RC-LACE flat-rate stay report

Study of the radiation, cloud's microphysics and atmospheric precipitation sensitivity by taking into account the atmospheric aerosols impact using the AROME model.

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The scientific stay in Prague was part of task PH6 focused on cloud/aerosol/radiation (CAR) interactions included in the Rolling Work Plan 2023. The aim of my visit was to finalize the model development related to aerosol interaction in radiation for AROME and ALARO models. The reference branch was CY46T1_bf7. The new branch includes developments suggested by Ján Mašek, Daniel Martín Pérez, Laura Rontu and Ana Šljivić.

In the new pack, developments suggested by authors give possibility to use three different sources of atmospheric aerosols in the ALARO and AROME model (Tegen climate files, monthly CAMS aerosol MMRs and near-real time CAMS forecast/analysis). Currently in operational forecast, information about aerosol concentration comes from outdated data source - climatological files containing six Tegen aerosol types (sea salt; soil dust (1-10µm); soil dust (<1µm); sulfate (H_2SO_4); carbonaceous aerosol; black carbon). In addition to these, hardcoded background values for tropospheric and stratospheric AOD550 are assumed when preparing aerosol optical properties for the default radiation scheme.

In aim to improve the quality of model forecast, work was carried out to use updated climatological files (eleven CAMS aerosol MMRs) as well as daily analyses and forecasts of atmospheric aerosol (CAMS global near-real time). The AROME model validation and testing includes analysis of data transfer of aerosol MMRs in the model but also their impact on the forecast by using two different radiation schemes (ACRANEB2 and FMR/RRTM radiation scheme from IFS CY25).

This stay was continuation of the work presented in scientific report of work done in Helsinki with Laura Rontu (Sekula, P. 2023). The previous report describes: (1) list of modified routines in CY46T1_bf7 including some namelist updates and (2) preparation of the new climate files.

1. Sources of atmospheric aerosols

In the new branch were tested 4 different experiments with: (1) no aerosols; (2) monthly Tegen climatology – 4 aerosol types; (3) monthly CAMS aerosol MMRs – 11 aerosol types ; (4) near-real time CAMS forecast/analysis – 14 aerosol types.

The monthly climate fields of aerosol species coming from Tegen and CAMS can be both stored in the climate files, but in the experiment only one source of aerosols must be chosen. The variable which stores the information about the number of aerosol fields is **YSD_VAD%NUMFLDS** which is used in routine **apl_arome.F90**.
Switching on Tegen and CAMS climatology simultaneously can cause that the numerical forecast in some configurations is wrong, e.g. AROME with IFS radiation scheme.

2. Vertical distribution of aerosols

In aerosol climatology based on Tegen et al. (1997), the aerosol optical depth between the model top and given level is described by power function $\left(\frac{p}{p_0}\right)^{\frac{H}{\xi}}$, where:

p – atmospheric pressure;
p_0 – the surface pressure;
H – the scale height of the standard atmosphere equal to 8.434 km
ξ – fixed global-mean scale height for each aerosol component.

The constant scale height ξ in Tegen climatology is equal to 3 km for dust, and 1 km for the other species (sea salt, sulfate, carbonaceous aerosol, black carbon). The calculation of vertical redistribution is done in routine **radaer.F90** by using analytical function provided by routine **suaerv.F90**.

The studies presented in Bozzo et al. (2020) indicate that scale height for selected aerosol species may vary significantly during the year. The strongest seasonal variability was observed for dust species ranging from ~ 2 m in winter to ~ 3 km in summer. Such strong dynamics is the result of interaction between emission, long-range transport, variation of the mixing boundary layer over the deserts, and the seasonal patterns of large-scale synoptic circulations. For the other species, ξ can be approximated by a constant value throughout the year: for sea salt aerosols and black carbon equal to 1 km, for organic matter equal to 2 km and for sulfate about 3 km.
Analysis of 3D monthly climate files presented in this article has pointed out that vertical distribution of aerosols is characterized by a maximum located near the PBL top. Due to this fact new vertical redistribution using gamma distribution was proposed. Example plot of vertical aerosol concertation for point representing Krakow city (50°N 20°E) is presented in Figure 1.

