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Research Paper

The brightness temperature adjusted dust index: An improved approach to detect dust storms using MODIS imagery

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ABSTRACT

Moderate Resolution Imaging Spectroradiometer (MODIS) imagery provides a good data source for timely and accurate monitoring of dust storms. However, effective MODIS-based dust indices are inadequate. In this study, we proposed an improved brightness temperature adjusted dust index (BADI) by integrating the brightness temperatures of three thermal infrared MODIS bands: $band_{20}$ (3.66–3.84 μm), $band_{31}$ (10.78–11.28 μm) and $band_{32}$ (11.77–12.27 μm). We used the BADI to monitor several representative dust storms over the Northeast Asia between 2000 and 2011. When compared to commonly used MODIS-based dust indices, such as the brightness temperature difference index in $band_{32}$ and $band_{31}$ ($BTD_{32\text{-}31}$) and the normalized difference dust index (NDDI), the BADI captured the spatial extent and density of dust storms more accurately. The BADI detected dust storm extent with an overall accuracy >90%, which was 7% and 29% higher than the results derived from $BTD_{32\text{-}31}$ and NDDI, respectively. The BADI also demonstrated good agreement with the density indicator of MODIS Deep Blue Aerosol Optical Depth ($R^2 = 0.59$, $P < 0.01$). We suggest that the BADI is an effective tool to monitor large-scale dust storms.

1. Introduction

With the definition of the World Meteorological Organization, a dust storm is 'strong winds that lift large quantities of dust particles, reducing visibility to between 200 and 1000 m' (WMO and UNEP, 2011). It is often quantified by two principal characteristics of the dust extent and dust density (Yang et al., 2001;WMO and UNEP, 2011). Dust storms are hazardous weather events that commonly occur over drylands worldwide (Yang et al., 2001). Dust storms aid in nutrient redistribution and geochemical circulation over large distances and encompass a variety of substances such as bacteria, organic pollutants and trace elements (Mahowald et al., 2005; Ro et al., 2005; Erel et al., 2006; Schulz et al., 2012; Sanchez et al., 2013; Bozlaker et al., 2013). Dust storms directly influence climate with respect to the absorption and reflection of solar radiation (Bishop et al., 2002; Choobari et al., 2014; Gunaseelan et al., 2014). Dust storms also reduce visibility, which can be a major hazard for aircraft and motorists (Yang et al., 2001). In addition, dust storms confer an increased risk of health-related problems such as respiratory disease (Chen et al., 2004; Honma et al., 2004; Kaiser, 2005). Therefore, it is imperative to detect dust storms in a timely and accurate manner.

A variety of approaches for dust storm monitoring have been proposed and evaluated. These include field observations (Holben et al., 1998; Christopher and Jones, 2010; Kurosaki et al., 2011), model simulations such as the National Oceanic and Atmospheric Administration (NOAA) Hybrid Single-Particle Lagrangian Integrated Trajectory model (Lee et al., 2010) and remote sensing (Banks et al., 2013). Compared with other approaches, remote sensing is becoming one of the most popular methods to detect dust storms at large scales due to its ability of efficient global coverage (Takashima and Masuda, 1987; Brindley and Russell, 2006; Schepanski et al., 2012). In particular, Moderate Resolution Imaging Spectroradiometer (MODIS) imagery is widely used to detect dust storms because of its high spectral and temporal resolution (Kaufman, 2005; Zhang et al., 2008; Karimi et al., 2014; Jafari and Malekian, 2015).

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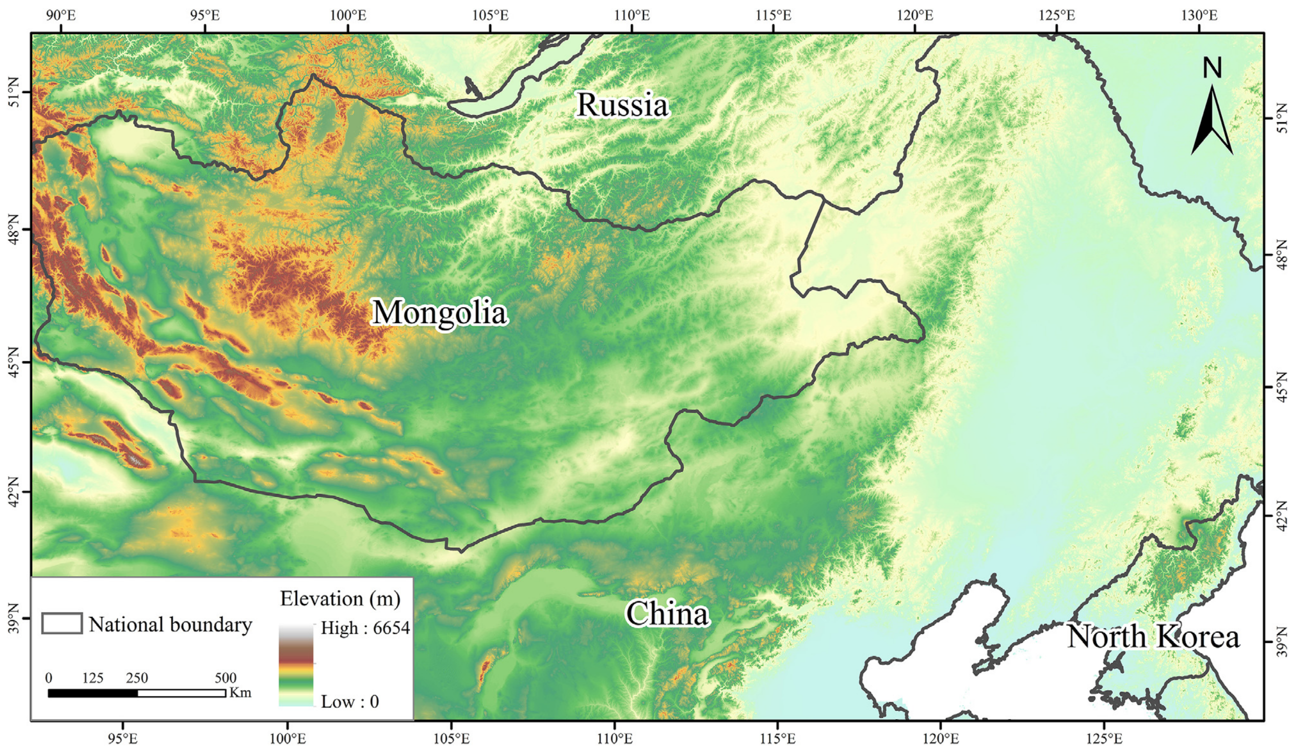

