RC-LACE stay report

Latest upgrades of TKE-based mixing length formulation and TOUCANS code

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1 Introduction

During this stay, the main goal was to finalize the development of TKE-based turbulence length scale (TLS) formulation in TOUCANS, test its performance and prepare the related code for merging with local CY46 branch at CHMI. The other topic was related to ALARO refactoring, i.e., introducing new structures and directives into ALARO and TOUCANS code to facilitate the transformation into form suitable for application on Graphical Processing Unit (GPU). Due to deadline for submitting contributions to CY49T1, this topic was given a priority during first two weeks. The report is organized as follows. An overview of the work on refactoring of TOUCANS code is given in Chapter 2. The latest upgrade of TKE-based TLS formulation is elaborated in Chapter 3, while related code contribution is described in Chapter 4. Finally, a summary and conclusion are given in Chapter 5.

2 The work on the ALARO refactoring

The starting point of this task was newly created **apl_alaro.F90** subroutine, i.e., the version of former **aplpar.F90** cleaned from options that are either not used by ALARO or being outdated. Along with the above and introduction of new structures/directives for CPU to GPU code translators, the goal was to make **apl_alaro.F90** code free of initializations and computations that should be performed within the lower level subroutines. Additionally, larger blocks of interconnected computations are grouped into blocks (e.g., individual parametrizations, common initializations, correction of negative humidity, etc.) encompassed with intermediate structuring subroutines (layer between **apl_alaro.F90** and lower level subroutines), improving the **apl_alaro.F90** handling and readability.

My contribution included work on two such blocks: i) mixing length, stability functions and exchange coefficient computations and ii) turbulence, with surface computations and preparation for deep convection. Finally, it resulted with two intermediate subroutines named **apl_alaro_mixing.F90** and **apl_alaro_turbulence.F90**. The list of lower level subroutines whose calls are contained in each of them is provided in Table 1. Additionally, I have provided support to block for surface and turbulence preparation as some computations (call to **acfluso.F90**), originally being in the above two blocks, were moved there.

Table 1: The content of two intermediate TOUCANS subroutines created during the ALARO refactoring (in the order of calling).

apl_alaro_mixing.F90	**apl_alaro_turbulence.F90**
acmriss.F90	acptke.F90
acclph.F90	acdifv1.F90
acmixlenz.F90	aro_ground_param.F90
acmixelen.F90	aro_ground_diag.F90
acmris.F90	acaa1.F90
acmrip.F90	aro_ground_param.F90
actkecoefk.F90	acdfiv2.F90
accoefk.F90	actkecoefkh.F90
/	acdifv3.F90

The impact is validated against non-refactored code, providing bit identical norms for ALARO-0 and ALARO-1 configurations. The latter included configuration with and without the prognostic graupel. Finally, the code created was merged with other ALARO-related contributions and submitted as contribution to CY49T1.

3 The upgrade of TKE-based turbulence length scale in TOUCANS

This task is a direct continuation of work done during the previous stay [3]. The latest update considers a regime-dependent upper-air asymptotic limit given by Eqs. (13)-(16) in [3]. In statically stable conditions, when gradient of moist entropy potential temperature ($\Delta\theta_s$) across PBL is a large positive number, the mixing (provided by the existing formulation) near PBL top and above is very weak (nearly zero). Given that the same value is applied up to the model top, this can considerably affect the upper-air jet stream by suppressing (or completely destroying) the potential for turbulent mixing in its vicinity, i.e., so high in the atmosphere. For this reason, and following the correspondence with Ivan Bašták Ďurán, we decided to implement a transition of TKE-based TLS (L_{TKE}) towards the constant upper-air TLS (L_{UTLS}). Further, the experiments with latest setup indicated that having a symmetric dependency of near PBL top L_{TKE} on $\Delta\theta_s$ around zero is not optimal, i.e., on stable side there should be more strict condition. Following that, we introduced different thresholds in terms of absolute value for statically stable (lower limit activation) and unstable conditions (upper limit activation).

