Regional Cooperation for Limited Area Modeling in Central Europe

LACE
nwp central europe

On Refining the Vertical Resolution of Numerical Weather Prediction Models

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Introduction

- The NWP community continuously seeks to benefit from increased Δx (adapting the physical processes and exploiting high-resolution surface/observations datasets), while Δz typically remains unchanged
- Main reason: necessity of lowering the First Model Level (FML). If placed considerably below 10-m without adjustments: possible violation of Monin-Obukhov Similarity Theory (MOST), increased sensitivity to surface dataset errors, coupling inconsistencies with the upper-air turbulence scheme, numerical stiffness, etc.
- This presentation focuses on aspects related to the turbulence scheme and builds on the discussion from the Autumn Surface Working Week 2023

Introduction: surface layer and MOST

- MOST is a scaling theory for the surface layer of the PBL (based on several characteristic scales; L, u_* and s_*):

$$\frac{\kappa(z+z_{0m})}{u_*}\frac{du}{dz}=\phi_m\left(\frac{z+z_{0m}}{L}\right) \xrightarrow{integr.} u(z)=\frac{u_*}{\kappa}\left[\ln\left(\frac{z+z_{0m}}{z_{0m}}\right)-\psi_m\left(\frac{z+z_{0m}}{L}\right)\right]$$

$$\frac{\kappa(z+z_{0h})}{s_*}\frac{ds}{dz}=\phi_h\left(\frac{z+z_{oh}}{L}\right) \xrightarrow{integr.} s(z)=s_0+\frac{s_*}{\kappa}\left[\ln\left(\frac{z+z_{0h}}{z_{0h}}\right)-\psi_h\left(\frac{z+z_{0h}}{L}\right)\right]$$

$$L=\frac{s_0u_*^2}{\kappa g s_*},\quad u_*=\left[\overline{(u'w')_s}^2+\overline{(v'w')_s}^2\right]^{1/4},\quad s_*=-\frac{\overline{(s'w')_s}}{u_*}$$

$$\overline{(\chi'w')_s}=C_{M/H}\sqrt{[u^2(z)+v^2(z)]}\,[\chi(z)-\chi_s];\quad \chi\equiv u,v,s \text{ and } q_t$$

Assumptions: constant-flux layer, homogeneous surface and $z >> z_{0m,h}$!

L - Monin-Obukhov length; u_*/s_* - characteristic scales; $\phi_{m,h}$ - universal similarity functions; $\psi_{m,h}$ - integrated $\phi_{m,h}$

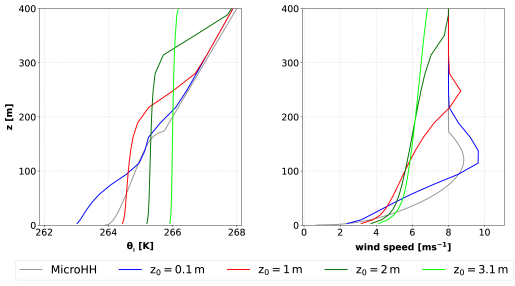
Introduction: implementation of MOST into NWP model

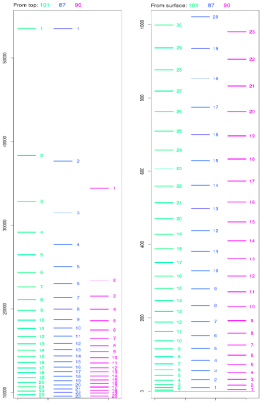
- In NWP models, a reference (forcing) height is defined ($z = Z_F$), from which atmospheric variables are used to compute surface fluxes via MOST; typically, Z_F=Z_1 (Z_1 - FML height)
- When the FML is pushed towards the surface, we approach the limit of MOST ($Z_F \longrightarrow z_{0m,h}$); decoupling the forcing level (Z_F) from the lowest model level (Z_1)
- Over heterogeneous surf., MOST breaks down locally. FML should be related to blending height, above which progn. variables no longer depend on local $z_{0m,h}$

