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Summer precipitation in the Vosges-Black Forest-region: pre-COPS investigations

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Summary

As a preliminary investigation for the COPS experiment, a series of 10 rainy days from summer 2006 was studied with the Meso-NH model, run at very high-resolution (2 km), initialized and forced with the ECMWF and ARPEGE analyses. In most cases, the results were not very sensitive to the type of analysis and the model succeeded reasonably well in reproducing the observed precipitation. In the few cases for which the sensitivity to the analysis was significant, the model performance was quite poor. It seems that a discrepancy between the ECMWF- and ARPEGE-driven simulations could be an indicator of low predictability. Furthermore, model skill appears weaker for the precipitation occurring over the Black Forest than for the precipitation affecting the Vosges.

1. Introduction

The Convective and Orographically-induced Precipitation Study (COPS, Wulfmeyer et al. 2008) took place in June/July/August 2007 in southwestern Germany and eastern France, in a region of moderate orography which includes the Vosges and Black Forest mountains. This field experiment was strongly motivated by the poor ability of numerical weather prediction models to

accurately forecast quantitative precipitation. As a preliminary investigation, prior to COPS, a series of rainy days from summer 2006 was selected and studied with the Meso-NH model run at very high resolution.

The main objective was to gain some insight into the predictability of the precipitating events which were expected during COPS. It was also the opportunity to extend some previous works carried in the context of Alpine heavy precipitation events and addressing with cloud-resolving models issues related with quantitative precipitation forecasting (Richard et al. 2007) or predictability over complex topography (Walser et al. 2004, Hohenegger et al. 2006; Hohenegger and Schär 2007).

2. Numerical setup

The numerical simulations were conducted with the French research model Meso-NH (Lafore et al. 1998) Three interactively nested domains were used with horizontal mesh sizes of 32, 8 and 2 km. The area corresponding to the coarsest domain is presented in Fig. 1a together with the location of the nested domains. The topography of the innermost domain, centred over the COPS area, is shown in Fig. 1b. Subgrid-scale con-

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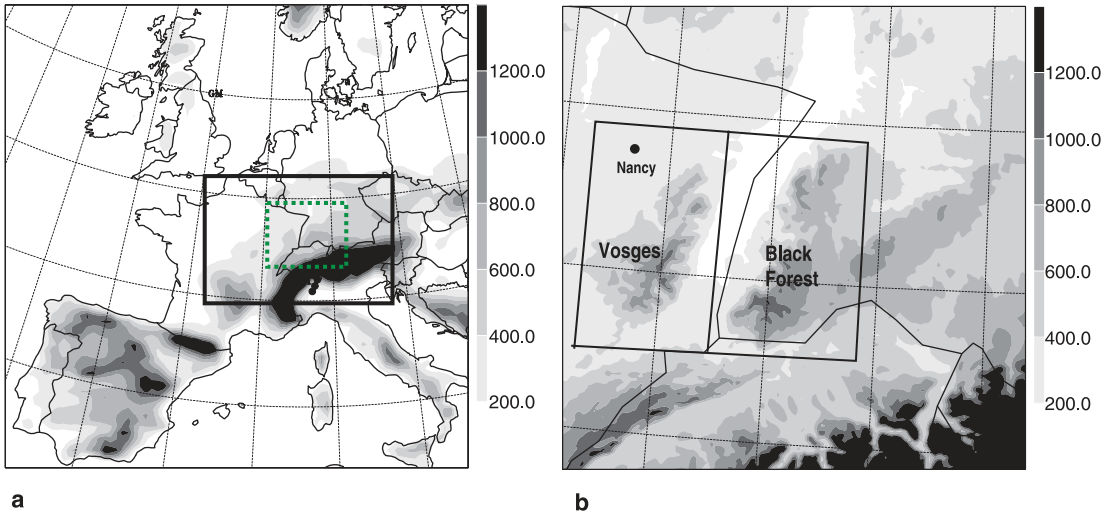


Fig. 1. (a) Geographical domains used for the nested simulations. The outer frame shows the 32 km grid-mesh model domain and its topography (in m). The location of the 8 km (2 km) grid-mesh domain is indicated by the solid (dashed) square. (b) Topography of the 2 km grid-mesh model. The two black boxes indicate the location of the Vosges and Black-Forest domains used in Fig. 6

vection was parameterized for horizontal resolutions of 32 and 8 km by a mass-flux convection scheme, whereas for the inner grid with a horizontal resolution of 2 km, convection was assumed to be explicitly resolved.

The initial and boundary conditions were taken from either the ECMWF or ARPEGE analyses. All simulations were integrated over a period of 30 h, starting at 00 UTC. The 10 selected days corresponded to the rainiest days of summer 2006 over the COPS region. Most of them were associated with strong synoptic forcing and a mid-level low located over north-western Europe but only one of them (27 June 2006) presented a strong convective activity.

