RC-LACE flat-rate stay report
PH6: Interfacing CAMS aerosols with radiation schemes

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1. Introduction:

This stay was a continuation of the work from my last stay in Prague in 2023. As described in the report from that stay [1], the final goal is implementing near real-time aerosol concentrations from the CAMS (Copernicus Atmosphere Monitoring Service) model in the ACCORD system.

During this stay, the main aim was to finalize the code, debug it, and make some technical tests. To make the model more consistent, some variables have been renamed, there was also added namelist consistency checking. An option enabling to use combination of climatological and near real-time (n.r.t.) CAMS aerosols was coded.

In the new approach, CAMS aerosols (climatological and n.r.t.) during the integration are stored in 3D GFL array which is described in the namelist. The user can define which source of data they want to use:

A) only 2D CAMS climatological aerosols (maximum number of species 11)

B) only 3D n.r.t. CAMS aerosols (maximum number of species 42)

C) combination of 2D CAMS climatological aerosols and 3D n.r.t. CAMS aerosols (maximum number of species 42)

The final code contains developments introduced by Laura Rontu, Ján Mašek and Ana Šljivić:

- reading 2D CAMS climatological aerosols
- externalization of aerosol optical properties from ACRANEB2 radiation
- conversion of CAMS aerosol mass mixing ratios (MMRs) to aerosol optical properties
- vertical distribution of 2D CAMS climatological aerosols
- externalization of the cloud liquid and ice effective radii from ACRANEB2 radiation

The modifications were first tested in CY46 and then they were introduced in CY50.

The proposed code changes slightly impact on the results reproducibility, impact of individual changes was checked carefully. The differences between references and new experiments were meteorologically insignificant.

3. Code modifications in CY50

The aerosol-related modifications were first applied to CY46, then they were added to CY50.Below is a list of modified routines:

E923 climate generation:
aladin/c9xx/eincli9.F90
aladin/c9xx/eincli12.F90 - new routine
arpifs/c9xx/incli0.F90

arpifs/fullpos/hpos.F90
arpifs/fullpos/sufptr2.F90
arpifs/fullpos/sufpc.F90
arpifs/fullpos/sufprfpbuf_clim.F90

arpifs/module/model_physics_mf_mod.F90
arpifs/module/yomafn.F90
arpifs/module/type_aero.F90 - new routine
arpifs/module/yomfpc.F90
arpifs/module/yomphy.F90
arpifs/module/field_definitions.F90
arpifs/module/surface_fields_config.yaml - 2D fields list to read
arpifs/module/yomphy3.F90
arpifs/module/par_gfl.F90
arpifs/module/yomaero.F90 - new routine
arpifs/module/field_gfl_wrapper.F90
arpifs/module/surface_fields_mix.F90

arpifs/namelist/namaero.nam.h - new namelist block
arpifs/namelist/namafn.nam.h
arpifs/namelist/namphy.nam.h
arpifs/namelist/namfpc.nam.h
arpifs/namelist/namphy3.nam.h - effective radius modification
Arpifs/namelist/naerad.nam.h

arpifs/phys_dmn/suphy3.F90 - effective radius modification
arpifs/phys_dmn/radaecmr.F90 - new routine
arpifs/phys_dmn/correct_aero_neg.F90 - new routine

arpifs/phys_dmn/apl_alaro.F90
arpifs/phys_dmn/suphmf.F90
arpifs/phys_dmn/apl_alaro_radiation.F90
arpifs/phys_dmn/aplpar.F90

arpifs/phys_radi/acraneb_aer_550.F90
arpifs/phys_radi/rad_aer_mmr.F90
arpifs/phys_radi/acraneb2.F90
arpifs/phys_radi/ac_cloud_model2.F90
arpifs/phys_radi/acraneb_rad_eff.F90 - new routine – effective radius modification
arpifs/phys_radi/suecrad.F90

arpifs/setup/su_surf_flds.F90
arpifs/setup/su0phy.F90
arpifs/setup/suaero.F90 - new routine
arpifs/setup/suafn3.F90
arpifs/setup/suafn1.F90
arpifs/setup/suafn2.F90

Due to the fact that in CY50 the code structure was changed compared to the CY46, it required some code modifications.

