REPORT ON LACE STAY AT CHMI, PRAGUE,
9th August - 10th September 2021.

Impact studies with OPERA reflectivity observations

Suzana Panežić

Meteorological and Hydrological Service, Croatia

In colaboration with Alena Trojáková and Antonín Bučánek (CHMI, Czech Republic)

21/10/2021

1 Introduction

Data assimilation of radar reflectivities has been a priority for RC LACE. The use of the radar reflectivity observation operator within ALARO model configuration was investigated by Trojáková [4]. The study of Bučánek [3] focused on enhanced understanding of 1D Bayesian retrieval of pseudo observed relative humidity originally proposed by Wattrelot [2].

The pseudo observed relative humidity is computed using N simulated reflectivity profiles in the vicinity of observed reflectivity column, see Figure 1. The inversion is computed by the following formula using the notation from Bučánek [3]. As explained in Watterlot [2] the observation error σ acts as weight in the inversion. For large σ, the retrieval will be an average of all model profiles, therefore small σ was proposed originally.

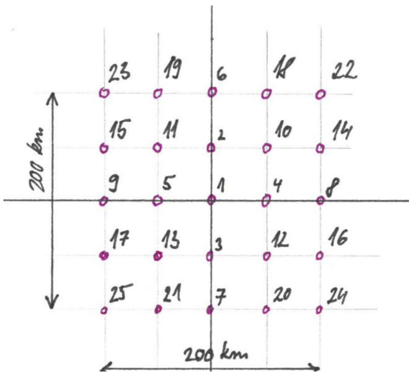

Figure 1: Positions of simulated reflectivity profiles from Bučánek [3].

$$\text{ZREHU(jl,jc)} = \frac{\sum_{\text{jp}} \text{ZHU(jl,jc,jp)} \exp\left(\dfrac{-\sum_{\text{jc}}\left(O_{\text{refl}}(\text{jl,jc}) - M_{\text{refl}}(\text{jl,jc,jp})\right)^2}{2\sigma^2 N(\text{jp})}\right)}{\sum_{\text{jp}} \exp\left(\dfrac{-\sum_{\text{jc}}\left(O_{\text{refl}}(\text{jl,jc}) - M_{\text{refl}}(\text{jl,jc,jp})\right)^2}{2\sigma^2 N(\text{jp})}\right)}$$

Similar formula is used for derivation of pseudo-observed profile of reflectivity, for more details and notation see Bučánek [3].

This study is devoted to impact studies of reflectivity data assimilation using ALARO/CZ (2.3km) configuration. The aim is to run sensitivity tests on the number of model simulated profiles, the selection box size of the model simulated profiles and on the reflectivity observation error σ. The drying effect of reflectivity data assimilation is explored as well, due to the regular drying effect appearance.

2 OPERA radar data

Reflectivity radar data were provided by the OPERA Internet File Server (OIFS) and were processed by the Homogenization Of Opera Files (HOOF) tool, version 1.9. The option of no data splitting was used for the processing of OPERA data with HOOF.

NOTE: Naming of log files in version 1.9 for the option of no data splitting is bugged so some code modification was required for HOOF to properly process the OPERA data.

When checking if all OPERA files that passed HOOF passed BATOR as well, it was evident that some radars were completely rejected by BATOR: all radars from Poland, Romania and Serbia as well as radar at Isle of Borkum (*deasb*) from Germany. After detailed inspection of the data it was concluded that these OPERA files had no uncorrected reflectivity factor (TH) coded inside and were, as a result, rejected. From the year 2021 Polish radar files contain TH data, while those from Romania and Serbia remain with the uncoded TH. The radars that were used (and were not rejected by BATOR) for case studies can be found in Figure 2.

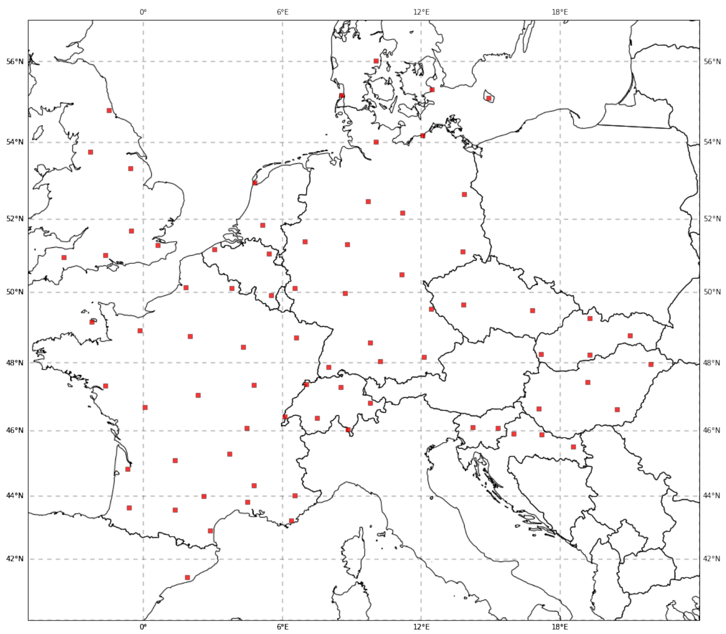

Figure 2: Radars used for the case studies.

3 Model setup specification

- **Model:** ALARO NH-v1B cy43t2
- **Domain:** ALARO/CZ; $\Delta x = 2.3$ km; 1069x853 GP; 87 vertical levels; mean orography
- **Coupling:** 3h space consistent coupling from ARPEGE; synchronous
- **Forecast:** $\Delta t = 90$ s; up to +72/54h at 00, 06, 12/18UTC
- **Upper air analysis:** BlendVar scheme (DF blending, filtering at truncation E102x81) followed by 3D-Var; 6h Assimilation cycle; REDNMC=0.5, Ensemble data assimilation B matrix based on AEARP; +-1.5h assimilation window; VarBC 24h cycling
- **Assimilated observation:** SYNOP(Ps), TEMP(t,q,u,v), AMDAR(t,u,v), SEVIRI(channels 2,3), Mode-S MRAR CZ/Mode-S EHS from KNMI (t,u,v), HR-AMV, wind profiler (u,v), ASCAT

Prognostic graupels have been implemented in ALARO by Bogdan Bochenek in 2017 following previous works of Michiel Van Ginderachter and Joris Van den Bergh. Lately Radmila Brozkova and David Nemec fixed the graupel code and added a flash diagnostic. The modset is available in the local CHMI release cy43t2ag.

The ALARO with prognostic graupels (LGRAPRO=T) with retuned Wegener–Bergeron–Findeisen process (RWBF1=300) were used in all experiments. The effect of added graupels for the radar reflectivity observation operator itself was not studied.

Radar assimilation code used for these studies was back-phased from cy46t1 to cy43t2 and was provided by Maud Martet.

Modifications include:

- reflectivity obs operator (reflsim_2dop.F90 and sugoms.F90 to add ice content in the goms)
- some modifications in the Bayesian inversion (more data used in the lower layers, low values of double polarized S band radars no longer rejected, bug correction for interpolation between first and last model level)

- modifications in the thinning to try suppressing too close observations

Code can be acquired on demand.

4 Blacklisting

AROME operational blacklists was examined in order to see what data has been blacklisted and if some LACE radars require the same treatment.

`ROUTINE: arpifs/op_obs/inv_refl1dstat.F90`

In this routine, before code modification, all observations from S band radars with the height above 3600m and reflectivity below 8dBZ were blacklisted. In the back-phased version this was reduced only to reflectivity data below 8dBZ for the single polarization S band radars. The dual polarization S band radars are considered to have efficient enough ground clutter elimination to be assimilated without any data rejection (*Maud Martet personal communication*).

In LACE domain, single polarization S band radars exist in Romania, Serbia and Croatia but since no Romanian or Serbian radars pass BATOR for now, only Croatian radars fall into this category and should be evaluated. It is also worth to note that Croatia will replace all of its radars with the C band radars within the next few years, so this evaluation might not be necessary.

`BLACKLIST: LISTE_LOC`

In this blacklist, all data from the French X band radars have been blacklisted due to precipitation attenuation (*Maud Martet personal communication*). In the LACE domain, besides French radars there are only three X band radars, from which two are in Germany and one is in Serbia, but none of them are available in OPERA, so this blacklisting should not be necessary for them.

`BLACKLIST: blacklist/mf_blacklist.b`

In this blacklist, lowest elevations for the selected French radars located near the mountains were blacklisted. This is due to inability to differentiate if the non-rainy pixel behind the mountain is truly because there is no rain in the pixel or due to the beam blockage (*Maud Martet personal communication*) which can in term cause problems with dry profile assimilation. Some radar data (Ajaccio, 07760) are blacklisted only by the azimuth where beam blockage percentage exceeds 70% [Figure 3].

Looking at the OPERA data for the said radar, it appears that OPERA is doing a good job at the quality control of radar beam blockage [Figure 4] when considering QC threshold of 0.7 in BATOR. But an open question remains why these additional procedures exist (additional to OPERA quality control) for AROME, what is the impact and should this type of blacklisting for elevations and azimuths also be incorporated for the other LACE radars.

