MONITORING THE SOURCE OF TRANS-NATIONAL DUST STORMS IN NORTH EAST ASIA

L.Ochirkhuyag [a, b *], R.Tsolmon [b]

a Wildlife Conservation Society Mongolia Program, Amar str-2, INTERNOM bookstore building Rm#305, Ulaanbaatar, Mongolia - olkhamjav@wcs.org
b National University of Mongolia, School of Physics-Electronics, Laboratotay for Remote sensing/GIS NUM-ITC-UNESCO, Ulaanbaatar, Mongolia - tsolmon@num.edu.mn

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ABSTRACT:

The vast expanse of the Gobi desert across the Mongolian plateau features frequent dust storms. In this isolated region remote sensing techniques can provide an effective measurement of dust storms. Brightness temperature channels 4, 5 of AVHRR/NOAA satellite data, emissive bands of MODIS/TERRA satellite data, and meteorological station measurement data were used and tested for dust and sandstorm mapping in the desert area of Mongolia and northern China. The differences between thermal bands in combination with GIS layers were used for mapping in this study. The results show that dust and sand storm maps can be achieved from emissive bands for monitoring of dust and sandstorms. Most active dust storm sources can occur in truly remote areas where there is little or no human activity though many sources are associated with areas where human impacts are well documented. Thus on a regional scale dust mobilization appears to be dominated by natural sources.

1. INTRODUCTION

Desert dust and related dust storms have major significance for the physical environment and the world's inhabitants. Deriving from surface material erosion in dryland regions the impacts of wind-blown desert dust are global in scope. Resulting dust storms can impact climate, air temperature, and influence ocean cooling (Goudie and Middleton, 2006). Dust may affect soil formation, create geomorphologic formations in drylands, and remove cover from desert surfaces. At the same time dust can transmit pathogens harmful to humans, impair respiratory function, cause air pollution, and disrupt communications and transport. Environmentally such storms can accelerate soil erosion and encourage desertification. Rosenfeld et al. (2001) identified that the effect of dust on cloud properties can be sufficient to inhibit precipitation. This reduction in precipitation can cause drier soil, which may lead to more dust, in a possible positive feedback loop. Such occurrences could potentially intensify drought conditions.

In the Mongolian plateau of Inner Asia dust storms are recurring events (Middleton 1991). Climatic variability and anthropogenic activities have led to an increase in dust storm activity in the region (Chen and Tang 2004). Debate continues over the source and changing frequency of dust storms along the northern China-Mongolian corridor (Wang et al. 2004; Natsagdorj et al. 2003). The impact of dust storms continues to be investigated as it affects land degradation and desertification processes in both countries (Wesche and Retzer 2005; Yang et al. 2005). Dust from this desert region becomes an international concern as it affects other nations, such as Japan and Korea, as it moves out to the Pacific Ocean as well as in a southwesterly direction towards Taiwan (Ma et al. 2001; Youngsin and Lim, 2003).

Dust activity is extremely sensitive to many environmental parameters, thus further research can address environmental and human concerns in this densely populated region. The identification methods of major sources in this study will enable us to focus on critical regions and to characterize emission rates in response to environmental conditions. With such methods we will be better able to improve global dust models and to assess the effects of climate change on emissions in the future. This can be done with remote sensing techniques.

Previously satellite products have been useful in characterizing dust transport over the oceans (see Husar et al. 1997; Moulin et al. 1998), though they cannot be readily used to identify sources because of difficulties associated with the large temporal and spatial variability of the albedo of land surfaces. Techniques based on measurements of upwelling thermal (infrared) emissions (Ackerman, 1997), while useful, and suffer from various difficulties including the effects of cloud and water vapor so that it is difficult to detect coherent spatial patterns over dust source regions. It has recently been shown that the Total Ozone Mapping Spectrometer (TOMS) on the Nimbus 7 satellite yielded data that can be used to map the distribution of absorbing aerosols which are largely comprised of black carbon (i.e. soot) emitted primarily from biomass burning regions, and mineral dust most commonly emitted from sources in arid regions but also from occasional volcanic eruptions. The TOMS data show that on a global scale the dominant sources of mineral dust are all located in the Northern Hemisphere, mainly in North Africa, the Middle East, and Central Asia (Herman et al. 1997; Torres et al. 1998).

