

**Radar assimilation and latent heat nudging in  
AROME Nowcasting/AROME-PI  
11. October-21. November 2015  
Météo France (Toulouse, France)**

**RC - LACE stay report**

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## **Introduction**

The aim of the stay was to improve the exploitation of RADAR data for the AROME model in nowcasting mode. Firstly some modifications in the 3D-Var data assimilation proposed by Eric Wattrelot and Ludovic Auger were tested for several case studies: Modification of observation error, thinning length, and search radius for humidity profiles in the 1D reflectivity-humidity conversion (Caumont et al. 2010, Wattrelot et al. 2014). Furthermore saturation and even supersaturation of pseudo observation humidity profiles in case of observed reflectivity was tested. These experiments were done within the OLIVE scripting and running environment on Météo France super computer with cy40\_op2 version of AROME-PI, the pre-operational version of AROME-Nowcasting in Météo France with a horizontal grid space of 1.3km and 90L. As reference precipitation fields from the Météo France ANTILOPE precipitation analysis system (combination of RADAR and rain gauge measurements over France on 1km grid, Laurantin 2008) was used.

In the second part of the stay the coding of latent heat nudging (LHN hereafter) within the AROME framework was done and tested. Due to the heavy workload of the MF computer at that time, the latter was mostly done via remote connection on ZAMG super computer with cy38t1 export code version (cy40\_op2 was not available there). Also a cy40\_op2 version of LHN was coded, but could not be successfully tested till the end of the stay due to a bug, which led to crashes. Meanwhile an improved LHN version based on cy40t1 export code version is also available.

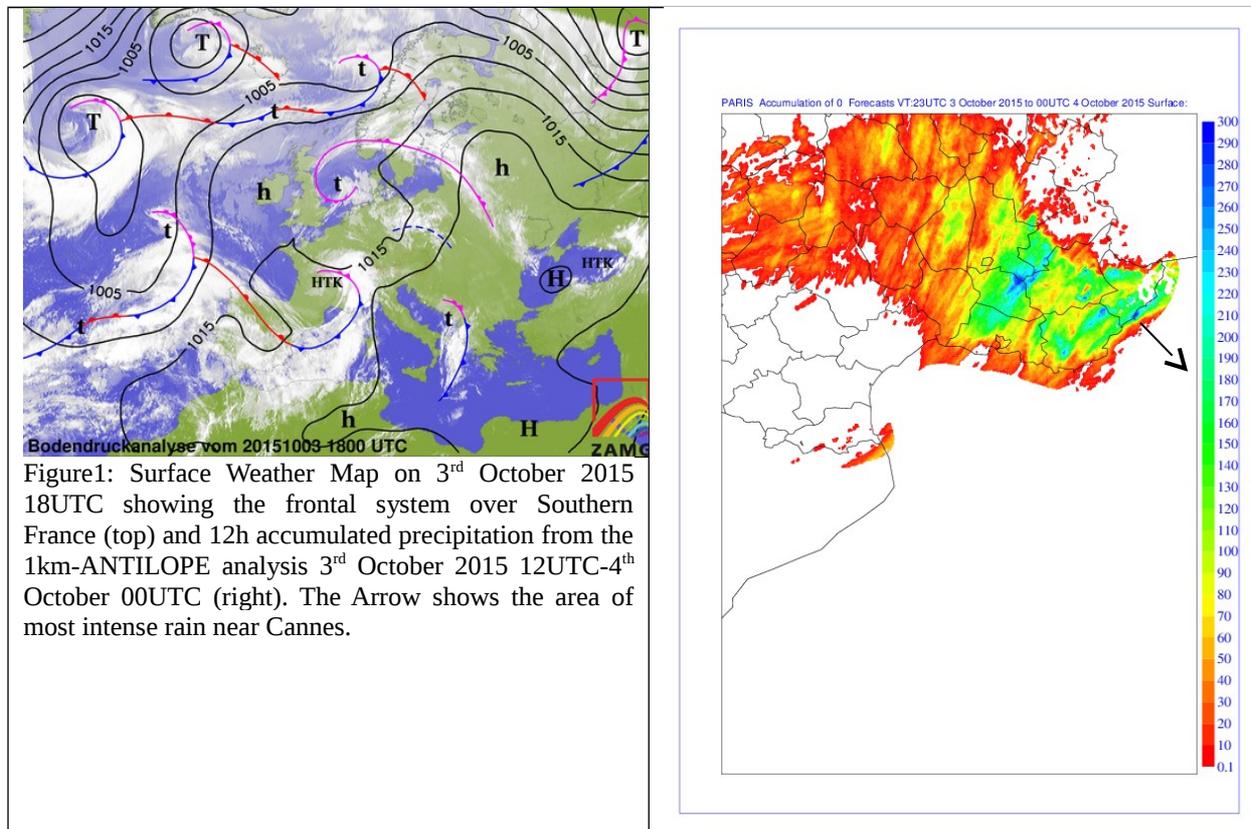
## **AROME-PI-System**

The AROME-PI system is the nowcasting configuration of Météo France AROME version, running hourly up to +6h on the same domain (1536x1440 grid points) and with the same resolution (1.3km/90L) as the operational French AROME system at that time. Its lateral boundary conditions come from downscaled Arpège model. Main differences to the operational “AROME France” are: A very short cutoff time for the observations of 15min for the 3D-Var data assimilation system, which enables very early availability of the forecast, but reduces the number of available and used observations, usage of operational AROME forecasts as first guesses such that there is not a closed assimilation cycle as in the operational AROME version, stronger tuning towards observations with REDNMC=3.0 in minimization step and not using incremental analysis update. Soil fields are either taken from former AROME-PI forecasts or operational AROME. So no own soil assimilation is run. See also Auger et al. 2015 and Hagelin et al. 2014 for a description of former versions of this system.

## **Case studies: 3<sup>rd</sup> October 2015 and 23<sup>rd</sup> August 2015**

For the RADAR assimilation experiments over France two cases of severe convection have been chosen: On 3<sup>rd</sup> of October 2015 in the evening, severe thunderstorms fuelled by warm humid air from the Mediterranean Sea formed a squall line on the east side of an upper level trough over Southern France and hit the South Eastern part of France. The event caused 20 casualties due to flash flooding and significant other damages. According to an internal Météo

France report the Département Alpes-Maritimes was especially affected, where in the Commune of Cannes 195.5mm of precipitation in 24h (106.8 mm within one hour, 18-19 UTC) were observed, and where in Mandelieu-la-Napoule 159mm (98.7mm in one hour) fell. Although AROME-PI simulated heavy rains of more than 140mm in 12h in the correct area, the local maxima were significantly underestimated. This kind of event albeit not with that exceptional intensity is quite often observed in autumn in this region.



On 23<sup>rd</sup> of August 2015 also severe thunderstorms hit the French Mediterranean area, but that time more to the West between the coast and the Cévennes Mountains (Départements Gard and Dep. Hérault), where according to the ANTILOPE analysis more than 290mm of precipitation in 12h occurred. The thunderstorms developed on the warm side of a slowly southeastward moving front extending from the British Islands via the Massif Central in France to Eastern Spain. As on 03<sup>rd</sup> October, AROME-PI forecast the convective rain, but underestimated the local maxima. On the other hand the area of light rain in the first hours was significantly overestimated.

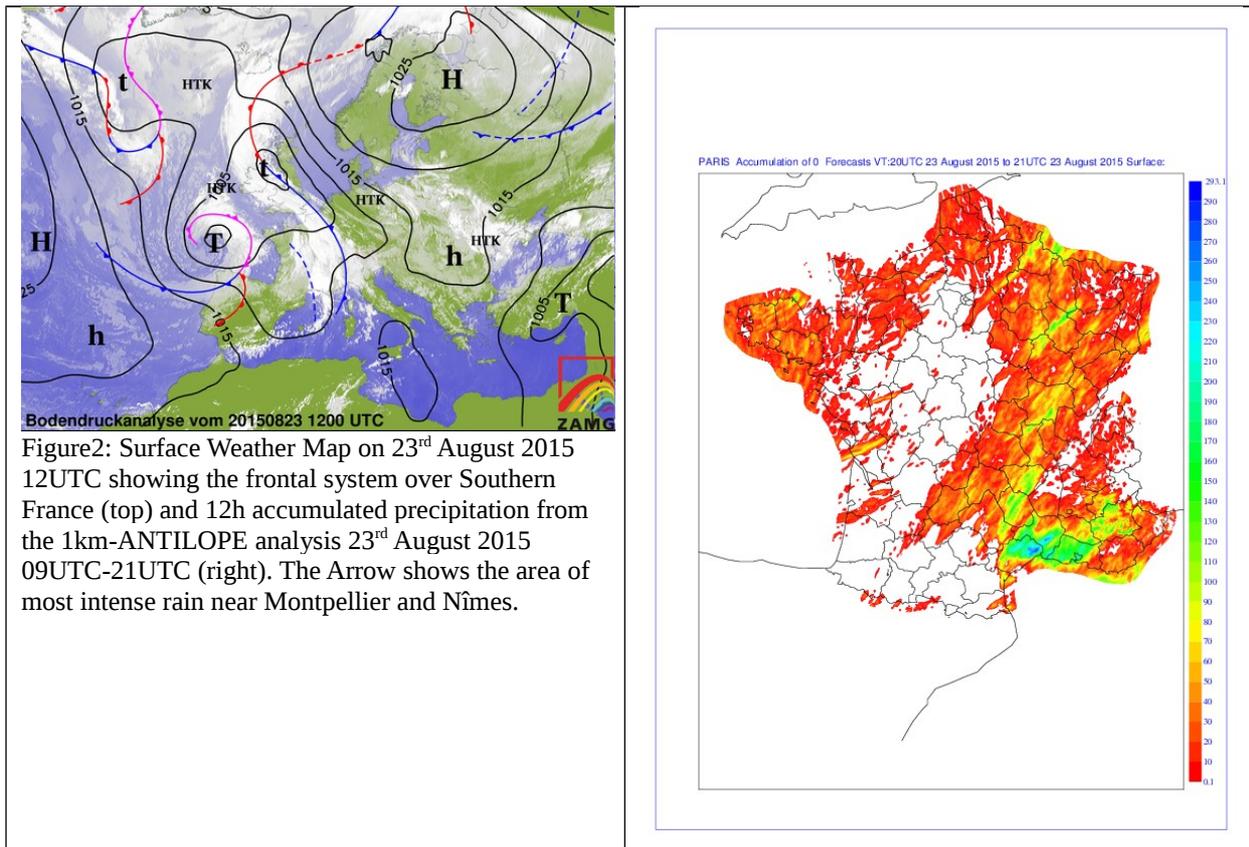


Figure2: Surface Weather Map on 23<sup>rd</sup> August 2015 12UTC showing the frontal system over Southern France (top) and 12h accumulated precipitation from the 1km-ANTILOPE analysis 23<sup>rd</sup> August 2015 09UTC-21UTC (right). The Arrow shows the area of most intense rain near Montpellier and Nîmes.