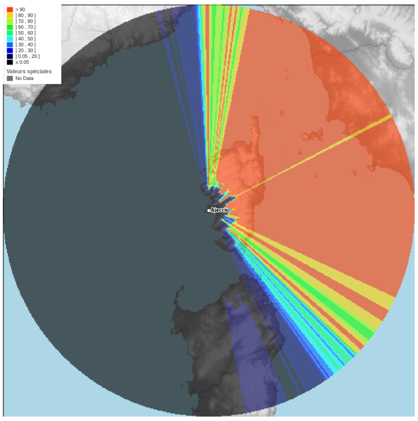

Figure 3: Ajaccio radar beam blockage by MF diagnostics [Courtesy to Maud Martet].

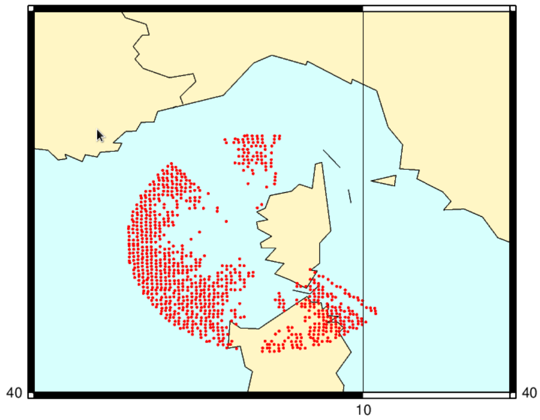

Figure 4: Ajaccio radar data from the OPERA file for elevation 0.4.

5 Case studies

In order to test the radar data assimilation sensitivity to various variables, a set of tests has been performed with the changing number of model simulated reflectivity profiles inside the box (NOBSPROFS), reducing the size of the box to a 100km square and reducing the reflectivity observation error (ZXSIG). All sensitivity experiments are summarized in Table 1 at the end of this section.

The dates chosen for the case studies are August 14th 2020 and August 22nd 2020 when there was enough rain over the Czech Republic.

Two reference experiments have been set up for the comparison:

- ALAS - no radar data assimilation
- DREF - reflectivity radar data assimilation with the values:
  - Box size: 200 [km]
  - Number of profiles: NOBSPROFS = 225
  - Thinning box: RMIND = 8340 [m]; RFIND = 16680 [m]
  - Reflectivity observation error: ZXSIG = 5 [dBZ]

5.1 Number of profiles

Two sensitivity experiments have been set up:

- P121 - Number of profiles changed to NOBSPROFS = 121 as opposed to the DREF experiment
- P289 - Number of profiles changed to NOBSPROFS = 289 as opposed to the DREF experiment

To get a quick overview, at first only the assimilation cycle was evaluated for the first three days of 12-14 August 2020. Verification (VERAL) scores were calculated with respect to SYNOP and TEMP observations over all computational domain of ALARO/CZ domain. Overall VERAL scores showed very little sensitivity to the number of profiles, but the drying effect appears to be prevalent at the heights below 500 hPa [Figure 5] for all experiments with the radar data assimilation. Between 500 and 250 hPa, reduced bias of relative humidity suggests there is mostly a moistening effect. At the heights above 250 hPa, there is once again the drying effect (not shown).

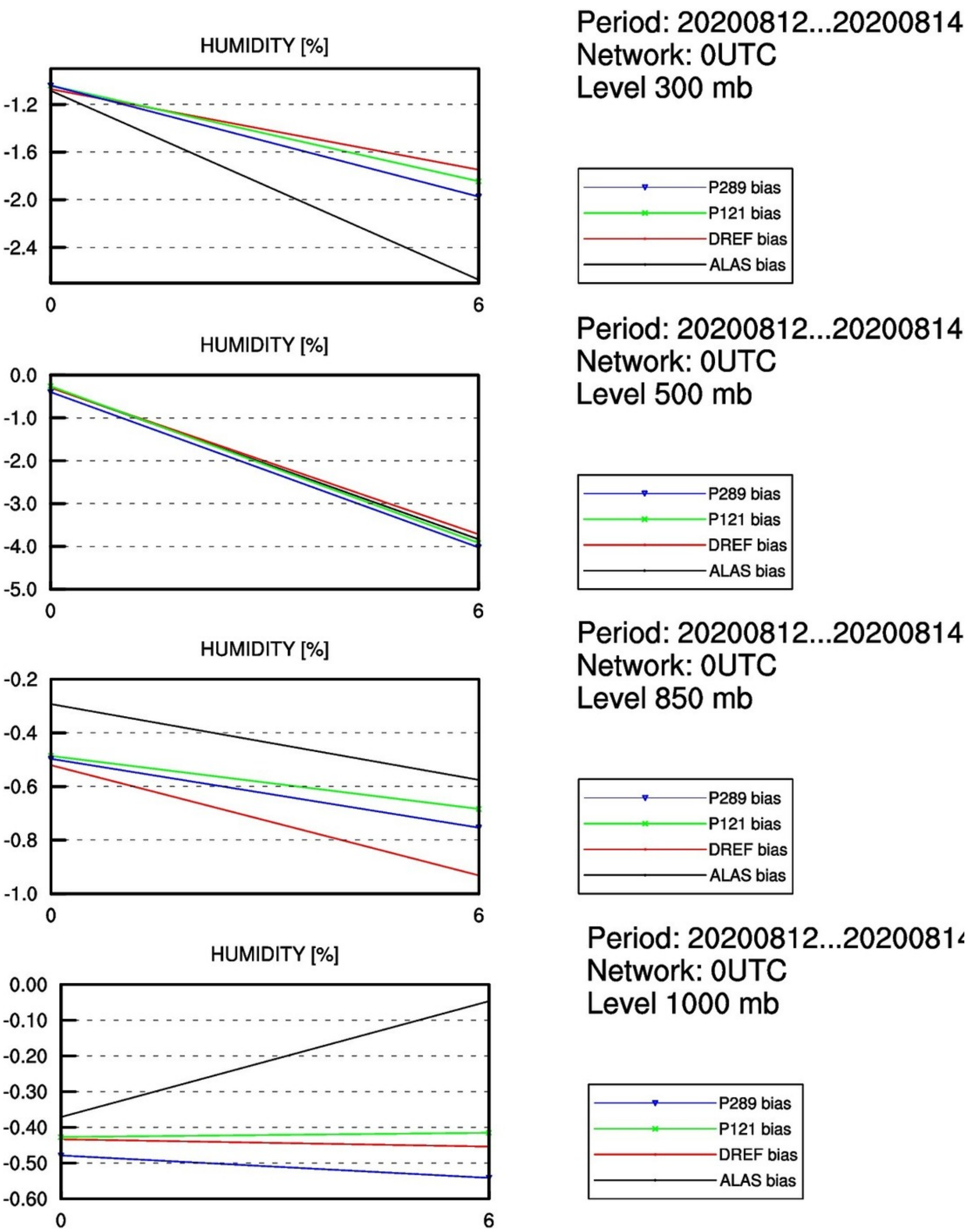

Figure 5: Bias of relative humidity with height for the assimilation period of 12-14 August 2020 for all ranges (00, 06, 12 and 18 UTC).

5.2 Size of the box and the number of profiles

Three sensitivity experiments have been set up:

- B121 - Box size changed to 100km; number of profiles changed to NOBSPROFS = 121 as opposed to the DREF experiment
- B081 - Box size changed to 100km; number of profiles changed to NOBSPROFS = 81 as opposed to the DREF experiment
- B049 - Box size changed to 100km; number of profiles changed to NOBSPROFS = 49 as opposed to the DREF experiment

We examined ODB departures of simulated reflectivity, pseudo-observed relative humidity and pseudo-observed reflectivity derived by the 1D Bayesian inversion for the first three days of the assimilation cycle, 12-14 August 2020. The statistics (BIAS, STD) per height show that even though there is very little sensitivity for the number of profiles, there is some sensitivity when the experiments with box size 200 and 100 km are compared. In Figure 6 we can

