CONVECTION DIURNAL CYCLE AND PROGNOSTIC ENTRAINMENT IN THE ALARO FRAMEWORK

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1. Introduction

The correct simulation of the diurnal cycle of convection is one of the big challenges of the numerical weather prediction models. The idea of the historical convective entrainment appeared in order to cure the too early triggering of the convection in the ARPEGE/ALADIN model (Piriou, 2005). The prognostic convective scheme of the ALARO model, developed by Luc Gerard, contains as well a prognostic approach for the entrainment convective rate, representing a revision and a synthesis of the ideas of Jean-Marcel Piriou (2005) and Dimitrii Mironov & Bodo Ritter (2005).

After the last developments of the ALARO-0 carried out during 2008-2009, including several changes in the formulation of the prognostic entrainment rate (Banciu, 2008), it was decided to evaluate, in a more systematic way, the model performance in simulating the diurnal cycle of convection and the impact of the prognostic entrainment on it.

The diagnosis of the convection diurnal cycle was realized for 15 days of the 2009 summer. The results, presented in section 2, showed deficiencies of the model in simulating the diurnal cycle of convection in both cases of the switch off-on of the convective prognostic entrainment. In oder to improve the diurnal cycle simulation a new tuning of the parameters involved in the entrainment rate formulation was tried without too much success (section3). Again a change in the prognostic entrainment rate formulation was tried, which is described in section 4.

2. Diagnosis of the convection diurnal cycle

For the evaluation of model performance a 15 days period was chosen between 21st of June - 5th July 2009, when the convection presented a pronounced diurnal cycle over the Czech Republic as one could notice on radar images (Fig. 1).

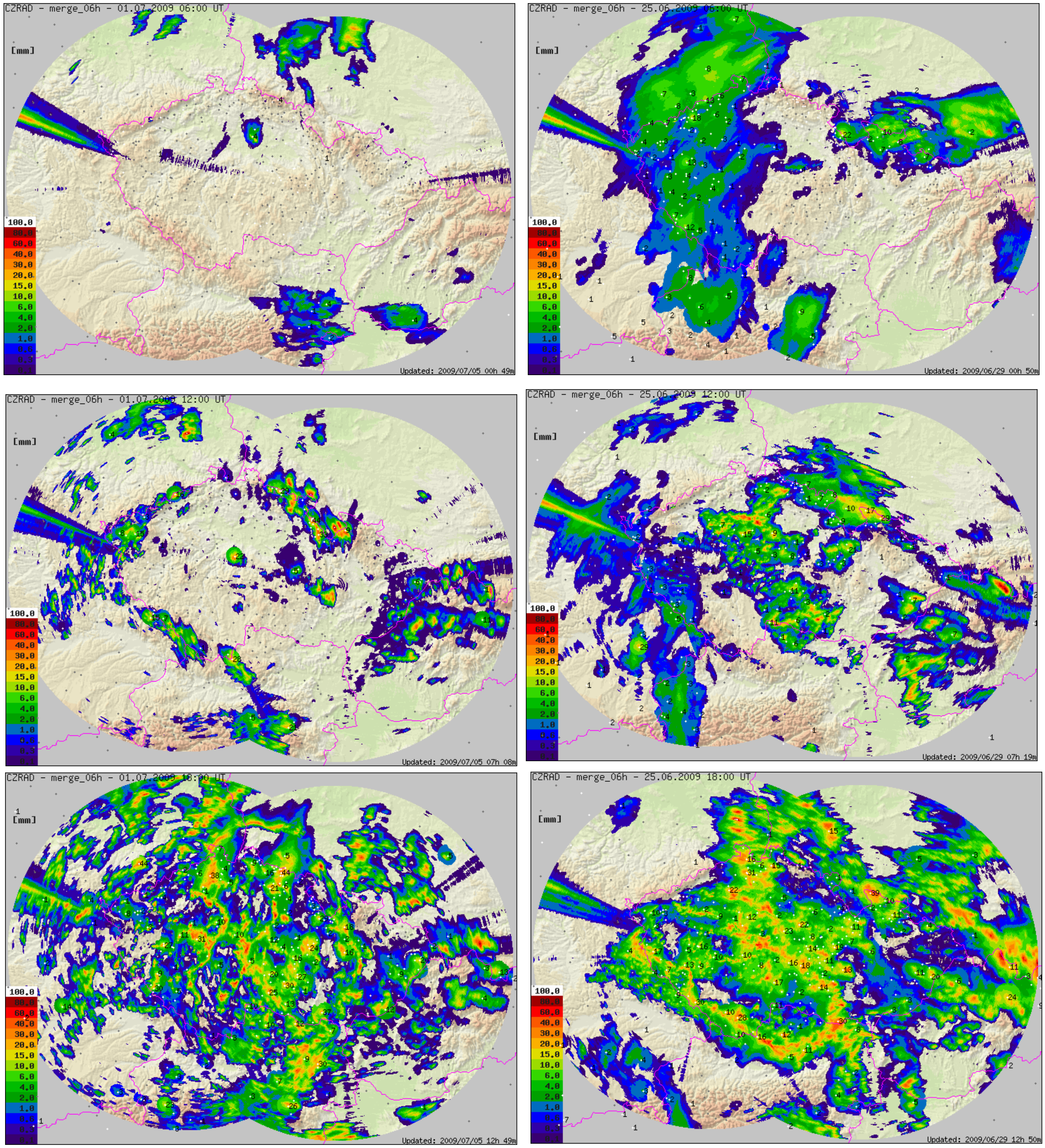

Fig. 1. Last 6h cumulated precipitation (radar data merged with gauge measurements) for 01.07.2009 -left, 25.062009 – right: 06 – top, 12 – middle , 18 UTC - bottom

The hourly cumulated precipitation provided by the 2 Czech radars merged with gauge measurements, available in a regular grid with 1 k resolution, where summed over the domain covered by these radars. Similarly the hourly cumulated precipitation simulated through the the operational suite in Czech Republic based on the ALARO-0 model, including 3MT (cy32t1), were summed over almost the same area (47.5 – 52.5 º N, 10 -20 º E) up to the 54 forecast range. In order to make these 2 data sets (approximatively) comparable, the observed precipitation were scaled by a factor tacking into account the numbers of points inside the area, for the model and for observations.

The comparison between the simulated and observed precipitation for all the 15 days is presented in Annex 1. It should be considered only qualitatively, due the approximations involved for computing the precipitation sum over the considered area and to the lack of radar data for certain periods of time. However it could offer valuable information regarding the ALARO skill in simulated the diurnal cycle of convection.

The model performance depends on the situation and on the forecast range, the precipitation peak from the first forecast day being generally better represented than for the the second forecast day. For instance the diurnal cycle appears to be corrected simulated for 1st of July 2009 while on 25th of June there is a big discrepancy (see the black and blue lines in figure 2 and 3).

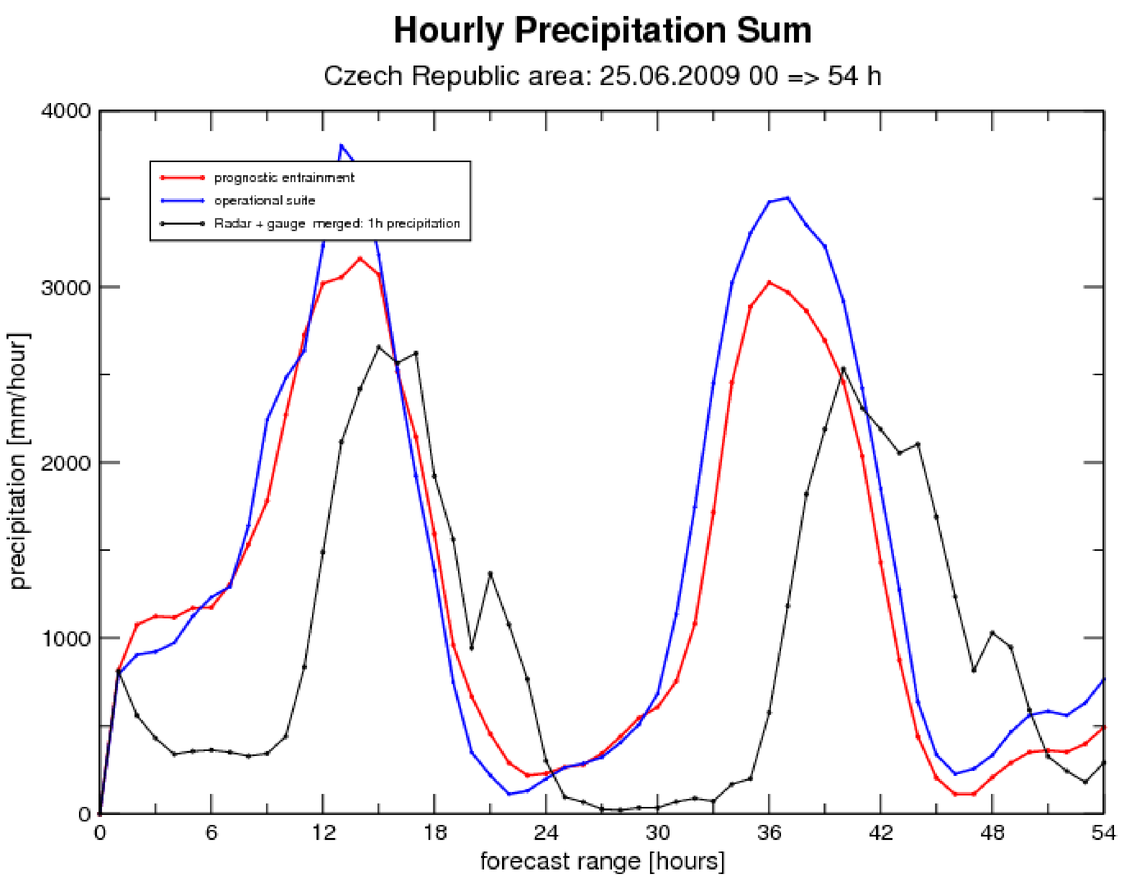

Fig. 2. Hourly cumulated precipitation for 25.06.2009: radar data merged with gauge measurements – black line, ALARO with diagnostic entrainment (operational suite) -blue line ALARO with prognostic entrainment – red line

