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Prediction Success with Integrated, Process-Based Wind-Erosion Model

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Introduction

The value of any prediction tool is measured by how well the results from the tool match accurate measurements from the process to be modeled. The value is also measured by how easy data can be obtained to run the model, how easy the model is to use, and how wide a range of conditions over which the model can be used. It is desirable to have both an accurate and robust model.

The **TEAM** (**T**exas Tech **E**rosion **A**nalysis **M**odel) is an integration of many mathematical models each derived or developed to describe specific physical processes that affect the wind erosion process. To provide stability and efficiency in calculations, any differential mathematical form has been integrated to describe the process in real instead of differential space. **TEAM** has two major functions: (1) a maximum-transport component and (2) a length factor, which varies between zero and one. Input variables to each of these functions, such as threshold friction velocity, are often a function of other processes and variables. The combination of these variables defines a system of equations that use inputs of wind speed, relative humidity, soil particle size distribution, clay content, residue and vegetative cover, soil aggregate cover, field length, and wind break height and porosity to model wind erosion. Soil ridges perpendicular to wind direction are treated as cover if the ridge is solid or if the surface of the ridge is covered with stable aggregates. Ridges parallel to wind direction are considered non-effective as a treatment to reduce wind erosion.

Objective

The objective of this paper is to overview some of the unique features of **TEAM** and discuss the success of **TEAM** as a prediction tool to model wind erosion. Some limitations of **TEAM** will also be discussed.

Overview and Discussion

TEAM is a dynamic model that predicts real time rate of soil movement by wind. It does have two time-limiting processes. **TEAM** includes a gust factor to account for variable wind conditions. The gust factor is based on a 2- to 5-second minimum time period to avalanche particle movement with the saltation process. This is equal to about 10 particle bounces. **TEAM** also uses an average wind profile to calculate friction velocity. Greeley and Iversen (1985) have indicated that 30 minutes is sufficient to determine an average profile. Our experience is that 10 minutes is usually sufficient to determine a reasonable average profile for given wind conditions. The gust factor we use is the ratio of the gust factor for 2 to 5 seconds, which is approximately constant in this time range, over that for the time period used to determine the average wind profile. The gust factor for a 1-hour time period is 1.0. That for a 2- to 5-second period is about 1.5. Thus, if hourly wind speeds are used as wind input, we use a gust factor of 1.5. This factor goes down as we reduce the period over which we average the wind speed. A practical lower time limit for **TEAM** is about 10 minutes, although it has been used to generate soil detachment and dust generation with the pressure wave and wind velocity resulting from explosions.

There is considerable confusion in the literature about the effects of soil moisture on threshold friction velocity. **TEAM** calculates threshold friction velocity based on relative humidity of the air. The equation for threshold friction velocity was developed from data from Darwish (1991) and Belly (1964). These researchers were careful to make measurements with the soil system in equilibrium with the air above the soil. Some researchers have attempted to measure soil moisture for surface conditions by collecting surface soil 0.5 to 1 cm deep. This technique grossly miss calculates the soil moisture at the surface when the relative humidity of the air is not in equilibrium with the soil, especially for sandy soils with very low unsaturated hydraulic conductivity. A simple calculation shows the error of this process. We have noticed other researcher misuse our threshold friction equation by using measured soil moisture near the surface instead of using the equations to convert air relative humidity to surface soil moisture then making the calculation. While this process of calculating threshold friction velocity is generally an advantage for the **TEAM** model, it caused one limitation in use. **TEAM** will under estimate surface soil moisture immediately after a rain. **TEAM** moisture equations are not accurate until stage I drying (surface appears wet) has pasted. For sands, the time for stage I drying is often less than one-half day. We correct for this problem with long-term simulations by multiplying by a factor that expresses the probability of the surface being wet, which is based on soil type and the probability of getting rain (Solorzano-Campos, 1990).

TEAM is an energy-based energy-driven wind erosion model. The maximum transport component of **TEAM** uses the average sized non-clay particle to determine threshold friction velocity. Theoretically, we should use the mode of the particle size distribution; however, the average, D_{50}, is a close approximation of the mode and is less confusing to the user. Thus, the model is more robust by using the mean particle size with little loss in accuracy. **TEAM** also uses the D_{75} or average of the upper one-half of the particle size distribution less than 1 mm in diameter as an indicator of potential to return wind energy to the soil surface through the saltation process. This 1-mm upper limit is very close to the 0.8-mm diameter used by USDA researchers (Chepil and Woodruff, 1963). Theoretically, wind velocities exist during some dust storms that could move particle sizes larger than 1 mm. Generally, however, soils do not contain particles in the 1 to 8 mm range (Pettijohn et al., 1972). Winds high enough to move particles larger than 8 mm, such as roofing gravel, sometime exist but are too short in duration to contribute to significant soil movement. Particles less than 0.08 mm in diameter return to the surface too slowly to transfer significant detachment energy. Thus, the difference between D_{75} and 0.08 is used to consider the influence of particle size distribution on the maximum transport rate. The ideas are similar to work by Bagnold (1941).

When wind speeds are high compared to threshold wind velocity, the maximum transport rate is a cubic function of wind speed and varies with the soil particle size distribution as observed by Bagnold (1941). The maximum transport rate also varies with relative humidity because the energy needed to detach loose soil particles varies with the threshold friction velocity. This component of **TEAM** has a theoretical basis and was verified with wind tunnel measurements (Wilson, 1994). Thus, the maximum transport component of **TEAM** is both dynamic and robust including effects of wind, water, and soil.