## RADAR assimilation experiments

Several experiments have been conducted for both cases. On 3<sup>rd</sup> October the 12 UTC runs were evaluated, on 23<sup>rd</sup> August 2015 the 09 UTC runs. The different experiments are listed in Table1 and Table2 respectively. First, the thinning length for RADAR data was reduced by a factor of 0.5 in BATOR (ZSAMPL\_RADAR switch) and screening step (RMIND\_RADAR, RFIND\_RADAR), which increases the amount of used RADAR observations significantly, hoping this would also lead to a more accurate precipitation field (e. g. higher maxima) in the first forecast hours. The reduction of thinning length might be justified by the recent increase of model resolution (2.5km to 1.3km grid space). However, there is some risk due to the assumption of uncorrelated observation errors by the assimilation algorithm. This experiment is named EXP1. In addition the observation error was modified by introducing a tuning factor SIGMAO\_COEF(13)=1.2 for RADAR in bator\_ecriure\_mod.F90. It was found, that there is a namelist definition of RADAR observation error in bator\_init.F90 ECTERO(NRADAR,1,,:)=1.5, but different to other observations it is not used later anymore except for reflectivity, but the definition in bator\_ecriure\_mod.F90 L1564ff (EXP6). The idea was to compensate a bit the increased weight of radar due to the reduced thinning and to take into account the fact that the observation errors should be slightly increased due to possible spatial error correlations. Other modifications were done within the 1D-Bayes algorithm, which converts reflectivity to relative humidity observations during screening: Firstly the relative humidity pseudo observations were replaced by the maximum of 100% and the original observation in case the observed reflectivity exceeded a threshold of 8.0 dBz or if 5.0dBz were exceeded and no reflectivity simulated (EXP7). To avoid later rejection of the modified profiles the ZDIFF variable in inv\_refl1dstat.F90 was set to 0.1 in that case. This experiment was also combined with reduced thinning and obs error modifications (as in

EXP6) and in this case named EXP8. Also the search radius for suitable first guess humidity profiles could be increased by setting  $zdist=200000.0$  instead of  $100000.0$  in `arpifs/obs_preproc/radar_prof.F90` or reduce the weight of individual profiles by increase the error  $ZXSIG=5dBz$  instead of  $0.2dBz$  in `arpifs/op_obs/inv_refl1dstat.F90` (where  $ZXSIG = \sigma_z$  is the standard deviation of observed and simulated observation in Caumont et al. 2010). These two changes have already been made in an AROME France test-suite and where also tested in the two case studies. Hereafter these experiments are named EXP12. Finally the too big area of light rain was considered: This might be partially caused by hydrometeor blending after minimization, leading to usage of falling hydrometeors from first guess, which might not perfectly fitting the updated analysis. By supersaturating the pseudo relative humidity observations to 105% in case that observed reflectivity exceeds a threshold of 5.0 dBz, this supersaturation is immediately converted to falling hydrometeors by the model physics within the first timestep of integration. These hydrometeors were assumed to fit better to the observed reflectivities and therefore might lead to a better precipitation forecast at the beginning of the model run, even if the thresholds and supersaturation were set somehow arbitrary. This test was called EXP13.

Table1: List of experiments on 3<sup>rd</sup> October 2015

REF	Simulation with AROME-PI standard settings
ZAMG	Simulation with AROME-Austria
EXP1	Modified RADAR thinning: ZSAMPL_RADAR=2500, RMIND_RADAR=0.035, RFIND_RADAR=0.075 half the values of standard AROME-PI settings
EXP2	as EXP1 ECTERO(NRADAR)=1.8 instead 1.5
EXP6	As EXP2 but SIGMAO_COEFF(13)=1.2
EXP7	As REF but modified 1D Bayes function in case of obs refl.> threshold set RH to MAX(RH,1.)
EXP8	As EXP6 but modified 1D Bayes function in case of obs refl.> threshold set RH to MAX(RH,1.)
EXP12	as REF but settings as in AROME_MF_ESUITE Thinning number of profiles search length
EXP13	no hydrometeorblending but supersaturation in RADAR RH

Table2: List of experiments on 23<sup>rd</sup> August 2015

REF	Simulation with AROME-PI standard settings
EXP6	as REF but modified BATOR and thinning length
EXP7	as REF but modified reflectivity-humidity inversion:
EXP8	modifications of EXP6 and EXP7
EXP9	as EXP7 but instead setting RH to 1.0 setting to 1.15
EXP12	as REF but settings as in AROME_MF_ESUITE Thinning number of profiles search length
EXP13	no hydrometeorblending but supersaturation in RADAR RH

## Results

As already mentioned the AROME-PI simulated precipitation maxima (168.7mm) clearly underestimated the observed values on 3<sup>rd</sup> October 2015 (Fig. 3). This is even more valid for the ZAMG simulation which might be related to lower model resolution (2.5km instead of 1.3km in AROME-PI) and the fact that the event occurred quite close to the Austrian AROME domain boundary. However, both simulations managed to simulate a strong convective event in the Alpes-Maritime area. The area affected by light rain is clearly overestimated in both simulations. Similar can be found for the 23<sup>rd</sup> August (Fig. 4), even if we have to take into account, that some kilometres from the coast line no precipitation analysis is available due to lack of RADAR coverage and surface observations, which does not affect the AROME

simulations. Reducing the thinning length in EXP1 (Fig. 5 top left), leads to a very slight higher maximum (171.2mm/12h instead of 168.7 mm/12h) even if the number of radar observations used is significantly higher (more than factor 20 according to minimization node file). Increasing additionally the observation error value ECTERO in bator\_init\_mod.F90 (Fig. 5 top right) even lowers the maximum to 161.4mm/12h. Increasing the observation error for reflectivity, Doppler wind and pseudo humidity profiles by a factor of 1.2 clearly improves the forecast maximum precipitation for both 3<sup>rd</sup> October and 23<sup>rd</sup> August (Fig. 5 bottom left and right). This is especially unexpected, because increased observation error should keep analysis closer to first guess than observations. The number of observations is almost unchanged by this latter modification. Further investigations would be necessary to understand the effects of the observation error modification better.

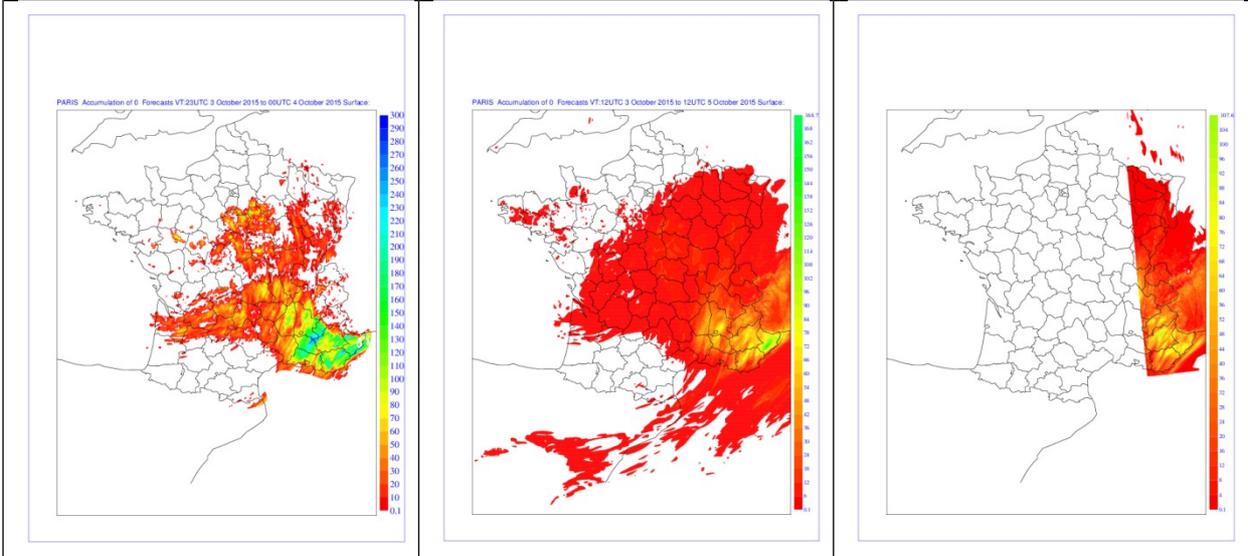


Figure 3: 12h accumulated precipitation from the 1km-ANTILLOPE analysis 3<sup>rd</sup> October 2015 12UTC-24UTC (left) and simulated AROME-PI (middle) and ZAMG operational AROME version (right).

