THREE-DIMENSIONAL HISTOGRAM METHOD FOR ASIAN DUST IDENTIFICATION USING MODIS IMAGES

Izumi Nagatani[1, 2] and Jun-ichi Kudoh[1]
[1]GSIS Tohoku University
6-3-09 Aramaki aza Aoba, Aobaku Sendai, Japan
E-mail: nagatani@affrc.go.jp
Email: kudoh@cneas.tohoku.ac.jp

[2]Agriculture, Forestry and Fisheries Research Information Technology Center,
2-1-9 Kannondai, Tsukuba, Ibaraki 305-8601, Japan; Tel: + 81-29-838-7341;
E-mail: nagatani@affrc.go.jp

KEY WORDS: Asian dust identification, Three-dimensional histogram, Image feature extraction

ABSTRACT: Asian dust storm is a meteorological phenomenon in East Asia, which is originated in arid and semi-arid region such as Taklamakan and Gobi deserts. The heavy Asian dusts are occasionally carried by strong winds to Korea, Japan, even to North America. These dusts cause respiratory disease, transportation disturbances, and other disruptions of social and economic activities. Monitoring these dust transports is essential and remote sensing technique and fast computer visualization are required. However, it is not easy to identify Asian dust over Japan Sea, which is relatively low dense and coexists with cloud, fog, and other haze. To overcome this issue, we used a three-dimensional histogram technique developed by J. Kudoh. The original was developed for identifying land, cloud, sea, fog, etc., from NOAA AVHRR reflectances. Instead, we used three MODIS indices, which are Brightness Temperature Difference (BTD), Normalized Difference Dust Index (NDDI), and Normalized Difference Vegetation Index (NDVI). The BTD is sensitive to high-density dust but less sensitive to low-dense. NDDI is hard to discriminate Asian dust from bare land. Using the three indices, the proposed method identified Asian dust very well. Compared to meteorological observing stations, it is found that the observation of low-density dust is required for Japan and the proposal method is useful for this purpose. Advantages of the three-dimensional histogram method are fast detection and identification capabilities of Asian dust from various dust behaviors and this is useful for automatic dust detection.

1. INTRODUCTION

Asian dust storm is a meteorological phenomenon in East Asia which is originated in arid and semi-arid region such as Taklamakan desert of China, Gobi desert, and etc (Shao, 2006). The heavy Asian dusts are occasionally carried by strong winds to Korea, Japan, even to the west coast of North America (Takemura, 2003). These Asian dust storms cause respiratory disease, transportation disturbances and other disruptions of social and economic activities. In that case, the dust warning is essential and the monitoring of Asian dust movement is important for not only human activities but also climate change study. Conventional systems of Asian dust observations are meteorological visibility, lidar, and sky radiometer measurements at each meteorological station, and etc. Murayama et al. introduced a ground-based network that has been in use since 1997 to observe the Asian dusts during springtime (Murayama, 2001). Recently, several satellite remote sensing techniques have been proposed.

Terra and Aqua satellite's MODIS data are useful for dust detection with their high spatial resolution including 250m (bands 1-2), 500m (bands 3-7) and 1km (bands 8-36) and with 36 spectral bands which from VIS-NIR (405-877nm), SWIR(1230-2,155nm) to thermal IR(3,660-14,385μm) wavelengths. In the past research, several MODIS indices for Asian dust observation had been developed. Ackerman demonstrated the Brightness Temperature Differences (BTD) between the 11μm and 12μm wavelengths (Ackerman, 1997), and John J. Qu et al., developed the Normalized Difference Dust Index (NDDI) from blue and IR reflectance (Qu, 2006). J. Huang et al., proposed a method using both BTD and Microwave radiation measurements of AMSR-E observation in which BTD is used for cloud-free dust storm and AMSR-E is used for cloud-over dust storm (Huang, 2007).

