REPORT ON LACE REMOTE STAY
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Assimilating OPERA reflectivity observations in the AROME-HU system

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1 Introduction

Radar data assimilation is a crucial part of state-of-the-art short-range forecasting and nowcasting systems and also an important research objective for RC LACE. For this reason, there were already some attempts in Hungary to include radar reflectivity data in the AROME-HU model (most recently by Máté Mester [1]), but there was little to no progress in recent years. The main objective of this remotely organized stay was to create an experimental setup for the purpose of testing the assimilation of radar reflectivity data retrieved from the OPERA (Operational Programme for the Exchange of Weather Radar Information) in the AROME-HU model.

2 Initial model setup

In order to evaluate the impact of the inclusion of radar data on the analysis and the forecast, several experiments were setup with only slight differences. The reference run is equivalent to the current operational AROME-HU setting, while the two test experiments only differ from the reference run in the inclusion of radar data. The main settings for all the experiments described in this paper are as follows:

- Model: AROME-HU cy43t2
- Time period: 2021/06/27-2021/07/31 (spin-up period: 2021/06/27-2021/07/01)
- Domain: 2.5 km horizontal resolution, 60 vertical levels, 490x310 grid points
- Coupling: 1 h coupling from IFS (lagged)
- Forecast: 4 forecasts per day at 00, 06, 12 and 18 UTC with a forecast length of 36 h
- Assimilation method: 3h assimilation cycle, no initialization, B matrix from EDA, OI-Main for surface and 3D-Var for upper air analysis
- Observations assimilated: SYNOP, TEMP, AMDAR + Mode-S MRAR, OPERA radar (except for the reference run)

For the test experiments, the radar data was obtained from the OPERA Internet File Server (OIFS), which was then pre-processed by the HOOF 2.0 (Homogenization of Opera Files) before being submitted to the BATOR. Some of the binaries (BATOR, MASTERODB) were also recompiled in these experiments using the code provided by Maud Martet in order to enable the assimilation of radar data.

3 Technical issues

As the first step, the SMS scripts and namelists responsible for carrying out the first part of the data assimilation (downloading the data and submitting it to BATOR) were modified based on the ecFlow scripts provided by Benedikt Strajnar. One of the most important modifications was implementing the HOOF software, which is responsible for homogenizing the radar data previously downloaded from the OIFS. As only reflectivity data was intended to be assimilated in the test experiments, dealiasing and suberobbing were switched off in the HOOF namelist. For the purpose of these tests the HOOF namelist was modified to include all radars available on the AROME-HU domain, although this list of radars was later reduced in one of the test experiments due to issues described later in this section. There was also an issue with one of the Hungarian radars ('huhar') which made it impossible to include this radar in the data assimilation. This problem probably surfaced due to the radar data not yet correctly coded in this dataset as it is the most recent Hungarian radar.

For the BATOR, more adjustments were needed compared to the HOOF. The script responsible for running the BATOR had to be modified to create a separate batormap file for the radar data since a different ECMA database is made for radar than for conventional observations. Some more modifications were also necessary in the BATOR namelist and the file param.cfg to account for the inclusion of of HDF5 files; for this purpose, the recompilation of the BATOR binary based on the code provided by Maud Martet was also essential. Due to some memory-related issues discussed in detail in the next paragraph, the main settings in the BATOR namelist had to be rather conservative, namely the HODIM%Sample was set to 6000.

Regarding the screening and minimization (3D-Var) tasks, few alterations were made in the scripts themselves, the namelists however had to be modified heavily in order to make these tasks suitable for assimilating radar reflectivity data. These modifications were mostly based on the settings used by Suzana Panežić [3] as a similar setup was intended. Later on, however, there were several memory-related issues while running the minimization task in the test experiments, therefore an attempt was made to further adjust these settings in order to make the screening and minimization work properly. Different values for PBS resource allocation and other memory-related parameters were also tried out with the hope of finding a suitable solution. In the end, a decision was made to run an experiment with less amount of radar data (including only Hungarian and Slovenian radars) in order to avoid the memory-related issues. The final settings used in the screening namelist were as follows:

RFIND_RADAR=16000.,
RMIND_RADAR=8000.,
ZRADARXSIG=5,
XYSHIFT_THIBOX(13)=1,

which was combined with the following ODB settings in the script itself (also used in the minimization):

ODB_IO_METHOD=4
ODB_IO_FILESIZE=128
ODB_IO_GRPSIZE=$BATOR_NBPOOL

For the other test experiment which included all initially selected radars, further modifications were made based on suggestions from Alena Trojáková with the goal of making minimization work using all available radar datasets, however this approach did not yet solve all the issues related to the minimization crashes.

