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Comparison of wind erosion based on measurements and SWEEP simulation: A case study in Kangbao County, Hebei Province, China

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ABSTRACT

Farmland especially dry farmland managed in traditional ways has high wind erosion risk and contributes mainly to dust emission in arid area. Modeling predicting provides a general view to soil erosion susceptibility, and is very helpful for the understanding of potential spatial source of wind erosion. This study applied the Single-event Wind Erosion Evaluation Program (SWEEP) to predict soil wind erosion of farmland in the study area. SWEEP is a standalone version of the erosion sub-model from the Wind Erosion Prediction System (WEPS). It needs fewer calculation parameters than WEPS and is often used for single erosion events of limited size. The objective of this study was to test the feasibility of using SWEEP to estimate annual wind erosion of farmland over large areas (downwind distance >1600 m) with limited wind data (2005–2011) from weather stations. We validated the simulation results by comparing them with field measurements and wind tunnel data for the same soils. The soil material eroded by wind included PM10, suspension, saltation, and creep particles. Suspension particles were the main component involved in the soil loss (averaged 61.8%). However, saltation and creep particles dominate the particle clouds for fields with a downwind length of less than 550 m (averaged 56.6%), and the mass flux dominated by suspension particles stabilizes when this length is longer than 1000 m (averaged 83.4%). PM 10 always has very low proportion (<2.3%). Our validation results suggest that it is feasible to use SWEEP for large areas with limited wind data. However, SWEEP could not simulate the small soil losses that occur especially at low wind velocities well. Many factors contribute to this problem, but the main one is overestimation of the threshold wind velocity. Previous research suggest that it will be difficult to replace SWEEP's calculation algorithms for the threshold wind velocity, but both these algorithms and some SWEEP parameters must be improved to provide accurate predictions of soil erosion.

1. Introduction

Soil is the key factor in major cycles of global biogeochemical, it provides fundamental ecosystem services, and related closely to biodiversity, energy security, climate change, ecosystem services, food security, human health, land degradation, and water security (Brevik et al., 2015; Smith et al., 2015). Unfortunately, soil erosion especially on agricultural land, are several magnitude higher than its formation (Verheijen et al., 2009). The area affected by wind erosion took more than one third of the land surface of the earth (Chen and Fryrear, 1996). Severe soil erosion by wind usually related close to land use. Farmland strongly affected by frequent human activities commonly increased in soil erosion and has high erosion risk (Ginoux et al., 2012; Chen et al., 2014).

In China, soil erosion by the wind affects about half of the national territorial area (Chen et al., 1994). Previous studies has clarified the influencing factors of wind erosion and its affects to environment, established control measurements, found effective evaluation indexes for wind erosion, and improved study

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technique and methods (Gao et al., 2016; Jiang et al., 2016; Wang et al., 2015; Yang et al., 2013). The main issues have to be solved in the future include promoting study on multiple-forces erosion, finding sustainable land use patterns that benefit both environment and economy. North China is the area with high wind erosion susceptibility. Although many farmlands have turned into grasslands and woodlands with the implementation of “Grain for Green” project, there are still wide farmlands in cultivation. Moreover, Farmers lost farmlands living on the government subsidy will not last forever. Farmers have to find livelihoods. Therefore, it is important and urgent to find suitable cultivate practices of farmland benefit both environment and economy to instead of “Grain for Green” project. Prior to this, it is necessary to clear the wind erosion condition in China. Kangbao County in Hebei province is located in a farming and pastoral zone in northern China. Dry farmland in this region that has been managed in traditional ways has undergone serious wind erosion and become a major dust emission source that creates dusty weather farther east, in the Beijing and Tianjin areas (Liu et al., 2003). Although large national ecological restoration projects such as “Grain for Green” have reduced the area of easily eroded land and weakened wind erosion (Gao et al., 2008), farmland still remains the main land use type in the dust source region for eastern China, where much of the land is vulnerable to strong soil erosion by the wind.

Previous research studied the factors and mechanisms that influence wind erosion, control methods, and the temporal and spatial distributions of soil erosion in the field by measurements and investigations (Hagen, 2004; Li et al., 1994; Zhang et al., 2010), wind tunnel experiments (Liu et al., 2007; He et al., 2013) and remote sensing method (Wang et al., 1991; Yue et al., 2015). These study methods have limitations. Wind tunnel experiments are easier to control but difficult to apply to the real world, whereas field experiments allow researchers to more closely emulate natural conditions, but are more difficult to control and have been carried out at a limited range of sites, so the results may not be applicable to other sites (Cole, 1984; Zhao et al., 2006). Though remote sensing method could estimate soil loss on a large scale, results were barely matched with field ones or difficult to verify for lacking of information in large scale. Moreover, it often predicts the erosion risk rather than estimates actual erosion (Chappell, 1998; Jiang et al., 2003). However, remote sensing is useful to develop models and improve their prediction accuracy (Gong et al., 2014; Yue et al., 2015). Modeling predicts soil erosion potential usually and output verify-needed results, which is similar to remote sensing, it may overcome the problems of field measurements, wind tunnels experiments and remote sensing by estimating and predicting wind erosion. Of the currently available models, the Wind Erosion Prediction System (WEPS) is the most advanced and widely used (Woodruff and Siddoway, 1965; Cole et al., 1983; Hagen, 1991a, 2004; Fryrear et al., 1996; Funk et al., 2004).