Fig. 1. The study area.

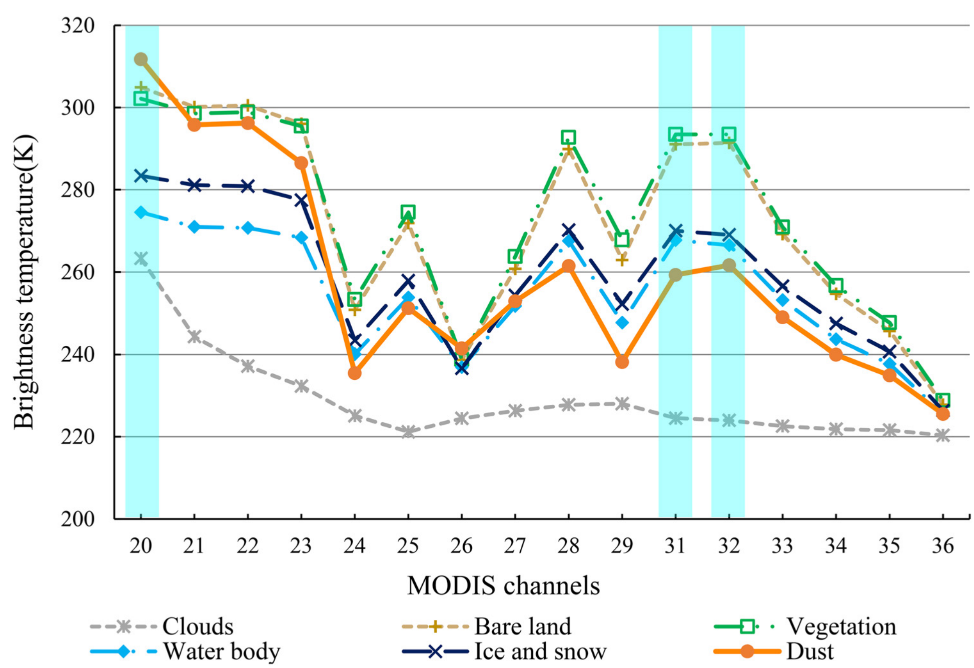

Fig. 2. Moderate Resolution Imaging Spectroradiometer (MODIS) brightness temperature features.
Note: $Band_{20}$ represents the wavelength range 3.66–3.84 μm, $Band_{31}$ 10.78–11.28 μm, and $Band_{32}$ 11.77–12.27 μm.

Several MODIS-based dust indices have been developed to detect dust storms (Takashima and Masuda, 1987; Miller, 2003; Qu et al., 2006; Jafari and Malekian, 2015). Among them, brightness temperature difference (BTD) and normalized difference dust index (NDDI) are two widely used indices (Table 1). The BTD index, originally defined by Ackerman (1989, 1997), has been widely used for MODIS bands with comparisons between $band_{20}$ (3.66–3.84 μm) and $band_{31}$ (10.78–11.28 μm) – '$BTD_{20\text{-}31}$' – and between $band_{32}$ (11.77–12.27 μm) and $band_{31}$–'$BTD_{32\text{-}31}$' (Huang et al., 2007; Zhang et al., 2008; Baddock et al., 2009). $BTD_{20\text{-}31}$ indicates the depth of dust storms and clearly differentiates between dust and bare land; however, it cannot distinguish between clouds and dust storms (Ackerman, 1989). $BTD_{32\text{-}31}$ is able to differentiate dust and clouds; this allows for locating and tracking dust storm initiation, but cannot easily be used to quantify dust density (Hao and Qu, 2007). Unlike BTD, the normalized difference dust index (NDDI) is a visible and near-infrared data-based index. It is based on the observation that the reflectance of dust generally