GABLS1 case

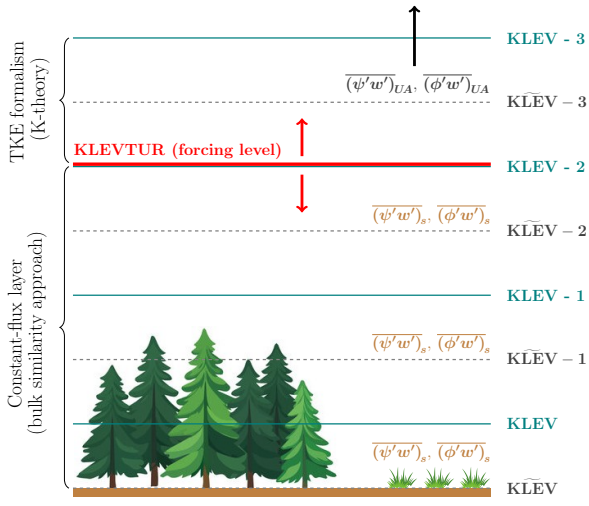
(101 levels)

z_1=3.12 m, z_F=3.12 m





Initial approach for the safe lowering of the FML



Computation of turbulent fluxes:

$$\overline{(\psi' w')}_{UA} = -K_M \frac{\partial \overline{\psi}}{\partial z}; \quad \overline{(\phi' w')}_{UA} = -K_H \frac{\partial \overline{\phi}}{\partial z} + TOMs$$

$$K_M = C_K L_K \chi_3 \sqrt{e_k}; \quad K_H = C_3 C_K L_K \phi_3 \sqrt{e_k}$$

$$\overline{(\psi' w')}_s = C_M \sqrt{[\overline{u}^2(Z_F) + \overline{v}^2(Z_F)]} \left[\overline{\psi}(Z_F) - \cancel{\overline{\psi}_s}\right]$$

$$\overline{(\phi' w')}_s = C_H \sqrt{[\overline{u}^2(Z_F) + \overline{v}^2(Z_F)]} \left[\overline{\phi}(Z_F) - \overline{\phi}_s\right]$$

$$C_M = \frac{\kappa^2}{\ln^2\left(1 + \frac{Z_F}{z_{0m}}\right)} F_M(Ri_g)$$

$$C_H = \frac{\kappa^2}{\ln\left(1 + \frac{Z_F}{z_{0h}}\right) \ln\left(1 + \frac{Z_F}{z_{0m}}\right)} F_H(Ri_g)$$

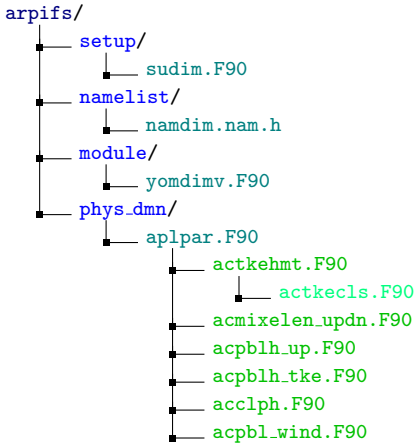
Screen-level interpolation:

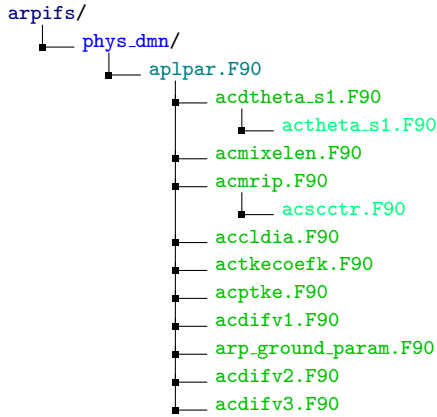
Based on Z_F rather than Z_1

$\psi = u, v;\ \phi = s_L, q_t;\ Z_F$ – forcing height

Initial approach for the safe lowering of the FML

- Currently implemented only in the ALADIN + ISBA framework within CY46T1_op3; activated via the namelist parameter NFLEVTUR

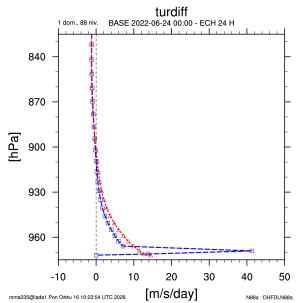




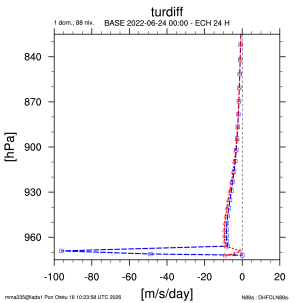
Initial approach for the safe lowering of the FML

- The analysis using DDH budgets reveals spikes in tendencies due to turbulence at the interface between the constant-flux layer and the overlying layer employing the TKE formalism (new approach)

