Manuscript prepared for Atmos. Chem. Phys.
with version 3.2 of the LaTeX class copernicus.cls.
Date: 5 December 2011

Online supplement to 'Aerosol-cloud-precipitation effects over Germany as simulated by a convective-scale numerical weather prediction model'

Axel Seifert[1]**, Carmen Köhler**[1,2]**, and Klaus D. Beheng**[3]

[1]Deutscher Wetterdienst, Offenbach, Germany
[2]Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre,Oberpfaffenhofen, Germany
[3]Karlsruher Institut für Technologie, Institut für Meteorologie und Klimaforschung, Karlsruhe, Germany

Abstract. This online supplement provides some additional information and figures.

1 Introduction

Here we provide some additional information and figures which are mostly redundant to the corresponding figures of the main article, but may nevertheless be interesting for some readers.

2 Precipitation fields

Figure 1 shows the monthly mean precipitation amounts of those experiments which were not given in the main text. In addition the monthly mean precipitation amount as estimated for radar data is provided. The latter shows some obvious artifacts, but the quantitative values are rather unimportant for current study which focuses on the analysis of the model simulations. This radar-derived precipitation map also shows a nice example of the difficulties in measuring area averaged precipitation amounts.

Tables 1-3 provide some quantitative evaluation of the relative differences in area averaged precipitation for different domains. In each table a different experiment is chosen as the reference.

The relative difference in monthly mean precipitation is provided in Fig. 2 for the full model domain. It is evident that in the low CCN simulations more precipitation forms in the western part of the model than in the high CCN simulations. This is reasonable as in a low CCN environment moist air masses rain out faster, and less moisture is transported eastwards over continental Europe. To some extent, this may also be a response to the lateral boundary conditions which do not take into account any changes in CCN assumption, i.e. the moisture and the hydrometeor variables of the lateral boundary conditions are in this sense inconsistent with the simulations. To exclude or at least reduce the effect of boundary conditions a larger model domain would be desirable and, in addition, the large-scale models which provide the boundary conditions should also incorporate the CCN/IN perturbations. The latter is, of course, difficult or even infeasible as long as the aerosol-cloud effects on deep convection are hardly understood and insufficiently represented in parameterizations of deep convection.

Correspondence to: Dr. Axel Seifert, Deutscher Wetterdienst, Frankfurterstr. 135, 63067 Offenbach, Germany.
Email: axel.seifert@dwd.de

3 Precipitation statistics

The variability of localized grid-scale precipitation amounts, i.e. individual grid points of the 2.8 km mesh, is analyzed with help of Fig. 3.

The main effect that we find is that high CCN assumptions lead to a slight reduction of grid-scale precipitation amounts, i.e. the statistical distribution is shifted towards smaller values. Although the local precipitation intensities in the convective cores may also increase in a 'high CCN' convective system, e.g. due to increase in hail formation (Khain et al., 2011), the main increase in precipitation in our simulations is due to an increase in the occurrence of light to moderate precipitation in the 'high CCN' case, i.e. larger stratiform regions of the convective systems.

4 Time series

Figure 4 provides the timeseries of the integrated water vapor path for experiment 3 vs 4 and 2 vs 4, corresponding to Fig. 3 of the main text which shows experiments 1 vs 2 and 1 vs 3.

