

*Regional Cooperation for
Limited Area Modeling in Central Europe*



Physics activities in RC-LACE

Mario Hrastinski & RC-LACE physics team



Czech
Hydrometeorological
Institute



ARSO METEO
Slovenia

TOUCANS turbulence scheme upgrades

The microphysics-related developments (presentation by David Němec)

Cloud-Aerosol-Radiation (CAR) activities

ALARO in single-precision

Regional climate modeling with ALARO at CHMI (presentation by Ján Mašek)

Surface physics activities (in presentation by Martina Tudor)

Other activities

Future work

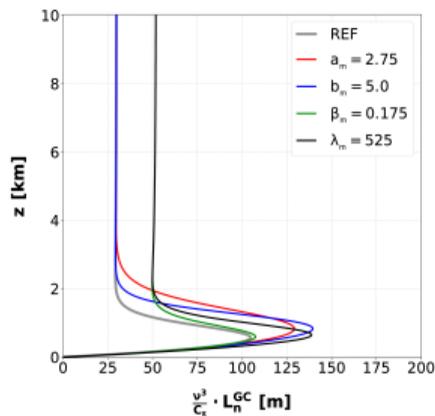
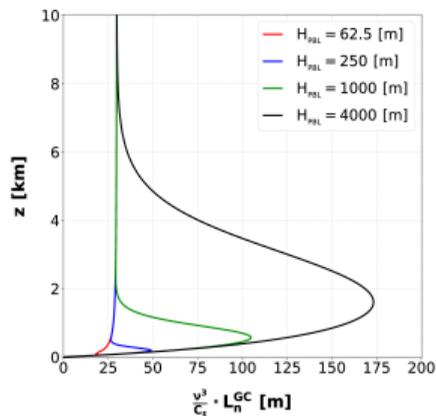
The list of activities:

- ▶ Development and validation of a new Turbulence Length Scale (TLS) formulation
- ▶ The implementation of new PBL height (H_{PBL}) diagnostics
- ▶ Introducing weighted Ri_f (combining local and non-local estimates after Bašták Ďurán et al. (2022))
- ▶ Towards the pseudo 3D turbulence within the ALARO CMC

Development and validation of a new TLS formulation

- ▶ Currently, the Geleyn-Cedilnik formulation (L_n^{GC}) is a default choice in TOUCANS:

$$L_n^{GC} = \frac{C_\epsilon}{\nu^3} \frac{\kappa z}{1 + \frac{\kappa z}{\lambda_m} \left[\frac{1 + \exp(-a_m \sqrt{\frac{z}{H_{PBL}} + b_m})}{\beta_m + \exp(-a_m \sqrt{\frac{z}{H_{PBL}} + b_m})} \right]} \quad (1)$$



1. Very sensitive to the H_{PBL} est.
2. Too strong mixing in SABL
3. Only one/primary max. (by design)
4. Small variability (in practice)
5. $UAL=const.$ (should vary!)

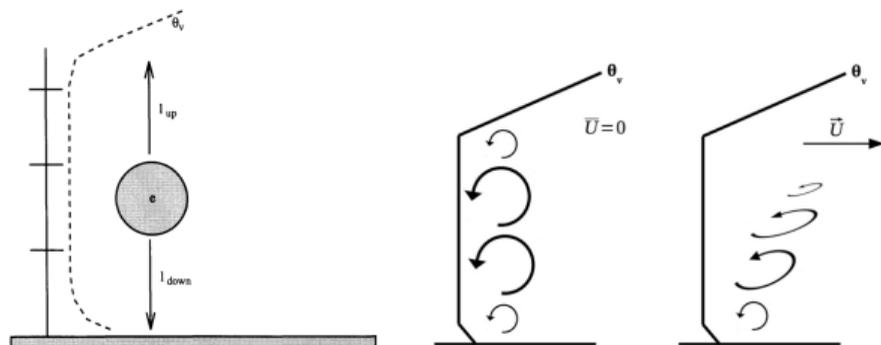
REF: $a_m=4.5$, $b_m=3.0$, $\beta_m=0.1$ and $\lambda_m=300$

