2. Tests on mixing length parameterization in 1- D model

The PBL height is usually sensitive to the parameterization of the mixing length (in the case that both are not only tunables). This dependence works also in the opposite direction, because certain expressions for mixing length use the parameterization of the PBL height. A typical example is the current parameterization of mixing length used in the "base" and "MaTu" experiments, which was introduced by J.-F. Geleyn and Jure Cedilnik in 2005 (hereafter signed as GC05 or "jure"). The GC05 kind of parameterization was used also in the previously described tests with PBL height. The formula for the mixing length yields:

$$l_{m/\theta} = \frac{\kappa\left(z+z_{0/\theta}\right)}{1+\frac{\kappa\left(z+z_{0/\theta}\right)}{\lambda_{m/\theta}}\left(\frac{1+\varepsilon_{m/\theta}}{\beta_{m/\theta}+\varepsilon_{m/\theta}}\right)},$$

Where $\varepsilon_{m/\theta}$ is an exponential shaping function of the original empirical mixing length formula proposed by Blackadar (1962) and it depends on the height of the PBL.

$$\varepsilon_{m/\theta} = e^{-\alpha_{m/\theta}\sqrt{\frac{\left(z+z_{0/\theta}\right)}{h_{PBL}}}+\beta_{m/\theta}}$$

The course of the mixing length with height is depicted in figure 4.

The reference experiment (EBREF) uses the Bougeault-Lacarrère type of mixing length parameterization, which compares the turbulent kinetic energy and the integral buoyancy of the transported parcel (Bougeault and Lacarrère, 1989, hereafter "BL89"). It is supposed that for each level in the atmosphere the mixing length can be related to distance that a parcel originating from this level, and having an initial kinetic energy equal to the mean TKE of the layer (e), can travel upward and downward before being stopped by buoyancy effects. Thus, different mixing lengths exist for the upward transport (l_{up}) and downward transport (l_{down}) defined as follows:

$$\int_{z}^{z+l_{up}} \frac{g}{\theta}\left(\theta\left(z\right)-\theta\left(z'\right)\right)dz' = e\left(z\right) \quad \text{and} \quad \int_{z-l_{down}}^{z} \frac{g}{\theta}\left(\theta\left(z'\right)-\theta\left(z\right)\right)dz' = e\left(z\right)$$

Finally, the mixing length is computed from averaged l_{up} and l_{down} mixing lengths. For the current parameterization (Pascal Marquet, 2003, ARPÈGE-CLIMAT, ACBL89 routine of the code) the averaging yields:

$$l_m = \left(\frac{l_{up}^{-\frac{2}{3}}+l_{down}^{-\frac{2}{3}}}{2}\right)^{-\frac{3}{2}}$$

The BL89 mixing length treats for instance situations with unstable layers capped by inversions – where the vertical depth of the unstable layer is automatically selected as the length scale for the turbulence.

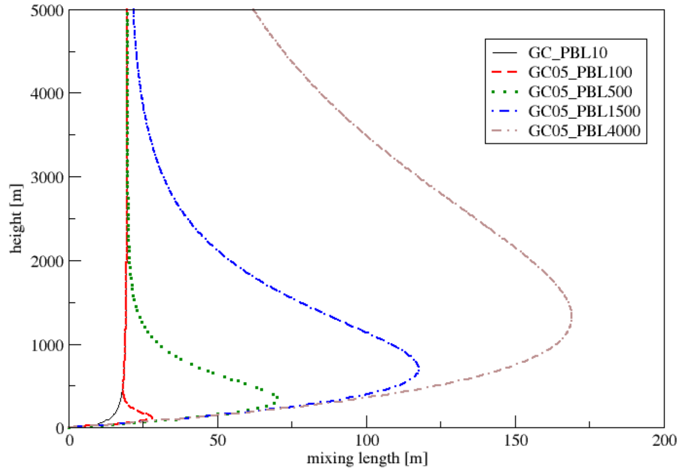

Figure 4: Course of the GC05 momentum mixing length with height for various heights of the PBL (10, 100, 500, 1500 and 4000 m).