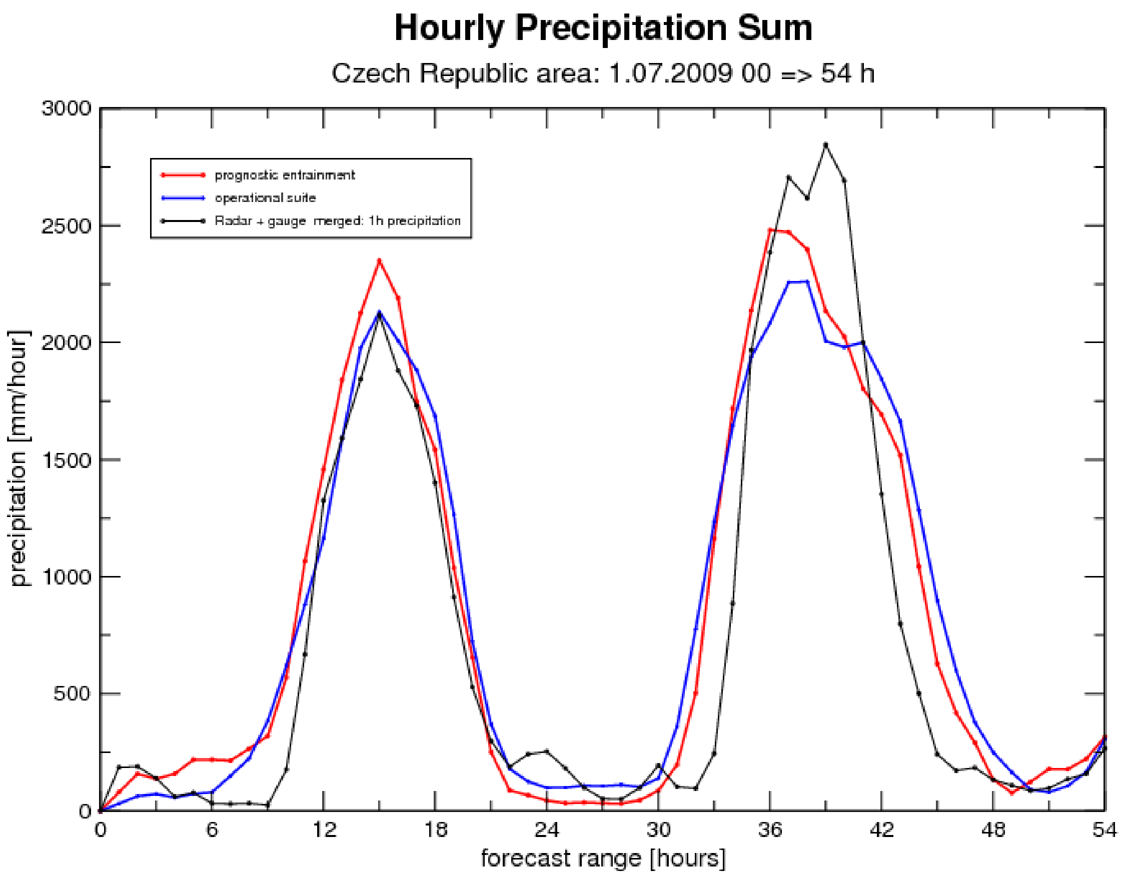

Fig. 3. Hourly cumulated precipitation for 1.07.2009: radar data merged with gauge measurements – black line,
ALARO with diagnostic entrainment (operational suite) -blue line
ALARO with prognostic entrainment – red line

A parallel suite (including the assimilation cycle) was established for the chosen period, where the prognostic entrainment was switch on. For each day, the hourly cumulated precipitation were extracted on the same area and represented on the graphics together with the observed and simulated precipitation bye the operational suite (Annex 1).

The results show that there is no significant impact of the the prognostic entrainment on the diurnal cycle simulation. There are rather small differences in the evolution of the precipitation and the moment when the precipitation maximum is reached. Sometimes the precipitation amount simulated with prognostic entrainment is bigger than that simulated with diagnostic one, sometimes smaller.

More differences could be found in the spatial precipitation distribution. The precipitation bands are a little bit better structured and positioned in the case of prognostic entrainment. For exemplification the Figures 4 and 5 present the spatial distribution of the 6 hour cumulated precipitation for the 25th of June and 1st of July which are to be compared with the observed precipitation from figure 1.

Generally there is no clear sign of a positive impact of the prognostic entrainment in the simulation of the diurnal cycle of convection.

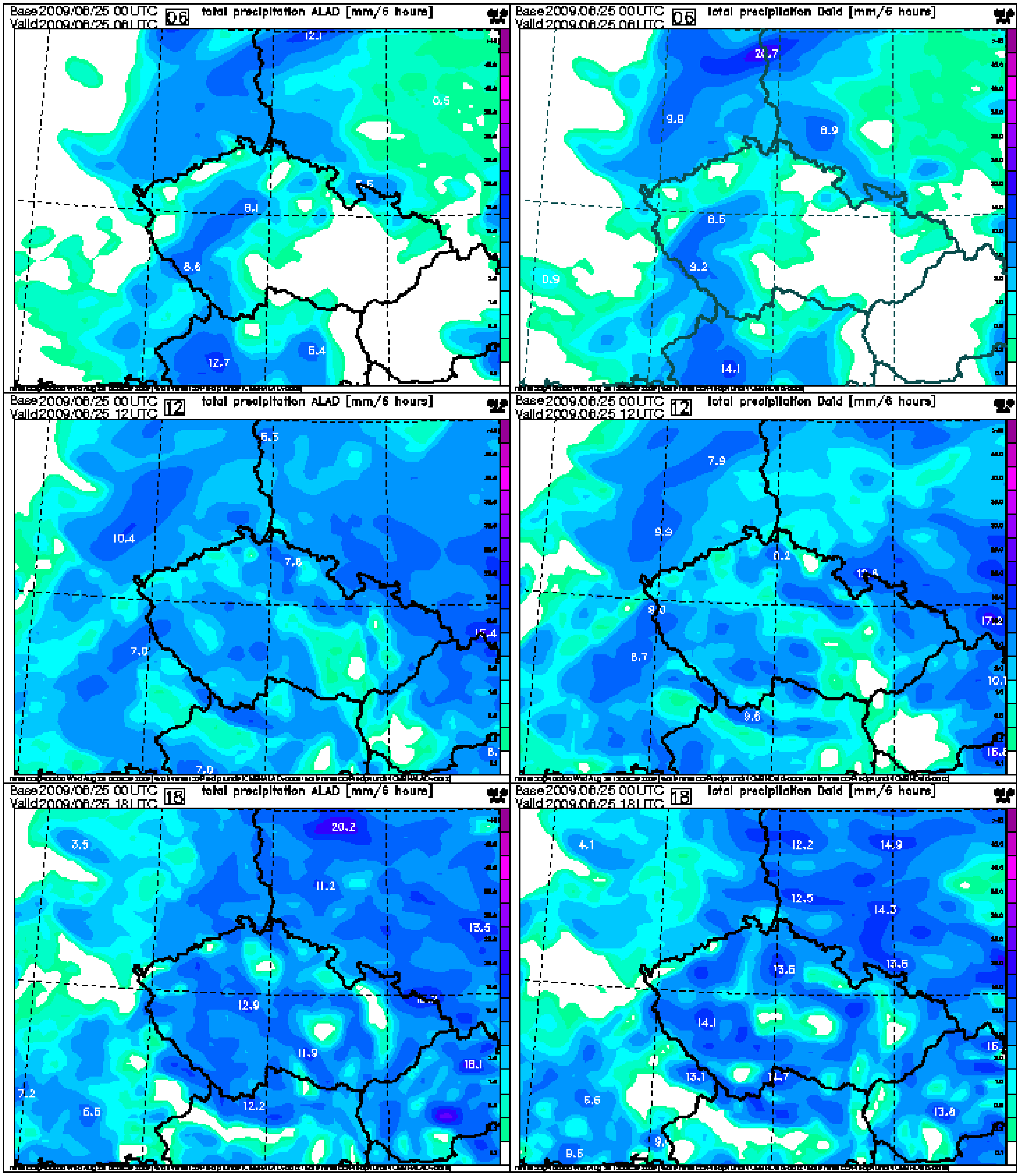

Fig. 4. Last 6 h cumulated precipitation for 25.06.2009:
ALARO with diagnostic entrainment (operational suite) – left column and with prognostic entrainment -right column
06 UTC – top, 12 UTC – middle, 18 UTC – bottom