The length effect for TEAM was first derived by Gregory (1984) and later re-derived as reported by Wilson (1994) to provide a more stable and theoretically based function for the avalanching effect. The original derivation considered length of field, soil erodibility, and cover conditions. The newer derivation also considers wind speed, soil moisture through relative humidity, and particle size distribution. With the newer derivation, the length factor is dynamic though out a windstorm. For relatively dry pure sand, the length before maximum transport is achieved varies between 2 and 4 m depending on wind speed. For soil conditions, especially with about 30 percent clay content, the length until maximum transport is achieved can be several hundred meters. The length factor in **TEAM** is robust enough to describe the full S-shape of soil detachment and transport with length of erosion area.

The current version of **TEAM** is easy to calibrate to new field and weather conditions. It requires wind speed at a known height, relative humidity, clay content, soil particle size distribution to get D_{50} and D_{75}, field length, aggregate diameter and height of cover, residue cover and plant canopy cover and height. Once soil and cover conditions are known and entered only wind and relative humidity are needed to simulate an erosion event. The soil erodibility that is the primary controlling variable in the length function is calibrated from clay percentage for solid soil conditions typical after a wet period or a tilled condition after a wet period. Both an advantage and limitation occurs with this variable. If several cycles of light rainfall occur that do not saturate the soil, the weathering associated with the wetting and drying cycles will greatly reduce the soil strength. **TEAM** has a weathered or "drought condition" calibration, which increases soil erodibility by four times the normal amount (Singh, 1992). This alternative erodibility selection increases the robustness of **TEAM** but leaves the user with a judgment as to which setting to use. The current **TEAM** does not have a set of equations to automatically calculate this observed weathering effect. More research is needed to develop weathering equations that are both accurate and robust for field use.

Results

TEAM generally predicts measured results with an R^2 of 0.8 or better and generally has an α level of 0.01 or lower indicating it is not a random fitting of numbers. Wind-tunnel data generally does not have gust effects unless the experiment was designed to produce gust. Thus, the gust factor for wind-tunnel data is 1.0. Otherwise, calibration for wind-tunnel data is the same as field data, provided the wind profile in the wind tunnel is in equilibrium with the surface roughness conditions of the experiment.

We have attempted to show the prediction success of **TEAM** for a variety of sites and conditions in Table 1. We are especially pleased with the success in predicting the results for the Big Spring, Texas data. We calibrated for this site using the average clay percentage, soil particle size distribution, and the reported description of surface and previous rainfall history to determine whether to use normal or weathered condition. We entered the average of 10-minute wind velocity and relative humidity from date and time of cleaning samplers to date and time for new cleaning. **TEAM** predicted the correct downwind total movement and predicted the correct movement with length of field.

Table 1 Prediction success by **TEAM** for various data sources and conditions.

Type of Prediction	R^2	**α**	**Data Reference**
Transport rate as a function of field length and soil type assuming a constant value for wind speed and humidity	0.93	0.001	Chepil (1957)
Transport rate as a function of friction velocity and relative humidity in a wind tunnel for 0.55-mm diameter sand	0.97	0.001	Wilson (1994)
Total amount of soil moved as a function of length and variations in wind velocity and relative humidity and soil conditions for the 5 largest or most complete small movement individual storms	0.82	0.001	Big Spring, TX field data collected by Bill Fryrear
Total amount of soil moved as a function of length and variations in wind velocity and relative humidity and soil condition for the largest storm	0.89	0.001	Big Spring, TX field data collected by Bill Fryrear

Conclusions

TEAM is a comprehensive wind erosion model that accurately predicts particle movement ranging from sands to soils with zero to 30 percent clay content. It accurately responds to both wind and relative humidity weather data and accurately predicts changes in particle movement as a function of length. While the focus of this paper has been on predictions for bare soil conditions, the cover factor was verified with several data sets by Gregory (1984). It is, thus, close to a complete wind erosion model. It currently has one weakness--it lacks the ability to adjust soil eordibility on a continuous bases as a function of rainfall and wetting and drying cycles. It currently appears to have the correct calibration for both non-weathered and fully weathered conditions but does not have a function to adjust erodibilty between these two conditions.

TEAM has several factors often not included in other wind erosion models. These factors include relative humidity, wind gust factor, particle size distribution, and a dynamic length factor. It also self adjusts displacement height and aerodynamic roughness as a function of surface roughness conditions. Even with all of these considerations, **TEAM** is relatively easy to use and quickly calculates soil movement. A more complicated programming of **TEAM** even allows up to 10 sequential length segments that can have different soil and/or cover conditions. In this form, **TEAM** can consider wind breaks and also predict deposition. **TEAM** is, thus, a very robust model.

Summary

TEAM is a process-based prediction tool that simulates the movement of sand or soil by wind. Many of the functions were originally derived from a differential expression describing the process. All of these differential forms, however, were integrated to obtain final function in real time and space. This integrated from increases both stability and speed in calculations.

As shown in the Results section, **TEAM** is a successful predictor of either sand or soil movement caused by wind. Part of the success of **TEAM** is due to the inclusion of unique features such as a gust factor, relative humidity, particle size distribution, and a dynamic length factor. **TEAM** is, thus, a very robust yet relatively easy to use single-event wind erosion prediction tool.

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