Improved parametrization of the boundary layer in Harmonie-Arome (focusing on low clouds)

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1 Introduction

With the introduction of the HARATU turbulence scheme (Lenderink & Holtslag 2004, de Rooy 2014, Bengtsson 2017) in cycle 38, Harmonie-Arome improved on several output parameters, especially 10m wind speed. From the moment HARATU is included at KNMI (in 2015), Harmonie-Arome clearly and consistently outperforms wind speed forecasts of Hirlam, ECMWF and Harmonie-Arome with CBR turbulence. However, from cy38 onwards, the model underestimates low clouds and overestimates the cloud base height of low clouds, both crucial for e.g. aviation purposes. Within the Hirlam consortium this problem is considered as the most important deficiency of Harmonie-Arome.

Parameterization schemes most relevant for low cloud predictions are the cloud, turbulence and convection scheme. Together with increased physical realism of these boundary layer parameterizations, coupling between them becomes stronger. For example, turbulent and convective activity is used as input in the cloud scheme to determine sub-grid variance in humidity and temperature, key parameters in a statistical cloud scheme. Another example of such a direct, i.e. fortran coded, coupling is convective activity being used as a source term in the TKE budget equation of the turbulence scheme (so-called energy cascade term). Apart from these direct couplings, there are well-known indirect feedbacks, e.g.: more clouds lead to less radiation at the surface which will in turn influence turbulent and convective activity. Due to strong connectedness, the boundary layer parameterizations need to be developed and optimized together. Using such an integral approach, substantial modifications have been made to the Harmonie-Arome cloud, turbulence and convection scheme leading to clear improvements, especially in low cloud forecasts.

While this paper focuses on the impact of these modifications, a detailed description and motivation of the adjustments will be described in a separate paper (in preparation). The modifications are based on a wide variety of arguments. Some are founded on theoretical considerations, like a correction in the thermodynamic derivation of the statistical cloud scheme. Another example is the modification of the turbulence scheme based on similarity theory. In addition, we use process studies in which LES and 1D model results are compared in detail for a wide variety of cases. Finally, Harmonie-Arome 3D sensitivity runs as well as long-term simulations are used to optimize uncertain parameters.

2 Results

Results of Harmonie-Arome cycle 40 including all modifications in turbulence, convection and cloud scheme will be referred to as cy40NEW whereas the reference is denoted as cy40REF (as described in Bengtsson et al. 2017)

Clouds

We start with a clear example of underestimation of low clouds and overestimation of low cloud base heights in cy40REF.

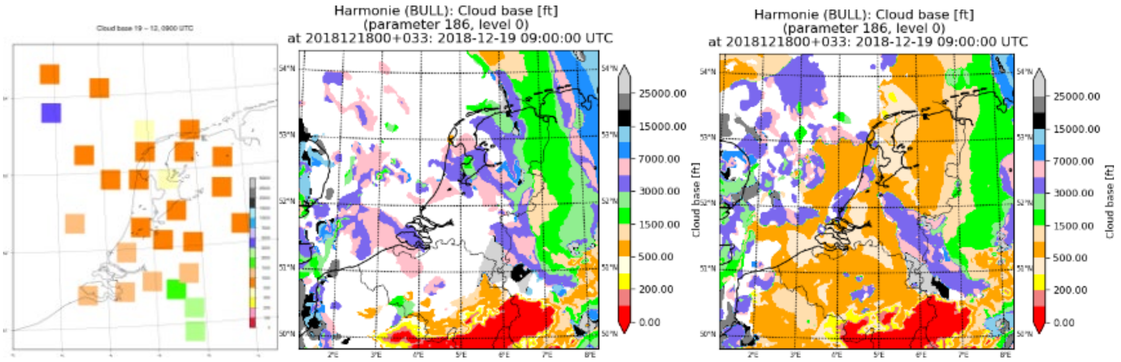

Figure 1:Cloud base height in feet on the 19th of December 2018 at 9:00 UTC. Left panel: observations at discrete locations. Middle and right panel show the results of cy40REF and cy40NEW resp. In the middle and right panel, white means no cloud base detected in the model.

