Regional Cooperation for
Limited Area Modeling in Central Europe

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Physics activities in RC-LACE

Mario Hrastinski and RC-LACE Physics Team

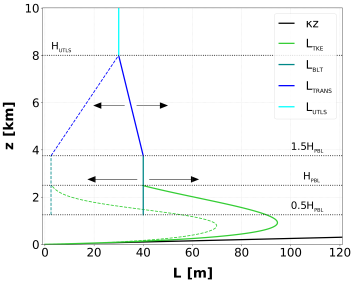
GeoSphere Austria · DHMZ · Czech Hydrometeorological Institute · IMGW · HungaroMet Hungarian Meteorological Service · METEO ROMANIA · SHMU · ARSO METEO Slovenia

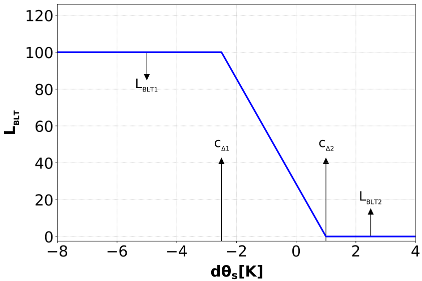
Outline

- TOUCANS turbulence scheme developments
- Testing ecRad scheme within the ALARO-CMC
- Introduction of CAMS aerosols
- The development of a two-moment microphysics scheme
- ALARO physics in single precision
- Diagnostics and validation
- Summary and plans

Testing the new TLS formulation

- The scheme of the final solution (more details in Hrastinski et al., 2025):





L_{TKE}: generalized BL89 type of TLS after Rodier et al. (2017); L_{BLT}: regime-dependent near PBL top TLS

L_{TRANS}: linear transition between L_{BLT} and L_{UTLS} (constant upper-air TLS)

A stability-dependent blending of L_{TKE} and κz TLS

Testing the new TLS formulation

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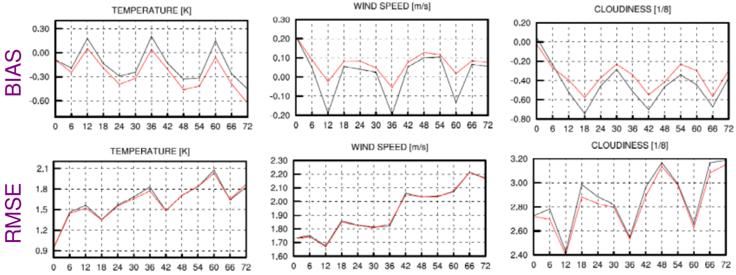
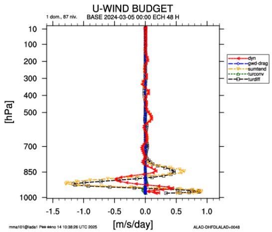
- The initial experiments and internal TLS tuning were performed in a nearly dry case (7 September 2023)
- The evaluation continued in various weather conditions: 3-10 March 2024 (Sc regime), 15-30 June 2024 (convection), 9-18 September 2024 (floods) and 26-30 December 2024 (statically stable period with fog)
- Further tuning addressed the thermodynamic adjustment, the cloud scheme, and soil-vegetation interactions; similar scores for March and September periods





— REF — EXP

3-10 March 2024

The work of Radmila Brožková

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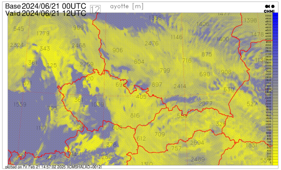
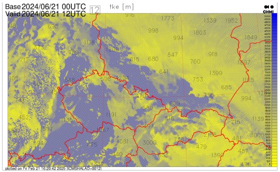
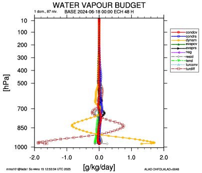
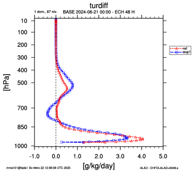
Testing the new TLS formulation