WEPS is a process-based and modular program that can simulate weather, field conditions, and wind erosion in farmland at a daily time-step (Hagen et al., 1995). The sub-models of WEPS are supported by large databases on erosion-control barriers, soils, agricultural operations, crop growth, decomposition of residues, and climate. Implementation of WEPS required databases that covered the whole United States (Wagner, 2013). Unfortunately, it is difficult to apply WEPS outside the United States due to a lack of data with acceptable resolution and accuracy to parameterize the model and allow an accurate simulation. For example, when the model is used for areas outside the United States, wind data are usually generated stochastically because historical data are unavailable. For quality control, the stochastic wind data must be based on historical wind data recorded for more than 5 years at hourly intervals. Other required weather data includes the station elevation (m AMSL), daily temperatures (maximum, minimum and mean values) (°C), precipitation (mm), and solar radiation (ly d^{-1}) (Van Donk et al., 2005; USDA, 2010). Although WEPS permits wind erosion simulations based on field-measured data (Funk et al., 2004; Hagen, 2004) or limited data (Van Donk et al., 2008; Chen et al., 2012), but basic information about the study area's climate, soils, surface conditions, crop managements, and residues are still required (USDA, 2010). It is not easy to collect sufficient data, even for a small area.

One alternative would be to use the Single-event Wind Erosion Evaluation Program (SWEEP). SWEEP is a standalone version of the WEPS's wind erosion sub-model. Soil loss and deposition can be calculated for a single erosion event in which the friction velocity exceeds the static threshold friction velocity required for entrainment of soil particles. The calculation of both the friction velocity and the threshold friction velocity by SWEEP is based on surface conditions in a simulated rectangular region. Users must provide data on the field size, plant biomass, soils, surface conditions, and weather to support the simulation (Hagen, 1995; USDA, 2008).

Previous research using SWEEP to simulate wind erosion were carried out for limited study areas and short durations using data from wind tunnel and field tests (Feng and Sharratt, 2009; Gao et al., 2014; Liu et al., 2014; Pi et al., 2014b). The feasibility of SWEEP for soil wind erosion prediction in large area (such as a county) and relative long duration (such as years) is unknown. This study assumes that SWEEP should achieve to predict soil wind erosion during long time in a relative large area outside of the USA. The present study applied SWEEP (http://www.weru.ksu.edu/weps/) to simulate wind erosion over the course of years (2005–2011) using hourly-resolution wind data recorded at a weather station, and then to validate the SWEEP's estimation of soil loss in comparison with field measurements and the results of wind tunnel experiments using the same soils. The goal was to evaluate the feasibility of using SWEEP to simulate wind erosion using a small wind dataset for a large simulation area. Based on the results of this analysis, we discuss the feasibility of simulating annual average wind erosion based on individual erosion events and needs for future research.

2. Materials and methods

2.1. Study area

Kangbao County is located in northern China's Inner Mongolia plateau. It is located between 41°25′24″N and 42°08′57″N, and between 114°11′21″E and 114°55′57″E. The average elevation is 1450 m AMSL. Low mountains and hills with a gentle slope cover the eastern and northern parts of the county; plains with undulating terrain cover the southern and western parts. The climate is a mid-latitude temperate monsoon climate with obvious continental characteristics. The mean annual temperature is 1.2 °C. The annual precipitation averages 351.7 mm, 66.7% of which occurs from June to August. Both temperature and precipitation show high inter-annual variation. The average wind velocity is 3.7 m s^{-1}, and the dominant winds blow from the north and northwest in the winter and spring averaged 4.1 m s^{-1}, but from the west and southwest during the growing season averaged 3.1 m s^{-1}. Blown sand and dust events occur most frequently in the spring, with a cumulative duration more than 1440 h per year. The main soil type is a Chestnut soil (a Mollisolin the USDA classification) with a high erosion risk.

In 2000, farmland and grassland accounted for 69.0 and 21.0% of this Kangbao County (total county area is 3365.7 km^2), respectively, and forest covered only 2.6% of the area before implementation of the national “Grain for Green” project in areas that served as sandstorm sources for the Beijing-Tianjin area. By 2009, this