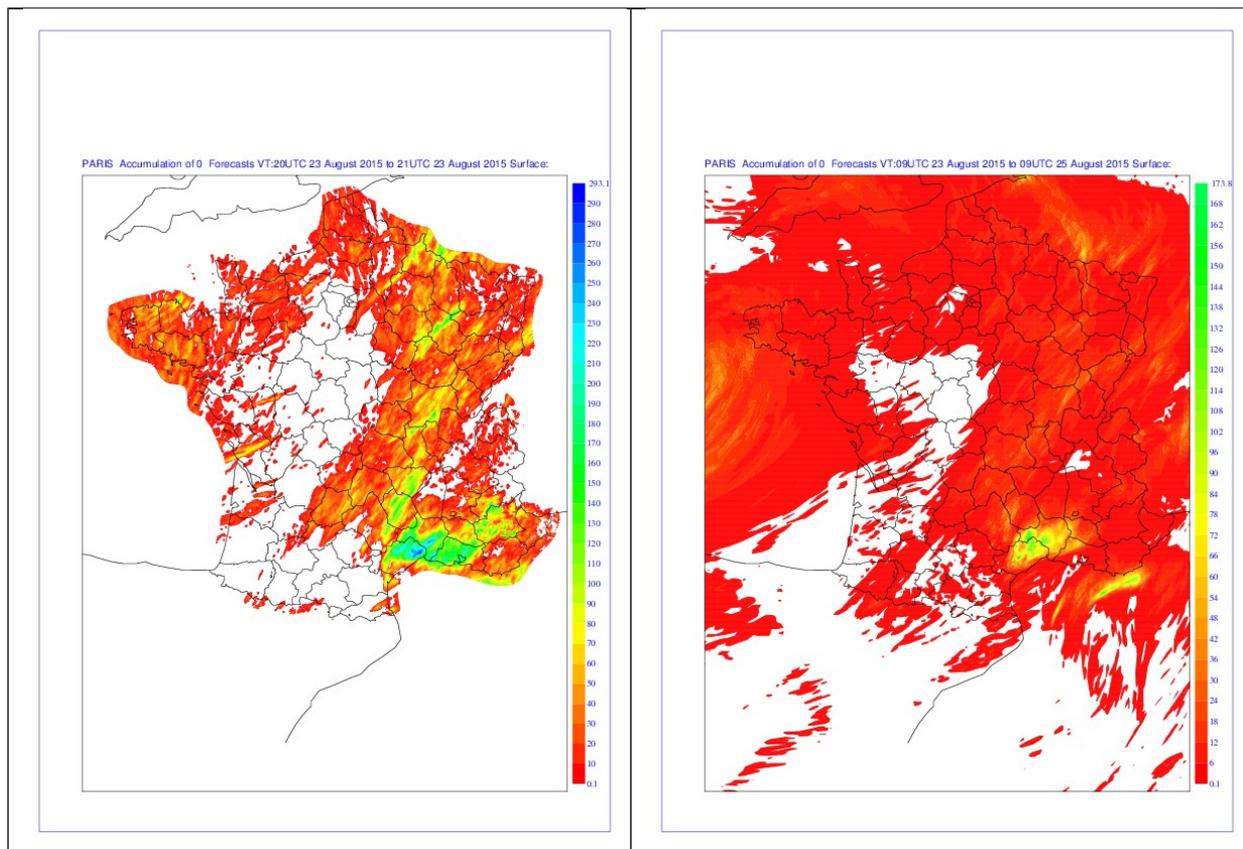
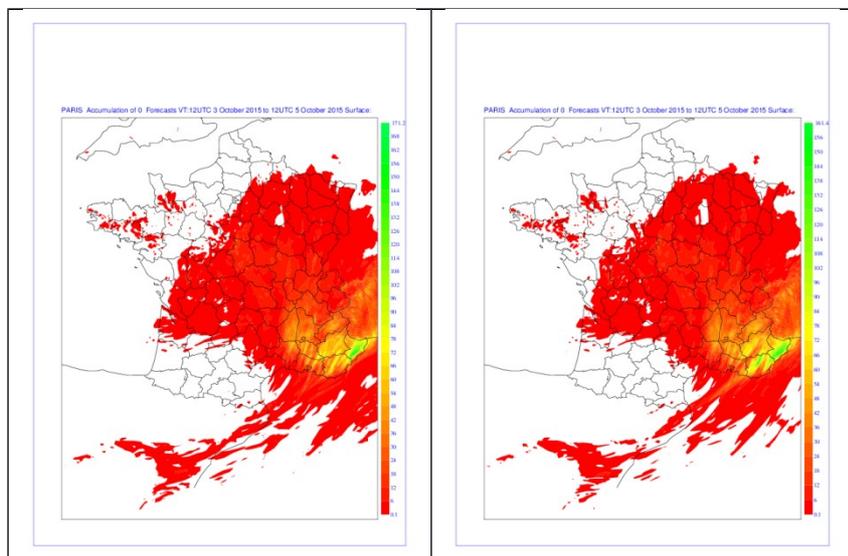


Figure 4: 12h accumulated precipitation from the 1km-ANTILOPE analysis 23<sup>rd</sup> August 2015 09UTC-21UTC (left) and simulated AROME-PI (right), ZAMG AROME configuration does not cover the area of interest in this case.



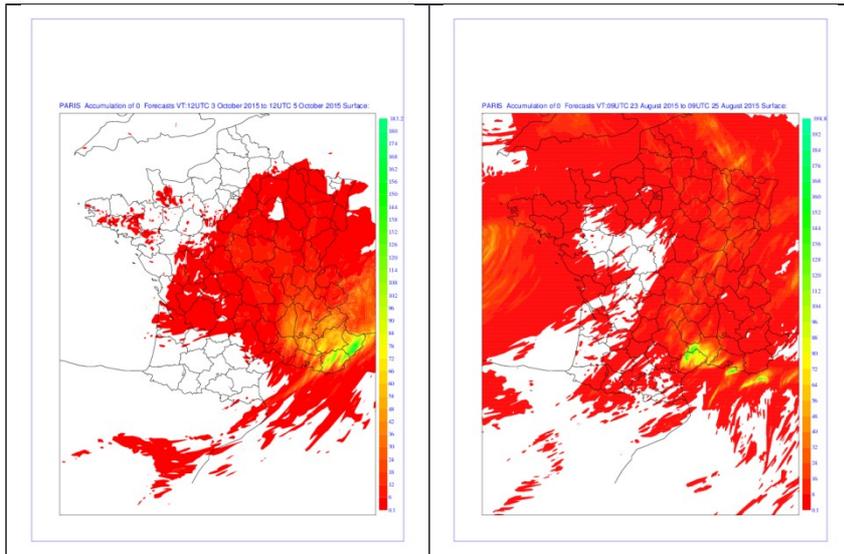


Figure 5: 12h accumulated precipitation from EXP1 (top left), EXP2 (top right), EXP6 (bottom left) on 3<sup>rd</sup> October and from EXP6 on 23<sup>rd</sup> August 2015 (bottom right).

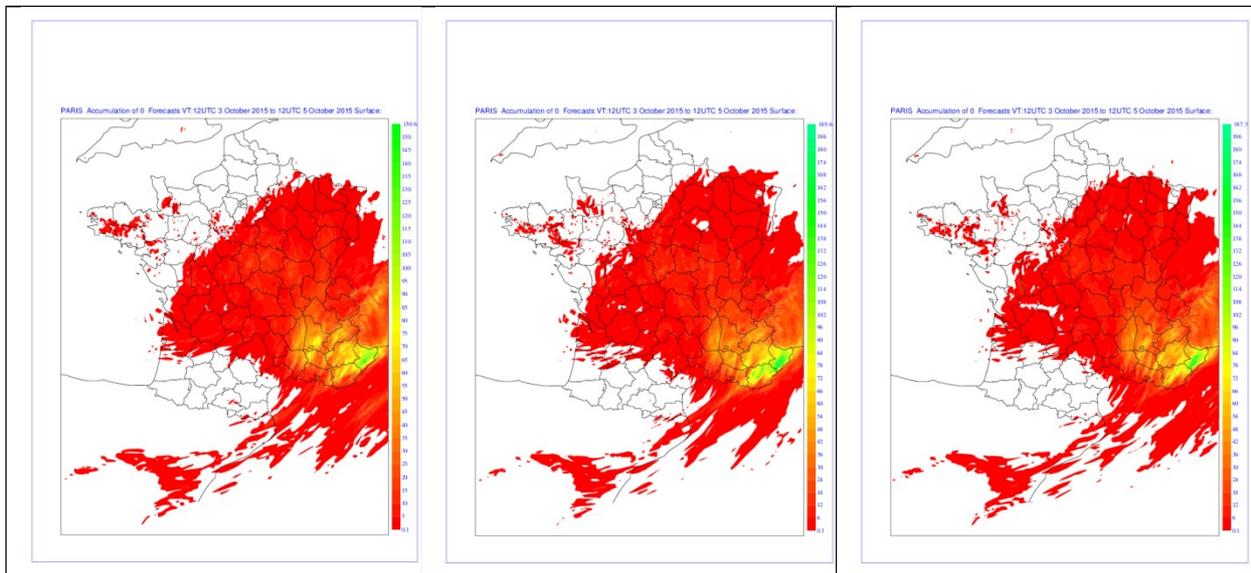


Figure 6: 12h accumulated precipitation from EXP7 (left), EXP8 (middle), EXP12 (right) on 3<sup>rd</sup> October 2015 12-24UTC.

Figure 6 shows the results for the 1D-Bayes algorithm modifications on 3<sup>rd</sup> October 2015. The saturation of profiles with observed reflectivity above 8 dBz (EXP7 left) shows minor impact. The maximum rainfall amount is even slightly reduced compared to the reference (Fig.3 middle) and some slight shifts of local maxima are found. Adding this modification to the observation error and thinning modification (EXP8; Fig. 6 middle) delivers on contrary an even more pronounced maximum of 189.6 mm than found in EXP6, which is not surprising, because if more humidity observations are used, it is also more likely that they are affected by the additional saturation. Interestingly increasing the profile search radius to 200km and the Error ZXSIG (EXP12), has an impact on the precipitation of similar strength than all other modifications together: The maximum is strongly intensified. Similar results are found for the August case (Fig. 7, 8): The saturation of profiles EXP7 leads to only minor modifications of the precipitation field even if the maximum is slightly higher than in the reference here (187.6mm instead 173.8 mm). Again the combination with reduced thinning and higher observation error leads to an even more pronounced maximum (232.1mm) closer to the ANTILOPE analysis (293.1mm, Fig. 4 left). The modification of search radius for pseudo observations and ZXSIG modification in EX12 delivers an even higher maximum (272.2mm). It is also noteworthy that in this case the simulated convection over the Mediterranean Sea (small areas of high rain rates) close to the French coast is significantly influenced by the different modifications. For this case study another experiment has been conducted, where profiles with observed reflectivities over 8dBz, where not only saturated as in EXP7, but supersaturated to 115% (EXP9, Fig. 8). This leads to a weaker maximum of the rain rate and a larger area covered with light rain and

therefore to an unwanted degrading compared with EXP7. So the saturation of profiles seems to be not suitable to get better maxima of extreme precipitation events.

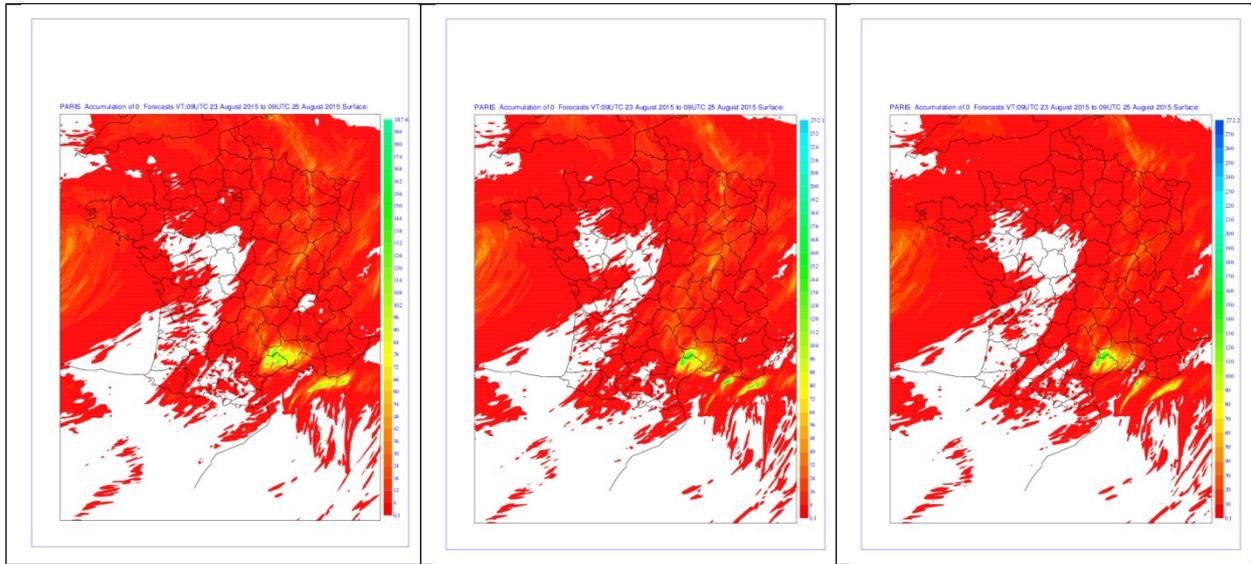


Figure 7: 12h accumulated precipitation from EXP7 (left), EXP8 (middle), EXP12 (right) on 23<sup>rd</sup> August 2015 09-21UTC.

