An assessment of deficiencies and sensitivities of operational quantitative precipitation forecasts using the COSMO model

S. Dierer[1], M. Arpagaus[1], U. Damrath[2], A. Seifert[2], J. Achimowicz[8], E. Avgoustoglou[7], T. Andreadis[7],
M. Baldauf[2], R. Dumitrache[9], V. Fragkouli[7], F. Grazzini[3], P. Louka[7], P. Mercogliano[6], P. Mezzasalma[3],
M. Milelli[4], D. Mironov[2], A. Morgillo[4], E. Oberto[4], A. Parodi[5], I. V. Pescaru[9], U. Pflüger[2], A. Sanna[4],
F. Schubiger[1], K. Starosta[8], and M. S. Tesini[3]

[1]MeteoSwiss (CH), [2]DWD (D), [3]ARPA-ER (IT), [4]ARPA-P (IT), [5]Uni Genova (IT), [6]CIRA-CMCC (IT), [7]HNMS (GR), [8]IMGW (PO), [9]NMA (RO)

Introduction

Quantitative precipitation forecast (QPF) is an important purpose of limited-area numerical weather prediction models - for forecasters and customers. Indications from verification and forecasters suggest that the operational implementations of the COSMO model (7-14 km horizontal grid spacing) – like other numerical weather prediction models - have deficiencies in forecasting precipitation. This was the motivation to launch the COSMO Priority Project 'Tackle deficiencies in quantitative precipitation forecasts'. The aim of the present study is to investigate which parts of the modelling system have a significant impact on QPF. Investigations are focussing on numerical methods and physical parameterizations, while the effect of inaccurate initial and boundary conditions is disregarded in this study. Identifying the most important and weakest parts of the model will not only, or maybe not at all, lead to direct improvements, but can provide guidance for future research and development.

Test cases and sensitivity studies

The first step of the project is the selection of test cases reflecting typical forecast errors of the COSMO model at 7 km grid spacing. The cases are selected in a way that the forecast error is probably not caused by wrong synoptic conditions in the initial or boundary data. A final list of 25 test cases is selected for the QPF sensitivity studies. The selected test cases divide into two main groups of forecast errors: 9 cases of overestimated stratiform precipitation, (mainly in Germany, Switzerland and Poland) and 6 cases of underestimated convective precipitation (mainly in Italy and Greece).

The second step is the preparation of a set of sensitivity studies concerning initial conditions, numerical methods and physical parameterizations. The sensitivity studies, the expected changes and the kind of study are described in Table 1–3. The list defines about 20 sensitivity runs with the COSMO model that are performed for all test cases. The evaluation of sensitivity experiments is based on the 24h area average precipitation. Evaluation regions are selected with a minimum size of 100kmx100km. By this method, the focus is on larger scale over- or underestimations. Problems of wrong localization or wrong temporal simulation are not captured.

No.	Sensitivity study	Expected	Kind of study
1	Reduction of soil moisture 20%	Homogenous reduction of precipitation	idealized
2	Increase of soil moisture 20%	Homogenous increase of precipitation	idealized
3	Reduction of initial humidity 10%	Homogenous reduction of precipitation	idealized
4	Increase of initial humidity 10%	Homogenous increase of precipitation	idealized

Table 1: Sensitivity studies regarding initial values.

No.	Sensitivity study	Expected	Kind of study
5	Halved time step	Optimal case: nothing	idealized
6	Leapfrog, tri-cubic semi-Lagrange advection of QR and QS	Less diffusive advection of precipitation	option
7	Runge-Kutta, tri-cubic semi-Lagrange advection of QV, QC, QI QR and QS	Less diffusive, improved flow over terrain, improved advection of all moisture variables	option
8	Runge-Kutta, flux-form advection of QV, QC, QI, QR and QS	Less diffusive, improved flow over terrain, improve advection and mass conservation of all moisture variables	option
9	Runge-Kutta, flux form advection and T'-p' dynamics	Less diffusive, improved flow over terrain, improved advection and mass conservation and a better treatment of buoyancy terms	option
10	increased orography filtering	Slightly decreased orographic precipitation	idealized

Table 2: Sensitivity studies regarding numerical methods.

No.	Sensitivity study	Expected	Kind of study
Microphysics			
11	New warm rain scheme (Seifert and Beheng; 2001)	Reduced drizzle	option
12	Strong changes of ice microphysics and new warm rain scheme	Reduced drizzle and precipitation amount and increased transport of precipitation to mountain lee side	idealized
13	Moderate changes of ice microphysics and new warm rain scheme	Reduced drizzle and precipitation amount and increased transport of precipitation to mountain lee side	development
Convection			
14	Modified Tiedtke scheme	Weaker convection	development
15	Kain-Fritsch/Bechtold scheme	Modified convection	development
16	No parameterization of deep convection	Unrealistic up-scaling of convection, deteriorated forecast	idealized
Planetary boundary layer			
17/ 18	Decreased/increased scaling factor of height of laminar boundary layer for heat	Increased/decreased vertical exchange of heat and moisture	idealized
19/ 20	Decreased/increased stomatal resistance	Increased/decreased vertical exchange of moisture	idealized
21/ 22	Decreased/increased laminar scaling factor for heat over sea	Increased/decreased vertical exchange of heat and moisture	idealized

Table 3: Sensitivity studies regarding physical parameterizations.

