Comments on "Horizontal Velocity Spectra in an Unstable Surface Layer"

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Kaimal (1978) shows that the low-frequency parts of the longitudinal and lateral (u and v) spectra in the surface layer scale on the mixed-layer thickness $z_i$ and the friction velocity $u_w$, instead of scaling on the local $z$ and $u_*$ with some influence of $z/L$ as is the case with $w$ spectra. The purpose of this comment is to point out that the same phenomenon is found in (neutral) laboratory boundary layers (Townsend, 1961; Bradshaw, 1967). The explanation is that eddies in the outer part of the layer tend to grow until they fill the layer; close to the surface, the boundary condition $w=0$ confines the velocity fluctuations of the eddies to the $x$-$y$ plane. Specifically, if an outer-layer eddy has wavelength $\lambda$ and all three velocity components of the same order, then the continuity equation ensures that for $z\ll\lambda$ we have $w=ue/\lambda=uv/\lambda$. (This is the reason that synoptic-scale motion is nearly two-dimensional; by definition it has $z\ll\lambda$.) Similar arguments apply if the outer-layer eddies influence the flow near the surface via pressure-induced irrotational fluctuations rather
than via vortical motions. Clearly, if $w \ll u$, $\bar{uw} \ll \bar{u}^2$; since $\bar{u}^2 \approx u_*^2$, $|\bar{uw}| \ll u_*^2$ and the fluctuations induced in the surface layer have little effect on the shear stress $-\rho uv$ or the turbulent energy production $-\rho uv \partial U/\partial z$. For this reason the induced motion has been called the "inactive motion." The part of the turbulence that carries the shear stress and the energy production is unaffected and so, therefore, is the dissipation (i.e., the energy transfer to the small-scale motion). Therefore the small-scale (high-frequency) motion scales as usual, and the only effect of the inactive motion is to add low-frequency energy to the $u$ and $v$ spectra. Since the outer-layer eddies scale on $z_i$ and $u_*$, so do the extra spectral contributions.

It is interesting to note that the inactive motion can affect the rate of lateral dispersion of a plume in the surface layer, which is at least roughly related to $\bar{u}^2$.

REFERENCES