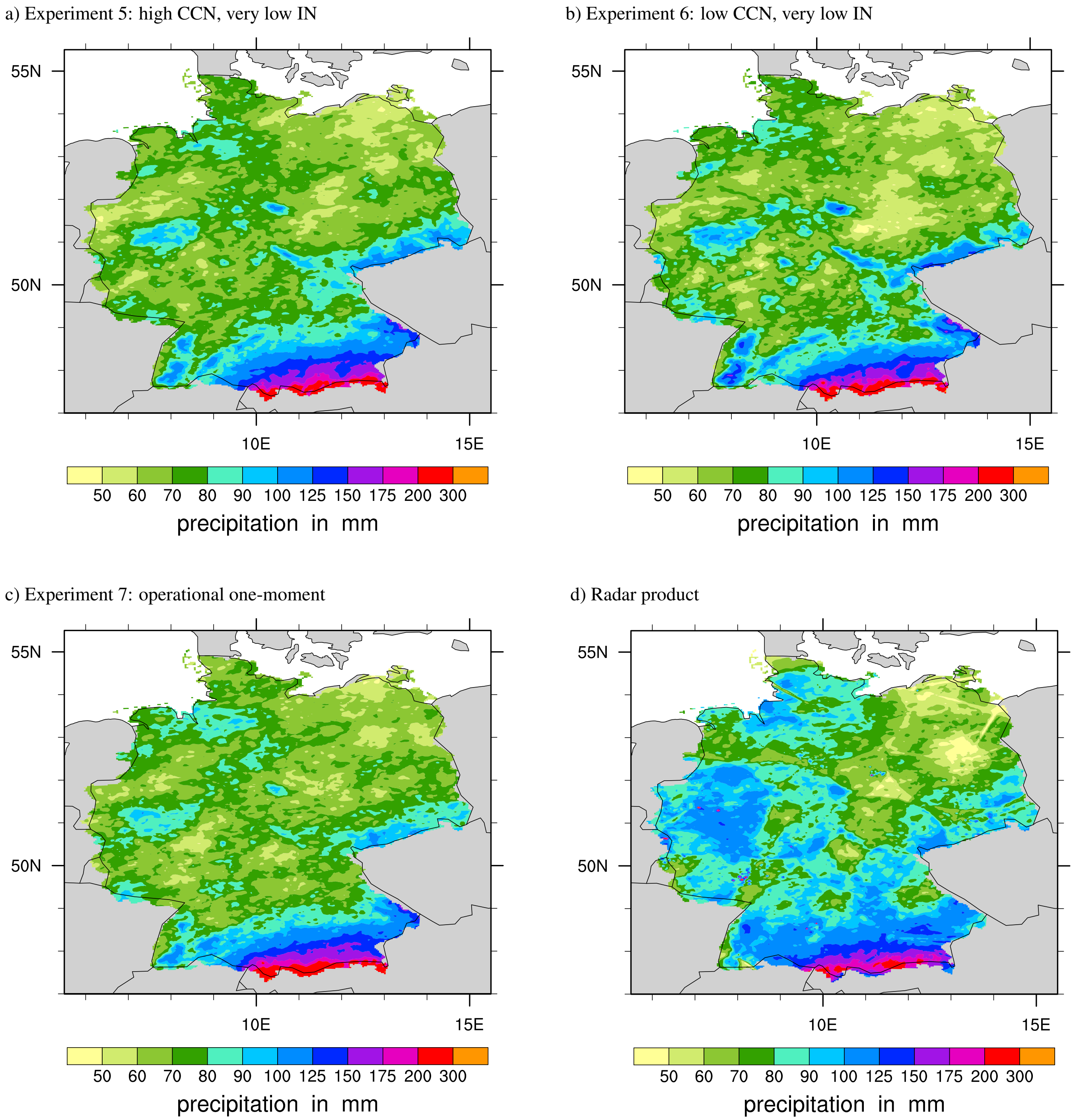

Fig. 1. Monthly mean precipitation amount of JJA 2008, 2009 and 2010. Shown are experiment 5, 6, and 7 as well as the radar product.

