B-4 Aerosol and Cloud Environmental Studies with Combined Active and Passive Sensors (ACECAP)

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1. Introduction

As concluded in the third report of the Intergovernmental Panel for Climate Change (IPCC, 2001), there is a large uncertainty in the estimate of the radiative forcing at the top of the atmosphere caused by the direct and indirect effects of anthropogenic aerosols since the industrial revolution. Especially the magnitude of the indirect effect of aerosols is scarcely understood. The current estimate ranges from 0 to -2 W/m^2 even for the first kind of indirect effect. This fact means that we do no know if the anthropogenic aerosols produced negligible effect or a significant cooling effect to compensate the radiative forcing of +2.5 W/m^2 from greenhouse gases. In either case, we have to re-organize our global warming model. The cloud itself is also difficult to be simulated by current climate models. The uncertainty in the radiative forcing produced by clouds has not been reduced since the second report of IPCC (1996). This difficult situation of assessing the aerosol and cloud radiative forcings in spite of large research investment suggests that we have to start a research, based on a new idea, to make a breakthrough to the successful estimation of the indirect effect forcing. In this study, named ACECAP (Aerosol and Cloud Environmental studies with Combined Active and Passive sensors), we propose a new atmospheric monitoring system by combining active and passive remote sensors in order to provide key information to improve the radiative forcing estimate of anthropogenic aerosols.

2.Research Objective

The final goal of this study is to give an accurate estimate of the radiative forcing produced by the direct and indirect climate effects of anthropogenic aerosols. For this purpose, we want to develop a new atmospheric monitoring system by combining a cloud-profiling radar and a near ultraviolet (NUV) high resolution spectral lidar with passive sensors such as visible-infrared imager and Fourier transform spectrometer. We will observe the three dimensional microphysical structures of aerosol and cloud systems by the new monitoring system on ground surface and aircraft. Based on this experimental result, we further propose a mission requirement for a satellite system to carry cloud radar and NUV lidar instruments. The proposed radar is with 3 mm wavelength and lidar is with high resolution NUV spectral channel for simultaneous measurement of Mie and molecular scatterings. We expect such a system will provide a key information for evaluating the indirect effect of aerosols and of cloud radiative forcing.

Combining active/passive observation with climate modeling we want to evaluate the radiative forcing of anthropogenic aerosols with an accuracy of 0.2 W/m^2.

3. Results

(1) Study on advanced cloud observation techniques using cloud radar and synergy algorithms.

Hiroshi Kumagai and Yuichi Ohno (National Institute of Information and Communications Technology); Toshiaki Takano (Chiba University); Hajime Okamoto (Tohoku University)

It has been recognized that clouds and aerosols affect the earth's climate significantly through their impact to change earth's radiation budget. This sub-group studies methods of accurately measuring the horizontal and vertical structure of the cloud system. For this purpose millimeter-wave radars are developed and the analysis method is also studied.

The main instrumentations are a pulse-type airborne cloud radar (SPIDER) and FMCW-type cloud radars (FALCON), with sensitivity high enough to measure vertical structure of cloud systems in detail, which has been developed in FY2003. FALCON-1 (two antennas) and FALCON-2 (one antenna) were originally developed by Chiba Univ. with low cost and they were introduced by newspapers and news on TV, several times.

Using these cloud radars, many campaigns of cloud observations were conducted. Airborne radar observations using SPIDER were conducted in spring 2003 and February 2006 with airborne lidar. Long-term cloud observations from the ground using SPIDER were also made in FY2003-FY2006. These profiles show statistically meaningful cloud height occurrences. Short-term observation from ground at Sumatra Indonesia was also conducted to compare with Equatorial Atmospheric Radar (EAR) observation. Ship-borne measurements were conducted with FALCON-1 in FY2004-FY2006 to obtain maritime cloud systems over a wide oceanic area from North Pacific Ocean to Tropical Pacific and Indian Ocean. Cloud occurrence profiles observed by FALCON-1 at North Pacific Ocean and Tropical Pacific Ocean are compared to study cloud climatology.

