Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)

ACG06-25 Room:315 Time:April 29 15:15-15:30

Shortwave direct aerosol radiative forcing using CALIOP and MODIS measurements

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The aerosol direct effect occurs by direct scattering and absorption of solar and thermal radiation. Shortwave direct aerosol radiative forcing (SWDARF) under clear-sky condition is estimated about 5 Wm^{-2} from satellite retrievals and model simulations [e.g., *Yu et al*., 2006]. Simultaneous observations of aerosols and clouds are, however, very limited to validate the estimation of SWDARF under cloudy-sky condition. In 2006, the CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) satellite was launched with the space-borne lidar, CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization). This enabled us to get data of the vertical distribution of aerosols and clouds all over the world. *Oikawa et al.* [2013] estimated SWDARF under clear-sky, cloudy-sky, and all-sky conditions using CALIOP Version 2 data and MODIS (Moderate resolution Imaging Spectrometer) data. They investigated four scenarios for evaluating the SWDARF: clear-sky, the case that aerosols exist above clouds (above-cloud case), the case that aerosols exist below high-level clouds (below-cloud case), and the case that aerosols are not detected by CALIOP in cloudy-sky condition. The cloudy-sky SWDARF is, then, estimated by the latter three scenarios. The all-sky SWDARF is the combination of clear-sky and cloudy-sky SWDARF weighted by the cloud occurrence.

We calculated SWDARF from 2007 to 2009 using CALIOP Level 2 Cloud and Aerosol Layer Products Version 2 (V2) and Version 3 (V3) with the method of *Oikawa et al.* [2013]. The procedure of daytime calibration, cloud screening, and aerosol-cloud classification are improved in the V3 algorithms [*Powell et al*., 2010; *Vaughan et al*., 2010; *Liu et al*., 2010]; therefore, the distributions of aerosols and clouds are significantly changed from V2 data. Compared V3 data with V2 data, the total cloud fraction and occurrence probability of above-cloud case decrease. In clear-sky condition, marine aerosols increase and single scattering albedo (SSA) of total aerosols increases over the ocean. In cloudy-sky condition, smoke and polluted dust decrease. Annual zonal averages of SWDARF from 60^oS to 60^oN under clear-sky, cloudy-sky, and all-sky are -2.85, -0.16, and -0.78 Wm^{-2} for V2 data and -3.70, -1.07, and -2.02 Wm^{-2} for V3 data. It indicates that SWDARF largely depends on the retrieval and classification algorithms of aerosols and clouds.

Previous studies reported that the aerosol absorption above clouds cause the underestimation of cloud optical thickness (COT) in the satellite retrievals [*Haywood et al*., 2004; *Coddington et al*., 2010]. We, therefore, have a plan to examine the effect on SWDARF from underestimation of COT.

Keywords: aerosol, radiative forcing, DARF, CALIPSO, CALIOP