The lower limit of L_{TKE} (L_{MIN}), applied from the height of L_{TKE} maximum within the PBL to the model top, is now computed as a ramp function over three separated layers (Fig. 1):

$$\mathrm{L_{MIN}} = \mathrm{f(L_{BLT}, L_{UTLS}, z)} \tag{1}$$

where L_{BLT} is a regime-dependent minimum allowed TLS within the layer $z \in [0.5H_{PBL}, 1.5H_{PBL}]$, L_{UTLS} is a minimum allowed value from $z=H_{UTLS}$ (8000 m) to the model top, and for $1.5H_{PBL} \leq z \leq H_{UTLS}$, there is a linear transition between the two (denoted as L_{TRANS} in Fig. 1). The computation of L_{BLT} is modified as follows:

$$\Delta\theta_s < C_{\Delta_1}: \quad \mathrm{L_{BLT}} = \mathrm{L_{BLT1}} \tag{2}$$

$$C_{\Delta_1} \leq \Delta\theta_s \leq C_{\Delta_2}: \quad \mathrm{L_{BLT}} = \mathrm{L_{BLT2}} + \frac{\mathrm{L_{BLT2}} - \mathrm{L_{BLT1}}}{C_{\Delta_2} - C_{\Delta_1}}(\Delta\theta_s - C_{\Delta_2}) \tag{3}$$

$$\Delta\theta_s > C_{\Delta_2}: \quad \mathrm{L_{BLT}} = \mathrm{L_{BLT2}} \tag{4}$$

$$\Delta\theta_s = \theta_s(z = 1.5 \cdot \mathrm{H_{PBL}}) - \theta_s(z = 0) \tag{5}$$

where L_{BLT1}=100 m and L_{BLT2}=0 m are its regime-dependent maximum and minimum values, while C_{Δ_1}=-5 K and C_{Δ_2}=2 K are related thresholds. The value of L_{UTLS} is set to the upper-air limit of Geleyn-Cedilnik TLS formulation, currently used in the operational ALARO-1 setup at CHMI, i.e., L_{UTLS}=75 m. Finally, L_{TRANS} is computed as:

$$L_{TRANS} = L_{BLT} + \frac{L_{UTLS} - L_{BLT}}{H_{UTLS} - 1.5H_{PBL}} (z - 1.5H_{PBL}) \tag{6}$$

where z is height. Finally, L_{TKE} computed from vertical displacements is "corrected" above its maximum in the PBL as:

$$L_{TKE} = \max\left(L_{TKE}, L_{MIN}\right) \tag{7}$$

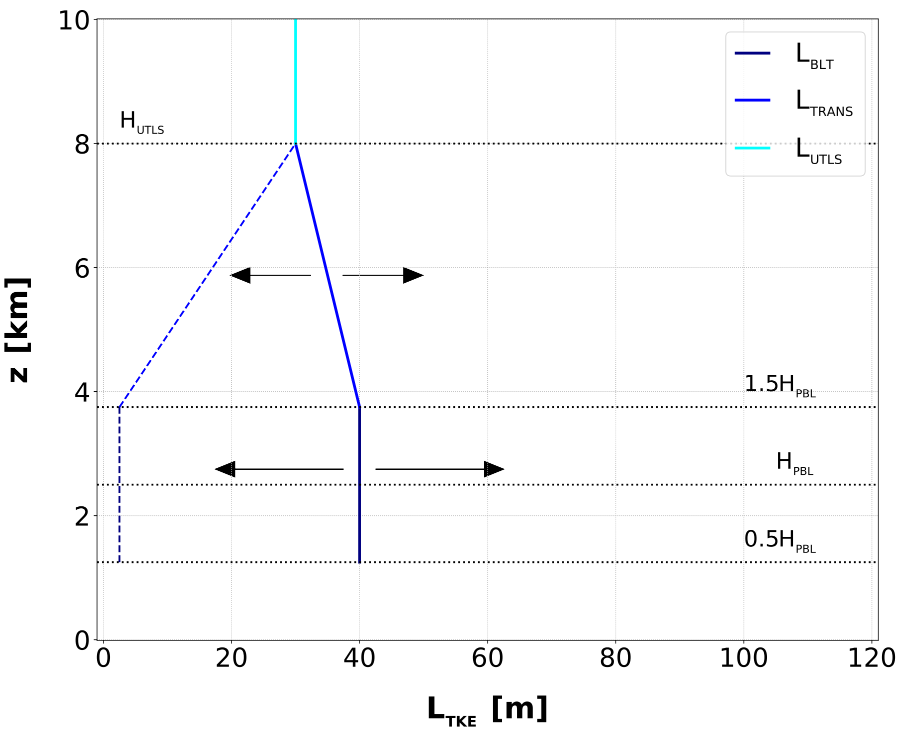

Figure 1: Construction of minimum allowed L_{TKE} value (L_{MIN}) above the height of its PBL maximum from L_{BLT} and L_{UTLS}. Arrows denote variable nature of L_{BLT} and consequently L_{TRANS}, while dashed and full lines represent different regimes within the PBL.

Following the work of [1], a similar correction has been implemented within the Geleyn-Cedilnik formulation. However, there it is applied to a tunable parameter β_{m} (cf. their Eqs.(28)-(30)), which mostly affects the upper-air limit. Finally, when the TLS is computed using a modified value of β_{m}, the TLS itself is modified in correspondence to the TKE-based formulation, i.e., above $1.5\mathrm{H}_{\mathrm{PBL}}$ it linearly approaches to the value given by unmodified β_{m} (30 m with the current tuning and after κ scaling).

The initial tests point to a small impact of the above changes to Geleyn-Cedilnik formulation. Most probably it is related to unchanged, and still too strong, mixing within the PBL. Contrary, the changes inside PBL come naturally with the TKE-based method. However, the impact of applying $\mathrm{L}_{\mathrm{UTLS}}$ is also small. Further testing on cases with upper-air jet stream is needed and will follow after this stay. There is a publication in preparation that will describe the development of TKE-based TLS formulation and demonstrate its added value over Geleyn-Cedilnik approach. It is expected that manuscript will be submitted in the first half of 2024.

Further, a technical note for the usage and fine tuning of TKE-based formulation is in preparation. It should be released early in 2024. Finally, check the content of Appendix for additional confirmation of κ scaling.

4 The TKE-based turbulence length scale code contribution

Along with the above described changes to the computation of TKE-based and Geleyn-Cedilnik TLS formulations, the prepared code also:

- includes additional option CGMIXLEN='EL2', which in statically stable conditions replaces the above described TKE-based formulation with local approach following [2]
- excludes the crossing parcels treatment as it causes too strong mixing when combined with κ scaling (confirmed by LES tests in collaboration with Ivan Bašták Ďurán)
- provides a new subroutine to compute $\mathrm{H}_{\mathrm{PBL}}$ from the profile of TKE, enabling also the selection among the existing methods
- includes protection of $\mathrm{H}_{\mathrm{PBL}}$ from above by already available namelist parameter XMAXLM

5 Conclusion

The development of TKE-based TLS formulation in TOUCANS is now considered as finalized, i.e., containing all the necessary ingredients. Hence, it is ready for extensive testing and fine tuning.

The preliminary tests point to a considerable improvement of model performance in statically stable conditions, in particular of low cloudiness and fog. However, the introduction of TKE-based formulation will not completely solve this aspect of the ALARO-based forecast. Further work on the unification of cloud scheme is desirable, while introduction of a more realistic aerosol representation should help as well.

For completeness, it is worth noting that in convective situations the performance of TKE-based TLS formulation looks promising when compared to Geleyn-Cedilnik. Further validation will be conducted from home.

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References

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Appendix - The LES-based turbulence length scale diagnostics

The TLS diagnostics based on LES budget equations for turbulent variances of momentum (TKE), liquid water potential temperature (θ_l) and total specific moisture (q_t) is shown on Figs. 2-3. As it can be seen, three TLS from LES somewhat differ, but also depend on the resolution. However, the κ scaling of TLS in NWP ensures satisfying match with LES near the surface and PBL top, while for l_m=$C_K/\nu \cdot L_{TKE}$ scaling the mixing is mostly to weak in these regions. On the other hand, in-between the mixing with κ scaling is mostly too strong.

