

ACCORD Stay Report
Tuning the ALARO model following the incorporation of CAMS aerosols

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1. Introduction

This scientific stay, conducted as part of Task PH6 on Cloud-Aerosol-Radiation (CAR) interactions in the ACCORD Rolling Work Plan 2025, continued the work initiated during my previous stay in Prague in November 2024 (see Sekula and Mašek (2024)). Its objective was to determine the optimal configuration for climatological aerosol concentrations from the CAMS (Copernicus Atmosphere Monitoring Service) database within the ACCORD system. For these studies cases with clear sky conditions in different seasons were selected. We expected that using CAMS near-real-time (n.r.t.) aerosols in these cases would enable us to determine an appropriate tuning of the stratospheric aerosol backgrounds¹. In contrast, achieving such a tuning for CAMS climatological aerosols would require simulations spanning one to several years to average out the observed aerosol variability. The forecasted 1-hour average surface shortwave (SW) global radiation was compared against the observations from Czech radiation network. The verification of the default model configuration using 3D n.r.t. CAMS aerosols mass mixing ratios (MMRs) and active tropospheric and stratospheric background aerosols has shown that model considerably overestimates surface SW global radiation (up to 20-30 W/m²). By tuning the model, we tried to reduce this positive bias.

The work was done using local CHMI version of CY48T3, including latest ALARO developments and modifications related to CAMS aerosols treatment. The results of performed tests are presented in Sections 2-8.

2. Solar constant studies

The first step in tuning the ALARO model radiation budget was adjusting the solar constant.

The default value of the solar constant is determined in the routine:

arpifs/module/yomcst.F90

¹ Tropospheric and stratospheric background values are prescribed baseline aerosol burdens, expressed as MMRs, that are added to the climatological aerosol field to account for background aerosol not represented by the climatology. In the CAMS implementation, they are applied separately in the troposphere and stratosphere and added to the hydrophobic organic matter field; their magnitudes were derived from Tegen background AOD550 values and tuned to achieve a comparable SW-radiative impact. More details can be found in Šljivić and Mašek (2024B)

Then this variable is used in the routine:

arpifs/utility/updtim.F90

The ACRANE2 scheme uses variable **RIIO** giving direct normal irradiance at the top of the atmosphere. It is set in the routine **updtim.F90**, based on the solar constant **RI0** and the actual Sun-Earth distance.

The variable **RI0** has a default value of 1366 W/m^2 . It can be modified in the namelist block as follows:

```
&NAMSCEN
  RI0=1360.,
/
```

However, within CY48 and CY50, there is a small bug in the routine **yomcst.F90**, due to which namelist setting of **RI0** was ignored. It will be corrected in CY50.

Sensitivity to solar constant was studied over one day with clear sky day conditions, 1st July 2025. Reducing it from 1366 W/m^2 to 1361 W/m^2 has a small impact on surface SW global radiation (reduction at noon by 4 W/m^2 compared to the reference) and minimal impact on 2m air temperature, up to 0.1°C colder compared to the reference. In this experiment, 2D Tegen climatological aerosols were used.

2.1. Solar constant in IFS radiation scheme

The alternative option is to use the IFS radiation scheme and read predefined solar constant and greenhouse gas (GHG) concentrations from the NetCDF file.

The user must add several variables to the namelist:

```
&NAERAD
  NHINCSOL=4,      ! we use solar constant from NetCDF
  LHGHG=.TRUE.,    ! we use solar constant from NetCDF
  CSOLARIRRADIANCEFILE='./total_solar_irradiance_CMIP6_47r1.nc'
  CGHGTIMESERIESFILE='./greenhouse_gas_timeseries_CMIP3_A1B_46r1.nc'
/
&NAMPHY
  LMPHYS=.TRUE.,
  LRAYFM=.TRUE.,
/
```

The NetCDF files listed above can be obtained on Meteo-France high-performance computer (belenos) by using the following commands:

```

$ genv oper-arpege
$ gget rrtm.const.04.tgz
$ tar xvfz rrtm.const.04.tgz total_solar_irradiance_CMIP6_47r1.nc
$ tar xvfz greenhouse_gas_timeseries_CMIP3_A1B_46r1.nc

```

They must be present in the working directory.

3. Background aerosols tuning

In the next step, the impact of background aerosol concentration was analyzed. For simulation with CAMS aerosols, there is a possibility to determine tropospheric and stratospheric aerosol background values in the namelist. Those variables are included in the following block:

&NAMAERO

```

RBGST_MMR_OM=4.5E-10 ! Unit: kg/kg, equivalent of Tegen #5
!background stratospheric AOD@550=0.007
RBGTR_MMR_OM2=1.65E-09 ! Unit: kg/kg, equivalent of Tegen #1
! background tropospheric AOD@550=0.0534
/

```

The values above were derived by transforming Tegen background values, projecting them to the corresponding CAMS type (hydrophobic organic matter for tropospheric and stratospheric background) and tuning them to have the similar impact on SW radiation as for the Tegen climatology. More information can be found in Šljivić and Mašek (2024B).

To find optimal values of background aerosols, we analyzed clear sky case of 1st July 2025, using 3D n.r.t. CAMS aerosols. Thereby, we assume CAMS tropospheric aerosols reliable. Due to this, we set tropospheric aerosol background equal to 0 and tuned stratospheric aerosol background to reduce positive bias in surface SW global radiation.

As a reference, we used measurements from 18 stations in Czech Republic. The optimal value of the stratospheric background was 60 times bigger than the default value (**RBGST_MMR_OM2=2.7E-08**). The mean bias of predicted global solar radiation for four experiments listed below is presented in Figure 1.

N200 – ALARO model with 2D Tegen climatological aerosols (reference)

N202 – ALARO model with 2D CAMS climatological aerosols and aerosol backgrounds (tropospheric and stratospheric)

```

&NAMAERO
  RBGST_MMR_OM2 = 4.50 E-10,
  RBGTR_MMR_OM2 = 1.65 E-09,
/

```

P302 - ALARO model with 3D CAMS n.r.t. aerosols with both aerosol backgrounds (tropospheric and stratospheric)

&NAMAERO

RBGST_MMR_OM2 = 4.50 E-10,

RBGTR_MMR_OM2 = 1.65 E-09,

/

P310 - ALARO model with 3D CAMS n.r.t. aerosols with no tropospheric aerosol background and increased concentration of aerosols in stratosphere (60 times bigger than the default value):

&NAMAERO

RBGST_MMR_OM2 = 2.7E-08,

RBGTR_MMR_OM2 = 0.0,

/

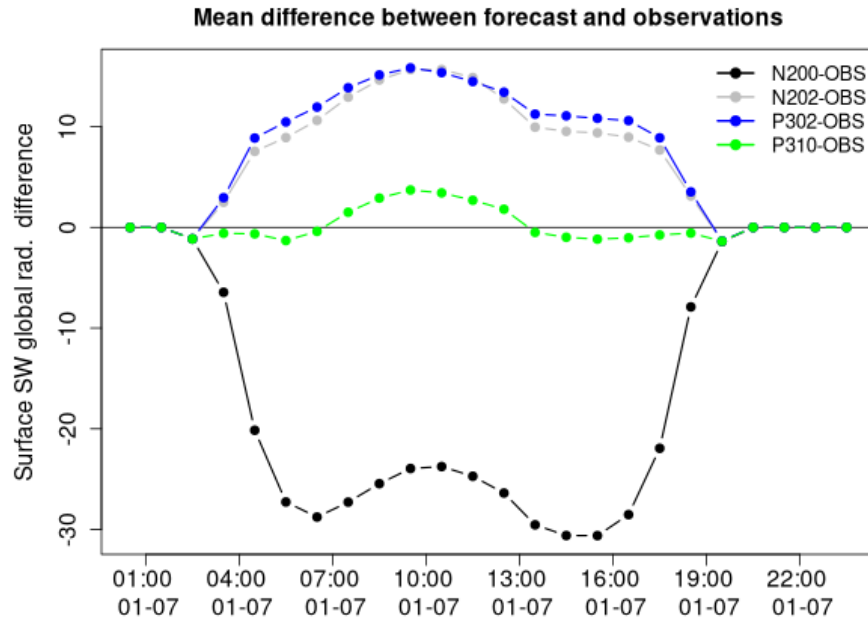


Figure 1. Mean bias of surface SW global radiation for 4 experiments described above for 1st July 2025.

To analyze the impact of increased stratospheric background aerosols, we prepared DDH budgets of air temperature. Figure 2 presents differences between two pairs of experiments (P302-N200 and P310-P302) for the 24 hour forecast initialized at 00 UTC on 1st July 2025. The impact of CAMS n.r.t. aerosols compared to Tegen climatological aerosols is presented in Figure 2a. In both experiments, default stratospheric and tropospheric backgrounds are included. In the upper troposphere, i.e., above 500 hPa, the difference between two experiments is negligible due to similar aerosols' concentrations in both configurations. However, large differences are visible in the troposphere between 700 hPa and 1000 hPa.

