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Simulations of wind erosion along the Qinghai-Tibet Railway in north-central Tibet

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ABSTRACT

Wind erosion along the Qinghai-Tibet Railway causes sand hazard and poses threats to the safety of trains and passengers. A coupled land-surface erosion model (Noah-MPWE) was developed to simulate the wind erosion along the railway. Comparison with the data from the ^{137}Cs isotope analysis shows that this coupled model could simulate the mean erosion amount reasonably. The coupled model was then applied to eight sites along the railway to investigate the wind-erosion distribution and variations from 1979 to 2012. Factors affecting wind erosion spatially and temporally were assessed as well. Majority wind erosion occurs in the non-monsoon season from December to April of the next year except for the site located in desert. The region between Wudaoliang and Tanggula has higher wind erosion occurrences and soil lose amount because of higher frequency of strong wind and relatively lower soil moisture than other sites. Inter-annually, all sites present a significant decreasing trend of annual soil loss with an average rate of $-0.18\,kg\,m^{-2}\,a^{-1}$ in 1979–2012. Decreased frequency of strong wind, increased precipitation and soil moisture contribute to the reduction of wind erosion in 1979–2012. Snow cover duration and vegetation coverage also have great impact on the occurrence of wind erosion.

1. Introduction

Desertification is one of the main environmental problems caused by climate change and human activities in arid, semi-arid and semi-humid areas (Gao et al., 2015a,b; Wang et al., 2006; Yang et al., 2005; Zhao et al., 2005). As a main type of desertification, aeolian desertification is characterized by soil loss driven by wind (Dong et al., 2009; Zhao et al., 2005). In cold regions, the influence of aeolian desertification on the hydrological cycles and ecological systems is more complex because of the impacts of snow, permafrost and glaciers (Wang et al., 2014; Xue et al., 2009; Yang et al., 2004).

The Qinghai-Tibet Plateau (QTP) is the highest plateau in the world with an average elevation over 4000 m. The Qinghai-Tibetan Railway is a huge project extending from the central-north to central-south of the QTP, serving as a main transportation in Tibet (Fig. 1) (Cheng and Wu, 2007). The railway from Golmud to Lhasa is one of the most difficult railways to build in the world which started to construct in 2001 and completed in 2005. Strong sand hazards were found threatening the railway's operation safety (Xie et al., 2014), though many sand prevention measures have been taken since the railway was constructed (Wang et al., 2014; Xie et al., 2014). Meanwhile, the QTP has been experiencing a faster pace of warming than global average at the same latitudes in the past decades (Liu and Chen, 2000; Liu, 2000). Snowpack and permafrost at shallow soil layers melt faster in warmer climate, and this probably results in a less covered and drier soil surface (Xue et al., 2009; Yang et al., 2004). Under such a hypothesis, the Qinghai-Tibet Railway would be threatened by more frequent and more severe sand hazards under future climate warming. Previous assessments reported an intensified desertification in late 1990's in northern QTP (Dong et al., 2009; Li et al., 2016; Xue et al., 2009), while evidences also revealed a reverse change in southeastern QTP (Gao et al., 2015b; Harris, 2010). In central-western QTP, the results of Gao et al. (2015a,b) showed a significantly wetting trend during 1979–2012 using station observations. However, the desertification variation trend along the railway is still unknown and need to explore.

Aeolian desertification in arid and semi-arid agricultural areas and pastureland has been widely analyzed using field observations, wind tunnel experiments, and numerical modeling (Cong et al., 2016;

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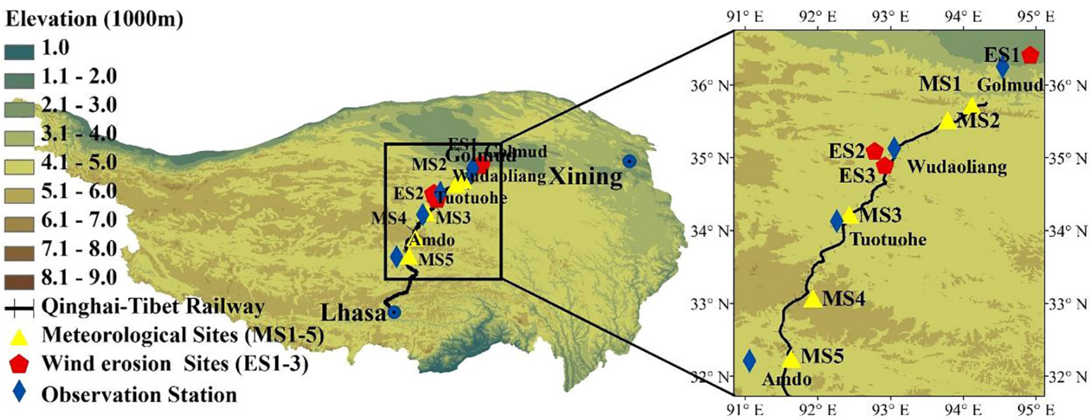

Fig. 1. Study area (cut from the Chinese Digital Elevation Model (DEM) Data Set of 1 km Revolution (http://westdc.westgis.ac.cn)).

