Effect of atmospheric and surface properties on the retrieval of aerosol optical depth from geostationary satellite

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Abstract: The aerosol optical depth(AOD) retrieval using low-earth-orbit satellites such as MODIS(Moderate-Res olution Spectroradiometer) or MISR(Multiangle Imaging SpectroRadiometer) has limitation in temporal resolution. To understand temporal variation of aerosols, benefits of geostationary orbit satellites can be introduced. Due to the limited number of channels in the conventional meteorological imager onboard the geostationary satellite, an AOD retrieval algorithm utilizing a single visible channel has been introduced. In this presentation, the effects of various atmospheric and surface properties on the retrieval of AOD from the geostationary satellite, GMS are investigated.

Keywords: Aerosol Optical Depth, GMS, AERONET, Surface Reflectance, TOA Reflectance, BRDF

1. Introduction

The impact of atmospheric aerosols on the earth's climate has been recognized as an important problem for understanding the climate change, especially after numerous previous studies have pointed out that aerosols are the source of the large uncertainties in evaluating climate forcing. But the retrieval of aerosol optical depth(AOD) method using low-earth-orbit satellites such as MODIS(Moderate-Resolution Spectroradiometer) or MISR(Multiangle Imaging SpectroRadiometer) has limitation in temporal resolution. Understanding temporal variation of aerosols, we can introduce benefit from geostationary satellite(eg. GMS-5) [1]. In order to obtain the surface reflectance, we convert minimum TOA reflectance for 30 days into surface reflectance using calculated LUT(Look Up Table) by radiative transfer model, 6S. The LUT for surface reflectance is calculated as functions of TOA reflectance, AOD, surface reflectance, and geometric variables. With the known surface reflectance, TOA reflectance can provide information of AOD through a separate LUT for AOD. This study presents retrieval processes of AOD using a single visible channel of geostationary satellites. The retrieved results are compared with the AODs observed by AERONET and the MODIS to investigate the quality of retrieval. Many uncertainties exist in the AOD retrieval algorithm, for example the background optical depth, radiative transfer model, atmospheric properties, and surface reflectance. The uncertainties in this retrieval process are investigated for BRDF, gaseous transmittance and background optical depth. This result can be applied to the aerosol events(eg. Asian dust in 2001) in the East Asian region.

2. GMS5

The GMS5, launched in March 1995, is positioned over 0°N and 140°E at an altitude of about 36,000km. This satellite makes measurements of visible channel (0.55-0.9µm) and three infrared channels (6.5-7.0µm, 10.5-11.5µm, and 11.5-12.5µm) every hour. Among the measurements, visible channel is used to convert TOA(Top Of Atmosphere) reflectance, and IR1 channel(10.5-11.5µm) is used to remove cloudy pixels(Fig. 1.)

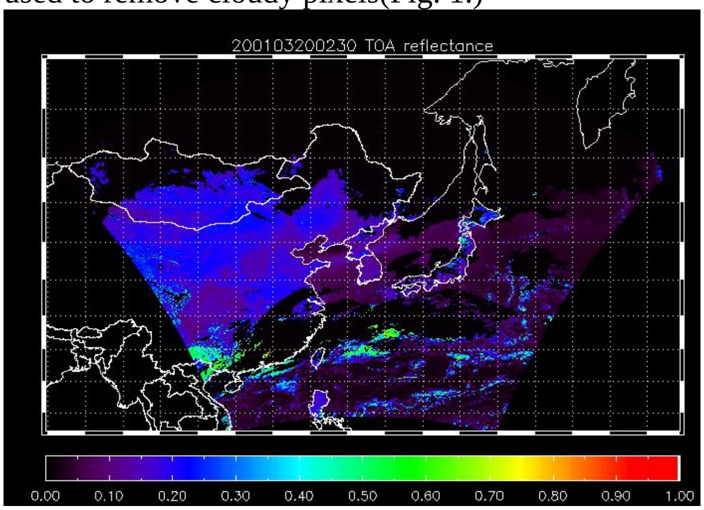

Fig. 1. GMS TOA reflectance after cloud masking using IR1 channel on March 20, 2001 at 02:30 UTC.