In the experiment with CAMS n.r.t. (named P302) there is stronger cooling in the troposphere due to reduced solar absorption (green). There is a compensating response of turbulence (light blue), dynamics (red) and reduced longwave cooling (black line). In total, the temperature tendency in the lower troposphere is slightly negative, reaching -0.1 K/day (gray).

Figure 2b shows the impact of significantly increased stratospheric aerosol background on 24-hour temperature budget. For this test, we used 3D CAMS n.r.t. aerosols. The experiment with default background aerosols (named P302) was compared with experiment named P310 (no tropospheric aerosol background and 60 times increased stratospheric aerosol background). In experiment P310, there is visible stronger warming of the stratospheric air (green) compensated by dynamics (red). In fact, higher concentration of scattering aerosols in the stratosphere means less SW radiation passing to the troposphere. In the lower troposphere, there is a weak negative tendency equal to -0.2 K/day (gray).

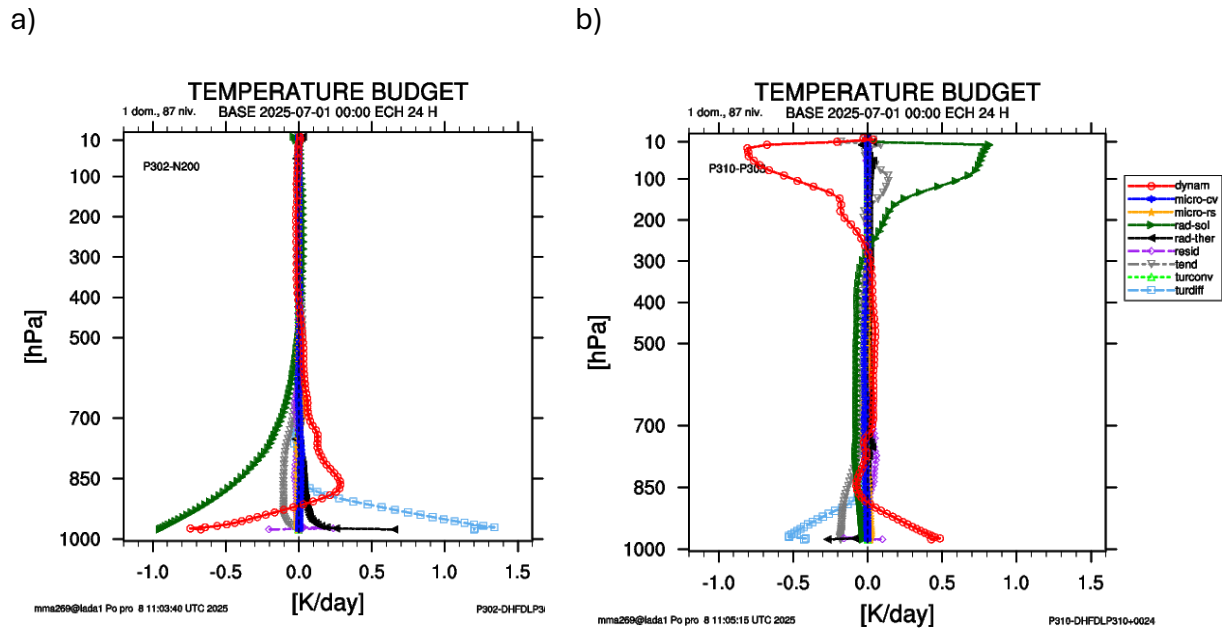


Figure 2. DDH budget differences between pair of experiments a) P302-P200 and b) P310-P302 for 24h of the forecast starting on 1st of July 2025 at 00 UTC.

A comparison of two experiments, one with the default stratospheric background aerosols and the other without them, shows that their impact on the surface SW global radiation flux is approximately 0.3 W/m². Reducing the positive bias in surface SW global radiation would require increasing the concentration of stratospheric background aerosols by a factor of 60. Such a substantial increase in aerosol concentration leads to warming of the stratosphere, which is partially compensated by atmospheric dynamics (Figure 2b). Another consequence of the enhanced concentration of scattering aerosols in the stratosphere is a reduction in SW radiation reaching the troposphere. In the lower troposphere, this results in a weak negative temperature tendency of approximately -0.2 K/day (gray line in Figure 2b).

4. Impact of volcanic aerosols

The climatological field of volcanic aerosol, obtained from CMIP6 (Coupled Model Intercomparison Project, phase 6) specification, was almost constant over the studied domain. Due to this, the field SURFAEROS.VOLCAN, with constant value AOD@550=0.014, was added to the initial file for sensitivity studies. The optical properties of stratospheric volcanic aerosols can be represented by CAMS sulfates. To include the volcanic aerosols in the model, two keys were added to the integration namelist:

```
&NAMAERO
  NUMGFL_AERO_SU=11, ! GFL position of sulfate
/
&NAMPHY
  LAEROVOL=.TRUE., ! Reading the field SURFAEROS.VOLCAN
/
```

More detailed information about type of aerosols can be found in Šljivić and Mašek (2024B).

To check the impact of volcanic aerosols on radiation budget, the experiment with 10 times bigger total optical depth than the reference was prepared (field with constant value equal to 0.14). Increase of volcanic aerosol didn't reduce generally positive bias for surface SW global radiation. Comparison of this experiment with observations for individual stations is presented in plots in APPENDIX A. The sensitivity study has shown that omission of volcanic aerosols in the ALARO model has only a minor impact on the positive bias in the radiation balance. It is likely that this element is a one of the components which result in the overestimation of surface SW global radiation.

5. Impact of ozone concentration

As part of the analysis of aerosol impacts on radiative exchange, an additional step was proposed to examine the vertical distribution of ozone, which directly affects radiative absorption processes in the model.

The vertical distribution of climatological ozone is defined in the routine:

arpifs/phys_dmn/suozon.F90

It's described by the equation presented below:

$$X_i = \frac{2A}{1 + \left(\frac{B}{p_i}\right)^c}$$

$$Q_{O_3} = \frac{X_i - X_{i-1}}{2 \cdot dp}$$

where:

dp – pressure layer sickness

p_i – pressure at level (i)

In the climatological file there are three fields containing parameters A, B and C
 SURFA.OF.OZONE - values between **0.04732 – 0.07065** with annual variation [Pa]
 SURFB.OF.OZONE - constant value equal to **3166** [Pa]
 SURFC.OF.OZONE - values between **2.80 - 3.072** with annual variation [unitless]

The spatial maps of A and C coefficients are presented in Figure 3, indicating the need to update these data in the ACCORD system. In the **subsection 5.1**, the preliminary procedure for generating new climatological files for ozone is described.

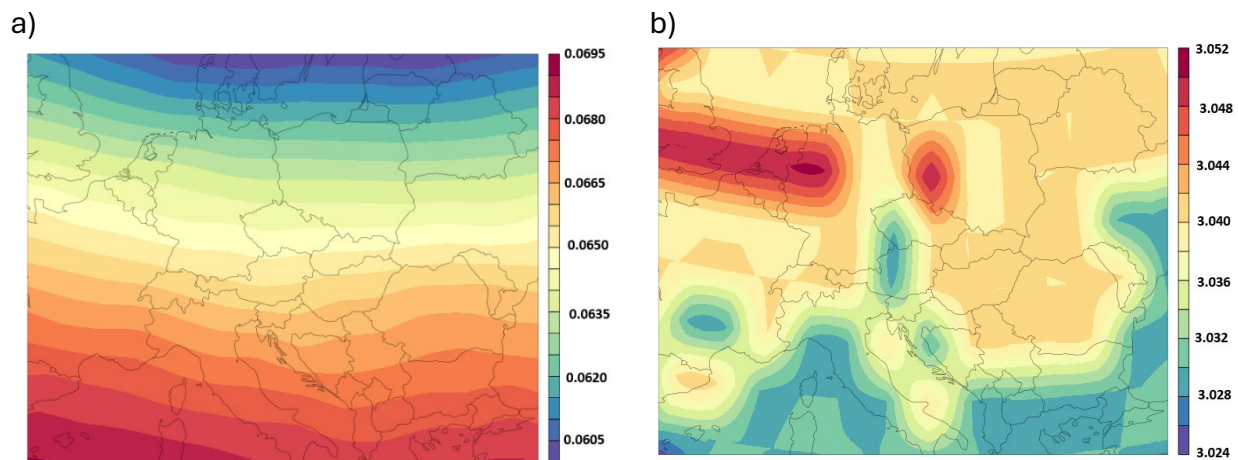


Figure 3. Climatological fields used for vertical distribution of ozone for July (a) parameter A and (b) parameter C.

