Identification of hydrological controls on dust emissions from Xilingol Grassland of Inner Mongolia, China

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Abstract. In view of various impacts on biosphere and possible cross-regional environmental problems, dust attracts global concerns. We employed multiple spatial resolution satellite images to identify dust sources and the relevantly hydrological land covers. We used true-colour composite images of MODIS to obtain the preliminary information on dust emissions and then distinguished the land covers of dust sources in Landsat images of Xilingol Grassland. The study found that hydrologically associated land covers, such as ephemeral lakes, bajadas, ephemeral river beds, dry lakes and their margins, dominated dust emission areas. Factors responsible for aeolian dusts are from both natural and human aspects. Besides abnormal weather phenomena, factors contributed to dust emissions include ecological and water balance destructions caused by human activities in alkali and coal exploitations and water pumping from rivers or lakes for agriculture and industry. This study will help grassland manager combat land desertification and control dust emission in the future.

1. Introduction

Aeolian dust, in meteorology, is a weather phenomenon that strong winds entrain small soil particles into the atmosphere. The effects of dust activities lie in many aspects [1], including weather and climate, industry, agriculture and marine productions, land formation, animal and plant lives, and human health and civilization [2]. Many conventional methods, such as physical and chemical analyses of dust particles [3], meteorological analysis of dust episode [4] and visibility changes [5], are used to observe aeolian dust phenomena, but it is difficult to precisely describe the whole dust weather process. Remote sensing is now a unique, and the most effective method for monitoring aeolian dusts. Many sensors or satellites have been applied to the study on dust phenomena, such as TOMS (Total Ozone Mapping Spectrometer) [6], Sea WiFS (the Sea-viewing Wide Field-of-view Sensor) [7], AVHRR (Advanced Very High Resolution Radiometer) [8], METEOSAT (meteorological satellite) [9], geostationary satellite, FY-2C geostationary meteorological satellite [10] and MODIS (Moderate Resolution Imaging Spectroradiometer) [11]. Many dust detection algorithms were developed to study aeolian aerosol [11]. Remote sensing technology provides conveniences for aeolian dust research, as it possesses many merits in dust information retrievals, including the synchronous and large-area observations, data integration potentials and easy accesses.

Xilingol Grassland is located in Inner Mongolia Plateau where the lands degrade severely. Desertification emerged in the grassland, such as the formation of Otintag Sandy Land which was
covered by lush vegetation in the past, inducing severe sandstorms damaging people's health. Dust emissions are assumed to be controlled by human activities and environmental factors. In fact, dust often comes from some small but relatively consistently active dust-producing spots in large homogeneous areas [12]. Active dust sources, hot spots, have been identified in the study area [5, 11, 13], dry lakes, river beds, playas, and their margins have been recognized as major contributors to dust emission in Inner Mongolia, but main land covers responsible for dust emissions in Xilingol Grassland still needs identifications and summarizations. Dust weather monitoring in Xilingol Grassland has an important significance in the people's health care, social stability, and the sustainable development of eco-environment. We used MODIS composite images to observe dust activities, and then analyzed Landsat images of active dust sources to identify their land covers. The objective of this study is to provide theoretical and decision-making basis for desertification combat and dust control in the management of grassland ecological environment.

2. Data and methods

2.1. Study area
Xilingol Grassland (central coordinates, 44N, 116E) lies in Xilingol League (the middle of Inner Mongolia Autonomous Region, China), with a total area of 202 580 km², of which 180 000 km² is high-quality natural grasslands. The study area includes 12 administrative regions (Figure 1). Located in the mid-temperate semi-arid and arid continental monsoon climate zone, Xilingol Grassland has four distinct seasons, the climate is cold, windy and dry. Annual precipitation northwest-southeastwards increased from 150 to 400mm. Westerly wind prevails with an average magnitude of 3.5–4.0m/s [14]. Otintag Sandy Land is in the south of the study area, where is recognized as the main dust source region [11, 13, 15].

2.2. Data and methods
MODIS L1B data (1 km spatial resolution) were used to observe the dust emission, transportation and deposition. The data were downloaded from LAADS (the Level 1 and Atmosphere Archive and Distribution System, https://ladsweb.modaps.eosdis.nasa.gov/), covered 98 dust events captured from January, 2000 to June, 2018, including all the dusts emitted from Xilingol Grassland [5, 11, 13].
Landsat data (30 m spatial resolution; Landsat 8, Operational Land Imager sensor) were used to identify the specific sources of dusts. Satellite remote sensing of aeolian aerosols can separate the dust from water, land, and cloud. To quickly check dust emissions in the last 19 years, we used true-color composite images of MODIS band 1 (0.62-0.67 μm), 4 (0.545-0.565 μm) and 3 (0.459-0.479 μm) to visually display and to interpret dust information, and then overlaid high spatial resolution Landsat image to identify the land covers of dust sources.

