The Detection of Yellow Sand Dust Using the Infrared Hybrid Algorithm

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ABSTRACT:

We have developed Hybrid algorithm for yellow sand detection. Hybrid algorithm is composed of three methods using infrared bands. The first method used the differential absorption in brightness temperature difference between 11μm and 12μm (BTD_1), through which help distinguish the yellow sand from various meteorological clouds. The second method uses the brightness temperature difference between 3.7μm and 11μm (BTD_2). The technique would be most sensitive to dust loading during the day when the BTD_2 is enhanced by reflection of 3.7μm solar radiation. The third one is a newly developed algorithm from our research, the so-called surface temperature variation method (STV). We have applied the three methods to MODIS for derivation of the yellow sand dust and in conjunction with the Principle Component Analysis (PCA), a form of eigenvector statistical analysis. PCI shows better results for yellow sand detection in comparison with the results from individual method. The comparison between PCI and MODIS aerosols optical depth (AOD) shows remarkable good correlations during daytime and relatively good correlations over the land.

KEY WORDS: Brightness Temperature Difference, Surface Temperature Variation, MODIS
Principle Component Analysis, Aerosol Optical Depth

1. Introduction

A sandstorm that is affecting the Korean peninsula occurs frequently in the spring season in the arid and semi-arid area of sand deserts in the Asian continent. The area of Asian dust source regions covers most of northern China and Mongolia. The travelling low-pressure systems accompanied with strong winds behind the associated cold fronts cause to raise dust into the atmosphere (Yellow sand). Aerosols are air pollution that is harmful to human health, ecosystem, industry activity, and production of goods. In addition, aerosols affect the radiation budget of the Earth-atmosphere system directly by scattering and absorption of solar and thermal radiation, and have the indirect effects by modifying the optical properties and lifetimes of clouds as a role of the cloud condensation nuclei. Therefore, the measurement of aerosols is crucial to understand its impact on human-earth system.

Ground-based observation provides high quality of data, but it provides only limited spatial and temporal coverage. Therefore, satellite measurement is adequate to investigate the global impact of aerosols.

Detection of yellow sand aerosol using satellite observation has been utilized from various bands from ultraviolet to infrared channels. Though infrared band has shown a weakness in detecting aerosols due to relatively high error to shortwave bands it has an advantage of detecting aerosols over high reflecting surface and during nighttime. In order to detect yellow dust we have developed the Hybrid method using Infrared bands of 3.75, 11.03, and 12.02 μm.

2. Data and Methodologies

2.1 Data

For the application of our developed algorithm, we have selected MODIS data for March and April of 2001 and 2002 when the yellow sand loading was frequently observed. The period of March 2001 is especially interested because of intensive aerosols loading that have been transported to US. The channels that have used for this study are MODIS band 20(3.7μm), band 31(11μm), band 32(12μm)

2.2 Methodologies

2.2.1 BTD_1 (11 - 12μm)

A thermal infrared remote sensing retrieval method developed by *Wen and Rose*[1994], which retrieves particle sizes, optical depth, and total masses of silicate particles in the volcanic cloud. Upwelling thermal infrared radiation between 11 and 12μm from the earth's surface is selectively scattered and absorbed by airborne particles. Ice and liquid water particles preferentially absorb longer wavelengths while aerosol particles preferentially absorb shorter wavelengths. Therefore it cause a negative brightness temperature difference (BTD_1<0). In laboratory experiments, *Vickers and Lyon*[1967] found that the emissivity of siliceous the principal ingredient of yellow sand has a minimum value between 8.0 and 9.7μm, which then increase with longer wavelength, becoming a maximum around 12-13μm. Based on this theory, *Gu and Rose*[2003] was applied the algorithm to determine the sandstorm over northern China, using MODIS .

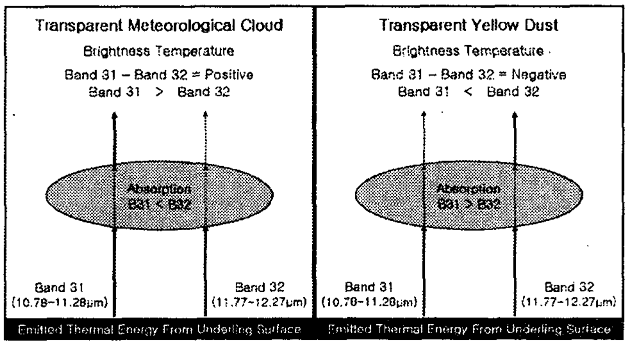

Figure 1. Schematic diagram showing how two band thermal IR transmission through meteorological and yellow sand is different. Bands 31 and 32 refer to MODIS detectors [Gu and Rose, 2003].