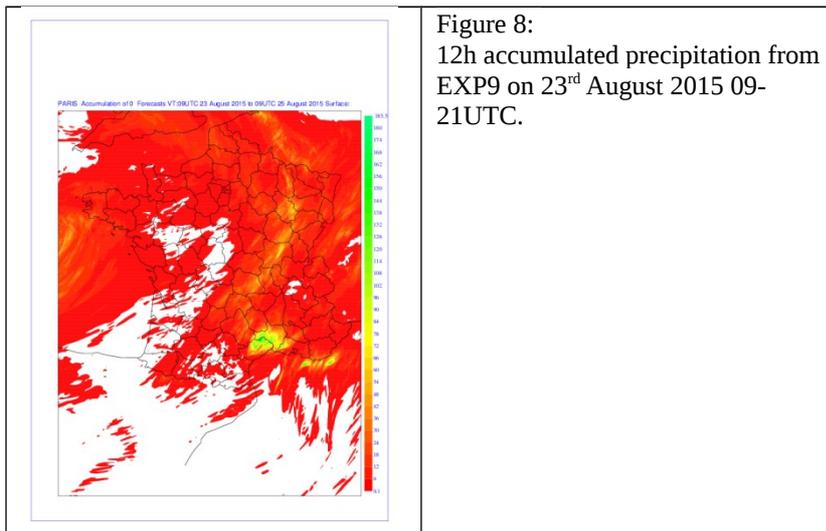


Figure 8:  
12h accumulated precipitation from  
EXP9 on 23<sup>rd</sup> August 2015 09-  
21UTC.

In a last experiment, it was tried to improve the overestimation of the area of light rain compared to ANTILOPE. This was found already to occur in the first forecast hour (Fig. 9, 10 left, middle) in both of the investigated cases. Therefore, it was supposed to be related to the blending of falling hydrometeors (rain, snow, graupel) from the first guess into the analysis after the 3D-Var. Falling hydrometeors are not part of the 3D-Var minimization process, because there is lack of observations and the relation to other components of the trajectory is rather complex and nonlinear (such that a multivariate approach by a simple balance assumption is not promising). However, it can be assumed that these hydrometeors are present if higher values of radar reflectivity are observed. Therefore, it makes sense to supersaturate the pseudo humidity radar observations there, such that hydrometeors are immediately formed by the AROME microphysics' saturation adjustment, just after start of the integration by redistribution of the extra liquid water. Even the fast production of a solid component can be achieved depending on the model temperature. In EXP13 this was tried, by simply switching off the blending after minimization and supersaturate pseudo humidity observation profiles to

105% in case observed reflectivity exceeds 5dBz. However, an empirical fit of reflectivity and amount of supersaturation would be necessary to get not only the right place of rainfall, but also realistic rain rates. Nevertheless, improvement of the area covered by light rain was found compared to the regular blending method (Fig. 9, 10, right). The effect on 12h sum is shown in Fig. 11. Different to the EXP7 results the areas covered with light rain are not enhanced. However, a small reduction of the maximum rain rate is found for 3<sup>rd</sup> October, but not for 23<sup>rd</sup> August. Another disadvantage of this method is, that it cannot deliver realistic results in areas not covered by RADAR or if RADAR observation data are not available. Therefore, a combination with hydrometeor blending, where amount of hydrometeors blended is reduced or other observation derived hydrometeor initialisation like satellite based, should be envisaged. In the 2.5km version of AROME-Nowcasting at ZAMG an underestimation of the area covered by light rain is normally found during the first hour of integration. Therefore, different impact of the method can be expected.

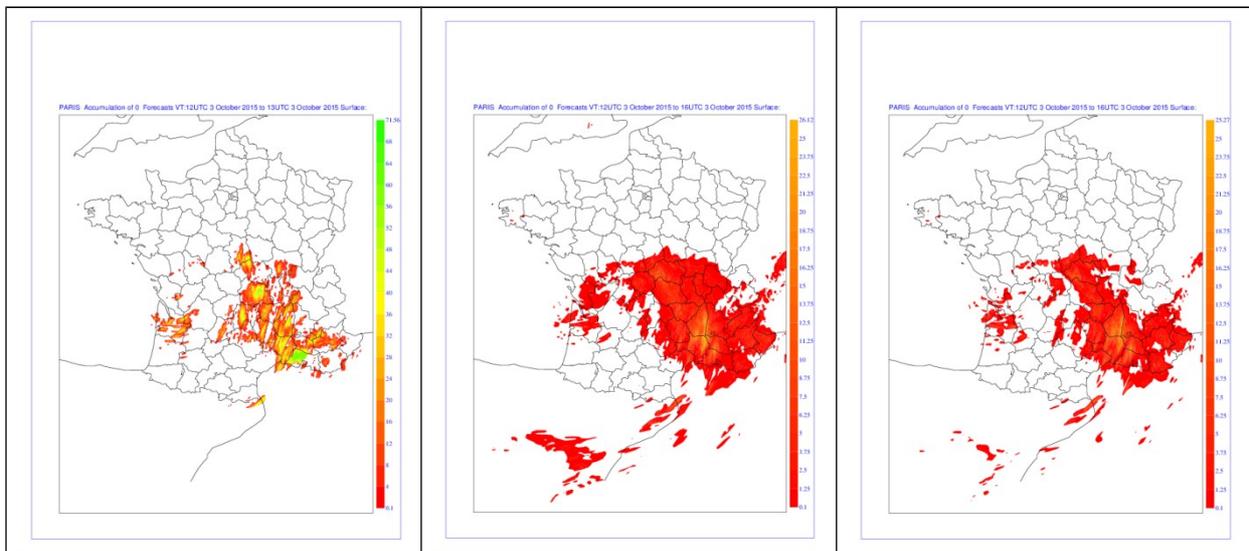


Figure 9: 1h accumulated precipitation from ANTILOPE (left), REF (middle), EXP13 (right) on 3<sup>rd</sup> October 2015 12-13UTC (fist forecast hour).

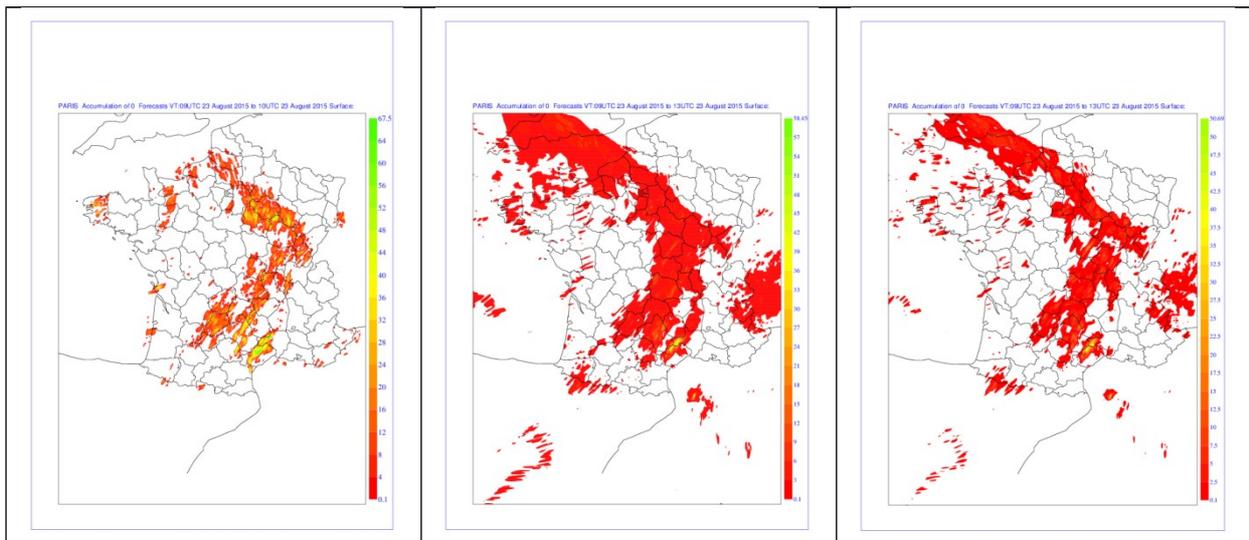


Figure 10: 1h accumulated precipitation from ANTILOPE (left), REF (middle), EXP13 (right) on 23<sup>rd</sup> August 2015 09-10UTC (fist forecast hour).

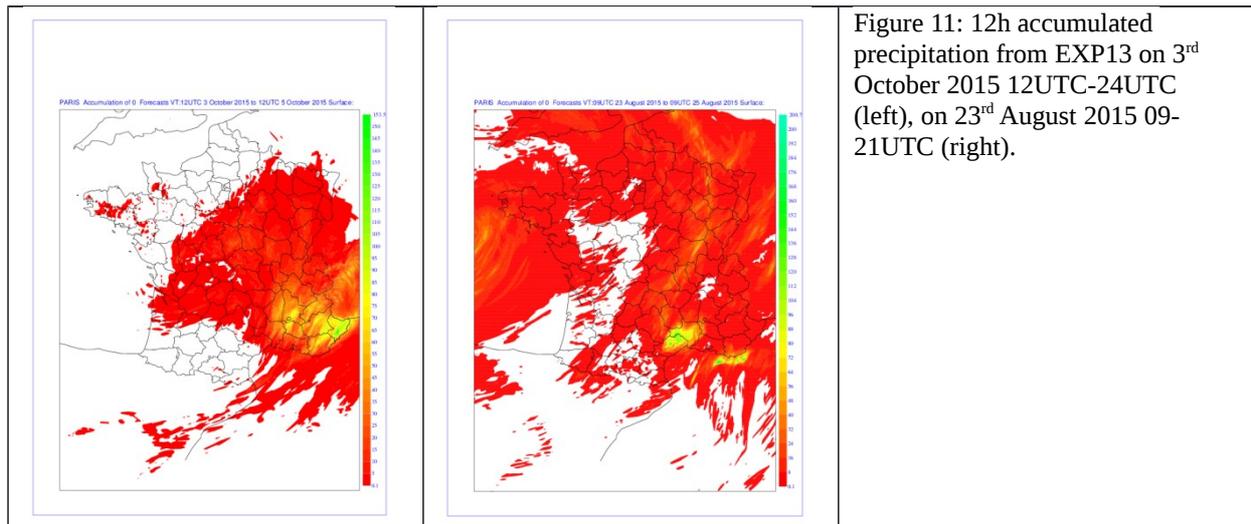


Figure 11: 12h accumulated precipitation from EXP13 on 3<sup>rd</sup> October 2015 12UTC-24UTC (left), on 23<sup>rd</sup> August 2015 09-21UTC (right).

