On the Recent Progress of Atmospheric Satellite Remote Sensing and Radiation Budget Studies

Teruyuki Nakajima (teruyuki@ccsr.u-tokyo.ac.jp)
Center for Climate System Research, The University of Tokyo

1. Introduction

In the last two decades the atmospheric satellite remote sensing and radiation budget studies have made a great progress partly because of the strong demand of accurate evaluation of the radiative forcing of anthropogenic climate change factors such as direct and indirect climate effects of man-made aerosols. IPCC (e.g., IPCC, 2001) has devoted a considerable effort on accessing these various radiative forcings. Another important key to the progress is that the modeling of atmospheric radiative transfer processes has become more comprehensive and accurate to describe the processes in the real earth's atmosphere. Optical properties of aerosols and clouds have been extensively measured and modeled in several large-scale field experiments of aerosols and radiation as in INDOEX (Ramanathan et al., 2001), IGAC/ACE-Asia (Hubert et al., 2003), Japan Science and Technology Corporation/APEX (Nakajima et al., 2003), etc. Surface networks, such as NASA AERONET (Holben et al., 2001), WCRP/BSRN, and JAXA SKYNET, also have started providing quantitative data useful for validating the satellite remote sensing and model simulation.

In this paper I like to discuss the recent progress in satellite remote sensing of atmosphere and radiation budget studies, especially those related with radaiative forcing evaluation issue.

2. Studies on satellite remote sensing of atmosphere and radiation budget

A variety of satellite remote sensing techniques of atmospheric aerosols and clouds have been proposed in the last two decades. ADEOS-II/GLI, EOS/MODIS, ENVISAT/MERIS are new satellite-borne sensors to explore the utilities of information included in multi-wavelength spectral radiances. Radiances at wavelengths from UV to near infrared spectral regions have provided good information to retrieve the aerosol optical thickness, size index or Ångström exponent, and aerosol types. Further use of bidirectional angular information and polarization are also found to be useful to stabilize the inversion process such as aerosols over land area. Figure 1 shows an example of aerosol type classification using the four channel algorithm of Higurashi and Nakajima (2002) with MODIS radiances from UV to near infrared spectral region. Comparing with surface-measured values of optical thickness contributions from sulfate, carbonaceous, mineral dust, and sea salt aerosols, it is found that the technique can provide useful information about the dominant aerosol type that determines satellite-received radiances. Our study found that the most popular aerosol type in the East Asian region is of carbonaceous that absorb strongly the solar radiation in blue spectral region. The single scattering albedo (SSA) of aerosols from AERONET also shows a typical value about 0.9 in most areas where anthropogenic aerosols are dominant.

It is interesting to study what is the globally averaged clear sky radiative forcing of anthropogenic aerosols with such low SSA. Kaufman et al. (2003) derived the clear sky direct radiative forcing of anthropogenic aerosols as -0.46 W/m^2 from MODIS global measurements of aerosols as summarized in Fig. 2. On the other hand, -0.70 W/m^2 is our value of the clear sky direct radiative forcing of anthropogenic aerosols estimated by CCSR/NIES AGCM combined with SPRINTARS aerosol chemical transport model (Takemura et al., 2005). These values show that the anthropogenic aerosols have very small forcing even in the clear sky condition due to their strong absorption of solar radiation. It is also important to find that the direct forcing of anthropgenic aerosols in the whole sky condition is as small as -0.02 W/m^2. This large reduction of the magnitude of forcing is a result of large positive forcing due to strong absorption by aerosols in cloudy regions. Since the MODIS clear sky forcing is smaller in magnitude than that from GCM, the real value of the radiative forcing in the whole sky condition may be near zero or positive. This discussion suggests that measurements of solar radiation absorption by aerosols in cloud regions will be needed for better estimation of the aerosol direct forcing.