Several experiments were done with introduction of the BL89 scheme for the pTKE turbulence parameterization. BL89 parameterization of mixing length (the same as for ARPÈGE) was used in the TKE computation (inside ACDIFUS_PTKE) and combined with the GC05 kind of mixing length used only for the computation of the turbulent exchange coefficients (ACCOEFK_PTKE). Another test was provided with BL89 parameterization of mixing length used in the entire pTKE computation. The mixing length for enthalpy was obtained by multiplying the BL89 mixing length for momentum $l_{m\,(BL89)}$ by ratio of the diagnostically computed mixing lengths of enthalpy $l_{\theta\,(GC05)}$ and momentum $l_{m(GC05)}$ according to GC05 parameterization.

$$l_{\theta\,(BL89)} = l_{m(BL89)} \frac{l_{\theta\,(GC05)}}{l_{m(GC05)}}$$

Finally, the mixing length of Troen and Mahrt (Troen and Mahrt, 1986) was also used for comparison (Figure 5).

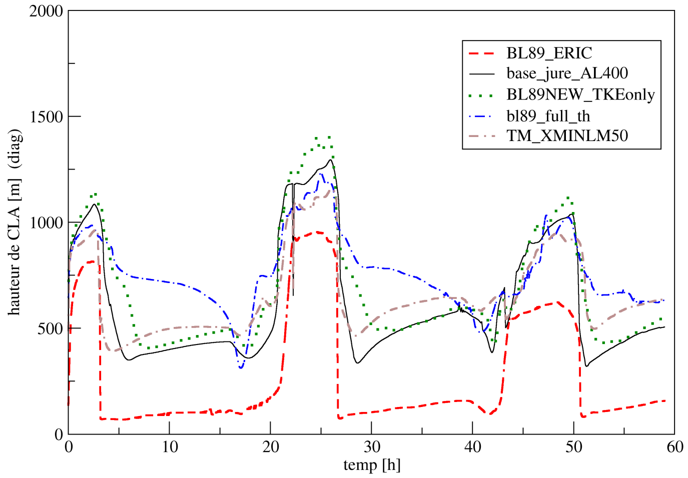

Figure 5: GABLS2 diagnostics of the PBL height for various parameterizations of the mixing length. The reference is the BL89_Eric (EBREF) experiment showed by dashed line. Solid line denotes the experiment using the "jure" (GC05) kind of mixing length (base) with asymptotic mixing length ALMAV=400. The dotted line shows the result with BL89 mixing length introduced only for the TKE computation and combined with the GC05 mixing length for K coefficients. The dashed-dotted line denotes the full BL89 mixing length application for pTKE, both for momentum and enthalpy. The double- dashed and dotted line represents the evolution of the PBL height with parameterization of Troen and Mahrt.

The comparison shows that the diagnosed PBL height is systematically higher with respect to the reference experiment (EBREF). The partial BL89 introduction for TKE computation makes that the evolution of the PBL height is smoother with respect to the "base" experiment; however, the top of the PBL is further increased. On the other hand, the full BL89 mixing length application suppresses the daily course of the PBL height significantly (the same is experienced also when setting $l_{\theta\ (BL89)} = l_{m\ (BL89)}$).

It is interesting that in the "base" experiment the resulting diagnostic PBL height is much higher than the used PBL height parameterization (refer to figure 3). This can be related to certain incompatibilities between the computation of the PBL height and current formulation of the GC05 mixing length. The dimensions of this type of mixing length is controlled by asymptotic parameters ALMAV (λ) for maximum and BEDIFV (β) for the minimum value (ALMAV.BEDIFV). However, these dimensions are currently constant during the run. Hence, it may happen by very low PBL heights that the mixing length overlaps the depth of the PBL. This is not very realistic, since the mixing length symbolises also the dimensions of the turbulent eddies. Changes of the PBL height might be connected also with the changes in the dimensions of the mixing length, because in stable conditions with low PBL height the size of the turbulent eddies is usually smaller than in the well mixed PBL. The sensitivity of the PBL height evolution on the mixing length dimensions seems to be confirmed after couple of tests with different setup of ALMAV (Figure 6).

