ESTIMATING THE GREATEST DUST STORM IN EASTERN AUTRALIA WITH MODIS SATELLITE IMAGES

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1. INTRODUCTION

On the 23rd of September 2009, Sydney encountered its most severe dust storm in 70 years. That morning, Sydney awoke to a strange red haze. Gale-force winds had brought the red dust from the Lake Eyre Basin, sweeping through half of Australia from the outback to the Australia Capital Territory, New South Wales, and Queensland. The storm also wreaked havoc on the Hunter Valley of NSW, where the dusty air reduced visibility to between 100 and 200 m. The official air quality index for New South Wales also recorded pollutant levels as high as 4,164 in Sydney. A level above 200 is already hazardous (http://www.environment.nsw.gov.au/AQMS/aqi.htm). Dust storms in Australia are not uncommon because of our country's dry condition but are usually restricted to inland areas. Occasionally however, during a widespread drought, dust storms reach coastal areas. Furthermore, Australia is the driest inhabited continent; only Antarctica is drier. When prevailing drought conditions that reduce vegetation cover is added to aforementioned factors, the soil surface is at its most vulnerable to wind erosion. The dust storms stripped valuable topsoil from primary eastern farmlands. At one stage up to 75,000 tonnes of dust per hour was blown across Sydney and dumped in the Pacific Ocean, according to Australian ABC news report. It is estimated that the dust storms stripped 5 million tonnes of valuable farmland topsoil. But the exact amount of dust dumped on Sydney is still being calculated. Scientists are reluctant to directly link climate change with extreme weather events such as storms and drought, saying these fluctuate according to atmospheric conditions, but green groups link the two in their calls for action. Regardless of the debate on climate change, it remains a challenge to estimate the dust mass efficiently and accurately using space borne images in order not only to monitor these storms but also to caution public to reduce its harmful effect.

The authors have researched MODIS satellite optical imagery in order to monitor this severe dust storm, and have extracted the information from the satellite images through computing the brightness temperature difference of two thermal infrared channels of the MODIS image. This method is effective in separating dust and clouds. The mass of the dust plume, therefore, has been estimated using a retrieval model. However, the result of the mass is believed to be under-estimated because the extent of dusts was too great to be covered by a single MODIS image.

2. **METHODOLOGY**

Remote sensing is a powerful technique for studying dust storms over a great spatial area [1]. Sensors on polar orbiting or geostationary satellites detect radiances of Earth surface and contents in atmosphere through different spectral channels, which can then identify dust storms using optical satellite image based on the radiation and scattering characteristics of dust particles. Furthermore, the physical characteristics of dust storms can be determined by analyzing those remote sensing images [2]. That is, the aerosol optical thickness and extent can be estimated using the image acquired by Advance Very High Resolution Radiometer (AVHRR) [3] and Moderate Resolution Imaging Spectroradiometer (MODIS) [2]. Also, the dust storms have been able identified from satellite images of visible and near-infrared (VIR) and thermal infrared (TIR) images.

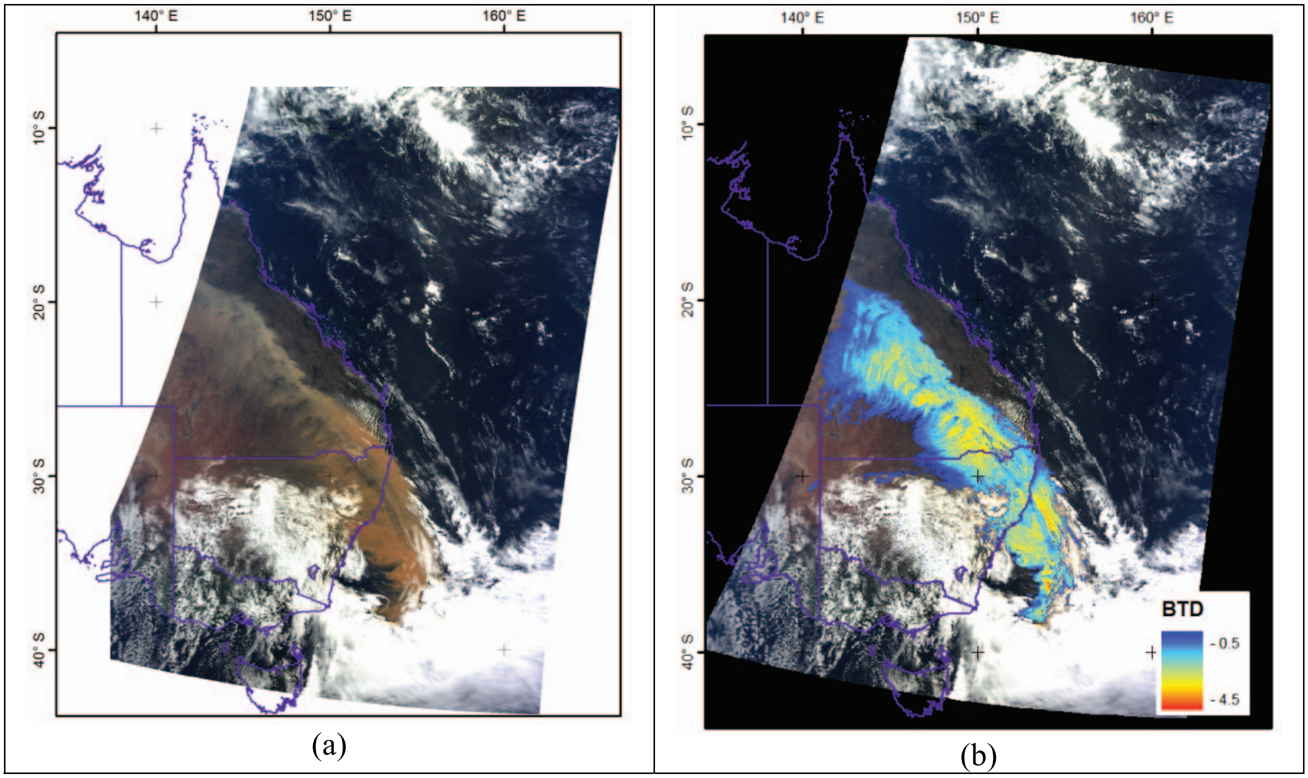
TIR algorithm, for measuring the dust particle size and estimating the dust mass, is using the AVHRR or MODIS data acquired in the wavelengths of 11 and 12μm. The concept of the algorithm is similar to that applied in the retrieval of cirrus clouds by the Brightness Temperature Difference (BTD) [4, 5]. But it has been demonstrated that the detection of dust storm using MODIS data is optimized by using the data acquired in 8.6μm [6].

