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Simulation of Wind Speed and Direction from Limited Data

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Abstract
The Wind Erosion Prediction System (WEPS) requires hourly wind data but these are not always available. Therefore, a procedure was developed to stochastically generate wind speed and direction from temporally limited wind data. For three locations, two statistical datasets were created to be used with the WEPS stochastic wind generator, based on 1) the full dataset with 24 observations per day and 2) a subset of 4 observations per day: at 2, 8, 14, and 20 hours local time. Erosive wind power densities, calculated from both datasets, agreed well with each other. The same was true for prevailing wind erosion direction and WEPS-simulated soil loss. In spite of temporally limited wind data, it is possible to use WEPS to estimate wind erosion hazard and relative effectiveness of various conservation practices.

Résumé
Le système de prévision d'érosion éolienne (Wind Erosion Prediction System, WEPS) emploie des données de vent horaires mais celles-ci ne sont pas toujours disponible. Donc, un procédé a été développé pour simuler la vitesse et la direction de vent à partir des données limitées. Deux ensembles de données statistiques ont été créés, basé sur: 1) un ensemble de données de 24 observations par jour et 2) un sous-ensemble de 4 observations par jour: à 2, 8, 14, et 20 heures. Les densités de puissance éolienne érosives, calculées à partir des deux ensembles de données, étaient bien d'accord l'un avec l'autre. Le même était vrai pour la direction dominant d'érosion éolienne et le déplacement de sol simulée par WEPS. Malgré des données de vent limitées, il est possible d'employer WEPS pour estimer le risque d'érosion éolienne et l'efficacité relative de diverses pratiques de conservation.

Introduction

Wind erosion is a serious problem in many parts of the world. It is worse in arid and semiarid regions. To better cope with the ravages of wind erosion, an effort has been in progress for several years by the USDA – Agricultural Research Service (ARS) to better understand the processes involved and develop a process-based Wind Erosion Prediction System (WEPS).

Wind is the principal driver of WEPS. It is not practical to use measured historical wind data with WEPS, since many multi-year wind records have missing data. Also, one may want to simulate wind erosion for a longer period than the length of the measured data record, e.g. for 40 years, which is a typical WEPS simulation run. In addition, the measured data require much more computer disk space than wind summary statistics combined with a stochastic wind generator. Therefore, a stochastic wind generator is often more appropriate for use with WEPS than using the measured data directly (Skidmore and Tatarko, 1990; van Donk et al., 2005).

In 2005 ARS delivered WEPS to the USDA Natural Resources Conservation Service (NRCS) for testing before implementation for conservation planning. Workshops about WEPS

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are now being held not only in the United States but in other countries as well. At a workshop in China it was recognized that at some locations where wind erosion is a problem only limited wind data are available. For example, at Yulin, China, wind data have been recorded at only 4 times a day: at 2, 8, 14, and 20 hours local time. WEPS requires 24 wind speed observations per day. Therefore the object of this research was to develop a procedure to simulate wind speed and direction from temporally limited data for use in WEPS.

Methods

A quality controlled hourly wind data set (TD-6421, version 1.1) was obtained from the National Climatic Data Center (NCDC). The hourly data are samples (1 or 2-minute averages) taken every hour. They refer to a height of 10 m. Three stations were selected from this data set for this study: La Junta, Colorado; Sidney, Nebraska; and Pendleton, Oregon. La Junta and Sidney represent the windy Great Plains region of the central USA, whereas Pendleton lies is the very different climatic region of the northwestern USA, which is also know for problems with wind erosion.

For each of the three locations, two statistical datasets were created to be used with the WEPS stochastic wind generator (van Donk et al., 2005): one based on the full NCDC data set with 24 hourly observations per day and a second one using only a subset of 4 hourly observations per day: at 2, 8, 14, and 20 hours local time, to mimic data availability such as that of Yulin, China.

Erosive wind power density (WPD) was chosen to evaluate how well the two data sets agree with each other, because WPD is proportional to sediment transport by wind (Bagnold, 1941; Skidmore, 1998). In addition, prevailing wind erosion direction (PWED) was calculated using equations from Skidmore (1965). Monthly and annual WPD and PWED were calculated from both wind data sets. Also, WEPS simulations were conducted for winter wheat – fallow rotations using both wind data sets, for both conventional tillage and reduced tillage.

