MONITORING RESULTS OF 2013 AND 2014 TRANSBOUNDARY ASIAN DUST EVENTS IN JAPAN USING MODIS DUST INDICES

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ABSTRACT: Asian dust event is a weather phenomenon in spring time in Japan. The mineral dusts occurred by strong wind in Gobi deserts are frequently transported over the Japan Sea. These airborne dust become causes of respiratory disease, transportation disturbances, and other disruptions in social activities. Remote sensing technology is useful for detecting and monitoring the Asian dust distributions and movements.
Aiming to understand the Asian dust events, we have developed a methodology for detecting transboundary Asian dust events using two MODIS indices, Brightness Temperature Difference (BTD) and Normalized Difference Dust Index (NDDI). In this paper, we propose a new index Normalized Dust Layer Index (NDLI) which is a composite index of the BTD and NDDI and demonstrate a time series analysis of 2013 and 2014 Asian dust events using NDLI products. We found that from their bar-chart analysis of the number of dust pixels, the 2014 dust events were relatively calmer than the 2013 dust events. The proposed index NDLI was useful for a time series analysis of dust events.

1. INTRODUCTION

Operational monitoring of Asian dust storms is essential for not only daily meteorological forecast but also understanding their phenomenon. Heavy dust storms originated in arid and semiarid region in China and Mongolia are transported eastward by strong wind and a dust air-mass frequently reach into Japan and cause some problems on human health such as respiratory disease and social activities.
To mitigate such problems, a variety of dust monitoring system such as ground observatories and LIDAR observation network have been operated. Satellite remote sensing is useful for monitoring in continental scale. Terra/Aqua MODIS data is commonly used and their Brightness Temperature Difference (BTD) (Ackerman, 1977) and Normalized Difference Dust Index (NDDI) (Qu, 2006) are common dust indices. In previous paper, we proposed an Asian Dust Index (ADI) which was a composite index of the BTD and NDDI and useful to detect Asian dust more accurately than each previous index and demonstrated an Asian dust categorization (Nagatani and Kudoh, 2012). To use it more reliably, in this study the ADI methodology was reviewed and its modified index Normalized Dust Layer Index (NDLI) was developed.
An air pollution monitoring system has been operated since 2013 at Tohoku University located in Sendai, Japan in which the NDLI method was adopted to detect Asian dust events.
In this paper, we describe the NDLI methodology and demonstrate a time series analysis of 2013 and 2014 Asian dust events using NDLI products of the Tohoku University's monitoring system. The capability of NDLI data usage is investigated.

2. METHODOLOGY

2.1 Dust detection

A variety of dust detection methodologies using satellite data had been developed by many researchers in previous studies. It seems that a common and effective method is computing brightness temperature difference (BTD) between 11 μm and 12 μm wavelength bands. This technique is demonstrated by Ackerman (Ackerman, 1997) and widely used in resent studies. We also use this technique in this study with MODIS emissive bands. However, as is well known, this index causes some false detection in arid area. To solve this problem, another index derived from MODIS reflectance bands is considered to be used complementary. That is the Normalized Difference Dust Index (NDDI)

(Qu, 2006) which is derived from 2.11 μm (MIR) and 0.465 μm (Blue) reflectance. In our previous study, a composite index of BTD and NDDI was proposed to detect dust aerosol more accurately than using each index alone. In this study, we propose a new composite index Normalized Dust Layer Index (NDLI) to use for dust detection.
Firstly, the conventional indices, BTD and NDDI are described below,

$$BTD_{12-11} = BT12 - BT11 \tag{1}$$

$$NDDI = (R_{MIR} - R_{blue})/(R_{MIR} + R_{blue}) \tag{2}$$

where, the BTD_{12-11} is brightness temperature difference between 12 μm and 11 μm wavelength. The *BT12* and *BT11* is MODIS brightness temperature measurements regarding 12 μm and 11 μm wavelength, respectively. The NDDI is normalized difference dust index and the R_{MIR} and *Rblue* is reflectance measurement of MODIS band 7 and band 3, respectively.
It is experimentally considered that the BTD shows dust intensity within the range of between 0.0 – 4.0. More than 4.0 is invalid value. While the NDDI range is between -0.2 to 1.0. Before compositing these indices, those valid range is coordinated to a range of 0.0 – 2.0 by linearly stretching functions as below,

$$EBTD = (1.0/2.0) * BTD_{12-11} \tag{3}$$

$$ENDDI = (1.0/2.0) * NDDI + 0.1667 \tag{4}$$

where, the EBTD stands for Enhanced Brightness Temperature Difference and the ENDDI is Enhanced Normalized Difference Dust Index.
The composite index, Normalized Dust Layer Index (NDLI) is computed by following function,

$$NDLI = (EBTD - ENDDI)/(EBTD + ENDDI) \tag{5}$$

The NDLI indicates a dust aerosol condition within a range of 0.0 - 1.0. Medium value of NDLI (0.4-0.7) represent an initial stage of dust storm occurred by strong wind in arid and semi-arid region. Higher value of NDLI (>0.7) is a blowing dust stage which is dust air mass transported by strong wind. Lower value of NDLI (<0.4) represent a weak and floating dust aerosol.

