Reasons for the breakdown of the Monin-Obukhov-Theory above rough surfaces

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Breakdown of the theory

Above rough surfaces as forests or agricultural crops one observes **smaller gradients** than predicted by the Monin-Obukhov-theory (MO) (see e.g. Thom 1975, Garratt 1978 or Cellier and Brunet 1992). This 'roughness sublayer' (Raupach et al. 1980) reaches approximately up to twice the canopy height (figure 1). Beside his there is a local maximum inside the canopy, below which counter-gradient fluxes are observed (Denmead and Bradley 1985).

Explanation attempts

Since the gradient is smaller at the same turbulent flux the **exchange** must be **more intensive**. There have been some qualitative attempts for an explanation:

- Thom (1975) proposes 'wake diffusion' and 'thermal seeding' i.e. eddies in the lee of the roughness elements and plumes of warm air developing between the plants.
- Denmead and Breadly (1985) assume that close to the anopy a single height coordinate as used in MO-theory is not valid.
- Rauppach et al. (1996) propose the use of mixing layer theory instead of boundary layer theory.

None of these attempts lead to a quantitative description of the roughness sub layer.

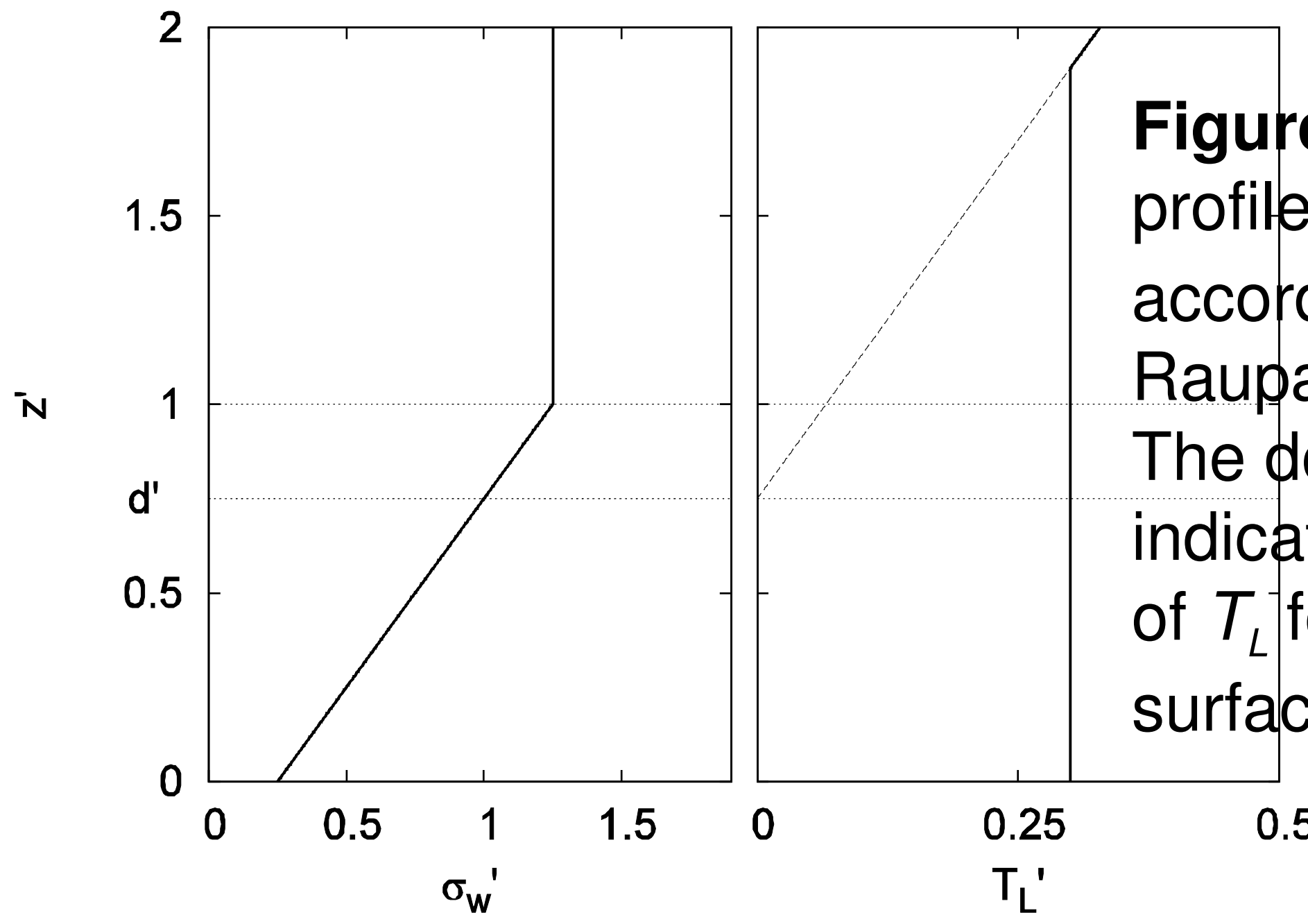

Figure 2: scaled profiles of σ_w and T_L according to Raupach (1988). The dotted line indicates the course of T_L for a solid surface at *d*.

