A hierarchy of one- and two-moment microphysical parameterizations in the COSMO model

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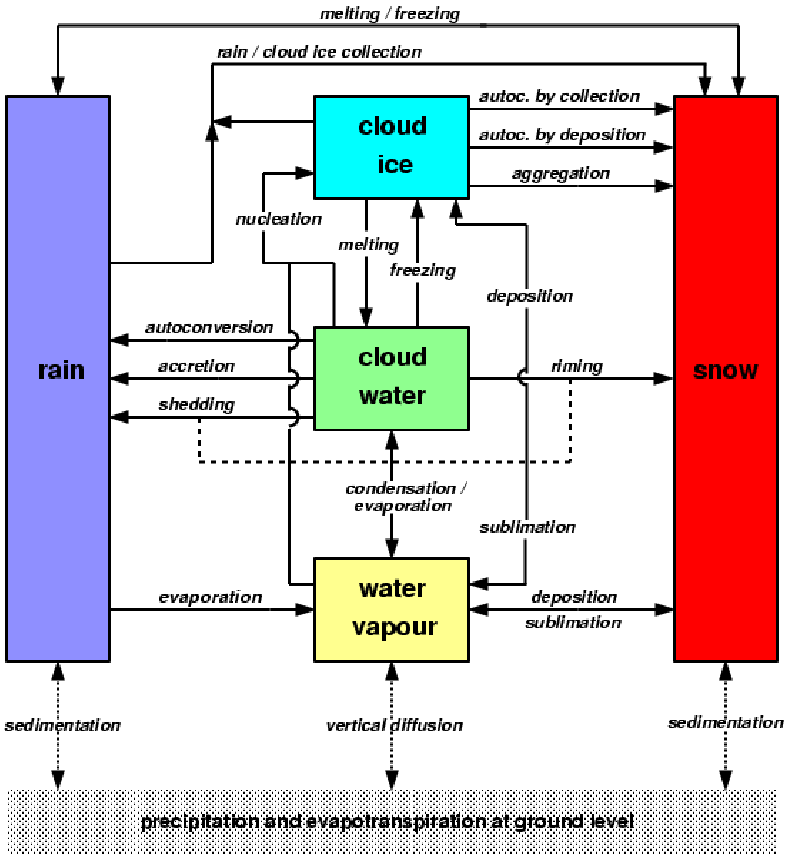
Why does the COSMO model need several cloud microphysics schemes?

- Microphysical processes are **scale-dependent**, i.e., graupel and especially hail can only be represented at very high spatial resolution.
- More advanced/sophisticated schemes include **more detailed physical processes**, like hail formation or aerosol-cloud-precipitation effects.
- Sophisticated microphysics parameterizations need more **input data**, like information about the aerosol properties and concentration which is often not available.
- The more complex schemes are **computationally very expensive**, i.e., the runtime of the model can increase by a factor of two and more. Often this additional computing time is not available, e.g., in operational NWP or climate modeling.

⇨ **Need for a hierarchy of microphysics scheme of increasing complexity.**

The COSMO two-category ice scheme (also known as the 'cloud ice scheme')

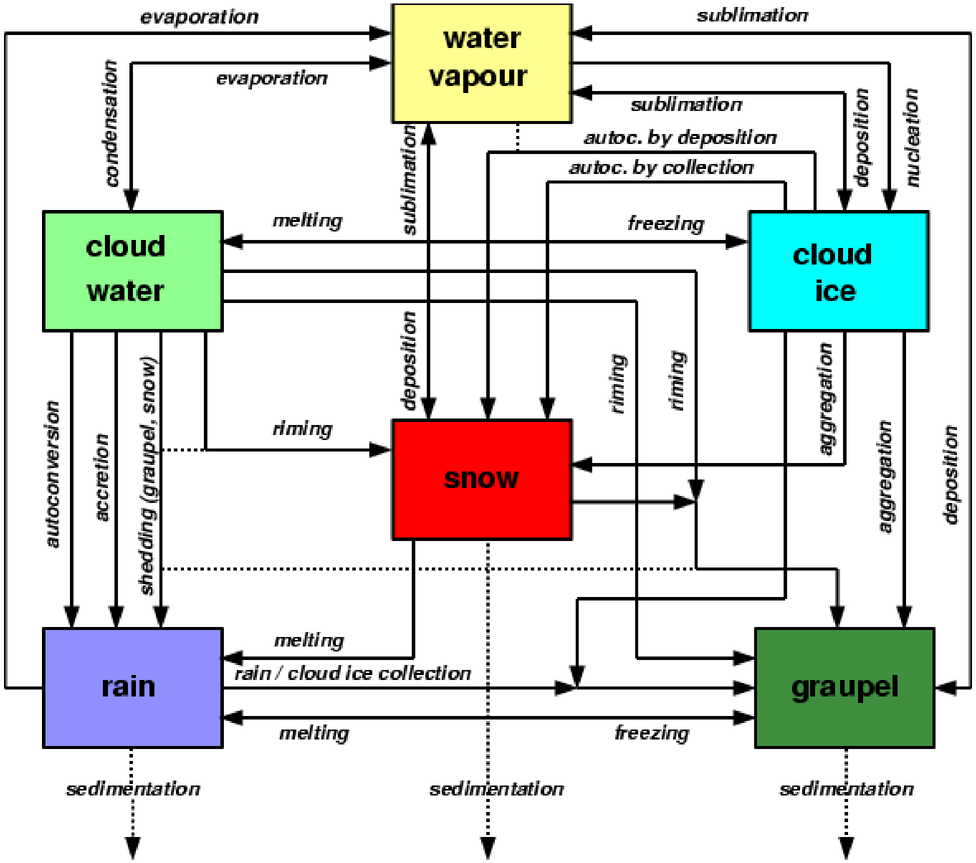


subroutine: hydci_pp

namelists: itype_gscp=3
lprogprec=.true.

- Includes cloud water, rain, cloud ice and snow.
- Prognostic treatment of cloud ice, i.e., non-equilibrium growth by deposition.
- Developed for the 7 km grid, e.g., DWD's COSMO-EU.
- Only stratiform clouds, graupel formation is neglected.

The COSMO three-category ice scheme (also known as the 'graupel scheme')



subroutine: hydci_pp_gr

namelist setting:

itype_gscp=4

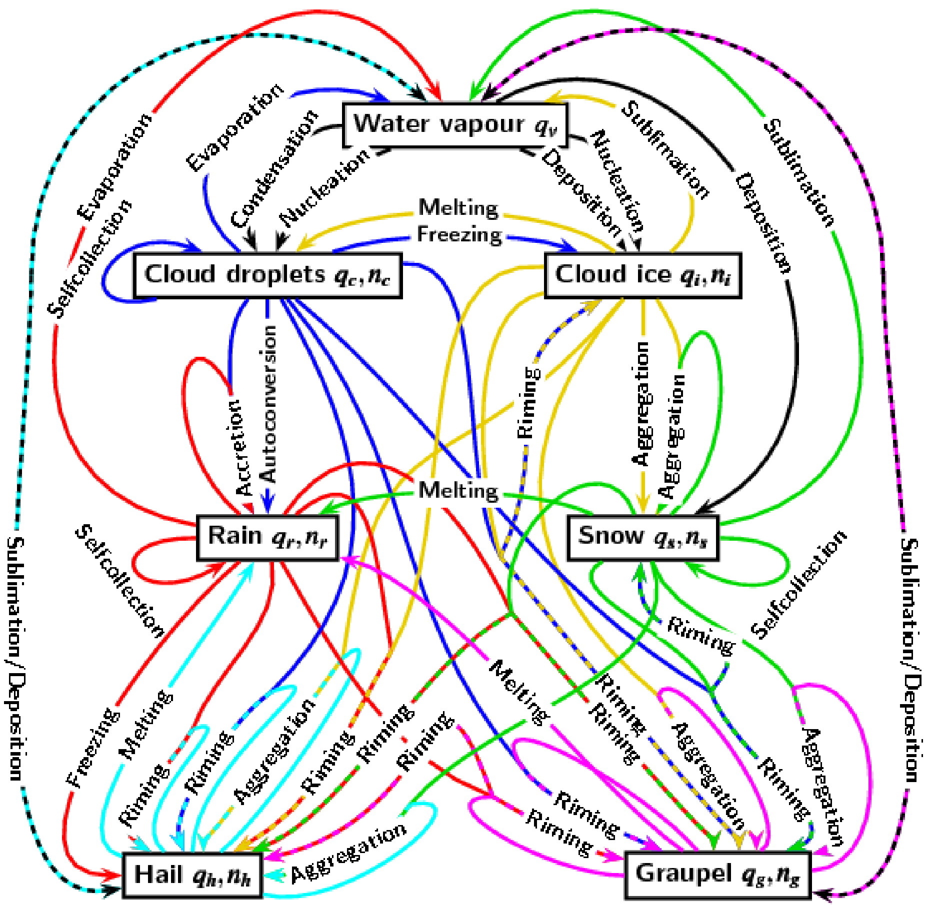
lprogprec=.true.