O'Loingsigh et al., 2014; Sharratt and Vaddella, 2012; Sherman and Li, 2012; Wang et al., 2015; Zhang et al., 2015). However, few studies were done to explore the aeolian desertification condition in QTP. Yan et al. (2001) and Shao et al. (2011) evaluated the wind erosion conditions in several regions of QTP using the ^{137}Cs technique but observation sites were limited. Thus, the Geographic Information System (GIS) technology was applied to monitor the extent of wind erosion in the southeastern and northern QTP (Dong et al., 2009; Li et al., 2016). Compared with the routine measurement approaches, numerical modeling is also a powerful method to quantify the wind erosion and its responses to the fast warming in recent decades.

The first generation of wind erosion model is simple equations, such as the Wind Erosion Equation (WEQ) and the Revised Wind Erosion Equation (RWEQ) (Fryrear et al., 2001a,b; Vanpelt and Zobeck, 2004; Wagner, 2013). Then the modular wind erosion model—the Wind Erosion Prediction System (WEPS) was developed by combining the Revised Wind Erosion Equation (RWEQ) with other achievements in wind erosion research (Fryrear et al., 2001a,b; Hagen, 2008, 2004; Wagner, 2013). Previous studies showed that the WEPS performs well in the prediction of sand storm and wind erosion events over the agricultural land surface (Chung et al., 2013; Cong et al., 2016; Feng and Sharratt, 2009; Funk et al., 2004; Gao et al., 2013; Hagen, 2004; Hagen et al., 2009; Pi and Sharratt, 2017; Pi et al., 2017, 2016; Visser et al., 2005). However, many studies showed that the simulation accuracy of wind erosion models was strongly influenced by the uncertainties of threshold friction velocity (Chung et al., 2013; Feng and Sharratt, 2009, 2007; Gao et al., 2013), which is highly sensitive to surface hydrological processes, such as the soil moisture. Previous studies have indicated that soil moisture is not well present by wind erosion models, such as the WEPS (Chung et al., 2013; Visser et al., 2005). This is probably associated with the highly simplified climate and hydrology modules of WEPS. Compared to wind erosion model, the land surface models have detailed physical parameterizations for land surface processes. Thus, it simulates the main parameters of land surface well, such as the temperature, and moisture for canopy, snow and soil. Applying results of land surface models also showed good performance in simulating hydrological processes in the upper soil layers (Barlage et al., 2015; Chen et al., 2014b; Gao et al., 2015a; Niu et al., 2005). Combining the advantages of the land surface model and the wind erosion model, a coupled land-surface wind-erosion model is expected to improve the wind erosion simulation accuracy.

The main objectives of this study are: 1) to develop a coupled land-surface wind-erosion model for aeolian desertification simulations; 2) to analyze the aeolian desertification in terms of its spatial distribution, annual variability, and responses to the climate change in recent decades along the Qinghai-Tibetan Railway; and 3) to explore the dominant factors affecting the aeolian desertification occurrence and variations along the railway.

2. Study area and data used

2.1. Study area

The Qinghai-Tibet Railway crosses the central Tibet from Xining in the north to Lhasa in the south. The study area covers the central Qinghai-Tibet Railway (the rectangle in Fig. 1). The north boundary of the study region is located in the Qaidam Basin, with an extremely arid regime where average annual precipitation is less than 100 mm. The main study region represents the typical climate and surface condition of QTP over 4000 m with mean annual precipitation ranging from 200 to 500 mm, and a semi-arid to semi-humid climate regime. The dominant vegetation type is alpine grassland. Eight sites along the railway were selected to simulate the wind erosion, named the ES1, ES2, ES3, MS1 (Xidantan), MS2 (D66), MS3 (Tuotuohe), MS4 (Tanggula) and MS5 (Amdo) (Table 1 and Fig. 1). ES1-3 are the wind erosion observation sites, and MS1-5 are the meteorology observation sites. Their detailed location information is listed in Table 1.

2.2. Observations and the forcing data

The in-situ observations of wind speed at MS2, MS3 and MS5 were provided by the Global Energy and Water Cycle Experiment Asian Monsoon Experiment over the Tibetan Plateau (GAME/Tibet) (http://monsoon.t.u-tokyo.ac.jp/tibet/data/) observed from 1997 to 1998 during the prephased and intensive observing period. Observation records at MS1, MS4, and Wudaoliang from 2005 to 2006 were provided by the Cryosphere Research Stations on Qinghai-Tibet Plateau, Chinese Academy of Sciences (http://www.crs.ac.cn/). Here only the half-hourly wind speed of those in-situ observations was used. Daily observations of wind speed at four sites—Golmud (ES1), Tuotuohe (MS3), Wudaoliang and Amdo in our study area (Fig. 1) maintained by the China Meteorological Administration (CMA) were used to evaluate the forcing data of wind speed. Several other data sets from CMA and the

Table 1
The latitude (LAT.), longitude (LON.), elevation height (ELEV., m), average annual precipitation (PREC, mm), temporal mean leaf area index (LAI) and vegetation type (VEG.) for eight sites and Wudaoliang.

	LAT. (N)	LON. (E)	ELEV.	PREC	LAI	VEG.
ES1	36.42°	94.92°	2810	51.8	0.04	Coppice dune
ES2	34.90°	92.92°	4590	294.9	0.14	Alpine grassland
ES3	35.10°	92.78°	4740	272.8	0.15	
MS1	35.72°	94.12°	4538	535.1	0.10	
MS2	35.52°	93.78°	4580	186.9	0.06	
MS3	34.22°	92.43°	4540	241.8	0.11	
MS4	33.07°	91.93°	5100	495.9	0.30	
MS5	32.24°	91.63°	4700	388.4	0.67	