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Modelling of sand/dust emission in Northern China from 2001 to 2014

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ABSTRACT

Wind erosion is a major contributing factor to soil degradation and environmental pollution. As a hot spot of wind erosion, Northern China suffers from severe wind erosion hazards. Besides, there is an ongoing controversy regarding the magnitudes of sand/dust emissions of anthropogenic sources. To understand the mechanism of soil degradation and environmental pollution caused by wind erosion, and to resolve the controversy whether sand/dust emissions is from natural or anthropogenic sources in Northern China, accurate spatio-temporal distributions of sand/dust emission should be obtained. Herein, a wind erosion model with a high spatio-temporal resolution was developed and employed to identify the sand and dust emissions of areas with different land cover types. The sand and dust emission hot spots from 2001 to 2014 were mainly distributed in the Gashun Gobi and Kumutage Deserts, those are all natural areas. In these regions, the average sand and dust emissions exceeded 10,000 kg/m/y (year) and 240 g/m^2/y, respectively. The intensities of sand and dust emissions demonstrated significant decreasing trends during this time. According to Moderate Resolution Imaging Spectroradiometer (MODIS) land cover data, the average sand/dust emission rates in natural sources were much higher than that in anthropogenic areas, e.g. from 2001 to 2014, the average annual dust emission of Northern China was about 130 Tg/y, and only approximately 3.7% of dust emissions originated from anthropogenic areas. Dust deflation correspondingly caused the entrainment of soil nutrients into atmosphere and result in soil degradation. Our results also show that the Soil Organic Carbon (SOC) loss due to wind erosion in Northern China was about 0.9 Tg/y and that 32.5% and 7.5% of the SOC loss originated from grasslands (including woody savannas, savannas, and grasslands) and farmlands (including croplands and cropland/natural vegetation mosaics), respectively. With regard to such severe sand and dust emissions, we believe that the results of this study could provide valuable information for the creation of strategies to cope with wind erosion hazards and measures to control the extent of wind-blown sand. In addition, the proposed model could be of interest to ecological and environmental researchers.

1. Introduction

Wind erosion is a common phenomenon that occurs in many arid and semi-arid regions (Goudie, 1983; Liu, 1985; D'Almeida, 1986; Gillette and Hanson, 1989), and approximately 28% of the global land area experiences wind erosion (Oldeman, 1994; Callot et al., 2000; Prospero et al., 2002; Webb et al., 2006). Wind erosion constitutes a major contributing factor to soil degradation by changing the soil texture and nutrient content through the entrainment of fine particles (i.e., dust) enriched in nutrients that facilitate the growth of vegetation (Larney et al., 1998; Lee, 1999; Warren et al., 2005; Wang et al., 2006a; Berhe et al., 2018). In addition, dust particles carrying soil nutrients can travel thousands of kilometers, thereby impacting the global biogeochemical cycle (Webb et al., 2012). According to an estimation provided by Shao et al. (2011), approximately 2000 Tg of dust is emitted globally into the atmosphere each year. However, the dust emissions of East Asia determined through different model estimations are highly uncertain, and the emission rates range from 27 to 727 Tg/y (Huneeus et al., 2011). Much of the uncertainty in these models has originated from limitations in model parameterization due to lacking of high resolution data. Therefore, it is highly important to develop a wind erosion model with a high spatio-temporal resolution that can accurately estimate sand/dust emissions.

Wind erosion processes are highly sensitive to variability in soils, weather, vegetation, topography, etc. (Martínez-Graña et al., 2014a; Webb et al., 2017). Therefore, the most spectacular wind erosion examples occur in arid and semi-arid areas because of the loose soil texture, the low moisture content of the topsoil and the sparsity of

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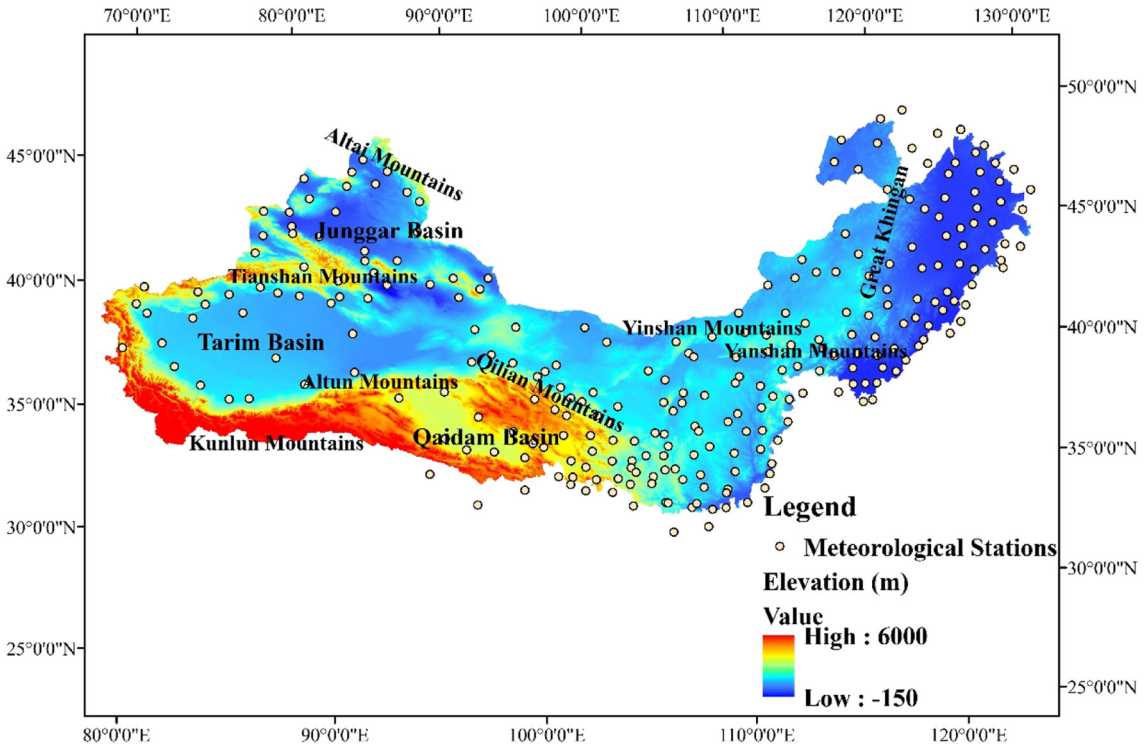