Synergy algorithms for estimation of cloud physical parameter such as effective radius and ice water content were also developed using cloud radar data (SPIDER, FALCON). Those algorithms include cloud radar alone methods and combination methods of cloud radar and lidar. It has been proved that our developed algorithm has good accuracy comparing with other foreign algorithms. The result using this algorithm suggests that high level cloud fraction obtained by AGCM is higher than that from observation. This information will be useful to modify cloud process in the climate models. Using aerosol data obtained by lidar and cloud parameter estimated by synergy algorithm, an interaction between aerosol and cloud were discussed.

Japan and European Space Agency are jointly planning to develop the EarthCARE satellite scheduled to be launched in 2012, which will embark cloud radar and lidar in order to measure global cloud and aerosol distribution. Radar-lidar synergy algorithm will be used in the satellite measurement to generate higher level products of such as cloud effective radius, ice/liquid water content. The radar-lidar synergy algorithm developed in this study will be the base for the algorithms to be developed for EarthCARE satellite measurement.

(2) Study on observation methods for clouds and aerosols using lidar methods.

Nobuo Sugimoto, Atsushi Shimizu, Ichiro Matsui (National Institute for Environmental Studies); Boyan Tatarov (National Institute for Environmental Studies); Takao Kobayashi (Fukui University)

This sub-group developed methods of deriving aerosol optical characteristics and cloud microphysical characteristics by lidar methods and synergetic use of lidar, cloud radar, and multi-spectral imager. One of the important tasks was to develop high-spectral resolution lidar (HSRL) techniques at both 532 nm and 355 nm. A 532nm HSRL using an iodine molecular filter was developed by NIES and used for long-term observation in Tsukuba. Climatology of the lidar ratio (the extinction-to-backscattering ratio) was determined for spherical and non-spherical aerosols and for ice clouds through a statistical analysis of the HSRL data for more than two years. At the same time, validation experiments of NASA space-borne lidars ICESAT/GLAS and CALIPSO/CALIOP were performed at NIES, Tsukuba. A data analysis method using the 532nm HSRL was also developed. Distributions of black-carbon, water-soluble, and dust (or sea-salt) aerosols were successfully derived with the extended two-wavelength algorithm including 532nm lidar ratio data. Furthermore, a new lidar technique for measuring silica contained in mineral dust particles in the atmosphere was successfully demonstrated by adding a Raman scattering channel to the 532nm HSRL.

A HSRL technique using the third harmonic of a Nd:YAG laser (355 nm) and a Fabry-Perot filter was developed at Fukui University. Observations of clouds and aerosols were performed with the developed 355nm HSRL under various meteorological conditions, and the lidar ratio was analyzed statistically for water and ice clouds, spherical and non-spherical aerosols.

To obtain a data set for demonstrating the combined lidar cloud radar algorithm to derive cloud microphysical parameters, observations were performed with an aircraft and with R/V MIRAI of JAMSTEC. An airborne Mie-scattering lidar was developed for the Gulfstream II aircraft, and the combined measurements were performed with the cloud radar SPIDAR of NICT. Observations on R/V MIRAI were performed in the western tropical Pacific with the NIES two-wavelength (1064nm/532nm) polarization (532nm) lidar and a FMCW cloud radar developed by Chiba University. Continuous long-term observations were also performed with a compact automated two-wavelength lidar on R/V MIRAI in a wider area including southern hemisphere. Using these observation data, analysis was performed for deriving aerosol and cloud stratifications that can be compared with the results of aerosol climate modeling.

(3) A study of aerosol and cloud systems with use of satellite data and models.

1) A study of retrieving cloud and atmospheric properties from visible and infrared imagers and Fourier transform spectrometer.