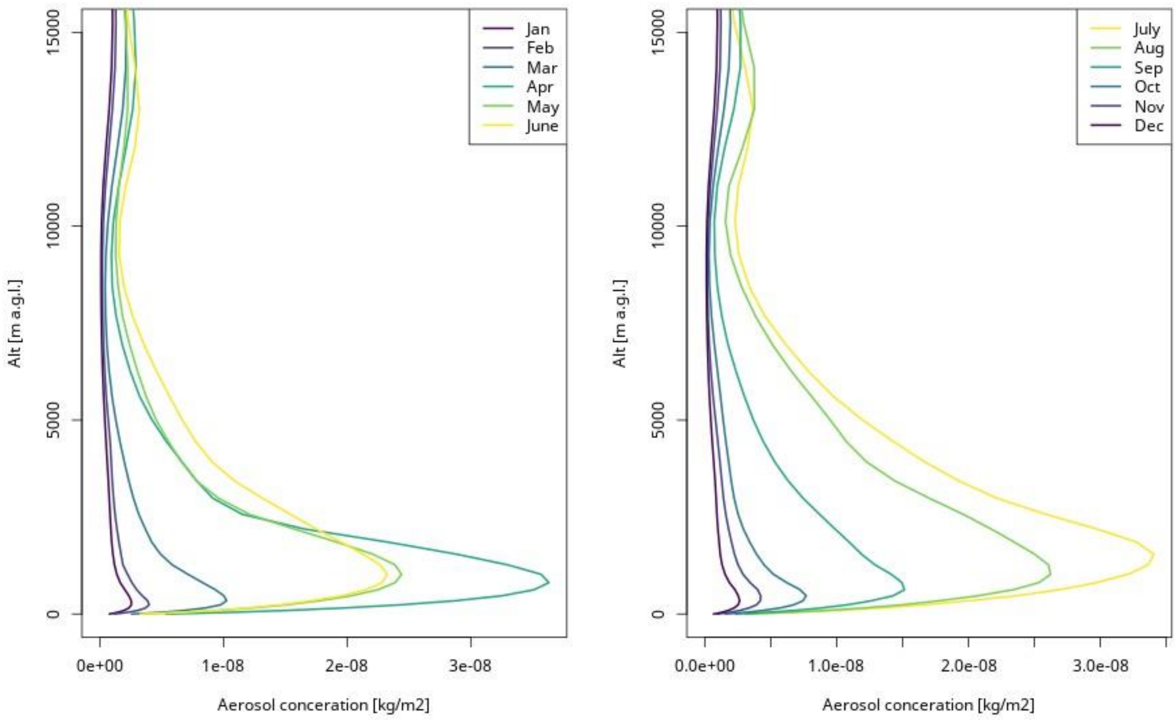

Figure 1. Monthly hydrophilic black carbon vertical profile for point representing Kraków city from aerosol CAMS 3D climatology 2003-2013 (Bozzo et al. 2020).

A new routine based on the source radaer.F90 was prepared, in order to vertically redistribute CAMS aerosol MMRs The mass mixing ratio vertical profile is computed analytically with an exponential function by using the equation:

$$(r_a)_l = \frac{m_a \cdot g}{(1 - q_{vl})\Delta p_l} \cdot \left(e^{\frac{-z_l}{\xi}} - e^{\frac{-z_{l-1}}{\xi}}\right)$$

where:
$(r_a)_l$ – mass mixing ratio at level l
m_a – mass of aerosol column per unit area [mg/m^2]
g - standard gravity acceleration
q_{vl} – specific humidity at level l
Δp_l – pressure thickness of layer l
ξ - the aerosol height scale
z_l – height of half-level l
z_{l-1} – height of half-level *l-1*

In the next version of the routine it is planned to replace exponential distribution monotonically decreasing with height by a more general gamma distribution, which enables to represent PBL peak of aerosol concentrations. Instead of single tuning parameter (height scale), there will be two parameters (height scale and gamma-function exponent) per aerosol type, set individually via namelist. Backward compatibility for Tegen climatological aerosols will be ensured, since for exponent zero the gamma distribution reduces back to exponential one.

3. Monthly climate data sources

The dataset of climatological total CAMS MMRs used in this study covers period 2003-2013 and horizontal resolution of all species is equal to 3° x 3°. The ASCII files used in climate files generation were created by using python script by extraction of the data from netCDF file. Example file containing source data and scripts provided by Laura Rontu can be found in link:

https://hirlam.org/trac/attachment/wiki/Aerosol/camsaero2har.tgz

The Copernicus Service provides product CAMS global reanalysis (EAC4) with horizontal resolution 0.75°x0.75° and temporal coverage from 2003 to 2022 with 3 hour resolution. One of the possible products are vertically integrated masses of 11 aerosols species presented in Table 1. The data can be downloaded in grib and netCDF formats, the only disadvantage is very long time of data preparation and downloading. Such obtained data would require some post processing methods (average over the time and interpolation to the selected model domain).