Validation of the NDLI was examined with ground measurements of suspended particulate matter (SPM). A NDLI dataset derived from MODIS data of March 21, 2010 was used and less cloud influenced pixels were selected using a cloud mask layer. The cloud mask creation method is described next section. A vector data of political boundary of Japan was downloaded from the ESRI Japan web site, “http://www.esrij.com/ (in Japanese)” and was utilized to calculate a maximum NDLI for each prefecture. While, a maximum SPM of each prefecture corresponding to MODIS monitoring time was obtained from the SPM ground measurements which was downloaded from the NEIS web site, http://www.nies.go.jp/igreen (in Japanese). Figure 1 shows a relationship between NDLI and SPM ground measurements. This is proving their high correlation with contribution ratio (R-square) of 0.876.

2.2 Cloud mask

To eliminate false detection from the dust detection procedure, cloud masking is required. White cloud is identifiable by their high reflectance and an index of Aerosol Enhancement (AE) (Function 6) is usable. The AE shows aerosol reflectance intensity and the cloud pixel is identified by AE>0.2.

$$AE = 2.0 * R_{blue} - R_{red} \tag{6}$$

where, the R_{blue} and R_{red} is reflectance of MODIS band 3 and band 1, respectively.

2.3 Time series analysis

On a trial basis, the number of dust pixels is counted from an NDLI imagery and a time series analysis is conducted to understand the characteristics of annual Asian dust events.

In previous study, we defined three stages of Asian dust process which are initial stage, blowing stage and floating stage. The initial stage represent a sand/dust storm blown up by strong wind. The blowing stage is transported condition of dust air mass in high altitude atmosphere. The floating stage is the weak/end of dust storm and dust particles are still floating in atmosphere. Each stage is roughly appeared in each particular geological region. Therefore, three particular areas (15°x15°) are set for each dust stage to conduct dust analysis in each particular area. Figure 2 shows the location of three areas labeled as area-A, area-B and area-C. The area-A, red colored area (N:33°-48°, E:95°-110°) is dominant of initial dust stage, the orange (area-B: N:33°-48°, E:110°-125°) is dominant of blowing dust stage and the yellow (area-C: N:33°-48°, E:125°-140°) is dominant of floating dust stage. The entire study area is N: 30°-50°, E: 95°-150° in a latitude-longitude coordinate system on which MODIS imageries are mosaiced and resampled. Asian dust pixels are identified when NDLI > 0.20 and the number of dust pixels are counted for each area and time series analysis is conducted for each year.

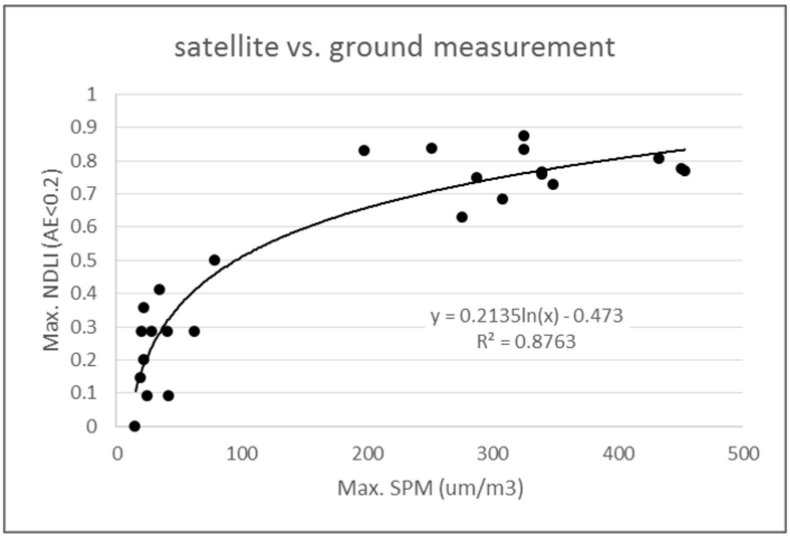

Figure 1. Correlation between maximum NDLI and maximum SPM calculated for each prefectural areas of Japan

