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Derivation of component aerosol direct radiative forcing at the top of atmosphere for clear-sky oceans

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Abstract

A two-step approach is proposed to derive component aerosol direct radiative forcing (ADRF) at the top of atmosphere (TOA) over global oceans from 60°S to 60°N for clear-sky condition by combining Terra CERES/MODIS-SSF shortwave (SW) flux and aerosol optical thickness (AOT) observations with the fractions of component AOTs from the GSFC/GOCART model. The derived global annual mean component ADRF is $+0.08\pm0.17\,W/m^2$ for black carbon, $-0.52\pm0.24\,W/m^2$ for organic carbon, $-1.10\pm0.42\,W/m^2$ for sulfate, $-0.99\pm0.37\,W/m^2$ for dust, $-2.44\pm0.84\,W/m^2$ for sea salt, and $-4.98\pm1.67\,W/m^2$ for total aerosols. The total ADRF has also been partitioned into anthropogenic and natural components with a value of -1.25 ± 0.43 and $-3.73\pm1.27\,W/m^2$, respectively. The major sources of error in the estimates have also been discussed. The analysis adds an alternative technique to narrow the large difference between current model-based and observation-based global estimates of component ADRF by combining the satellite measurement with the model simulation.

Keywords: Aerosol direct radiative forcing; Aerosol optical thickness

1. Introduction

Since aerosols cause the largest uncertainties in assessing the climate forcing of atmospheric constituents associated with anthropogenic activity [1], various approaches have been used to study global aerosol radiative forcing and to narrow the related uncertainties. In this paper, we refer the term "aerosol radiative forcing" in a rather broad way, which is the effect of both natural and anthropogenic aerosols on the radiative fluxes. The aerosol radiative forcing due to aerosol effect on radiative fluxes through the scattering and absorption of

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aerosol particles is referred as aerosol direct radiative forcing (ADRF). Traditionally, model calculations were used to compute the global ADRF [2–10]. Since the publication of the third assessment report of the Intergovernmental Panel on Climate Change (IPCC) in 2001, satellite measurements have been more and more widely used in the study of global ADRF [11–23]. However, there are still large differences between observation-based and model-based global estimates of ADRF. A comprehensive review of recent model- and measurement- based studies of ADRF has been given by Schulz et al. [10] and Yu et al. [24], respectively.

Due to successful launch of more advanced satellite instruments, such as the Moderate Resolution Imaging Spectroradiometer (MODIS), more aerosol information contents become available from satellite measurement, which makes it possible for an in-depth study of global ADRF using satellite observations. For example, MODIS aerosol size information (such as fine-mode aerosol fraction of aerosol optical thickness (AOT)) has been utilized to discriminate ensemble anthropogenic aerosol from natural aerosol (NA) [25] and to estimate the global ADRF of anthropogenic aerosols [18–19,21,25,26]. However, it is still difficult to use satellite observations alone to further discriminate aerosols into more detailed components (such as sea salt (SS), dust (DU), sulfate (SU), black carbon (BC), and organic carbon (OC)) over the globe as well as to derive their direct radiative forcing. Since the ADRF of different aerosol components are different (e.g., even the sign of a forcing can be reversed), the accurate estimation of component ADRF becomes important and deserves to be explored. Here, we present an approach that combines satellite derived ADRF from the Clouds and Earth's Radiant Energy System (CERES) instrument on the EOS-Terra satellite with the optical thickness fractions of major aerosol components from the Goddard Chemistry Aerosol Radiation and Transport (GOCART) model to determine the ADRF for the major aerosol components over the global oceans from 60°S to 60°N. The satellite observation and model simulation are introduced in Section 2; the methodology is explained in Section 3; evaluation on the approach is performed in Section 4; results are given in Section 5; uncertainty estimations and some discussions are presented, respectively, in Sections 6 and 7; and a summary is given in the closing section.

2. Satellite and model products

In this study, aerosols are divided into five major components: BC, OC, SU, DU, and SS, following the aerosol classification in the GOCART model [27–30]. The total AOT (or τ) is the sum of the component AOTs (or $\tau_{TOT} = \tau_{BC} + \tau_{OC} + \tau_{SU} + \tau_{DU} + \tau_{SS} = \sum_{i=1}^{5} \tau_i$). Moreover, BC, OC, and SU are further grouped as anthropogenic aerosols (AN) after removing the contributions from natural OC (OCn) and natural sulfate (SUn) (or $\tau_{AN} = \tau_{BC} + \tau_{OC} + \tau_{SU} - \tau_{OCn} - \tau_{SUn}$). τ_{OCn} and τ_{SUn} are calculated in the GOCART model and can be output for our application. The NAs are determined by subtracting the anthropogenic component from the total aerosols ($\tau_{NA} = \tau_{TOT} - \tau_{AN}$). τ_{TOT}, τ_{BC}, τ_{OC}, τ_{SU}, τ_{DU}, τ_{SS}, τ_{AN}, and τ_{NA} from the GOCART model are used to determine the fraction (r_i) of individual component AOT for BC, OC, SU, DU, SS, AN, and NA using the relationship $r_i = \tau_i/\tau_{TOT}$ (i = BC, OC, SU, DU, SS, AN, and NA). The aerosol optical parameter used to derive ADRF in our approach is the AOT at 0.55 μm (or $\tau_{0.55}$) from the Terra/CERES-MODIS single scanner footprint (SSF) Edition-1A data.

The Terra/CERES-MODIS SSF shortwave (SW) fluxes at the top of atmosphere (TOA) and the standard MODIS AOTs aggregated to the CERES footprints are used in the current study. The Terra CERES SSF product [31,32] combines CERES radiances and fluxes with scene information from coincident high spectral and spatial resolution MODIS measurements, and assimilated meteorological fields. Radiative fluxes are determined using angular distribution models (ADMs) described in Loeb et al. [33]. There are two aerosol products in the SSF data, called AVHRR-type and MODIS product, respectively. Detailed description, comparison, and validation of these two aerosol products can be found in Zhao et al. [34,35]. The MODIS product is selected and used here due to its better global and regional validation result against the surface AERONET observations. The SSF MODIS aerosol product is obtained by averaging the standard 10 km MODIS aerosol products [36,37] over the ocean in each CERES footprint weighted by the CERES point spread function (PSF). The MODIS Collection 3 aerosol product (MOD04) was used in the Edition-1A SSF data. SSF AOTs at $\lambda = 0.55$ μm and TOA SW fluxes of 2001 are used in our analysis since the two SSF aerosol products for the same year had been analyzed and evaluated in detail [34,35]. The SSF-MODIS AOTs are averaged to obtain daily and monthly mean values. The daily and monthly AOTs (τ_{TOT}) are then partitioned