4. Aerosol inherent optical properties

In the ACRANEB2 radiation scheme, the aerosol inherent optical properties (IOPs) are read from the NetCDF file by the routine **suaero.F90.** Detailed analysis showed that in this routine was a small bug which led to wrong aerosol mapping from the NetCDF file. The bug was fixed. In case of 2D monthly climate files of aerosol species their order is determined in **mf_phys.F90**. Below is included a list of 2D monthly climate files coming from CAMS MMRs. Reading CAMS MMRs fields is done in routine **su_surf_flds.F90**. The knowledge of the order of aerosol types is crucial to assigning them the correct physical properties that are stored in the netCDF file (aerosol_ifs_rrtm_46R1_with_NI_AM.nc). In Appendix A is included a short description of aerosol physical properties stored in the netCDF file.

The assigning of physical properties to the aerosol fields is done via namelist, in the block **&NAMAERO**.

Below is included configuration for monthly 11 CAMS aerosol MMRs. In this configuration it was assumed that hydrophilic black carbon has the same optical properties as hydrophobic black carbon.

```
&NAMAERO
  MAP_AERO_GFL2NC=-1,-2,-3,1,2,3,-4,10,11,11,-8,
/
```

The detailed description of eleven CAMS aerosol MMRs is included in the Table 1.

Table 1. Aerosol species of monthly climate file coming from CAMS MMs.

ID	FA name	Acronym	Description	NetCDF index (+phobic; -philic)
1	SURFAEROMMR.SS1	SS1	sea salt (0.03 - 0.5 um)	-1
2	SURFAEROMMR.SS2	SS2	sea salt (0.5 - 5 um)	-2
3	SURFAEROMMR.SS3	SS3	sea salt (5 - 20 um)	-3
4	SURFAEROMMR.DD1	DD1	dust (0.03 - 0.55 um)	1
5	SURFAEROMMR.DD2	DD2	dust (0.55 - 0.9 um)	2
6	SURFAEROMMR.DD3	DD3	dust (0.9 - 20 um)	3
7	SURFAEROMMR.OM1	OM1	hydrophilic organic matter	-4
8	SURFAEROMMR.OM2	OM2	hydrophobic organic matter	10
9	SURFAEROMMR.BC1	BC1	hydrophilic black carbon	11
10	SURFAEROMMR.BC2	BC2	hydrophobic black carbon	11
11	SURFAEROMMR.SU	SU	sulphate	-8

N.R.T. aerosol mapping

Below is included list of near-real time CAMS forecast/analysis aerosol types.

```
&NAMAERO
  MAP_AERO_GFL2NC=-1,-2,-3,1,2,3,-4,10,11,11,-5,-9,-10,-8,
/
```

Table 2. Aerosol species of near-real time CAMS forecast/analysis.

ID	Shortname in CAMS file	FA name	Description	NetCDF index (+phobic; -philic)
1	aermr01	SEA.SALT1	sea salt (0.03 - 0.5 um)	-1

2	aermr02	SEA.SALT2	sea salt (0.5 - 5 um)	-2
3	aermr03	SEA.SALT3	sea salt (5 - 20 um)	-3
4	aermr04	DES.DUST1	dust (0.03 - 0.55 um)	1/4/7
5	aermr05	DES.DUST2	dust (0.55 - 0.9 um)	2/5/8
6	aermr06	DES.DUST3	dust (0.9 - 20 um)	3/6/9
7	aermr07	ORG.MAT1	hydrophilic organic matter	-4
8	aermr08	ORG.MAT2	hydrophobic organic matter	10
9	aermr09	BLACK.CAR1	hydrophilic black carbon	?
10	aermr10	BLACK.CAR2	hydrophobic black carbon	11/12/13
11	aermr11	SULPHATE	sulphate	-5
12	aermr16	NITRATE1	fine mode Nitrate	-9
13	aermr17	NITRATE2	coarse mode Nitrate	-10
14	aermr18	AMMONIUM	ammonium	-8

CAMS n,r,t, aerosol MMRs were prepared in two steps:

1) GRIB files were extracted from MARS using request:

```
retrieve,
  accuracy=16,
  area=58.4/-6.0/37.6/36.0,
  class=mc,
  database=marser,
  date=<yyyymmdd>,
  expver=1,
  grid=0.4/0.4,
  levelist=1,
  levtype=ml,
  param=z,
  process=local,
  step=0,
  stream=oper,
  time=<HH>,
  type=an,
  target="cams_z_[date][time].grb"
retrieve,
  levelist=1/to/137,

param=130/133/152/210001/210002/210003/210004/210005/210006/210
007/210008/210009/210010/210011/210247/210248/210249,
  step=0/3/6/9/12/15/18/21/24,
  type=fc,
  target="cams_mmr_[date][time]+[step].grb"
```

In order to reduce file size, we do not extract global CAMS fields, but only their zoom over latlon rectangle covering the area of interest. First part of request extracts orography, second part temperature, humidity, surface pressure, and aerosol MMRs.

