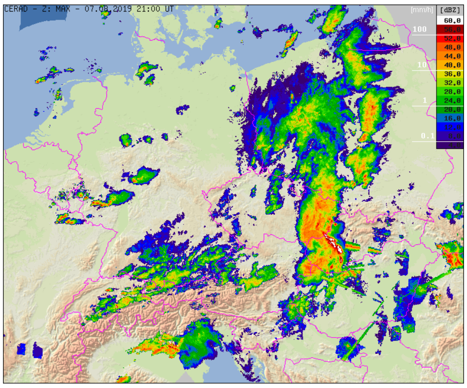
Regional Cooperation for
Limited Area Modeling in Central Europe

ALARO tests of radar observation operator



report from RC LACE stay in Ljubljana, 24/02/ - 13/03/2020

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Contents

1 Introduction

The observation operator provides NWP model equivalents of observations at their locations. The radar reflectivity observation operator implemented in the ALADIN system (Termonia *et al.*, 2018) is described in detail by Wattrelot *et al.* (2014). The Rayleigh method is used to compute the backscattering of precipitating hydrometeors. The hydrometeor size distribution is the same as used in the AROME microphysical scheme ICE3 (Pinty and Jabouille, 1998). ICE3 considers cloud water, rain, graupel, snow and primary ice. However in the current AROME implementation **only rain, snow and graupel are considered in the radar reflectivity observation operator**. Reflectivity is not assimilated directly but a 1D Bayesian retrieval of relative humidity profiles followed by 3D-VAR has been adopted.

The aim of this study is to investigate the use of the reflectivity observation operator within ALARO model configuration. The ALARO microphysics scheme was inspired by Lopez (2002). It considers six species - dry air, water vapor, suspended liquid and ice cloud water, rain, and snow. Introduction of prognostic graupels has been investigated recently by Bochenek (2017). A specific focus of this study concerns effects of adding graupel in the ALARO microphysics on simulated radar reflectivity.

Section 2 contains descriptions of performed tests and conclusions are summarized in Section 3.

2 ALARO tests of radar observation operator

2.1 NWP model configuration

Experiments were based on the ALADIN/SI model configuration operational at Slovenian Environment Agency (ARSO) which includes:

- **ALARO-v1B** package of physical parameterizations
- model cycle cy43T2
- 432 x 432 grid points, 4.4km resolution, 87 vertical levels
- 180s time-step
- ECMWF LBCs, space consistent coupling (no DFI)
- 3-hourly 3D-VAR data assimilation of SYNOP, TEMP, AMV, AMDAR, Mode-S MRAR/EHS, SEVIRI, AMSU&MHS, IASI, and ASCAT for upper-air analysis
- optimal interpolation of SYNOP for soil analysis

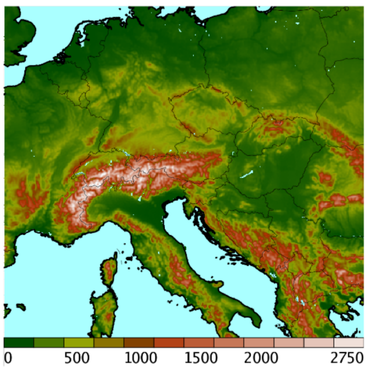


Figure 1: ALADIN/SI model domain

2.2 Prognostic graupels in ALARO

Prognostic graupels has been implemented in ALARO by Bogdan Bochenek (2017) following previous works of Michiel Van Ginderachter and Joris Van den Bergh. The modset is available in a research branch Arp_mma247_CY43t2plus_graupel based on CHMI release CY43T2plus.

The first task of this stay was to phase the prognostic graupel modset to the local model version. Technical details can be found in the appendix A. The modset was validated by comparing precipitation forecast with and without prognostic graupels which should provide qualitatively similar forecast (*Neva Pristov personal communication*). Precipitation forecast for the case of 25 February 2020 is shown in Figure 2. Precipitation structures are very similar, only a small decrease of precipitation amount was observed in the experiment with activated prognostic graupels (left-panel of Figure 2).

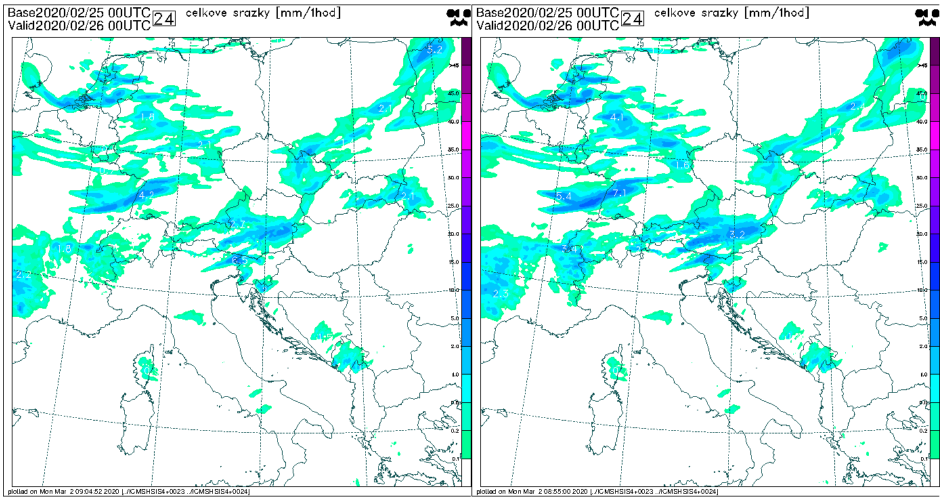


Figure 2: 1h precipitation forecast for 25 February 2020 00UTC for lead time of +24h for ALARO with prognostic graupels (left) and reference without graupels (right).

2.3 OPERA radar data

Volume radar data of reflectivity with quality flags are provided via OPERA Internet File Server (OIFS). A local archiving of the OPERA data at ARSO have been set up only in January 2020. Unfortunately the first months of 2020 were affected by missing quality index based on satellite filtering (*confirmed by Stefan Klaus personal communication*). The Homogenization Of Opera Files (HOOF) tool (version 1.6) was not able to process the data due to missing quality indices. Necessary upgrades of HOOF are still under development by Peter Smerkol (ARSO).

The test period was changed to the summer 2019 using OPERA data archived at CHMI. The summer period was chosen to include a more intense convection when effects of graupels could be more pronounced. In July 2019 the quality indices were missing completely for German radars, so finally the period of 30 July - 15 August 2019 was considered (although later it turned out that radar data from Poland and France were not used due to missing the beam-blockage quality index). Furthermore, occasional segmentation faults were encountered when processing German radars within BATOR. Due to lack of time, these cases were simply excluded from the analysis without serious impact on number of data available for the statistics. However, this issue will need further case by case investigation. The radar sites used in this study are illustrated on Figure 3.