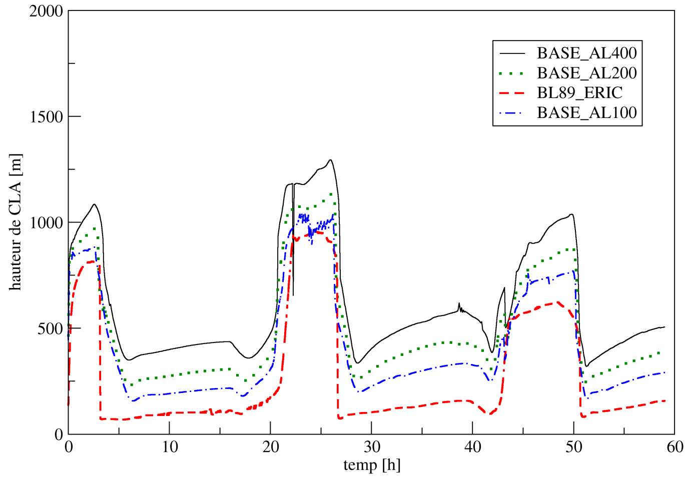

Figure 6: GABLS2 diagnostics of the PBL height for the GC05 mixing length parameterization using various setup of the ALMAV asymptote: ALMAV=400 (solid), ALMAV=200 (dotted), ALMAV=100 (dash-dotted). The reference (EBREF) is denoted by dashed line.

The lowering of ALMAV asymptote systematically decreases the height of the PBL both in the daily minimum and maximum part. However, the transitions of the PBL height to night/day regime are still smoother than in the reference experiment. It is interesting that smaller ALMAV reduces the magnitude of the oscillations which appeared in the "base" experiment with ALMAV=400. However, smaller fibrillations appear when ALMAV is decreased to 100. Similar positive influence of smaller ALMAV can be experienced also in the partial BL89 use for the pTKE scheme.

How look the mixing length profiles and their changes during the GABLS2 run ?
The BL89 mixing length of the reference (EBREF) experiment shows values up to 500 during the day-time and sudden drop during the transition to the night-time regime. Except of certain noisy patterns, high values of mixing length are concentrated below the model level 52 (of 100 levels), after there is a fast decrease of the mixing length, probably above the PBL height (Figure 7).

The GC05 kind of mixing length shows significantly smaller maxima of the mixing length but values over 20 appear higher than by EBREF, above the diagnosed top of the PBL (Figure 8). The transition up to the top of the model atmosphere (approximately 4 km deep) is also very smooth in this parameterization.

The TKE evolution shows higher daily maxima for the BL89 paramterisation (Figure 9) as for the GC05 scheme (Figure 10). On the other hand, small amounts of TKE appear over the PBL in the latter parameterization. Higher PBL values of TKE are produced in GC05 also during the night as a consequence of higher PBL top.

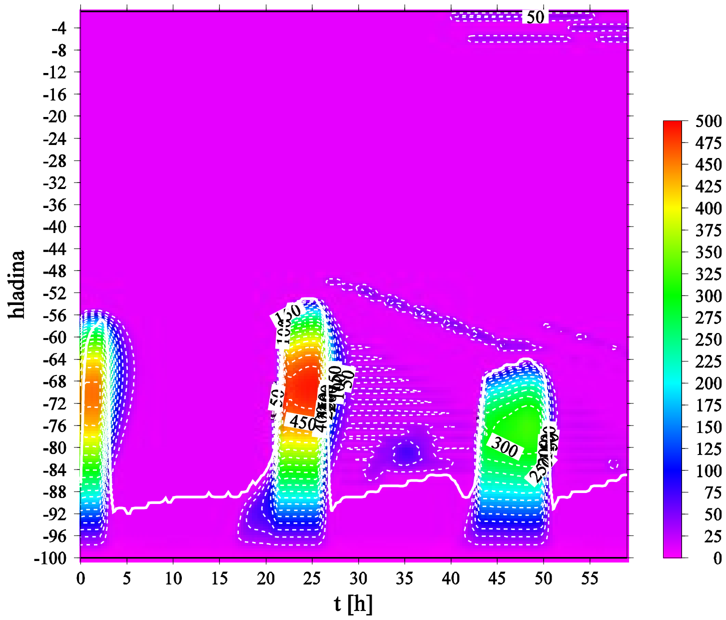

Figure 7: Time evolution of the momentum mixing length in the GABLS2 experiment for the BL89 parameterization used in the reference run (EBREF). The vertical axis is in model levels (-1 at the top of the troposphere and -100 at bottom). White line denotes the course of the diagnostic PBL height.