In CY50 the surface fields which are used in the model are described in yaml file, **surface_fields_config.yaml.** The CAMS fields were added in the block next to the Tegen fields which were already defined in the code.

In order to avoid negative values of CAMS n.r.t. aerosolMMRs, a simple function **correct_aero_neg.F90** was added. This routine corrects negative values of aerosol MMRs, preserving vertically integrated aerosol mass.

This modification has almost no impact on the results. The analysis was computed on the 7th September 2023.

It's worth mentioning that in CY46, the maximum number of CAMS aerosol types for climatological and n.r.t. aerosols are equal to 11 and **19**, respectively (variables JPAEROCMS and JPAERO). They are defined in the routine **par_gfl.F90.**

In CY50, the maximum number of n.r.t. aerosol species was increased to **42.**

In the model namelist fort.4, a new block &NAMAERO was added.

The user should be aware that in the CY50, there are two variables LAEROMMR/LAERONRT which will be replaced with LAEROMASS2D/LAEROMMR3D. This is caused by the fact that in AROME and HARMONIE-AROME models some near real time aerosol developments were introduced earlier, using old logical keys. Below is included a list of old and new keys.

Routine: **arpifs/module/yomphy.F90** and **arpifs/namelist/namphy.nam.h**

Old way:

LAEROMMR: KEY TO USE CLIM. AEROSOL MASS MIXING RATIOS IN RADIATION
LAERONRT: KEY TO USE NRT AEROSOL MASS MIXING RATIOS IN RADIATION

New way:
LAEROMASS2D : **NEW KEY** INTRODUCED TO USE CLIMATOLOGICAL AEROSOL MASS MIXING RATIOS IN RADIATION IN ALARO/AROME/HARMONIE-AROME MODELS
LAEROMMR3D: **NEW KEY** INTRODUCED TO USE N.R.T. AEROSOL MASS MIXING RATIOS IN RADIATION IN ALARO/AROME/HARMONIE-AROME MODELS

Calling tree for CAMS aerosols reading:

APL_ALARO - new ALARO physics driver; old APLPAR not shown
|
APL_ALARO_RADIATION - radiation driver
|
RADAER / RADAECMR - distribute total Tegen/CAMS 2D climatological aerosols vertically
|
CORRECT_AERO_NEG - correct negative values of CAMS n.r.t. aerosol MMRs
|
ACRANEB_AER_550 / RAD_AER_MMR - calculate optical properties of Tegen/CAMS aerosol mixture
|
ACRANEB_RAD_EFF - calculate effective radii of cloud liquid and cloud ice
|
ACRANEB2 - perform radiation calculations
|
AC_CLOUD_MODEL2 – determine cloud optical properties

For technical details on how to run the experiment with CAMS aerosols please see the **Technical document** on RC LACE or ACCORD PH6 webpage:

https://redmine.umr-cnrm.fr/projects/accord/wiki/PH6_Cloud-Aerosol-Radiation_(CAR)_interaction

https://www.rclace.eu/physics

The verification of the modifications was done using ALARO model with horizontal resolution 2.3km and 87 vertical levels (operational Czech domain).

The selected case was 7th September 2023, with only little clouds in Central Europe. ALARO experiments in CY50 without any aerosols have shown that the results with old and new code are bit identical.
Externalization of aerosol optical properties from ACRANEB2 radiation required some changes that do not ensure bit reproducibility for Tegen aerosols, even though the underlying equations are equivalent. The differences between two Tegen experiments (with old and new code) were acceptable. This work was done during the scientific stay of Ana Šljivić in CHMI in 2021, more details are included in her scientific report [5].

