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Monin-Obukhov similarity relationships for structure parameters of temperature and humidity under unstable conditions - results from surface-layer resolving LES

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Turbulent fluctuations of the refractive index (n) in the atmospheric boundary layer are related to local fluctuations in the air density, which can be expressed by the refractive-index structure parameter (C_n^2). Since these fluctuations depend mainly on temperature and humidity, it is possible to relate C_n^2 to the structure parameters of temperature (C_T^2) and humidity (C_q^2).

A set of high-resolution LES of the atmospheric boundary layer with grid spacing of $2 - 4$ m is carried out in order to determine C_T^2 and C_q^2 in the surface layer for different conditions, ranging from near-neutral to convective boundary layers. Universal functions, relating the structure parameters to the surface fluxes of sensible and latent heat by means of Monin-Obkhukov similarity theory (MOST) and local free convection (LFC) scaling, are calculated for the first time from the LES data and compared with the proposed formulations in the literature.

The LES data suggest that both C_T^2 and C_q^2 follow MOST, when entrainment of dry air at top of the boundary layer is neglible (e.g. when the ratio between the surface flux and the entrainment flux is around 0). The similarity functions are found to be well within the range of the proposed functions in literature. When entrainment becomes dominant (entrainment ratio > 0.5), C_q^2 does no longer follow MOST and no universal function exist that relates C_q^2 to the surface flux of latent heat.

We show that LFC can be considered even for conditions with moderate wind shear without introducing an error of more than 5% in the surface flux. However, as for MOST, no LFC relationship exists for C_q^2 when entrainment of dry air dominates the humidity distribution in the boundary layer.

Moreover, we show that neglecting the effect of humidity on the buoyancy flux, as often done in practice, leads to non-universal MOST and LFC relationships and is a rather questionable approximation.