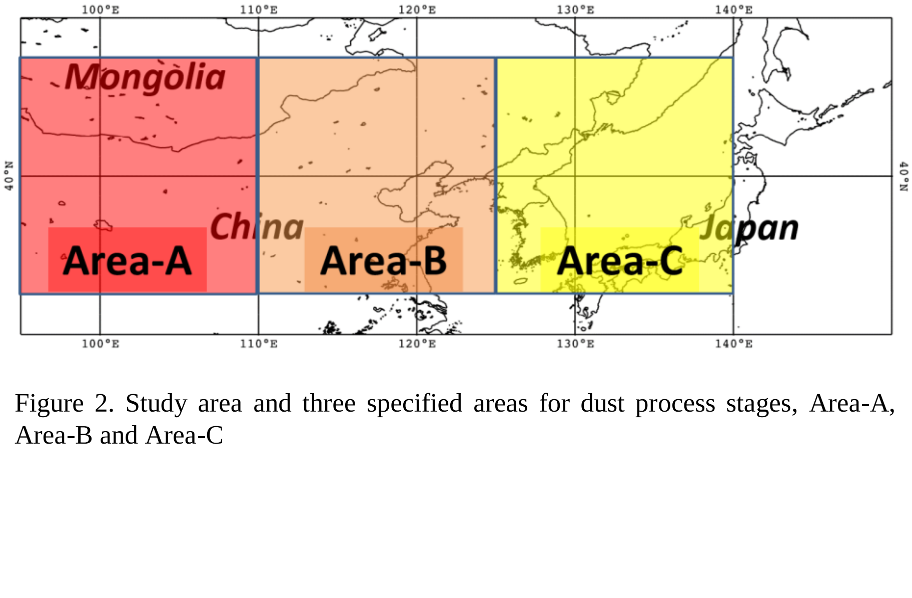

Figure 2. Study area and three specified areas for dust process stages, Area-A, Area-B and Area-C

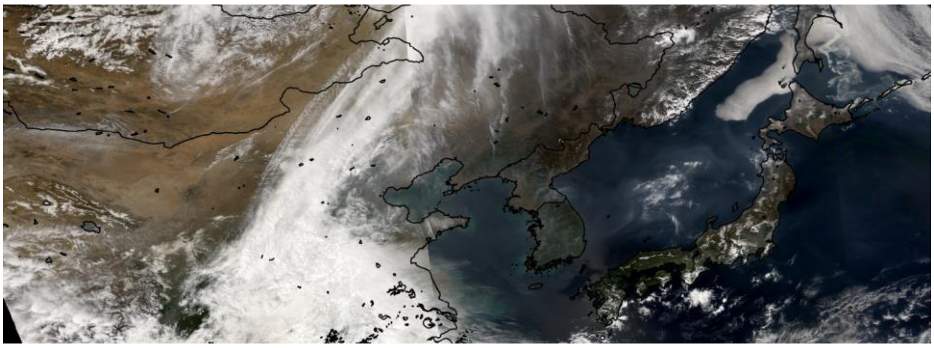

Figure 3(a). Aqua MODIS true color image (April 25, 2014)

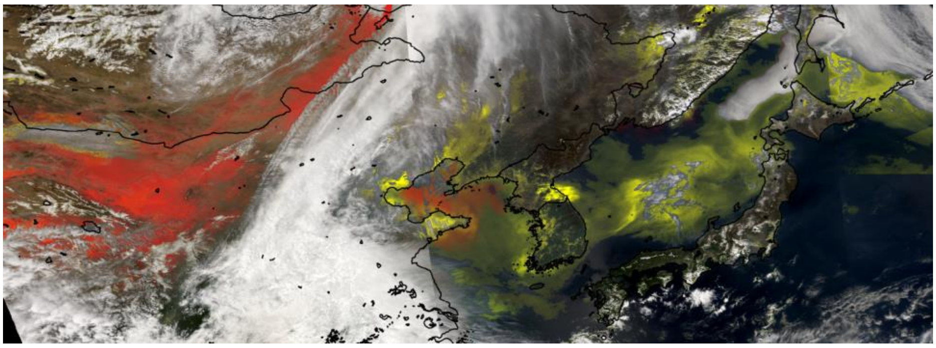

Figure 3(b). Dust and air pollution visualized image (April 25, 2014)

3. RESULT OF 2013 AND 2014 DUST EVENT ANALYSIS

The transboundary air-pollution monitoring system of Tohoku University has been operated since January 2013. From this system's archived data, the dust products of Aqua-MODIS from January to May in 2013 and 2014 were utilized. In addition, 2010's MODIS dataset had been processed exceptionally and their products were utilized as a reference of the more frequent dust storms occurrence. The dust pixels were identified when NDLI>0.2 and the number of dust pixels were counted for each specified area, area-A, area-B and area-C in Figure 2. Their characteristics of the time series occurrence were investigated by chart analysis.