2.2.2 BTD_2 (3.7 - 11μm)

The Brightness Temperature Difference between 3.7 and 11μm(BTD_2) was investigated as a possible method for aerosols detection [Ackerman, 1989]. The BTD_2 method shows an ability to enhance a strong signal from daytime solar reflectance, which results in a positive value in BTD_2. However, it has a disadvantage that does not distinguish the aerosols from meteorological clouds because the aerosols reflectivity is about the same as of clouds. Therefore, it is required to remove clouds from aerosols scene.

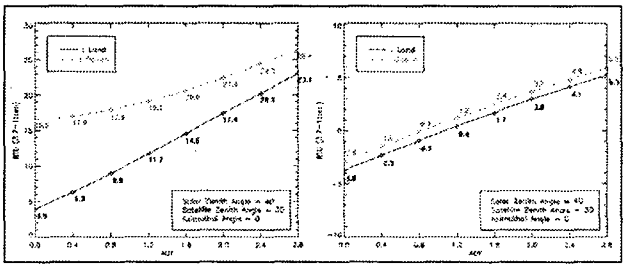

Figure 2. Radiative temperature difference (3.7-11μm) as a function of AOT for a satellite viewing angle of 30° and a solar zenith angle of 40° . Left figure represent a day case while right figure represent a night case.

The Radiative Transfer model analyses with the assumption of uniformly mixed layer between 3-5km, spherical particle shape, and the uniform size distribution indicate the positive values of the BTD_2. The differences between the two brightness temperatures are shown in Fig.2 as a function of optical thickness over land and ocean and during night and daytime. BTD_2 values change according to satellite and solar zenith angle, and the magnitude of BTD_2 is larger over ocean than over land. This technique appears to work better during the day than night. The application of this method for nighttime measurements is valid, but less sensitive.

2.2.3 Surface Temperature Variation (STV) Method

We have shown that the BTD_1 and 2 are the useful tool for detecting yellow sand aerosols, but suffer the error associated with aerosols optical property, surface type, and night time measurements. These errors hinder to make a decision of aerosols existence. Therefore, we have developed an additional algorithm to enhance the aerosols signal. This algorithm has used the concept brightness temperature in clear sky condition is higher than that in the yellow sand loaded atmosphere. The background brightness temperature for clear sky conditions defined the highest brightness temperature at 11μm band for last ten days of measurements in each pixel. Then temperature difference is calculated by subtracting brightness temperature of our target date from the background temperature on the assumption that temperature over clear pixel is higher than aerosols loaded pixel.

2.2.4 Hybrid Method

In order to combine the aerosols indexes from three methods, the principal component analyses from EOF is adapted. The advantage of this analysis help technique combine common signal and separates the noisy. The first component (PCA-1 image) contains the most significant from all the methods. The second and subsequent PCA images contain information not explained by previous components.

We have performed by separating the analysis over the land and ocean after screening the cloud interference.

3. Application and Results

The Figure 3 shows aerosols optical thickness over Korea from MODIS on March 20, 2001

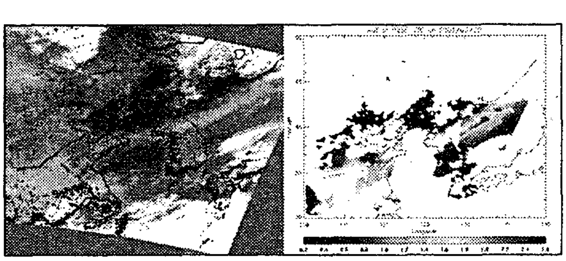

Figure 3. MODIS RGB image and AOT at 02 : 55 UTC, March 20, 2001

The BTD_1 with less than zero is defined as yellow sand and the BTD_1 with more than zero is defined as cloud.

This threshold separates the yellow sand aerosols in case of marginal difference of brightness temperature over land and ocean. We have found that the threshold between -2.5° and 0° resides an error range because of a big retrieval error in these channels relatively to other channels. Radiative transfer model analysis shows a negative value when sea salt particles exist over ocean. This error occurs when yellow sand aerosols are at high altitude or with clouds.

The threshold between 0° and 50° in BTD_2 is related to and yellow sand signal over land and ocean. The brightness temperature difference from BTD_2 is larger than from BTD_1, and thereby efficient for yellow sand detection both over land and ocean. However, the 3.7μm band produces an error over highly reflecting surface as of most visible and near IR channels.