A characteristics of Asian dust around Japan, especially over Japan Sea is relatively low dense and coexist with cloud, fog, and other haze depending on weather situation. It is not easy to identify Asian dust from such various conditions. In this paper, we propose a three dimensional histogram method for Asian dust identification using three MODIS indices, BTD, NDDI, and NDVI. The BTD is well used for this purpose however the BTD is sensitive to high-density dust but less sensitive to low-dense. The NDDI is hard to discriminate Asian dust from bare land because it is sensitive to both dust and bare land, but it has sensitivity to low-density dust especially over sea water.

Thus, in the proposed method we used these three indices effectively. The NDVI is difficult to identify Asian dust by itself but its steadiness value of dust is useful.

2. METHODOLOGY

2.1 Three-dimensional histogram method

A three-dimensional histogram method is an image analysis technique developed by J. Kudoh and S. Noguchi (Kudoh, 1991a) for extraction of physical features such as sea, land, cloud, etc., from a NOAA AVHRR multi-channel image. This is a simple and user-friendly method to identify clusters from a three-dimensional histogram (Kudoh, 1991b). The definition of how to create a three-dimensional histogram is shown below in equation (1),

$$P[\alpha_1,\alpha_2,\alpha_3] = \sum_{x=x\min}^{x\max}\sum_{y=y\min}^{y\max}\delta\{\alpha_1, I_1(x,y)\}\cdot\delta\{\alpha_2, I_2(x,y)\}\cdot\delta\{\alpha_3, I_3(x,y)\} \tag{1}$$

where $P[\alpha_1,\alpha_2,\alpha_3]$ is the three-dimensional histogram array indicated by α_1, α_2, and α_3. The *P* is a total number of pixels. ”$\delta\{i, j\} \equiv \delta_{ij}$“ is Kronecker’s Delta. The I_1, I_2, and I_3 are pixel values of three input images at (x, y) pixel location, which moves from upper-left (xmin, ymin) to lower-right (xmax, ymax) corner of user-specified rectangle area. The *P* is counted at each pixel value combination of three images.

Three MODIS index images which are Brightness Temperature Difference (BTD), Normalized Difference Dust Index (NDDI), and Normalized Difference Vegetation Index (NDVI) are used in this study. These are defined as follows:

$$\begin{aligned} BTD &= BT12 - BT11 \\ NDDI &= (b7 - b3)/(b7 + b3) \\ NDVI &= (b2 - b1)/(b1 + b2) \end{aligned} \tag{2}$$

where the *BT*11 and *BT*12 is brightness temperature of 11μm and 12μm wavelength, respectively. The *b*1, *b*2, *b*3, and *b*7 is the top of atmosphere (TOA) reflectance of MODIS band 1 (620-670nm), band 2 (841-876nm), band 3 (459-479nm), and band 7 (2,105-2,155nm), respectively.
The indices are converted to discrete number to create three-dimensional histogram by using equation (3). The data type is unsigned 8 bits integer. These conversions lead to lose some data information but to enhance histogram feature.

$$\begin{aligned} BTD_8 &= (BTD + 2.0) * (100 / 10.0) \\ NDDI_8 &= (NDDI + 1.0) * (255 / 2.0) \\ NDVI_8 &= (NDVI + 1.0) * (255 / 2.0) \end{aligned} \tag{3}$$

The three index images are used as inputs of a three dimensional histogram. In order to extract dust feature from the histogram, focusing data space and enhancing histogram are required. In this study, two data spaces were defined experimentally. One is for high or middle-dense dust (Type A) and another is for relatively low-dense dust especially over ocean (Type B).

$$\text{Data space for high-dense dust (A):}\quad \begin{cases} BTD \ge 30 \ \&\ BTD \le 100 \\ NDDI \ge 160 \ \&\ NDDI \le 250 \\ NDVI \ge 120 \ \&\ NDVI \le 150 \end{cases} \tag{4}$$

$$\text{Data space for low-dense dust (B):}\quad \begin{cases} BTD \ge 25 \ \&\ BTD \le 100 \\ NDDI \ge 80 \ \&\ NDDI \le 160 \\ NDVI \ge 120 \ \&\ NDVI \le 150 \end{cases} \tag{5}$$

These data space setting is essential for avoiding misidentifying dust pixels. Secondly, for enhancing histogram, width of histogram intervals of 8 was set. It was defined experimentally to extract feature from a histogram.