Development and validation of a new TLS formulation

- ▶ We start from the generalized version of BL89 TLS following [Rodier et al. \(2017\)](#):

$$\int_z^{z+L_{\text{up}}} \left\{ \frac{g}{\theta_v(z')} [\theta_v(z') - \theta_v(z)] + c_0 \sqrt{e_k(z')} S(z') \right\} dz' = e_k(z) \quad (2)$$

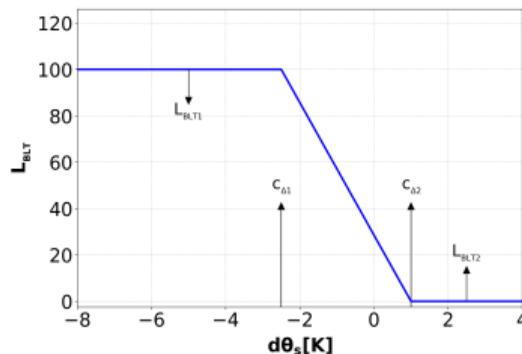
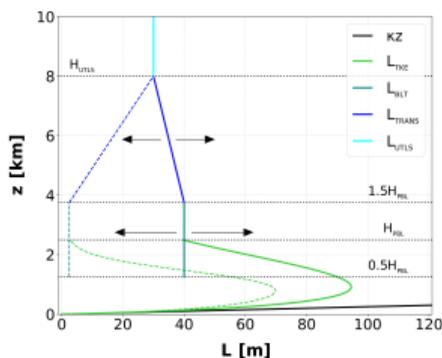
$$\int_{z-L_{\text{down}}}^z \left\{ \frac{g}{\theta_v(z')} [\theta_v(z) - \theta_v(z')] + c_0 \sqrt{e_k(z')} S(z') \right\} dz' = e_k(z) \quad (3)$$



$$L_{\text{TKE}} = \left(\frac{L_{\text{up}}^P + L_{\text{down}}^P}{2} \right)^{\frac{1}{P}} \quad (4)$$

Development and validation of a new TLS formulation

- The final solution:



L_{BLT} - a regime-dependent near PBL top min. TLS

L_{UTLS} - non-vanishing (constant) upper-air TLS

L_{TRANS} - linear transition between L_{BLT} and L_{UTLS}

L_{TKE} - i) scaled with κ (L_n^{H24}) or ii) not-scaled with κ (L_n^{H24*})

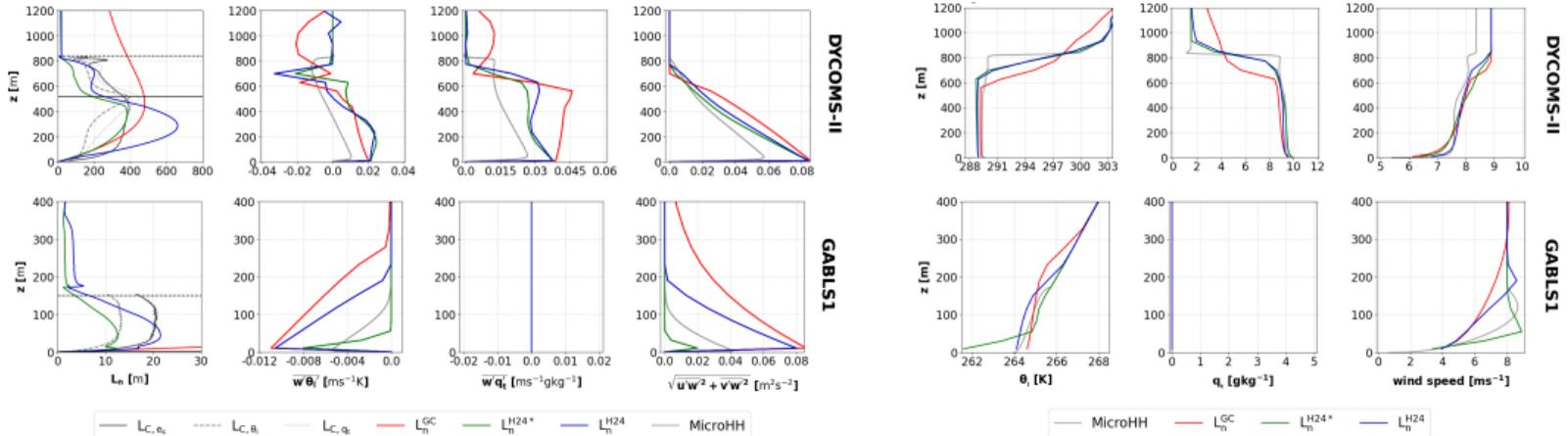
We need a reliable "tool" to validate the solution → LES-based TLS diagnostics after Reilley et al. (2022)