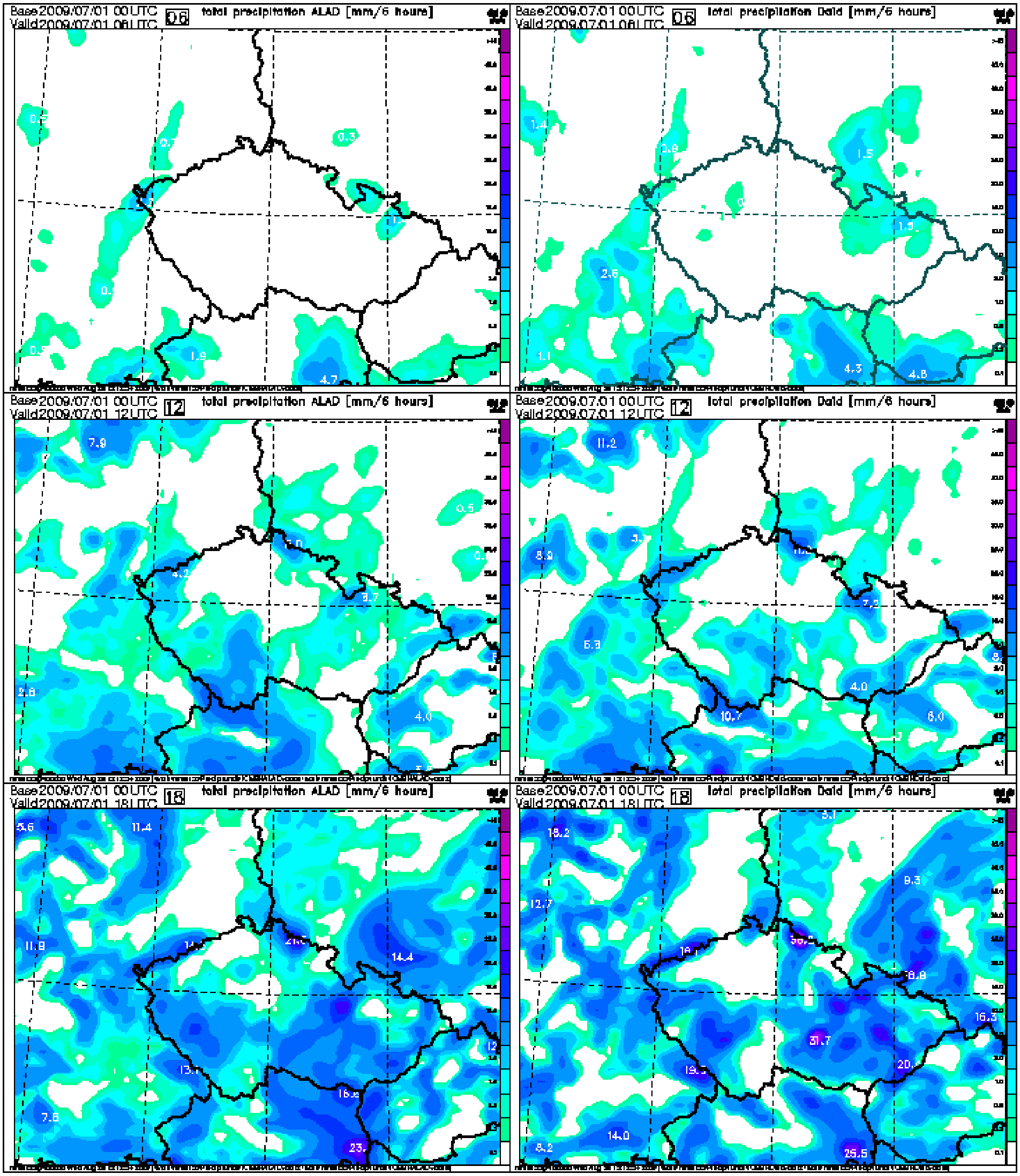

Fig. 5. Last 6 h cumulated precipitation for 01.07.2009:
ALARO with diagnostic entrainment (operational suite) – left column and with prognostic entrainment -right column
06 UTC – top, 12 UTC – middle, 18 UTC – bottom

3. Tuning of the free parameters involved in the prognostic entrainment

Even if the tuning of the free parameters was realized after the last modification of the he prognostic entrainment formulation it was tried to find a better combination of them in order to improve the diurnal cycle simulation in the situations where model showed a low performance but keeping the model skill for the situations with correct simulated diurnal cycle.

The first candidate for the new tuning was τ (GPETAU), the characteristic time of the downdraft dissipation, expected to have a big impact on the convection diurnal cycle simulation and previously set to the value prescribed by Piriou (2007). To save computing time, within the experiments, the model was integrated only 18 hours. The results underlined the week sensitivity of the simulated diurnal cycle in respect with the variation of this parameter over a large interval of values, for both days chosen representative for poor (25.06.2000) and correct (01.07.2009) simulated diurnal cycle (fig.6).

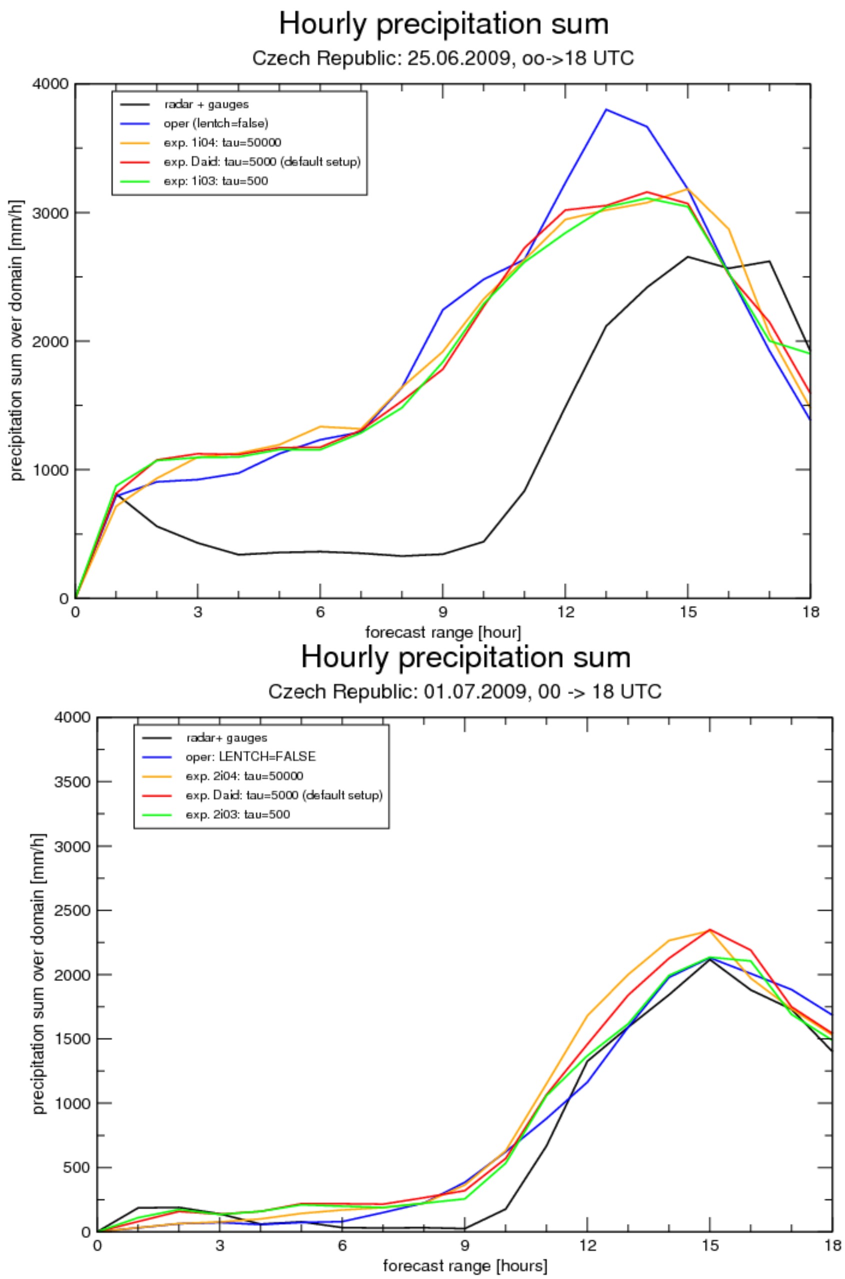

Fig. 6. Hourly cumulated precipitation: radar data merged with gauge measurements – black line, ALARO with diagnostic entrainment (operational suite) -blue line, prognostic entrainment : τ=500. - green line, τ=5000. (default set up)– red line, τ=50000. -orange line. 25.05.2009 - top, 1.072009 - bottom

It became more and more clear that it is not possible to get any improvement of the diurnal cycle of convection by using the current prognostic entrainment, while Piriou et al. [2007], with quite similar formulation as that of Gerard, 2007(on what the ALARO entrainment computation is based) reported more encouraging results.