5.1. Update of ozone climate fields

The ozone climatological fields can be updated using **CAMS global reanalysis (EAC4) monthly averaged fields** (access online: <https://ads.atmosphere.copernicus.eu/datasets/cams-global-reanalysis-eac4-monthly?tab=download>). Data are available for period 2003-present, for 25 pressure levels (from 1hPa to 1000hPa) with horizontal resolution $0.75^\circ \times 0.75^\circ$. In the data curation we used Climate Data Operators (CDO), R and python language. The unit of ozone MMR on pressure levels is kg/kg. The work was done in several steps:

Step 1. Calculate monthly mean from grib file for period 2005-2024:

```
cdo ymonmean CAMS_ozone_2005_2024.grib CAMS_ozone_2005_2024_monthly.grib
```

Step 2. Divide files into months:

```
cdo splitmon CAMS_ozone_2005_2024_monthly.grib CAMS_ozone_2005_2024_mon_
```

Step 3. Convert grib files to netcdf format:

```
for mm in 01 02 03 04 05 06 07 08 09 10 11 12
```

```
do
```

```
  cdo -f nc copy CAMS_ozone_2005_2024_mon_${mm}.grb CAMS_ozone_2005_2024_mon_${mm}.nc
done
```

Step 4. Run R script for fitting data (the code is included in Appendix A)

```
R CMD BATCH ozone_climatology_final.R
```

Step 5. Copy netcdf to grib format using cdo

```
for mm in 01 02 03 04 05 06 07 08 09 10 11 12
```

```
do
```

```
  cdo -f grb copy AC_month_${mm}.nc AC_month_${mm}.grb
done
```

Step 6. Convert grib file to e923 binary file by using procedure described in Šljivić and Mašek (2024A).

Figure 4 presents new fields of parameters A and C for July the whole globe obtained from **CAMS global reanalysis (EAC4)** for period 2005-2024.

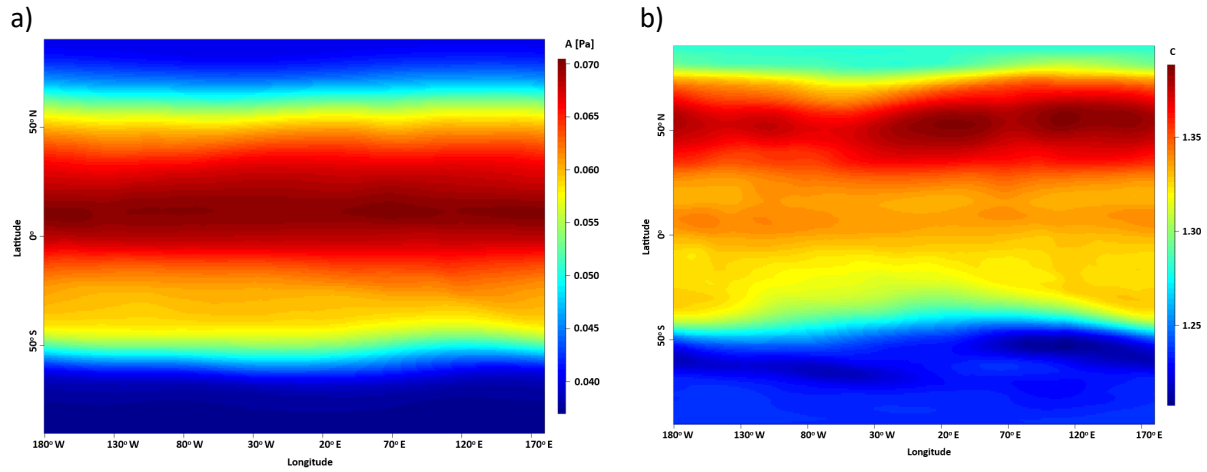


Figure 4. New climatological fields obtained from CAMS global reanalysis used for vertical distribution of ozone for July (a) parameter A and (b) parameter C.

Figure 5 shows the vertical profile for location 50°N 20°E obtained from global reanalysis, fitted curve using new fields (CAMS global reanalysis) and fitted curve using parameters from the climate file.

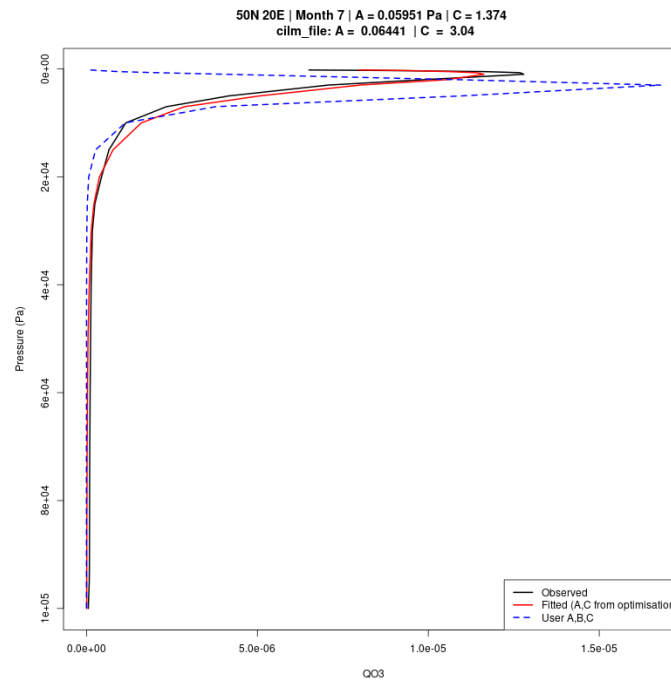


Figure 5. Vertical distribution of ozone obtained from black line - global reanalysis; red line - fitted global reanalyzes via parameters A, B, C; blue line - climatological fields from ACCORD system. The text over the figure gives fitted parameters A and C for this point, and their old values coming from e923 climate file.

The example files and scripts to convert data from GRIB to ASCII and then to BINARY FILES are at CHMI's supercomputer lada1:

/home/mma269/CAR_Dec_2025/ozone_climatology/

This subtask has not yet been completed. A procedure for generating new climatological files for ozone has been proposed. The next step involves creating new climatological files containing updated A and C fields for ozone, followed by an assessment of the atmospheric model sensitivity. The task will be continued in the near future.

5.2. Update of ozone climatological field “A”

The second option to update the ozone climatological fields is to use the 2D field of monthly total column ozone [kg/m^2], which has been available since 2003. The horizontal resolution of this field is $0.75^\circ \times 0.75^\circ$. Parameter A can be derived directly from it, converting total ozone mass to pressure units. Parameter B is kept, and for parameter C either old or new value can be used. The binary file is then created following the procedure described in Šljivić and Mašek (2024A).

To analyze the sensitivity to this parameter, the new climatological field “A” was calculated from 21 years monthly average fields. To obtain the field SURFA.OF.OZONE available in the climatological file, the average field was multiplied by gravity acceleration ($g = 9.80665 \text{ m/s}^2$).

The new binary file containing field A of ozone was used in the E923 procedure to prepare the corresponding field for the target domain. The new and original field A of ozone is presented in Figure 6.

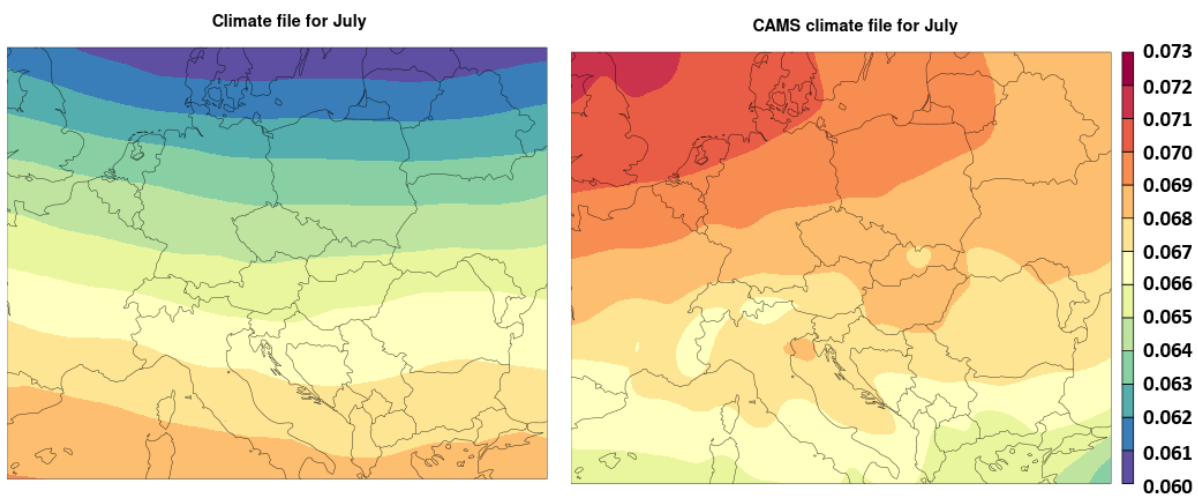


Figure 6. Field SURFA.OF.OZONE for July obtained from old climatological file (left) and new map obtained from monthly total column ozone from CAMS (right).

To summarize, the update of the ozone climatology has only a limited impact on surface SW global radiation. Compared to the reference simulation, the surface global flux is reduced by up to 0.8 W/m² around the noon for the summer case (1st of July 2025). The influence of the revised ozone climatology during the remaining months may differ, not only because of variations in total ozone content, but also due to changes in solar elevation angle. The current climatological fields therefore require updating to better represent present-day ozone conditions. Further investigation of this effect is required.