- Includes cloud water, rain, cloud ice, snow and graupel.
- Graupel has much higher fall speeds compared to snow
- Developed for the 2.8 km grid, e.g., DWD's convection-resolving COSMO-DE.

- Necessary for simulation without parameterized convection. In this case the grid-scale microphysics scheme has to describe all precipitating clouds.

The Seifert and Beheng two-moment scheme:

New Version by Blahak, Noppel, Beheng and Seifert (2008)



Number and mass concentrations of 6 different species

- cloud droplets
- rain drops
- cloud ice
- snow
- graupel
- hail (new!)

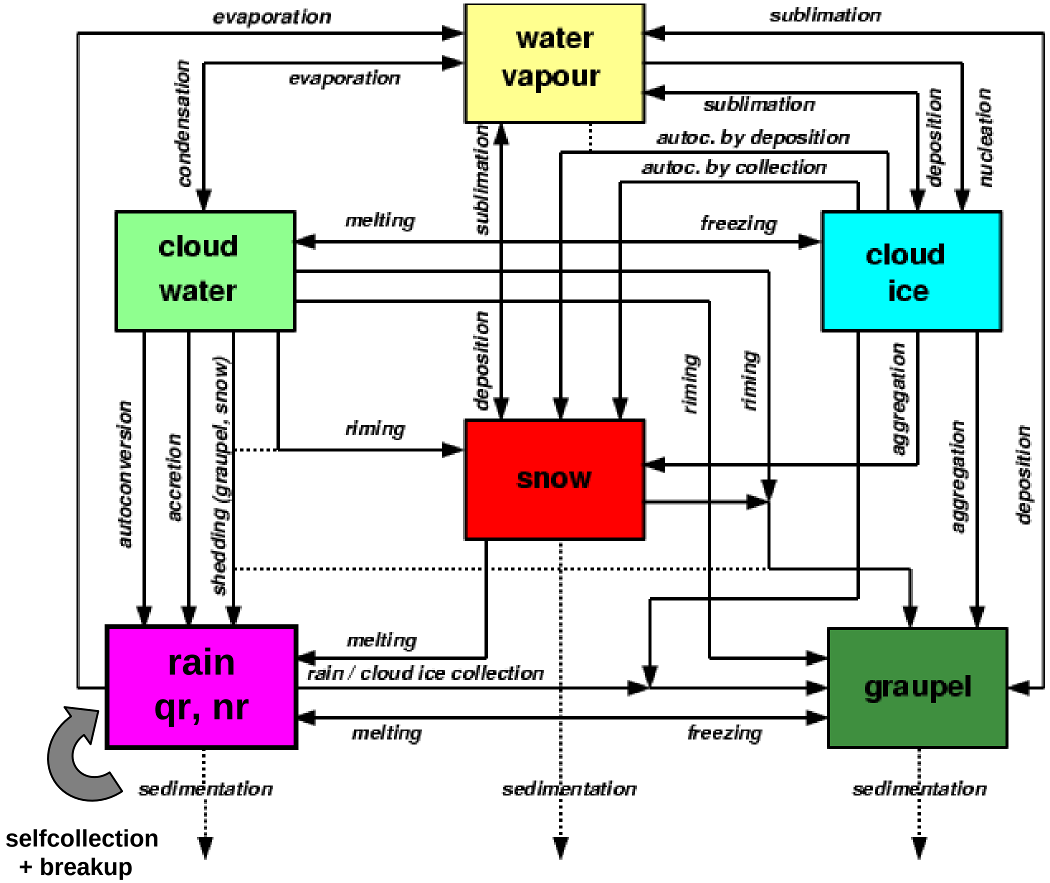
New activation/nucleation scheme Segal&Khain (2006) parameterization

New evaporation scheme (Seifert 2008)

Hail formation by spectral partitioning of freezing processes (Blahak 2008)

Will soon be available in the official code, but very expensive increasing the total runtime by almost a factor of 2.

Extending the COSMO graupel scheme with two-moment rain: a new hybrid scheme



Prognostic number concentration of raindrops

Two-moment rain advantages:

- New rain evaporation scheme
- Gravitational sorting of raindrops
- Explicit selfcollection and breakup of raindrops
- Improved autoconversion and accretion

Simplifications:

- Pre-defined mean raindrops diameters for:
  - melting of graupel (1 mm)
  - melting of snow (0.3 mm)
  - shedding (0.1 mm)
- Assume that other mixed-phase collection processes do not change the mean size of raindrops.

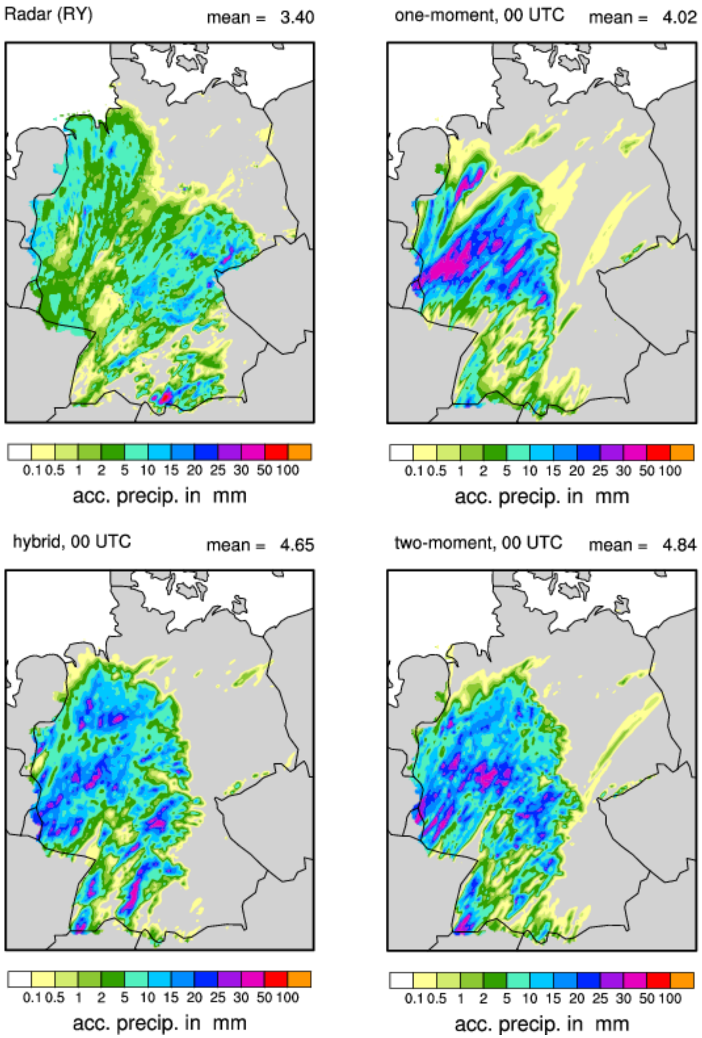
COSMO-DE experiments for summer 2007

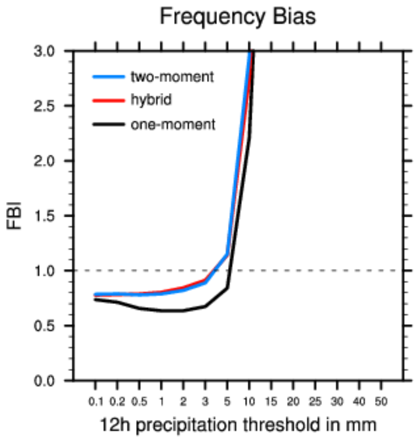
(COPS period 1 June to 31 August 2007)

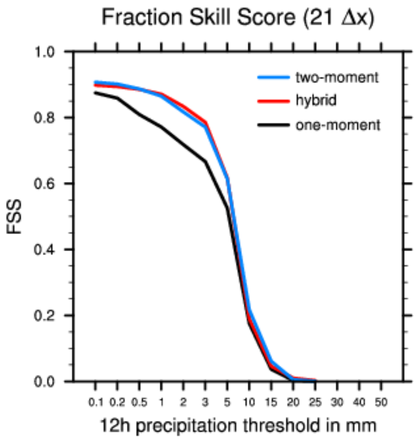
- 1st control run with COSMO-DE with modified PBL parameters (*turlen* and sub-grid cloud cover).
  Full data assimilation including LHN with the operational graupel scheme.
- 2nd control run, COSMO-DE 00 and 12 UTC forecasts without LHN in nudgecast.
- COSMO-DE experiments with
  - SB two-moment scheme, low aerosol concentration
  - SB two-moment scheme, high/polluted aerosol assumptions
  - New hybrid two-moment rain scheme

  but without own data assimilation or LHN in nudgecast.