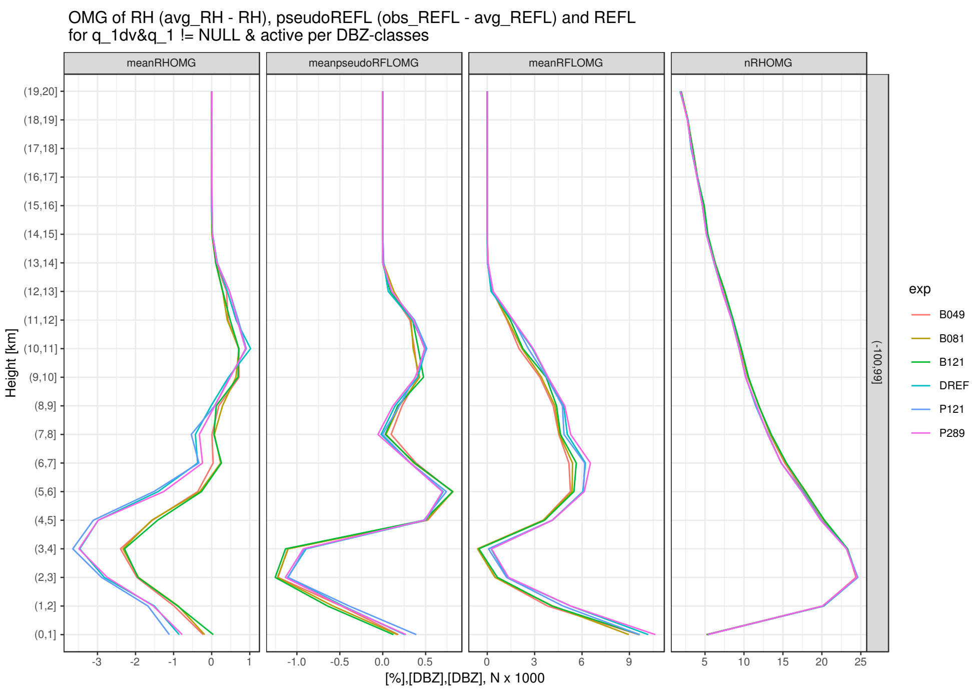

Figure 6: BIAS of departures for pseudo-observed RH, pseudo-observed reflectivity and simulated reflectivity and number of departures for DREF, P121, P289, B049, B081, B121 experiments.

see the clustering of box size 200 and 100 km experiments respectfully with smaller box size showing a smaller BIAS of pseudo-observed RH (less drying) of the atmosphere. For standard deviation (STD) statistics per height in Figure 7 we can also notice a smaller random errors of pseudo-observed RH departures for the 100 km box size.

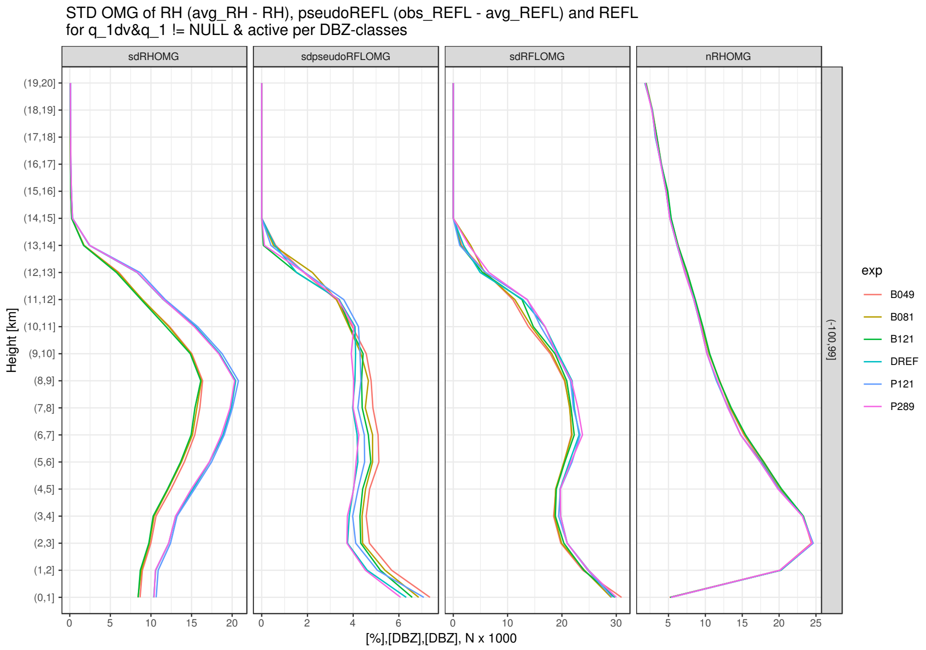

Figure 7: STD of departures for pseudo-observed RH, pseudo-observed reflectivity and simulated reflectivity and number of departures for DREF, P121, P289, B049, B081, B121 experiments.

VERAL scores for this batch of experiments show less deviation from the ALAS experiment but with the drying effect below 500hPa still present in it [Figure 8].

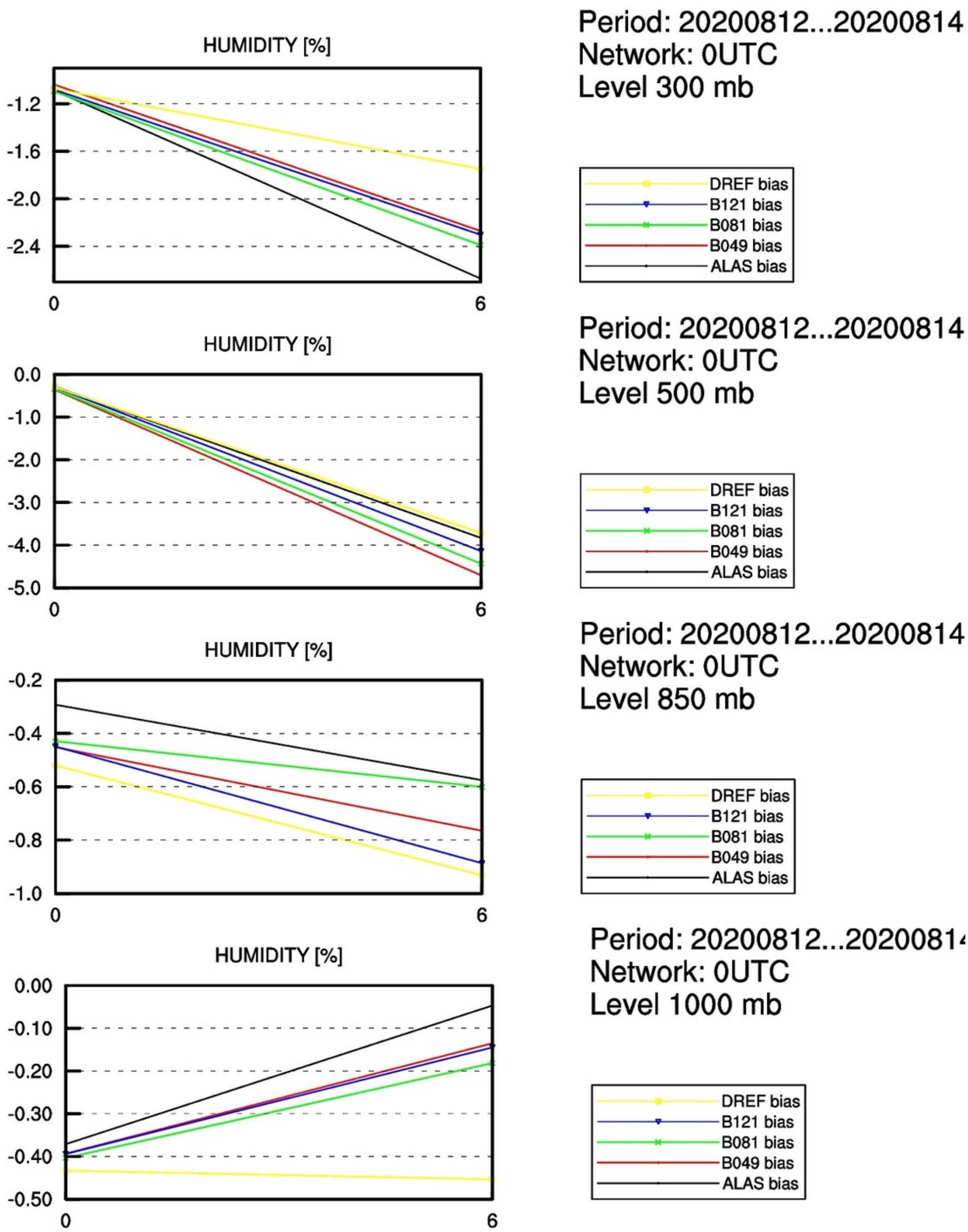

Figure 8: Bias of relative humidity with height for the assimilation period of 12-14. August 2020 for all ranges (00, 06, 12 and 18 UTC).

5.3 Observation error (Sigma)

To retrieve humidity profiles from the reflectivity columns, observation error needs to be specified. These errors originate from the observation operator and from the reflectivity measurement [2].

Two sensitivity experiments have been set up:

- ZS12 - Sigma of reflectivity changed to ZXSIG = 1.2 as opposed to the DREF experiment
- ZS02 - Sigma of reflectivity changed to ZXSIG = 0.2 as opposed to the DREF experiment

Departures statistics in Figure 9 and Figure 10 show that the lower observation error means the better fit of both reflectivity and pseudo-observed reflectivity to observation but a larger BIAS and STD of pseudo-observed relative humidity (more drying).