Ryoichi Imasu (Tokyo University)

Collaborators: Vyacheslav Zakharov (Ural State University); Takashi Nakajima (Tokai University)

In order to construct synergy datasets which consist of cloud microphysical properties derived from satellite and active remote sensing systems such as a cloud profiling radar (CPR) and LIDAR, we developed an automated data processing system that deals with Terra/MODIS data for regional analyses, particularly focusing on East Asia, and ADEOSII/GLI data for global analyses. The accumulated data analyzed and archived on our system show some seasonal variation and regional characteristics of aerosols, cloud microphysical properties, and their interactions. These data have been distributed to world wide scientists via internet. Since the microphysical properties derived from satellite data showed generally good agreement with those from a combination of CPR and LIDAR, synergetic datasets we have constructed would be useful for investigate complicated aerosol-cloud interactions in various temporal and time scales.

On the other hand, we have carried out ground-based measurements of the atmospheric thermal infrared spectrum using a Fourier transform spectrometer (FTS). The spectrometer was operated simultaneously with CPR and LIDAR to construct a synergy of the ground-based measurement data. FTS sometimes detected optically thin clouds that can not be detected by CPR. Although optical depths of these clouds measured by LIDAR were in the order of 1-2, down-welling infrared radiation flux estimated from FTS was not negligible ranging sometimes more than 10-20 W/m2. FTS system can also provide us with exact information on atmospheric vertical structure and radiation field. We can retrieve vertical profiles of temperature and water vapor from observed infrared spectrum. It was shown that cloud height information derived from a LIDAR is very helpful for exact retrieval of atmospheric parameters under cloudy conditions.

Also can be analyzed from the thermal infrared spectra are cloud microphysical parameters such as optical depth and mean droplet size of cloud particles. These data showed good agreement with those from CPR+LIDAR system for optically thick clouds, and FTS system supported by a LIDAR for providing cloud height information can also be sensitive to optically thin clouds that can not be detected by CPR. It shows that a very wide range of cloud optical thickness can be covered by a combination of two types of systems, namely, CPR+LIDAR for thick clouds and FTS+LIDAR for thin clouds. We expect that a total system consists of these passive and active sensors could be a very powerful system for studying aerosol-cloud interactions if it would be launched in space.

2) A study of retrieving aerosol properties from visible and infrared imagers.

Akiko Higurashi (National Institute for Environmental Studies)

This sub-sub group developed and improved aerosol retrieval algorithms with use of satellite-borne passive sensors to make an accurate assessment of the global aerosol characteristics for evaluation of aerosol climate effects. Using the algorithms thus developed, we started a semi-real time processing satellite radiances to retrieve the distributions of aerosol optical thickness, Ångström exponent, and aerosol types. We furthermore validated the satellite-retrieved aerosol characteristics through comparison with ground-based measurement values. It is found that the result of the satellite aerosol type classification was in a good agreement with chemical compositions obtained by a filter sampling.

We also applied the algorithm to the global data of MODIS/Terra from Feb. 2000 through Dec. 2005 and of GLI/ADEOS-II from Feb. 2003 through Oct. 2003. It is found that the global distributions of aerosol optical thickness, Ångström exponent, aerosol types from satellite retrievals fairly agreed with those from the general circulation model simulation, though there is an overestimation of the aerosol optical thickness in the pristine region over ocean as +0.03, which is smaller than +0.05 that commonly found by satellite remote sensing. There is also a tendency of increased differences between satellite-retrieved and model-simulated values in regions of highly complicated aerosol mixtures. We need in future to improve the type classification algorithm for such cases.

3) A study of cloud formation process and aerosol-cloud interaction phenomenon using a climate model.

Teruyuki Nakajima and Masaaki Takahashi (The University of Tokyo)

Collaborators: Toshihiko Takemura (Kyushu University), Kentarou Suzuki, Makiko Mukai, Takamichi Iguchi, Daisuke Goto, Satoru Fukuda, Tatsuya Mitsui, Haruo Tsuruta, and Nick Schutgens (Center for Climate System Research)

This sub-sub group studies the aerosol and cloud microphysical properties using models and supporting data from satellite and surface observation. One of important tasks is to evaluate the strength of radiative forcing caused by aerosol indirect effect.