3. The AOD retrieval algorithm

There have been numerous studies to retrieve AOD by using one or two-channels[2]. When satellite data are corrected for the atmospheric property, it is convenient to use equivalent reflectance(ρ) instead of the radiance in the radiative transfer calculation:

$$\rho(\lambda) = \frac{\pi L(\lambda)}{F_0(\lambda)\cos\theta_0} \qquad (1)$$

where $L(\lambda)$ is the measured radiance, $F_0(\lambda)$ is the normal solar flux density at the TOA, and Θ_0 is solar zenith angle. Assuming that the surface is of uniform Lambertian reflectance, radiative flux density can be expressed by:

$$F = \pi L(\lambda) \qquad (2)$$

The surface reflectance can be calculated by 6S obtained from the TOA reflectance obtained from satellite measurements.

1) Creation of the surface reflectance.

To make the surface reflectance, two basic assumptions are made :1) at least one day for the previous 30 days is free from aerosol and 2) the surface conditions do not vary much during the 30 day period. Then the minimum TOA reflectance for the past 30 day period is converted into semi-surface reflectance using calculated LUT(Look Up Table) by 6s. The calculated LUT lists the TOA reflectance as functions of surface reflectance, and solar and satellite geometry (eg., solar zenith angle, relative azimuth angle, satellite zenith angle, and so on).

2) Atmospheric correlation of the surface reflectance .

Atmospheric effects including gaseous absorption, molecular scattering and aerosol extinction are removed via inversion of the satellite-detected reflectance to surface reflectance estimate. The surface reflectance retrieved is an estimate of the surface reflectance used for the 6S radiative transfer model.

3) Retrieval of Aerosol Optical Depth.

With the surface reflectance composite obtained above, AOD can be retrieved from the TOA reflectance by using the calculated LUT. This LUT lists the TOA reflectance as functions of AOD, surface reflectance and related geometry.

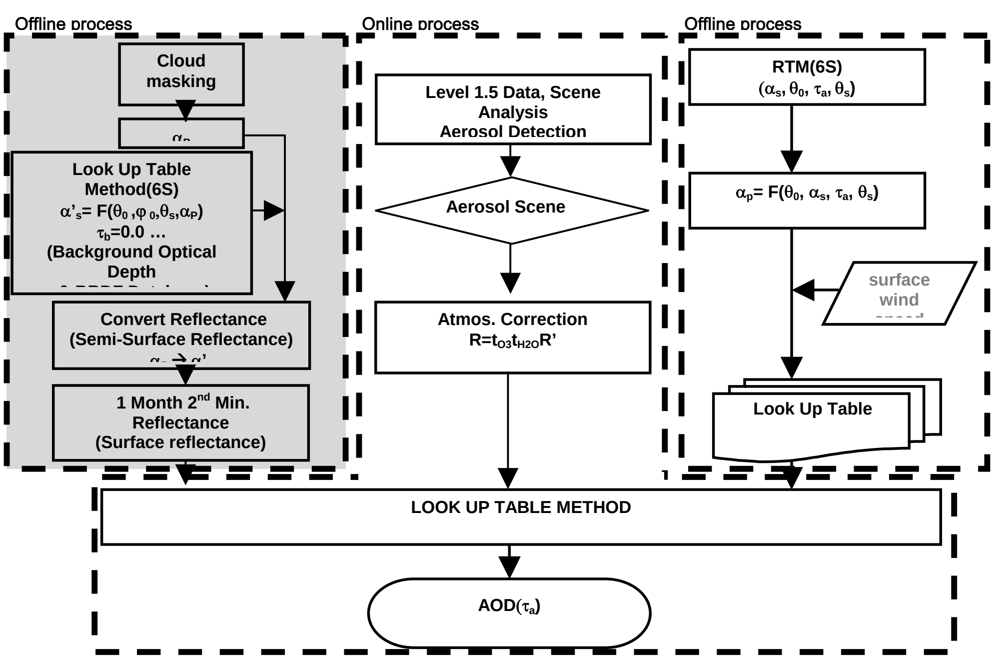

Fig. 2. The AOD retrieval algorithm(Flow Chart).

