The Improvement of Infrared Brightness Temperature Difference Method for Detecting Yellow Sand Dust

Jong-Sung Ha, Jae-Hwan Kim
Department of Atmospheric Science, Pusan National University, Korea

(Tel) +82-51-510-2172
(Fax) +82-51-510-1689
(E-mail) [jongsung, jaekim]@pusan.ac.kr

ABSTRACT:
The detection of yellow sand dust using satellite has been utilized from various bands from ultraviolet to infrared channels. Among them, Infrared channels have an advantage of detecting aerosols over high reflecting surface as well as during nighttime. Especially, brightness temperature difference between 11 and 12μm(BTD) was often used to distinguish between water cloud and yellow sand, because Ice and liquid water particles preferentially absorb longer wavelengths while aerosol particles preferentially absorb shorter wavelengths. We have found that the BTD significantly depends on surface temperature, emissivity, and zenith angle and thereby the threshold of BTD. In order to overcome these problems, we have constructed the background brightness temperature threshold of BTD and then subtracted it from BTD. Along with this, we utilized high temporal coverage of geostationary satellite, MTSAT-1R, to verify the reliability of the retrieved signal in conjunction with forecasted wind information. The statistical score test illustrated that this newly developed algorithm showed a promising result for detecting mineral dust by reducing the errors in the current BTD method.

KEY WORDS: Yellow sand dust, Infrared channels, Brightness Temperature Difference, MTSAT-1R

1. INTRODUCTION

In recent years, more intense and frequent dust storms in East Asia have increased. Aerosol particles, including yellow sand dust, affect the radiation budget of the Earth-atmospheric system directly by the scattering and absorption of solar the thermal radiation, and as cloud condensation nuclei. They also have an indirect effect by modifying the optical properties and lifetime of clouds. Moreover, they decrease visibility and cause health problems, such as sore throat and respiratory difficulties, in residents. Therefore, detection of yellow sand is necessarily required to evaluate these effects and prevent serious damage.

Satellite observation is more efficient way to determine aerosol physical properties on the temporal and spatial scales needed to understand and monitor their effects on the earth-atmospheric system. Aerosol satellite-based retrievals have been utilized from various bands from ultraviolet(UV) to infrared(IR) spectral bands. IR remote sensing is extensively used for determining the key atmospheric and oceanic properties such as the atmospheric temperature profile, water vapour, trace gases, and sea surface temperature. Also, previous studies have already demonstrated that atmospheric dust causes the noticeable effect on the IR outgoing radiances at the top of the atmosphere observed by satellite sensors (Ackerman, 1997). *Prata*[1989] introduced the technique for the detection of volcanic ash by using brightness temperature difference(BTD) between the "split window" IR band centered near 11μm wavelength (band 4 on AVHRR), and the IR window at 12μm(band). The images of 11 and 12μm are similar and their single band images are not very sensitive to yellow sand dust. However, the difference of these split window bands is very useful for detecting airborne silicate dust particles such as yellow sand.

We have found that the BTD significantly depends on surface temperature, emissivity, and zenith angle and thereby the threshold of BTD. For these reasons, there is a need to know the sensitivity of BTD threshold value using radiative transfer model. This paper analyzed about parameter effecting the threshold value of BTD, and discussed the results of the observation of the yellow sand phenomena using MTSAT-1R(Multi-functional Transport Satellite-1R) data. Also, we developed new algorithm on the base of these results and calculated adequate threshold value. This study has focused on detection of yellow sand dust on the Northeast Asia for March-April. Used Radiative transfer model in this study is Rstar5b that developed CCSR (Center for Climate System Research).

2. SENSITIVITY STUDY

2.1 Radiative Transfer model

For the TOA simulations we employ the radiative transfer model (Rstar5b) developed by *Nakajima and Tanaka*[1988] using the transfer scheme of *Nakajima and Tanaka*[1986] for an atmosphere with plane-parallel geometry and horizontally homogeneous layers. The rstar5b simulate radiation fields in the atmosphere-land-ocean system at wavelengths regime between 0.2 and

200μm. A plane-parallel atmosphere is divided into several homogeneous sub-layers with assumed underlying ground or ocean surface. Since rstar5b model does not have a specific yellow sand data despite of 11 different particle types, we used HITRAN (HIgh-resolution TRANsmission) data related to aerosols.