6. Sensitivity test of GHG concentrations

To analyze the impact of GHG concentrations on radiation budget, the narrowband 1D radiation model was used. Studies have shown that update of GHG concentrations have a small impact on radiation exchange; the difference compared to the reference is in range 0.1-0.3 W/m². Below is included table with global GHG concentrations in 2010 and 2024.

Table 1. The global greenhouse gas concentrations in the years 2010 and 2024. Reference: <https://wmo.int/news/media-centre/carbon-dioxide-levels-increase-record-amount-new-highs-2024>

gas/year	2010	2024
CO ₂	389.0 ppm	424.0 ppm
CH ₄	1.808 ppm	1.942 ppm
N ₂ O	0.323 ppm	0.338 ppm

It's worth to mention that ACRANEB2 transmissions of the composite of well mixed GHGs (CO₂, CH₄, and N₂O) assume their 2010 concentrations. Their fitting coefficients are set in the routine:

arpifs/phys_dmn/suphy3.F90

Based on the obtained results (reduction of SW flux by 0.1-0.3 W/m²), we decided that updating of GHG concentrations is not necessary.

7. Tuning MMR in the troposphere

In Section 3 we found that overestimated surface SW global radiation cannot be compensated by stratospheric background aerosols, since their amount would have to be unrealistically high. A question arose how much we would have to increase **tropospheric** CAMS n.r.t. aerosols to remove the bias. For this reason we have added a scaling factor for tropospheric aerosols in the research version of the code. It can be set via model namelist:

```

&NAMAERO
  RBGTR_SCALE=1.0,
/

```

The scaling of CAMS n.r.t. MMRs is done over local array in routine **rad_aer_mmr.F90**. Due to this, the original CAMS MMRs are not modified during the simulation. The default value of the new parameter was set to 1 to keep model reproducibility. This modification was done only for testing; it won't be part of the common ACCORD system. Below is presented a list of modified routines:

```

arpifs/namelist/namaero.nam.h
arpifs/module/yomaero.F90
arpifs/setup/suaero.F90
arpifs/phys_radi/rad_aer_mmr.F90

```

Figure 7 presents mean difference of SW global radiation between forecast and measurements from the 18 stations located in Czech Republic for two clear sky cases. The location of the stations is presented in Figure 8. In **APPENDIX A**, there are presented differences between individual stations for two clear sky cases.

Selected experiments (the colors match to experiments in Figure 7):

N200 - ALARO model with 2D Tegen climatological aerosols (reference)

N202 - ALARO model with 2D CAMS climatological aerosols with aerosol backgrounds (default values for tropospheric and stratospheric)

P302 - ALARO model with 3D CAMS n.r.t. aerosols with both aerosol backgrounds (default values for tropospheric and stratospheric)

P305 - ALARO model with 3D CAMS n.r.t. without both background aerosols

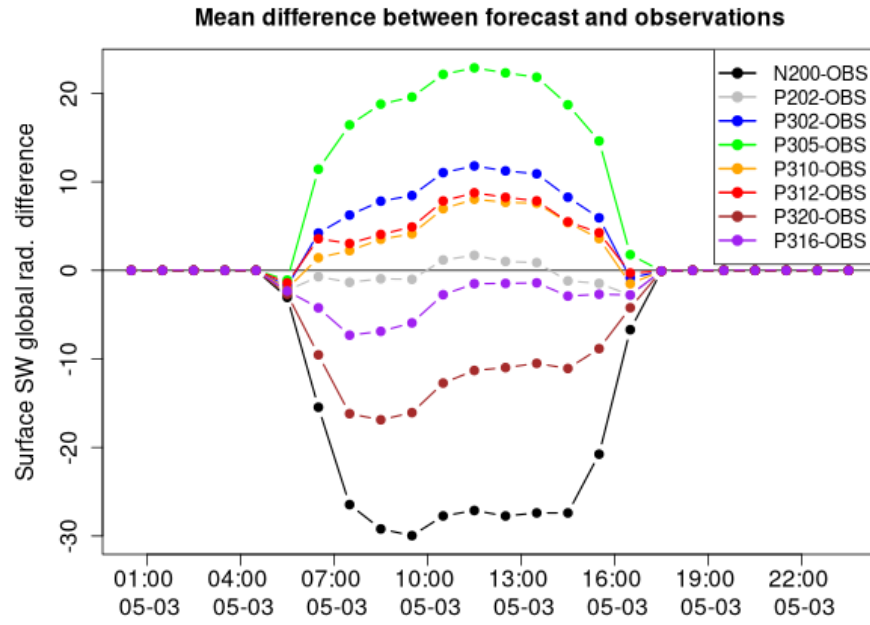
P310 - ALARO model with 3D CAMS n.r.t. with 60 x default stratospheric background and no tropospheric background

P312 - ALARO model with 3D CAMS n.r.t. without default backgrounds but with increased volcanic aerosols concentration (volcanic aerosol mass 10x bigger than default)

P316 - ALARO model with 3D CAMS n.r.t. aerosols multiplied by 3, without default backgrounds (tropospheric and stratospheric)

P320 - ALARO model with 3D CAMS n.r.t. aerosols multiplied by 4, without default backgrounds (tropospheric and stratospheric).

a)



b)

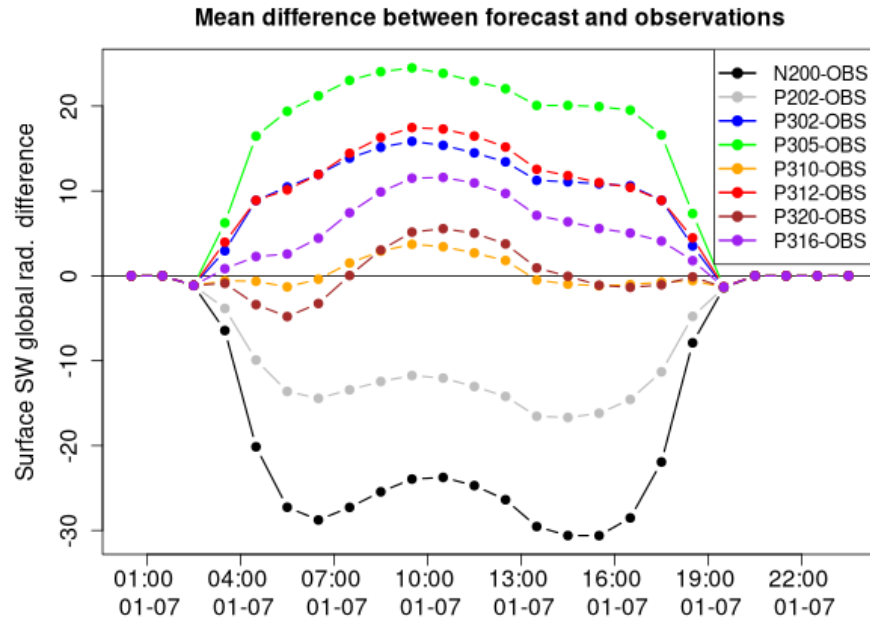


Figure 7. Mean bias of surface SW global radiation for selected experiments described in Figure above for two cases a) 5th March 2025 and b) 1st July 2025.

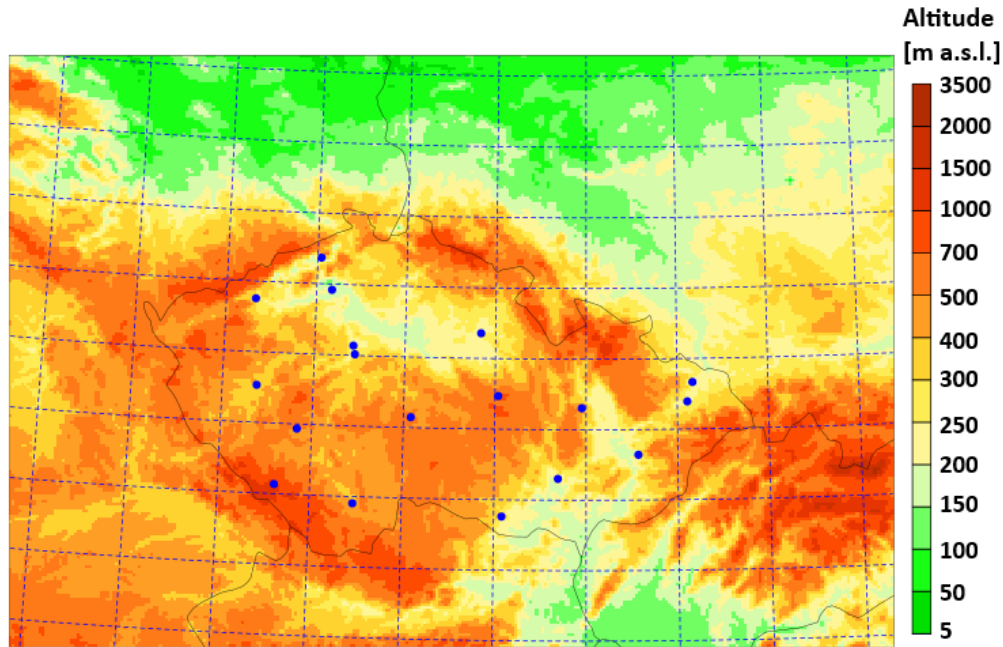


Figure 8. Location of CHMI stations (blue points) presented on topography map of ALARO with horizontal resolution 2.325km used for verification of surface global radiation.