On the other hand, the recent evaluation of indirect forcing is still in confusion. Even with the same SPRINTARS model with CCSR/NIES AGCM, there have been several estimates ranging from -0.94W/m^2 to -2.4 W/m^2 as summarized in Fig. 2, depending on what parameterization is adopted for conversion of aerosol particle number to cloud particle number (Takemura et al., 2005) and for autoconversion of cloud water to precipitation (Suzuki et al., 2003). A lower value of of -0.94 W/m^2 is obtained when they take into a updraft velocity effect and a large background aerosol number (Takemura et al., 2005). A key parameter for the magnitude of the indirect forcing is the increase rate of number of anthropogenic aerosols after industrial revolution, i.e., $\nu = N_{a,present}/N_{a,pre\text{-}industrial}-1$. The ν-value takes 1.3 in Takemura et al. (2003) and 0.3 in Takemura et al. (2005) suggesting a large uncertainty in the estimation of aerosol number increase after the industrial revolution. This suggests that a study of natural source aerosols is important for better estimation of anthropogenic aerosol forcings.

Satellite remote sensing techniques can also be used to estimate the aerosol indirect forcing. Nakajima et al. (2001) used AVHRR-retrieved aerosol and cloud optical thickness and effective radius (or Ångström exponent) to derive column numbers of aerosols and clouds. They found a decrease in the effective particle radius and an increase in the aerosol optical thickness with increasing column aerosol number. By assuming $\nu = 0.30$, they found the indirect forcing over ocean as -1.3 W/m^2. Sekiguchi et al. (2003) re-examined this analysis more carefully and found that for the forcing is similar as -1.4 W/m^2. They also newly found that there is a cloud fraction increase with increasing aerosol number. A contradiction, however, is that the forcing becomes very small as -0.18 W/m^2 over ocean and -0.14 W/m^2 over land when they use POLDER-retrieved parameters. It is suggested that we need a more careful study of remote sensing data for evaluation of the indirect radiative forcing.

3. Conclusions

As discussed in the previous section, the direct forcing of anthropogenic aerosols is close to zero due to a large absorption of solar radiation by aerosol particles. This conclusion consequently raises a question: how large is the surface forcing by aerosol particles. Large absorption causes a large reduction in the solar radiative flux reaching the earth's surface, but at the same time the evaluation of forcing becomes difficult. So far, our GCM simulation produces surface radiative forcing values of -1 W/m^2 and -2.3 W/m^2 over ocean and land, respectively, so that there is a large diabatic forcing between ocean and land areas to drive secondary general circulation. More studies should be devoted for simultaneous measurements of surface radiative flux and aerosol absorption. Key parameters to be studied for better understanding of the radiative budget in cloudy regions are the single scattering albedo of aerosols and also the CCN ability of aerosols. Especially water activity of carbonaceous aerosols and size distribution should be studied more intensively. Considerable efforts are now being planned in a new project of UNEP/Atmospheric Brown Cloud (ABC) for comprehensive understanding the aerosol effects to climate, agriculture, and public health (Ramanathan et al., 2003).

References

Higurashi, A., and T. Nakajima, 2002: Detection of aerosol types over the East China Sea near Japan from four-channel satellite data. *Geophys. Res. Lett.*, **29**(17), 1836, doi:10.1029/2002GL015357.

Holben, B.N., D. Tanré, A. Smirnov, T.F. Eck, I. Slutsker, N. Abuhassan, W.W. Newcomb, J.S.Schafer, B. Chatenet, F. Lavenu, Y.J. Kaufman, J.V. Castle, A. Setzer, B. Markham, D. Clark, R. Frouin, R. Halthore, A. Karneli, N.T. O'Neill, C. Pietras, R.T. Pinker, K. Voss, and G. Zibordi , 2001: An emerging ground-based aerosol climatology: Aerosol optical depth from AERONET. *J. Geophys. Res.*, **106**, 12067-12097.

Huebert, B.T., T. Bates, P.B. Russell, G.Y. Shi, Y.J. Kim, K. Kawamura, G. Carmichael, and T. Nakajima, 2003: An overview of ACE-Asia: Strategies for quantifying the relationships between Asian aerosols and their climatic impacts. *J. Geophys. Res*., **108**, No. D23, 8633, doi:10.1029/2003JD003550.

Kaufman, Y.J., A., 2003: The global aerosol system and its direct forcing of climate results from MODIS, AERONET and GOCART. *IUGG General Assembly, Sapporo*, June 30-July 4.

IPCC, 2001: Climate Change 2001-The Scientific Basis J. T. Houghton, Ed., Cambridge Univ. Press.

Nakajima, T., A. Higurashi, K. Kawamoto, and J. E. Penner, 2001: A possible correlation between satellite-derived cloud and aerosol microphysical parameters. *Geophys. Res. Lett.*, **28**, 1171-1174.

