The Prediction of Horizontal Soil Fluxes During Wind Erosion Events

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Introduction

The horizontal flux of soil above eroding surfaces is often claimed to be proportional to a power of the friction velocity (or some other measure of the strength of the eroding wind field), with by far the most popular value of the power being 3. However, there is considerable variation between both the “goodness of fit” of a power law and the value of the power obtained from different data sets. The work described in this paper is part of an attempt to explain these differences, with the hope that such understanding will contribute to useful prediction methods. It is based on some results from a steady-state mathematical model due to Hopwood and Scott(1997). For a given friction velocity and boundary soil- size -distribution the model simulates height profiles of the concentration, horizontal mass-flux and mean diameter of airborne soil particles, and also the total (i.e. summed over height) horizontal mass-flux. In this paper we will be concerned only with the simulated total horizontal fluxes and their variation with friction velocity.

The Model

A detailed description of the equations specifying the model and the reasoning underpinning their construction may be found in Hopwood and Scott(op. cit.). The basic ideas and assumptions on which the model is built are summarized in the following list.

1. The behavior of heavy(saltating) soil particles in an air stream is significantly different from that of light(suspended) particles.

2. A particle is light if the parameter $v_t/ku_* < 1$, and heavy otherwise. Here v_t, k and u_* denote the terminal speed of the particle, von Karman's constant, and the friction velocity, respectively. It follows that as u_* increases some 'heavy' particles will become 'light'.

3. The friction velocity depends on the over-riding wind and is not affected by the presence or absence of erosion. This statement may be controversial; our justification for it depends largely on the work of Scott and Carter(1986).

4. A mixture of air and light soil particles may be treated as a fluid of variable density, the density at a point in space depending on the concentration of particles at that point.

5. The stress due to the interaction of heavy particles and the air is a function of the average (mean) difference between the speed of ascending and of descending particles.

The quantities which need to be specified as input to the model are the friction velocity, the roughness of the surface before the onset of erosion, the ejection speeds and drag coefficients for heavy particles, and the mass concentration of particles in each size class at a height of one roughness length above the surface. In our experiments with the model we used a variety of formulations of these quantities, based on experimental and theoretical results available in the literature. There is neither time-dependence nor variation in the horizontal space-dimension in the model.

Results

Model runs were made for five values of friction velocity for each of two hypothetical boundary soil-size distributions, shown in Fig. 1 and Fig. 2 below. That is, the results consist of two sets showing total flux as a function of friction velocity, with the boundary mass-concentration for each size-class fixed for each set. This assumption of no variation of surface concentration with friction velocity for a given soil is not an intrinsic requirement of the model but the model's structure implies that it is equivalent to the upward flux of heavy particles at the boundary being proportional to the square of the friction velocity, which is consistent with some theoretical work of Sorensen (1991).

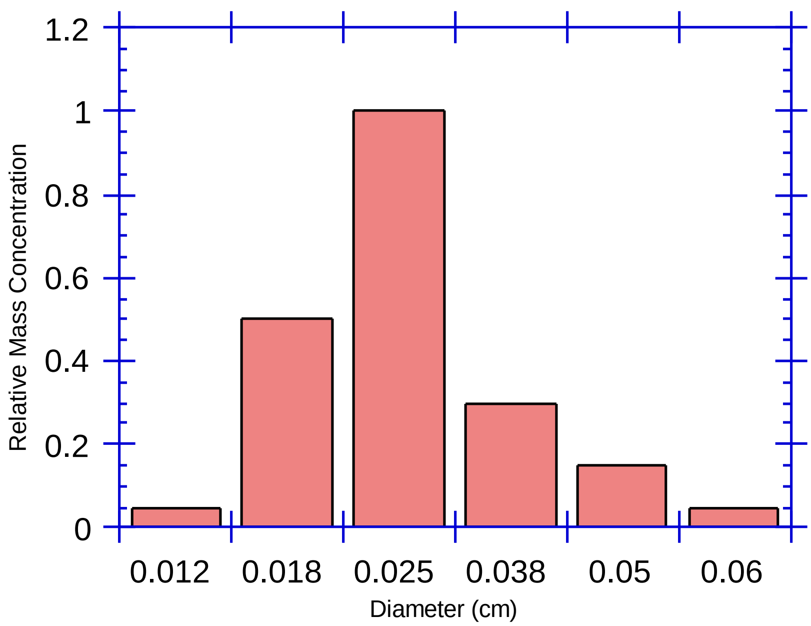

Figure 1. Relative mass-concentrations at one roughness length above the surface of the six sizes of particles in a hypothetical soil used in model experiments.

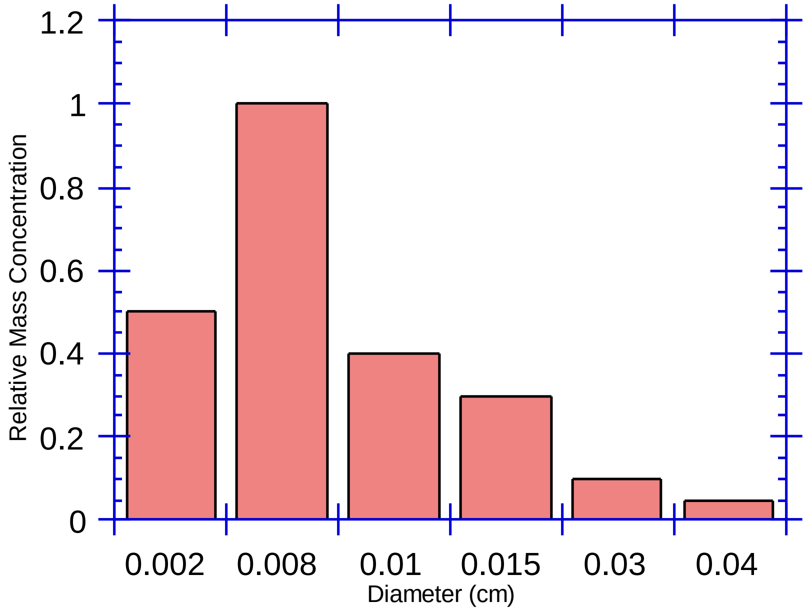

Figure 2. As for Fig.1 but with smaller(lighter) particles.