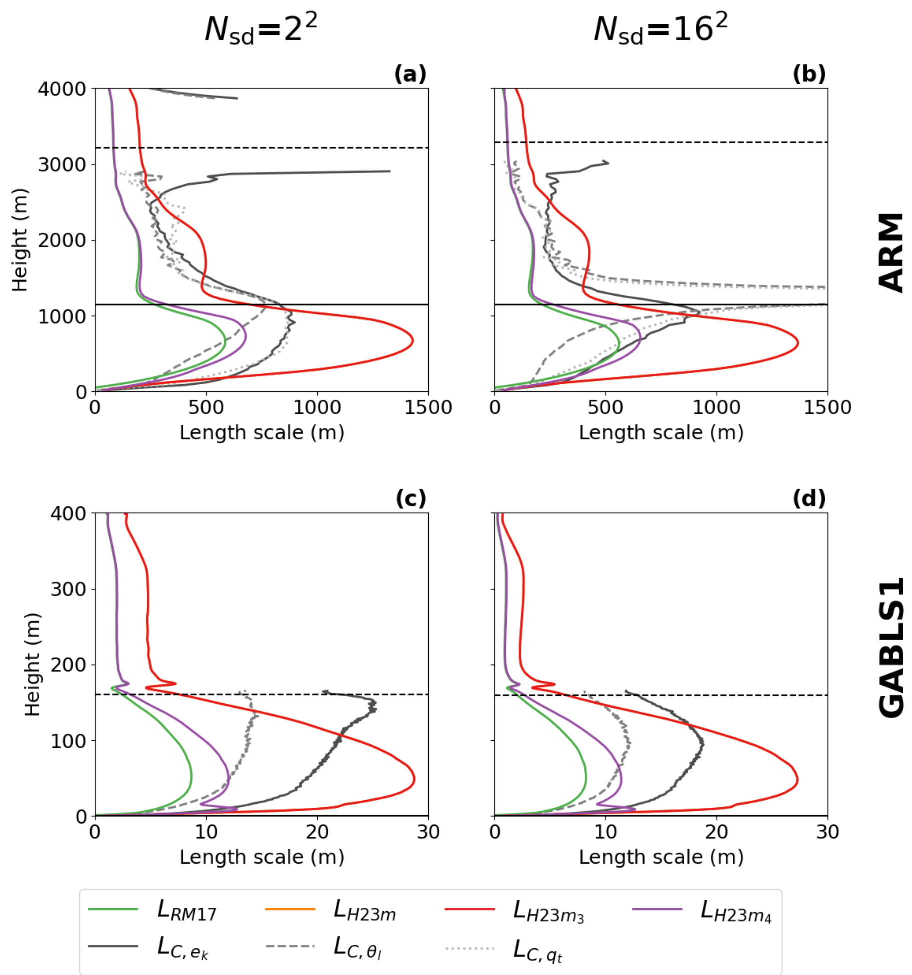

Figure 2: Budget-based LES diagnostics of turbulence length scale (TLS) at different resolutions (N_{sd}) for ARM (continental cumulus) and GABLS1 (stable boundary layer) cases (cf. [4] for details). L_{RM17} is [5] formulation (our starting point), L_{H23m} and L_{H23m3} correspond to our formulation with L_{MIN}=f(L_{BLT}) and differ in C_{Δ_1} value, while L_{H23m4} differs from L_{H23m3} in scaling, i.e., instead of l_m=$\kappa \cdot L_{TKE}$, it applies l_m=$C_K/\nu \cdot L_{TKE}$. L_{C,e_k}, L_{C,θ_l} and L_{C,q_t} are TLS obtained from TKE, $\theta_l'^2$ and $q_t'^2$ LES budgets. The horizontal dashed and solid lines denote the PBL top and the cloud base height, respectively.

Nevertheless, in a well-mixed layer, with vertical gradients of diffused conservative fields being nearly zero, this is not so important (although it may be in transitional situations). Additionally, the perfect matching of TLS between LES and NWP model is not needed/expected as the latter includes assumptions (simplifications), while TLS itself evolves. In LES it is only diagnosed at a certain point after the initialization.