It is also worth mentioning that there were some fairly minor issues in relation to integration and observation monitoring. The integration crashes occurred in the reference run at seemingly random dates and timesteps, the cause of which was uncertain from the output. After some investigation, it was determined that the crashes are related to the surface data assimilation.

Helga Tóth than suggested to run the Canari script with only one CPU, which indeed solved the crashes experienced. In the case of the observation monitoring, only a small modification was necessary in the script to account for the memory-related settings that were altered previously.

4 Analysis increments

In order to test the inclusion of radar reflectivity data in the assimilation cycle, it is useful to look at the analysis increments at the end of the spin-up period. This way it can be determined if the inclusion of the new observation type leads to any meaningful difference in the analysis fields and the analysis increments themselves.

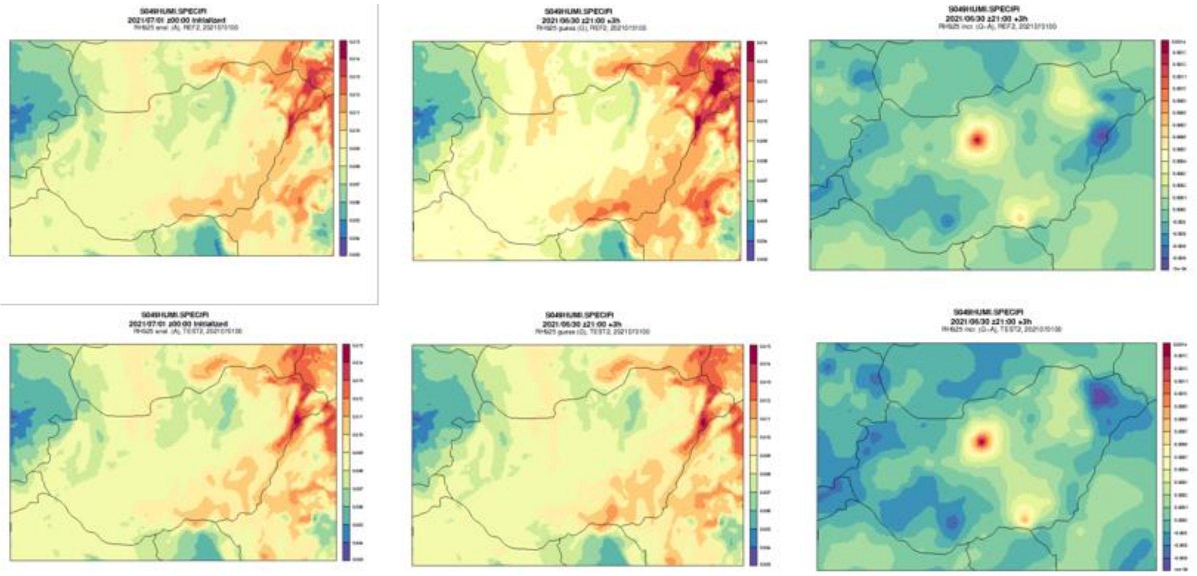

Figure 1. Analysis (left), guess (middle) and analysis increment (right) of 925 hPa relative humidity for the reference run (upper row) and the test experiment (lower row) for the first forecast time after the spin-up period (2021/07/01 0 UTC).

For example, the analysis increments of the relative humidity field on different vertical levels (namely 925 hPa and 700 hPa) show substantial differences between the test experiment and the reference run (see *Fig. 1* and *Fig. 2*). The spatial distribution of these differences seem to indicate that the inclusion of radar data does indeed influence the analysis increment fields, although this influence is much less pronounced in the case of the analysis fields.