MicroHH DNS and LES model (van Heerwaarden et al. 2017)

The work of: Mario Hrastinski, Ján Mašek, Ivan Bašták Ďurán, Branko Grisogono and Radmila Brožková

Development and validation of a new TLS formulation

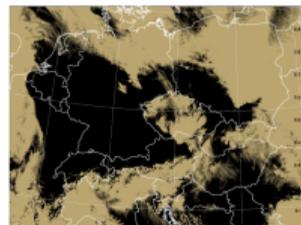
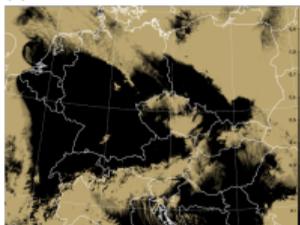
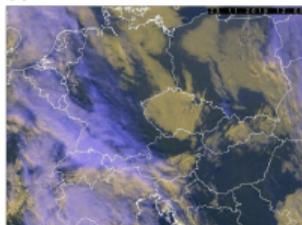
- ▶ The evaluation in idealized cases (1-h averaged profiles): i) convective PBL (ARM and BOMEX; at +10-h and +7-h) and ii) stable PBL (DYCOMS-II and GABLS1; at +3-h and +4.5-h)
- ▶ In convective cases, L_n^{H24} and L_n^{GC} perform similarly, while L_n^{H24*} underestimates TLS and fluxes
- ▶ An improvement over L_n^{GC} in more stable cases and near the PBL top (essential role of the κ scaling)



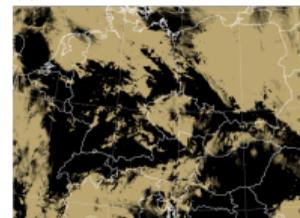
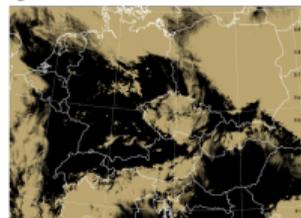
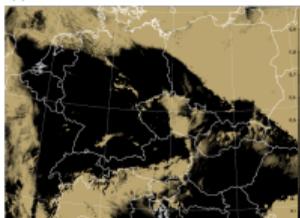
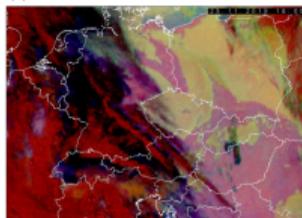
Development and validation of a new TLS formulation

- ▶ ALADIN-CZ model at $\Delta x=2.3125$ km and 87 levels, NH-dynamics and ALARO-1 physics; IC: local DA suite and LBC: ARPEGE 3-h frequency
- ▶ AC period with persistent inversion over Czechia (23 November 2019 case): L_n^{H24} retains more low-level clouds during the day and builds them up earlier in the evening (improved vert. profiles of temp. and wind speed)

