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DISCUSSION

Discussion of: Ke, Xiankun; Collins, M.B., and Poulos, S.E., 1994. Velocity Structure and Sea Bed Roughness Associated with Intertidal (Sand and Mud) Flats and Saltmarshes of the Wash, U.K. *Journal of Coastal Research,* 10(3), 702–715.

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INTRODUCTION

In the recent paper by Ke *et al.* (1994) on intertidal-zone bed roughness, linear regression is misused in the analysis of vertical velocity profiles. Several papers have dealt with the misuse of regression in the earth sciences (*e.g.*, Mark and Church, 1977; Wadsworth, 1984; Mann, 1987; Troutman and Williams, 1987), and at least two articles have explicitly addressed the implications of 'backward' regression to the analysis of velocity profiles (Bauer *et al.*, 1992; Bergeron and Abrahams, 1992). 'Backward' (or inverse) regression refers to a procedure where the independent variable is treated as a dependent variable, and the variable ordering is reversed in the calculation of regression statistics. Ke *et al.* (1994: KCP henceforth) mis-designate velocity as the independent, rather than dependent, variable for their velocity profile analysis. It is from this basis that our discussion is offered. The central concerns lie with their: (1) presentation of inappropriate equations to calculate shear velocity (u_*) and roughness length (z_o); (2) introduction of inaccurate estimates of u_* and z_o into the coastal literature; and (3) drawing of questionable, if not misleading, conclusions based on problematic analysis of intertidal-zone data.

(1) Inappropriate Equations. KCP represent the law of the wall in the form,

$$\ln(z) = \ln(z_o) + \left(\frac{\kappa}{u_*}\right)u \tag{1}$$

which follows an intuitive convention that plots elevation on the vertical axis of a graph. Although the equality is mathematically sound, the parameterization is physically invalid because the functional dependence of velocity (dependent variable) on distance from the boundary (independent variable) is reversed (*c.f.*, Bauer *et al.*, 1992). Thus, their equations for roughness length (KCP Equation 3) and shear velocity (KCP Equation 4) that follow are inappropriate and should be replaced by (*e.g.*, Middleton and Southard, 1984, Appendix 6),

$$z_o = e^{\left(\frac{b_1}{m_1}\right)} \tag{2}$$

$$u_* = m_1\kappa \tag{3}$$

where 'm' and 'b' refer to the slope and intercept of the regression line, respectively, and subscript '1' indicates normal regression with velocity as the dependent variable. It is unfortunate that the inverted forms of equations (2) and (3) continue to reappear in the literature because their frequent recurrence may be perceived as legitimating their use.

(2) Inaccurate Estimates of u_* and z_o. Because KCP misuse regression in their analysis of velocity profiles, their estimates of shear velocity and roughness length in an intertidal zone are inaccurate. Bauer *et al.* (1992) presented analytical expressions that can be used to quantify the potential errors associated with backward regression for shear velocity.

$$(u_{*_2} - u_{*_1})/u_{*_1} = 1/r^2 - 1 \tag{4}$$

and for roughness length,

$$(z_{o_2} - z_{o_1})/z_{o_1} = e^{(\bar{u}/m_1)(1-r^2)} - 1 \tag{5}$$

where subscript '2' indicates backward regression, and overbar indicates the sample mean rather than the true (population) mean. Backward regression leads to overestimation of u. and z_0. The magnitude of error increases with decreasing r^2—zero error occurs only if $r^2 = 1$. BAUER *et al.* (1992) display this graphically using data digitized from over 100 wind-speed profiles derived from aeolian systems. For shear velocity, an overestimate of about 12% is introduced when $r^2 = 0.9$. The error rises to more than 50% when $r^2 = 0.8$, the value used as a minimum by KCP. For roughness length, the potential error depends on r^2 but also on the ratio of the mean to the slope of the velocity profile—the error increases with greater $\bar{u}/m_1$. For example, with $r^2 = 0.9$ and $\bar{u}/m_1 > 3$, the error in z_0 exceeds 40%. The magnitude of error in KCP's estimates of u. and z_0 remains uncertain (see Discussion below), but for all cases both shear velocity and roughness length will be overestimated.

(3) **Misleading Conclusions.** Several of the conclusions reached by KCP are questionable in light of the methodological issues discussed above. For example, they report that

> "mean roughness lengths derived for the intertidal flats vary between 0.32 cm to 1.65 cm (Table 2 and Figures 4, 5, 6) ... Such a value is higher than would be expected for a flat very fine sand bed with a mean grain size of 3 to 3.5 ϕ (0.09 to 0.13 mm, assuming that $z_0 = D/30$ ..." (p. 706).

The true estimates of roughness length may indeed be greater than expected, but the uncertain results of KCP should not be used as the foundation for such an assessment.

Their evaluation of the aerodynamic equations of LETTAU (1969) and WOODING *et al.* (1973) seems superficial and misdirected. KCP suggest that these equations produce values of roughness length that are much lower than those derived from the velocity-profile data. They conclude (p. 708) that,

> "It is likely, therefore, that previously established aerodynamic models (LETTAU, 1969; WOODING *et al.*, 1973) cannot be applied simply to the flow over the intertidal flat environment."

In the subsequent sentence, however, they offer a simple solution by claiming that,

> "For such an application, the constants in Equations 5 and 6 [those of LETTAU and WOODING *et al.*, respectively] should be multiplied by 5.4 and 3.1, respectively."

Because their analyses of the velocity profiles is flawed, their conclusions about the applicability of the LETTAU (1969) and WOODING *et al.* (1973) models may be inapppropriate. The updated empirical coefficients that KCP propose (*i.e.*, 5.4 and 3.1) are clearly inaccurate and should be reevaluated.

