Development of the operational NWP system at DWD

Axel Seifert
Deutscher Wetterdienst
Offenbach, Germany

Overview:

Most relevant for QPF and clouds are

- Runge-Kutta dynamical core for COSMO-EU

  → Experiments for Feb/March 2010 and Aug 2009

  → Nesting of COSMO-DE in COSMO-EU/RK

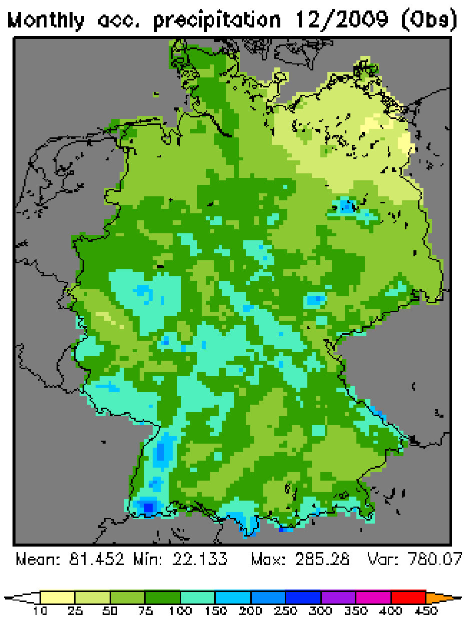
- Density correction for terminal fall velocity of hydrometeors (GME and COSMO-EU)

  → Has traditionally been neglected in the COSMO model
  (reasons are unknown, probably some tuning considerations)

  → In GME and COSMO-EU/RK this modification might help to improve the cloud structures and precipitation forecasts.

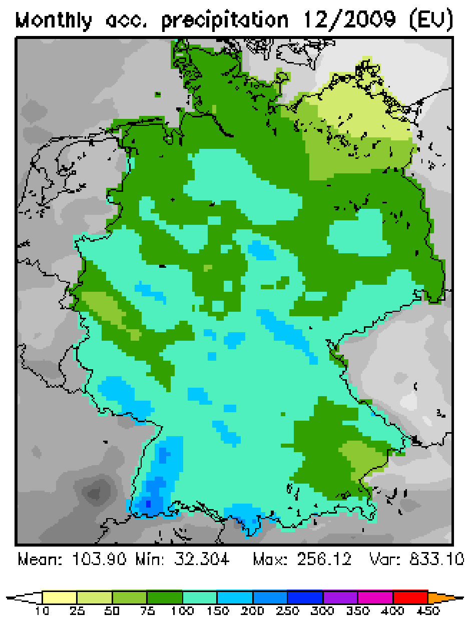
COSMO-EU with Runge-Kutta core: accumulated precip for December 2009

REGNIE



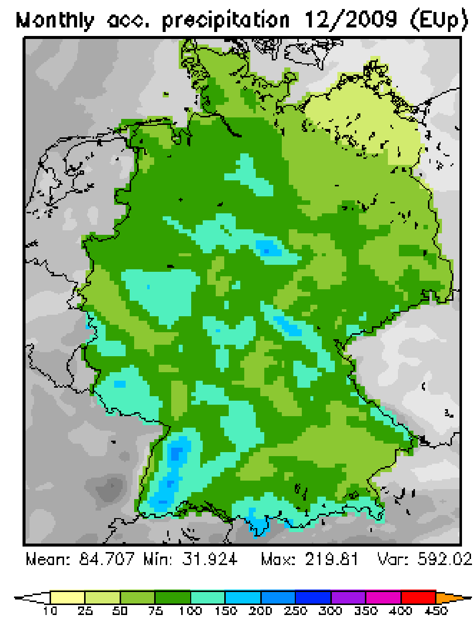
AVG: 81 mm

COSMO-EU



AVG: 104 mm

COSMO-EU RK

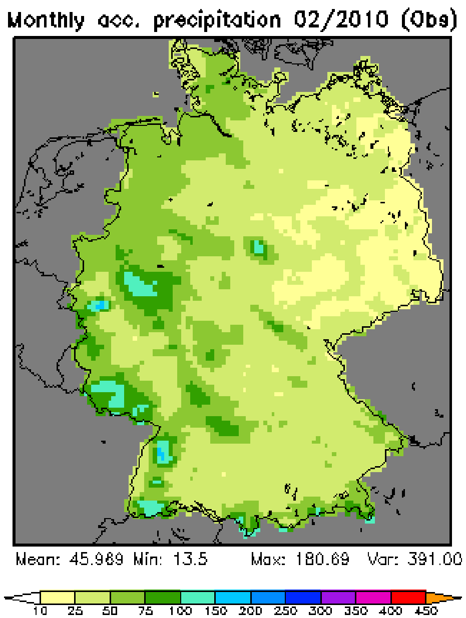


AVG: 85 mm

➔ The overestimation of precipitation is reduced!

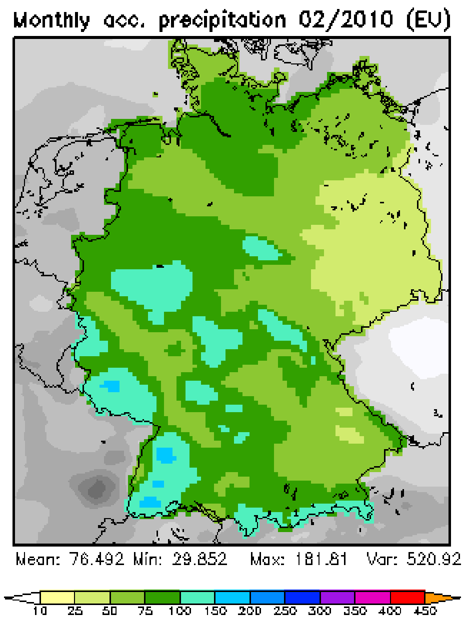
COSMO-EU with Runge-Kutta core: accumulated precip for Feb 2010

REGNIE



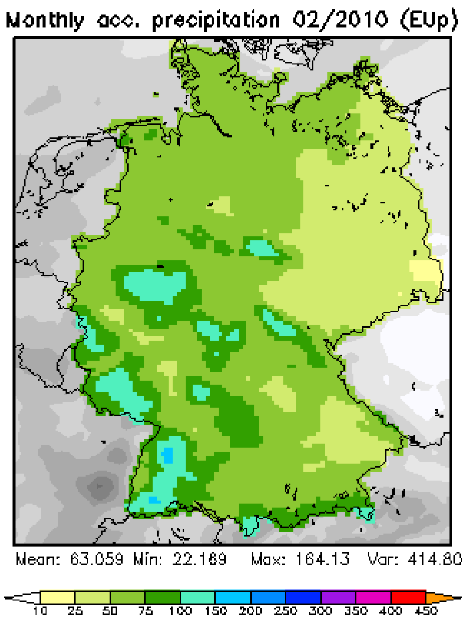
AVG: 46 mm

COSMO-EU



AVG: 76 mm

COSMO-EU RK

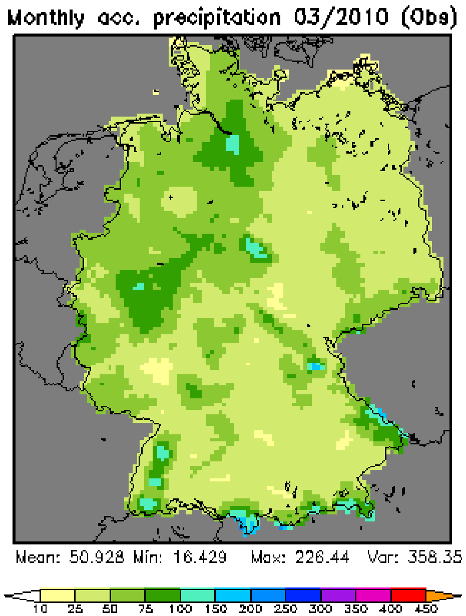


AVG: 63 mm

➔ The overestimation of precipitation is reduced!