Nakajima, T., M. Sekiguchi, T. Takemura, I. Uno, A. Higurashi, D.H. Kim, B.J. Sohn, S.N. Oh, T.Y. Nakajima, S. Ohta, I. Okada, T. Takamura, and K. Kawamoto, 2003: Significance of direct and indirect radiative forcings of aerosols in the East China Sea region. *J. Geophys. Res.* , **108**(D23), 8658, doi: 10.1029/2002JD003261.

Nozawa, T., S. Emori, A. Numaguti, Y. Tsushima, T. Takemura, T. Nakajima, A. Abe-Ouchi, and M., Kimoto, 2001: Projections of future climate change in the 21st century simulated by the CCSR/NIES CGCM under the IPCC SRES scenarios, In 'Present and Future of Modeling Global Environmental Change-Toward Integrated Modeling', Matsuno, T. and H. Kida eds., *Terra Scientific Publishing Company*, Tokyo, pp.15-28.

Ramanathan, V., P.J. Crutzen, J. Lelieveld, A.P. Mitra, D. Althausen, J. Andersen, M.O. Andreae, W. Cantrell, G.R. Cass, C.E. Chung, A.D. Clarke, J.A. Coalkey, W.D. Collins, W.C. Conant, F. Dulac, J. Heinzenberg, A.J. Heymsfield, B. Holben, S. Howell, J. Hudson, A. Jayaraman, J.T. Kiehl, T.N. Krishnamurti, D. Lubin, G. McFarquhar, T. Novakov, J.A. Ogren, I.A. Podgorny, K. Prather, K. Priestley, J.M. Prospero, P.K. Quinn, K. Rajeev, P. Rasch, S. Rupert, R. Sadourny, S.K. Satheesh, G.E. Shaw, P. Sheridan, and F.P.J. Valero, 2001: Indian Ocean Experiment: An integrated analysis of the climate forcing and effects of the great Indo-Asian haze, *J. Geophys. Res*., **106**, 28371-28398.

Ramanathan, V., and P.J. Crutzen, 2003: New directions: Atmospheric Brown Clouds, *Atmos. Environ.*, **37**, 4033-4035.

Sekiguchi, M., T. Nakajima, K. Suzuki, K. Kawamoto, A. Higurashi, D. Rosenfeld, I. Sano, and S. Mukai, 2003: A study of the direct and indirect effects of aerosols using global satellite datasets of aerosol and cloud parameters. *J. Geophys. Res.*, in press.

Suzuki, K., T. Nakajima, A. Numaguti, T. Takemura, K. Kawamoto, and A. Higurashi, 2003: A study of the aerosol effect on a cloud field with simultaneous use of GCM modeling and satellite observation. *J. Atmos. Sci.*, in press.

Takemura, T., T. Nakajima, O. Dubovik, B. N. Holben, and S. Kinne, 2002: Single scattering albedo and radiative forcing of various aerosol species with a global three-dimensional model. *J. Climate*, **15**, 333-352.

Takemura, T., 2003: Private communication regarding SPRINTARS simulations with different aerosol-cloud interaction parameterizations.

Takemura, T., T. Nozawa, S. Emori, T.Y. Nakajima, and T. Nakajima, 2005: Simulation of climate response to aerosol direct and indirect effects with aerosol transport-radiation model. *J. Geophys. Res.*, doi:10.1029/2004JD005029.