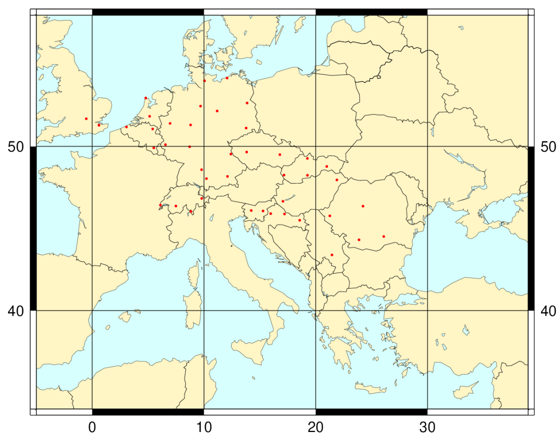


Figure 3: Radar sites used in this study.

2.4 Methodology and results

During the testing it turned out that graupel initialization needs a special attention in case prognostic graupel is not activated. In first trials the graupel namelist switches (YG_NL%LGP, YG_NL%NREQIN,...) were omitted in the screening. This lead to extremely high simulated reflectivities compared to the experiment with graupel values initialized by zero values (YG_NL%NREQIN=0), see Figure 4. The initialization of graupels should be better understood, eventually fixed.

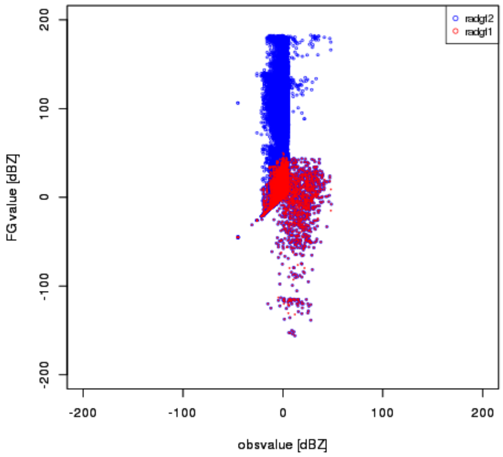


Figure 4: Observed against simulated reflectivity for ALARO without prognostic graupels with non-initialized graupel values (blue) and with graupels initialized to zero (red) for 30 July 2019 06UTC.

Two experiments with and without prognostic graupels were designed to evaluate effects of graupels within ALARO on simulated radar reflectivities. Both experiments included OPERA data, but only in a passive mode, not to influence the analysis while allowing computation of NWP model equivalents by the radar observation operator.

The first (reference) experiment **radgf1** run without prognostic graupels but graupel values were initialized by zero values (YG_NL%NREQIN=0) in the screening. The second experiment **radgt1** run with prognostic graupels and graupel values initialized by guess values (YG_NL%NREQIN=1). Both experiments were initialized from the operational suite/forecast valid for 30 July 2019 0UTC. The testing period of 16 days was considered. The experiments used in total 45 radars from Belgium, Croatia, the Czech Republic, Germany, Hungary, the Netherlands, Romania, Serbia, Slovakia, Slovenia, Switzerland, and the United Kingdom. Technical details can be found in the appendix B.

Experiment name	prognostic graupels	graupel initialization
radgf1	no (LGRAPRO=F)	zero values (YG_NL%NREQIN=0)
radgt1	yes (LGRAPRO=T)	guess values (YG_NL%NREQIN=1)

Table 1: List of experiments

2.4.1 Impact of adding prognostic graupels on simulated radar reflectivities in ALARO

Statistical analysis of results focused mainly on reflectivity, a brief overview of 1D Bayesian retrieval of relative humidity (RH) is included just for completeness. Table 2 and Table 3 summarize innovation (OMG) statistics. The overall BIAS and STD of reflectivity innovations slightly decreased when prognostic graupels were included in ALARO.

Experiment name	Number of REFL [N]		Mean OMG [DBZ]		STD OMG [DBZ]	
	Total	Active	Total	Active	Total	Active
radgf1	23398441 (100.0%)	(5.37%)	-0.41	-2.06	8.67	14.73
radgt1	23398441 (100.0%)	(5.51%)	-0.37	-1.77	7.76	13.15

Table 2: Number and OMG statistics for reflectivity for period of 30 July - 15 August 2019.

Experiment name	Number of RH [N]		Mean OMG [%]		STD OMG [%]	
	Total	Active	Total	Active	Total	Active
radgf1	3268947 (100.0%)	1255970 (38.42%)	-3.43	-4.28	13.95	14.10
radgt1	3327634 (101.8%)	1286509 (39.36%)	-3.33	-4.12	14.02	14.15

Table 3: Number and OMG statistics for retrieved RH for period of 30 July - 15 August 2019.

Innovations were separated by height, distance from the radar and reflectivity thresholds into hardly noticeable/mist (0-10 DBZ), light rain (10-30 DBZ), moderate rain (30-45 DBZ), and heavy rain (above 45 DBZ) categories. ALARO with graupels (radgt1) showed a smaller random error (STD) mainly for light, moderate and heavy rainy categories, see Figure 5 and Figure 6. Each rain category was further separated by the distance from the radar. A consistent results with respect to separation distances were found for all rainy categories (Figure 7), while for the hardly noticeable one the decrease of STD for ALARO with graupels is apparent mainly below 80km distances (Figure 8). Histograms of reflectivity innovations show small differences, noticeable is a decrease of a secondary mode around 150dBZ, see illustration for the moderate rain category Figure 9. Unexpectedly large number of reflectivity innovations (89%) are equal to zero which is unrealistic and need further investigations, see Figure 10.

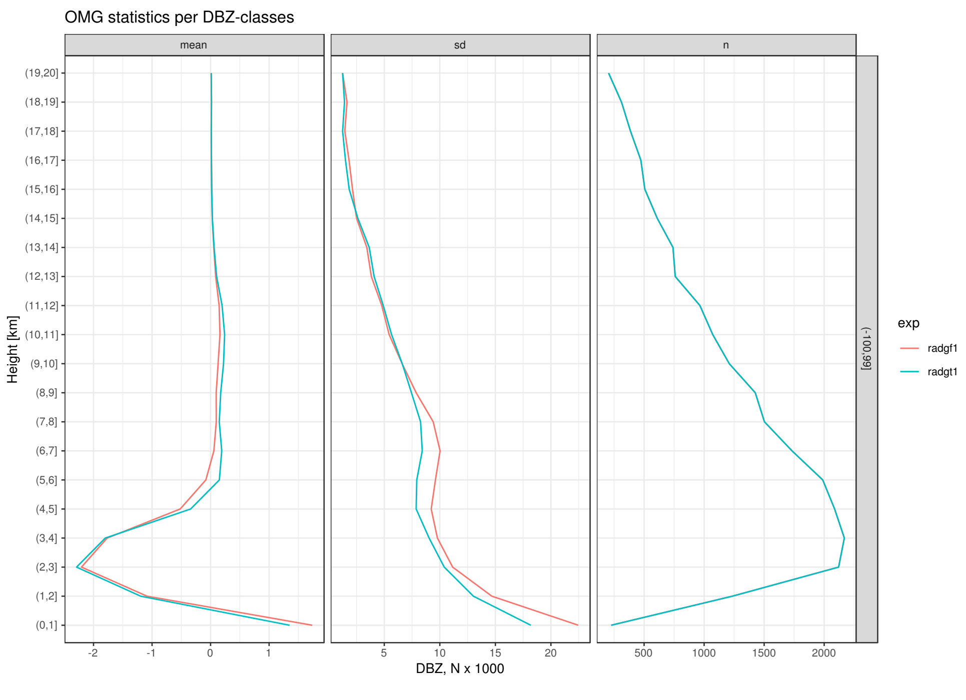


Figure 5: Vertical profile of reflectivity innovations. BIAS (left), STD (middle) and number of innovations for ALARO without graupels (red) and with graupels (green)