The results show that compensating the excessive surface SW global radiation would require multiplying CAMS tropospheric aerosol concentrations by a factor of 3–4. Such scaling is regarded as non-physical, since it would correspond to unrealistically large aerosol burdens. This suggests that the diagnosed radiation bias cannot be attributed solely to underestimated aerosol concentrations in CAMS and that other components of the model radiation system likely contribute to the problem.

8. Sensitivity studies of surface albedo in ALARO model

Impact of spectral albedo can be shown using the ecRad scheme. Below is presented list of 5 pairs of experiments testing sensitivities to different aspects. Figure 9 presents differences for selected experiments between predicted and measured surface global radiation flux (a) and between pair of experiments for 18 points over Czech Republic. Two experiments named **N213** and **2N13** differ from remaining experiments by source of aerosols (Tegen climatology for **N213** and **2N13** and CAMS n.r.t. elsewhere). Due to this, the bias of surface global flux is negative for those two experiments, up to -30 W/m^2 (presented in Figure 9a). In the two experiments 2N13 and N213, ALARO model was running with ecRad scheme, while in remaining experiments ACRANE2 was used.

List of experiments:

N201 - ALARO with ISBA scheme, new solar constant, 2D CAMS climatological ozone and 3D n.r.t. CAMS aerosols, **RLAMB_SOLID=0.6**,

201N – ALARO with ISBA scheme, new solar constant, 2D CAMS climatological ozone and 3D n.r.t. CAMS aerosols, **RLAMB_SOLID=1.0** to better correspond with SURFEX,

2N01 - ALARO with ISBA scheme, new solar constant, **old climatological ozone file**, and 3D n.r.t. CAMS aerosols, RLAMB_SOLID=0.6,

20N1 - ALARO with ISBA scheme, **old solar constant**, old climatological ozone file, and 3D n.r.t. CAMS aerosols, RLAMB_SOLID=0.6

N202 - ALARO with SURFEX scheme, new solar constant, 2D CAMS climatological ozone and 3D n.r.t. CAMS aerosols

2N13 – ALARO with **ecRad scheme (spectrally flat albedo)**, new solar constant, CAMS climatological ozone, SURFEX scheme, **2D Tegen aerosols**

N213 – ALARO with **ecRad scheme (spectral albedo)**, ISBA, new solar constant, CAMS climatological ozone, SURFEX scheme, **2D Tegen aerosols**

The colors of pair of experiments corresponds to colors in Figure 9b.

N202-201N: SURFEX versus ISBA surface scheme

- Slight reduction of surface global flux up to 2 W/m^2 for SURFEX scheme compared to ISBA.

N201-201N: RLAMB_SOLID=0.6 versus 1

- Lambertian coefficient equal to 0.6 compared to 1 increase surface global flux in morning and evening hours **up to 1 W/m^2** and reduce flux **up to 2 W/m^2** during the day.

N201-2N01: CAMS versus e923 ozone climatology

- New climatological field of parameter “A” reduce incoming surface global flux **up to $0.5\text{-}1 \text{ W/m}^2$** .

2N01-20N1: new versus old solar constant

- Reduction of solar constant reduce incoming surface global flux **up to $3.5\text{-}4 \text{ W/m}^2$** .

N213-2N13: spectral versus spectrally flat albedo (ecRad scheme)

- Change of albedo has similar impact as reduction of solar constant, the incoming surface global flux is reduced **up to $3.5\text{-}4 \text{ W/m}^2$** .

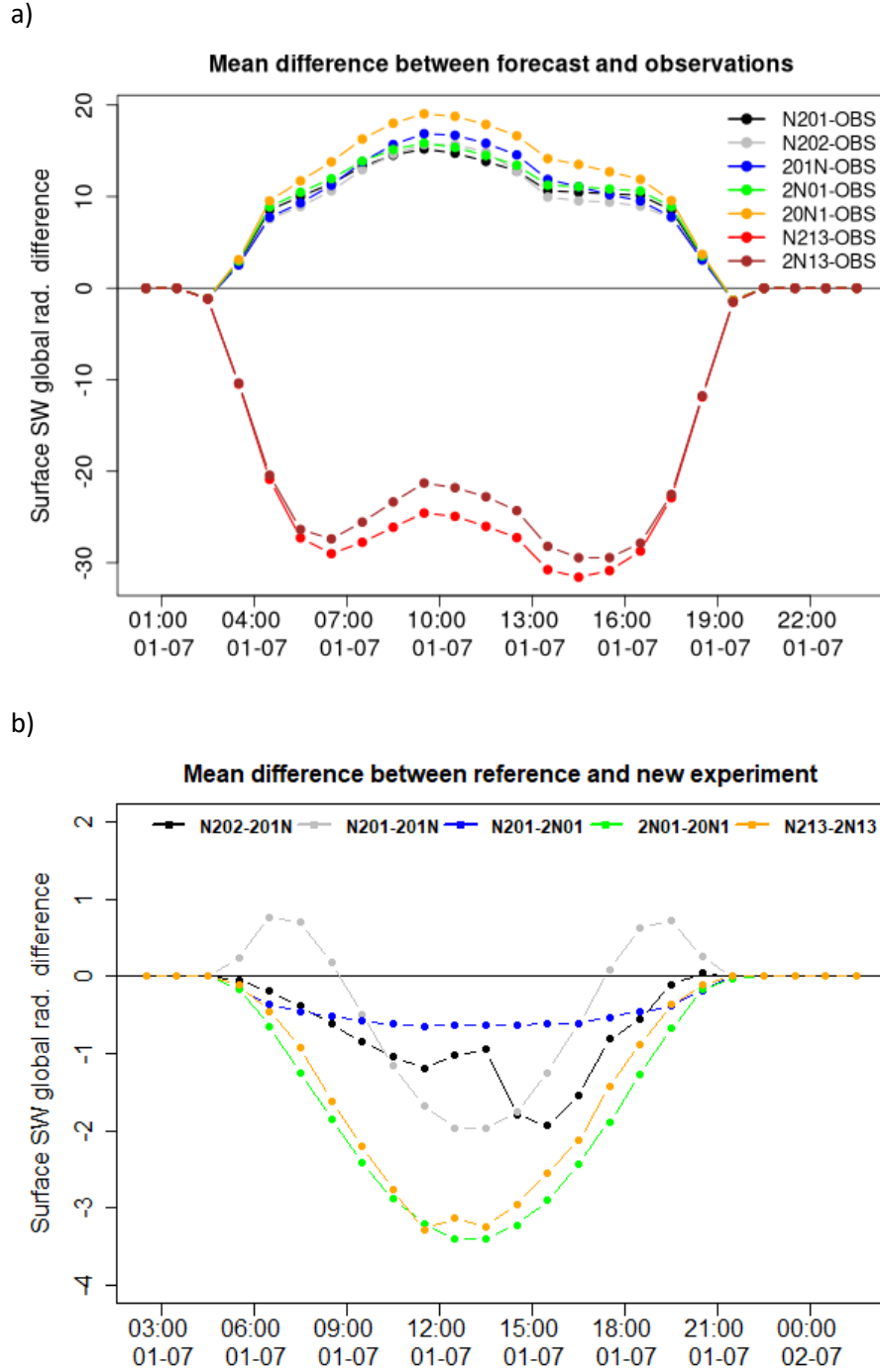


Figure 9. Sensitivity tests of surface albedo and ozone climatology verified against observation (a) and pairs of experiments (b).

The sensitivity experiments indicate that several factors contribute to the surface SW global radiation bias, although their individual impacts are relatively limited. The use of SURFEX instead of ISBA surface scheme

leads to a small reduction of surface global radiation, typically up to 2 W/m^2 . This reduction is related to the lower average surface albedo in SURFEX scheme, which weakens multiple ground–atmosphere reflections and consequently reduces the downward SW radiation reaching the surface. Modifications of the Lambertian coefficient which is used for albedo calculation (more details included in Sekuła and Mašek (2025)) and ozone climatology have even smaller effects, generally below $1\text{--}2 \text{ W/m}^2$. A more pronounced impact is obtained by reducing the solar constant, which decreases the incoming surface global radiation by approximately $3.5\text{--}4 \text{ W/m}^2$.

A comparable reduction is achieved when using spectral albedo in the ecRad radiation scheme instead of spectrally flat albedo (with Tegen climatology). This demonstrates that the spectral representation of surface albedo can significantly affect the simulated surface radiation budget and has an impact similar in magnitude to the change of the solar constant itself. Further insight may be obtained from additional ALARO–ecRad experiments employing both climatological and near-real-time CAMS aerosols. These investigations are planned for the near future.