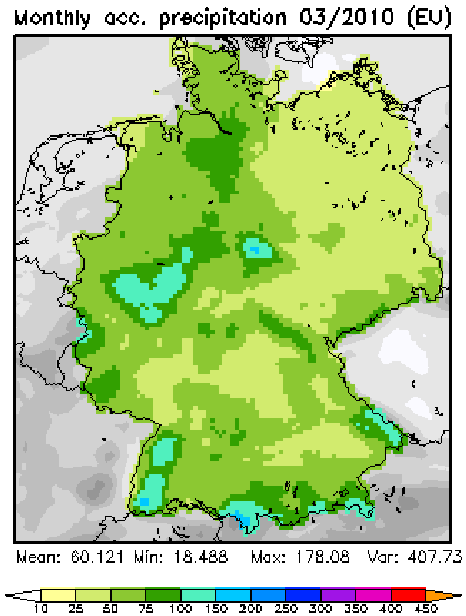
COSMO-EU with Runge-Kutta core: accumulated precip for March 2010

REGNIE



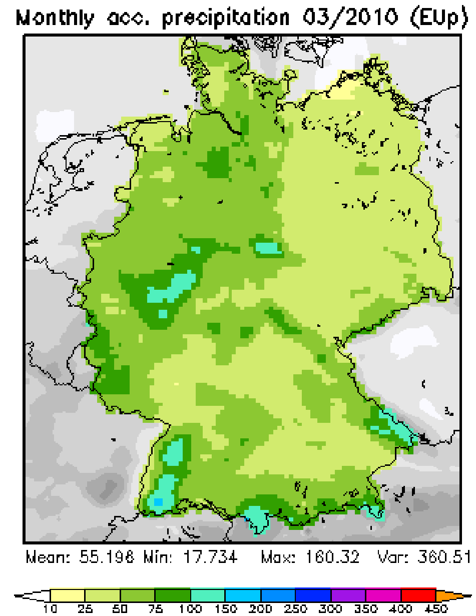
AVG: 46 mm

COSMO-EU



AVG: 76 mm

COSMO-EU RK

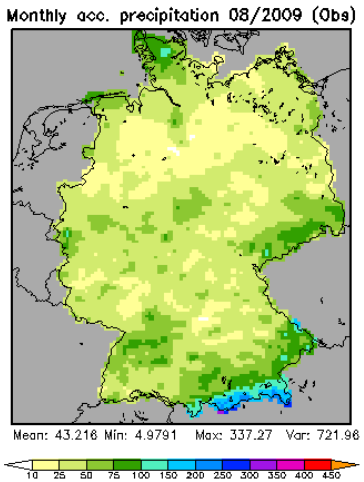


AVG: 63 mm

➔The overestimation of precipitation is reduced!

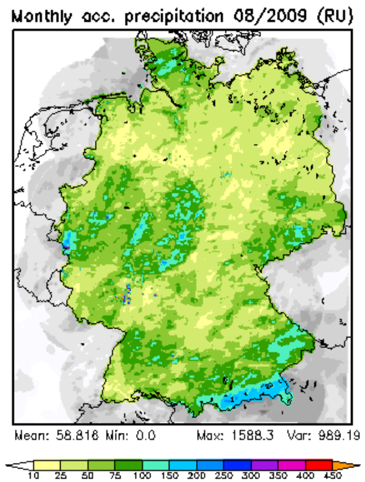
COSMO-EU with Runge-Kutta core: accumulated precip for August 2009

REGNIE



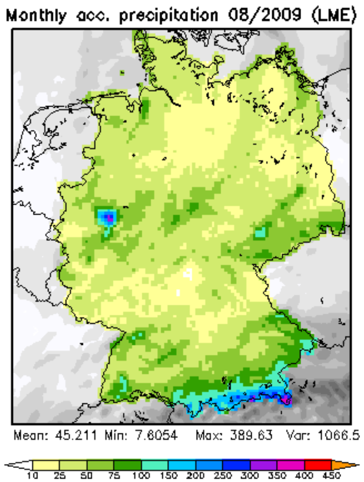
AVG: 43 mm

RU (Radar)



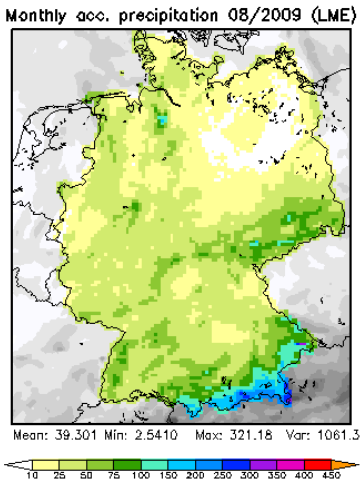
AVG: 59 mm

COSMO-EU



AVG: 45 mm

COSMO-EU RK

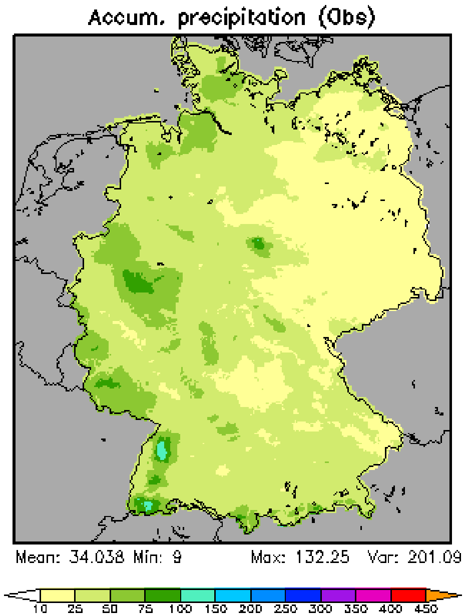


AVG: 39 mm

➔ For summertime precipitation the COSMO-EU/RK shows a dry bias, especially compared to the radar data.

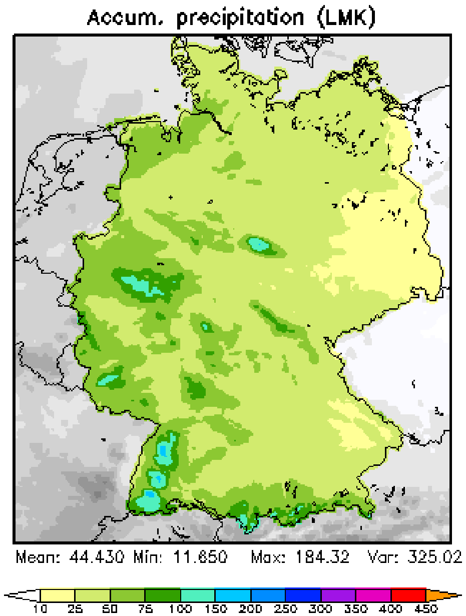
COSMO-DE nested in COSMO-EU/RK: accumulated precip for 4 – 28 Feb 2009

REGNIE



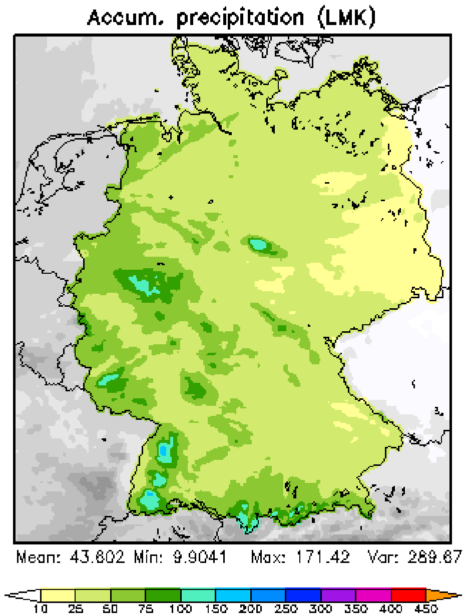
AVG: 34 mm

B.C. COSMO-EU



AVG: 44 mm

B.C. COSMO-EU RK



AVG: 43 mm

➔ Little impact of numerics of COSMO-EU on the precipitation accumulation of COSMO-DE