Results

Effect on area average precipitation

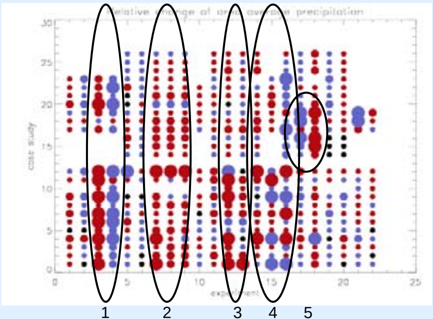

Figure 1:Blue (red) circles indicate an increase (decrease) of 24h area average precipitation relative to the basic simulation ($\Delta rel = rr_{sens}-rr_{ref}/rr_{ref}$). The big circles indicate changes bigger than 30%, medium ones between 10% and 30% and small ones between 0% and 10%, black circles indicate no change. Experiment numbers are the ones in Table 1-3. Marked are changes of initial humidity (1), Runge-Kutta runs (2), microphysics (3) and convection (4) changes and changed vertical exchange (5).

The sensitivity experiments show that the strongest effect on QPF is caused by changes of initial humidity and of convection schemes. Both cause changes of the area average precipitation values in the range of 40% (Figure 2). Increasing (decreasing) initial humidity increases (decreases) the precipitation. There are indications from verification that there are deficiencies in the humidity simulation motivating a closer look at atmospheric humidity in order to approve or disprove its influence on QPF deficiencies. Using the Kain-Fritsch/Bechtold scheme causes increase as well as decrease of precipitation.

Using the Runge-Kutta time integration scheme instead of Leapfrog and a modified warm rain and snow physics scheme change the area average precipitation by about 10% (Figure 2). Using the Runge-Kutta scheme reduces the area average precipitation for most of the cases, convective as well as stratiform. The reason has not yet been investigated, but might be related to using centered differences. For the Roman and Greece test cases, both regions affected by the sea, the heat and moisture exchange between surface and atmosphere is of great importance causing changes in the range of about 25%. Changes of orography filtering and time step have a negligible effect on the area average precipitation.

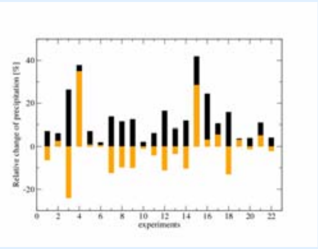

Figure 2: The sum of relative changes of area averaged precipitation ∑Δrel is given as yellow bars. The sum of the absolute values of the relative changes of area average precipitation ∑| Δrel | is given as black bars. The relation between yelllow and black bars indicates if changes have predominantly one direction.

Improvement of QPF?

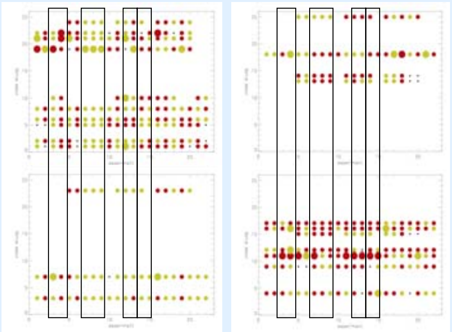

Figure 3:Ratio of the bias of the reference version and of the sensitivity study bias$_{exp}$/bias$_{ref}$ for cases with overestimation of stratiform (upper panel, left) and convective (lower panel, left) precipitation and with underestimation of stratiform (upper panel, right) and convective (lower panel, right) precipitation. Green circles indicate a smaller bias, while red circles indicate a higher bias in the sensitivity study. Big circles show a more than halved (doubled) bias, small circles show an up to halved (doubled) bias. Points indicate no change.Black frames like in Figure 1.

For overestimation cases, reducing initial humidity and using the Runge-Kutta scheme have a positive effect. Convective overestimations are additionally reduced by using the modified Tiedtke or the Kain-Fritsch/Bechtold (KFB) convection scheme. Using the Runge-Kutta scheme improves also cases of underestimation. Thus, the Runge-Kutta scheme has an overall positive effect on QPF. Most underestimation cases are imroved by increasing the initial humidity. The change of microphysics (exp. 13) and the modified Tiedtke scheme have a predominantly negative effect. Using the KFB scheme has a neutral impact, improving some and worsening other cases. Concludingly, there is no clear positive impact on cases of convective underestimation.

Cross experiments

The cross experiments combine those changes that have a positive effect on overestimated stratiform precipitation. The simulations are performed with a model version including microphysics changes similar to exp. 13 (Table 1). Runs are performed using this version (exp. 25), with KFB (exp. 27) and modified Tiedtke scheme (exp. 29) and additionally with Runge-Kutta and reduced initial humidity (exp. 26, 28, 30, respectively). The results show a positive effect on QPF of cases with overestimated stratiform precipitation for most cross experiments.

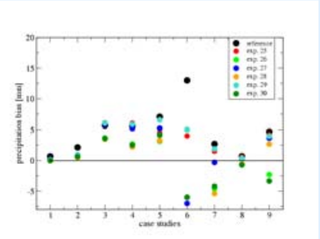

Figure 4: Bias of the reference simulation and cross experiments (see text) for cases with overestimated of stratiform precipitation.

Conclusions

- ➢ **Strongest effect on area average precipitation by changed**
  - ➢**initial humidity**
  - ➢**time integration scheme (Runge-Kutta instead of Leapfrog)**
  - ➢**parameterization of convection and microphysics**
- ➢ **Runge-Kutta, changed microphysics and convection improve cases of stratiform overestimation**