Case 20 July 2007:
Cold-front induced Squall Line

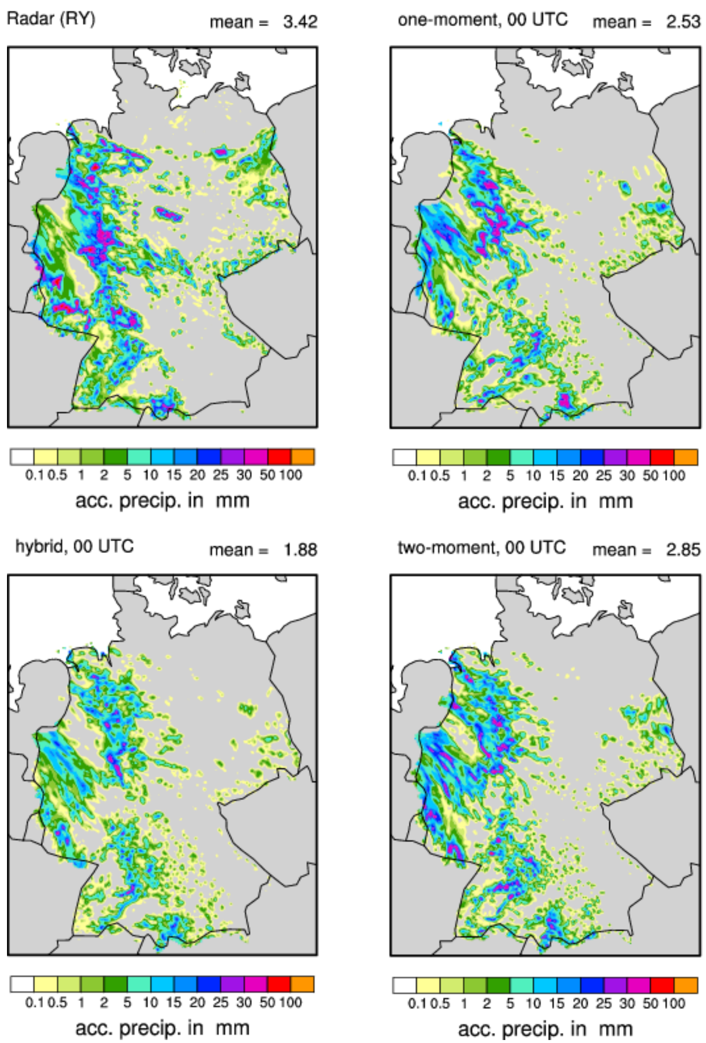


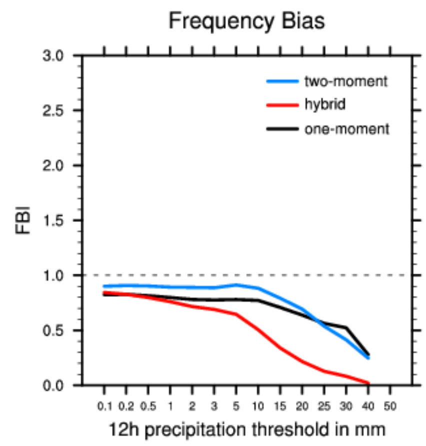


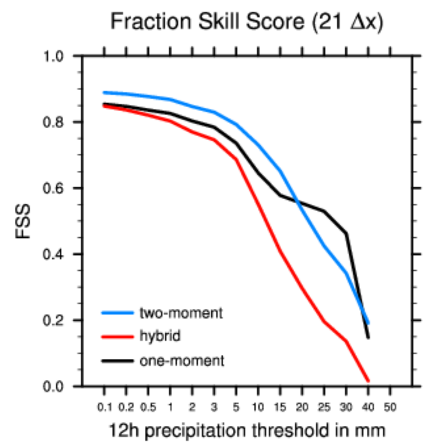


- Overprediction of strong precipitation or is the radar affected by attenuation or?
- The two-moment scheme and the new hybrid scheme behave similar and significantly different from the operational one-moment scheme.

Case 9 June 2007, 06 – 18 UTC: Convergence line ahead of cold front



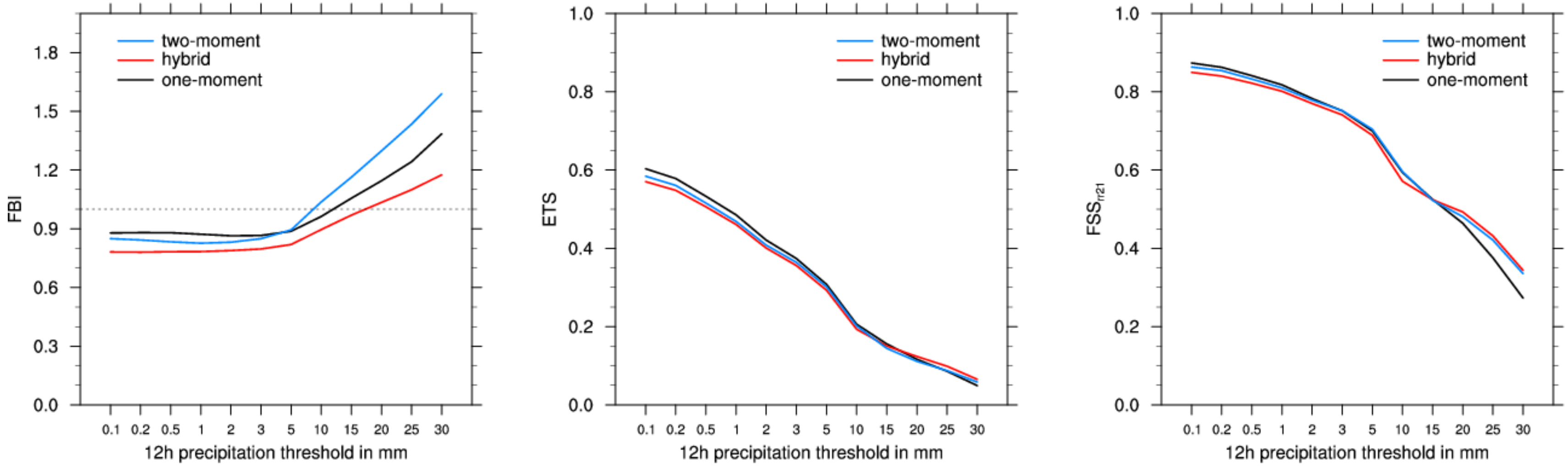




- SB two-moment scheme gives the best forecast, but only marginally better than the one-moment scheme.
- The hybrid scheme underpredicts the intensity of the convective systems.

QPF scores FBI, ETS and FSS for JJA 2007

(00 UTC and 12 UTC runs, vv=06-18 h accumulation vs radar data)



- Slightly different bias behavior (FBI) of the three schemes. Overprediction of high amount in the SB two-moment scheme, underprediction of weak precipitation with the new hybrid scheme. Operational model seems to be well tuned for the 2.8 NWP application

Although the hybrid scheme shows some potential, the current version has a significant dry bias. Further development and tuning is needed, before it can be used operationally and put in the official code.

Aerosol-Cloud-Precipitation effects:

Aerosol-Cloud interactions are a major uncertainty in climate models and may play also a role in NWP, although this is has not yet been proven.