2.2 Sensitivity test

Threshold values of BTD are highly sensitive to satellite zenith angle, water vapor profile, and surface temperature and types. We analyzed threshold values of BTD as a function of satellite zenith angle with 10°, 30°, 50°, and 60° (Fig. 1). Increasing the satellite zenith angle over a clear-sky increases threshold values of BTD from about 0.6°K to 1.3°K. While the more aerosol amount increases and satellite zenith angle is high, it becomes dramatically decrease. Fig. 1b reveals the relationship of the Aerosol Optical Thickness (AOT) to the Brightness Temperature (BT) at 11μm and 12μm about above reason. As the AOT increases, BT at 11um is more decrease than 12μm, because 11μm is more absorbed than 12μm by dust particles.

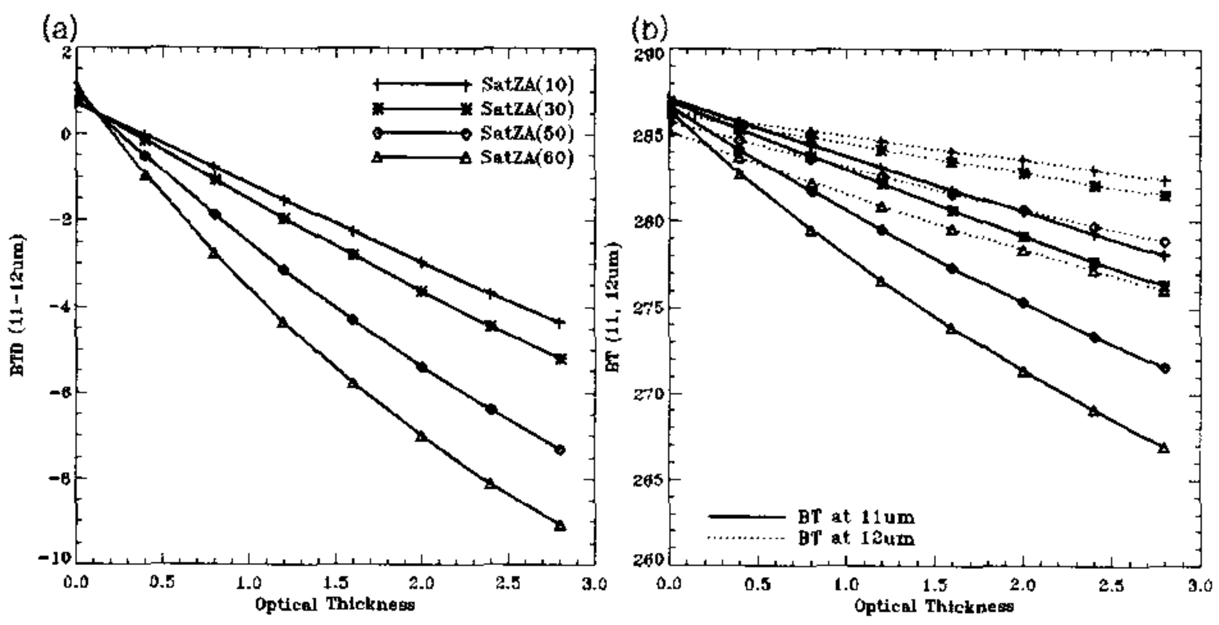

Figure 1. The variation of (a)BTD and (b)BT as a function of satellite zenith angle.

Water vapor content has a large impact on the threshold value of BTD. Fig. 2 depicts the effects of water vapor. It shows that when the water vapor amount changes from about 4000PPMV to 20000PPMV on the surface, threshold value of BTD changes from about 0.5°K to 1.8°K. Positive threshold values of BTD result from stronger water vapor absorption at 12μm.