12 UTC



18 UTC



MSG

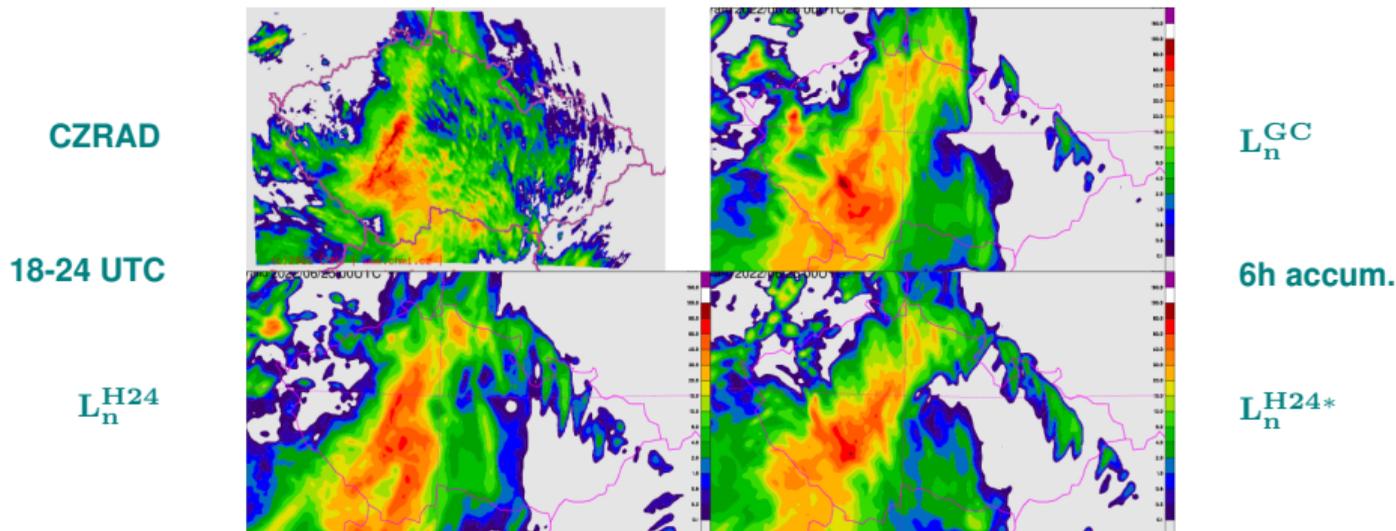
L_n^{GC}

L_n^{H24}

L_n^{H24*}

Development and validation of a new TLS formulation

- ▶ MCS on 24 June 2022 (> 100 mm of precipitation in Prague); L_n^{H24} slightly improved spatial patterns
- ▶ Statistical performance: RMSE of L_n^{H24} is nearly-neutral with L_n^{GC} and 15-20% smaller than L_n^{H24*} for majority of surf. and upper-air parameters (10-day periods); random error of surf. param. and extreme wind are improved



The implementation of new PBL height (H_{PBL}) diagnostics

- ▶ There is no method estimating H_{PBL} accurately enough for different stability conditions:

The Weak-Capping-Inversion Method (WCIM):

$$\theta_v(z_i) \geq \frac{1}{z_i} \int_0^{z_i} \theta_v(z) dz + 0.25K \quad (5)$$

convective and near-neutral PBL

Ayotte et al. (1996)

TKE-based method:

$$H_{\text{PBL}} = \frac{z_{05}}{0.95} \quad (6)$$

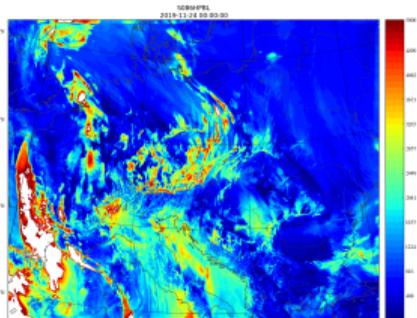
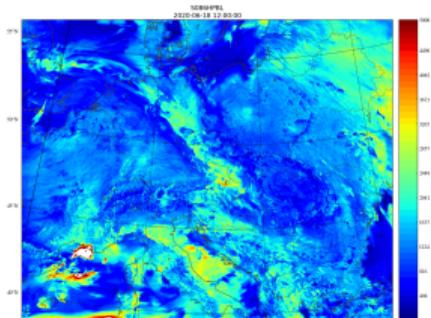
more general