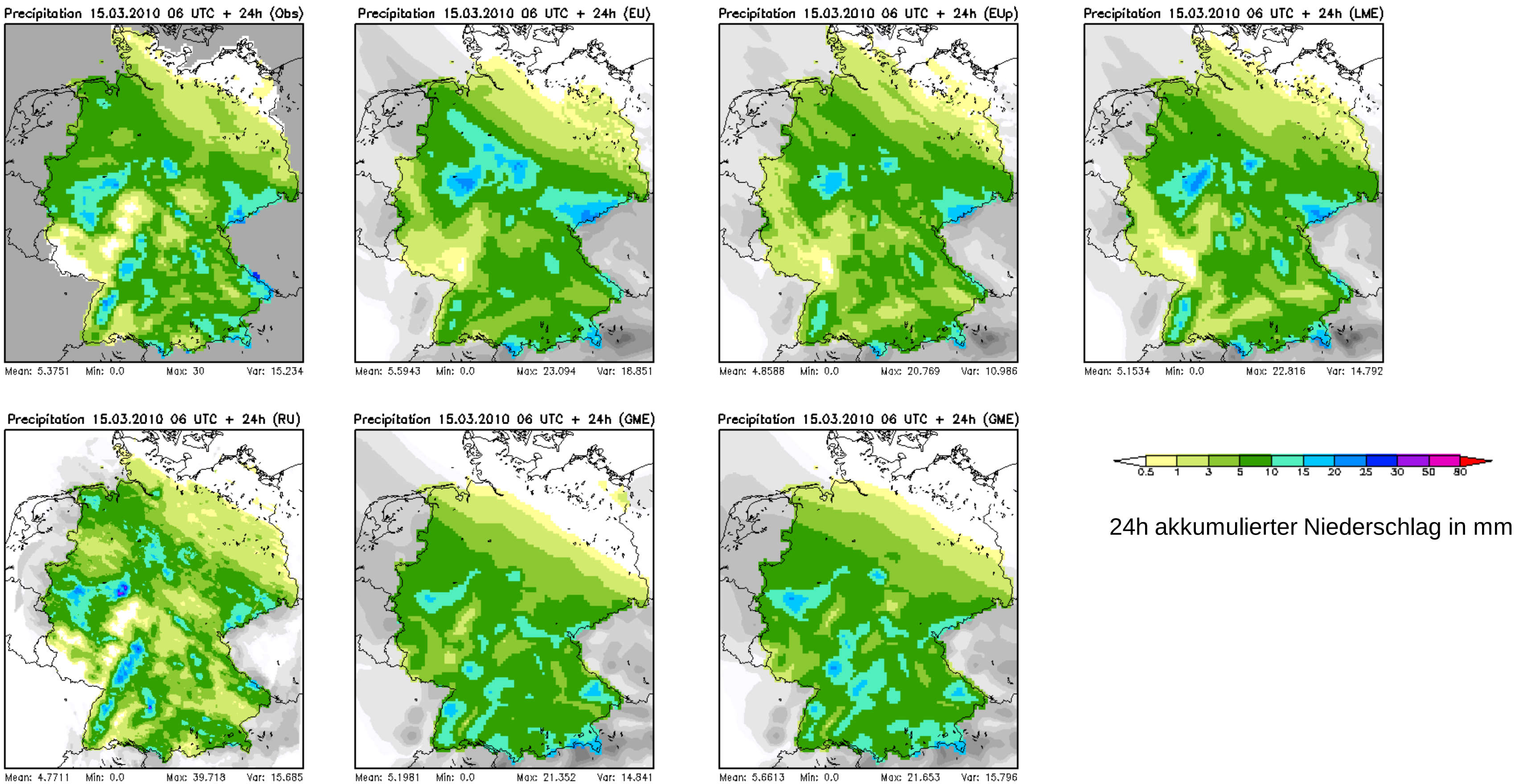
Density correction of hydrometeor fall speeds

Due to the decreasing air density hydrometeors fall faster in the atmosphere compared to measurements at ground level. Therefore an correction has to be made depending on the actual air density:

$$v_T = \sqrt{\frac{\rho_0}{\rho}} \cdot v_0$$

Up to now this has been neglected in the COSMO model, probably as some tuning to reduce the overestimation of orographic precipitation.

GME and COSMO-EU with density correction
Accumulated precip for 15 March 2010



➔ Density correction leads to an increase of orographic precipitation, which, in this case, improves the forecasts of GME and COSMO-EU/RK.

Aerosol-cloud-precipitation effects in COSMO-DE

Axel Seifert and Carmen Köhler

German Weather Service
Offenbach, Germany

Motivation:

Aerosol-cloud-precipitation effects are a major uncertainty in climate models, and might also be relevant for numerical weather prediction.

The topic is obviously very difficult due to the complexity of clouds themselves, and the variability of the atmospheric environment in which the clouds grow. In the scientific literature the effects of aerosol on precipitation are highly controversial.

Using a model setup which is close to an operational NWP model, we might be able to shed some light on the variability of aerosol-cloud-precipitation effects.

The investigation might also show what part of the uncertainty of precipitation forecast is due to the unknown aerosol composition, maybe with some relevance for the design of ensemble prediction systems.

Aerosol effects on precipitation: cloud condensation nuclei

- In polluted air the higher number of cloud condensation nuclei (CCN) will slow down the rain formation by warm rain collision-coalescence, which can lead to a reduction of precipitation amounts (cloud lifetime effect).
- The higher number of CCN leads to smaller cloud droplets. Those are less efficiently collected by ice particles leading to a reduction of riming, and reduced surface precipitation.
- Especially in convective clouds a slower warm rain process can lead to an increased glaciation of the cloud, which leads to an increase in latent heat release. This invigorates the dynamics of the cloud and can eventually lead to an increase in surface precipitation (aerosol-dynamics effect).
- Clouds in an environment that favors a slower warm rain process will grow deeper giving them access to more condensate, which eventually yields more surface precipitation (cloud deepening effect)

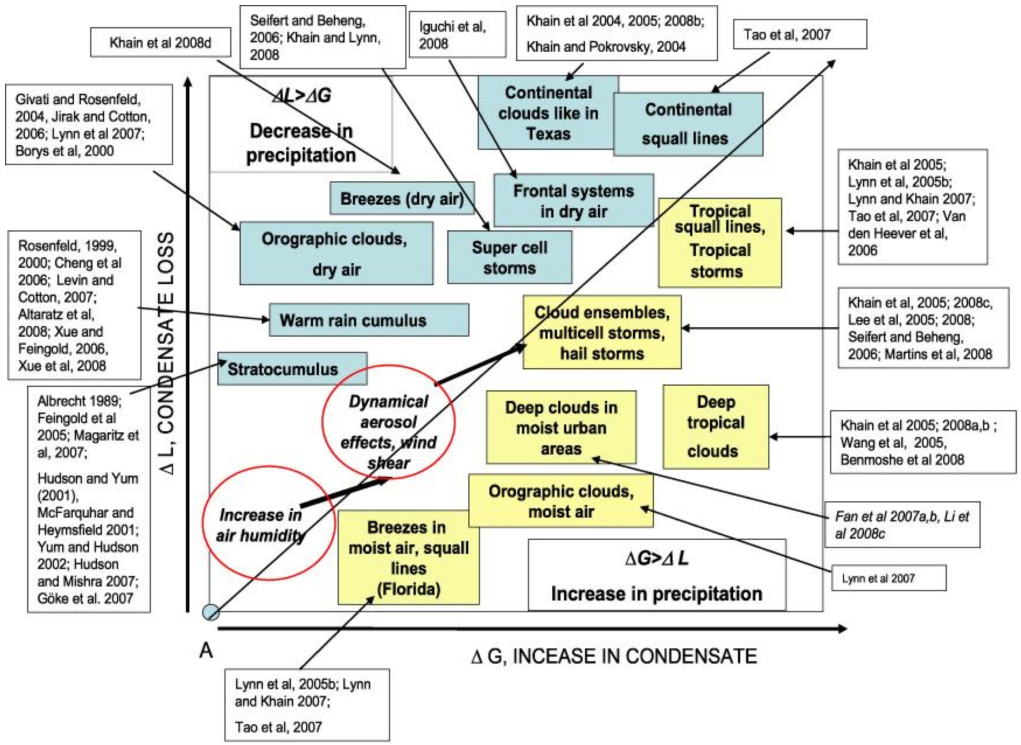
Aerosol effects on precipitation: ice nuclei