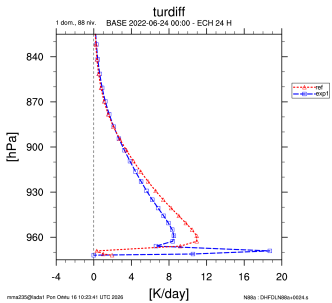
- Stronger near-surface wind than in KLEV=KLEVTUR experiment (old approach), with progressive distortion of wind and temperature fields aloft; adjustment of the concept is needed



zonal wind

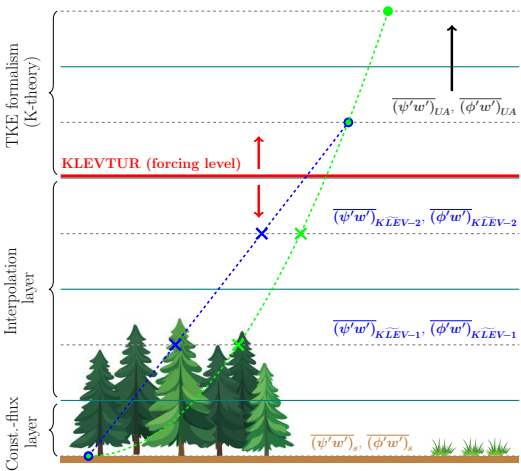


meridional wind



temperature

Revised approach for the safe lowering of the FML



Fluxes $(\ldots)_{\widetilde{KLEV-1}}$ and $(\ldots)_{\widetilde{KLEV-2}}$: interpolation between $\widetilde{KLEV}$ and $\widetilde{KLEV}-3$ (and $\widetilde{KLEV}-4$)

Computation of turbulent fluxes:

$$\overline{(\psi'w')}_{UA} = -K_M \frac{\partial \overline{\psi}}{\partial z}; \quad \overline{(\phi'w')}_{UA} = -K_H \frac{\partial \overline{\phi}}{\partial z} + TOMs$$

$$K_M = C_K L_K \chi_3 \sqrt{e_k}; \quad K_H = C_3 C_K L_K \phi_3 \sqrt{e_k}$$

$$\overline{(\psi'w')}_s = C_M \sqrt{[\overline{u}^2(Z_F) + \overline{v}^2(Z_F)]}\,[\overline{\psi}(Z_F) - \overline{\psi}_s]$$

$$\overline{(\phi'w')}_s = C_H \sqrt{[\overline{u}^2(Z_F) + \overline{v}^2(Z_F)]}\,[\overline{\phi}(Z_F) - \overline{\phi}_s]$$

$$C_M = \frac{\kappa^2}{\ln^2\left(1 + \frac{Z_F}{z_{0m}}\right)} F_M(Ri_g)$$

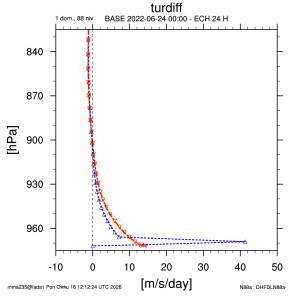
$$C_H = \frac{\kappa^2}{\ln\left(1 + \frac{Z_F}{z_{0h}}\right) \ln\left(1 + \frac{Z_F}{z_{0m}}\right)} F_H(Ri_g)$$

$\psi = u, v;\ \phi = s_L, q_t;$

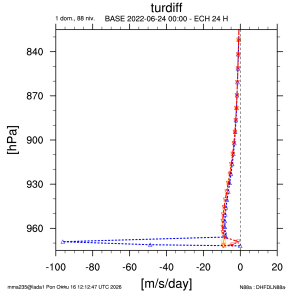
Z_F – forcing height

Revised approach for the safe lowering of the FML

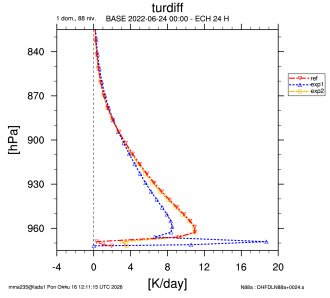
- In revised approach: (i) near equilibrium (SP + BP $\approx \epsilon$), the TKE scheme asymptotically converges to MOST (interp. layer effectively ”invisible”); (ii) farther from equilibrium: controlled departure from MOST, ensuring smooth and physically consistent coupling with the TKE-based scheme.
- Removes spikes in tendency profile and closely reproduces KLEV=KLEVTUR exp., except near the surf.
- Adjustment is required for TKE and TTE diagnostics below KLEVTUR; affects their advection and diffusion