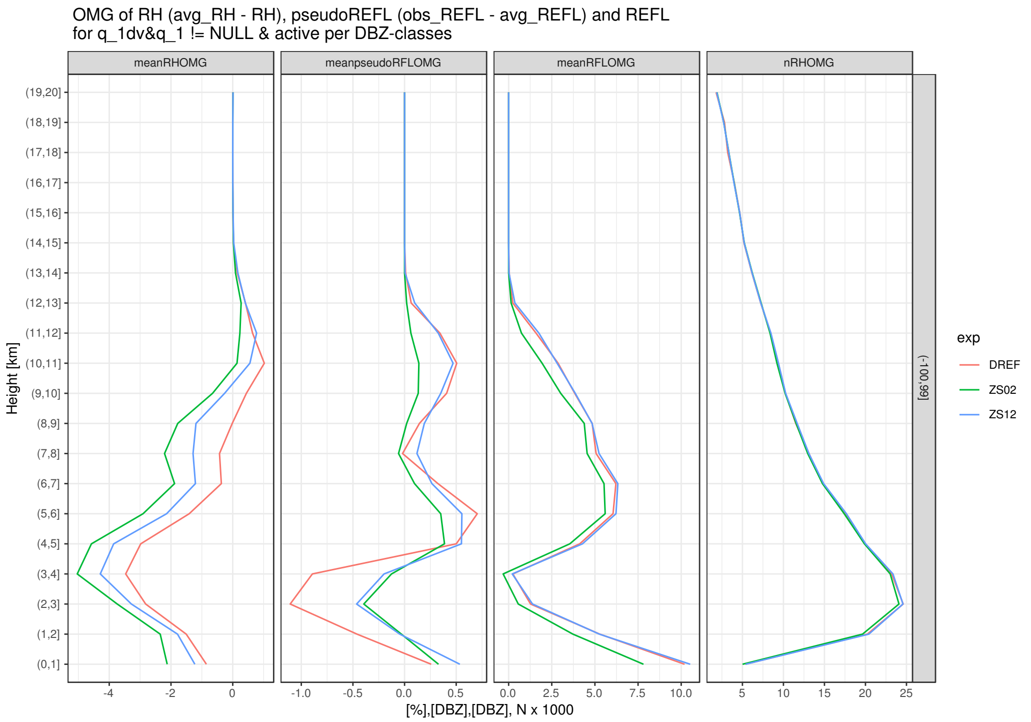

Figure 9: BIAS of departures for pseudo-observed RH, pseudo-observed reflectivity and simulated reflectivity and number of departures for DREF, ZS12, ZS02 experiments.

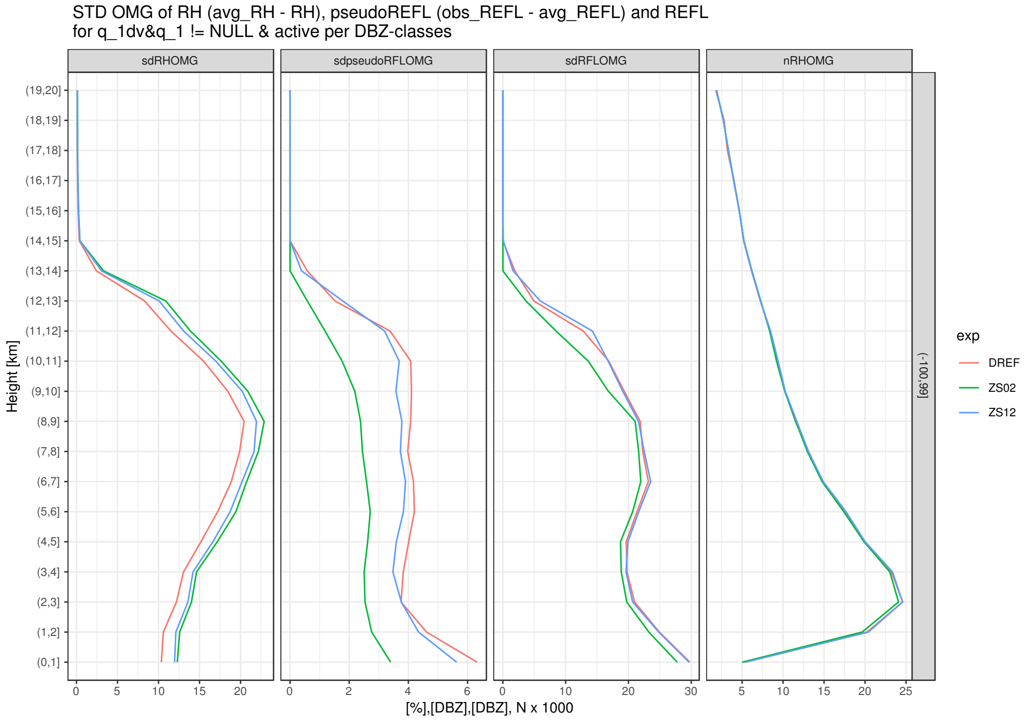

Figure 10: STD of departures for pseudo-observed RH, pseudo-observed reflectivity and simulated reflectivity and number of departures for DREF, ZS12, ZS02 experiments.

VERAL scores show prevalent drying effect for this batch of experiments as well[Figure 11].

5.4 Summary

Overall VERAL scores show very little sensitivity between different experiments of the same batch but there is some sensitivity related to the selection box size of the simulated profiles. All experiments show drying of the atmosphere. It was concluded that before any more sensitivity studies are performed, the issue of the drying effect should be evaluated.

Since Météo France plans to make the option of ZXSIG = 0.2 operational, it will be further evaluated in the next experiments.

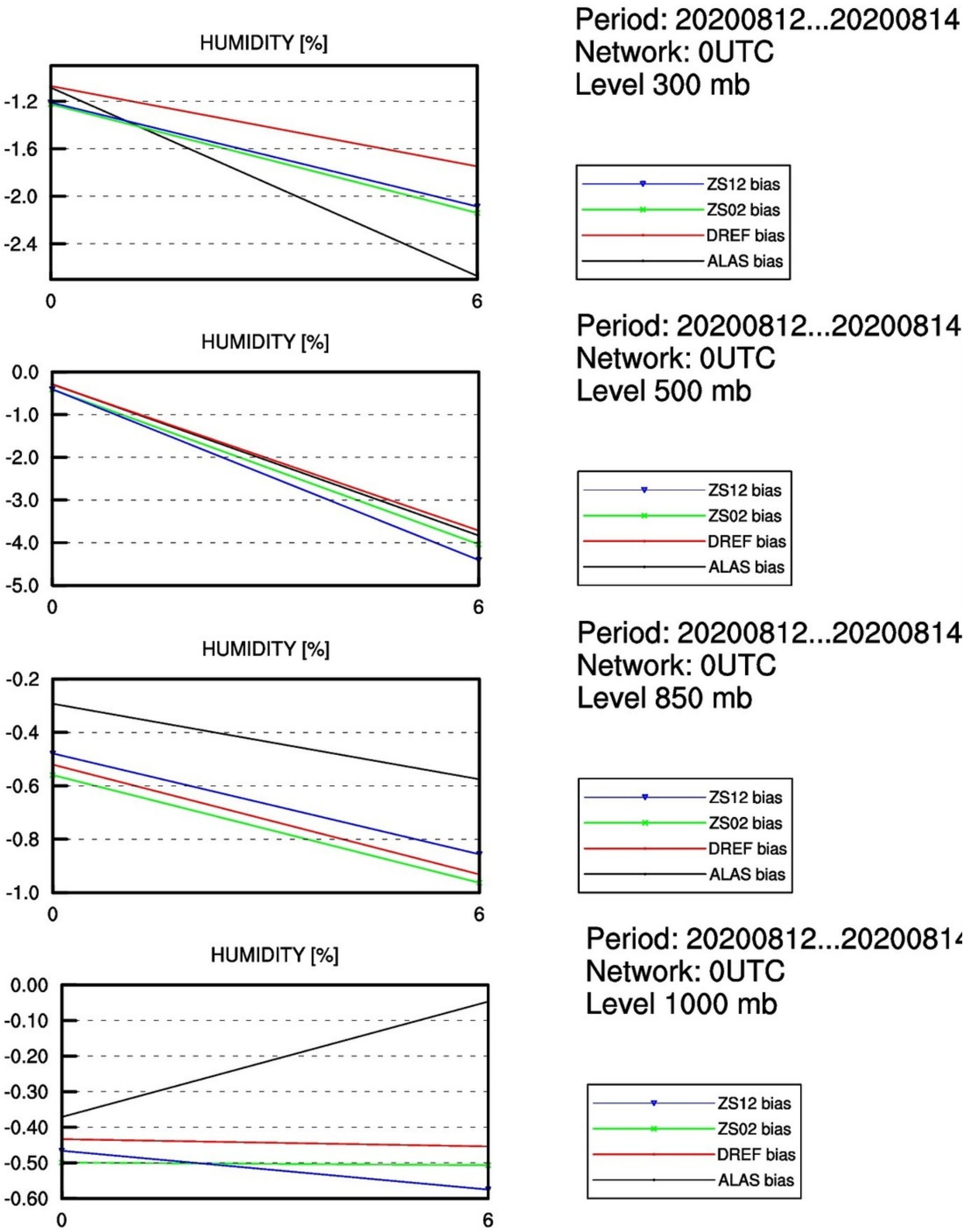

Figure 11: Bias of humidity with height for the assimilation period of 12-14 August 2020. for all ranges (00, 06, 12 and 18 UTC).

