P1.4 GLOBAL DISTRIBUTION OF AEROSOL OPTICAL PROPERTIES SIMULATED WITH THE SPRINTARS

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ABSTRACT

Global distributions of the aerosol optical thickness, Ångström exponent, single scattering albedo, and radiative forcing are simulated by an aerosol climate model, SPRINTARS. All the main tropospheric aerosols are treated, that is, carbonaceous (black and organic carbons), sulfate, soil dust, and sea salt. The global and annual mean radiative forcing of anthropogenic aerosols is estimated to be –0.18 W m^{-2} for the direct effect and –1.02 W m^{-2} for the indirect effect. The large scale Asian dust storm, transported to the North Pacific, is also successfully simulated by the SPRINTARS.

1. INTRODUCTION

Anthropogenic and natural aerosols are recognized as significant atmospheric substances for the past, present, and future climate change (IPCC 2001). There are two effects that aerosols affect the earth's radiation budget. One is a direct effect in which aerosol particles scatter and absorb the solar and thermal radiation, and the other is an indirect effect in which they alter the cloud optical properties and the cloud lifetime acting as cloud condensation nuclei. The atmospheric aerosol distributions have been, however, difficult to be simulated by climate models because of short lifetime, various chemical components, and various size distributions of aerosol particles, so that their radiative forcing has not been quantitatively understood well.

To minimize the uncertainty we develop a global three-dimensional aerosol climate model, SPRINTARS (Spectral Radiation-Transport Model for Aerosol Species) in this study. It can calculate not only aerosol concentration but also its radiative properties, such as optical thickness, Ångström exponent, single scattering albedo, and radiative forcing. These simulated parameters are compared with optical observations acquired from the ground-based and satellite remote sensing in detail, so that the confidence level of the estimation of the aerosol radiative forcing can become higher than past studies. The long-range transport of the Asian dust to the North Pacific in 2002 is also simulated.

2. MODEL DESCRIPTION

The SPRINTARS has been developed at the Center for Climate System Research (CCSR), University of Tokyo (Takemura et al. 2000, 2002). It treats main tropospheric aerosols, which are carbonaceous (black carbon and organic carbon), sulfate, soil dust, and sea salt. The simulated transport processes are emission, advection, diffusion, sulfur chemistry, wet deposition, dry deposition, and gravitational settling. It is driven by the atmospheric general circulation model (AGCM) of CCSR and National Institute for Environmental Studies (NIES), Japan, and combined with the radiation scheme in the AGCM for calculating scattering and absorption of the radiation by aerosol particles. The horizontal resolution of the triangular truncation is set at T42 (approximately 2.8° by 2.8° in latitude and longitude) and the vertical resolution at 11 layers. The reanalysis data of the National Centers for Environmental Prediction (NCEP)/National Center for Atmospheric research (NCAR) are used for nudging wind, temperature, and specific humidity. The meteorological condition in 2000 is supposed in this study except for the Asian dust simulation in 2002. The aerosol radiative properties are calculated assuming the Mie theory in consideration of refractive index depending on wavelengths, size distribution, and hygroscopic growth of each aerosol component. Both the cloud albedo effect (first indirect effect) and the cloud lifetime effect (second indirect effect) are considered for the aerosol indirect effect in the model. The cloud effective radius and the precipitation rate are estimated by the relationship between aerosol number concentration and cloud droplet number concentration (Takemura et al. 2001).

3. RESULTS AND DISCUSSION

Figure 1 shows the annual mean distributions of the simulated aerosol optical thickness, Ångström exponent, single scattering albedo, and direct radiative forcing for the mixture of all aerosol species. Saharan dust particles are transported to the subtropical Atlantic by the trade wind through the year with small Ångström exponent values, which means the predominance of large-size aerosol particles. Large optical thickness values by soil dust also seen in the Arabian region in Northern Hemisphere summer caused by the strong monsoon wind. Biomass burning aerosols are remarkable over central and southern Africa, Amazon, and Southeast Asia with a large Ångström exponent and a small single scattering albedo during the dry season in each region. The latitude of the maximum optical thickness off the west coast of Northern Africa shifts