3. Results

3.1 Overview

Figure 2 presents the time evolution of the simulated precipitation (averaged over the high-resolution domain) for each day and compares the results obtained with the two sets of analyses. For 7 of the 10 selected days, simulated precipitation is not very sensitive to the type of analysis: the time evolution of the spatial mean of the precipitation is similar whatever analysis is used. Nevertheless, significant discrepancies can be seen for June 27, and August 3 and 15.

To get a rough idea of the quality of each simulation, various statistical parameters were computed between the observed and simulated precipitation accumulated over 24 h. For reasons of data availability, two sets of computations were performed. The first one used measurements from the French climatological stations (188 stations over the COPS domain) providing accumulated precipitation from 06 to 06 UTC on the following day. The second one used data from the German stations of Baden-Wurtemberg (212 stations over the COPS domain) which were made available to us as daily sums (from 00 to 24 UTC).

The two sets of results are presented on Figs. 3 and 4. Figure 3 shows the Heidke Skill Scores (HSS) obtained for the 10 events for the French and German stations (top and bottom, respectively). The HSS is commonly used to assess the skill of precipitation forecasts. It is computed from a two-class contingency table and basically measures the model skill over random chance. In this study, the threshold between the two classes was set equal to 10 mm which roughly corresponds to the averaged value of the observed precipitation for the 10 selected days. Looking first at the French data, it can be seen that the HSS are reasonably high most of the time (exceeding 0.2) and consistent between the two sets of simulations, except for the three days mentioned above for

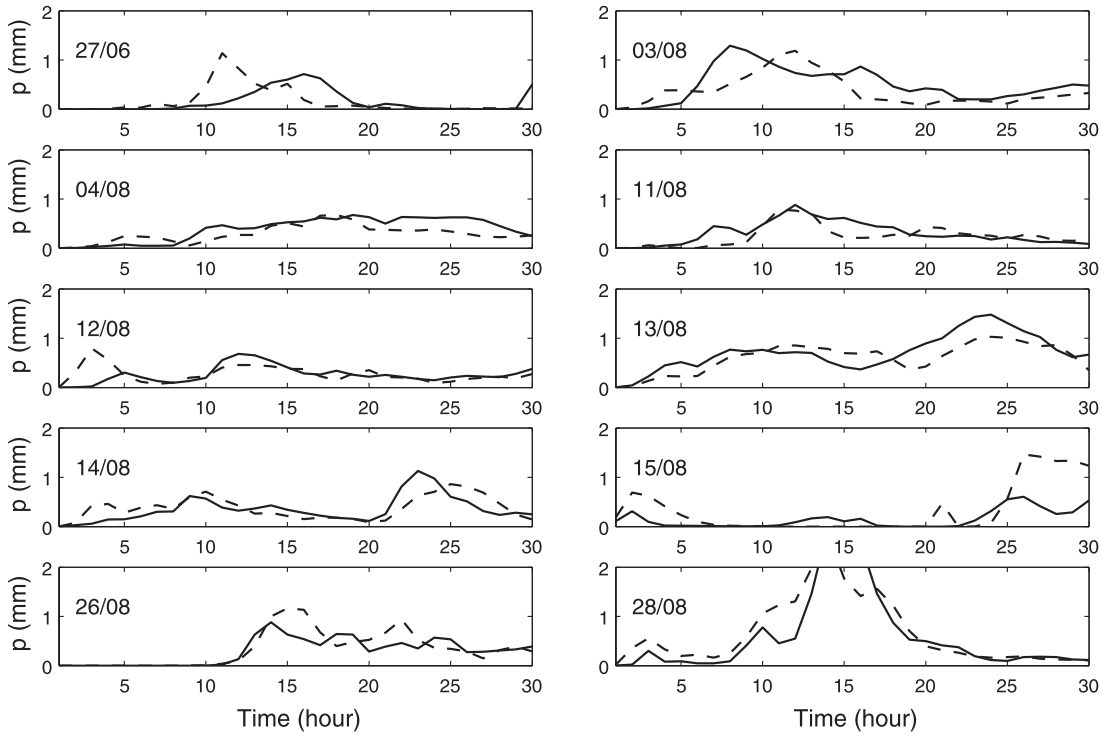


Fig. 2. Time evolution of the spatially averaged precipitation for the 10 selected days: simulations driven by ECMWF analyses (solid line) and ARPEGE analyses (dashed line)