Figure 1 shows a typical example of a poor low cloud forecast with cy40REF and the large impact and improvement with cy40NEW. The strong impact of the modifications is confirmed in long term verification. As an example we present the frequency bias in cloud base height for December 2018 in The Netherlands (Fig. 2). Note the large underestimations of cy40REF, where e.g. the +24h forecasts produce less than 20% of the observed number of cloud base heights around 176 ft. The negative biases are clearly smaller in cy40NEW. Also in other months there is substantial improvement in low cloud base height distributions with cy40NEW (not shown).

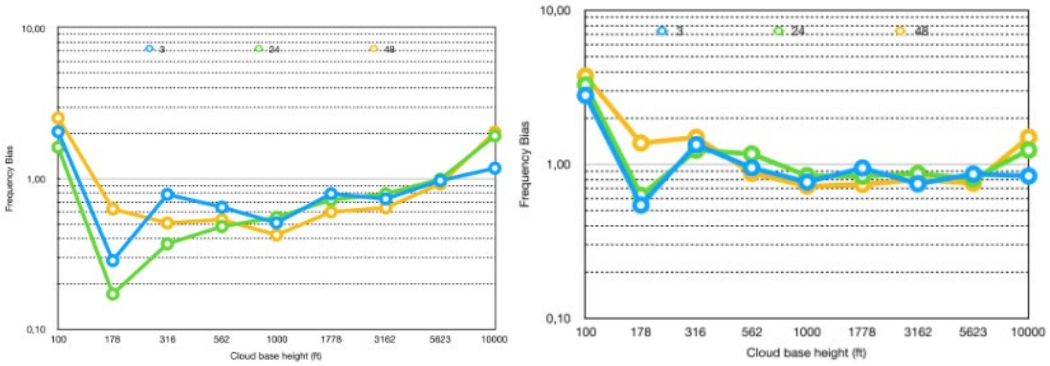

Figure 2:Frequency bias (1 is optimal) of cloud base height in feet for December 2018 above The Netherlands. Left panel, cy40REF and right panel cy40NEW.