## Conclusions

For the two cases investigated, the modification of thinning length alone leads to usage of much more RADAR observations within the analysis, but does not significantly change the shape of the strongest convective cells. The change of observation error (factor 1.2) in `bator_ecriture_mod.F90` in addition or the change of search radius for humidity profiles (200 instead of 100km) and ZXSIG (the latter modifications are used in an E-suite at Météo France) delivers much more pronounced precipitation maxima, leading to better results in the case studies. Saturating or even supersaturating the pseudo observation moisture profiles has some impact and might be used to improve the precipitation field in the first hour of integration. However, the effects are not always positive, so a more sophisticated evaluation including fitting of thresholds and supersaturation would be needed, before a reasonable application instead of hydrometeor blending could be envisaged.

## Latent heat Nudging

### Background

Latent heat nudging (LHN) is a quite well established technique to exploit RADAR data in NWP. It is currently used for example in UK-Unified model (Jones and Macpherson 1997) but also COSMO model (Stephan 2008). A similar technique based on divergence instead of latent heating is also available for HIRLAM (Korsholm et al. 2014). Some tests were done even with ALADIN (Cedilnik 2005), but not with AROME so far. Different to the regular 3D-Var algorithm in AROME, this approach just uses 2D-RADAR rain rate products  $RR_{OBS}$ . These are compared to the simulated rain rate  $RR_{model}$  of the model and according to that, the latent heat tendency of the model  $\Delta\theta_{phys}$  is intensified or weakened during the first timesteps of model integration by an additional tendency term  $\Delta\theta_{LHN}$  (see Eq.1-4 after Jones and Macpherson 1997). The aforementioned modification is only done in a certain range of  $RR_{model}$  determined by the constants  $\alpha$  and  $\varepsilon$ . Otherwise model precipitation and latent heat profile from the surrounding grid points are evaluated, if they fit into the interval of Eq.1 (see Eq.2). If this also fails, Eq.3 or Eq.4 are applied. In all cases the 2D-Information is spread into 3D tendency changes. It is assumed that the error in simulated precipitation on the ground is related to a wrong heating profile and that its correction will deliver better precipitation forecasts.

$$\Delta \theta_{LHN} = \Delta \theta_{phys} \frac{RR_{obs} - RR_{model}}{RR_{model}}; \varepsilon RR_{OBS} < RR_{model} < \frac{1}{\alpha} RR_{OBS} \quad (1)$$

$$\Delta \theta_{LHN} = \frac{RR_{obs}}{RR_{model_{near}}} \Delta \theta_{phys_{near}} - \Delta \theta_{phys} \quad (2)$$

$$\Delta \theta_{LHN} = \frac{1}{\varepsilon} \Delta \theta_{phys}; RR_{OBS} > RR_{model} \quad (3)$$

$$\Delta \theta_{LHN} = (\alpha - 1) \Delta \theta_{phys}; RR_{OBS} < RR_{model} \quad (4)$$

Equation 1-4: Calculation of the LHN increment after Jones & Macpherson. They chose  $\varepsilon=1/3$  and  $\alpha=1/3$ , Stephan 2008 propose  $\varepsilon=0.5$  and  $\alpha=0.5$ . In AROME  $\varepsilon$  and  $\alpha$  can be set by namelist.

This method is advantageous, because it is very fast and efficient, it does not need full 3D volume data and it can also take into account data at several timestamps, such that a temporal development of the observed features can be passed to the model. On the other hand there is no real 3D information used and in case the model is quite far from real state of the atmosphere just modification of heat rate might be dangerous. Furthermore there is a time delay between the diagnosed difference in rain rate and the effect of the correction by the increment, which could be problematic especially, if mean/accumulated values of rain observations are used (as it is done in INCA used at ZAMG) or the convective cells move or develop very fast. Finally a reasonable heating rate profile has to be defined, if no physics tendency is available due to lack of precipitation/condensation in the model, but rain is observed. Also the quality of the radar precipitation product is an important issue: Artificial echos like clutter etc. could severely deteriorate the model forecast, if not filtered out. As precipitation observations the ANTILOPE analyses (Laurantin 2008) for AROME-PI and INCA analyses (Haiden et al 2010) for AROME-Nowcasting at ZAMG were selected. The latter combines RADAR and rain gauge data in a 5min or 15min interval (accumulated rain). INCA also includes a conventional precipitation nowcasting based on motion vectors derived from former analyses. So also INCA forecasts could be and were nudged by the new scheme. Both datasets are available on a 1km grid.

## Technical steps

The LHN in AROME consists of two main steps: First the rain observations (ANTILOPE, INCA, other) are interpolated to AROME model grid by nearest neighbour interpolation, which is fast and does not smooth the precipitation objects. The observations are written to a FA file called RROBS1.fa as field S001RAIN-S0XXRAIN, where S001RAIN is the first observation closest to analysis time followed by later observations coded as S002RAIN and so on. That means the number of observation time stamps is technically limited to the number of vertical levels, which is normally not a significant restriction. In a second step, we run modified 001 configuration, where the main part of LHN is done.

### 1. Preparation: Create FA file for observations

First the observations have to be interpolated onto the AROME grid and saved in a readable file. An arbitrary AROME history file from a former AROME-PI/AROME run is taken and renamed to RROBS1.fa. The 3D RAIN field S001RAIN-S0XXRAIN is set to NAN value -9999.99 by running a modification of BLENDSUR binary called CLEANRROBS. To compile /aladin/programs/cleanrrobs.F90 a new binary cleanrrobs has to be defined in

~/gmkpack/link directory. The files name, projlist, entry, ldflags have to be edited: name=CLEANRROBS, projlist=aladin,arpifs,ifsaux, entry=al\*d\*/programs/cleanrrobs.o, ldflags as in blendsur. Then the binary can be compiled. The only input and output file is RROBS1.fa. CLEANRROBS has to be called consecutive times (as often as number of model levels, because one level is set to NAN at each run of the binary), where the output FA is the input for the next step and the field name in namelist rises from S001RAIN to SXXXRAIN. This step has to be done only once as long as model domain/resolution does not change. This file will be always the first input for step3, therefore keep a safe copy of it, which cannot be overwritten during step3. Example of namelist fort.4 (\$count=001-NLEVEL):

```
&NAMINTERRROBS
  CL_CVARB(1)='$${count}RAIN'
/
&NAMDYNCORE
/
&NAMSCEN
/
```

## 2. Generating AROME coordinate ASCII file with Epygram tool:

Run epygram fa\_2geo.py (epy\_conv.py 'geo') on an AROME history file to get an ASCII coordinate file of the AROME domain: ICMCHAROM+0011.SURFTEMPERATURE.geo. If Epygram is not installed, also EDF tool could be used. This would need a small adaptation of the INTERROBS routine to the edf output format. This step has to be done also only once as long as AROME domain remains unchanged.

## 3. Convert observations to ASCII

In case of INCA, observations are already available in ASCII-format, in case of ANTILOPE it is grib, which can for example easily converted to ASCII by grib\_api. It is important, that first observation time has to be after initial time of the AROME/AROME\_PI run (physics has to run before).

## 4. Observation interpolation and writing to FA file

Another modification of BLENDSUR called INTERRROBS (ANTILOPE) and INTERRROBS3 (INCA) respectively was coded, which reads the RROBS1.fa file with NAN RAIN (called KUKU inside the binary), the AROME ASCII coordinates file (fort.13), the ASCII-observation file(s) (fort.12) and a namelist (fort.4) and does the nearest neighbour interpolation and writing to FA. In case of INCA, where INCA coordinates are not saved in the observation file an additional file with the INCA grid coordinates (fort.11) is read. INTERRROBS/INTERRROBS3 have to be compiled like CLEANRROBS by adding the fortran routine to the userpack and defining new binary in .gmkpack file. This is done for several observation timestamps by consecutive calls to INTERRROBS, INTERRROBS3 respectively using KUKU/RROBS1.fa output of the former step as input for the next time stamp, replacing ASCII-observation data file fort.12 with that of the new timestamp and changing the field name from S001RAIN to S002RAIN etc. in the namelist. Take care that you do not re-use the output RROBS1.fa file for other observation preparation experiments, because this might lead to a corrupted observation file (mixture of old and new observations). Use a copy of the original version after cleanrrobs step instead. At the moment, the code can only handle one observation (precipitation accumulation) time interval. In case we want to use 5min and 15min INCA analyses combined, we use 15min analyses 3 times and divide the

precipitation amount by 3 and set the time interval to 5min for the whole nudging period. As namelist for interrrobs the same as in step 1 for cleanrrobs can be used.

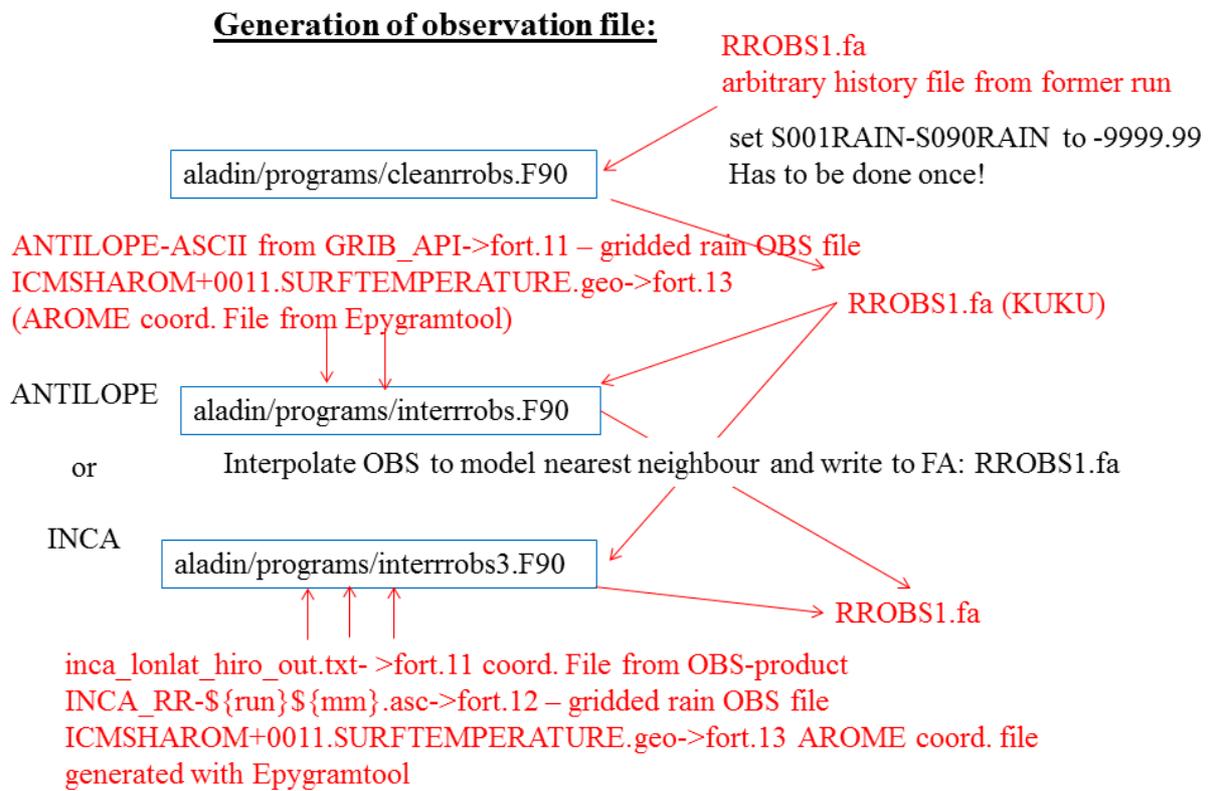


Figure 12: Schematics of the preparation step (observation interpolation and writing to FA)