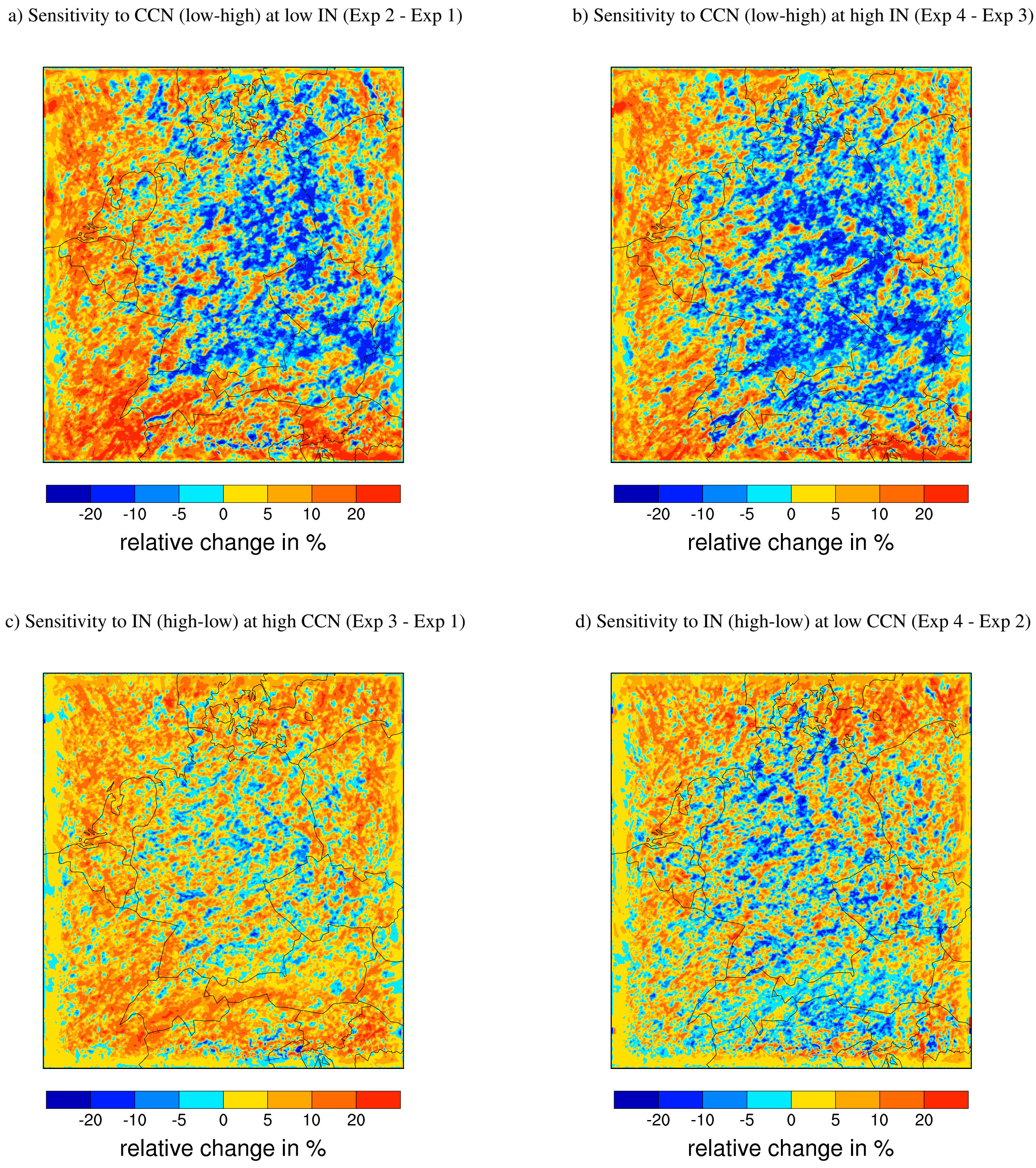

Fig. 2. Relative difference in % of the monthly mean accumulated precipitation of JJA 2008-2010 comparing different experiments. Shown is the full model domain in the original rotated lat-lon coordinates including the nudging zone at the lateral boundaries.

Table 1. Relative differences in % of monthly mean precipitation amounts with respect to Experiment 1 with high CCN, low IN. Domains as in Table 1 of the main text, i.e. 0− Germany, 1− southern domain, 2− center of domain, 3− northern domain, 4− full evaluation domain (1,2,3).

CCN	IN	0− Germany	1−southern domain	2−center of domain	3− northern domain	4− full domain	unit
high	low	-	-	-	-	-	-
low	low	-0.92	-2.60	-0.40	-1.22	-1.52	%
high	high	2.88	3.28	1.91	2.18	2.54	%
low	high	-0.66	-2.11	-1.20	-1.69	-1.70	%
high	very low	-4.64	-4.91	-4.39	-4.39	-4.60	%
low	very low	-5.66	-7.30	-5.20	-6.09	-6.30	%
one-moment		-5.10	-8.46	-7.75	-2.18	-6.43	%

Table 2. Relative differences in % of monthly mean precipitation amounts with respect to Experiment 2 with low CCN, low IN. Domains as in Table 1 of the main text, i.e. 0− Germany, 1− southern domain, 2− center of domain, 3− northern domain, 4− full evaluation domain (1,2,3).

