Flux tower on Ice Station Weddell

The Fallacy of Drifting Snow

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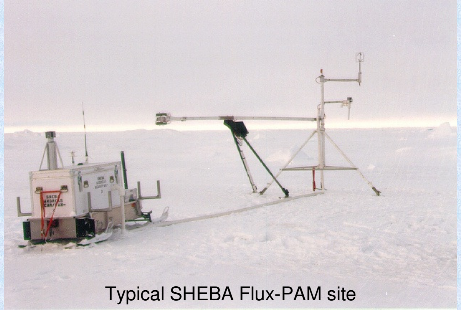

Typical SHEBA Flux-PAM site

1. Abstract

A common parameterization for the roughness length z_0 over snow-covered surfaces undergoing saltation is

$$z_0 = \alpha u_*^2 / g , \qquad (1)$$

where u_* is the friction velocity, g is the acceleration of gravity, and α is an empirical constant. Plots here based on two large eddy-covariance datasets collected over snow-covered sea ice seem to support this scaling (Figure 1). But in these and in most such plots from the literature, the independent variable, u_*, was used to compute z_0 in the first place; the plots thus suffer from fictitious correlation that causes z_0 to unavoidably increase with u_* without any intervening physics. The belief in (1) when snow is drifting is a fallacy fostered by analyses that suffered from fictitious correlation.

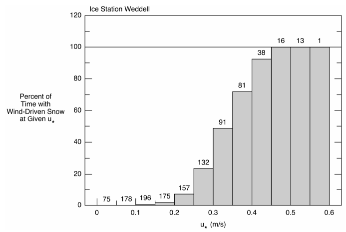

Figure 2. Frequency of wind-driven snow as a function of the measured friction velocity, u_*, on Ice Station Weddell. The number above each bar counts the observation periods for which u_* was in that bin. Clearly, the threshold for drifting snow on Ice Station Weddell was in the u_* range 0.25–0.35 m s^{-1}.

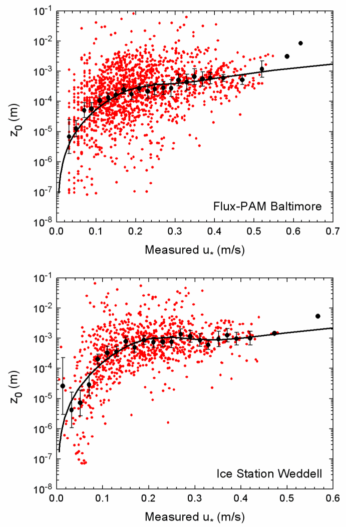

Figure 1. Hourly measurements of the aerodynamic roughness length z_0 from (2) made over winter sea ice (red circles) are plotted against measured values of the friction velocity, u_*. The data come from the SHEBA Flux-PAM site named Baltimore and from Ice Station Weddell. The black circles are geometric mean values of z_0 in u_* bins. The equation for the solid curves is

$$z_0 = \frac{\alpha u_*^2}{g}\left\{F\exp\left[-\left(\frac{u_* - 0.18}{0.10}\right)^2\right] + 1\right\},$$

where α = 0.035 and F = 1 in the Baltimore panel, and α = 0.060 and F = 3 in the Ice Station Weddell panel.

2. Math

From eddy-covariance measurements of u_*, we compute z_0 from

$$z_0 = r\exp\left\{-\left[\frac{kU_r}{u_*} + \psi_m\left(\frac{r}{L}\right)\right]\right\} . \qquad (2)$$

Here, r is the measurement height; U_r, the wind speed at r; k, the von Kármán constant; L, the Obukhov length; and ψ_m, a stability correction.

Because Figure 1, for example, shows $\ln(z_0)$ plotted versus u_*, consider (2) in the form

$$\ln(z_0) = \ln(r) - \left[\frac{kU_r}{u_*} + \psi_m\left(\frac{r}{L}\right)\right] . \qquad (3)$$

Taking differentials of this and ignoring the generally small ψ_m term yields

$$d\ln(z_0) = \frac{dr}{r} + \frac{kU_r}{u_*}\left(\frac{du_*}{u_*} - \frac{dU_r}{U_r}\right) . \qquad (4)$$

Because kU_r/u_* is always positive, errors in $\ln(z_0)$ are always positively correlated with errors in u_*. As a result, plots of $\ln(z_0)$ versus u_* have an unavoidable tendency to show z_0 increasing with u_* simply because of the shared quantities in the dependent and independent variables. See Figure 1. This is fictitious correlation, not real physics.

3. The Data

I have large data sets obtained from Ice Station Weddell (in the Antarctic) and from SHEBA, the experiment to study the Surface Heat Budget of the Arctic Ocean. Both experiments included eddy-covariance measurements of u_*, of the Obukhov length (L), and of mean meteorological quantities. These data provide measurements of z_0 from (2) and allow calculating a bulk flux estimate of u_* with the Andreas et al. (2010) algorithm. The winter data from both experiments include many instances of drifting and blowing snow, where (1) is presumed to apply.

4. Results

The data in Figure 1 show z_0 increasing with the measured u_* for all u_* values, not just in the drifting snow regime where $u_* \geq 0.3$ m/s (see Figure 2). This behavior is just what (4) predicts.

In Figure 3, where I plot z_0 against the u_* value from a bulk flux algorithm (i.e., Andreas et al. 2010), however, z_0 is independent of the bulk u_* in the blowing snow regime. Moreover, Figure 3 also exhibits the known aerodynamically smooth scaling that was obscured by the choice of variables in Figure 1.

Because using the bulk flux algorithm to compute u_* minimizes the fictitious correlation between z_0 and u_*, I conclude that *(1) is a fallacy that has been perpetuated by flawed analyses.*

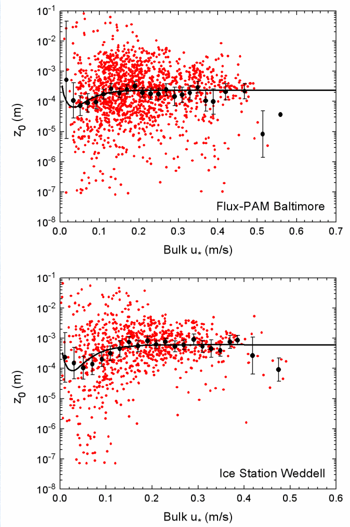

Figure 3. Same z_0 values as in Figure 1. Here, though, the independent variable is the u_* value from a bulk flux algorithm, u_{*B}. The curves in the two panels are

$$z_0 = 0.135\frac{\nu}{u_{*B}} + B\tanh^3(13u_{*B}) ,$$

with $B = 2.3\times10^{-4}$ for the Baltimore panel and with $B = 6.0\times10^{-4}$ for the Ice Station Weddell panel.

5. References

Andreas, E. L, P. O. G. Persson, R. E. Jordan, T. W. Horst, P. S. Guest, A. A. Grachev, and C. W. Fairall, 2010: Parameterizing turbulent exchange over sea ice in winter. *J. Hydrometeor.*, **11**, 87–104.