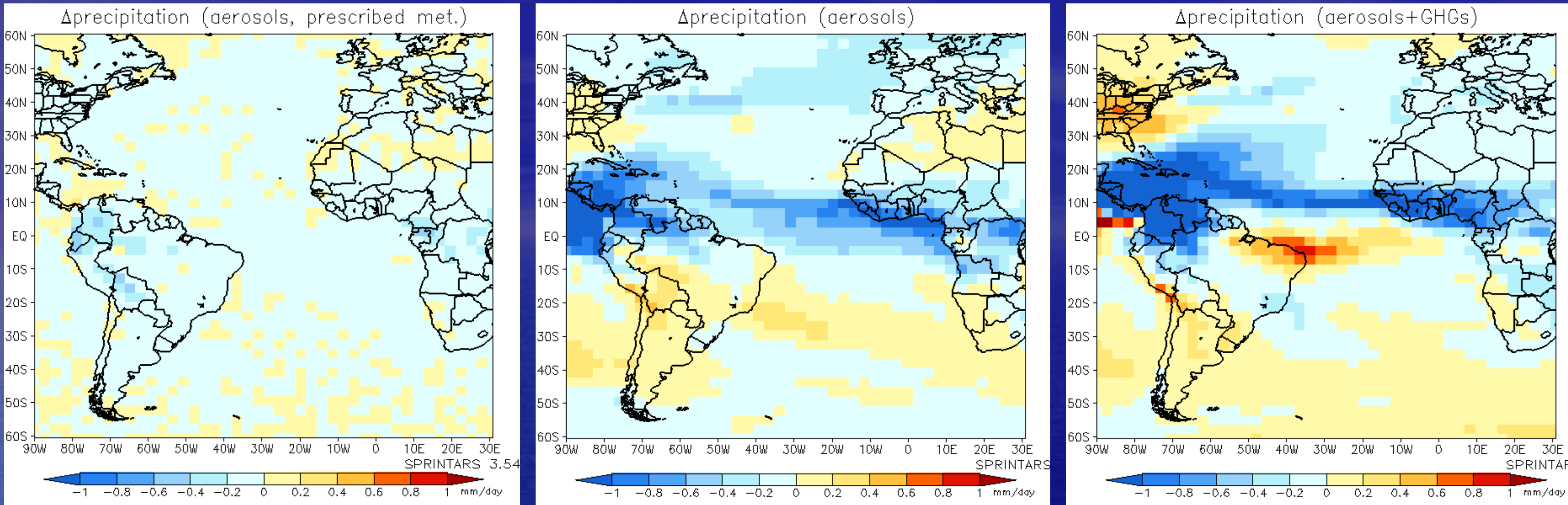
Changes in the simulated liquid water path from pre-industrial to present days due to aerosols with prescribed meteorological field (left), and due to aerosols (middle) and aerosols+GHGs (right) with a mixed-layer ocean model.

With an increase in anthropogenic aerosols …

- An increase in liquid water due to the aerosol second indirect effect.
  … Response of cloud microphysical processes.
- A decrease in liquid water due to
  - a decrease in the solar radiation at the surface by the aerosol direct and indirect effects, leading to a decrease in evaporation of water vapor from the surface.
  - the aerosol semi-direct effect.

  … Change in hydrological cycle.