Kosović and Curry (2000)

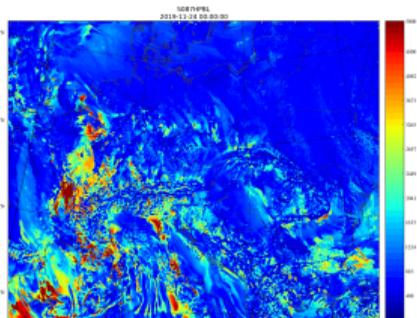
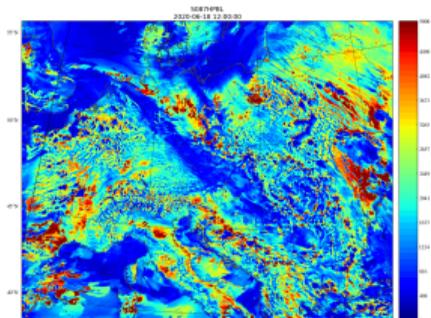
- ▶ A new and more robust method following Baštak Đuran et al. (2022) is also coded:

$$H_{\text{PBL}} = c_{\text{pblh}} \cdot \sqrt{\int_{z=0}^{z_{\text{top}}} L_{\text{up}} \cdot dz}, \quad c_{\text{pblh}} = 1.75 \quad (7)$$

The implementation of new PBL height (H_{PBL}) diagnostics



WCIM method (used with L_n^{GC} TLS formulation)



TKE-based method (used with L_n^{H24} and L_n^{H24*} TLS formulations)

summer

winter

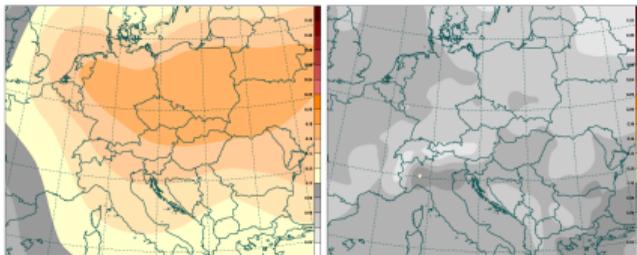
The work of:
Mario Hrastinski and Ján Mašek

The list of activities:

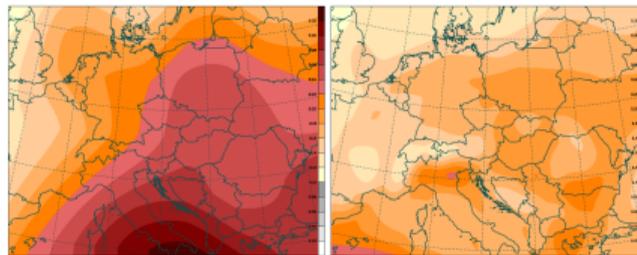
- ▶ The preparation of CAMS aerosols
- ▶ The vertical distribution of climatological aerosols
- ▶ The case studies using different representation of aerosols

The preparation of CAMS aerosols

- ▶ The dataflow for 2D/3D climatological and 3D n.r.t aerosols is finalized and tested (the work of **Piotr Sekuła** and **Ján Mašek**; report available at www.rclace.eu)
- ▶ Besides the code, a set of tools and procedures to handle CAMS aerosols is developed, documented and available at Météo-France's HPC (the work of **Ján Mašek** and **Ana Šljivić**; report at www.rclace.eu)
- ▶ The content of climatological aerosols (details in the talk of **Ján Mašek** at 4th ACCORD ASW):
 - ▶ Tegen: aerosol optical depth at 550nm (AOD550) for 6 aerosol types (4 tropospheric + 2 stratospheric)
 - ▶ 2D CAMS: vertically integrated mass/area for 11 aerosol species (based on the period 2003-2022; 0.75° x 0.75° grid)