- ↘ In polluted air the higher number of ice condensation nuclei (IN) will lead to more, but smaller ice crystals. This will reduce the collision efficiency and lead a reduction of precipitation (cloud lifetime effect).
- ↗ Smaller ice particles grow more efficiently by depositional growth, but can sublimate/evaporation can also be faster. In a moist environment this can leads to an increase in precipitation, while in a dry environment the opposite might happen (↘)
- ↗ More ice nuclei lead to a more complete or more rapid glaciation of the cloud. This gives access to more condensate, due to the lower saturation pressure of ice, and the additional latent heat release can invigorate the dynamics. Both contributes to an increase in surface precipitation.

These are just some examples of feedbacks that are most obvious, excluding the more complex cloud-radiation interactions.

Aerosol-cloud-precipitation classification:

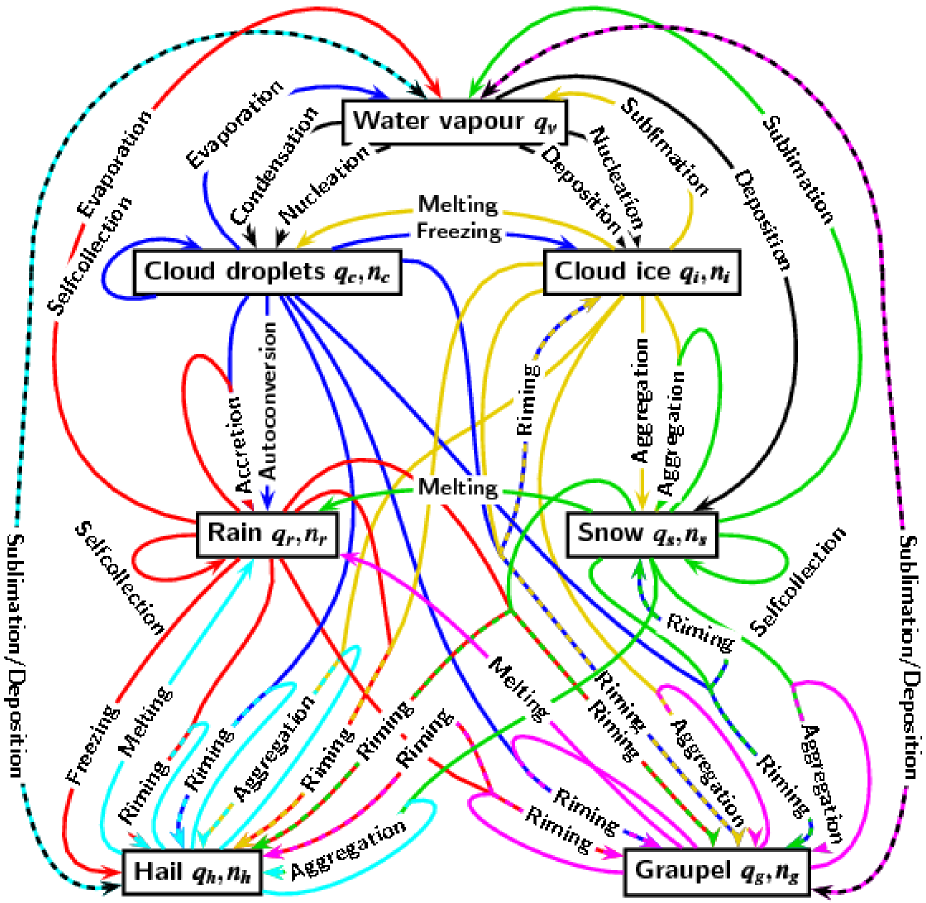
An attempt to classify different cloud regimes and their response to changes in CCN/IN has been made by Khain (2009, Env. Res. Lett.)



While this classification tends to focus on the microphysical processes, Stevens and Feingold (2009, Nature) emphasized the importance of dynamical feedbacks, i.e., clouds as a buffered system.

The Seifert and Beheng two-moment scheme:

Extended version by Blahak, Noppel, Beheng and Seifert



Number and mass concentrations of 6 different species

- cloud droplets
- rain drops
- cloud ice
- snow
- graupel
- hail (see poster of Uli Blahak)

Drop activation/nucleation scheme: Segal&Khain (2006) parameterization

Homogeneous ice nucleation based on Kärcher et al. (2008)

Heterogeneous ice nucleation using the empirical scheme of Phillips et al. (2008).

Aerosol-cloud-precipitation experiments with COSMO-DE

- COSMO-DE domain and setup, but replacing the standard one-moment graupel microphysics with the SB two-moment scheme.
- No data assimilation, no latent heat nudging, all simulation start from the operational analysis. To investigate spin-up effects the simulations are run for 48 hours (only 00 UTC runs).
- No aerosol model is applied. We modify only the assumptions in the microphysics scheme.
- Aerosol-cloud-radiation interaction is taken into account, i.e., particle size information for liquid and ice clouds is passed to the radiation scheme. Parameterizations based on Edwards et al. (2007) and Hu and Stammes (2003). Code provided by Elias Zubler, ETH Zürich.

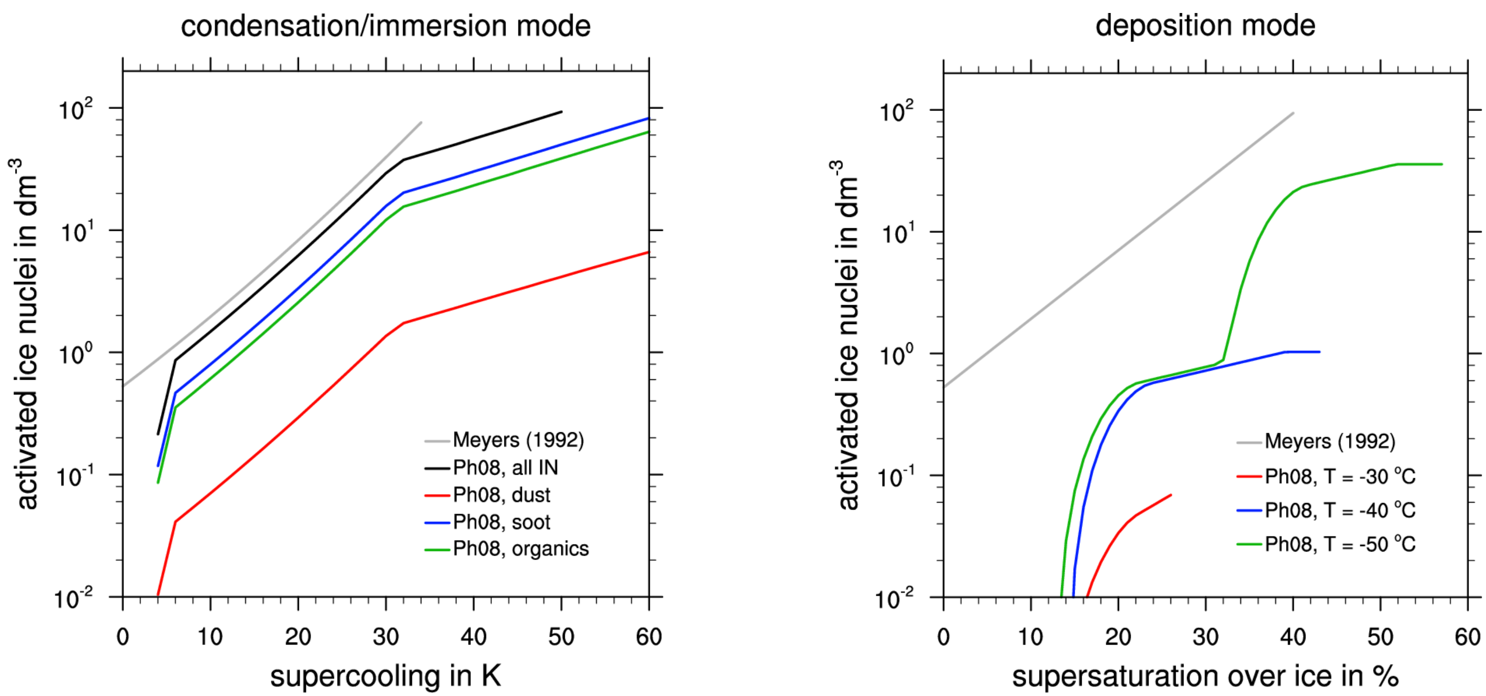
Aerosol-cloud-precipitation experiments with COSMO-DE