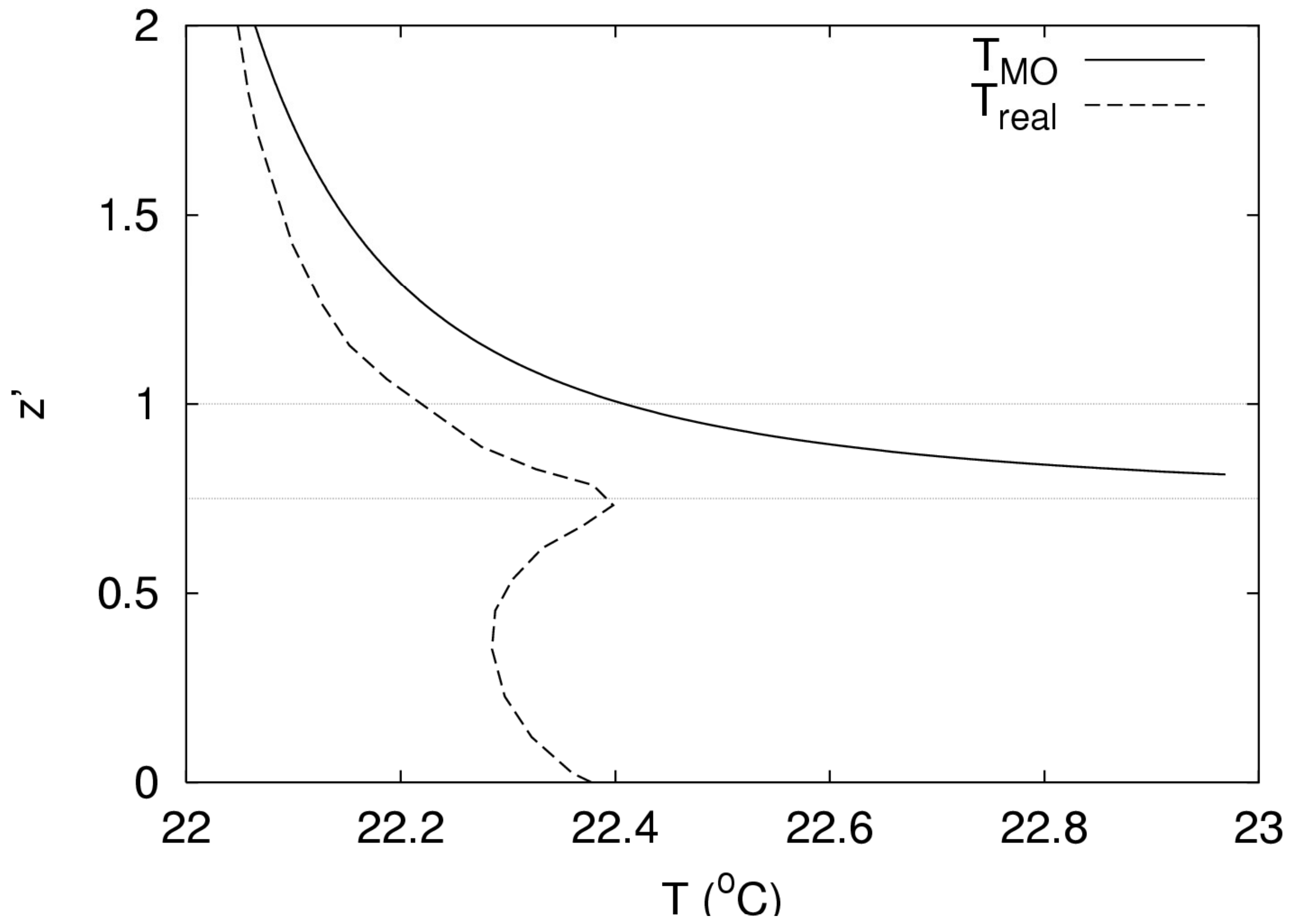

Figure 1: Schematic of the Temperature profile above a plant canopy as predicted by Monin-Obukhov-Theory (T_{MO}) and a temperature profile (T_{real}) typically observed during daytime. Vertical coordinate z' is scaled with canopy height.

Localized near field theory

The localized near field theory (LNF, Raupach 1989) describes turbulent exchange within the canopy. It relates the source distribution *S* inside the canopy to concentration *c* in and above the canopy. Turbulent exchange is split into near and far field. Exchange in the far field is described by K-theory with coefficient K_f. In the near field turbulent exchange is less efficient and the source distribution influences the form of the profile via a kernel function k_n:

$$c(z)-c(z_R)=\int_z^{z_R}\frac{\int_0^{\min(z_f)}S(z_s)\,dz_s}{K_f(z_f)}\,dz_f + \int_0^h S(z_s)\cdot k_n(z,z_s)\,dz_s \qquad \text{(Eq. 1)}$$

Turbulent exchange is incorporated in the LNF via standard deviation of vertical velocity σ_w and the Lagrangian time scale T_L. Raupach (1988) gave profiles for these parameters valid for a wide range of canopies (Fig.2). Especially the constant T_L indicates enhanced turbulence.