Aerosol effects on precipitation — Atlantic

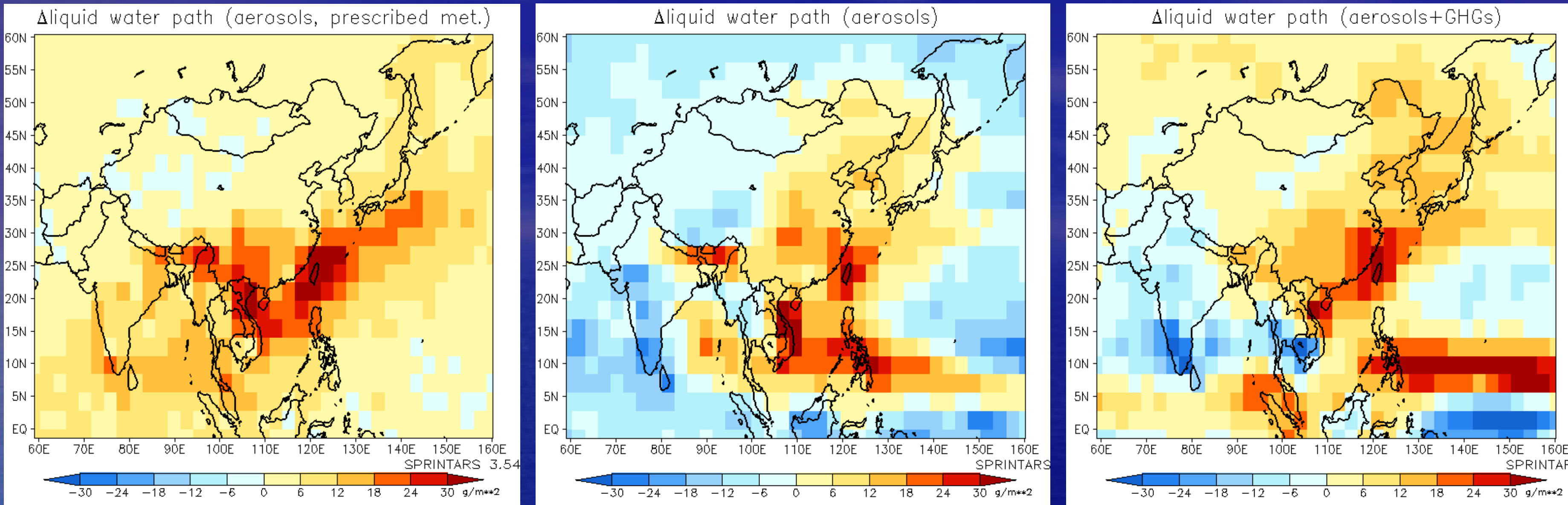


Changes in the simulated precipitation from pre-industrial to present days due to aerosols with prescribed meteorological field (left), and due to aerosols (middle) and aerosols+GHGs (right) with a mixed-layer ocean model.

With an increase in anthropogenic aerosols …

- A decrease in precipitation due to
  - The aerosol second indirect effect.
  - A decrease in evaporation of water with solar dimming by anthropogenic aerosols.