The following sensitivity experiments are being performed to investigate the effects of aerosols

1) Clean CCN + standard IN
2) Polluted CCN + standard IN
3) Polluted CCN + 10 x decreased soot and organics
4) Polluted CCN + 10 x increased soot and organics
5) Polluted CCN + 10 x increased dust
6) Polluted CCN + 100 x increased dust
7) Polluted CCN + 1000 x increased dust

Heterogeneous ice nucleation experiments

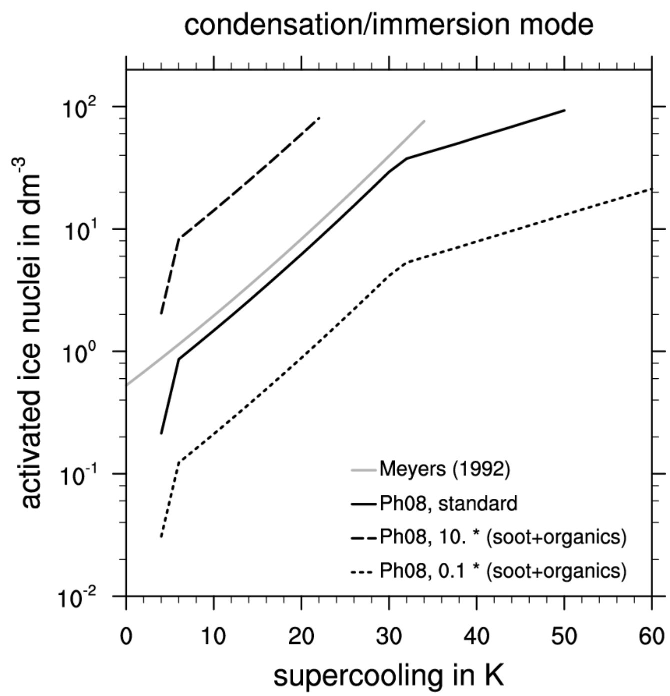
Relations for the Phillips et al. (2008) scheme with standard aerosol assumptions.

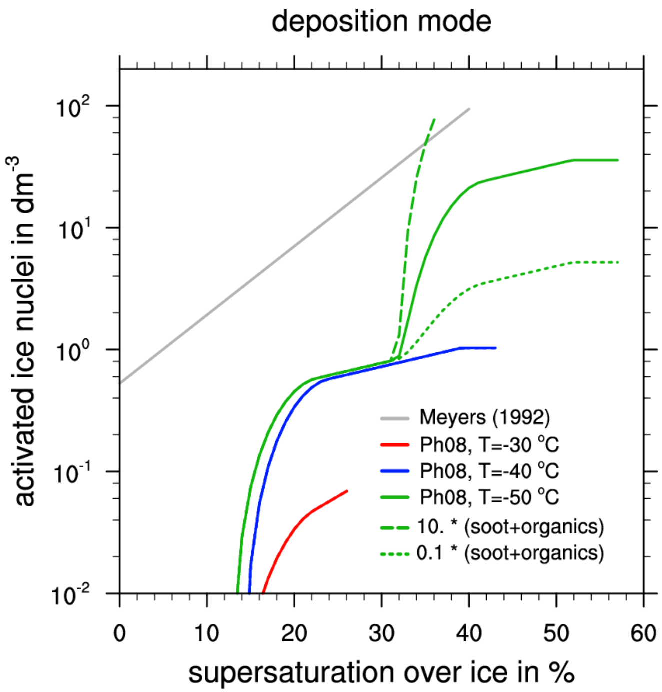


Especially the deposition mode is much less efficient when compared to Meyers (1992). Immersion freezing is dominated by soot, deposition mode above -40 C is dominated by dust.

Heterogeneous ice nucleation experiments

Relations for the Phillips et al. (2008) scheme for soot+organics experiments.



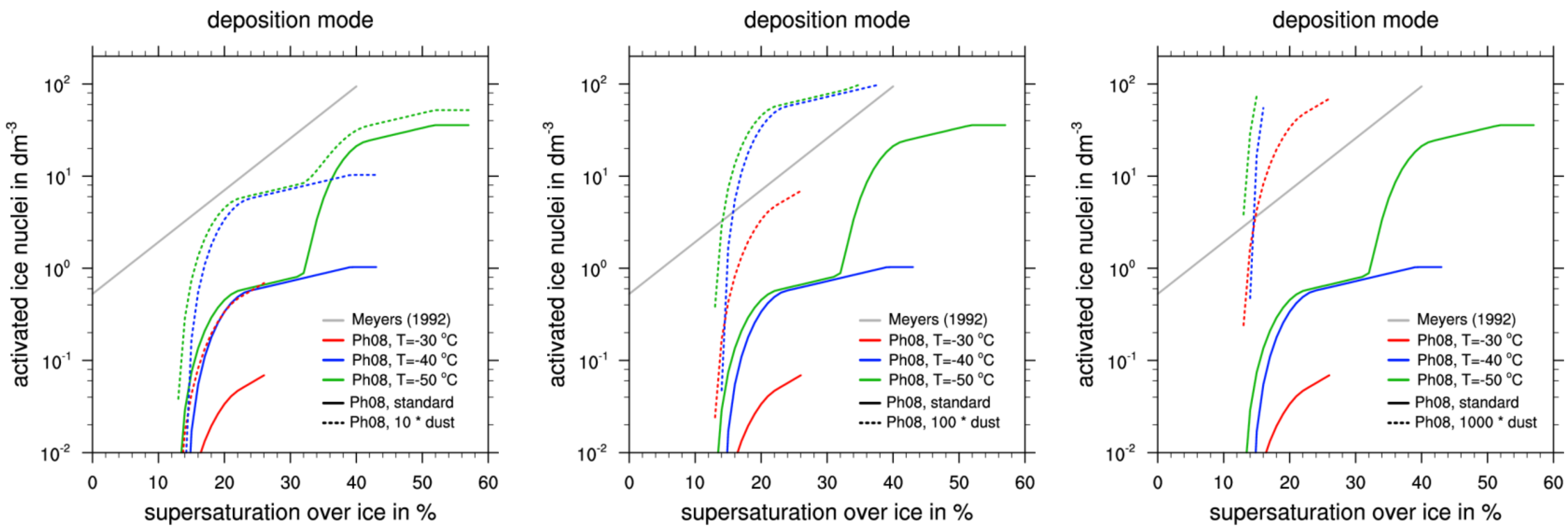


By changing soot+organics the immersion mode is modified, but the deposition mode is hardly affected. In all experiments the maximum number of heterogeneous IN is set to 100 per liter.