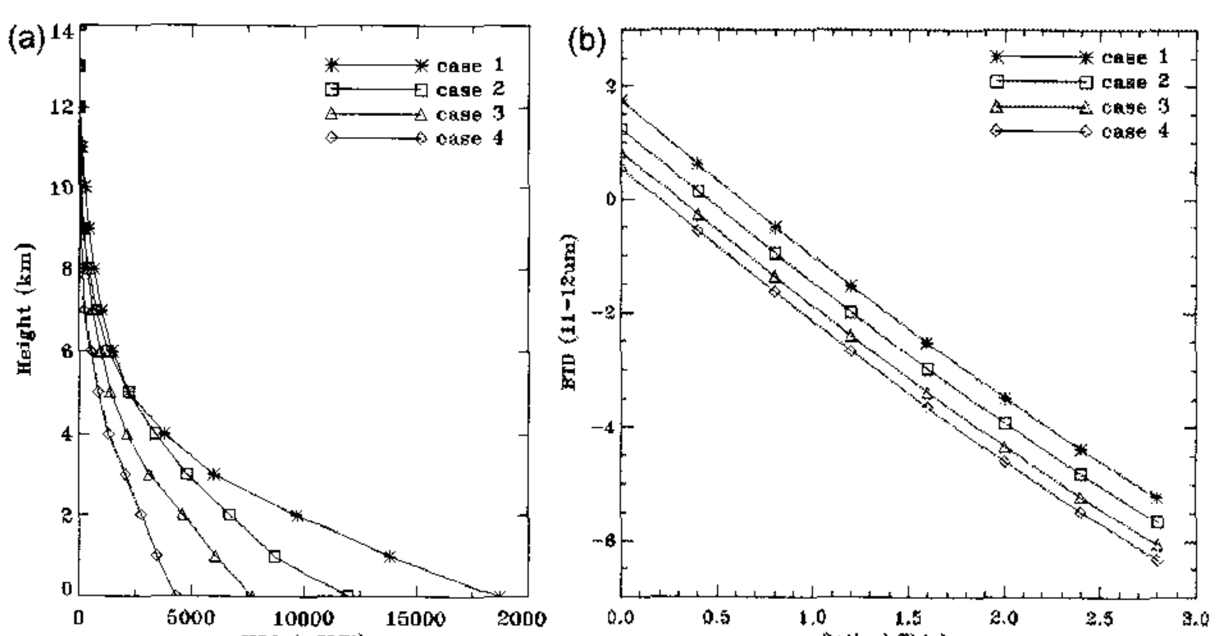

Figure 2. (a)The atmospheric vertical water vapour profile used the radiative transfer model, and (b)the variation of BTD according to the water vapour profile in (a).

Infrared emitted by the temperature of the object are intimately associated with surface temperature. We analyzed threshold values of BTD according to surface temperature and types (snow/ice, green broadleaf forest, arid bare soil). In arid bare soil case, threshold value changes from -1.6°K to 0.8°K according to surface temperature (Fig. 3). The variance may be caused by an error about 100% in aerosol detection. Therefore, based on analysis of BTD threshold, we need to correction about satellite zenith angle, surface temperature and types, and emissivity.

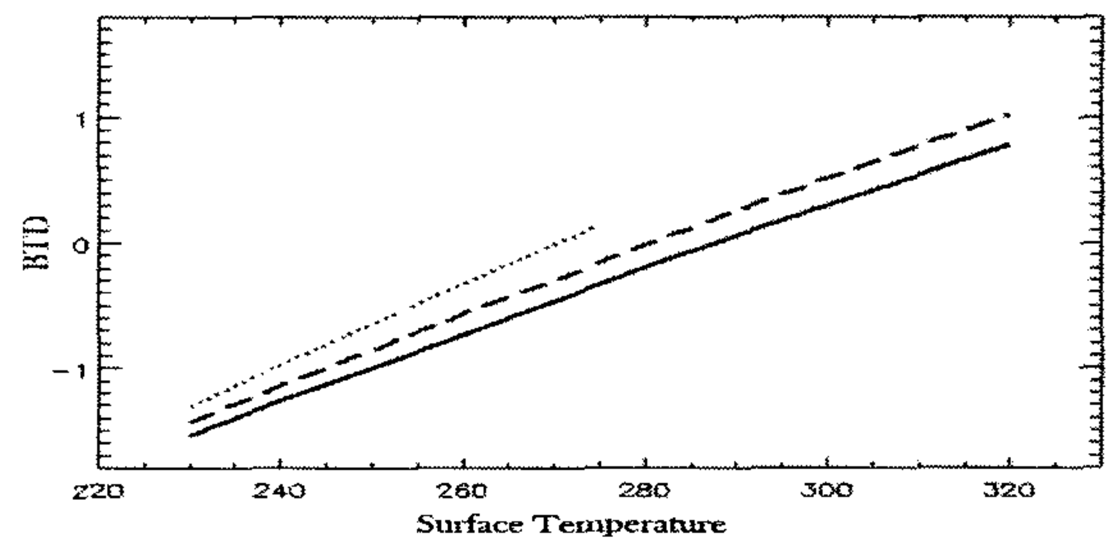

Figure 3. The threshold value of BTD as a function of surface temperature and surface types: dotted line is for "Snow/ice"; dashed line is for "Green broadleaf forest"; solid line is for "arid bare soil".