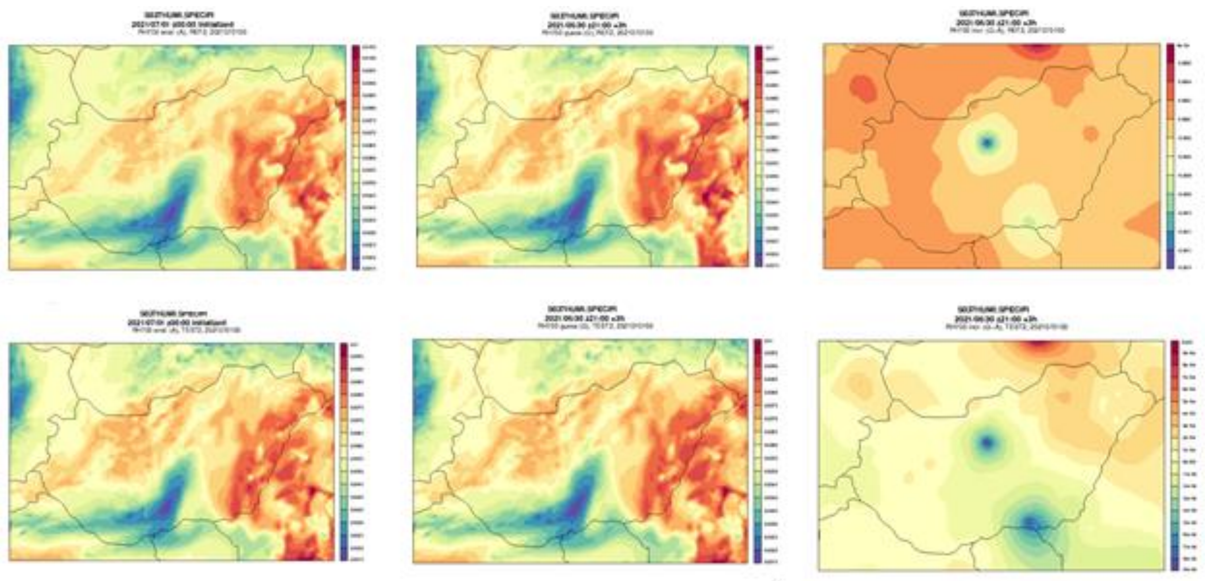

Figure 2. Analysis (left), guess (middle) and analysis increment (right) of 700 hPa relative humidity for the reference run (upper row) and the test experiment (lower row) for the first forecast time after the spin-up period (2021/07/01 0 UTC).

5 Verification

To assess the impact of assimilating radar reflectivity data on the quality of the forecast, pointwise verification and SAL verification was carried out for many different meteorological parameters. The main parameters examined were precipitation, relative humidity and cloud cover, as these parameters are the ones directly influenced by the inclusion of radar reflectivity data. In addition to this, the experimental period (July 2021) was specifically chosen to contain several convective weather events, which made it possible to have an in-depth look at the very same parameters (and also some others, e.g. wind gust). Other parameters not directly influenced by the assimilation of radar data were also examined with pointwise verification.

The results of the pointwise verification vary greatly depending on which meteorological parameter is considered. Verification scores for precipitation are mostly positive, or at least neutral, which indicates a strong improvement over the reference run. For example, the SEDI scores for the 21-hour long forecast of the 3-hour sum of precipitation shown on *Fig. 3* indicates a clear improvement for every threshold. Similarly, in the case of cloud cover there is an almost entirely positive impact on the forecast as the relatively large overestimation experienced in the AROME/HU system is significantly reduced (*Fig. 4*). Thus the drying effect, a rather commonly experienced problem in radar data assimilation (see for example [4]) seems to be beneficial in this specific case. Similar, albeit much smaller differences can be observed in the case of relative humidity and other related parameters, such as dew point. For other surface variables, such as 2-meter temperature and 10-meter wind speed and wind gust, however, the verification results are mostly neutral and sometimes even slightly negative. It should also be noted that the reference run and the operation model show some considerable differences in the verification results, which can be attributed to the fact that the latter also included GNSS data.