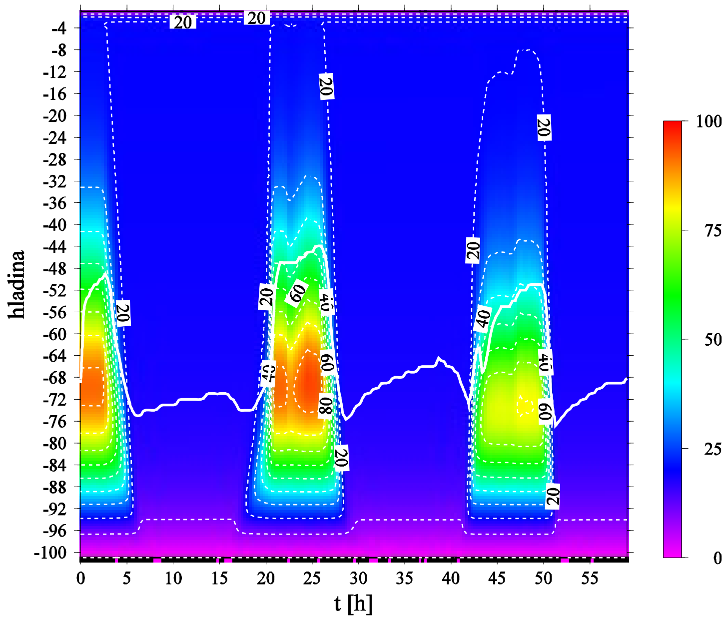

Figure 8: The same as Figure 7, except for the GC05 kind of parameterization

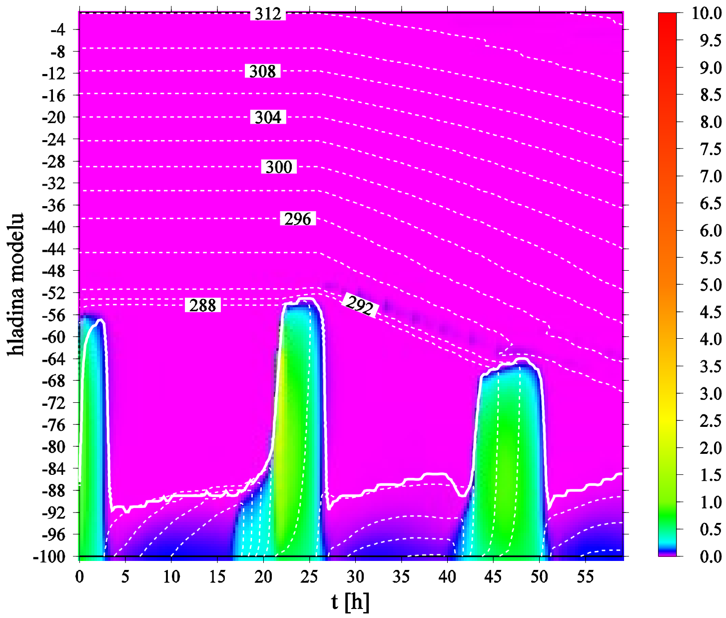

Figure 9: Evolution of TKE (in color), potential temperature (dashed lines) and height of the PBL (solid line) with the reference BL89 type of mixing length parameterization (EBREF) in GABLS2 experiment

