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Temperature structure in the atmospheric boundary layer

Ann-Sofi Smedman
Uppsala University, Department of Earth Sciences, Uppsala, Sweden (ann-sofi.smedman@met.uu.se, +46 18 551124)

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It is well established from experimental and theoretical studies that the temperature structure in the atmospheric boundary layer is depends on stability. During free convection conditions the flow is dominated by circular thermals but when stratification is becoming slightly unstable longitudinal roll structures that extend vertically throughout the entire boundary layer will be present. In close to neutral conditions on the unstable side (the UVCN regime) when the Obukhov length is much greater than the surface layer depth, it is observed that the structure of the surface layer turbulence does not accord with standard similarity theory. In particular the efficiency of the turbulent exchange of sensible and latent heat is observed to be more strongly enhanced than is consistent with the standard model. Also the profiles of dissipation of turbulent kinetic energy and temperature fluctuation variance are found to depend on the structure of the whole boundary layer (i.e. are non-local), indicating that a large-scale transport process is at work. At the same time, co-spectral analysis shows how the large scale eddy motions that determine the heat transport process near the surface are typically 1/5 of the surface layer depth. All these features are found to be similar in measurements at two marine sites, in the Baltic Sea and in Lake Ontario respectively and at several flat land sites (around Uppsala and at the Island of Gotland), indicating that they are determined by the dynamics of the whole boundary layer rather than being simply dependent on the surface boundary conditions.

The observed structures can also be interpreted as possible manifestations of a bifurcation of the large scale eddy structure towards a state in which there are quasi-steady longitudinal rolls and, on a smaller scale, unsteady detached eddies. Our interpretation of the results from the measurements is that, in the UVCN regime, the latter component plays a significant role for the exchange of sensible and latent heat. Thus, high-speed air from above the surface layer is engulfed into the surface layer and brought down to the surface as detached eddies. Linear theory (Townsend, 1976) predicts that for a field of such detached eddies, the eddy diffusivity for heat can be as great as 5/2 as that for momentum. This is consistent with our observations.