2) GRIB files were transferred to belenos, where we converted them to FA format using GL tool. In order to be able to use GL, environment must be prepared and some modules loaded:

```
$ . /home/gmap/mrpm/seity/gl/config/setenv.belenos
```

The conversion script is:

```
/home/gmap/mrpm/masekj/cams_mmr/run_cams_grib2fa
```

Look inside to see where the input files are taken from. Apart from GRIB files with aerosol MMRs, GL needs also GRIB file with CAMS orography in order to make vertical interpolations, and the climate file to determine target FA geometry and orography. In GL namelist, target vertical levels are specified via A and B coefficients. In order to reduce undershoots, we set order of horizontal interpolations to 1 (bilinear), but some undershoots can still be created by vertical interpolations. In the GL namelist there is also a table of short GRIB field names, and their matching FA counterparts.

5. Namelist modifications

No aerosols:

```
&NAERAD
  NAER=0, ! this variable is crucial in AROME model configuration
/
&NAMPHY
  LAERODES=.F.,
  LAEROLAN=.F.,
  LAEROSEA=.F.,
  LAERONRT=.F.,
  LAEROCMR=.F.,
  LAEROSOO=.F.,
/
```

Tegen climatology:

```
&NAERAD
  NAER=1,
/
&NAMPHY
  LAERODES=.T.,
  LAEROLAN=.T.,
  LAEROSEA=.T.,
  LAERONRT=.F.,
  LAEROCMR=.F.,
  LAEROSOO=.T.,
/
```

Monthly CAMS aerosol MMRs:

```
&NAERAD
  NAER=1,
/
&NAMPHY
  LAERODES=.F.,
  LAEROLAN=.F.,
  LAEROSEA=.F.,
  LAERONRT=.F.,
  LAEROCMR=.T.,
  LAEROSOO=.F.,
/
&NAMAERO
  MAP_AERO_GFL2NC=-1,-2,-3,1,2,3,-4,10,11,11,-8,
/
```

Near-real time CAMS forecast/analysis:

```
&NAERAD
  NAER=1,
/
&NAMPHY
  LAERODES=.F.,
  LAEROLAN=.F.,
  LAEROSEA=.F.,
  LAERONRT=.T.,
  LAEROCMR=.F.,
  LAEROSOO=.F.,
/

&NAMGFL
   NAERO=14,
! definition of 14 GFL fields – fields names are included in the Table 2
   YAERO_NL(1)%CNAME='SEA.SALT1',
   YAERO_NL(1)%LADV=.T.,
   YAERO_NL(1)%LGP=.TRUE.,
   YAERO_NL(1)%LQM=.TRUE.,
   YAERO_NL(1)%LREQOUT=.TRUE.,
   YAERO_NL(1)%LSP=.FALSE.,
   YAERO_NL(1)%NCOUPLING=1,
   YAERO_NL(1)%NREQIN=1,
   YAERO_NL(1)%LPT=.TRUE.,
   YAERO_NL(1)%LPC=.TRUE.,
[…]
   YAERO_NL(14)%CNAME='AMMONIUM',
   YAERO_NL(14)%LADV=.T.,
   YAERO_NL(14)%LGP=.TRUE.,
   YAERO_NL(14)%LQM=.TRUE.,
   YAERO_NL(14)%LREQOUT=.TRUE.,
   YAERO_NL(14)%LSP=.FALSE.,
   YAERO_NL(14)%NCOUPLING=1,
```

```
    YAERO_NL(14)%NREQIN=1,
    YAERO_NL(14)%LPT=.TRUE.,
    YAERO_NL(14)%LPC=.TRUE.,

  &NAMAERO
   MAP_AERO_GFL2NC=-1,-2,-3,1,2,3,-4,10,11,11,-5,-9,-10,-8,
  /
```

6. Results - comparison with no aerosols in the model

Analysis of new modifications was done on case 20 February 2021, when strong intrusion of Saharan dust over Europe was observed. Tests confirmed that modifications in ACRANEB2 radiation scheme are correct, results of new model are consistent with the reference for case without any aerosols and with use Tegen climatology. The first set of tests included only radiation interaction by using ACRANEB2 radiation scheme in ALARO and AROME model. In aim to check if ACRANEB2 is working properly with new 2D monthly climate files coming from CAMS MMRs, there was done experiment where AEROPT was used with ACRANEB2 scheme. The modified AEROPT routine was provided by Laura Rontu. The obtained results were consistent with experiment using ACRANEB2 with new routine for computing weighted IOP's of aerosols provided by Ján Mašek. - routine RAD_AER_MMR. On Figure 2 and 3 are presented temperature differences between experiment with no aerosols and (1) CAMS monthly climate files of MMRs, (2) CAMS forecast/analysis n.r.t. of MMRs and (3) Tegen climatology. Analysis of the results has shown that for ALARO and AROME models the strongest differences were observed for Tegen climatology. In case of use CAMS monthly climate files of MMRs in the forecast the differences of air temperature with case without aerosols for the dominant region were within ±0.2°C.