2.2 Mean and Standard deviation estimation

Regarding each data spaces, a set of mean and standard deviation are estimated for each index. The mean index value is determined by the maximum number of pixels. And standard deviation is estimated by using normal distribution function. Using five bins including mean's bin and its neighboring four bins, an optimal standard deviation is estimated by using normal distribution function. When total differences between relative frequencies and normal probabilities are minimal, standard deviation is optimal. Figure 1 shows an example of estimating a standard deviation of BTD. The bar graph shows a histogram of dust pixels and its frequency is relative value (probability in Figure 1). The maximum is adjusted to 0.4. The red line shows that the normal distribution function derived with the mean and standard deviation of 11. From this function, dust probability (DP) of each index value is calculated. Table 1 shows an example of estimated means and standard deviations of March 16 data.

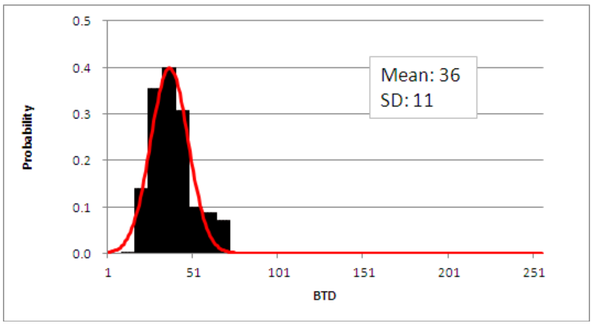


Figure 1. Estimation of Standard Deviation (SD)

Table 1. Estimated Mean and Standard Deviation (SD)

DATE	Type	Index	Mean	SD
March 16	A	BTD	60	10.8
	A	NDDI	172	8.4
	A	NDVI	140	3.7
	B	BTD	28	6.1
	B	NDDI	156	10.5
	B	NDVI	140	19.0

2.3 Dust identification

Final probability is a multiplied value of dust probabilities of three indices. This multiplied probability indicates distance from a center of dust cluster to a dust pixel. To evaluate the distance easily, the multiplied probability is modified using natural logarithm as follows,

$$D = \ln\left(10^{9} * DP_{BTD} * DP_{NDDI} * DP_{NDVI}\right) \tag{6}$$

where D is cluster distance index, DP is dust probability of each index. The maximum DP is 0.4 and the D indicates between 0 and 18.

3. CASE STUDY

3.1 Study area and data

MODIS scenes taken on March 15-17, 2002 were used for a case study. These images show strong dust storms which were observed at many meteorological ground stations by the Japan Meteorological Agency. We collected the Terra MODIS Level1b products from the NASA LAADS site, (http://ladsweb.nascom.nasa.gov/). The atmospheric corrected reflectance and brightness temperature datasets were created by using CREFL and MOD14 software which were distributed by the NASA Direct Readout Laboratory, (http://directreadout.sci.gsfc.nasa.gov/) and three index images, BTD_8, $NDDI_8$, and $NDVI_8$ were created. And then these index and reflectance images were re-sampled and mosaic to latitude-longitude map coordination covering from east China to Japan (30.0 º – 46.0º N, 110.0 º – 146.0º E).