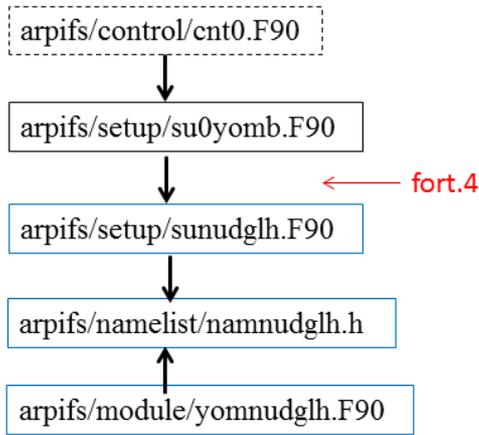
## 5. Running modified 001 configuration

The main part of LHN is done during integration (001 configuration of MASTERODB) using a modified binary MASTERODB and a modified 001 namelist (fort.4) and the result of step4 “RROBS1.fa”, which has to be copied into the working directory.

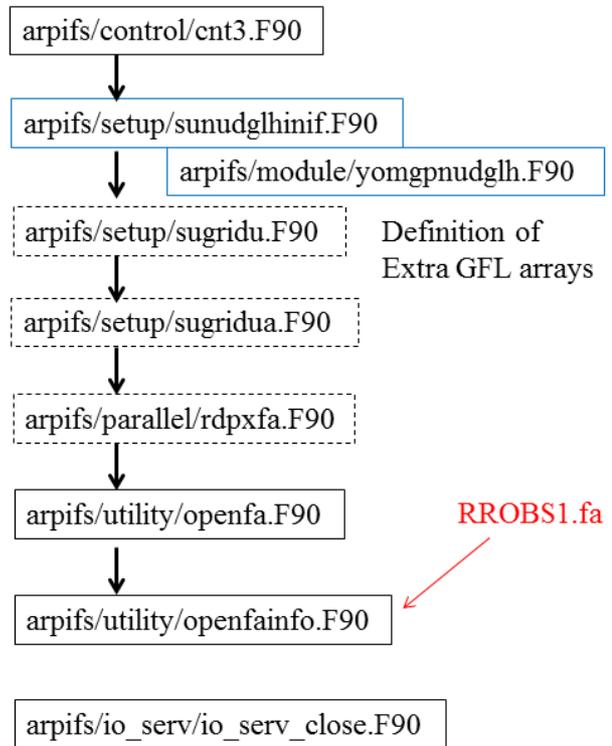
The modified binary reads the new namelist group `namnudglh.h` at the beginning of the run. This needs also a small modification of `su0yomb.F90` (call to new namelist group) and setup file `sunudglh.F90` (default values) and module `yomnudglh.F90`. By default (empty `namnudglh` group in 001 namelist) LHN is switched off. Also at the beginning of 001, the observation file produced in steps 1-4 is read (via `sugridu`) and the observations are written into a GFL array `GPNUDGLHGFL` (level 3-N). Level 1 of `GPNUDGLHGFL` is used in `nudglh.F90` to save the accumulated model precipitation of the current nudging step, such that the accumulated amount for the nudging time interval at next nudging step can be derived by subtract this saved value from total accumulated values since start of the model run `SURFACCPUIE` etc. for the next nudging step. Level 2 is used to save the nudging factor (ratio of observation-model/model precipitation). This factor can be re-used also in the following timesteps depending on `NTAUNUDGLH` namelist switch. A setup routine `sunudglhinif.F90` and a module `yomgpnudglh.F90` were coded for the definition and filling of `GPNUDGLHGFL` array. Also the utility files `faopen.F90` and `faopeninfo.F90` were modified such that they can treat the `RROBS` file. This namelist and file reading follows the approach used in IAU

routines coded by Pierre Brousseau. It was found, that the reading of FA file requires also some small change in io\_server\_close routine (character length of CLINC=16) to avoid model crash.

**Reading Namelist:**



**Reading all precip. Observations from FA file to GFL array in one go at start of integration:**



call →  
 file unchanged - - -  
 file changed ———  
 new file ——— (blue)  
 Input file ——— (red)

Figure 13: Schematics of the namelist reading routines in 001 (left) and the observation reading part of the code (right). Arrow means “call to subroutine”, dashed routines are as in export version, solid routines are modified for LHN, blue ones are completely new coded.

### Collect phys. tendencies, apply LHN during integration:

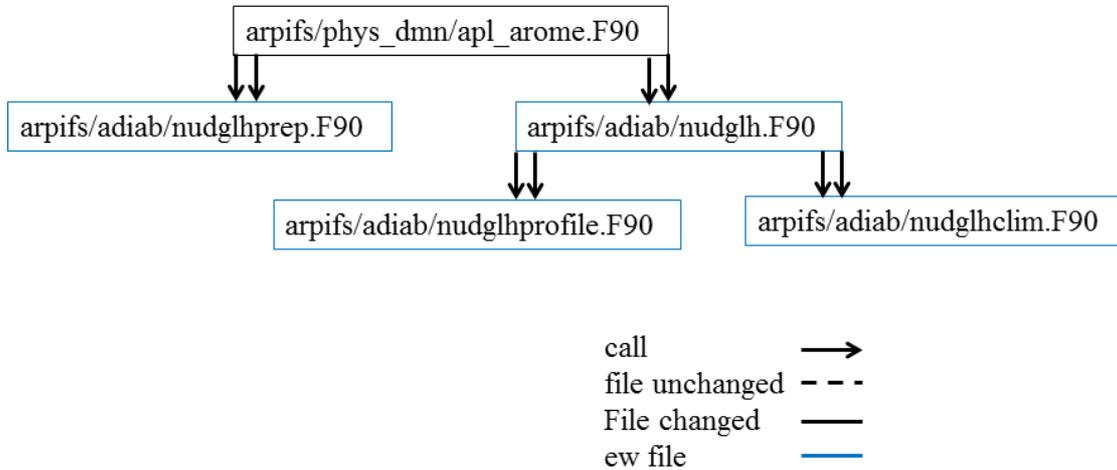


Figure 14: Schematics of the main part of LHN: Physics tendencies are collected in `apl_arome.F90` which calls `nudglhprep.F90` one timestep before nudging timestep to save latent heat profiles and main routine `nudglh` at nudging timesteps. The resulting LHN tendency is afterwards added to physics temperature tendency. `Nudglh.F90` calls `nudglhprofile` to find suitable latent heating profiles in the neighbourhood, if the one at the grid point itself is not usable and `nudglhclim` to use artificial idealised latent heat profiles if none of the former two fits (for example no rain at all in the model).

The main part of LHN is called from `apl_arome.F90` (physics steering routine). There, the latent heat tendencies from different physics schemes: saturation adjustment, `ARO_SHALLOW_MF` and `ARO_RAIN_ICE` are collected under `ZTENDT`. If, according to namelist settings, a timestep before nudging timestep is reached, `ZTENDT` is saved in `GPNUDGLHGFL2` array by a call to `nudglhprep.F90`. This is done, because in `nudglhprofile.F90` also neighbored latent heating profiles are considered, if the one at the grid point is not suitable, which might cause problems in current timestep due to parallelisation. At nudging timesteps, `nudglh.F90` is called, which is the main routine of LHN. After the call to `NUDGLH`, the resulting LHN tendency is limited by an upper and lower boundary, multiplied with an amplification factor `RAMPLIFY`, converted from potential temperature to temperature tendency using Exner function and added to the physics temperature tendency.

#### **Differences to LHN scheme by Jones and Macpherson**

The LHN coded here follows mostly Jones and Macpherson 1997. However, due to the structure of the AROME code some modifications are made: Jones and Macpherson do a horizontal smoothing of the increments, which is not done here, because in the model physics environment (`apl_arome`) everything is done on columns (1D) and in subdomains due to parallelisation without any connection to the neighbored grid points. So a simple 9 grid point filter cannot be applied without complicated MPI communication, which would very likely

destroy the computational efficiency. However, Stephan 2008 mentions, that the smoothing should be reduced in high resolution simulations anyway. For the same reason also the search for suitable environment profiles (Eq.2) is limited to the level of NGPTOT. Eq.1, 3, 4 are coded in LHN main routine nudglh.F90, Eq.2 in nudglhprofile.F90. In case rain is observed, but not in the model at all, no search in the neighbourhood is applied but an artificial latent heat profile is assumed. This idealised profile consisting of a sinus function above the maximum LH and a cosine like decay below the maximum is defined in nudglhclim.F90. Its shape can be adapted via namelist (Fig. 15). There is also a possibility to nudge a stabilizing profile into the model in case there is no rain observed at all on a grid point, but something modelled by the microphysics. In this case a linearly, with height increasing potential temperature profile is used with a maximum on top, which should be located close to the tropopause to avoid instability aloft. Also the amplitude of the heating should be very small and should be chosen quite carefully. There are some hard coded safety values in nudglhclim.F90 to avoid LHN close to model top (stratosphere) or surface, which might cause instability. In case of elevated orography the artificial maximum heating rate RHEATNUDGLH can be reduced by another namelist switch RORONUDGLH, because high LH values cannot be expected in very high levels. In the future a replacement of these artificial and somehow arbitrary heating profiles by climatological monthly mean values of LH profiles should be envisaged. The EZDIAG diagnostics can be used to print out such heating from the model physics in apl\_arome.F90.