Figure 3(a) and 3(b) show the example of the satellite image products from the monitoring system. Figure 3(a) is a true color image of Aqua MODIS acquired on April 25, 2014 in which some onset of sand/dust storms are recognized as a light brown color at the down of Mongolia in central China. Figure 3(b) is the dust storm visualized image of the same scene in which red pixels represent dust aerosol and yellow pixels represent airborne pollutants. From this image, it is easily recognized that a massive dust storms (red) is blown up to large extent in China. However, this event did not reach to Japan. The dust storm events indeed had not observed in Japan by a horizontal visibility in April, 2014.

Figure 4(a) to 4(c) are bar-charts of the number of dust pixels regarding area-A for each year 2010, 2013 and 2014, respectively. Focusing on the days before the April 1, some vertical long bars (Num. pixels>400,000) are recognized in 2010 and 2013 (Figure 4(a) and 4(b)). By contrast, there is no existence of such a long bar before the April 1 in the 2014 chart (Figure 4(c)). That is a characteristic of the 2014 dust event and the long bars appear in late May.

Figure 5(a) and 5(b) are the dust storm visualized images of May 26 and 27, 2014. This massive dust event was reached Japan and observed over the country in the days after that. That was the last dust event of that season in Japan by observing horizontal visibility.

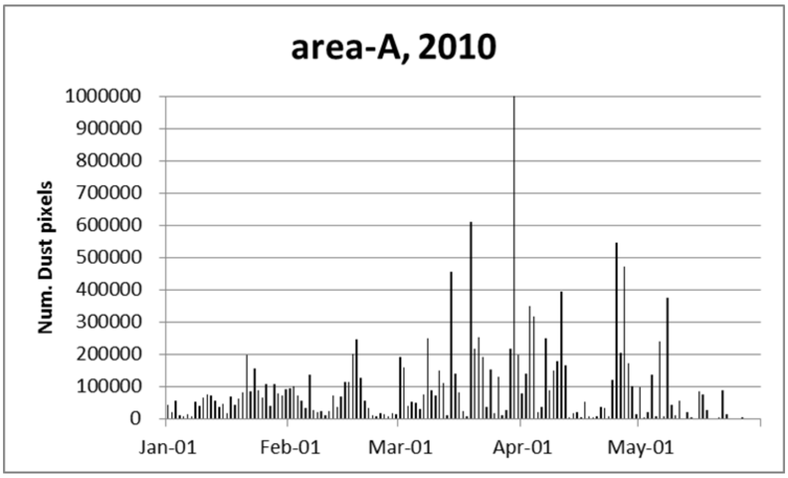

Figure 4(a). Number of dust pixels in the area-A of the daily NDLI of 2010

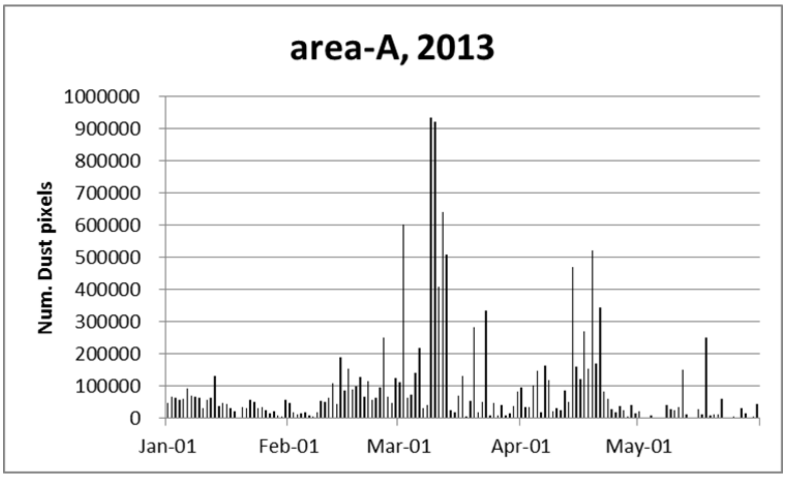

Figure 4(b). Number of dust pixels in the area-A of the daily NDLI of 2013

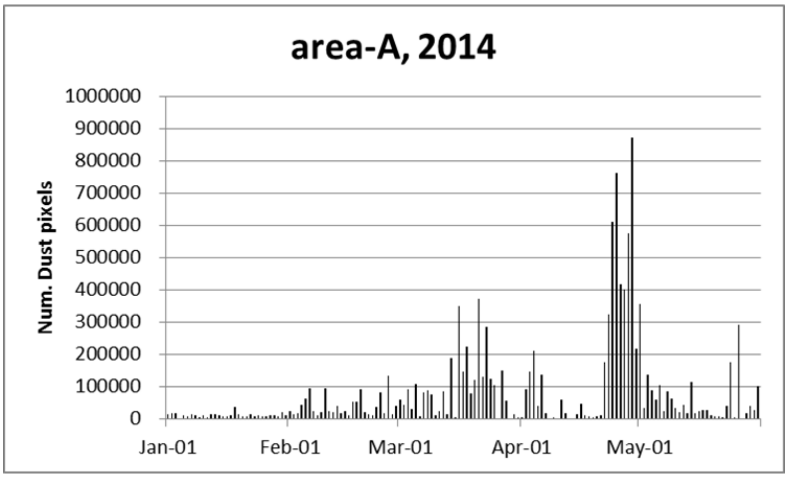

Figure 4(c). Number of dust pixels in the area-A of the daily NDLI of 2014