The comparison of the ALARO forecast with Tegen aerosols for two models, with and without modifications, is presented in Figure 1. The differences with structure of noise are visible only over Poland and Ukraine, they are related to the minor differences in the cloudiness field.

a) b)

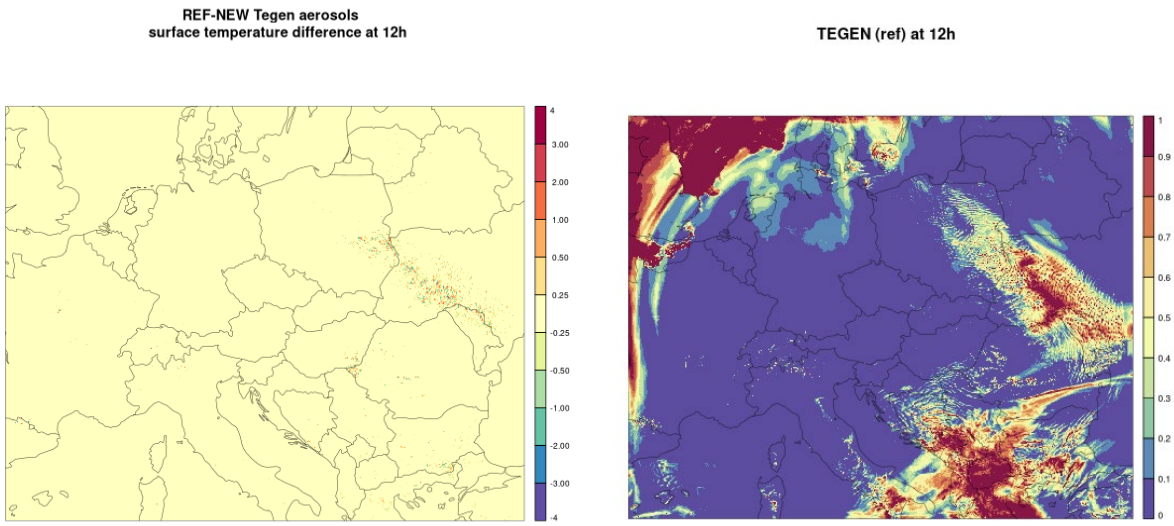
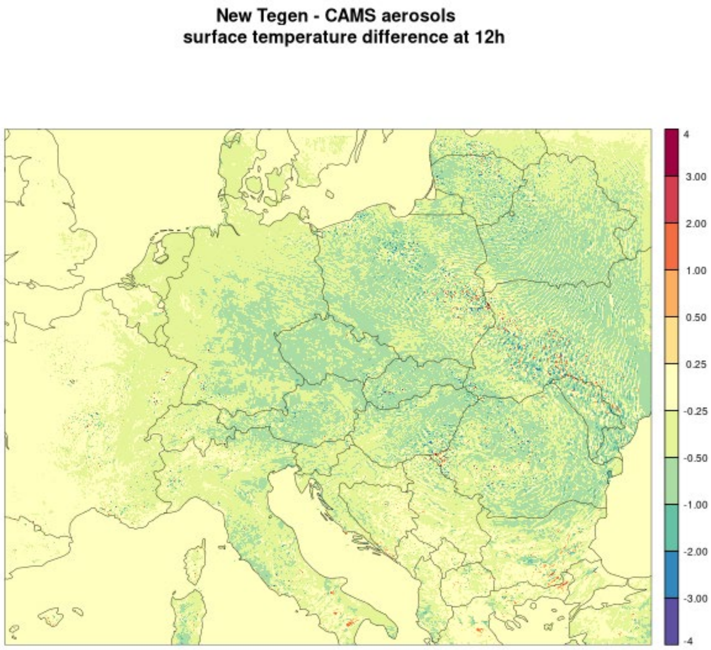