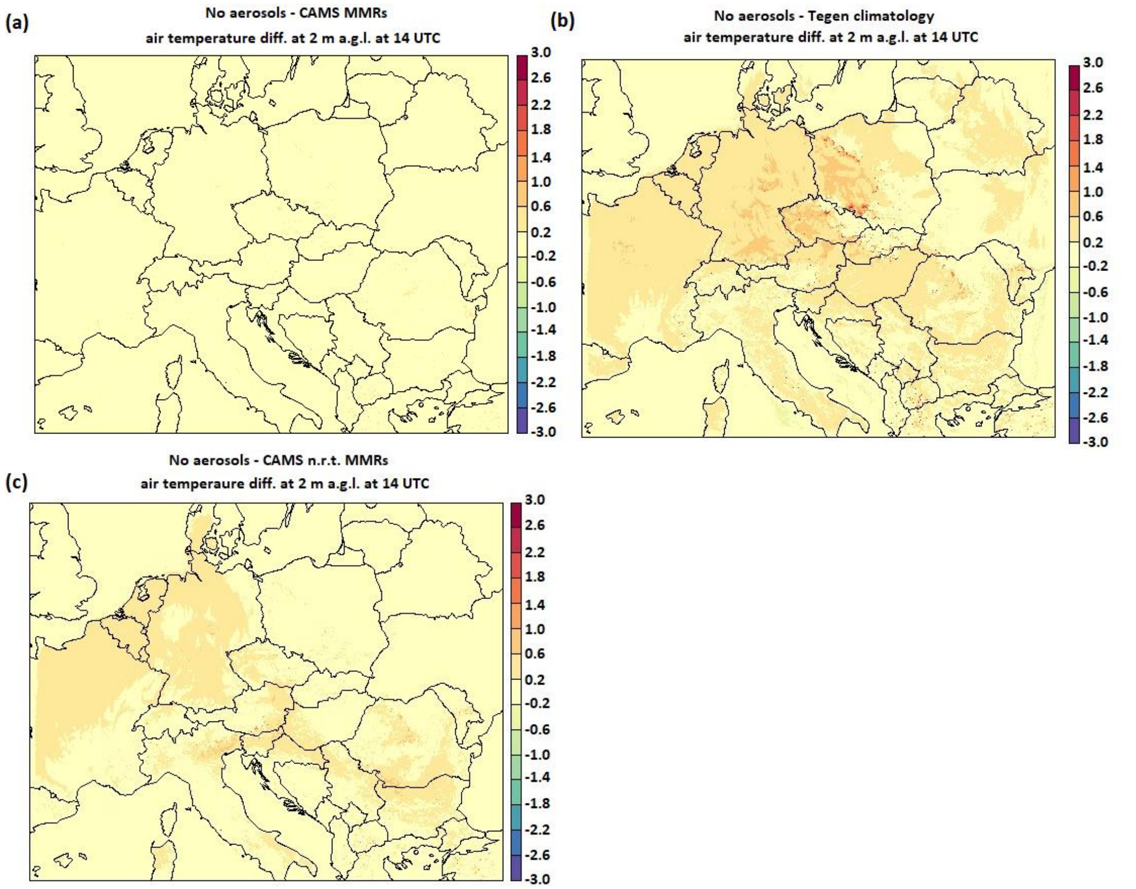

Figure 2. Differences of predicted air temperature between case without any aerosols and (a) CAMS monthly climate files, (b)Tegen climatology and (c) CAMS n.r.t. MMRs for ALARO model at 14 UTC 20 February 2021.