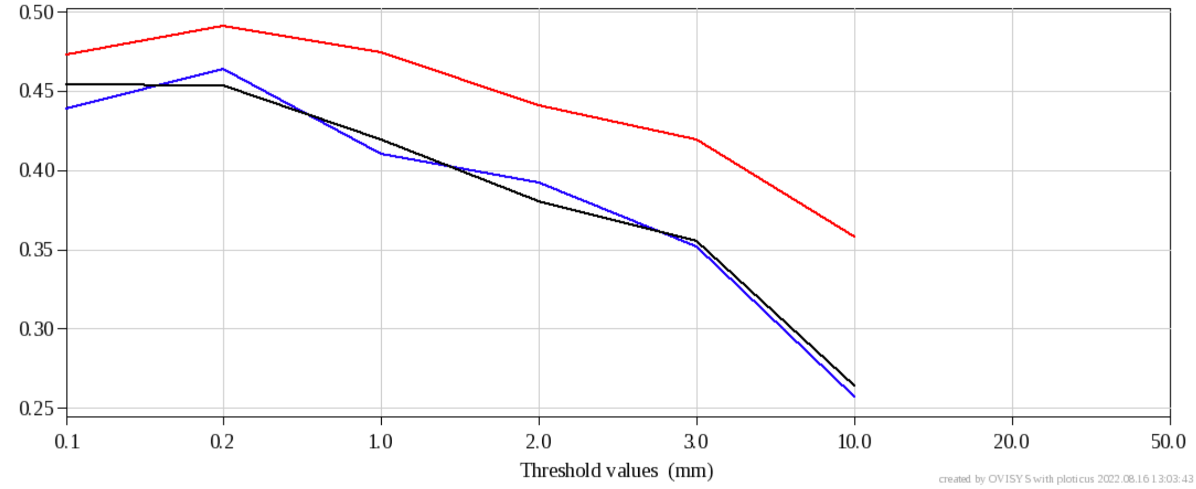

Figure 3. SEDI scores of 3-hour precipitation for pre-defined threshold values for the 06UTC+21h forecasts of the test experiment (red), the reference run (blue) and the operational AROME (black).

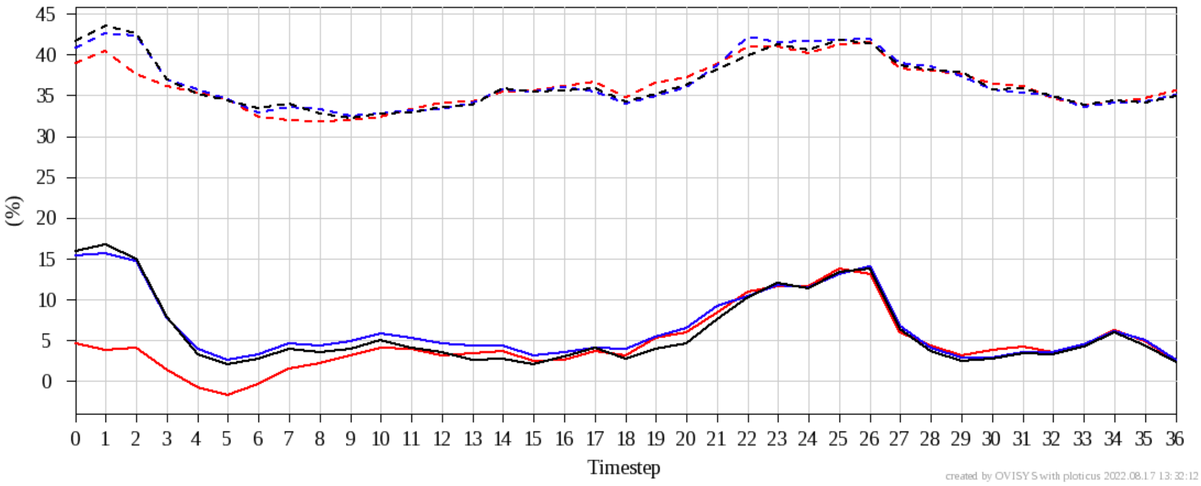

Figure 4. Bias (straight line) and RMSE (dashed line) scores of total cloudiness in relation to the lead time for the 0 UTC runs of the test experiment (red), the reference run (blue) and the operational AROME (black).

In the case of precipitation, SAL verification was also carried out, as pointwise verification can only use SYNOP and TEMP data, which may be insufficient for the purpose of precipitation verification. SAL verification, however, compares the spatial distribution of the precipitation forecast to radar measurements, which is a useful indicator of the quality of the forecast. Verification results show that the S (structure), A (amplitude) and L (location) components used in SAL verification differ only negligibly between the two experiments. Looking at the results for different variables like domain average precipitation (*Fig. 5*) or average object intensity in relation to lead time, it is clear that both experiments heavily overestimate the amount of precipitation during the whole forecast interval. In the case of domain average precipitation, this overestimation seems to be somewhat improved in the test experiments, while for the other similar variables neither of the two experiments seems to yield better results.

