Limitations of MOST and z_{0T}

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The history of micrometeorology is dominated by studies of "perfect" sites, but the real world is quite different. As far back as 1959, Priestley suggested that it was well time to step past studies of perfect sites and to focus instead on natural landscapes. The development of advanced numerical models makes the matter a source for considerable concern, since the models of today accept (and extend) outdoor-laboratory relationships that have been largely unimproved by the advances in instrumentation and understanding since they were first promulgated.

In the days of the initial field studies, instrumentation was inadequate to reveal features that are quite evident today. In the early 1960s, there were no measurements of u_*; instead, values of u_* were estimated by applying a constant of proportionality to wind speed measured very near the surface – typically at 0.5 m above pasture. Subsequent analysis followed the MOST construct, with ϕ_H and later ϕ_m being plotted against $-z/L$, on log-log graph paper. Data were too scattered to look into the stable case – all of the published results first addressed unstable.

The relationships that have become embedded in the micrometeorological culture were initially drawn, for ϕ_H, using a French curve. The eventual adoption of a similar formulation to describe ϕ_m was intentionally promoted because it imposed a convenient equality between z/L and Ri in unstable conditions. The data were sufficiently scattered to permit this simplification.

In modern times, the relationships that were initially proposed have been adopted for use in numerical models. In many model applications, it is not the original formulations that are used but their integrals. There are two approaches to this. First, the original data can be evaluated so as to quantify the integral ψ-functions directly from the measurements; second the approximations to these data expressed as the ϕ-functions can be formally integrated. The modeling community clearly prefers the latter.

All of the early analyses accepted the Monin-Obukhov similarity theory (MOST) construct, and hence accepted as an experimental goal the description of how stability changes modified the basic logarithmic wind profile at neutral. The question of how well the surface controlling variables (H, u_*, z) explained observed fluctuations in profiles ($\partial\theta/\partial z$ and $\partial u/\partial z$) was left unanswered, because there was no independent direct measure of u_*. Modern data permit the matter to be addressed directly. To this end, data from six experiments have been used – conducted in field studies in Texas, South Carolina, Alabama, Idaho, Utah and Zimbabwe. The surfaces represented range from desert to forest. Using statistical methods, the region of best applicability of the MOST framework is found to vary from site to site, but is generally less than the range $-0.2 < z/L < 0.1$.

Agreement between new field data and conventional descriptions of flux-gradient relations can be attributed, in part at least, to the ravages of the "shared variable" syndrome. Scrutiny of the data now assembled indicates a requirement to modify the accepted view of convective regimes. In particular, free convection is found to cut in much closer to neutral than is often assumed – it is partially a contributing process at $-z/L = 0.03$, and it appears to be in full control by $-z/L \approx 0.2$ (this, largely in agreement with results from the 1950s). On the stable side, intermittency becomes a strong feature beyond $z/L \approx 0.1$.

The formulation of flux/gradient relationships is only a part of the overall puzzle. In order to extend the profile considerations to the surface itself, it is now common to make use of the documented roughness length appropriate for a grid cell under consideration, and to quantify the corresponding thermal roughness length via consideration of the quantity $\ln(z_0/z_{0T}) = kB^{-1}$. Early work in pipes and wind tunnels showed kB^{-1} depended on the roughness Reynolds number $Re_* = u_* z_0/\nu$, and a power law relationship evolved. Attempts to extend this laboratory result to the outside world revealed (a) that the power law relationship between kB^{-1} and Re_* applied best for a "fibrous" canopy (like a coniferous forest), and (b) that for other surfaces there was little variation of kB^{-1} with Re_*. A value of $kB^{-1} = 2$ was proposed as an optimum.

Recent data indicate that kB^{-1} is highly variable, but does indeed average to a value in the range 0 to 2 in daytime. However, at night no order is evident. Reliance on any power-law association between kB^{-1} and Re_* is therefore of dubious validity. This is emphasized by considering a randomization of field data, yielding a power law dependence similar to that found for the laboratory case. The power law approach, as is seen in some models, is therefore not a dependable description of the air-surface exchange characteristics of the surface.

Having shown the limitations of currently assumed relationships, both in the air and at the air-surface interface, the question arises as to what alternative could be better. Preliminary analyses indicate that there could be profit in adopting the methodologies common in fluid mechanics – relying on gross parameterizations of the surface layer rather than detailed micrometeorological descriptions. The use of a 10 m reference level invites consideration of formulations based on the friction coefficient ($Cf = u_*/u$) for the momentum flux, and the Stanton number for heat fluxes. Use of the Stanton number (defined as $St = \overline{w'T'}/(u_*(T_s - T_a)$, where T_s is the infrared surface temperature and T_a is air temperature at 10 m height) is attractive now that satellite-derived surface temperatures are available.