4. Modification of the prognostic entrainment variable formulation

It becomes more and more clear that it is not possible to get any improvement of the diurnal cycle of convection by using the current prognostic entrainment, while Piriou et al. [2007], with quite similar formulation as that of Gerard, 2007(on what the ALARO entrainment computation is based) reported more encouraging results.

Both formulations of the entrainment rate of Piroiu and Gerard involve the same prognostic variable in the computation of the entrainment rate (for more details see Banciu, 2009, Annex A). The differences come from its expression, driven by the specific convection parameterization scheme, where it is used.

Pirou expresses this prognostic variable (ζ) through the equation:

$$\frac{\partial \zeta}{\partial t} = c\frac{I_E}{\sigma_u} - \frac{\zeta}{\tau} \qquad (1)$$

where:

- c is a tunable parameter (0.1 $kg^{-1}\ m^2$);
- I_E the precipitation evaporation is the integral of the precipitation evaporation from the top up to the current level ;
- σ_u the fractional area occupied by the updrafts (0.02);
- τ is the characteristic time of downdraft dissipation (tunable parameter). In this way the rate of protected ascents at a given level, ζ increases with the precipitation evaporation and decreases with the characteristic time of downdraft dissipation.

Following the work of Piriou, Gerad uses inside his prognostic convective updraft parametrization the following equation:

$$\frac{\partial \zeta}{\partial t} = \alpha_E \hat{\sigma}_D - \frac{\zeta}{\tau_E} = \frac{1}{\tau_E}\left(\kappa_E \hat{\sigma}_D - \zeta\right) \qquad (2)$$

where:

- $\hat{\sigma}_D$ is the fractional area of the downdraft (vertically smoothed)
- τ_E he time for what ζ returns to zero when downdraft disappear
- κ_E is a tunable parameter

The current formulation uses a slight different formula in order to assure a smooth transition of ζ towards both 0 and 1, through the exponents N) and N1.

$$\frac{\partial \zeta}{\partial t} = \alpha_E \hat{\sigma}_D (1-\zeta)^{N1} - \frac{\zeta^{N0}}{\tau_E} = \frac{1}{\tau_E}\left[\kappa_E \hat{\sigma}_D (1-\zeta)^{N1} + \zeta^{N0}\right] \qquad (3)$$

The first step to get a deeper view on the prognostic entrainment variable behavior in ALARO was to check the supposed correspondence between the integral of the precipitation evaporation (the downdraft source) and the fractional area of the downdraft. So, the distribution of the integral of the enthalpy due to the precipitation and melting against $\hat{\sigma}_D$ was computed for different time intervals during the model integration. The results for 25.06.2009 showed in figure 7 (left) do not confirm the expected correspondence.

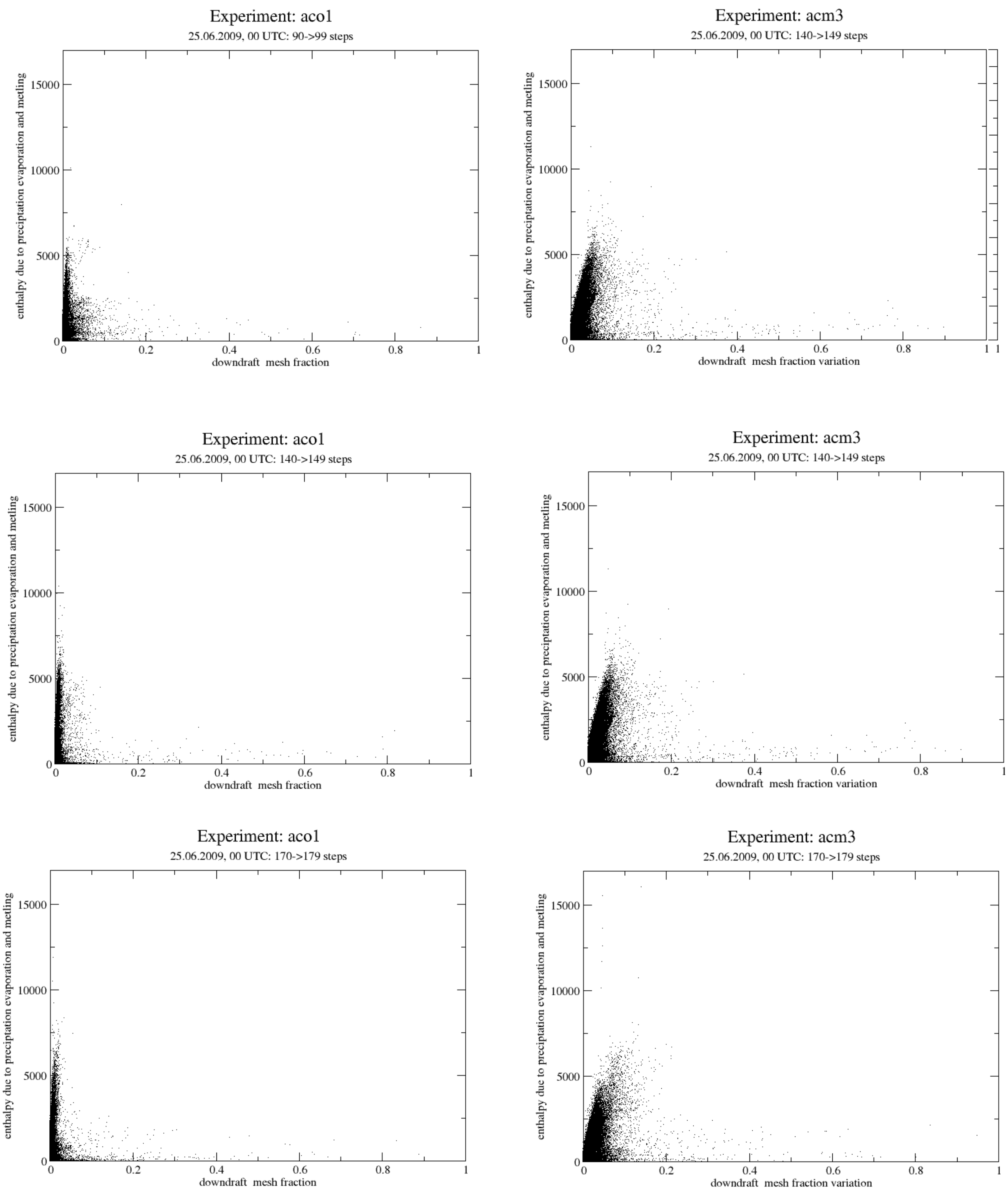

Fig. 7. Distribution of the enthalpy due to the precipitation evaporation and melting against downdraft fractional area - left column and against the variation of the downdraft positive fractional area -right colon the for 25.06.2009: for 00+08 → 00+09 (top), 00+13 → 00+14 (middle) and 00+15→00+16 UTC (bottom)

Following the idea of Jean-Francois Geleyn, a better correspondence was found between the enthalpy due to the precipitation evaporation and melting and the local increase of the downdraft fractional area due to precipitation evaporation as one can notice in figure 7, right column. Consequently a new form of ζ equation was derived

$$\frac{\partial \zeta}{\partial t} = \alpha_E \Delta \sigma_D (1-\zeta)^{N1} - \frac{\zeta^{N0}}{\tau_E} = \frac{1}{\tau_E}\left[\kappa_E \Delta \sigma_D (1-\zeta)^{N1} + \zeta^{N0}\right] \quad \text{for} \quad \sigma_D > 0$$

$$\frac{\partial \zeta}{\partial t} = -\frac{\zeta^{N0}}{\tau_E} \quad \text{for} \quad \sigma_D \leq 0 \qquad (4)$$

For the computation of $\Delta \sigma_D$ only the enthalpy due to the evaporation/melting of precipitation (the input term from the downdraft closure,equation 5) is taken into account:

$$\underbrace{\frac{\partial \sigma_D}{\partial t} \cdot \int_{p_t}^{p_b} \left[(h_d - h_d^{'}) + \frac{\omega_d^2 - \omega_e^2}{2(\varrho g)^2} \right] \frac{\partial p}{g}}_{storage} = \underbrace{\sigma_D \cdot \int_{p_t}^{p_t} -F_b \frac{\partial \omega_D}{\varrho g}}_{-\ consumption} + \underbrace{\varepsilon \cdot \int_{p_t}^{p_t} -g \frac{\partial F_{hP}}{\partial p}}_{input} \qquad (5)$$

$$\Delta \sigma_D = \frac{\varepsilon \cdot \Delta t \int_{p_t}^{p_t} -g \frac{\partial F_{hP}}{\partial p}}{\int_{p_t}^{p_b} \left[(h_d - h_d^{'}) + \frac{\omega_d^2 - \omega_e^2}{2(\varrho g)^2} \right] \frac{\partial p}{g}} \qquad (6)$$

with the constraints: $0 \leq \sigma_D \leq \sigma_P$

where: σ_P is the precipitation fractional area ($\sigma_P = 1 - \sigma_u$)

5. Re-tunning of the free parameters of the prognostic entrainment

The modification of the entrainment rate formulation implied the necessity of a re-tuning of all free parameters involved. For this the Czech case of 21.06.2006, used for the first tunning (Banciu, 2008) was again considered. First the several values for κ parameter was tested and best one was found to be 6500 (see figure 8).