The results were summarized as follows. As the resut, we have evaluated the global radiative forcing with an accuracy of 0.5 W/m^2, which is a twice larger than the goal we have set. This is because we still have several complicated processes to be evaluated to get better accuracy. More detailed cloud physics modeling is also needed to improve the accuracy. As for precipitation impact, we have shown that aerosols can affect a significant change in the regional scale precipitation change comparable to that by greenhouse gases. This research results can be a good suggestion for the research direction and also provide useful research tools to conduct next projects. We want to propose a research for constructing an operational monitoring system of aerosol and cloud forcing.

* We have developed SPRINTARS+GCM model and NHM+HUCM bin-type cloud-aerosol regional model for radiative forcing and precipitation evaluation.
* We found that the GCMs, including models from US, have a problem in simulating realistic aerosol and cloud stratification. They overestimate the scale height of aerosol layers and upper level-clouds.
* The above mentioned problem may produce an underestimation of the magnitude of the aerosol radiative forcing at TOA.
* Indirect forcing has a large contribution to the globally averaged TOA forcing, where as the direct forcing has a small contribution.
* On regional scale, however, the large direct forcing is applied in the East China sea region.
* As a result, a reduction of SST happens in this region and furthermore can cause a secondary general circulation to change the precipitation of continental scale. Cloud amount is reduced over China.
* We have succeeded in simulating the characteristic correlation between aerosol amount and cloud parameters, such as optical thickness and effective particle radius, by the bin-type non-hydrostatic cloud-aerosol regional model.

Major Publications

1) H. Okamoto : J.Geophys. Res.、 107 (D22、4628)、doi: 10.1029/2001JD001386 (2002)、“Information content of the 95GHz cloud radar signals: Theoretical assessment of non-sphericity and error evaluation of the discrete dipole approximation”

2) H. Okamoto、 S. Iwasaki、 M. Yasui、 H. Horie、 H. Kuroiwa and H. Kumagai: J.Geophys. Res.、 108、 D7、 4226、 doi:10.1029/2001JD0001225 (2003)、 “An algorithm for retrieval of cloud microphysics using 95-GHz cloud radar and lidar”

3) S. Iwasaki、 R. Shirooka、 Y. Tsushima、 I. Matsui、 A. Shimizu、 N. Sugimoto、 A. Kamei、 H. Kumagai、 H. Kuroiwa、 M. Katsumata、 K. Yoneyama、 H. Okamoto: Geophys. Res. Lett.、 31、 L09103、 doi:10.1029/2003GL019377 (2004)、 “Subvisual cirrus clouds observation with the 1064-nm lidar、 the 95-GHz cloud radar、 and radiosondes on the warm pool”

4) S. Iwasaki、 H. Okamoto、 H. Hanado、 K. K. Reddy、 H. Horie、 H. Kuroiwa、 and H. Kumagai: J. Meteor. Soc. Japan、 83、 771-782(2005)、 “Retrieval of Raindrop and Cloud Particle Size Distributions with 14 GHz and 95 GHz Radars”

5) K. Yasunaga、 K、 Yoneyama、 K、 H. Kubota、 H. Okamoto、 A. Shimizu、 H. Kumagai、 M. Katsumata: J. Atmos. Sci.、 63、 11、 3020-3032(2006)、 “Melting layer cloud observed during R/V Mirai cruise MR01-K05”

6) R. Nagasawa、 T. Iwasaki、 S. Asano、 K. Saito、 and H. Okamoto: J. Meteor. Soc. Japan.、 84、 969-987(2006)、 “ Resolution Dependence of Nonhydrostatic Models in Simulating the Formation and Evolution of Low-Level Clouds during a Yamase Event”

7) K. Sato and H. Okamoto: J. Geophys. Res.、 111、 D22213、 doi:10.1029/2005JD006959 (2006)、 “Characterization of Ze and LDR of nonspherical and inhomogeneous ice particles for 95-GHz cloud radar: Its implication to microphysical retrievals”

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11) N. A. J. Schutgens: Accepted J. Atmos. Oceanic Technol. (2007)、”Simulated Doppler radar observations of inhomogeneous clouds; Application to the EarthCARE space mission”

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