4. CONCLUSION

We developed a new methodology for detecting airborne dust and a dust index NDLI. Asian dust events could be detected more accurately from this proposed index than conventional index such as BTD and NDDI separately. The capability of this index was investigated.

The air pollution monitoring system at the Tohoku University, Japan has been operated since 2013 and their archived products of MODIS NDLI were used to investigate the overview of the 2013 and 2014 dust events. The MODIS NDLI products of from January to May in 2013 and 2014 were analyzed with comparing to a reference products of 2010. From the bar-chart analysis of the number of dust pixels, the 2014 dust events were relatively calm comparing to the 2013 dust events in the major dust months of March and April.

We confirmed that the proposed index NDLI was useful for a time series analysis to understand the yearly overview of dust events. To understand the dust events more deeply, further studies are required.

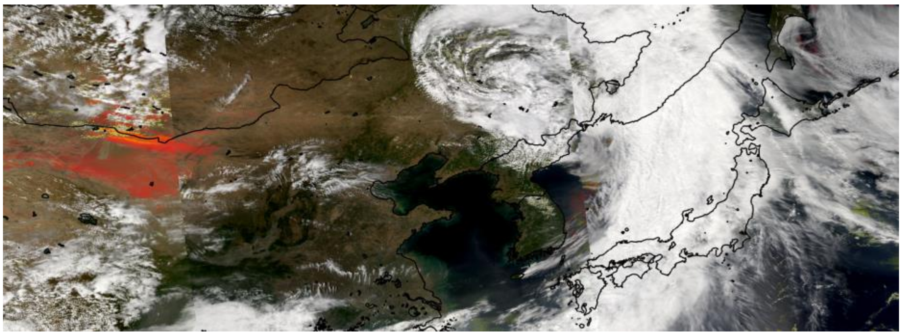

Figure 5(a). Asian dust and air pollution visualized image (May 26, 2014)

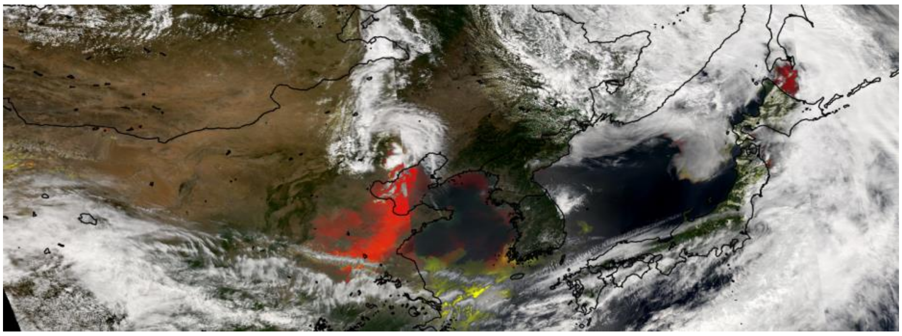

Figure 5(b). Asian dust and air pollution visualized image (May 27, 2014)

REFERENCES

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

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, pp. 484-486.

Nagatani, I. and Kudoh, J., 2011. Three-dimensional histogram method for Asian dust identification using MODIS images, Proceedings of the 32nd Asian Conference on Remote Sensing, Taipei, P198_9-2-11 cd-rom.

Nagatani, I. and Kudoh, J., 2012.Asian dust categorization by modis dust indices, Proceedings of the 33rd Asian Conference on Remote Sensing, Pattaya, Thailand, cd-rom.