An improved cloud screening algorithm for skyradiometer measurements and its application to Asian dust monitoring

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1. Introduction

It is well known that aerosols have an important effect on climate and its uncertainty is relatively larger than other greenhouse gases. The ground-based remote sensing instruments give great opportunity for better understanding of aerosol effects on climate. Aerosol optical properties retrieved ground-based instruments is also widely used for validating of satellite products and model simulations as well as aerosol monitoring. It has been recognized that critical issue to produce accurate aerosol optical products from ground-based instruments is the separation of cloud-free data from cloud-affected data. Because cloud-affected data generally have high optical thickness, this error could induce a misreading such as strong aerosol direct radiative forcing on climate.

There are well known two ground-based remote sensing networks: Aerosol Robotic Network (AERONET) and Sky radiometer Network (SKYNET) using CIMEL sun photometers and PREDE skyradiometers, respectively. Globally distributed AERONET is based on Dubovik retrieval and cloud screening proposed by *Smirnov et al.*, [2000]. In contrast, SKYNET, which is mainly distributed in East Asia and recently extended by South Asia and Europe, uses the retrieval based on SKYRAD.pack and cloud screening suggested by *Khatri and Takamura*, [2009]. Regarding the difference of SKYNET and AERONET, it was reported that single scattering albedo (SSA) from SKYNET is systematically larger than AERONET in spite of almost identical aerosol optical thickness (AOT) over Beijing, China. Although it is hard to judge which network reflects reality, the overestimated SSA in SKYNET regarded as cloud contamination effect. Therefore, a better cloud screening is essential to improve the accuracy of aerosol optical products in SKYNET.

Current operational cloud screening method of SKTNET consists of three tests: global irradiance test, spectral variability test, and statistical analyses test [*Khatri and Takamura*, 2009]. The first test may be the most powerful test because quantitative cloud information can be inferred from global solar irradiance measured by pyranometer. However, it has a weakness requiring pyranometer adding to skyradiometer measurements for cloud screening. Thus, it cannot fulfill a consistent cloud screening when global solar irradiance does not exist. The second test uses spectral difference of AOT retrieved from direct solar and diffuse sky radiation with minimum three minute resolution over 15 minutes. It has an essential weakness in time resolution compared to AERONET using triplet direct solar radiation which is taken 30 second apart. On the contrary to this, the retrieval of SSA and size distribution requiring diffuse radiation is possible every three minutes in SKYNET, but 30 or 60 minutes in AERONET. The third test is composed of diurnal stability test, data smoothness test, and three standard deviation criteria test for whole daily measurements and thus it cannot be used to real time display. Moreover, the cloud screening algorithm is developed empirically in SKYNET as well as AERONET and validated with time series of some cases or the

elimination of data having high AOT and low angstrom exponent (AE) suspected as cirrus. Therefore, the algorithm should be objectively validated using other cloud observations.

2. Methods

We develop new cloud screening algorithm for skyradiometer maximizing both the advantage of AERONET and SKYNET . It is possible by using direct radiation with the minimum interval of 30 seconds as well as direct and diffuse radiation with the time resolution from three to ten minutes. The use of direct radiation every 30 seconds allows the chance of similar ability to the triplet stability criteria test, which is main part of cloud screening in AERONET. Furthermore, aerosol optical product (e.g., volume size distribution) retrieved from direct and diffuse radiation of SKYNET with fine time resolution in comparison to AERONET can be used directly to cloud screening. The algorithm developed in this study is verified with cloud amount and lidar measurements. The attempt is very important because the lack of evidence for thin cirrus contaminated cases has been considered as a weakness of previous algorithm [*Khatri and Takamura*, 2009].

Cloud screening algorithm can be immediately applied to improve the dust monitoring of skyradiometer. Asian dust called as Yellow Sand is uplifted from northern China and Inner Mongolia and transported to wide regions over East Asia and adjacent Pacific regions. Dust monitoring in metropolitan area (e.g., Seoul) is very important because it causes much socioeconomic damage and health problem. Skyradiometer is very useful instrument to detect quantitatively total column of atmosphere, thus can observe not only dust reaching surface but also dust particle passing upward atmosphere which have potential to be deposited at the surface. This study decides the dust detection criteria from cloud-screened optical properties and validates the criteria on the basis of SYNOP dust reports and lidar measurements. Finally, we describe the cloud screening effect on reducing the uncertainty of dust radiative forcing. Cloud screening method developed in this study will be applied to Korean skyradiometer network (KSNET, http://metsat.snu.ac.kr/) and used for aerosol monitoring, especially dust and air pollution.

3. Results

A cloud screening algorithm containing variability test and coarse mode test was developed in order to eliminate cloud-affected data in the skyradiometer measurements taken under partly cloudy conditions. The results compared to cloud amount from weather station reports and lidar measurements show that the variability test appears to effectively remove thick low level cloud while the use of size distribution is effective for removing thin high level cloud. The new algorithm demonstrated that cloud screening is more effectively performed in comparison to the method currently used for SKYNET data processing.

The developed cloud screening method has been applied for the dust detection from skyradiometer measurements. The performance of dust detection for skyradiometer was validated on the basis of SYNOP dust reports and the yellow sand index from lidar measurements. It is shown that the developed cloud screening methods helps to detect dust cases, effectively removing cloud-contaminated signals from the dust signals. In turn this algorithm contributes to improving the accuracy of the dust influence on radiative forcing and its efficiency by reducing uncertainties in the AOT and SSA retrievals.

Acknowledgements

This work was supported by the "Development and Application of the Techniques on Asian Dust Monitoring and Prediction" of the National Institute of Meteorological Research (NIMR), funded by the Korea Meteorological Administration (KMA). This research was also supported by the BK21 Project of the Korean Government.

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