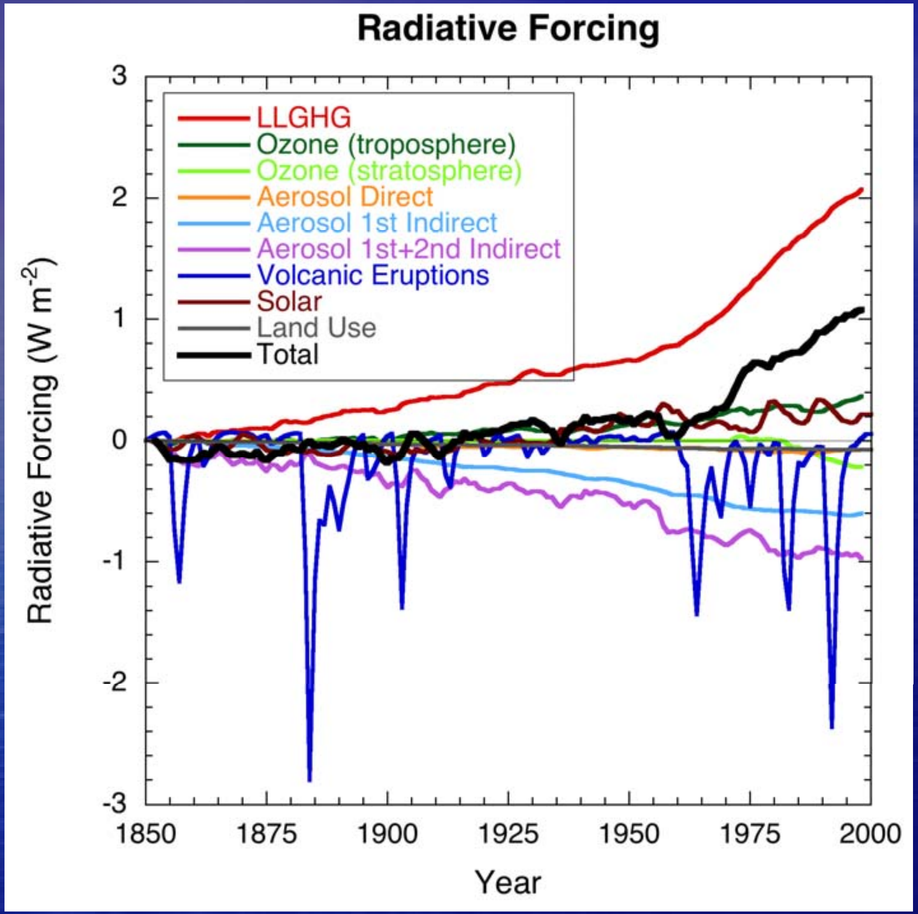
Aerosol effects on clouds — Asia

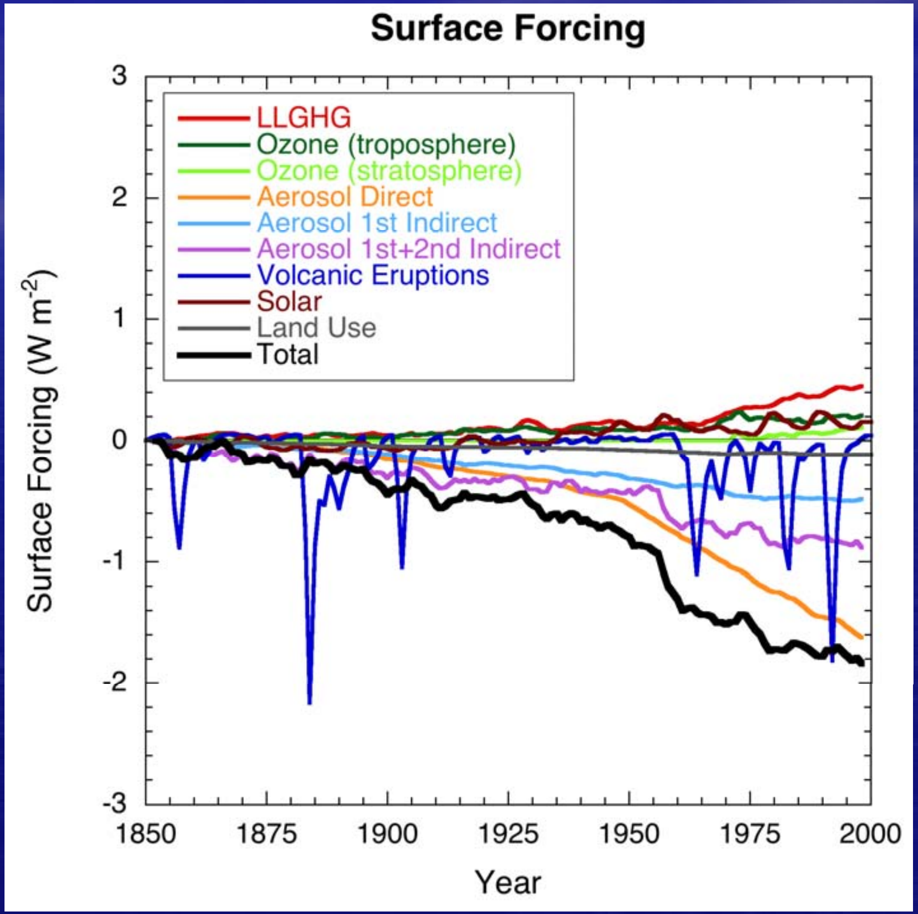


Changes in the simulated liquid water path from pre-industrial to present days due to aerosols with prescribed meteorological field (left), and due to aerosols (middle) and aerosols+GHGs (right) with a mixed-layer ocean model.

- East Asia
  An increase in liquid water by the strong aerosol second indirect effect due to abundant anthropogenic aerosols even with change in the hydrological cycle.
- South Asia
  A decrease in liquid water by a decrease in the solar radiation due to the aerosol direct effect at the surface leading to a decrease in evaporation of water vapor from the surface and by the aerosol semi-direct effect both due to black carbon.

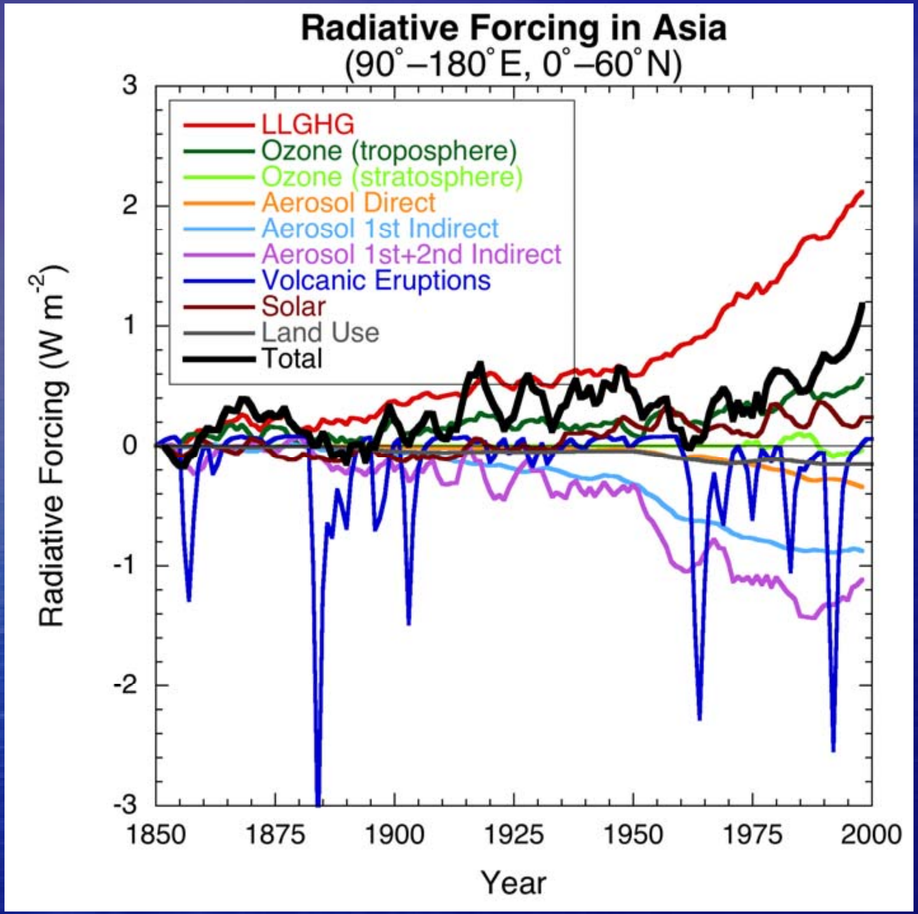
Time evolution of radiative forcing — Global