3. DATA AND ANALYSIS

3.1 Data

For the application of our developed algorithm, we have selected MTSAT-1R data for March and April of 2006 when the yellow sand loading was frequently observed. Yellow sand took place in Seoul for about 10 days during the period of March-April 2006. The study area is located over the Northeast Asia between 110-140°E and between 30-50°N.

MTSAT-1R satellite was launched in February 2005, and has 5 spectral channels. Channels VIS, IR1 and IR2 centered at 0.675, 10.8 and 12.0μm are used to analyze yellow sand in this study. To validate, we utilized Ozone Monitoring Instrument (OMI) aboard the AURA satellite launched in July 2004. OMI is a nadir viewing spectrometer that measures solar reflected and backscattered light in a selected range of the UV and visible spectrum, and calculate tropospheric and stratospheric ozone, aerosol index (used in this paper), and air quality, etc.

3.2 Application and analysis

The BTD with less than zero is defined as yellow sand and the BTD with more than zero is defined as water cloud. This threshold separates the yellow sand aerosols and clouds. BTD values range from -3°K to 0°K in the presence of yellow sand, but have a little difference over land and ocean (Fig. 4). It has a high sensitivity over land than ocean in spite of yellow sand signal of uniform size (Fig. 4b). Moreover, BTD images show that yellow sand would be occurred in night over China (Fig. 4c). This is caused by because threshold values were decreased by dropping surface temperature. Therefore, the BTD values may be contained the uncertainties due to components, which are mentioned sensitivity test.