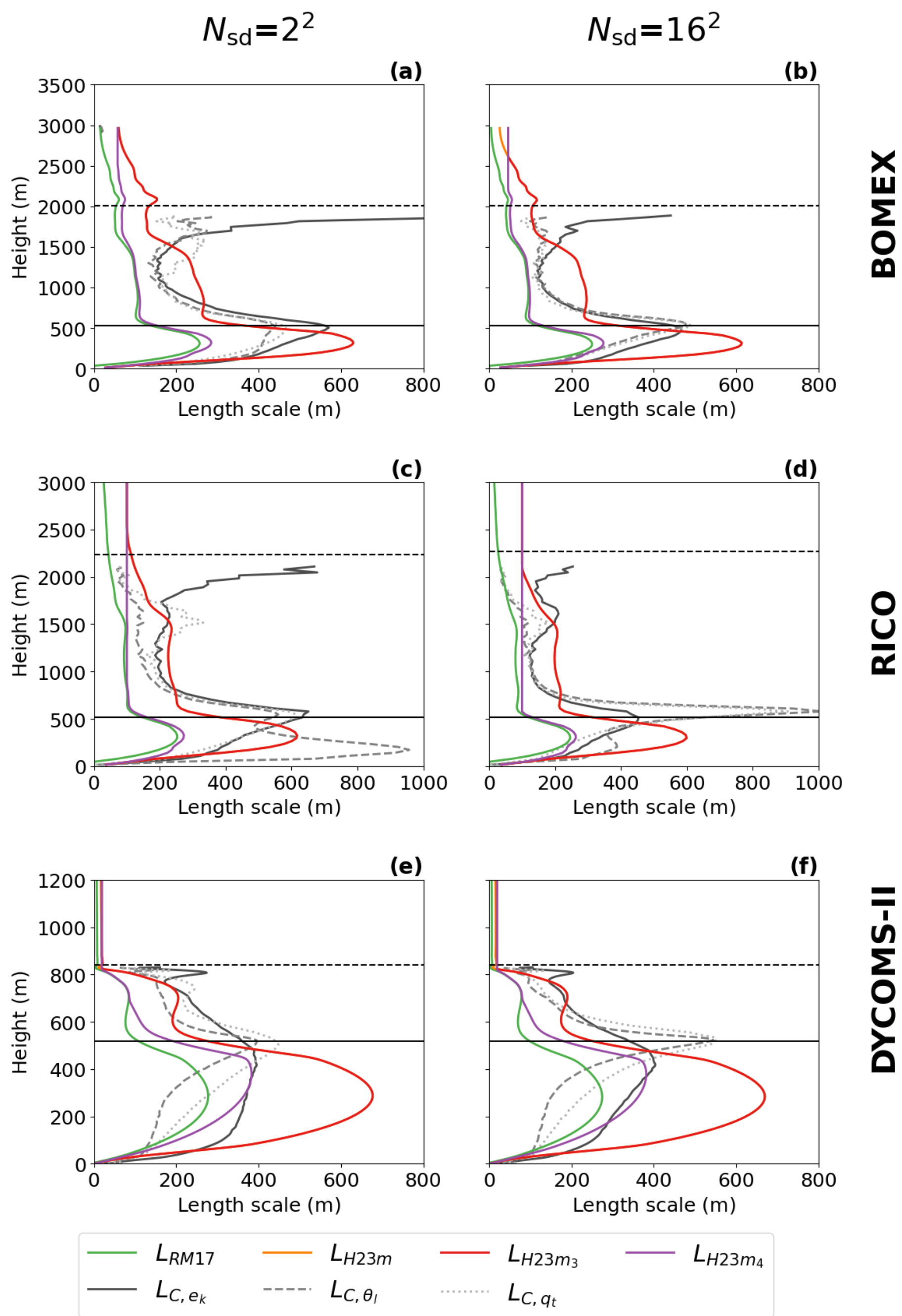

Figure 3: The same as Fig. 2, but for BOMEX, RICO and DYCOMS-II cases.