EXP	NOBSPROFS	BOXSIZE	σ [dBZ]	
ALAS				no radar DA
DREF	225	200	5.0	REFL DA
P121	121	200	5.0	REFL DA
P289	289	200	5.0	REFL DA
B121	121	100	5.0	REFL DA
B081	81	100	5.0	REFL DA
B049	49	100	5.0	REFL DA
ZS12	225	200	1.2	REFL DA
ZS02	225	200	0.2	REFL DA

Table 1: Summary of experiments to test sensitivity to the number of model simulated reflectivity profiles (NOBSPROFS), size of the box (BOXSIZE) and reflectivity observation error (ZXSIG).

6 Drying effect

In order to evaluate the drying effect, several diagnostic methods were used to explore the ODB content as well as the model fields themselves.

Production (+48h) of ALAS and DREF experiments were calculated for the period from 14-29 August 2020 for 0UTC only and were compared. Vertical cross-section of RMSE and BIAS differences show some degradation of the forecast as well as drying of the atmosphere at the 850-500 and 300-150 hPa during the first 12 - 24 hours [Figure 12]. These levels seem to be the most sensitive ones when assimilating radar reflectivity.

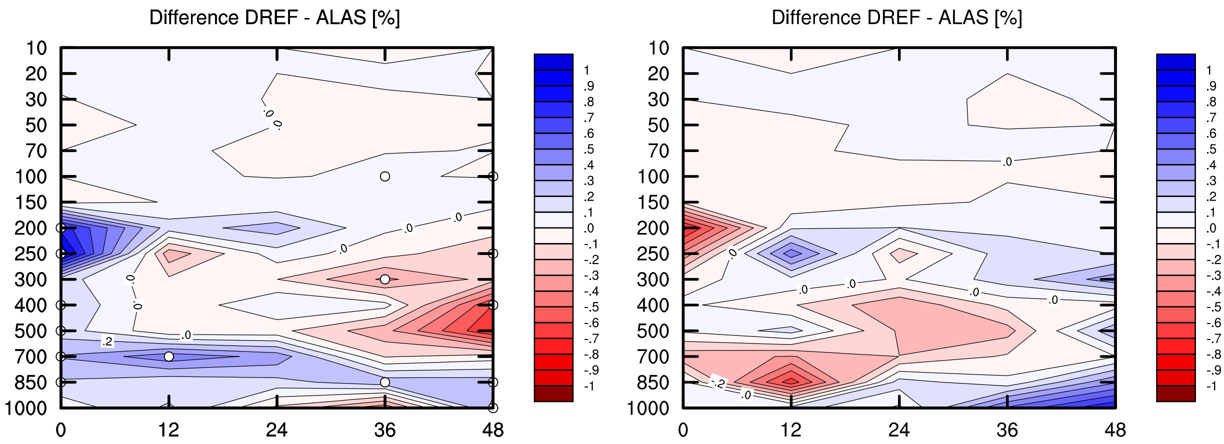

Figure 12: Vertical cross-section of RMSE (left) and BIAS (right) differences between DREF and ALAS experiments for the period from 14-29 August 2020 0UTC.

Total precipitation fields were calculated from the guess fields valid at the analysis time of ALAS and DREF experiments to check if the drying effect was negatively affecting the precipitation in the model. Visual comparison showed that the inclusion of radars in the data assimilation caused the decrease in the precipitation as well, while the increase appeared very sporadically and in too small quantities over the whole model domain [Figure 13].

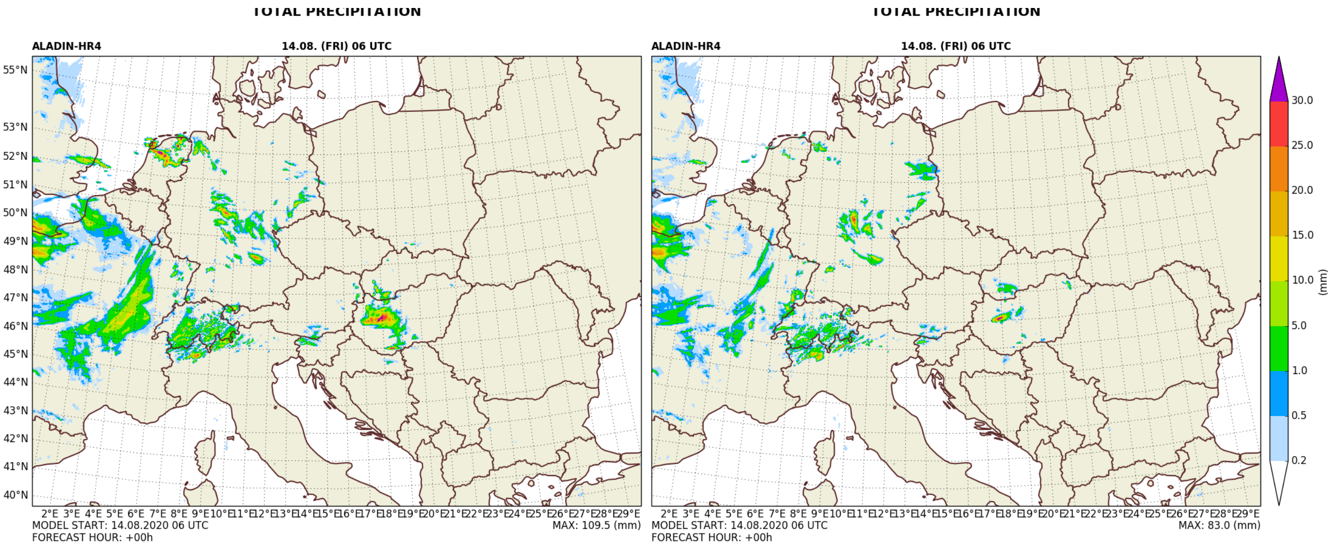

Figure 13: Total precipitation field from the ALAS (left) and DREF (right) experiment.

Effect of radar data assimilation on the relative humidity fields for the dry (flgdyn = 0) and moist (flgdyn = 8) pseudo-observation were evaluated separately. 2D histograms of relative humidity per height were created for both first guess and analysis. Full lines drawn over them are relative humidity pseudo-observation medians, while dashed ones are median of first guess and analysis values respectively.

While looking at the 2D histograms of dry pseudo-observations, it was evident that there is a large number of them at the heights above 200hPa [Figure 14]. It is questionable if this is realistic or should these pseudo-observations be removed. Further understanding is needed.

In Figure 15 on the left it can be seen that for the dry pseudo-observations the model is generally too moist, while on the right it can be seen that the data assimilation brings the analysis very close to the pseudo-observed values (by drying the atmosphere). On the other hand, in Figure 16 it is apparent that the effect of the moist pseudo-observations is much smaller then it was for the dry ones. Moistening appears to be the strongest at the heights above 500 hPa, which is in agreement with the VERAL scores, but the overall effect is drying of the atmosphere.

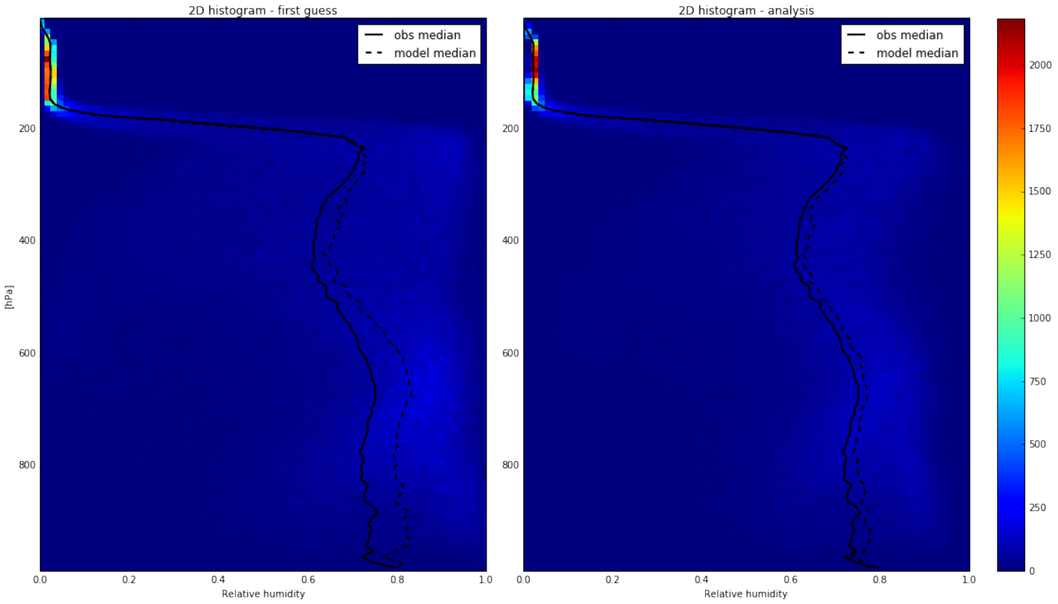

Figure 14: Dry pseudo-observations: relative humidity per height inside DREF experiment first guess and analysis; 12th-14th August 2020.