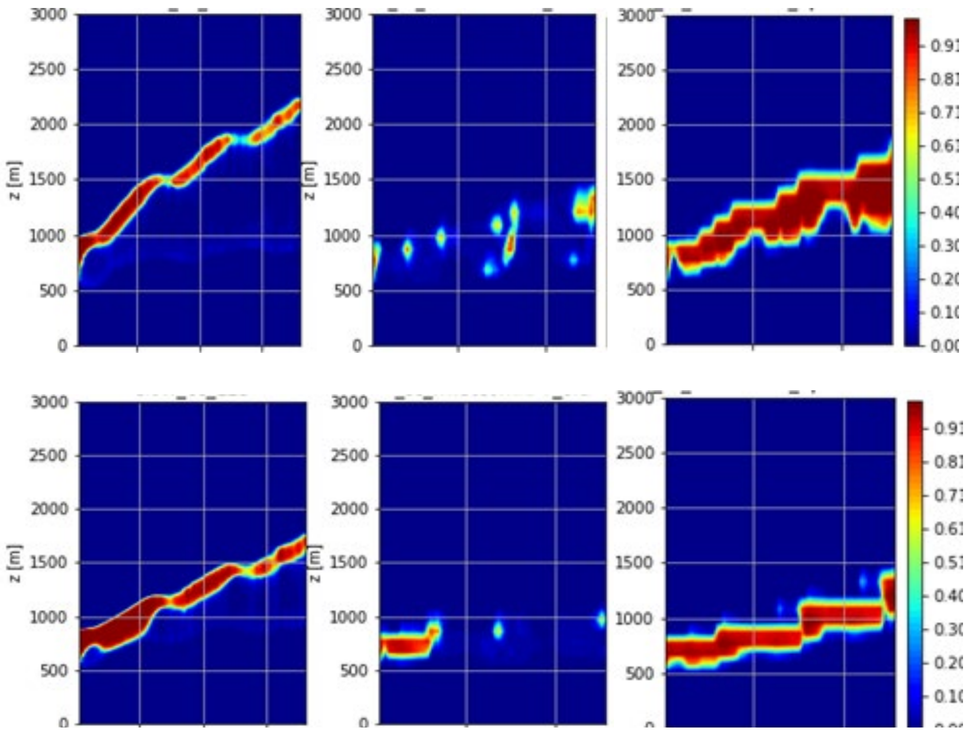

Figure 3:Cloud cover versus height and time (red is high, blue is low fraction) for intercomparison case ASTEX fast (upper panels) and ASTEX slow (lower panels). Left, middle and right panels show LES, cy40REF, and cy40NEW results resp.

Precipitation

Apart from impact on low clouds, increased atmospheric inversion strengths influence triggering of resolved deep convection and the associated precipitation. This is illustrated in Fig. 4, where intense precipitation was observed but not triggered in cy40REF. By contrast, cy40NEW did produce resolved convection and rain. Fig. 4 reveals the stronger building up of humidity under the inversion in cy40NEW which enables upward motions and finally, deep resolved convection.

