B-1.1 Study on the evaluation of the effects of atmospheric aerosols and water substances for the global scale climate change.

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Abstract

In order to reduce the uncertainties in the future projection of the global climate, we study the effects of aerosols and clouds in the atmosphere, utilizing climate model experiments as well as observational data analyses.

As a result, we established a sophisticated technique to treat the primary four aerosol species (sulfate, carbon, soil dust, and sea salt) in the troposphere both in the numerical model and in the satellite data retrievals. The aerosol model was also improved including the indirect radiative effects of aerosols. Finally, based on the above achievements, we performed climate change experiments with a new set of aerosol emission scenario (IPCC, 2000) utilizing the CCSR/NIES climate model and discussed the differences in the future projections of climate change among the different scenario runs.

Key Words Aerosol, Clouds, IPCC Scenario, Climate Model, Satellite Remote Sensing, Indirect Effects

1. Introduction

The uncertainties in the future projection of the global climate with the numerical model experiments remain still large compared to the amplitude of the projected global warming. Among them, the understandings of the effects of aerosols and clouds on climate is behind others. IPCC95 report also emphasized the importance of further understandings of the processes concerning aerosols and clouds.

The radiative effects of the tropospheric aerosols have not been satisfactorily treated yet in the climate models. It is due to their large dependencies on chemical compositions and size distributions, as well as to the large spacial and temporal variations of the tropospheric aerosol amounts. The uncertainties in treating clouds, on the other hand, also remain difficult to overcome, since their feedback processes to the climate change are very complicated. Moreover, the importance of indirect effects of aerosols; the process that the aerosols affect the climate through changing clouds and precipitation properties, has been strongly emphasized since the IPCC95. However, the studies of their indirect effects are still in the state of try and error, internationally.

Following are the primary achievements of our study;

1. Future climate projection with increased CO_2 scenario (IS92a) was reevaluated with the CCSR/NIES climate model implemented with the improved radiative transfer code (Nakajima *et al.*, 1995) which precisely calculates the radiative effects of the aerozols (Emori *et al.*, 1999).

2. A high-accuracy technique to estimate the cloud and aerosol radiative forcing was established utilizing the observed station data and a radiative transfer model (Takayabu *et al.*, 1999).

3. Three-dimensional simulation of the global distribution of the primary four tropospheric aerosol species was performed, utilizing a transport model based on the CCSR/NIES global atmosphere model (Takemura *et al.*, 2000).

4. The aerosol model was reevaluated to include the aerosol indirect effects as well as the sophisticated treatments of primary four tropospheric aerosol species. Global features of the aerosol distribution were retrieved utilizing the multi-channel satellite data (Higurashi and Nakajima, 1999; Suzuki, 2000; Usui, 2000).

5. Climate change experiments with a new set of aerosol emmission scenario (SRES scenarios) utilizing the CCSR/NIES climate model was performed to discuss the differences in the future projections of climate change among the different scenario runs (Nozawa *et al.*, 1999).

Among them, we introduce some of the latest results in the following sections.

2. Improvements of the Aerosol Transport Model and the Satellite Retrievals

One of the most important issues emphasized in the recent studies of climate variabilities is the impacts of aerosols on climate. Aerosol radiative effects are two ways. One is the 'direct effects' in which aerosols scatter or absorb the solar radiation. The other is the 'indirect effects', in which aerosols affect climate through changing cloud microphysical properties by working as cloud condensation nuclei (CCN). Recent studies suggest that these aerosol effects could cancel out, up to about one third of the effects of increasing greenhouse gases. However, because of the lack of our knowledge about the aerosols, these estimates still convey large uncertainties. In order to reduce these uncertainties, further observational studies of the aerosol characteristics and their modeling are strongly required.

[Improvements of the aerosol transport model]

We developed the basic structure of the aerosol transport model that treats the primary four species of the tropospheric aerosols (sulfate, carbon, soil dust, and sea salt). Utilizing this model, the global distribution of the aerosols was simulated and compared with the satellite observations. As a result, it was indicated that we cannot neglect the effects of the cabonatious aerosols compared to those of the sulfate aerosols. Also, it was shown that over the central Atlantic Ocean, the optical thickness of the soil dust and carbonatious aerosols are about the same (Fig. 1, by Takemura et al. 2000). These resutls are cited in the IPCC reports and international journals (*e.g.* Kinne 2000) and compared internationally with other models. And our model was evaluated to have higher accuracy among them. On the other hand, it was also revealed that our model still has some defficencies that there still are regional differences compared with observations. Therefore, we also performed some sensitivity experiments by changing model spatial resolution from T21 and T42, as well as by changing the mixing status of the cloud and aerosols to evaluate their effects on the radiative forcing and the single scattering albedo.

