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Intercomparison of methods for the estimation of displacement height and roughness length from single-level eddy covariance data

Alexander Graf (1), Anneke van de Boer (2,3), Dirk Schüttemeyer (2), Arnold Moene (3), and Harry Vereecken (1)

(1) Forschungszentrum Jülich, Agrosphere, ICG-IV, Jülich, Germany (a.graf@fz-juelich.de), (2) Meteorological Institute, University of Bonn, Germany, (3) Meteorology and Air Quality Department, Wageningen University, the Netherlands

The displacement height d and roughness length z_0 are parameters of the logarithmic wind profile and as such these are characteristics of the surface, that are required in a multitude of meteorological modeling applications. Classically, both parameters are estimated from multi-level measurements of wind speed over a terrain sufficiently homogeneous to avoid footprint-induced differences between the levels. As a rule-of thumb, d of a dense, uniform crop or forest canopy is 2/3 to 3/4 of the canopy height h, and z_0 about 10% of canopy height in absence of any d. However, the uncertainty of this rule-of-thumb becomes larger if the surface of interest is not "dense and uniform", in which case a site-specific determination is required again.

By means of the eddy covariance method, alternative possibilities to determine z_0 and d have become available. Various authors report robust results if either several levels of sonic anemometer measurements, or one such level combined with a classic wind profile is used to introduce direct knowledge on the friction velocity into the estimation procedure. At the same time, however, the eddy covariance method to measure various fluxes has superseded the profile method, leaving many current stations without a wind speed profile with enough levels sufficiently far above the canopy to enable the classic estimation of z_0 and d. From single-level eddy covariance measurements at one point in time, only one parameter can be estimated, usually z_0 while d is assumed to be known. Even so, results tend to scatter considerably. However, it has been pointed out, that the use of multiple points in time providing different stability conditions can enable the estimation of both parameters, if they are assumed constant over the time period regarded. These methods either rely on flux-variance similarity (Weaver 1990 and others following), or on the integrated universal function for momentum (Martano 2000 and others following). In both cases, iterations over the range of possible d values are necessary.

We extended this set of methods by a non-iterative, regression based approach. Only a stability range of data is used in which the universal function is known to be approximately linear. Then, various types of multiple linear regression can be used to relate the terms of the logarithmic wind profile equation to each other, and derive z_0 and d from the regression parameters. Two examples each of the two existing iterative approaches, and the new non-iterative one are compared to each other and to plausibility limits in three different agricultural crops. The study contains periods of growth as well as of constant crop height, also allowing for an examination of the relations between z_0, d, and canopy height. Results indicate that estimated z_0 values, even in absence of prescribed d values, are fairly robust, plausible and consistent across all methods. The largest deviations are produced by the two flux-variance similarity based methods. Estimates of d, in contrast, can be subject to implausible deviations with all methods, even after quality-filtering of input data. Again, the largest deviations occur with flux-variance similarity based methods. Ensemble averaging between all methods can reduce this problem, offering a potentially useful way of estimating d at more complex sites where the rule-of-thumb cannot be applied easily.

Martano P (2000): Estimation of surface roughness length and displacement height from single-level sonic anemometer data. Journal of Applied Meteorology 39:708-715.

Weaver HL (1990): Temperature and Humidity flux-variance relations determined by one-dimensional eddy correlation. Boundary-Layer Meteorology 53:77-91.