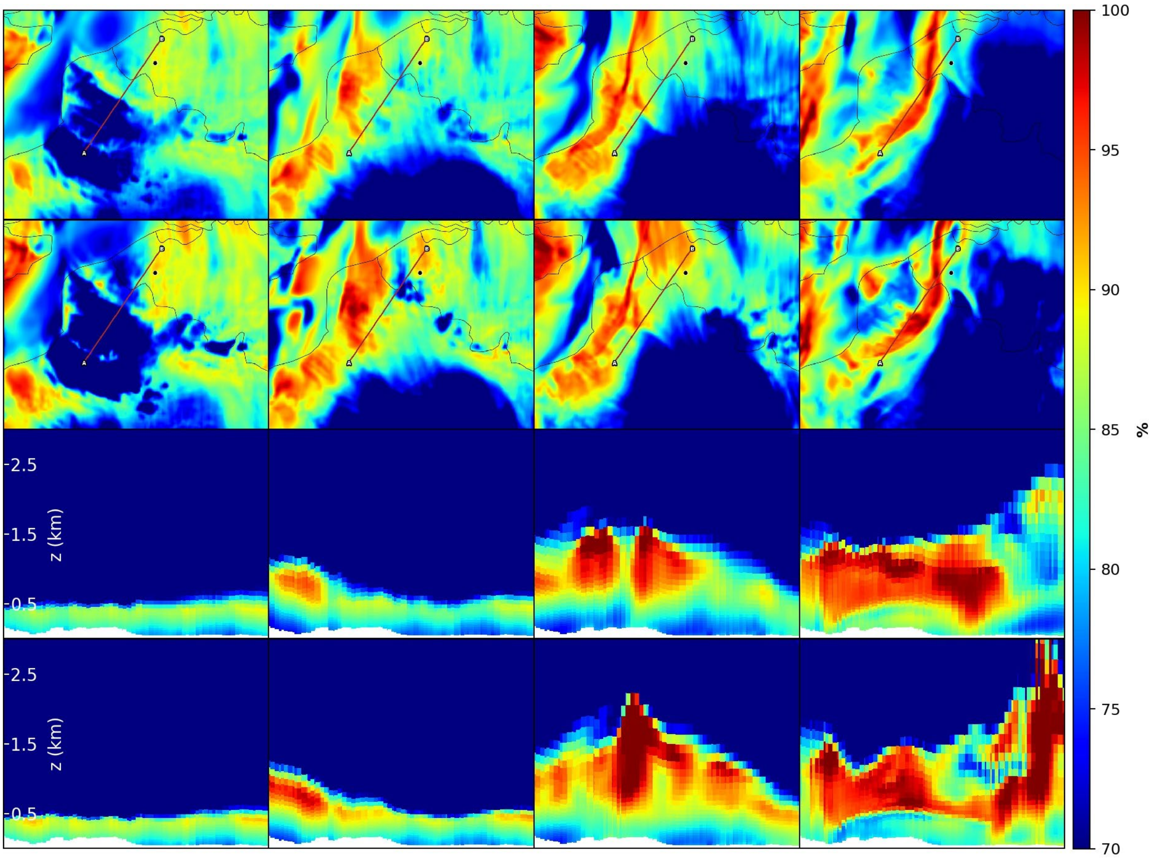

Figure 4: Relative humidity plots (red means high, blue low relative humidity) for the 10th of September 2011. The four columns refer to hours 12, 14, 16 and 18 UTC. The first row(cy40REF) and second row (cy40NEW) show a map of The Netherlands, Belgium and the North West of France as well as a black line. Along this line a vertical atmospheric cross-section is shown in the third (cy40REF) and fourth (cy40NEW) row. In the cross-sections, the boundary layer can be recognised by relatively high relative humidity values.

The improvement on precipitation forecasts is confirmed in long-term verification. Figure 5 shows the Fraction Skill Score (higher values means better) above The Netherlands for a 8month period in 2019. Cy40NEW performs significantly better than cy40REF (and cy36).

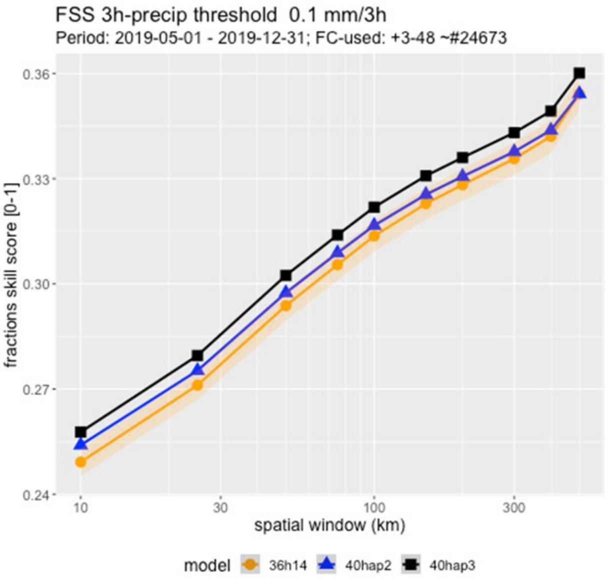

Figure 4:Fraction skill scores for precipitation amounts > 0.1mm in 3h over The Netherlands as a function of the spatial window. Calibrated radar data is used as observation. Shown are the results for cycle 36 (orange), cy40REF (blue) and cy40NEW (black).

Apart from the impact on clouds and precipitation, the modifications influence several aspects of the model. For example, results for GABLS1 reveal improved vertical profiles (less mixing) during moderately stable conditions (not shown). Good results for 10m wind speed with cy40REF are preserved in cy40NEW.

4 Conclusions

Strong feedback between boundary layer schemes demands an integral approach to develop and optimize the parameterizations involved. In such an approach, substantial changes have been made to the Harmonie-Arome turbulence, convection and cloud scheme based on theory, process studies (LES) and evaluation of 3D model runs. The modifications result in a clear improvement, especially on clouds and precipitation. At KNMI, Harmonie-Arome including all modifications (cy40NEW), already runs in parallel to cy40REF and cy36 since May 2019. Therefore, long term verification was possible, firmly substantiating the improvements and demonstrating the conservation of cy40REF's good performance on e.g. wind speed (de Rooy & de Vries, et al. 2017).
All modifications will be included in the tagged Harmonie-Arome cycle 43. In a later stage, the improvements will also become available for Harmonie Climate (Belušić, 2020) with undoubtedly impact on e.g. precipitation extremes in future weather experiments (Lenderink et al. 2019). All modifications and the corresponding argumentations will be described in a separate paper (in preparation).
Verification of model clouds is notoriously difficult. As part of the CRIME project we therefore developed a cloud validation system based on a combination of Cloudnet and satellite observations. First validation results will soon become available and be published.

Acknowledgements

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