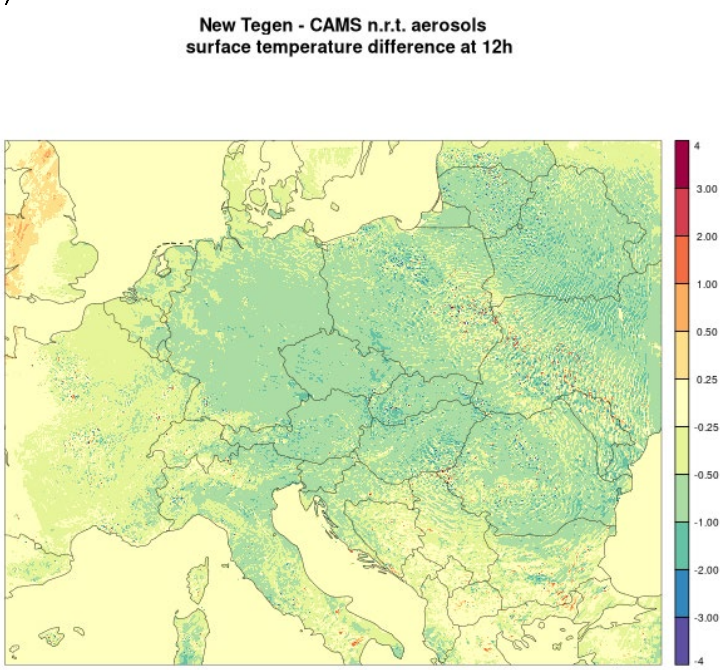
Figure 1. 12-hour ALARO forecast starting on 7th September 2023 at 00 UTC, using Tegen aerosols: a) impact of the new code on the surface temperature; and b) predicted total cloudiness using the old code.

More significant differences were observed between experiments which use different aerosol inputs. Experiments with Tegen aerosols compared to the CAMS aerosols (climatological and n.r.t.) have shown that surface temperature at 12 UTC was colder by 0.5-1°C for Tegen experiment (Figure 2). This points to an overestimated total optical depth of Tegen aerosols. In a given case, CAMS n.r.t. aerosols are optically thinner than CAMS climatological aerosols.

a)


New Tegen - CAMS aerosols
surface temperature difference at 12h
4
3.00
2.00
1.00
0.50
0.25
-0.25
-0.50
-1.00
-2.00
-3.00
-4

b)


New Tegen - CAMS n.r.t. aerosols
surface temperature difference at 12h
4
3.00
2.00
1.00
0.50
0.25
-0.25
-0.50
-1.00
-2.00
-3.00
-4

c)