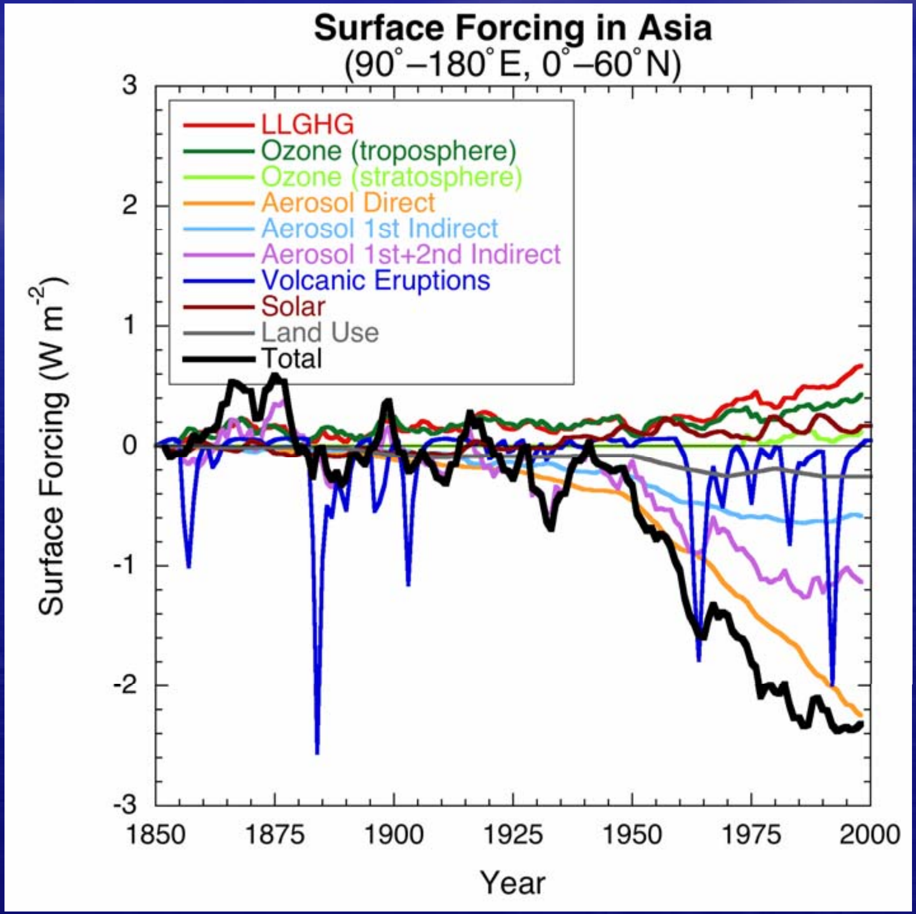




Time evolution of global mean instantaneous radiative forcings from 1850 to 2000 due to various climate forcing agents at the tropopause (left) and surface (right) calculated by CCSR/NIES/FRCGC GCM (MIROC) (Takemura et al., GRL, 2006GL026666, 2006).