[The modeling of the cloud-aerosol interactions]

In order to model the interactions between aerosols and clouds, we related the cloud droplet numbers to the numbers of aerosols in our model. Then, the Berry's parameterization, which determines the cloud water generation including the aerosol indirect effects through changing the lifetime of the clouds, was introduced. As a result, we could simulate the large-scale features of the global distribution of the effective radius of cloud droplets compared with the satellite data estimates. However, large systematic errors were also observed over the tropical regions where the convective clouds and resulting upper-level cirrus are ubiquitous. Comparing with the Kessler's parameterization, the importance of the inclusion of the aerosol indirect effects was shown to simulate the observed features of the cloud distribution (Suzuki, 2000).

[Estimate of the optical features of the aerosols]

First, the global distribution of the aerosol optical thickness and Angstrom index was obtained by applying the visible-and-infrared-channnel algorithms. Then, we developed a new algorithm to discriminate the primary four species of the tropospheric aerosols by using the four-channel data observed from an ocean-color satellite (SeaWiFS). It was shown that we could discriminate the aerosol species by using the droplet size distribution with the blue light absorptance, and the effectiveness the scheme was confirmed by applying the technieque to the SeaWiFS data (Usui, 2000).

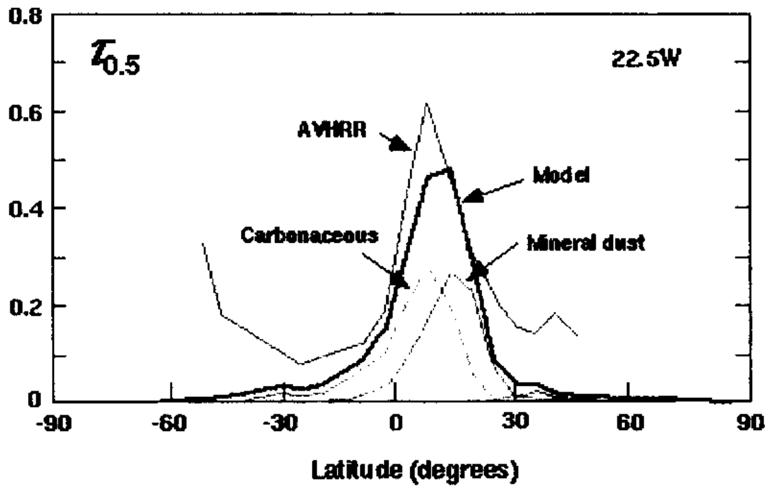

Fig. 1: Latitude distribution of the simulated aerosol optical thickness over the Atlantic Ocean. (Takemura et al., 2000)

3. Projections of Future Climate Change Simulated by a CCSR/NIES Climate Model Under the IPCC SRES Scenarios

In recent climate studies, the importance of the indirect effects (indicated also in the above section) of aerosols as well as their direct effests are emphasized (IPCC, 1996). In this study, we implemented the CCSR/NIES Climate Model with the aerosol models treating direct and indirect effects of primary four species of tropospheric aerosols (sulfate, carbon, soil dust, and sea salt), and performed future projection experiments of the global climate under IPCC's new emission scenarios (SRES scenarios) (IPCC, 2000).

[Model and Experiments]

The model consists of CCSR/NIES AGCM (nominal 5.6 ° horizontal grids and 20 vertical levels), CCSR OGCM (2.8 ° horizontal grids and 17 levels), a thermodynamic sea ice model, and a river routing model. Flux adjustment for atmosphere-ocean heat and water exchange is applied to prevent a drift of the modeled climate. A radiation scheme based on the k-distribution, two-stream discrete ordinate method (DOM) is adopted for the atmosphere.

The numerical simulations are carried out for all the four "marker scenarios";

[A1] A world of rapid economic growth and rapid introduction of new and more efficient technology
[A2] A very heterogeneous world with an emphasis on family values and local traditions
[B1] A world of "dematerialization" and introduction of clean technologies
[B2] A world with an emphasis on local solutions to economic and environmental sustainability

Well-mixed greenhouse gases of CO_2, CH_4, and N_2O are considered individually and temporal variations of their concentrations depend on the scenarios. In almost all the cases, these GHGs continue to increase throughout the 21st. century. For example, the CO_2 concentration in 2100 for the A2 scenario is the largest and about 800 ppmv, whereas that for the B1 is the lowest and about 550 ppmv.