9. Summary of the results

To find the optimal configuration, several options were tested:

- Modifying the **solar constant** from 1366 W/m^2 to $1360\text{--}1361 \text{ W/m}^2$, thus reducing the incoming surface solar flux at noon by 4 W/m^2 , decreasing 2m air temperature by $\sim 0.03 \text{ K}$.
- Testing the sensitivity to **tropospheric** and **stratospheric background** aerosols.
Removing the corresponding background aerosols has a minimal impact on radiation budget in the stratosphere ($+0.3 \text{ W/m}^2$) but a much stronger impact in the troposphere ($+8\text{--}10 \text{ W/m}^2$)
- Determine the optimal stratospheric background to reduce the positive bias.
Without tropospheric background aerosols, the optimal stratospheric value is **60** times the reference value.
- Testing the impact of default volcanic aerosol background.
The volcanic background has a negligible impact, reducing the bias by up to -1 W/m^2 .
- Estimate the impact of outdated GHG concentrations (CO_2 , N_2O , CH_4).
Updated GHG concentrations have a minimal impact, reducing surface SW global radiation by **$0.1\text{--}0.3 \text{ W/m}^2$** .
- Check the total climatological ozone amount and estimate its impact on the radiation budget (e923 ozone climatology).
Increasing the ozone concentration by 15% had a slight impact on radiative forcing, reducing it by up to **$0.8\text{--}1 \text{ W/m}^2$** .
- Check the impact of the surface scheme, SURFEX versus ISBA.
Slight reduction of surface global flux up to 2 W/m^2 for SURFEX scheme compared to ISBA.
- Check the impact of albedo calculation by using the **generalized Geleyn formula** (Mašek et al. (2016)).

Setting Lambertian coefficient to 0.6 (compared to 1) results in increasing surface SW global flux in the morning and evening hours **up to 1 W/m²** and **reducing** it up to **2 W/m²** during the day.

- Define the **optimal scaling** of MMR of **n.r.t. aerosols** in the troposphere.
Without default background aerosols (tropospheric and stratospheric) the MMR of n.r.t. aerosols should be **increased by factor 3-4**, depending on the analyzed period.
- Estimate the error of **ACRANEB2** compared to the **narrow band radiation scheme**.
The ACRANEB2 **underestimates** the surface SW global radiation by **3 W/m²** compared to the narrow band radiation scheme.
- Estimate the error due to the outdated ozone climatology.
The impact of CAMS versus e923 ozone climatology on radiation budget is small. The **reduction** of SW surface radiation **up to 0.8 W/m²** in July.

10. Conclusions

The scientific stay was carried out within task PH6 of the Rolling Work Plan 2025, focused on cloud–aerosol–radiation (CAR) interactions in the ACCORD system. The work continued previous studies conducted in Prague in November 2024 and aimed to determine the optimal configuration for implementing new climatological aerosol concentrations from the CAMS database in ALARO. Clear-sky cases from different seasons were analyzed, and forecasted 1-hour averaged surface SW global radiation was verified against observations from the Czech radiation network. Simulations were performed using the CHMI’s version of CY48T3 with the latest ALARO developments and CAMS aerosol modifications.

The verification of the default configuration, using 3D CAMS n.r.t. aerosols together with active tropospheric and stratospheric background aerosols, revealed a systematic overestimation of surface SW global radiation by approximately 20–30 W/m². Several sensitivity studies were therefore performed to identify the main contributors to this positive radiation bias.

One important modification was the reduction of the solar constant from 1366 W/m² to 1361 W/m². This decreased surface SW radiation by about 4 W/m² at noon and slightly reduced 2m air temperature by up to 0.1°C. In contrast, the default stratospheric aerosol background had only a negligible effect on the radiation budget (~0.3 W/m²). Compensating the bias by using stratospheric aerosols only would require increasing their concentration by a factor of 60, which was considered unrealistic and resulted in additional stratospheric warming and slight cooling in the lower troposphere.

The impact of volcanic aerosols was found to be minor, suggesting that they contribute only marginally to the radiation bias. Similarly, updating greenhouse gas concentrations produced only a very small reduction in SW global radiation (0.1–0.3 W/m²), and therefore was considered unnecessary.

Additional work focused on updating ozone climatology using CAMS reanalysis data. Preliminary results showed that the revised ozone fields reduced surface SW radiation by up to 0.8 W/m² in the summer. Although the direct impact was limited, the current ozone climatology was identified as outdated and requires modernization. Further work on generating and testing new climatological ozone fields will continue.

Sensitivity tests also demonstrated that correcting the radiation bias solely through aerosol concentrations would require increasing CAMS tropospheric aerosol MMRs by a factor of 3–4, which is physically unrealistic. This indicates that the bias cannot be explained only by underestimated aerosol concentrations and that other components of the radiation or aerosol–cloud interaction system are likely involved.

Finally, experiments related to surface albedo and radiation schemes showed that several smaller factors contribute to the bias. The use of SURFEX instead of ISBA reduced surface radiation by up to 2 W/m², while changes in direct albedo formulation and ozone climatology had impacts below 1–2 W/m². The use of spectral albedo in the ecRad radiation scheme produced a reduction of 3.5–4 W/m², comparable to the effect of lowering the solar constant. Change due to overestimated ACRANE2 gaseous transmissions is even bigger. Unfortunately, the last two bias sources specific to ACRANE2 single-band approach cannot be addressed in a short term. There is a hope, to be confirmed by ecRad with CAMS n.r.t. aerosols, that the combined effects of all identified sources will remove the positive bias in surface SW global radiation almost fully, with residual bias to be addressed by tuning of stratospheric aerosol background.

11. References

Mašek, J., Geleyn, J.-F., Brožková, R., Giot, O., Achom, H.O. and Kuma, P. (2016), Single interval shortwave radiation scheme with parameterized optical saturation and spectral overlaps. Q.J.R. Meteorol. Soc., 142: 304-326.

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Sekuła, P. and Mašek, J. (2024). PH6: Interfacing CAMS aerosols with radiation schemes. RC-LACE research stay report.

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Sekuła, P. and Mašek, J. (2025). Testing ALARO model with SURFEX scheme. ACCORD flat-rate stay report.

Available at: https://www.rclace.eu/media/files/Physics/2025/PS_2025P_AL_SUR.pdf

Šljivić, A. and Mašek, J. (2024A). Producing new CAMS aerosol input for climate files. CHMI technical document.

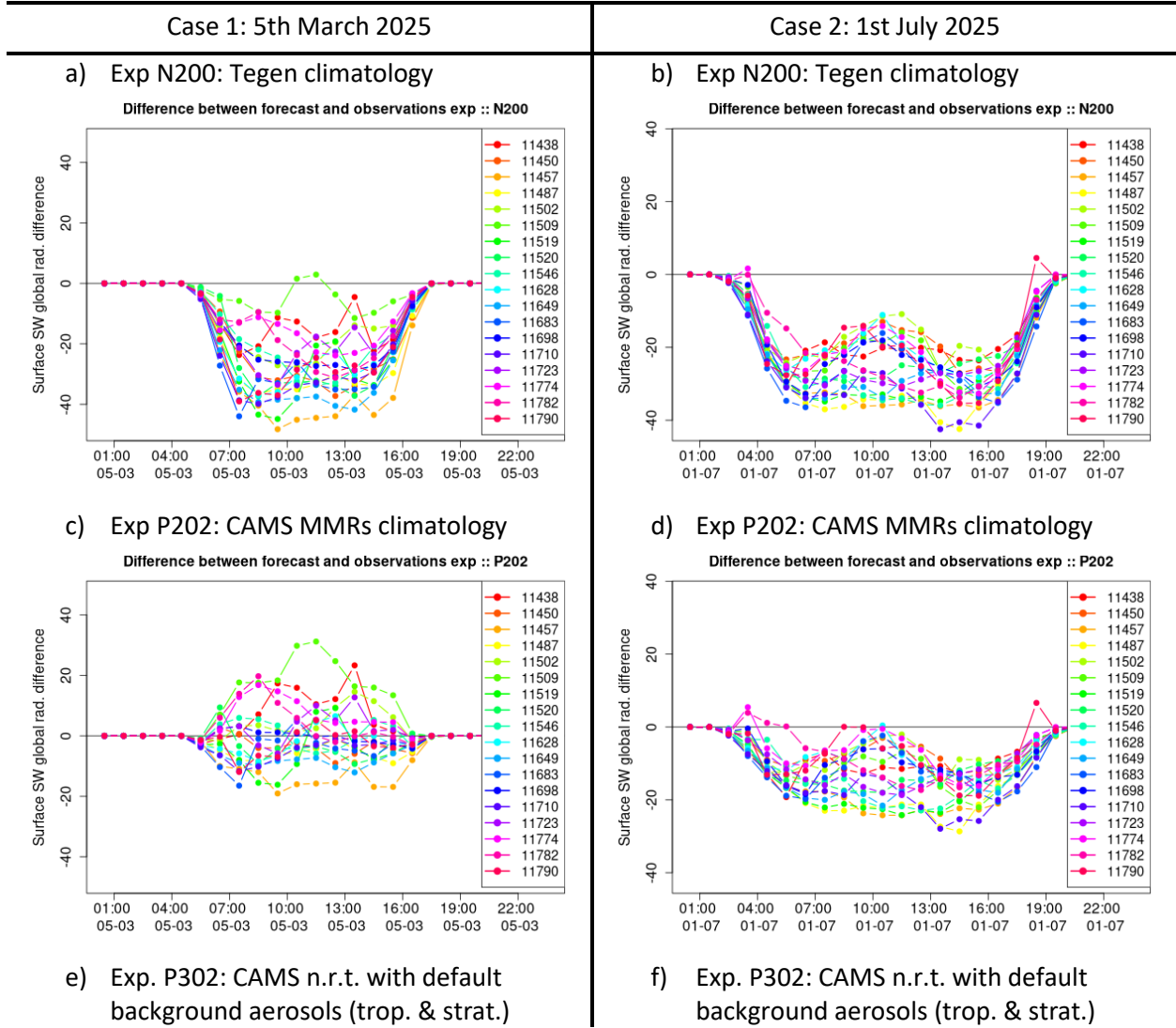
Available at: https://www.rclace.eu/media/files/Physics/2024/aerosols_for_climatology-9.pdf