After that the sensitivity of the diurnal cycle of convection to the variation of κ , τ , $N0$ and $N1$ parameters was checked for the two test cases: 25[th] of June and 1[st] of July 2009. The results are presented in figures 9-11. They show that there is a bigger sensitivity to the free parameters when the new formulation based on $\Delta \sigma_D$ is used. On the other hand they confirm the 2008 choice of N0=2 and N1=2 as the best solution. Unfortunately even with large variations of the κ and τ values it was not possible to obtained the observed diurnal cycle of convection.

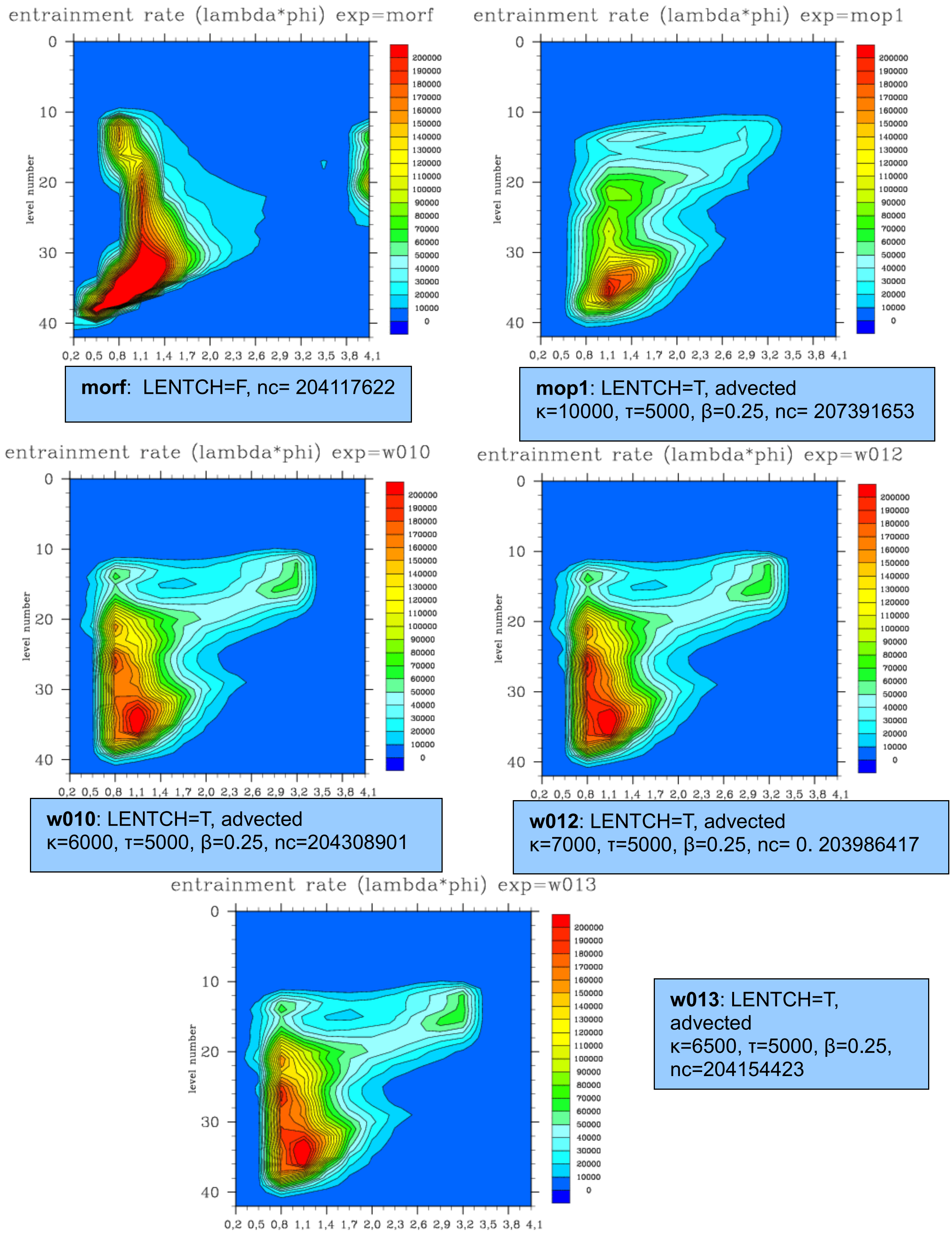

Fig.8. Entrainment rate vertical distribution for 21.06.2006, 00+06 →00+12 UTC: reference, diagnostic entrainment – top, left; prognostic entrainment, old formulation – top right; new forfulation of prognostic entrainment for $\kappa = 6000$ - middle left, $\kappa = 7000$ - middle right, $\kappa = 6500$ - bottom

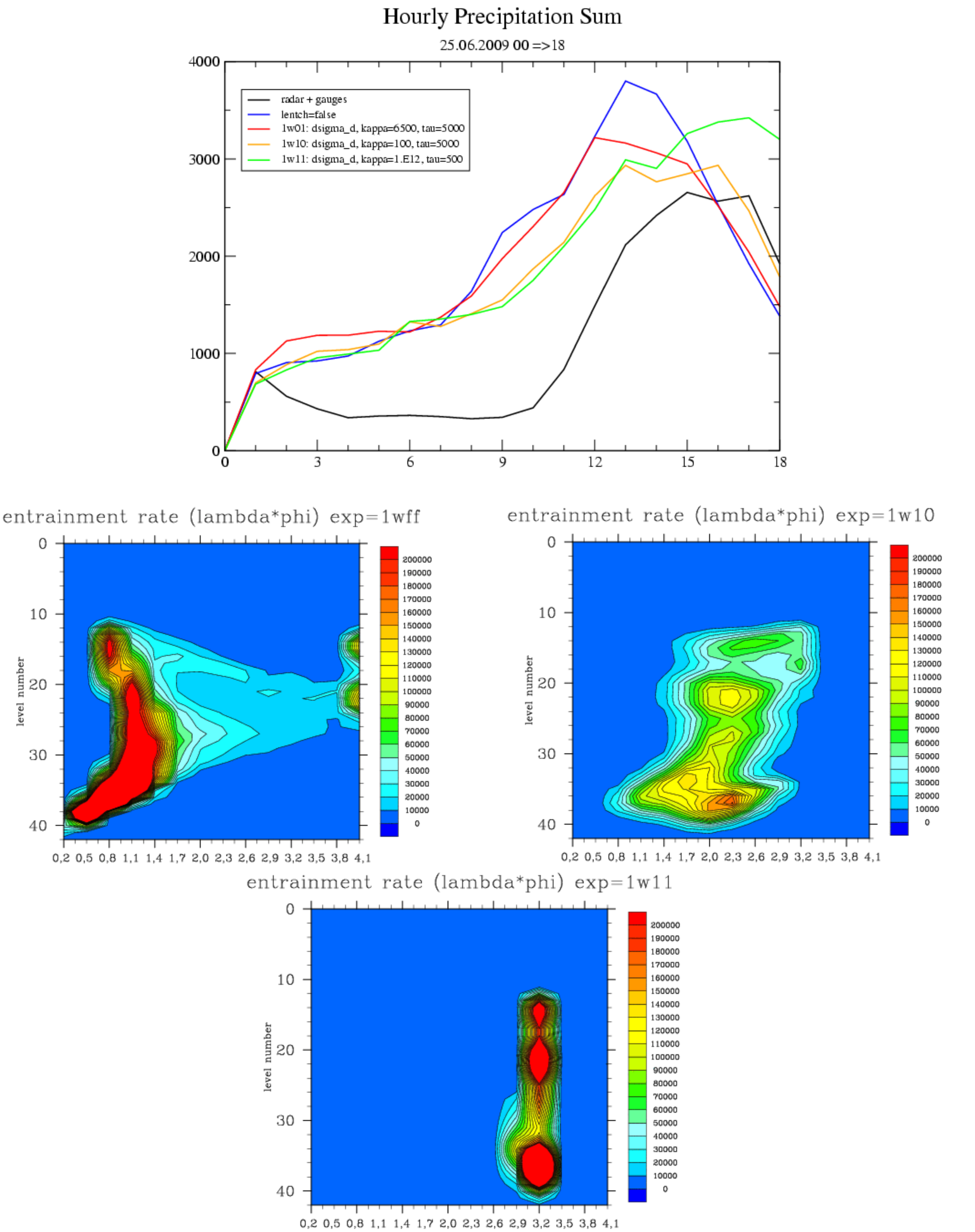

Fig. 9 25.06.2009: Hourly cumulated precipitation for - top: radar data merged with gauge measurements – black line, ALARO with diagnostic entrainment (reference) -blue line, prognostic entrainment (new formulation) : κ=6500. - red line, κ=100 – orange line, κ=1.E-12. - green line and τ=5000