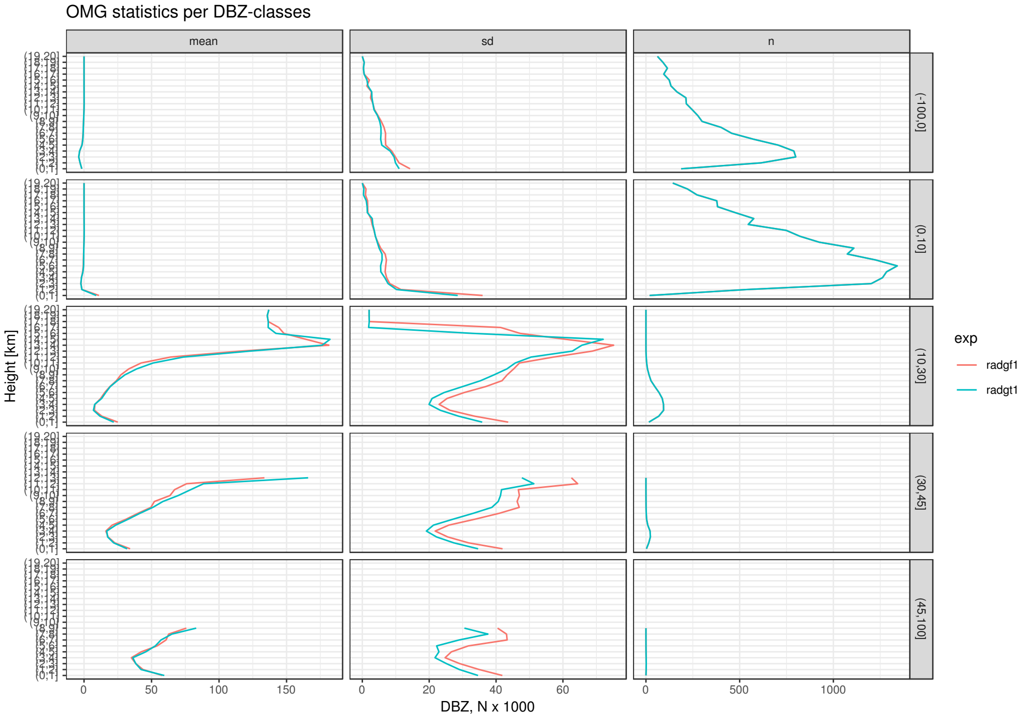


Figure 6: Vertical profile of reflectivity innovations separated by DBZ-classes. BIAS (left), STD (middle) and number of innovations for ALARO without graupels (red) and with graupels (green).

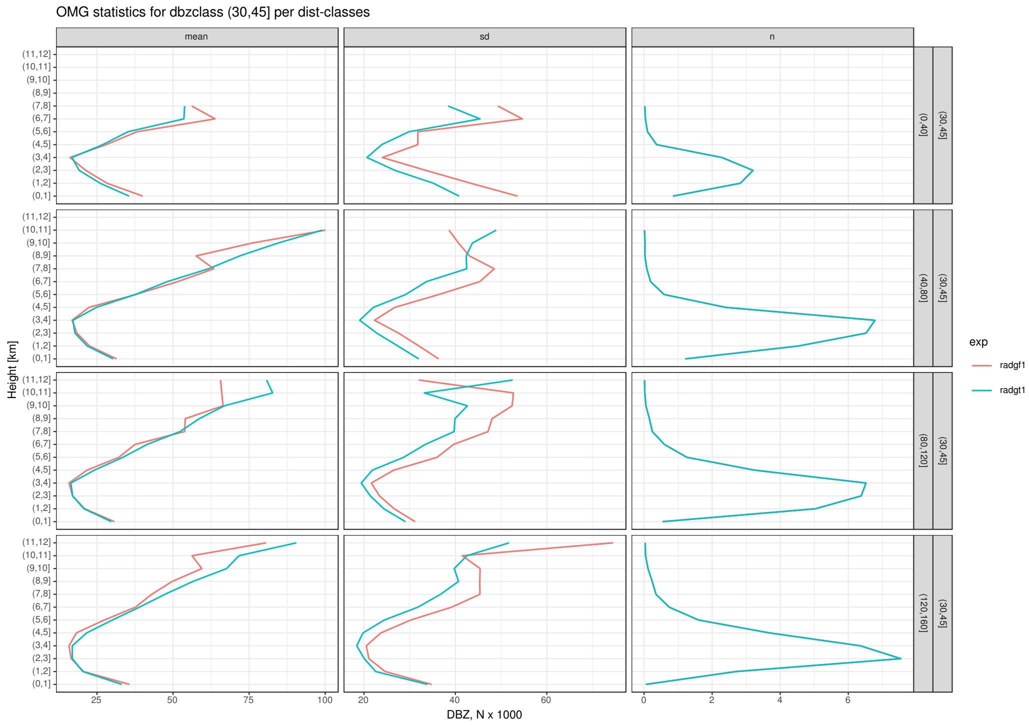


Figure 7: Vertical profile of reflectivity innovations separated by distance from radar (rows) to 0-40km, 40-80km, 80-120km and 120-160km for moderate rain category (30-45 DBZ). BIAS (left), STD (middle) and number of innovations for ALARO without graupels (red) and with graupels (green).