- Surface BIAS-es are mostly improved (e.g., W10m, RH2m and CLD), while STD for some parameters (T2m, RH2m and W10m) is worse in the convective period (15-30 June 2024)
- Possible causes of increased STD: (i) noise-prone $\mathrm{H}_{\mathrm{PBL}}$ field and (ii) moisture transport (feedback with the shallow convection scheme)
- Statically stable period (26-30 December 2024) is very sensitive to the horizontal diffusion settings (SLHD); further adjustments or upgrades are needed









More details at: https://opensource.umr-cnrm.fr/projects/accord/wiki/ALARO1_WDs_2025 (two talks)

Towards the 3D turbulence scheme

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- The goal: to have a $\Delta x \sim< 1$km configuration providing an added value to the existing operational models; addressing dynamics and physics settings
- Introducing 3D turbulence effects (1D + 2D scheme and Goger et al. 2018, 2019):

$$K_{M,ver} = L_K C_K \sqrt{e_k}\chi_3(Ri_g)$$

$$K_{M,hor} = L_K^H C_K^H \sqrt{e_k}\chi_{3,hor}(Ri_g)$$

$$K_{H,ver} = L_K C_K C_3 \sqrt{e_k}\phi_3(Ri_g)$$

$$K_{H,hor} = L_K^H C_K^H C_3 \sqrt{e_k}\phi_{3,hor}(Ri_g)$$

$$SHP_{3D} = \underbrace{-\overline{u'w'}\frac{\partial \overline{u}}{\partial z} - \overline{v'w'}\frac{\partial \overline{v}}{\partial z}}_{SHP_{vert}} \underbrace{-\overline{u'u'}\frac{\partial \overline{u}}{\partial x} - \overline{u'v'}\frac{\partial \overline{u}}{\partial y} - \overline{u'v'}\frac{\partial \overline{v}}{\partial x} - \overline{v'v'}\frac{\partial \overline{v}}{\partial y}}_{SHP_{hor}}$$

$$SHP_{hor} = \left(L_K^H\right)^2 \cdot \left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \frac{1}{2}\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2\right]^{\frac{3}{2}}$$

SHP_{hor} based on Smagorinsky (1963); L_K^H after Wang et al. (2021)

More details at: https://www.rclace.eu/dynamics-and-coupling (several reports) and https://opensource.umr-cnrm.fr/projects/accord/wiki/ALARO1_WDs_2025 (presentation)

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Towards the 3D turbulence scheme

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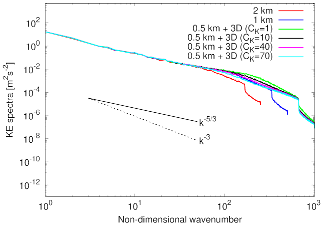
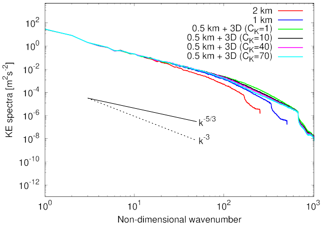
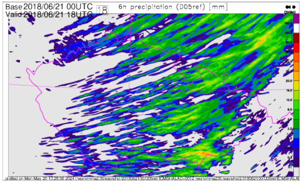
- The impact off 3D turbulence at $\Delta x = 0.5$ km (by Mario Hrastinski and Petra Smoliková):



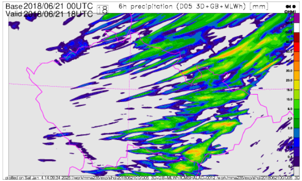


Convection case (21 June 2018)

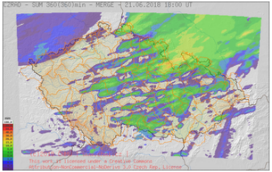
KE spectra at levels 80 ($\sim$ 230 m; left) and 50 ($\sim$ 3000 m; right)



1D turbulence



3D turbulence



radar + rain gauges

6-h accum. prec.