Entrainment rate vertical distribution: diagnostic entrainment -middle left, prognostic entrainment with κ=100 – middle -right and with κ=1.E-12 -bottom

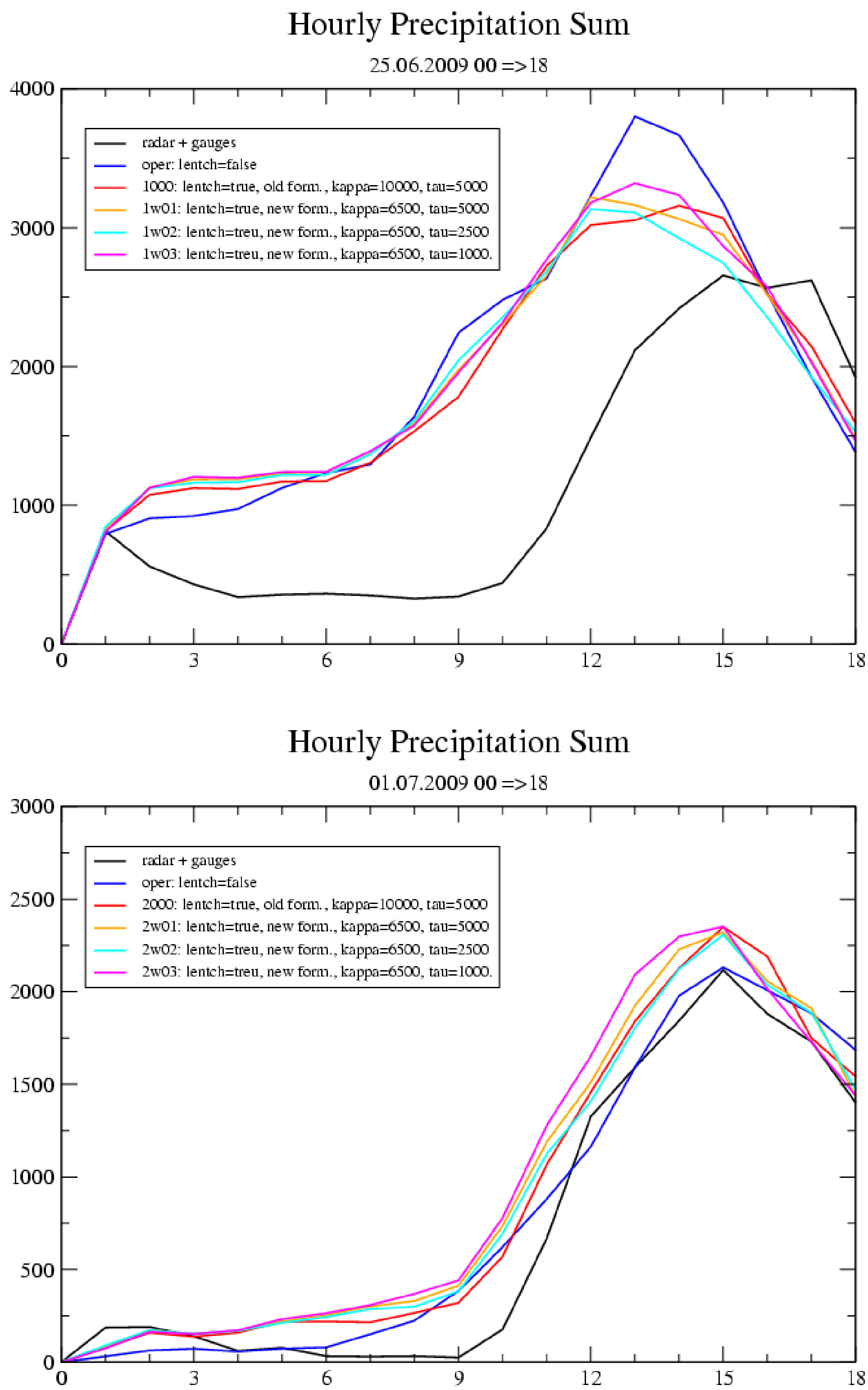

Fig.10 Hourly cumulated precipitation for 25.06.2009 – top and 01.07.2009 bottom :
radar data merged with gauge measurements **–** black line**,** diagnostic entrainment (reference) -blue line,
prognostic entrainment :old formulation - red line (κ=10000. τ=5000.)
prognostic entrainment : new formulation τ=5000 – orange , τ=2500 - green , and τ=1000 – violet line (κ=6500)

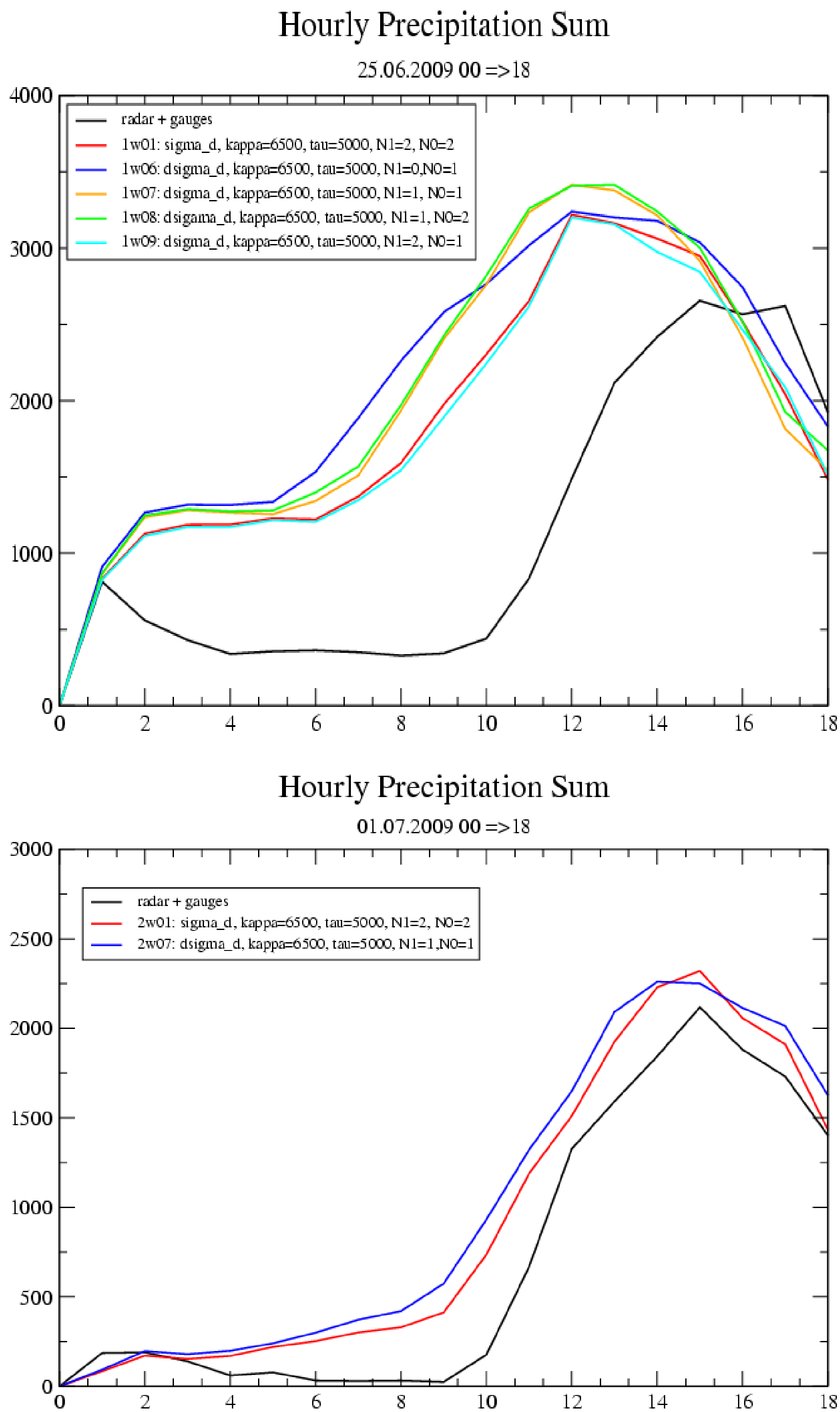

Fig.11 Hourly cumulated precipitation for 25.06.2009 – top and 01.07.2009 bottom, κ=6500, τ=5000 : for different combination of N0 and N1 sa explained in the figures legend

Acknowledgments

I am grateful to Jean-Francois Geleyn for the very fruitful discussions and for proposing always new solutions in deadlock situation. I would like to thanks to the entire Czech team for their hospitality. Many thanks particularly to Radmila Brozokva for her constant support of my work and to Filip Vana for his help in using the technical environment as well as for the interesting discussions concerning different NWP topics.