4. Comparison

The retrieved AOD from GMS5 are compared with AERONET data, as shown in Fig. 3. After the initial comparison, the GMS5 AOD is reprocessed with the standard deviation method[3], within a 5X5 pixel region, where the retrieved values with larger standard deviation are filtered out. The retrieved AOD from GMS5 are also compared with MODIS data, as shown in Fig. 4.

5. Uncertainty study

These results still require further refinement to resolve uncertainties in the algorithm. Various uncertainties exist in the AOD retrieval algorithm, for example aerosol model, surface reflectance, background optical depth, atmospheric properties, etc. The most dominant error source is surface reflectance. Proper selection of optical properties of aerosol is also very important to calculate the correct LUT. The background optical depth error also affects the retrieved AOD values as shown in Fig. 5 (A) and (B). The uncertainties due to O_3 and H_2O variations are small as shown in Fig. 5 (C) and (D).

The reflectance observation from the GMS are limited in viewing geometry, but are affected by the bidirectional reflectance of the surface. BRDF also affects the retrieved AOD, especially near the hot spot. Differences in retrieved AODs for the Lambertian surface reflectance and BRDF from [7] are shown in Fig. 6. The errors reach up to the order of magnitude depending on the geometry. Accurate BRDF database can improve the accuracy of the AOD retrieval significantly.

Other than the above uncertainties, the composite surface background which is estimated from a one month composite of visible images may lead to errors due to surface reflectance variations during the time period selected, growing season of vegetation or rainfall, in particular.

6. Conclusions

The AOD is retrieved from a single visible channel onboard the GMS-5 by using the LUT method. LUT is constructed with the 6S. There exists many uncertainties, thus need to improve the accuracy of retrieved AOD by selecting proper aerosol models, bidirectional reflectance, and other atmospheric properties.

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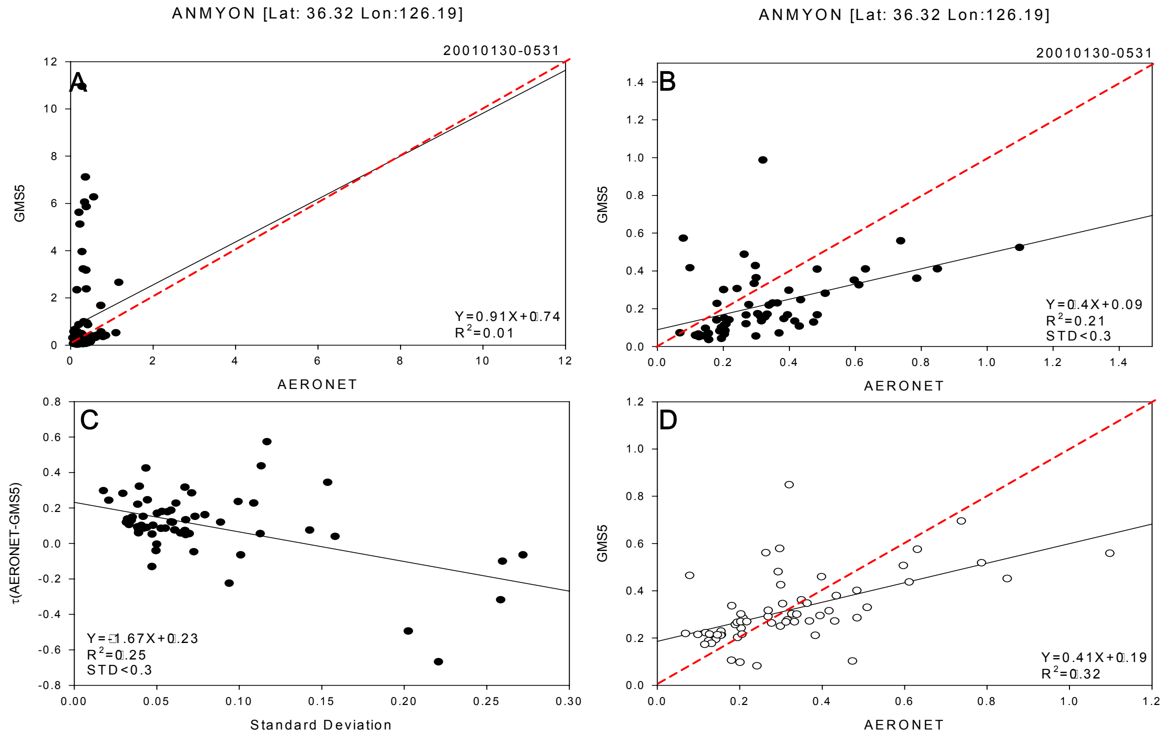