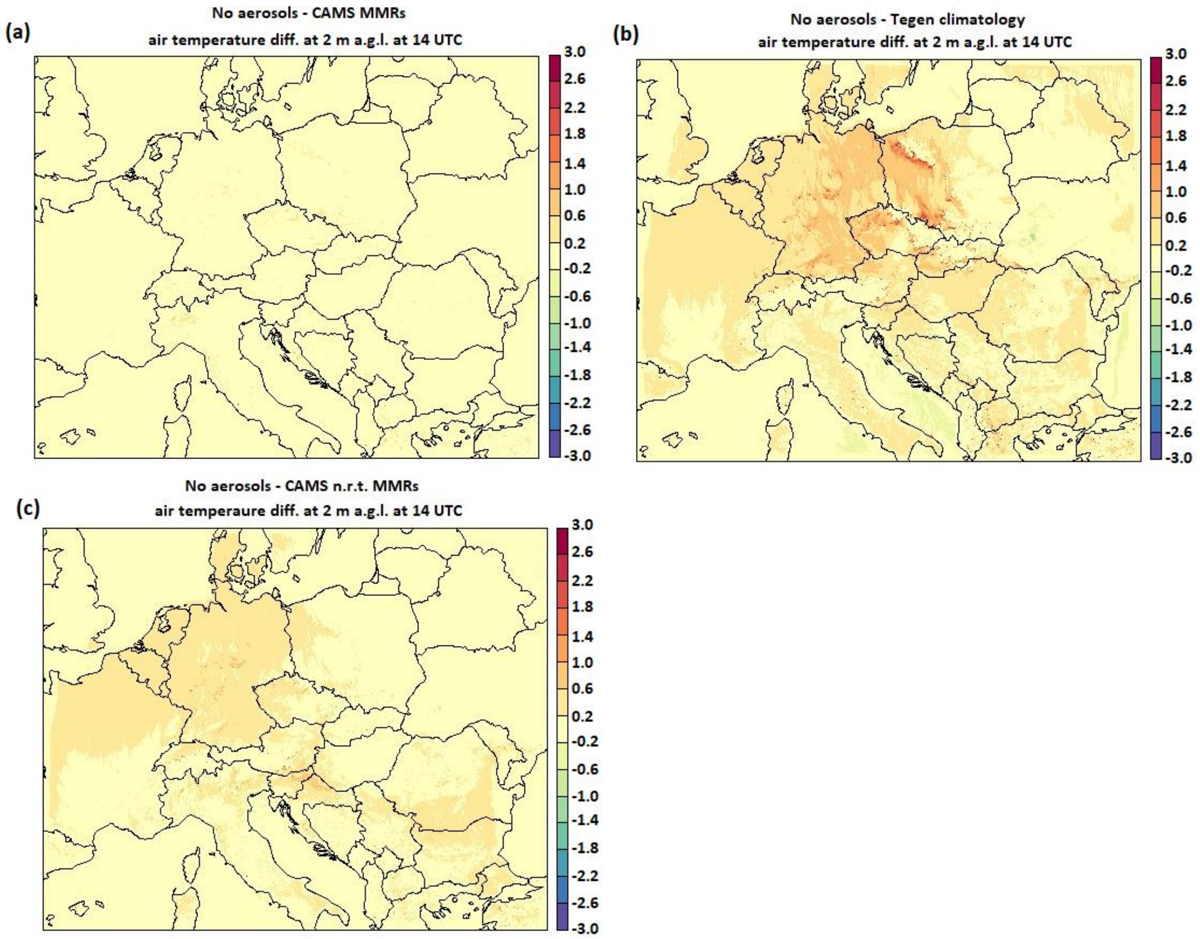

Figure 3. Differences of predicted air temperature between case without any aerosols and (a) CAMS monthly climate files, (b)Tegen climatology and (c) CAMS n.r.t. MMRs for AROME model at 14 UTC 20 February 2021.

7. Tests of OLD3 microphysics modifications – Daniel Martin

In aim to analyze the model sensitivity to microphysics modifications were prepared 7 configurations which are described in Table 3. The strongest differences were observed between ***Reference*** and first configuration (***MIC 1***). Switching on the key **LCAMS_NRT** to **TRUE** had strong impact on cloudiness and air temperature but also on integrated values of aerosols in total column (Figure 4).

Analysis has shown that changing variables **LAEIFN** and **LAERDRDEP** from FALSE to TRUE (***MIC 2-4***) has no impact on the results, they are identical as results from first configuration (***MIC 1***).

Variable **LAERDRDEP** is responsible for removal of sea salt and dust from the lowest level, the analysis of integrated values of aerosols in total column did not show any change after switching this variable. Only small change of model results compared to the first configuration (***MIC 1***) were visible for the configuration 5 and 6 (***Case 5 and 6***), where **LAECCN2CLDR** is set to TRUE.

There was done also another test with setting LOCND2 to TRUE (Karl-Ivar's scheme) to have in AROME model all the parametrizations that use cloud droplet number concentration. Unfortunately, tests have shown that reference AROME model was not ready for this configuration. The model integration stopped at 0-time step, the test was done also for reference branch.