1) Aerosol-Precipitation effect:

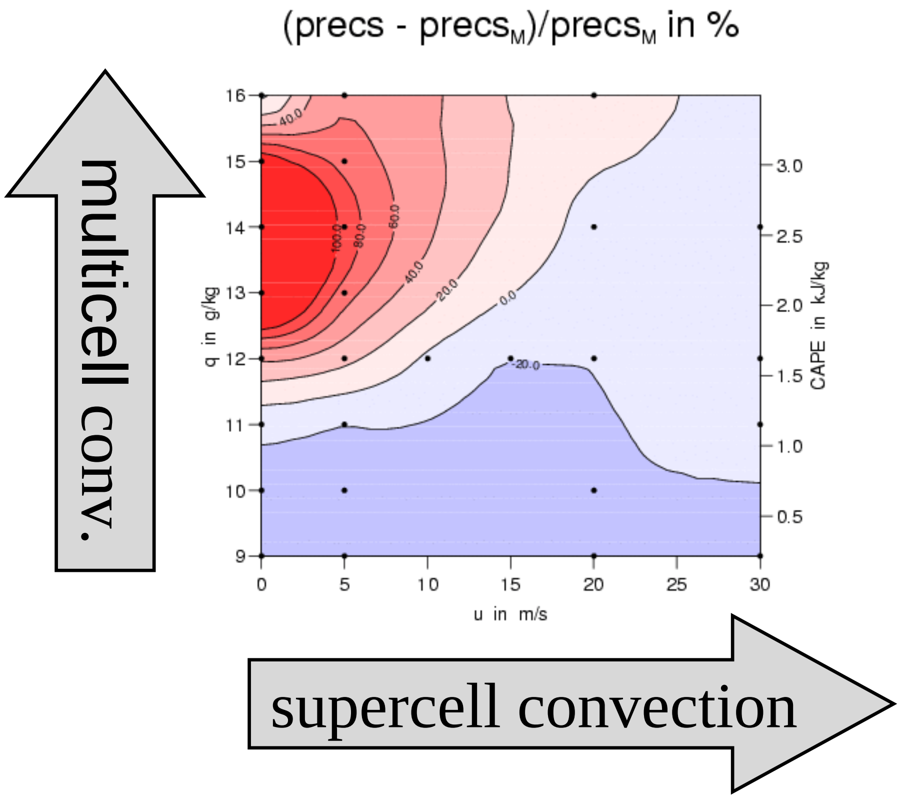
More CCN ➔ More, but smaller droplets

➔ Slower rain formation ➔ Reduced precipitation

2) Aerosol-Cloud dynamics effect:

More CCN ➔ More, but smaller droplets
➔ Slower rain formation
➔ More liquid water in lifted to the freezing level
➔ Increased latent heat release ➔ Stronger updrafts
➔ More condensate ➔ More precipitation

For example, Seifert and Beheng (2006) found a reduction of precipitation for ordinary convective cells and supercells, but an increase of precipitation for multicell storms.



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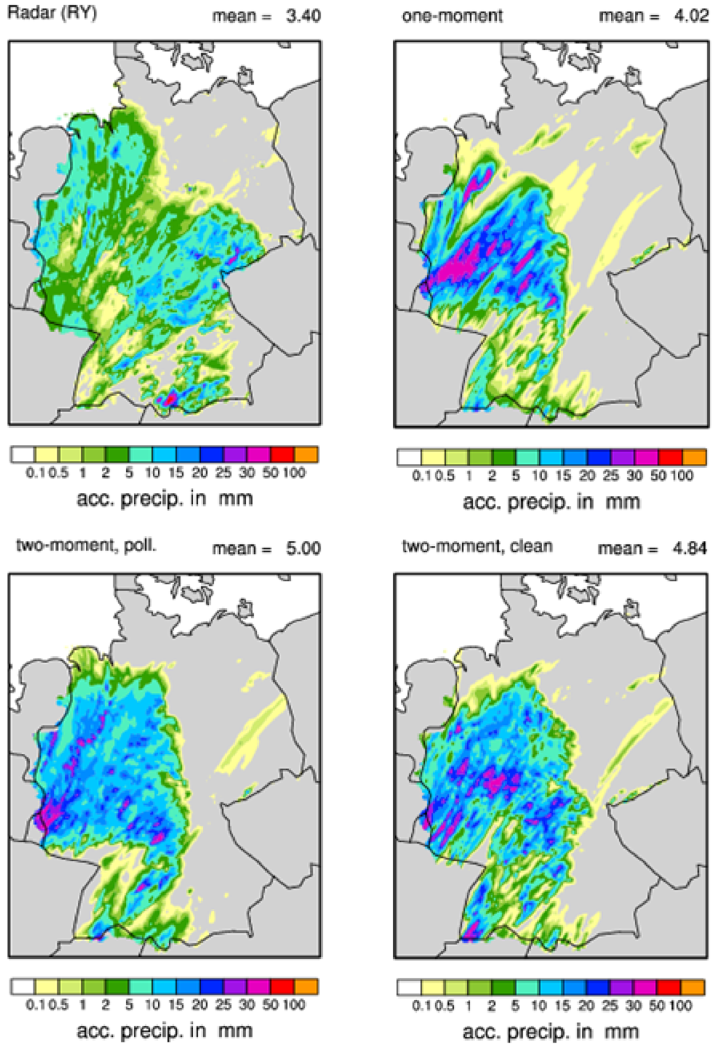
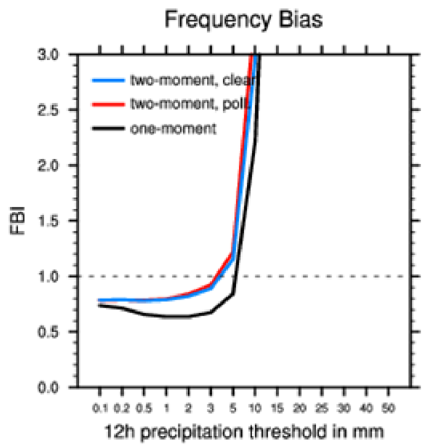
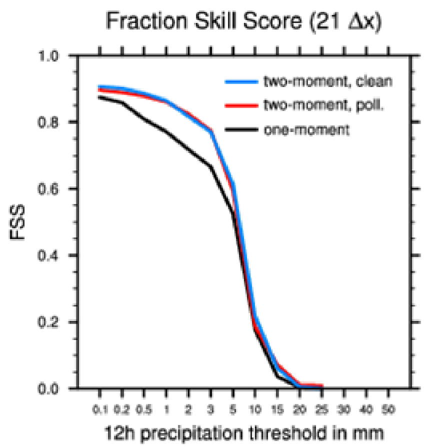




