Radiative Properties of Greenhouse Gases, Aerosols and Clouds in Korea

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We analyzed radiative properties of aerosols, CO_2 and clouds using Optical Properties of Aerosols and Clouds(OPAC) and the Column Radiation Model (CRM). From OPAC, if the soot component is disregarded, dust-like components depict the highest extinction values in the solar spectral range and the lowest single scattering albedoes, which are attributable to the presence of large particles. In the dust aerosol, the high absorptivity in the infrared may induce a warming of the lower atmospheric layer in the nighttime. The radiative properties of aerosols, clouds and double CO_2 using the CRM model at Seoul (37N, 127.4 E) on 3 April 2003 were calculated. The solar zenith angle is 65°, and the surface albedo is 0.1836 during the clear day. The aerosol optical depth change 0.14 to 1.7, which is derived during Asian dust days in Korea. At this time, abedo by aerosols is considered as 0.3. In cloudy condition, the short wave cloud forcing on both the TOA and the surface is -193.89 Wm^{-2} and -195.03 Wm^{-2}, respectively, and the long wave cloud forcing is 19.58 Wm^{-2} and 62.08 W m-2, respectively. As a result, the net radiative cloud forcing is -174.31 Wm^{-2} and -132.95 Wm^{-2}, respectively. We calculate also radiative heating rates by double CO_2 during the clear day. The CO_2 volumn mixing ratio is 3.55E-4.

Key words : Optical Properties of Aerosols and Clouds(OPAC), Column Radiation Model (CRM), Forcing, Radiative heating rates

1. Introduction

Aerosols cause climate forcing in several ways: the direct effect that aerosols scatter and absorb the solar and infrared radiation, indirect effects that aerosols alter the cloud properties such as cloud drops, cloud brightness, cloud lifetime and cloud cover acting as cloud condensation nuclei (CCN), and an albedo change of cloud, snow, and ice due to black carbonaceous or other aerosols$^{1)}$. Moreover, mineral dust aerosols are involved in many important processes such as direct radiative forcing, nutrient transport, land-use change, and ecosystem$^{2)}$. An adequate aerosol transport model including optical properties of mineral dusts help improve our understanding of these processes of aerosols in past, present, and future climate.

In addition, the spatial and temporal distribution of anthropogenic and natural aerosols are highly uncertain because of their short lifetime, various chemical components, and optical properties.

In recent years, total optical properties for aerosols have been obtained by remote sensing technologies from SeaWIFS, METEOSAT, NOAA, GMS, GOES, MODIS, and TOMS satellites, as well as lots of ground-based instruments. It is important to find method for comparing optical remote sensing data with model data. Above all, to minimize uncertainties for aerosol optical properties in the Chemical Transport Model (CTM) simulations, the mixed aerosol components of various origins with the use of a dataset of typical clouds in the selected spectral range should be involved within the CTM.

The primary goal of this study is to produce the radiative characteristics needed for radiation codes in global or regional aerosol transport models.

2. Radiative properties of aerosols and clouds

The radiative properties of clouds and aerosols are highly variable, both in time and space. In this study, to consider aerosols optical properties of various origins in aerosol transport model, we use the software package OPAC (Optical Properties

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of Aerosols and Clouds). OPAC consists of two parts. One is a dataset of microphysical properties and the resulting optical properties of cloud and aerosol components at different wavelengths and for different humidity, which includes six types of water clouds, three ice clouds, 10 aerosol components. The other is a FORTRAN program that allows the user to calculate optical properties of clouds and aerosols. This is valid for the microphysical properties of aerosols and clouds such as the extinction, scattering, and absorption coefficients, the single scattering albedo, the asymmetry parameter, and the phase function[3]. OPAC are also calculated for the optical properties like size distribution, refractive index and shape, and for the height distribution.

In order to calculate radiative properties of greenhouse gases and aerosols including clouds, we make use of the Column Radiation Model (CRM), The CRM is a standalone version of the column radiation code employed by the NCAR Community Climate Model (CCM3). Thus the CRM is a physical process model which isolates the energetics of radiative transfer from the rest of the CCM3. The CRM is built from the radiation routines from CCM3, along with a simple text interface for the user to input information needed by the radiation calculation, and is a useful tool for scientific studies of the Earth's solar and infrared energy budgets, greenhouse gas and aerosol radiative forcing, and column closure experiments.

Spectral irradiances are used to estimate changes in air temperature due to radiative heating or cooling. If only radiative effects are considered, the local time rate of change in temperature of a layer is found from the net flux divergence equation:

$$\partial T/\partial t = (1/Cp, m)\,(dQ\ solar/dt + dQ\ ir/dt) = [1/(Cp, m\ \rho)][\partial Fn/\partial z] \qquad (1)$$

where $Fn = \int (F-, \lambda - F+, \lambda)\, d\lambda$ is the net downward minus upward radiative flux (W/m-2), Q solar and Q ir are solar and infrared radiative heating rates (J/kg-1), respectively. Cp, m is the specific heat of moist air at constant pressure, and ρ is the air density.