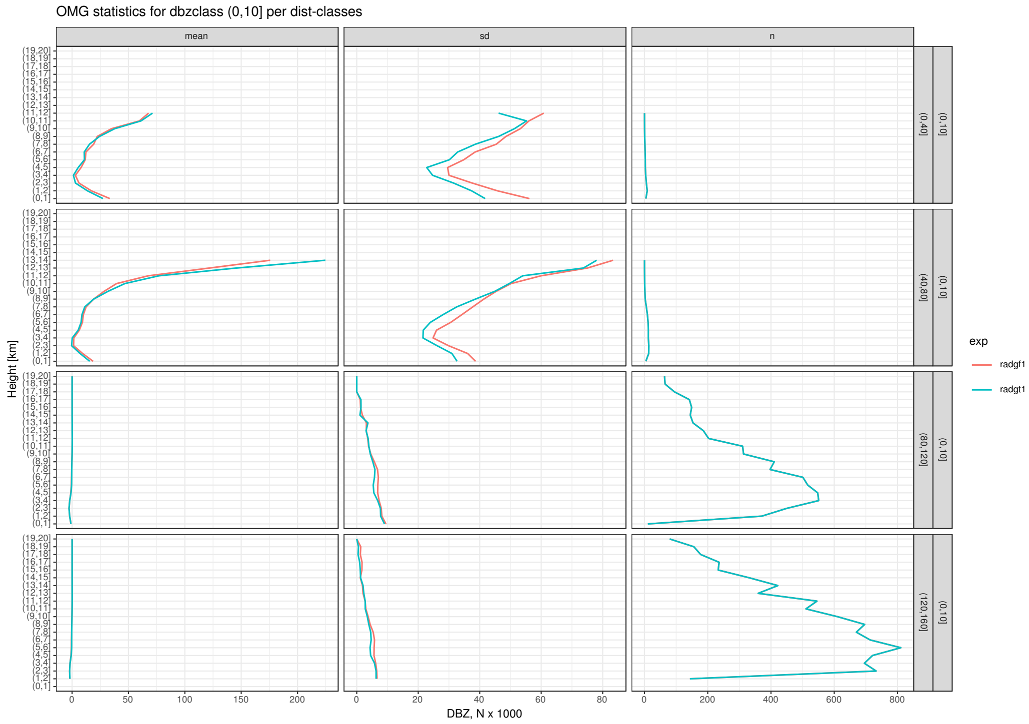


Figure 8: As Figure 7 for hardly noticeable rain category (0-10 DBZ).

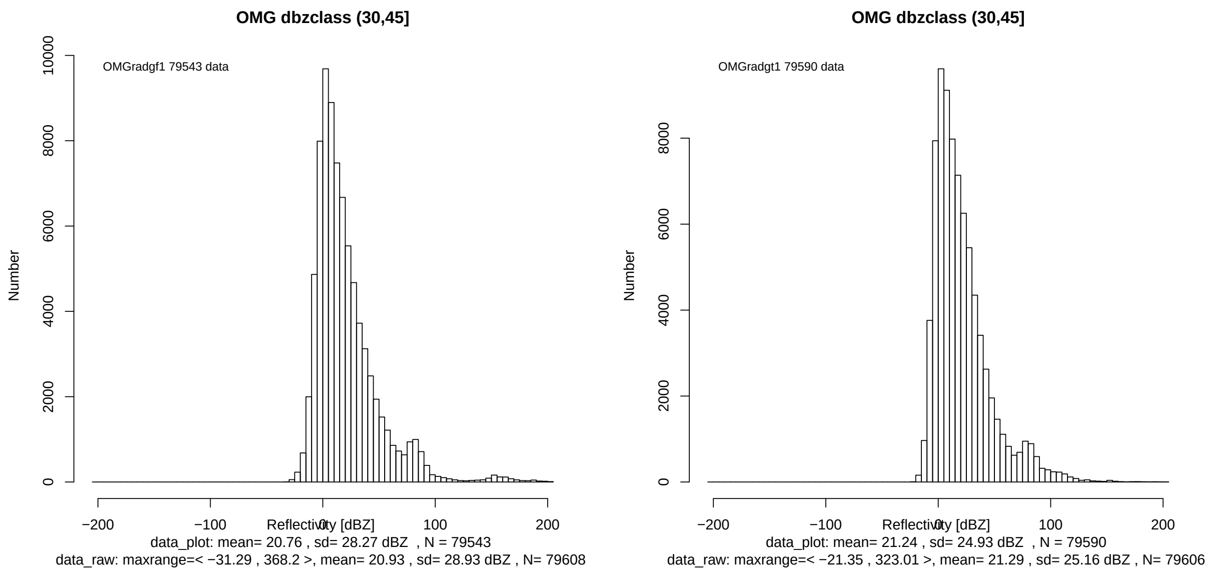


Figure 9: Histograms of reflectivity innovations for moderate rain (30-45 DBZ) category for ALARO without (left) and with graupels (right). Only the displayed value range was used to compute histograms and extreme values are indicated below the plots.

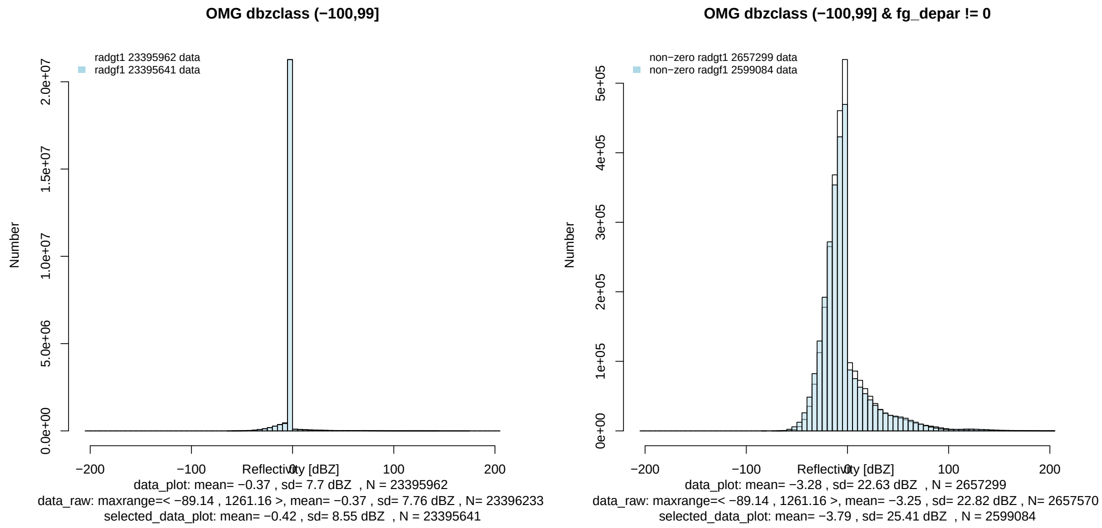


Figure 10: Histograms of reflectivity innovations for all DBZ categories (all values on left and non-zero values on right panel) for ALARO without (blue) and with graupels (white). Only the displayed value range was used to compute histograms and extreme values are indicated below the plots.

2.4.2 Impact of adding prognostic graupels on retrieved relative humidity

Pseudo-observations of relative humidity are retrieved from observed reflectivity vertical profiles through a Bayesian inversion. Overall innovation statistics of retrieved RH profiles for ALARO with and without graupels are very similar, see Table 3. For ALARO with prognostic graupels the number of profiles increased by 1.8%. Distribution of retrieved RH innovations follows the normal distribution quite well for both ALARO experiments, see Figure 11-12. The separation by reflectivity thresholds showed larger BIAS above 3km for ALARO with graupels for rainy categories, see Figure 13. There is a good correspondence of positive reflectivity BIAS (model has too little precipitating hydrometeors) resulting in the positive RH innovations (assimilation will add humidity) in rainy areas.