CCN	IN	0− Germany	1−southern domain	2−center of domain	3− northern domain	4− full domain	unit
high	low	1.65	2.67	0.41	1.23	1.54	%
low	low	-	-	-	-	-	-
high	high	4.40	6.04	2.32	3.44	4.12	%
low	high	0.50	0.50	-0.80	-0.47	-0.19	%
high	very low	-3.19	-2.37	-4.00	-3.21	-3.13	%
low	very low	-4.59	-4.83	-4.82	-4.93	-4.86	%
one-moment		-3.73	-6.02	-7.38	-0.98	-4.99	%

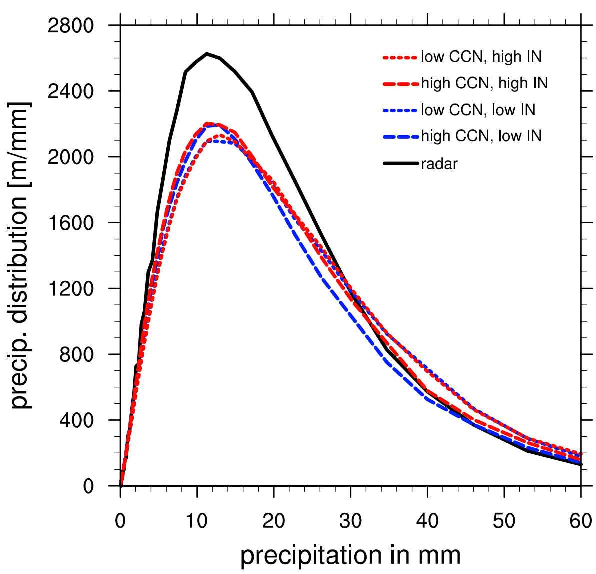

Fig. 3. Precipitation distribution function $P(R) = N(R)R\,p(R)$, where R is a 12-h accumulated grid-scale precipitation amount, $p(R)$ is the probability density function of R, and $N(R)$ is the number of events.

Figure 5 shows the precipitation rate time series averaged for the northern and central domains. Note that the model produces a strong secondary nocturnal precipitation peak which is not that obvious in the radar data, although the northern domain suggest such a feature also in the observations. This nocturnal peak is most pronounced for the operational one-moment scheme.

5 Precipitation scores

Skill scores have not been discussed in the main text, mostly because it is questionable whether the radar observations are sufficiently accurate to provide a useful reference, especially given that the differences between the experiments are rather small. Nevertheless, we provide here some results of standard precipitation scores like FBI, ETS and Fraction Skill Score (FSS), see e.g. Wilks (1995) as well as Roberts and Lean (2008) for the definition of these score. Figure 6 shows that the two-moment microphysics leads to a marginal improvement, and the experiments with high CCN do score better than those with low CCN. Interestingly, for Germany the high CCN assumption might indeed be the most realistic one. On the other hand, this result may be simply due to the fact that somewhat smoother fields, as provided by the high CCN simulation, do often score slightly better than more localized spatial distributions.

Table 3. Relative differences in % of monthly mean precipitation amounts with respect to Experiment 3 with high CCN, high IN. Domains as in Table 1 of the main text, i.e. 0− Germany, 1− southern domain, 2− center of domain, 3− northern domain, 4− full evaluation domain (1,2,3).

CCN	IN	0− Germany	1−southern domain	2−center of domain	3− northern domain	4− full domain	unit
high	low	-2.49	-3.18	-1.78	-2.13	-2.48	%
low	low	-3.56	-5.69	-2.27	-3.32	-3.96	%
high	high	-	-	-	-	-	-
low	high	-3.34	-5.22	-3.05	-3.78	-4.14	%
high	very low	-7.10	-7.93	-6.18	-6.43	-6.96	%
low	very low	-8.16	-10.25	-6.98	-8.09	-8.62	%
one-moment		-7.58	-11.37	-9.48	-4.27	-8.75	%

