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Study on the Monitoring Effects of Aerosol and Cloud on the Surface Radiation Budget by the Spectral Radiation Measurements and Data Assimilation Model （Abstract of the Interim Report）

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1. Introduction

The Earth's radiation budget is important essentially for climate system. The effects of aerosol and cloud in the atmosphere continue to contribute the largest uncertainty to the total radiative forcing estimate (IPCC, 2013)[1)]. In this study, in order to advance the monitoring system of the effects of aerosol and cloud on the surface radiation budget, the spetroradiometer is developed and observes aerosol and cloud continuously. Furthermore, we develop and improve the data assimilation model using these observational data.

2. Research Objective

In order to achieve the objectives of this study, the following two sub-studies are performed:

(1) Monitoring the effects of aerosol and cloud on the surface radiation budget by the ground-based spectral radiation measurements;

To measure accurate spectral irradiances, high optical resolution spectroradiometer is developed. The spectroradiometer and a various kinds of radiometers are employed for the continuous measurements on the ground-based observation sites and the effects of aerosol and cloud on the surface radiation budget are investigated. The monitoring system is advanced.

(2) Elucidating aerosol distribution and improving cloud distribution reproducibility using global and regional aerosol transport models.

Improving global and regional aerosol transport model by verifying the outputs with the high precision radiation data operated by Japan Meteorological Agency (JMA). In addition, we have a plan to reproduce aerosol distribution in East Asia by combining aerosol transport model and data assimilation technique, aiming to improve the reproducibility of cloud distribution using an aerosol transport model including aerosol indirect effect process. Finally, our goal is to evaluate the impacts on the surface radiation budget using the aerosol distribution obtained by this analysis.

3. Research Method

(1) Monitoring the effects of aerosol and cloud on the surface radiation budget by the ground-based spectral radiation measurements

In order to obtain highly accurate data from the radiometer network, it is necessary to periodically perform radiometer calibration. Therefore, the calibration measurements were performed at Mauna Loa Observatory (MLO, NOAA) from October to November 2018. The spectroradiometers

(MS-711N, MS-712, and MS-713) were calibrated using the Langley method, which accounts for gas absorption[2]. We consider that the columnar water-vapor amount was estimated from the data of the 940 nm channel by reference sky radiometer data when we determined the calibration constant for spectroradiometers with Langley-plot technique.

In order to maintain the accuracy of measurements with spectroradiometer and sky radiometer, the reference solar spectral radiometers are calibrated every year. Side-by-side inter-comparisons between the reference and the other radiometers are conducted in Meteorological Research Institute after the calibration at Mauna Loa Observatory[3]. At the radiation observation site we continuously measure spectral irradiances by the spectroradiometer and sky radiometer in order to estimate optical and physical properties and to investigate the effect of aerosol and cloud on the surface radiation budget.

The precise spectroscopic solar radiation observation system was developed and was installed at Tsukuba and Minamitorishima. The continuous observation was started by using spectroradiometers.

(2) Elucidating aerosol distribution and improving cloud distribution reproducibility using global and regional aerosol transport models.

We have developed a high-speed data assimilation system (2D-Var) using an aerosol transport model that has been modified for verification with spectroscopic pyranometer observation data[4]. An assimilation experiment of aerosol optical thickness obtained from the Himawari-8 was conducted to confirm the performance of the data assimilation system. Using this data assimilation system, we assimilate the aerosol optical depth obtained from the satellite sensor (MODIS) of the National Aeronautics and Space Administration (NASA) into a global aerosol transport model (MASINGAR mk-2; horizontal resolution 110 km), we produced aerosol reanalysis (JRAero) of homogeneous quality up to 2015 and started data disclosure to researchers. JRAero confirmed that the reproduction accuracy of the aerosol has been greatly improved compared to the experiment where data assimilation was not performed.

We developed a regional aerosol transport model to reproduce detailed aerosol distribution in the East Asia region[5]. In this model, three aerosol representation methods are implemented to the purpose of regional climate, air quality, and operational forecast. Case studies using this regional aerosol transport model were conducted.

In addition, in order to evaluate and validate this regional or global aerosol transport model appropriately, a mass flux analysis method which is often used in the meteorological field etc. was newly introduced to analyze transport routes such as aerosol[6].

4. Result and Discussion

(1) Monitoring the effect of aerosol and cloud on the surface radiation budget by the ground-based spectral radiation measurements

Spectroradiometers (MS-711N, MS-712, and MS-713) were performed calibration measurement at Mauna Loa Observatory and they were calibrated using the Langley method. The calibration constants of spectroradiometers were accurately and stably determined with the root mean squares (RMS) error less than 1%, except the low signal region and strong water vapor absorption wavelength range. Spetroradiometers were measured the sensor output nonlinearity at Mauna Loa Observatory. The sensor output nonlinearity for MS-711N and MS-712 was about 0.5% and less than 0.2%, respectively. The sensor output nonlinearity for MS-713 became uncertain because S/N of MS-713 was not good. The difference between the MS-711N and MS-712 calibration constants in 2017 and 2018 was within ± 1.5% and about 0.4%, respectively. The trend of the calibration constant of MS-711N and MS-712 was small.

The calibration constants of reference sky radiometer were accurately and stably determined with the root mean squares (RMS) error less than 0.7%. The trend of the calibration results of reference sky radiometer from 2014 to 2018 shows the difference of 0.1 - 2%. The trend has small change. Otherwise, the trend of the calibration constants of sky radiometers at Tsukuba, Fukuoka, and

Miyakojima from 2014 to 2018 shows the difference 0.4-9%, 0.1-11%, and 0.4-6%, respectively. This means the necessity of regular calibration in order to maintain the accuracy of measurements by radiometers.

At Tsukuba and Minamitorishima continuous observation was started by the developed precise spectroscopic solar radiation observation system. In the future, it is necessary to accumulate observation data and to proceed with data analysis.

Japan Meteorological Agency (JMA) started operational observation of sky radiometer as aerosol observation in FY2018. In this research project, the JMA cooperated with the verification observation at the MLO, provided a program for analyzing the obtained data, and provided inter-comparison data analysis program for sky radiometers, contributing to the development of the JMA sky radiometer observation.

Side-by-side inter-comparisons between the reference sky radiometer and the other sky radiometers contributed SKYNET, GOSAT ground validation group, etc. Meteorological Research Institute has provided the ground validation data for JAXA GCOM-C from December 2017.

(2) Elucidating aerosol distribution and improving cloud distribution reproducibility using global and regional aerosol transport models

The spatial distribution of the aerosol optical depth (AOD) by re-analysis was very close to the distribution by satellite observation. The 5-year mean difference distribution (re-analysis value vs. model free run) generally indicates that data assimilation increases aerosol optical thickness in the central Pacific. The experiments without data assimilation indicate that the AOD of the global aerosol transport model is relatively low against observations.

Analysis of Beijing haze using the regional aerosol transport model has shown that the atmospheric concentration of aerosol is about 10% higher due to its own radiation effect (suppression of mixed layer development). According to more extensive verification results in the East Asia region, although the mass, particle size, etc. of the aerosol were in good agreement with the observations, it was suggested that the sea salt and dust concentrations need to be improved.

By using mass flux analysis, we were able to easily and quantitatively understand the aerosol transport route, and it became possible for us to compare with observation and efficient extraction of information.

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