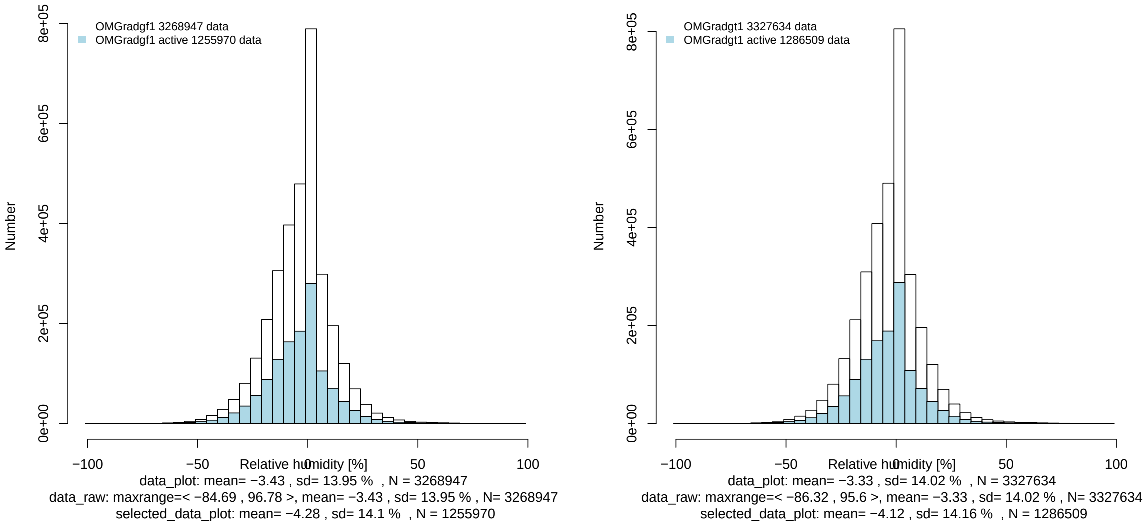


Figure 11: Histograms of retrieved RH innovations for ALARO without graupels (left) and with graupels (right). Active data are in blue. Only the displayed value range was used to compute histograms and extreme values are indicated below the plots.

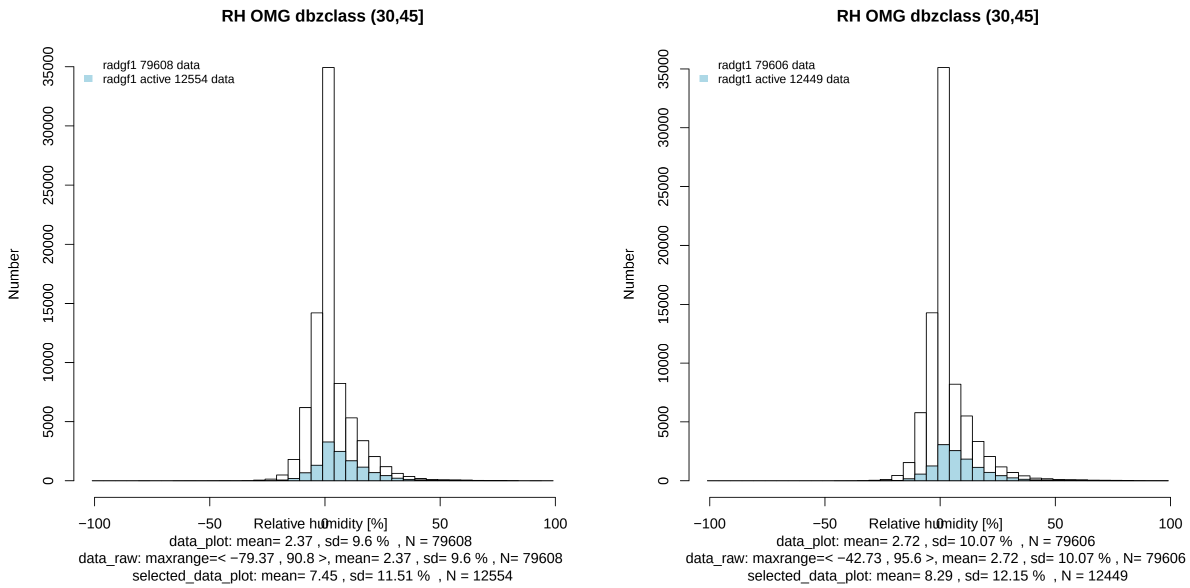


Figure 12: As Figure 11 but for moderate rain (30-45 DBZ) category.

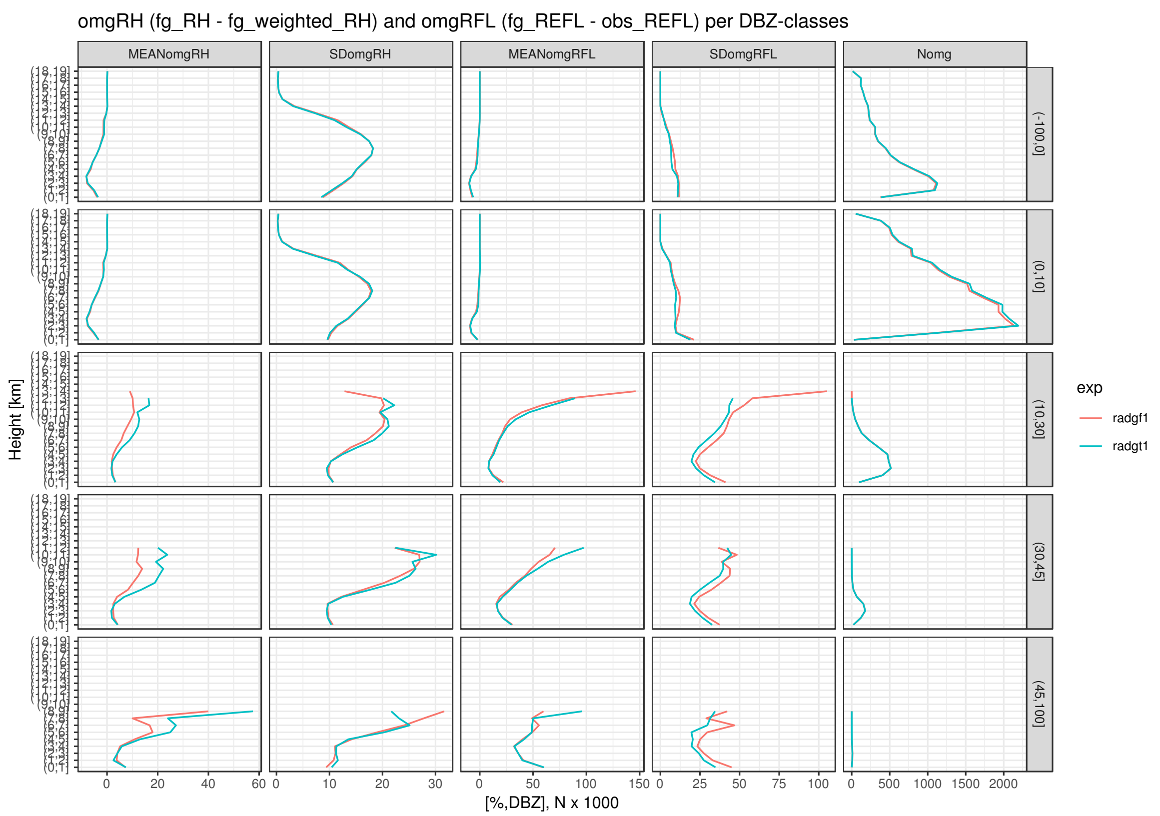
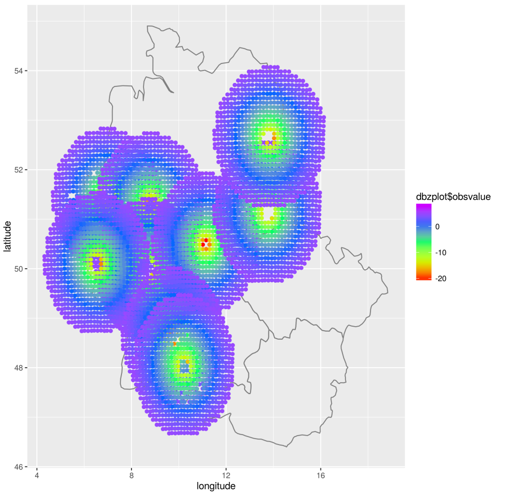