Fig. 3. (A) Comparison of initial AODs from GMS5 with those from AERONET, (B) retrieved AOD witht the standard deviation less than 0.3 in 5x5 pixels, (C) AOD difference between GMS5 and AERONET plotted against the standard deviation of the GMS5 AOD inside a 5x5 pixels around AERONET station (Anmyon, lat=36.32, lon=126.19). (D) comparison of AERONET AOD with the re-processed AOD from GMS5 on March 30, 2002 to May 31, 2001.

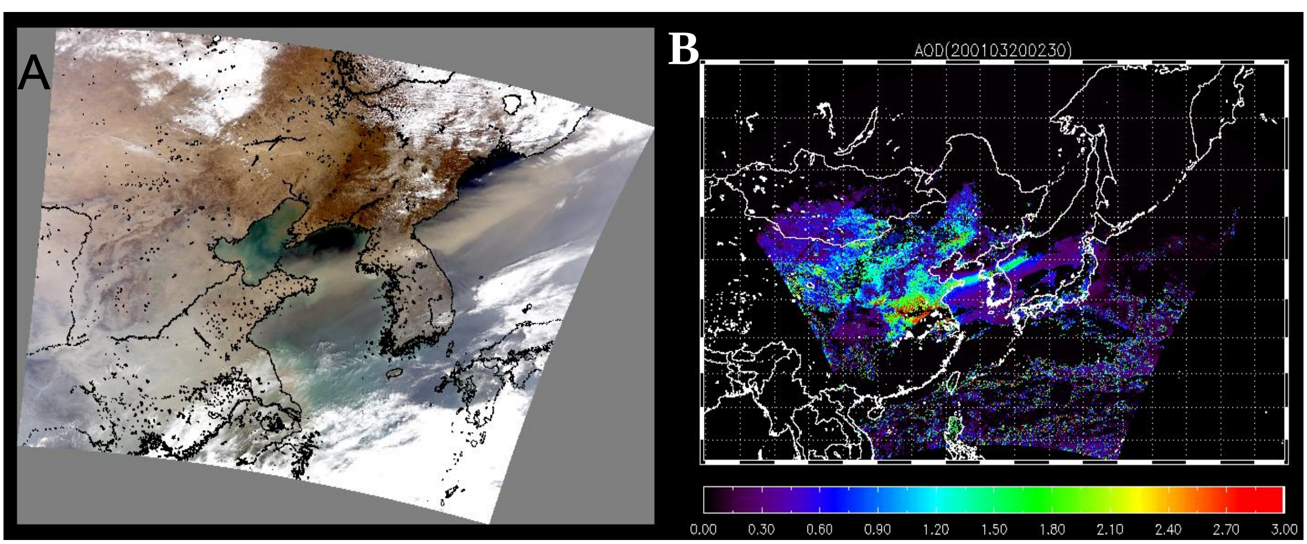

Fig. 4. Comparison of (A) the MODIS true color image and (B) retrieved GMS5 AOD on March 20, 2001 at 02:30 UTC.