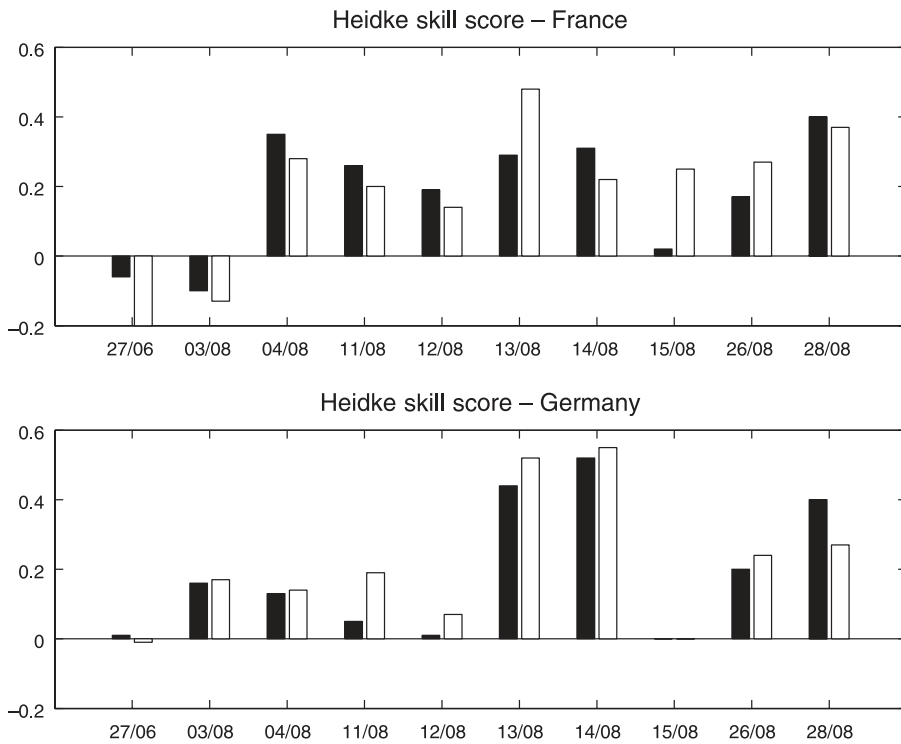


Fig. 3. Heidke skill scores for the simulated 24-hour precipitation for the 10 selected days computed for: the French data accumulated from 06 to 06 UTC (top) and the German data accumulated from 00 to 00 UTC (bottom). The simulations driven by the ECMWF and ARPEGE analyses are reported in black and white, respectively

which they drop dramatically and even some time become negative. At first sight, it seems that the discrepancy noticed on Fig. 2 between

the ECMWF- and ARPEGE-driven simulations could be an indicator of poor predictability of the situation. However, this feature is not as clear

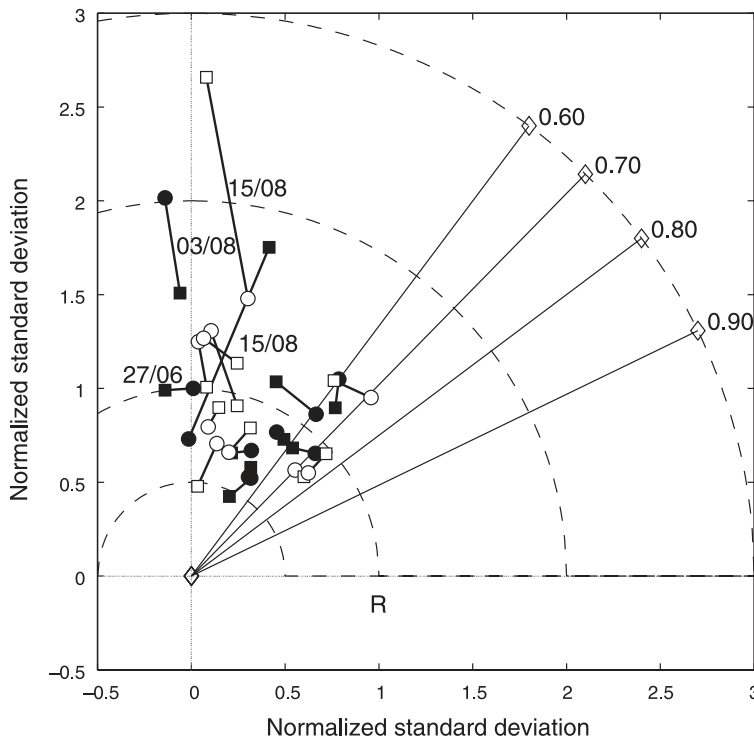


Fig. 4. Normalized pattern statistics showing the difference between observed and simulated 24-h accumulated precipitation. Full (open) symbols correspond to the French (German) stations. For each day, a solid line connects the ECMWF-driven simulation (circle) to its ARPEGE counterpart (square). The radial distance from the origin to a point is proportional to the normalized standard deviation, the azimuthal position gives the correlation between the observations and the simulations. The centered root mean square error is given by the distance between a point and the reference point (R)

from looking at the results obtained for the German stations. Among the seven cases with good skill over France, three of them (4, 11 and 12 of August) now present very low skill (despite the fact that the spatially averaged precipitation of the ECMWF- and ARPEGE-driven simulations remain consistent even when they are averaged over a domain limited to the Black Forest region).