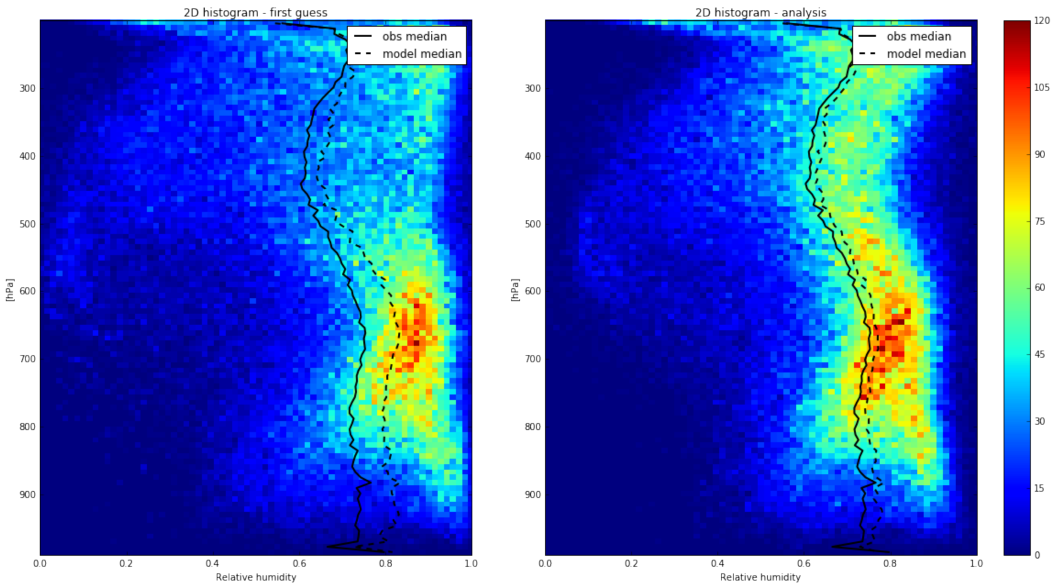

Figure 15: Dry pseudo-observations: relative humidity per height inside DREF experiment first guess and analysis below 200hPa; 12th-14th August 2020.

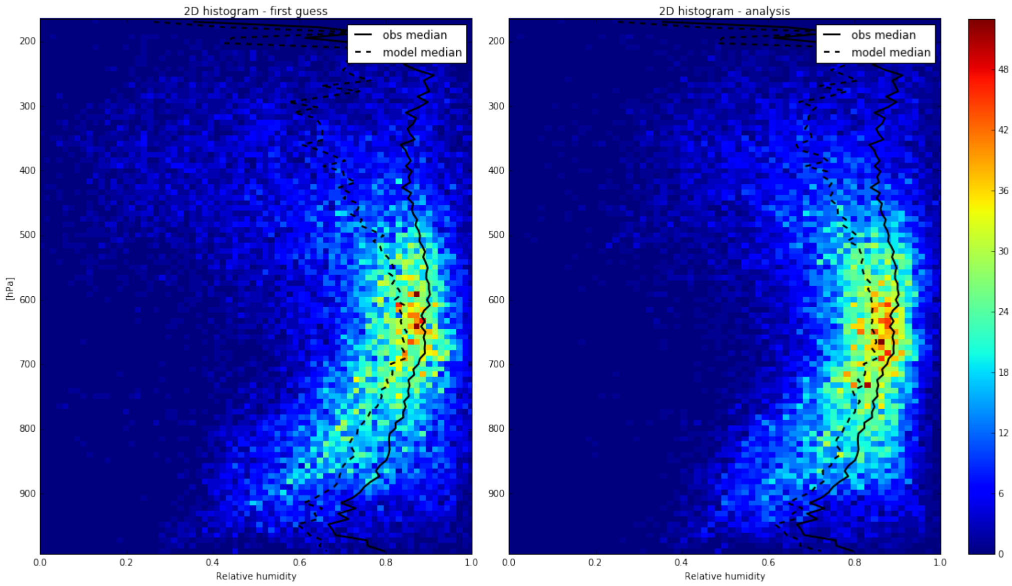

Figure 16: Moist pseudo-observations: relative humidity per height inside DREF experiment first guess and analysis; 12th-14th August 2020.

In order to see if the drying effect is present even when there is no precipitation present, a dry case has been selected from the newer dates: August 24th 2021. The options of this radar data assimilation experiment (v47S) are equivalent to the DREF experiment. It is compared to the no radar data assimilation version of ALARO (v46S), equivalent to ALAS experiment. In Figure 17, it can be seen that the drying effect persists even in the case where there is no precipitation present.

It can be concluded that the problem lies with the dry observation data assimilation.

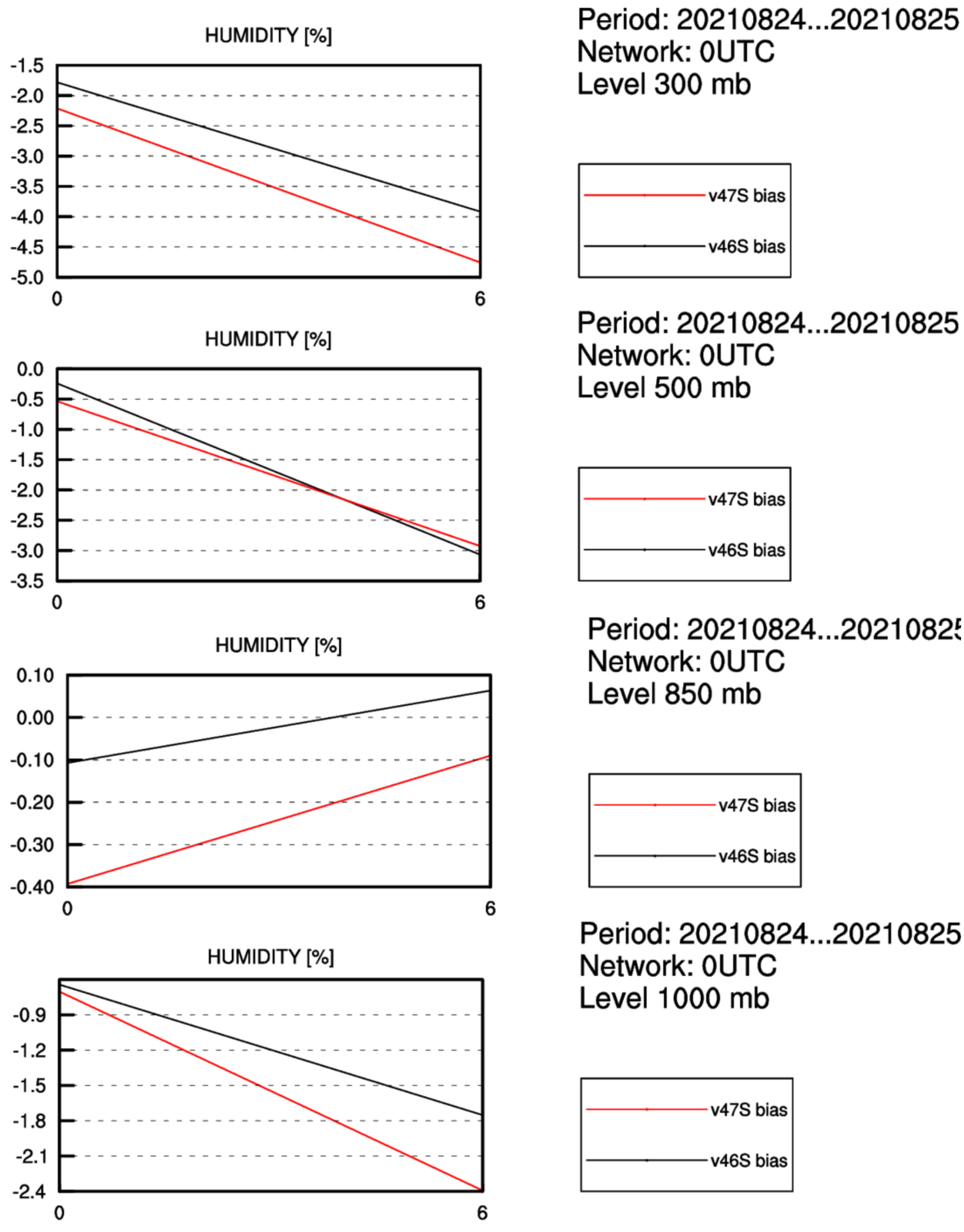

Figure 17: Bias of humidity with height for the assimilation period of 24-25 August 2021. for all ranges (00, 06, 12 and 18 UTC).

For further evaluation several new experiments were conducted:

- NDRY - experiment equivalent to DREF, with all dry pseudo-observation (flgdyn = 0) removed from the data assimilation
- NDRP - experiment equivalent to DREF, with removal of observation columns where all elevations are dry from the data assimilation
- HIRL - experiment equivalent to DREF, with modified HIRLAM solution which expects that there is a low precision of detection threshold or a problem in model observation operator which is unable to produce low enough values ($M_{refl} < 0$). For more details see [3].