Figure 13: Vertical profile of RH innovations (BIAS on left, STD on right) and reflectivity innovations (BIAS on left, STD on right) separated by DBZ-classes and number of innovations for ALARO without graupels (red) and with graupels (green).

2.4.3 Intercomarison with AROME-FR

The reflectivity observation operator is used operationally by AROME France (AROME-FR) configuration 1-hour 3D-VAR assimilation cycle and horizontal resolution of 1.3km and 90 vertical levels. It uses the OPERA data (except over France) but without the HOOF pre-processing step. AROME-FR innovation statistics of reflectivity were considered as another validation reference.

Only a common subdomain of AROME-FR and ALARO/SI was considered in the intercomparison (over Germany). This reduced the original sample to 25%. Furthermore, the data at the same locations were selected to eliminate different resolutions and thinning in both configurations which reduced the sample by 60%), see Figure 14 for an illustration.



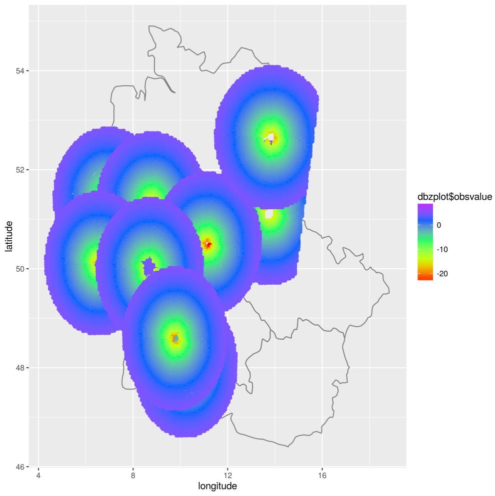


Figure 14: Observed radar reflectivity for ALARO/SI (left) and AROME-FR (right) over the common subdomain for 30 June 2019 06UTC.

Reflectivity innovations were compared as in the previous subsection. The aim was just a qualitative overview in order to identify eventual issues of ALARO precipitating hydrometeors (generated by the different microphysics scheme) which are used as input to the observation operator. The innovations of ALARO with graupels and AROME-FR have quite similar behavior, i.e. the larger average BIAS for the larger rain category (observed values). For the light rain category the BIAS mostly decreases with height for AROME-FR while for ALARO it decreases below 3km but mostly increases above, see Figure 15. Higher random errors (STD) of AROME-FR might be related to its higher resolution of 1.3km. AROME-FR innovations represent smaller scales and can be handicapped due to double-penalty. The separation by the distance from the radar showed consistent results (Figure 16). Distribution of innovations has two modes which are more pronounced for AROME-FR then for ALARO, see Figure 17.

Experiment name	Number of REFL [N]	Mean OMG [DBZ]	STD OMG [DBZ]
radgt1	2379848	0.62	7.79
radMF	2379848	2.30	16.80

Table 4: Number and OMG statistics for reflectivity over Germany resampled to ALARO resolution for period of 30 July - 15 August 2019

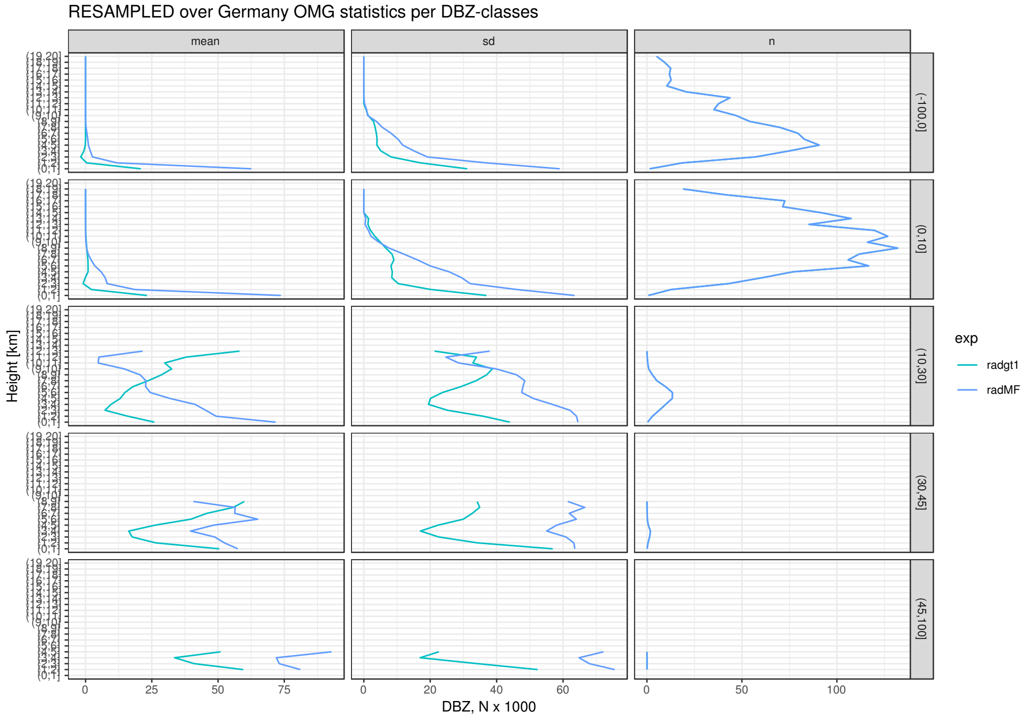


Figure 15: Vertical profile of reflectivity innovations separated by DBZ-classes. BIAS (left), STD (middle) and number of innovations for ALARO with graupels (green) and AROME-FR (blue).