It is not obvious to us why KCP have chosen to evaluate equations derived for aerodynamic systems when several alternative formulations for estimating roughness lengths on the basis of bedform dimensions in hydrodynamic systems are available. For example, a simple estimate for roughness length may be obtained using the relationship cited by GRANT and MADSEN (1982): $z_0 = 0.92\ (H)\ (h/\lambda)$. Using this method to estimate roughness lengths with the summary data presented in KCP's Table 4, a mean value of 0.19 cm is predicted, just slightly larger than the WOODING *et al.* (1973) result. However, this method presumes that all roughness results from bedform geometry. It is well established that there are other sources of apparent roughness that are acting at least for part of KCP's study. These include the wave boundary layer effect that they note, but dismiss (*e.g.*, GRANT and MADSEN, 1982; or SHERMAN and GREENWOOD, 1984), and the effect of a bed load or saltation layer. Saltation has been shown to increase apparent roughness length (*i.e.*, the roughness length indicated by velocity profile characteristics) in wave-dominated (GRANT and MADSEN, 1982), fluvial (WIBERG and RUBIN, 1989), and aerodynamic systems (SHERMAN, 1992). The extent of these influences on KCP's data cannot be assessed here. However one observation can be offered. Their Table 4 data include measurements from 0.3 hours before high water, at a point in time when mean flows, and therefore sediment transport, were minimal. The effects of the wave boundary layer should also be minimized. At this time, their velocity profile estimate of z_0, 0.09 cm, coincides well with the 0.11 cm estimate using the Grant and Madsen approximation and matches exactly the WOODING *et al.* (1973) estimate. These results may be coincidental but certainly warrant further consideration.

KCP also draw questionable conclusions about the importance of large-scale bed morphology in controlling the magnitude of roughness length on the lower mudflat (p. 709), suggesting that

> "the critical control on roughness length would appear to be neither grain size, nor the scale of the small bedform (such as ripples on the surface of the flats) ... the creeks/gullies and muddy depositional bodies constitute, in themselves, a form of large-scale bedform; these, in turn, influence the structure of the velocity profiles and the z_0 values."

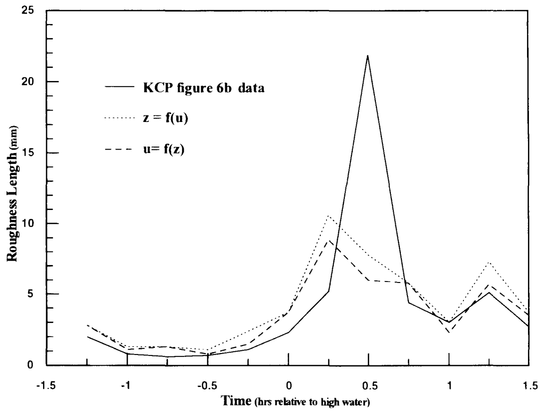

Figure 1. Roughness length variation over an Arenicola sand flat as a.) traced from Figure 6b in KCP (solid line); b.) reconstructed from KCP velocity profiles in their Figure 6a using 'backward' regression (dotted line); and c.) using 'normal' linear regression (dashed line).

Although we have no basis to refute these conclusions, it is noteworthy that the velocity profiles measured over the lower mudflats were characterized by the lowest r^2 values of any of the environments they examined (KCP Table 2; Figures 4, 5, 6) and therefore estimates of z_0 derived therefrom are susceptible to greatest uncertainty and overestimation.

DISCUSSION

It had been our intention to correct KCP's estimates of u_* and z_0 by analyzing digitized versions of their velocity profiles. However, we were not able to reproduce their results to an appropriate degree of precision. Figure 1 shows three traces of roughness-length estimates obtained by, (a.) digitizing the KCP roughness-length estimates directly from their Figure 6b, and from digitizing the KCP Figure 6a velocity profiles and performing (b.) backward regression and (c.) normal regression. In most cases, the difference between our backward and normal regression estimates was of the same order as the difference between our backward regression estimates and their backward regression estimates. The latter two traces should coincide exactly but they do not. We ascribe most of the inaccuracies to imprecision in our digitizing procedures. However, additional sources of error were apparent in the KCP figures. For example, the spike in roughness length at HW + 0.50 (see our Figure 1 and their Figure 6b) is not reproduced in our backward regression trace and their estimate seems inordinately large given the identical shape of the preceding velocity profile (see KCP Figure 6a). This is not a digitization-derived error on our part, and we can think of no dynamical reason for roughness length to increase and then decrease two-fold within the span of 1 hour under flow conditions, during high tide, that are otherwise well behaved. The spikes in roughness-length estimates shown in KCP Figure 5b are similarly difficult to address because of the selective inclusion/exclusion of data from the velocity sensors positioned at 41 cm and 82 cm and because the sensor positions shown in Table 1 do not conform to those of the plotted data in Figure 5a. These ambiguities prevented us from pursuing the analysis further, although we encourage KCP to re-analyze their original data and report on the results.

As a final note, we wish to stress that the line fitting procedure associated with linear regression is based upon a statistical foundation. Therefore, results should be interpreted accordingly. KCP's Figure 6 data from HW − 0.75, KCP, for example, has $r^2 = 0.995$. For these data, we would have confidence at the 95% level that the 'true' value for roughness length lies between 0.10 cm and 0.16 cm, a range of about 60%. As r^2 decreases, the range of roughness length estimates increases rapidly (this is one reason why many oceanographers restrict their velocity profile analyses to cases where r^2 exceeds 0.99; *e.g.*, CACCHIONE *et al.*, 1987). We also use this consideration as a basis to reiterate the suggestion of WILKINSON (1984), to present confidence intervals around estimates of u_* and z_0 so that true variability in natural processes can be distinguished from statistical uncertainty.

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