Testing ecRad scheme within the ALARO-CMC

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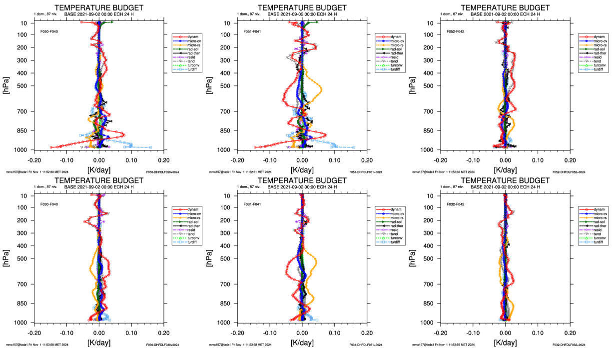
- Testing in ALARO-CMC on CY48T3 during Sophia Schaefer's stay at CHMI (supported by Ján Mašek)
- Testing in 1D and 3D models (intermittency): (i) ecRad shortwave fluxes are more accurate, (ii) ACRANEB2 intermittency is more time consistent and (iii) ecRad 5-35% higher cost (15-min and no-intermittency)

1-h

15-min

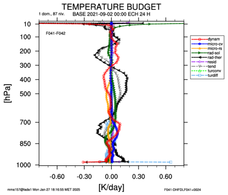


old IFS scheme

ecRad

ACRANEB2

1. scheme settings as close as possible (cloud optics)
2. narrowband model also compared to ecRad



ecRad - ACRANEB2

Introduction of CAMS aerosols

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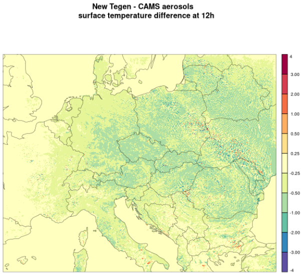
- The dataflow for CAMS aerosols is completed and pull request submitted to CY50T1; currently works for configurations using the ACRANEB2 scheme
- Additionally, tools have been created to handle file conversion and CAMS aerosol preparation
- A pull request was submitted to CY50 and includes (individual components described in several; see https://www.rclace.eu/physics):
  - Importing different types of CAMS aerosols: 2D or 3D climatology, near-real-time or hybrid
  - Externalization of ACRANEB2 aerosols
  - The conversion of CAMS MMRs to aerosol optical properties
  - The vertical distribution (gamma) of 2D CAMS climatological aerosols
  - Externalization of the effective radius from ACRANEB2 scheme
- The technical document on the use of CAMS aerosols can be found at: https://redmine.umr-cnrm.fr/attachments/6098

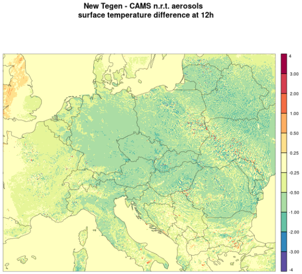
The work of: Ján Mašek, Piotr Sekuła and Ana Šljivić (with inputs from Laura Rontu)

Introduction of CAMS aerosols

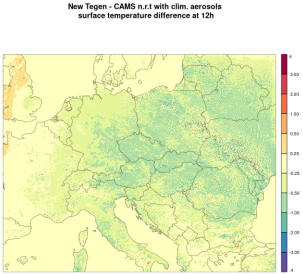
- The validation was performed in a clear sky case (7 September 2023); the differences between the new and old code using Tegen aerosols were minor and estimated as acceptable
- Aerosol sources substantially affect T_s (0.5-1.0 ℃), while the impact of updated vertical distribution (gamma) remains relatively small
- The first steps towards the operational use of 2D CAMS aerosols were undertaken at CHMI: (i) strong impact, (ii) avoid tropospheric background values (adjust stratospheric ones) and (iii) tuning of other schemes