Heterogeneous ice nucleation experiments

Relations for the Phillips et al. (2008) scheme for dust experiments.

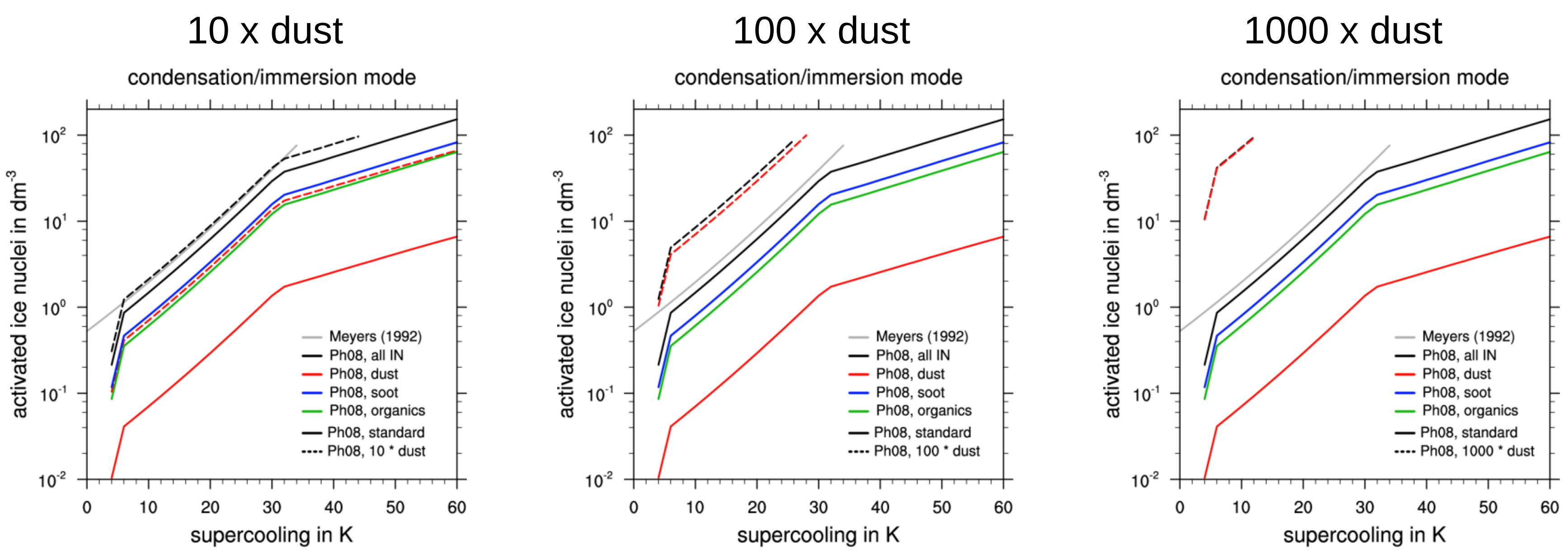
10 x dust 100 x dust 1000 x dust



By increasing the dust concentration the deposition mode becomes more important and is shifted to warmer temperatures.

Heterogeneous ice nucleation experiments

Relations for the Phillips et al. (2008) scheme for dust experiments.

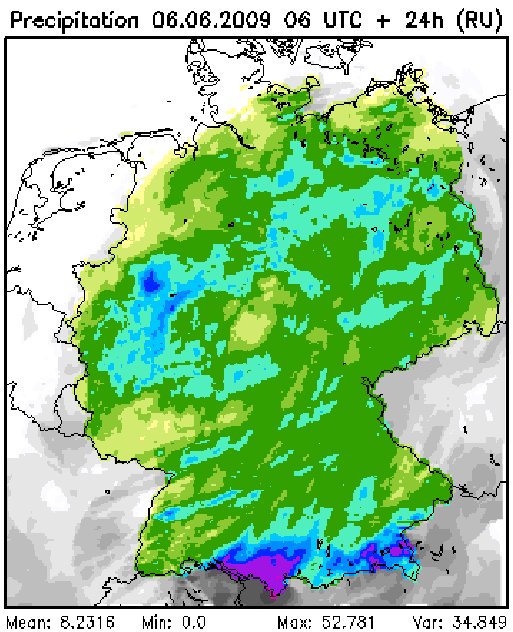


For 10 x dust the immersion mode is hardly affected, for higher dust concentrations dust becomes also the dominant immersion nuclei.

Some preliminary results: CCN experiments

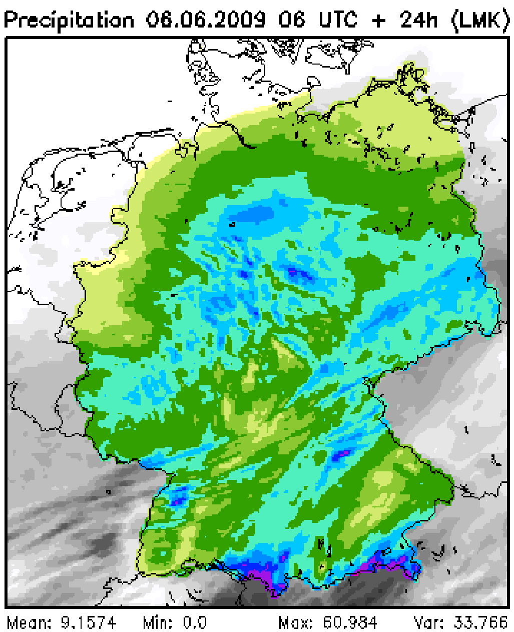
24h accumulation for 06.06.2009:

Radar (RU)