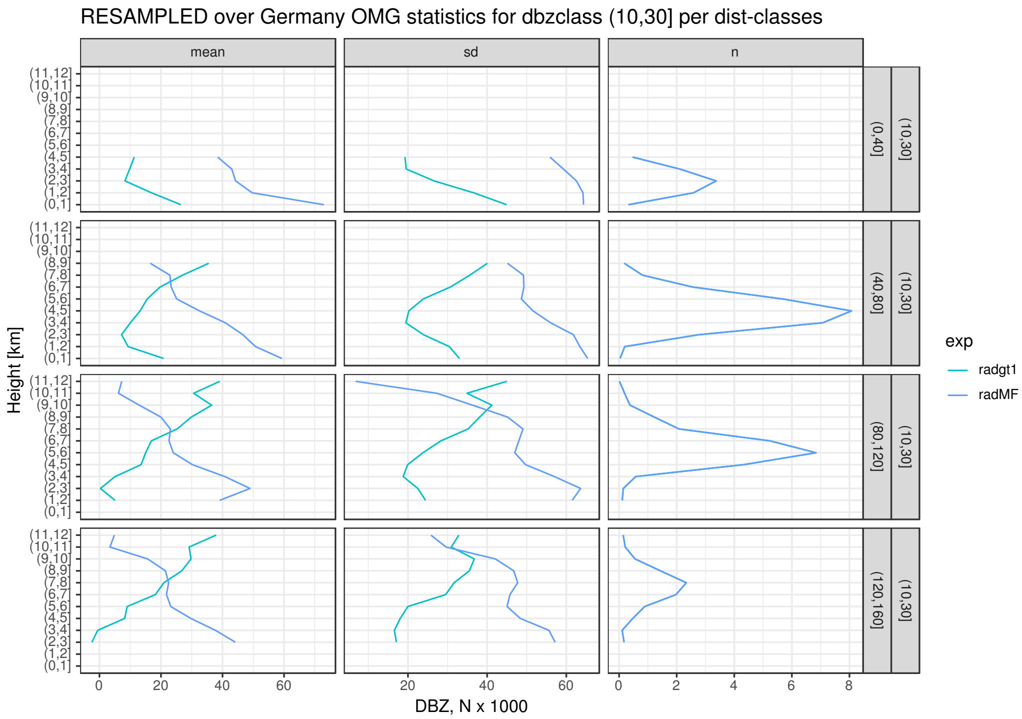


Figure 16: Vertical profile of reflectivity innovations separated by distance from radar (rows) to 0-40km, 40-80km, 80-120km and 120-160km for light rain category (10-30 DBZ). BIAS (left), STD (middle) and number of innovations for ALARO witht graupels (green) and AROME-FR (blue).

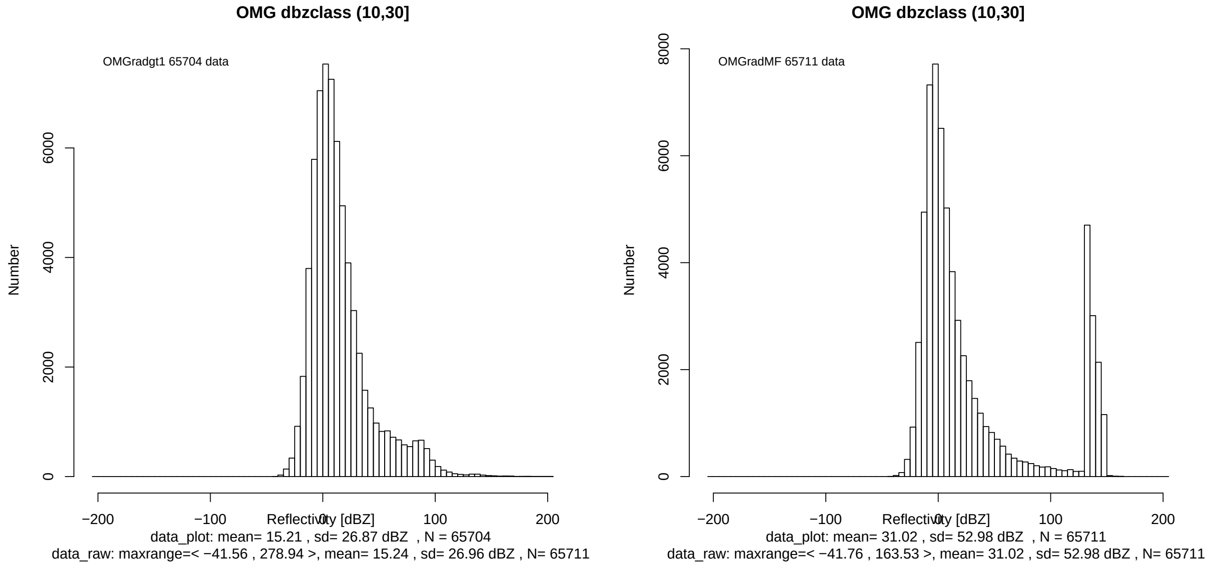


Figure 17: Histograms of reflectivity innovations for light rain (10-30 DBZ) category for ALARO (left) and AROME-FR (right). Only the displayed value range was used to compute histograms and extreme values are indicated below the plots.

3 Conclusion

OPERA provides volume radar data of reflectivity with by default four quality flags via OIFS. Some quality flags may be missing and HOOF has to be adapted to handle such cases. Furthermore, several unexplained BATOR crashes were encountered for German radars which need further understanding.

The aim of this study was to investigate use of the radar reflectivity observation operator within ALARO model configuration, in particular to test effects of adding graupel in the ALARO microphysics scheme on simulated radar reflectivity. Only a short tests have been performed so following conclusions are still preliminary.

- The ALARO version with prognostic graupel provides very similar precipitation structures with slightly smaller intensities compared to the version without prognostic graupels. This conclusion was based on a single case study. The prognostic graupels in ALARO are still considered as a very fresh development which needs detailed evaluations in NWP context.
- The graupel initialization to zero (YG_NL%NREQIN=0,YG_NL%LGP=.T.,YG_NL%LREQOUT=.F.) is necessary for the reflectivity observation operator even in case of ALARO without prognostic graupels to avoid extremely high simulated reflectivities. The initialization of graupels should be better understood, eventually fixed.
- Adding prognostic graupels in ALARO miscrophysics has positive effect on simulated reflectivities, namely by a small reduction of random error (STD) of reflectivity innovations.
- The comparison of ALARO and AROME-FR reflectivity innovations provided qualitatively similar statistics which give us more confidence for further testing of radar reflectivity data assimilation within ALARO configuration.

The stay enabled valuable discussions and a good progress in validations of reflectivity observation operator for ALARO but several items needs further efforts and understanding, e.g. HOOF, BATOR, graupel initialization, unexpectedly large number of zero reflectivity innovations and more extensive testing is required for further progress in radar reflectivity data assimilation within RC LACE.