Results and discussion

Wind power density calculated from the full 24-hour data set and that calculated from the 4-hour data set agreed well with each other for most months for the three locations (Table 1). The discrepancy was greatest for La Junta with a difference of 0.8 W m^{-2} for the year. Prevailing wind erosion direction also showed good agreement between the two data sets (Table 1). The agreement was best at Pendleton where winds are very dominant from the west all year.

WEPS-simulated wind-blown sediment crossed field boundaries roughly in the same direction between the two wind data sets (Table 2). WEPS-simulated average annual soil loss also indicated good agreement between the two wind data sets (Figure 1). When simulating reduced tillage, simulations with either wind data set showed marked reductions in soil loss. This indicates that, even though simulation results between the two wind data sets were not exactly the same, WEPS can use limited wind data to do what it is intended for: to assess the effect of alternative management practices on wind erosion.

The choice of the time of measurement is important with temporally limited data. Daytime wind speeds overestimate the wind resource. WPD based on only wind speeds measured at 14 hours was almost two times greater than WPD based on the full 24-hour data set (data not shown). At 14 hours, the atmosphere is typically more unstable than during the night, resulting in more vertical mixing and thus greater wind speeds close to the earth's surface. The atmosphere is typically more stable during the night. WPD based on only wind speeds measured at 2 hours was almost two times less than WPD based on the full 24-hour data set (data not shown). Apparently, the hours used in this study (2, 8, 14, and 20 hours) are a good mix of daytime and nighttime wind speeds.

Conclusions

Wind power density calculated from the full 24-hour data set and that calculated from the 4-hour data set agreed well with each other for most months for the three locations. The same was true for prevailing wind erosion direction. WEPS simulations showed that wind-blown sediment crossed field boundaries roughly in the same direction using either wind data set. WEPS-simulated average annual soil loss also corresponded well between the two data sets. Even though simulation results between the two wind data sets were not exactly the same, WEPS can use limited wind data to do what it is intended for: to assess the effect of alternative management practices on wind erosion. In spite of temporally limited wind data, it is possible to use WEPS to estimate wind erosion hazard and relative effectiveness of various conservation practices.

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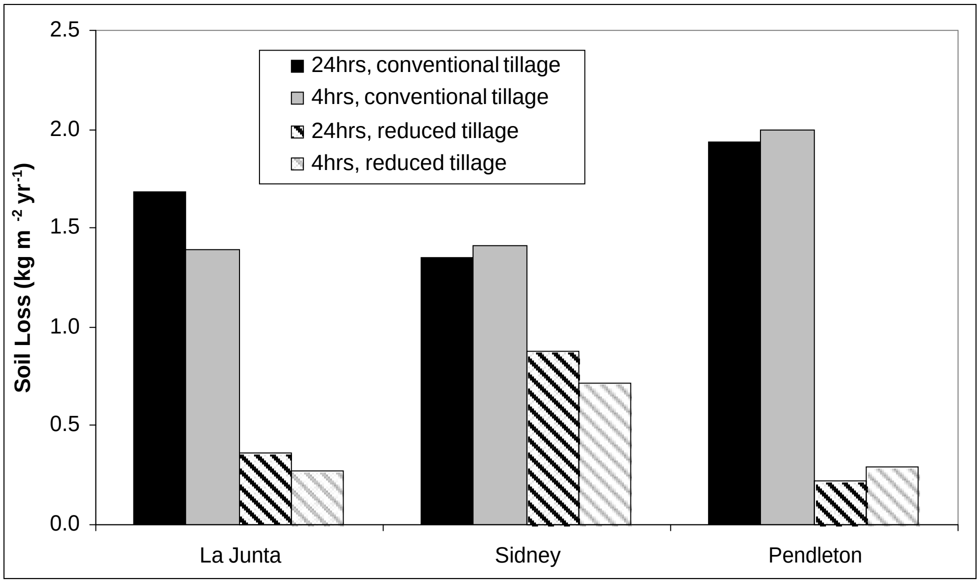

Figure 1. WEPS-simulated average annual field soil loss, based on the full NCDC wind data set with 24 hourly measurements per day (24hrs) and based on a subset using only 4 hourly measurements per day: at 2, 8, 14, and 20 hours local time (4hrs) for winter wheat – fallow rotations with conventional tillage and reduced tillage.