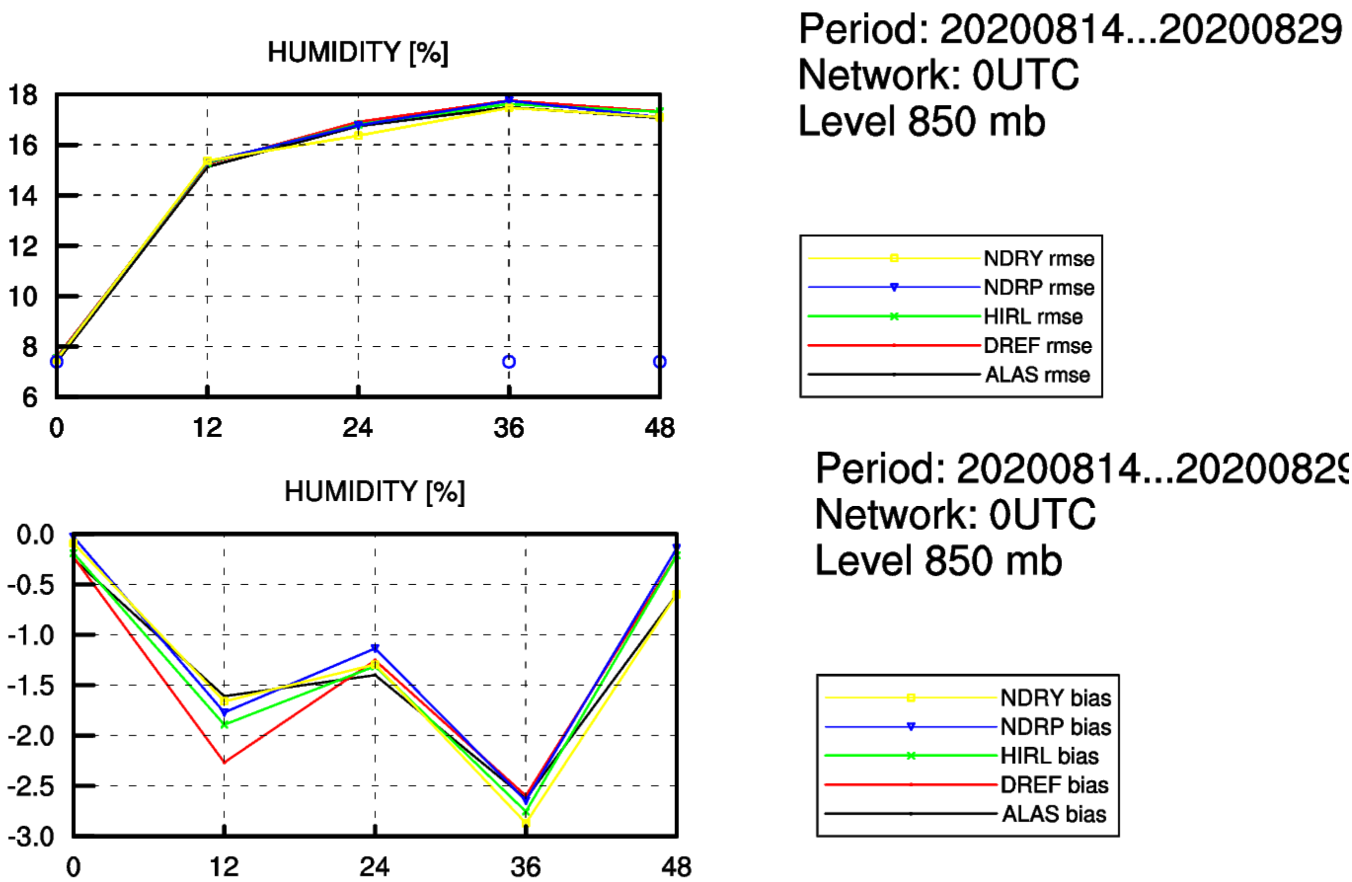

Figure 18: RMSE and bias for 850 hPa relative humidity field, period 14-29 August 2020 00 UTC, ALAS, DREF, HIRL, NDRP, NDRY experiments.

Long period scores (14-29 August 2020) have been calculated for ALAS, DREF, HIRL, NDRP, NDRY and ZS02 (not shown) experiments. Results show rather mixed results with no clear solution to the drying problem among the verified tests. [Figure 18] shows RMSE and bias scores for the 850 hPa relative humidity field of said experiments.

For the whole assimilation cycle (14-30 August 2020, all ranges) frequency bias has been calculated per precipitation categories for the ALAS, DREF, HIRL, NDRP, NDRY and ZS02 experiments. It can be seen (by comparing the ALAS and DREF experiments) that the inclusion of radar data lowers the mean value of frequency bias so in general, rain is removed. The experiments where the dry pseudo-observations are removed give better scores in general, but the categories with larger amount of rain have a larger spread, showing the appearance of spurious convection with large amounts of precipitation [Figure 19].

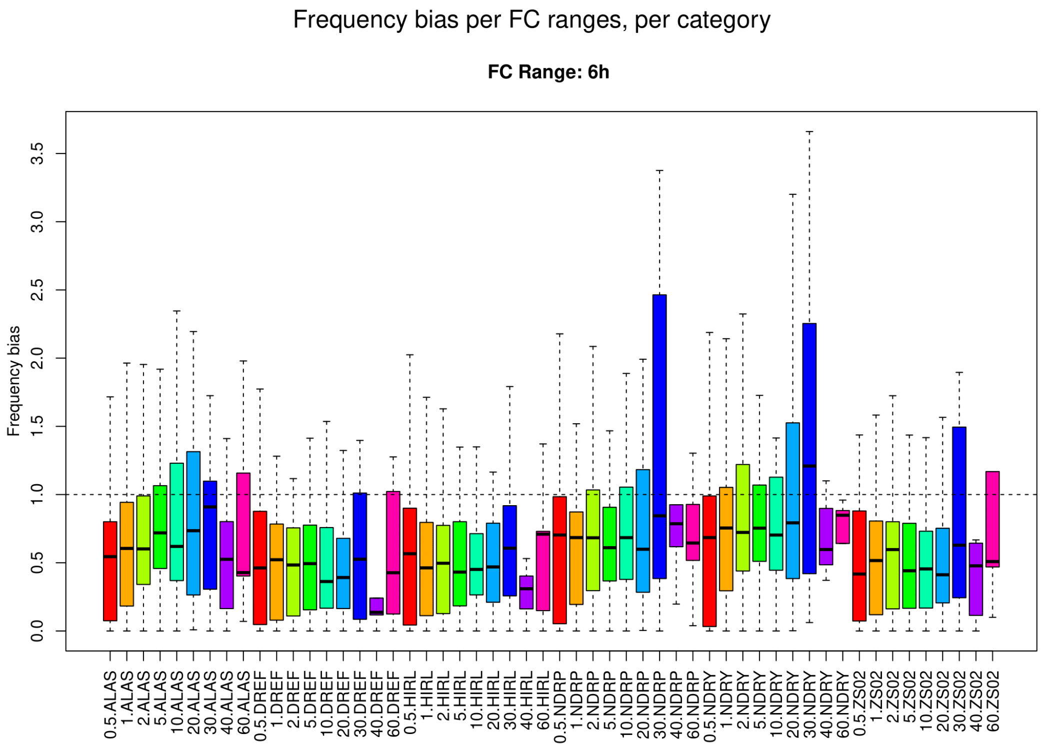

Figure 19: Box plot diagram of frequency bias per FC ranges (14-30 August 2020), per category, for all ranges: ALAS, DREF, HIRL, NDRP, NDRY, ZS02 experiments.

The same can be seen by visualising such events. Total precipitation fields (6h accumulation) from various experiments guess files were compared with the CHMI 6h precipitation estimate (radar values adjusted with rain gauges by krieging with external drift method). It can be seen that the removal of dry pseudo-observations partially mitigates the drying effect problem, but in turn can raise the values of precipitation too high [Figures 20 and 21].

7 Conclusion

The aim of this study was to test sensitivity of reflectivity data assimilation on the number of model simulated profiles, the selection box size of the model simulated profiles and on the reflectivity observation error. The performed tests show that there is small sensitivity to the selection box size, with smaller ones being a better choice. The smaller observation error shows a better fit of pseudo-observed reflectivity to the observations, but a larger bias of pseudo observed relative humidity.

Case studies suggested that reflectivity data assimilation with the current setup is effectively drying the atmosphere, in particular in lower troposphere and consequently removing precipitation from the model forecast. Drying effect persists even in the no precipitating conditions which suggests the problem lies within the dry observation data assimilation. A large number of dry pseudo observations was found above 200hPa. It's questionable if it's realistic and further understanding is needed.

By reducing the number of dry observation, problem is partially mitigated but in turn the added moisture in the atmosphere creates strong and spurious convection with excessive amounts of rain.

No firm solution to the drying problem is offered. For the next steps it is proposed to revisit the calculation of radar detection threshold in BATOR, to consider modification of weights in the inversion process and/or deeper investigation of the reflectivity observation operator.