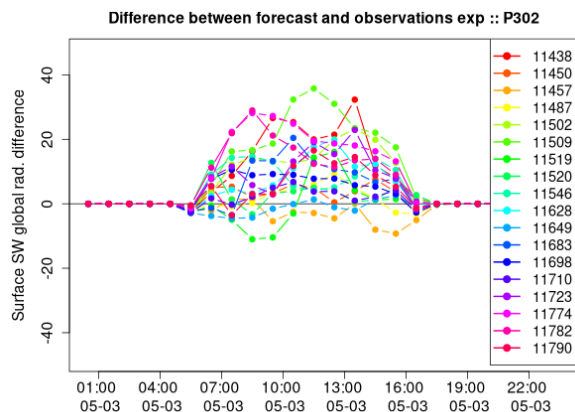
Šljivić, A. and Mašek, J. (2024B). Vertical distribution of climatological aerosols. CHMI research note.

Available at: https://www.rclace.eu/media/files/Physics/2024/radaecmr_subroutine-6.pdf

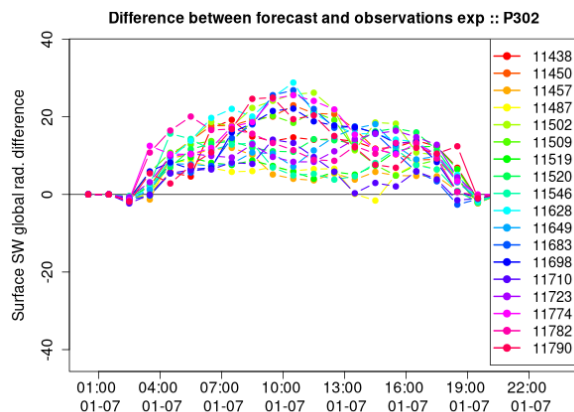
APPENDIX A

Figure 10. Difference between forecast and measurements from the 18 stations located in Czech Republic for two clear sky cases: left column 5th March 2025 and right column 1st July 2025.

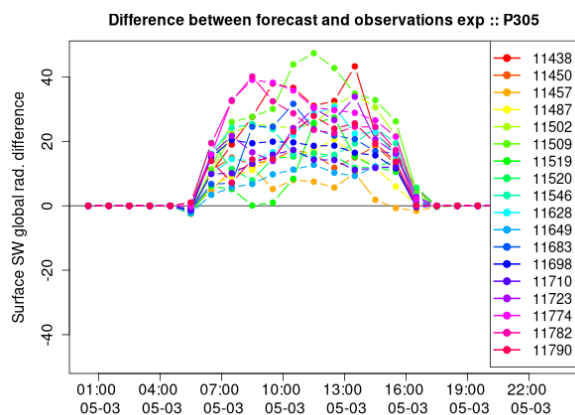




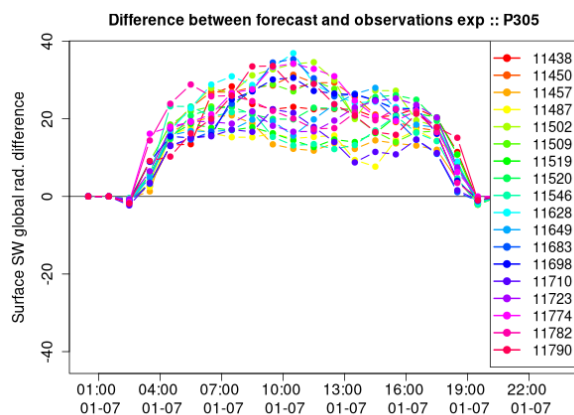
g) Exp. P305: CAMS n.r.t. no background aerosols



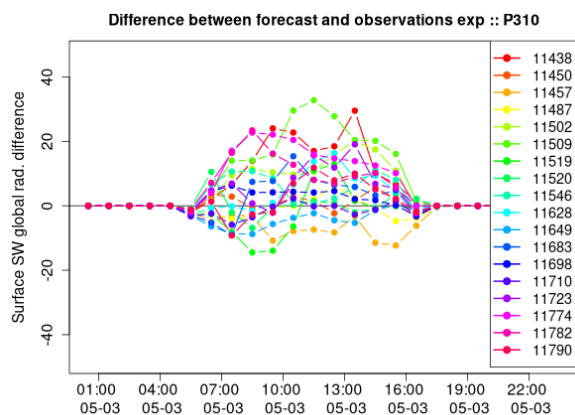
h) Exp. P305: CAMS n.r.t. no background aerosols



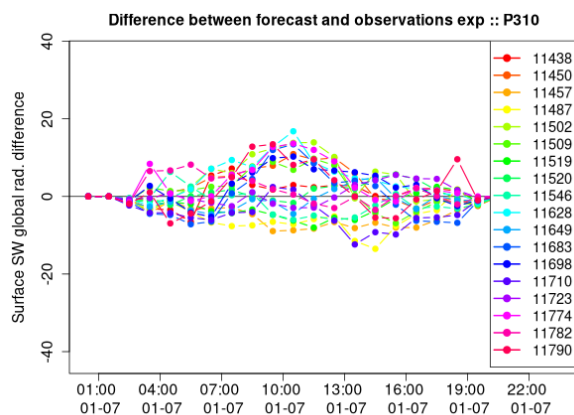
i) Exp. P310: CAMS n.r.t. with 60 x def. strato. background and no tropo. background



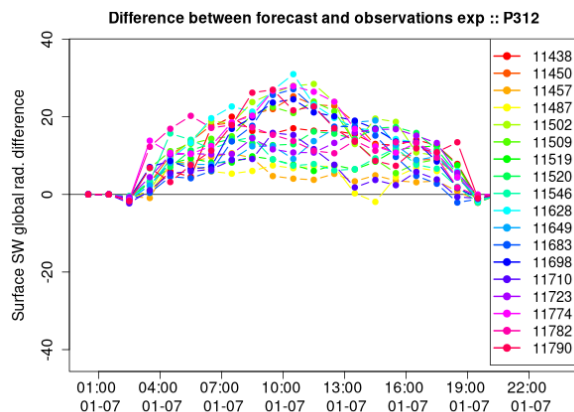
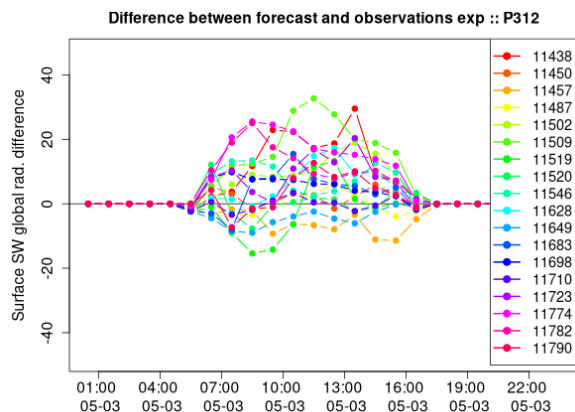
j) Exp. P310: CAMS n.r.t. with 60 x def. strato. background and no tropo. background



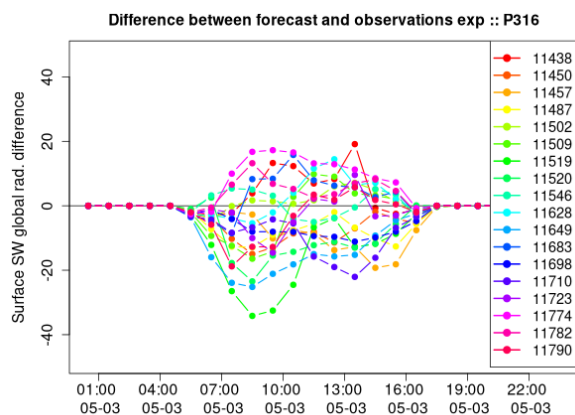
k) Exp. P312: CAMS n.r.t. without def. background but with volcanic aerosols (aerosol mass 10x bigger than default)