a) CCN sensitivity at high IN

b) IN sensitivity at low CCN

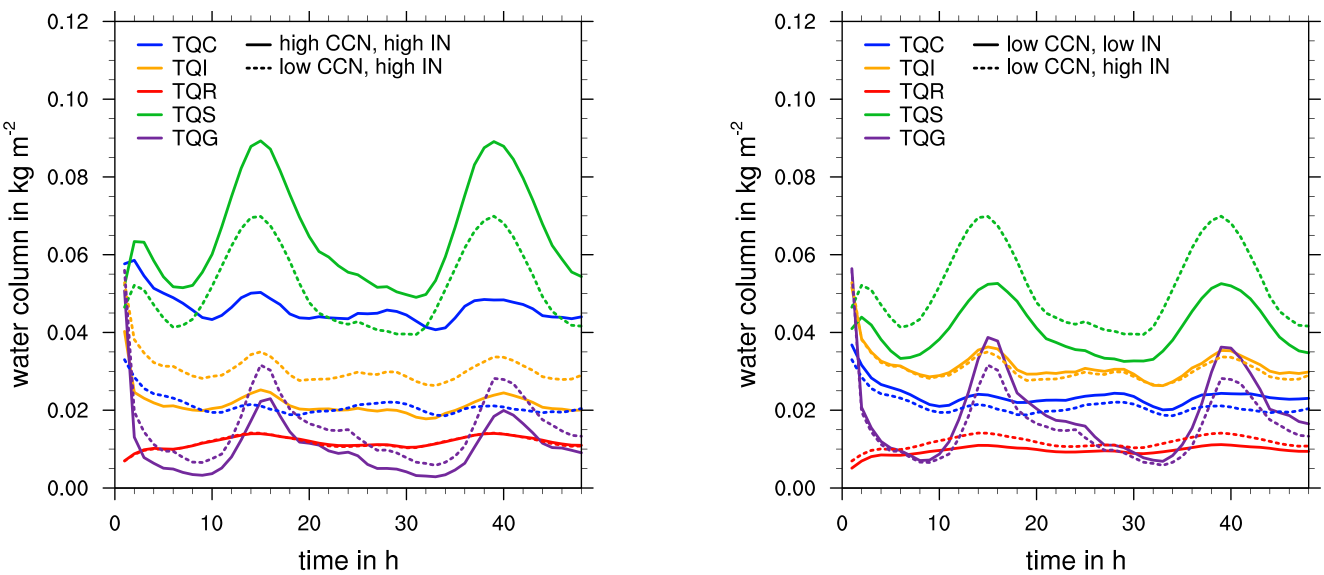

Fig. 4. As Fig. 3 of the main text, but comparing the CCN at high IN (left), and IN perturbation experiments at low CCN (right).

6 PDF of ice fraction

Figure 7 shows the probability density function of ice fraction in mixed-phase clouds in % as a function of temperature for Experiment 7 with the operational one-moment scheme. This scheme does obviously lead to a very different glaciation characteristic of mixed-phase clouds. The reasons for the different behavior are not yet understood. Possible explanations include (1) additive time integration of the microphysical terms instead of Marchuk-splitting as used in the SB scheme, (2) one-moment vs two-moment parameterization, with the one-moment scheme being unable to properly represent the growth of small ice particles (3) different ice nucleation parameterizations. Unfortunately, there are only little to no observations of in-cloud ice fraction of convective cores that could help to decide which behavior is actually more realistic.

7 Conclusions

The additional figures provided in this online supplement support the conclusions of the main article.

References

Khain, A., Rosenfeld, D., Pokrovsky, A., Blahak, U., and Ryzhkov, A.: The role of CCN in precipitation and hail in a mid-latitude storm as seen in simulations using a spectral (bin) microphysics model in a 2D dynamic frame, Atmos. Res., 99, 129–146, 2011.

Roberts, N. M. and Lean, H. W.: Scale-Selective Verification of Rainfall Accumulations from High-Resolution Forecasts of Convective Events, Mon. Wea. Rev., 136, 78–97, 2008.

Wilks, D.: Statistical Methods in the Atmospheric Sciences, Academic Press, 1995.