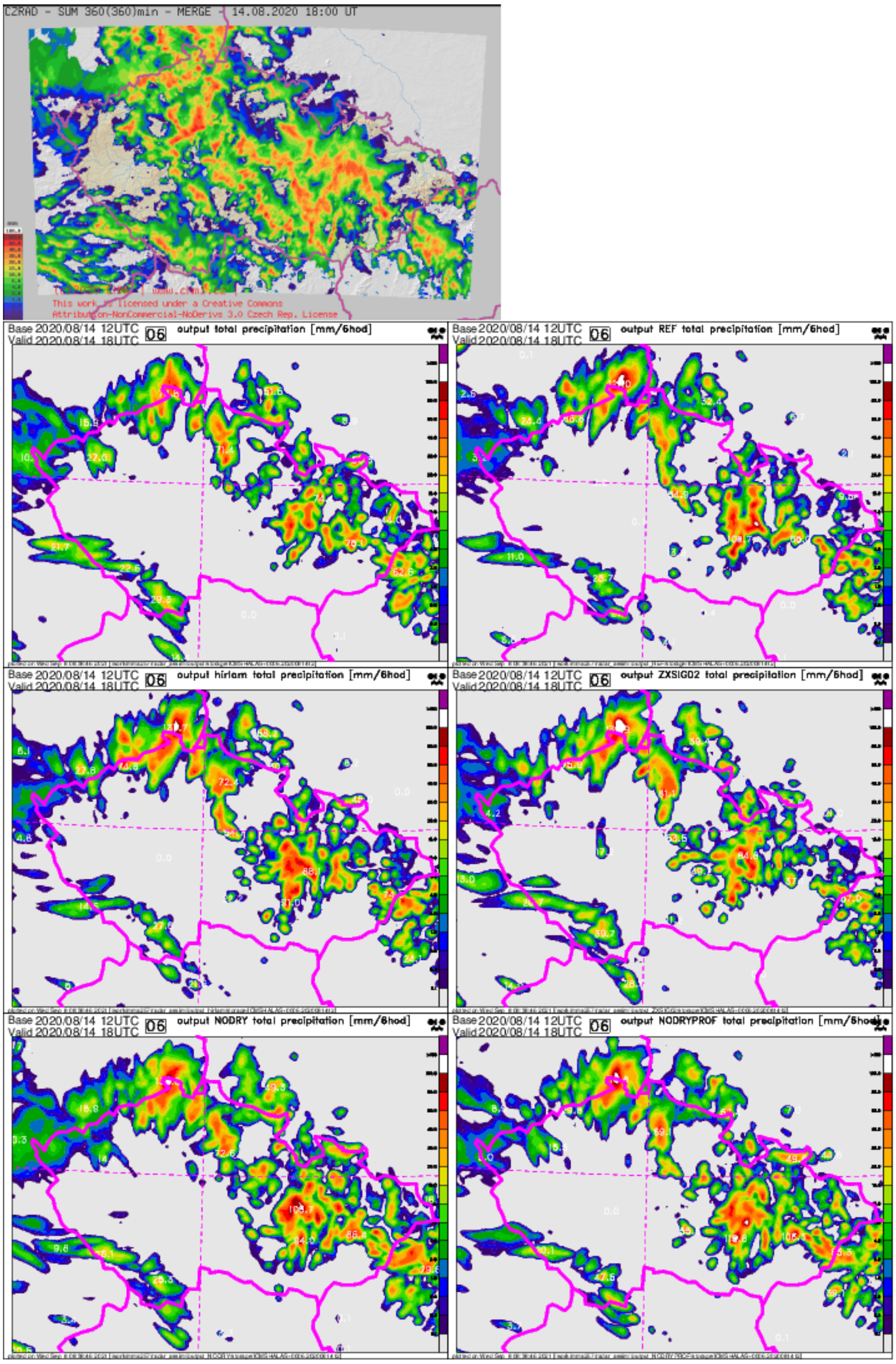

Figure 20: Total precipitation field for 14.08.2020. 18UTC, from left to right: precipitation estimation, ALAS, DREF, HIRL, ZS02, NDRY and NDRP.

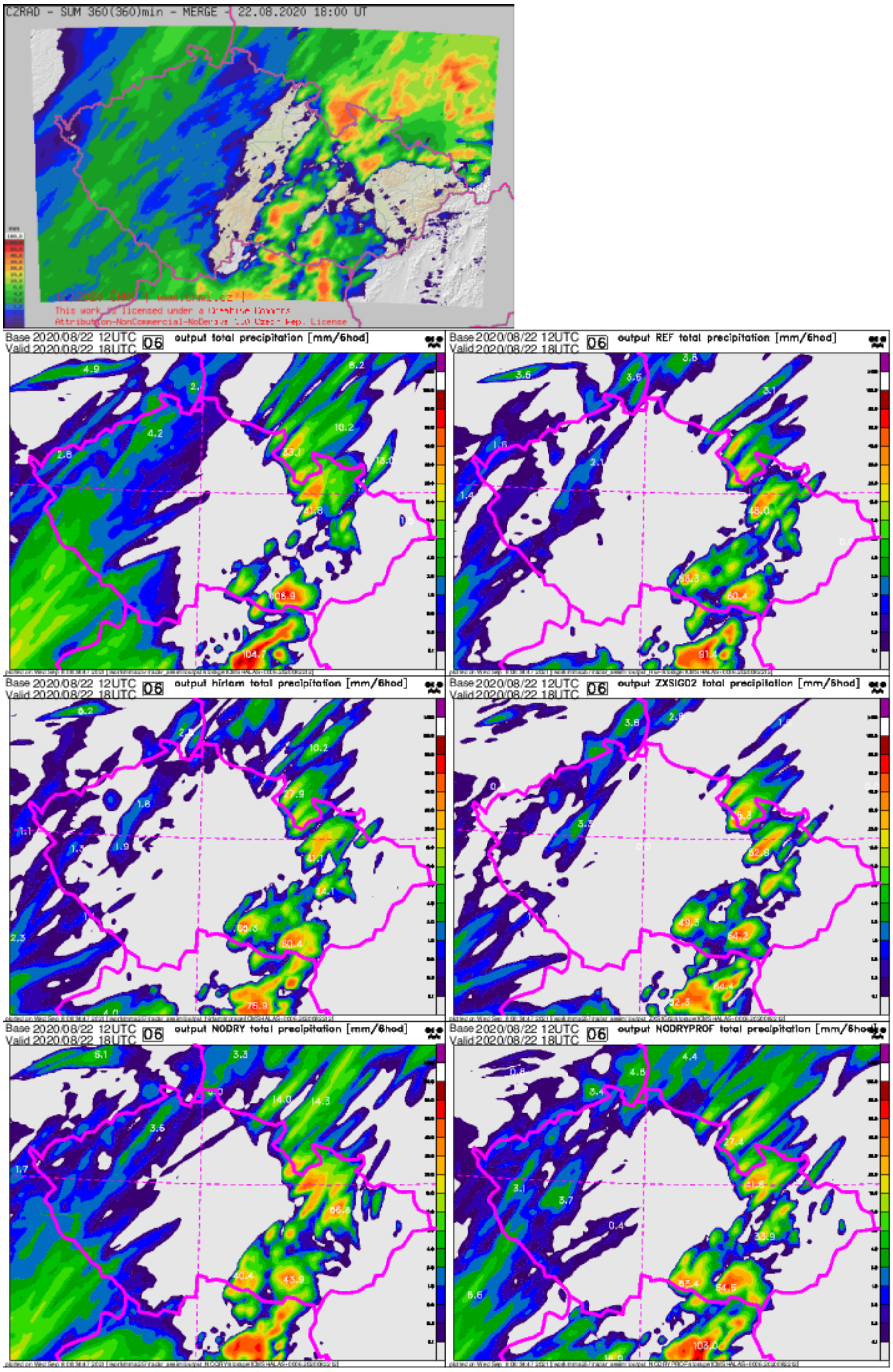

Figure 21: Total precipitation field for 22.08.2020. 18UTC, from left to right: precipitation estimation, ALAS, DREF, HIRL, ZS02, NDRY and NDRP.

References

[1] Olivier Caumont, Véronique Ducrocq, Éric Wattrelot, Geneviéve Jaubert and Stéphanie Pradier-Vabre; *1D+3DVar assimilation of radar reflectivity data: a proof of concept;* Tellus A: Dynamic Meteorology and Oceanography, vol. 62, issue 2, pp. 173-187, 2010.

[2] Éric Wattrelot, Olivier Caumont, and Jean-François Mahfouf; *Operational Implementation of the 1D+3D-Var Assimilation Method of Radar Reflectivity Data in the AROME Model;* Monthly Weather Review, vol. 142, issue 5, pp. 1852–1873 , 2014.

[3] Antonín Bučánek; *Processing of radar reflectivities in screening;* 2020., 10 pp

[4] Alena Trojáková; *ALARO tests of radar observation operator;* 2020., 16 pp

[5] Tomislav Kovačić; *An overview of ODIM HDF5 files from radars within Croatian ALARO NWP model domain;* 2018., 15 pp

Appendix A: Paths on kazi

Source code:

/work/mma257/radar_assim/build_CY43t2ag_david_maud

Scripts for experiments:

/home/mma257/radar_assim

Outputs for experiments:

/work/mma257/radar_assim/

Veral scores:

/home/mma257/radar_assim/veral/scores

Veral pictures:

/work/mma257/veral

Other pictures:

/work/mma257/radar_assim/output_pics/