Satellite imagery clearly shows that dust aerosols often cover very large ocean areas. Indeed, the values of aerosol optical thickness associated with dust transport are much greater than those attributed to pollution aerosols transported from sources in North America, Europe, and Asia; furthermore, the dust plumes cover a much larger area, are more persistent, and occur more frequently than those associated with pollutant aerosols (Husar et al. 1997). Owing to the recognition of the importance of atmospheric aerosol properties (Tegen et al. 1996), interest in developing methods to retrieve such information from satellite data has increased. Several methods have been developed to identify the signal related to the radiative effect of atmospheric aerosols, including single and multiple channel reflectance,

* Corresponding author.

multi-angle reflectance, contrast reduction, polarization, and thermal infrared (TIR) emission (King et al. 1999). Several other dust aerosol models are being used for the daily forecasting of dust storms. These models are similar to the CARMA-Dust model in that they use data from standard weather models such as ETA, NOGAPS or MM5. The University of Malta and the University of Athens use a modified version of the ETA weather model to make dust forecasts over northern Africa. The TOMS aerosol algorithm is described in detail by Herman et al. (1997) and Torres et al. (1998). MODIS satellite sensors can provide more quantitative information on aerosol optical depth and properties - for example aerosol optical thickness, fine model fraction etc. (Kaufman 1997; King et al. 1999; Remer et al. 2005).

Though big dust events occur every spring there is limited research work carried out on dust storm sources in southern Mongolia and northern China. This paper discusses the synergy of MODIS and NOAA satellites for mapping sand storms and their occurrence in some parts of Asia. It has been observed that every year from March to April yellow sand originates from Mongolia and China flies to the North Pacific archipelago and the west coast of America. A dust and sand storm study of such a phenomena has useful applications in the meteorological field.

The distribution of the number of dust storm days occurs mainly in south Gobi region which borders China. The number of annual days with dust storms is less than 5 days over the central and northern Khangai, Khuvusgul and Khentei mountainous areas of Mongolia, 10-17 days over the western area of Great Lakes, and 20-37 days over the desert and the semi-desert areas in Mongolia (figure 1).

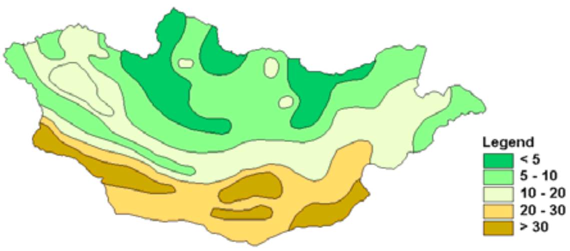

Figure 1. Number of days with dust storms observed in Mongolia. (Source: L.Natsagdorj, D.Jugder)

The highest frequency of dust storms is over three areas in the Gobi Desert in Mongolia. These include the south side of the Altai Mountains, around Ulaan-nuur Lake, and Zamiin-Uud. It should be noted that the distribution of dust storms has coincided well with the distribution of strong wind (L.Natsagdorj, 1982; D.Jugder, 1999) and soil conditions.

Dust storms take on particular importance on the Mongolian plateau because of their significance for the formation of loess in China (Derbyshire et al. 1998). They also appear to have been a major source of the dust in Late Pleistocene ice layers in Greenland (Svensson, et al. 2000). Moreover, according to Kes and Fedorovich (1976), the Tarim Basin has more dust storms than any other location on Earth, with 100–174 per year. There are stations to the northwest of the 750-mm annual rainfall isohyet that have dust storms on more than thirty days in the year (Goudie 1983). These storms can cover immense areas and transport particles to Japan and beyond (Ing 1969; Willis et al. 1980; Betzer et al. 1988). Their frequency in Mongolia is most notable in the southern region of the Gobi, where Zamiin Uud has over 34 dust storms per year (Middleton 1991). Studies of dust loadings (Chen et al. 1999) and fluxes have suggested that there are two main source areas: the Taklamakan and the Badain Juran (Zhang et al. 1998). In all, it has been estimated that about 800 Teragrams of Chinese dust is injected into the atmosphere annually which may be as much as half of the global production of dust (Zhang et al. 1997).

2. APPROACH

We attempted to monitor dust and sand storms using AVHRR/NOAA data from the NOAA receiving station of the National Remote Sensing Center (NRSC) and MODIS/TERRA data from LP DAAC/NASA. For this purpose we used brightness of temperature differences in the thermal infrared bands from AVHRR/NOAA and the emissive bands of MODIS/TERRA. For the monitoring true-color display three bands of MODIS 1 (red), 4 (green) and 3 (blue) by detecting yellow sand when RGB is displayed in figure 2. Brown color represents sand and dust storm. The figure shows dust and sand storms in the northeast Asia, which is in brown color, moving to the North Pacific archipelago. It moves from southeast Mongolia to China's northeast and after 2 days it reaches Korea, Japan and the Japanese sea.