3. Computation of the radiative characteristics of aerosols

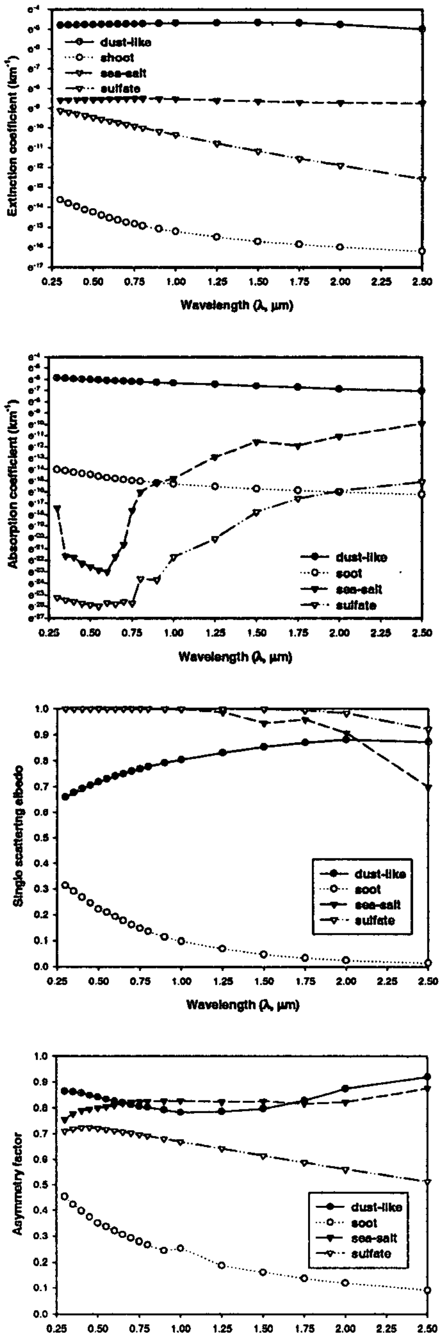
With reference to aerosol particles, whether for climate modeling purposes or remote sensing applications, an adapted equation of the radiative transfer and corresponding solutions are required.

In a given location, atmospheric aerosols are generally characterized by their concentration, their size distribution, their shape, their chemical composition indicating their real and imaginary refractive index. In first approach, the spectral behaviour of the dry particles is described for all aerosol types (dust-like, water-soluble, soot, and oceanic or sea-salt). In second step, the radiative characteristics (optical depth, extinction, scattering, absorption coefficients, single scattering albedo, and asymmetry factor) of all aerosol types normalized to particle number density (/cm^3) are presented as function of relative humidity. Finally, we are to apply to radiative transfer model or aerosol transport model.

Fig. 1 shows radiative characteristics (extinction coefficient (km^{-1}), scattering coefficient (km^{-1}), single scattering albedo, and asymmetry factor) of the aerosol components (dust-like, soot, sae-salt, and sulfate). From these results, it becomes apparent that if the soot component is disregarded, dust-like components depict the highest extinction values in the solar spectral range and the lowest single scattering albedoes, which are attributable to the presence of large particles. The single scattering albedo is presented as the ratio of energy scattered by aerosols to total attenuation under the first impingement by direct radiation. This property is also valid to, a large extent, for the mineral component of the arid regions.

Fig. 2 shows normalized radiative characteristic of the desert aerosol in wintertime as functions of the solar wavelengths. Dust components are conservative with respect to relative humidity changes. It indicates that neutral or nearly neutral extinction and relatively high absorption values throughout the spectral range considered. The high absorptivity in the infrared may induce a warming of the lower atmospheric layer in the nighttime. Depending on the amount and residence time of the airborne particular matter, the warming may produce, similarly to some trace gases, a greenhouse effect in the concerned environments.

Fig. 3 shows the hourly global distributions of the simulated optical thickness at a wavelength of 0.55 m for dust, carbonaceous, sulfate and sea-salt, respectively, in the Model for Atmospheic Chemistry and Transport (MATCH), which is an offline transport model developed by NCAR.