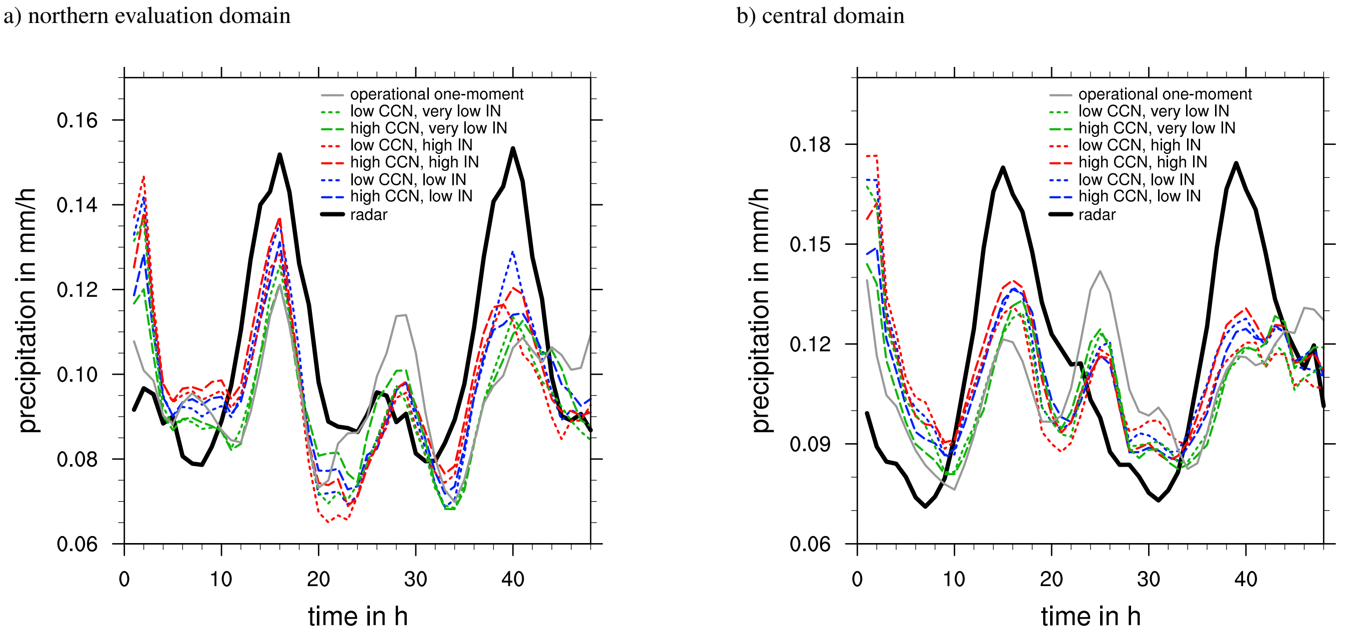

Fig. 5. As Fig. 7 of the main text. Time series of hourly rain rate averaged over the (a) the northern evaluation domain, and (b) the central evaluation domain. Shown are the radar data, the six two-moment microphysics experiments, and the control simulation using the operational one-moment scheme (all simulations initialized at 00 UTC).