zonal wind



meridional wind



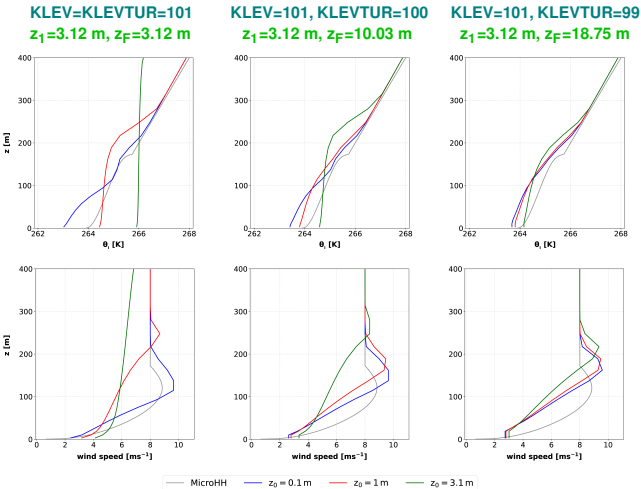
temperature

Revised approach for the safe lowering of the FML

- The impact of revised approach and Z_F in the GABLS1 case (SABL)
- When $z_F \rightarrow z_0$:

  (i) Old approach: turbulent mixing is too strong (flat θ_l and WSPD profiles)

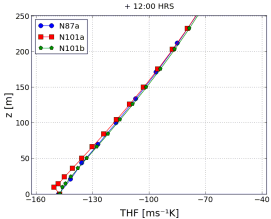
  (ii) New approach (revised): less sensitivity to errors in surf. databases and $z_{0m,h}$
- 3D model: strong impact of z_F on the near-surface WSPD profile (revised approach)

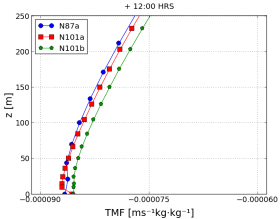


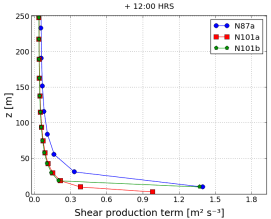
Revised approach for the safe lowering of the FML

- Domain-averaged turbulent fluxes of scalars and the shear term from 3D model (24 June 2022)

+ 12:00







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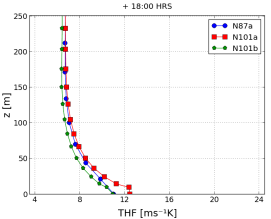
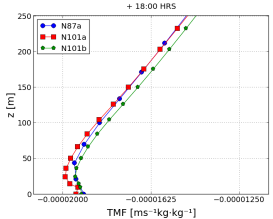
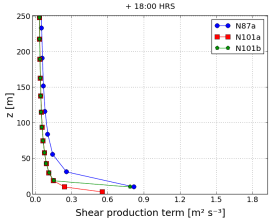




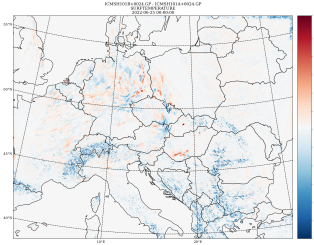


Revised approach for the safe lowering of the FML

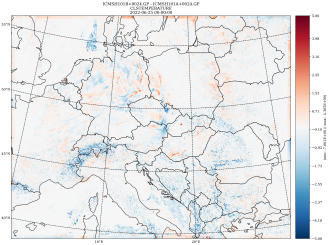
- Spatial differences in near-surface fields 24-h after the initialization (new approach - old approach)
- The statistical verification on winter and summer periods is ongoing:

  (i) clear improvement in T2m, W10m and CLD over the 87-level reference; N101b and N101a comparable

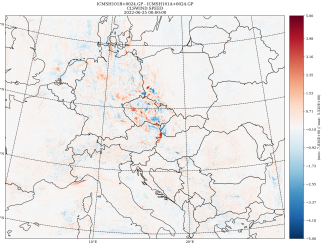
  (ii) grouping stations based on z_0 or z_F/z_0



surf. temperature



2-m temperature



10-m wind speed

Summary and further steps

- Old vs. new (revised) approach for a safe decrease of the FML:

aspect	**old (KLEV = KLEVTUR)**	**new (KLEV $<$ KLEVTUR)**
MOST application	Always	Relaxed farther from equilibrium
Constant-flux layer	Strictly enforced	Relaxed farther from equilibrium (departure can be bounded)
Numerical stability	Problematic when $z_F \to z_0$	Enhanced
Consistency with the TKE scheme	Potential inconsistency near the surface	Enhanced due to smooth transition
Sensitivity to $z_{0m,h}$	High	Reduced
Suitable for heterogeneous gridbox	No	Partly

- Further steps: (i) code refinement/reorganization and more detailed validation, (ii) preparing IAL code contribution and (iii) implementation within the ALARO + SURFEX framework (relating z_F to blending height?)
- There is a related report at: https://www.rclace.eu/media/files/Physics/2025/MH_2024-2025P_KLEVTUR.pdf

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