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We are interested in the representation of the flux-friction velocity relationship as a power law and so the results for each set are presented as a plot of the logarithm of the total horizontal flux versus the logarithm of the friction velocity (Figs 3 and 4). The graph and equation of the regression line and corresponding correlation coefficient are shown also.

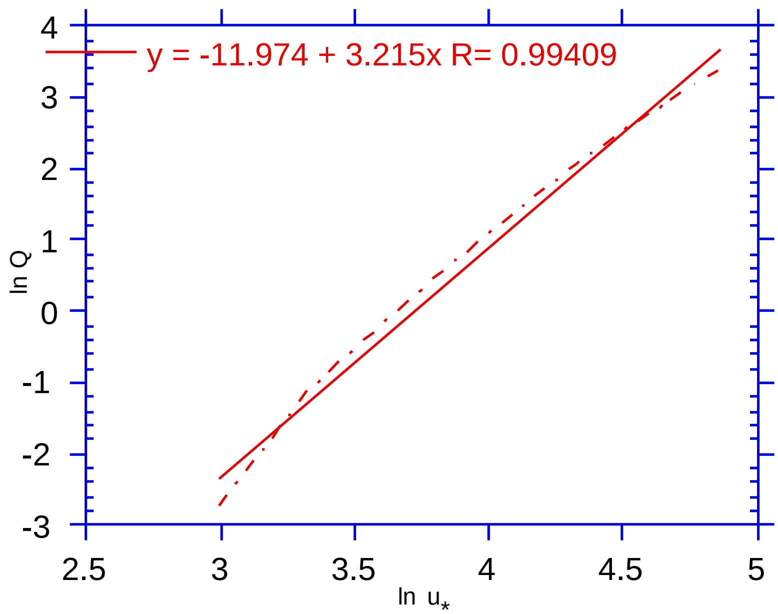

Fig. 3. Dashed curve shows the logarithm of total horizontal mass-flux (Q) *vs* logarithm of friction velocity, for the distribution in Fig. 1. Also shown are the regression line (solid), its equation, and R, the correlation coefficient.

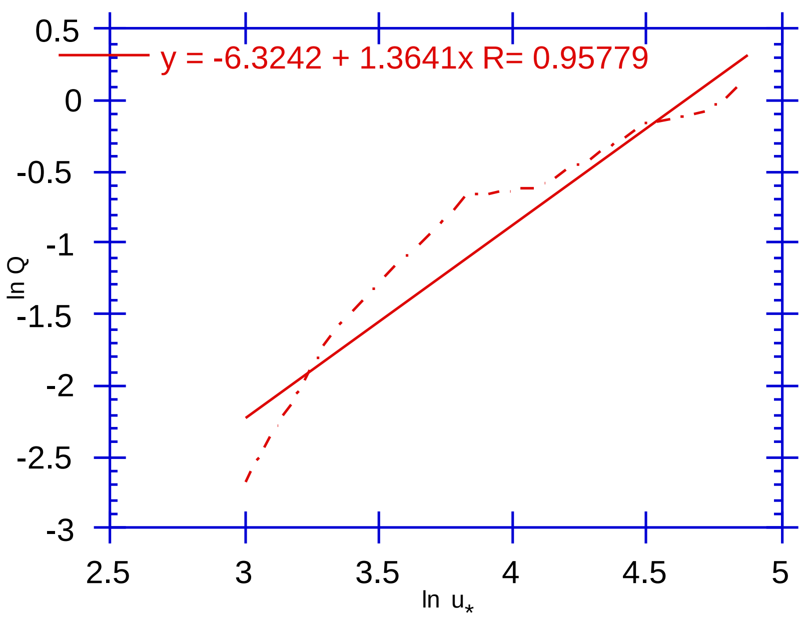

Figure 4. As Fig. 3 but for the distribution in Fig.2

It will be seen that for the soil represented by Fig. 1 the total horizontal flux is indeed very nearly proportional to the cube of the friction velocity, but for the distribution in Fig.2 in which very small particles predominate the value of the power is close to 1.4. This is consistent with the observations of Leys(1991) of fluxes above finely-textured soils. In both cases the correlation between the model results and the regression line is high but there is some curvature apparent, with the slope tending to decrease with increasing friction velocity. This is particularly striking in the case of the 'light soil' of Fig. 5 where it may be seen that for low u_* the slope of the curve is considerably larger (indeed, close to 3) than the slope of the fitted line. The explanation is that at low values of u_* almost all the particles are classified as 'heavy' but as the friction velocity increases more particle sizes become 'light' and the fluxes are affected accordingly.

Conclusion

The model experiments produced plots of horizontal flux versus friction velocity which are well fitted by a power law, with the power being close to 3 for the heavier soil and smaller (1.4) for the lighter. However, they also exhibited deviations from an exact power law which are explicable in terms of particles in some size classes changing status from 'heavy' to 'light' as wind speed increases. An implication is that for high enough friction velocities the rate of increase of horizontal soil-flux with friction velocity will decrease and may even become negative. It would be interesting to know whether such behavior has been observed by experimentalists.

Bibliography

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