It is also interesting to note that the cases for which the model skill is good for both geographical regions (August 13, 14, 26 and 28) are the cases for which convection is the weakest. On the other hand, the association low model skill – strong convection is not so clear. It is only true for June 27 and August 15 which were clearly the two most convective cases.

To complement this analysis, Fig. 4 shows a Taylor diagram which combines on the same display standard deviation, correlation coefficient and centred root mean square error (Taylor 2001). From this diagram, it can be shown that the biggest outliers in terms of correlation and root mean square error are associated again with June 27, August 3 and 15. Once these outliers excluded, it also seems that, in general, slightly better results are obtained for the French stations than from the German stations. Two reasons

might explain this behaviour. First, the time period considered for the precipitation accumulation over Germany includes the period of model spin-up. This may partially degrade the agreement with the observations. Second, it could be hypothesized that the precipitation over the Black Forest is less predictable than the precipitation over the Vosges. Being in the lee of the Vosges – which is the case for all the 10 selected days –, the Black Forest region might be quite sensitive to any forecast errors that may have occurred upwind over the first massif. However, the size of our sample is certainly too small to draw a solid conclusion with that respect.

3.2 The case of 27 June

Because of the poor results obtained for 27 June, this case was studied in more detail. Figure 5 displays the simulated precipitation obtained with both analyses and accumulated from 06 to 12 UTC and from 12 to 18 UTC. These fields can be compared with the rainfall estimate deduced from the radar observations made in Nancy. According to the radar, an elongated rain band, oriented south-west north-east, moved across the area in the morning whereas, in the afternoon, precipitation mainly occurred over north-eastern

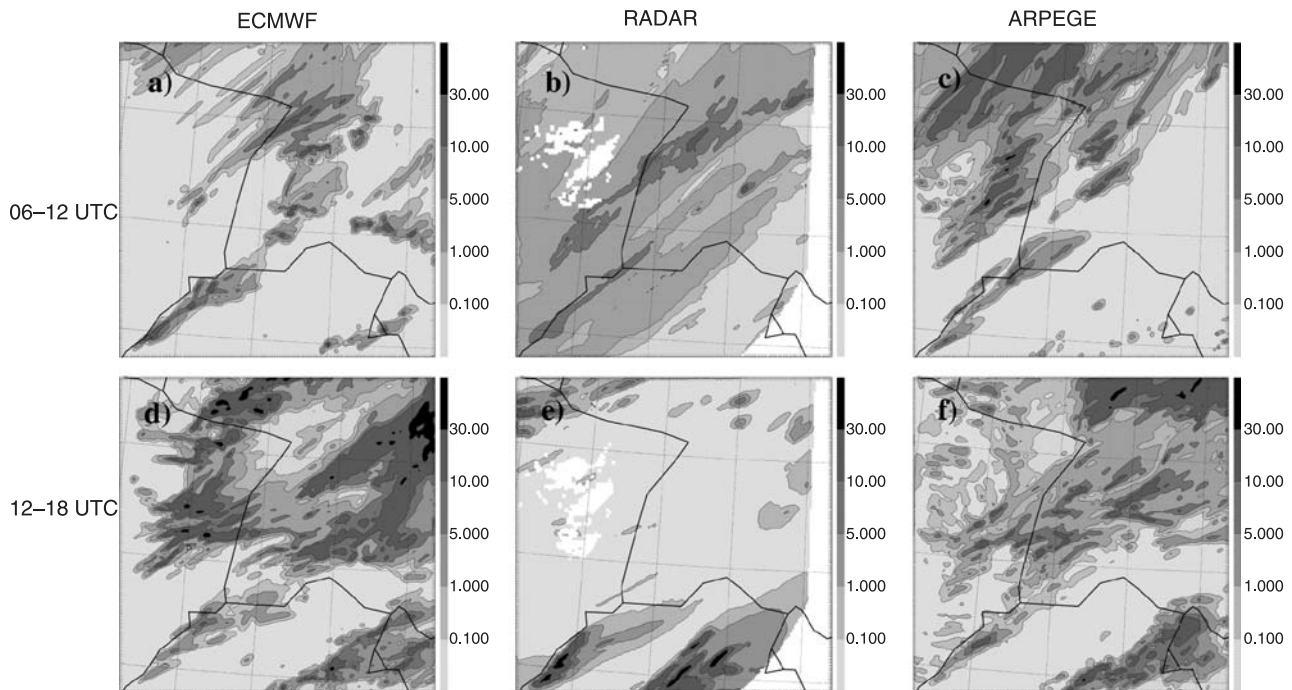


Fig. 5. Precipitation (in mm) accumulated from 06 to 12 UTC (top) and from 12 to 18 UTC (bottom) on 27 June 2006, computed from the ECMWF- and ARPEGE-driven simulations (left and right, respectively), and estimated from the Nancy radar measurements (middle)