Time evolution of radiative forcing — Asia

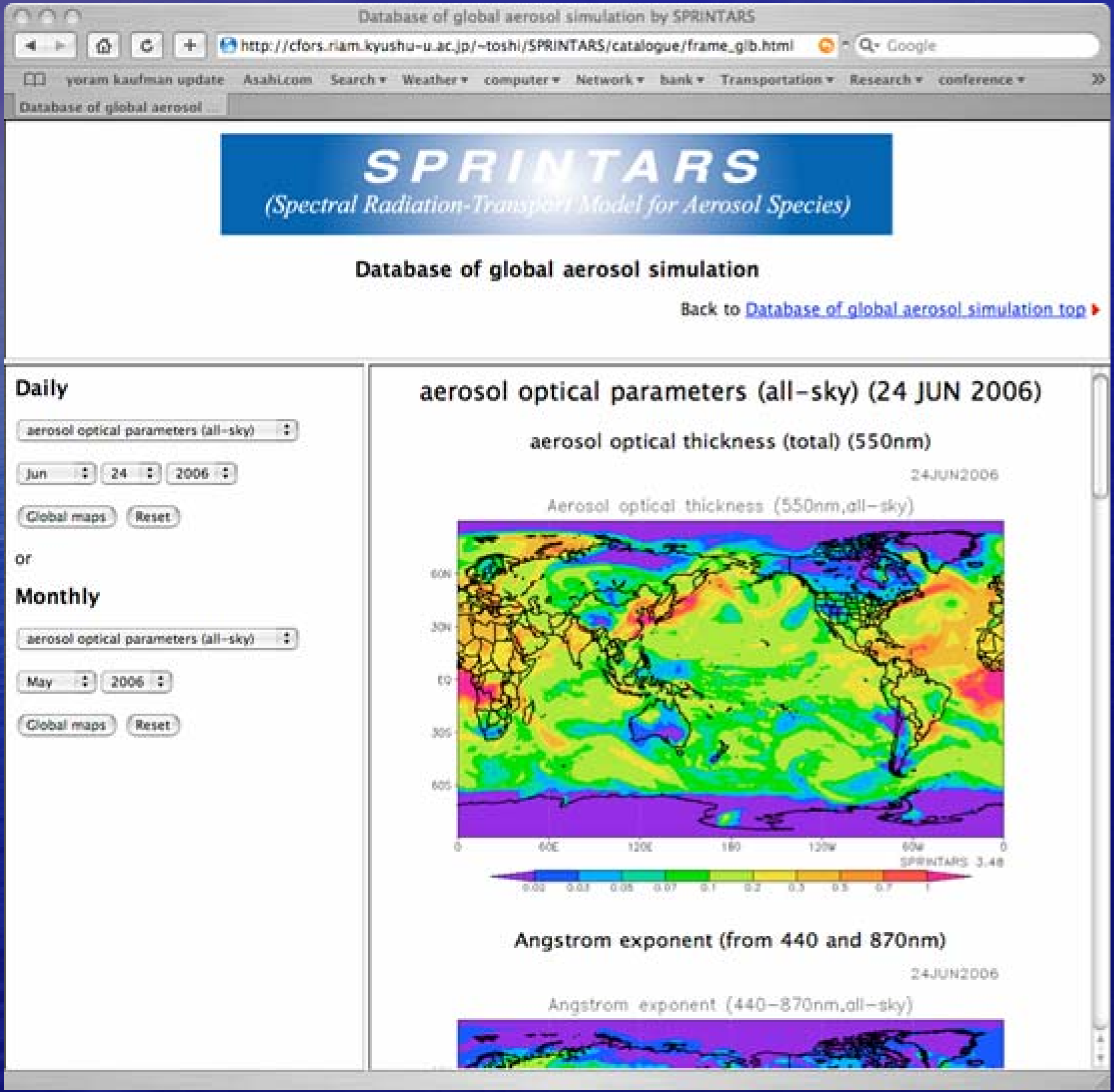




Time evolution of regional mean instantaneous radiative forcings in Asia from 1850 to 2000 due to various climate forcing agents at the tropopause (left) and surface (right) calculated by CCSR/NIES/FRCGC GCM (MIROC).

SPRINTARS homepage

http://cfors.riam.kyushu-u.ac.jp/~toshi/SPRINTARS/catalogue/



Period

January 1, 2000 to semi-realtime

Parameters

- aerosol optical parameters (optical thickness, Ångström exponent, single scattering albedo)
- aerosol mass concentration
- Aerosol mass column loading
- aerosol deposition flux
- aerosol direct radiative forcing
- cloud parameters (effective radius, optical thickness, fraction, top temperature)

Global section

- maps (daily and monthly mean)

Asian section

- maps (daily and monthly mean)
- vertical profiles (daily mean) and time series at several observatories

Summary

o Analysis of changes in cloud and precipitation by anthropogenic aerosols with a global aerosol climate model, SPRINTARS.

→The cloud microphysical and dynamic-hydrological effects.

o Estimation of time evolution for various radiative forcings in the 20th century.

→Importance of estimating radiative forcing at the surface as well as at the tropopause.