Fig. 1. Sketch map of Northern China.

vegetation therein (Martínez-Graña et al., 2014b, 2015). Human activities over recent years have increased the frequency and magnitude of wind erosion processes through changed land use types (Dostal et al., 2006; Funk and Reuter, 2006; Wang et al., 2006b, 2017). Some researchers have claimed that human activities have significantly enhanced wind erosion through over agricultural exploitation and over grazing (Y. Wang et al., 2006). However, some model studies suggested that agricultural dust contributes < 10% of the global emissions (Tegen et al., 2004), although satellite-based estimates indicated a contribution on the order of 20–25% with strong regional variations (Ginoux et al., 2012). Consequently, the emissions of sand and dust from anthropogenic resources still constitute a contentious research topic with large uncertainties at the regional scale. To address this issue, we developed a wind erosion model with a high spatio-temporal resolution (1 km, 10 days) to identify the sand/dust sources in Northern China and accurately calculate the sand and dust emissions in anthropogenic and natural areas.

As a hot spot of wind erosion, Northern China encompasses extensive arid and semi-arid regions with several topographic depressions that are recognized as sand/dust sources (Prospero et al., 2002). Under the influences of climate change, frequent and sustained droughts in this region have triggered enhanced wind erosion processes (Wang et al., 2008). Moreover, a series of destructive, eco-environmental overexploitation projects, including excessive deforestation, overgrazing, over farming, and urbanization, have exacerbated environmental deterioration and land degradation in recent years. The most obvious manifestation of land degradation in China is aeolian desertification, which has extended the area of land that is being exposed to wind erosion (Wang et al., 2004; Li et al., 2016a, 2016b; Xue et al., 2017). In Northern China, for example, the total area of aeolian desertification was $3.759 \times 10^5\,km^2$ in 2011 (Wang et al., 2011; Han et al., 2015; Song et al., 2015; Yan et al., 2015). In 2001, the Chinese Ministry of Water Resources issued the Second National Survey of Soil Erosion Reports of China, which included the spatial distribution of the wind erosion intensity (Zhang et al., 2001). However, the spatio-temporal distribution of wind erosion intensities during the 1990s detailed in the report is evidently different from the current distribution as a consequence of climate change and human activities. Therefore, to investigate the sand/dust emissions of natural and anthropogenic areas in Northern China during the early 21st century, we must first obtain an accurate spatio-temporal distribution of wind erosion. Besides, due to the different particle sizes between sand and dust, the sand and dust emissions represent different entrainment and transport mechanisms, and their transport distances also much different. For instance, dust could transport thousands of kilometers downwind, whereas, sand only several kilometers at most. Herein, the influences of dust emission are local and regional or even global, whereas the influences of sand emission are mainly local. However, using wind erosion density data issued by the Chinese Ministry of Water Resources, we are unable to distinguish between these two processes. Consequently, we require a model capable of separately calculating sand and dust emissions to resolve this problem.

Accordingly, our main objective is to develop a new wind erosion model possessing a high spatio-temporal resolution that can calculate the sand and dust emissions, independently. Using this model, the wind erosion intensities (i.e., sand and dust emissions) in areas with different land use types were identified according to land cover data. We believe our study can provide data supporting for understanding the mechanism of land degradation, and some credible evidence to resolve the longstanding controversy regarding whether sand/dust emissions primarily originate from natural or anthropogenic areas. The distribution of wind erosion intensities also could provide some valuable information for the generation of strategies to cope with wind erosion hazards and measures to control sand-blown emissions.

2. Materials and methods

2.1. Study area

In this study, the coverage of the Three-North Shelter Forest Program (TNSEP), which encompasses both arid and semi-arid areas that are subjected to severe wind erosion, was used to delineate