Switzerland. Both simulations succeed in reproducing the precipitation pattern over Switzerland but neither of them correctly captured the time evolution of the rain band that crossed the Vosges and Black Forest. The ARPEGE-driven simulation gave too much precipitation over the Vosges in the morning and the ECMWF-driven simulation too much in the afternoon. For this case, which is by far the most convective event of the sample, both simulations appear to have a strong phase error.

4. Sensitivity study

In an attempt to identify some of the factors that could impact on the predictability of the 27 June event, two types of sensitivity experiments were carried out. The first one was intended to address the problem of uncertainty on the synoptic scale. By using the Ertel potential vorticity (PV) inversion method proposed by Arbogast et al. (2008), the upper-level PV anomaly of the ARPEGE analysis of 27 June 00 UTC was modified to obtain a better match with that of the ECMWF analysis. In one experiment (ARP-PV1), the PV streamer extending from the north-western tip of Spain almost to Denmark was slightly reinforced

in its central section whereas, in another experiment (ARP-PV2), the streamer extent was also elongated towards the north-east.

The second series of experiments was designed to investigate the role of mesoscale uncertainties and was based upon the lagged initialization method proposed by Walser et al. (2004) and Hohenegger et al. (2006). The driving simulations (32 km and 8 km) were initialized with the ECMWF analysis at 00 UTC while the ensemble members were spun off at 01 UTC (member 1, ECM-LAG1), 02 UTC (member 2, ECM-LAG2) and so on until 05 UTC (member 5, ECM-LAG5). The ensemble was then integrated to 06 UTC on the next day without any rescaling of the perturbation amplitudes.

Figure 6 presents the time evolution of the hourly precipitation for all these experiments, spatially averaged over a first domain restricted to the Vosges area and a second domain restricted to the Black Forest area. In addition, the evolution of the radar-derived precipitation is superimposed on each figure.

Over the Vosges (Fig. 6a), it is quite interesting to note that neither of the methods was able to significantly alter the results. The ARPEGE-driven simulations show very little sensitivity to

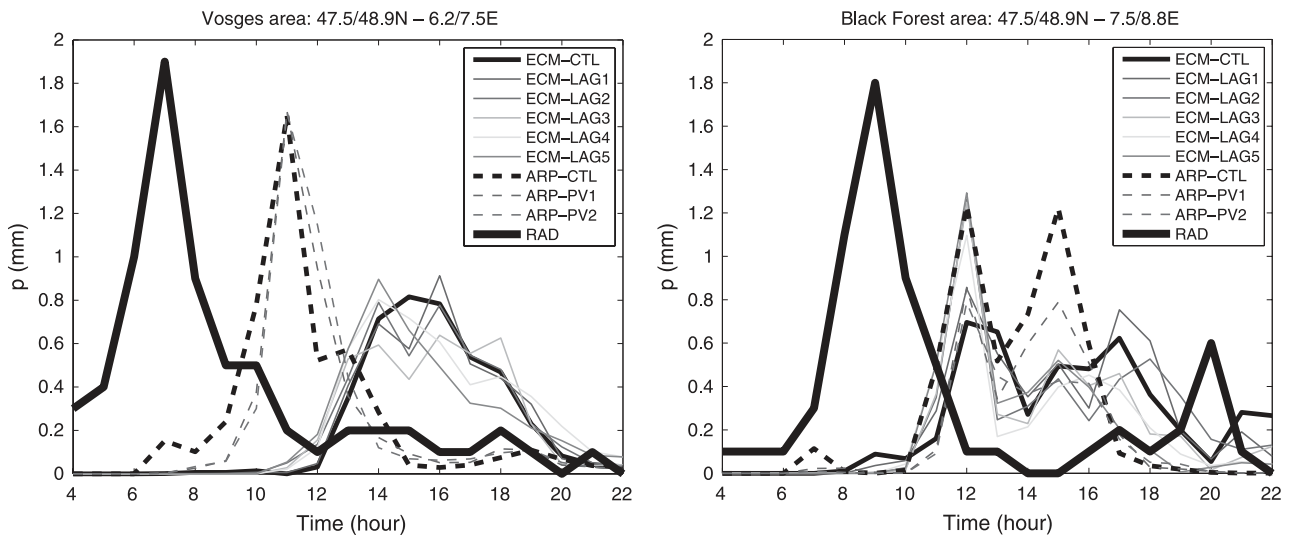


Fig. 6. Time evolution of the hourly precipitation averaged over the Vosges (left) and Black Forest (right) regions (thick black line: radar observations; solid thin lines: ECMWF driven simulations; dashed thin lines: ARPEGE driven simulations; CTL refers to the control experiments). The geographical boundaries of the domains are indicated on top of each frame and are also shown on Fig. 1b