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Table 1. Wind Power Density (WPD) and Prevailing Wind Erosion Direction (PWED) based on the full NCDC wind data set with 24 hourly measurements per day (24hrs) and based on a subset using only 4 hourly measurements per day: at 2, 8, 14, and 20 hours local time (4hrs).

La Junta	WPD 24hrs ($W m^{-2}$)	WPD 4hrs ($W m^{-2}$)	WPD diff. ($W m^{-2}$)	PWED 24hrs (degr.)	PWED 4hrs (degr.)	PWED diff. (degr.)
JAN	7.2	8.1	-0.9	322	303	19
FEB	16.4	16.1	0.3	349	350	-1
MAR	22.0	19.8	2.2	329	328	1
APR	24.8	23.4	1.4	351	331	20
MAY	22.2	19.6	2.6	10	11	-1
JUN	13.6	11.7	1.9	214	39	175
JUL	8.1	4.0	4.1	38	39	-1
AUG	5.8	2.3	3.5	8	11	-3
SEP	4.9	5.5	-0.6	13	12	1
OCT	10.4	10.0	0.4	9	5	4
NOV	9.9	17.9	-8.0	356	354	2
DEC	7.5	4.7	2.8	343	332	11
year	12.7	11.9	0.8			
Sidney						
JAN	14.4	14.4	0.0	314	311	3
FEB	18.1	18.7	-0.6	316	314	2
MAR	17.4	14.8	2.6	319	320	-1
APR	19.2	19.2	0.0	320	319	1
MAY	13.3	14.8	-1.5	324	322	2
JUN	4.7	5.1	-0.4	308	304	4
JUL	3.8	1.4	2.4	167	159	8
AUG	1.8	1.2	0.6	171	232	-61
SEP	4.2	7.0	-2.8	317	319	-2
OCT	11.6	13.9	-2.3	320	322	-2
NOV	12.1	16.0	-3.9	314	318	-4
DEC	18.0	17.1	0.9	312	315	-3
year	11.5	11.9	-0.4			
Pendleton						
JAN	7.7	6.1	1.6	252	251	1
FEB	8.4	7.8	0.6	256	255	1
MAR	13.1	12.5	0.6	261	262	-1
APR	12.1	12.3	-0.2	266	265	1
MAY	7.5	6.4	1.1	266	266	0
JUN	7.1	6.9	0.2	268	268	0
JUL	4.3	4.7	-0.4	269	269	0
AUG	3.1	2.6	0.5	268	267	1
SEP	5.4	5.5	-0.1	267	267	0
OCT	4.1	4.6	-0.5	259	257	2
NOV	9.5	10.0	-0.5	256	256	0
DEC	10.4	9.2	1.2	251	249	2
year	7.7	7.4	0.3			

PWED: 0 degrees is North, 90 degrees is East, 180 degrees is South, and 270 degrees is West

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Table 2. Percent of WEPS-simulated wind-blown sediment crossing the boundaries of a square field, based on the full NCDC wind data set with 24 hourly measurements per day (24hrs) and based on a subset using only 4 hourly measurements per day: at 2, 8, 14, and 20 hours local time (4hrs).

	La Junta			Sidney			Pendleton		
field	24hrs	4hrs	diff.	24hrs	4hrs	diff.	24hrs	4hrs	diff.
boundary	%	%	%	%	%	%	%	%	%
southern	52.6	62.5	-9.9	15.3	23.2	-7.9	3.2	0.4	2.8
western	12.9	6.3	6.7	11.4	5.2	6.2	1.7	0.1	1.6
northern	18.5	5.7	12.8	38.5	31.9	6.6	5.0	11.7	-6.7
eastern	16.0	25.6	-9.6	34.8	39.7	-4.9	90.1	87.8	2.3
total	100.0	100.0	0.0	100.0	100.0	0.0	100.0	100.0	0.0