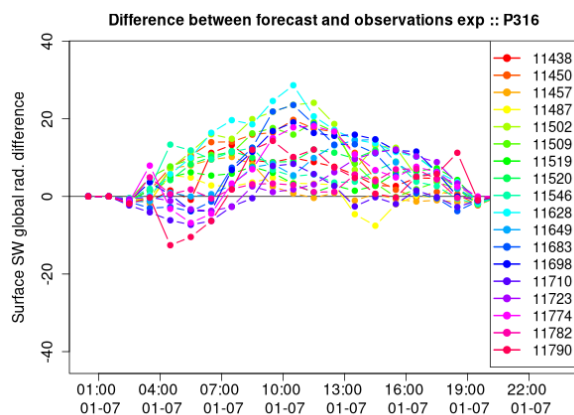
l) Exp. P312: CAMS n.r.t. without def. background but with volcanic aerosols (aerosol mass 10x bigger than default)



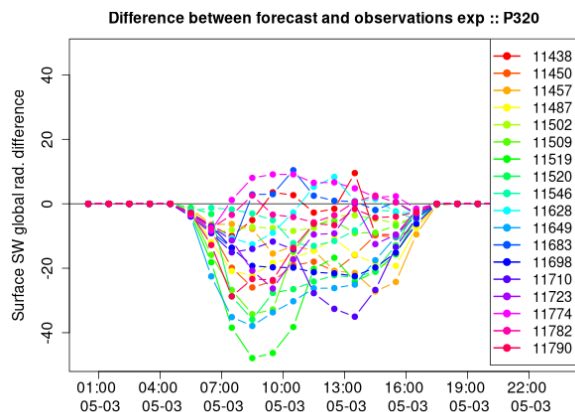
m) Exp. P316: CAMS n.r.t. multiplied by 3, without default backgrounds (tropo. and strato.)



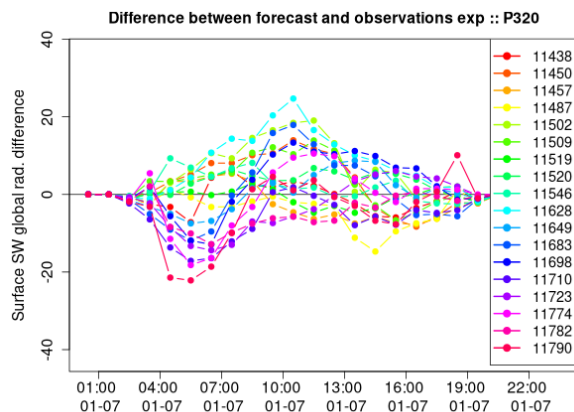
n) Exp. P316: CAMS n.r.t. multiplied by 3, without default backgrounds (tropo. and strato.)



o) Exp. P320: CAMS n.r.t. multiplied by 4, without default backgrounds (tropo. and strato.)



p) Exp. P320: CAMS n.r.t. multiplied by 4, without default backgrounds (tropo. and strato.)



R script used for vertical interpolation:

```
# script for preparing new ozone fields for ACCORD NWP models
# Piotr Sekula
# 2026-02-13

#### Short description:
# The vertical distribution of climatological ozone is defined in the routine:
#   arpifs/phys_dmn/suozone.F90
#
# It's described by the equation presented below:
#
# 
$$X_i = 2A / (1 + (B/p_i)^C)$$

# 
$$QO3 = (X_i - X_{i-1}) / (2 * dp)$$

# where:
#   dp   pressure layer thickness
#   p     pressure at level i
#
# In the climatological file are three fields which describes parameter A, B and C
# SURFA.OF.OZONE - values between 0.04732 - 0.07065 varies during the year [Pa]
# SURFB.OF.OZONE - constant value equal to 3166 [Pa]
# SURFC.OF.OZONE - values between 2.80 - 3.072 varies during the year [unitless]

#### 2026-02-12
#### Data downloaded from https://ads.atmosphere.copernicus.eu/datasets/cams-global-reanalysis-eac4-monthly?tab=download
#### Monthly data of ozone on pressure levels for global grid for period 2005-2024 (20 years)
#### Resolution: 0.75-0.75
#### Vertical levels: 1 2 3 5 7 10 20 30 50 70 100 150 200 250 300 400 500 600 700 800 850 900 925 950 1000

#### Steps to be done FIRST
#### 1. Calculate monthly mean for multiyear 2005-2024
# cdo ymonmean CAMS_ozone_2005_2024.grib CAMS_ozone_2005_2024_monthly.grib
#
#### 2. Divide files into months
# cdo splitmon CAMS_ozone_2005_2024_monthly.grib CAMS_ozone_2005_2024_mon_
#
#### 3. Copy files into netcdf
# for mm in 01 02 03 04 05 06 07 08 09 10 11 12
# do
#   cdo -f nc copy CAMS_ozone_2005_2024_mon_${mm}.grb CAMS_ozone_2005_2024_mon_${mm}.nc
# done
#
#### 4. Run this R script for fitting data
####
####   WARNING: paths must be changed by the user
####
#### How to run:
#### R CMD BATCH ozone_climatology_final.R
#
#### 5. Copy netcdf to grib format using cdo
# for mm in 01 02 03 04 05 06 07 08 09 10 11 12
# do
#   cdo -f grb copy AC_month_${mm}.nc AC_month_${mm}.grb
# done
```

```
#####
# Fit parameters A & C for each grid point
#####
remove(list = ls())
library(ncdf4)
library(minpack.lm)
library(fields)

B <- 3166 # Pa

#####
# MODEL
#####
model_Q03 <- function(p, A, C) {
  Xi <- 2*A / (1 + (B/p)^C)
  dp <- diff(p)
  dX <- diff(Xi)
  return(dX / (2 * dp))
}

residual_fun <- function(par, p, Q_obs) {
  A <- par[1]
  C <- par[2]
  model_Q03(p, A, C) - Q_obs
}

#####
# Fitting function for each month separately
#####
fit_month_grid <- function(ncfile) {

  cat("Processing:", ncfile, "\n")

  nc <- nc_open(ncfile)

  lon <- ncvar_get(nc, "lon")
  lat <- ncvar_get(nc, "lat")
  p <- ncvar_get(nc, "plev")
  Q03 <- ncvar_get(nc, "var203")

  nc_close(nc)

  nlon <- length(lon)
  nlat <- length(lat)
  nlev <- length(p)

  A_field <- matrix(NA, nlon, nlat)
  C_field <- matrix(NA, nlon, nlat)

  for(i in 1:nlon){
    for(j in 1:nlat){

      Q_profile <- Q03[i,j,]

      if(all(is.na(Q_profile))) next

      Q_profile <- Q_profile[-1]

      if(any(is.na(Q_profile))) next
    }
  }
}
```

```

fit <- tryCatch({
  nls.lm(
    par = c(5000, 2),
    fn = residual_fun,
    p = p,
    Q_obs = Q_profile,
    control = nls.lm.control(maxiter = 100)
  )
}, error = function(e) NULL)

if(!is.null(fit)){
  A_field[i,j] <- fit$par[1]
  C_field[i,j] <- fit$par[2]
}

}
}

return(list(A=A_field, C=C_field,
           lon=lon, lat=lat))
}

#####
# loop over months
#####
m=1
for(m in 1:12){

  # file must be in working directory or define paths
  file <- sprintf("CAM5_ozone_2005_2024_mon_%02d.nc", m)

  res <- fit_month_grid(file)

  A_field <- res$A
  C_field <- res$C
  lon <- res$lon
  lat <- res$lat

  #####
  # Save to NETCDF
  #####

  dim_lon <- ncdim_def("lon", "degrees_east", lon)
  dim_lat <- ncdim_def("lat", "degrees_north", lat)

  var_A <- ncvar_def("A", "Pa",
                    list(dim_lon, dim_lat),
                    missval = NA,
                    longname = paste("Fitted A month", m))

  var_C <- ncvar_def("C", "-",
                    list(dim_lon, dim_lat),
                    missval = NA,
                    longname = paste("Fitted C month", m))

  outfile <- sprintf("AC_month_%02d.nc", m)

  nc_out <- nc_create(outfile, list(var_A, var_C))

```

```

ncvar_put(nc_out, var_A, A_field)
ncvar_put(nc_out, var_C, C_field)

nc_close(nc_out)

#####
# Plot fields A and C
#####

# --- check if latitude is increasing ---
if(lat[1] > lat[length(lat)]) {
  lat <- rev(lat)
  A_field <- A_field[, ncol(A_field):1]
  C_field <- C_field[, ncol(C_field):1]
}

# --- Parameter A ---
png(sprintf("A_month_%02d.png", m), 1000, 800)

image.plot(lon, lat, A_field,
           xlab = "Longitude",
           ylab = "Latitude",
           main = paste("A (Pa) - Month", m),
           col = tim.colors(64),
           legend.lab = "A (Pa)")

dev.off()

# --- Parameter C ---
png(sprintf("C_month_%02d.png", m), 1000, 800)

image.plot(lon, lat, C_field,
           xlab = "Longitude",
           ylab = "Latitude",
           main = paste("C - Month", m),
           col = tim.colors(64),
           legend.lab = "C")

dev.off()

cat("Month", m, "done\n")
}

#####
# END
#####

```