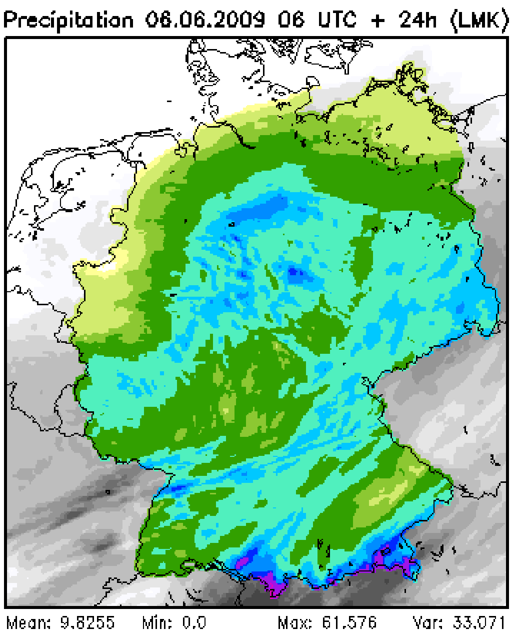
Mean 8.2 mm
Max 52 mm

clean CCN

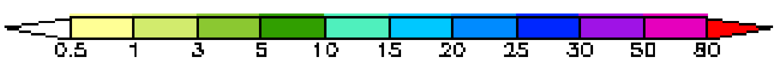


Mean 9.1 mm
Max 61 mm

polluted CCN



Mean 9.8 mm
Max 61 mm

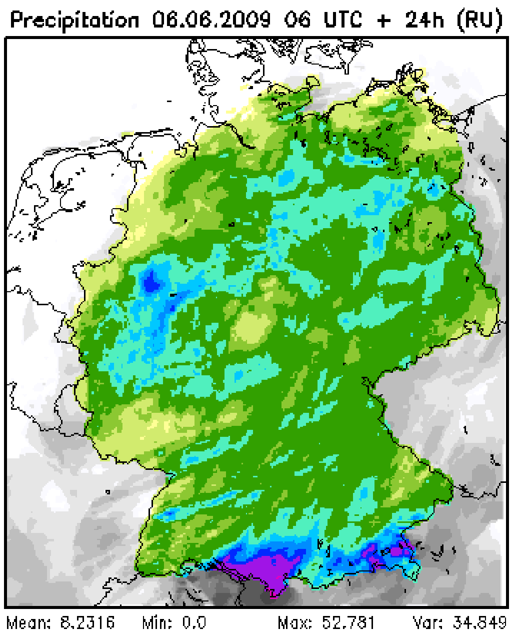


24h accumulated precipitation in mm

Some preliminary results: soot experiments

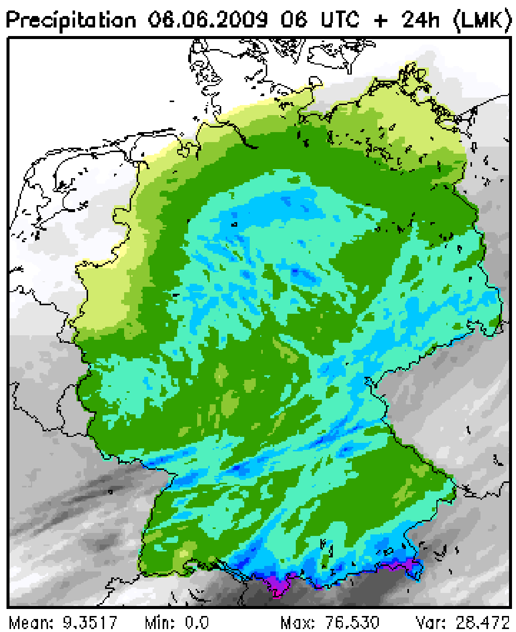
24h accumulation for 06.06.2009:

Radar (RU)



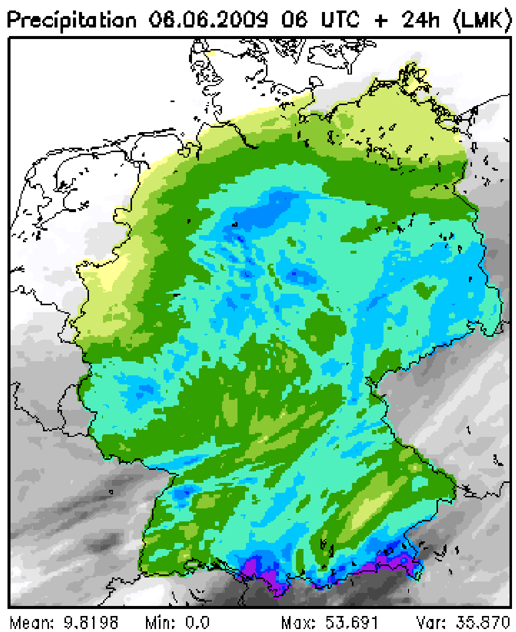
Mean 8.2 mm
Max 52 mm

0.1 x soot

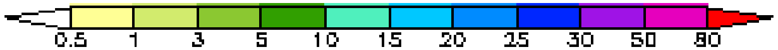


Mean 9.3 mm
Max 76 mm

10 x soot



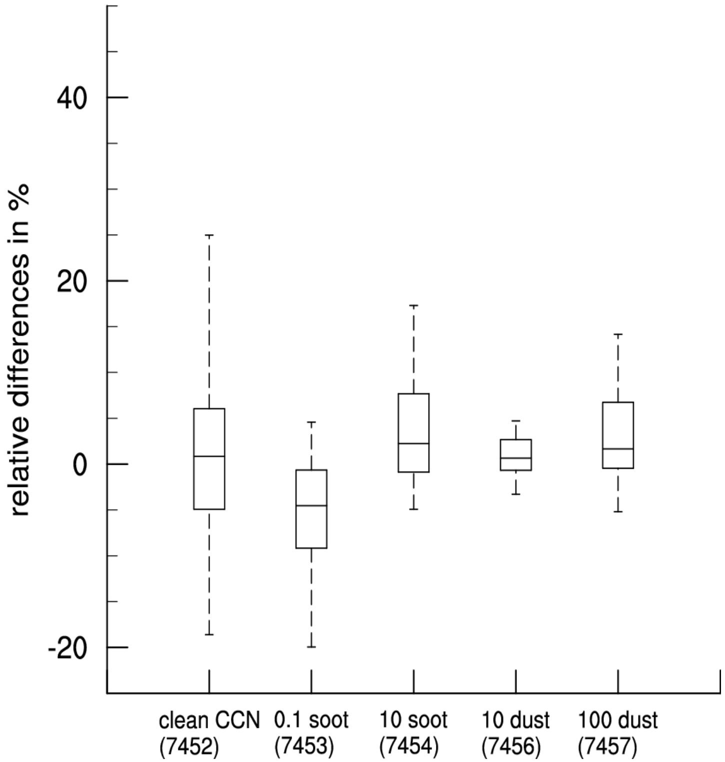
Mean 9.8 mm
Max 53 mm



24h accumulated precipitation in mm

Some precip statistics: June/Juli/Aug 2009

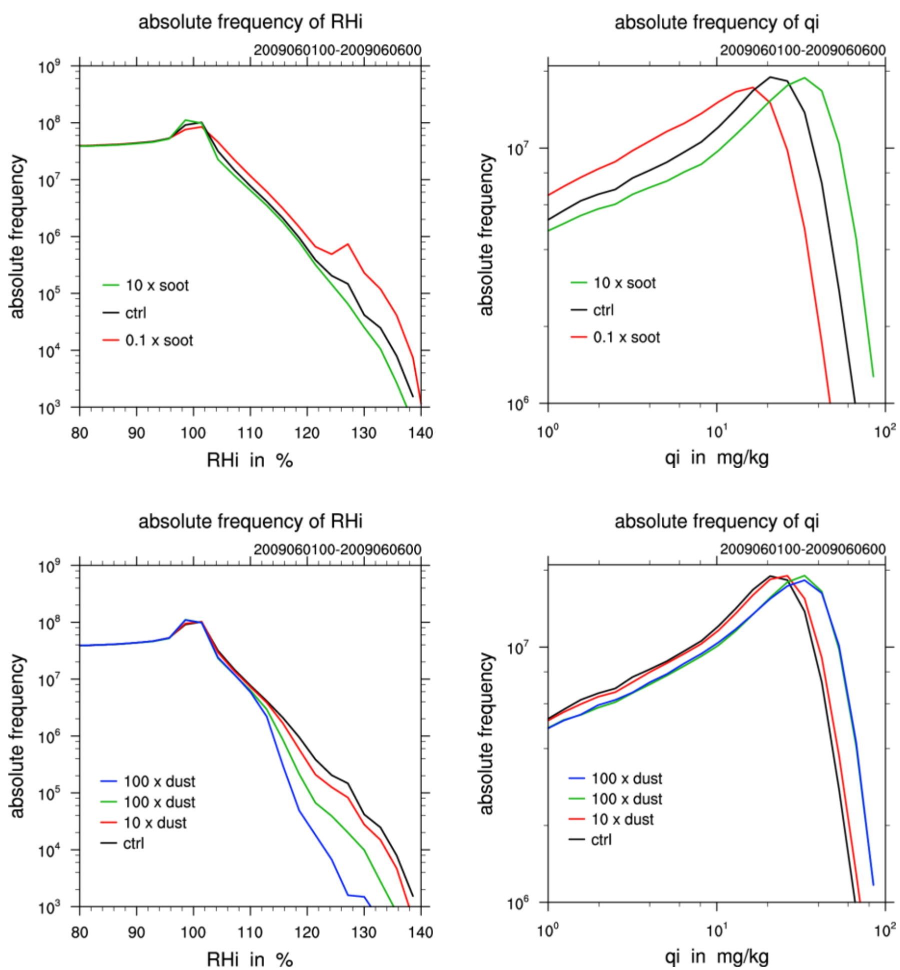
Relative differences of 12h precipitation accumulation (average over Germany):



- ➔ Averaged over a large area like Germany the aerosol-precipitation effects are for most cases below 10 % in precipitation amount.
- ➔ CCN variations introduce a variability in precipitation, but over a longer period there is no net effect on the precipitation amount.
- ➔ For ice nuclei there is a trend that more immersion nuclei (soot, organics) yield slightly more precipitation.