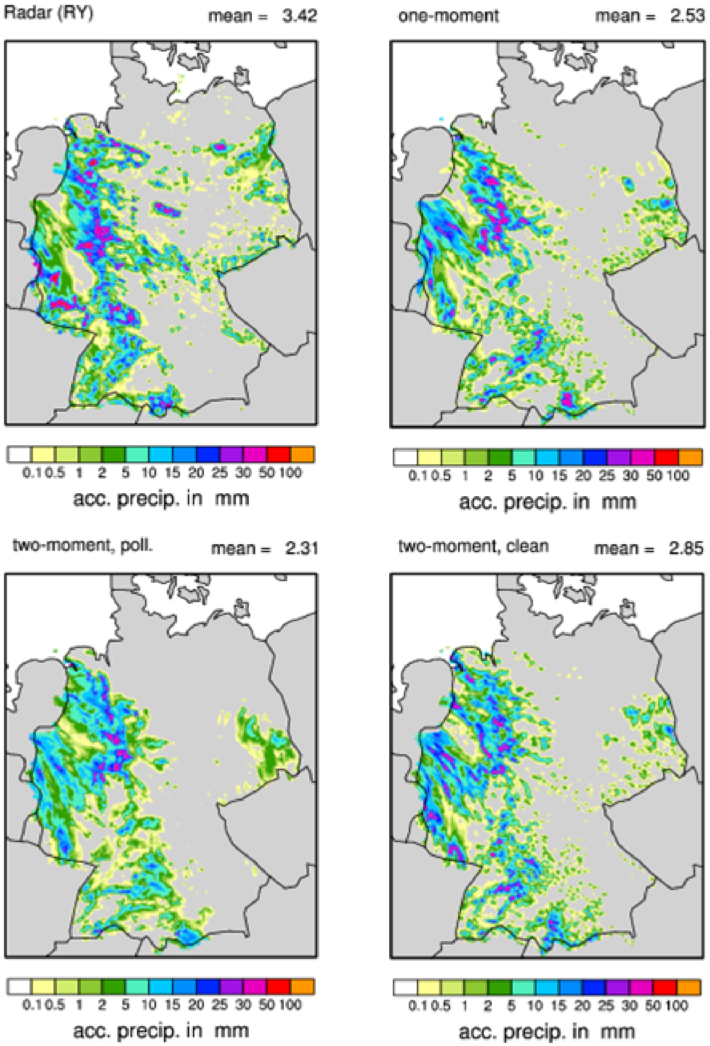


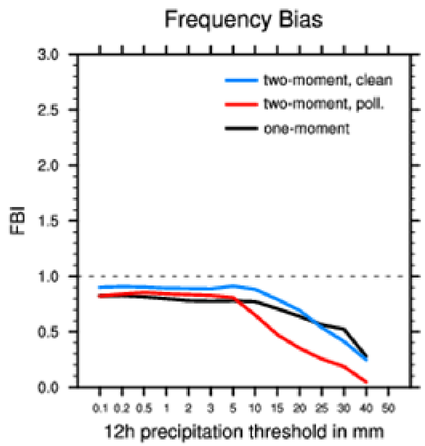
Slightly more precip., **5.0 mm vs 4.84 mm,** from run with polluted CCN assumptions

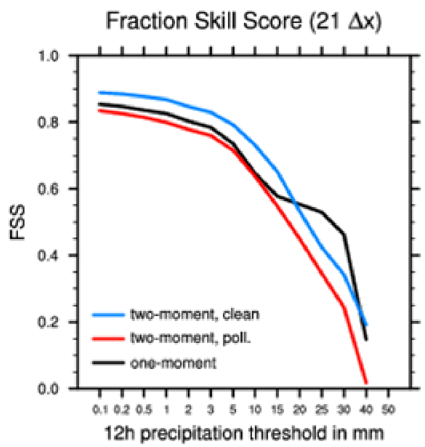
➔ Aerosol-Dynamics effects dominates over microphysics

Skill scores identical for both two-moment runs, but improved compared to the operational scheme

Case 9 June 2007, 06 – 18 UTC:
Convergence line ahead of cold front





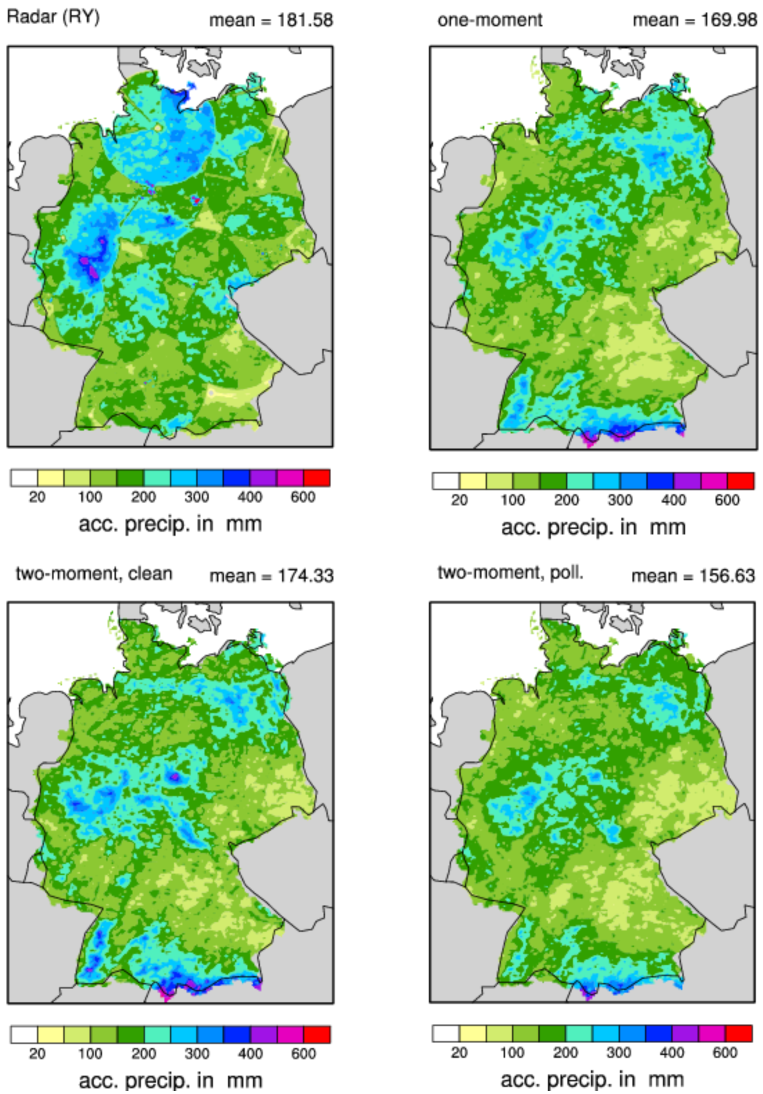


Slightly less precip., **2.3 mm vs 2.8 mm,** from run with polluted CCN assumptions

➔ Aerosol-Coalescence effect dominates

Skill scores show an improvement only for the two-moment run using clean CCN assumption.

Total accumulated precip during JJA 2007
(daytime only, i.e. 06-18 UTC)



The total accumulated precipitation is quite robust to microphysical assumptions:

Average of acc. precip. for Germany:

Radar		**2M-Clean**		**1-Moment**		**2M-Pollutted**
182	>	174	>	170	>	157

im mm/(3 month)

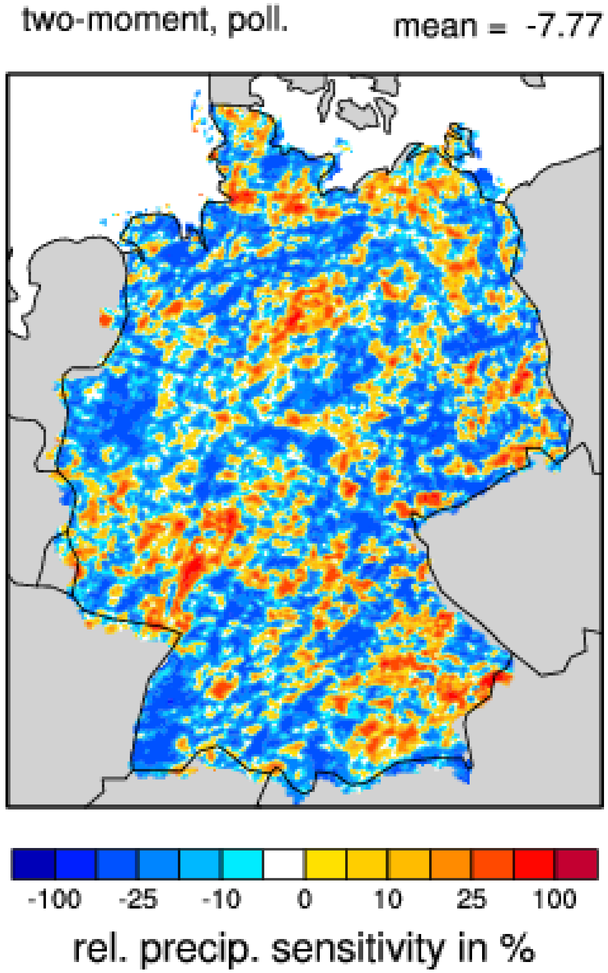
Daytime precipitation sensitivity JJA 2007