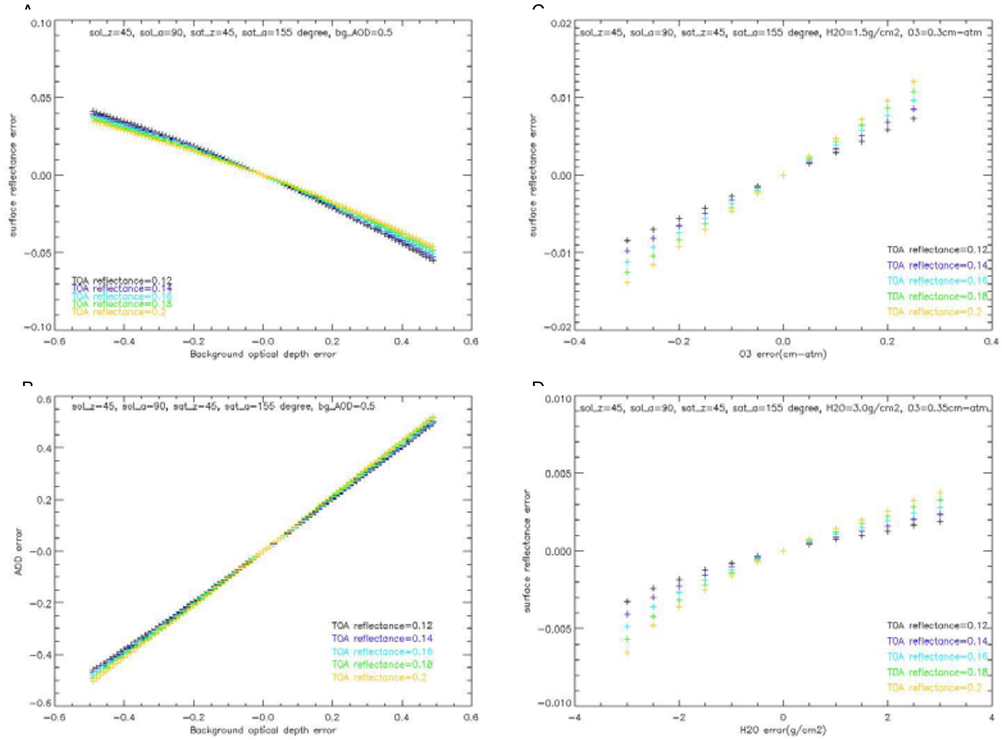

Fig. 5. (A) Error in retrieved surface reflectance as a function of background optical depth error, (B) error in retrieved aerosol optical depth as a function of background optical depth error, (C) error in surface reflectance error as a function of total O_3 error, (D) error in surface reflectance error as a function of H_2O content error.

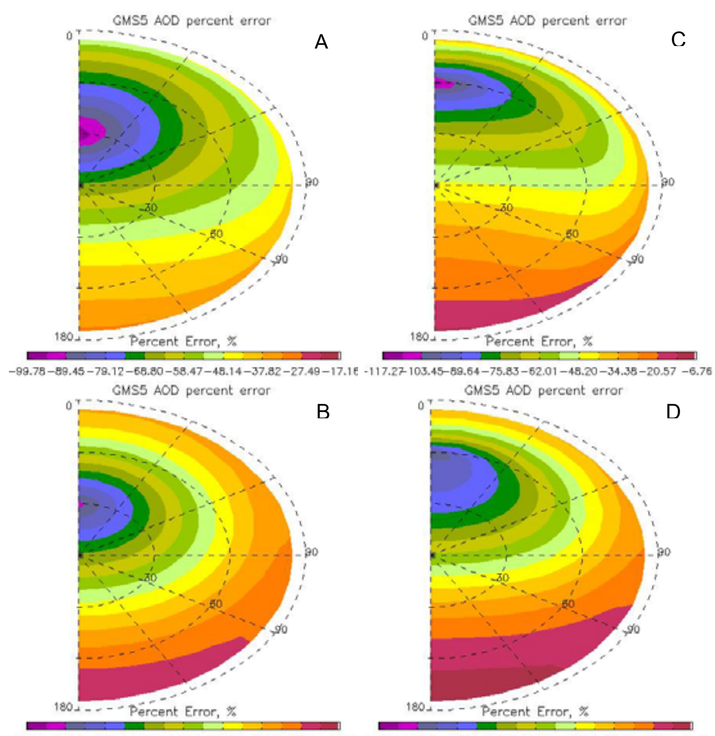

Fig. 6. Percentage error for the GMS5 AOD reflectance by neglecting the BRDF of a grass land with the sun at $\theta_o = 30^o$ and $\varphi_o = 0^o$ for A) τ=0.2. and B) τ=1.5, and at $\theta_o = 60^o$ and $\varphi_o = 0^o$ for C) τ=0.2. and D) τ=1.5.

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