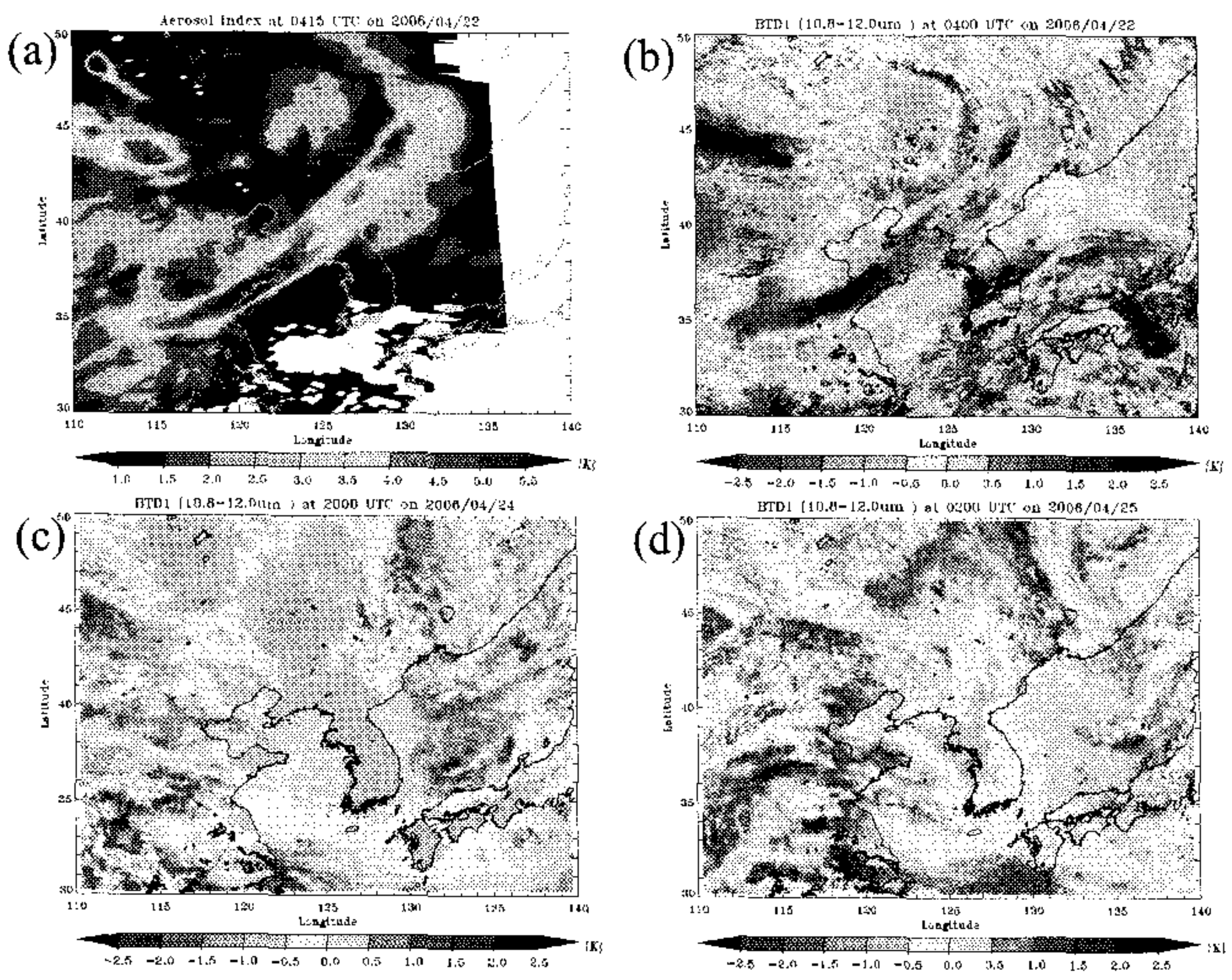

Figure **4.** **(a)**Aerosol Index of the OMI and (b,c,d)BTD images calculated from MTSAT-1R satellite for April 22-24, 2006 : (c) is for night time; (d) is for daytime.

4. IMPROVED ALGORITHM

4.1 Methodology

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 12μm while aerosol particles preferentially absorb 11μm. Meteorological clouds generally have positive BTD, whereas aerosols have negative BTD. But, BTD threshold varies according to satellite zenith angle, surface temperature, and surface emissivity. Therefore, in this section the threshold value of BTD is calculated in pixels, and defined Background Threshold Value (BTV). Preferentially, cloud pixels are eliminated using visible channel of 0.65μm and BT at 11μm because it get decrease yellow sand signals. Because BT at 11μm is decreased by dust particles, we retrieved maximum BT for each bands at the same time and the same position during 10 days, and we defined difference between maximum BT at 11μm and 12μm as BTV. The difference between BTD and BTV is finally yellow sand areas, and modified BTD (BTD').

4.2 Results

There are differences between daytime and night, and land and ocean in BTV images. It totally has the negative values in BTV in land, whereas the values in ocean has positive and zero (Fig. 5b). Negative values in BTV get decrease yellow sand signals, and positive get increase yellow sand signals. Therefore, BTD' image eliminated errors for detecting yellow sand, and boundary of between land and ocean (Fig. 5). This method shows elevated yellow sand aerosols signal and proves a strong potential of detecting aerosols.