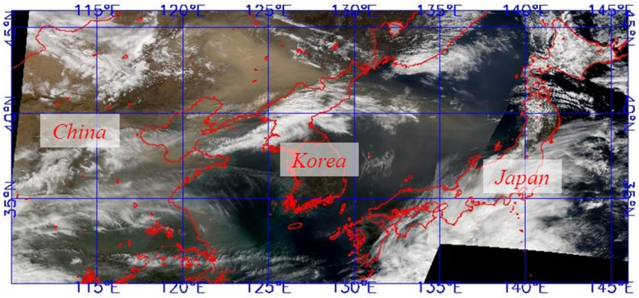


Figure 2. Study area with MODIS image taken on March 16, 2002

3.2 Results and discussions

Figure 3 shows an example of dust identification result which is laid on MODIS true color image (Figure 2). The dust identified pixels are colored by ocher and yellow-red gradient color table. Red color shows high-probability of dust pixels and yellow shows low-probability of dust pixels. Ocher color shows type-B dust pixels which is relatively low dense dust over ocean. Figure 4 shows the BTD and NDDI images that were used for generating the result. The left image, BTD shows physical value of dust density. The high BTD indicates high dust density and low BTD indicates low dust density. However, the BTD has difficulties of identifying low-dense dust especially over ocean. The right image, NDDI indicates dust pixels around 0.5. However, it is difficult to discriminate dust pixels from lands. Compared with both indices, the result image of proposed method identified dust pixels well.

Figure 5 shows some example of result images (Left) and the number of meteorological stations (Right) of the Japan Meteorological Agency in which Asian dust were identified by visual observation. These are time-series results of from March 15 to 17, 2002 and these show a tendency of Asian dust. The (a) shows a result of March 15 and the number of meteorological stations is 6, it is small. The (b) shows Asian dust flying over Japan Sea and the number of meteorological stations is 15. The (c) shows Asian dust reaching Japan and the number of meteorological stations is 23. Though it is hard for the proposed method to detect all Asian dust particles, low-density dust identification is required and the time-series results are useful for understanding Asian dust movements.

The proposed method identifies an Asian dust cluster which is derived from means and standard deviations of three indices. Normally Mahalanobis distance method such as Maximum Likelihood Classification is more reliable in this purpose. However, it is hard to calculate Mahalanobis distance from a three-dimensional histogram. Meanwhile the proposed method could detect Asian dust faster and automatically.

4. CONCLUSIONS

We proposed a three-dimensional histogram method for Asian dust identification using Terra MODIS indices, BTD, NDDI, and NDVI. This method was useful for identifying even low-density dust over Japan Sea coexisting with cloud, fog, and other haze. BTD is sensitive to high-density dust but less sensitive to low-dense. NDDI is hard to discriminate Asian dust from bare land. The proposed method which uses three indices identified Asian dust very well. The images of March 15-17 2002 were processed as a case study. It was confirmed that the proposed method has advantage for identification of low-density dust which is hard to be identified by BTD and NDDI alone.

Compared to the number of meteorological stations, it was found that monitoring of low-density dust over Japan Sea is important and the time-series results would be useful for understanding Asian dust movements.

The three-dimensional histogram method identifies an Asian dust cluster which is derived from means and standard deviations of three indices. Though Mahalanobis distance method is more reliable than this method, it is hard to calculate Mahalanobis distance from a three-dimensional histogram. Meanwhile advantages of the three-dimensional histogram method are fast detection and identification capabilities of Asian dust from various dust behaviors and this is useful for automatic dust detection.

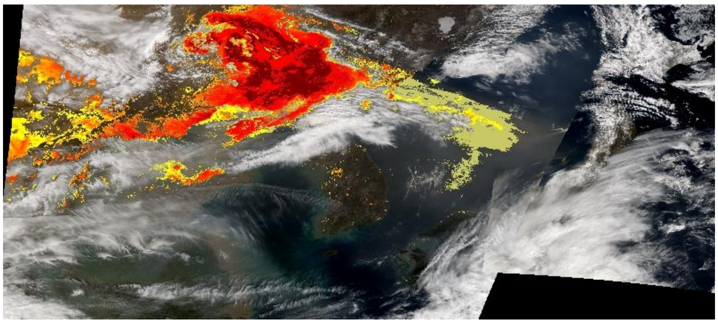


Figure 3. Result of Asian dust identification (March 16, 2002)