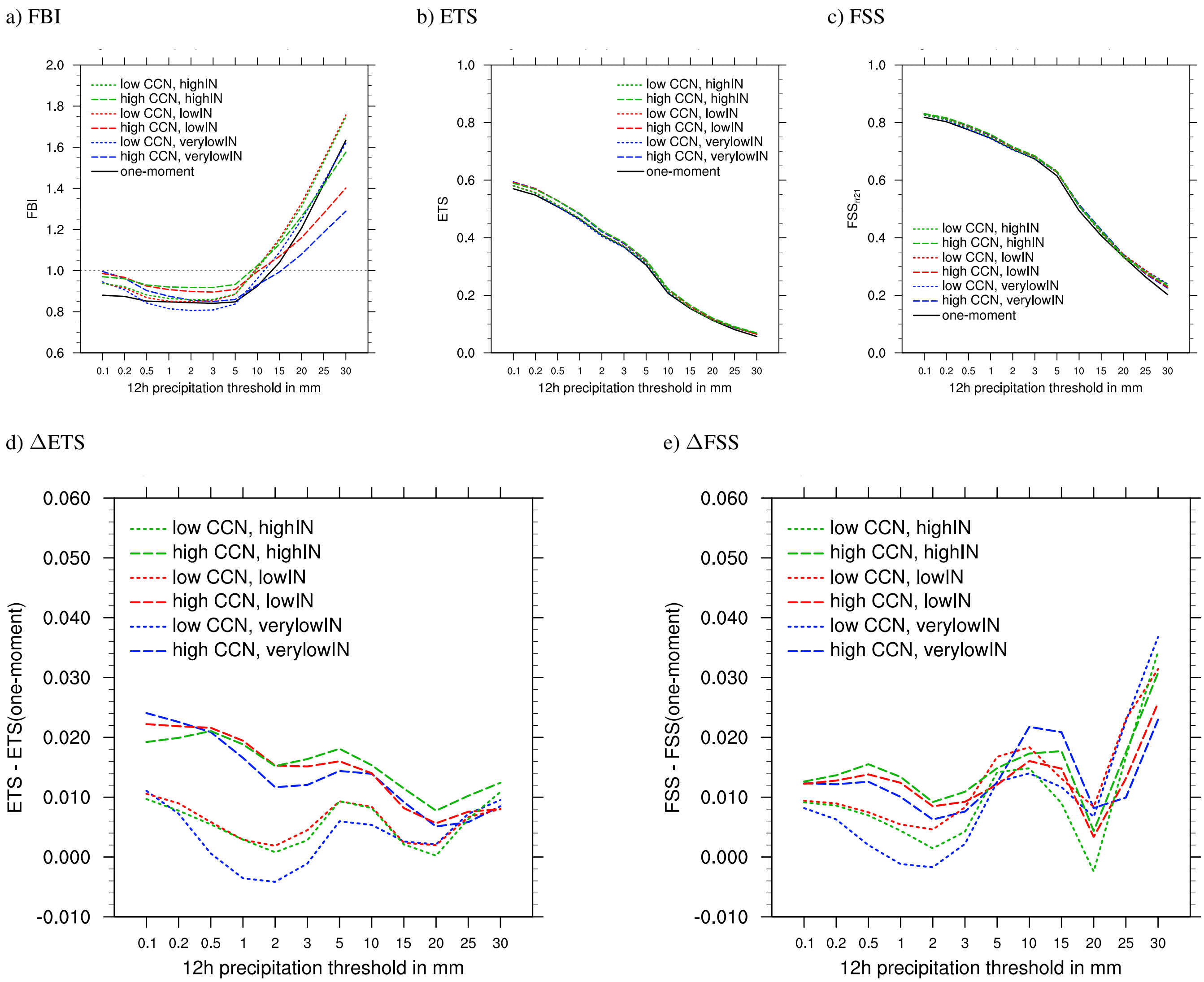

Fig. 6. Precipitation scores for 12-h accumulated precipitation with reference to radar observations. The absolute differences given in (d) and (e) are calculated w.r.t. the operational one-moment scheme (Exp. 7).

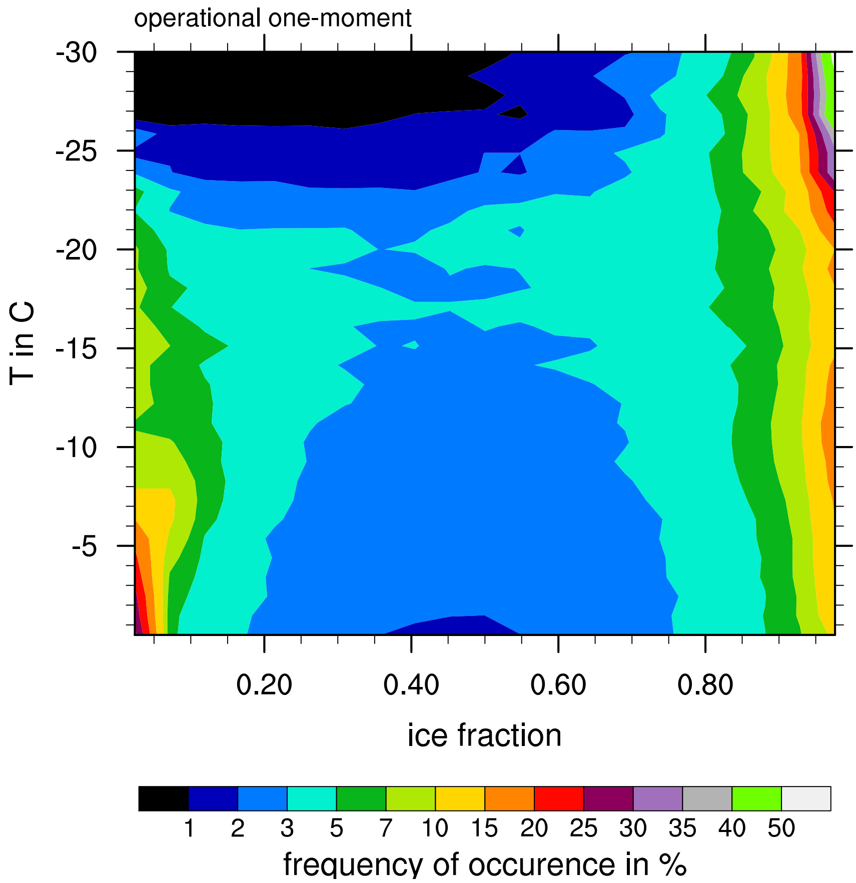

Fig. 7. As Fig. 6 of the main text, but for the operational one-moment microphysics scheme (Exp. 7).