The threshold between 0° and 20° is strongly related to yellow sand aerosols in STV. It is more efficient for detection in land than ocean, and thereby it is required to remove cloud pixel carefully.

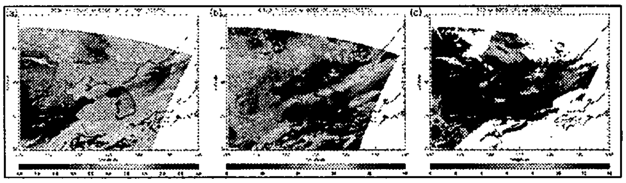

Figure 4. Brightness Temperature Difference of the MODIS between 11.0μm and 12.0μm channels(a), between 3.75μm and 11.0μm channels(b) and STV(c) at 02:55UTC on 20th, March 2001.

Fig. 5 shows Mode 1 (PCI-1) from the PCA analysis. The results after cloud screening show significantly elevated yellow sand signal. The analysis clearly shows distinguishable feature between land and ocean However, it is little lower over land than over ocean because of reduction of sensitivity of 3.7μm band over land. We have weighted differently over land and ocean to match up with MODIS AOT in Figure 5(c).

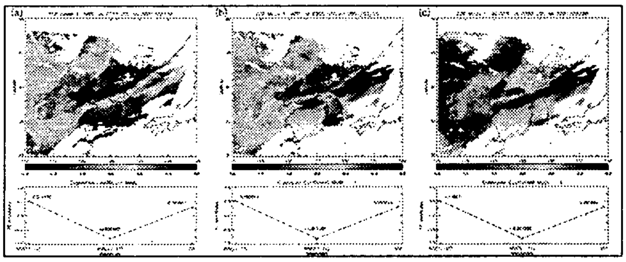

Figure 5. A principal component analysis (PCA) image with cloud screening (a), distinguished land and ocean (b) and weighted land (c).

4. Verification

4.1 Comparison with MODIS AOT

We have found that MODIS aerosols algorithm has considered aerosols pixel as cloud and screening out. We have compared with calculated PCI-1 MODIS AOT. It shows a negative correlation of 0.65 for March 20 2001, and between 0.7 and 0.8 for March 2002 cases. However, the correlation over individual land and ocean shows a remarkably high.

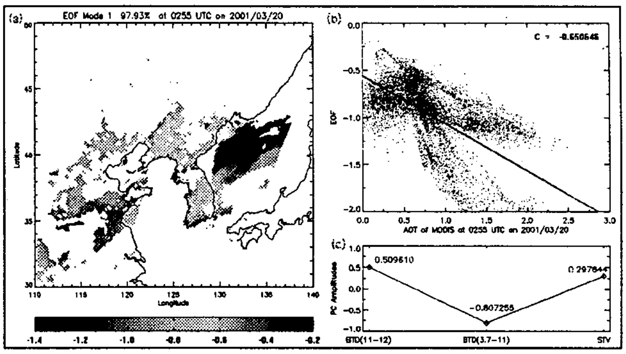

Figure 6. PCI mode 1 at 02:55UTC on 20th, March 2001 (a), Correlation between PCI mode 1 and AOT of MODIS (b), PCA (c)

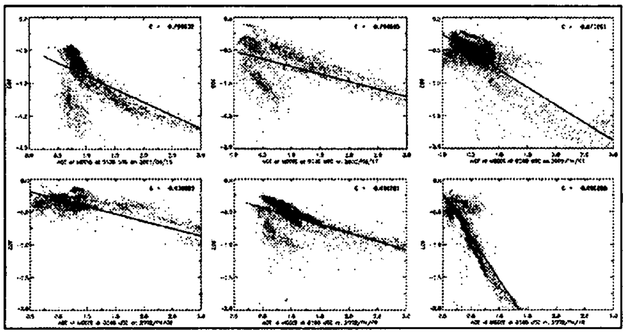

Figure 7. The correlation between AOT of MODIS and EOF mode 1 on yellow sand cases. 'C' represented the coefficient correlation between AOT of MODIS and EOF mode 1(PCI-1)

5. Conclusions

Yellow sand detection with STV and BTD with 3.7, 11, and 12μm bands of MODIS obtains both strength and weakness in all methods. However, the hybrid of the three methods shows elevated yellow sand aerosols signal and proves a strong potential of detecting aerosols even in night time measurements.

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