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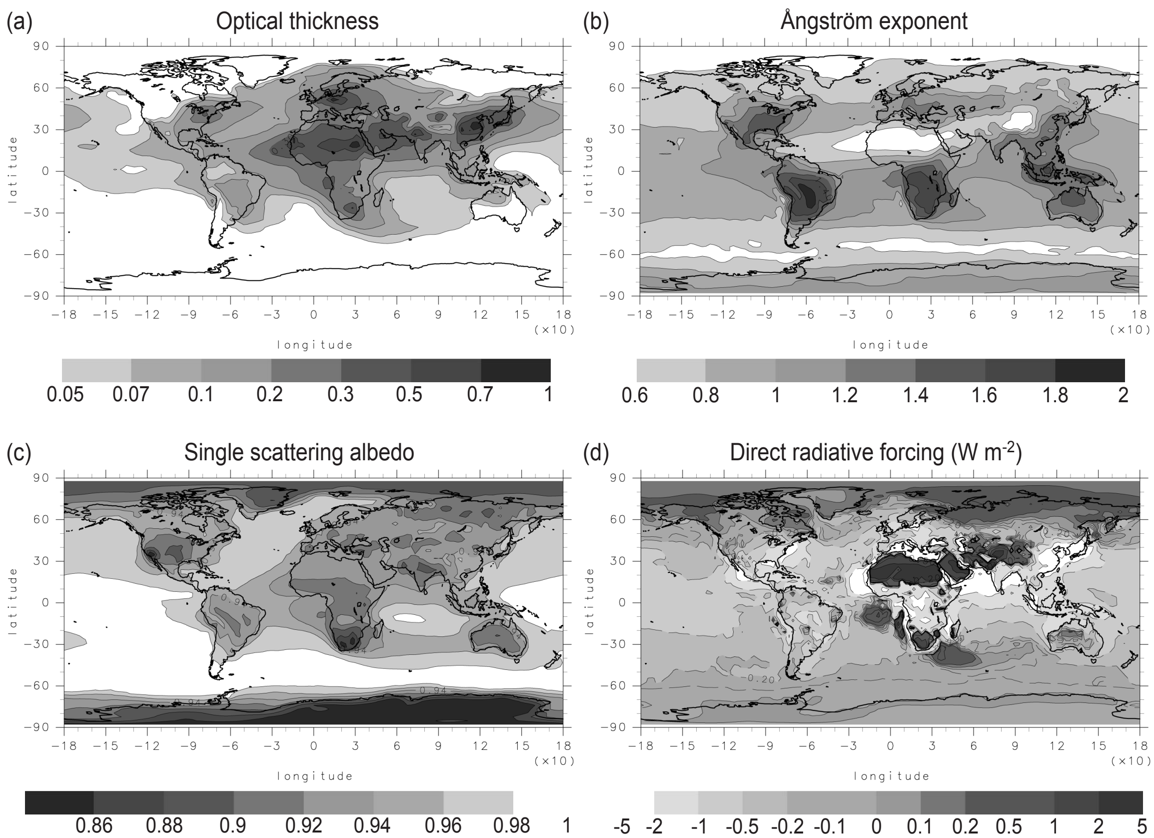

FIG 1. Annual mean distributions of the simulated (a) optical thickness at 0.55 μm (b) Ångström exponent, (c) single scattering albedo at 0.55 μm, and (d) direct radiative forcing for the mixture of carbonaceous, sulfate, soil dust, and sea salt aerosols.

seasonally as detected by the satellite remote sensing (Higurashi et al. 2000), which is 10˚N in Northern Hemisphere winter and 20˚N in summer. The simulation suggests that it is caused not only by change of wind directions but also by biomass burning over the coast of the Gulf of Guinea in Northern Hemisphere winter (Takemura et al. 2000). There is a large amount of anthropogenic aerosols, such as sulfate and carbonaceous aerosols, over East and South Asia, North America, and Europe with a large Ångström exponent and a single scattering albedo as low as 0.9. The simulated aerosol optical thickness, Ångström exponent, and single scattering albedo are consistent with satellite and ground-based observations (Takemura et al. 2000, 2002).

The simulated positive forcing by soil dust aerosols over deserts is due to absorption of the solar and thermal radiation by particles and the high surface albedo (Fig. 1d). On the other hand, the forcing changes to negative values over oceanic outflow regions because of the dark surface. The simulated single scattering albedo was much lower than the ground-based measurements over the Saharan region if the imaginary part of the dust refractive index was supposed to be 0.008 in the visible wavelength, which is the same value in many past modeling studies (Takemura et al. 2002). It is, therefore, set at 0.002 in this study. The biomass-burning aerosols, which include high carbonaceous aerosol content, have the negative forcing over land in Africa, Amazon, and Southeast Asia except for the bright surface area in southern Africa. Their direct radiative forging is, however, positive over the oceanic outflow regions because carbonaceous aerosols absorb the multiple scattered solar radiation enhanced by cloud layers. Sulfate and sea salt aerosols have negative forcings globally in the simulation. The strong negative forcing is seen over the industrialized areas, such as North America, East Asia, and Europe where carbonaceous and sulfate aerosols are mainly intermingled. Figure 2 summarize the simulated global and annual mean radiative forcing in the present. The total direct forcing by anthropogenic aerosols is estimated to be –0.18 W m^{-2}, while the estimation of the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC TAR) is –0.5 W m^{-2} (IPCC 2001). The indirect radiative forcing is simulated to be –1.02 W m^{-2} in this study, which is within the range of the IPCC TAR (0 to –2 W m^{-2}). It should be, however, noticed that the IPCC TAR estimate is only the first indirect effect.