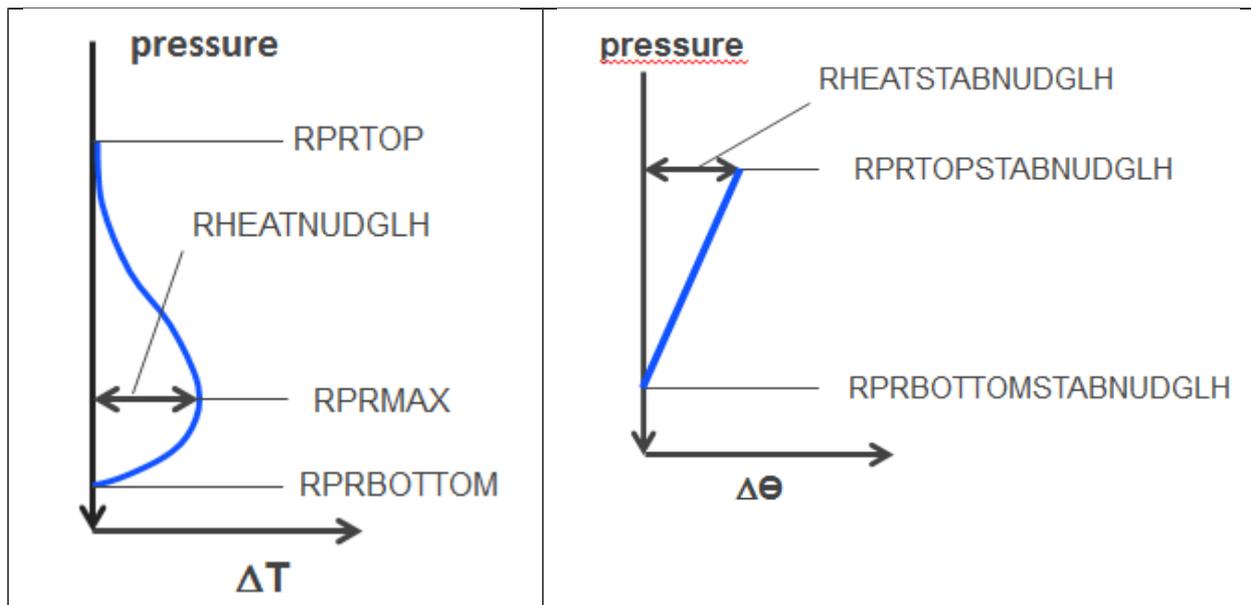


Figure 15: idealised LH profile adapted if no rain at grid point in model, but observed. The pressure levels  $RPRBOTTOM$ ,  $RPRMAX$ ,  $RPRTOP$  (Pa) and the maximum LH ( $RHEATNUDGLH$ ) in K can be set via namelist for convective case C (observed rain rate  $>7\text{mm}/30\text{min}$ ) and stratiform case S else. If no rain is observed at all and rain is in the model, a stabilizing LH profile  $\Theta$  increases slightly and linear with height can be applied (right).

Another modification of Jones and Macpherson is the possibility to apply the same LHN factor (precipitation ratio) also on some timesteps ( $NTAUNUDGLH$  in namelist) after the LHN timestep to smooth the LHN increment in time. The 3D LH profile multiplied with this factor in the following time steps is taken from that time steps physics output. The amplitude of the increment for this later time steps can be damped by another factor  $RDAMPNUDGLH$  set in namelist.

## **Namelist switches in new namelist group namnudglh (default values)**

LNUDGLH=.FALSE. -> LHN main switch; switched off  
LNUDGLHCLIM=.FALSE. -> LOGICAL to activate replacement of 0-LH profile by horizontal mean profile (TRUE not well tested)  
NTAUNUDGLH=0\_JPIM -> number of timesteps after NUDGING timestep where LHN factor is still applied  
TSTARTNUDGLH = 0.0\_JPRB -> time in s after init, where LHN starts (first LHN step)  
TSTOPNUDGLH = 3600.0\_JPRB -> time in s after init, where LHN stops  
TINTNUDGLH = 900.0\_JPRB -> interval in s of LHN observations =15min  
NBOTTOMNUDGLH = 1000\_JPIM -> bottom level below which LHN is not applied  
NTOPNUDGLH = 0\_JPIM -> upper model level above which LHN is not applied  
RDAMPNUDGLH = 0.0\_JPRB -> damping factor for LHN factor for time steps following the LHN step, if NTAUNUDGLH>0  
RPRTOPSNUDGLH = 22000.00\_JPRB -> setting for idealised profile top of latent heating for stratiform rain pressure in Pa  
RPRTOPCNUDGLH = 25000.00\_JPRB -> setting for idealised profile top of latent heating for convective rain pressure in Pa  
RPRTOPSTABNUDGLH = 20000.00\_JPRB -> setting for idealised profile top of latent heating for no rain pressure in Pa  
RPRMAXSNUDGLH = 57000.00\_JPRB -> setting for idealised profile level of max latent heating for stratiform rain pressure in Pa  
RPRMAXCNUDGLH = 60000.00\_JPRB -> setting for idealised profile level of max latent heating for convective rain pressure in Pa  
RPRBOTTOMSNUDGLH = 85000.00\_JPRB -> setting for idealised profile bottom of latent heating for stratiform rain pressure in Pa  
RPRBOTTOMCNUDGLH = 88000.00\_JPRB -> setting for idealised profile bottom of latent heating for convective rain pressure in Pa  
RPRBOTTOMSTABNUDGLH = 90000.00\_JPRB -> setting for idealised profile bottom of latent heating for no rain pressure in Pa  
RHEATSNUDGLH = 2.0\_JPRB -> setting for idealised profile max LH value (K) for stratiform rain  
RHEATCNUDGLH = 6.0\_JPRB -> setting for idealised profile max LH value (K) for convective rain  
RHEATSTABNUDGLH = 0.3\_JPRB -> setting for idealised profile max LH value (K) for no rain  
RAMPLIFY = 1.0\_JPRB -> amplification factor for LHN increment  
RMAXNUDGLH = 3.0\_JPRB -> upper limit for LHN increment  
RMINNUDGLH = -0.001\_JPRB -> lower limit for LHN increment  
RORONUDGLH = 1.5\_JPRB -> reduce LHN over mountains  
RALPHANUDGLH = 0.5\_JPRB -> ALPHA in Jones and Macpherson 1997  
REPSILONNUDGLH = 0.3333\_JPRB -> EPSILON in Jones and Macpherson 1997

## **Namelist most recent settings for LHN:**

```
&NAMNUDGLH
  LNUDGLH=.TRUE.,
  LNUDGLHCLIM=.FALSE.,
  TSTARTNUDGLH=0., ! time starts at 0s first obs at +5min
  TSTOPNUDGLH=2710., !25min 5min INCA analysis + hh:15min INCA forecast+15min +30min divided by 3
  NTAUNUDGLH=2,
  RDAMPNUDGLH=0.5,
  RAMPLIFY=1.0,
  TINTNUDGLH=300., ! 5min interval
  NTOPNUDGLH=10,
  NBOTTOMNUDGLH=77,
  RMAXNUDGLH=3.0,
  RMINNUDGLH=-0.3,
  RPRTOPSNUDGLH=30000.0,
  RPRMAXSNUDGLH=70000.0,
  RPRBOTTOMSNUDGLH=88000.0,
  RPRTOPCNUDGLH=30000.0,
```

```

RPRMAXCNUDGLH=70000.0,
RPRBOTTOMCNUDGLH=88000.0,
RPRTOPSTABNUDGLH=20000.0,
RPRBOTTOMSTABNUDGLH=90000.0,
RHEATSNUDGLH=2.0,
RHEATCNUDGLH=6.0,
RHEATSTABNUDGLH=0.0,

```

/

## Experiments

Two case studies with LHN have been conducted during the stay at Météo France: 9<sup>th</sup> November 2015 09 UTC run with stratiform rain over Czech Republic (Fig. 17) and 8<sup>th</sup> August 2015 12UTC run with Convection in many parts of Austria (Fig. 18). All experiments were made with cy38t1 and on ZAMG domain only, because cy40\_op2 (AROME-PI) version of latent heat nudging was unfortunately bugged, which was not fixed before the end of the stay and led to crashes of the integration due to wrong memory allocation. However, the preparation of observation files from ANTILOPE worked (Fig. 16). It is important to mention, that numbers of vertical levels in AROME physics changed from cy38t1 to cy40\_op2, down->top to top->down. Therefore many changes of index numbering are necessary also in LHN between cy38t1 and cy40. In both cases, where LHN was applied (Fig.17, 18), it improved the precipitation forecast for the first hour clearly. However, it leads also to some overestimation of the area and amount of precipitation. This is especially true for the 8<sup>th</sup> August and longer lead times (Fig. 19). The stabilising of the profile in case of rain in the model, but not in observation, seems to reduce this overestimation, but cannot completely suppress it. On 9<sup>th</sup> November the rain over Czech Republic was not captured by Austrian radars, but by Czech rain gauges. Therefore, the impact of LHN in addition to 3D-Var radar assimilation is quite strong in that case.

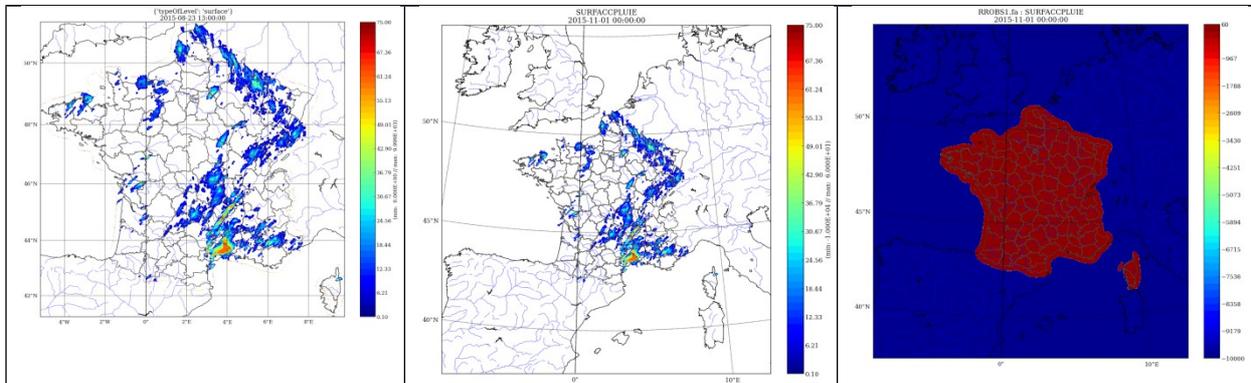


Figure 16: 1h-ANTILOPE precipitation analysis on original grid (left), interpolated to AROME-PI domain (middle) and if values outside ANTILOPE domain are set to -9999.99 (right) as it is done by the INTERROBS interpolation routine. Outside the ANTILOPE domain LHN produces 0 increments.