our modifications of the large scale environment and, similarly, the ECMWF-driven simulations are not strongly modified by small changes in the mesoscale environment. All three ARPEGE-driven simulations produced the same precipitation peak at 11 UTC, which is late by four hours when compared with the radar observations. All

six ECMWF-driven simulations produced moderate rain in the afternoon and early night whereas almost no precipitation was detected by the radar during this time period. In response to the mesoscale perturbations introduced in the initial fields, some fluctuations of the precipitation intensity appeared but they remained very weak.

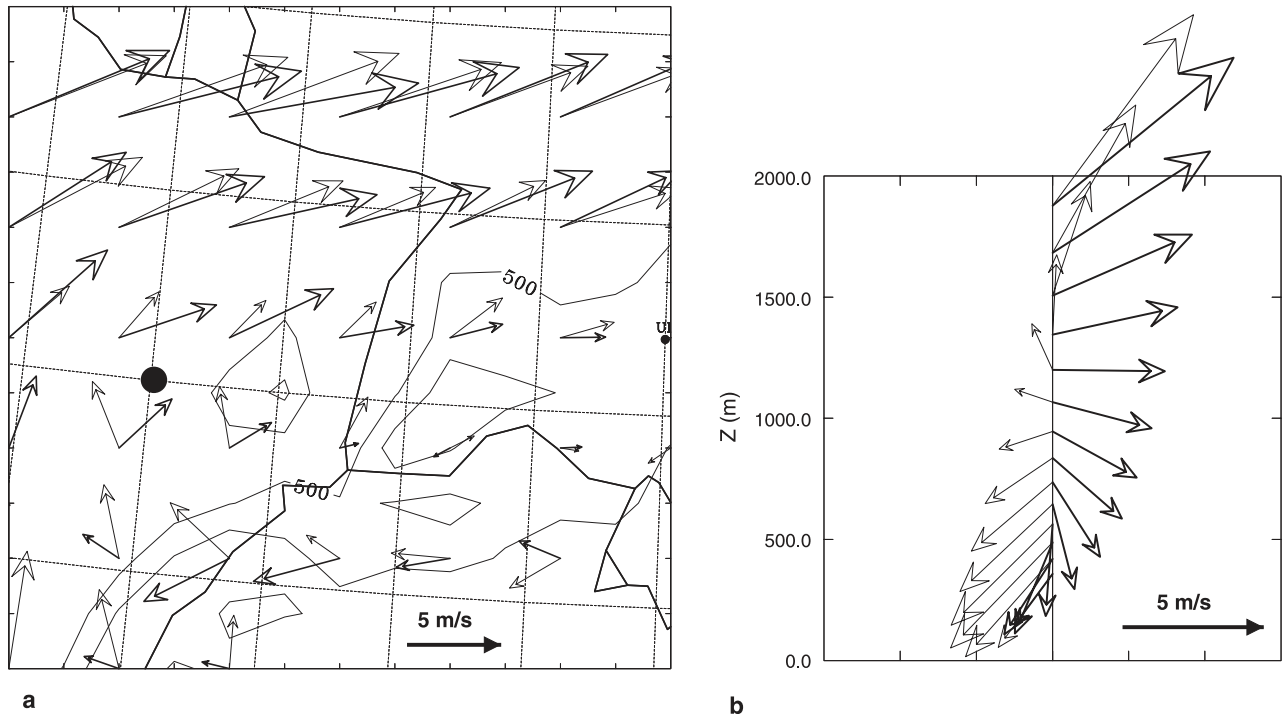


Fig. 7. Horizontal wind vectors derived from the 27 June 2006 00 UTC ECMWF analysis (thick arrows) and ARPEGE analysis (thin arrows): (a) horizontal field at 1500 m ASL, (b) vertical profile taken at 48N/6E (see black dot for location)

In comparison with the Vosges, the spread between the different simulations was larger over the Black Forest. The intensity of the first precipitation peak now varied in a range of 40%. Furthermore, the second peak present in the ARPEGE control experiment was considerably reduced in the experiments with modified upper-level PV, which then became more consistent with the ECMWF experiments.