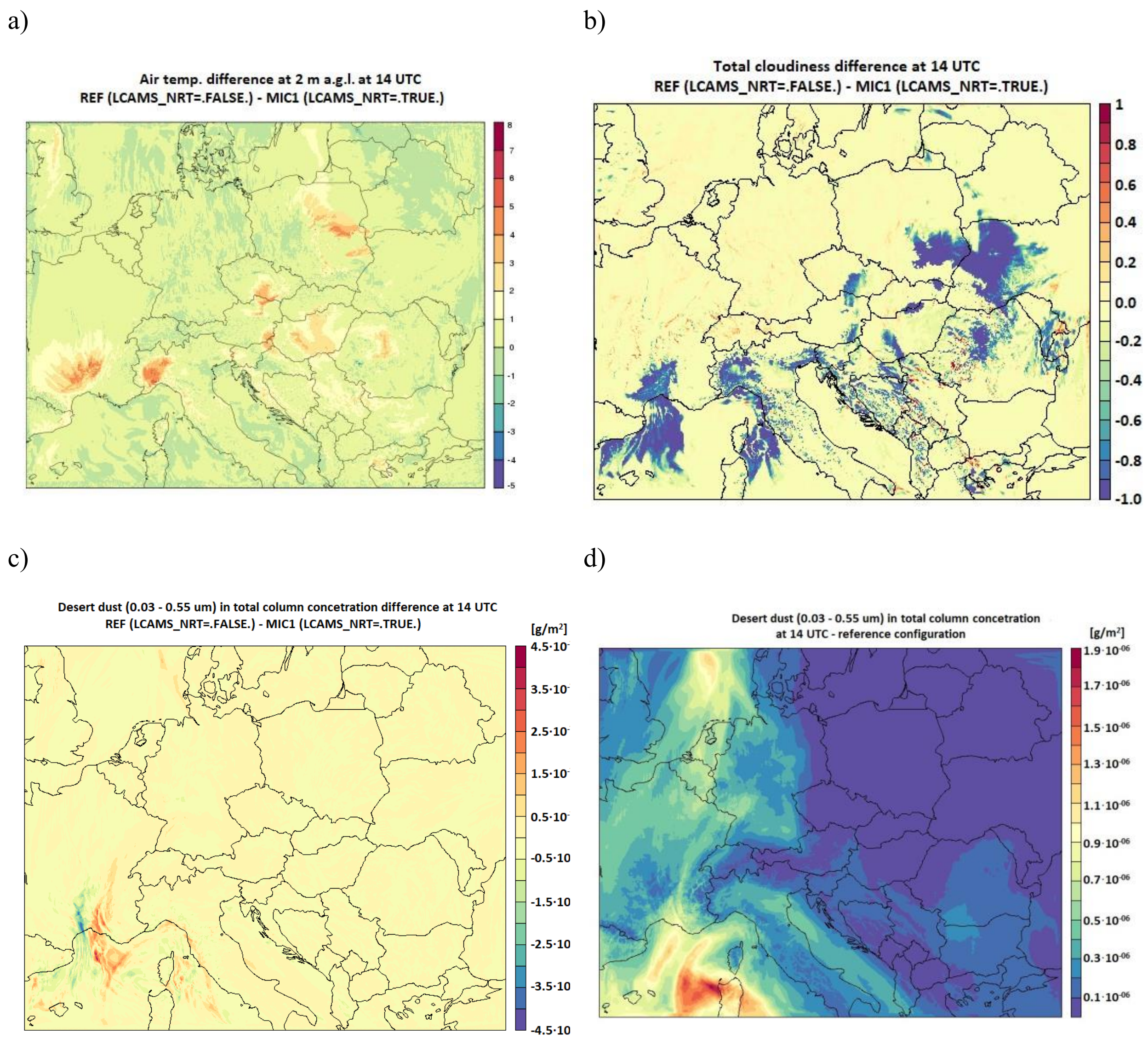

Figure 4. Sensitivity of changes in the OLD3 microphysics scheme to the weather prediction using AROME model (Case 1) at 14 UTC 20th February 2021: a) air temperature differences; b) total cloudiness differences; c) desert dust (0.03-0.55 um) in total column differences and d) desert dust (0.03-0.55 um) in total column for reference configuration.

Table 3. Model configurations used in tests in OLD3 microphysics scheme.