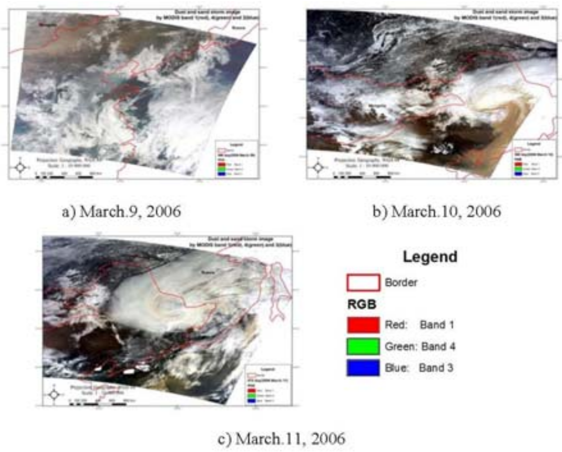

Figure 2. Dust and sand storm true color composite *images* using MODIS data

Brightness temperature difference index (BTDI) of two bands can distinguish dust storms and the density of dust and sand. BTDI is related to the particle size of sand and dust. In this research dust and sand storm images were determined by the following equations.

BTDI =ch32-ch31 by MODIS/TERRA (1)

Here: Ch31：MODIS-31 (10.780µm～11.280µm)

Ch32：MODIS-32 (11.770µm～12.270µm

BTDI = ch4-ch5 by AVHRR/NOAA (2)

Here: Ch4：AVHRR-4 (10.3µm～11.3µm);

Ch5：AVHRR-5 (11.5µm～12.5µm);

Equation 1 was applied to MODIS data for the day's 9-11 March, 2006 for the dust and sand storm distribution over northeast Asia (figure 3) while equation 2 was used for NOAA/AVHRR (figure 4). Equation 1 was applied for MODIS data for March 6 and March 9, 2006 in Mongolia. The GIS layer of wind direction and meteorological stations were used in the

Mongolian area (figure 5). Blue points mark locations of meteorological stations and black characters identify the wind direction (figure 5a). The dust and sand storms area are represented in yellow (low dust) and orange (high dust) color on the derived images from the approach (figure 3-5).

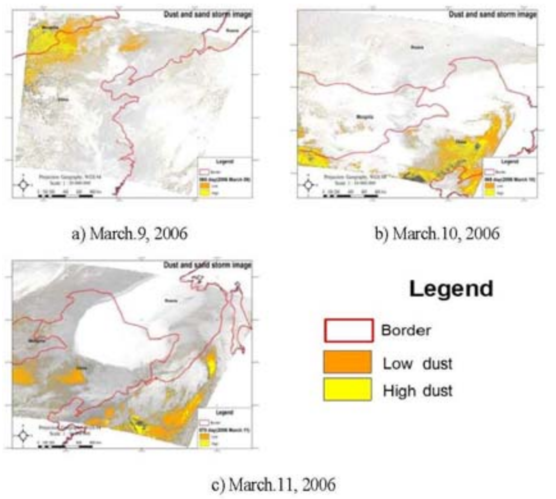

Figure 3. Dust and sand storm images derived from BTDI approach using MODIS data

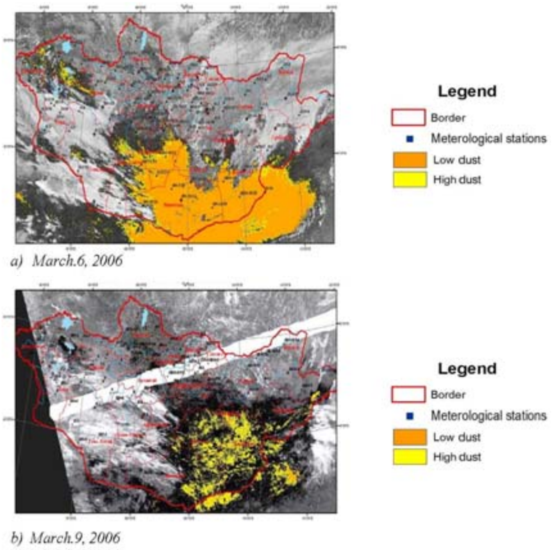

Figure 4. Dust and sand storm images derived from BTDI approach using NOAA/AVHRR data

Digital values of temperature brightness images were converted into centigrade degrees. Selection for the dust storm area was based on brightness temperatures between -9 to 6 C degrees, within the range where most Gobi spring dust events occur. Southwesterly, westerly, northwesterly and northerly winds predominate during dust storms. If wind speed is less than 5 ms-1 a dust storm does not form. Wind speed was between 12-28 ms-1. Wind speed is usually from 6 ms-1 to 15 ms-1 during a dust storm. For the validation of our method we used meteorological station data that was recorded during sand storm occurrence in the study area.