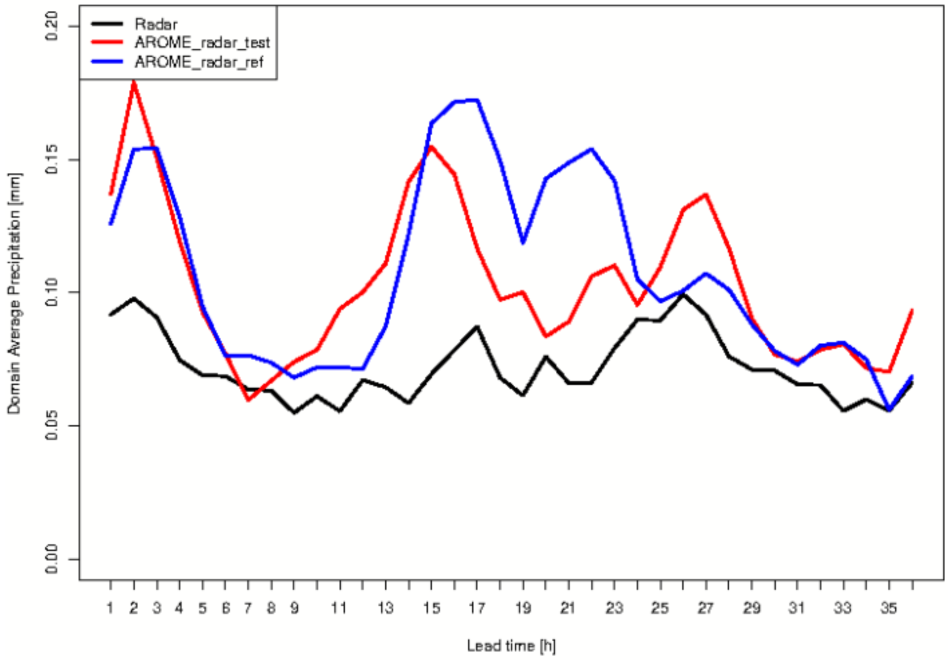

Figure 5. Domain average precipitation (mm) in the 0 UTC runs for the test experiment (red), the reference run (blue) and the radar data itself (black).

6 Case studies

A specific day (9 July 2021) was chosen from the experimental period to perform a case study regarding some of the meteorological parameters that are interesting in relation to radar data assimilation. On this day, a frontal wave influenced the weather over Hungary, leading to high amounts of precipitation and also some severe weather events. This made this day suitable to use for studying the impact of assimilating radar reflectivity on the quality of the forecast.

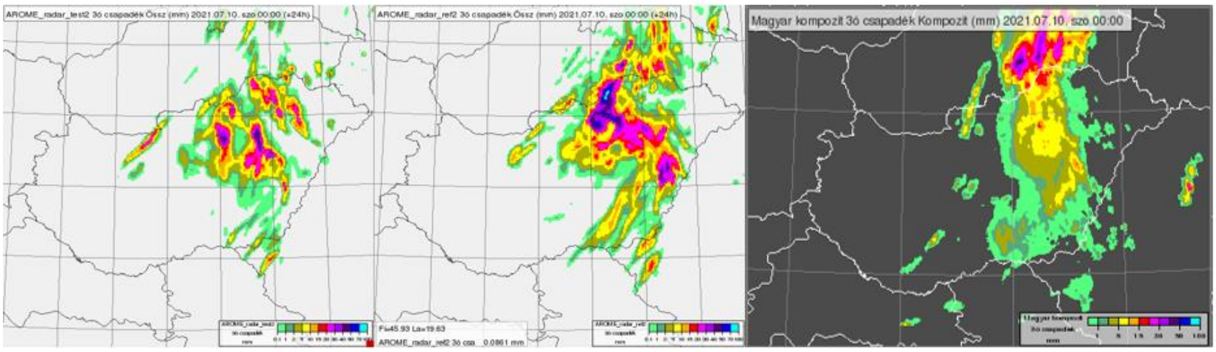

Figure 6. 24-hour forecast of the 3-hour sum of precipitation for the 0 UTC runs of the test experiment (left) and the reference run (middle) and the 3-hour sum of precipitation measured by radar (right) on 0 UTC, 10 July 2021.