Next step

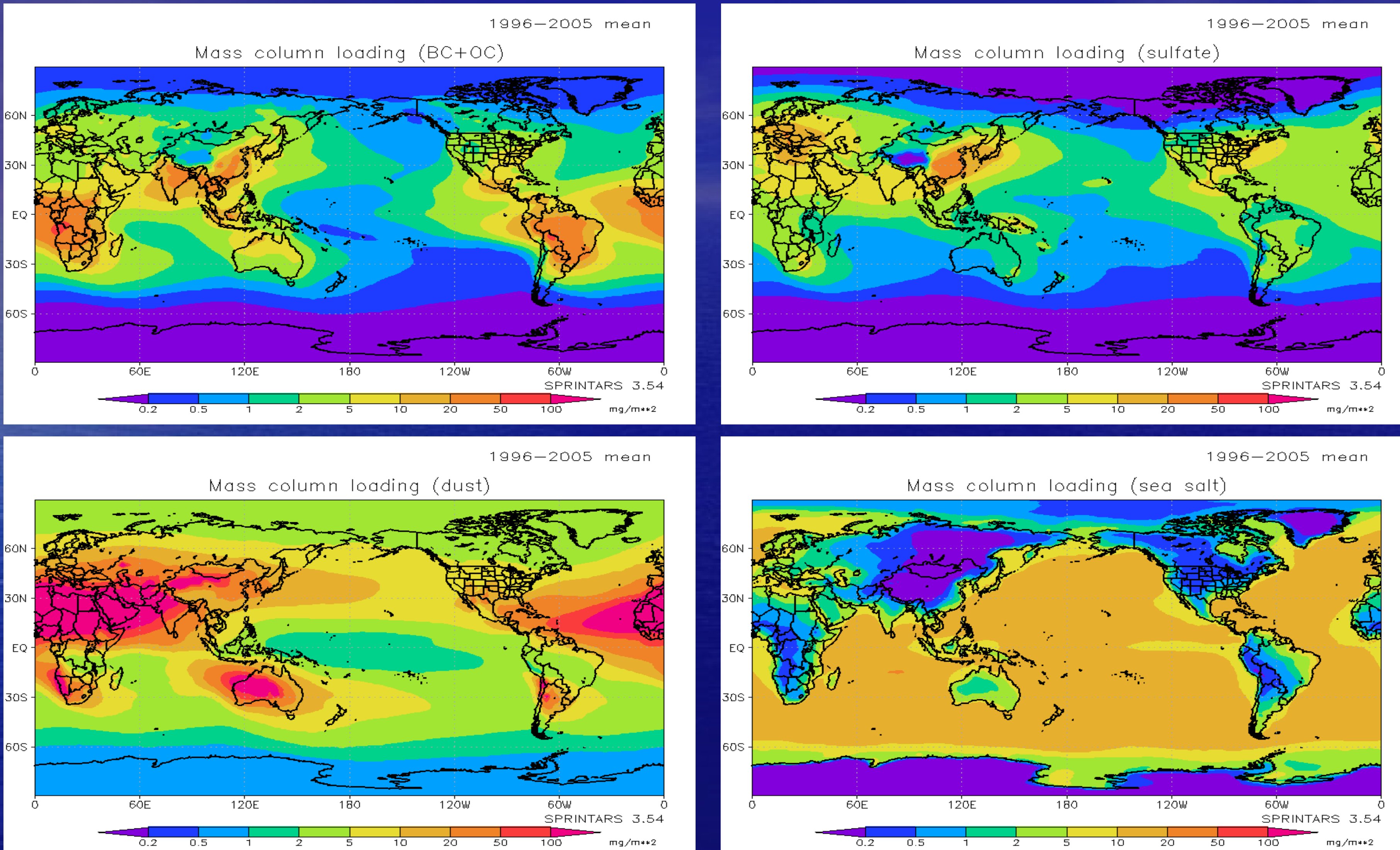
- Comparisons of vertical profiles for aerosols and clouds with observations.
- Parameterization of relationship between ice clouds and aerosols.
- Introducing SPRINTARS into global/regional non-hydrostatic models.
- Construction of prediction mode.
- etc …

Acknowledgments

Contributors to development of CCSR/NIES/FRCGC GCM

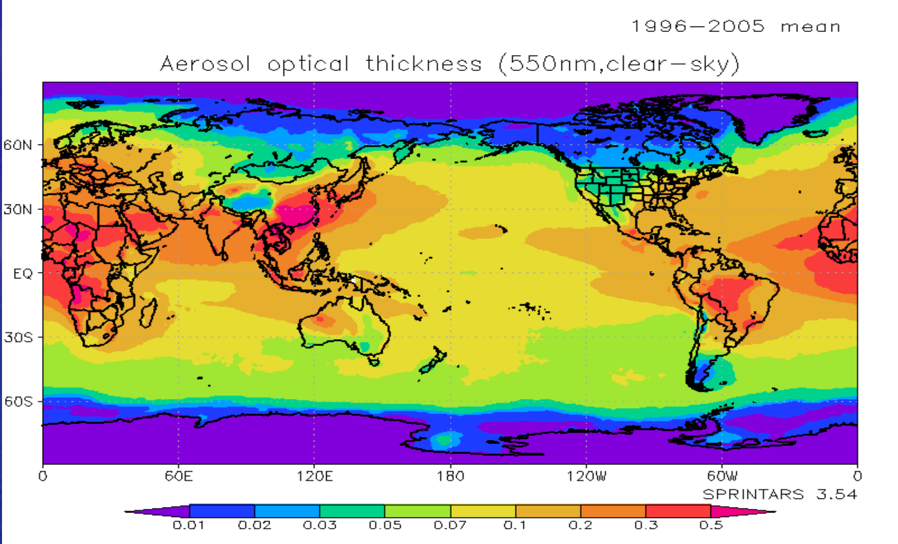
Contributors to development of SPRINTARS