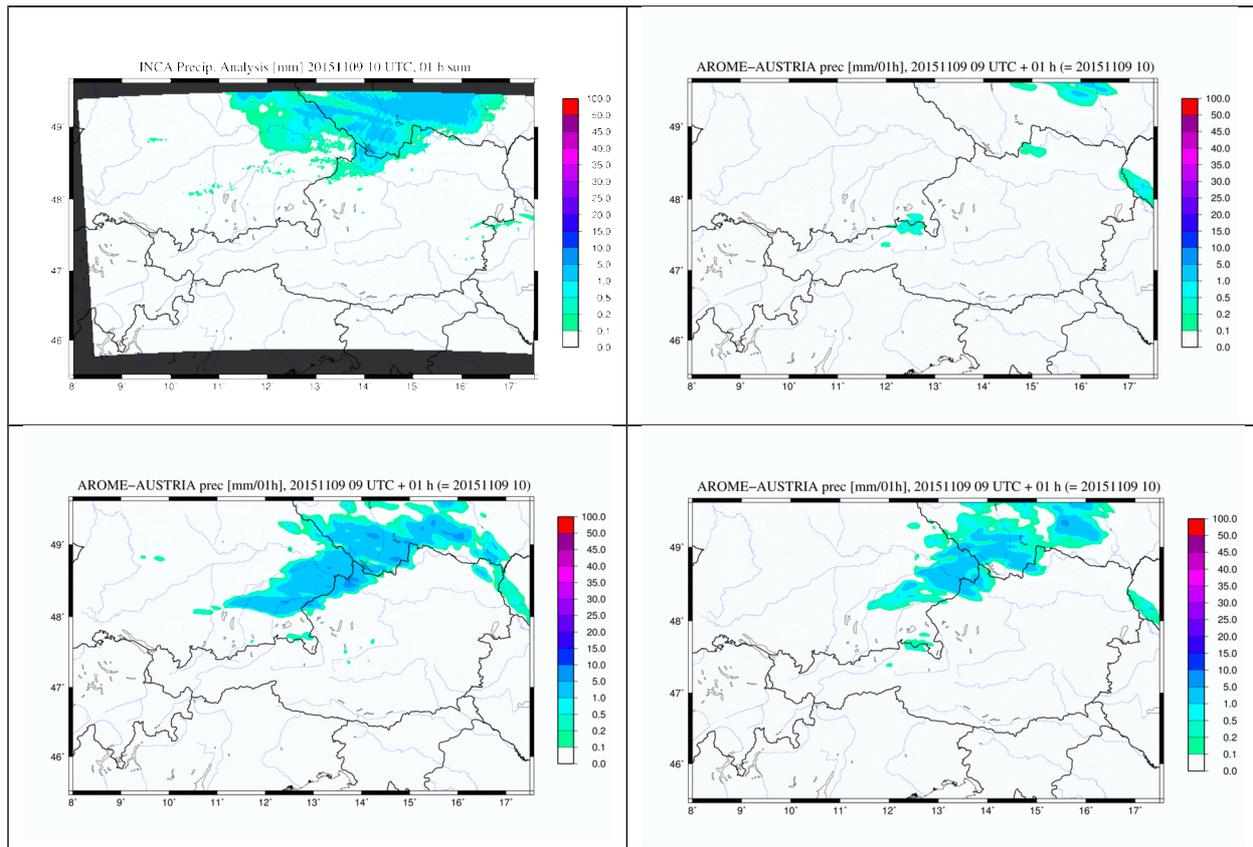
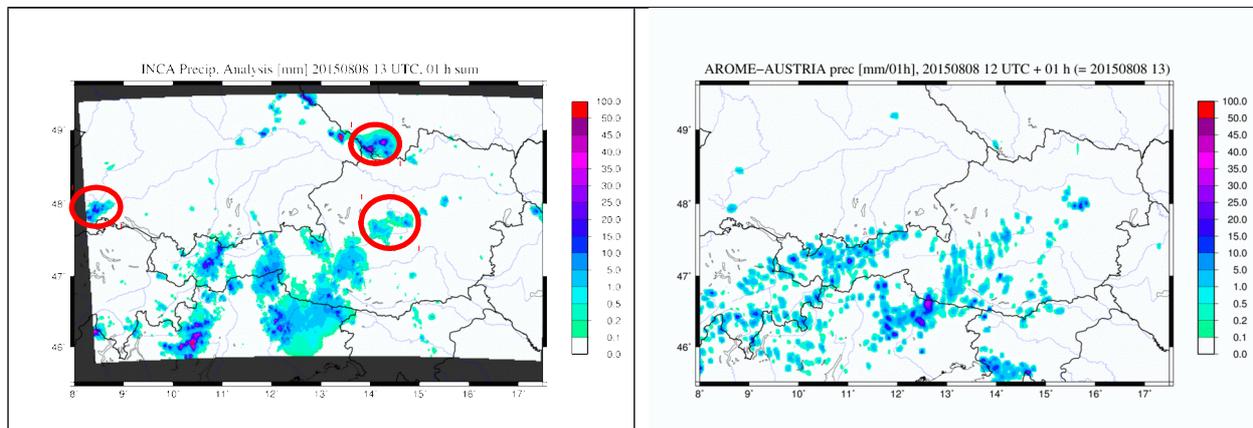


Figure 17: precipitation 09<sup>th</sup> November 2015 09-10UTC: INCA analysis (top left), AROME-Nowcasting+3D-VAR RADAR (top right), AROME-Nowcasting+3D-Var RADAR+LHN (bottom left), AROME-Nowcasting+3D-Var RADAR+LHN including stabilizing function where RAIN in model but not observed (bottom right). Nudging period was 30min with 5min INCA precipitation analysis.



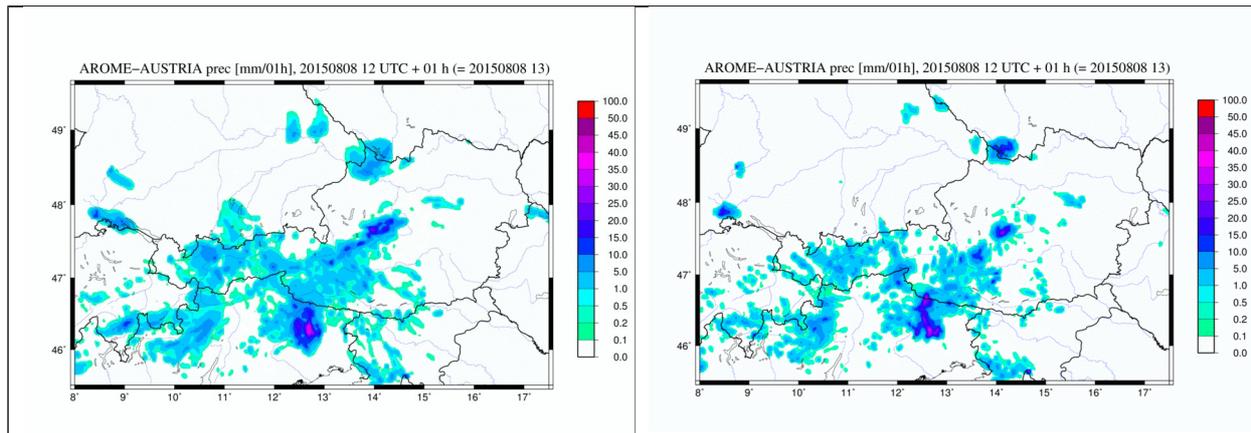


Figure 18: as figure 17 but for 08<sup>th</sup> August 2015 12-13 UTC.

Further more detailed evaluation is needed to optimise the usage of LHN in AROME. Besides the exchange of the idealised heating profiles with climatological mean profiles, the application on different domains and with different observation data (like for example OPERA composite) and the evaluation of a longer period of application should be envisaged in the future.

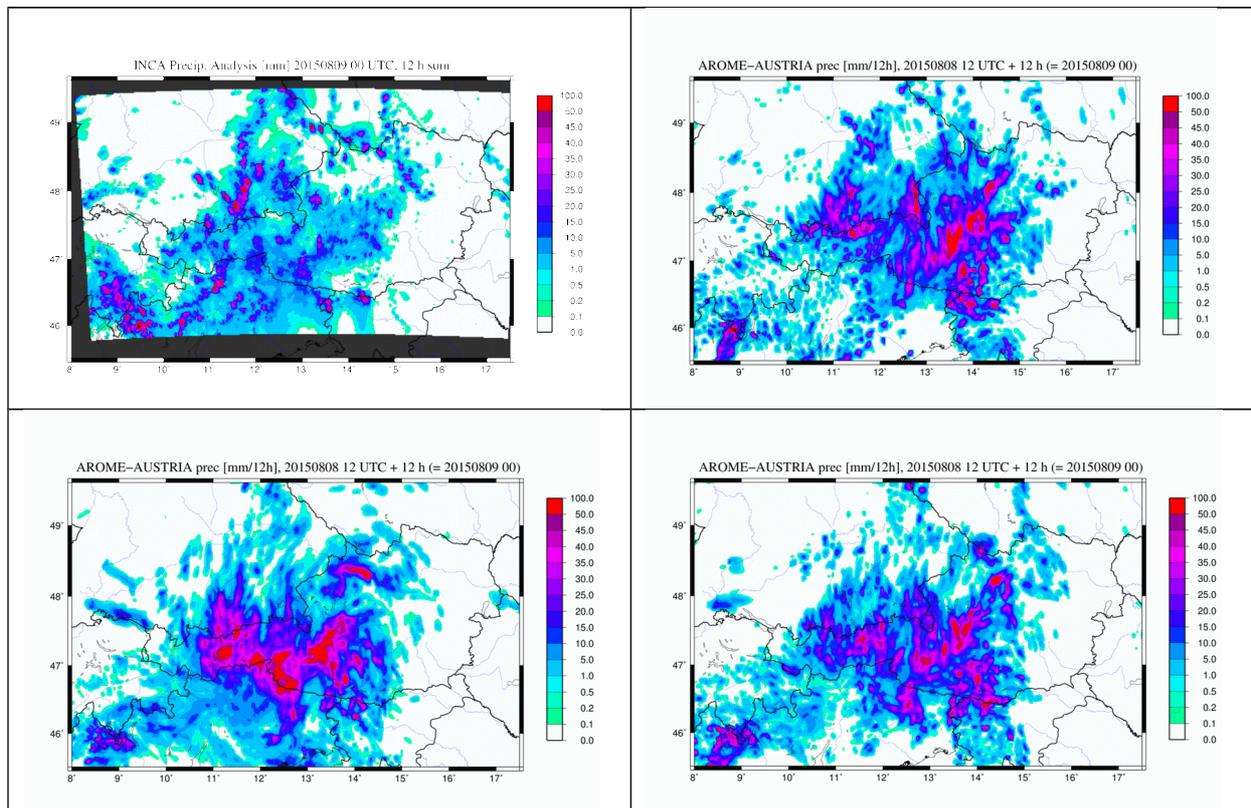


Figure 19: as figure 18 but 12h precipitation sums 08<sup>th</sup> August 2015 12-24UTC.

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