TEGEN - 2D CAMS



TEGEN - n.r.t. CAMS



TEGEN - "hybrid" 2D+n.r.t. CAMS

The development of a two-moment microphysics scheme

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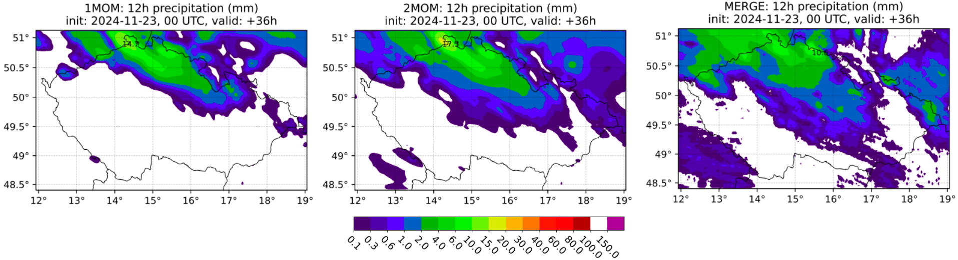
- The aim is to better distinct between different weather regimes: prognostic q and N
- 5 hydrometeors in ALARO (gamma size distrib.): cloud water, cloud ice, rain, snow, and graupel
- 2 new processes: (i) activation (Feingold and Heymsfield, 1982) and (ii) self-collection + breakup (Verlinde et al., 1990; Beheng, 1994); liquid phase is ready for testing (23 November 2024 case)



1-moment scheme | 2-moment scheme | radar + rain gauges

The development of a two-moment microphysics scheme

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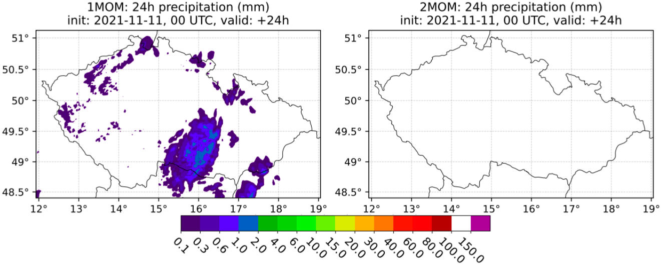
- Additional case with no precipitation (11 November 2021)
- The development of ice phase has just started. There are several open questions: (i) separation between the cloud ice and snow, (ii) the shape of snow particles, (iii) size distributions and (iv) phase split (MPACE tests with CAMS aerosols vs. f (T))



1-moment scheme 2-moment scheme

More details at:

https://www.rclace.eu/physics (report)

https://opensource.umr-cnrm.fr/projects/accord/wiki/ALARO1_WDs_2025 (presentation)

The work of David Němec

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ALARO physics in single precision

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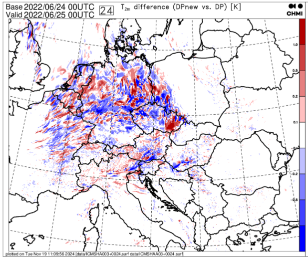
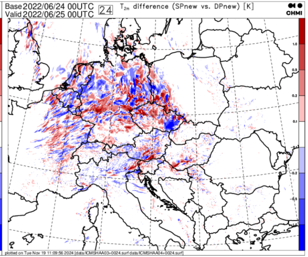
- Starting point: CY46T1-bf07 with local developments of CHMI (29 subroutines)
- Problems in the hydrostatic VFE were traced to the integral operator for the geopotential and the upper BC formulation; fixes implemented into the A-LAEF update on ECMWF's HPC
- The focus shifted towards CY49T2 which includes the latest SURFEX updates and enables testing the refactored code (GPU adaptation)



DP_{fix} vs. DP



SP_{fix} vs. DP_{fix}

MCS case (24 June 2022):

(1) The impact of DP fixes comparable to SP vs. DP

(2) The differences occur where "something happens"

The work of Oldřich Španiel and Ján Mašek

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ALARO physics in single precision