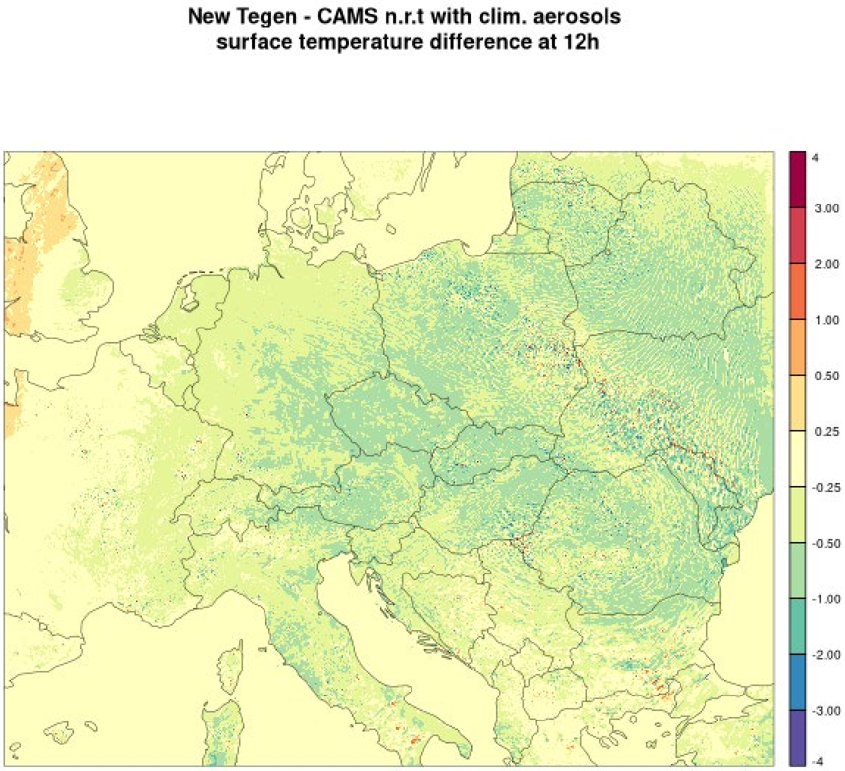


Figure 2. Comparison of predicted surface temperature at 12 UTC (run from 7th September 2023 at 00 UTC) between: a) Tegen and CAMS climatological aerosols; b) Tegen and near-real time CAMS aerosols; and c) Tegen and combination of near-real time (only 3 dust species) and climatological CAMS aerosols (8 of 11 aerosol species) for the final branch including all modifications.

The one of additional tests of the new branch was analysis of externalization of the effective radius from radiation. This modification has a slight impact on the results, presented in Figure 3. Over most of the domain there is no impact, the differences between reference and new experiment are related to the location of cloudiness which is very sensitive to the code changes.

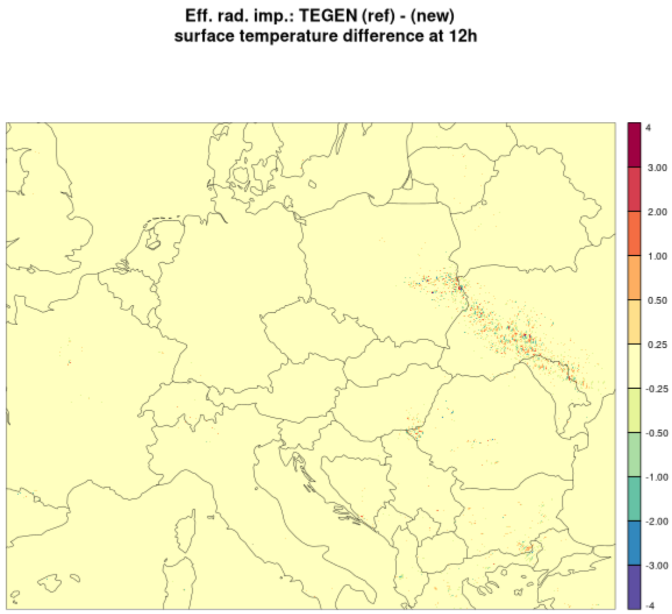


Figure 3. Comparison of surface temperature at 12 UTC (run from 7th September 2023 at 00 UTC) of ALARO model with Tegen aerosols in CY50 with and without effective radius externalization.

The last experiment aimed to compare the ALARO model results when using APLPAR and refactored APL_ALARO routine. The refactored code has a slight irreproducibility, differences in spectral norms appear after sunrise. They are meteorologically insignificant, occurring in the same places as in the previous tests, pointing to a common sensitive region of the cloudiness field.

In Figure 4 are presented differences of surface temperature between runs with APLPAR (non-refactored code) and APL_ALARO (refactored code). Impact for CAMS climatological aerosols (right panel) is stronger than for Tegen aerosols (left panel), but it is still weak and meteorologically insignificant.