Tegen vs. 2D CAMS at AOD550 (January)



Tegen vs. 2D CAMS at AOD550 (July)

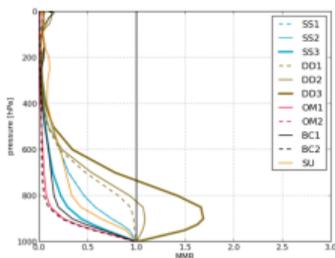
The vertical distribution of climatological aerosols

- ▶ There is a need to apply different idealized distribution to redistribute the 2D CAMS aerosols vertically than in Tegen's case (primary maximum higher in the PBL)
- ▶ A new term (red) is added into the existing vertical distribution function for aerosol MMR ($r_{aer}(z)$):

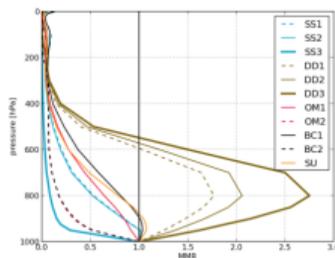
$$r_{aer}(z) = C \cdot \left(\frac{z}{H_{aer}} \right)^{\beta-1} \exp\left(-\frac{z}{H_{aer}}\right) \quad (8)$$

C - calibration constant; β - exponent in gamma distribution
 z- height; H_{aer} - aerosol height scale

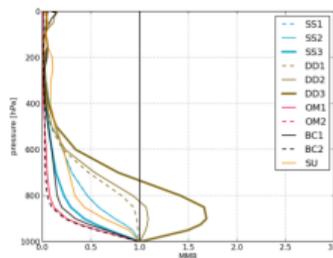
- ▶ Based on 3D climatology in period 2003-2022: i) high seasonal variability and ii) a different β exponent is proposed for each month and aerosol type



(a) January



(b) June



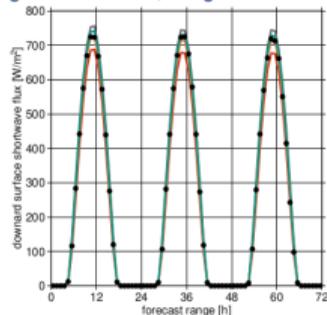
(c) all months

The report of:
 Ana Šljivić and
 Ján Mašek
www.rlace.eu

The case studies using different representation of aerosols

- ▶ A clear-sky case (7-9 September 2023; the work of Ján Mašek and Ana Šljivjić):
 - ▶ Removing the background values results in shifting the error towards the control experiment
 - ▶ Keeping only stratospheric background values (tuning or take prognostic values)

global radiation, Prague

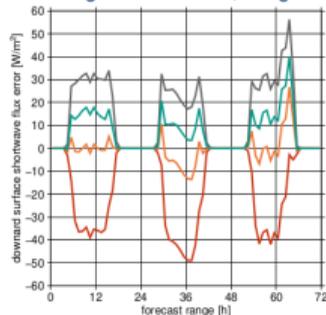


background AOD:

TRBKG = 0.030
 STBKG = 0.045
 volcanic ashes = 0.007
 (hardcoded)

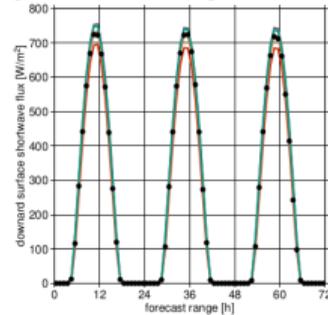
0.082

error of global radiation, Prague



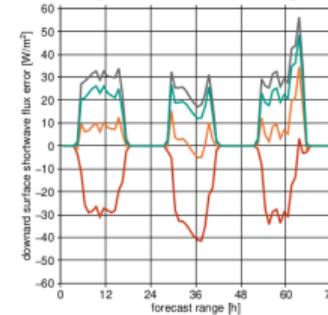
— no aerosols
 — Tegen climatological aerosols

global radiation, Prague



— CAMS 2D climatological aerosols
 — CAMS 3D near real time aerosols

error of global radiation, Prague



background AOD:

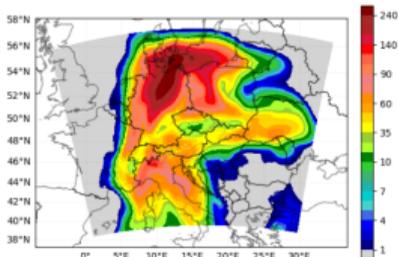
TRBKG = 0.000
 STBKG = 0.000
 volcanic ashes = 0.000
 (hardcoded)

0.000

The case studies using different representation of aerosols

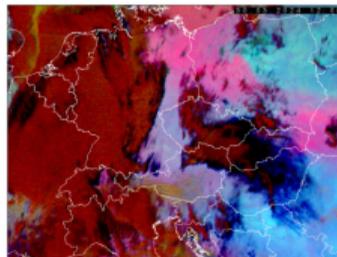
- ▶ An intrusion of Saharan dust (30 March 2024, 12:00 UTC; the work of **Ján Mašek** and **Ana Šljivić**):
 - ▶ The dust front propagated within the first 12-h but was not seen on the MSG imagery due to spacious and deep cloud layer
 - ▶ There is a big error in global radiation as model did not capture most of the clouds; n.r.t. option was more successful in a few windows with almost no clouds
 - ▶ 2D CAMS aerosols are ready for pre-operational testing (n.r.t. option needs some brainstorming)

vertically integrated dust (DD1 + DD2 + DD3)



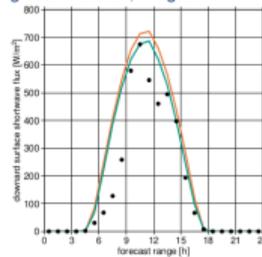
Shown is ratio of CAMS n.r.t. aerosols to CAMS climatology (gray means n.r.t. below climatology).

MSG 24h microphysics

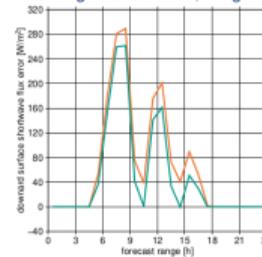


Colors: red – vertically extensive clouds; beige – low/medium clouds; pink – dust.

global radiation, Prague



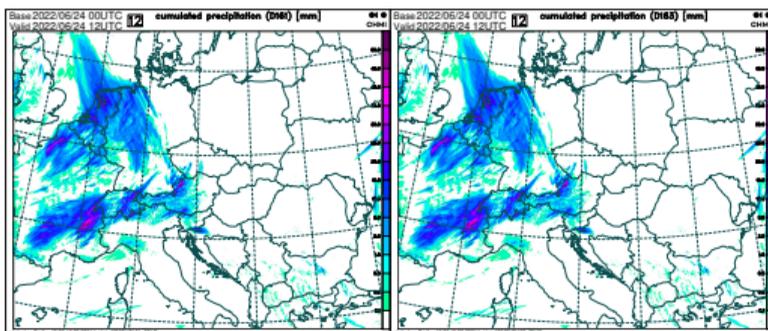
error of global radiation, Prague



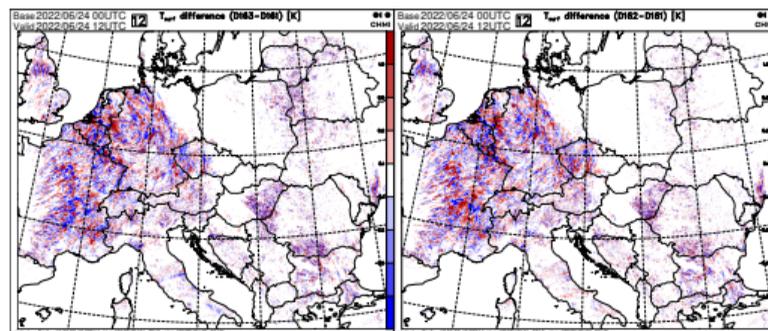
background AOD:
 TRBK_G = 0.030
 STBK_G = 0.045
 volcanic ashes = 0.007
 (hardcoded) **0.082**