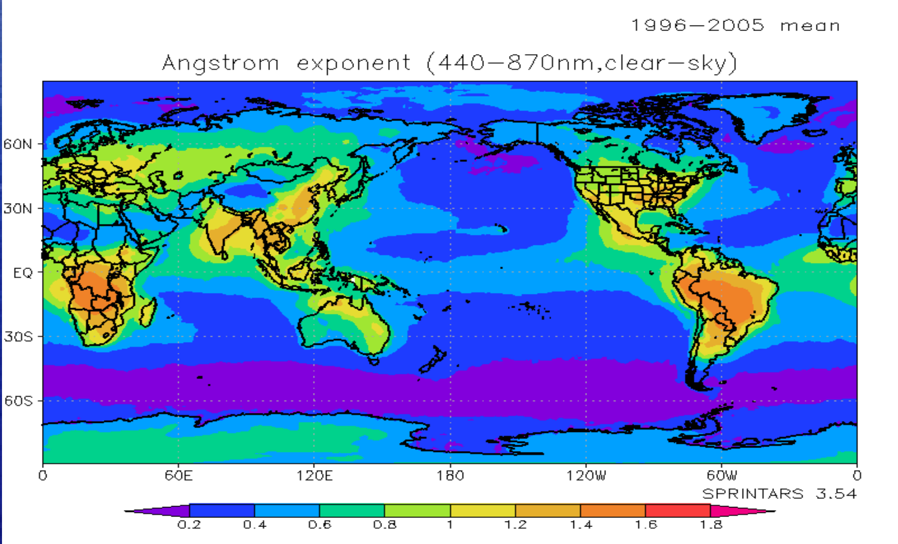
Global aerosol mass column loading

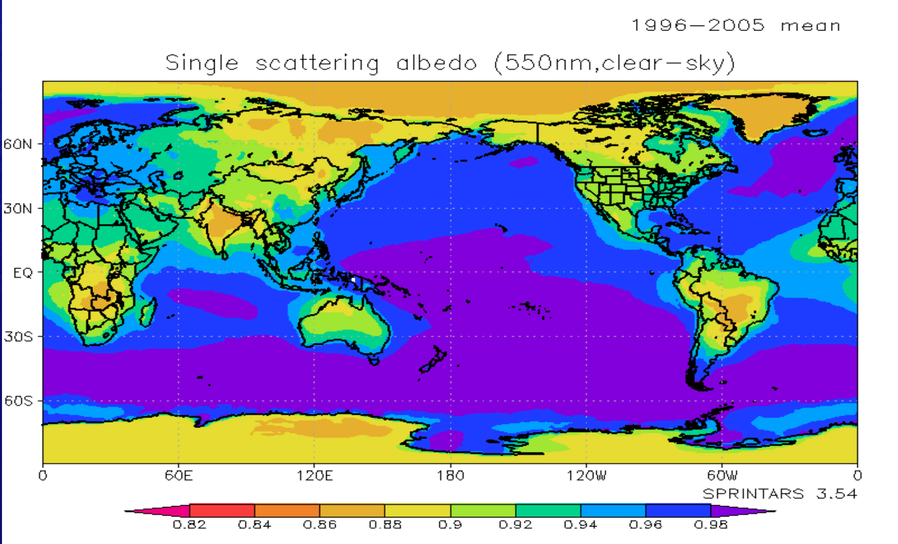


Annual mean mass column loading for BC+OC (top left), sulfate (top right), soil dust (bottom left), and sea salt (bottom right).