As far as the spread can be related to the predictability, the above results tend to reinforce our hypothesis of a weaker predictability of the precipitation above the Black Forest than above the Vosges. However, they do not explain why the ECMWF- and ARPEGE-driven simulations differ so much in their precipitation results over the Vosges. A more systematic inspection of the differences between the two analyses of 00 UTC revealed some interesting features. Examples of some of these differences are shown on Fig. 7a, which displays the 1500 m horizontal wind vectors of the ECMWF analysis superimposed with the corresponding ARPEGE field. The differences, both in terms of intensity and direction, are unusually large especially in the south-west of the domain which provides the upwind conditions to the flow impinging the Vosges. A vertical profile taken upwind of the Vosges and shown on Fig. 7b indicates that the differences are quite pronounced up to a height of 2 km. Clearly, the two analyses provide quite a different picture of

the approaching front in this area of complex orography. This contrasted dynamical behaviour is also reflected in the moisture field. Figure 8 shows a vertical west-east cross section (crossing the Vosges and Black Forest mountains) of the water vapour mixing ratio derived from the ECMWF and ARPEGE analyses on 27 June 00 UTC. The ARPEGE analysis exhibits a faster propagation and also much moister conditions in the low levels. In particular the depth of the moist layer upwind of the Vosges is much more pronounced.

The discrepancy found between these two analyses is about twice that found among the different members of the lag ensemble or the PV inversion ensemble (which may explain the partial failure of any of the ensemble method to modify the precipitation over the Vosges) and is also much larger than the discrepancy found between the ECMWF and ARPEGE analyses on the other simulated days.

As a final sensitivity study, a third series of experiments was carried out to test the sensitivity of our results to initial moisture conditions. This parameter has a crucial role on the onset and development of precipitation. However, among the different analysed fields, moisture is the field which exhibits the largest uncertainty and is often the field for which different analysis systems provide the largest spread especially over mountainous regions (see for instance Lascaux et al.

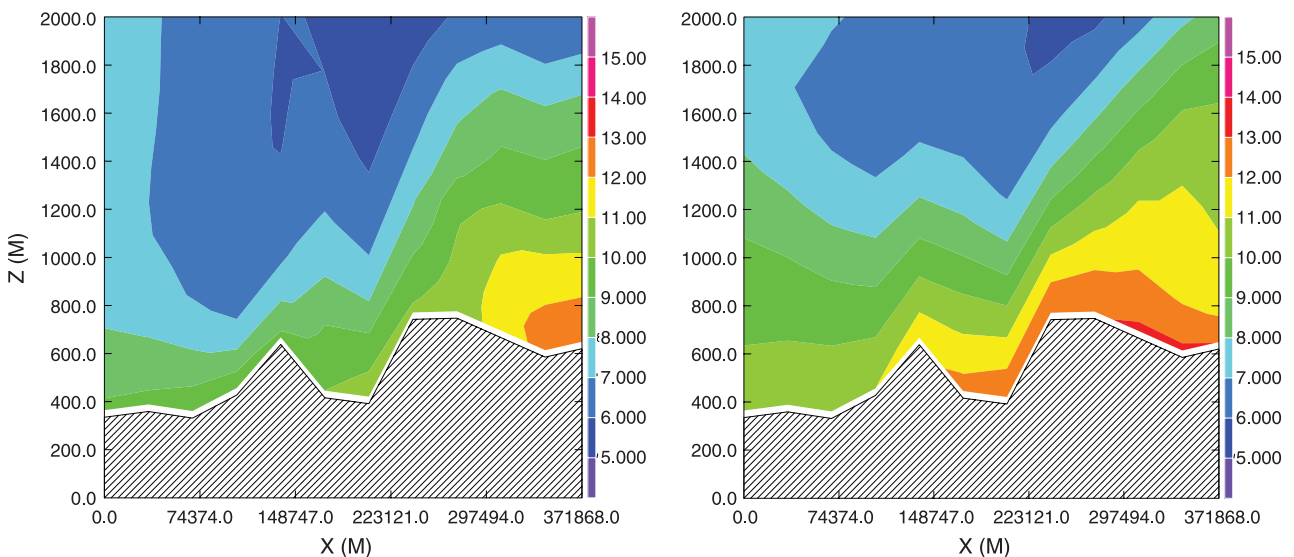


Fig. 8. Vertical cross section from 48N/5E to 48N/10E of the water vapor mixing ratio (in g/kg) derived from the 27 June 2006 00 UTC ECMWF analysis (left) and ARPEGE analysis (right)