Indirect effects (both the cloud albedo effect and the cloud lifetime effect) of aerosols as well as direct ones are considered through a relationship between the cloud droplet number concentrations and the aerosol number concentrations. Primary four species of aerosols (sulfate, carbon, soil dust, and sea salt) are considered and their concentrations are calculated offline by an aerosol transport model of CCSR (Takemura *et al.*, 2000). Concentrations of anthropogenic sulfate and carbonaceous aerosols follow the scenarios. The SO_2 emissions increase in the next two or three decades then decrease for the A1 and A2 scenarios, whereas the SO_2 emissions decrease throughout the next century for the B1 and B2 scenarios. The black and organic carbon emissions (which are constructed from the emissions by fossil fuel, biofuel, and forest fire) increase for almost all the scenarios. The soil dust and sea salt aerosols are supplied as climatology with seasonal variations.

[Results]

Compareing the time series of the radiative forcings, an increase with the CO_2 is dominant among those of the greenhouse gases. Global mean direct effects of the carbonaceous and the sulfate aerosols are positive and negative, respectively. They mostly cancel out, despite large differences among the scenarios. Indirect effect (cloud albedo effect only) does not vary much and stays around -0.6 $W\,m^{-2}$ except for the A2 run in which it attains around -1.0 $W\,m^{-2}$ and keeps that value afterwards. Offline estimates of another indirect effect (cloud

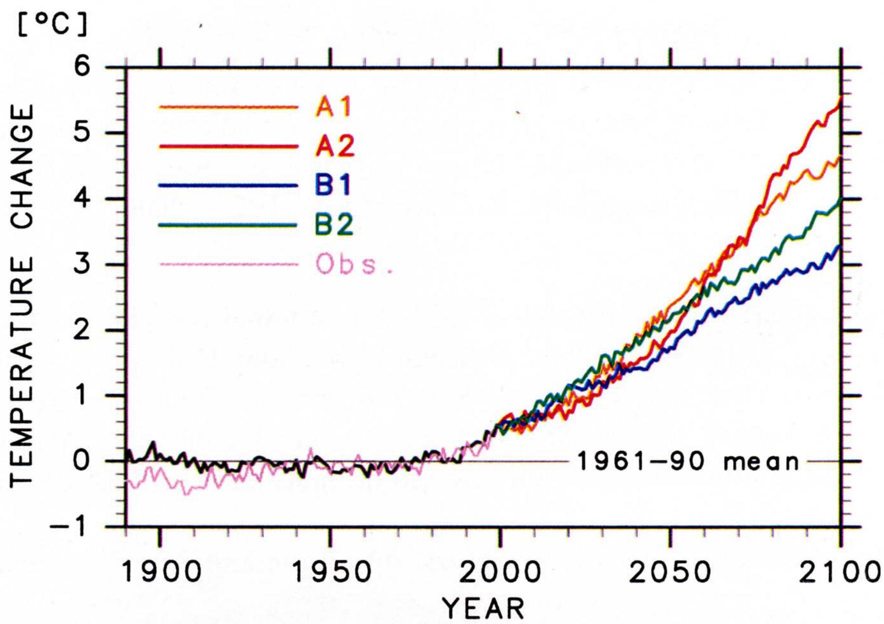

Fig. 2: Time series of the global and annual averaged surface temperature. Anomalies from the 30 years average (1961-1990) are plotted.

lifetime effect) for 1990 was about -0.56 W m^{-2}, which is comparable with the cloud albedo effect. Therefore, by assuming that the relative importance of two indirect effects will stay similar in future, we can estimate the future climate effects of aerosols as about -1.2 W m^{-2} for scenarios A1, B1, and B2, and about -2.0 W m^{-2} for the scenario A2.

Time series of the global and annual averaged surface temperature anomalies are plotted in Fig. 2. It increases for all the scenarios. The global warming is decelerated (accelerated) with an increase (decrease) in the sulfate aerosols, because their indirect effects have a significant cooling impact. The global mean temperature change in 2100 is the largest and about 5.5 $^\circ$ C for the A2 scenario, whereas it is the smallest and about 3.3 $^\circ$ C for the B1.

4. Conclusions

In order to reduce the uncertainties in the future projection of the global climate, we s-tudy the effects of aerosols and clouds in the atmosphere, utilizing climate model experiments as well as observational data analyses.

After our study, we can conclude that it is essential to establish a high-accuracy aerosol model to obtain the detailed global features of the multi-aerosol species, and utilize it in the projection of the future climate change with climate models. Also, the importance of the aerosol indirect effects, which affects the climate through the change of the cloud and precipitation processes, was reemphasized.

Further integration of basic knowledges on the aerosol indirect effects, cloud processes, and their parameterization scheme, as well as further improvements of our satellite data retrieval technieques are required.

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