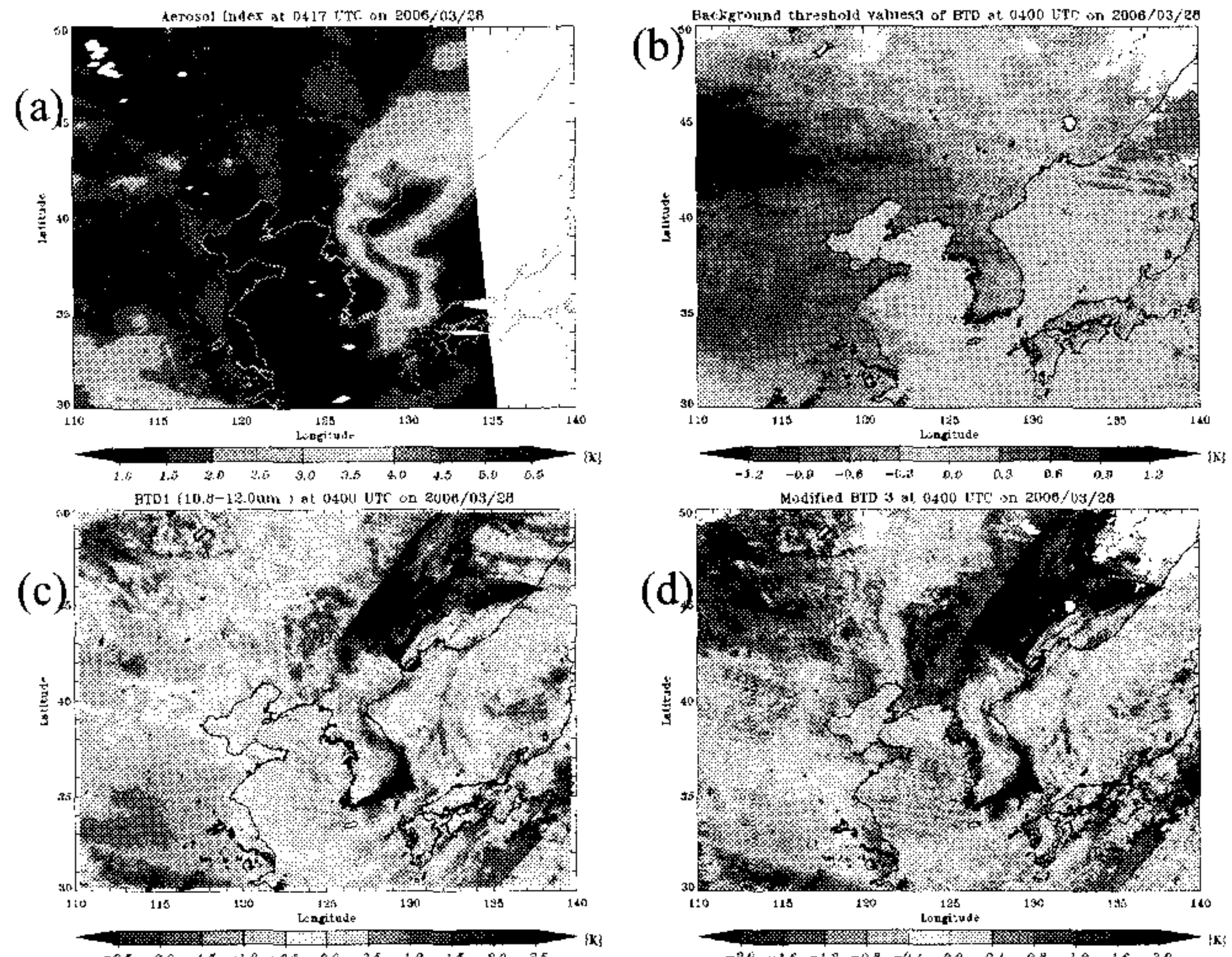

Figure **5.** Aerosol Index of the OMI(a), BTV(b), BTD(c), and BTD'(d) images for March 28, 2006

5. VALIDATION

We used OMI Aerosol Index (AI) data and BTD' to verify a region of the detected aerosol, and we start with a contingency table that shows the frequency of "yes" and "no" forecast and occurrence pixels. The four combinations of forecast (yes or no) and observation (yes or no) pixels, called the joint distribution, are:

Hit – pixel forecast to occur, and did occur

Miss – pixel forecast not to occur, but did occur

False alarm – pixel forecast to occur, but did not occur

Correct negative – pixel forecast not to occur, and did not occur

We calculated indexes such as Accuracy, Bias, False Alarm Ratio (FAR), and Probability of False Detection (POFD). The calculated values by contingency table will be a useful way to verify.

Table 1. Contingency Table.

		Observed pixel		
		yes	**no**	**Total**
forecast pixel	**yes**	Hits	false alarms	forecast yes
	no	Misses	Correct negatives	forecast no
	Total	observed yes	observed no	Total (T)

The results of average for eleven scenes which recorded yellow sand in 2006, the accuracy values of BTD and BTD' are 0.62 and 0.7, respectively. This value indicates that roughly 70% of the observed yellow sand pixels were correctly predicted. The values of FAR and POFD in BTD' are slightly lower than BTD. Therefore, this approach will result in reducing the error associated with BTD method.

References from Journals:

Ackerman, S. A., 1997. Remote sensing aerosols using satellite infrared observations. *Journal of Geophysical Research* 102(D14), 17069-17079.

Nakajima, T. and M. Tanaka, 1986. Matrix formulations for the transfer of solar radiation in a plane-parallel scattering atmosphere, *J. Quant. Spectrose. Radiat. Transfer.* 35, 13-21.

Nakdjima, T. and M. Tanaka, 1988. Algorithms for radiative intensity calculations in moderately thick atmospheres using a truncation approximation, *J. Quant. Spectrose. Radiat. Transfer,* 40, 51-69.

Prata, A. J., 1989. Observations of volcanic ash clouds in the 10-12 micrometer window using AVHRR/2 data, *International Journal of Remote Sensing* 10, 751-761.

Acknowledgements

This work was supported by COMS (Communicate, Oceanic and Meteorological Satellite) Program. This research was partially supported by the Brain Korea 21(BK21) program for the fellowship Jong-Sung Ha.