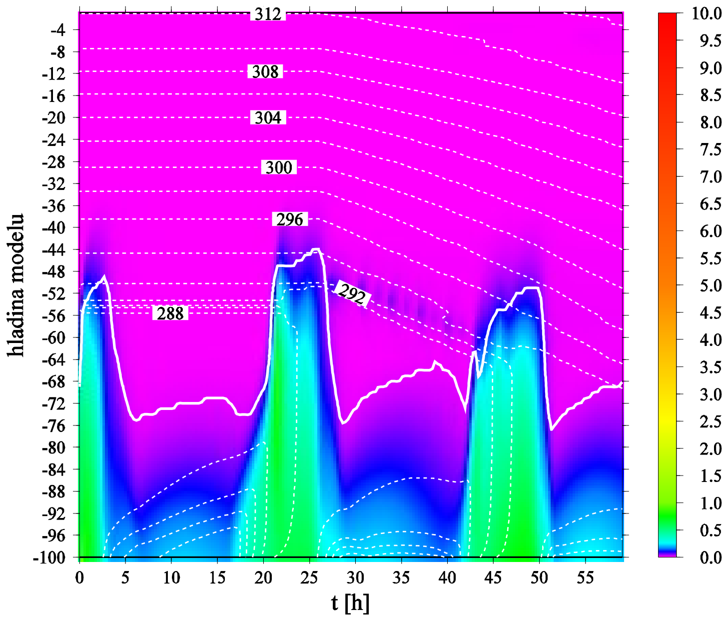

Figure 10: as in Fig. 9, except for the GC05 parameterization of the mixing length

The influence of the PBL parameterization on the evolution of the mixing length can be well observed when using the “MaTu” kind of PBL height computation (refer to previous figures and to Figure 11).

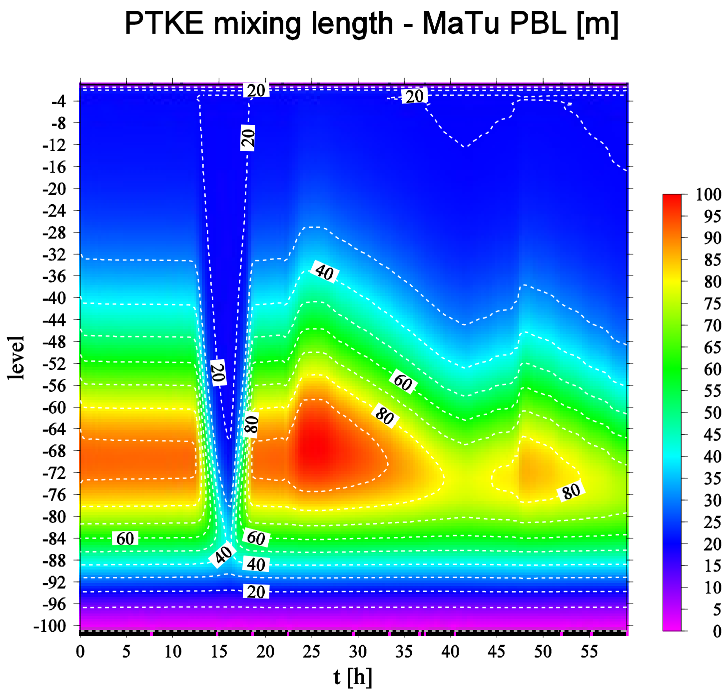

Figure 11: The same as Figure 8, except for the "MaTu" parameterization of the PBL height.

The partial use of the BL89 parameterization combined with GC05 mixing length for the K coefficient computation gives a mixing length for TKE, which is close to the reference EBREF profile. However, it is possible to see the "penetrating tops" above the daily mixing length maxima, which do not appear in the reference BL89 profile. This is likely the influence of the smooth transition of the GC05 mixing length above the PBL (Figure 12).

The full BL89 application shows even higher values of mixing length and a strong tendency to connect the daytime maxima of the mixing length (Figure 13).

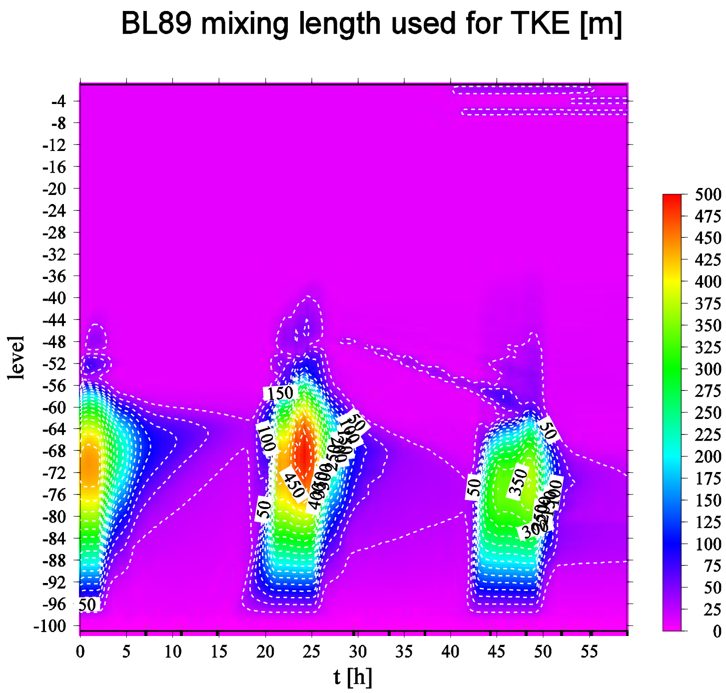

Figure 12: As Figure 7, except for BL89 used for the TKE computation (combined with GC05 mixing length for the K coefficient computation). The ALMAV asymptote is set to 400.