Reference:	**MIC 1:**
&NAMPARAR	&NAMPARAR
CMICRO='OLD3',	CMICRO='OLD3',
	/
&NAMNRTAER	&NAMNRTAER
LCAMS_NRT=.FALSE.,	**LCAMS_NRT=.TRUE.,**
LAECCN2CLDR=.FALSE.,	LAECCN2CLDR=.FALSE.,
LAEIFN=.FALSE.,	LAEIFN=.FALSE.,
LAERDRDEP=.FALSE.,	LAERDRDEP=.FALSE.,
/	

/

MIC 2:

&NAMPARAR
CMICRO='OLD3',
/
&NAMNRTAER
LCAMS_NRT=.TRUE.,
LAECCN2CLDR=.FALSE.,
LAEIFN=.TRUE.,
LAERDRDEP=.FALSE.,
/

MIC 3:

&NAMPARAR
CMICRO='OLD3',
/
&NAMNRTAER
LCAMS_NRT=.TRUE.,
LAECCN2CLDR=.FALSE.,
LAEIFN=.FALSE.,
LAERDRDEP=.TRUE.,
/

MIC 4:

&NAMPARAR
CMICRO='OLD3',
/
&NAMNRTAER
LCAMS_NRT=.TRUE.,
LAECCN2CLDR=.FALSE.,
LAEIFN=.TRUE.,
LAERDRDEP=. TRUE.,
/

MIC 5:

&NAMPARAR
CMICRO='OLD3',
/
&NAMNRTAER
LCAMS_NRT=.TRUE.,
LAECCN2CLDR=. TRUE.,
LAEIFN=. FALSE.,
LAERDRDEP=. FALSE.,
/

MIC 6:

&NAMPARAR
CMICRO='OLD3',
/
&NAMNRTAER
LCAMS_NRT=.TRUE.,
LAECCN2CLDR=. TRUE.,
LAEIFN=.TRUE.,
LAERDRDEP=. TRUE.,
/

8. References:

1. Bozzo, A., Benedetti, A., Flemming, J., Kipling, Z., Rémy, S. (2020). An aerosol climatology for global models based on the tropospheric aerosol scheme in the Integrated Forecasting System of ECMWF. Geoscientific Model Development, vol. 11, no. 3, 1007-1034 pp., DOI: 10.5194/gmd-13-1007-2020 https://gmd.copernicus.org/articles/13/1007/2020/#App1.Ch1.S1.F14
2. Sekula. P. (2023). Study of the radiation, cloud's microphysics and atmospheric precipitation sensitivity by taking into account the atmospheric aerosols impact using the AROME model. ACCORD flat-rate stay report. https://www.rclace.eu/media/files/Physics/2023/PS23H_aerosols_report_final.pdf

APPENDIX A

1. Description of netCDF file containing aerosol physical properties
   (file: aerosol_ifs_rrtm_46R1_with_NI_AM.nc available at belenos supercomputer)

   Instruction how to get the file:
   /home/mf/dp/marp/gco/apps/gco_toolbox/default/bin/gget rrtm.const.04.tgz
   tar xvfz rrtm.const.04.tgz aerosol_ifs_rrtm_46R1_with_NI_AM.nc

NETCDF FILE

Description hydrophobic

1: Desert dust, bin 1, 0.03-0.55 micron, (SW) Dubovik et al. 2002 (LW) Fouquart et al. 1987,
2: Desert dust, bin 2, 0.55-0.90 micron, (SW) Dubovik et al. 2002 (LW) Fouquart et al. 1987 ,
3: Desert dust, bin 3, 0.90-20.0 micron, (SW) Dubovik et al. 2002 (LW) Fouquart et al. 1987,
4: Desert dust, bin 1, 0.03-0.55 micron, Fouquart et al 1987,
5: Desert dust, bin 2, 0.55-0.90 micron, Fouquart et al 1987,
6: Desert dust, bin 3, 0.90-20.0 micron, Fouquart et al 1987,
7: Desert dust, bin 1, 0.03-0.55 micron, Woodward 2001, Table 2,
8: Desert dust, bin 2, 0.55-0.90 micron, Woodward 2001, Table 2,
9: Desert dust, bin 3, 0.90-20.0 micron, Woodward 2001, Table 2,
10: Hydrophobic organic matter, OPAC (hydrophilic at RH=20%),
11: Black carbon, OPAC,
12: Black carbon, Bond and Bergstrom 2006,
13: Black carbon, Stier et al 2007,
14: Stratospheric sulfate (hydrophilic ammonium sulfate at RH 20%-30%),

Description hydrophilic

1: Sea salt, bin 1, 0.03-0.5 micron, OPAC,
2: Sea salt, bin 2, 0.50-5.0 micron, OPAC,
3: Sea salt, bin 3, 5.0-20.0 micron, OPAC,
4: Hydrophilic organic matter, OPAC,
5: Ammonium sulfate (for sulfate), GACP Lacis et al https://gacp.giss.nasa.gov/data_sets/ ,
6: Secondary organic aerosol - biogenic, Moise et al 2015,
7: Secondary organic aerosol - anthropogenic, Moise et al 2015,
8: Fine mode Ammonium sulfate (for ammonia), GACP Lacis et al
9: Fine mode Nitrate, GLOMAP,
10: Coarse mode Nitrate, GLOMAP,