Relative change of accumulated precipitations between clean and polluted CCN assumptions:

$$S_x = \frac{P_x - P_{clean}}{P_{clean}}$$

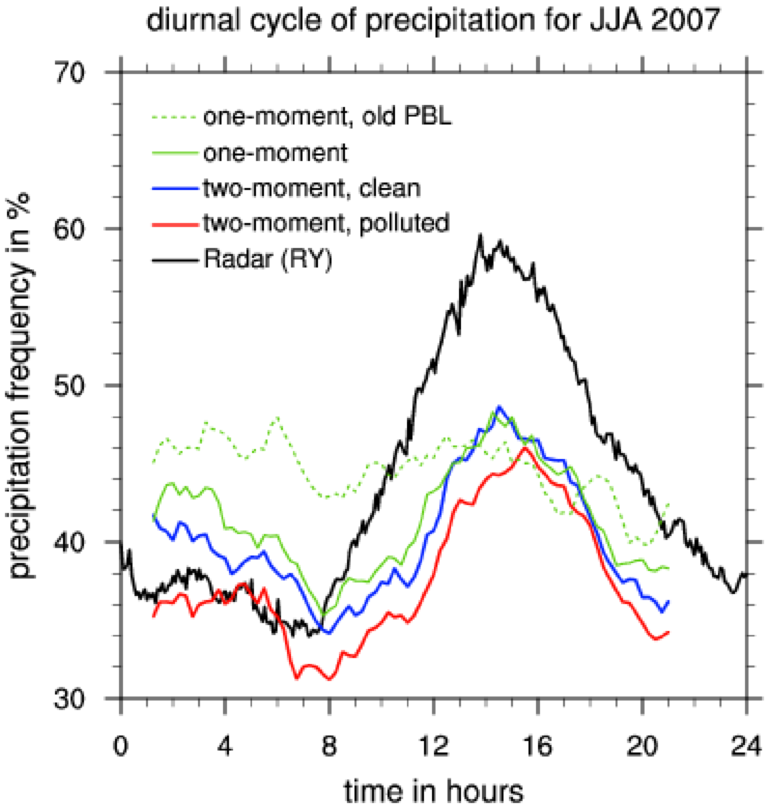
In the model an increased number of CCN lead to a reduction of precipitation. Overall a small reduction of about 8 % when assuming pollution CCN conditions.

Especially over low mountain ranges, e.g. the Black Forest, the precipitation is reduced. Elsewhere the variability seems to be random.



Sensitivity of diurnal cycle of precipitation frequency during JJA 2007

Precipitation frequency in Germany:



- Radar data shows a pronounced diurnal cycle in precipitation frequency with a maximum at 14 UTC
- The diurnal cycle in the model is too weak, but the timing is correct.
- Assuming polluted CCN conditions leads to a delay in the diurnal cycle of about 1 hour.

Summary and Conclusions

- A **hierarchy of state-of-the-art microphysical schemes** is available in the COSMO model, including advanced two-moment schemes.

- Depending on the application, the appropriate scheme can be used, e.g., for the specific grid resolution or research question. In the future **specialized hybrid schemes**, e.g., with two-moment rain or two-moment cloud ice will become available.

- For convective-scale NWP at 2-3 km grid spacing the standard graupel scheme is a **good compromise of efficiency and accuracy**, but for individual cases the more sophisticated schemes can be superior.

- Simulations during Summer 2007 using the two-moment scheme in a COSMO-DE-like configuration suggest that the **aerosol-precipitation effect is small**, but negative. For individual cloud systems a positive effect can occur, as suggested by the aerosol-dynamics effect.

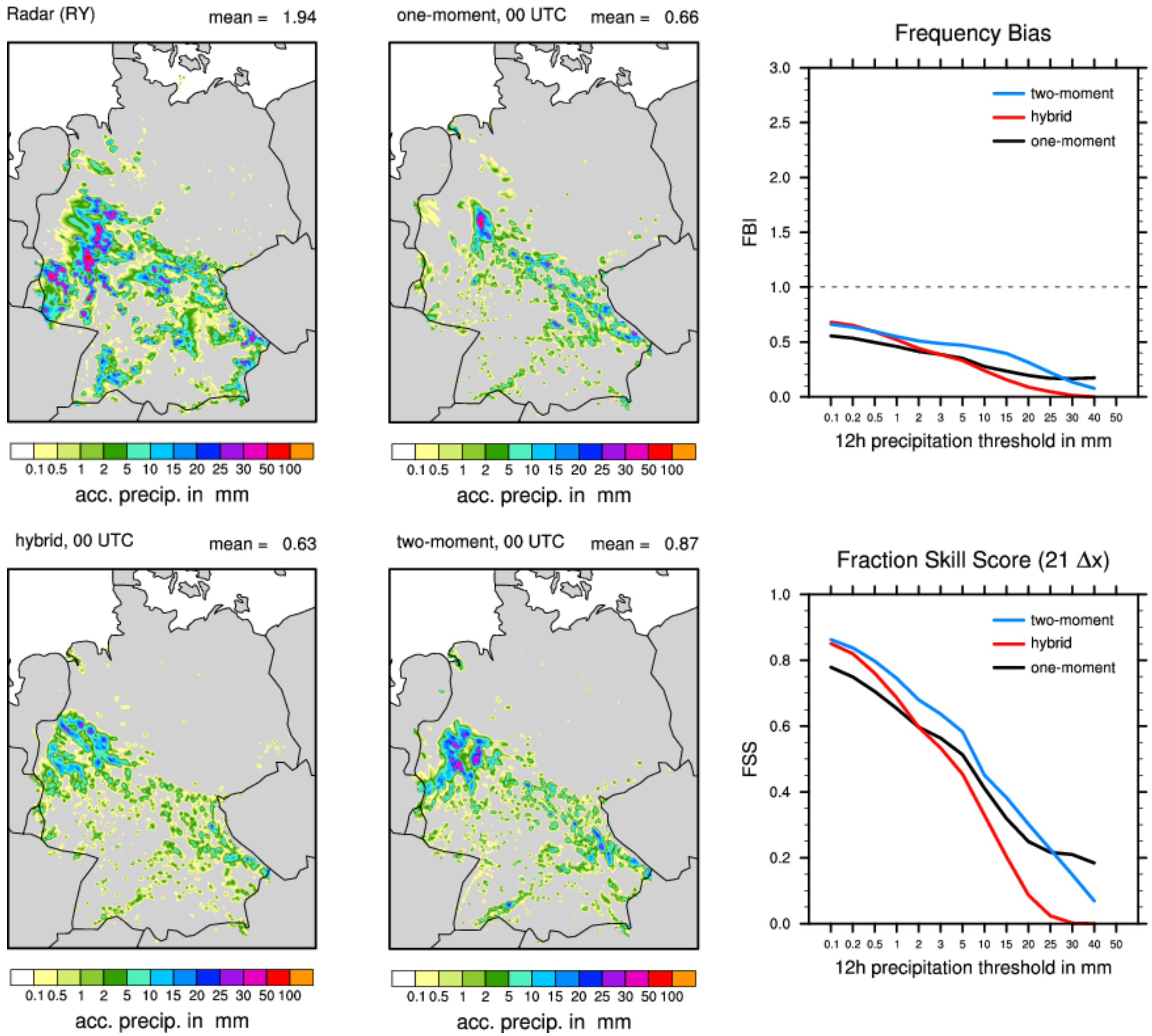
additional slides ….

Motivation: Why cloud microphysics?

- It is well known, that cloud microphysics plays a crucial role in the life cycle and organization of deep convection, especially for the formation of the cold pool. A good parameterization is therefore a prerequisite for **successful storm-scale simulations**.
- **Precipitation forecasts** are the major application of limited area NWP models.
- High-resolution **data assimilation** demands good model physics and realistic forward operators.

⇨ Need for the 'best' microphysics scheme for the specific application.

Case 10 June 2007, 06 – 18 UTC: Convergence line



- SB two-moment scheme gives the best forecast, but all schemes underpredict the intensity of the system.
- Again the hybrid scheme simulates a too weak system.