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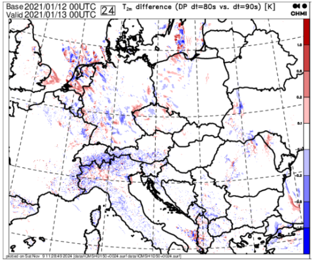
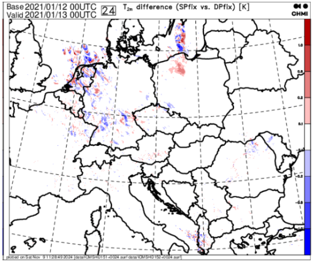
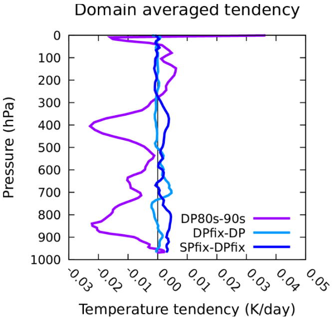
- Differences between SP and DP runs are smaller than those due to the time step reduction (12 January 2021 case); differences are even bigger at higher levels
- The savings on elapsed time: (i) DEODE domain at ECMWF's HPC system (1500 x 1500 GP) - 50% and (ii) CRO domain on Belenos (Meteo-France; 1620 x 1500 GP) - 56%



timestep impact



DP_{fix} vs. SP_{fix}



Diagnostics and validation

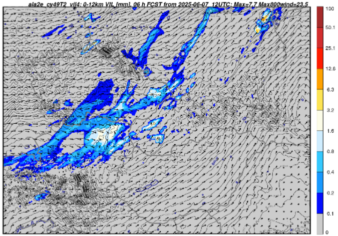
- Diagnostics of Vertically Integrated Liquid (VIL) after Greene and Clark (1972):

$$\mathrm{VIL} = 0.001 \int_{z=0}^{z=12\ \mathrm{km}} \left(\frac{Z}{C}\right)^{\frac{1}{D}} dz$$

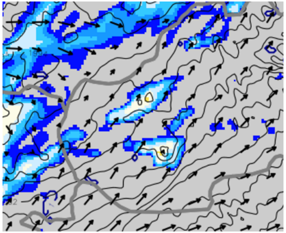
Z - radar reflectivity factor (in $\mathrm{mm}^6\mathrm{m}^{-3}$)

C, D - given by the radar provider

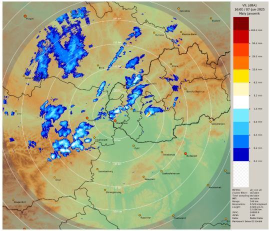
- Model-based VIL is considerably lower in storm cores due to underestimated reflectivity



MODEL VIL diagnostics



MODEL VIL diagnostics (zoom)



RADAR diagnostics

The work of Andre Simon

Diagnostics and validation

- Further refinement of VIL is foreseen, as well as preparing vertical integrals of individual hydrometeors and developing cloud-top skin temperature diagnostics
- Preparing a database of well-known idealized cases (e.g., ARM, BOMEX, DYCOMS-II, GABLS1, MPACE, and SCLD), along with tools for generating forcings:
  - private GitHub repository of David Němec (access is available on request): `https://github.com/DavNemec/musc`
  - actively used in development/testing of microphysics and turbulence schemes (comparison with LES)

Summary and plans

- Currently, there is an ongoing development of a two-moment microphysics scheme and ALARO-CMC in single-precision
- Several developments are in a mature stage and ready for pre-operational testing (or already being tested): (i) the new TLS formulation and (ii) CAMS-based aerosols
- Meanwhile, a process-oriented validation framework is being developed in collaboration with other groups within ACCORD
- A considerable effort has been devoted to transitioning from the old ISBA scheme to a more advanced SURFEX model (the talk of Martina Tudor)
- Given the proximity of kilometric resolutions in the operational environment, enhancing the scale-aware properties of individual schemes and incorporating 3D effects is needed
- Long-standing issues, such as stable PBL representation, should also be addressed, with the new TLS formulation seen as a preliminary step

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