— CAMS 2D climatological aerosols
 — CAMS 3D near real time aerosols

- ▶ The starting point is CHMI's operational model based on the CY46T1-bf07; $\Delta x=2.3125$ km and 87 vert. levels, NH-dynamics and ALARO-1 physics (two turbulence energies, prognostic graupel, Lopez evaporation, etc.), IC: local DA suite and LBC: ARPEGE 3-h frequency
- ▶ ALARO-0 Single Precision (SP) worked immediately (more detailed validation will follow), while for ALARO-1 additional work in turbulence and moist physics was needed
- ▶ A comparison with the Double Precision (DP) experiment for the 24 June 2022 MCS chase points to differences corresponding to the impact of a slightly shorter time-step:



DP vs. SP



DP vs. SP

DP1 vs. DP2

- ▶ The TOUCANS scheme developments focus on three main topics: i) introducing 3D effects (ongoing work), ii) ensuring its scale awareness, and iii) addressing the issue of representing the stable boundary layer. Additionally, reformulating the shallow convection cloudiness computation is foreseen.
- ▶ Both radiation and microphysics schemes aim to profit from introducing the CAMS aerosols: i) the former is approaching the operational implementation (addressing background values is also planned) and ii) the latter is still in the development phase (two-moment scheme).
- ▶ The planned radiation-related activities also include: i) achieving interoperability of ACRANEB2 and ecRAD schemes between ACCORD CMCs, ii) investigating approaches to introduce the 3D effects and iii) revising broadband gaseous transmissions.
- ▶ Getting towards the operational implementation of ALARO physics with the SURFEX model and exploiting advanced options of the latter.
- ▶ Further development of the validation framework, focusing on the process-oriented approach.

*Regional Cooperation for
Limited Area Modeling in Central Europe*



Thank you for your attention!



ARSO METEO
Slovenia

Ayotte, K. W., and Coauthors, 1996: An evaluation of neutral and convective planetary boundary-layer parameterizations relative to large eddy simulations. *Bound.-Lay. Meteorol.*, **79**, 131–175, DOI: 10.1007/BF00120078

Bašták Ďurán, I., M. Sakradzija, and J. Schmidli, 2022: The two-energies turbulence scheme coupled to the assumed PDF method. *J. Adv. Model. Earth Syst.*, **14**, e2021MS002922, DOI: 10.1029/2021MS002922

Kosović, B., and J. A. Curry, 2000: A Large Eddy Simulation Study of a Quasi-Steady, Stably Stratified Atmospheric Boundary Layer. *J. Atmos. Sci.*, **57**, 1052–1068, DOI: 10.1175/1520-0469(2000)057<1052:ALESSO>2.0.CO;2

Reilly, S., I. Bašták Ďurán, A. Theethai Jacob, and J. Schmidli, 2022: An Evaluation of Algebraic Turbulence Length Scale Formulations. *Atmosphere*, **13** (4), DOI: 10.3390/atmos13040605

Rodier, Q., V. Masson, F. Couvreux, and A. Paci, 2017: Evaluation of a Buoyancy and Shear Based Mixing Length for a Turbulence Scheme. *Front. Earth Sci.*, **5**, DOI: 10.3389/feart.2017.00065

van Heerwaarden, C. C., B. J. H. van Stratum, T. Heus, J. A. Gibbs, E. Fedorovich, and J. P. Mellado, 2017: MicroHH 1.0: a computational fluid dynamics code for direct numerical simulation and large-eddy simulation of atmospheric boundary layer flows. *Geosci. Model Dev.*, **10**, 3145–3165, DOI: 10.5194/gmd-10-3145-2017