References

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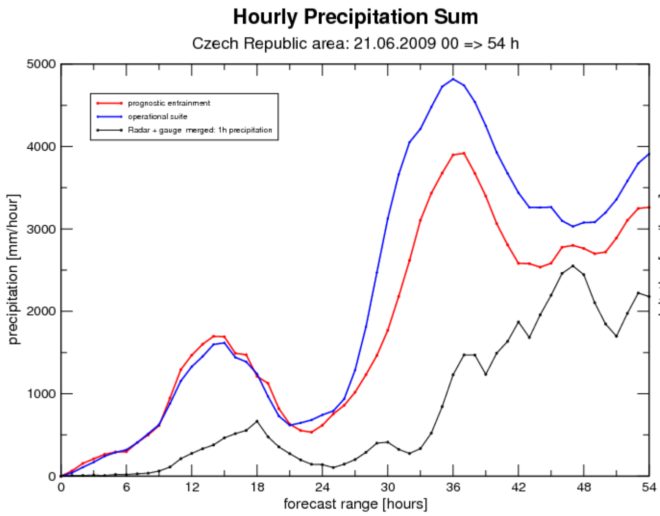
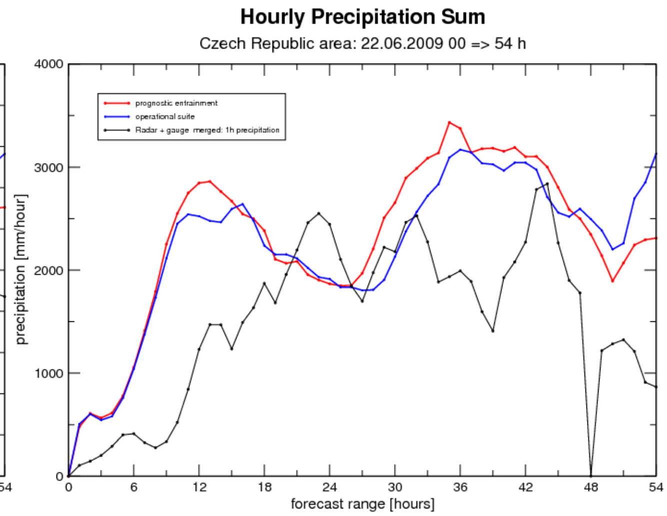
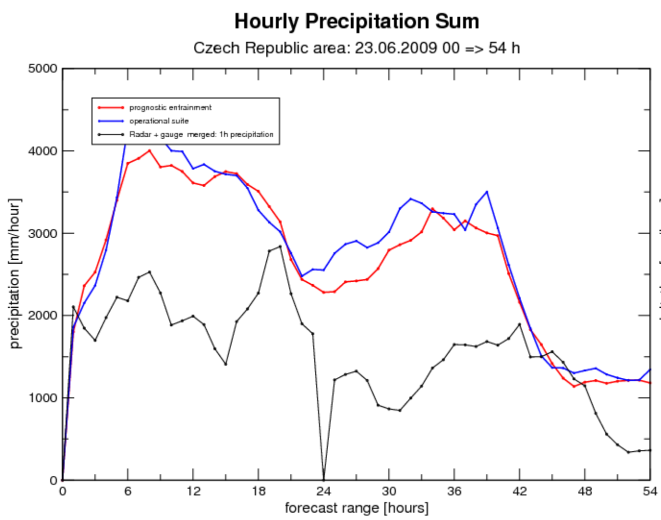
Gerard, L., 2007: Personal documentation on updraught, *http://www.rclace.eu/?page=74*

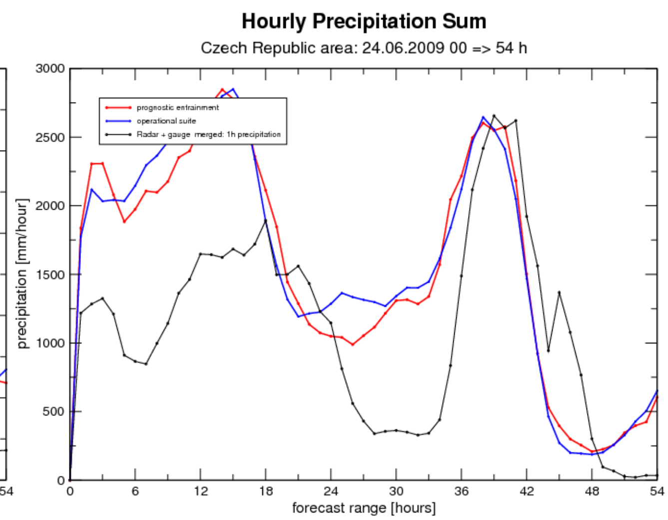
Piriou J.-M., J.-L. Redelsperger, J.-F. Geleyn, J.-P. Lafore, and F. Guichard, ***2007:*** An approach for convective parameterization with memory, in separating microphysics and transport in grid-scale equations***.*** *J. Atmos. Sci.,* **64**, 4127–4139

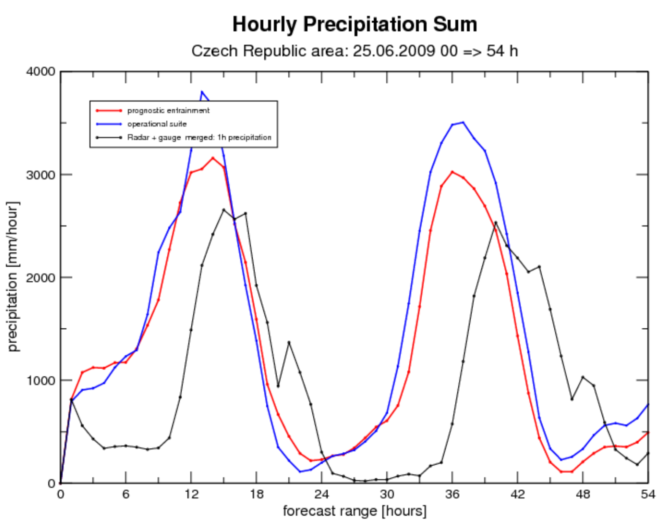
ANNEX 1 – Convection diurnal cycle: 21.06 -5.07.2009 over Czech Republic