Global aerosol optical properties

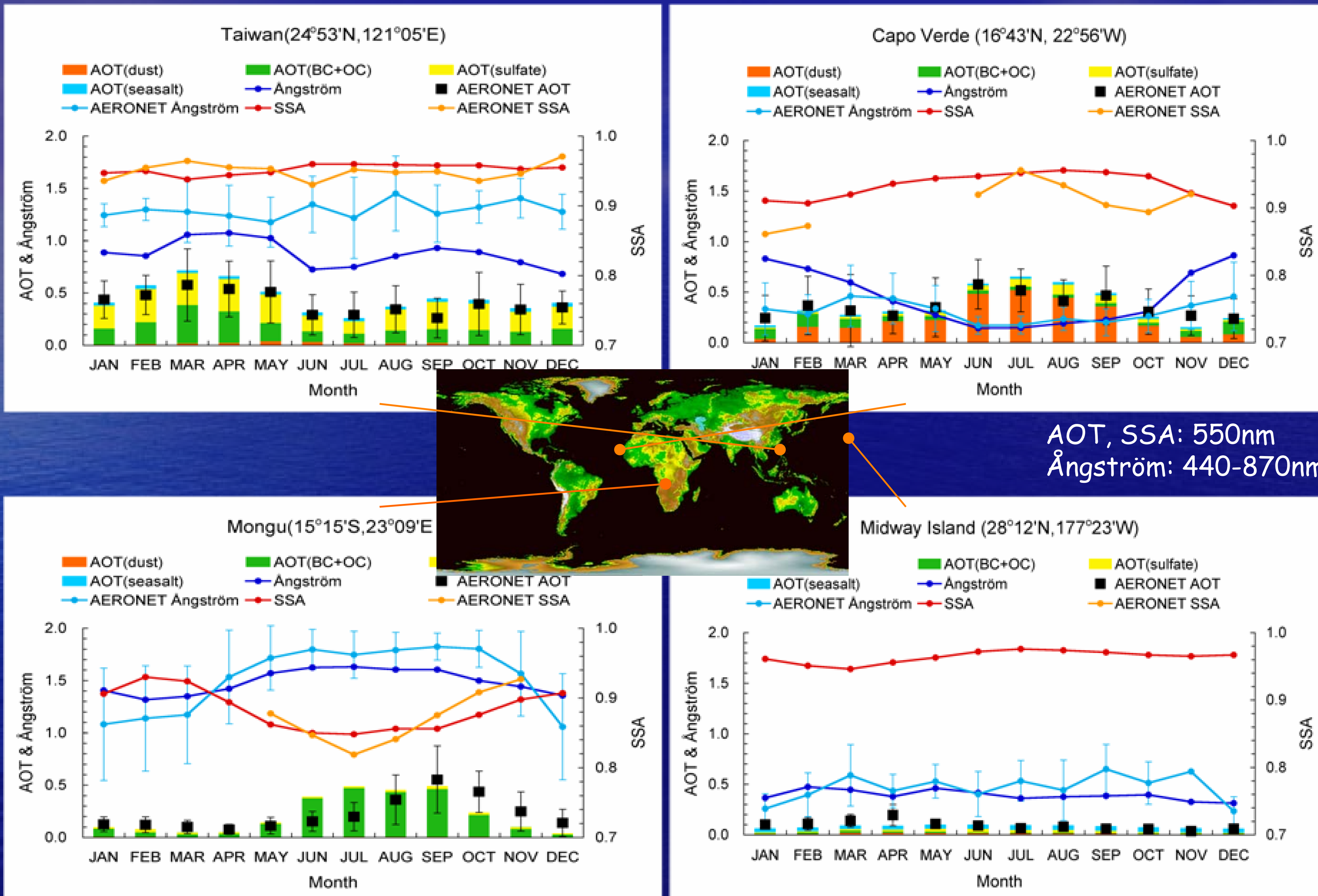






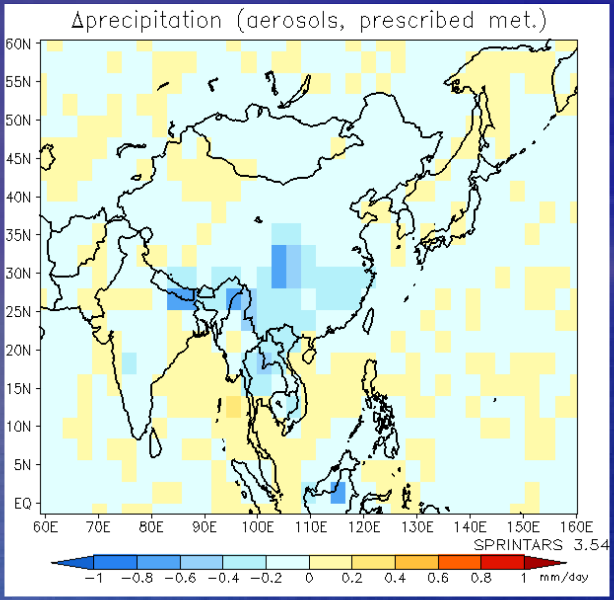
Annual mean aerosol optical optical thickness (top), Ångström exponent (bottom left), and single scattering albedo (bottom right) under clear-sky.

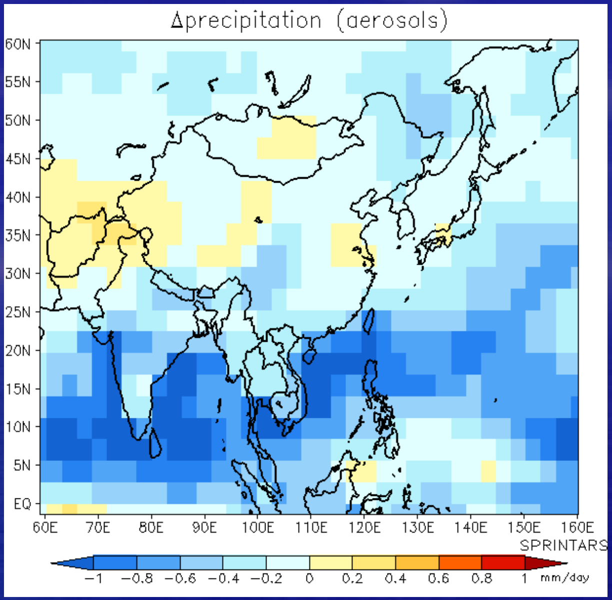
Comparison with AERONET

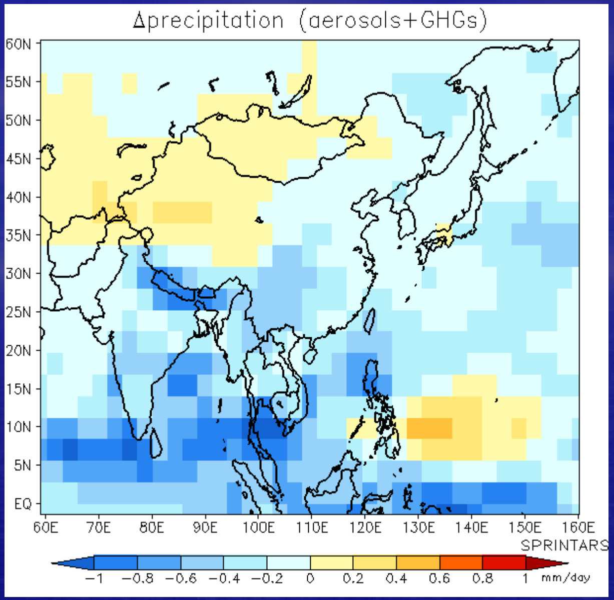


AOT, SSA: 550nm
Ångström: 440-870nm

Aerosol effects on precipitation — Asia







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+GHGs (right) with a mixed-layer ocean model.