3. Results

3.1. Identification of dusts in colour composite images
MODIS L1B true-color images captured the dust emission and transport during May 10-12, 2011 (figure 2). In the images, the cloud is white, the land under clear sky is dark brown and the dust is tan with feathery texture (figure 2b). The dust blew off the southeast of Mongolia on May 11, 2011, appearing as an opaque tan blur over the southeast of Mongolia and the large parts of Xilingol League, Inner Mongolia, China. As other dusts from this region, the dust moves in an anticlockwise direction. The dust plumes originated from the southeast of Mongolia and the east of Inner Mongolia, China, transported eastwards and impaired the air quality in southeastern Mongolia and northeastern China (Inner Mongolia, Jilin and Liaoning provinces) [5].

![Figure 2. Monitoring of a dust event using MODIS L1B data.](image)

3.2. Remote sensing monitoring of dusty weathers using MODIS data
In 2000-2018, dusty days were more frequent during 2000-2002, 2005-2007 and 2016-2018 but considerably less in 2003, 2009-2010 and 2013-2014 (figure 3). Dusty weathers have an obvious
seasonal pattern. More dusts occurred in March-May (25.5% in March, 36.7% in April and 16.3% in May), and only 21.5% in the other months. Dusty days in spring, summer, autumn and winter accounted for 78.6%, 3.0%, 6.1% and 12.3% of the total number, respectively.

![Graph showing seasonal pattern of dust events](image)

**Figure 3.** Dusty weathers observed by MODIS in 2000-2018.

### 3.3. Land cover identification of dust sources

![MODIS image of dust emission](image)

**Figure 4.** MODIS image of the dust emission (May 4, 2001) and the corresponding hot spots (ephemeral lakes) in Landsat image.

![MODIS image of dust emission](image)

**Figure 5.** MODIS image of the dust emission (November 5, 2005) and the corresponding hot spots (bajadas) in Landsat image.

![MODIS image of dust emission](image)

**Figure 6.** MODIS image of the dust emission (May 4, 2001) and the corresponding hot spots (dry ephemeral rivers) in Landsat image.

Through classification of hotspot land covers of Landsat images corresponding to typical dust sources identified by MODIS data, several hydrologically associated lands, such as ephemeral lakes (figure 4),
bajadas (figure 5), ephemeral river beds (figure 6), dry lakes (figure 7) and their margins, dominated land covers recognized as active dust sources in the study area. All these places are located in sedimentary environments where sediment accumulates by ephemerally flooding.

4. Discussion and conclusions

Using remote sensing and GIS (Geographic Information System) techniques, we could first identify the main dust sources by visual interpretation of MODIS color composite images, and then determine the land covers of dust sources on high resolution Landsat images by overlay analysis.

Spring is a frequently dusty season in Xilingol Grassland [5]. Several facts explain the frequent occurrences of dust storms in spring, including wind speed, temperature and precipitation [16-18]. First, the study area is in the temperate semiarid-arid continental monsoon climate zone, cold air outbreak is frequent, the wind is strong, and the windy days are more concentrated in spring. Second, the temperature rises rapidly in spring, soil thaws, and the ground is unevenly heated because the underlying surfaces are different in nature, forming an unstable atmospheric stratification. This might induce the strong development of cyclones and cause dust outbreaks. Third, precipitation is less in spring but evaporation is huge, dry and loose surfaces without vegetation cover could not reduce wind speed. As a result, topsoil could be easily blown off into the air.

Analysis on dust source regions ascertains that hydrologically associated land covers, such as ephemeral lakes and lake bed [19], bajadas, ephemeral river beds, dry lakes [11] and their margins, dominated dust emission areas in Xilingol Grassland. Dust sources occurred on sand sheets, sand dunes, loess, playa and alluvial in West Texas and eastern New Mexico, USA [19]. Factors responsible for aeolian dusts are from both natural and human aspects [11, 19]. Natural factors include weather conditions, abnormal weather phenomena, etc., and human factors include ecological balance destruction, water resource abuse, land desertification caused by irrational human production and development activities. Anthropogenic influence on the spatial pattern of observed dust sources is strong [18]. Unreasonable human development and utilization of mineral [5] and water resources (water system destroy caused by alkali and coal exploitation, and water pumping from rivers or lakes for agriculture and industry) might produce dust sources, indicating that human activities are also responsible for dust emissions.

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