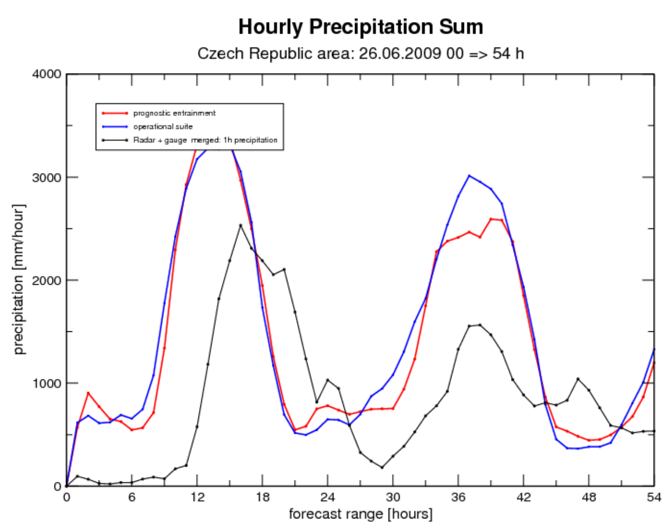


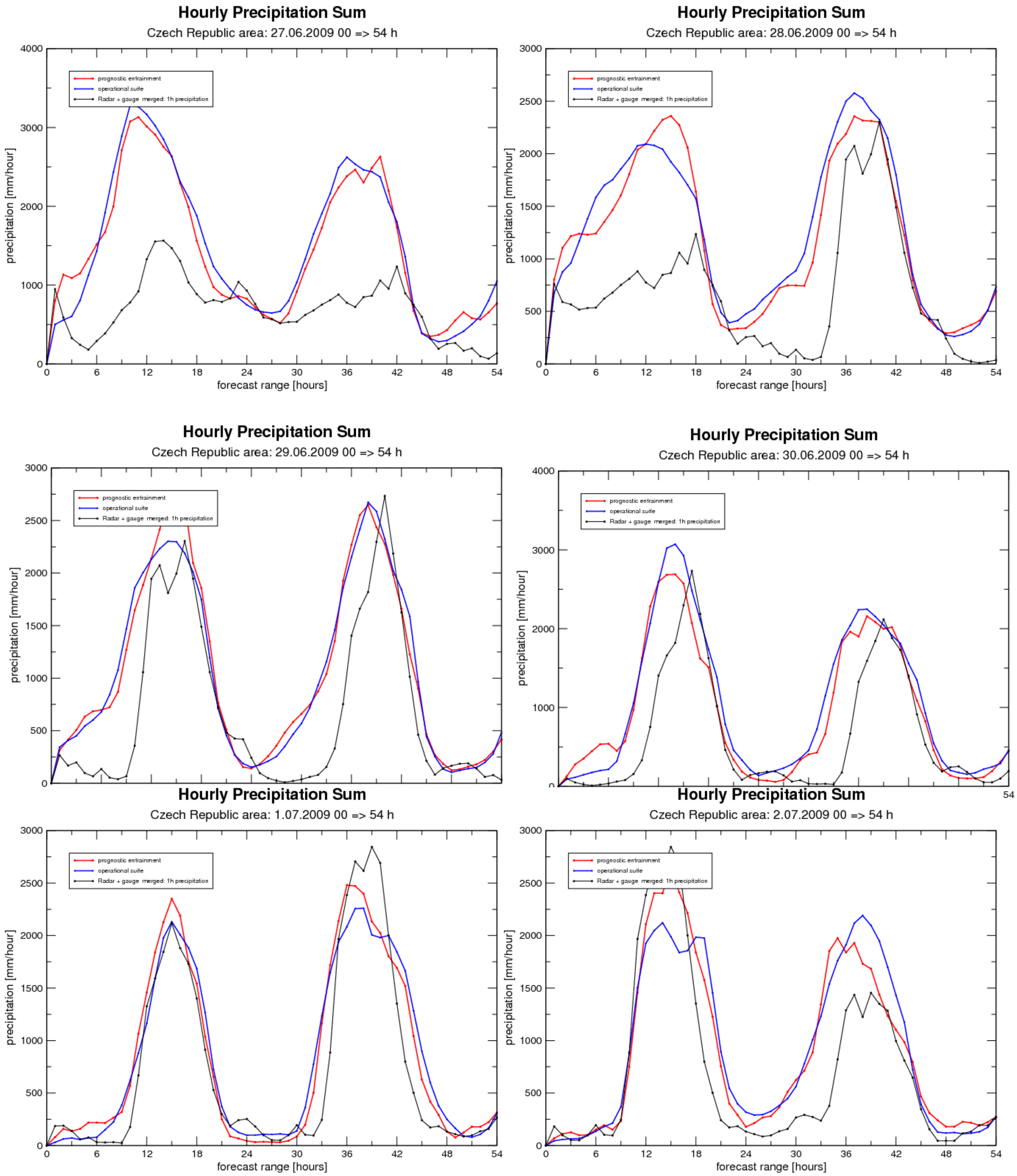











Hourly Precipitation Sum
Czech Republic area: 27.06.2009 00 => 54 h
prognostic entrainment
operational suite
Radar + gauge merged: 1h precipitation
precipitation [mm/hour]
forecast range [hours]
0
1000
2000
3000
4000
0
6
12
18
24
30
36
42
48
54
Hourly Precipitation Sum
Czech Republic area: 28.06.2009 00 => 54 h
prognostic entrainment
operational suite
Radar + gauge merged: 1h precipitation
precipitation [mm/hour]
forecast range [hours]
0
500
1000
1500
2000
2500
3000
0
6
12
18
24
30
36
42
48
54
Hourly Precipitation Sum
Czech Republic area: 29.06.2009 00 => 54 h
prognostic entrainment
operational suite
Radar + gauge merged: 1h precipitation
precipitation [mm/hour]
0
500
1000
1500
2000
2500
3000
Hourly Precipitation Sum
Czech Republic area: 30.06.2009 00 => 54 h
prognostic entrainment
operational suite
Radar + gauge merged: 1h precipitation
precipitation [mm/hour]
0
1000
2000
3000
4000
54
Hourly Precipitation Sum
Czech Republic area: 1.07.2009 00 => 54 h
prognostic entrainment
operational suite
Radar + gauge merged: 1h precipitation
precipitation [mm/hour]
forecast range [hours]
0
500
1000
1500
2000
2500
3000
0
6
12
18
24
30
36
42
48
54
Hourly Precipitation Sum
Czech Republic area: 2.07.2009 00 => 54 h
prognostic entrainment
operational suite
Radar + gauge merged: 1h precipitation
precipitation [mm/hour]
forecast range [hours]
0
500
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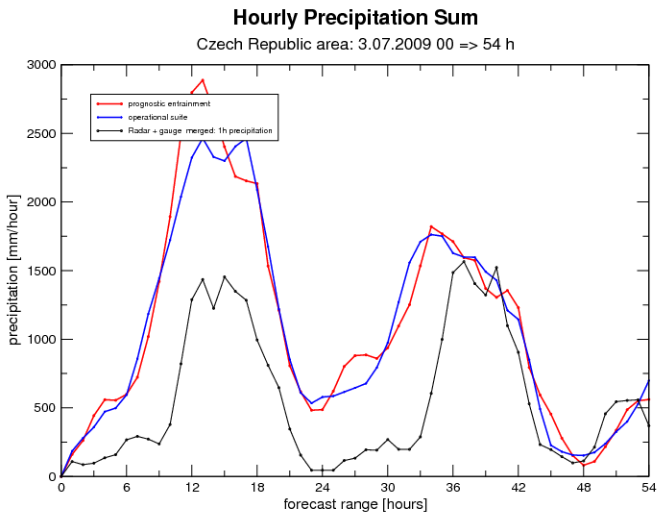
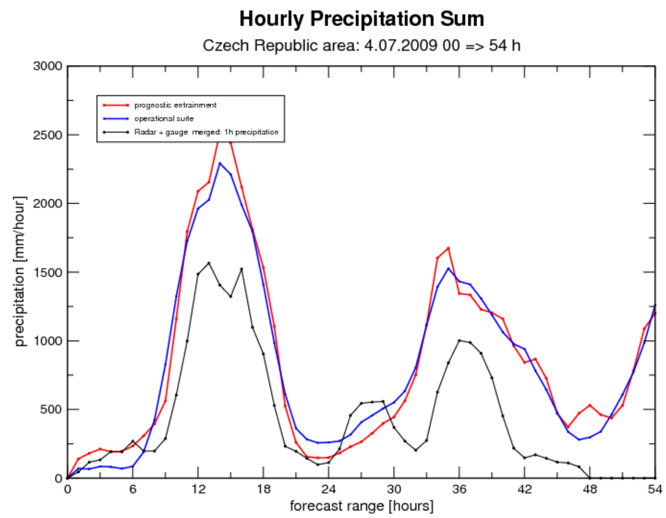
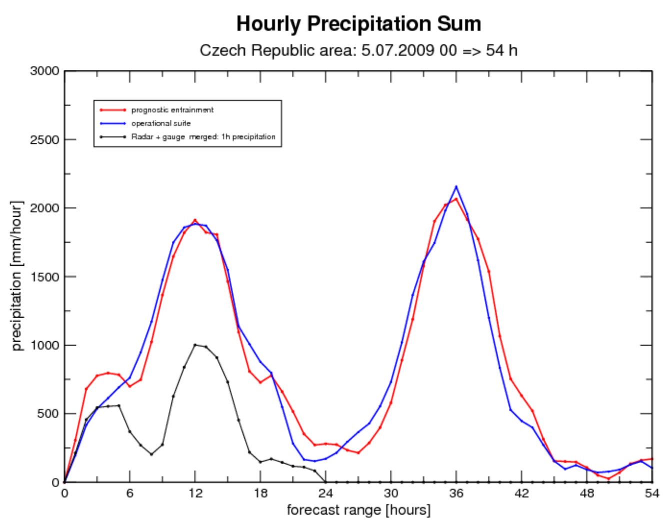

Hourly Precipitation Sum
Czech Republic area: 3.07.2009 00 => 54 h
prognostic entrainment
operational suite
Radar + gauge merged: 1h precipitation
precipitation [mm/hour]
forecast range [hours]


Hourly Precipitation Sum
Czech Republic area: 4.07.2009 00 => 54 h
prognostic entrainment
operational suite
Radar + gauge merged: 1h precipitation
precipitation [mm/hour]
forecast range [hours]


Hourly Precipitation Sum
Czech Republic area: 5.07.2009 00 => 54 h
prognostic entrainment
operational suite
Radar + gauge merged: 1h precipitation
precipitation [mm/hour]
forecast range [hours]