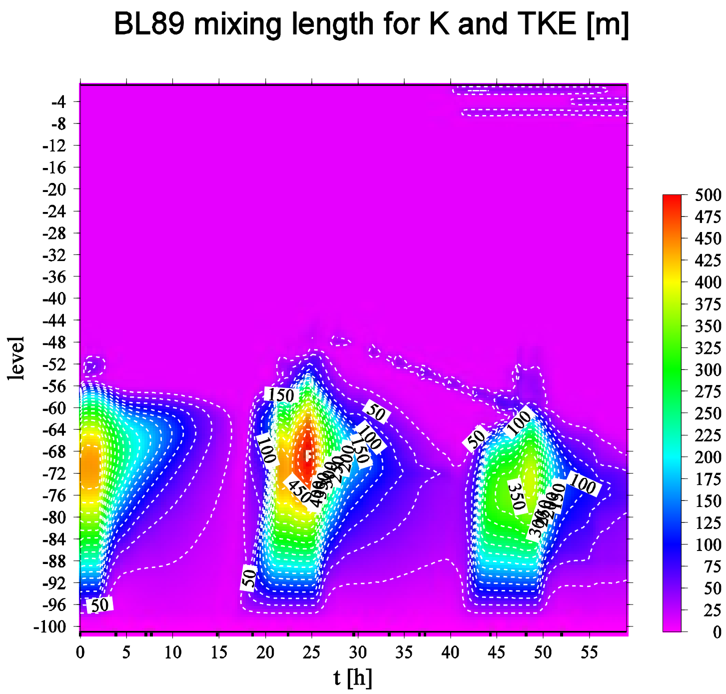

Figure 13: The same as Figure 12, except for the fully applied BL89 scheme for pTKE computation.

The Troen and Mahrt type of mixing length gives smaller values of the mixing length and a profile similar to GC05 mixing length, except of not-realistic night-time transitions in the bottom PBL part (Figure 14).

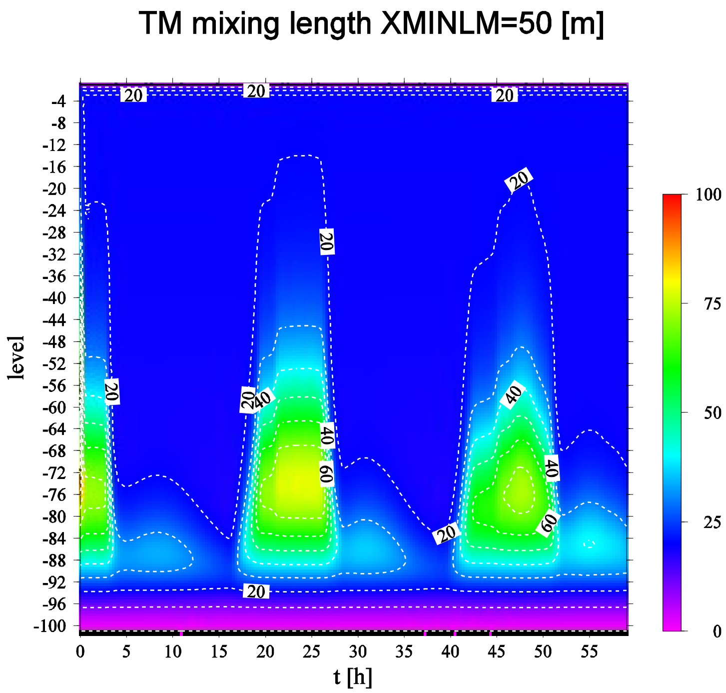

Figure 14: As in Figure 7, except for the Troen and Mahrt parameterization of the mixing length.