論文内容の要旨

A study of atmospheric aerosol remote sensing with use of near ultraviolet wavelengths

（近紫外領域の波長を利用した大気エアロゾルのリモートセンシング手法の研究）

氏名　福田悟

Atmospheric aerosols play a significant role in our climate. They affect our climate system directly or indirectly. As accessed by the IPCC-AR4 report, however, the uncertainty of aerosol radiative forcing is still large. The satellite remote sensing is hence needed as an indispensable tool to observe the characteristics of aerosols. We propose in this study a new remote sensing method of aerosols using Thermal And Near-infrared Sensor for carbon Observations – Cloud and Aerosol Imager (TANSO-CAI) which is a pushbroom type imager equipped on Greenhouse gases Observing SATellite (GOSAT). It has 4 bands from near ultraviolet (380nm) to near infrared (1600nm).

Aerosol remote sensing algorithms over ocean were successfully developed early in 1980s, because the sea surface reflectance is small and estimated theoretically. On the other hand, satellite remote sensing algorithms for land aerosols were developed rather late in 1990s and still there are many issues to be studied to improve the accuracy of the retrieval. This is because the high land surface reflection is difficult to be corrected from radiances received by satellites. Also the reflectance largely changes spatially and temporally and is difficult to be theoretically or empirically modeled for accurate correction. To solve this difficult problem, new satellite remote sensing algorithms have been proposed by using radiances at blue to ultraviolet (UV) wavelengths. A pioneering study is the aerosol detection by TOMS UV bands. At UV wavelengths, the land surface reflectance is smaller than that at visible wavelengths even if the area is arid and highly reflective at

visible wavelengths. It is then possible to significantly reduce the retrieval error. But it is known that the TOMS field of view is very coarse as 50km at nadir and the obtained aerosol index tends to suffer from a significant cloud contamination. In this context, it is important to note that the 380nm band of ADEOS-II/GLI and GOSAT/CAI satellite-borne imagers is very useful, because the channel is at enough short yet enough sensitive to attain a fine field of view from 500m to 1km.

The purpose of this study is to develop an algorithm of satellite remote sensing with use of 380nm band of ADEOS-II/GLI and GOSAT/CAI. We also developed various algorithms of correction and selection to extract suitable clear sky pixels for accurate aerosol remote sensing. First, a statistical analysis is performed to correct the stripe pattern which appears in the raw radiance data caused by inhomogeneous sensitivities of array photo-detectors. We also developed a cloud shadow correction algorithm by using 1st minimum and 2nd minimum of band-1 (380nm) and band-3 (870nm) of CAI. Rayleigh scattering contributions largely different in the two bands, so that the difference between 1st minimum and 2nd minimum of band-1 reflectance is small, but that of band-3 reflectance is large when the pixel of 1st minimum is in the cloud shadow. We then developed a new surface reflectance correction algorithm, called a modified Kaufman method. This algorithm uses band-1 and band-2 minimum reflectance data which are constructed by selecting pixels of minimum reflectance during a prescribed time window, say one month. These minimum reflectance pixels are supposed to correspond to pixels in a very clear sky condition during the period at the location without much aerosol loading after rainfall or intrusion of clear air mass from other regions. We found, however, a large aerosol effect still remains in the minimum reflectance data of GOSAT-CAI because of their 3-day recurrence orbit. With this special orbit, most of the area is observed once every 3 days and significantly reduces the number of days observing clear sky areas compared to that of the TERRA and AQUA satellites. In this situation, the modified Kaufman method successfully removed this aerosol contamination in the minimum reflectance data and estimated a ground surface reflectance enough accurate for reliable aerosol remote sensing. In this study, we propose a parameterization of the ratio of band-1 reflectance to band-2 reflectance in terms of Normalized Difference Vegetation Index (NDVI) to apply the modified Kaufman method to different land types.

The aerosol optical thickness (AOT) was finally retrieved by solving the radiative transfer problem of the aerosol-laden atmosphere from clear sky pixel radiances after various corrections as stated above, i.e., destriping, cloud and cloud shadow screening and correction of land surface reflectance. Retrieved AOTs with and without the modified Kaufman method correction are compared with that of AErosol RObotic NETwork (AERONET). It is found from the comparison that AOT with modified Kaufman method agree better with AOT from AERONET, whereas AOT without correction underestimates the AERONET value.

We produced monthly mean global AOT maps both over land and ocean by GOSAT/TANSO-CAI data from May 2009 to December 2009. The results show that thick land aerosol layers are found in Central Asia, South Asia, Southeast Asia, and Central Africa. Over ocean, large AOTs are found in the north part of Indian Ocean, North Pacific Ocean, and the Central Pacific Ocean. Characteristic seasonal variations are also found in the maps. In Amazon area, an aerosol plume caused by biomass burning is obvious in November 2009. The North Pacific has more aerosols in May 2009 than in other seasons in this year. We also produced monthly mean global maps of AOT of small particles and that of large particles over the ocean during the same period. The North Pacific is dominated by small particles in May 2009. These particles are thought to come from East Asian continental region. In the west coast of Central Africa, small particles are dominated in June, July, August, and September 2009. This is thought to be of continental area origin. Around Indonesian region, small particles are dominant compared with large particles in September 2009. In the coastal area of South Asia, Southeast Asia, and East Asia, small particles are highly visible in October, November and December 2009. Large particles are dominant in the central part of Atlantic Ocean in November and December 2009. These phenomena seem to be attributed to dust particles from North Africa.

We further compared the monthly mean products in August 2009 with other studies, such as Terra and Aqua/MODerate resolution Imaging Spectroradiometer (MODIS) Dark Target method, Terra and Aqua/MODIS Deep Blue method, and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations/Cloud-Aerosol Lidar with Orthogonal Polarization (CALIPSO/CALIOP) product. The results show a general agreement among the products, but there are several characteristic differences depending on the retrieval methods. In North African area, the AOT derived from Terra and Aqua/MODIS Deep Blue is higher than that of CALIPSO/CALIOP and/or our result from CAI. In central African area, the AOT of Terra and Aqua/MODIS Dark Target method is higher than that of GOSAT/TANSO-CAI and/or CALIPSO/CALIOP. This comparison hence suggests that the value of AOT over land from CAI is more consistent with that from CALIOP lidar which is regarded to be the most reliable method for detecting aerosols over land without effect of land surface reflection which is the serious problem for aerosol remote sensing from passive imagers. It should be recognized, however, a part of these differences are caused by a difference in sampling time not only by retrieval errors. The swath of Terra and Aqua/MODIS is about 2,300km and that of GOSAT/TANSO-CAI is 1,000km. On the other hand, the CALIPSO/CALIOP is nadir looking and can only observe aerosols just below the sensor. The best way to understand aerosol's global features is to use these products comprehensively with full understanding the characters of each product, i.e., sampling method, retrieval method and so on. Introduction of data assimilation techniques is another important future work to identify errors in the remote sensing products and produce quality-controlled aerosol products reconciling differences among the methods.