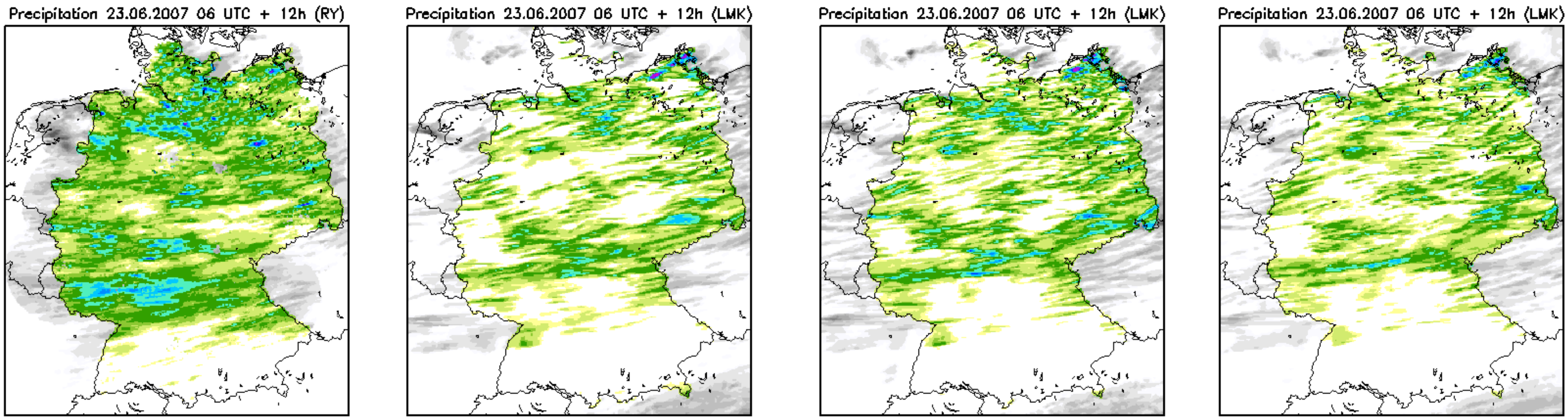
Application of the new evaporation scheme in the COSMO model:

- Implemented in the most recent version of the Seifert and Beheng mixed-phase two-moment scheme:
  - ➔ Test for June/July 2007 look promising.
  - ➔ Official release in the COSMO code maybe end of 2008.

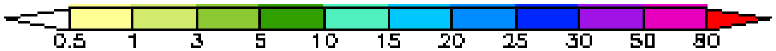
- New microphysics scheme that combines the operational Lin-type one-moment scheme with a two-moment rain formulation:
  - ➔ Could help to improve organized summertime convection, as well as reduce the positive precipitation bias during wintertime.
  - ➔ Test for June/July 2007 are running.

Case study 23 June 2007: Summertime scattered convection

Radar (RY) | **ONE-MOMENT** | **SB-CLEAN** | **SB-POLLUTED**



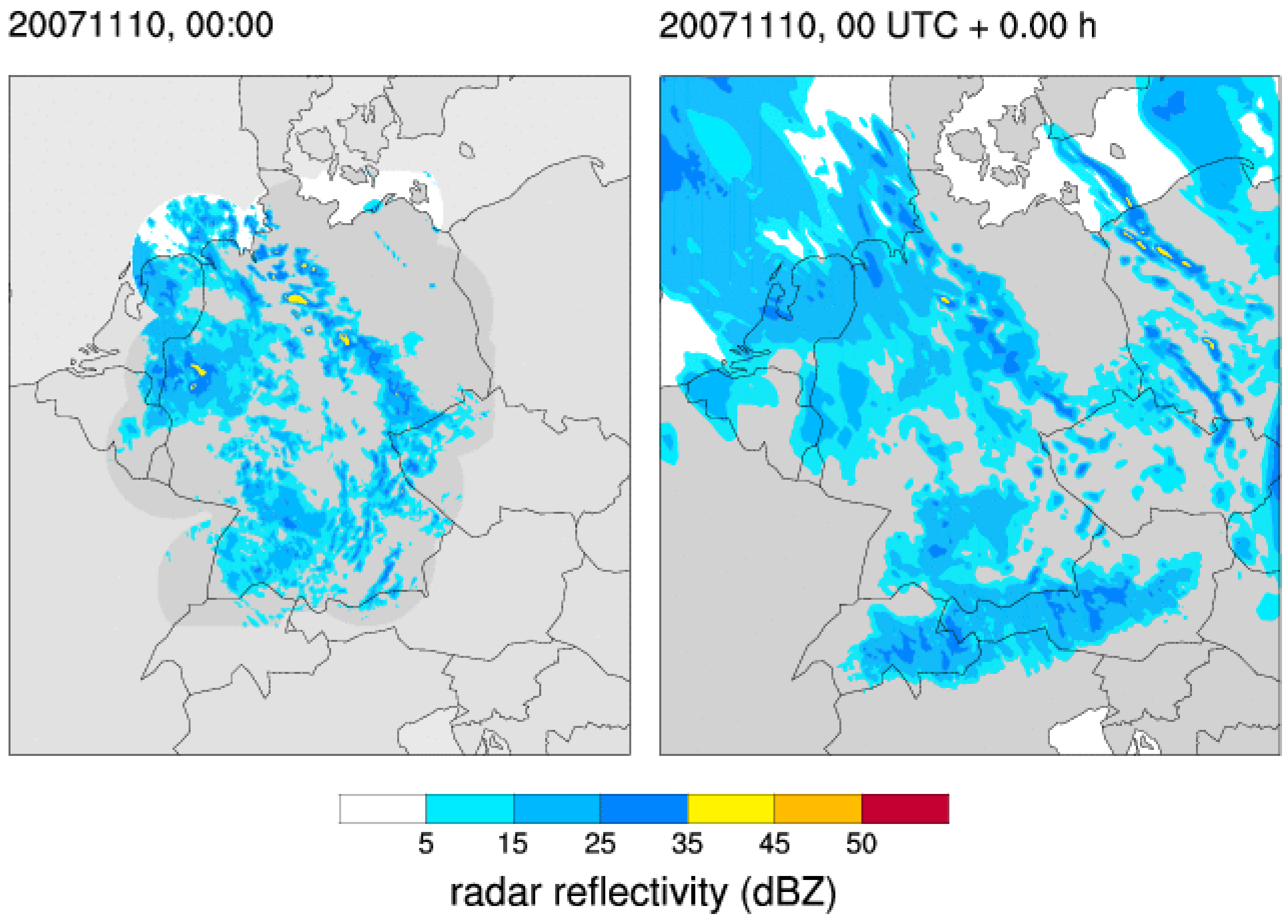
AVG: 4.5 mm | AVG: 2.2 mm | AVG: 2.7 mm | AVG: 2.0 mm



accumulated precip in mm

- The result of the operational one-moment scheme is somewhere between clean and polluted assumptions of the two-moment scheme.
- Compared to the radar accumulation the COSMO model underestimates the precipitation amount. How good is the radar estimate for such a case?

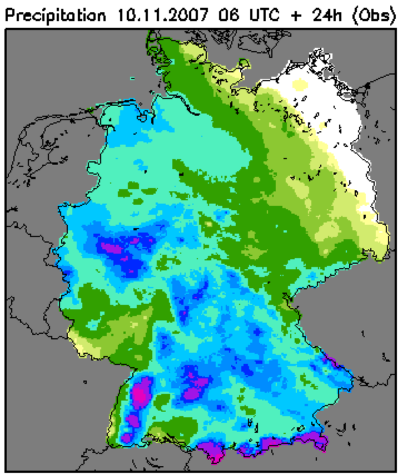
Case study 11 Nov 2007: Winter-time frontal system



Typical wintertime large-scale flow with orographic precipitation enhancement

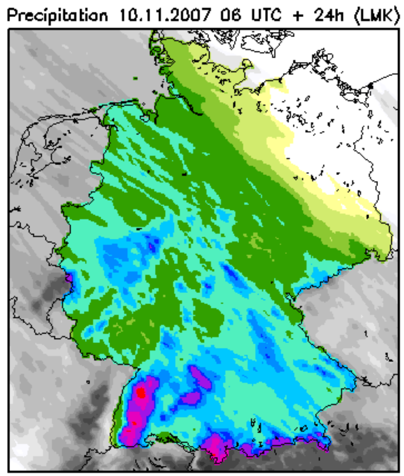
Case study 11 Nov 2007:
Winter-time frontal system

Gauges (REGNIE)