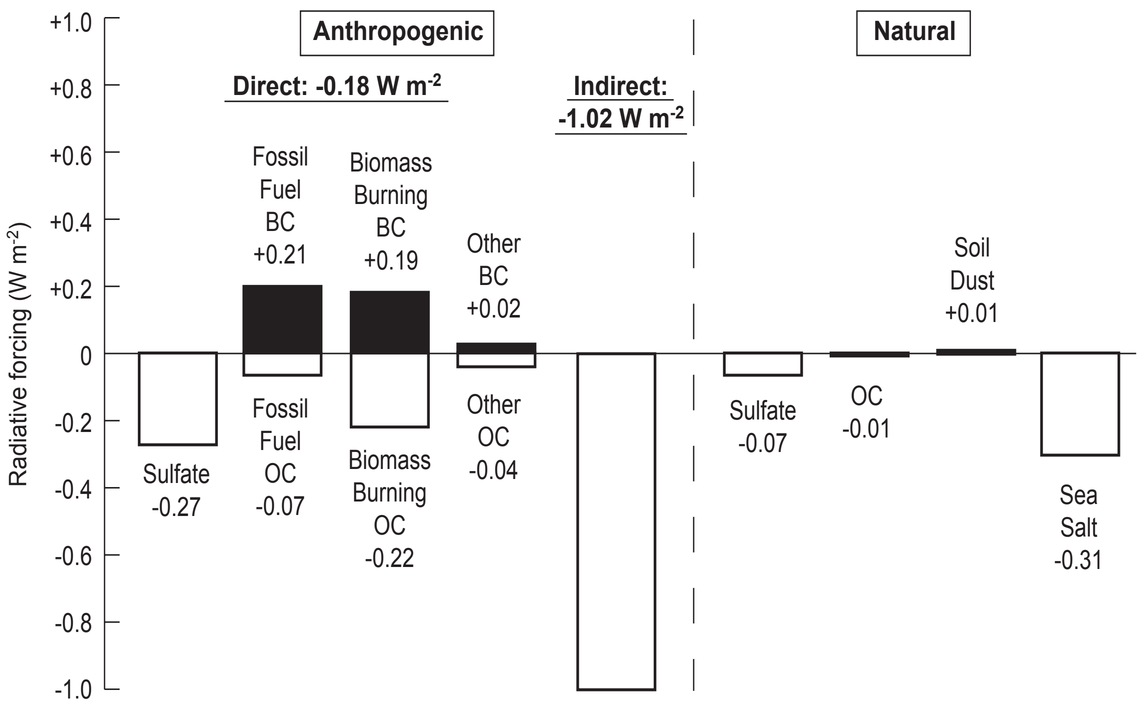

FIG 2. Annual and global mean aerosol radiative forcings simulated by the SPRINTARS.

The simulated Asian dust export by the SPRINTARS can be also investigated in detail. Figure 3a shows the large Asian dust storm crossing the North Pacific on March 2002, which is detected by the aerosol index from the Total Ozone Mapping Spectrometer (TOMS) and the image from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS). It is important to point out that anthropogenic carbonaceous and sulfate aerosols from East Asia are transported to the North Pacific with the Asian dust (Fig. 3b). The SPRINTARS shows that the optical thickness of anthropogenic aerosols in the air mass is as large as or larger than that of the Asian dust. This suggests that air pollution originating from the East Asian continent extends over a wider area.

The most important and complicated problem for the aerosol effect on the climate system is to evaluate the indirect forcing correctly. It is useful to incorporate microphysical processes of the cloud-aerosol interaction with an aerosol climate model, such as the SPRINTARS.

ACKNOWLEDGMENTS

The authors are grateful to contributors to development of the CCSR/NIES AGCM. This study is supported by the APEX project of the Core Research for Evaluational Science and Technology of the Japan Science and Technology Corporation.

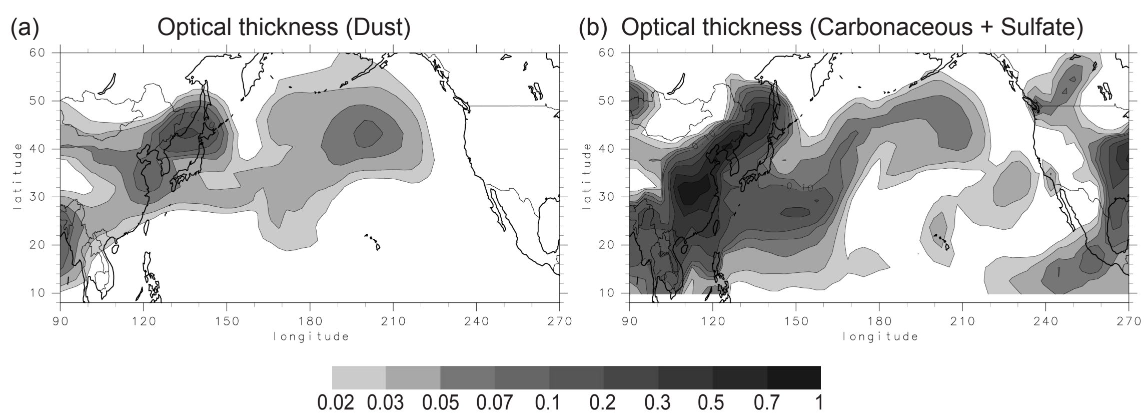

FIG 3. Daily mean distributions of the simulated optical thickness of (a) soil dust aerosols and (b) carbonaceous plus sulfate aerosols on March 25, 2002.

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