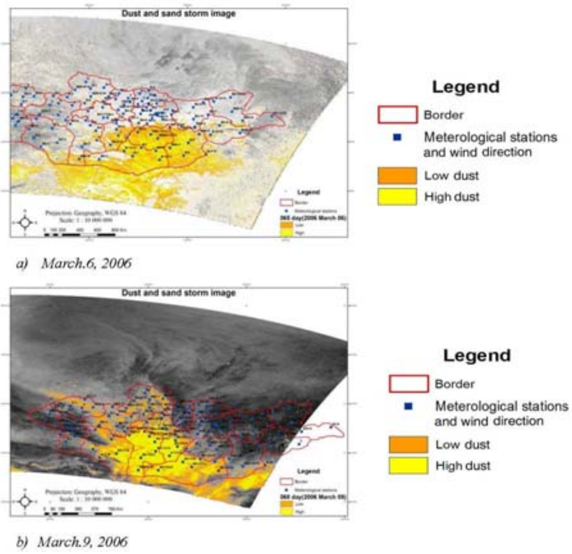

Figure 5. Dust and sand storm images derived from BTDI approach by MODIS data

There are 118 meteorological stations Mongolia; each day a different number of stations were covered by dust storms. Table 1 outlines meteorological stations recording strong wind and describes how many dust storms occurrences are detected according to NOAA AVHRR and MODIS from 6 March to March 9, 2006. On 6 March from twenty-two potential stations seven were used to make records according to AVHRR data. Another twelve stations recorded with MODIS data have results similar to AVHRR in the dust and sand storm area. On 7 March 2006 strong wind was recorded at nine stations but the dust and sand storm area was out of Mongolian territory so data was not available. Daily records on 8 March 2006 showed strong wind at five out of twenty-two stations according to AVHRR data. Another seven stations recorded by MODIS data had similar results in the dust and sand storm area. Of forty-five potential stations that documented dust occurrence in the area on 9 March 2006 ten were used by AVHRR data. The fourteen stations that recorded by MODIS data showed similar results to the dust and sand storm area (table 1). Overall dust storm images derived from MODIS covered more stations than the images from NOAA for the same days.

Wind speed (m/s) / Satellite	**6, March, 2006**								
	12	14	16	18	20	21	22	24	28
NOAA	2	2	1	0	2				
MODIS	4	5	1	1	1				
	8, March, 2006								
	12	14	16	18	20	21	22	24	28
NOAA	1	3	1						
MODIS	0	7	0						
	9, March, 2006								
	12	14	16	18	20	21	22	24	28
NOAA		0	3	2	1	0	1	2	1
MODIS		2	2	3	2	1	0	3	1

Table 1. Meteorological stations recording strong wind according NOAA/AVHRR and MODIS

3. RESULTS

The results of the use of the two thermal infrared bands of AVHRR/NOAA data and emissive band of MODIS/TERRA data were compared with meteorological data from stations in southern Mongolia. The meteorological station data for dust and sand storm days was entered into the GIS format and investigated jointly with weather observed on those days.

Spring time dust and sand storms are common in the Gobi Desert of southern Mongolia and northern China and move to the Pacific Ocean. From the given approach we produced dust and sandstorm maps for the period March 6 to March 9, 2006. The true-color images from MODIS bands of 1(red), 4(green) and 3(blue) were applied for detecting yellow sand (figure 2). Dust and sand storm images were made with GIS layers of wind speed and direction data at the meteorological station. This is most effective for dust and sand storm monitoring and modeling. Further quantitative studies using MODIS/TERRA emissive bands are important for a comparative study with other satellites and ground observation data from Lidar and numerical simulation based on meteorological models.

Many dust sources are associated with areas where human impacts are well documented, for example the Caspian and Aral Seas, the Tigris-Euphrates River Basin, southwestern North America, and the loess lands in China. Nonetheless, the largest and most active sources are located in truly remote areas where there is little or no human activity. Thus on a global scale dust mobilization appears to be dominated by natural sources. Dust sources, regardless of size or strength, can usually be associated with topographical lows located in arid regions with annual rainfall under 125 mm. For this reason we selected the study area in the Gobi. Mapping reveals that the geometry of the dust distributions over specific regions can often be associated with geomorphologic features, in particular topographical lows in arid or semiarid regions, such as the Mongolian plateau.

A synergy between high-resolution MODIS and NOAA data may greatly enhance the operational success of satellite-based dust monitoring and mapping. This study represents an effective application of Remote Sensing techniques to create a dust and sandstorm map of the Mongolian plateau, concentrating on Mongolian station data. In the future information from China and other affected Asian regions can be examined for validation. The next step of dust research over Asia will integrate station data from across the region, and hence such trans-national dust storm studies will greatly contribute to the "Digital Earth" concept.

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