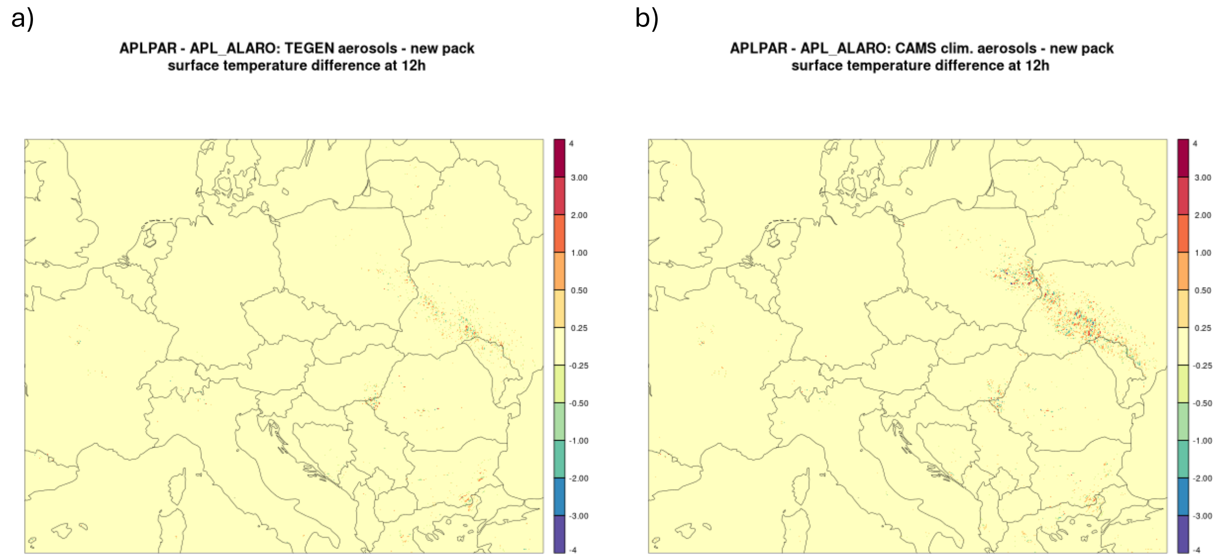


Figure 4. Comparison of the surface temperature prediction at 12 UTC (run from 7th September 2023 at 00 UTC) for the new branch of CY50 using APLPAR and APL_ALARO for a) Tegen aerosols, and b) CAMS climatological aerosols.

5. Negative values of aerosol MMRs in the output file

In the initial file and coupling files, negative values of aerosol mass mixing ratio can occur, it is related to the interpolation type used in their preparation. Due to this fact the correction function has been added to the code (subroutine **correct_aero_neg.F90**).

For each vertical column, starting from the top of the model (i.e., the highest model level) and proceeding downward, the algorithm checks whether the aerosol mass mixing ratio at a given level (JLEV) is negative. If so, aerosol mass is redistributed by borrowing from the adjacent lower level (JLEV+1) in order to eliminate the negative value. This method ensures the conservation of aerosol mass within the domain. The equations employed in this correction function are presented below.

Specific mass of dry air at level JLEV (ZQD_{JLEV}):

$$ZQD_{JLEV} = 1 - PQV_{JLEV} - PQL_{JLEV} - PQI_{JLEV} - PQR_{JLEV} - PQS_{JLEV} - PQG_{JLEV} - PQH_{JLEV}$$

where:
PQV: full level specific humidity [kg/kg]
PQL: full level specific cloud liquid [kg/kg]

PQI: full level specific cloud ice [kg/kg]
PQR : full level specific rain [kg/kg]
PQS: full level specific snow [kg/kg]
PQG: full level specific graupel [kg/kg]
PQH: full level specific hail [kg/kg]

Correction of mass mixing ratio at level JLEV:

$$PAEMMR3D_{JLEV+1} = PAEMMR3D_{JLEV+1} +$$

$$MIN(PAEMMR3D_{JLEV}, 0) \cdot ZQD_{JLEV} \cdot \frac{PDELP_{JLEV}}{(ZQD_{JLEV+1} * PDELP_{JLEV+1})}$$

$$PAEMMR3D_{JLEV} = MAX(PAEMMR3D_{JLEV}, 0)$$

where:

PAEMMR3D : 3D aerosol mass mixing ratios [kg/kg]

PDELP : pressure thickness of the layer [Pa]

The correction function is not applied in a part of extension (E) zone where physics computations are skipped. This part can contain negative aerosol MMRs that do not affect the model results. However, when output MMR fields are packed, slight negative values can appear also in geographical region as a GRIB packing artefact. To confirm this, we performed an experiment without packing of output fields by setting NVGRIB=0 in the namelist block &NAMFA. Output ICMSH file was three times bigger, but dump of aerosol MMR fields in the geographical (C+I) zone did not contain any negative values. Minimum value printed in grid-point norm diagnostics can still be negative, since it is calculated over full C+I+E zone. It is important to know that eventual negative minimum originates from E zone, therefore it is harmless.

6. Conclusions

The research stay in Prague made it possible to gather all the developments introduced by Laura Rontu, Ján Mašek, and Ana Šljivić. The modifications described above were introduced in CY50. The module responsible for utilizing atmospheric aerosol in the ACCORD system was designed in such a way that users can easily employ climatological and near-real-time aerosols (CAMS or MOCAGE). The aerosol inherent optical properties (IOPs) used in radiation are read from a NetCDF file. In the new approach, aerosols (both climatological and near-real-time) are stored during the integration in a 3D GFL array, which is defined in the namelist. The tests has shown that code changes slightly impact on the results reproducibility. The differences between references and new experiments were meteorologically insignificant.

Analysis of experiments with different aerosol inputs (climatological and n.r.t. CAMS aerosols) pointed out that total optical depth of Tegen aerosols is overestimated. Experiments with Tegen aerosols compared to the CAMS aerosols (climatological and n.r.t.) have shown that surface temperature at 12 UTC was colder by 0.5-1°C for Tegen experiment.

The studies are not yet finished. To reduce warm T2m bias observed for ALARO with CAMS aerosols, use of updated solar constant and tuning of stratospheric aerosol background is planned. The tuning should be ideally done in the clear sky cases well captured by the model, using CAMS n.r.t. aerosols. This should enable us to obtain meaningful tuning using a relatively short period. With CAMS climatological aerosols the tuning period would have to be longer in order to eliminate short-term fluctuations of real aerosol loads around climatology.

The effectiveness of the new tuning will be evaluated across different seasons, including periods with significant cloud cover, in order to assess its robustness under a range of atmospheric conditions. The tuning will be verified for CAMS climatological aerosols, and in case of dust intrusion cases also for more expensive CAMS n.r.t. aerosols. Additionally to T2m, global radiation from the Czech radiation network will be used as a quantity more directly related to aerosol load.

References:

[1] Piotr Sekuła, Study of the radiation, cloud's microphysics and atmospheric precipitation sensitivity by taking into account the atmospheric aerosols impact using the AROME model, RC LACE stay, Prague, 17.09.2023-14.10.2023

[2] A. Bozzo et al. "An aerosol climatology for global models based on the tropospheric aerosol scheme in the Integrated Forecasting System of ECMWF". In: Geoscientific Model Development 13.3 (2020),pp. 1007–1034. doi: 10.5194/gmd-13-1007-2020. url: https://gmd.copernicus.org/articles/13/1007/2020/.

[3] Ana Šljivić and Ján Mašek, Producing new CAMS aerosol input for climate files, CHMI technical document, Prague 2024

[4] Ana Šljivić and Ján Mašek, Vertical distribution of climatological aerosols, CHMI research note, Prague 2024

[5] Ana Šljivić, 2021: Interfacing near real-time aerosols with radiation schemes, RC LACE stay report, Prague, 27.09.2021 - 22.10.2021