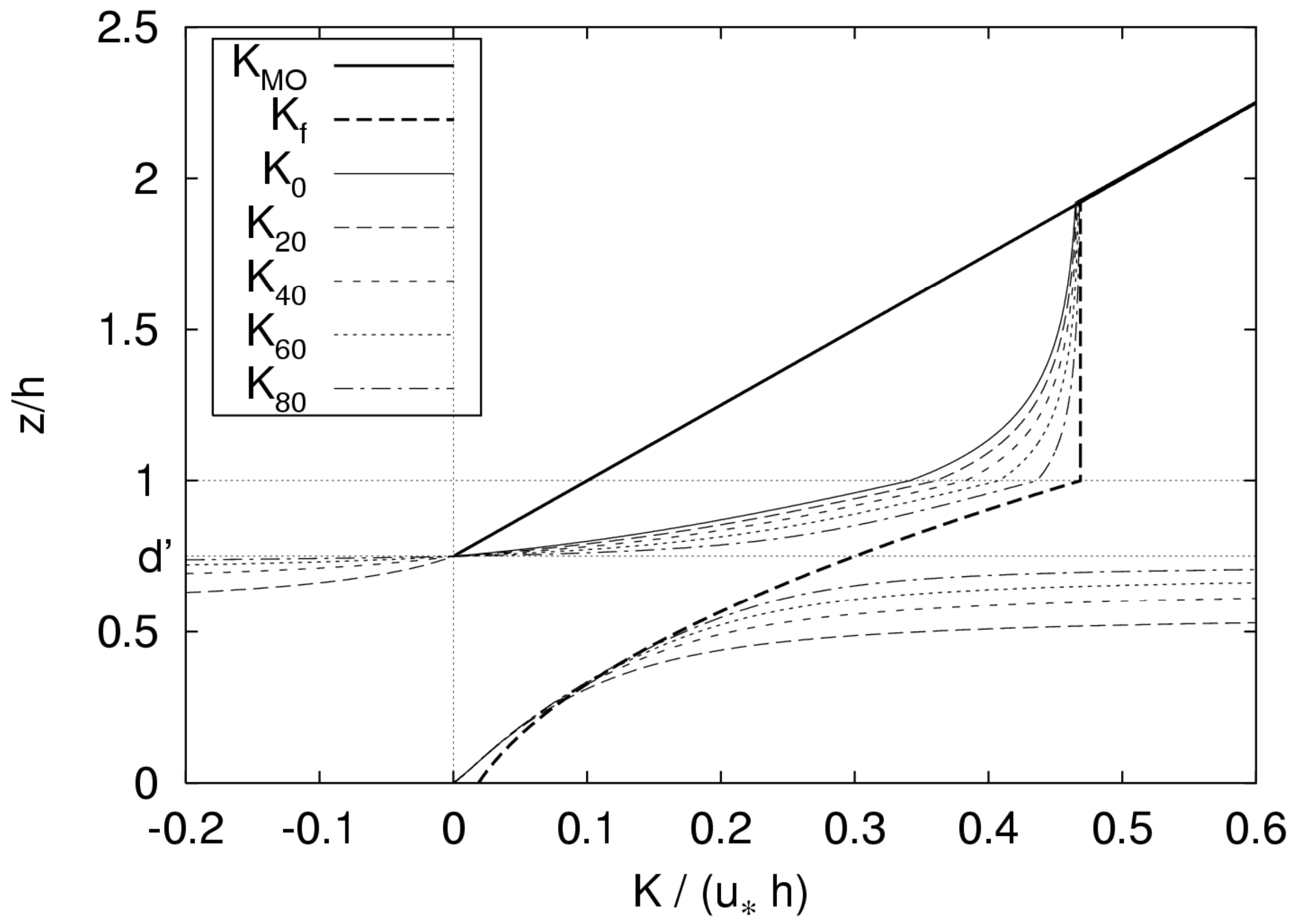

Figure 3: Profiles of dimensionless exchange coefficients at neutral stratification under the assumption of planar sources at d'=0.75 and at z'=0. K_{MO} is the exchange coeffcient according to MO-theory, K_f the exchange coefficient of the far field and K_0…K_{80} the 'real' exchange coefficients for a source strength at the floor of 0…80% of the total source strength.

Exchange coefficients

Under neutral stratification the exchange coefficient according to MO-theory is

$$K_{MO}=u_*\cdot\kappa\cdot(z-d)$$

The far field exchange coefficient is

$$K_f=\sigma_w^2\cdot T_L$$

The 'real' exchange coefficient can be calculated from Eq. 1 with the flux at level z equal to the integrated source strength below:

$$K_{\text{real}}(z)=-\frac{\int_0^{\min(z,h)}S(z_s)\,dz_s}{\left.\frac{dc}{dz}\right|_z}$$

All three coefficients are plotted in Figure 3 for a simple source configuration with varying source strengths. Two planar sources are assumed: one at the ground and one at $z = d$ .The relative strength of the ground source is varied.

Result

The far field exchange coefficient K_f is larger than K_{MO} due to the enhanced turbulence described by σ_w and T_L. But the near field effects reduces this and K_{real} is smaller than K_f. The stronger the upper source at z=d is the smaller becomes the exchange coefficient.

Also visible is the range below d where negative values of K_{real} indicate counter gradient fluxes.

Conclusion

There are two effects modifying the gradients in the roughness sub layer:

- Enhanced turbulence reduces gradients.
- The source distribution inside the canopy enhances the gradient above.

The source distribution inside the canopy strongly influences the form of the profile in the roughness sub layer. A universal correction function for the roughness sub layer as proposed by e.g. Garratt (1978) can not account for this.

The empirical parameterizations for σ_w and T_L given by Raupach (1988) show that turbulence is enhanced in the roughness sub layer but they do not explain why.

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