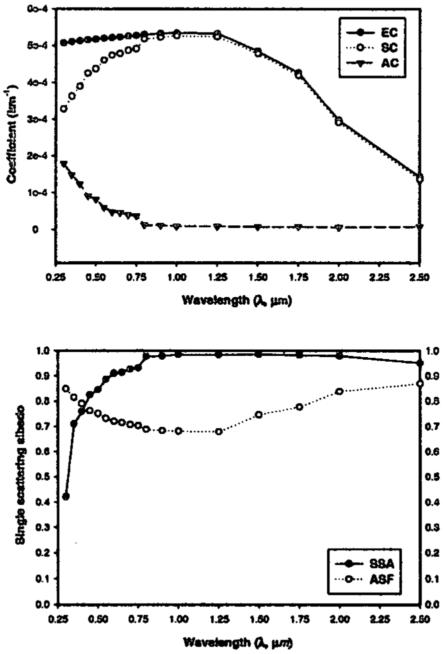
(a)

(b)

(c)

(d)

Fig. 1. Normalized radiative characteristics of the aerosol components (dry particles). (a) Extinction coefficient (km^{-1}), (b absorption coefficient (km^{-1}), (c) single scattering albedo, and (d) asymmetry factor.



(a)

(b)

Fig. 2. Normalized radiative characteristics of the desert aerosol in wintertime as functions of the solar wavelengths. (a) Extinction coefficient (EC, km^{-1}), scattering coefficient (SC, km^{-1}), and absorption coefficient (AC, km^{-1}), and (b) single scattering albedo (SSA) and asymmetry factor (ASF).

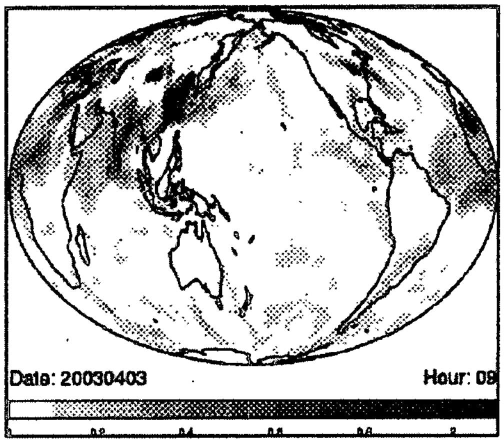


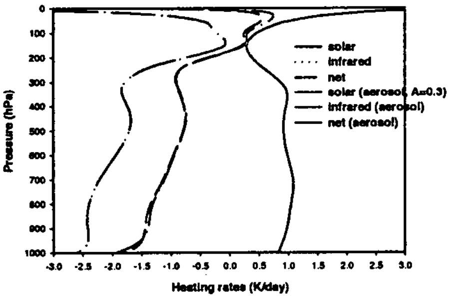
Fig. 3. Hourly global distributions of the simulated optical thickness of total aerosols at a wavelength of 0.55 m using MATCH.

A large amount of aerosols are seen around China, which can be explained by the strong regional wind in this day or season.

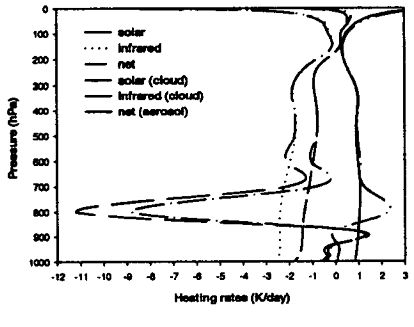
Fig. 4 shows radiative and climate properties of aerosols and clouds using the CRM model at Seoul (37N, 127.4 E) on 3 April 2003. The solar zenith angle is 65o, and the surface albedo is 0.1836 during the clear day. The aerosol optical depth change 0.14 to 1.7, which is derived during Asian dust days in Korea. At this time, abedo by aerosols is considered as 0.3 (see Fig. 4(a)). In cloudy condition, SW cloud forcings on the TOA and surface are -193.89 Wm^{-2} and -195.03 Wm^{-2}, respectively, and LW cloud forcings on the TOA of surface are 19.58 Wm^{-2} and 62.08 W m-2, respectively. As a result, the net radiative cloud forcing on the TOA and surface are -174.31 Wm^{-2} and -132.95 Wm^{-2}, respectively (see Fig. 4(b)). We calculate also radiative heating rates by double CO_2 during the clear day (see Fig. 4(c)). The CO_2 volumn mixing ratio is 3.55E-4.

4. Conclusions

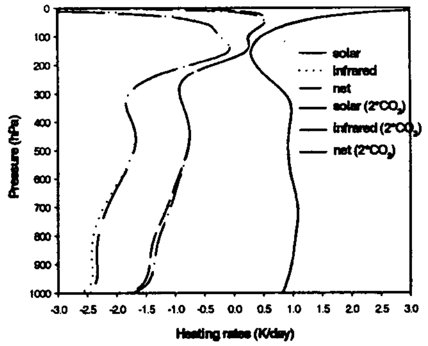
Mie theory has been used to compute the radiative characteristics of dry and wet aerosol particles, clouds, and greenhouse gases such as CO_2 using OPAC and CRM models.



(a)



(b)



(c)

Fig. 4. Comparisons of radiative heating rates due to aerosols (a), clouds (b) and double CO2 (c) on 3 April 2003.

In the future, we need to validate the radiative properties of aerosols and clouds with aerosol transport models and remote sensing data in the east Asian region.

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