Fig. 6 shows how the 24-hour forecast of the 3-hour sum of precipitation fared compared to the radar data. The subjective verification of this case does not give any clear implication of improvement, which is not surprising considering the results of SAL verification. Nevertheless, it can be observed that the test experiment does not yield an objectively worse forecast for precipitation and even improves somewhat on the overestimation appearing in the reference run. Similarly, in the case of wind gust forecast, there is a rather large overestimation of wind gust in the reference run, which is considerably improved in the test experiment (*Fig. 7*). All in all, the case study for this specific day implies that the quality of the forecast is similar in both experiments, but the test experiment can potentially slightly improve the forecast quality, which is most likely linked to the drying effect mitigating the large overestimation of humidity in the AROME/HU model.

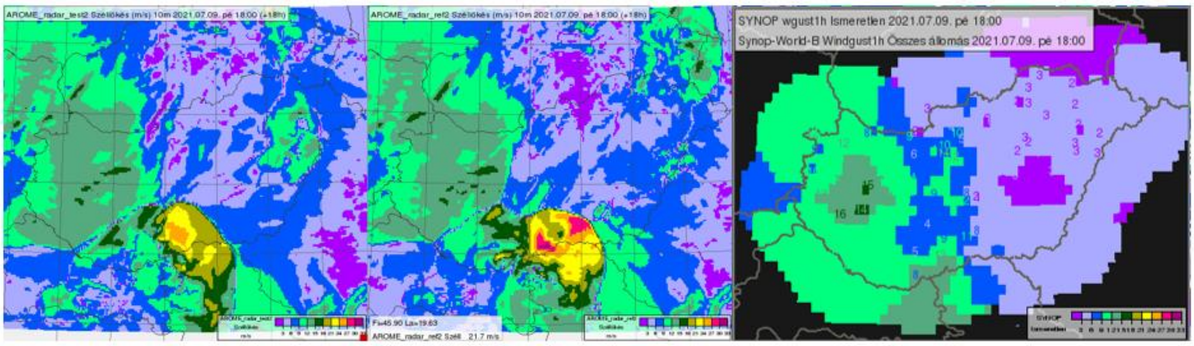

Figure 7. 18-hour forecast of wind gust for the 0 UTC runs of the test experiment (left) and the reference run (middle) and the SYNOP measurements of wind gust (right) on 18 UTC, 9 July 2021.

7 Conclusion

The experimental setup described in this report was one of the first radar-related work in Hungary. During the time period of this remote stay, substantial progress was made towards assimilating radar reflectivity data in the AROME/HU system. Many of the technical difficulties related to the inclusion of radar data were resolved, which also made it possible to set up a proper test experiment that yielded promising results. In this sense, it was quite beneficial to be able to implement the HOOF and other related material (e.g. the code needed for recompilation) into the AROME/HU system right from the beginning, as this will make further experiments much easier in the future. The verification results from some rather important parameters, such as precipitation and cloud cover also show that the assimilation of radar reflectivity data may result in better forecast quality, which makes further experiments worthwhile.

For the future, there are several ways in which to proceed. It would be most beneficial to circumvent the aforementioned memory-related issues in order to be able to use more radar data available on the AROME/HU domain, which could possibly improve the positive impact of the reflectivity assimilation on the forecast. Tackling these issues would also make it easier to set up more experiments, for example by implementing superobing in the HOOF system, or adding radial wind measurements in the assimilation cycle.

References

[1] Máté Mester: *Towards homogenization of OPERA radar data*, report from RC LACE Stay, 2018, 4 pp.

[2] Éric Wattrelot, Olivier Caumont, 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] Suzana Panežić: *Impact studies with OPERA reflectivity observations*, report from RC LACE Stay, 2021, 27 pp.

[4] Ida Maiello, Rossella Ferretti, Sabrina Gentile, Mario Montopoli, Errico Picciotti, Frank Silvio Marzano, Claudia Faccani: *Impact of radar data assimilation for the simulation of a heavy rainfall case in central Italy using WRF-3DVAR*. Atmospheric Measurement Techniques, 7, 2919-2935, 2014.