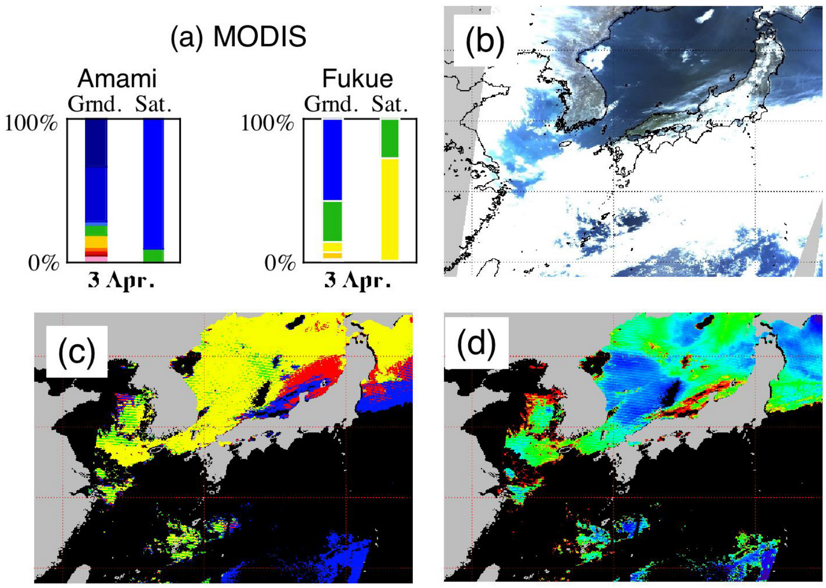

Fig. 1. Satellite classification of aerosol chemical properties by the four channel algorithm of Higurashi and Nakajima (2002) applied to a East Asian region. The panel (a) shows a comparison of aerosol optical thickness contributions of sulfate (green), carbonaceous (yellow), mineral dust (red), and sea-salt (blue)

compositions as estimated by the satellite remote sensing (Sat.) and surface chemical measurements (Grnd.) at Fukue-jima Island and Amami-Oshima Island on 3 April 2003. RGB composite (b), aerosol types (c), and optical thickness (d) are also shown.

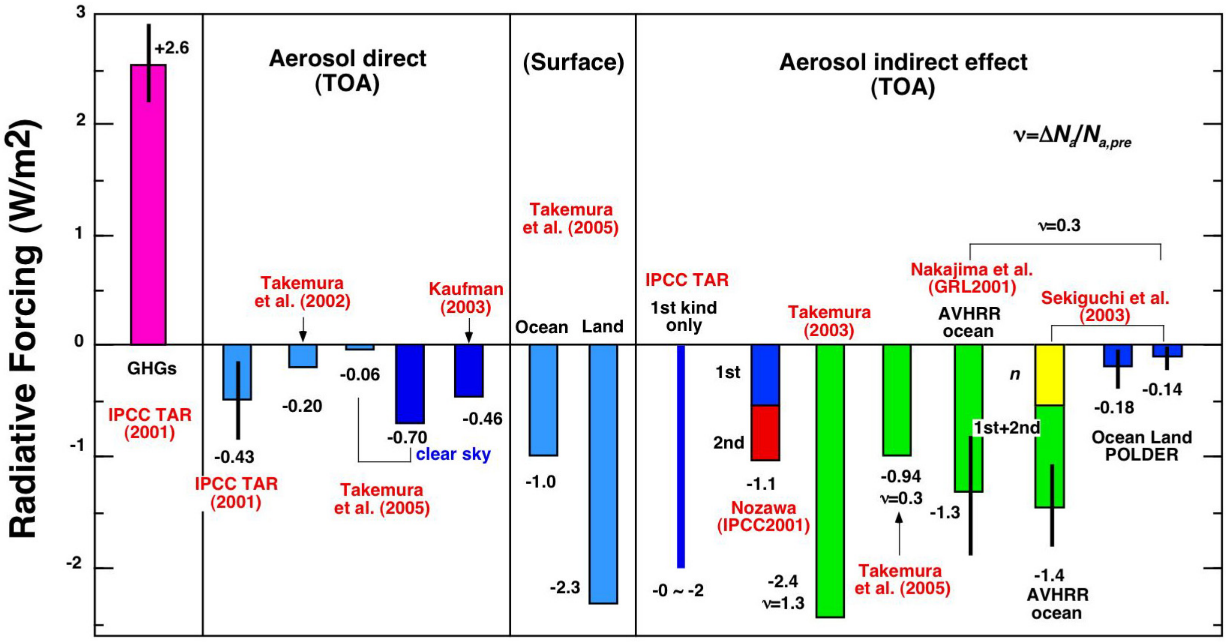

Fig. 2. Radiative forcing of anthropogenic greenhouse gases and aerosols since 1850 as estimated by IPCC (2001), Takemura et al. (2002; 2003; 2005); Kaufman et al. (2003); Nozawa et al. (2001); Nakajima et al. (2001); Sekiguchi et al. (2003). ν□□the inrease rate of aerosol number since 1850.