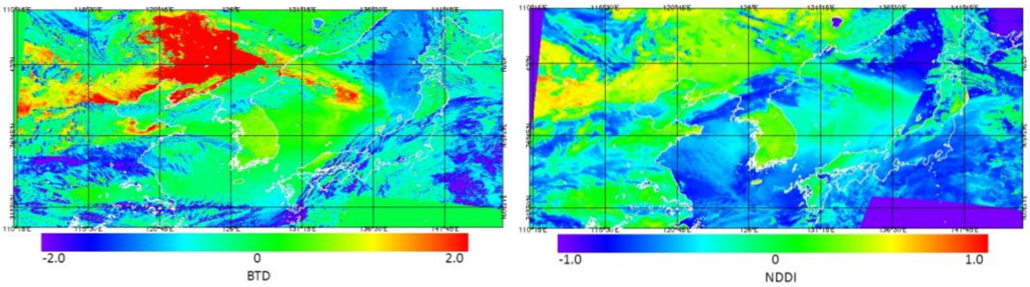
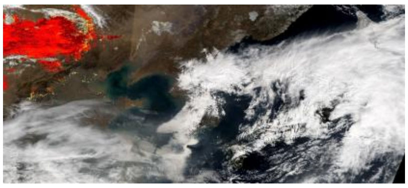
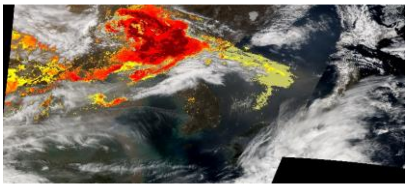


Figure 4. BTD image (Left) and NDDI image (Right) of March 16, 2002



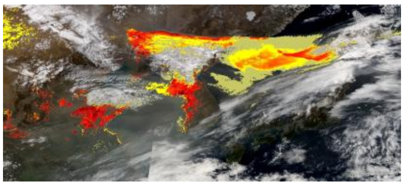
Num. stations: 6

(a) March 15, 2002



Num. stations: 15

(b) March 16, 2002



Num. stations: 23

(c) March 17, 2002

Figure 5. Asian dust identification and number of meteorological stations where observed Asian dust

ACKNOWLEDGMENT

MODIS data were provided from NASA Goddard Space Flight Center, and MODIS processing software were provided from NASA Direct Readout Laboratory.

REFERENCES

Ackerman, S. A., 1997. Remote sensing aerosols using satellite infrared observations, Journal of Geophysical Research, 102 (D14), 17069-17080.

Huang, J., Jinming Ge, and Fuzhong Weng, 2007. Detection of asia dust storms using multisensor satellite measurements, Remote Sensing of Environment, 110, 186-191.

Kudoh, J. and S. Noguchi, 1991a. A study of three-dimensional histogram using the NOAA AVHRR images, IEEE Trans. Geosci. Remote Sensing, 29, 5, 736-741.

Kudoh, J. and S. Noguchi, 1991b. Identification of fog with NOAA AVHRR images, IEEE Trans. Geosci. Remote Sensing, 29, 5, 704-709.

Murayama, T., N. Sugimoto, I. Uno, K. Kinoshita, K. Aoki, N. Hagiwara, Z. Liu, I. Matsui, T. Sakai, T. Shibata, K. Arao, B. Sohn, J. Won, S. Yoon, T. Li, J. Zhou, H. Hu, M. Abo, K. Inokibe, R. Koga, and Y. Iwasaka, 2001. Ground-based network observation of Asian dust events of April 1998 in east Asia, Journal of Geophysical Research, 106, D16, 18345-18359.

Qu, J. J., Xianjun Hao, Menas Kafatos, and Lingli Wang, 2006. Asian dust storm monitoring combining terra and aqua modis srb measurements, IEEE Geosci. Remote Sensing Letters, 3, 4, 484-486.

Shao, Y. and C. H. Dong, 2006. A review on east asian dust strom climate, modeling and monitoring, Global and Planetary Change, 52, 1-22.

Takemura, T., T. Nakajima, A. Higurashi, S. Ohta, and N. Sugimoto, 2003. Aerosol dustributions and radiative forcing over the asian pacific region simulated by spectral radiation-transport model for aerosol species (SPRINTARS), J. Geophysical Research, 108, D23, 8659, doi:10.1029/2002JD003210.