Some preliminary results: upper troposphere

Statistical distributions of RHi and QI in the upper troposphere

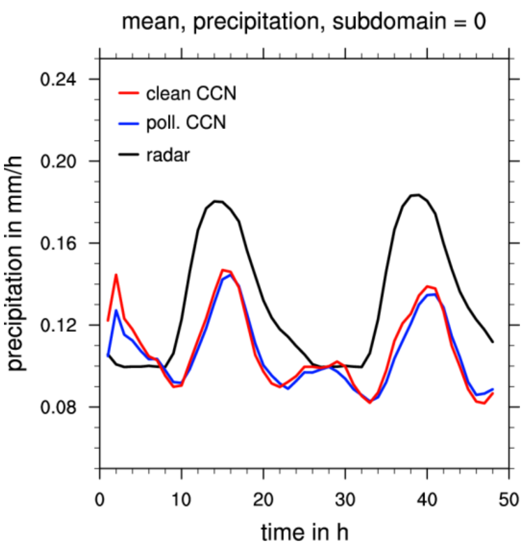


➔ More soot decreases RHi, and increases QI

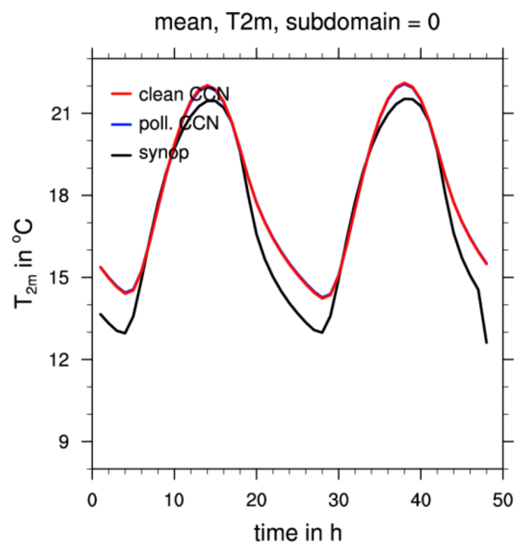
➔ And the same for dust.

Time series of spatially averaged quantities for CCN experiments (Germany, 1-25 June 2009, 00 UTC + 48 h)

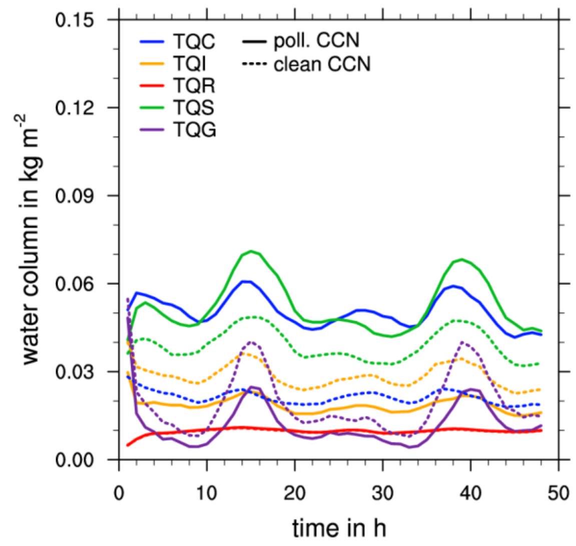
Precipitation



2m-Temperature



water column



- ➔ **Almost no effect of CCN on precipitation and 2m-temperature.**
- ➔ **For polluted condititions the cloud liquid water column increases by a factor of 2, slight increase of snow column, but decrease in cloud ice.**

Time series of spatially averaged quantities for soot experiments (Germany, 1-25 June 2009, 00 UTC + 48 h)

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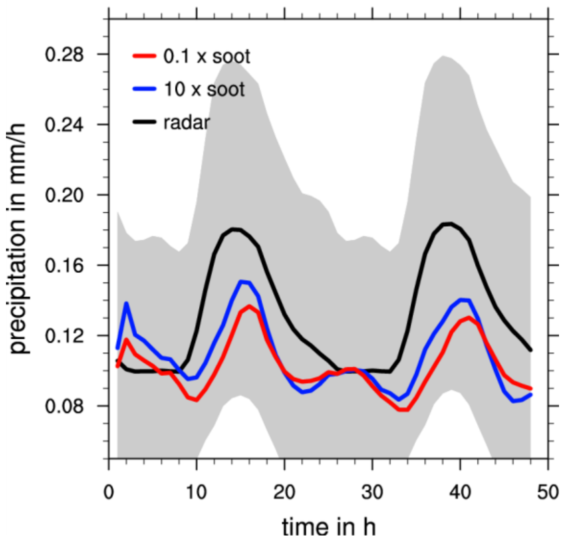
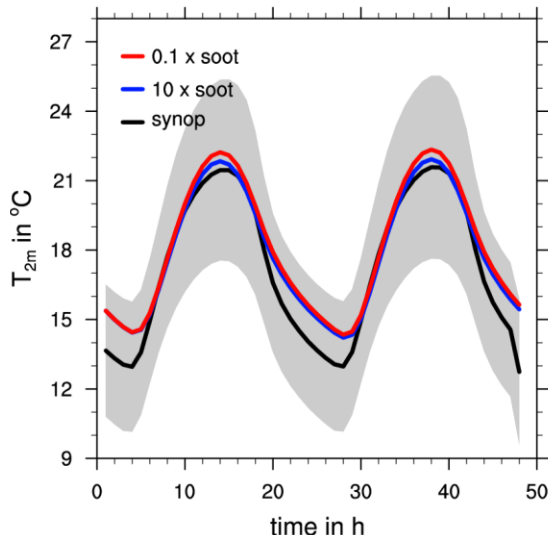
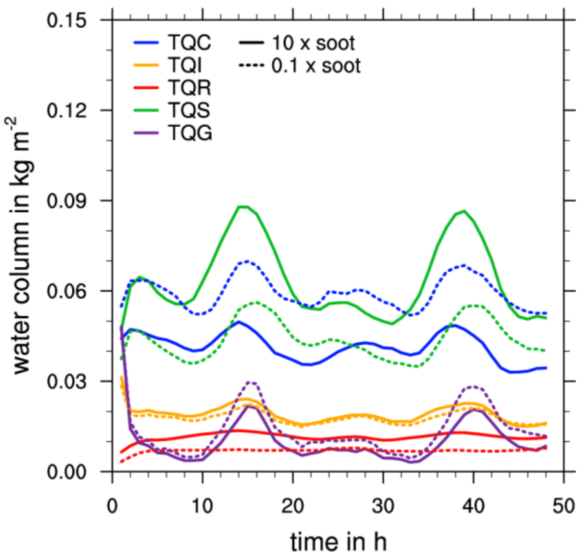
Precipitation



2m-Temperature



water column



- ➔ **More soot results in an increase in precipitation, here by about 5 %, probably due to the stronger glaciation and associated increase in latent heat release.**
- ➔ **Maximum T2m decreases slightly, about 0.5 K, when more soot is assumed (note that direct aerosol effect is not taken into account).**
- ➔ **The increased glaciation results in a higher snow water column, and a decrease in the cloud liquid water column.**

Summary and Conclusions

- ➔ The Seifert-Beheng two-moment microphysics scheme has been updated with state-of-the-art parameterizations of homogeneous and heterogeneous ice nucleation.
- ➔ Sensitivity experiments are being performed to investigate the effects of heterogeneous IN, which are often unknown in NWP, on precipitation and other variables.
- ➔ The simulations confirm that aerosol-cloud-precipitation effects are highly variable in space and time, and depend on the cloud regime. For Germany we find that the CCN effects on precipitation are on average very small. The effects of soot, which is active as immersion freezing nuclei, seems to be more significant.
- ➔ The simulations can be seen as reference experiments for future simulations with fully coupled aerosol and chemistry models (COSMO-ART).