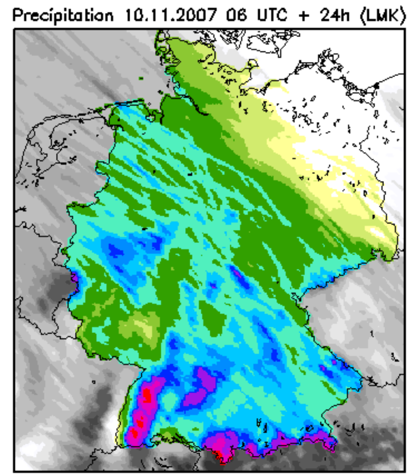
AVG: 11.7 mm

ONE-MOMENT



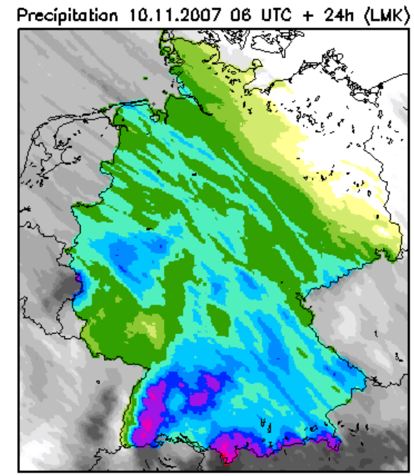
AVG: 10.7 mm

SB-CLEAN

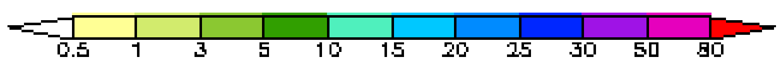


AVG: 11.4 mm

SB-POLLUTED



AVG: 11.0 mm



accumulated precip in mm

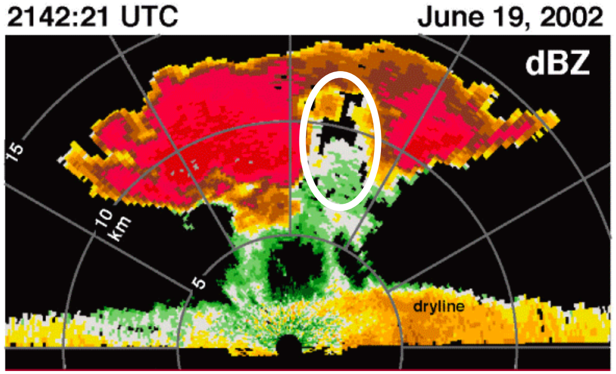
- Wintertime stratiform precipitation structures are quite robust to the chosen microphysics scheme. The operational one-moment scheme gives very similar results as the two-moment scheme assuming a low CCN number
- The local maximum values, e.g. at mountain tops, show some sensitivity to CCN assumptions.

A hybrid two-moment rain, one-moment everything-else scheme microphysics

Maybe just adding the number concentration of rain can already improve the scheme and make it more similar to the full two-moment SB scheme. Why?

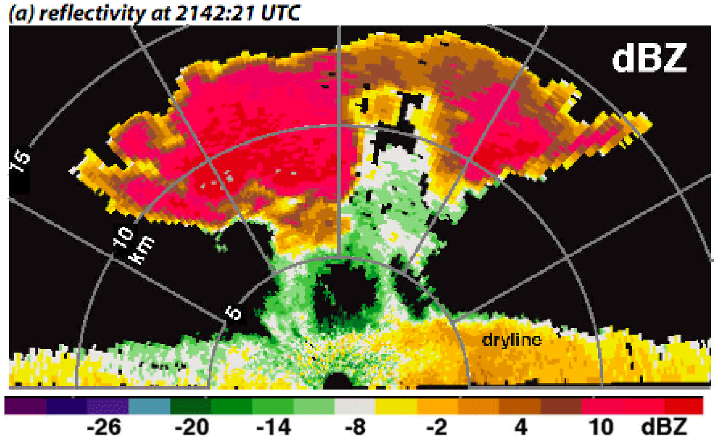
- Evaporation of raindrops is strongly size dependent.
- Two-moment rain improves the sedimentation and prevents the too formation and fall out of rain in deep convection.

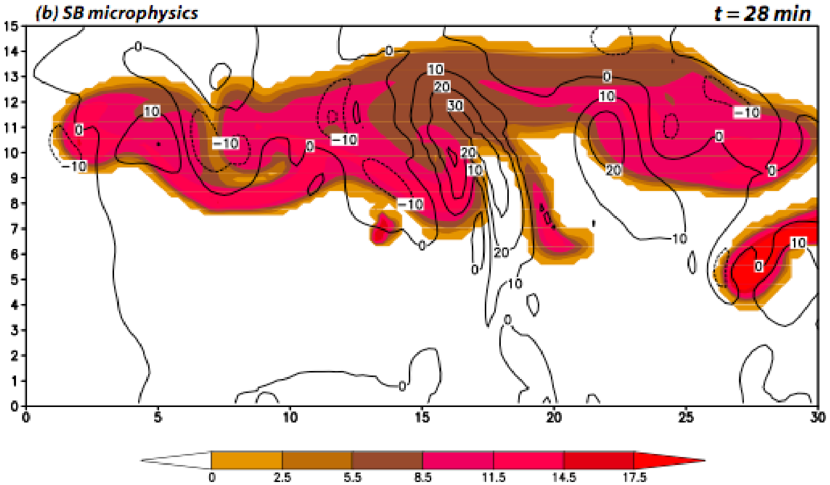
The 19 June 2002 IHOP "Mantle Echo" Case



weak echo region

WRF Simulation of the IHOP “Mantle Echo” Case





- The model is able to reproduce the weak echo region.
- The simulation did not produce any surface precipitation, while the observed storm did give a significant amount of hail. Initialization problem or microphysics?

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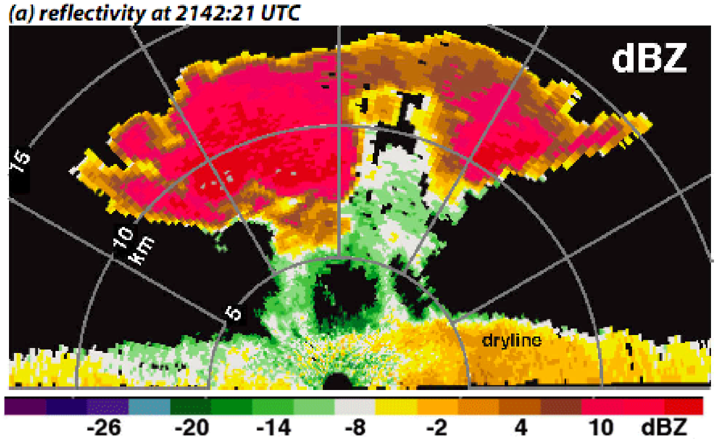
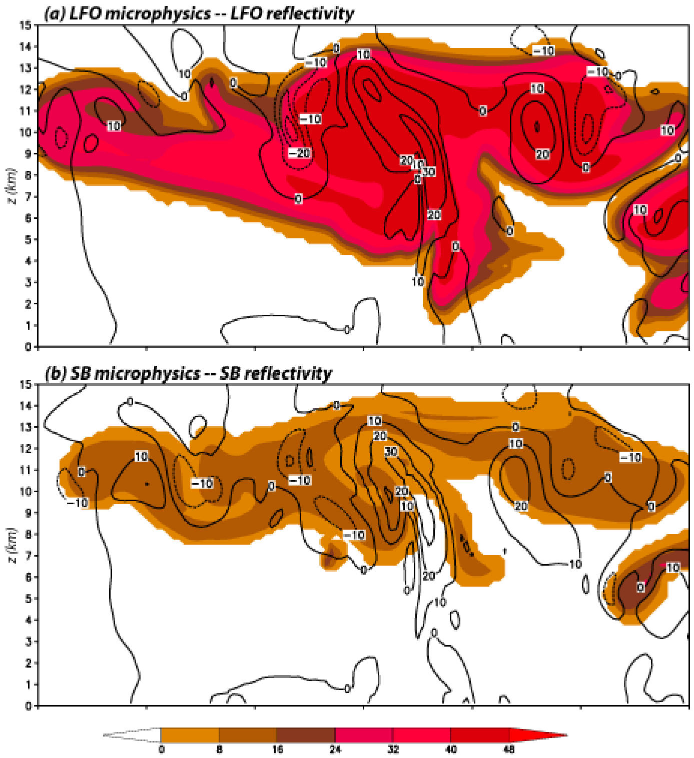
(Fovell and Seifert 2005, WRF Workshop)

WRF Simulation of the IHOP “Mantle Echo” Case





Even a tweaked Lin-type one-moment scheme was not able to give similar results.

Different color scale between models and radar!

(Fovell and Seifert 2005)