Atmos. Chem. Phys., 6, 613-666, 2006
www.atmos-chem-phys.net/6/613/2006/

A review of measurement-based assessments of the aerosol direct radiative effect and forcing

H. Yu[1,2], Y. J. Kaufman[2], M. Chin[2], G. Feingold[3], L. A. Remer[2], T. L. Anderson[4], Y. Balkanski[5], N. Bellouin[6], O. Boucher[6,7], S. Christopher[8], P. DeCola[9], R. Kahn[10], D. Koch[11], N. Loeb[12], M. S. Reddy[7,13], M. Schulz[5], T. Takemura[14], and M. Zhou[15]

[1]Goddard Earth Science and Technology Center, University of Maryland at Baltimore County, Baltimore, Maryland, USA

[2]Laboratory for Atmospheres, NASA Goddard Space Flight Center (GSFC), Greenbelt, Maryland, USA

[3]NOAA Environmental Technology Laboratory (ETL), Boulder, Colorado, USA

[4]University of Washington, Seattle, Washington, USA

[5]Laboratoire des Sciences du Climat et de l'Environnement, CEA/CNRS – LSCE, L'Orme des Merisiers, France

[6]Met Office, Exeter, UK

[7]Laboratoire d' Optique Atmosphérique (LOA), Villeneuve d'Ascq, France

[8]University of Alabama, Huntsville, Alabama, USA

[9]NASA Headquarters, Washington, D.C., USA

[10]NASA Jet Propulsion Laboratory (JPL), Pasadena, California, USA

[11]NASA Goddard Institute for Space Studies (GISS), New York, New York, USA

[12]NASA Langley Atmospheric Research Center (LaRC), Hampton, Virginia, USA

[13]NOAA Geophysical Fluid Dynamics Laboratory (GFDL), Princeton, New Jersey, USA

[14]Kyushu University, Fukuoka, JapanC., USA

[15]Georgia Institute of Technology, Atlanta, Georgia, USA

Abstract. Aerosols affect the Earth's energy budget directly by scattering and absorbing radiation and indirectly by acting as cloud condensation nuclei and, thereby, affecting cloud properties. However, large uncertainties exist in current estimates of aerosol forcing because of incomplete knowledge concerning the distribution and the physical and chemical properties of aerosols as well as aerosol-cloud interactions. In recent years, a great deal of effort has gone into improving measurements and datasets. It is thus feasible to shift the estimates of aerosol forcing from largely model-based to increasingly measurement-based. Our goal is to assess current observational capabilities and identify uncertainties in the aerosol direct forcing through comparisons of different methods with independent sources of uncertainties. Here we assess the aerosol optical depth (τ), direct radiative effect (DRE) by natural and anthropogenic aerosols, and direct climate forcing (DCF) by anthropogenic aerosols, focusing on satellite and ground-based measurements supplemented by global chemical transport model (CTM) simulations. The multi-spectral MODIS measures global distributions of aerosol optical depth (τ) on a daily scale, with a high accuracy of $\pm0.03\pm0.05\tau$ over ocean. The annual average τ is about 0.14 over global ocean, of which about 21%±7% is contributed by human activities, as estimated by MODIS fine-mode fraction. The multi-angle MISR derives an annual average AOD of 0.23 over global land with an uncertainty of ~20% or ±0.05. These high-accuracy aerosol products and broadband flux measurements from CERES make it feasible to obtain observational constraints for the aerosol direct effect, especially over global the ocean. A number of measurement-based approaches estimate the clear-sky DRE (on solar radiation) at the top-of-atmosphere (TOA) to be about -5.5±0.2 Wm^{-2} (median ± standard error from various methods) over the global ocean. Accounting for thin cirrus contamination of the satellite derived aerosol field will reduce the TOA DRE to -5.0 Wm^{-2}. Because of a lack of measurements of aerosol absorption and difficulty in characterizing land surface reflection, estimates of DRE over land and at the ocean surface are currently realized through a combination of satellite retrievals, surface measurements, and model simulations, and are less constrained. Over the oceans the surface DRE is estimated to be -8.8±0.7 Wm^{-2}. Over land, an integration of satellite retrievals and model simulations derives a DRE of -4.9±0.7 Wm^{-2} and -11.8±1.9 Wm^{-2} at the TOA and surface, respectively. CTM simulations derive a wide range of DRE estimates that on average are smaller than the measurement-based DRE by about 30-40%, even after accounting for thin cirrus and cloud contamination.

A number of issues remain. Current estimates of the aerosol direct effect over land are poorly constrained. Uncertainties of DRE estimates are also larger on regional scales than on a global scale and large discrepancies exist between different approaches. The characterization of aerosol absorption and vertical distribution remains challenging. The aerosol direct effect in the thermal infrared range and in cloudy conditions remains relatively unexplored and quite uncertain, because of a lack of global systematic aerosol vertical profile measurements. A coordinated research strategy needs to be developed for integration and assimilation of satellite measurements into models to constrain model simulations. Enhanced measurement capabilities in the next few years and high-level scientific cooperation will further advance our knowledge.

Citation: Yu, H., Kaufman, Y. J., Chin, M., Feingold, G., Remer, L. A., Anderson, T. L., Balkanski, Y., Bellouin, N., Boucher, O., Christopher, S., DeCola, P., Kahn, R., Koch, D., Loeb, N., Reddy, M. S., Schulz, M., Takemura, T., and Zhou, M.: A review of measurement-based assessments of the aerosol direct radiative effect and forcing, Atmos. Chem. Phys., 6, 613-666, 2006.