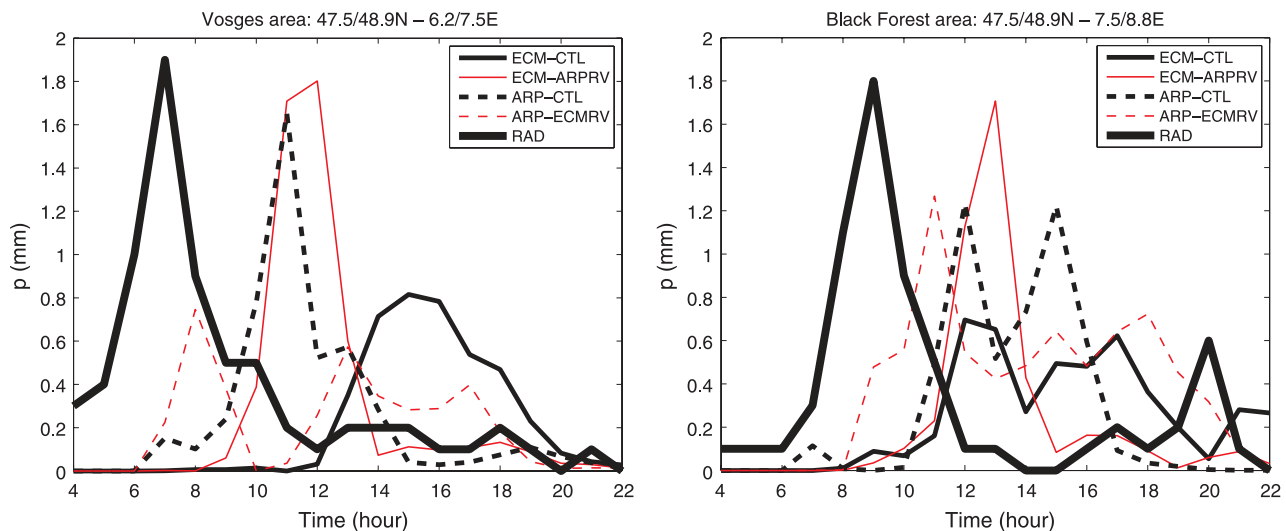


Fig. 9. Time evolution of the hourly precipitation averaged over the Vosges (left) and Black Forest (right) regions (thick black line: radar observations, solid thin lines: ECMWF driven simulations; dashed black lines: ARPEGE driven simulations; CTL refers to the control experiments). The geographical boundaries of the domains are indicated on top of each frame and are also shown on Fig. 1b

2004). As moisture presents a relatively low level of coupling with the others fields, it is possible to modify the initial moisture field without perturbing too much the balanced atmospheric state provided by the analysis. Therefore, two additional experiments were performed with modified initial moisture conditions. In the ECMWF-driven experiment, the initial moisture field was replaced by the moisture field of the ARPEGE analysis and similarly in the ARPEGE-driven experiment, the initial moisture field was replaced by the moisture field of the ECMWF analysis. These two additional experiments are designated by ECM-ARPRV and ARP-ECMRV respectively.

The results of these last two experiments are shown in Fig. 9. The modification of the moisture field has a much greater impact than any modification performed so far. In the case of the ECMWF driven simulation, it brings the results closer to the control ARPEGE experiment and in general closer to the observations. In the case of the ARPEGE driven simulation, it clearly degrades the results over the Vosges and has a weak impact over the Black Forest.

All these results seem to indicate that large (i.e., global) scale analysis should not be taken as a true representation of the atmospheric state. As long as different assimilation systems lead to uncertainties in the initial conditions which are larger than the ones considered so far in ensemble prediction systems, it seems that a substantial

improvement in terms of quantitative precipitation forecasting could be derived as well from a better local scale analysis.

5. Conclusion and outlook

A series of 10 cases of rain episodes over the COPS area has been studied with the Meso-NH model initialized and forced either with ECMWF or ARPEGE analyses. Most of the time, the simulated precipitation are reasonably good and not very sensitive to the initial analysis. In general, the model skill was found to be higher over the Vosges mountains than over the Black-Forest massif. It is hypothesized that the downwind position of the Black-Forest with respect to the Vosges may induce an additional loss of predictability. However, in a small number of cases, the model performance remains very poor and results strongly differ depending upon the type of analysis. Sensitivity studies carried out for the case of 27 June show that the discrepancy of the results can be only marginally explained with small uncertainties either in the synoptic conditions or in the mesoscale conditions. Close inspection of the different analyses revealed an unusually large discrepancy between the 00 UTC ARPEGE and ECMWF analyses used to initialize the model for this specific day. It would be difficult to trace back the reasons for such a discrepancy in the two analysis systems but it is

likely that some crucial information might have been missing or have arrived too late to enter the analysis systems. These results highlight the necessity to have a denser observation network or, at least, to make better use of the existing one.

Future work will involve further investigations on the role of the mesoscale environment. In particular, the new potential offered by assimilation techniques at the convective scale will be explored. Indeed the large number of additional data collected during COPS will provide a unique opportunity to assess the benefit of these new techniques.

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