Specifically in our study, we use MODIS data to monitor the dust storm in Australia on 23rd September 2009. The brightness temperature difference using TIR imagery was applied in the data processing to generate the physical parameters and mass of the dust storm. The three bands TIR imagery acquired at 8.6, 11 and 12 μm were used to simulate a forward radiative transfer model, and so estimate the total mass and particle size of the dust storm [2].

Brightness temperature is a measure of the energy emitted by the particles in the air, such as dusts or clouds, or land surfaces. For the MODIS data, the brightness temperature at the wavelength of 11.03μm ($\boldsymbol{B_{11}}$) in channel 31 represents the dust storm top temperature. That is, the lower the value of $\boldsymbol{B_{11}}$, the higher the altitude of dust storm. In the meantime, the brightness temperature at the wavelength of 12.02 μm ($\boldsymbol{B_{12}}$) in channel 32 represents the temperature of the earth surface. In general, a dust storm contains large amounts of dust and sand particles. Mineral dusts have a unique spectral signature from those given by clouds or other gases. Silicate dusts tend to cause a negative brightness temperature difference between 11μm and 12 μm. The silicates absorb the shorter wavelengths while the ice and water particles absorb longer wavelengths in the spectral range of 10.5 – 12.5μm. Thus, the brightness temperature difference (BTD = $\boldsymbol{B_{11} - B_{12}}$) tends to show a negative condition from dust particles. Through this, the tracking and mapping of dust storms is made possible.

3. RESULTS

The MODIS visible image acquired on 23rd September 2009, as shown in Figure 1(a), indicates that the dust plume is more than 500 km wide and 2,000 km long. The dust front covers from northern Queensland to southern New South Wales and the southern part extended and deposited into the Tasman Sea. The BTD method, similar to volcanic clouds cover range and sandstorms mass retrieval by [7, 8], have been applied here in order to extract the coverage of the dust recorded by MODIS on 23 September 2009 at around 10am local time in Australia. The BTD (B11 – B12) result of MODIS from the channels of 31 and 32 is shown in Figure 1(b). Please note that the negative BTD values indicate the coverage of the dust storm.



(a) (b)

Figure 1.(a) MODIS RGB image (channel 1, 4, 3) shows the 23 September 2009 dust storm, acquired on 23 September 2009 at 00:00 to 00:05 UTC; (b) MODIS BTD result of the image (a).

It can be seen from Figure 1(a), the dust storm was moving to Queensland then to the Tasman Sea. The dust storm coverage was extracted using negative BTD value and overlaid on the RGB image shown in Figure 1(b). In order to estimate the dust mass, necessary assumptions have been made, e.g., the dust particles are spherical in uniform size and monodisperse within each pixel. Furthermore, the complex refractive index describing the interaction of the radiation and matter has been given the same as for the Sahara dust. Thus, final retrieval result suggested a total area of 0.975 million km^2 covered by the dust and the density of dust was about 3.23 tons/km^2. Therefore, in this image covered area, the dust mass has been estimated as 3.15 million tons, although we have noticed that a report for 5 million tons of erupted dust.

4. CONCLUDING REMARKS

This research demonstrated the capability of using the optical satellite imagery to monitor the dynamics of dust storms, where the spatial extent of the dust storm can be estimated using brightness temperature difference of two thermal infrared channels of MODIS. Fundamentally, a dust storm retrieval model was computed based on the information extracted from the MODIS imagery of thermal infrared. This retrieval model was then used to estimate the mass of the dust plume. The results suggested that at least 3 million tonnes of topsoil was blown away as dust, which blanketed half of Australia as captured by MODIS on 23 September. We believe this mass is under-estimated because the extent of the dusts is too large to be fully covered by a single MODIS image due to the limited swath width of satellite imagery. Also, some of the parameters, such as dust diameter, refraction index, used in the preliminary retrieval model were based on other case studies of dust storm in the past. More localized modeling parameters could be estimated through future satellite images in collaborating with ground observation in Australia, which will then be used to further improve the accuracy and immediacy of results.

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