

We appreciate the constructive comments and suggestions by Reviewer 1. Point-by-point responses to the Reviewer comments are provided below (with Reviewer comments in *italics*).

The AROME model has (to my knowledge) not been used yet for simulation of aerosol-cloud interactions, which is the probable reason why a deficiency in the simulation of vertical velocity has not been noted and addressed in previous studies. One other study with a mesoscale model at similar resolution is cited (Ivanova and Leighton, 2008), but there are many more. For example, Muhlbauer and Lohmann (2008) use a 2km horizontal resolution for the simulation of aerosol impact on orographic clouds, and Zhang et al. (2009) for a tropical cyclone. In these more extreme situations, the resolved vertical velocities were apparently sufficient. On the other hand, models at somewhat coarser resolutions are usually adding a subgrid-contribution to the resolved vertical velocity (e.g. Bangert et al., 2011; Zubler et al., 2011, with grid sizes of 14 and 50 km). It would be a logical extension of this study to analyse whether the addition of a TKE-term would also improve the AROME results.

We agree with the Reviewer; our understanding is that AROME has not yet been used for simulation of aerosol-cloud interactions, and we are not aware of any previous direct comparisons regarding the cloud base vertical velocities. The additional references suggested by the Reviewer are considered for citation in the manuscript. We have followed the Reviewer's suggestion and studied the impact of adding a TKE term to the resolved vertical velocities in the model. This analysis is included in section 5.1.1 of the revised manuscript, and the results are shown in Fig. 5c and Fig. 5f. We found that, when the TKE term is added to the grid-scale vertical velocity in AROME, the modelled σ_w is similar to the observed σ_w , but only below an altitude of about 1-2 km (within the model boundary layer); at higher altitudes, the TKE-term is relatively small. This is due to the use of the Eddy Diffusion Mass Flux scheme (Pergaud et al. 2009) for non-local turbulent eddies and shallow convection (as anticipated by Reviewer #2).

The observed cloud cases are all lumped together for the analysis. It would be useful to spend some effort on the classification of the clouds for which the cloud-base vertical velocity is derived. E.g., in June at the SGP site, a higher variability of the vertical velocity is observed, and this is explained with more convective clouds in summer. Is the model underestimation of σ_w equally bad for convective and stratiform clouds? Does the model predict the correct frequency of occurrence of convective clouds? Parameters which could be used to quantify the convectivity (and other characteristics) of the observed cases include CAPE from reanalysis data, cloud top heights, LWP, IWP, and/or cloud cover.

Note that we had to apply a screening procedure to avoid precipitating and drizzling clouds in the analysis, as described in section 4 of the manuscript. This screening has unavoidably limited the selection of cloud types available for analysis.

We have now tried several approaches for classifying different types of clouds. One approach that we found to be directly applicable for both model and observations was classifying clouds by geometrical thickness. We have investigated whether there was a distinction between shallow stratiform cloud-layers and deeper cumulus clouds. The case best suited for this analysis proved to be SGP data for June, due to the higher occurrence of relatively deep, non-precipitating clouds. The results are given in an additional subsection (5.1.2 in the revised manuscript); Figure 6 in the revised manuscript shows the statistics of vertical velocity for three subclasses, separated by cloud

geometrical thickness (0-250 m, 250-500 m and > 500 m). Figure 6a shows a tendency for mean values of the cloud base vertical velocity simulated by AROME to increase with cloud geometrical thickness while the observed mean value becomes more negative for the deepest clouds (most likely because of a bias due to selective sampling in the screening procedure, please see our response to Reviewer 2). The standard deviation of vertical velocity (σ_w) tends to increase gradually in AROME with increasing cloud geometrical thickness (Fig. 6b). However, the same does not appear to be true for observations, as a significant increase in σ_w is only seen for the deepest cloud layers (> 500 m deep). This analysis was performed also for Lindenberg, which showed qualitatively similar characteristics but suffered from significantly lower occurrence of cases especially for the deepest clouds.

From your observations, can you answer the question which model resolution would actually be necessary to properly resolve the cloud-base updrafts in the observed clouds? This would basically require extending Figure 8 to smaller spatial averaging scales, ideally for different cloud regimes.

This is a very interesting question, which we have recently started to analyse. It is part of our plans for the near future to make a rigorous spectral investigation using a more extensive dataset than that included in Fig. 8 (moved to Fig. 9 in the revised manuscript), which we expect to provide more insight on this issue. Because a thorough description of a spectral decomposition analysis would substantially increase the length of this manuscript, we feel it is outside the scope of the current paper.

However, based on the results presented in the current manuscript, we provide a qualitative answer: One can speculate that the necessary model resolution in terms of representing cloud base vertical velocities, at least for boundary layer clouds, should be such that the model would resolve at least a portion of the inertial subrange of turbulent kinetic energy spectrum related to vertical velocity. For vertical velocities in turbulent boundary layer, the inertial subrange is expected take place at wavelengths comparable with the boundary layer top height, or lower. Thus, the model should be able to resolve features at least at a ~ 1 km resolution. Fig. 9 in the revised manuscript shows that the effective resolution of AROME is slightly more than 4 times the grid spacing of the model (in the individual case presented). In a more general case, this estimate will likely be larger, as the most estimates usually end up with 6-9 times the grid resolution (for AROME, see e.g. the presentation slides by Arbogast and Boisserie, 2010). This result might also depend on whether the full three dimensional motion field, or a single component (i.e. vertical velocity) of the flow is used. Assuming that the effective resolution is something around 6 times the grid resolution, and that this relationship also holds if the model grid is made finer, the grid spacing necessary for resolving the cloud-base updrafts should be on the order of a couple of hundred meters or less.

Could you add a summary of the observed variability of the vertical velocity in the form of a table, such the data could be easily re-used for evaluation of other models?

We have added a table displaying the mean observed and modelled σ_w (averaged over all altitudes).

I am not in the position to comment in detail on the screening procedure applied to the measurements in order to avoid retrieval artifacts. However, the same screening should be applied to the model data (i.e. liquid, non-drizzling clouds only), because the clouds which are screened out in the retrieval might have different turbulence characteristics.

Similar screening has been applied to both the model and the observations in order to match the sampling statistics, as pointed out in section 4.1.

Technical comments:

All four points noted by the Reviewer have been corrected.

References

Arbogast, P., Boisserie, M.: Activities on model error at Météo- France. CNRM-GAME, Toulouse, 7-9 July, 2010 [available at http://www.wmo.int/pages/prog/arep/wwrp/new/documents/18_BOISSERIE_ARBOGAST.pdf, accessed 27.6.2011]

Pergaud, J., Masson, V., Malardel, S., Couvreux, F.: A parameterization of dry thermals and shallow cumuli for mesoscale numerical weather prediction. Bound-Layer Meteor., 132, 83-106, 2009