Acknowledgment
The author wishes to thank Benedikt Strajnar for the support and cooperation and all NWP group for their warm welcome and hospitality. This stay was made possible by the financial support of the RC LACE (Regional Cooperation for Limited Area Modelling in Central Europe) project.

References

Bochenek B. 2017. Implementation and validation of prognostic graupel computation into ALADIN code cy43t2. 6 pp.

Lopez P. 2002. Implementation and validation of a new prognostic large-scale cloud and precipitation scheme for climate and data-assimilation purposes. *Quarterly Journal of the Royal Meteorological Society* **128**(579): 229–257, doi: 10.1256/00359000260498879, URL `https://rmets.onlinelibrary.wiley.com/doi/abs/10.1256/00359000260498879`.

Pinty JP, Jabouille P. 1998. A mixed-phase cloud parameterization for use in mesoscale non-hydrostatic model: simulations of a squall line and of orographic precipitations. In: *Conf. on Cloud Physics*. Amer. Meteor. Soc Everett, WA, pp. 217–220.

Termonia P, Fischer C, Bazile E, Bouyssel F, Brožková R, Bénard P, Bochenek B, Degrauwe D, Derková M, El Khatib R, Hamdi R, Mašek J, Pottier P, Pristov N, Seity Y, Smolíková P, Španiel O, Tudor M, Wang Y, Wittmann C, Joly A. 2018. The ALADIN System and its canonical model configurations AROME CY41T1 and ALARO CY40T1. *Geoscientific Model Development* **11**(1): 257–281, doi: 10.5194/gmd-11-257-2018, URL `https://www.geosci-model-dev.net/11/257/2018/`.

Wattrelot E, Caumont O, Mahfouf JF. 2014. Operational Implementation of the 1D+3D-Var Assimilation Method of Radar Reflectivity Data in the AROME Model. *Monthly Weather Review* **142**(5): 1852–1873, doi: 10.1175/MWR-D-13-00230.1, URL `https://doi.org/10.1175/MWR-D-13-00230.1`.

A Source code modifications

Used executables were based on the local pack **cy43t2_operpack_nov19** compiled using Intel compiler version 16.02. The local pack **cy43t2_operpack_nov19** contains cy43t2_bf10 + CHMI modset for visibility, precipitation types and ACARANEB2 + ARSO convection diagnostics.

Two user packs were prepared to test the prognostic graupel in ALARO. Both packs contain the prognostic graupel modset from Bogdan Bochenek. The second pack contains the additional bugfix for the minimization of radar reflectivities by Benedikt Strajnar. No modifications were done in other model configurations (BATOR, ...).

- **cy43t2_operpack_nov19#graupel** (prognostic graupel)

  - can be found on **ventus:/home/atrojakova/packs/cy43t2_operpack_nov19#graupel**.

  - based on cy43t2_operpack_nov19

  - added Bogdan Bochenek's groupel modset (CHMI branch Arp_mma247_CY43t2plus_graupel)

  - Modified sources:

```
arpifs/adiab/cptend_new.F90
arpifs/adiab/cptend_new.F90
arpifs/adiab/cpg.F90
arpifs/module/yomphy.F90
arpifs/module/yomphy0.F90
arpifs/setup/su0phy.F90
arpifs/phys_dmn/initaplpar.F90
arpifs/phys_dmn/mf_phys.F90
arpifs/phys_dmn/acacon.F90
arpifs/phys_dmn/accdev.F90
arpifs/phys_dmn/aplmini.F90
arpifs/phys_dmn/aplpar.F90
arpifs/phys_dmn/accsu.F90
arpifs/phys_dmn/accoll.F90
arpifs/phys_dmn/acupd.F90
arpifs/phys_dmn/acmodo.F90
arpifs/phys_dmn/acupm.F90
arpifs/phys_dmn/accvud.F9
arpifs/phys_dmn/acevmel.F90
arpifs/phys_dmn/aplmphys.F90
arpifs/phys_dmn/suphy0.F90
```

- **cy43t2_operpack_nov19#graupelmin** (prognostic graupel + minim bugfix)

  - can be found on **ventus:/home/atrojakova/packs/cy43t2_operpack_nov19#graupelmin**.

  - based on cy43t2_operpack_nov19#graupel

  - added Benedikt Strajnar's modification to avoid segmentation fault in the minimization using radar data

  - Modified sources:

```
arpifs/module/gfl_subs_mod.F90

  ! commented lines 771-773
  ! CALL FALSIFY_GFL_COMP(YR)
  ! CALL FALSIFY_GFL_COMP(YS)
  ! CALL FALSIFY_GFL_COMP(YG)
```

Technical validations: MASTERODB_cy43t2_operpack_nov19#graupel with switched-off graupel modifications (LGRAUPEL=F) gives identical spectral norms with respect to the reference executable (cy43t2_operpack_nov19) for +48H forecast. A tiny differences in QC flags (FG TOO BIG) were found when using MASTERODB_cy43t2_operpack_nov19#graupelmin therefore this executable will be used only in the minimization (passive assimilation of reflectivities)!

B Experiments

All experiments can be found on **ventus:/home/atrojakova/exp**. Here follows a summary of performed tests:

- eg01 - **'zero' experiment adapted from refexp="ose" & refuser="bstrajnar"**
  - technical test of ecflow suite & OPERA radar data assimilation
- radgf - **experiment without the prognostic graupels (LGRAPRO=F)**
  - MASTERODB_cy43t2_operpack_nov19graupelmin (for both e002 & e131)
  - abandoned due to missing graupel initialization & small effect the executable on QC flags
- radgf1 - **experiment without the prognostic graupels & graupels initialized by zero**
  - LGRAPRO=F & YG_NL%NREQIN=0,
  - MASTERODB_cy43t2_operpack_nov19graupel for e002
  - MASTERODB_cy43t2_operpack_nov19graupelmin for e131
  - radar experiment without the prognostic graupels in ALARO
- radgt1 - **experiment with the prognostic graupels**
  - LGRAPRO=T & YG_NL%NREQIN=0 for the first run, then YG_NL%NREQIN=1
  - MASTERODB_cy43t2_operpack_nov19graupel for e002
  - MASTERODB_cy43t2_operpack_nov19graupelmin for e131
  - radar experiment with the prognostic graupels in ALARO

C Radar data

This appendix contains details radar data used in this study.

- **OPERA OIFS radar data** from 1 June 2019 till 15 August 2019 archived at CHMI
  - can be found on **ventus:/tscratch/atrojakova/data/radar/OIFS**
- **Meteo France (MF) radar data** from hendrix
  - can be found on **ventus:/tscratch/atrojakova/data/radar/MF**
  - OMG values from AROME France exctracted locally (ecma_full_odim.dat)
- **CERAD ZMAX radar figures**
  - can be found on **ventus:/tscratch/atrojakova/data/radar/CERAD**